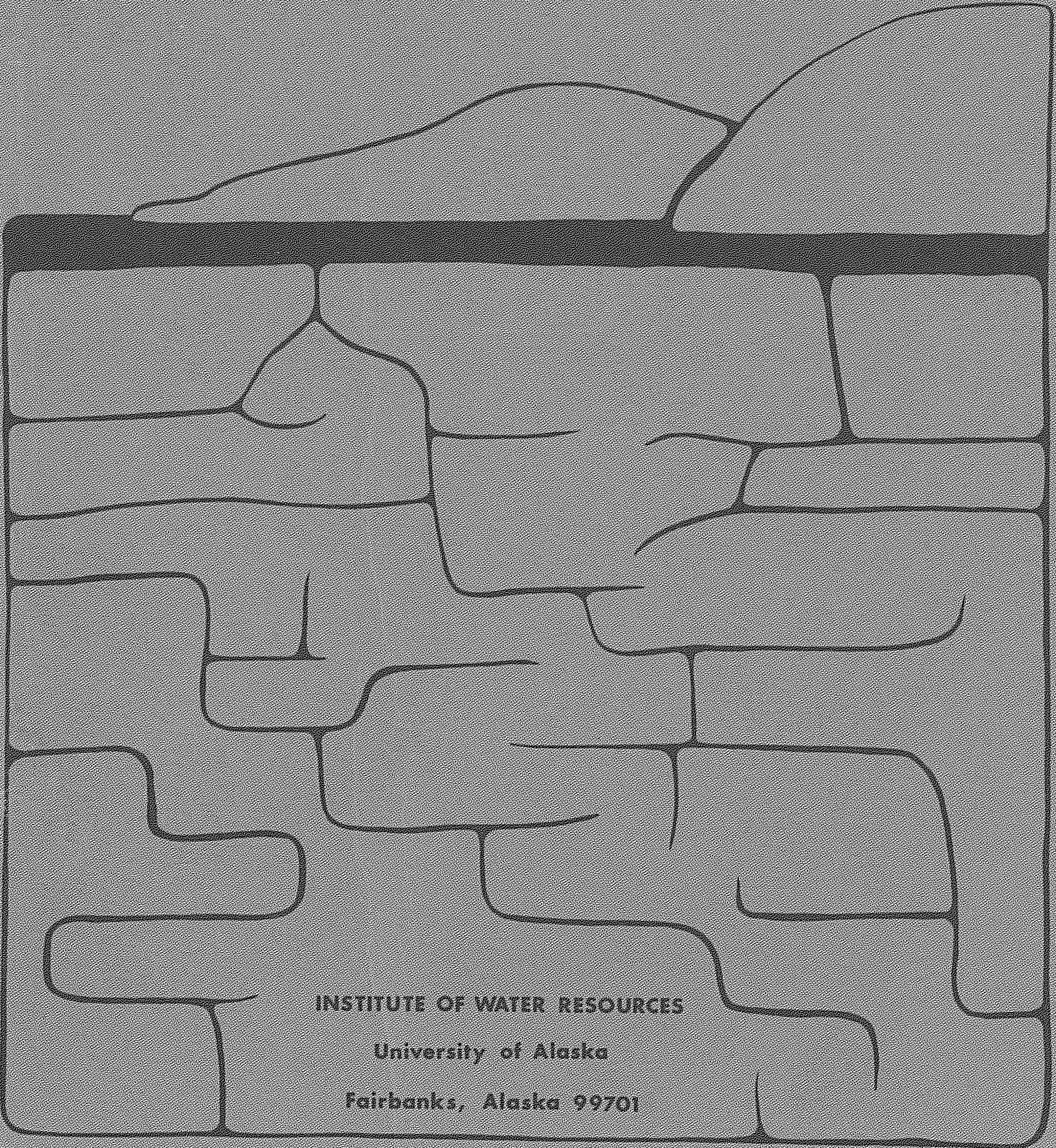
EFFECTS OF THERMAL DISCHARGE UPON A SUBARCTIC STREAM



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EFFECTS OF THERMAL DISCHARGE
UPON A SUBARCTIC STREAM

Completion Report

OWRT Project B-020-ALAS

Effects of thermal discharge upon a subarctic stream: Completion report

by

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INTRODUCTION

This report describes a study of the effects of thermal discharge on the Chena River in Fairbanks, Alaska, during the 1971-72 winter season. The objective of the research was to gain a better understanding of the thermal discharge phenomenon in northern streams which, in the winter season, are dominated by very cold temperatures and extensive ice-covered reaches. Readers familiar with the Fairbanks area will recognize the Fairbanks Municipal Utilities System (MUS) power plant cooling water discharge as the primary thermal discharge. Other important thermal discharges at that time included: the north Fort Wainwright power plant, the north Fort Wainwright sewage treatment plant, the city of Fairbanks sewage treatment plant, and numerous other small commercial operations. This study concentrated on the effect of the MUS discharge upon the physical and chemical characteristics of the stream: temperature, pH, color, turbidity, solids, dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD).

Most of the field work and analyses was carried out by two graduate students, William Armstrong and Richard Williams, enrolled in the Environmental Quality Engineering program at the University of Alaska, Fairbanks. The two worked on this project as a part of their educational program and as research assistants with the Institute of Water Resources. Much of the material in this report has been extracted from project notes, a completed thesis by Armstrong (1973), and an unpublished manuscript by Williams (1974). Some of the material has been transmitted previously in a short memorandum to the Municipal Utilities System (Carlson and Tilsworth, 1974), and in brief comments included in a paper by Carlson (1974).

The intent of this report is to present certain highlights of the work, material not covered by Armstrong and Williams, and conclusions which may be drawn from the study.

Some of the important conclusions are:

1. The present MUS thermal discharge does not increase appreciably the temperature of the Chena River because of the relatively small discharge volume compared to the Chena River flow.
2. The discharge causes an open reach of water which varies from 8 to 15 acres during the winter and extends from ¼ to ½ mile downstream.
3. The variation in extent of the open stretch may be controlled by discharge method: a surface spreading scheme results in a faster but more concentrated heat and water vapor rejection, and a direct jet discharge results in the heat and vapor rejection being slightly more spread.
4. A notably beneficial effect of the thermal discharge on the stream is a definite improvement in the DO content of the river as it passes through the MUS discharge reach.

BACKGROUND

The National Situation

The nature of thermal-power generation and the relationship of the necessary cooling process can be best understood in relation to the national situation. Although not directly applicable, many aspects of the Fairbanks plant are shared by wider national concern. A brief general discussion is included here.

In 1978 it is not necessary to emphasize the importance and critical nature of energy generation and consumption in the United States. Many of the figures and data are well known as the result of numerous newspaper and popular-magazine articles.

According to Parker and Krenkel (1969 and 1970), electric power generation in the United States has doubled every ten years since 1945. This power demand has been met by conventional thermal generation plants. These plants generally use some type of primary fuel such as coal or petroleum to fire a high-pressure steam boiler and cause electrical energy to be generated as a result of the release of the energy of the steam. A conventional thermal generation plant is shown in Figure 1.

Much has been written about the need for increased efficiencies of electrical generation plants; however, the basic laws of thermodynamics will not allow the thermal efficiency of fossil-fuel plants to increase much beyond 40%. Although nuclear reactors are held to be the most promising future alternative for large scale increases in thermal energy generation, thermal efficiencies are even lower, approximately 35%.

All conventional thermal plants require some type of heat rejection. The most economical rejection method at the present time is once-through cooling in which water is used as an intermediate sink with the atmosphere as the ultimate sink. Sometimes this process can be circumvented somewhat by direct rejection to the atmosphere with cooling towers or

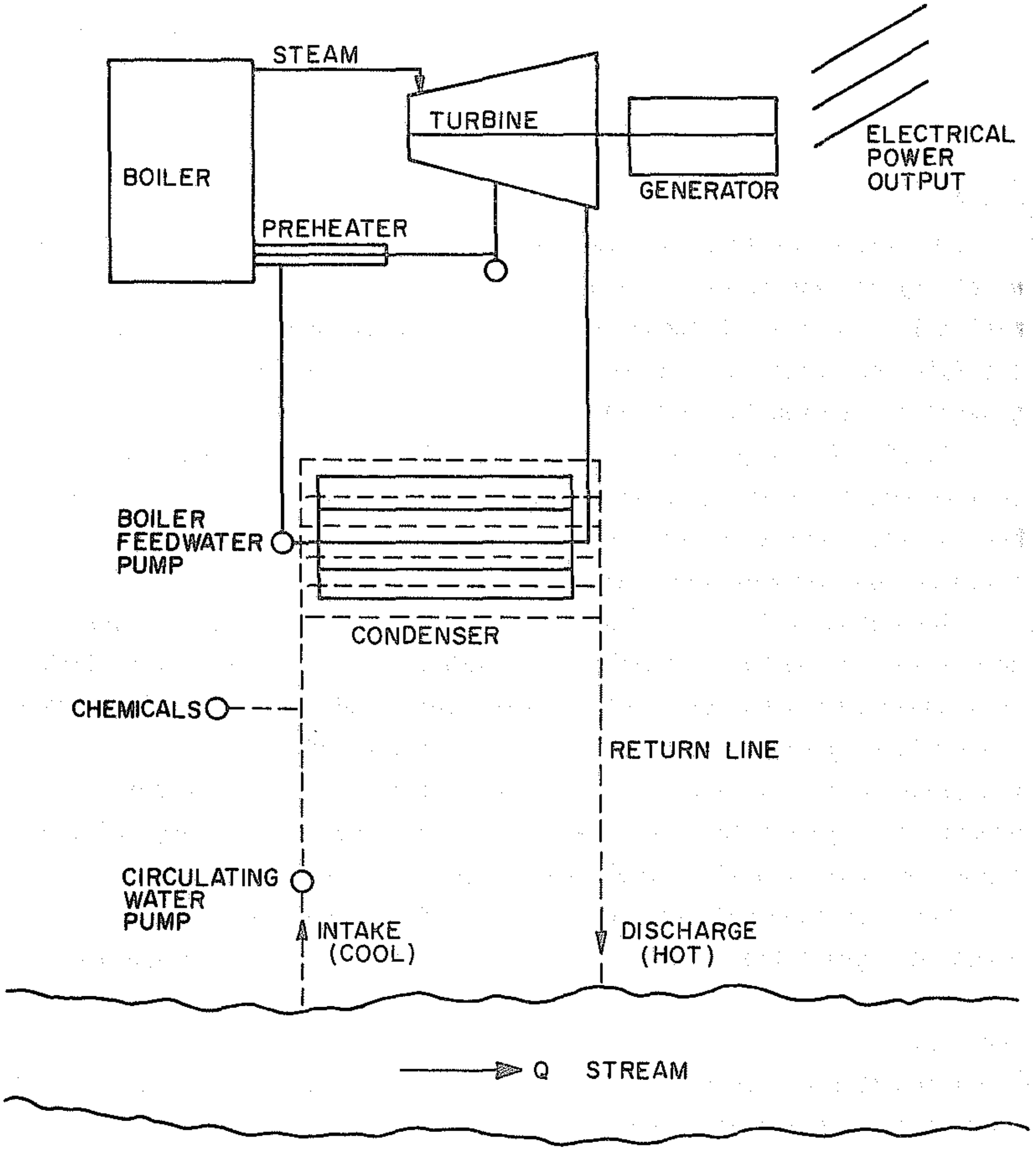


Figure 1. A simplified schematic diagram of the main processes of a thermal-powered electricity-generating station. (After Parker and Krenkel, 1970).

ponds. Many new plants of 100-megawatt capacity or more use these methods.

It should be noted that electricity is a secondary form of energy and can be produced only through use of primary forms of energy such as coal, oil, gas, radiation, or water power. Electrical energy meets demands that only it can satisfy, as well as other demands such as heating and industrial uses which can also be provided by direct primary energy consumption. However, because of its convenience, use of electrical energy has been growing at a more rapid rate than total energy use in general. Some information on the projected consumption of electrical energy in the United States is shown in Figure 2. Note that electrical energy is expected to play an increasingly important part in total energy use and that the traditional generation schemes (hydropower and fossil fuel) will become less important while nuclear power, which has an inferior thermal efficiency, will become more important. If the power consumption within the United States continues to increase at the present rate of about 7% a year, doubling every ten years, it is quite obvious that thermal discharges will also be increasing at the same rate.

It is most likely that, given the convenience of electrical generation, it will indeed continue to command an ever-increasing role of the total energy consumption picture in the United States. It follows, then, that nuclear power plants will provide an increasing part of the load. With their inherent inferior thermal efficiencies, one cannot help but look forward to an increasing need for thermal cooling facilities for some time to come.

The Northern Situation

Many of the considerations described above are also true, at least in part, of the northern regions of the world. The subarctic and arctic will be faced with increased power requirements as a part of the generally expected increased economic activity throughout the United States. In addition, power requirements will increase due to the greatly accelerated resource extraction requirement faced by much of the north. The

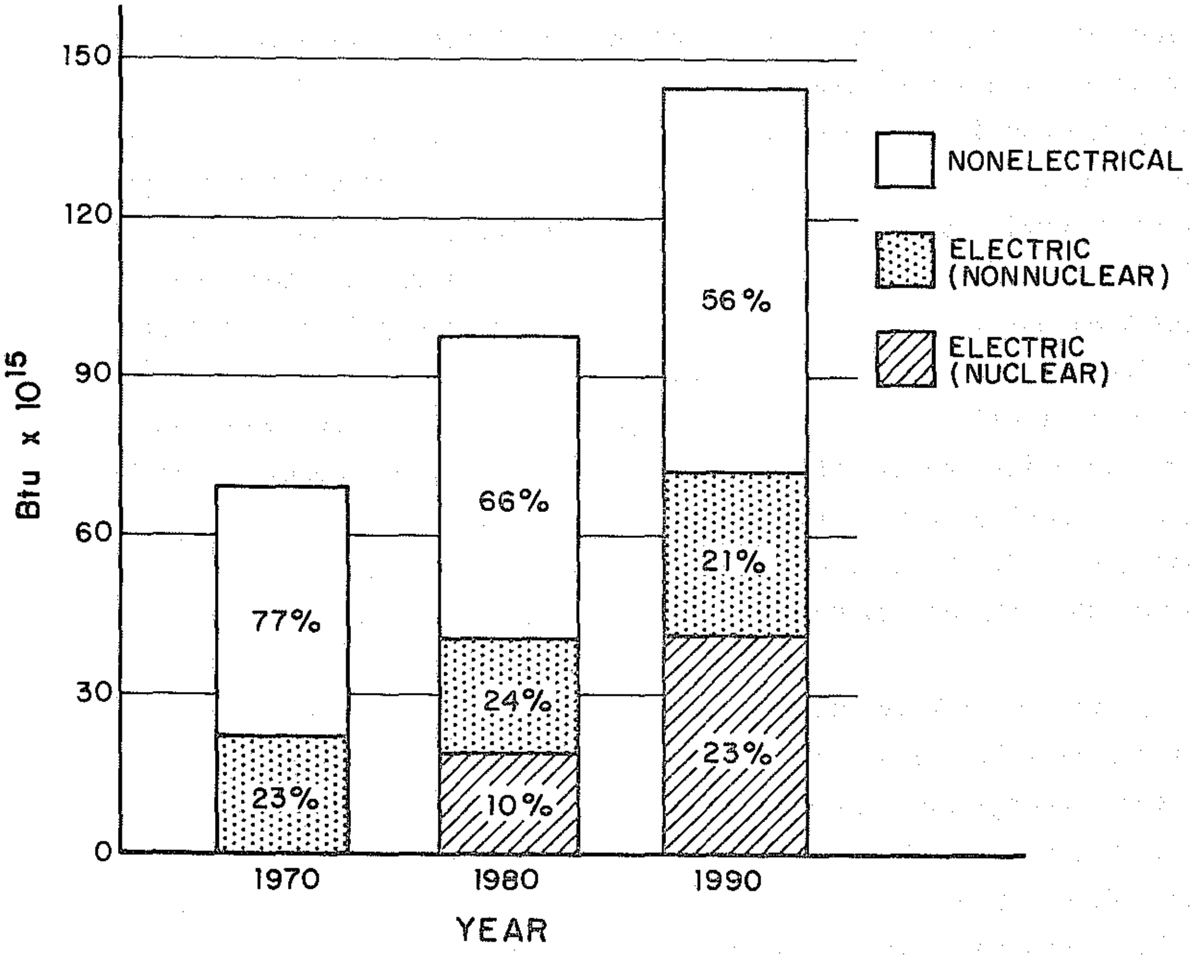


Figure 2. Users of primary energy: 1970, 1980, and 1990. (After Scott, 1973).

most well known is the primary and secondary activity induced by oil and gas extraction, and many economists are forecasting a greater resource extraction activity. Thus one can expect a greater-than-normal power requirement in the north.

One would expect, because of the cold temperatures found in the north, that the availability of adequate cooling would not necessarily be a problem. Nevertheless, the practicability of thermal plant requirements almost always dictates that, although the atmosphere be used as the final heat rejection sink, the most economical cooling source will be medium and large streams. As an example, the primary interior Alaskan power plants use the Chena River in Fairbanks (mean flow, 1484 cfs) and the Nenana River at Healy (mean flow 3557 cfs) (USGS 1975). Anchorage power facilities use Ship Creek for once-through cooling. Other types of thermal loads are caused by the direct use of water and its ultimate rejection through waste-treatment facilities. This use and the projected increase in electrical energy demand led to this study of thermal discharge into a subarctic stream.

The main impact of increased thermal discharge in northern regions is much like that of other parts of the country; that is, increased stream temperatures. However, in the arctic the increased stream temperature occurs in a special circumstance: through much of the year a stream is in a naturally ice-covered state. In interior Alaska this season occurs for the six winter months, beginning in November and lasting until the spring breakup in early May. During the summer months, the stream temperatures are much like those in the most northern of the 48 contiguous states and normally reach 10°-15°C (USGS 1975). It should be pointed out that seldom do stream temperatures reach the 27° or 32°C range of many of those streams which are exposed to continuous direct sunlight and rather long periods of high air temperatures.

Besides the normal problems, most areas in the north share a special concern caused by open water surfaces in the winter. In any simple, once-through cooling scheme, large quantities of water vapor are rejected along with the heat. At cold temperatures, this vapor soon turns into a dense fog, which may or may not become a true ice fog, but which often causes a visibility problem.

Thermal discharge problems of the north share many of the features of that found elsewhere. The north also has special circumstances: the normal low temperatures, the ice-covered regime of most northern streams, and the possible formation of ice fog--a phenomenon which can have deleterious effects.

The Fairbanks Situation

This study took advantage of the excellent field situation and good example of many aspects of northern thermal discharge offered by the MUS power plant. We were also encouraged by the fact that the MUS management expressed interest in the study in light of its own questions about MUS's thermal discharge.

Local problems that are quite real in the Fairbanks area include thermal regulation criteria imposed by enforcement agencies and the occurrence of widespread ice fog. The region continues to face increased resource development activity and is likely to face a great power expansion, both in the city proper and within interior Alaska. Thus, the study will provide some needed design information for further expansion of the present MUS plant and for construction of new facilities in other parts of the interior. The study emphasized the impact of the thermal discharge upon the Chena River. There are, of course, many other aspects of thermal discharges or thermal pollution which can be related roughly to physical, chemical, and biological effects.

The field study is related specifically to a reach of river between Fort Wainwright and Pike's Landing, in the vicinity of Fairbanks, on the Chena River (Figure 3). Although no attempt is made to present our results as generalizations, interested users should be able to apply them to their own design problems and areas of interest. Within the study reach described, particular attention is paid the MUS discharge with special consideration given to alternative discharge schemes available at the plant near downtown Fairbanks.

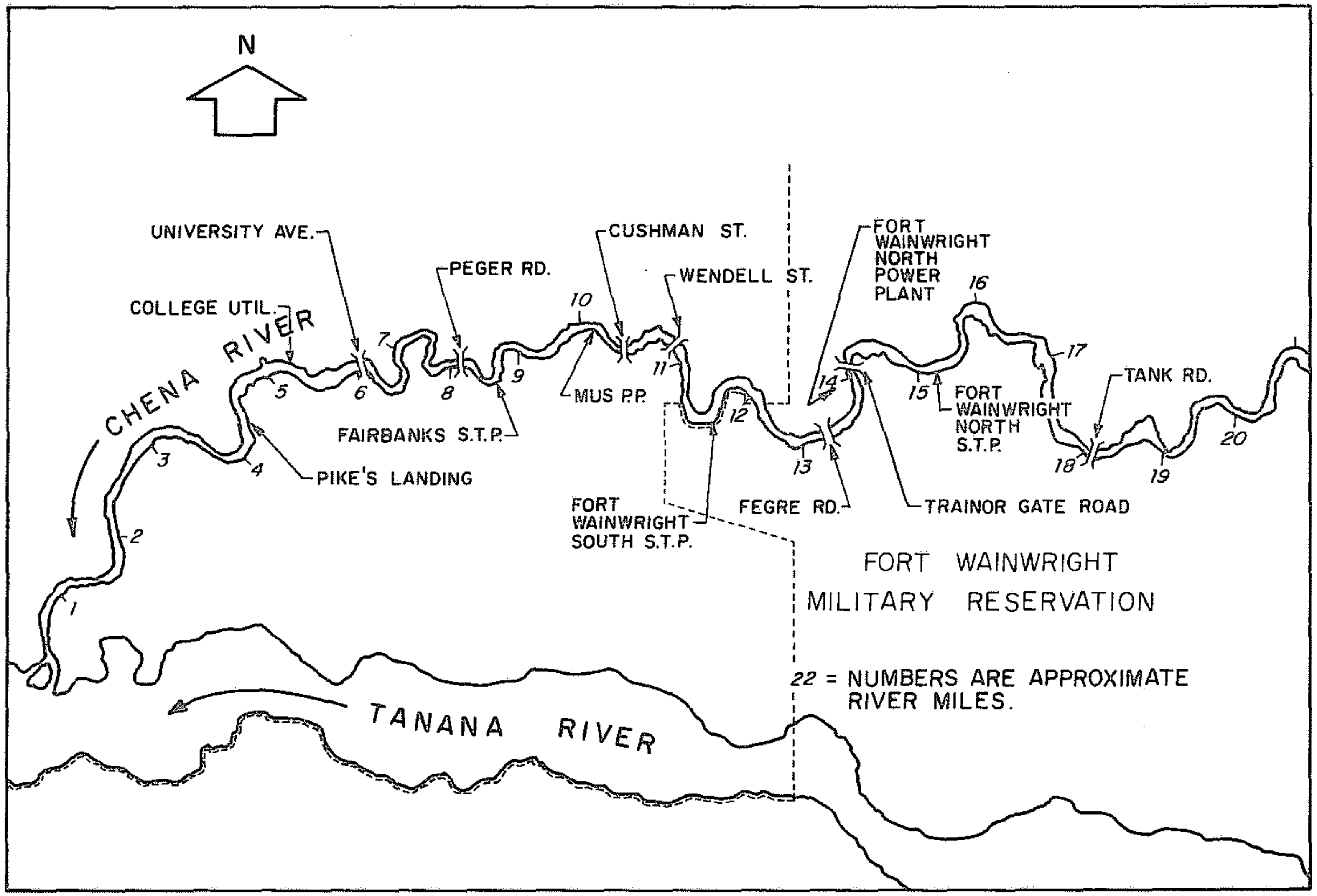


Figure 3. The Lower Chena River and the locations of the outfalls and sampling stations.

OBJECTIVES

The primary objective of the research project was to study the mechanism of power plant thermal discharges of a northern stream. The study centered on an evaluation of the MUS power plant discharge on the Chena River in Fairbanks, but the results are intended to be widely applicable to northern streams.

A second objective of the study was to evaluate the physical changes caused in a stream by warm water discharge in a severe winter environment.

INTRODUCTION TO DYNAMICS OF THERMAL PLANT COOLING

General Plant Layout

An understanding of some fundamental principles of thermal plant electrical generation and the role of cooling in their design will be helpful in understanding thermal pollution. Although thermal plants are found in practically every city and in many rural regions of the country, few people have had the opportunity to examine them. A simple diagram of a typical electrical generation plant which uses a steam turbine as a primary driver for an electrical generator is shown in Figure 1.

All coal-fired steam turbine generating power stations operate basically on the Rankine power cycle. This consists of four essential components: a boiler, a steam turbine, a condenser, and a boiler feedwater pump. Water from the feedwater pump flows into the boiler at high pressure where it is vaporized. From the boiler, the high-temperature, high-pressure steam is expanded through the turbine to a low temperature-pressure state and then is returned to a low-volume state in the condenser before flowing to the pump where it repeats the cycle.

That is the basic power cycle; the cooling cycle is separate, requiring an external supply of water. This is pumped through a heat exchanger (the condenser) to which excess heat is passed from the condensing steam. The cooling water itself may either be cooled through another heat exchanger and then returned to the condenser or it may be released to a stream. Commonly, this second heat exchanger may be either an open-surface cooling pond or a cooling tower or, less commonly, an air-cooled condenser. When the water is released to a stream, it is referred to as once-through cooling.

This last method, as it is used at most conventional plants, consists of an intake from a nearby river or lake, with a pump or the available river head utilized to pass the water through the heat exchanger and discharge it back into the river. The river water itself, usually at a temperature of 0° to 19°C, is used as a direct sink for the excess heat.

Cooling systems used for coal power generating stations in the Fairbanks area include open cooling ponds (Ft. Wainwright and Eielson A.F.B.), air-cooled condensers (University of Alaska), and once-through cooling at the MUS site, the focus of this study.

The MUS Power Plant

The MUS electric generating units Chena 1, 2, and 3 use well water as their source of coolant (2,000 to 7,000 GPM). This water is partially discharged into the Chena River--about one-third of the well water leaving the condenser is used in the water treatment facility. The Chena 5 unit uses cooling water (10,000 GPM) pumped from the Chena River; this water is totally discharged into the river after passing through its condenser.

In addition to direct once-through cooling, the Municipal Utilities System also has a device which directs part of the intake water past the plant and mixes it with the rejected hot water to allow a cooled effluent to enter the river proper. At normal loads, this effluent has a temperature of approximately 10°C.

Although seemingly a straightforward process, the rejection causes complex reactions. Because the density of water decreases with temperatures above 4°C (Figure 4), the injection of warm water into a colder environment results in a phenomenon known as stratified flow. MUS has employed two different discharge devices, one at the surface and one submerged, to manipulate this situation.

Mechanics of Thermal Discharge

Surface discharge is achieved in a number of ways, most of which are designed to float the warmer water onto the colder ambient water in a nearly undisturbed layer. The submerged discharge method uses a single- or multiple-port diffuser and injects the water directly into the stream to mix it completely with the surrounding ambient fluid. In a lake or reservoir, the design of the discharge structure can be quite

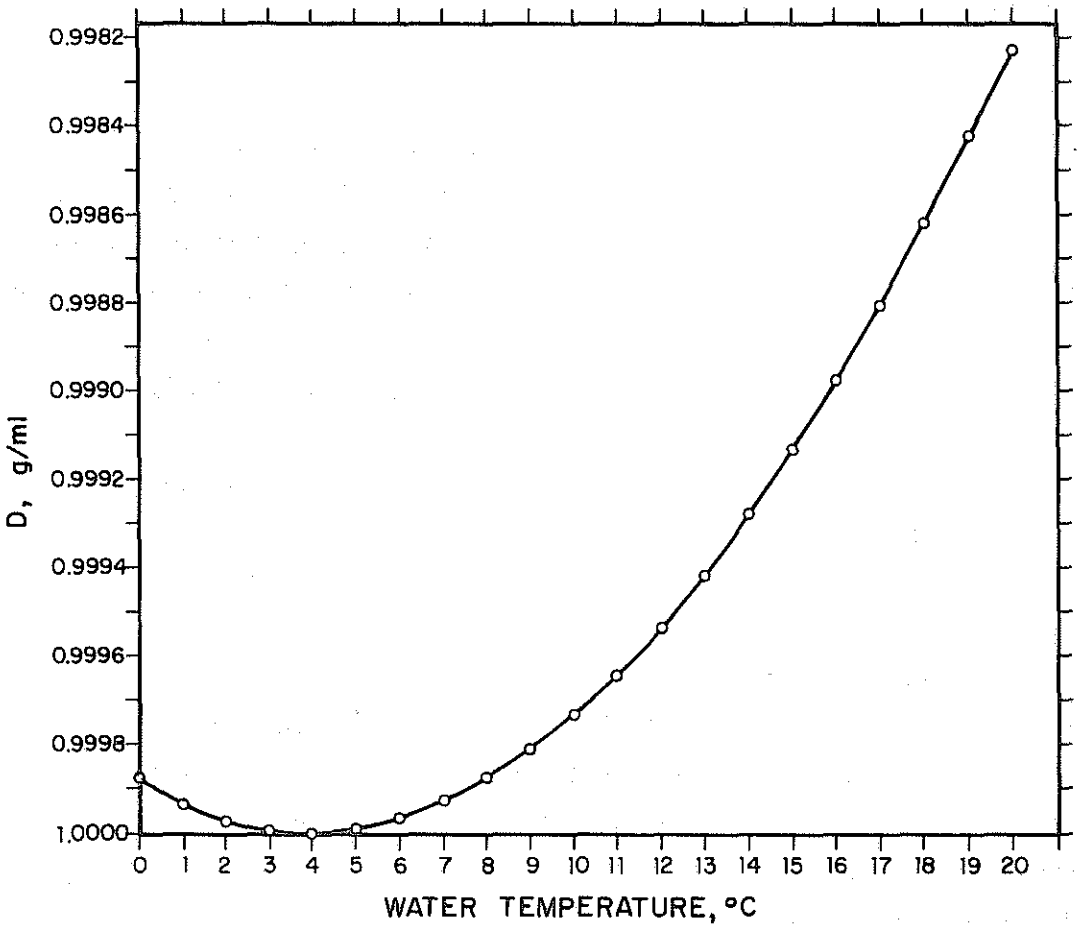


Figure 4. The variation of the relative density, D, and temperature of water.

complex since the water temperature distribution in the lake or reservoir itself must be taken into account. In a fast-flowing river, such as the Chena River which has velocities past the MUS plant of 4 to 10 feet per second, the design is less complex. Nevertheless, the discharge method can change the effect of the discharge on the river environment.

Some effects and advantages of surface discharges would be:

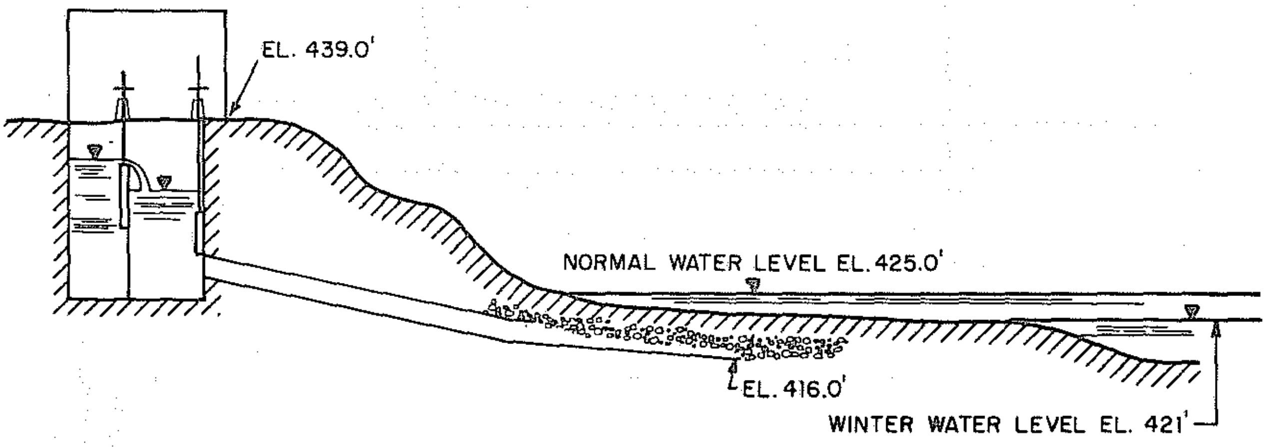
1. Temperature increase and high velocities along the bottom of the receiving river or stream may be avoided.
2. The travel time of organisms in the rejected water to the point at which oxygen becomes available to them is shortened.
3. The rate of initial heat dissipation from the surface of the receiving water is higher because stratification results in the presence of high temperature water on the surface.

Disadvantages also result:

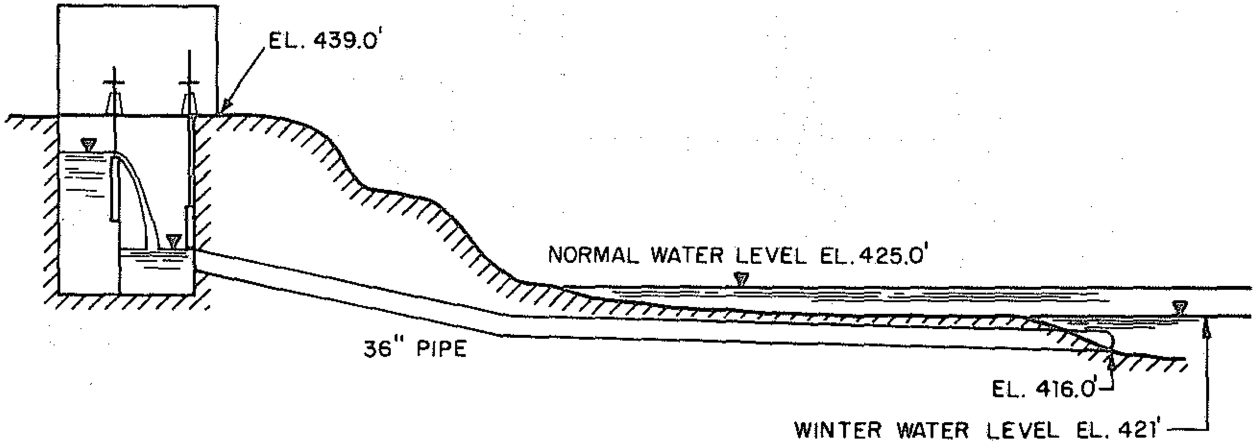
1. The heat rejection is concentrated within a shorter distance downriver from the discharge point.
2. Discharge in a stratified layer can prevent the lower water from mixing with the atmosphere.

One primary advantage of subsurface discharge is that the discharge water is mixed immediately with the river water, producing a lower overall temperature gradient immediately downstream from the discharge point. However, it is still possible to obtain stratified flow if the design of the submerged discharge is not carefully carried out. Schematic diagrams of the two systems at the MUS plant are shown in Figures 5 and 6.

Downstream from the discharge point, a flow field is established, either stratified or uniform throughout but warmer than the upstream regime. The stratification that may occur is the inverse of that expected in rivers at lesser latitudes because of the nature of water density below 4°C (Figure 4). Figure 7 illustrates a typical winter day near the MUS plant. The river temperature will eventually return to its natural value through rejection of heat to the atmosphere at the water surface.



SURFACE DISCHARGE SCHEME



SUBMERGED DISCHARGE SCHEME

Figure 5. Side view of the submerged and surface discharge structure at the MUS power plant.

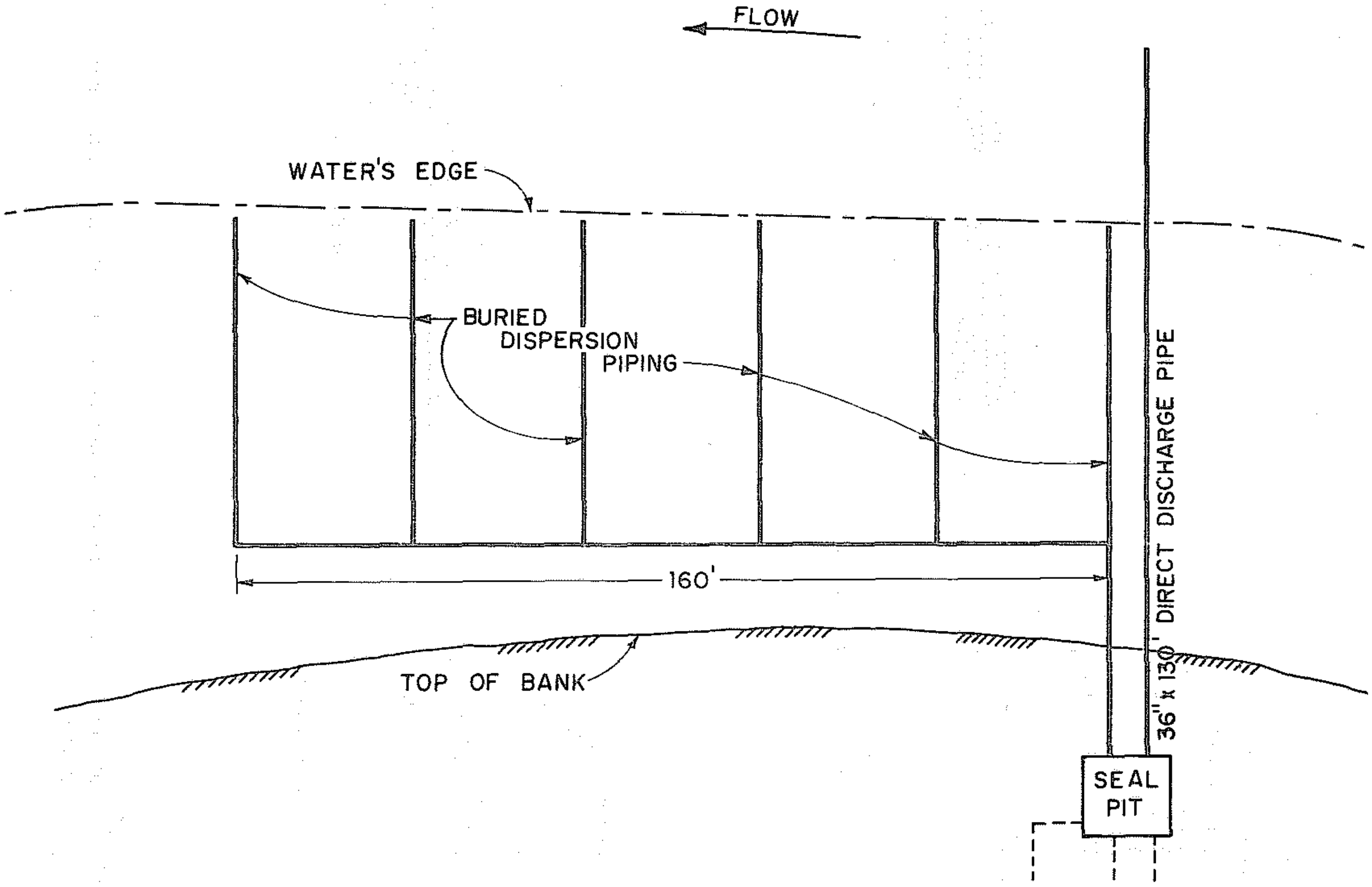
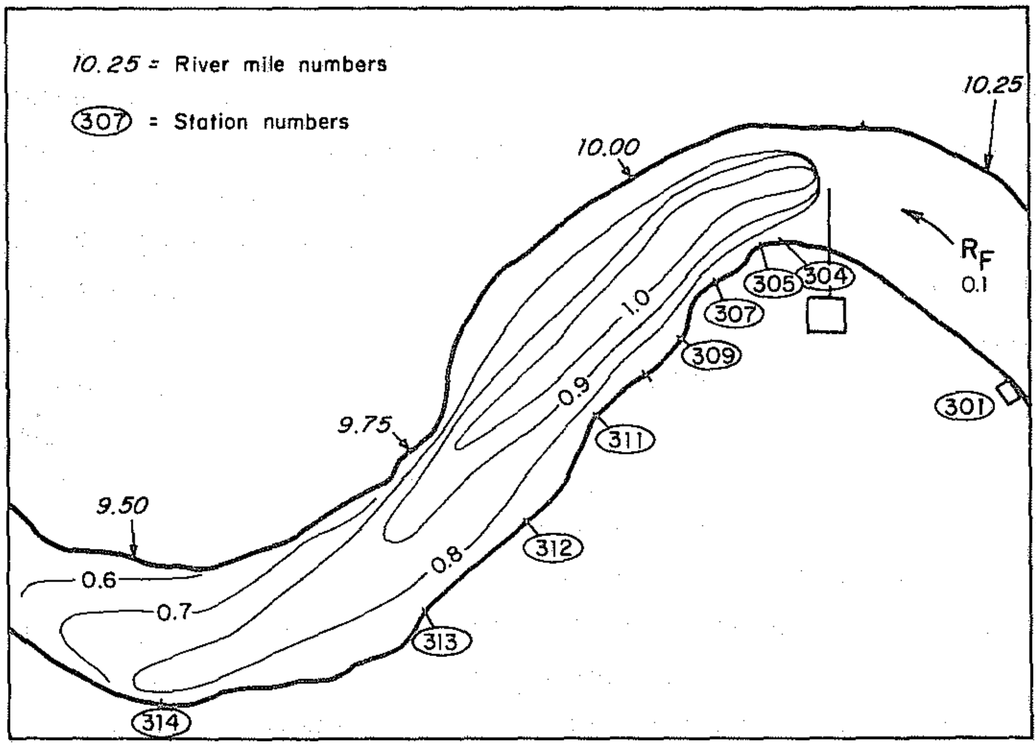
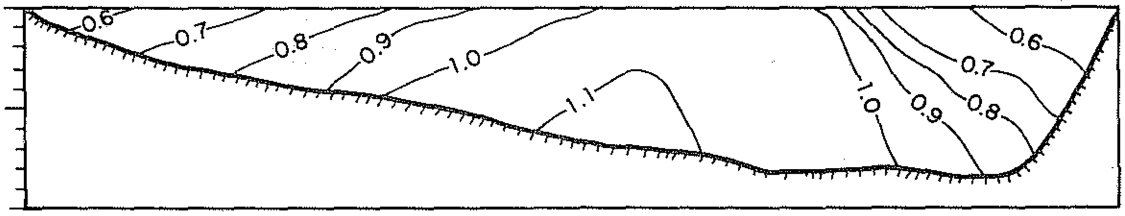


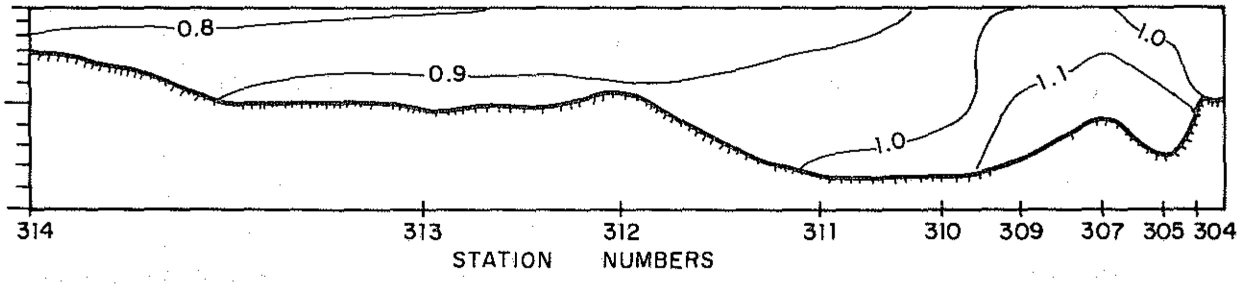
Figure 6. Plan view of the two discharge outlets used by MUS. The submerged pipe on the right discharges directly at the bottom at midstream. The dispersion field is on the left. Either or both may be used.



A: OBSERVED TEMPERATURE DISTRIBUTION, °C, AT THE WATER SURFACE.



B: TEMPERATURE DISTRIBUTION, °C, CROSS-SECTION AT STATION 309



C: TEMPERATURE DISTRIBUTION, °C, AT CENTER OF THE RIVER BETWEEN STATIONS 304-314.

Figure 7. Illustration of the temperature pattern of the view downstream of the MUS thermal discharge.

Heat is transferred across the water surface by several mechanisms. The primary ones are short-wave (solar) radiation, long-wave radiation, exchange with the overlying air through conduction, and liberation of heat by evaporation. Typical values are shown in Figure 8. It should be noted that these are national averages that are not necessarily typical of the interior Alaska area. Typical values of surface heat exchange from an open water surface during a Fairbanks winter are shown in Table I. A method of calculating the approximate temperature downstream from a discharge point for a given atmospheric condition can be devised easily. During a typical Fairbanks winter day with -29°C, the temperature differential between the air and the water is so great that the contribution from solar radiation is practically negligible. As a result the net rejection of heat to the atmosphere is often considered as a linear function of the temperature difference between the air and water. With such a specified value, a simple equation for predicting the length of the ice-free reach can be formulated (Dingman et al., 1968).

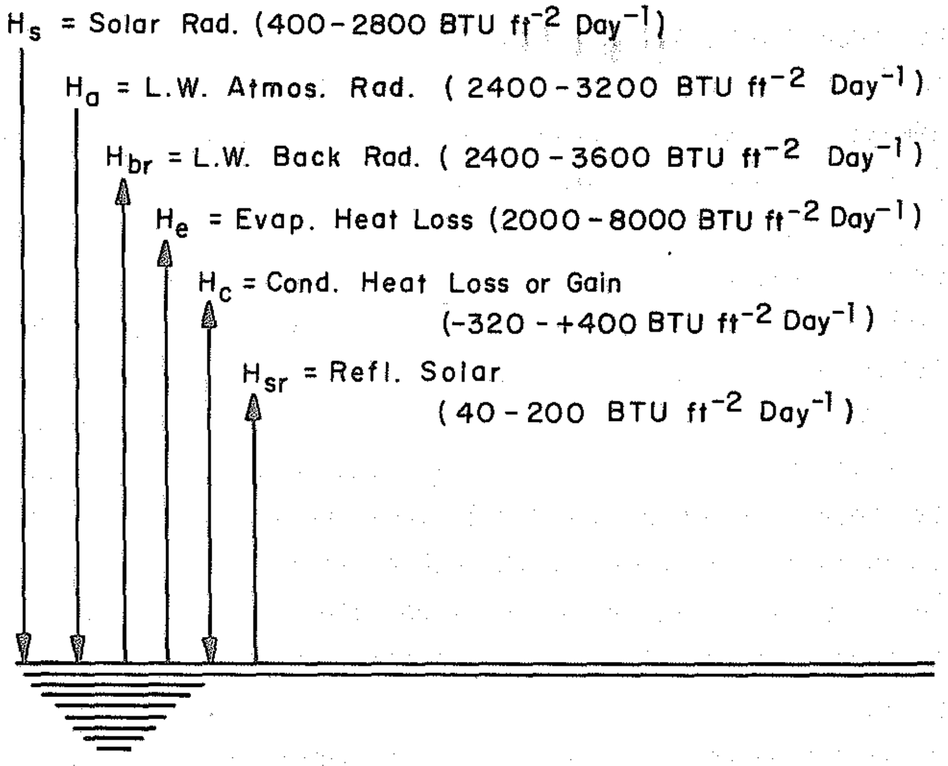
Table I

Values of Surface Heat Exchange from an Open-Water Surface for a Typical Winter Day in Fairbanks, cal/cm^2/day (After Behlke and McDougall, 1973)

Conductive Heat Loss	1109
Long-wave Loss	452
Evaporative Loss	355
Short-wave Gain	10

Effects of Thermal Discharges in Northern Rivers

Most of the essential features of thermal-plant discharge, especially as they relate to the MUS plant, have been described. However, one major feature of the wintertime regime of northern rivers should be re-emphasized. Many such rivers are ice covered during the winter, which prevents evaporative heat transfer and direct cooling by net long-wave rejection and greatly reduces the conduction-convection heat exchange with the low-temperature air. The effect is so great that, compared to open water, there is much less heat rejection. However, the ice cover



NET RATE AT WHICH HEAT CROSSES WATER SURFACE

$$\Delta H = (H_s + H_a - H_{sr}) - (H_{br} \pm H_c + H_e) \text{ BTU ft}^{-2} \text{ Day}^{-1}$$

Figure 8. Some typical values of surface heat exchange at the river water surface. Values are for conditions in temperate climates (From Parker and Krenkel, 1970).

itself represents an equilibrium condition, and any excess heat added to the river will quite likely result in open reaches downstream. It is common, for example, to find Alaskan rivers which have open water regularly throughout the winter as a result of the natural heat caused by the friction of the falling water along the streambed. Therefore, once heat is added to a stream the size of the Chena River, the water will be open downstream for some distance until sufficient cooling has occurred to allow the river to refreeze. A further explanation of the phenomenon with natural rivers is given in Dingman, et al. (1968) and Starosolszky (1970).

It should be noted that little can be done about altering the downriver extent of an open reach in a river by manipulating the discharge mechanism. This is borne out by the study of MUS's two systems which will be compared in a later section.

There are some beneficial effects of having an open reach. The most obvious is allowing free exchange with the oxygen in the atmosphere. The expected result would be an increase in dissolved oxygen as the river passes through a lengthy open reach. Also one would expect a slightly warmer temperature in the vicinity of a large discharge and more livable environment for a number of biological processes. It is highly unlikely, unless the river is very small or the discharge very large, that the temperature of the river would increase enough to cause many adverse effects.

STUDY ACTIVITIES

The funding for the project was received in late 1971 and the field work was done in the winter season of 1971-1972. The bulk of the work was accomplished by two research assistants, William Armstrong and Richard Williams, as graduate students in the Environmental Quality Engineering program at the University of Alaska, Fairbanks. Most of this material is based on their master's theses. Armstrong's is completed while Williams's is available only in an unfinished, unpublished form (Armstrong, 1973, and Williams, 1974).

Measurements were taken throughout the entire Chena River reach from Tank Road to the Pike's Landing area, a distance of about 14 river miles (see Figure 3 and Table II). Most measurements were concentrated in the vicinity of the MUS power plant (see Figure 9 and Table III).

The physical and chemical parameters measured were pH, color, turbidity, solids, and BOD (see Figures 12-20, Table IV, and Appendix A). These are all standard water quality parameters, and measurements were taken according to standard methods. Because of their importance, most emphasis is on measurement and analysis of the temperature and dissolved oxygen.

Temperature

The temperature data were gathered by remote-reading thermisters--some from a boat and the remainder from permanent installations on the bank. Measurements were made both downstream and upstream of the discharge points at the MUS plant (Figure 9 and Table A-II). At these sites, thermisters were inserted (Figure 10) and readings taken at periodic intervals by the field crew.

A summary of some of the acquired temperature data is included in several figures. The ambient temperature of the Chena River during the winter months is shown in Figure 11; detailed data are given in Table

Table II
Location of Chena River Data Collection Sites

Site Location	River Miles
Pike's Landing Road	4.5
College Utilities	5.2
University Avenue Bridge	6.1
Peger Road Bridge	8.2
Fairbanks Sewage Treatment Plant	8.8
MUS Power Plant Outfall	10.1
Cushman Street Bridge	10.4
Wendell Street Bridge	10.8
Fort Wainwright South Sewage Treatment Plant	11.6
Fegre Road Bridge	13.3
Fort Wainwright North Power Plant	14.0
Trainor Gate Road	14.2
Fort Wainwright North Sewage Treatment Plant	15.2
Tank Road Bridge	18.1

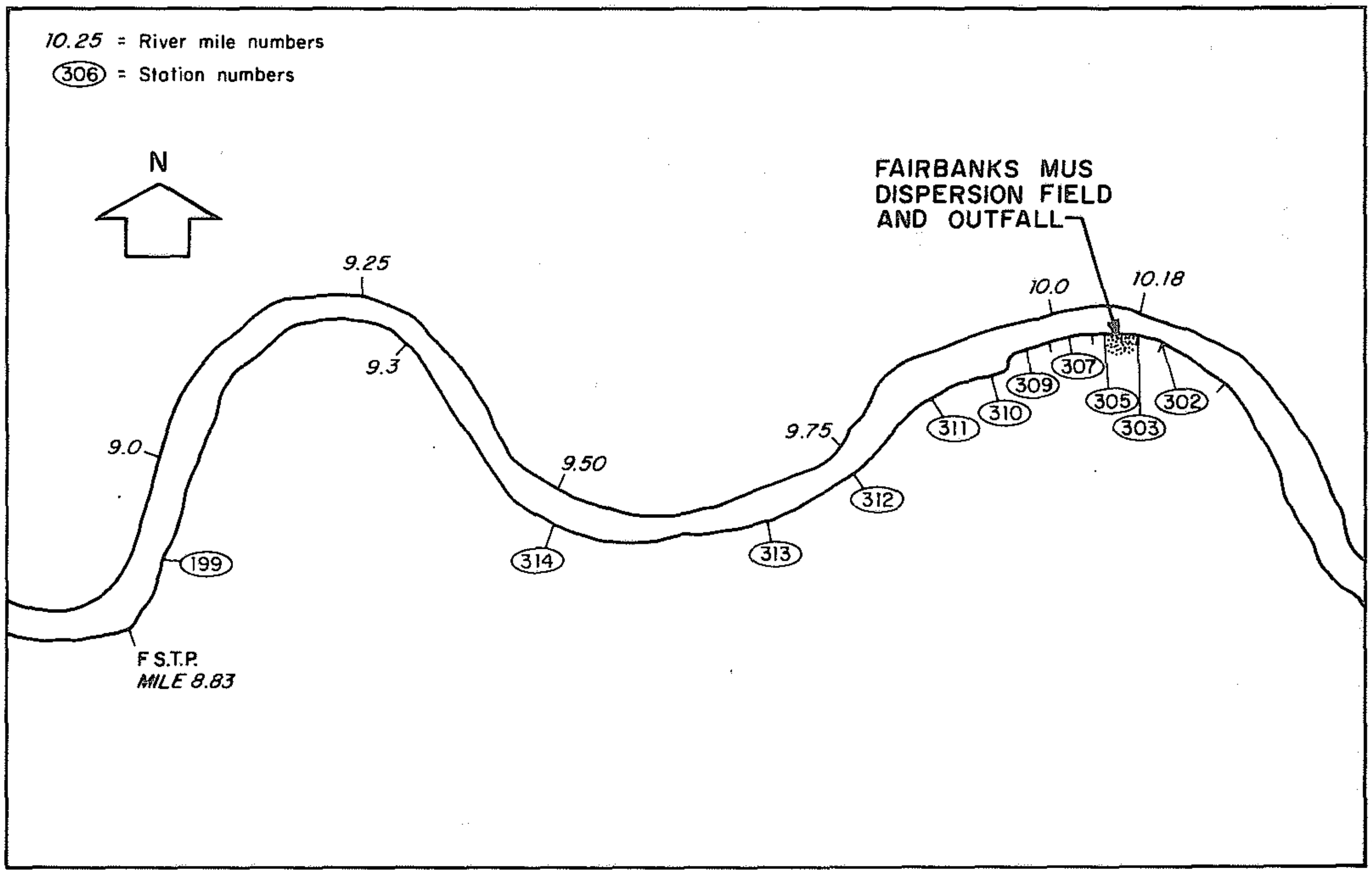


Figure 9. Sampling-station location in the vicinity of the MUS power plant.

Table III
Thermal Discharge Sampling Site Locations

Location	Distance Between Sites (feet)
302-303	105
303-304	80
304-305	80
305-306	50
306-307	100
307-308	100
308-309	100
309-310	200
310-311	300
311-312	500
312-313	500
313-314	1,000
314-199	3,200
TOTAL DISTANCE COVERED	6,315

Table IV
Selected List of Measured Physical Parameters

Date	Location	pH	Color	Turbidity (Jackson Units)	Suspended Solids (mg/l)	Total Solids (mg/l)	Volatile Solids (mg/l)	% Volatile Solids
10-29-71	199	7.15	25	2.9	1.00	118.8	30.4	25.5
10-29-71	302	6.80	25	2.8	1.00	119.6	29.2	24.4
10-31-71	302	6.85	25	3.2	0.05	114.4	31.2	27.2
11-14-71	311	6.85	20	4.8	0.25	125.6	20.0	15.9
11-20-71	301	7.00	15	4.8	0.50	142.8	26.0	18.2
03-24-72	199	7.00	40	11.0	0.50	156.4	12.8	8.1
03-24-71	304	6.90	35	12.5	17.50	182.4	27.6	15.1
06-01-71	301	7.20	50	12.5	93.60	174.4	41.6	23.8

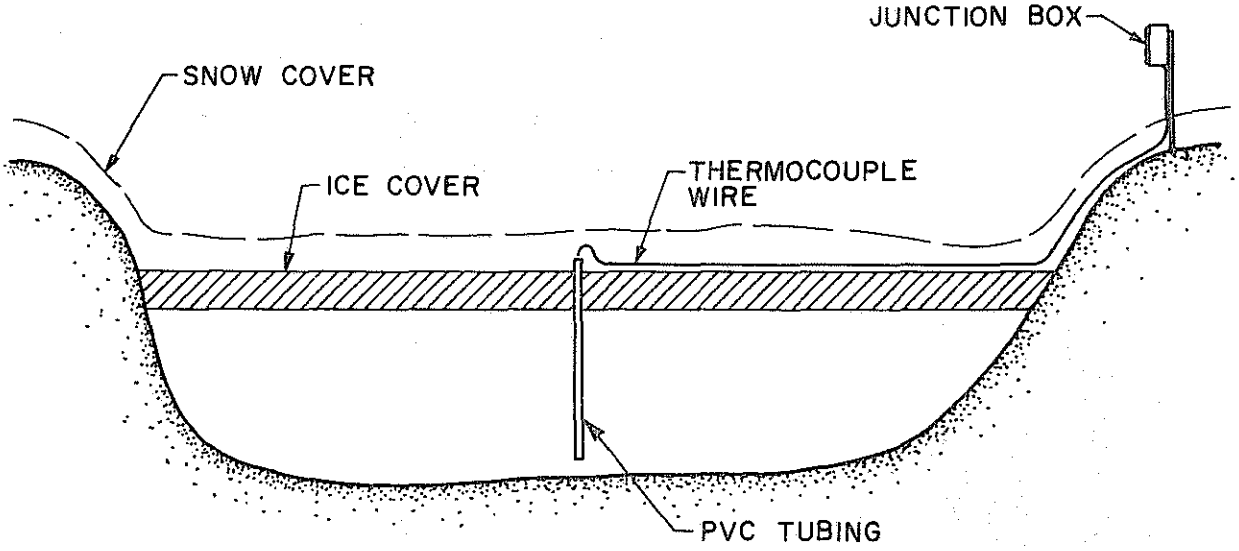


Figure 10. Typical setup for measurement of water temperature using thermocouples.

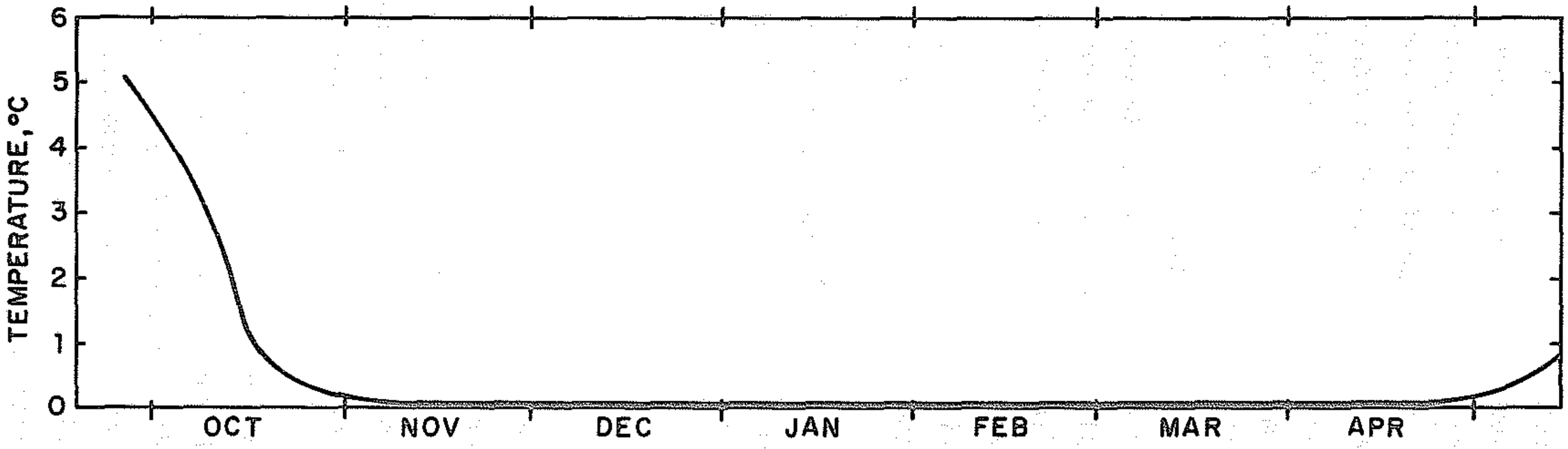


Figure 11. The ambient temperature of the Chena River during the winter months, 1971-1972.

A-II; and a typical temperature distribution is shown in Figures 7A-C. The effect of the discharge is readily apparent from these.

This effect varies somewhat depending upon which discharge method is used. The diffuser pipe allows the warm water to seep up, because of its lower density, to the surface of the receiving water and form a more local, higher temperature flow immediately adjacent to the bank. This water cools rapidly as it is swept down the bank, and as it becomes denser it eventually mixes with the underlying water.

The submerged diffuser jet acts in a somewhat different manner. The jet emerges as a fairly continuous stream of water that then mixes with the colder river water and quickly reaches the dense 4°C temperature. The jet then plunges and flows along the bottom. It is now heavier than the ambient water, and it remains a discrete entity for some distance downstream.

An important part of the study was to take numerous photographs of conditions upstream and downstream from the MUS plant under conditions of the two discharges so that an estimation could be made of open surface area. The calculated difference between them was approximately 7 acres during the coldest months with the submerged jet flow creating a 15-acre ice-free reach and the diffuser pipe flow creating an open 8 acres.

Dissolved Oxygen

The predominant effect of a thermal discharge on a northern river will be to disrupt the normal ice cover; this allows a free exchange of oxygen with the atmosphere. Data gathered in this study are shown in Figures 12-20. Oxygen concentrations upstream and downstream from the MUS power plant are shown in Figure 12 for the months of October through April.

The dissolved oxygen profile for the entire reach from Tank Road, upstream of the south Fort Wainwright sewage treatment plant, to Pike's Landing is shown in Figures 13-15 for several dates.

The measured DO effects on the stream caused by the open reach are shown in Figures 16-20. The effects of the open reach caused by the absence of the ice cover are quite apparent. The increase in DO caused

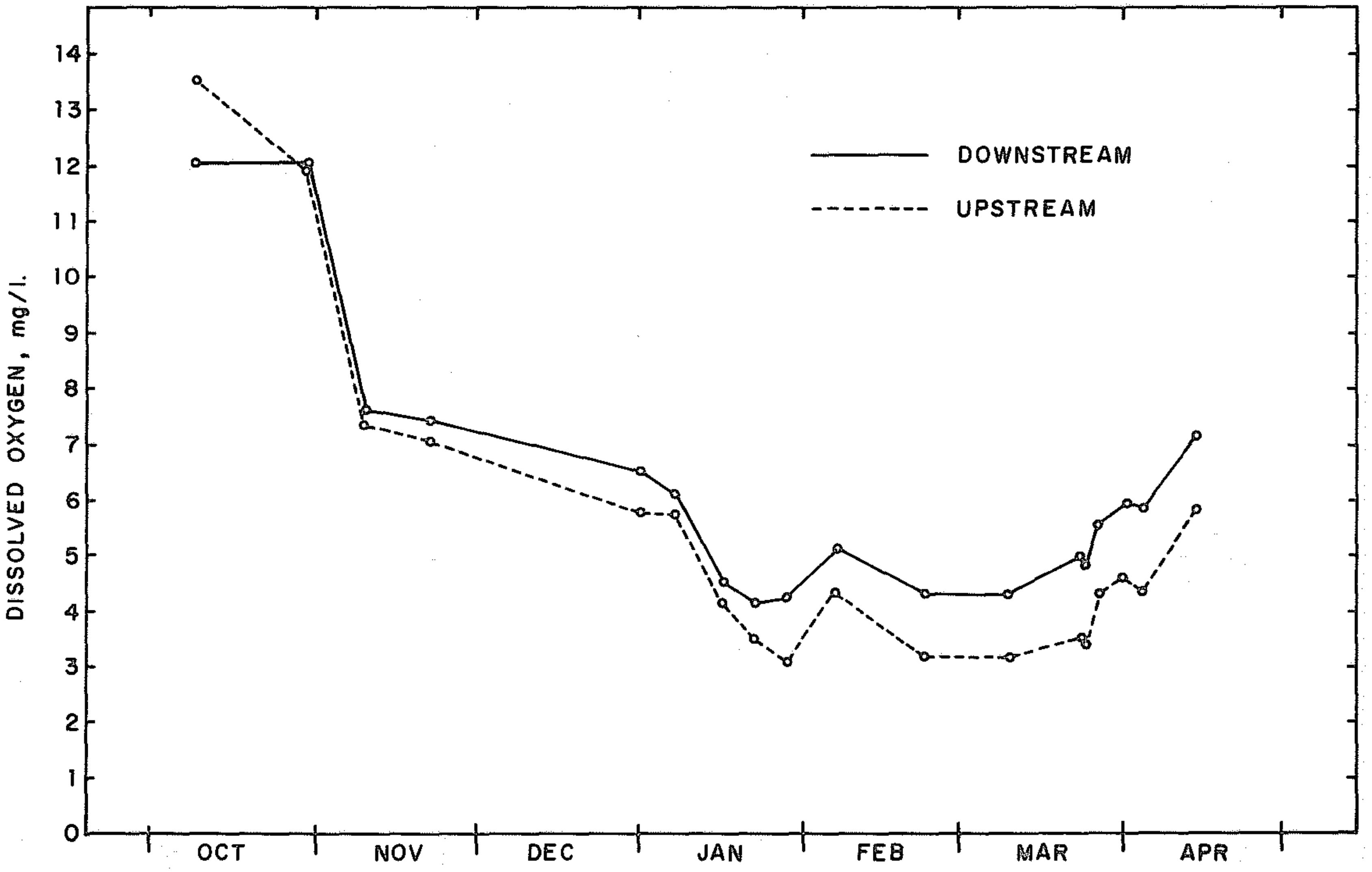


Figure 12. Dissolved oxygen concentrations recorded at the upstream and downstream ends of the MUS power plant open reach.

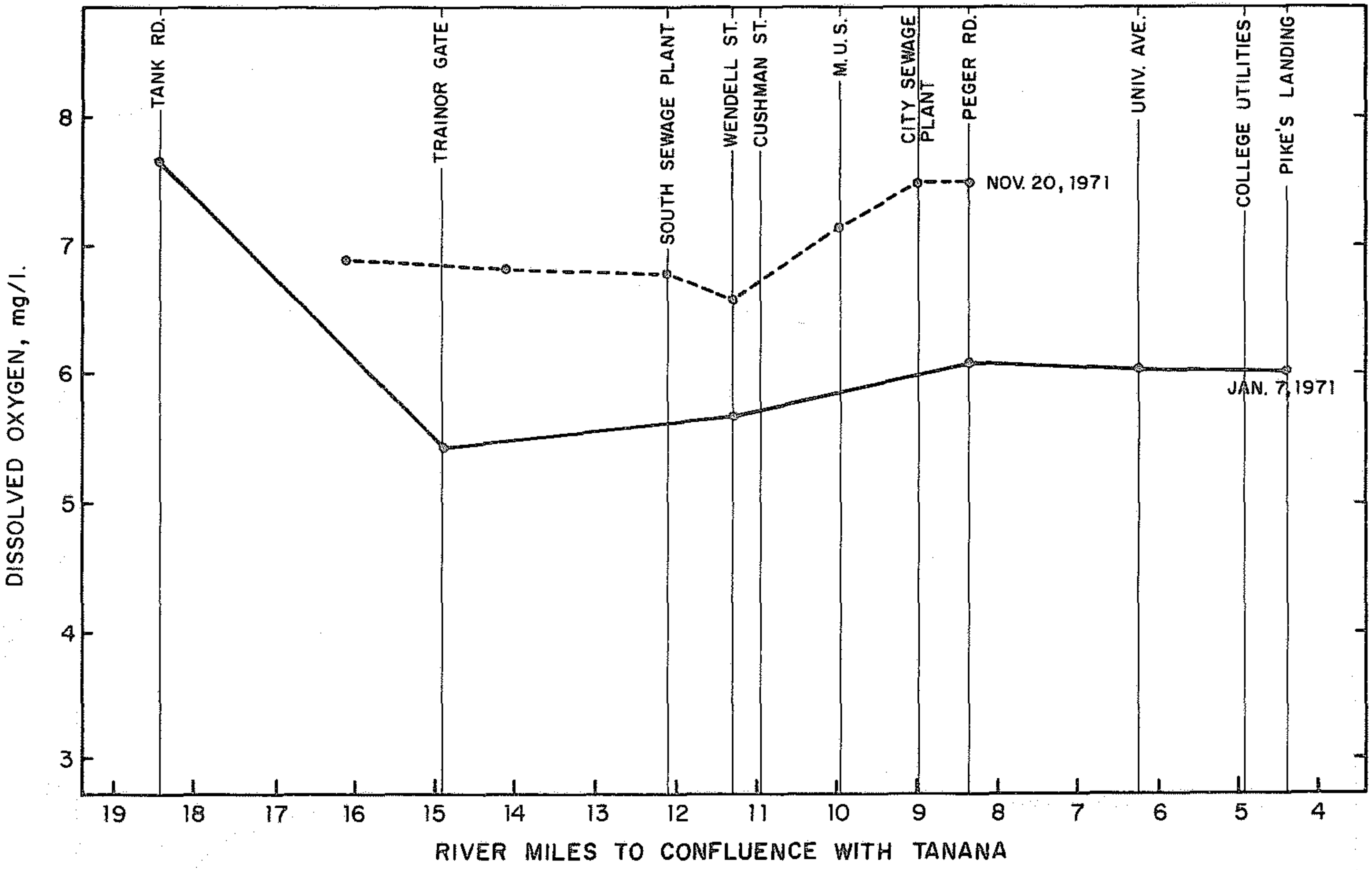


Figure 13. Dissolved oxygen profile of the lower river.

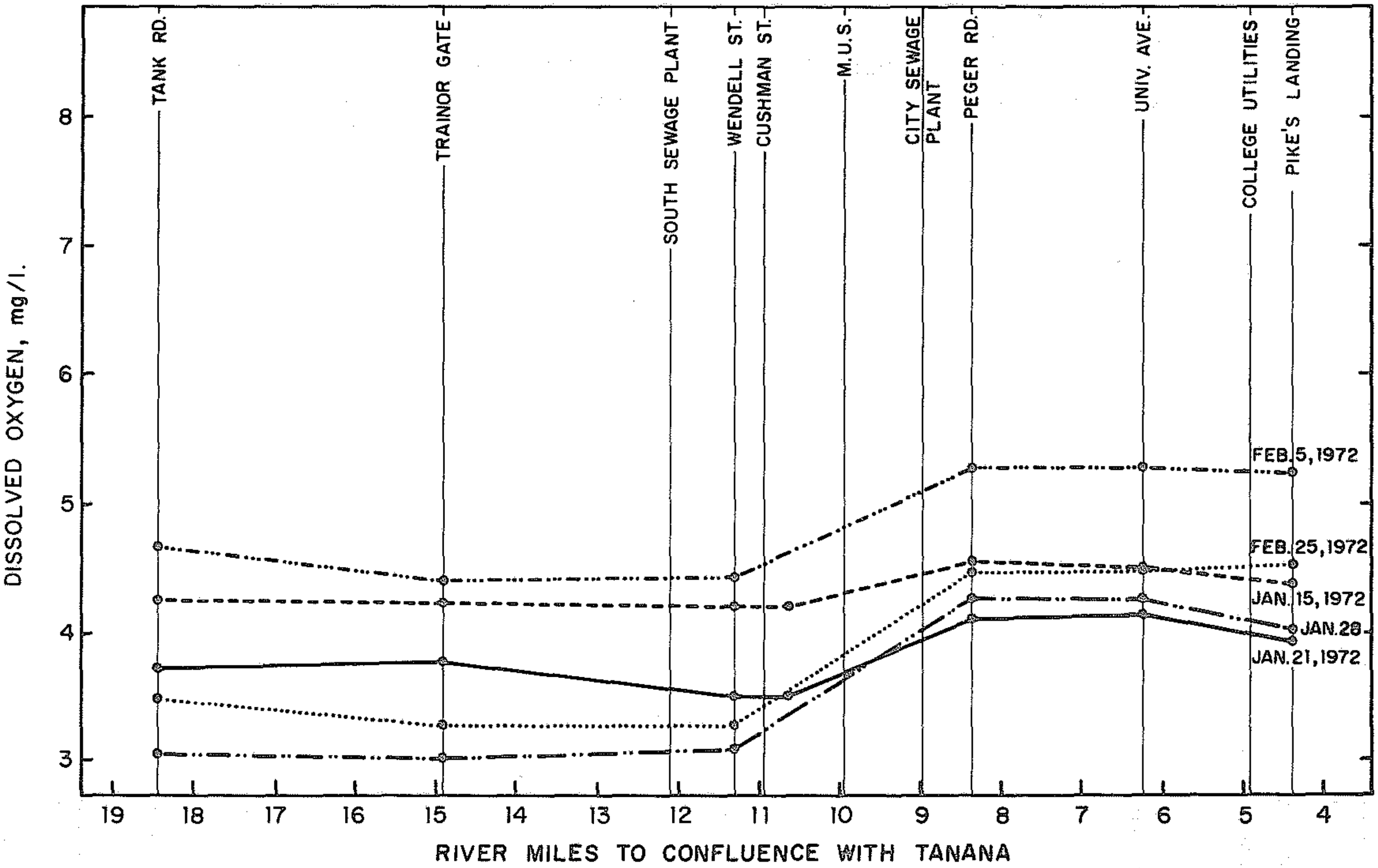


Figure 14. Dissolved oxygen profile of the lower river.

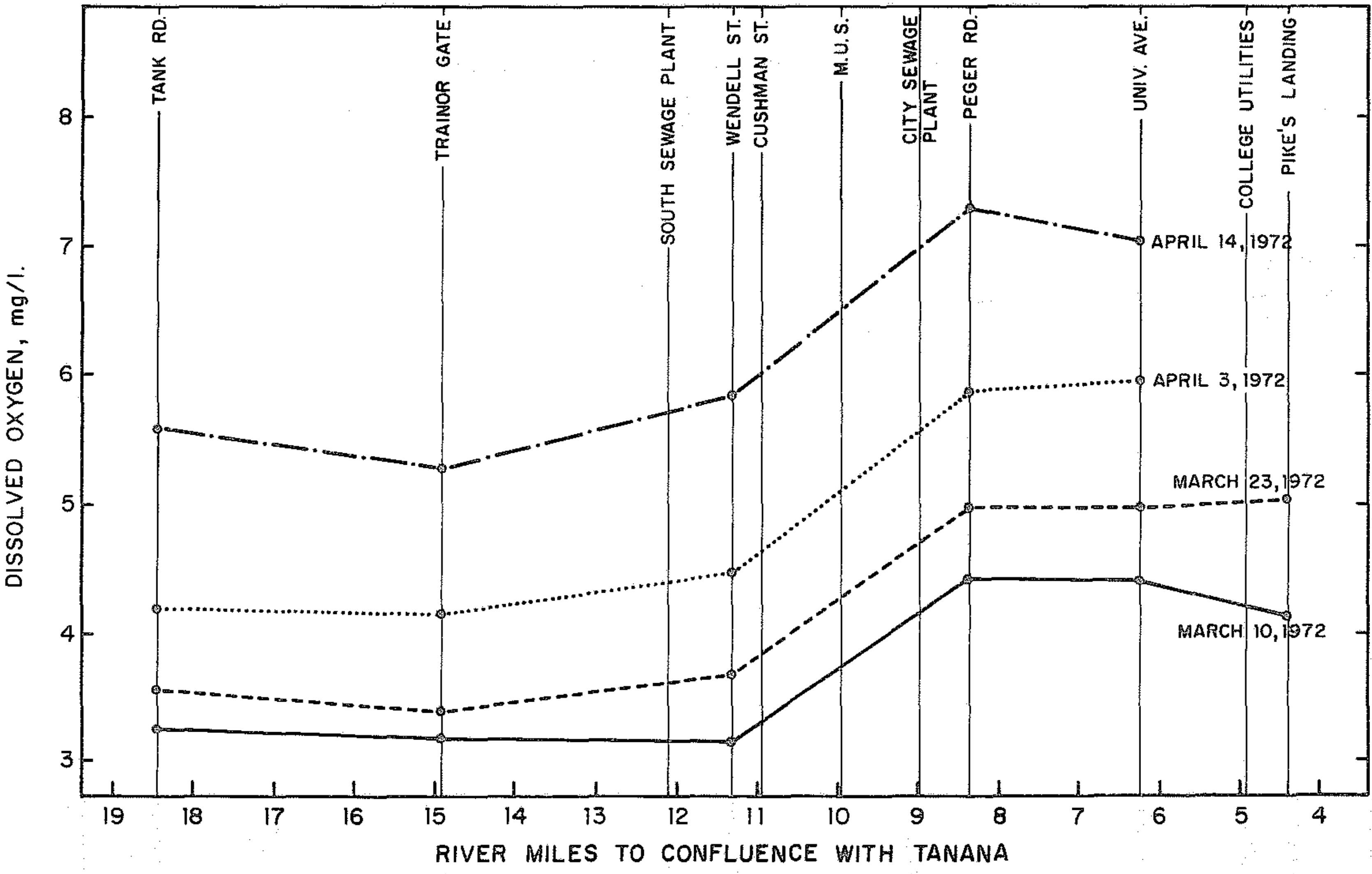


Figure 15. Dissolved oxygen profile of the lower river.

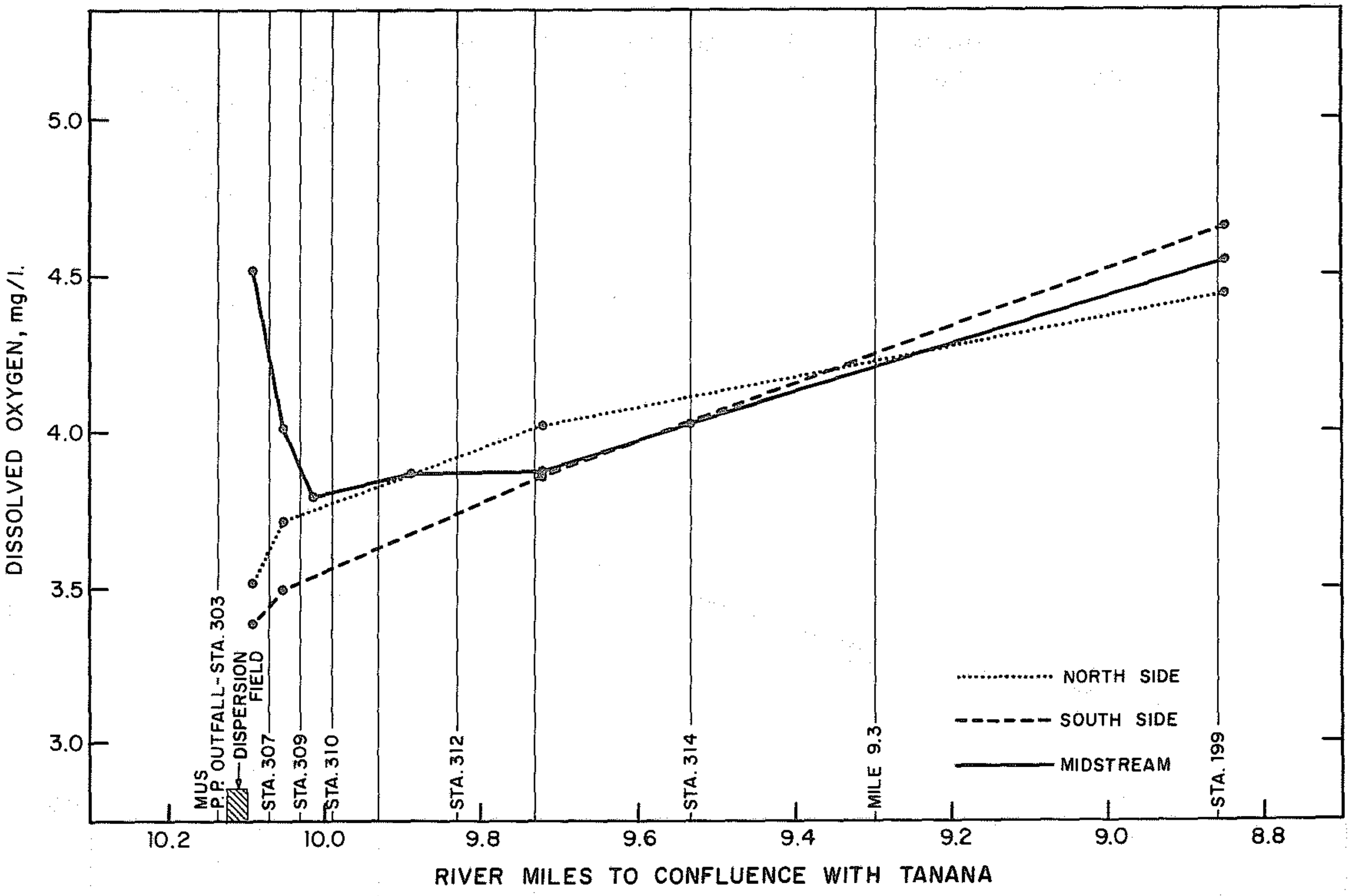


Figure 16. Dissolved oxygen profile of MUS open reach taken January 30, 1972.

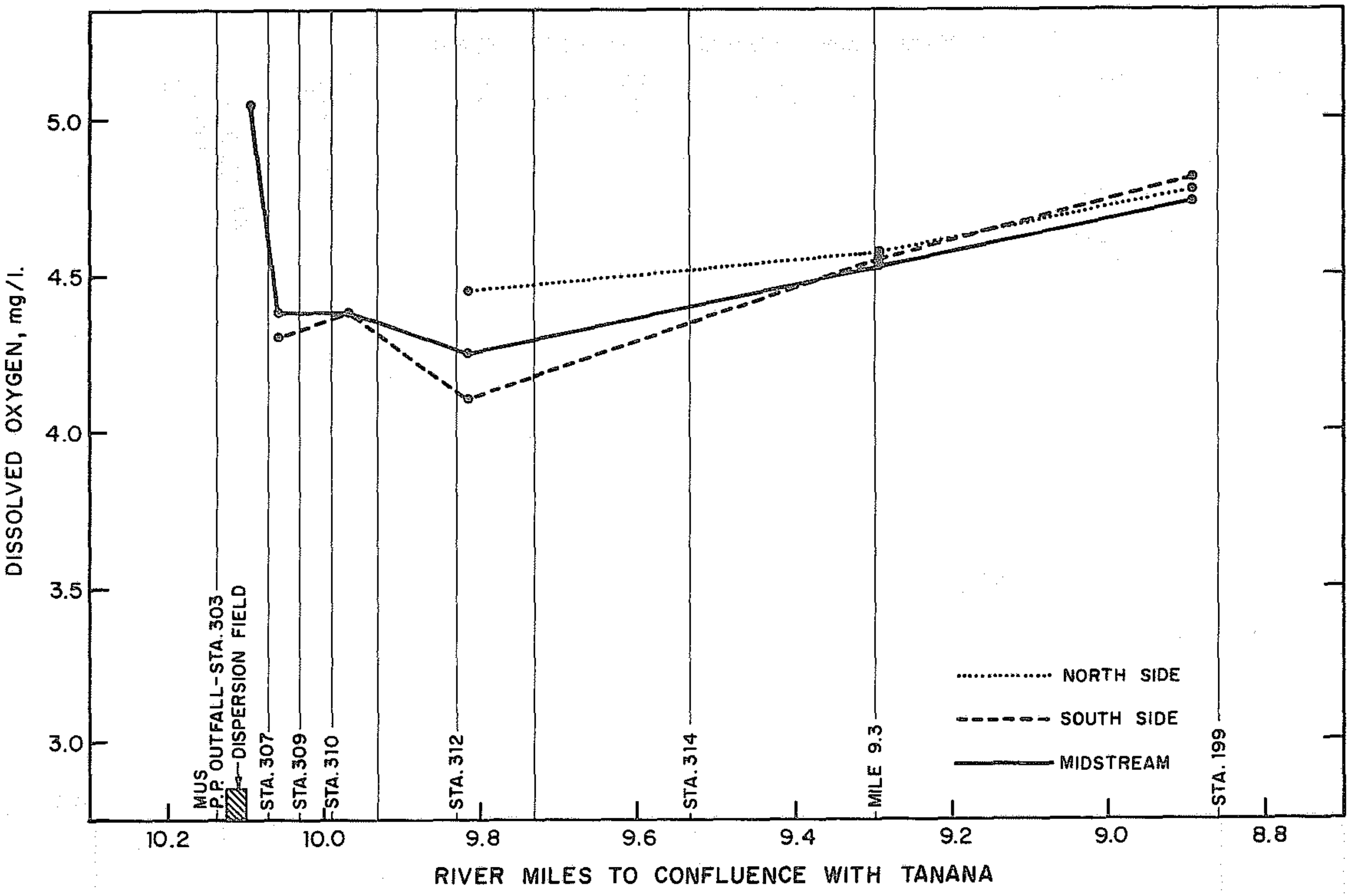


Figure 17. Dissolved oxygen profile of the MUS open reach taken on March 24, 1972.

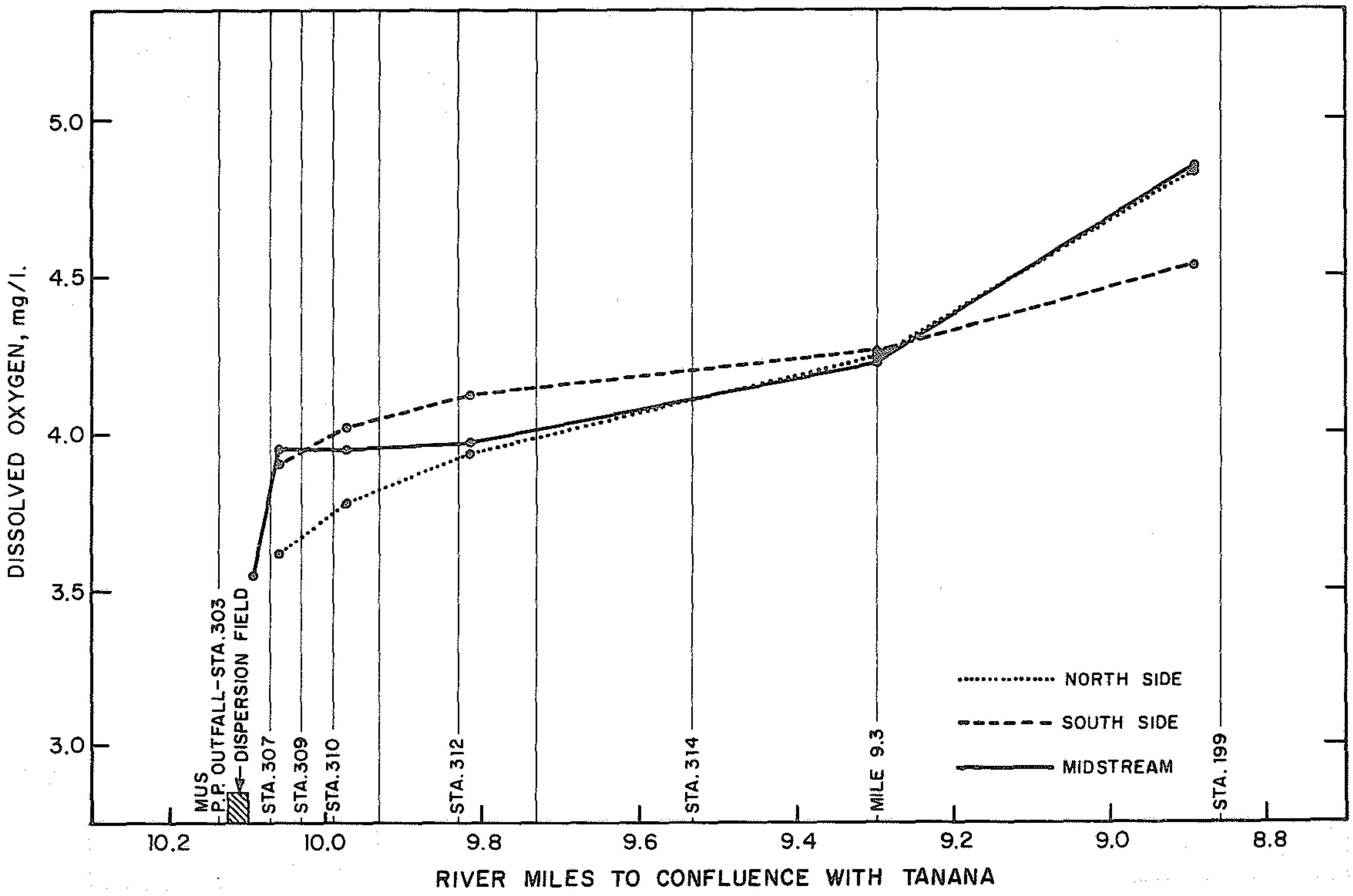


Figure 18. Dissolved oxygen profile of the MUS open reach taken March 26, 1972.

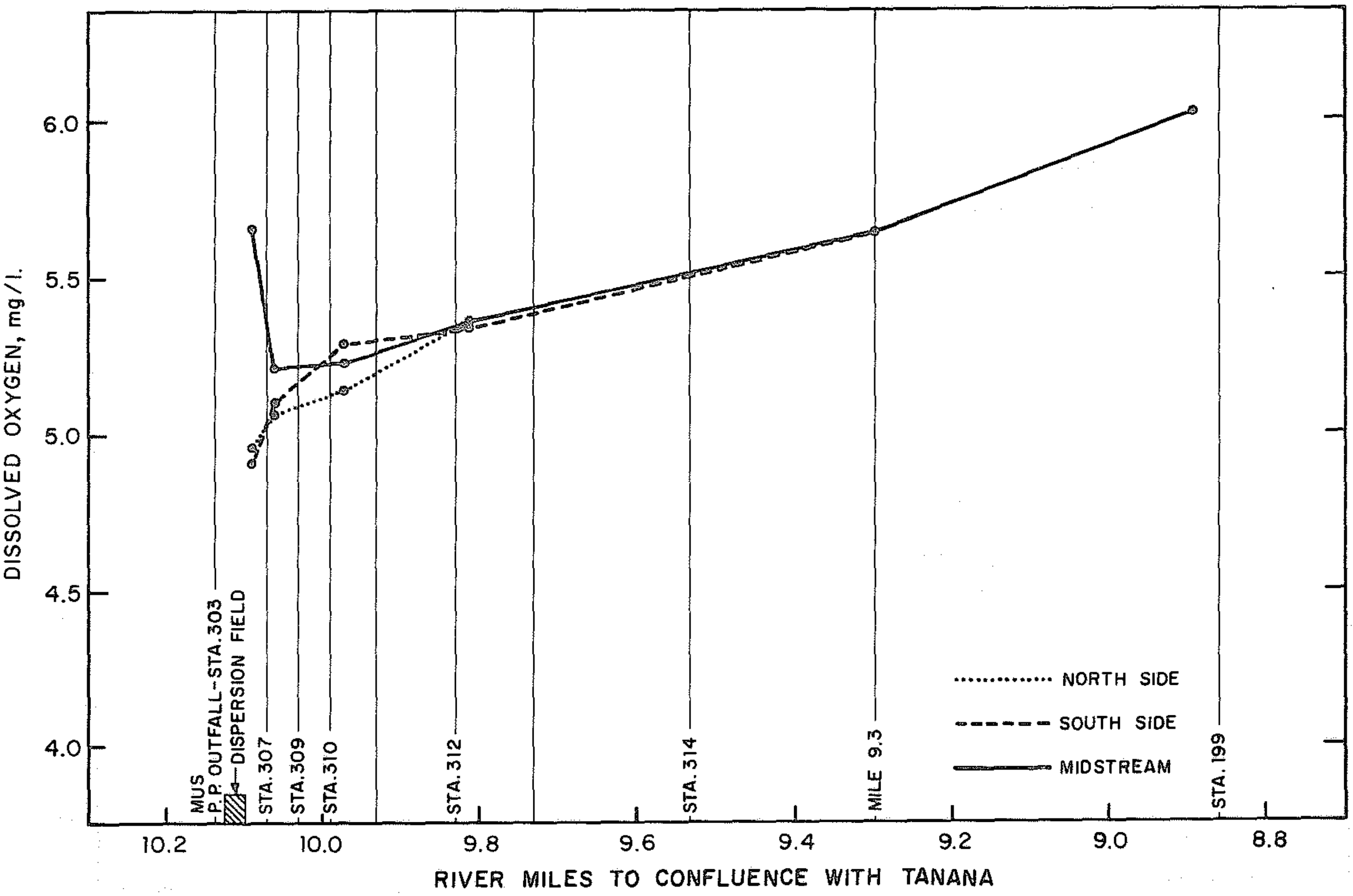


Figure 19. Dissolved oxygen profile of the MUS open reach taken April 1, 1972.

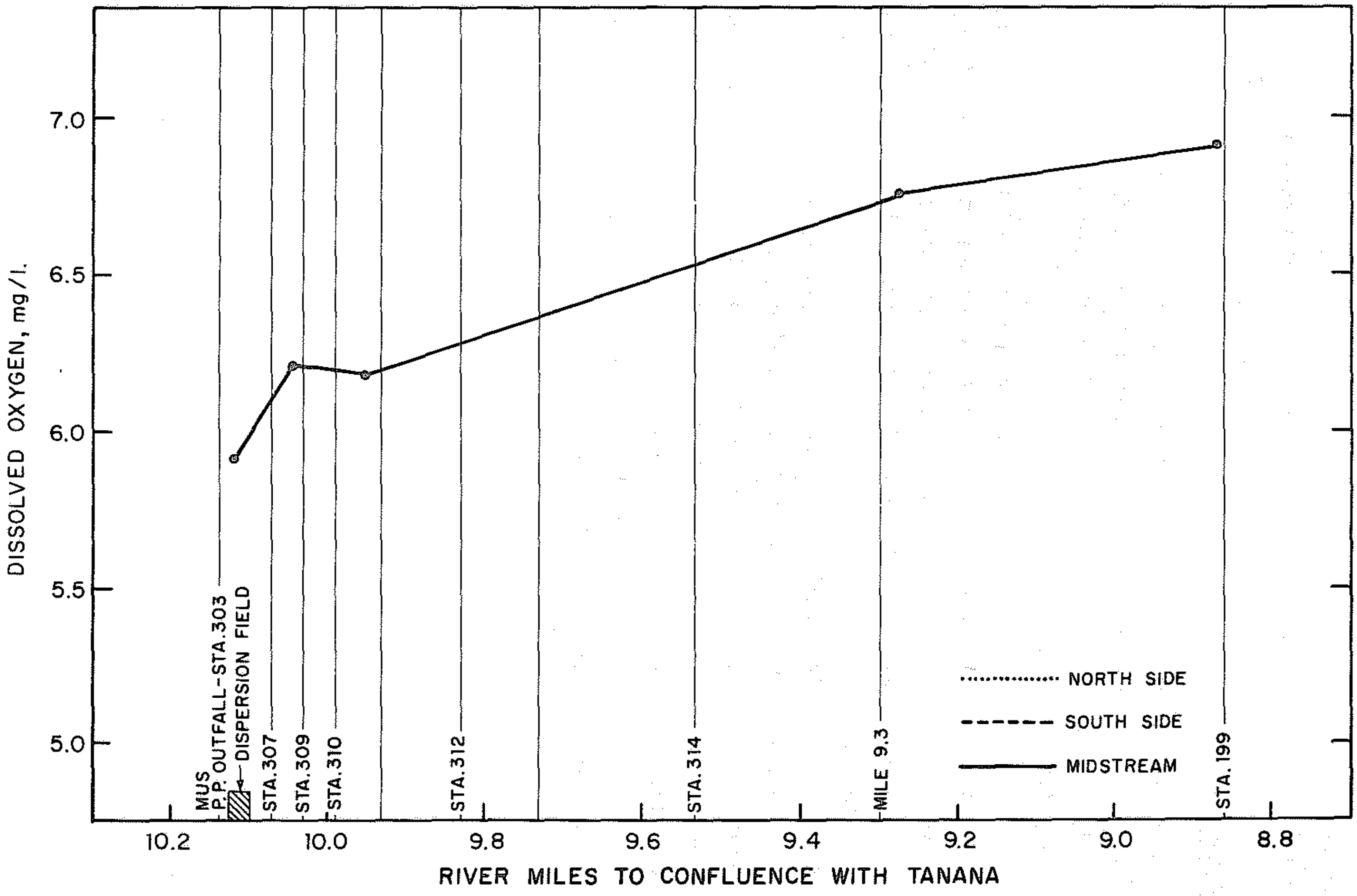


Figure 20. Dissolved oxygen profile of the MUS open reach taken April 12, 1972.

by the open reach is important when one keeps in mind that the river normally has DO values approaching the critical level of 3 parts per million of dissolved oxygen during the colder winter months.

Other Data Acquired

An important feature of any river study is the amount of streamflow. The Chena River flow data from August 1971 to May 1972 is shown in Figure 21a. A corresponding graph of the MUS thermal discharge for this period is shown in Figure 21b.

Several other parameters were calculated as a part of the study. Although we did not detect any important differences or effects from the thermal discharge, they do form an important picture of the overall physical and chemical environment of the stream. Selected values are shown in Table IV, and a more complete list is found in Appendix A. The pH values range from 6.65 to 7.7 with a weighted average of 6.98. The color analysis indicates high values in spring and early winter. Turbidity varies quite widely from 0.3 to 36.5 The consistently higher values were recorded during spring breakup and early summer, as might be expected, with some sporadically high values in early winter. Measurement of total solids indicated values from 114.4 to 608.8 mg/l during the low winter flow.

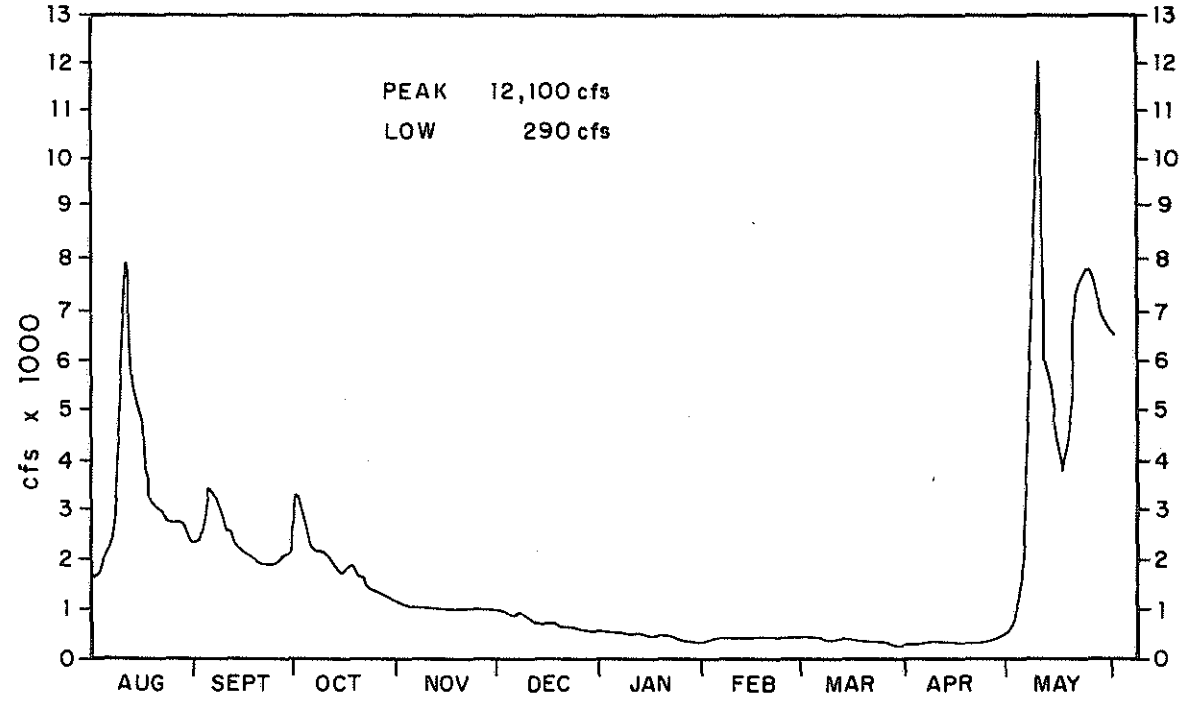


Figure 21a. Chena River flow for winter of 1971-72.

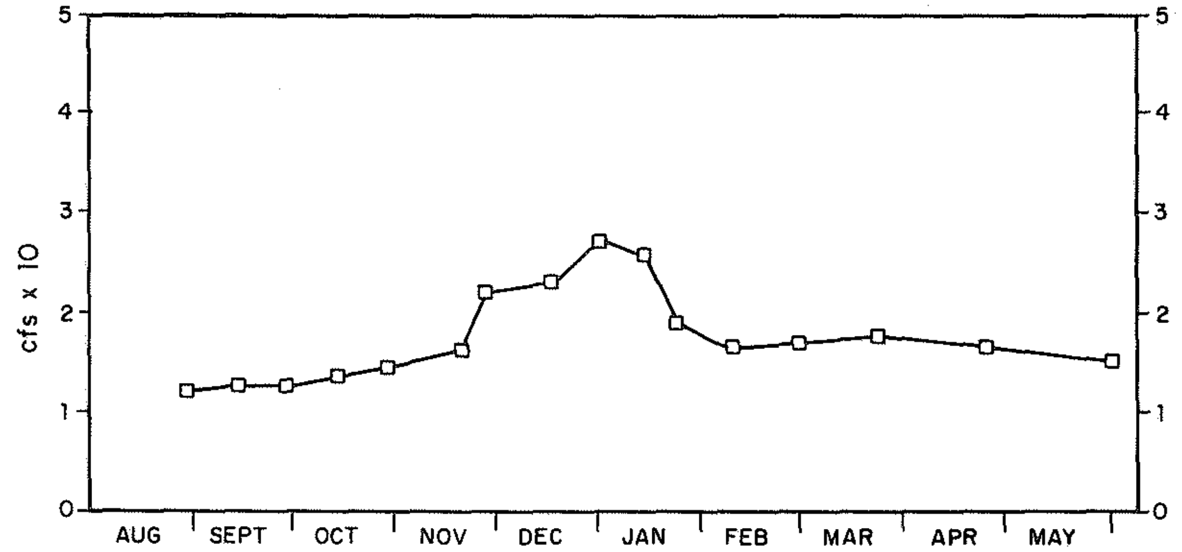


Figure 21b. MUS thermal discharge flow for winter of 1971-72.

SUMMARY AND CONCLUSIONS

This report has described a 1971-72 winter study of the thermal discharge into the Chena River. Several features of thermal plant dynamics, thermal phenomena, and discharges have been covered and the general nature of heat exchange of an open water surface with the atmosphere discussed. This section presents general conclusions based on the results of the study. Comments will be concentrated in two areas: 1)effects of the thermal discharge on the dissolved oxygen regime of the Chena River, and 2)the nature of the temperature regime in the vicinity of two different discharge schemes.

A great deal of effort was directed toward obtaining an accurate picture of the dissolved oxygen regime of the Chena River. DO measurements are more difficult and time comsuming compared to temperature measurements, especially at -40°C. However, we were able to obtain enough data to indicate several definite characteristics of the effect of the power plant discharge. The Chena River was, at the time of the study, affected by upstream sewage effluents which, in combination with a rather continuous ice cover throughout much of the river, caused a very low DO content of the stream upstream of the MUS plant. The values generally ranged about 3 or 4 ppm. However, as this range of values is typical of that found in other ice-covered subarctic streams, we can expect the winter DO regime at the present time to be approximately the same.

The most important result of the study is that, throughout the winter months, we consistently found an improvement in DO content as the stream water passed through the open water reach below the MUS plant. This effect is entirely expected and is a result of reaeration through the exposed water surface, a process prohibited by the ice cover upstream. This reaeration was most effective during the months of February and March, since during these times the upstream water nearly reached a

DO level of 3 ppm and achieved a recovery to over 4 and as much as 5 ppm downstream of the open reach. The primary effect of thermal discharge is one of a net benefit to the Chena River.

The results of the thermal part of the study are based on temperature data gathered both downstream from the discharge point and across the stream width. The primary emphasis of this particular aspect of the study was aimed toward determining the effects of the two alternative discharge methods used at the MUS plant. These two methods were direct discharge into the approximate center of the stream through a submerged pipe and discharge through a dispersion field installed along one bank of the stream downriver from the MUS plant. Because of the relatively limited use of the dispersion field during the study period, most of our data pertains to the submerged discharge. Some of the effects of the two discharge methods may be summarized as follows:

Submerged Discharge Method

1. The effluent water appears to mix almost completely within a few feet of the discharge pipe and quickly achieves a mixed temperature of about 1°C.
2. In comparing downstream temperatures with the incoming river water temperature of about 0.1°C, there seldom appears to be more than a 1°C rise after mixing.
3. We did note an interesting plume rise and subsequent plunge as the mixed effluent and river water obtained the heavier 4°C temperature. Because of this, there appeared to be higher-temperature (denser) water in the river bottom downstream from the discharge point.
4. Except for the slight stratification mentioned above, the stream appeared to be well mixed, both upstream and downstream and across its width throughout the open area. We seldom observed temperature differences of more than 2°C.

This well-mixed condition is a result of the Chena River's high velocity flow through this fairly shallow area. Therefore, although the surface water is lighter than that underlying it, it mixes quite readily with the water below because of turbulent eddies.

Dispersion Field Discharge

1. The main effect of the dispersion field is that it operates as a surface spreading scheme. That is, as the warmer effluent water emerges from the diffuser pipe underground, it rises and enters the stream along the surface.
2. The effect of the surface spreading is that the heat and water vapor rejection rate are more intense at the higher temperatures of 5° to 10°C, and both heat and water vapor are rejected at a faster rate closer to the plant.

Comparisons of the Schemes

1. During the month of December there appeared to be about 15 acres of open water below the MUS plant when the jet discharge method was used as compared to about 8 acres of open water when the dispersion-field method was used.
2. When using the dispersion field, the initial heat-transfer rate was about two times higher because of the higher surface area-to-volume ratio created as the effluent water formed a shallow flow over and interflow within the gravelled section bordering the river.
3. Because of the relatively low ratio of plant discharge to river flow and the fairly high velocity through this stretch, the discharge water becomes very well mixed once the 4°C temperature is reached. This condition is achieved immediately with the jet discharge and somewhat further downstream with the dispersion field.
4. The most noticeable effect when changing from the jet to the dispersion-field discharge method, with its initially higher heat transfer rate, is the growth of the ice from the opposite stream bank; this narrows the opening, rather than changing the distance to ice cover downstream.
5. Regardless of method, as the water emerges from the plant area it very quickly drops to near freezing, that is 1°C or less, and continues to lose heat until subsequent freezing downstream.

Effect on Biota

1. The effects of small increases in temperatures and significantly increased dissolved oxygen are well established in the literature. In general, some changes in the ecology of the stream may be expected, the thermal discharge perhaps increasing the activity of the river's biota.
2. A biota study, usually quite complicated and expensive, may have value in its own right but probably would yield little information relevant to the question of future heat-rejection magnitudes and methods.
3. Because upstream sewage discharge has now been diverted from the Chena River, it appears that there will not be a great deal of BOD stress on the stream biota in the vicinity of thermal discharge.
4. As the phenomenon is so local, even a considerable reduction of the present heat load would have no appreciable effect on downstream river water temperature and hence on temperature-dependent biotic activity.

Effect on Ice Fog Situation

A reduction in the total heat load would proportionally reduce the vapor rejection from the water surface, since the ratio of evaporative heat transfer to total heat transfer remains almost constant over the temperature range experienced at the MUS plant. Obviously, this reduces the ice fog contribution to the atmosphere. However, a quantitative prediction of this is practically impossible, as existing methods of measuring ice fog concentrations are quite imprecise. The ratio of water vapor put into the Fairbanks atmosphere by the MUS discharge to that from other sources is not known and is extremely difficult to estimate. Any proposed reduction of the MUS plant thermal discharge would be arbitrary and could not be shown to satisfy any established water or air quality standard.

In summary then, the main results of the study are:

1. The present MUS thermal discharge does not greatly increase the temperatures of the Chena River. This is primarily the result of relatively low discharge and cooling requirement relative to the Chena River flow.
2. The discharge does cause an open reach of water in the process of thermal rejection. The total amount of energy dissipated equals the amount injected by the thermal discharge. The resulting open reach varies from about 8 to 15 acres depending on the discharge method used.
3. The open stretch may be controlled somewhat by alternative discharge schemes. The dispersion method results in a more concentrated heat and mass rejection while the submerged discharge method results in the heat and vapor rejection being more spread out.
4. The primary effect of the thermal discharge on the stream is a definite increase in dissolved oxygen content of the river as it passes through the MUS discharge reach. The open reach caused by the thermal discharge allows the water to recover as much as 60% from about 3 ppm to 4-5 ppm.
5. The reduction or prevention of thermal discharge at the MUS location would result in little change in the stream temperature downstream from the discharge point. It would quite likely result in a reduction in dissolved-oxygen content of the stream.

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APPENDIX A

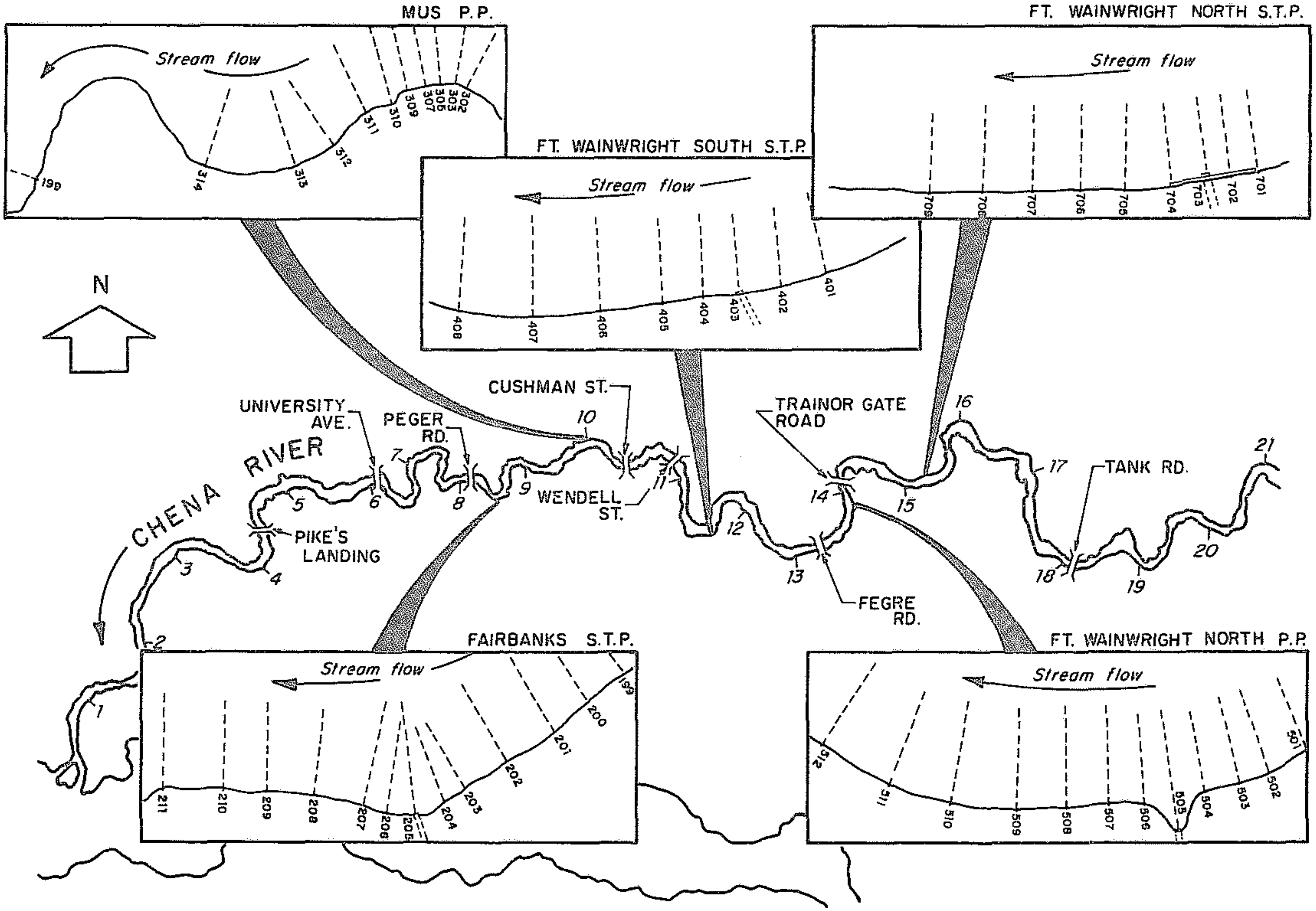

Figure A-1: LOCATION MAP FOR SAMPLING STATIONS LISTED IN TABLES A-I & A-II

Table A-I
Complete List of Physical Parameter Values

Date	Location	pH	Color	Turbidity Jackson Units	Suspended Solids mg/l	Total Solids mg/l	Volatile Solids mg/l	% Volatile Solids
10-29-71	302	6.80	25	2.8	1.00	119.6	29.2	24.4
	199	7.15	25	2.9	1.00	118.8	30.4	25.5
	211	6.85	30	3.6	0.50	118.4	36.0	30.4
10-31-71	401	6.85	20	3.5	0.50	135.2	41.6	30.7
	302	6.85	25	3.2	0.50	114.4	31.2	27.2
	201	6.90	25	3.7	0.50	122.8	40.4	32.8
11-14-71	503	6.90	10	3.8	0.50	143.6	17.6	12.2
	505	7.70	70+	22.5	3.50	233.6	29.2	12.5
	311	6.85	20	4.8	0.25	125.6	20.0	15.9
	311A	6.90	20	4.7	1.50	130.8	15.2	11.6
	314	6.85	15	4.5	0.25	130.0	16.0	12.3
	314A	6.85	10	4.5	1.00	125.6	16.0	12.7
	205	7.45	70+	36.5	92.00	608.8	222.8	36.5
	211	6.90	20	4.8	0.50	126.8	20.4	16.0
11-20-71	701	6.90	15	3.1	0.25	129.6	19.6	15.1
	701A	6.95	15	3.2	0.50	134.4	20.4	15.1
	503	7.00	15	3.4	0.50	152.8	22.0	14.3

A=alternate, nearby sampling site

continued

Table A-I Continued

Date	Location	pH	Color	Turbidity Jackson Units	Suspended Solids mg/l	Total Solids mg/l	Volatile Solids mg/l	% Volatile Solids
11-20-71	401	7.00	10	4.2	0.50	136.0	22.8	16.7
	Wendell	7.00	15	4.8	0.40	137.6	22.4	16.2
	Wendell	6.90	15	4.8	0.50	136.8	23.2	16.9
	301	7.00	15	4.8	0.50	142.8	26.0	18.2
	201	6.90	10	5.2	0.50	136.0	21.2	15.5
	211	7.00	10	5.6	0.50	135.6	24.8	18.2
01-07-72	Tank	7.10	10	3.0	1.50	144.4	20.4	14.1
	Trainor	7.00	10	4.2	0.25	130.0	20.8	16.0
	Wendell	6.85	15	5.1	0.25	137.6	24.0	17.4
	Peger	6.95	15	5.4	0.25	140.0	24.0	17.1
	University	7.10	15	5.0	0.25	136.2	24.4	18.0
	Pike's	6.95	15	4.8	0.50	137.2	24.8	18.0
01-28-72	Tank	6.70	15	3.6	2.00	132.4	26.8	20.2
	Trainor	6.75	20	3.1	0.25	135.2	27.6	20.4
	Wendell	6.70	15	3.5	0.50	136.8	24.4	17.8
	Peger	6.75	20	5.6	4.50	158.0	28.0	17.7
	University	6.80	15	2.5	1.00	145.2	22.4	15.4
	Pike's	6.80	15	3.2	1.50	149.6	29.6	19.9

continued

Table A-I Continued

Date	Location	pH	Color	Turbidity Jackson Units	Suspended Solids mg/l	Total Solids mg/l	Volatile Solids mg/l	% Volatile Solids mg/l
02-05-72	Tank	6.70	25	5.7	0.50	134.4	22.8	16.9
	Trainor	6.70	20	5.6	0.50	138.0	25.6	18.5
	Wendell	6.75	20	6.0	0.50	142.8	22.4	15.6
	Peger	6.90	30	7.7	1.00	155.6	24.8	15.9
	University	6.85	25	6.9	0.50	149.6	26.8	18.9
	Pike's	6.85	20	6.8	0.50	146.8	27.2	18.5
03-05-72	Tank	6.65	30	7.8	0.25	134.0	19.6	14.6
	701	6.7	30	7.2	---	136.8	16.4	11.9
	Trainor	6.7	30	7.8	0.50	138.8	18.0	12.9
	503	6.80	35	7.7	0.50	152.0	18.0	11.8
	505	7.70	70+	24.0	8.00	227.2	18.0	7.9
	401	6.80	25	8.5	0.50	146.4	20.0	13.6
	403	7.40	70+	32.0	57.50	427.6	102.0	23.8
	Wendell	6.80	25	8.0	0.50	146.4	18.4	12.5
03-10-72	Tank	6.80	30	8.9	0.50	137.2	20.4	14.8
	Trainor	6.80	25	7.5	0.50	141.6	21.6	15.2
	Wendell	7.00	25	8.3	0.25	144.0	18.4	12.7
	Peger	6.90	35	7.1	0.50	148.8	17.2	11.5
	University	7.00	30	8.0	0.25	147.2	21.6	14.6
	Pike's	7.00	35	8.2	0.50	163.6	22.0	13.4

continued

Table A-I Continued

Date	Location	pH	Color	Turbidity Jackson Units	Suspended Solids mg/l	Total Solids mg/l	Volatile Solids mg/l	% Volatile Solids
03-23-72	Tank	6.80	25	8.2	0.25	136.8	5.6	4.0
	Trainor	6.90	30	8.4	0.50	147.2	11.6	7.8
	Wendell	6.90	30	9.4	0.25	142.8	7.6	5.3
	University	7.00	40	10.5	0.25	157.2	12.8	8.1
	Pike's	7.00	40	10.0	0.50	156.8	15.6	9.9
03-24-72	304	6.90	35	12.5	17.50	182.4	27.6	15.1
	312	6.90	30	11.0	0.50	154.8	10.8	6.9
	199	7.00	40	11.0	0.50	156.4	12.8	8.1
	211	6.90	35	11.5	1.00	164.0	19.2	11.7
	Peger	6.80	45	11.5	2.00	156.8	16.8	10.7
04-03-72	Tank	6.80	15	1.2	0.80	138.8	27.6	19.8
	Trainor	7.20	10	0.3	0.80	141.6	31.2	22.0
	Wendell	7.20	10	2.1	2.80	154.8	30.8	19.8
	Peger	6.80	10	0.4	6.80	162.8	36.0	22.1
	University	7.10	10	4.8	4.40	158.4	34.0	21.4
04-28-72	401	7.30	10	0.8	20.40	139.2	27.6	19.8
	Peger	7.40	10	1.4	6.00	152.8	32.0	20.9

continued

Table A-I Continued

Date	Location	pH	Color	Turbidity Jackson Units	Suspended Solids mg/l	Total Solids mg/l	Volatile Solids mg/l	% Volatile Solids
06-01-72	Tank	7.30	45	13.0	92.00	163.6	33.2	20.2
	703	7.30	45	13.0	102.00	187.6	36.0	19.1
	Trainor	7.30	50	11.5	92.80	173.6	34.0	19.5
	Fegre	7.30	45	11.5	102.40	173.2	32.0	18.4
	403	7.20	45	12.5	84.00	164.4	36.0	21.8
	Wendell	7.20	45	11.5	86.00	165.2	35.2	21.3
	301	7.20	50	12.5	93.60	174.4	41.6	23.8
	201	7.20	40	12.0	72.80	151.6	46.4	30.6
	Peger	7.20	45	12.5	82.80	164.0	44.8	27.3
	University	7.20	50	9.5	82.80	142.0	43.6	30.7
	Pike's	7.20	45	10.5	74.80	154.4	35.2	22.7

Table A-II
Water Temperature in the Vicinity of the MUS Thermal Discharge, °C

Date	Station	Depth Surface	6"	1'	2'	3'	4'	5'	6'	7'	8'	Distance from South Bank, ft.
09-26-71	301	5.1		5.1	5.1	5.1	5.1	5.1				5
	303	5.1	5.1	5.1	5.1	5.2	5.2					15
	303	5.2	5.3	5.4	5.5	6.0	5.9	5.9	6.0			25
	303+25	5.1		5.2	5.2							15
	303+25	5.2	5.2	5.1	5.1	5.1	5.0					25
	303+55	5.0	5.0	5.1		5.3						15
	303+55	5.0	5.0	5.1	5.1	5.2	5.2					25
	304	5.0	5.1	5.2		5.4						15
	304	5.0	5.0	5.1	5.2	5.5	5.8					25
10-10-71	301	2.0	2.0	2.0		2.0			2.0			15
	302	2.2	2.2	2.2	2.2	2.2	2.5	2.4				50
	302	2.2	2.1	2.1	2.1	2.1		2.1				60
	303	2.5	2.8	2.8	3.0	3.5	3.8	5.0	5.8	6.5		50
	303	2.1			2.1	2.2	2.4		2.7	2.8		60
	303	2.2	2.1	2.0	2.0	2.0	2.1	2.1	2.2	2.5		70

continued

Table A-II (continued)

Date	Station	Surface	6"	1'	2'	3'	4'	5'	6'	7'	8'	Distance from South Bank, ft.
10-29-71	303	0.5		0.5	0.6	0.6	0.6	0.7	0.7	0.7		40
	303	0.4		0.4	0.4	0.4	10.2	10.2	10.7			50
	306	1.1		1.2	1.2	1.3	1.3	1.3	1.1			60
	306	0.5		0.5	0.5	0.8	0.9	0.8	0.7			75
	309	0.5		0.5	0.5							45
	309	0.5		0.5	0.5	0.7						55
	309	1.0		1.0	1.1	1.2	1.3	1.5				70
	309	0.9		0.9	0.9	0.9	0.9	1.0	1.0			85
	310	0.6	0.6	0.7	0.7	0.7	0.8					30
	310	0.6		0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	40
	310	0.6		0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	50
	310	0.8		0.9	1.0	1.0	1.0	1.0	1.0	1.1	1.1	60
	310	0.9		0.9	0.9	1.0	1.0	0.7	0.7	0.8		70
	310	0.5		0.5		0.6		0.6		0.6		100
	310	0.5		0.5		0.5		0.5		0.5		110
	311	0.8		0.8		0.9		0.9		1.0		50
	311	0.8		0.8		0.9		0.9		0.9		60

continued

Table A-II (continued)

Date	Station	Depth Surface	6"	1'	2'	3'	4'	5'	6'	7'	8'	Distance from South Bank, ft.
10-29-71	311	0.6		0.6		0.7	0.8	0.8	0.8	0.8	0.8	70
	311	0.4		0.5		0.5		0.6	0.6			85
	312	0.7		0.7		0.8		0.8	0.8	0.9	0.9	140
	312	0.6		0.7	0.7	0.8		0.8		0.9	0.9	150
	312	0.6		0.6	0.6	0.6		0.6		0.7		160
	312	0.6		0.6	0.6	0.6	0.6	0.6	0.7	0.7		200
	312	0.6		0.6	0.6	0.6	0.6	0.6	0.7	0.7		210
	313	0.6		0.6	0.7	0.7	0.7					60
	313	0.6		0.8	0.8	0.8	0.8	0.9	0.9	0.9	1.0	70
	313	0.6		0.8	0.8	0.8	0.8	0.8	0.9	0.0	1.0	80
	313	0.6		0.6	0.6	0.6	0.7	0.7	0.7	0.7		110
	313	0.5		0.5	0.6	0.7	0.7	0.8	0.8	0.8		120
	313	0.5		0.5	0.5	0.5	0.5	0.5	0.6	0.6		140
04-10-72	313	0.8		0.8	1.0		1.2					45
	313	1.4			1.4		1.5		1.5			60
	313	1.3		1.4		1.4		1.5		1.5		90
	313	1.2		1.2		1.3		1.4		1.4		100

continued

Table A-II (continued)

Date	Station	Depth Surface	6"	1'	2'	3'	4'	5'	6'	7'	8'	Distance from South Bank, ft.
04-13-72	302	0.1		0.1	0.1							50
	306	0.8		0.9		1.2		1.8				50
	306	0.9		1.1		1.2		1.5				60
	310	0.8		0.9		0.9		0.9		0.9		80
	314	0.6		0.7	0.7	0.7	0.7					4
	199	0.7		0.7	0.7		0.7		0.7			50
04-25-72	303						13.5					50
06-01-72	301	7.8					7.6					50
	309	7.8					7.7					50
	311	7.5					7.5					50

APPENDIX B

Power-Plant Thermal Discharge in the United States--Some General Features

During the study, a number of reference sources were examined. The information from these includes aspects of the nature and impact of electrical generating-plant thermal discharge on a nationwide scale. Although not directly applicable to the Fairbanks or northern situation, a brief discussion based largely on the work of Parker and Krenkel (1970) should be of interest to those readers desiring a broader understanding of the thermal discharge problem.

Some National Statistics and Facts--

In 1962, the best thermal-plant average power production rate was 8,588 Btu/kwh (8,588 Btu consumed for each kilowatt of electricity generated); the best system average is 9,390 Btu/kwh and the U. S. average is 10,558 Btu/kwh. This means that the thermal efficiencies, that is the ratio of electricity generated to thermal energy used, are 40%, 36%, and 32%, respectively (one kilowatt hour equals 3,413 Btu).

It is a thermodynamic fact of life that thermal process cannot be carried out without rejection of a certain amount of heat. As stated above, the present-day, central-station average thermal efficiency for the United States is only 32%; the best possible present design has a thermal efficiency of 42%. It is interesting to compare this to the maximum economic efficiency of a theoretical cycle, called the Carnot cycle, which has an efficiency of 60%, based on an ideal situation. The real world does have losses, "irreversibilities," such as friction, so we should not expect efficiences of modern thermal generating plants to increase beyond the 40% figure.

The significance of cooling-water discharge in a power plant system can be emphasized by considering that, for each hundred Btu inserted into an electrical plant, a maximum of 40 will be emitted to the electrical network, while 60 or more will be waste heat. Of the 60, ten will go into stack emissions and 50 will go into the cooling water. This has great implications for the economics of this part of the generation scheme.

The most economical cooling-water system design is once-through cooling. The mechanism of once-through cooling is simply pumping river or lake water through the condenser (Figure 1). A temperature rise of 8° to 11°C usually results.

According to standard designs, the next best alternative is a cooling pond, which normally requires a capital expenditure of about twice that required for once-through cooling. The various types of wet or dry mechanical- or natural-draft cooling towers require from two and a half to fifteen times the capital expenditure. Therefore, the most economical alternative examined by most power-plant designers is once-through cooling. It is only when extremely stringent conditions are encountered, e.g. the lack of availability of a suitable water source or the imposition of thermal criteria by government regulation, are the more expensive alternatives considered.

Given the fact that a large percentage of the thermal energy involved in power production is lost in the discharge stream and that the most economical and widely used discharge method is once-through cooling, the ramifications of this method on the receiving body become important. The direct impact is physical or physiochemical. The biological effects occur in response to this.

The primary impact, obviously, is increased temperature. The more important direct physical effects resulting from this are:

1. The decreased solubility of oxygen in the water
2. Increased evaporation
3. Changes in the effects of filtration, flocculation, and ion exchange for downstream water users
4. The direct impact of higher temperatures on water users.

Temperatures in excess of 15°C are considered objectionable. However, slightly increased temperatures increase the reaeration coefficient, which may be beneficial. The usual design specifications for waste heat disposal systems take into account these flow and temperature rises induced in the receiving water. Regulatory standards specify allowable ranges and designate the size of a mixing zone.

The chemical effects of thermal pollution include changes in ionic strength, conductivity, dissociation, solubility and corrosion.

Since an important effect of thermal discharge concerns the biological processes of the stream, most standards and criteria are at least indirectly focused toward effects on these. The primary biological effect results from increased temperature, as it is the single most important factor governing the occurrence and behavior of life. Generally speaking, the higher the temperature, the more active the microorganisms until a limiting level is reached. For example, increased temperatures may lead to an optimum growth condition for certain organisms. Some other effects are:

1. The effects of temperature on the oxidation rate which generally increases with increasing temperature.
2. Distribution of organisms may change quite drastically with a shift in temperature.
3. The reaction rate or the rate of biological activity may increase greatly; the maximum reaction rate is generally reached at about 32°C.
4. Increased temperatures have an effect on bacterial activity in relationship to various chlorine compounds which are inserted into the water to promote disinfection.

Quite often the injection of thermal discharges results in a complicated hydrodynamic phenomena known as stratification. Stratification has an effect on the waste assimilation, as mixing between the upper and lower layers is inhibited. Because of the lack of mixing, wastes in the lower layer have less oxygen contact, and a more concentrated organic load results. Thus the rate of oxygen depletion in the lower layer may be increased and the total waste assimilative capacity of the stream is reduced. Because of the decreased ability to absorb dissolved oxygen and the increased rate of BOD exertion, severe oxygen depletion may result.

The effect of thermal pollution is not entirely detrimental. Several beneficial effects of heat additions do occur. One is using thermal discharges as a low-grade heat addition for district heating in a municipal area. Some other beneficial effects are:

1. Increased biological production
2. Increased efficiency of waste treatment
3. Increased efficiency of water works treatment facilities
4. Increased temperature of irrigation water
5. Ice free access in a river or a lake or harbor
6. Beneficial effects on water and sediment discharge
7. A useful, high-temperature water source.

In summary, the main effects of thermal discharge are:

1. Stratification
2. A lower dissolved-oxygen capacity
3. Increased reaeration rates
4. Higher metabolic range
5. Smaller oxygen balance
6. Lower waste-assimilation capacity
7. Higher rate of chemical reaction
8. Higher irrigation efficiency.