THE UNIVERSITY OF MANITOBA

THERMAL EFFECTS OF BRANDON GENERATING STATION ON THE ASSINIBOINE RIVER

BY

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

WINNIPEG , MANITOBA

FEBRUARY , 1973

ABSTRACT

THERMAL EFFECTS OF BRANDON GENERATING STATION ON THE ASSINIBOINE RIVER

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The purpose of this study was to measure the physical, chemical, and biological effects of the thermal discharge from Brandon Generating Station on the Assiniboine River, and to compare the beneficial and detrimental effects of the thermal discharge on downstream water uses. It was found that the thermal discharge has a considerable impact on the thermal regime of the Assiniboine River, preventing the formation of winter ice cover on the river for a variable distance downstream from Brandon Generating Station. This stretch of open water is detrimental in that it prevents the local residents from crossing the river during the winter, but is beneficial in that it allows reaeration to take place, thus increasing the dissolved oxygen concentration of the river water. It appears that the thermal discharge has both beneficial and detrimental effects on the biota of the river, depending on the extent that water temperatures are altered. It was concluded that a final assessment of the relative value of beneficial and detrimental effects could not be made with the amount of data currently available on these effects and with present state of knowledge in resource economics.

ACKNOWLEDGMENTS

The success of a study of this nature is very much dependent on the aid, advice and cooperation of many individuals. I would like to thank the personnel of Brandon Generating Station for their helpful assistance, with special thanks to Mr. John McCulloch (Charge Engineer) and Mr. Alan Hattie (Station Chemist) who answered my many questions. Special thanks go to Mr. C. Hughes (Engineer, City of Brandon) for the use of the laboratory facilities at the Main Lift Station, and to Mr. Gordon Leadbeater for his assistance and information. Thanks also go to the following employees of the Manitoba Department of Mines, Resources, and Environmental Management for their advice and information: Mr. E. A. Sorba (Chemist, Environmental Protection Laboratory), Mr. G. H. MacKay (Head, Water Resources Section), Mrs. J. Crowe (Research and Development Branch), and Mr. J. Warrener (Environmental Protection Branch). Thanks go to Mr. Larry Grenkow and Mr. George Gevaert for their assistance with the field and laboratory studies. I am indebted to my adviser, Dr. A. B. Sparling, for his advice and assistance in carrying out this study and in preparing this manuscript, and also to Mr. J. Warrener and Mr. L. Buchanan for serving on my examining committee. Finally, I would like to acknowledge with gratitude the financial assistance that was made available for this project by Manitoba Hydro under Research Grant 355-2720-05.

TABLE OF CONTENTS

TABLE OF CONTENTS

(continued)

CHAPTER PAGE

TABLE OF CONTENTS

(continued)

TABLE OF CONTENTS

(continued)

TABLE OF CONTENTS

(continued)

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

I. INTRODUCTION

The demand for electrical energy has doubled every ten years since the 1920's in North America. In many areas this has meant a marked increase in the numbers and size of steam-generating plants fueled by fossil-fuels or nuclear energy. The water requirements for cooling purposes in these plants have also increased markedly, because steam-generating plants reject between 50 and 70% of the energy of the fuel consumed as waste heat. Water for cooling is commonly drawn from rivers, lakes, or oceans; heated, and then discharged back to the water body where the elevated temperatures have sometimes damaged water quality and aquatic plant and animal life.

Manitoba Hydro operates two such fossil-fueled, steam-generating plants. One is at Brandon on the Assiniboine River, and the other is at Selkirk on the Red River. These plants employ once-through cooling, which means that water is pumped from the river, passed through condensers where waste heat is transferred to it, and then discharged directly back to the river at an elevated temperature.

These plants are operated on a peaking basis. This means that they generate mainly during times of peak electrical demand, and thus their thermal discharges are intermittent and irregular. This mode of operation causes two significant results. First, because of the irregularity of the thermal discharge, large and rapid temperature fluctuations are created in the river. Second, Manitoba's peak demand for electricity occurs during the winter when the rivers are ice-covered and the natural water temperatures are very low.

This study is the first attempt to determine what effects thermal discharges from plants operating under these climatic conditions and generating patterns have on water quality and aquatic life.

1.1 STATEMENT OF THE PROBLEM

The purpose of this study is (1) to measure the physical, chemical, and biological effects of the thermal discharge from Brandon Generating Station on the Assiniboine River, and (2) to compare the beneficial and detrimental effects of the thermal discharge on downstream water uses.

1.2 IMPORTANCE OF THE PROBLEM

The effects of thermal discharges on receiving waters have been under investigation for approximately fifteen years. The results of these investigations have indicated that some of the discharges were beneficial, that some were harmful, and that some had little or no effect. One guideline that has emerged from these studies is that each instance of a thermal discharge has its own unique set of physical, chemical, and biological characteristics that determine the effect it will have on the aquatic environment(1)*. Thus, each thermal discharge must be examined separately.

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* The numbers in parentheses in the text indicate references that are listed in the List of References section.

The situation at Brandon Generating Station is no less unique. The climate, the station generating patterns, the flow pattern of the Assiniboine River, and physical arrangement of the outfall, all influence the effect that the thermal discharge has on the river.

1.3 DEFINITIONS OF TERMS USED

Benthic macroinvertebrates. These are aquatic invertebrates which are retained by a U. S. Standard No. 30 sieve, and which live in, crawl on, or attach themselves to the bottom of a water body[2]. They are also referred to as bottom fauna, macroinvertebrates, macrobenthos, or benthos.

1.4 THE STUDY

1.4.1 Winter study period.

A short study was conducted at Brandon Generating Station during February 21st to 25th, 1972. Measurements were made (1) to establish a water temperature profile downstream from the generating station, (2) to determine the dissolved oxygen conditions upstream and downstream from the generating station, and (3) to determine the ice conditions and extent of the open water downstream from the generating station.

1.4.2 Summer study period.

The summer study period extended from May 4th to November 3rd 1972, and consisted of monthly trips of one week duration to the study area. Seven trips in all were made during the summer study period. The purpose of these trips was (1) to collect benthic macroinvertebrate samples upstream and downstream from Brandon Generating Station, (2) to collect water samples for selected chemical analyses to provide background water quality data, (3) to establish water temperature profiles during periods when the generating station was discharging heated water, and (4) to establish a basis for predicting the waste heat load to the river at any given time.

1.5 LIMITATIONS OF THE STUDY

The major limitation of the study was the short duration of the study period. Biological samples should be collected for a full one year period to insure that the biological responses to the thermal discharge are recorded under all conditions of climate, generating pattern, and streamflow. In effect, the study only records the biological effects for a four month period; July, August, September, and October of 1972.

Another limitation of the study is that only one segment of the aquatic community, the benthic macroinvertebrates, were sampled. A complete study would include the sampling of all of the major components of the aquatic community including fish, planktonic fauna, algae, the periphyton, the rooted aquatics, and the benthic macroinvertebrates. However, for a study with limited time and resources the macroinvertebrates provide the best indication of whether or not stress is being placed upon the aquatic community by the thermal discharge.

2. LITERATURE REVIEW

This literature review will outline pertinent information relating to the following aspects of this study:

(1) The effects of thermal discharges on the aquatic environment.

(2) The surface-water temperature standards established by various environmental management agencies.

(3) The role of benthic macroinvertebrates in assessing the biological effects of a thermal discharge.

2.1 THE EFFECTS OF THERMAL DISCHARGES ON THE AQUATIC ENVIRONMENT

2.1.1 Introduction

It is desirable at this time to reiterate the conditions under which the thermal discharge from Brandon Generating Station occurs, so that the information presented here can be viewed in the light of these conditions.

These include:

(1) The generating station is located on the Assiniboine River in Manitoba where the winter climate is severe and lakes and rivers are covered with ice and snow for approximately five months of each year.

(2) The station operates mainly during these cold winter months.

(3) The station operates on a peaking basis, which produces

large and rapid fluctuations in the waste heat load to the river.

The literature on the effects of thermal discharges is voluminous, but literature on the effects of thermal discharges occurring under the above conditions is nearly non-existent. Most of the published literature on thermal effects pertains to situations in the United States and Britain, and contains little information on Canadian studies. A few studies are currently underway on thermal discharges from nuclear power stations in Ontario and Quebec, but no results have been published to date.

The difficulty with studies done in the United States and Britain, is that they were conducted under climatic conditions that are for the most part, significantly milder than those in Canada. A. M. Marko(3) has warned against extrapolating the results of investigations conducted in the United States to the Canadian scene. He suggests that the effects of thermal discharges in Canada may not be as severe as those in the milder climatic regions of the United States because Canada has larger lakes and rivers, lower seasonal temperatures, and a cold winter climate(4).

2.1.2 Dissolved oxygen resources

The dissolved oxygen concentration is the only chemical parameter significantly affected by a thermal discharge(5).

Theoretically, as the temperature of water increases, its capacity to hold dissolved oxygen decreases; the rate of reaeration increases; and the rate of biological deoxygenation increases. The net result of these interactions is usually assumed to be a decrease in the dissolved oxygen concentration[6]. Studies of the dissolved oxygen conditions upstream and downstream from thermal discharges however, have indicated that the dissolved oxygen concentration is not significantly reduced by the thermal discharges. Trembley[5] found an average decrease in the dissolved oxygen concentration of only 0.5 mg./1. downstream from Martin's Creek Generating Station on the Delaware River. Markowski[7] found that the dissolved oxygen concentration of a thermal discharge was the same or slightly higher after heating than before heating.

The dissolved oxygen content is not significantly reduced for three reasons:

(1) There is often great turbulence associated with a thermal discharge which aerates the water and tends to increase the dissolved oxygen content[5][7].

(2) The dissolved oxygen content can only be decreased in water that is initially saturated, and thus if the water is not saturated it may be heated until it reaches the temperature at which it becomes saturated, before losing dissolved oxygen[8].

(3) When water which is saturated with dissolved oxygen is heated, it tends to become supersaturated because the process of attaining equilibrium between the air and water at the new temperature is a relatively slow process. Thus, the decrease in the dissolved oxygen content is not as large as expected[8][9][10].

The above considerations are applicable to thermal discharges in Canada during the ice-free months of the year, but during the winter the situation is very different. In Canada, the most critical period for dissolved oxygen depletion in rivers is during the winter when streamflow is low and the rivers are capped with ice and snow[11][12]. The ice and snow cover is a physical barrier which (1) prevents atmospheric reaeration, and (2) prevents algal photosynthesis by preventing light from reaching the water. The stream's major sources of dissolved oxygen are thus removed, but the process of biological deoxygenation continues, and the dissolved oxygen concentration decreases as the water moves downstream.

A thermal discharge which melts this cover of ice and snow, opens the river to atmospheric reaeration and algal photosynthesis that recharge the water with dissolved oxygen[6]. Thus, in Canada, a thermal discharge during the winter can improve the oxygen resources of a stream for downstream uses.

2.1.3 The effects of rapid water temperature fluctuations on aquatic life

One cause of rapid temperature fluctuations in a stream is the intermittent and irregular discharge of heated water from a steam-generating plant operating on a peaking basis[13]. The generation pattern of a peaking plant tends to follow the daily and hourly changes in the demand for electricity. This results in a waste heat load that can vary widely during the course of one day because the waste heat rejected is directly proportional to the amount of electricity generated.

Jensen[14] states that the rate of change of temperature may be more important than the maximum temperature attained.

Rapid water temperature changes do not give aquatic organisms sufficient time to compensate for the change and thus organisms can be killed or damaged at temperatures below their maximum tolerable limit.

Hargis and Warinner[15], Burdick[16], and Cairns[1], all warn that the sudden shut-down of a generating station during the winter could kill fish and other aquatic life, because of the rapid temperature decrease in the stream when the thermal discharge ceases. This point is very significant because rapid temperature decrease is much more lethal than rapid temperature increase. Speakman and Krenkel[13] found that in the bluegill sunfish (Lepomis macrochirus), mortality occurred at rates of temperature decrease which were only one-twentieth as large as the rates of temperature increase which caused mortality.

The operation of a steam-generating plant on a peaking basis during the winter months could thus damage the aquatic community because of the effects of rapid water temperature fluctuations.

2.1.4 Early emergence of aquatic insects

A somewhat more subtle effect of thermal discharges during the winter months is that they may precipitate the premature emergence of aquatic insects[17][18][19].

Nebeker[18] found that the emergence of aquatic insects such stoneflies, mayflies, caddisflies, midges, and blackflies was controlled by seasonal water temperature patterns. He found that artificial warming of the water caused aquatic insects to emerge from two weeks to four months early depending on the species tested and the temperature increase used.

Coutant[19] discovered that a 1° C (1.8° F) temperature increase caused caddisflies downstream from the nuclear power station at Hanford, Washington to emerge two weeks earlier than the ones upstream from the station.

The reason for concern about the early emergence of aquatic insects is that if air temperatures are still too low, the aquatic insects may be killed or unable to mate[18]. This will reduce the aquatic insect population, and because aquatic insects are a primary food source for fish, it may ultimately affect the fish.

2.1.5 Winter chill period

Thermal discharges during the winter months may interfere with the development of organisms which require a period of low temperatures, or a "winter chill period" to stimulate the production of reproductive materials[17][20]. Little is known about the phenomenon of winter chill period and the references to it in the literature are brief and vague. The duration and minimum temperature required for this winter chill period for different species of aquatic life are unknown.

2.1.6 The effects on organisms of entrainment in cooling water

The entrainment of organisms in cooling water refers to the process in which small, drifting organisms are drawn into the cooling water intake, pumped through the condensers with the cooling water, and discharged back into the stream. This effect is applicable to all plants employing once-through cooling.

Organisms entrained in the cooling water are subjected to the following effects: (1) Acute thermal shock as they pass through the condensers.

(2) Pressure changes in the pumps.

(3) Mechanical mangling in the condenser tubes[21].

The effects of the thermal shock are dependent on both the magnitude of the temperature rise and the time of exposure to the elevated temperature. Severe shocks can lead to heat death or to death because of increased susceptibility to predation[21].

Assuming that some damage is done during entrainment, the overall impact of entrainment could be considerable at a generating station where a large portion of the stream is diverted through the condensers, as is often the case at Brandon Generating Station.

2.2 SURFACE-WATER TEMPERATURE STANDARDS

This section will review the surface-water temperature standards prescribed by the environmental management agencies of several Canadian provinces and of several states in the United States. This review is included so that the water temperature conditions existing at Brandon Generating Station can be compared to temperature standards in a subsequent section of this thesis.

The surface-water temperature standards in Table (1) are for water quality that is suitable for most uses including the propagation of fish, wildlife, and other aquatic life, with the exception of cold water fish. The standards of the province of Ontario are not in a numerical form and are summarized below.

TABLE 1 SURFACE-WATER TEMPERATURE STANDARDS OF VARIOUS PROVINCES AND STATES

State or Province	TEMPERATURE			Reference No.
	Maximum	Maximum Change	Max. Rate of Change	
Manitoba	---	$3^{o}C$ ($5.4^{o}F$)*	---	22
Saskatchewan	---	$3^{o}C$ ($5.4^{o}F$)*	---	22
Alberta	---	$3^{o}C$ ($5.4^{o}F$)*	---	23
North Dakota	$90^{o}F$	$5^{o}F$ ($2.8^{o}C$)*	---	24
Minnesota	$90^{o}F$	$5^{o}F$ ($2.8^{o}C$)*	---	25
Pennsylvannia	$87^{o}F$	$5^{o}F$ ($2.8^{o}C$)*	$2^{o}F$/HR.	25
Nebraska	$90^{o}F$	$5^{o}F$ (May-Oct) $10^{o}F$ (Nov-Apr)	$2^{o}F$/HR.	25
Montana	$89^{o}F$	$4^{o}F$, provided temperature $<40^{o}F$ in winter	$2^{o}F$/HR.	25

* Author's conversion.

ONTARIO. Heated discharges to inland waters are not allowed unless it is clearly shown that the discharge will not endanger the production and optimum maintenance of wildlife, fish, and other aquatic species. Their guidelines also require zones of passage in streams, such that at least two-thirds of the cross-sectional area of the stream is of favourable quality to the aquatic community at all times.

Finally, Ontario's guidelines require that the normal daily and seasonal temperature variations that were present before the thermal discharge be maintained[26].

2.3 BENTHIC MACROINVERTEBRATES

2.3.1 Introduction

A study of the biological effects of any waste discharge naturally requires that one or more of the various components of the aquatic community be examined to determine what damage, if any, has occurred. In this study, the benthic macroinvertebrates were chosen for this purpose, and this section will outline the role of the macroinvertebrates in assessing the biological effects of a thermal discharge.

Macroinvertebrates will be discussed under the following headings:

(1) The nature of the benthic macroinvertebrates.

(2) The reasons for choosing to examine this component of the aquatic community.

(3) Techniques in sampling the benthic macroinvertebrates.

(4) Analysis of benthic macroinvertebrate samples.

2.3.2 The nature of the benthic macroinvertebrates

Definition: The benthic macroinvertebrates are aquatic invertebrates which are retained by a U. S. Standard No. 30 sieve, and which live in, crawl on, or attach themselves to the bottom of a water body[2].

The benthic macroinvertebrates encompass a great variety of organisms such as clams, snails, leeches, crustaceans, crayfish, and the aquatic insects which include stoneflies, mayflies, caddisflies, dragonflies, damselflies, craneflies, midges, water bugs, and beetles. Many of these organisms serve as a primary food source for fish and other aquatic life, and thus are vitally important in the food web of the aquatic community[2].

2.3.3 Reasons for choosing the benthic macroinvertebrates

The macrobenthos have been used by many investigators to assess the biological effects of thermal discharges[5][27][28][29][30][31].

They are well-suited to serve as indicators of environmental stress for several reasons. First, because of their attached or sessile mode of life, they are relatively immobile organisms. They are thus more dependent on the water quality of the immediate area in which they live than are (1) fish which can move rapidly and perhaps avoid unfavourable water quality conditions[32], and (2) plankton which drift with the current of the river and may pass in and out of the area of unfavourable water quality without having to adapt to it[5]. Wurtz and Dolan[28] have referred to the macrobenthos as the most stable element in the aquatic population.

A second reason for the suitability of the macroinvertebrates as biological indicators is that they include species which are sensitive to environmental stress and which will respond quickly to changes in the environment, such as a significant change in the thermal regime[4].

The importance of the macrobenthos in the food web of the aquatic community also enhances their value as biological indicators.

If the macroinvertebrate population is damaged, the fish population will ultimately suffer due to a shortage of food[2].

Some authors cite the long life cycle (one year and longer) of some macroinvertebrates as an asset in their use as biological indicators. They claim that this makes it possible to evaluate the effects of a period of adverse water quality long after the water quality has returned to normal[33][34]. This seems illogical for rivers because of the continuous drift of eggs, larvae, and adults from upstream[9] which would repopulate the effected area once the water quality returned to normal.

2.3.4 Techniques in sampling the benthic macroinvertebrates

The first consideration when using the benthic macroinvertebrates to assess the effects of a waste discharge is where to sample. Cairns and Dickson[2] suggest the following guidelines be used in determining the location of sampling stations:

(1) Have one, or preferably two control stations upstream from the waste discharge under investigation.

(2) Have one station below the waste discharge. If the river is wide and/or the effluent is channelized in one part of the river, use several sub-stations.

(3) Have stations at various intervals downstream to determine the linear extent of the effects of the discharge.

(4) Bracket other waste discharges and tributary streams with stations to evaluate their effect on the stream.

(5) The stations must be ecologically similar to one another

before the benthic samples obtained at each station can be compared. This means that the following stream characteristics; bottom substrate (sand, gravel, mud, or rock), depth, velocity, width, bank cover, and the presence of pools and riffles, must be similar at each station.

This last guideline is the most difficult requirement to meet, because it may be difficult, if not impossible to find ecologically similar stations in the vicinity of the waste discharges[34].

The actual sampling of the benthic macroinvertebrates can be done in two different ways. The first method uses dredges, grabs, or nets to sample the benthos that inhabit the natural substrates on the bottom of the stream. The second method consists of placing artificial substrates on or near the stream bottom and then collecting the benthic organisms that colonize these samplers.

The dredges and grabs have the advantage of being able to sample the benthic population in situ, but they cannot be used to sample coarse gravel, rubble, or rocky bottoms. A disadvantage of dredges is that they collect large quantities of sand, gravel, mud and debris from which it is extremely time-consuming and tedious to separate the benthic macroinvertebrates. The labour involved is increased further because of the necessity of collecting several replicate samples per sampling station.

Replicate samples are necessary because of the uneven distribution of benthic organisms on the bottom of a water body, which causes a high degree of variability in benthic samples. To obtain more accurate estimates of the parameters of the population sampled, several replicate samples are reouired[2]. Cairns and Dickson[2] recommend that between 3 and 10 hauls per station be made when using a dredge, or that at least 3 artificial substrate samplers be used per station.

The artificial substrate samplers have the advantage of providing the same types of habitat for colonization at each station. This partially overcomes the problem of finding ecologically similar stations[2]. Artificial substrates also collect relatively little debris so that the labour involved in separating the macrobenthos from the debris is greatly reduced[2]. A disadvantage of artificial substrate samplers is that they are subject to vandalism unless well-hidden[35].

The two most common types of artificial substrate samplers are (1) cylindrical wire cages filled with rocks, and (2) multiple-plate samplers which consist of sauares of tempered hardboard, separated by spacers, all held together by an eyebolt through the centre of the plates and spacers[36].

2.3.5 Analysis of benthic macroinvertebrate samples.

The bottom fauna of unpolluted water is generally characterized by a wide variety of species, with relatively low numbers of individuals in each species because of natural predation and competition for food and space. A wide variety of species or high diversity is indicative of stability in a benthic population. This is because each species reacts to natural environmental changes in a different way and thus a natural change will only affect a small part of the population at any time which allows the benthic community to remain fairly stable.

Pollution, or stress however, tends to reduce the stability of a population by reducing the number of species present. The species that are sensitive to the pollutant will be eliminated, leaving only the tolerant species which tend to increase in numbers because of decreased predation and competition. The problem with this simplified community is that it is much more susceptible to being wiped out by natural environmental changes. If the community contains only a few species with large numbers of individuals per species, the population could be greatly reduced when natural changes make the environment unfavourable for one or two species[2].

The macrobenthos can be classified in three groups with respect to their tolerance to environmental stress or pollution:

(1) The pollution-intolerant species such as the immature or larval stages of mayflies, stoneflies, caddisflies, riffle beetles, and hellgramites[37].

(2) The moderately pollution-tolerant species such as black fly larvae, scuds, sowbugs, snails, fingernail clams, dragonfly nymphs, damselfly nymphs, and most kinds of midge larvae[37].

(3) The pollution-tolerant species such as sludgeworms, some midge larvae (bloodworms), some leeches, and certain snails[2].

The macrobenthos therefore contain species which will respond to environmental stress or pollution, and thus it is necessary to have some method by which the simplification or change in diversity of the benthic population can be assessed.

The simplest method of analyzing benthic samples is to count the total number and the number of kinds of organisms in a sample[2]. The disadvantage of this method, other than the fact that there are two numbers to work with, is that it does not distinguish between "rare" species with only small populations and species with large populations[38].

Diversity indexes are often used to overcome these problems. First, they summarize information on total numbers, numbers of kinds, and numbers per kind of organism into one parameter[39]. Second, they tend to reduce the distortion caused by "rare" species[38]. One problem with diversity indexes is that they usually require the analysis of a skilled biologist[38], while many of the people responsible for pollution control have chemistry or engineering backgrounds[2].

In an attempt to overcome this problem Cairns et al[38] and Cairns and Dickson[2] have developed a diversity index which can be used by non-biologists. The method is called the Sequential Comparison Index and requires no taxonomic expertise because organisms are sorted into taxa on the basis of color, size, and shape. It was found that there was no significant difference in the number of kinds of organisms determined by a taxonomic specialist and by a non-specialist[2].

The sequential comparison method was used in this study and will be described in detail in a subsequent chapter of this thesis.

3. DESCRIPTION OF THE STUDY AREA

3.1 INTRODUCTION

The study area is located on the Assiniboine River, in and adjacent to the City of Brandon, approximately 125 miles west of Winnipeg, the capital of Manitoba. Figure 1 is a map of the study area.

The City of Brandon has a population of approximately 30,000 people and is primarily a distribution centre for the surrounding agricultural area. Brandon has a modest amount of industry, including meat packing, fertilizer manufacturing, chemical manufacturing, and the Brandon Generating Station.

3.2 CLIMATE

The climate of the study area plays a major role in determining the effect that the thermal discharge from Brandon Generating Station has on the Assiniboine River.

3.2.1 Temperature

The mean annual air temperature in the Brandon area is 35.9° F, with the recorded temperatures ranging from a high of 110° F to a low of -52° F[40]. The seasonal pattern of air temperature in the Brandon area is illustrated in Figure 2. This figure emphasizes the length and severity of the winter since it shows that the mean daily temperature is below the freezing point of water (32° F) for five months, including November, December, January, February, and March. These sub-freezing temperatures result in the lakes and rivers in this area

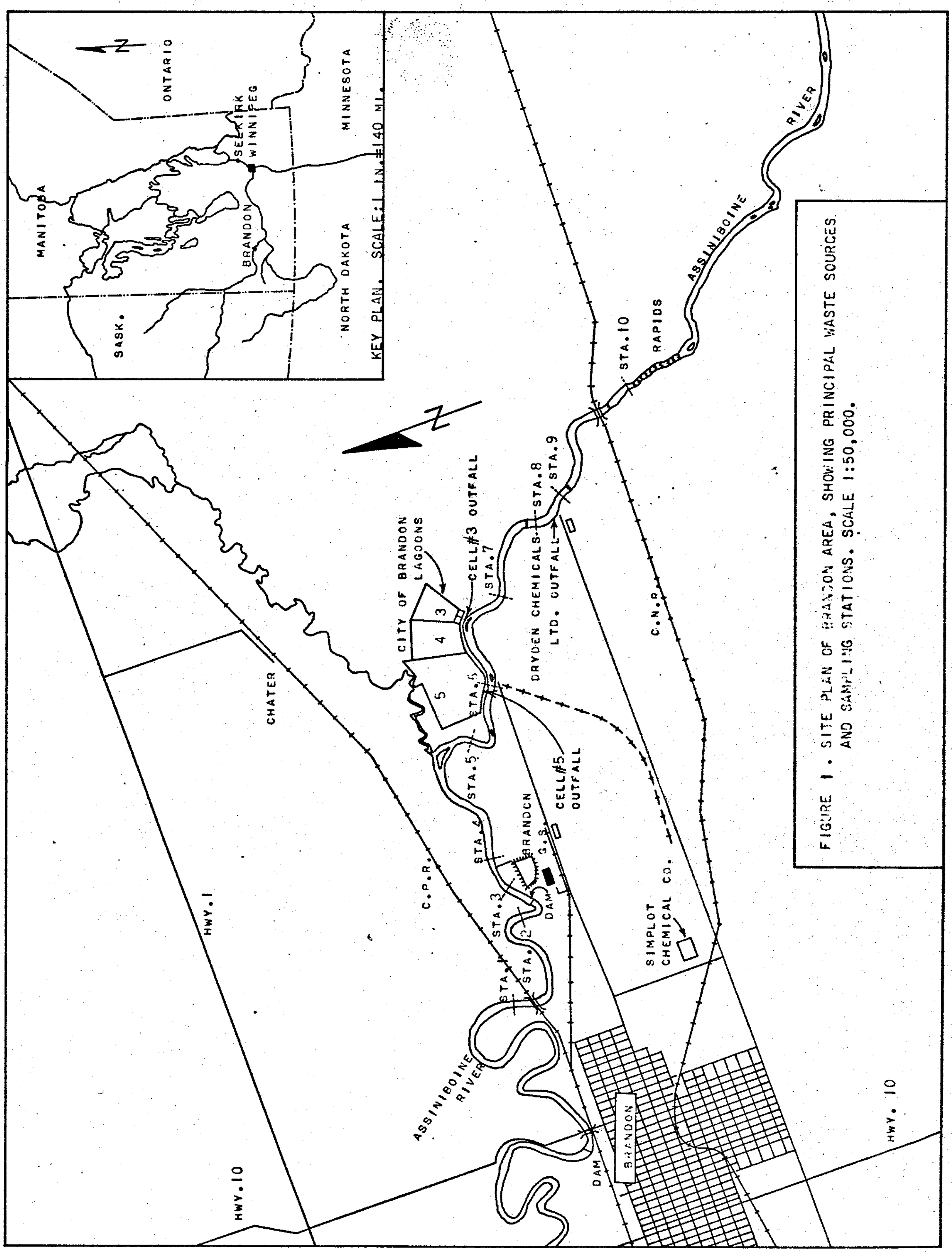

FIGURE 1. SITE PLAN OF BRANDON AREA, SHOWING PRINCIPAL WASTE SOURCES AND SAMPLING STATIONS. SCALE 1:50,000.

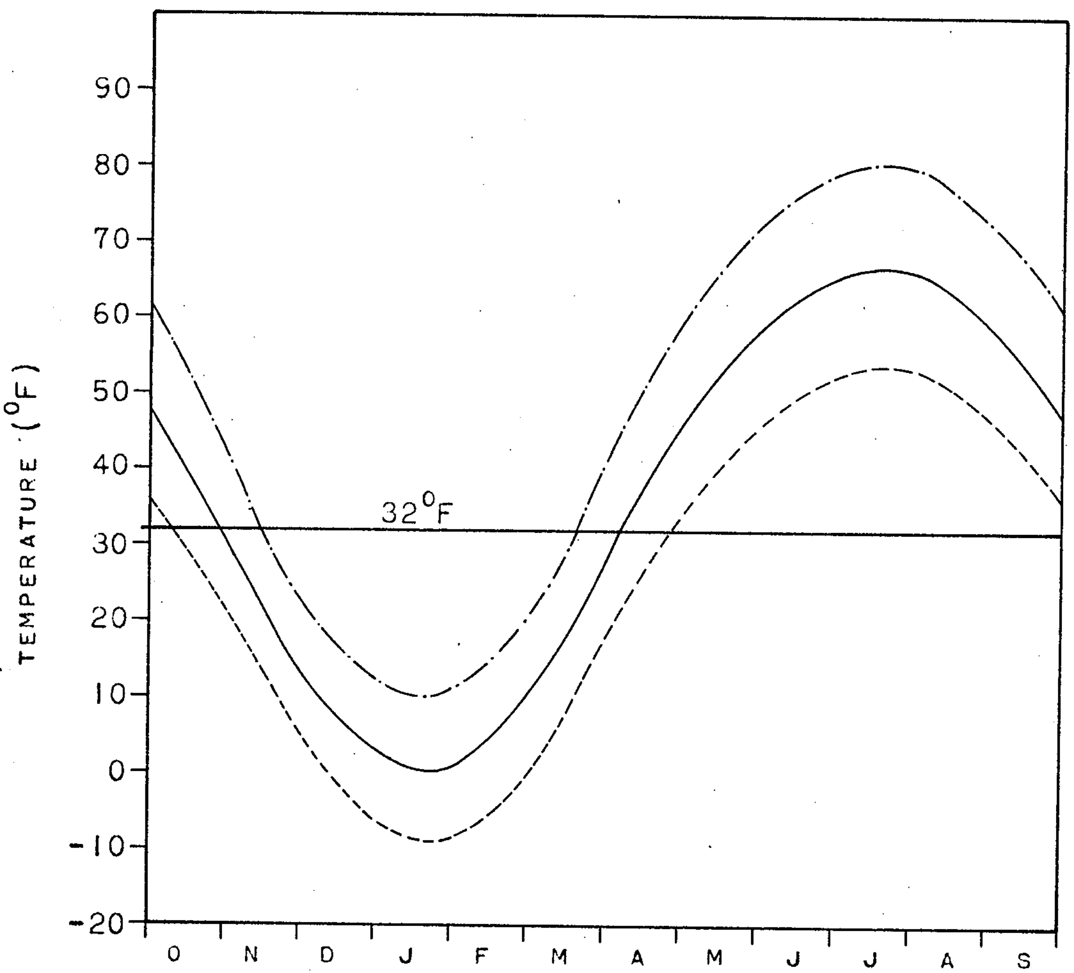

FIGURE 2. SEASONAL PATTERN OF AIR TEMPERATURE AT BRANDON, PERIOD OF RECORD: 1931-1960. (40)

—·—·—·— MEAN DAILY MAXIMUM TEMPERATURE.
———— MEAN DAILY TEMPERATURE.
- - - - - - MEAN DAILY MINIMUM TEMPERATURE.

being ice-covered during these months.

3.2.2 Snowfall

The length and harshness of winters in the study area can be further emphasized by noting that Brandon receives an average of 46.4 inches of snow per year[40] and that the median number of days with one inch or more of snowcover is approximately 140 days[41]. On the average, the snowpack begins to accumulate in the middle of November and remains until the beginning of April[41]. The seasonal distribution of snowfall is illustrated in Figure 3[40].

3.3 THE ASSINIBOINE RIVER

3.3.1 Introduction

The Assiniboine River rises north of Sturgis, Saskatchewan and flows in a southerly direction for some 200 miles to a point east of Virden, Manitoba, where it swings abruptly to the east and flows easterly for about 160 miles to its confluence with the Red River in Winnipeg. Its major tributaries are the Shell, Qu'Appelle, Minnedosa, and Souris Rivers.

3.3.2 Geologic setting

The Wisconsin period of glaciation which ended about 10,000 years ago shaped and determined the surficial geology of the entire area through which the Assiniboine River flows. The ancestral Assiniboine River, a glacial meltwater channel, carried vast quantities of water from the melting glaciers to Glacial Lake Souris and Glacial Lake Agassiz, leaving a channel of gigantic proportions. Today, a much

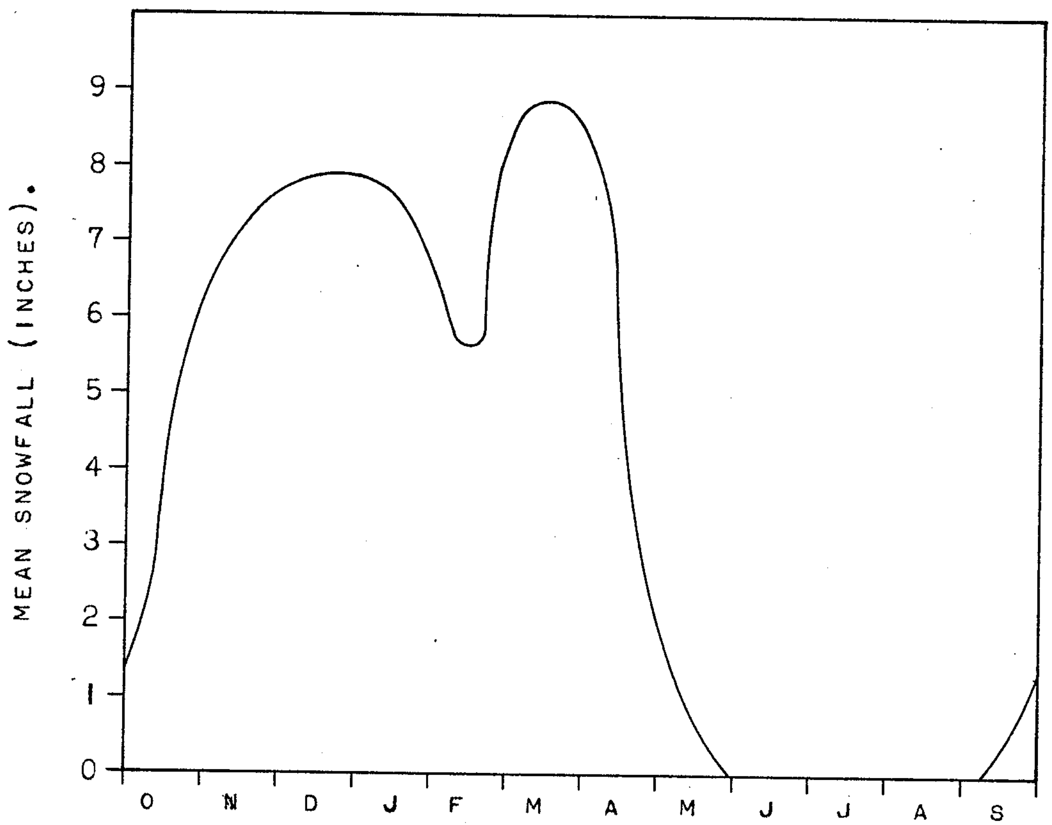

FIGURE 3. MEAN MONTHLY SNOWFALL AT BRANDON,
PERIOD OF RECORD: 1931-1960. (40)

smaller Assiniboine River meanders along the bottom of this mighty channel from near its headwaters in Saskatchewan all the way to Brandon. Between Brandon and Portage la Prairie the Assiniboine flows through the delta formed where the ancestral Assiniboine River emptied into Glacial Lake Agassiz. The last part of the Assiniboine's basin, between Portage la Prairie and Winnipeg, is across the bottom of Glacial Lake Agassiz[42].

The Assiniboine River at Brandon is in a zone of transition. Upstream from Brandon the Assiniboine flows through the sandy, silty lake deposits of Glacial Lake Souris, while downstream from Brandon it flows through the deltaic deposits laid down where the ancestral Assiniboine emptied into Glacial Lake Agassiz. This transition is probably responsible for the variety of river regimes that occur in the Brandon area.

3.3.3 River regime

The Assiniboine River in the study area can be roughly divided into three zones with respect to river regime. The first reach, from about four miles upstream from Brandon Generating Station to the Brandon Generating Station, has relatively low stream velocity, is fairly deep, with large meanders, and a bottom composed mainly of clay, silt, and fine sands. Right at Brandon Generating Station there is a short transition of about 1,000 feet between the first and second zones which has shallow, rapid water, and a bottom composed of coarse gravel and rubble. The second reach, from Brandon Generating Station to a point about 3.5 to 4 miles downstream from the station, has faster stream velocity, and tends to be shallower than upstream from

Brandon Generating Station, with a bottom composed mainly of sands and gravels. The third reach, from about 3.5 to 4 miles downstream of the station to the rapids downstream of station 10 (Figure 1), is much faster, with several rapids, and a bottom composed mainly of rock and rubble. The rapids just below station 10 prevented any further exploration downstream from this point.

3.3.4 Hydrology

The seasonal pattern of flows in the Assiniboine River at Brandon is illustrated in Figure 4, which is a plot of the mean monthly discharge at Brandon for the period, 1906-1970.

The seasonal flow pattern has been characterized by spring flood peaks during April and May, followed by a steady decline in discharge during the summer with the minimum flows occurring during the months of November, December, January, February and March. The range of discharge is considerable, from a maximum daily discharge of 23,000 cfs in May 7, 1923 to a minimum daily discharge of only 7 cfs. on February 21, 1942[43].

The mean monthly discharges of 161 cfs. in January and 144 cfs. in February indicate the extremely low winter flows that have occurred, with the discharge frequently dropping below 100 cfs. at Brandon[43]. These winter months, November, December, January, February, and March, have traditionally been the period of most critical water quality conditions, because of the low flows and the cover of ice and snow which cuts off the stream's sources of dissolved oxygen.

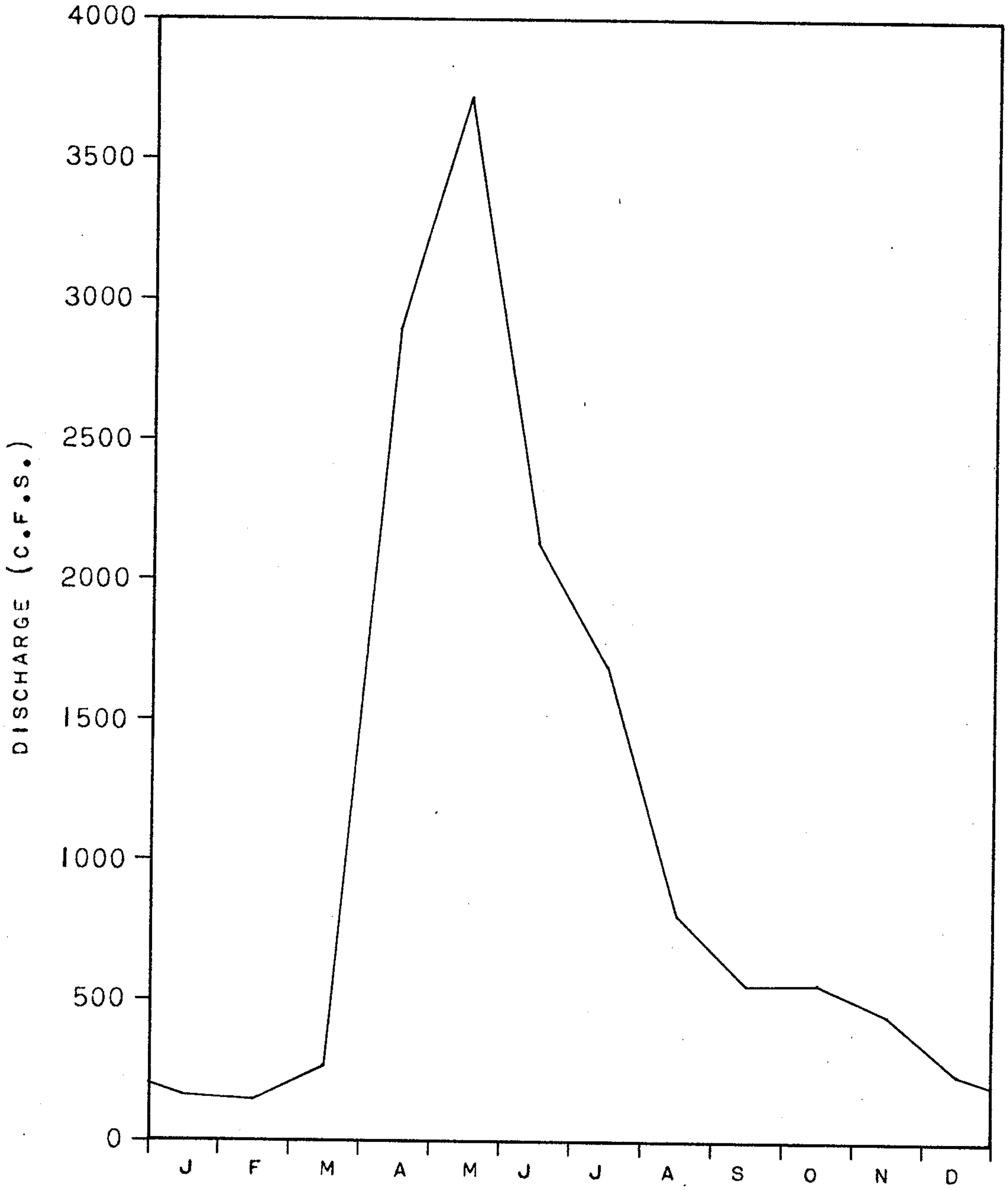

FIGURE 4 . MEAN MONTHLY DISCHARGE ON THE ASSINIBOINE RIVER AT BRANDON, 1906-1970.(43)

3.3.5 Flow regulation

There was essentially no flow regulation on the Assiniboine River prior to 1960, except for some releases from the Qu'Appelle River, which had an almost negligible effect. About 1960, the Rivers Reservoir on the Minnedosa River was completed and water was released over the winter months in an attempt to maintain a minimum of 100 cfs. in the Assiniboine River at Brandon. Ice-making on the Minnedosa and Assiniboine Rivers however, still occassionally caused the flows to fall below 100 cfs. at Brandon[44].

The newly constructed Shellmouth Reservoir, just below the confluence of the Shell and Assiniboine Rivers, was partially full by the fall of 1970, and releases of water were made to the Assiniboine River during the winter of 1970-71. In the fall of 1971, the Shellmouth Reservoir was full and water was released to the Assiniboine River at a rate 500-600 cfs. for the entire winter[44].

The effect that these winter releases from Shellmouth Reservoir had, were to maintain reasonably uniform flows in the Assiniboine River at Brandon of approximately 400 cfs. during the winter of 1970-71 and approximately 700 cfs. during the winter of 1971-72, both of which are far above the long-term average for the winter months.

The increased discharges in the Assiniboine River during the winter months can be expected to continue if the present operating pattern of Shellmouth Reservoir is maintained. This pattern of operation is as follows:

(1) Water is released from the reservoir during the winter

so that a reservoir water level of 1392' is reached by March 31st to maximize spring flood storage capacity.

(2) After the spring floods, water is released until a water level of 1402.5' is reached, and this level is maintained during the summer.

(3) Water is again released during the winter, starting on October 1st so that the level of 1392' may be reached by March 31st.

Periods of drought or a massive increase in the use of irrigation would naturally decrease the amount of water available for winter flow augmentation in the Assiniboine River. Under present conditions, however, it is felt that a guaranteed minimum flow of 250 cfs. can be maintained in the Assiniboine River at Brandon during the winter[44].

Figure 5 is a plot of the mean weekly discharge in the Assiniboine River at Brandon covering the period during which Brandon Generating Station has been employing once-through cooling. The effect of winter flow augmentation can be seen in this figure by the increased flows during the winter months of 1970-71 and especially during the winter of 1971-72 when the flows were maintained at the highest level for the period of record, 1906-1972. Note also that in 1971-72, because of winter flow regulation, the period of minimum flow was shifted from mid-winter to late summer and early fall.

3.3.6 Natural surface water temperatures

The seasonal pattern of surface water temperature in the Assiniboine River at Brandon is depicted in Figure 6[45][46]. Each

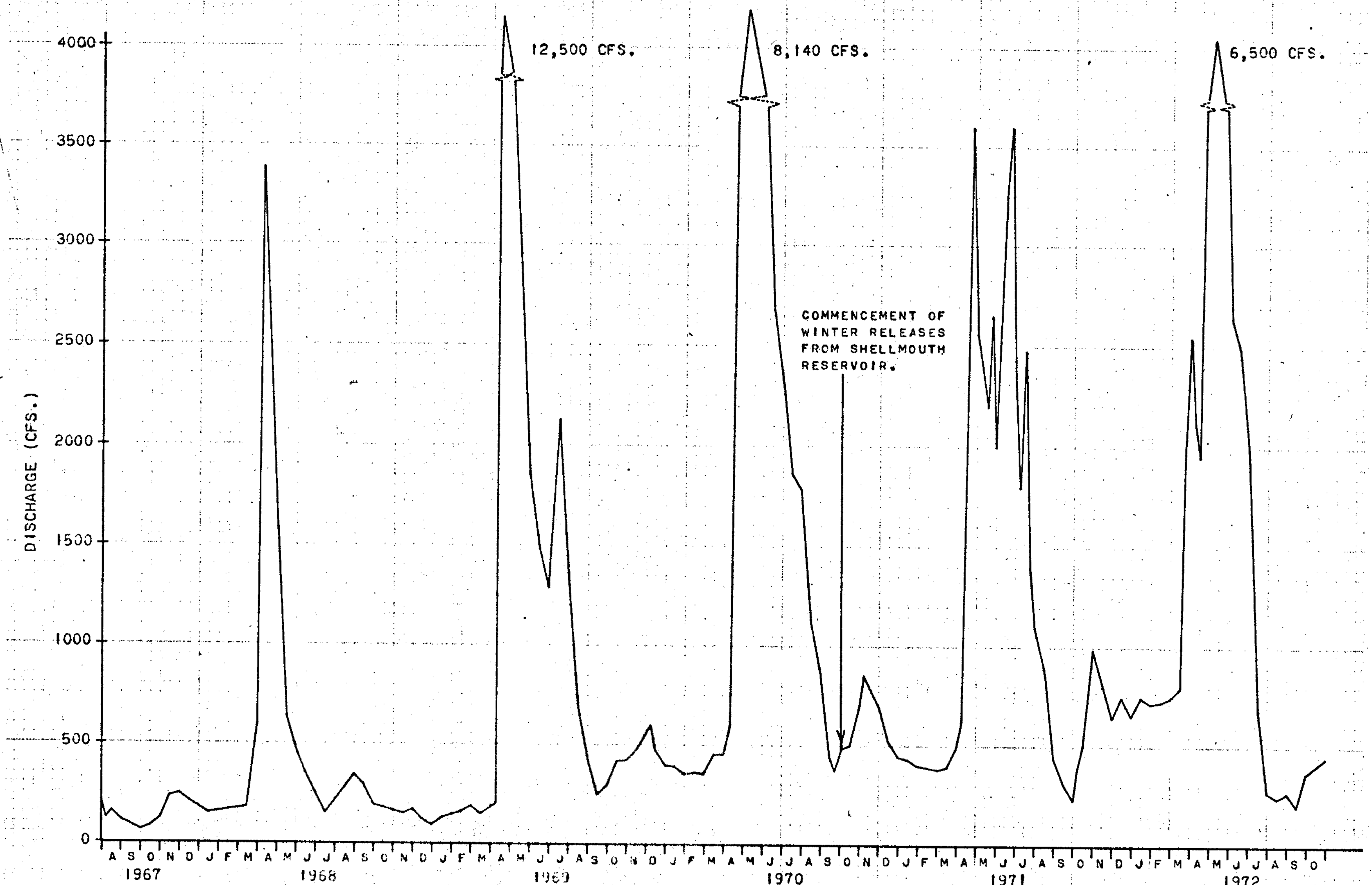

FIGURE 5. MEAN WEEKLY DISCHARGE ON THE ASSINIBOINE RIVER AT BRANDON, AUGUST 1967 TO OCTOBER 1972.

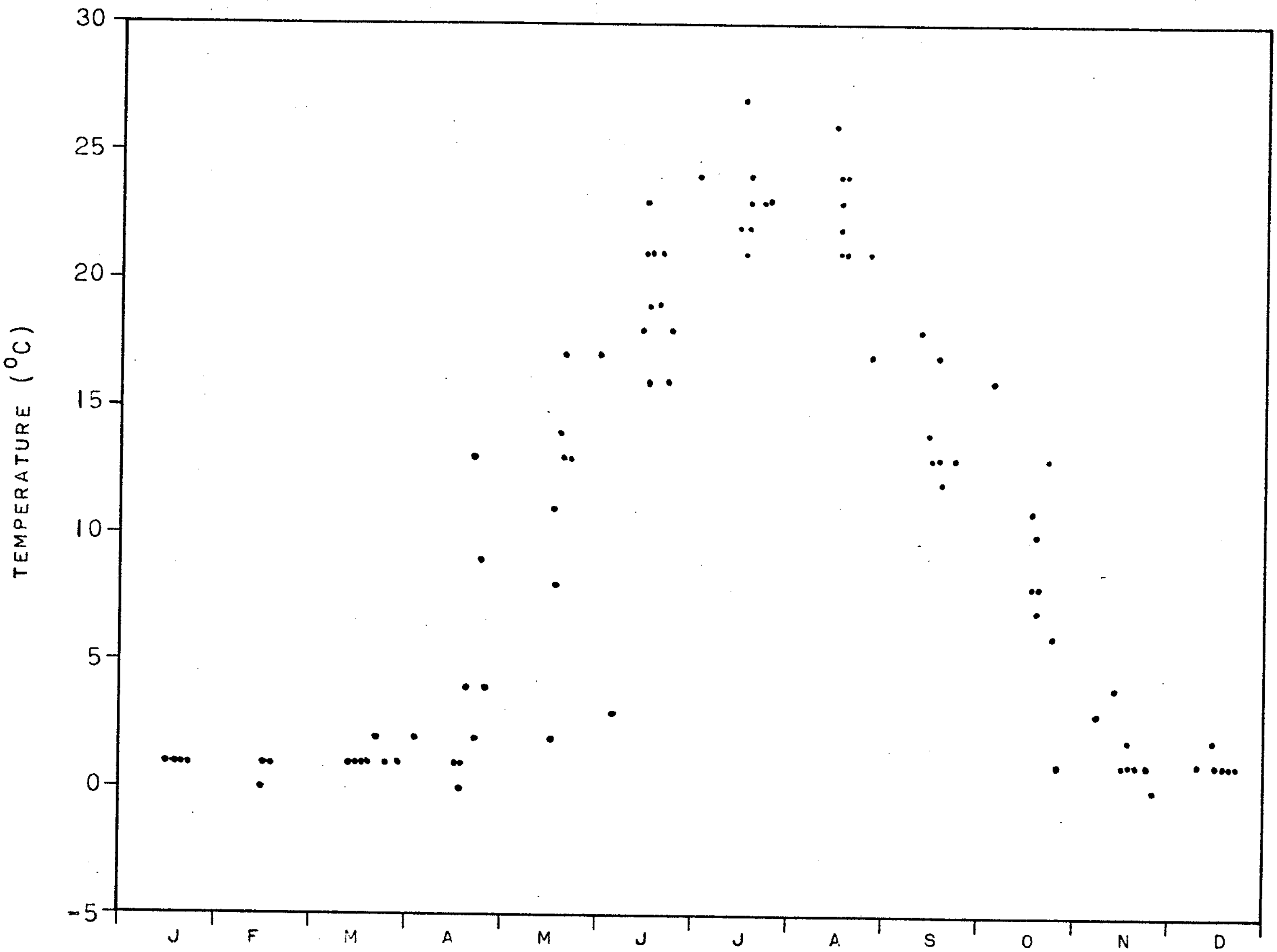

FIGURE 6 . SEASONAL PATTERN OF SURFACE WATER TEMPERATURE IN THE ASSINIBOINE RIVER AT BRANDON, 1960-1970. (45,46)

point in this figure represents a single water temperature measurement made during the years 1960 to 1970, inclusive.

Figure 6 indicates that the maximum water temperature recorded during this time was in July (27^{o} C (80.6^{o} F)), and that the water remains at approximately 0^{o} C (32^{o} F) for five months, from early or mid-November to the beginning of April. This interval roughly corresponds to the period of ice cover on the Assiniboine River.

No data has been published on natural rates of temperature change in the Assiniboine River. The maximum natural rate of change observed by this author was an increase of 1^{o} F/hour which occurred on two occassions, once in August (90-95^{o} F air temperatures) and once in September (75^{o} F air temperature). Natural rates of water temperature decrease were not measured.

3.3.7 Snowcover

Several references have previously been made to the fact that the Assiniboine River is covered with ice and snow during the winter months, thus removing the river's two major sources of dissolved oxygen, atmospheric reaeration and algal photosynthesis. There is an important distinction to be made on this point.

Ice cover by itself prevents atmospheric reaeration, but does not hamper algal photosynthesis because ice is an excellent transmitter of light[47] which is the energy source for photosynthesis. Snow however, is a poor transmitter of light and Figure 7 illustrates the exponential decrease in the percentage transmission of light with increasing depth of snow[48].

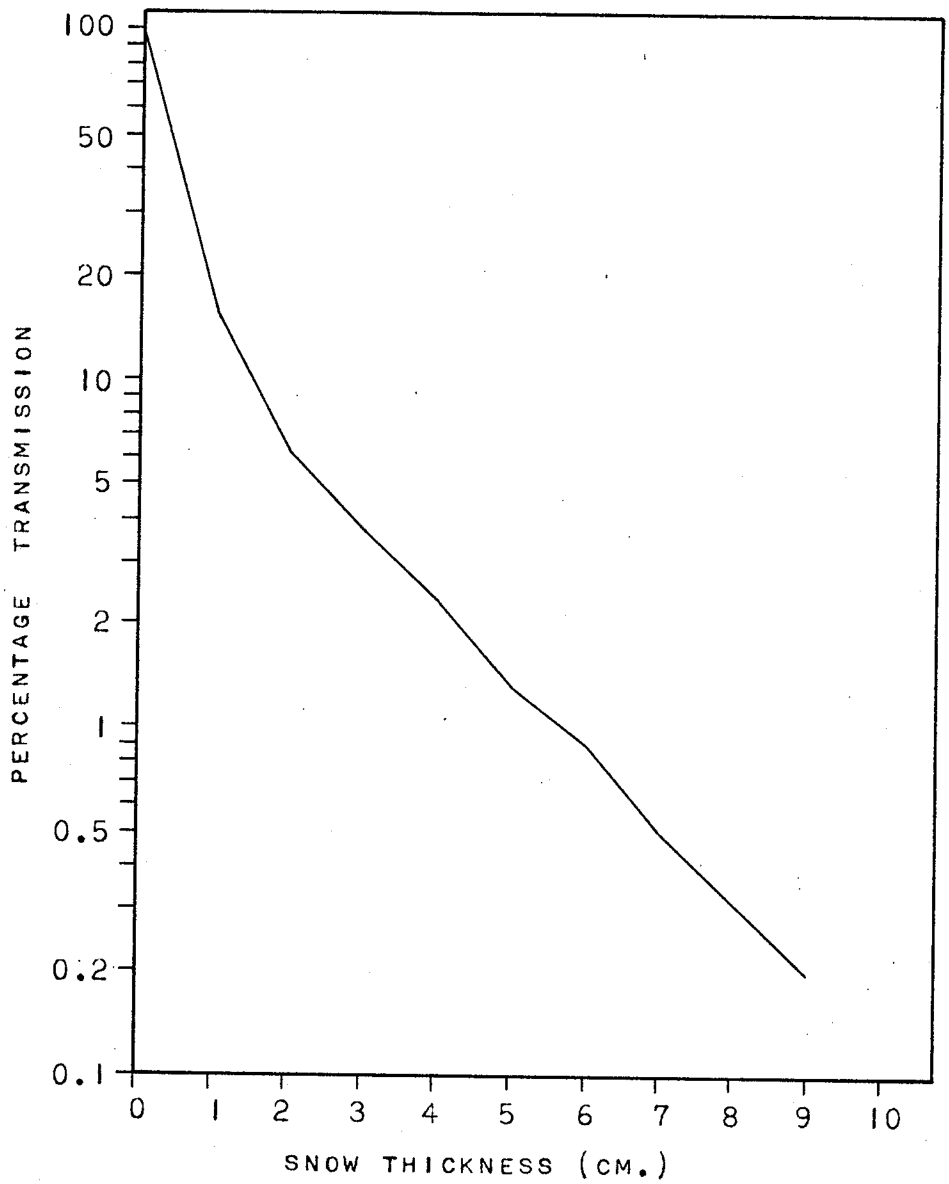

FIGURE 7. MEAN TRANSMISSION OF SUNLIGHT THROUGH SNOW. (48)

Determining the light requirements for algal photosynthesis is a complex problem dependent on such factors as the species of algae involved and temperature. Talling[49] however, states that once the light intensity is below one percent of the surface intensity, there is no appreciable growth or photosynthesis. Figure 7 shows that a depth of snow of only 6 cm. (2.4 inches) reduced the penetrant light intensity to this level of one percent of surface intensity.

The freezing air temperatures in the Brandon area in November and December (Figure 2) result in the formation of an ice cover on the Assiniboine River, and the mean snowfalls of 7.2 inches in November and 7.9 inches in December (Figure 3) result in a thick snow cover on the ice. The stability of the snow cover is enhanced by the high snow-retention coefficient of river beds. River beds tend to accumulate about three times as much snow as open prairie and about six or seven times as much snow as the open surfaces of lakes[41].

The thick snow cover on the Assiniboine River should be more than adequate to inhibit algal photosynthesis, in view of the relatively small depth of snow cover required to reduce the penetrant light to very low levels.

3.4 BRANDON GENERATING STATION

3.4.1 History

Brandon Generating Station commenced operation in 1957 with 4-30 MW* generating units, each capable of producing 33 MW on overload, to provide a maximum installed capacity of 132 MW. At that

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* megawatt

time, the station employed 3 mechanical draft cooling towers in a closed cooling system to dissipate the waste heat[50].

The closed cooling system consisted of (1) initially pumping the water for cooling from the river, (2) transferring waste heat to the cooling water in the condensers, (3) dissipating the waste heat in the cooling towers, and (4) re-routing the cooling water back through the condensers. The system was not completely closed because of the necessity of continuously adding river water to compensate for evaporative losses in the cooling towers. Employing this system, the station could operate with flows in the Assiniboine River as low as 7 cfs. [50].

One of the three cooling towers collapsed during the winter of 1966-67, because of the extreme temperature differentials that it was subjected to. The station continued to operate for the remainder of the winter, merely running the cooling water through the rubble of the collapsed tower.

The station suspended operation in the summer of 1967 to allow the construction of a once-through cooling system, which was placed in operation on September 8, 1967 and is still in use[50].

The maximum installed capacity was increased to its present level of 237 MW with the addition of a 105 MW generating unit, which began regular generation in November 1969.

Pulverized coal is the main fuel used at Brandon Generating Station, although gas and oil are occassionally used as auxiliary fuels[50].

3.4.2 Generating patterns

3.4.2.1 Introduction

The hydro-electric generating stations in Manitoba operate more or less continuously to satisfy the "base" of the electrical demand, while the steam-generating plants at Brandon and Selkirk operate to satisfy the "peaks" of the electrical demand. The demand for electricity is highly variable and thus the generation of a peaking plant is very irregular and often intermittent because it follows the variations in the electrical demand. The result of this type of operation is a waste head load to the river that is equally irregular and intermittent.

Brandon Generating Station also generates (1) when hydro-electric units are being repaired, (2) to conserve water at hydro plants during dry periods, and (3) when new equipment, hydro units, transmission lines, etc. are being tested[50]. Its operation both as a peaking plant and as a stand-by plant makes the task of predicting its operating patterns difficult. Generalizations will be made about the yearly, weekly, and daily operation patterns, but it must be remembered that the station can and does operate at any time and at any level of generation.

3.4.2.2 Yearly generating pattern

The yearly generating pattern of Brandon Generating Station is illustrated in Figure 8, which is a plot of monthly gross electrical generation from August 1967 to October 1972, the period in which once-through cooling has been in use. This figure shows that

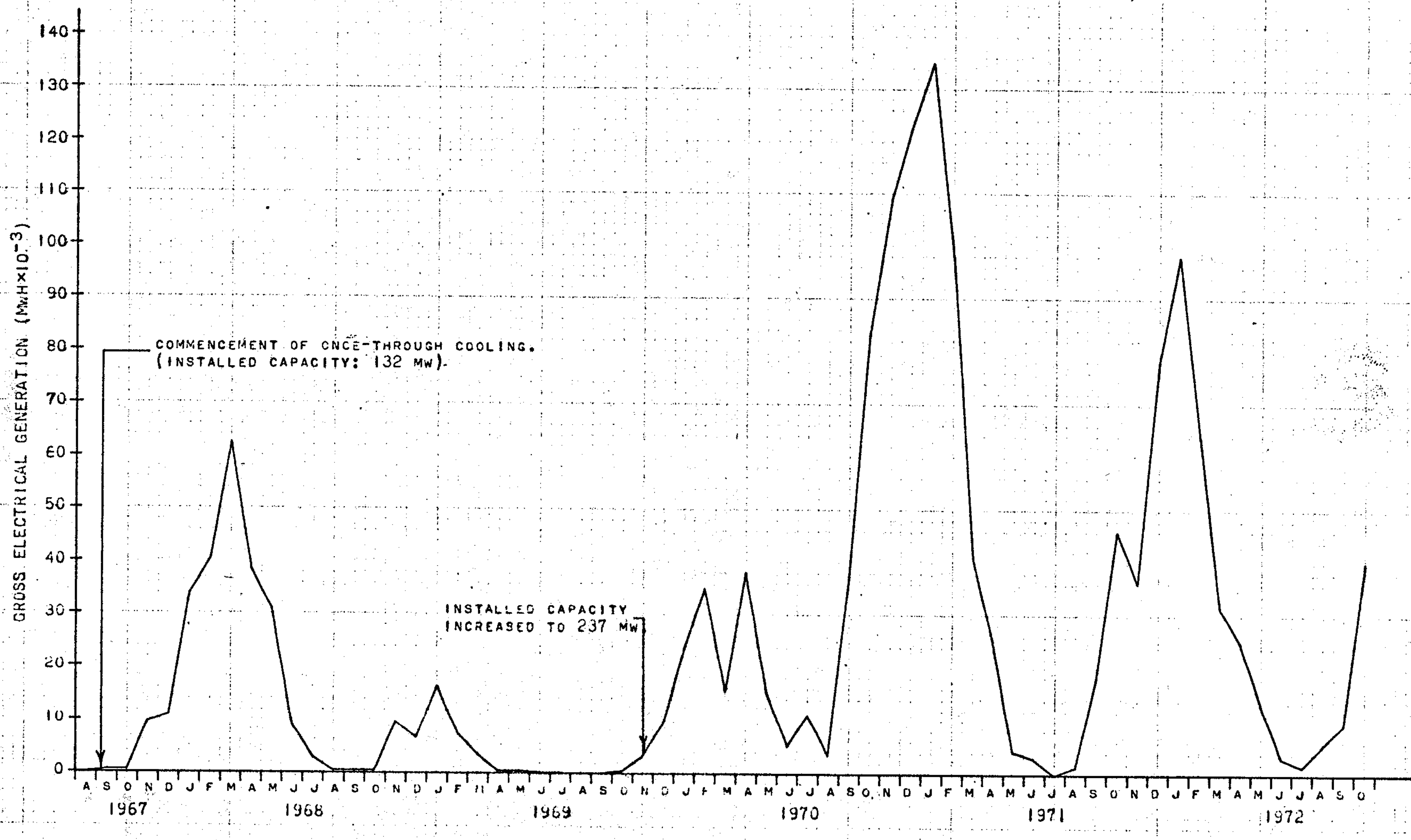

FIGURE 8. MONTHLY GROSS ELECTRICAL GENERATION OF BRANDON GENERATING STATION, AUGUST 1967 TO OCTOBER 1972.

the majority of generation has occurred during the months of September through May, with generally low generation during June, July, and August.

A comparison of Figure 5, showing the mean weekly discharge on the Assiniboine at Brandon, and Figure 8 showing the monthly gross electrical generation at Brandon Generating Station, indicates that the period of maximum generation coincides with the period of minimum discharge on the Assiniboine River. This is significant because it is during periods of maximum generation and minimum discharge that the waste heat discharge maximizes its effect on the thermal regime, creating the largest temperature fluctuations.

The comparison of Figures 5 and 8 also indicates that the period in which the largest temperature fluctuations in the river could occur has been shifted from mid-winter to late summer and early fall because of winter flow regulation. Prior to the winter releases from Shell mouth Reservoir the minimum flows occurred in January and December, whereas they now occur in August and September. This change in flow pattern should help to minimize the thermal effects since the probability of heavy generation is much higher in December and January than in August and September.

3.4.2.3 Weekly generating pattern

The demand for electricity on the week days, Monday to Friday, is relatively high, but on weekends (Saturday and Sunday) the demand is substantially less because of decreased commercial and industrial activity. Peaking plants therefore, may operate less or not at all on weekends. Brandon Generating Station follows such a pattern with higher generation during the week and then a reduction or shut-down in generation for the weekend.

3.4.2.4 Daily generation pattern

The daily generating pattern is illustrated in Figure 9 in which hourly spot generations of Brandon Generating Station for February 21st to 25th, 1972 have been plotted. This pattern is typical of the winter operation of the steam plant. Figure 9 illustrates the extreme variability and intermittent nature of the station's generating pattern, and because the waste heat load is directly proportional to the amount of electricity generated, a plot of waste heat to the Asssiniboine River versus time would be very similar in shape to this generation curve.

The largest and most rapid water temperature fluctuations in the river would be produced by the large variations in waste heat load associated with the daily start-up and shut-down of the station. (Figure 9).

3.4.3 Waste heat load

A very simplified description of the steam plant's operation is:

(1) Fuel (coal, oil, or gas) is burned in furnaces, and the heat produced is used to convert water to steam.

(2) The steam, at high temperature and pressure, enters a turbine where the energy of the steam is transferred to the turbine causing it to rotate. The turbine in turn spins a generator which

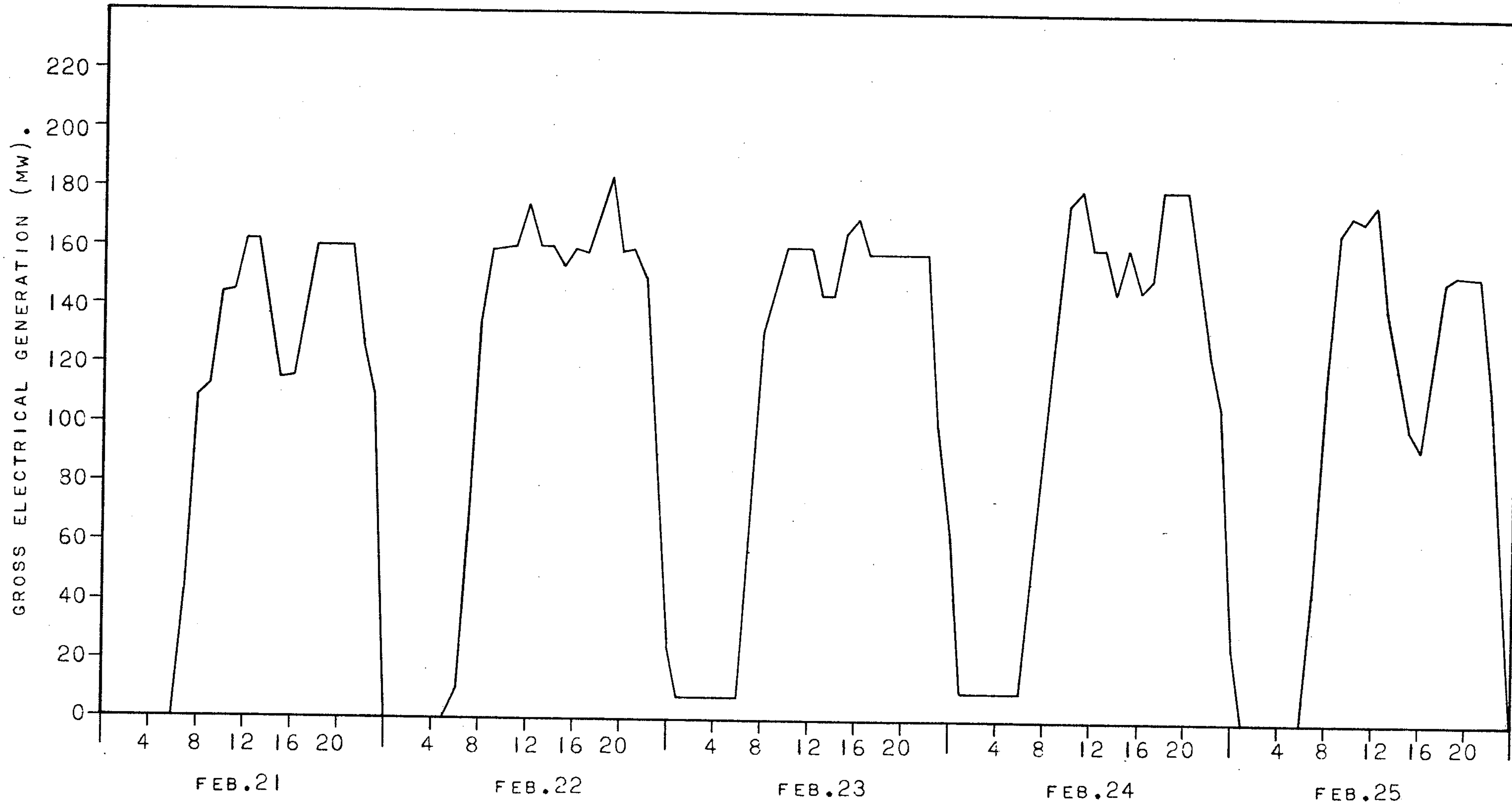

FIGURE 9 . GROSS ELECTRICAL GENERATION OF BRANDON GENERATING STATION, FEBRUARY 21-25, 1972.

produces electricity.

(3) On the exhaust side of the turbine, the steam, now at low temperature and pressure is condensed to water in condensers cooled by water from the Assiniboine River. The condensate is then reused as boiler feed water.

(4) The waste heat, primarily the latent heat of vaporization, is carried by the cooling water which is discharged directly to the Assiniboine River.

There are three sources of waste heat in this system:

(1) Waste heat released in the condensation of the steam.

(2) Waste heat from a hydrogen gas cooling system which is used to cool the electrical generators.

(3) Waste heat from an oil cooling system which cools the lubricating oil used in the turbines and generators.

The waste heat produced in the condensation of the steam is far greater than the waste heat contributed by the two auxiliary cooling systems[50].

An average of ten pounds of steam is required to produce one kilowatt of electricity, and the latent heat of vaporization released in condensing one pound of steam is 960 BTU*. To allow for over-cooling and the auxiliary cooling systems this value is increased to 1000 BTU/lb. of steam condensed. The turbines however, have a regenerative cycle which saves some of this latent heat. For all turbine loads, approximately 20% of the steam is bled from the turbines at various points and used to heat boiler feed water, and thus

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* British thermal unit.

only 80% of the steam is condensed in the condensers.

The waste heat load may be estimated from the gross electrical generation as follows:

$$\text{WASTE HEAT/HOUR} = \text{KW} \times 10 \times 0.8 \times 1000 \text{ (BTU/KW)}$$
$$= \text{KW} \times 8{,}000 \text{ (BTU/KW)}$$
$$= \text{MW} \times 8 \times 10^6 \text{ (BTU/MW)}$$ (50)

An initial attempt was made to base the waste heat estimation on the volume and temperature increase of the cooling water discharged, but although the intake and discharge temperature of the cooling water are continuously monitored, there is no way of accurately estimating the volume of the cooling water flow.

The above formula for the waste heat load is useful in estimating the impact of the thermal discharge on the thermal regime of the Assiniboine River. The water temperature change in the Assiniboine River may be calculated by the following equation which assumes that the mixing between the thermal discharge and the river is instantaneous and complete:

$$\Delta T = \frac{\text{MW} \times 8 \times 10^6}{Q \times 62.4 \times 3600} = 35.6 \frac{\text{MW}}{Q} \quad (^{\circ}\text{F})$$

where: ΔT = water temperature change in Assiniboine River in $^{\circ}$F.

MW = gross electrical generation in MW.

Q = discharge in Assiniboine River in cfs.

3.5 WATER USES IN THE BRANDON AREA

This section briefly outlines the major uses of the water of the Assiniboine River in the Brandon Area.

3.5.1 Water supply

A. Municipal

- City of Brandon draws its water supply from the Assiniboine River, approximately 8 miles upstream from Brandon Generating Station.

B. Industrial

- Brandon Generating Station uses Assiniboine River water for cooling, boiler feed water, ash sluicing and other in-plant uses.

C. Agriculture

- irrigation and livestock watering.

3.5.2 Waste disposal

A. Organic wastes

- City of Brandon lagoons, sewage by-passes, and urban drainage (storm sewers).
- Brandon Generating Station's domestic wastes.
- piggery (located about 1.2 miles upstream from Brandon Generating Station).

B. Inorganic wastes

- Simplot Chemical Company.
- Dryden Chemicals Ltd.
- Brandon Water Treatment Plant.
- City of Brandon Lagoons.
- Brandon Generating Station (ash lagoon discharge and other liquid wastes).

C. Thermal

- Brandon Generating Station.

3.5.3 Recreation

A. Fishing

There is no commercial fishery on the Assiniboine River at Brandon, but several sports fishermen were observed angling along the river, during every trip to the study area during the summer of 1972.

B. Canoeing, camping, hiking

C. Enjoyment of aesthetic value

3.5.4 Propagation of fish and wildlife

The Assiniboine River supports a wide variety of fish and wildlife species in the Brandon area, especially downstream from Brandon in areas that are relatively inaccessible.

The following species of fish are known to inhabit the Assiniboine River in the Brandon Area:

(1) Northern pike[51]

(2) Walleyed pike[51]

(3) White sucker[51]

(4) Northern redhorse sucker[51]

(5) Sauger[51]

(6) Flathead chub[51]

(7) Yellow perch[51]

(8) Rock bass[51]

(9) Mooneye[52]

(10) Carp[53]

(11) Goldeye[53]

Numerous fish were observed during the summer study period of 1972. The following kinds of wildlife were also observed during this period:

(1) muskrat

(2) beaver

(3) deer

(4) fox

(5) rabbit

(6) coyote

(7) raccoon

(8) blue heron

(9) several types of ducks

3.5.5 Transportation

Farmers downstream from Brandon have used the ice cover on the Assiniboine River as a means of crossing the river during the winter months. The thermal discharge from Brandon Generating Station has interfered with this practice by maintaining open water downstream from the station during the winter[54].

3.6 MAJOR SOURCES OF WASTE IN THE BRANDON AREA

3.6.1 Introduction

The locations of the major contributors of waste to the Assiniboine River and the chemical and biological sampling stations used in this study are depicted in Figures 1 and 10.

3.6.2 Brandon Generating Station

Figure 10 illustrates the physical layout of Brandon Generating

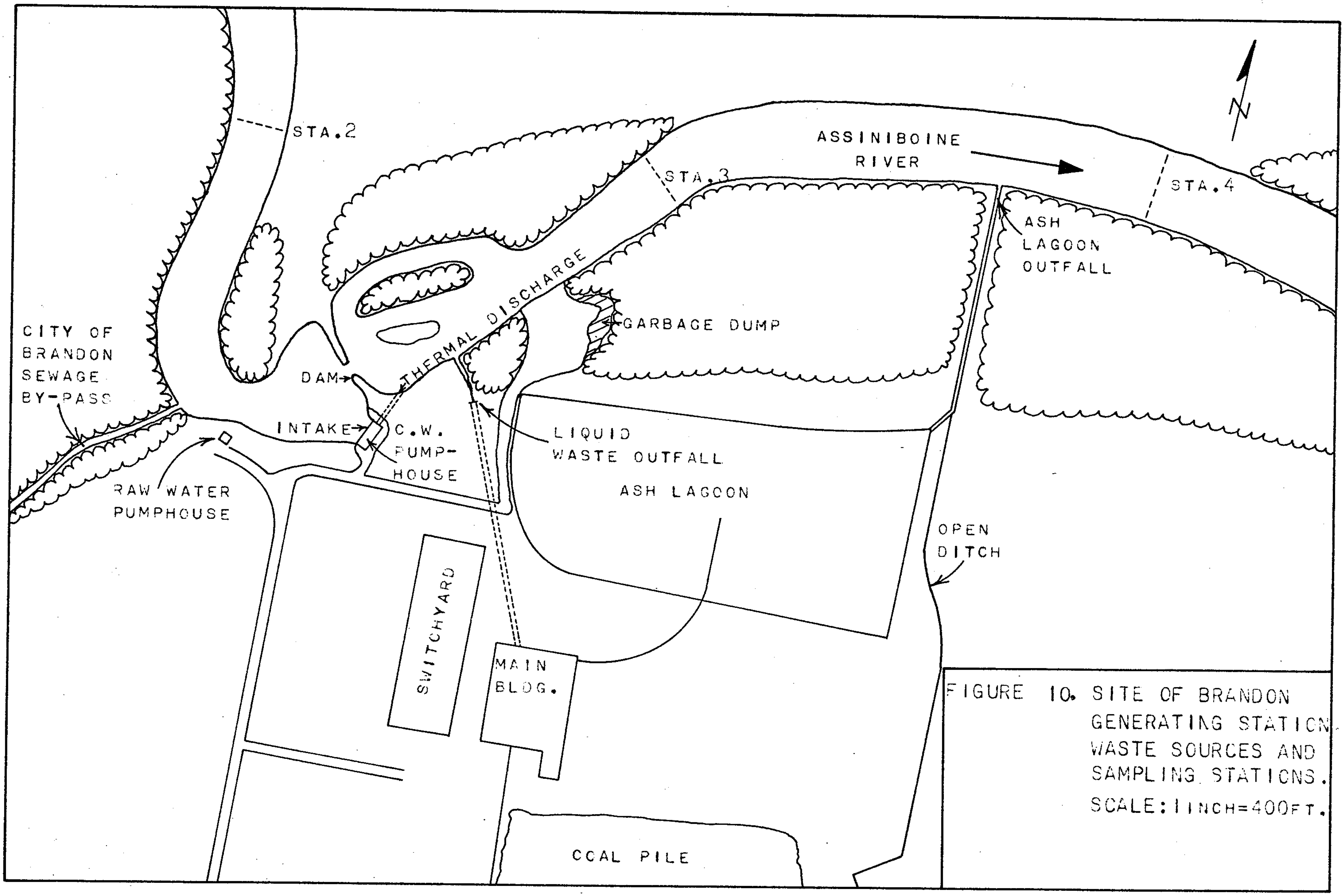

FIGURE 10. SITE OF BRANDON GENERATING STATION WASTE SOURCES AND SAMPLING STATIONS.
SCALE: 1 INCH=400FT.

Station, showing the three waste discharges from the plant; (1) the thermal discharge, (2) the liquid waste discharge, and (3) the ash lagoon discharge.

The dam just upstream from the thermal discharge is a temporary structure composed of rock, gravel, and fill material and is usually washed away by the spring floods, making it necessary to reconstruct it every fall. The purpose of the dam is to raise the water level to facilitate the pumping of cooling water from the river[50]. The dam only partially restricts the river's flow, so that there is a continuous flow in the river downstream from Brandon Generating Station, regardless of whether the plant is operating or not.

Figure 11 is a flow diagram of the water and wastewater in the Brandon Generating Station[55].

3.6.2.1 Thermal discharge

Water for cooling is drawn into the intake structure on the Assiniboine River by 4 - 22,500 U.S.G.P.M. pumps (approximately 200 cfs. maximum combined capacity). Before reaching the pumps the water must pass through a 1 in. x 1 in. stationary screen, and then through a ½ in. x ½ in. travelling screen on a rotating drum[50]. The pumps force the cooling water through the condensers where its temperature is raised (maximum temperature increase is 28^{o} F), and then discharge the cooling water downstream from the dam. Two weirs, one in the cooling water pumphouse and one on the river's edge, create considerable turbulence as the cooling water is discharged (Figure 10).

The waste heat content of the thermal discharge is directly proportional to the amount of electricity being generated as outlined

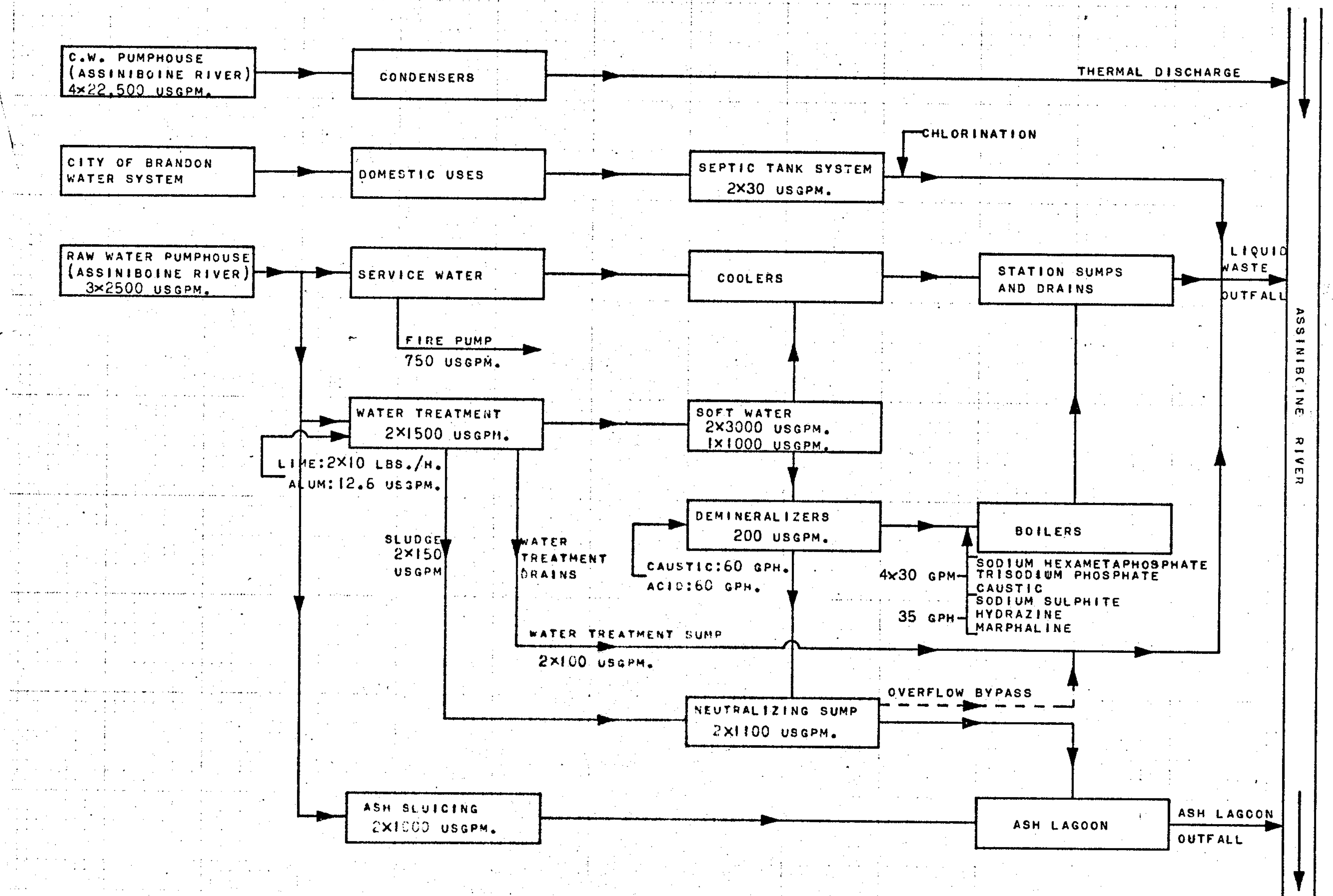

FIGURE 11. WATER AND WASTEWATER FLOW DIAGRAM FOR BRANDON GENERATING STATION.

in section 3.4.3.

3.6.2.2 Liquid waste discharge

Figure 11 indicates that the liquid waste discharge includes: septic tank effluent, boiler blowdown, cooling water, and miscellaneous plant drainage. No estimate of the volume of this discharge is available.

During the summer and fall of 1972, several barrels of oil were discharged to the Assiniboine River via tiny leaks in the oil cooling condensers. The oil pressure in the cooling condensers is greater than the cooling water pressure and thus the oil was discharged to the river with the cooling water[50].

3.6.2.3 Ash lagoon discharge

The effluent streams to the ash lagoon include, (1) sludge from the solids-contact units used in the preparation of boiler feed water, (2) backwash from the demineralizers, and (3) ash washed from the stack gases by the wet scrubbers. (Figure 11).

The volume and chemical composition of the effluent leaving the ash lagoon is not known.

3.6.3 Simplot Chemical Company

Simplot Chemical Company is a fertilizer manufacturing company. The types of fertilizer produced varies with the seasons and the market demand, and thus the chemical composition of its effluent varies accordingly[56].

Prior to July 29, 1972 Simplot Chemical Company discharged their waste into a lagoon which overflowed to a swampy area, with some of their effluent eventually reaching the Assiniboine River via an open ditch along the east edge of Brandon Generating Station's ash lagoon (Figure 10). At present, Simplot Chemical Company is using its effluent to irrigate forage crops[56].

The effluent from Simplot Chemical Company is characteristically high in nitrogen and phosphorus compounds. Chemical analyses performed by the Environmental Protection Laboratory on individual grab samples taken from the Simplot lagoon between April and December of 1971 produced the following results:

(1) Total nitrogen as N: Mean = 765 mg/1.
Range : 458 - 1125 mg/1.

(2) Total phosphate as PO_4: Mean = 22.7 mg/1.
Range : 4.7 - 56.0 mg/1.

The volume of waste being discharged from the Simplot plant has been estimated at 300,000 gallons per day (less than one cfs.)[56]. The percentage of this volume which actually reached the Assiniboine River is not known.

3.6.4 City of Brandon lagoons

The city of Brandon's sewage lagoons are located approximately 2.5 miles downstream from Brandon Generating Station and consist of two anaerobic cells of one acre each and three aerobic cells of 139, 82, and 86 acres respectively. Sewage flows to the Main Lift Station located opposite the Brandon Generating Station and is then pumped to the lagoons via a force main. The lagoons were first used on February 15, 1965. Prior to this date untreated sewage had been discharged to the Assiniboine River. The first discharge from the lagoons was from cell #5 on August 10, 1965[56].

The Clean Environment Commission requires that the following rules be observed in the operation of the lagoons:

(1) No discharges to the Assiniboine River are permitted between November 1st and May 15th, unless special permission is granted by the Clean Environment Commission.

(2) The coliform MPN (most probable number) in the lagoon must be less than 1500 before it can be discharged to the river.

Typical operation of the lagoons is as follows:

(1) raw sewage enters the anaerobic cells from the force main.

(2) the anaerobic cells overflow to the aerobic cells.

(3) the aerobic cells are discharged to the Assiniboine River when the coliform MPN is less than 1500 (except between November 1st and May 15th)[57].

The seasonal operating schedule is similar from year to year, and can be illustrated by outlining the procedure followed in 1971-72:

(1) No discharges to the Assiniboine River after November 1, 1971. Cells slowly fill over the winter.

(2) March 22, 1972. All cells were full and cell #5 began overflowing to the Assiniboine River. (The Brandon lagoons are no longer large enough to provide storage from November 1st to May 15th).

(3) May 29, 1972. Cell #3 began discharging to the Assiniboine River (Coliform MPN - 930, BOD_5 = 27 mg/1). The draining of a cell

usually takes several weeks and then the outlet to the river is closed and the cell refilled from one of the other cells.

(4) June 16, 1972. Cells #4 and #5 began discharging. (Cell #4: coliform MPN = 150, BOD_5 = 22 mg/l., cell #5: coliform MPN = 110, BOD_5 = 11 mg/l.).

(5) July 24, 1972. Cell #3 had been refilled and stabilized and began to discharge again. (Coliform MPN = 930, BOD_5 = 16 mg/l.).

(6) September 15, 1972. Cell #5 began to discharge again. (Coliform MPN = 730, BOD_5 = 11 mg/l.).

(7) October 20, 1972. Cell #4 began to discharge again. (Coliform MPN = 1500, BOD_5 = 27 mg/l.).

(8) November 1, 1972. No further discharges[57].

The actual volumes associated with these discharges is not readily available.

3.6.5 Dryden Chemicals Ltd.

Dryden Chemicals is a chloralkali plant and is located 4.3 miles downstream from Brandon Generating Station. Their basic operation consists of pumping salt brine from the Winnipegosis Limestone formation which lies 2,200 feet below the plant, and subjecting the brine to an electrolytic process to produce chlorine, caustic soda, soda ash, muriatic acid, sodium chlorate, and hydrochloric acid.

All process effluents flow to a balancing pond which is intended to settle solids, neutralize pH, and average the concentrations of the wastes. The pond overflows directly to the river via an underground sewer. The sludges that accumulate on the bottom of the pond are flushed out in the spring during periods of high discharge on the Assiniboine River[56].

The maximum waste discharge from Dryden Chemicals is 1250 I.G.P.M. (approximately 3.4 cfs.)[58].

The effluent from Dryden Chemicals is characterized by a high concentration of filterable residue (dissolved solids), high sodium and chloride ion concentrations, and a high specific conductivity. The analysis by the Environmental Protection Laboratory of four grab samples of Dryden Chemicals Ltd. effluent taken during 1971 and 1972 produced the following results:

(1) specific conductance: Mean = 4700 μ mhos
Range : 4000 - 5500 μ mhos

(2) pH: Mean = 7.6
Range : 6.6 - 9.2

(3) chloride ion: Mean = 1345 mg/1.
Range : 1220 - 1600 mg/1.

(4) sodium ion: Mean = 932 mg/1.
Range : 740 - 1200 mg/1.

(5) filterable residue: Mean = 2975 mg/1.
Range : 2600 - 3480 mg/1.

4. STUDY METHODS

4.1 WINTER STUDY PERIOD

4.1.1 Physical testing methods

Water temperature was the only physical parameter measured during the winter study period, to establish a water temperature profile downstream from Brandon Generating Station.

Water temperatures were measured from a boat using (1) a Yellow Springs (Model 54) Oxygen and Temperature Meter, and (2) a mercury-filled Fahrenheit thermometer. The Temperature Meter performed poorly with very slow meter response, probably because of the low air temperatures (about 0^{o} F) under which it was operated.

4.1.2 Chemical testing methods

Two chemical parameters were measured during the winter study period, (1) dissolved oxygen (DO), and (2) biochemical oxygen demand (BOD_5). The DO concentration and the BOD_5 of the river water upstream and downstream from Brandon Generating Station were measured to assess the impact of the thermal discharge on the oxygen resources of the Assiniboine River.

Water samples for DO and BOD_5 tests were collected in 300 ml. incubation bottles with ground-glass stoppers using a DO sampler. The DO sampler is a cylindrical, brass container of one liter capacity. When the DO sampler containing an unstoppered 300 ml. bottle is submerged in water, the bottle is filled with water from the bottom and overflows its volume twice before the actual DO or BOD_5 sample is taken. This method insures that extraneous oxygen does not enter the water sample.

The dissolved oxygen concentrations of the DO and BOD_5 samples were measured using the Azide Modification of the Winkler Method as described in Standard Methods For The Examination of Water and Wastewater[36], hereafter referred to as Standard Methods. The BOD_5 samples were incubated undiluted, for 5 days at 20° C in an air incubator with no attempt being made to reduce the DO concentration of supersaturated samples.

An attempt was made to measure the dissolved oxygen concentration of the river water using the Yellow Springs (Model 54) Oxygen and Temperature Meter, but slow response of the meter resulted in the abandonment of this method.

4.1.3 Biological testing methods

No biological testing had been planned for the winter study period, but two grab samples of filamentous algae growing on rocks at the thermal discharge outfall were collected.

4.1.4 Air photographs

Air photographs of the Assiniboine River downstream from Brandon Generating Station were taken by the Surveys Branch, Manitoba Department of Mines, Resources, and Environmental Management on February 24, 1972 to determine the ice conditions and the extent of open water.

4.2 SUMMER STUDY PERIOD

4.2.1 Establishing sampling stations

All physical, chemical, and biological data were collected in the vicinity of the ten sampling stations shown in Figures 1 and 10. These stations were established in accordance with the guidelines for locating biological sampling stations suggested by Cairns and Dickson[2], which have been outlined in section 2.3.4. A brief description of each sampling station is given in Appendix 1. The most difficult aspect of locating the sampling stations was finding stations that were ecologically similar (ie. similar velocity, depth, width, bottom substrate, etc.) within a given reach of the river.

4.2.2 Physical testing methods

The following physical measurements were made once a month at each station, during the summer study period:

(1) water temperature

(2) air temperature

(3) stream depth

(4) stream velocity

The water and air temperatures were measured using a mercury-filled Fahrenheit thermometer. Stream depth was measured using a calibrated piece of nylon rope weighted with a lead sounder. Stream velocity was measured at a depth of 0.6 of the stream depth using a Gurley current meter and a Stevens sounding reel.

4.2.3 Chemical testing methods

River water samples were taken once a month at each station, during the summer study period for the following chemical analyses:

(1) dissolved oxygen concentration (DO)

(2) biochemical oxygen demand (BOD_5)

(3) pH

(4) total and phenolphthalein alkalinities.

All water samples were collected in 300 ml. incubation bottles using a brass DO sampler as described in section 4.1.2. The DO and BOD_5 samples were analysed as described in section 4.1.2 with the exception that the DO samples were "fixed" with the manganous sulphate, alkali-iodide - azide, and concentrated sulphuric acid reagents immediately after collection.

The water samples for pH and alkalinity analysis were collected during the course of the day and analysed in the evening at the field laboratory (Main Lift Station). The pH was measured using a Radiometer (Type PHM 29) glass electrode pH meter as outlined in Standard Methods[36]. The phenolphthalein and total alkalinities were measured by titration with 0.02 N sulphuric acid to the end points of 8.3 and 4.5 respectively, as indicated by glass electrode pH meter (Standard Methods[36]).

4.2.4 Biological testing methods

4.2.4.1 Dredges

An initial attempt was made to sample the benthic fauna of the Assiniboine River using (1) a standard Ekman dredge (6 in. x 6 in.) and (2) a Petersen dredge (10 in. x 10.5 in.).

The standard Ekman was used during May 4-11, 1972 and proved to be unsatisfactory for two reasons. First, the standard Ekman was too light to be used in the fast current of the river (2-3 fps. at this time). To make it fall vertically and grab a sample from the bottom, it was necessary to tie a 15 lb. weight to the top of the Ekman, which interfered with its proper operation. Second, the standard Ekman was not suited to sampling the sands and gravels of the Assiniboine River since the jaws of the dredge were repeatedly jammed open by sand and gravel. The benthic samples taken during May were consequently taken from the inside of meanders, close to the shore, where clam water and find textured materials (clay and silt) could be located. Four dredge hauls (1.0 sq. ft.) were taken at each station, the sample washed through a No. 30 sieve, and the material retained on the screen was preserved with 65% ethyl alcohol. The benthic macroinvertebrates were later removed from the material retained on the No. 30 sieve, counted, sorted into groups on the basis of colour, size, and shape, and the total numbers, number of taxa, and the number per taxa recorded.

The Petersen dredge was used during June 6 - 10, 1972 and also proved to be unsatisfactory. The Petersen dredge was capable of sampling in faster water and in a wider variety of substrates than the Ekman dredge, but the Petersen dredge could not sample the coarse gravel, rubble, and rock found in parts of the Assiniboine River (section 3.3.3). It was also found that when sampling clay, silt, or sand bottoms, the Petersen dredge collected such large quantities of material that a great deal of time was required to remove the benthic macroinvertebrates from each sample.

The main reason for abandoning the Petersen dredge was because it was impossible to find similar bottom substrates in every reach of the river where a sampling station was required.

The samples taken in June with the Petersen dredge were taken on the inside of meanders where clays and silts could be found. The samples were treated in the same manner as those taken by the Ekman dredge, except that only two hauls (1.46 sq. ft.) were taken per station.

4.2.4.2 Artificial substrates

The problems encountered with the dredges led to the use of multiple-plate artificial substrate samplers as illustrated in Figure 12, for the remainder of the summer study period, July, August, September, and October. They are made from 3 inch squares of 1/8 in. tempered hardboard, separated by 1 inch squares of 1/4 in. tempered hardboard. A hole is drilled through the centre of each square and a 3/8 in. diameter eyebolt is passed through the squares.

The multiple-plate samplers were chosen for this study because they are inexpensive and easily made from locally available materials.

The multiple-plate samplers were mounted on cinder blocks (10 in. x 10 in. x 10 in. cubes), (2 samplers per block) and 3 blocks tied together with nylon rope as shown in Figure 13, with a styrofoam float to mark the position of the samplers. The samplers are suspended at about 2 inches from the bottom when the cinder blocks are in place on the river bottom. As shown in Figure 13, six samplers were used per station so that a reasonably accurate estimate of the population parameters could be made. Each multiple-plate sampler has an area of about 1 sq. ft., and thus a total area of 6 sq. ft. per station was available for colonization.

4.2.4.3 Field procedure

The procedure used in collecting the benthic samples from the multiple-plate samplers is as follows:

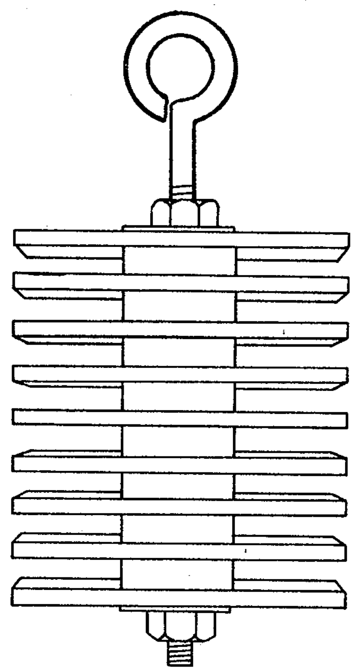

FIGURE 12. MULTIPLE-PLATE ARTIFICIAL SUBSTRATE SAMPLER.(36)

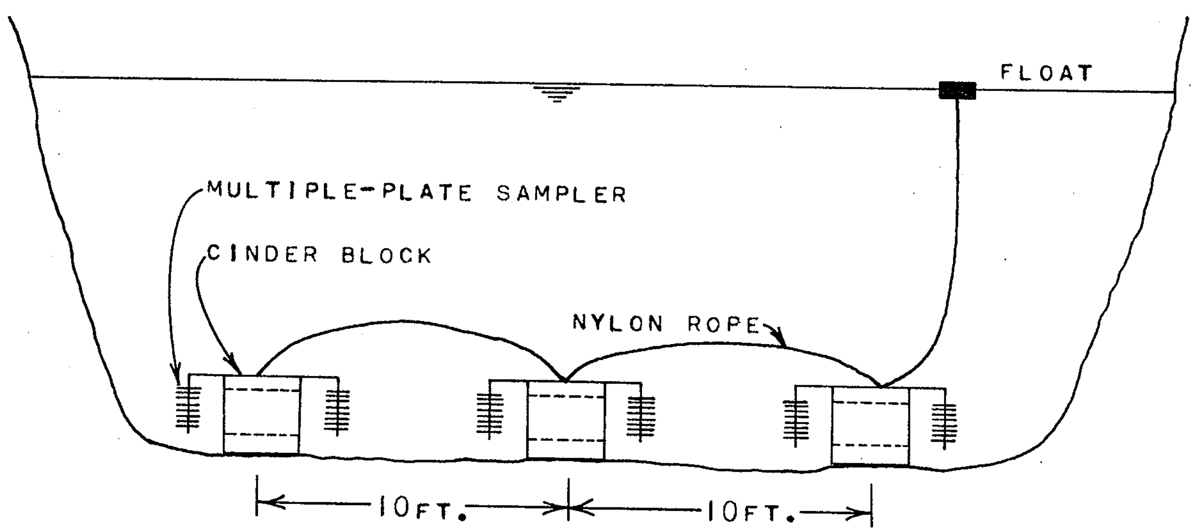

FIGURE 13. MULTIPLE-PLATE SAMPLERS IN POSITION ON THE RIVER BOTTOM.

(1) The samplers were placed on the river bottom as shown in Figure 13, and left there for a period of 28 days ($\pm$ 2 days) to allow time for a stable benthic population to colonize the samplers.

(2) After 28 days, each station was approached by boat from downstream (to minimize the disturbance of the samplers), the samplers pulled into the boat by the nylon ropes with which they were tied, and plastic bags slipped over each of the six multiple-plate samplers.

(3) The samplers were disassembled one by one, cleaned by hand, and the debris and fauna removed from them washed on a No. 30 sieve and preserved with 65% ethyl alcohol in 4 ounce sample bottles.

(4) The samplers were reassembled and placed on the river bottom for another 28 day period.

4.2.4.4 Laboratory procedure

The preserved samples from the multiple-plate samplers were treated in the following manner:

(1) Each sample was poured onto a white enameled tray, and the benthic macroinvertebrates removed from the debris.

(2) The benthic macroinvertebrates were sorted into groups or taxa on the basis of differences in colour, size, and shape.

(3) The following values were recorded:

- total number of benthic macroinvertebrates per sample
- number of taxa per sample
- number of benthic macroinvertebrates per taxa.

4.3 TREATMENT OF BIOLOGICAL DATA

A computer combination of sequential comparison techniques used by Cairns et al[38] and Cairns and Dickson[2] was developed for this study. The original techniques proposed by these authors proved to be very time-consuming, and because of the tediousness of these techniques, it was found that many errors were made. The computer technique was thus developed (1) to greatly reduce the time and labour involved in applying the sequential comparison method and (2) to increase the accuracy and precision of the data.

This computerized variation of the sequential comparison method was applied to the biological data collected with the multiple-plate samplers during the months of July, August, September, and October.

The biological data collected by dredges during the months of May and June was considered to be neither sufficiently quantitative nor sufficiently representative of the bottom fauna to be evaluated by the sequential comparison technique.

The description of the sequential comparison technique is lengthy and thus has been placed in Appendix 2.

5. RESULTS AND OBSERVATIONS

5.1 WINTER STUDY PERIOD

5.1.1 Water temperature profiles

The results of all water temperature profiles taken during the winter and summer study periods are contained in Table 2. Each profile is accompanied by the approximate discharge in the Assiniboine River at Brandon and the level of generation of Brandon Generating Station during the time when the profiles were taken.

Water temperature increases above ambient of 8^{o}F (Feb. 22), 10^{o}F (Oct. 6), 11^{o}F (Oct. 31), 8^{o}F (Nov. 1), and 9.5^{o}F (Nov. 2) were measured in the river after mixing between the river water and the thermal discharge was essentially complete. At a distance of one mile downstream the increases in water temperature above ambient were 5.5^{o}F (Feb. 22), 9^{o}F (Oct. 6), 7.5^{o}F (Nov. 1), and 9.5^{o}F (Nov. 2).

5.1.2 Dissolved oxygen conditions

The results of two sets of dissolved oxygen measurements taken upstream and downstream from Brandon Generating Station are presented in Table 3. These results indicate the dissolved oxygen concentration increased in the downstream direction to produce increases of 1.0 mg/l (Feb. 22) and 1.3 mg/l (Feb. 23) at Treesbank Ferry (27.5 mi. downstream from Brandon Generating Station).

A summary of dissolved oxygen measurements taken in the Assiniboine River during periods when it is normally covered with ice and snow is presented in Table 4. These measurements were taken by the Manitoba Department of Mines, Resources, and Environmental Management,

TABLE 2. WATER TEMPERATURE PROFILES IN THE ASSINIBOINE RIVER, 1972.

DATE	DISCHARGE (C.F.S.)†	GENERATION (MW)	MILES FROM BRANDON GENERATING STATION'S THERMAL DISCHARGE														
			UPSTREAM	DOWNSTREAM													
			B.G.S. DAM	0.1 N	0.1 M	0.1 S	0.2 N	0.2 M	0.2 S	0.5 N	0.5 M	0.5 S	1.0 M	1.7 M	2.5 M	3.5 M	4.2 M
FEB.22	694	159	32*	-	40	-	-	-	-	-	-	-	37.5	35.5	35.5	34	33
OCT. 6	365	103	49	57	60	60	58	58	59	-	59	-	58	52	50	50	50
OCT.31	465	155	32	-	-	-	42	43	43.5	-	-	-	-	-	-	-	-
NOV. 1	465	108	32	-	-	-	40	40	41	40	40	39	39.5	38.5	37.5	-	-
NOV. 2	465	140	32.5	34	47	48	41.5	41.5	42	42	42	42	42	41	38.5	33.5	33.5

*-WATER TEMPERATURE IN °F.

N-NORTH SHORE

M-MIDSTREAM

S-SOUTH SHORE

†-DISCHARGE IN THE ASSINIBOINE R. AT BRANDON.

TABLE 3 . DISSOLVED OXYGEN CONCENTRATION PROFILES OF THE ASSINIBOINE RIVER, FEBRUARY 22-23, 1972.

DATE	MILES FROM BRANDON GENERATING STATION'S THERMAL DISCHARGE										
	UPSTREAM	DOWNSTREAM									
	-0.1	0.1	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	27.5*
FEB.22/72	9.5+	9.8	9.8	9.9	10.0	10.0	10.0	10.0	10.0	10.1	10.5
FEB.23/72	9.0	9.5	9.5	-	-	-	-	-	-	-	10.3

*-TREESBANK FERRY (45 HOURS WAS ALLOWED FOR WATER TO TRAVEL FROM BRANDON TO TREESBANK

+-DISSOLVED OXYGEN CONCENTRATION IN MG/L.

TABLE 4. DISSOLVED OXYGEN CONCENTRATIONS IN THE ASSINIBOINE R., DURING PERIODS OF WINTER ICE COVER.

DATE	18TH ST. BRIDGE (-7.5 MI.)†	STEAM PLANT INTAKE (0 MI.)*	CITY OF BRANDON LAGOONS (3.0 MI.)*	TREESBANK FERRY (27.5 MI.)*
NOV.16/66	15.5	15.5	15.6	13.5
DEC.15/66	7.1	8.7	8.5	7.0
FEB.17/67	4.8	4.2	4.4	9.4
SEPT.8/67	COMMENCEMENT OF ONCE-THROUGH COOLING			
JAN.24/68	6.1	5.8	8.9	9.8
FEB.28/68	4.2	4.3	10.5	10.6
NOV.16/68	-	14.2	11.0	12.7
FEB.19/69	3.4	4.0	6.7	6.5
JAN.29/70	7.2	8.1	-	7.6
MAR.18/70	5.5	5.7	-	7.3
JAN.20/71	6.8	7.2	10.2	10.7
FEB.16/71	6.2	6.8	7.6	9.2
JAN.27/72	8.2	9.9	-	10.6
FEB.24/72	8.6	8.5	9.5	13.1

†-MILES UPSTREAM FROM BRANDON GENERATING STATION
*-MILES DOWNSTREAM FROM BRANDON GENERATING STATION

Environmental Protection Laboratory during their monthly Assiniboine River surveys between 1966 and 1972, inclusive. The measurements taken prior to the commencement of once-through cooling (September 8, 1967) represent the dissolved oxygen conditions in the Assiniboine River under unbroken ice and snow cover. The measurements after September 8, 1967 represent the dissolved oxygen conditions when the thermal discharge was maintaining open water downstream from Brandon Generating Station.

The results of two sets of measurements made during the winter study period to determine the changes in the temperature and dissolved oxygen content of cooling water as it passed through the condensers are contained in Table 5. It should be noted that although the temperature of the cooling water was increased by 21 - 22^{o}F, the dissolved oxygen concentration increased by 1.4 mg/l.

5.1.3 Ice conditions

The ice conditions in the Assiniboine River downstream from Brandon Generating Station on February 24, 1972 are illustrated in Figure 14, which was prepared using aerial photographs taken by the Manitoba Department of Mines, Resources, and Environmental Management, Surveys Branch. The discharge in the Assiniboine River at Brandon was approximately 700 cfs. at this time and Brandon Generating Station was generating in the 160 - 170 MW range during the day and shutting down between midnight and 6:00 a.m. (Figure 9). The mean daily temperature for the two-week period preceding February 24, 1972 was approximately 0^{o}F, which is slightly lower than the long-term mean daily temperature

TABLE 5 . TEMPERATURE AND DISSOLVED OXYGEN CONCENTRATION OF THE COOLING WATER AT THE INTAKE AND DISCHARGE , FEBRUARY 1972.

DATE	INTAKE		DISCHARGE		CHANGE	
	T (°F)	D.O. (MG/L)	T (°F)	D.O. (MG/L)	ΔT (°F)	ΔD.O. (MG/L)
FEB.24/72	32	8.8	53	10.2	+21	+1.4
FEB.25/72	32	8.6	54	10.0	+22	+1.4

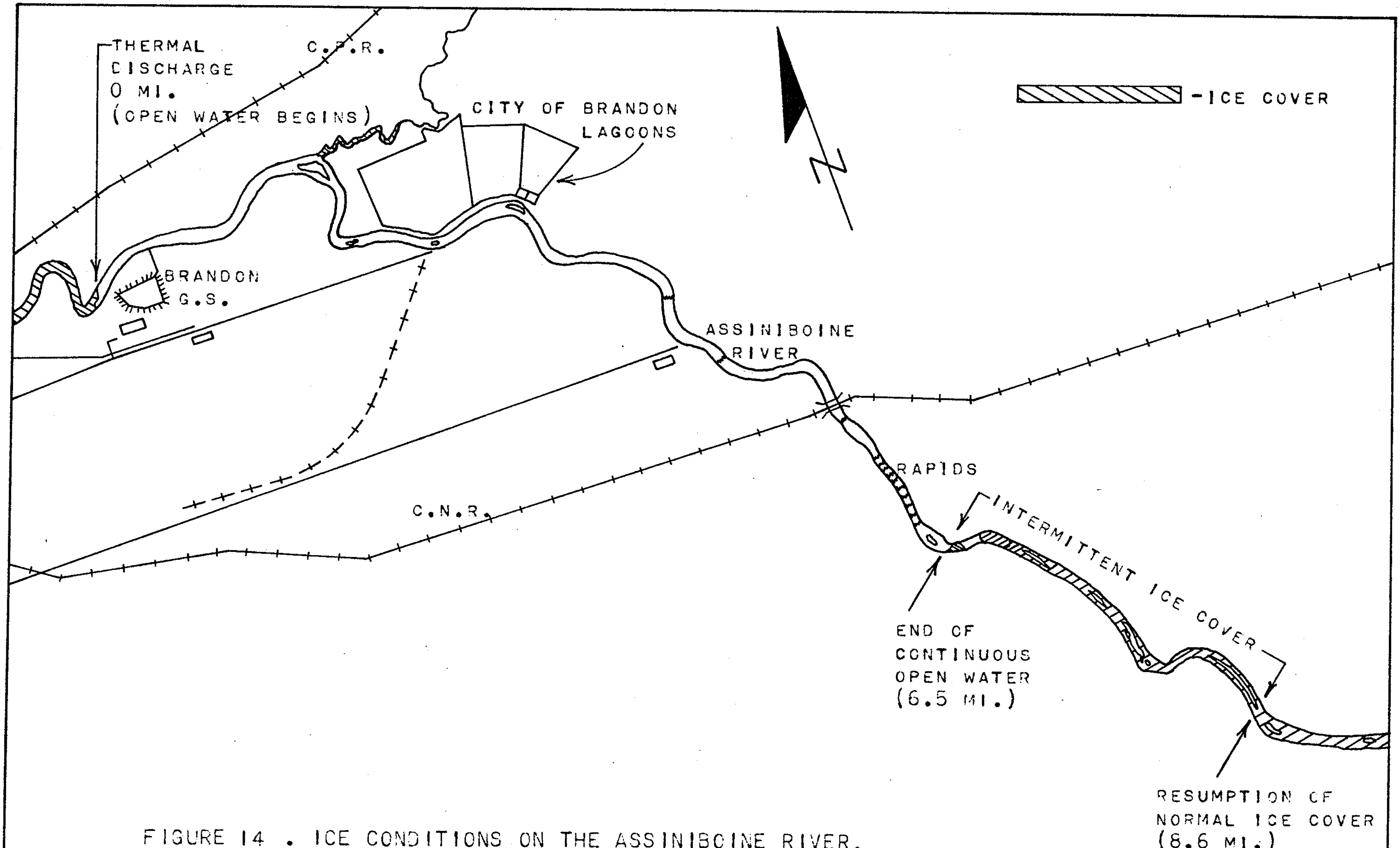

FIGURE 14 . ICE CONDITIONS ON THE ASSINIBOINE RIVER, DOWNSTREAM FROM BRANDON GENERATING STATION, FEBRUARY 24, 1972. SCALE 1:50,000.

for this period of 6°F.

The thickness of the ice cover upstream from Brandon Generating Station was between 15 to 18 inches during the week of February 21-25, 1972, with about 15 inches of snow cover on top of the ice.

5.1.4 Algal samples

The algae growing on the rocks right in the thermal discharge outfall during the winter study period consisted mainly of masses of a filamentous green algae in which lived several species of diatoms. Similar growths were found elsewhere during the summer study period growing on rocks in fast, shallow water. During the summer study period however, these filamentous algal growths died as the water temperature decreased in the fall. It would thus seem that the thermal discharge was allowing these algal growths to continue growing by artificially warming the river water in the immediate vicinity of the outfall.

5.2 SUMMER STUDY PERIOD

5.2.1 Chemical testing results

The dissolved oxygen concentration, biochemical oxygen demand, pH, total alkalinity and phenolphthalein alkalinity of the Assiniboine River water were measured once a month during the summer study period. The results of these measurements are summarized in Figures 15 through 19. Each parameter was measured at each of the ten biological testing stations (Figure 1), but since it was found that the various waste discharges had little or no influence on the magnitude of the parameters, the values presented are the averages of the ten values obtained.

The dissolved oxygen concentration (Figure 15) and the biochemical oxygen demand (Figure 16) showed more variation than the other chemical parameters and thus minimum, maximum, and mean values have been presented for these two parameters. The pH, total alkalinity, and phenolphthalein alkalinity generally showed little variation from station to station and thus only mean values are presented (Figures 17, 18 and 19). The pH meter was broken during the August trip to the study area and thus the pH and total alkalinity values for August are estimated values. The value of the phenolphthalein alkalinity for August was not estimated (Figure 19).

5.2.2 Physical testing results

The natural water temperatures (i.e. unaffected by the thermal discharge) in the Assiniboine River during the summer study period are illustrated in Figure 20. The values shown are the averages of the water temperature at all stations.

Stream depth and stream velocity measurements made at each station during the months of July, August, September, October, and November when multiple-plate samplers were in use are presented in Table 6. The mean weekly discharge in the Assiniboine River at Brandon for the week during which the depth and velocity were measured is also included in Table 6.

5.2.3 Temperature prediction model

The following equation for predicting temperature changes in the Assiniboine River at any given discharge in the Assiniboine River

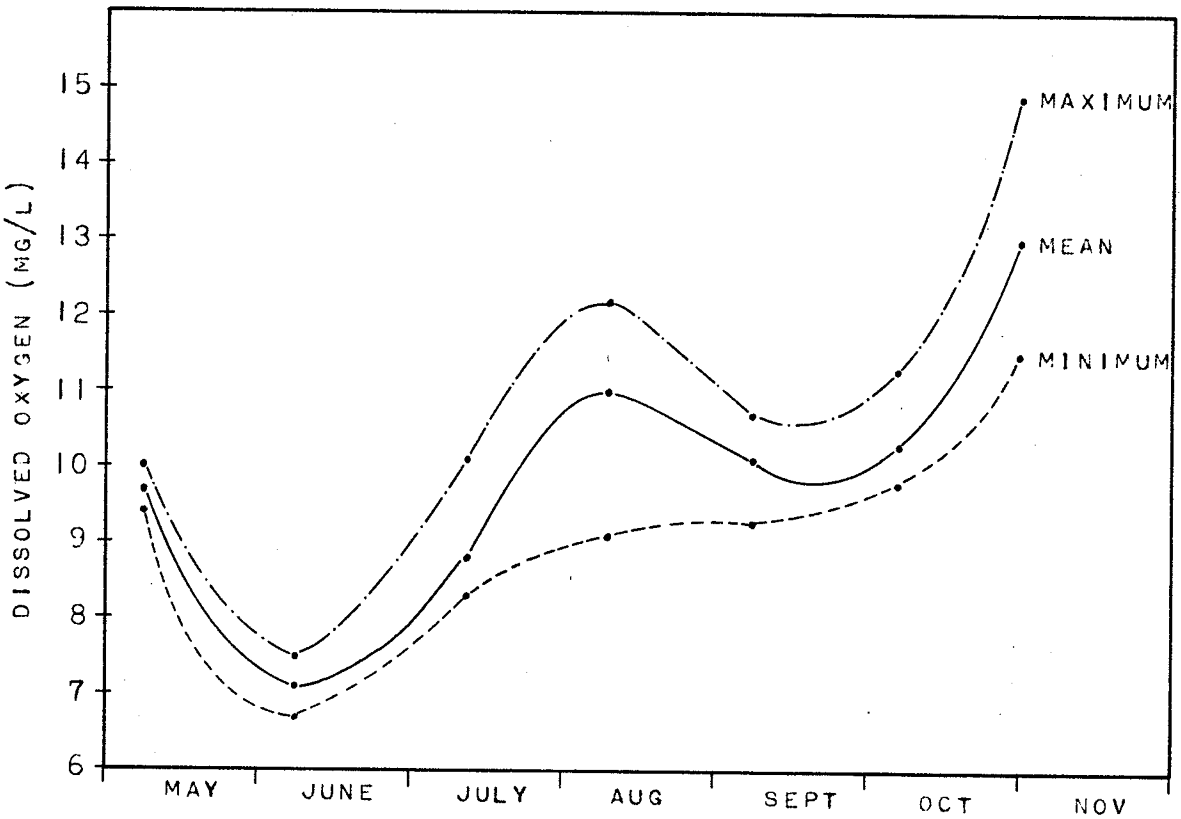

FIGURE 15. DISSOLVED OXYGEN LEVELS IN ASSINIBOINE R. NEAR BRANDON, MAY-NOVEMBER 1972.

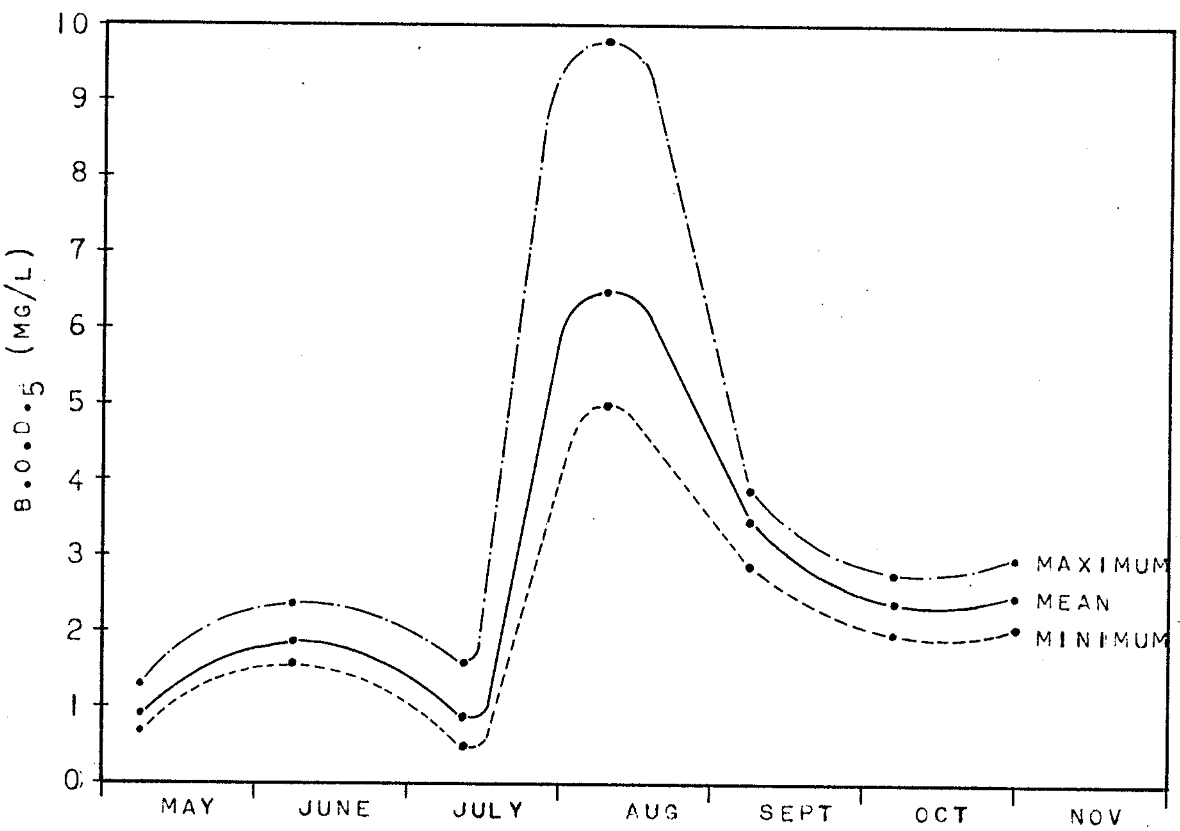

FIGURE 16. B.O.D.$_5$ LEVELS IN ASSINIBOINE R. NEAR BRANDON, MAY-NOVEMBER 1972.

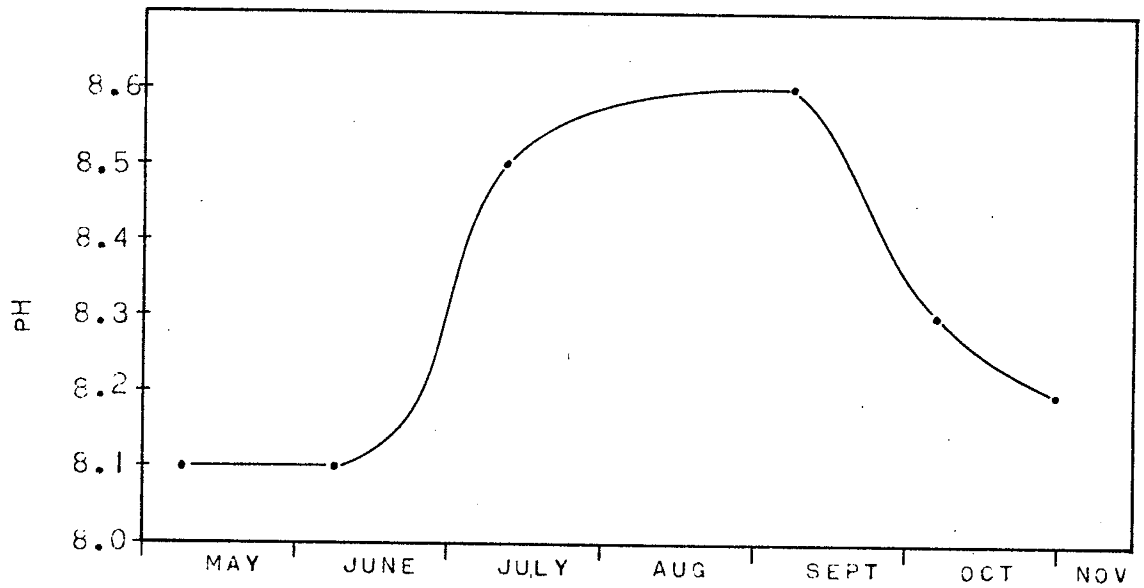

FIGURE 17. pH LEVELS IN ASSINIBOINE R. NEAR BRANDON, MAY-NOVEMBER 1972.

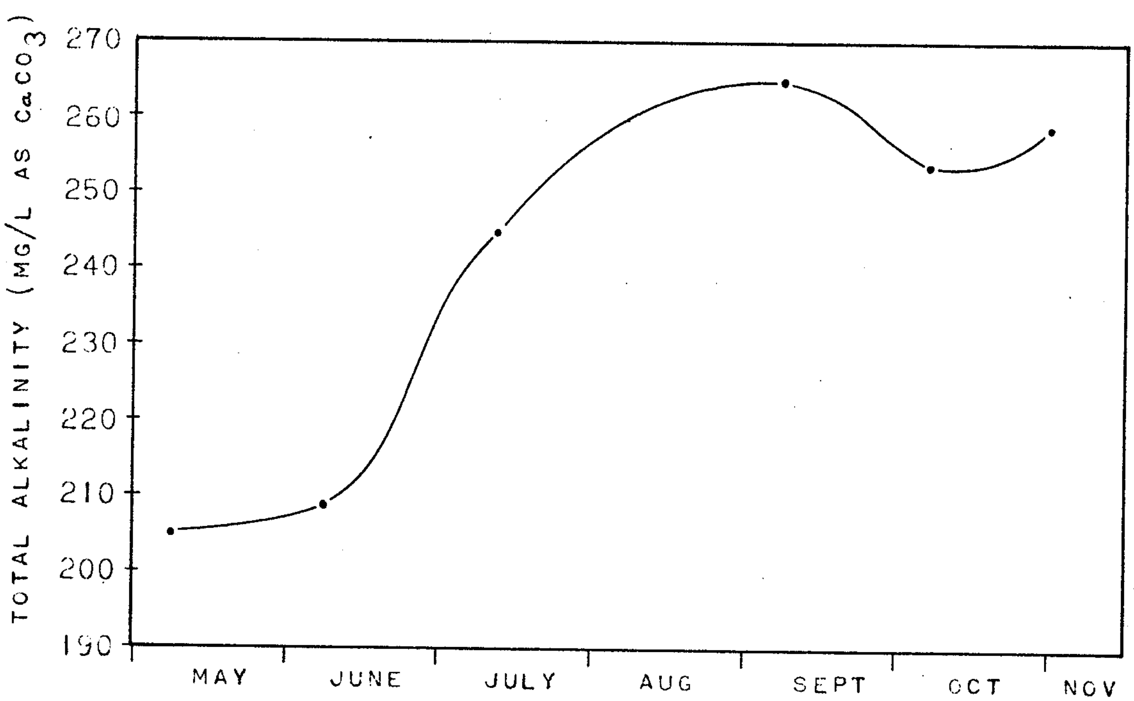

FIGURE 18. TOTAL ALKALINITY LEVELS IN ASSINIBOINE R. NEAR BRANDON, MAY-NOVEMBER 1972.

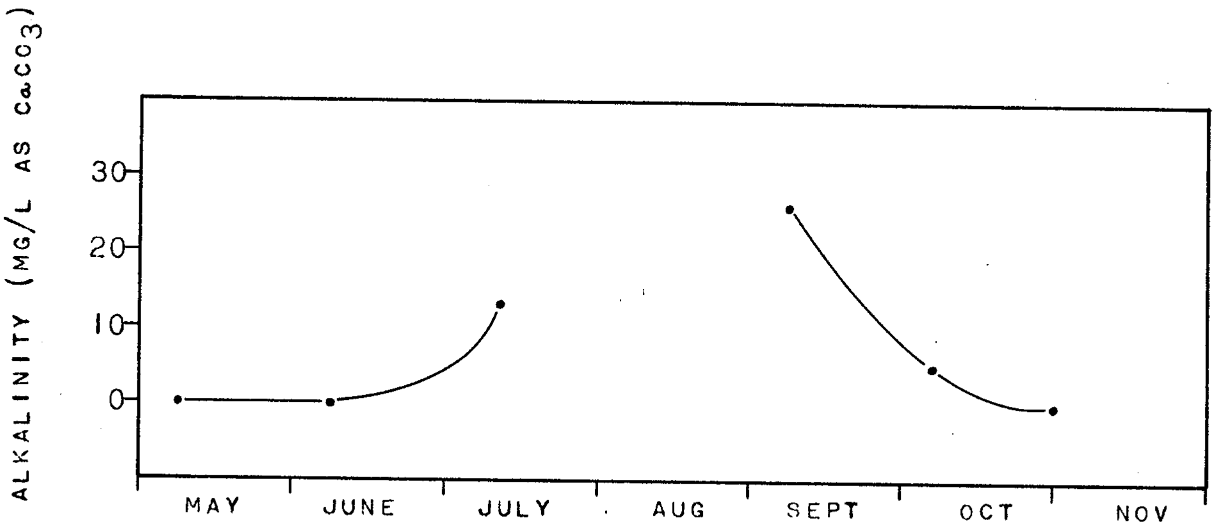

FIGURE 19. PHENOLPHTHALEIN ALKALINITY LEVELS IN ASSINIBOINE R. NEAR BRANDON, MAY-NOVEMBER, 1972.

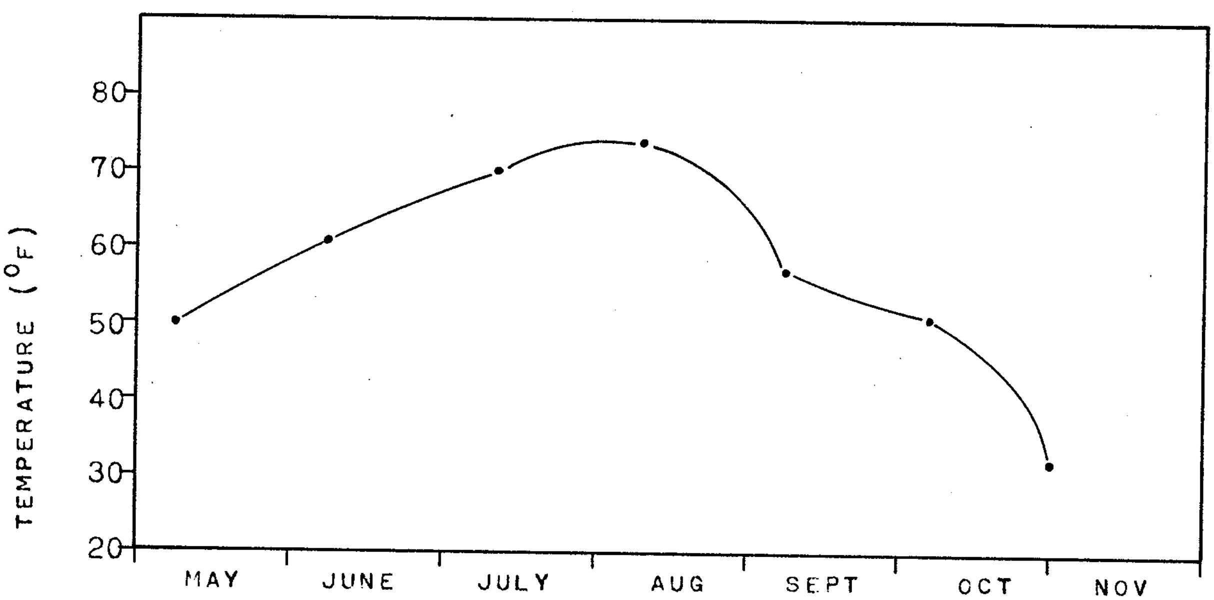

FIGURE 20. NATURAL WATER TEMPERATURES IN ASSINIBOINE R. NEAR BRANDON, MAY-NOVEMBER, 1972.

TABLE 6. DEPTH, VELOCITY, AND DISCHARGE IN ASSINIBOINE RIVER AT STATIONS 1-10, JULY-NOVEMBER, 1972.

STATION NUMBER	DEPTH (FEET)					VELOCITY* (FEET/SEC.)				
	JULY	AUG.	SEPT	OCT	NOV	JULY	AUG	SEPT	OCT	NOV
1†	4.5	3.0	-	-	-	0.76	0.81	-	-	-
2	7.0	5.0	5.0	5.0	6.0	0.75	0.66	0.35	0.71	0.57
3	5.5	4.5	3.0	4.0	4.0	1.16	0.29	0.67	1.03	0.84
4	2.0	2.0	1.5	2.0	2.5	0.77	0.52	0.60	0.89	0.82
5	4.5	3.5	6.0	6.0	6.0	0.46	0.27	0.51	0.58	0.48
6	3.5	2.5	2.0	3.0	3.0	0.80	0.49	0.57	0.84	0.72
7	3.0	4.5	3.5	5.5	5.5	0.74	0.41	0.46	0.70	0.66
8	4.0	3.5	3.0	2.5	2.5	0.75	0.25	0.84	1.22	1.19
9	4.0	4.0	4.0	4.0	4.0	1.08	0.82	0.64	1.03	0.78
10	4.0	3.0	3.0	3.0	3.0	0.83	0.49	0.51	0.60	0.72
DIS-CHARGE‡ (C.F.S.)	675	245	195	365	445					

* MEASURED AT 0.6 OF STREAM DEPTH.
† STATION# 1 ABANDONED IN SEPTEMBER.
‡ MEAN WEEKLY DISCHARGE FOR WEEK DURING WHICH DEPTH AND VELOCITY WERE MEASURED.

and at any level of generation of Brandon Generating Station (assuming complete and instantaneous mixing) was presented in section 3.4.3:

$$\Delta T = 35.6 \frac{MW}{Q}$$

This equation was used to prepare figure 21 which gives the initial water temperature increases downstream from Brandon Generating Station for a range of discharges and generation levels, assuming complete and instantaneous mixing. Figure 21 can also be used to estimate the rate of water temperature change by calculating the water temperature increases at the beginning and end of a known interval of time. The results of estimating the magnitude and rates of temperature change in the Assiniboine River for several generating patterns encountered during the study period is presented in Table 7.

5.2.4 Biological testing results

5.2.4.1 Dredged samples

The benthic macroinvertebrates were sampled using a Standard Ekman in May and a Petersen dredge in June during the summer study period. The results of the analysis of these samples are summarized in Table 8. The discharge in the Assiniboine at Brandon was high during the months of April, May and June (Figure 5) and thus the effect of the thermal discharge on the thermal regime of the Assiniboine River was negligible before and during the time that these samples were collected.

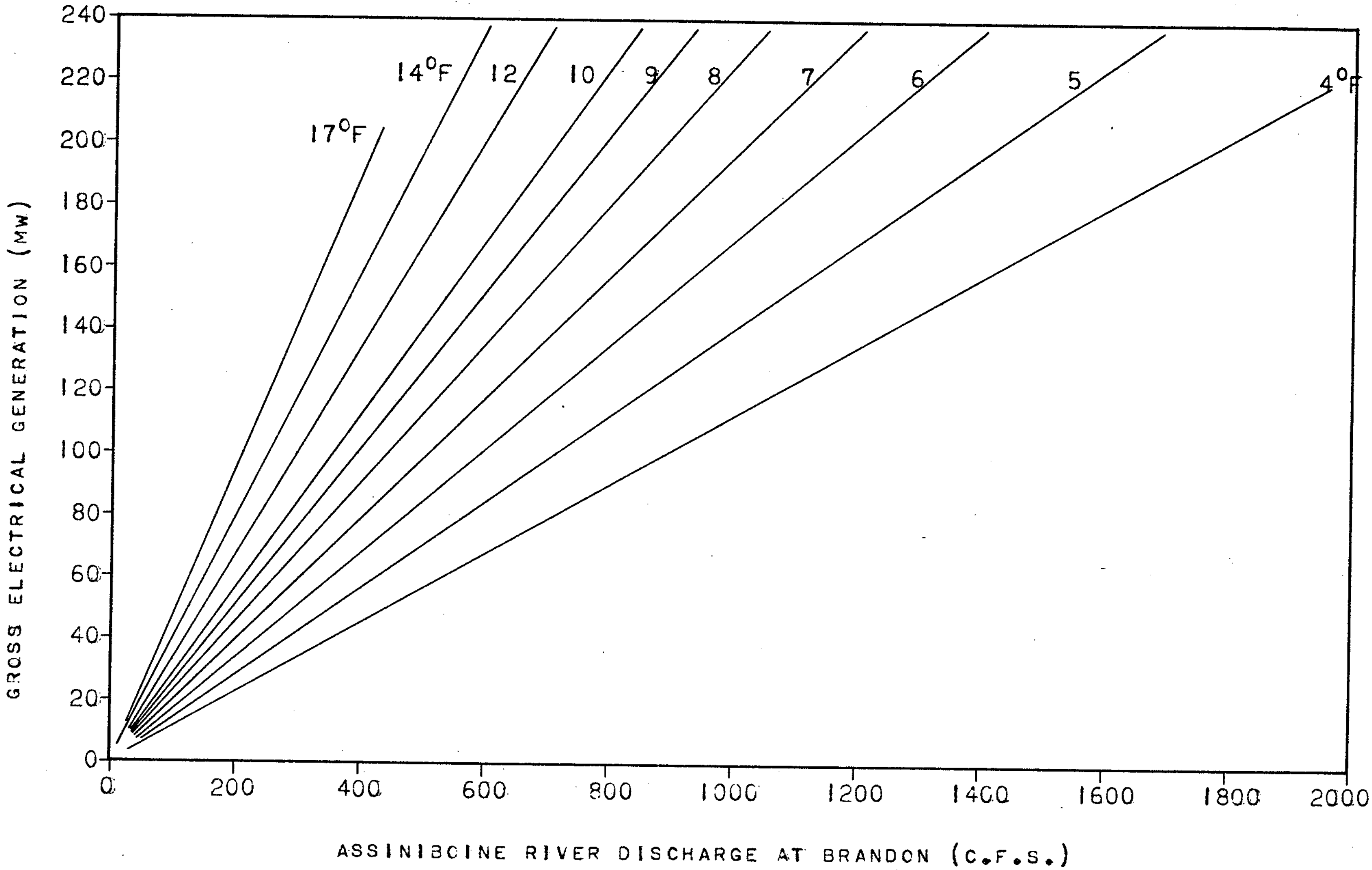

FIGURE 21. ESTIMATED TEMPERATURE INCREASE IN THE ASSINIBOINE RIVER DUE TO THE THERMAL DISCHARGE FROM BRANDON GENERATING STATION.

TABLE 7. ESTIMATED MAGNITUDES AND RATES OF WATER TEMPERATURE CHANGE IN THE ASSINIBOINE RIVER DOWNSTREAM FROM BRANDON GENERATING STATION.

DATE	TIME	MW	Q (CFS)	ΔT (^oF)	RATE OF CHANGE OF TEMPERATURE (^oF/HR.)	AVERAGE RATE OF CHANGE OF TEMPERATURE (^oF/HR.)
FEB.21	2100	160	714	8.0		
					-1.7	
	2200	126	714	6.3		
					-0.8	-2.7
	2300	110	714	5.5		
					-5.5	
	2400	0	714	0		
FEB.22	0500	0	694	0		
					0.8	
	0600	10	694	0.8		
					1.8	
	0700	50	694	2.6		2.1
					4.3	
	0800	135	694	6.9		
					1.3	
	0900	159	694	8.2		
OCT.23	2200	176	410	15		
					-5.7	
	2300	107	410	9.3		-7.5
					-9.3	
	2400	0	410	0		
OCT.27	2100	190	420	16		
					-4.5	
	2200	135	420	11.5		-8.0
					-11.5	
	2300	0	420	0		
NOV.2	0600	0	465	0		
					8.0	
	0700	103	465	8		
					3.0	4.2
	0800	142	465	11		
					1.5	
	0900	162	465	12.5		

TABLE 8 . SUMMARY OF BENTHIC MACROINVERTEBRATE SAMPLES TAKEN BY DREDGE, MAY-JUNE, 1972.

STATION NUMBER	MAY (STANDARD EKMAN DREDGE)		JUNE (PETERSEN DREDGE)	
	NUMBER/FT.^{2}	NUMBER OF TAXA	NUMBER/FT.^{2}	NUMBER OF TAXA
1	31	2	21	3
2	97	3	36	5
3	76	4	40	5
4	89	2	13	3
5	193	5	87	3
6	69	4	41	5
7	50	4	45	6
8	-	-	72	6
9	-	-	-	-
10	68	5	146	5
11*	-	-	21	4

* 500 FEET DOWNSTREAM FROM THERMAL DISCHARGE.

5.2.4.2 Artificial substrate samples

Multiple-plate artificial substrate samplers were used to sample the benthic macroinvertebrates during the months of July, August, September, and October. The results of the sequential comparison analysis of these samples are presented in Figures 22 through 25. In these figures, the sequential comparison diversity index (DI_T) for each station is represented by a bar which has three horizontal lines at the top. The centre line is the sequential comparison diversity index for the station (DI_T) as calculated by the computer program outlined in Appendix 2. The upper and lower lines are the upper and lower 95% confidence limits (i.e. the true value of DI_T will lie between these limits 95 times out of 100), and thus the probability of DI_T falling outside of these limits is small.

The biological testing stations and waste discharges in figures 22 through 25 are arranged in order from upstream to downstream as illustrated in figures 1 and 10.

The DI_T values for July, 1972 are presented in Figure 22. The multiple-plate samplers were placed in the Assiniboine River on July 11th, 12th, and 13th and the samples collected on August 9th, 10th, and 11th, (approximately 28 days later). The generation of Brandon Generating Station during this time was very low. The plant did not generate from July 11th to July 23rd, while from July 24th to August 11 it generated continuously at 8 MW with a few short periods of generation not exceeding the 30 MW level. For most of this 28-day interval the effect of the thermal discharge on the thermal regime of the Assiniboine

River was negligible, with a maximum estimated water temperature increase of $4^{o}F$ above ambient during generation at the 30 MW level.

The DI_T values for August, 1972 are presented in Figure 23. The multiple-plate samplers were placed in the river on August 9th, 10th, and 11th and the samples retrieved on September 7th, 8th, and 9th. The generating station operated continuously at 8 MW between August 12 and August 16th, while from August 17th to September 9th it operated very sporadically. During this period of sporadic operation, estimated water temperature increases of $11^{o}F$ were produced on two occasions.

The DI_T values for September, 1972 are contained in Figure 24. The multiple-plate samplers were placed in the river on September 7th, 8th, and 9th and the samples collected on October 3rd, 4th, and 5th. During this interval the operation of Brandon Generating Station continued to be sporadic. Discharge in the Assiniboine River was low during this interval and a few periods of heavy generation (190 - 195 MW) are estimated to have produced water temperature increases of up to $19^{o}F$. These water temperature increases were not actually observed, but merely estimated using Figure 21.

The DI_T values for October, 1972 are shown in Figure 25. The multiple-plate samplers were placed on the river bottom on October 3rd, 4th, and 5th, and the samples collected on October 31st, November 1st, and 2nd. During the first part of this interval (October 5th to October 15th) generation was sporadic producing estimated water temperature increases of no more than $8^{o}F$. During the latter part of this interval (October 16th to November 2nd), generation was fairly steady with the plant operating mainly between 6 a.m. and midnight. The level of generation was frequently in the 160 - 200 MW range during this time and estimated water temperature increases of between 13 - 17^{o}F were common.

The effect of the thermal discharge on the thermal regime of the Assiniboine River was thus almost negligible in July and early August (Figure 22) and then steadily increased in severity during September and October (Figures 23 and 24) with the most severe thermal alterations occuring in the latter half of October (Figure 25).

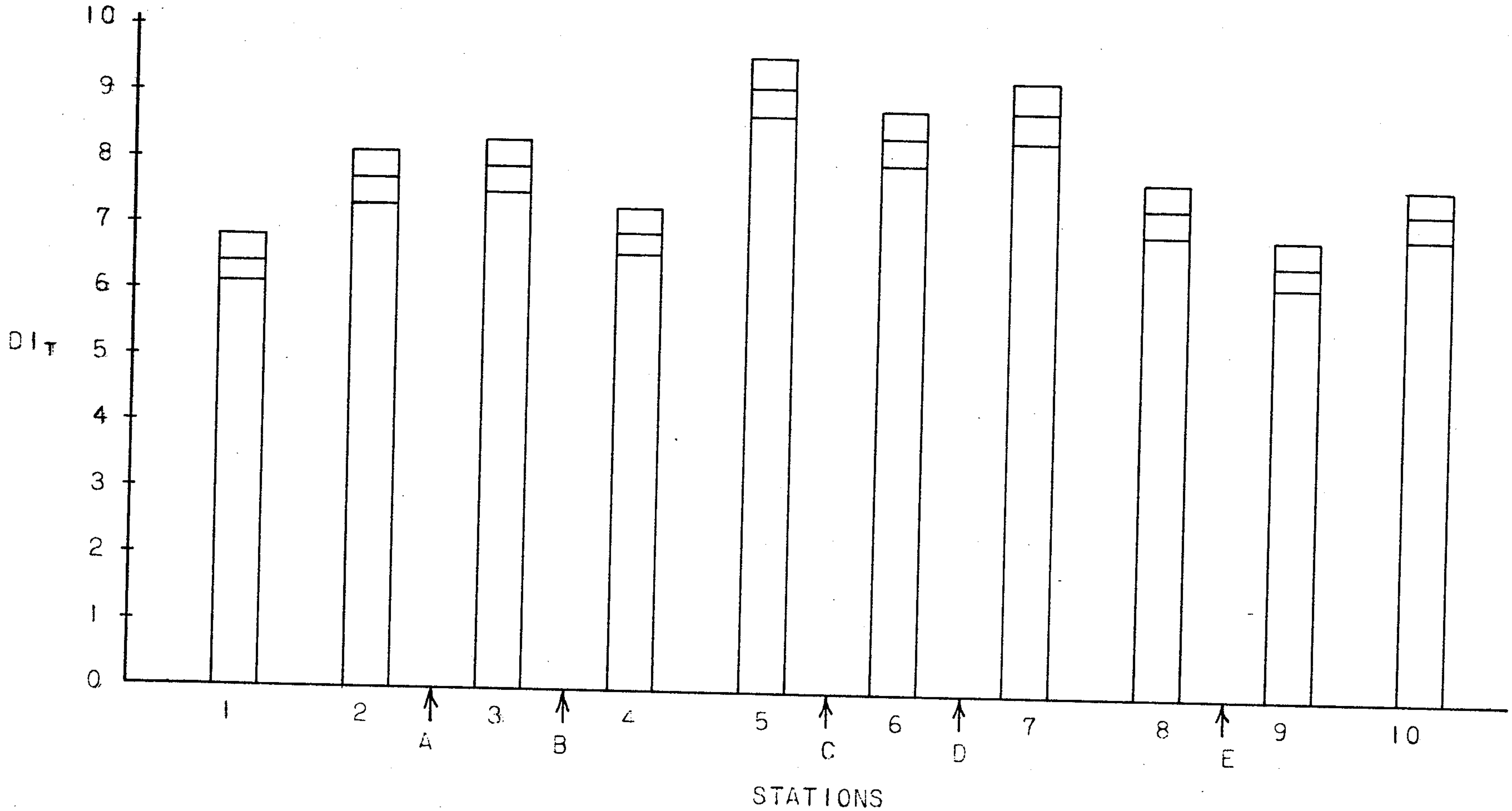

FIGURE 22. DI_T FOR TEN STATIONS IN THE ASSINIBOINE RIVER, JULY 1972.

A: BRANDON GENERATING STATION THERMAL DISCHARGE AND LIQUID WASTE OUTFALL.
B: BRANDON GENERATING STATION ASH LAGOON OUTFALL.
C: CITY OF BRANDON LAGOON OUTFALL, CELL # 5.
D: CITY OF BRANDON LAGOON OUTFALL, CELL # 3.
E: DRYDEN CHEMICALS LTD. OUTFALL.

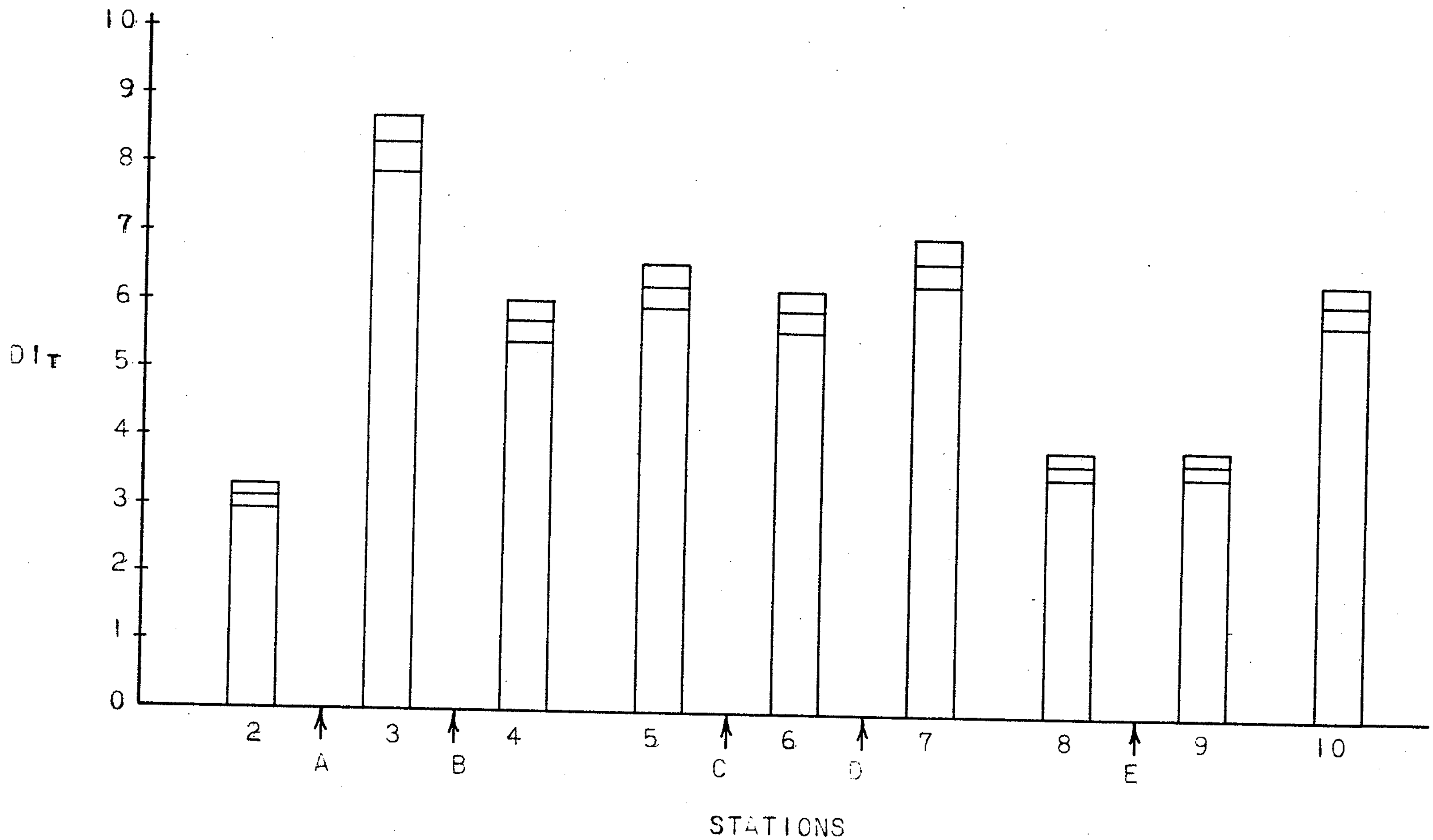

FIGURE 23. DI_T FOR NINE STATIONS IN THE ASSINIBOINE RIVER, AUGUST 1972.

A: BRANDON GENERATING STATION THERMAL DISCHARGE AND LIQUID WASTE OUTFALL.
B: BRANDON GENERATING STATION ASH LAGOON OUTFALL.
C: CITY OF BRANDON LAGOON OUTFALL, CELL # 5.
D: CITY OF BRANDON LAGOON OUTFALL, CELL #3.
E: DRYDEN CHEMICALS LTD. OUTFALL.

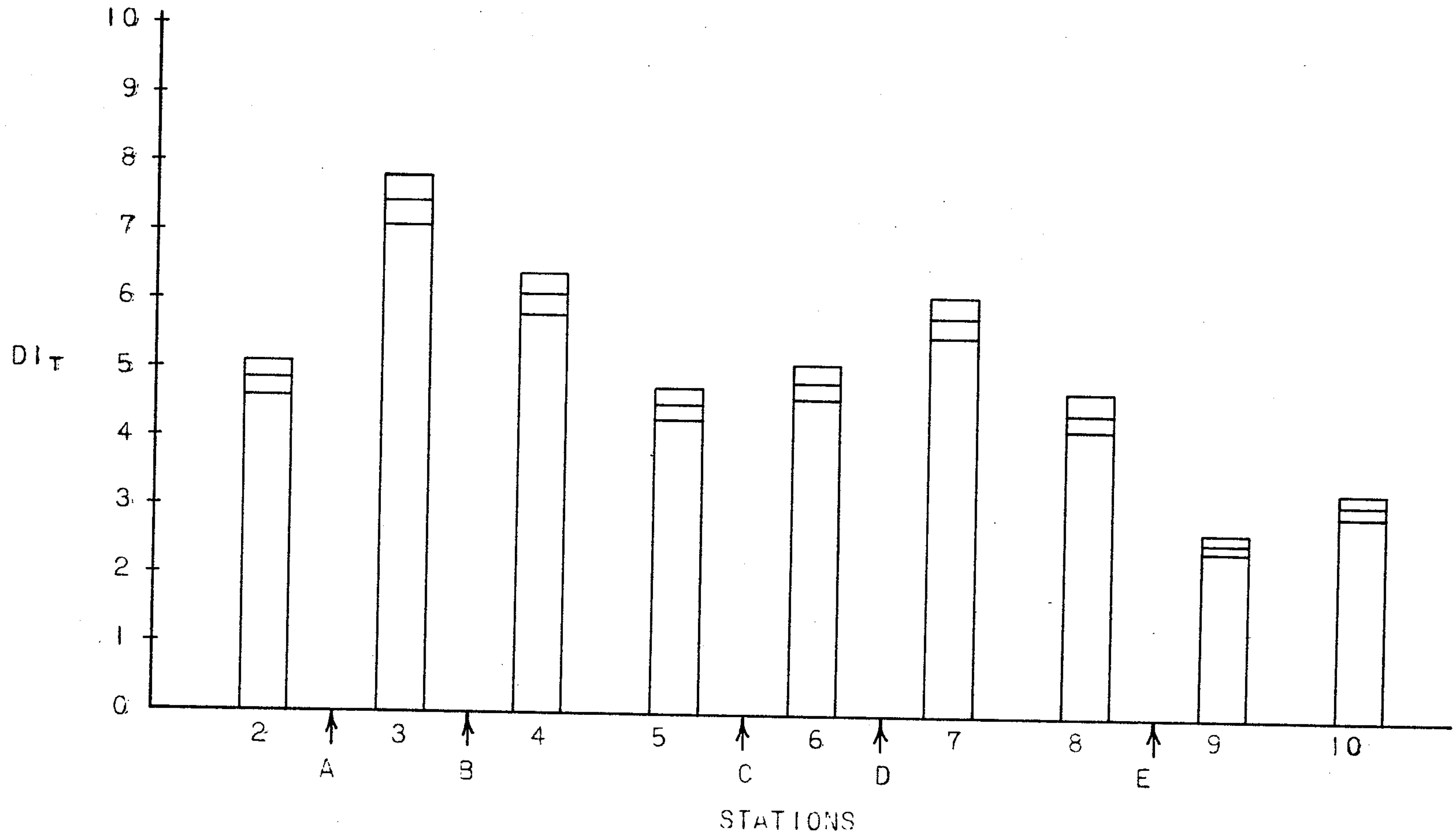

FIGURE 24. DI$_T$ FOR NINE STATIONS IN THE ASSINIBOINE RIVER, SEPTEMBER 1972.

A: BRANDON GENERATING STATION THERMAL DISCHARGE AND LIQUID WASTE OUTFALL.
B: BRANDON GENERATING STATION ASH LAGOON OUTFALL.
C: CITY OF BRANDON LAGOON OUTFALL, CELL # 5.
D: CITY OF BRANDON LAGOON OUTFALL, CELL # 3.
E: DRYDEN CHEMICALS LTD. OUTFALL.

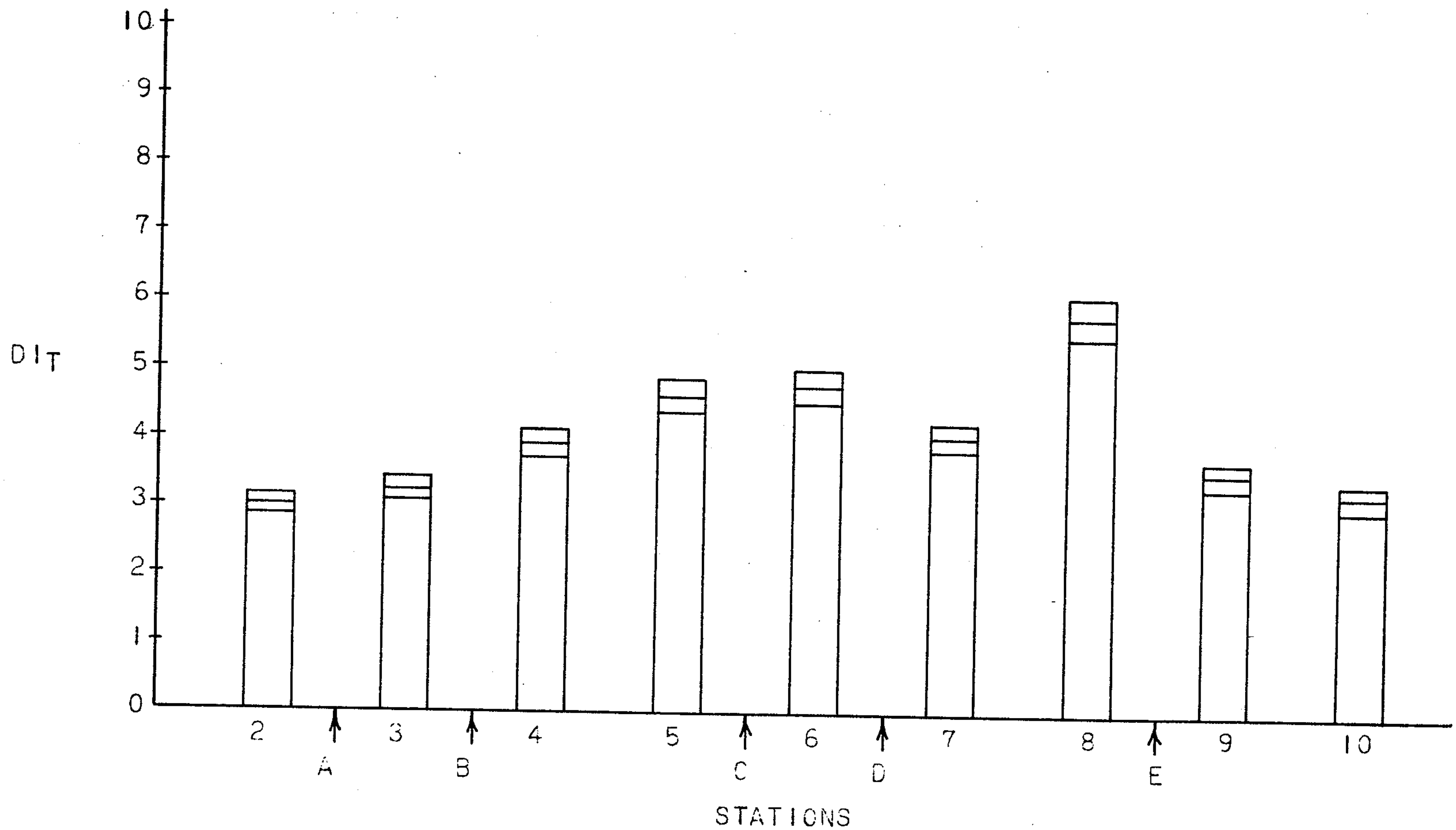

FIGURE 25 . DI$_T$ FOR NINE STATIONS IN THE ASSINIBOINE RIVER, OCTOBER 1972.

A: BRANDON GENERATING STATION THERMAL DISCHARGE AND LIQUID WASTE OUTFALL.
B: BRANDON GENERATING STATION ASH LAGOON OUTFALL.
C: CITY OF BRANDON LAGOON OUTFALL, CELL # 5.
D: CITY OF BRANDON LAGOON OUTFALL, CELL # 3.
E: DRYDEN CHEMICALS LTD. OUTFALL.

6. DISCUSSION

6.1 PHYSICAL EFFECTS OF THERMAL DISCHARGE

6.1.1 Thermal regime of Assiniboine River

6.1.1.1 Introduction

The magnitude of the water temperature increase in the Assiniboine River due to the thermal discharge from Brandon Generating Station depends on (1) the discharge in the Assiniboine River, (2) the level of generation of Brandon Generating Station, and (3) the mixing characteristics of the thermal discharge and the river water. Given an initial water temperature increase, the time (or distance) required for the river water to return to its normal ambient temperature depends on (1) the temperature differential between the air and water (the greater the temperature difference the faster the rate of heat dissipation), (2) the relative humidity of the air, and (3) the velocity and direction of the wind.

6.1.1.2 Temperature prediction model

The accuracy of the model proposed to predict water temperature changes in the Assiniboine River (assuming complete and instantaneous mixing) may be tested using the data in Table 2. The observed water temperature increases and the predicted water temperature increases (predicted using Figure 21 and the corresponding values of discharge and generation from Table 2) are:

	OBSERVED	PREDICTED
Feb. 22	8°F	8.1°F
Oct. 6	10°F	10°F
Oct. 31	11°F	11.9°F
Nov. 1	8°F	8.1°F
Nov. 2	9.5°F	10.3°F

This method of predicting temperature change would thus appear to be satisfactory within the range of discharge and generation found in Table 2, since the observed and estimated values are with 1°F of each other.

6.1.1.3 Water temperature profiles

The water temperature profiles presented in Table 2 indicate that the thermal discharge does have a considerable impact on the thermal regime of the Assiniboine River. The maximum water temperature increase observed (after mixing was essentially complete) was 11°F (Oct. 31) (Table 2). This however, is not likely the maximum temperature increase that occurred during the study period. More severe combinations of low discharge and high generation probably produced water temperature increases which have been estimated to be as high as 19°F. The examples in Table 7 from October 23 and October 27 show estimated water temperature increases of 15 and 16°F.

The water temperature profiles in Table 2 are misleading with respect to the rate at which the water temperature of the river returns to ambient. For example, on October 6 the water temperature is 58°F at 1.0 mi., 52°F at 1.7 mi. and 50°F at 2.5 mi. (1°F above ambient). This does not mean that the river returns to ambient temperature very rapidly but rather that the heated river water has not yet reached the

1.7 or 2.5 mi. points because of the time required for it to travel from the steam plant to these points.

The water temperature profiles taken on October 6, November 1, and November 2 indicate that little heat was lost between the 0.2 mi and 1.0 mi. points since the water temperatures at both points are practically the same (Table 2). The profile on February 22 however, indicates a 2.5°F decrease between 0.1 mi. and 1.0 mi. The higher rate of heat loss on February 22 was probably due to the larger temperature differential between the air and the water in February than in October and November.

The thermal discharge and the river water are essentially mixed within 0.2 miles (1000 feet) of the thermal discharge as shown by the almost uniform water temperatures at this point. (Table 2). The river is relatively swift and shallow in this reach, producing considerable turbulence which aids mixing. The length of the mixing zone will vary to some extent with the discharge of the Assiniboine River and the volume of heated water discharged.

The maximum allowable temperature changes specified by the environmental management agencies of the provinces (including Manitoba) and states in Table 1 are frequently exceeded in the Assiniboine River downstream from Brandon Generating Station (after mixing is completed). Brandon Generating Station however, rarely operates during July and August when natural water temperatures are high and it is unlikely that maximum allowable temperatures (87 - 90°F) (Table 1) will be exceeded. The water temperature increases thus produce resultant water temperatures which are within the natural range of temperatures of the Assiniboine River (about 32 - 80°F) (Figure 6) which are not in themselves lethal to aquatic life. The magnitude of the temperature changes and the rate at which the changes occur however, may damage some forms of aquatic life because of their inability to adjust to the rapid shifts in water temperature.

6 .1.1.4 Estimated magnitudes and rates of water temperature change

It was found that the largest and most rapid water temperature changes were associated with the starting and stopping of generating station and the examples of temperature increases and decreases in Table 7 were estimated to illustrate the magnitudes and rates of these temperature fluctuations. For example, on October 27 during the shut-down of the generating units the water temperature of the Assiniboine River dropped 16°F in 2 hours for an average rate of temperature decrease of -8°F/hour.

The estimated rates of temperature increase and decrease exceed the allowable maximum rate of change of 2°F/hour set by Pennsylvannia, Nebraska, and Montana (Table 1). The maximum natural rate of temperature increase in the Assiniboine River observed by this author was only 1°F/hour (natural water temperature decrease occurred at night during the study period and consequently natural rate of temperature decrease was not measured). Wurtz (32) has reported natural rates of temperature change of up to 3°F/hour. The rates of water temperature change created by the thermal discharge are thus considerably higher than those occuring by natural causes and those specified by environmental management agencies.

The data of Table 7 also reveal that the rates of decrease of water temperature may be somewhat larger than the rates of temperature increase (probably because more time is required to start a generating unit than to stop it). This is significant when it is remembered that decreasing water temperatures were found to be much more lethal than increasing water temperatures (13).

6.1.2 Ice regime of the Assiniboine River

The extent of open water created downstream from Brandon Generating Station is variable and depends on (1) the amount of waste heat discharged from Brandon Generating Station (which depends on the level of generation), (2) the discharge in the Assiniboine River, and (3) the prevailing climatic conditions of air temperature, relative humidity, and wind speed and direction.

Aerial photographs taken during the winter study period (Figure 14) show that the continuous open water extended for 6.5 miles downstream from Brandon Generating Station and that normal ice cover resumed 8.6 miles downstream. A detailed energy budget study would be required to predict the extent of open water under varying conditions of climate, waste head loading, and discharge.

6.2 CHEMICAL EFFECTS OF THERMAL DISCHARGE

6.2.1 Dissolved oxygen conditions

The data presented in Table 3 indicates that the open water downstream from Brandon Generating Station improves the dissolved content of the Assiniboine River. The dissolved oxygen concentration usually decreases in the downstream direction under a cover of ice and snow, but because of the open water downstream from Brandon Generating Station, reaeration can take place resulting in increases in dissolved oxygen concentration between Brandon and Treesbank Ferry.

A series of dissolved oxygen profiles taken during periods of normal ice cover before and after the commencement of the thermal discharge on September 8, 1967 are presented in Table 4. Two out of three profiles prior to the existence of the open water (i.e. under an unbroken cover of ice and snow) indicate that the dissolved oxygen concentration decreased between Brandon and Treesbank Ferry. (The exception is the profile of February 17, 1967, but it is suspected that the value of 9.4 mg/1 at Treesbank Ferry is too high, since the value at the next station downstream from Treesbank Ferry is only 4.5 mg/1). Nine out of ten profiles after the advent of the thermal discharge show that the dissolved oxygen concentration increased between Brandon and Treesbank Ferry. In some cases these increases in dissolved oxygen were minor while in others the dissolved oxygen content was as much as doubled.

The beneficial effect of the turbulence in the thermal discharge outfall on the dissolved oxygen concentration of the cooling water is shown in Table 5. In both sets of measurements the dissolved oxygen of the cooling water was increased by 1.4 mg/1. The aerating effect of the thermal discharge outfall is probably responsible for most of the increase in dissolved oxygen between the river water upstream from the outfall and that at 0.1 miles downstream (Table 3).

The value of the increased dissolved oxygen concentration of the river water to downstream users is not readily ascertainable. If the dissolved oxygen content was very low, 3 - 4 mg/l., and then was doubled by the existence of the open water downstream from Brandon Generating Station (as occurred on February 28, 1968 and February 19, 1969) (Table 4) the benefit to aquatic life would be considerable. However, the value of increasing the dissolved oxygen concentration from 9 mg/l to 10 mg/l as occurred during the winter study period (Table 3) is questionable. It should be noted that the dissolved oxygen concentrations of winter flows in the Assiniboine River are likely to continue to be high because of the oxygen-rich water released from Shellmouth Reservoir.

6.3 BACKGROUND PHYSICAL AND CHEMICAL DATA

The physical and chemical data presented in Figures 15, 16, 17, 18, 19 and 20 and Table 6 was compiled solely to aid in the interpretation of the biological data collected during the summer study period. It was found that the various waste discharges did not cause the chemical parameters to vary significantly between test stations and thus it was decided to average the values and present them to indicate the general environmental conditions during the summer study period.

The dissolved oxygen conditions (Figure 15) were relatively good during the summer with the lowest concentration recorded being 6.7 mg/l. The wide variation in dissolved oxygen values during August is due to a diurnal cycle created by photosynthesizing algae. The dissolved oxygen levels were lowest in the early morning and then steadily increased during the day to reach a maximum in the evening. The river water was literally "green" with algae during August.

The biochemical oxygen demand of the river water was generally low (Figure 16) with the exception of the month of August. The high values during August were probably caused by the large amount of algae in the samples which would decompose or respire thus increasing the oxygen demand of the sample.

6.4 BIOLOGICAL EFFECTS OF THERMAL DISCHARGE

6.4.1 Algal samples

The two grab samples of the algae that was growing on the rocks in the thermal discharge outfall during the winter study period cannot be used to draw any conclusions about the effects of the thermal discharge on the algae of the Assiniboine River. It is interesting however, to note that algae was growing there despite the fact that the water temperature fluctuations are at their most extreme (up to 28^{o}F above ambient) right in the outfall since mixing with river water has not yet occurred.

6.4.2 Dredge samples

The samples of benthic macroinvertebrates taken by dredge during the months of May and June were collected to determine whether or not the winter thermal discharge from Brandon Generating Station had any long-term effect on the benthic population of the Assiniboine River. This approach proved to be invalid for several reasons.

The first reason for the failure of this approach lies in the nature of heat when it is considered as a pollutant. When waste heat is discharged in sufficient quantities to significantly alter the thermal regime of the river, damage to the benthos may occur. Once the thermal regime returns to normal however, the quality of the aquatic environment returns to normal. There are no persistent effects on water quality or toxic residues to continue affecting aquatic life. Second, once the thermal regime has returned to normal, the area of the stream that was affected by the alteration of the thermal regime would be repopulated by the drift of eggs, larvae, and adult organisms from upstream[9]. Work done with artificial substrate samplers has shown that only 3 or 4 weeks would be required for a stable population to re-colonize a depopulated area[59]. Finally, had the benthic population been damaged by the winter thermal discharge, it is probable that any evidence of such damage would have been obliterated by the scouring action of the spring floods on the river bottom.

This year, the thermal regime of the Assiniboine River had returned to normal during the period extending from the last week in March through to the end of June since the high flows in the Assiniboine during this time (between 1950 and 6500 cfs) (Figure 5) made the impact of the thermal discharge on water temperature negligible. Spring flood peaks of 6000 to 6500 cfs. (Figure 5) occurred during the last two weeks in April. The benthic samples collected during May and June are thus unlikely to bear any evidence of the effects of the winter thermal discharge because of the repopulation of the benthos once water quality had returned to normal, and the obliterating action of the spring floods.

A summary of the results obtained from the samples taken in May and June is contained in Table 8. The data presented in this table is at best only semi-quantitative and thus comparisons between stations would be invalid. The data in Table 8 does show that if the benthic population was damaged, the evidence of the damage has either been erased or repaired since comparable numbers of organisms and numbers of taxa are found both upstream and downstream from the thermal discharge.

6.4.3 Artificial substrate samples

The benthic macroinvertebrates sampled during July, August, September and October with multiple-plate samplers were collected to assess directly the effects of the thermal discharge on the benthos of the Assiniboine River. The samplers were placed at ten stations that were as ecologically similar as possible in order that differences in benthic populations between the stations would be due solely to (1) differences in thermal regime caused by the thermal discharge, and (2) differences in water quality caused by the various waste discharges in the study area. It was not possible however, to locate stations that were completely similar in every reach of the river where a station was required, and thus some differences in benthic populations may be due to inequalities in ecological properties between stations.

A comparison of the DI_T values obtained in July, August, September, and October (Figures 22, 23, 24, and 25, respectively) show that diversity was highest in July and then progressively decreased (at most stations) during August and September with the lowest diversity occurring in October. This decline in diversity is part of a natural cycle of diversity (and abundance) in which diversity is high in summer and then decreases in the fall and winter. This was noted by Neel (60) and Anderson and Mason (61).

The DI_T values for July (Figure 22) range from 6.4 to 9.1, but it is unlikely that these differences are a result of the thermal discharge or the other waste discharges. It is more likely that they are a result of non-uniform ecological properties as mentioned earlier. For example, the DI_T at station 4 is slightly smaller than the DI_T at station 3 but this difference cannot be attributed to the discharge from the ash lagoon since little or no effluent from this source entered the river during July. Stations 8, 9, and 10 have a lower diversity than station 5, 6 and 7, probably because of the difference in properties between the two reaches of river. Stations 8, 9, 10 are located in a reach with a rock and rubble bottom whereas stations 5, 6, 7 have a bottom composed of finer materials (sand, silt, gravel). The effect of the thermal discharge on water temperatures was negligible during July and accordingly stations 2 and 3 show little difference in diversity.

The effects of the thermal discharge on the thermal regime of the river became a little more pronounced during August (Figure 23) and a comparison of July (Figure 22) and August indicates that the DI_T values decreased substantially at every station during August with the exception of station 3 whose DI_T increased slightly. It is possible that the moderate increases in water temperature downstream from the thermal discharge caused the diversity at station 3 to remain high while the other stations further downstream showed the natural decline in diversity with the approach of winter. This may also be the reason that station 4, the next station downstream from the thermal discharge, showed a smaller decrease in diversity in August than did most of the other stations.

A comparison of the DI_T values in August (Figure 23) and September (Figure 24) indicate that the diversity continued its natural downward decline at most stations with the exception of stations 2, 3, 4, and 8. The reason for the increase in diversity at station 2 cannot be explained, but the small increases in diversity at stations 3 and 4 may again be due to the artificial warming of the water by the thermal discharge. The increase in DI_T at station 8 is most likely due to the fact that the station was moved from a stagnant pool (August) to faster water in September, since diversity would generally be greater in faster water. The difference between stations 8 and 9 in September (Figure 24) could be due to the discharge from Dryden Chemicals Ltd. (E) since a white sediment was found on the sampler plates at station 9 (downstream from Dryden Chemicals) which was not seen at any other station.

The thermal discharge had the greatest impact on the thermal regime of the Assiniboine River during the latter half of October. A comparison of the DI_T values for October (Figure 25) and for the previous month, September, (Figure 24) shows that the DI_T for stations 3 and 4 decreased markedly in October whereas the DI_T at stations 5 and 6 remained the same as in September. It would thus seem that if the increases in thermal discharge caused the decline in diversity at stations 3 and 4, that these effects were not felt at stations 5 and 6. The DI_T data for

October (Figure 25) also show that although the diversity was reduced at stations 3 and 4, it is still at about the same level as the control station (#2) and is not much lower than that found at most of the other stations.

It should be noted that the water temperature fluctuations that occurred in the latter part of October are probably as severe as any that could occur during the winter operating season, since generation was heavy (160 - 200 MW range) and flows were relatively low (about 400 cfs.). During the winter, once Shellmouth reservoir begins to release water the flows rise to 600 - 700 cfs. and thus the magnitudes of the water temperature changes would be decreased.

The diversity of the benthic populations at stations 3 and 4 (0.2 and 0.5 mile downstream from the thermal discharge) thus appears to have been maintained at higher levels (than at other stations) due to the moderate thermal addition from Brandon Generating Station, but as the thermal alteration became more severe in October, the diversity of stations 3 and 4 dropped to a level similar to that found at most other stations. The effects of the thermal discharge (during October) do not appear to have reached stations 5 and 6 which are 1.7 and 2.5 miles downstream from the thermal discharge outfall.

The species found at stations 3 and 4 in October included caddisflies, mayflies, and stoneflies which are all considered to be intolerant to environmental stress. The thermal discharge may have reduced species diversity at stations 3 and 4 during October, but it certainly did not create a "biological desert" at these stations.

6.5 COMPARISON OF BENEFICIAL AND DETRIMENTAL EFFECTS

The thermal discharge from Brandon Generating Station has both beneficial and detrimental effects on the downstream uses of the Assiniboine River. The addition of waste heat prevents the formation of ice cover downstream from Brandon Generating Station, creating an open water area of variable length on the river. This stretch of open water is detrimental in that it prevents local residents from crossing the river in winter, but it is beneficial because it enables the river water to become recharged with dissolved oxygen. The thermal discharge probably has both beneficial and detrimental effects on the aquatic life of the river. Moderate changes in the thermal regime may benefit aquatic life by stimulating growth and by providing an environment that is more favourable than existing natural conditions. Extreme thermal changes, on the other hand, may create conditions which are unfavourable for the optimum maintenance of the species present.

The cost of the detrimental effect of the open water on the transportation habits of local residents can be assessed relatively easily. Knowledge of the number of people inconvenienced, the extra time and effort required to detour around the open water, the numbers of trips made, etc. can be easily obtained, evaluated and a dollar value assigned to this effect.

The beneficial value of the open water on the dissolved oxygen resources of the river is not readily ascertainable. A detailed study would be required to determine the value of increased dissolved oxygen concentrations to such downstream water uses as municipal and industrial water supply, and waste assimilation. The relative value of increased dissolved oxygen content to aquatic life depends on the dissolved oxygen conditions existing prior to the increase. If the dissolved oxygen concentration is very low (say 3 - 4 mg/l) and reaeration downstream from Brandon Generating Station increases it to 6 - 8 mg/l the benefit to the maintenance of aquatic life would be substantial. The relative value of this benefit has been decreased by winter flow augmentation from Shellmouth Reservoir. The increased winter flows and relatively high dissolved oxygen content of the reservoir releases have greatly improved the dissolved oxygen conditions in the river and minimized the possibility of dissolved oxygen depletion. In any event, it is not possible to place a value on the benefit gained through these increased dissolved oxygen resources.

The relative value of the biological effects of the thermal discharge is the most difficult to evaluate. There appears to be some beneficial effects to the benthos during moderate thermal changes, and detrimental effects during extreme thermal changes, but the resource economics to calculate the relative value of these effects simply does not exist. A study of this nature can at best discover whether or not damage to aquatic life is occurring, but can not determine the costs of the damage.

A final assessment of the relative values of the beneficial and detrimental effects of the thermal discharge to the river is therefore not possible with the amount of data currently available, on these effects, and with the present state of knowledge in resource economics.

7. SUMMARY

This study was undertaken to measure the physical, chemical, and biological effects of the thermal discharge from Brandon Generating Station on the Assiniboine River, and to compare any beneficial and detrimental effects discovered.

The study was conducted during a winter study period (February 21 to 25, 1972) and a summer study period (May 4 - November 3, 1972). During these two periods the measurements necessary to determine the effects of the thermal discharge were made. Information was gathered on water temperature changes and ice conditions downstream from Brandon Generating Station; on dissolved oxygen conditions upstream and downstream from Brandon Generating Station; and on the waste heat load discharged to the river. The benthic macroinvertebrate populations were studied upstream and downstream from Brandon Generating Station to assess the effects of the thermal discharge on the aquatic life of the river.

The reader is directed to the section RESULTS AND OBSERVATIONS for the presentation of the findings of this study and to the section DISCUSSION for a discussion of these findings. The Conclusions and Recommendations resulting from this study follow immediately.

8. CONCLUSIONS

1. The thermal discharge from Brandon Generating Station maintains an open water area of variable length downstream from the plant during the winter. The length of this open water area depends on the level of generation of Brandon Generating Station, discharge in the Assiniboine River, and climatic conditions. A detailed energy budget study would be required to predict the extent of open water under varying conditions.

2. Local residents are prevented from crossing the Assiniboine River during the winter because of the open water maintained downstream from Brandon Generating Station.

3. The dissolved oxygen levels in the river are increased downstream from Brandon Generating Station during the winter due to reaeration in the open water area.

4. Water temperature changes created in the Assiniboine River by the thermal discharge frequently exceed the allowable limits for water temperature changes established by environmental agencies of the United States and Canada, including the Province of Manitoba. The magnitude of the water temperature changes depend on the level of generation, discharge in the river, and the mixing characteristics of the thermal discharge and the river water.

5. The effects of the thermal discharge on the benthic population appears to be beneficial during moderate alteration of the thermal regime and detrimental during severe alteration of water temperatures.

Additional studies are required to more clearly establish the effects of various degrees of thermal change on the benthos and other aquatic populations.

6. The benthic population downstream from Brandon Generating Station is repopulated by organisms from upstream once the thermal regime of the river returns to a favourable condition.

7. A final assessment of the relative value of the beneficial and detrimental effects of the thermal discharge is not possible with the amount of data currently available on these effects, and with the present state of knowledge in resource economics.

8. The most serious threat to aquatic life under the present "peaking" operation of Brandon Generating Station appears to be the large and rapid water temperature fluctuations that are created in the Assiniboine River by the irregular nature of the waste heat discharge.

9. FUTURE STUDIES

1. Future studies should be done on the benthic population (or on other components of the aquatic community) of the Assiniboine River to assess the effects of the altered thermal regime. These studies should be accompanied by water temperature studies using continuous, automatic recorders to measure magnitudes and rates of temperature change. This would provide information on the extent of the thermal alterations and the corresponding biological response so that allowable temperature limits could be established.

2. There is a need for studies on the temperature tolerance of fish and other aquatic organisms native to Manitoban waters to establish the amounts of thermal change that they may safely withstand.

3. Future work could be done on the effects on organisms entrained in the cooling water of generating plants employing once-through cooling.

10. APPENDICES

10.1 APPENDIX 1

DESCRIPTION OF BIOLOGICAL SAMPLING STATIONS

The locations of all biological sampling stations are illustrated in Figures 1 and 10, and the values of stream depth and stream velocity for each station, recorded during July, August, September, October, and November are listed in Table 6.

STATION #1 is a control station located about 1.5 miles upstream from Brandon Generating Station and about 1000 ft. upstream of the C.P.R. bridge (Figure 1). The station is upstream from the City of Brandon storm sewer, and a small piggery, both located about 1.2 miles upstream from Brandon Generating Station. The bottom substrate is composed of silt and fine sand.

This station was abandoned when the artificial substrate samplers at the station were destroyed by vandals during August, 1972.

STATION #2 is a control station located 0.4 miles upstream from Brandon Generating Station. The river is approximately 170 ft. wide at this point and the bottom substrate is composed of coarse sand.

STATION #3 is located 1000 ft. downstream from Brandon Generating Station's thermal discharge. This location was chosen because it was found that mixing between the thermal discharge and the river water was essentially complete at this point. The river is about 180 ft. wide at this point with a bottom substrate of sand and gravel.

STATION #4 is located 0.5 miles downstream from the thermal discharge and about 450 ft. downstream from the ash lagoon outfall. The river is wide (240 ft.) and shallow in this reach, with a bottom substrate which is a mixture of gravel, sand, and clay.

STATION #5 is located about 1.75 mi. downstream from Brandon Generating Station and is a control station for the discharges from the Brandon lagoons as well as serving to assess the linear extent of the effects of the thermal discharge. The river is 180 ft. wide at this station, with a bottom substrate of silt and clay.

STATION #6 is located just downstream (300 ft.) from the outfall of cell #5 of the Brandon lagoons (2.5 mi. downstream from Brandon Generating Station). The river is about 200 ft. wide at this station, and the bottom substrate is sand and gravel.

STATION #7 is located 3.5 mi. downstream from Brandon Generating Station and about 0.4 mi. downstream from the outfall of cell #3 of the Brandon lagoons. The river is 160 ft. wide at this point with a bottom substrate of coarse gravel and rubble.

STATION #8 is located 4.2 miles downstream from Brandon Generating Station, and about 1000 ft. upstream from the outfall of Dryden Chemicals Limited. The station is located just downstream from a small rapids. The river is 240 ft. wide at this point, with a bottom substrate of rock.

STATION #9 is located 4.5 mi. downstream from Brandon Generating Station and about 1000 ft. downstream from the Dryden Chemicals Limited outfall. It was felt that the effluent from Dryden Chemicals and the river water should be mixed by this point. The river is 160 ft. wide with a rock bottom at this station.

STATION #10 is located 5.7 mi. downstream from Brandon Generating Station. This was the limit of the downstream exploration because the rapids downstream from this station could not be navigated with the boat and outboard motor combination that was used. The river is 200 ft. wide with a rock bottom at this station.

10.2 APPENDIX 2

THE SEQUENTIAL COMPARISON TECHNIQUE

To illustrate the sequential comparison technique, consider the treatment of a sample of benthic macroinvertebrates containing 7 organisms in 4 different taxa, distributed as follows:

Taxa A : 2

Taxa B : 1

Taxa C : 3

Taxa D : 1

7

Assign a number to each organism of each taxa as follows:

Taxa A : 1, 2

Taxa B : 3

Taxa C : 4, 5, 6

Taxa D : 7

Next, randomize the numbers from 1 to 7 by some method (eg. place each number on a piece of paper and draw them out of a hat, or use a computer randomizing technique) so as to create a vector of randomly distributed numbers containing all the numbers from 1 to 7, inclusive. An example of such a vector of numbers is : 2, 1, 6, 4, 3, 5, 7.

The next step is to go through the vector of random numbers and compare each number to the one adjacent to it. Using the above vector of numbers this procedure would be as follows:

(1) 2 and 1 are from the same taxa (A) and thus are part of the same "run".

(2) 1 and 6 are not from the same taxa and thus 6 is part of a new "run".

(3) 6 and 4 are from the same taxa (C) and thus are part of the same "run".

(4) 4 and 3 are not from the same taxa and thus 3 is part of a new "run".

(5) 3 and 5 are not from the same taxa and thus 5 is part of a new "run".

(6) 5 and 7 are not from the same taxa and 7 is part of a new "run".

Now, count the number of runs in the vector of numbers, which is 5 for this example $(\frac{2,\ 1}{1}, \frac{6,\ 4}{2}, \frac{3}{3}, \frac{5}{4}, \frac{7}{5})$.

The sequential comparison diversity index (DI) is them computed as follows:

$$DI = \frac{\text{number of runs}}{\text{number of organisms}} \times \text{number of taxa}$$

For our example, $DI = \frac{5}{7} \times 4 = \frac{20}{7} = 2.86$

The maximum diversity in our example would occur when all 7 organisms were from different taxa ($DI = \frac{7}{7} \times 7 = 7.0$). The minimum diversity would occur when all 7 organisms were from the same taxa ($DI = \frac{1}{7} \times 1 = 0.14$).

High diversity is indicated by high DI values, and low diversity is indicated by low DI values.

The computer program developed for this technique merely duplicates the above procedure for each sample. The input required is:

(1) total number of organisms in the sample (expressed by the variable "NO" in the program).

(2) number of taxa in the sample (expressed by the variable "TAXA" in the program).

(3) the last number assigned to each taxa (expressed by the variables A, B, C, D, E, F . . . etc. in the program).

The computer reads this input and produces a vector of "NO" randomly distributed numbers, containing all the integers between 1 and "NO", inclusive. The computer then goes through this vector of numbers, comparing one number to the next, counting the number of runs, and finally computes the sequential comparison diversity index (DI). To increase the precision of DI, the computer repeats this procedure a total of 9 times (ie. generates 9 different vectors of random numbers) for each sample, and then computes the average diversity index ($\overline{DI}$) for the sample.

The computer then repeats this procedure for each of the 6 samples from a sampling station and averages the resulting average diversity indexes ($\overline{DI}$) to obtain a final average diversity index (DI_T) for the station.

The DI_T values thus produced were found to be within 10% of the true value 95 times out of 100[2].

The following is a listing of this computer program:

```
C THIS PROGRAM CALCULATES THE SEQUENTIAL COMPARISION INDEX OF EACH SAMPL
      DIMENSION NUMBER(1200),ZO(1201),DI(9),DA(10,6)
      REAL    A,B,C,D,E,F,G,H,II,JJ,KK,LL,MM,NN,O,P,Q,R,S,T
      PRINT 300
  300 FORMAT('1',26X,'SAMPLES')
      PRINT 301
  301 FORMAT(' ',1X,'SITE')
      ZO(1)=0
      NSTART=13
      DO 112 K=1,8
      DO 111 I=1,6
      READ,NO,TAXA,A,B,C,D,E,F,G,H,II
      DO 100 J=1,9
      CALL DEAL (NSTART,NUMBER,NO,JR,KEEP)
      RUNS=0
      DO 2 L=1,NO
      IF(NUMBER(L).GT.A)GO TO 3
      ZO(L+1)=1
      GOTO 200
    3 IF(NUMBER(L).GT.B)GO TO 4
      ZO(L+1)=2
      GOTO 200
    4 IF (NUMBER(L).GT.C)GO TO 5
      ZO(L+1)=3
      GOTO 200
    5 IF(NUMBER(L).GT.D)GO TO 6
      ZO(L+1)=4
      GOTO 200
    6 IF(NUMBER(L).GT.E)GO TO 7
      ZO(L+1)=5
      GOTO 200
    7 IF(NUMBER(L).GT.F)GO TO 8
      ZO(L+1)=6
      GOTO 200
    8 IF(NUMBER(L).GT.G)GO TO 9
      ZO(L+1)=7
      GOTO 200
    9 IF(NUMBER(L).GT.H)GO TO 10
      ZO(L+1)=8
      GOTO 200
   10 IF(NUMBER(L).GT.II)GO TO 11
   11 ZO(L+1)=9
      GOTO 200
  200 IF(ZO(L+1).EQ.ZO(L))GOTO 2
      RUNS=RUNS+1
    2 CONTINUE
      RO=FLOAT(NO)
      DI(J)=RUNS/RO*TAXA
  100 CONTINUE
      DA(K,I)=(DI(1)+DI(2)+DI(3)+DI(4)+DI(5)+DI(6)+DI(7)+DI(8)+DI(9))/9
  111 CONTINUE
      TDA=(DA(K,1)+DA(K,2)+DA(K,3)+DA(K,4)+DA(K,5)+DA(K,6))/6
  112  PRINT 302,K,(DA(K,I),I=1,6),TDA
  302 FORMAT(' ',2X,I2,4X,F6.3,F7.3,F7.3,F7.3,F7.3,F7.3,F7.3)
      STOP
      END

      SUBROUTINE DEAL (NSTART,NUMBER,NO,JR,KEEP)
      DIMENSION NUMBER(1200)
```

```
      DO 1 I=1,NO
    1 NUMBER(I)=I
      DO 4 J=1,10
      DO 2 I=1,NO
      NSTART=NSTART*65539
      IF(NSTART.LT.0)NSTART=NSTART+2147483647+1
      JR=(NSTART-NSTART/NO*NO)+1
      KEEP=NUMBER(I)
      NUMBER(I)=NUMBER(JR)
    2 NUMBER(JR)=KEEP
    4 CONTINUE
      RETURN
      END
 $ENTRY
```

DATA CARDS

In this program:

NO = total number of organisms per sample

TAXA = number of taxa per sample

A, B, C, D, E, F, G, H, II = the last number assigned to each taxa

DI(J) = sequential comparison diversity index for a sample (DI)

DA(K, I) = average sequential comparison diversity index for a sample ($\overline{DI}$)

TDA = average sequential comparison diversity index for a station (DI_T)

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