THE UNIVERSITY OF MANITOBA

THERMAL EFFECTS OF BRANDON GENERATING STATION ON THE ASSINIBOINE RIVER

BY

LARRY W. POMMEN

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

BY

LARRY W. POMMEN

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

CHAPTER PAGE

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.

---

* 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°C (5.4°F)*	---	22
Saskatchewan	---	3°C (5.4°F)*	---	22
Alberta	---	3°C (5.4°F)*	---	23
North Dakota	90°F	5°F (2.8°C)*	---	24
Minnesota	90°F	5°F (2.8°C)*	---	25
Pennsylvannia	87°F	5°F (2.8°C)*	2°F/HR.	25
Nebraska	90°F	5°F (May-Oct) 10°F (Nov-Apr)	2°F/HR.	25
Montana	89°F	4°F, provided temperature <40°F in winter	2°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

<u>Definition</u>: 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 macro-benthos 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