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THERMAL POWER PLANT WASTE HEAT UTILIZATION IN ALBERTA: POTENTIAL AND PROBLEMS

by

© Frank Bruce MacKenzie

A THESIS

SUBMITTED TO

THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled THERMAL POWER PLANT WASTE HEAT UTILIZATION IN ALBERTA: POTENTIAL AND PROBLEMS, submitted by Frank Bruce MacKenzie in partial fulfilment of the requirements for the degree of Master of Science.

Arleigh H. Laycock
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Date July 20, 1979

ABSTRACT

The Wabamun, Sundance, Forestburg, Rossdale, and Clover Bar steam electric generating stations in Alberta rejected more than 85 x 10^{12} BTU's of heat energy to the environment in condenser cooling water in 1978. When the Keephills, Sheerness and Genesee power plants are commissioned in the late 1980's, this figure can be expected to double. This represents approximately 50 percent of the energy utilized by these plants to produce electricity.

The objective of the author in this thesis is to determine the theoretical and practical constraints involved in attempts to utilize this waste heat resource in Alberta. To this end, literature pertaining to the utilization of power plant reject heat is reviewed to provide an analysis of the various applications for this heat. A greenhouse heating project in Minnesota and two aquaculture projects in Trenton, New Jersey and Grand Lake, New Brunswick are described in detail. Practical experience from these and other operations is incorporated with documented knowledge of greenhouse heating and thermal aquaculture to provide some basic

conceptual designs and suggestions for future prototype studies in Alberta. Literature relating to the feasibility of district heating, open field soil warming, warm water irrigation, and wastewater treatment are also reviewed. In addition, a market analysis for eleven fresh vegetables, floral crops, and rainbow trout and shrimp is provided to demonstrate the potential demand for these products in Alberta.

It was concluded that thermal aquaculture has the greatest potential for development in Alberta. Greenhouse heating would be hindered by low supply water temperatures but this could be offset through the use of solar heating techniques and better insulation. Co-generation of heat and electricity is particularly attractive for supplying high temperature water or steam for district heating, greenhouse heating, and a variety of industrial processes. It also greatly improves the station net thermal efficiency. The other applications which have potential for development in Alberta include open field soil warming, warm water irrigation, wastewater treatment, and waterfowl habitat enhancement.

Several institutional constraints need to be overcome before power plant waste heat utilization is developed on a large scale in Alberta. The principal constraint is the traditional attitude of utilities that waste heat is a nuisance that should be dissipated as efficiently as possible. With changing energy costs and growing needs for conservation and a growing recognition by governments that they must participate in conservation programs, the old attitudes are being replaced. Several options are outlined by which Alberta might obtain better use of this waste heat resource in the future.

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First and foremost, I wish to thank my supervisor, Dr. A.H. Laycock, who was instrumental in my completion of this thesis. Dr. Laycock was always available for consultation, especially for some matters that seem so trivial now. The comments and suggestions of my two other committee members, Dr. E.L. Jackson, and Dr. N. Rajaratnam, are also gratefully acknowledged.

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CHAPTER I

INTRODUCTION

The Problem

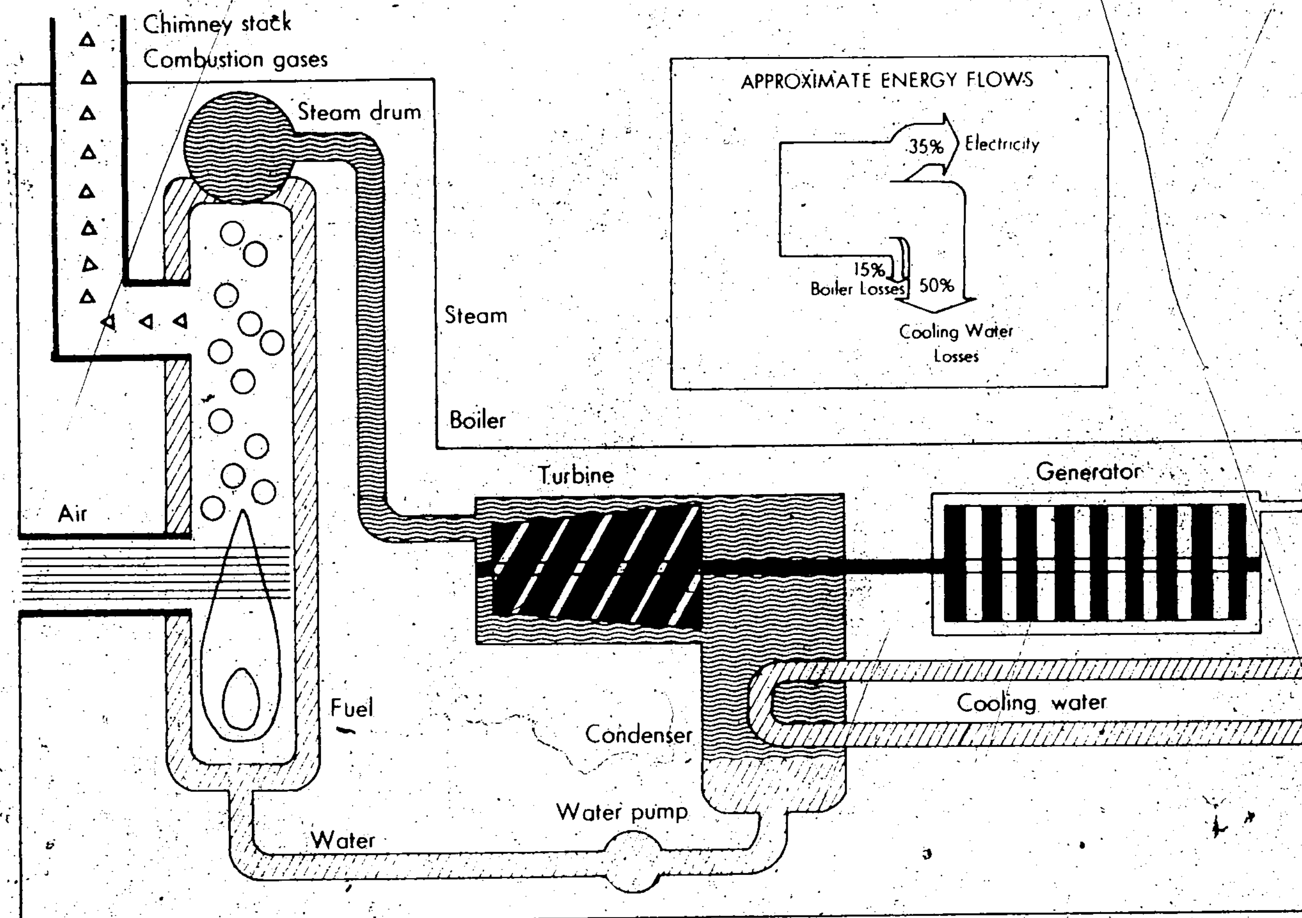
Thermal power plants in Alberta, and throughout the rest of the world, are rejecting tremendous quantities of energy to the environment. Approximately only 40 percent of the total energy consumed in a new fossil fuel power plant is used to produce electricity (Fisheries & Environment Canada, October 1977, p. 8). The remaining 60 percent is rejected as waste heat of which 45 percent is removed by condenser cooling water and 15 percent is lost via the stack. Nuclear power plants are even less efficient, about 30 percent with the 70 percent reject heat consisting of 5 percent miscellaneous losses and 65 percent removal by the cooling water. In other words, for every kilowatt of electricity (kW_e) produced in thermal power plants, from one and a half to over two kilowatts of energy (kW_t) are lost.

Unlike hydro electric plants, which use falling water to spin turbines that drive electric generators, thermal power plants utilize the heat energy of fossil fuels and uranium to produce steam pressure to turn the turbines. Unfortunately, the basic principles of thermodynamics limit the efficiency of energy utilization in these plants. Figure 1.1 is a simple schematic representation of a typical fossil fueled power plant. Briefly, the fuel is fed, with an ample supply of air, into a boiler where it is incinerated and the resultant heat is used to convert the cycle working fluid (water) into steam. The efficiency of energy conversion in this portion of the operation can vary widely with basic design and operating conditions. In the large units, similar to those in place in the newer power plants in Alberta, efficiencies greater than 90 percent can be achieved (Skrotski & Vopat, 1960, p. 152).

The steam, which at this point exhibits extremely high temperatures and pressures, is then allowed to flow through a nozzle to a lower pressure in the turbine. This converts part of the steam energy to kinetic jet energy at which point it attains a high velocity. The steam jet flows over moving blades which are fastened to the rims of rotating disks mounted on the turbine shaft. These moving blades convert the kinetic energy of the steam jet to a torque acting on the turbine shaft causing it to spin rapidly. The spinning turbine shaft then drives an electric generator

FIGURE 1:1

SCHEMATIC DIAGRAM OF A TYPICAL FOSSIL FUELED POWER PLANT



Source: Energy, Mines and Resources Canada, 1976, p. 11.

which produces electricity.

To maintain thermal efficiencies as high as possible, the spent steam, after it has passed over the turbine blades, is condensed and the condensate is returned to the boiler. Cooling water, drawn from an external source, is circulated through tubes in the condenser where heat from the exhaust steam is transferred to the water by convection. The circulating water is then pumped out of the plant and the heat is allowed to dissipate to the environment. By condensing the steam exhausted from a turbine, the condensers maintain a low pressure at the exhaust which in turn improves the efficiency of the power plant cycles (Skrotski & Vopat, 1960).

The amount of cooling water utilized, and correspondingly the amount of heat rejected, is of considerable proportions. For example, the 582 megawatt (MW) Wabamun power plant at Lake Wabamun, operating at maximum load, circulates 886,462 litres of water per minute (195,000 IGPM) and rejects 2030 x 10^6 BTU's of heat energy per hour (Crosby-Diewold & Railton, 1978, p. 64). The resultant temperature increase of the circulating water is approximately 17C (30F) above ambient during the winter and about 11C (19F) during the summer.

The problem, therefore, because thermal power plants reject so much energy in a time when energy is becoming an increasingly critical resource, is to develop methods of utilizing this waste heat for beneficial purposes. Given existing technology, it is highly unlikely that the inplant thermal efficiencies can be improved appreciably in the near future. Nor is the answer likely to be the conversion to alternative energy sources for the production of electricity. In fact, over the next thirty years in Alberta, thermal power is expected to occupy a much more predominant role in electricity production. In 1977, hydro power represented only 10 percent of the total electricity produced in Alberta but this figure is expected to decrease to 0.8 percent in 2006 (Electric Utility Planning Council, 1977, p. II-9). During the same period, the demand for electricity in this province is projected to increase from 3,084 MW in 1977 to 17,287 MW in 2006 (Electric Utility Planning Council, 1978, p. 12). Moreover, the vast coal reserves in Alberta are estimated to be sufficient to supply 39,000 MW of generating capacity for conventional coal-fired units capable of producing base load energy for thirty years (Electric Utility Planning Council, 1977, p. VII-6). Consequently, the amount of waste heat released by thermal power plants in Alberta can be expected to increase by several orders of magnitude over the next thirty years and thus now is the time to consider and implement practical uses of this resource.

Objective

The purpose of this study is to review the various beneficial uses of thermal power plant reject heat with the ultimate goal of determining which uses appear to have the greatest potential for development in Alberta. Due to the low grade nature of the heat in power plant cooling water, research efforts have largely concentrated on its use for enhancing biological processes. These include greenhouse heating, aquaculture, wastewater treatment, open field soil warming, and warm water irrigation. These applications will be investigated in detail in this thesis. The feasibility of upgrading the reject heat for heating urban areas will also be discussed. Waterfowl habitat enhancement, which has been an inadvertent result of power plant thermal discharges, will be described as well.

Implicit in this study is the approach that the theme is not to be considered one of "thermal pollution" reduction but rather, one of energy conservation and efficient utilization. During the past two decades, millions of dollars have been expended on research designed to examine the ecological effects of waste heat additions to water bodies. Some of the anticipated effects were lethal and sublethal involving food chain modifications and habitat changes in the aquatic systems. However, the results of this intensive research have failed to corroborate most of the dire predictions and it is now widely recognized that the effects of power plant thermal discharges in large water bodies are minimal and localized. This is substantiated by various sources. Fisheries and Environment Canada (June 1977, p. 16) reports that: "the results to date fail to indicate that stability of aquatic communities in large water bodies is deleteriously affected by thermal discharges." Griffing (1978, p. 7) also confirms these conclusions: "from the large body of accumulated documentation the overall results have not borne out the earlier dark predictions of the high magnitudes of impacts that some people thought might result." Levin et al (1972, p.229) conclude that, with a few exceptions, there has not been any major damage to the aquatic environment from the heated effluents of power plants and "... the satisfactory performance of existing steam electric plants supports the belief that controlled amounts of heated water can be added to aquatic systems without producing adverse biological consequences."

Another factor to be considered is the scale of an operation that would be required to utilize all the reject heat discharged from a thermal power plant. The Sherco

Greenhouse Project in Becker, Minnesota has been utilizing the warm water effluent from a coal-fired power plant to heat a 0.2 hectare (1/2 acre) greenhouse (Ashley, 1978). The greenhouse, at maximum heating requirements uses only about 2,728 litres per minute (600 IGPM) of the cooling water. Therefore, efforts to utilize the 886,462 litres per minute (195,000 IGPM) circulated at the Wabamun plant would require approximately 130 hectares (321 acres) of greenhouses with a heating system similar to that used at the Sherco greenhouse.

In light of the above, the emphasis of this thesis will not be directed towards alleviating thermal pollution, nor utilizing all the heat rejected from thermal power plants. Rather, an effort will be made to outline what can and should be done with some of the wasted energy that is available from steam electric generating stations. This should hopefully provide a conclusive argument for developing some form of waste heat utilization in Alberta.

Approach

The first part of this thesis is an inventory of the thermal power plant waste heat resource in Alberta. In line with this, the source of this resource, the power plants, will also be described. Five thermal power plants in Alberta were selected for this purpose as well as three new facilities that are scheduled to come on line in the 1980's. The locations of these stations are indicated in Figure 1:2. The five power plants currently in operation are the Wabamun and Sundance plants at Lake Wabamun (Calgary Power Ltd.), the Rossdale and Clover Bar plants in Edmonton (Edmonton Power), and the Forestburg station southeast of Camrose on the Battle River (Alberta Power Ltd.) These generating stations were selected for investigation on the basis of their size and together they produce approximately 90 percent of the total electrical power produced in the province (R. McLary, Electric Utility Planning Council, personal communication, October 1978).

The three proposed facilities to be discussed include the Keephills (CPL), Sheerness (APL), and Genesee (EP) power plants. Construction of the Keephills plant has begun and the first unit is scheduled for commissioning in 1982 (Calgary Power Ltd., 1976). Alberta Power has recently been granted permission by the Energy Resources Conservation Board to proceed with construction of the Sheerness power plant which is expected to begin producing electricity in 1985 (Edmonton Journal, January 27, 1979, p. A1). At the time of this writing, there remains some doubt and confusion as to whether or not Edmonton Power's application to con-

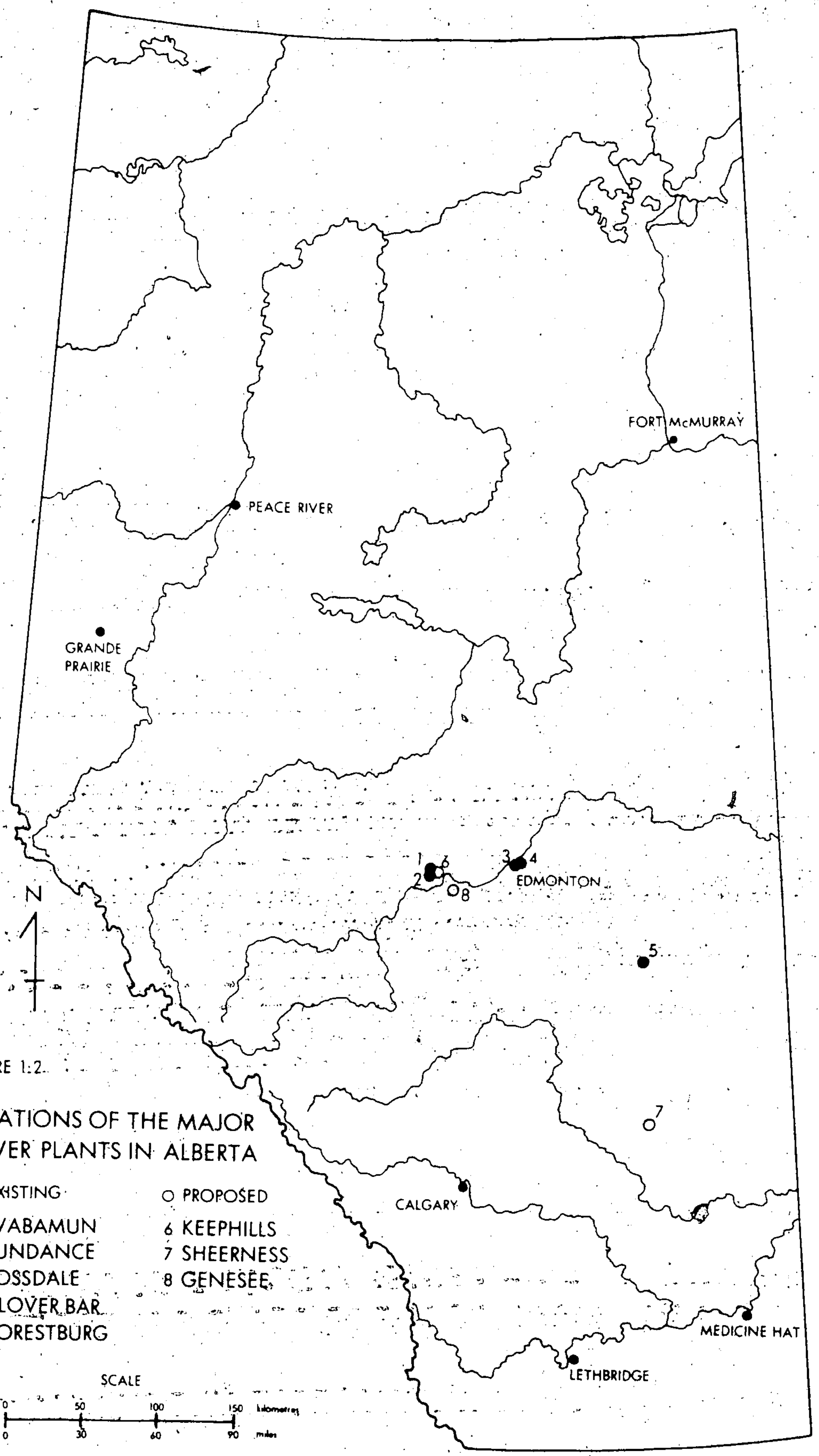


FIGURE 1:2

LOCATIONS OF THE MAJOR POWER PLANTS IN ALBERTA

● EXISTING
1 WABAMUN
2 SUNDANCE
3 ROSSDALE
4 CLOVER BAR
5 FORESTBURG

○ PROPOSED
6 KEEPHILLS
7 SHEERNESS
8 GENESEE

struct the Genesee power plant will be approved by the Energy Resources Conservation Board. The date for commissioning of the first unit at the Genesee plant was originally scheduled for 1985 (Edmonton Power, 1977a).

A detailed analysis of the generating capacities, methods of cooling, average circulating water quantities, average amounts of heat rejected in the circulating water, and the average temperature increase of the cooling water above the ambient conditions for each plant will be discussed in the second chapter. The relevant geographic features of each site will also be described. This will put the various practical constraints into context for the latter chapters of the thesis when possible applications of the reject heat will be outlined.

Chapters III, IV, and V will be a description of greenhouse heating, thermal aquaculture, and district heating respectively while Chapter VI will be a brief description of some miscellaneous applications. There is considerable documentation in both the Canadian and American literature on these subjects. This wealth of information, along with the documented experience of some pilot projects, will be incorporated to provide a detailed description of these waste heat applications and will be the basis for some basic conceptual designs.

The pilot projects to be described are an aquaculture operation at Grand Lake, New Brunswick and the now defunct greenhouse heating project at Lake Wabamun. Two American prototype studies, the previously mentioned Sherco Greenhouse Project and an aquaculture project at the Mercer generating station in Trenton, New Jersey, will also be described. These projects will be reviewed in considerable detail so as to provide an indication of the benefits and constraints associated with attempting to utilize thermal power plant waste heat for beneficial purposes.

Chapter VII of the thesis will be an analysis of the market in Alberta for some fresh vegetables, fish, and floral crops. These products would be produced in some of the waste heat applications to be outlined in this study. This analysis is being included in the thesis to provide additional weight to the argument for the need to implement beneficial uses of waste heat in Alberta.

Finally, Chapter VIII will consist of the conclusions and recommendations. This will include a summary of the findings and a discussion of their significance. These findings will indicate the need and feasibility of developing beneficial uses of power plant waste heat in this province and hopefully provide a stimulus for some long awaited action in this field.

CHAPTER II

THE MAJOR THERMAL POWER PLANTS IN ALBERTA

Introduction

The objective of this study is to investigate the feasibility of utilizing waste heat from thermal power plants in Alberta. Thus, it is necessary to first identify and take an inventory of this resource. To accomplish this, each of the previously mentioned generating stations will be described individually. This will include some basic information about the existing facilities such as electricity generating capacities, monthly production data, heat rejection rates, cooling water flows, temperatures of the discharge water, and the various methods employed by each plant for condenser cooling. Relevant geographical information pertaining to the location of each station will also be presented. In addition, the applications submitted to the Energy Resources Conservation Board by the three utilities for the Keephills, Sheerness, and Genesee power plants will be reviewed to provide an indication of what these stations will entail.

This information will be useful in determining which waste heat applications have the greatest potential for development in Alberta. Although there are numerous potential uses of power plant waste heat, not all are feasible for implementation at each generating station due to practical constraints. These constraints may relate to the waste heat resource itself or may be geographic in nature. For example, the Rossdale and Clover Bar power plants, because of their locations in the city of Edmonton, would probably be practical sites for only those applications of waste heat that are urban related. This chapter will outline these constraints and assist in determining which applications would be desirable from a development standpoint.

General Plant Description and Operating Statistics

The Wabamun generating station, owned and operated by Calgary Power Ltd., is a mine mouth, coal-fired thermal power plant located on the northeast shore of Lake Wabamun approximately 72 kilometres (45 miles) west of the city of Edmonton (Figure 2:1). Coal for the plant is obtained from the Whitewood Mine which constitutes part of a large coal seam found in the Paskapoo Geological Formation (Research Council of Alberta, 1970). This coal mine is located just north of the plant and about 1.8 million tonnes (2 million tons) of coal are surface mined each year for the Wabamun station (Calgary Power Ltd., 1975).

The first generating unit at Wabamun, with a rated net capacity of 69 MW, was commissioned in 1956 (Calgary Power Ltd., 1975). This unit was fueled with natural gas from the Alexander Field, 50 kilometres (31 miles) to the northeast. The second unit, with a capacity of 67 MW, was also gas-fired and became operational in 1958. Coal mine and coal handling facilities were first added to the Wabamun

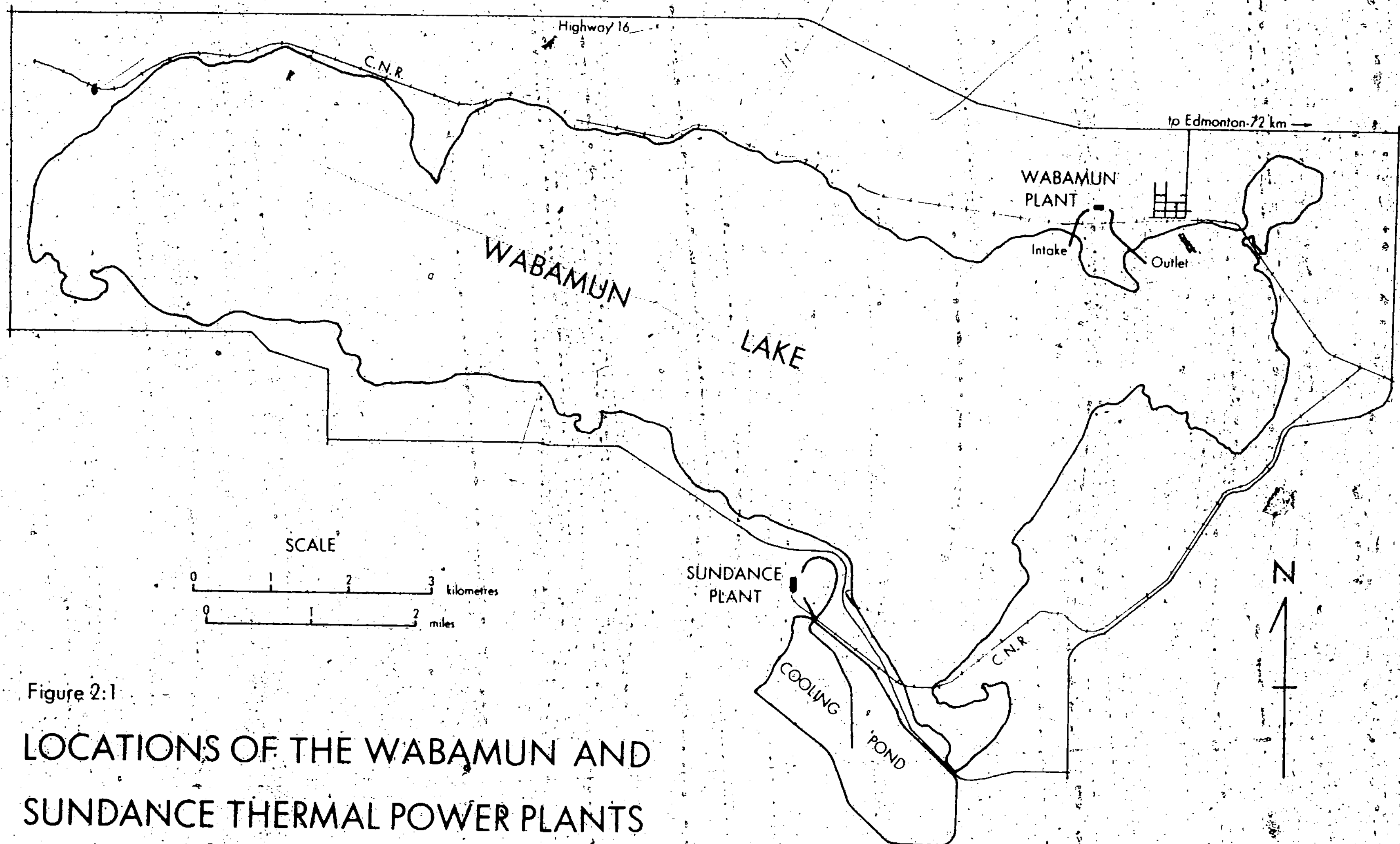


Figure 2:1

LOCATIONS OF THE WABAMUN AND SUNDANCE THERMAL POWER PLANTS

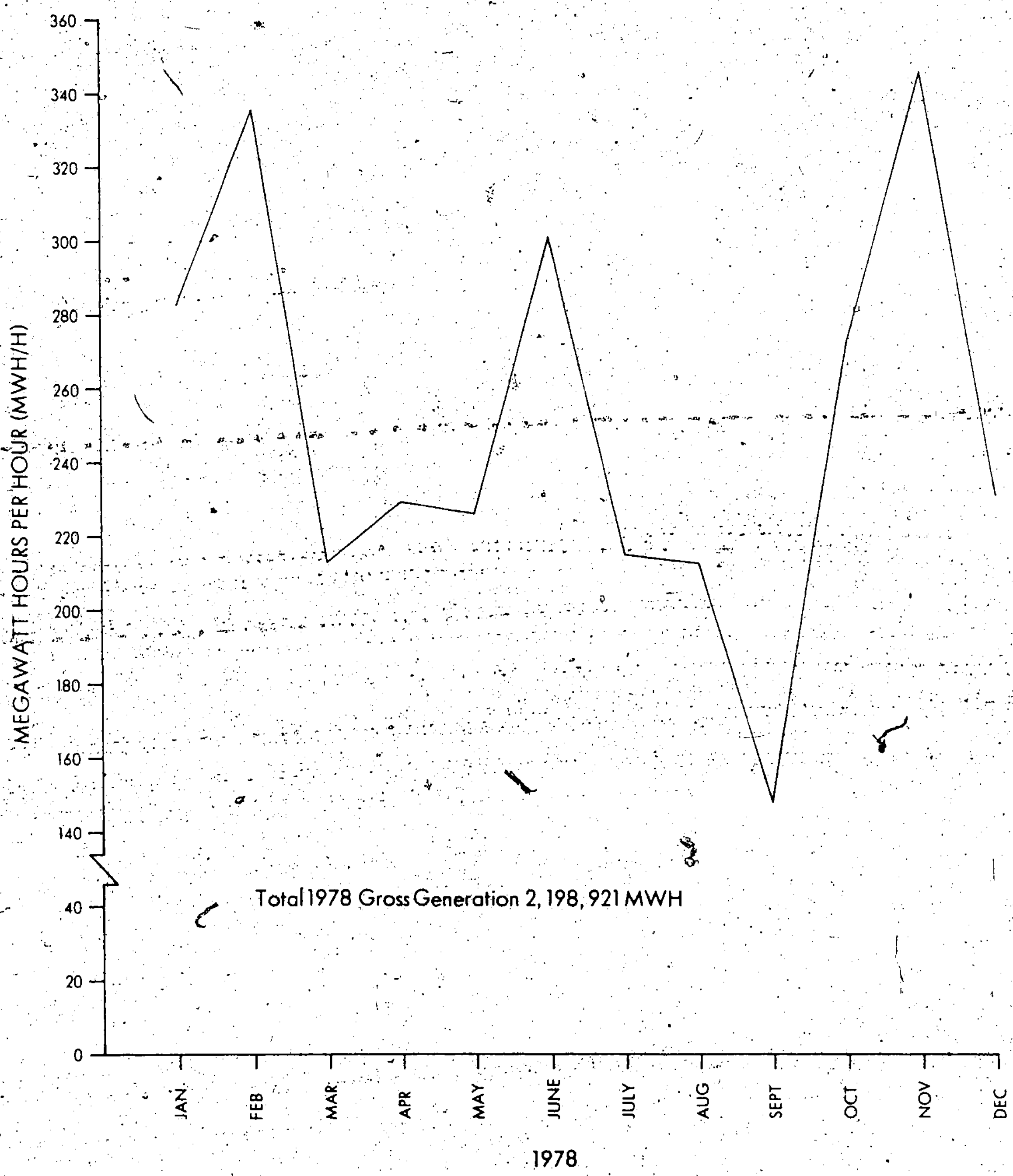
Source: Crosby-Diewold and Railton, 1978, p. 63.

station in 1962 with the commissioning of Unit 3. It's capacity is rated at 147 MW. In the same year, Unit 2 was converted to coal while Unit 1 continues to burn natural gas. Expansion of the plant was finally completed in 1968 with the installation of Unit 4, rated at 286 MW. These four units provide the Wabamun station with a maximum net capacity of 569 MW.

The Wabamun generating station was first constructed as a base load facility but it is now gradually being used to meet only peak electrical demands. The reason for this is the high coal mining costs associated with the Whitewood Mine, relative to Calgary Power's other coal-fired station, the Sundance power plant on the south shore of Lake Wabamun (R. Way, Calgary Power Ltd., personal communication, October 1978). This shift to a peak load facility is evident in the plant's 1978 monthly mean gross generation statistics (Figure 2:2). This graph reveals that the daily average production for 1978 was about 252 MWH per hour, considerably less than the rated maximum capacity. During the month of November, which had the highest average gross generation for the year, the Wabamun plant was operating at only 61 percent of it's rated capacity. On the other hand, the plant operated at an average of only 26 percent of capacity during the month of September. On the average, the Wabamun station was

Figure 2:2

WABAMUN 1978 MEAN MONTHLY GROSS GENERATION



Source: 1978 Production Statistics Provided by Calgary Power Ltd.

operating at approximately 44 percent of rated capacity in 1978.

Physical Characteristics of the Plant Site

The area in which the Wabamun generating station is located is characterized by gently rolling to rolling topography. Maximum relief in the area is about 68.16 m (200 ft, Canada Department of Energy, Mines and Natural Resources, NTS Map 83 G/9, 1970) with 5 to 15 percent slopes (Lindsay et al, 1968). The surficial materials consist of sands and gravels overlain by till while the principal soils of the region are typically Orthic Gray Wooded, rated as fair to fairly good for cultivation (Lindsay et al, 1968).

The major water resource in the plant area is Lake Wabamun. This lake is mildly eutrophic and is a popular recreational area for cottagers. There is a provincial park at the east end of the lake as well. Groundwater in the area is of fairly good quality. The principal chemical constituents of the groundwater are sodium, potassium, carbonate and bicarbonates (Research Council of Alberta, 1970). Traces of calcium and sulphate are also found however. The total dissolved solids are in the order of 1000 mg/l. The water table is very shallow, about lake level, while the probable well yields are in the range of 22.7 to 113.6 litres per minute (5 to 25 IGPM).

Condenser Cooling

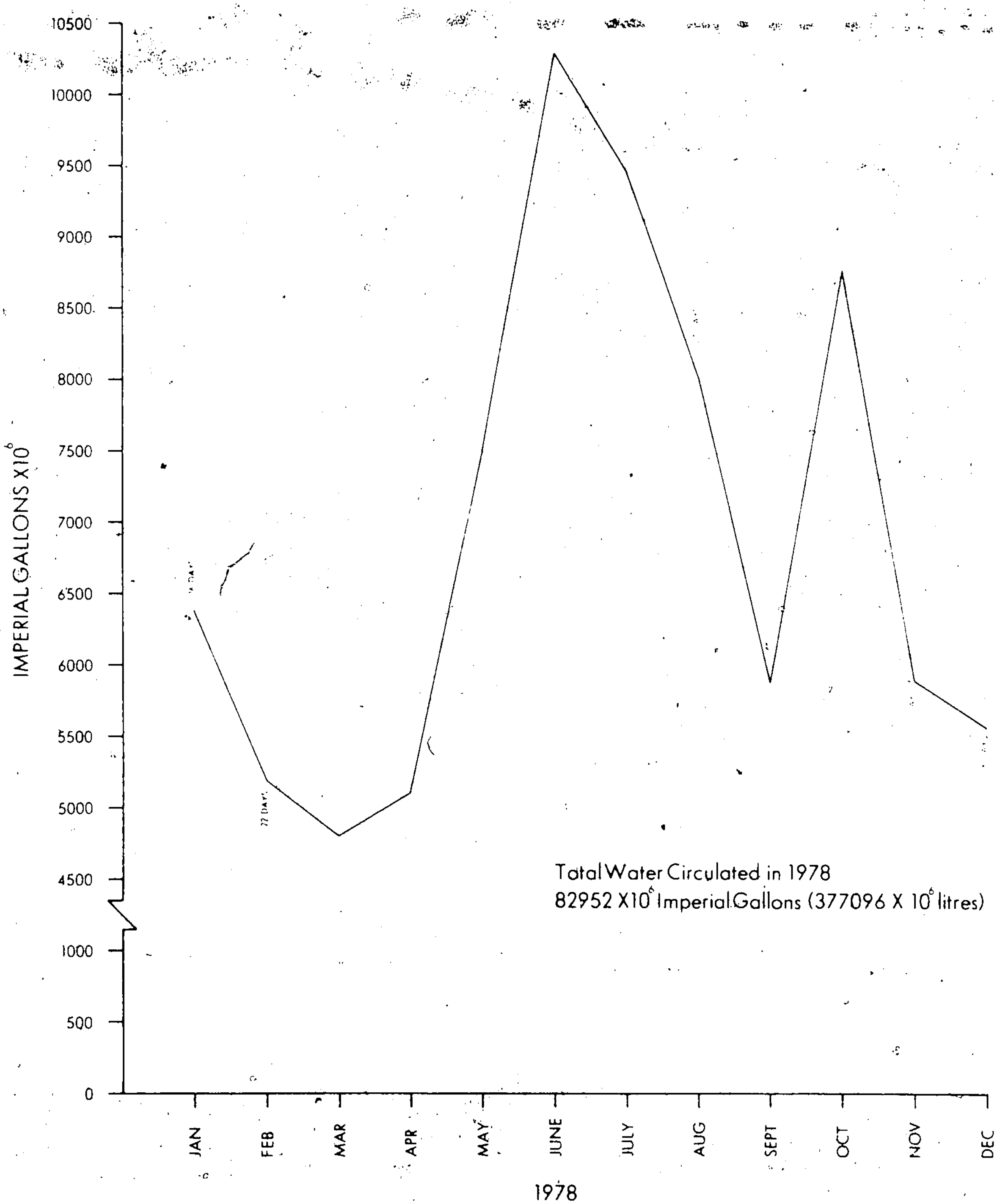
The method employed at the Wabamun generating plant for condenser cooling is a once-through cooling system with the lake acting as the water source. The inlet canal for the Wabamun plant is located on the west side of the station while the outlet canal discharges warm water into the lake on the east side of the plant (Figure 2:1).

The 1978 monthly circulating water flows for the Wabamun plant are presented in Figure 2:3. This graph illustrates the large amounts of water that are circulated through the condensers on a monthly basis. During the summer months, at maximum load, the cooling water discharge may be as much as 2,045,684 litres per minute (450,000 IGPM) which is the equivalent to moving 0.5 percent of the lake's volume through the condensers each day (Nursall et al, 1972).

The corresponding heat rejection rates and the monthly average inlet and outlet water temperatures are presented in Figures 2:4 and 2:5 respectively. The amount of energy lost in the condenser circulating water is of disturbing proportions, amounting to more than 12 x 10^{12} BTU's during 1978. This figure is relatively small in com-

Figure 2:3

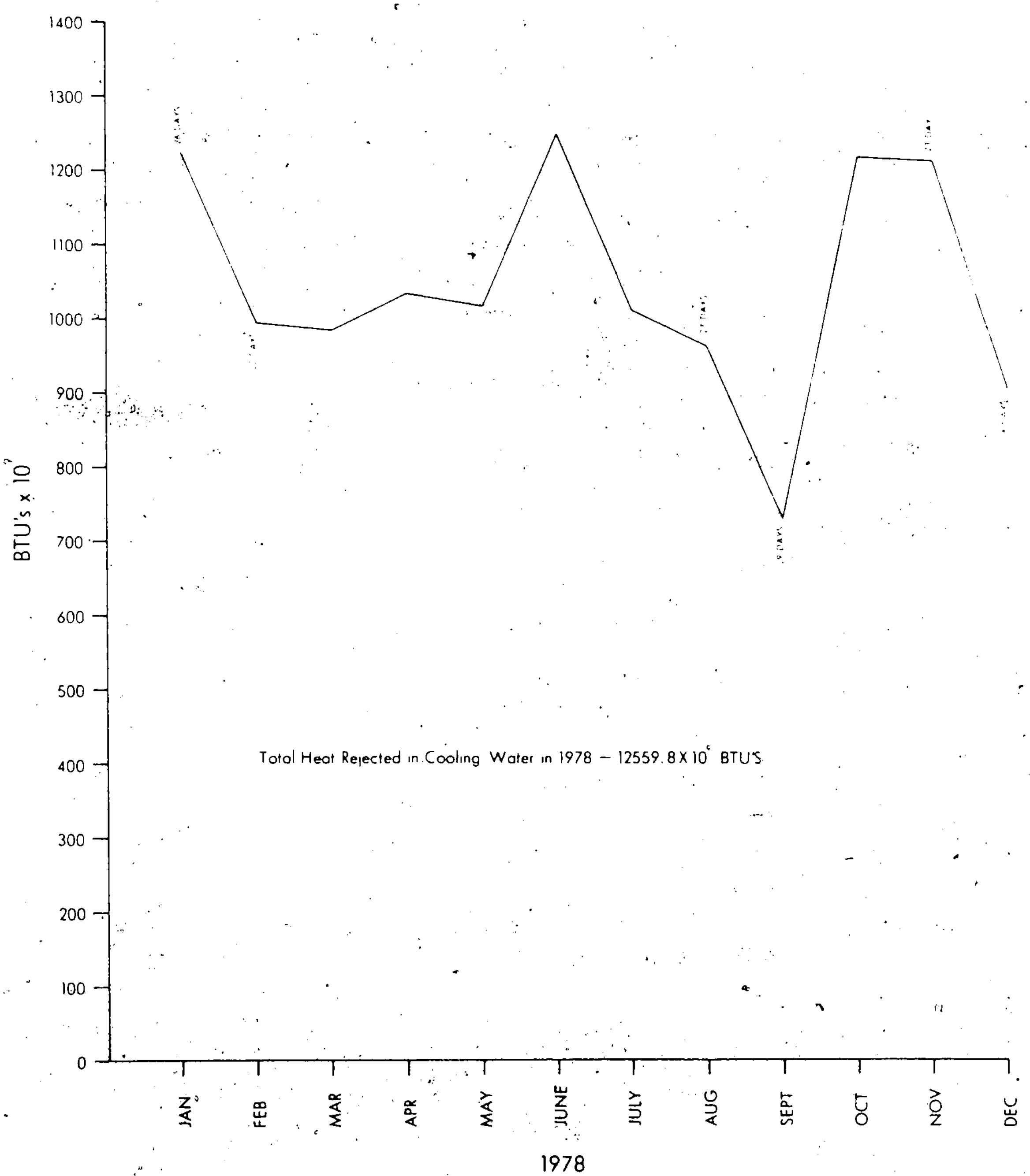
WABAMUN 1978 MONTHLY CONDENSER COOLING WATER FLOWS



Source: 1978 Production Statistics Provided by Calgary Power Ltd.

Figure 2:4

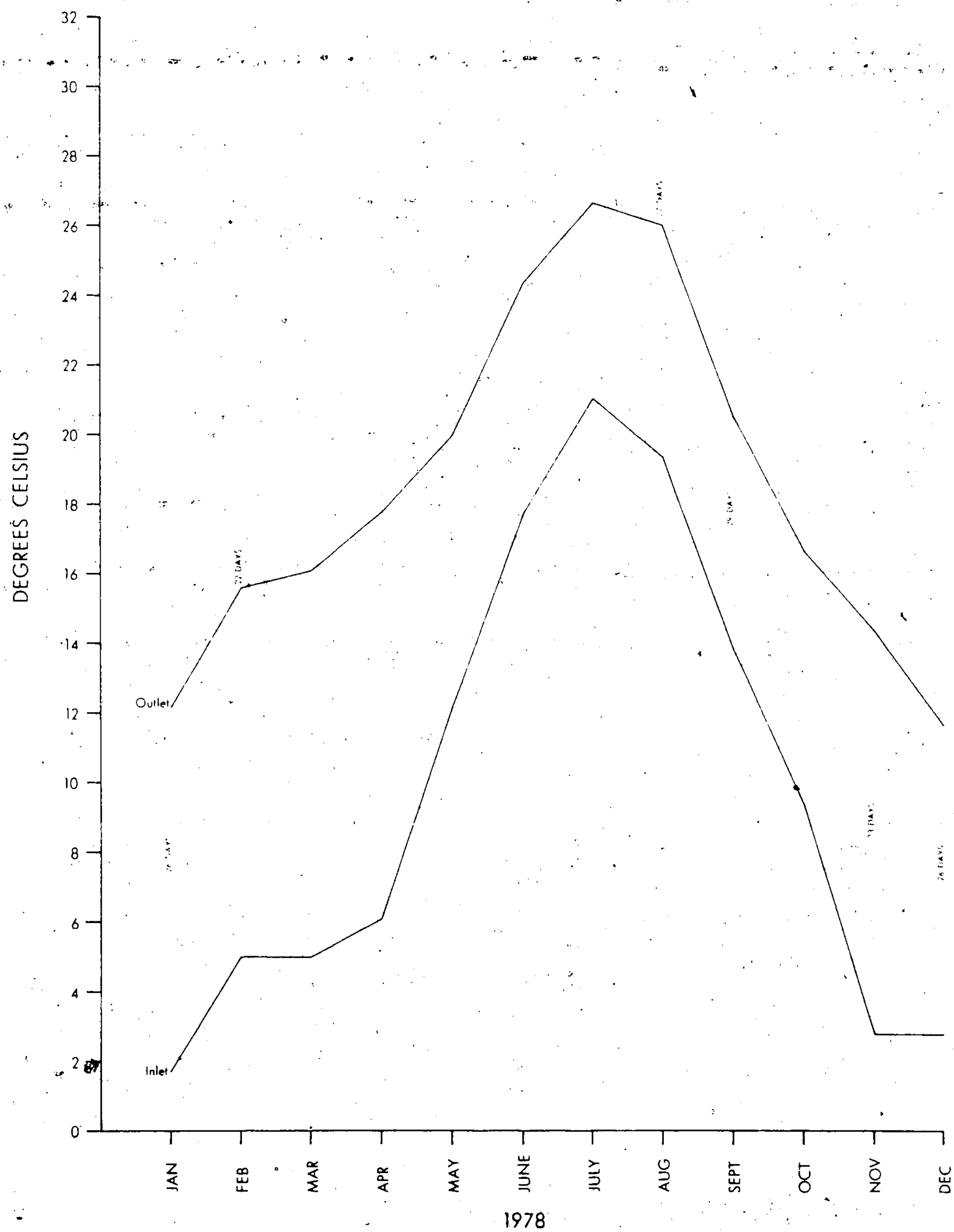
WABAMUN 1978 MONTHLY HEAT REJECTED IN COOLING WATER



Source: 1978 Production Statistics Provided by Calgary Power Ltd.

Figure 2:5

WABAMUN 1978 MONTHLY AVERAGE INLET AND OUTLET WATER TEMPERATURES



Source: 1978 Production Statistics Provided by Calgary Power Ltd.

parison to previous years when the Wabamun station was being operated at production levels closer to the plant's maximum capacity.

The water temperature data (Figure 2:5) provide a good indication of the problems associated with attempts to utilize the heat rejected in this water. Firstly, the outlet water temperatures are quite low during the winter months. These temperatures are substantially higher during the summer months but this is a period when heat is not required by many of the applications that are designed to utilize power plant reject heat. The second factor portrayed in the graph of the water temperatures is the fluctuating nature of these temperatures. These fluctuations are even more pronounced on a daily basis as various units are started up or shut down according to electricity demands. Furthermore, with the continued use of the Wabamun generating station as a peak load operation, these circulating water temperatures can be expected to exhibit even greater fluctuations over a daily cycle.

The heat rejected to Lake Wabamun in the condenser cooling water has led to serious environmental concerns. Consequently, a considerable research and technical effort has been spent over the past fifteen years in an attempt to document the impacts of the reject heat on the aquatic environment. The primary cause for concern at Lake Wabamun was the introduction and rapid spread of the macrophyte, Elodea canadensis. This aquatic weed is quite rare in central Alberta but it became established in Lake Wabamun during the 1960's (Crosby-Diewold & Railton, 1978). Once introduced, this macrophyte spread rapidly throughout the lake and residents often complained of weed rafting creating a nuisance for swimming and boating activities. As a mitigative effort, Calgary Power has conducted an aquatic weed control program since 1972 in the area of the lake receiving thermal discharges (Calgary Power Ltd., 1978). This program has consisted largely of mechanical harvesting and a floating weed boom but some experiments with herbicides were attempted.

In 1973 the Energy Resources Conservation Board requested a study into the effects of the discharge of waste heat into Lake Wabamun (Crosby-Diewold & Railton, 1978). To meet this request, Calgary Power contracted Beak Consultants Ltd. to investigate the problem. This study was to be completed in 1975 but an application was made in that year to extend the studies until 1979. In the interim, the study has been an intensive effort to map the distribution and density of Elodea throughout the lake. The final report of this study is not yet available but the preliminary results seem to indicate that there is some correlation between areas of maximum weed growth and areas receiving warm water discharges. There are also strong indications however, that the rate of Elodea growth has declined since its earlier levels of production (Crosby-Diewold & Railton, 1978).

If the Energy Resources Conservation Board should find the results of this investigation to be unacceptable, Calgary Power could then be faced with seeking alternative cooling facilities for the Wabamun plant. There is insufficient land in the area to build a cooling pond thus the alternatives under consideration are cooling towers or discharge to a deeper part of the lake (Crosby-Diewold & Railton, 1978). Neither of these alternatives are particularly desirable as cooling towers could cost upwards of $41 million while discharge to a deeper part of the lake could prove to be biologically unsound. Cooling towers also operate at relatively high noise levels and can create fog problems during the winter months. These will be factors that the Energy Resources Conservation Board, and the residents of the hamlet of Wabamun, will have to take into consideration when a decision is made on whether or not to allow Calgary Power to continue operating a once-through cooling system at the Wabamun plant.

SUNDANCE

General Plant Description and Operating Statistics

The Sundance generating station is a mine mouth, coal-fired thermal power plant located on the south shore of Lake Wabamun (Figure 2:6). The adjacent Highvale Mine provides the plant with its sole source of fuel. The Sundance plant, like the Wabamun station, is owned and operated by Calgary Power Ltd. Together, these two plants provide approximately 80 percent of the electric energy supplied throughout Calgary Power's system (Calgary Power Ltd., 1974).

The Sundance thermal power plant first commenced commercial production in 1970 with the commissioning of Unit 1, rated at 300 MW (Calgary Power Ltd., 1975). Since the installation of this first unit, the plant has undergone a rapid and continuous expansion program. A second 300 MW unit was commissioned in 1973 with two 375 MW units commissioned in 1975 and 1976. Unit 5, also rated at 375 MW, came on line in July 1978 with the sixth and final 375 MW unit scheduled for commissioning in 1980. When the

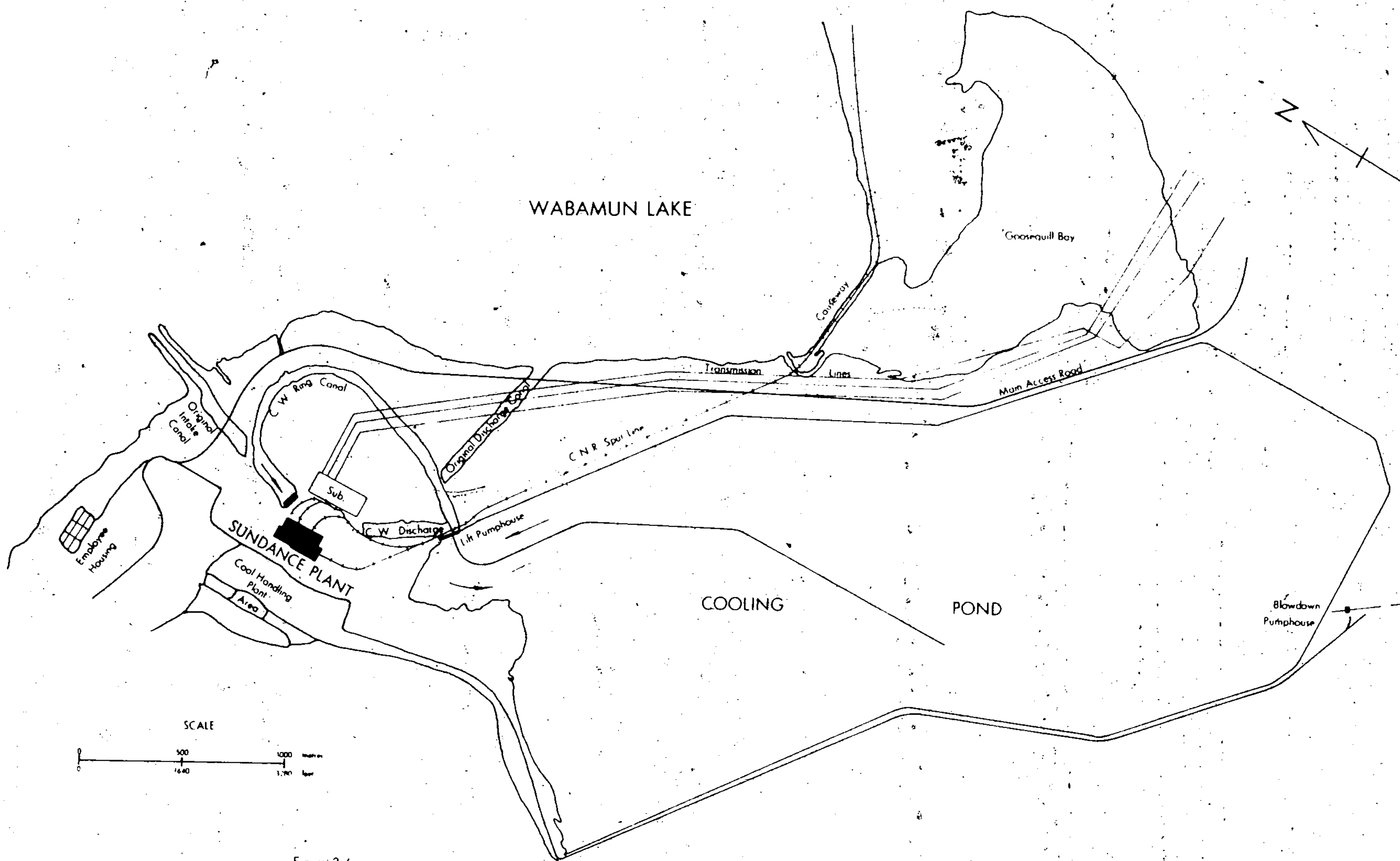


Figure 2:6

SUNDANCE PLANT COOLING FACILITY LAYOUT

Source Crosby Drewold and Railton 1978 p 68 sixth unit is finally installed, the plant's total capacity will be 2,100 MW, the largest in the province.

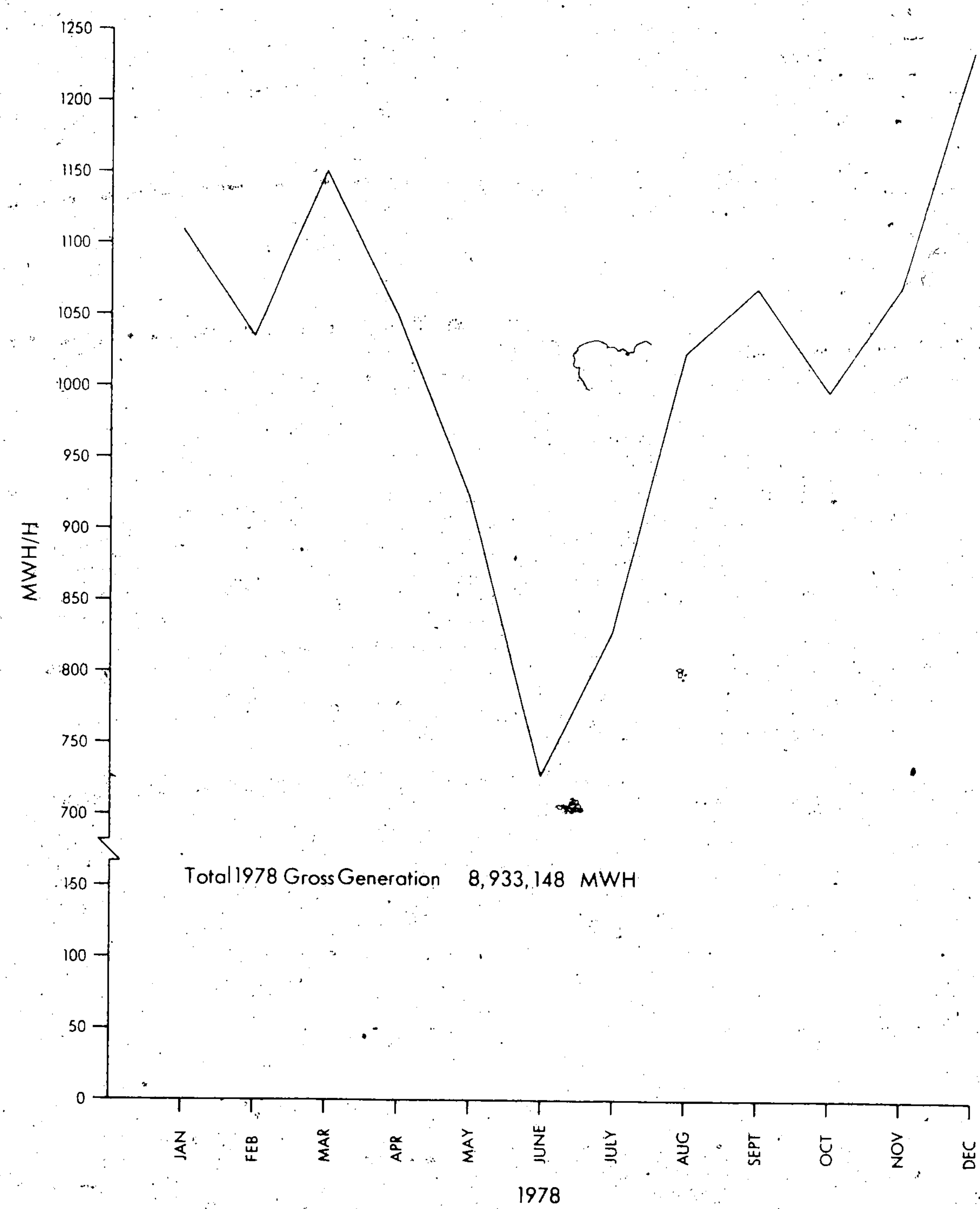
The 1978 monthly mean gross generation statistics for the Sundance plant are presented in Figure 2:7. This graph demonstrates a fairly large variation in the plant output over the year. The peak output on a daily basis in 1978 was 32,220 MWH on December 19 while the minimum daily electrical production recorded was only 13,286 MWH on July 1, a difference of 18,934 MWH. These two figures represent 78 percent and 41 percent respectively, of the plant's total capacity at these times. On the average, the Sundance plant operated at approximately 67 percent of capacity in 1978. This figure is considerably higher than the average output of 44 percent recorded for the Wabamun plant in 1978 and should improve in the future with the increasing demand for electricity.

Physical Characteristics of the Plant Site

The topography in the Sundance plant area is generally gently rolling to hilly with a good portion of the land in slope and maximum relief is about 136.3 m (400 ft, Canada Department of Energy, Mines and Natural Resources, NTS Map 83 G/7 & 83 G/10, 1970). The surficial materials consist of unconsolidated sands and clays which overlie the sandstones

Figure 2:7

SUNDANCE 1978 MEAN MONTHLY GROSS GENERATION



Source : 1978 Production Statistics Provided by Calgary Power Ltd.

and shales of the Paskapoo Geological Formation (Research Council of Alberta, 1970). Soils in the plant area are largely of the Solonetzic soil group with a scattering of Podzolic, Gleysolic and Organic soils found (Lindsay et al, 1968). These soils are rated from fair to good for cultivation by Lindsay et al.

There are two major water resources in proximity to the Sundance generating station; the North Saskatchewan River approximately 13 km (8 mi) to the southeast, and Lake Wabamun. As was previously noted, Lake Wabamun is mildly eutrophic and a popular cottage resort area. The Sundance plant originally employed a once-through cooling system drawing water from, and returning it to the lake but this was discontinued in 1975. Condenser cooling for the plant is now maintained by a cooling pond with make-up water being withdrawn from the North Saskatchewan River. This aspect will be elaborated upon later in this section.

Groundwater in the area of the plant site, as documented by the Research Council of Alberta (1970), is of fairly good quality with the major chemical constituents being sodium, potassium, carbonate and bicarbonate. Some undesirable calcium and sulphates are also found in the groundwater however. The total dissolved solids content is about 1000 mg/l. The depth of the water table can range anywhere from 17.0 to 85.2 m (50 to 250 ft) below the surface while the probable well yields are in the range of 22.7 to 113.6 litres per minute (5 to 25 IGPM).

Condenser Cooling

Condenser cooling at the Sundance power plant is maintained by a semi-closed, cooling pond system (Figure 2:8). The pond is situated adjacent to the plant on the southeast side and occupies 486 hectares (1200 acres). Initially, a once-through cooling system was employed at the Sundance plant with Lake Wabamun acting as the water source. The original inlet and outlet canals are evident in Figure 2:6. Shortly after the first unit was installed in 1970, the macrophyte, *Elodea canadensis*, began to grow in the area of the lake receiving thermal discharges from the Sundance plant and by 1973 was a dominant member of the aquatic plant community (Crosby-Diewold & Railton, 1978). There was also some concern expressed about the potential impact on a whitefish spawning ground located in that same area of the lake (Nielsen, 1972).

These factors, in conjunction with the Energy Resources Conservation Board's request in 1973 that Calgary Power determine whether the heated effluent was affecting

Figure 2:8 The 486 hectare (1200 acre) Sundance cooling pond on May 11, 1978. Thermal effluent enters the pond to the right of the dyke and circles around this dyke returning to the intake canal on the left side. Fog can be seen rising from the warmer side of the pond. Dredging of the former ash disposal site is noted in the right foreground in the pond.

the growth and spread of aquatic weeds in the lake, led Calgary Power to construct an off-lake cooling pond. The pond was completed in 1975 at a capital cost of $23 million (Calgary Power Ltd., 1975). In addition to the $23 million expenditure, approximately $17 million was spent by the utility for ancillary facilities (L. Panek, Calgary Power Ltd., personal communication, May 30, 1979). These included converting from a wet ash to a dry ash disposal system, a pumphouse on the North Saskatchewan River, blowdown and make-up pipelines from the cooling pond to the river, and land right-of-way purchases for the pipelines.

An American industry standard rule of thumb that is applied for cooling ponds is that they be sized at between 0.4 and 0.8 hectares (1 to 2 acres) effective surface area per MW of plant capacity (Harmsworth, 1974). Operating experience at the Sundance plant has indicated that this standard only applies for the summer months at this latitude as winter air temperatures are sufficiently low to dissipate the heat in the cooling pond (R. Way, Calgary Power Ltd., personal communication, February 19,1979). Consequently, as the Sundance plant expansion program is approaching completion at 2100 MW, the cooling pond, at 486 hectares, will be too small to dissipate the vast quantities of heat rejected in the cooling water during the summer months.

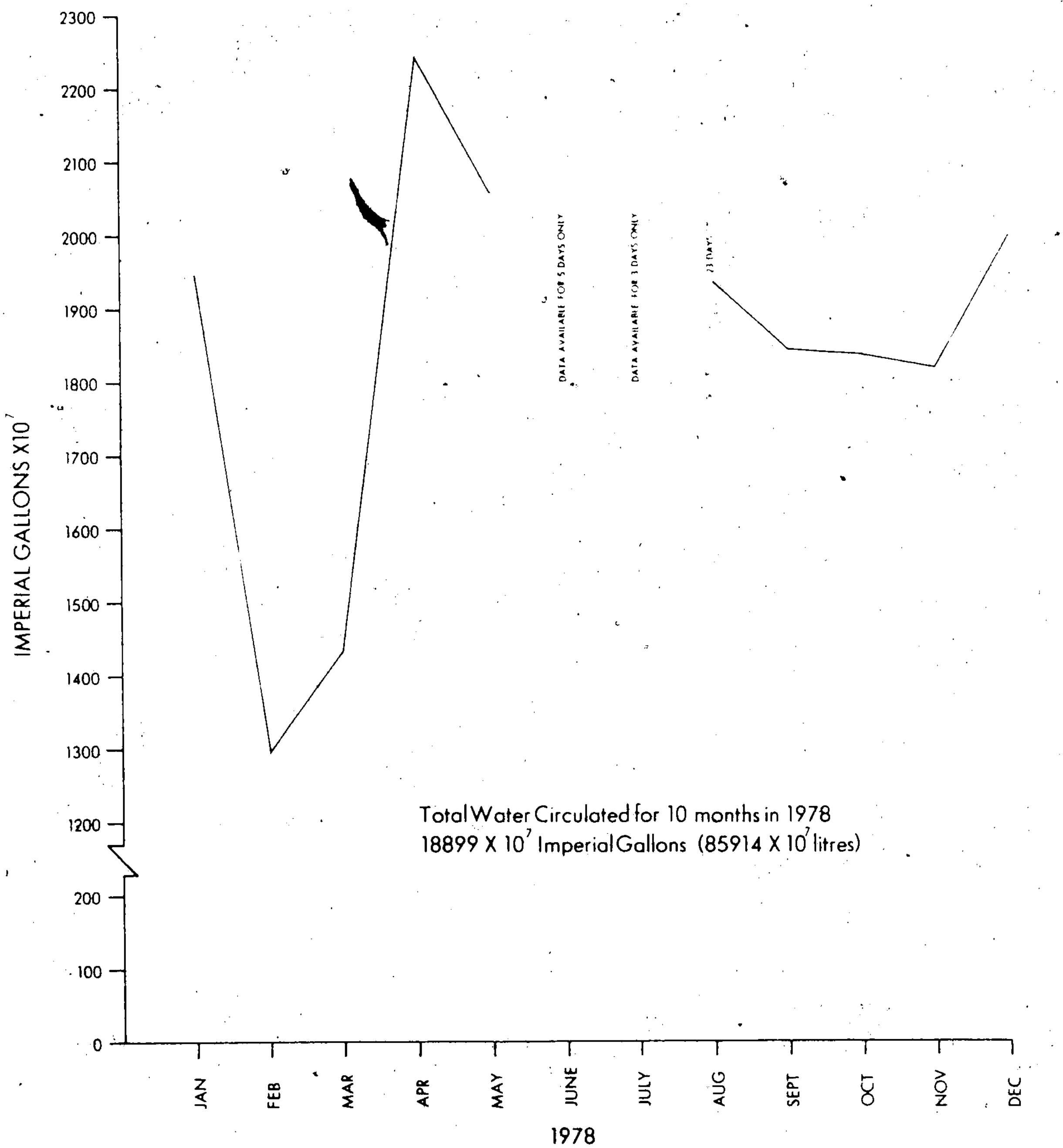
Therefore, in order to supplement the cooling pond's capacity, Calgary Power has installed 120 power spray modules in the discharge canal (Figure 2:9, Calgary Power Ltd., 1978). By spraying a portion of the warm effluent into the air, these modules aid in dissipating the reject heat to the atmosphere. To date, these sprays have reduced the effluent temperature by only about 1.6C (3F) before it enters the cooling pond (R. Way, Calgary Power Ltd., personal communication, February 19, 1979). This has resulted in the pond becoming less effective in dissipating the heat, and because the sprays require a considerable amount of energy, Calgary Power has not yet been able to calculate whether this system is actually a benefit. Nevertheless, they are planning to construct a cooling tower at the Sundance plant for summer cooling.

The 1978 monthly condenser cooling water flows are presented in Figure 2:10. The corresponding heat rejection rates as well as the 1978 average inlet and outlet water temperatures are illustrated in Figures 2:11 and 2:12 respectively. The total amount of water circulated through the condensers at the Sundance plant in 1978 was approximately 909 x 10^9 litres (200 x 10^9 Imperial gallons). Furthermore, during six months of the year, the total plant capacity was only 1350 MW. When the plant expansion is

Figure 2:9 The Sundance discharge canal containing the power spray modules. At the time this photo was taken (May 11, 1978) the modules had only recently been installed and were not yet operational. A portion of the intake ring canal and the former discharge canal can be seen in this photo with Lake Wabamun in the background.

Figure 2:10

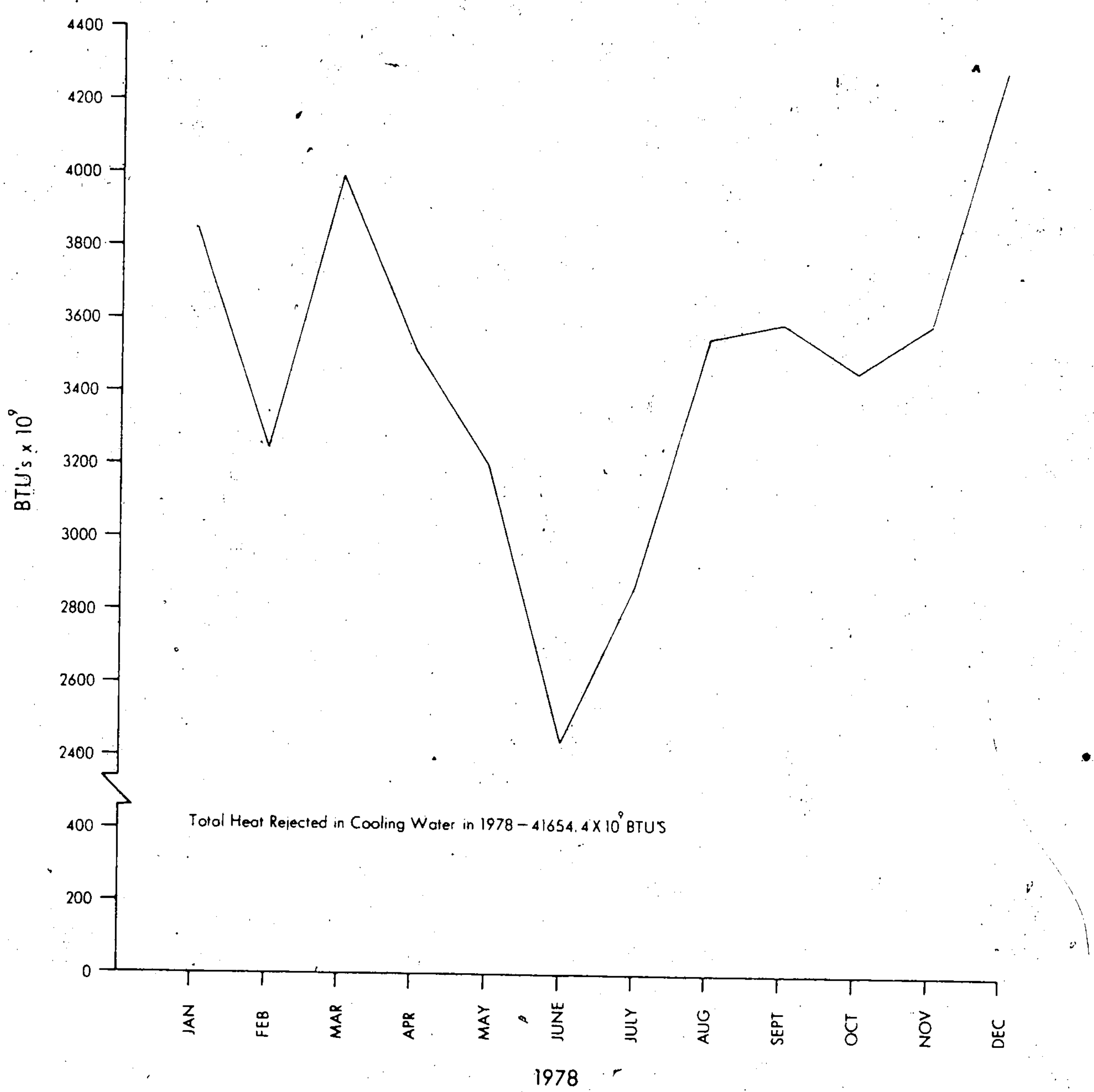
SUNDANCE 1978 MONTHLY CONDENSER COOLING WATER FLOWS



Source: 1978 Production Statistics Provided by Calgary Power Ltd.

Figure 2:11

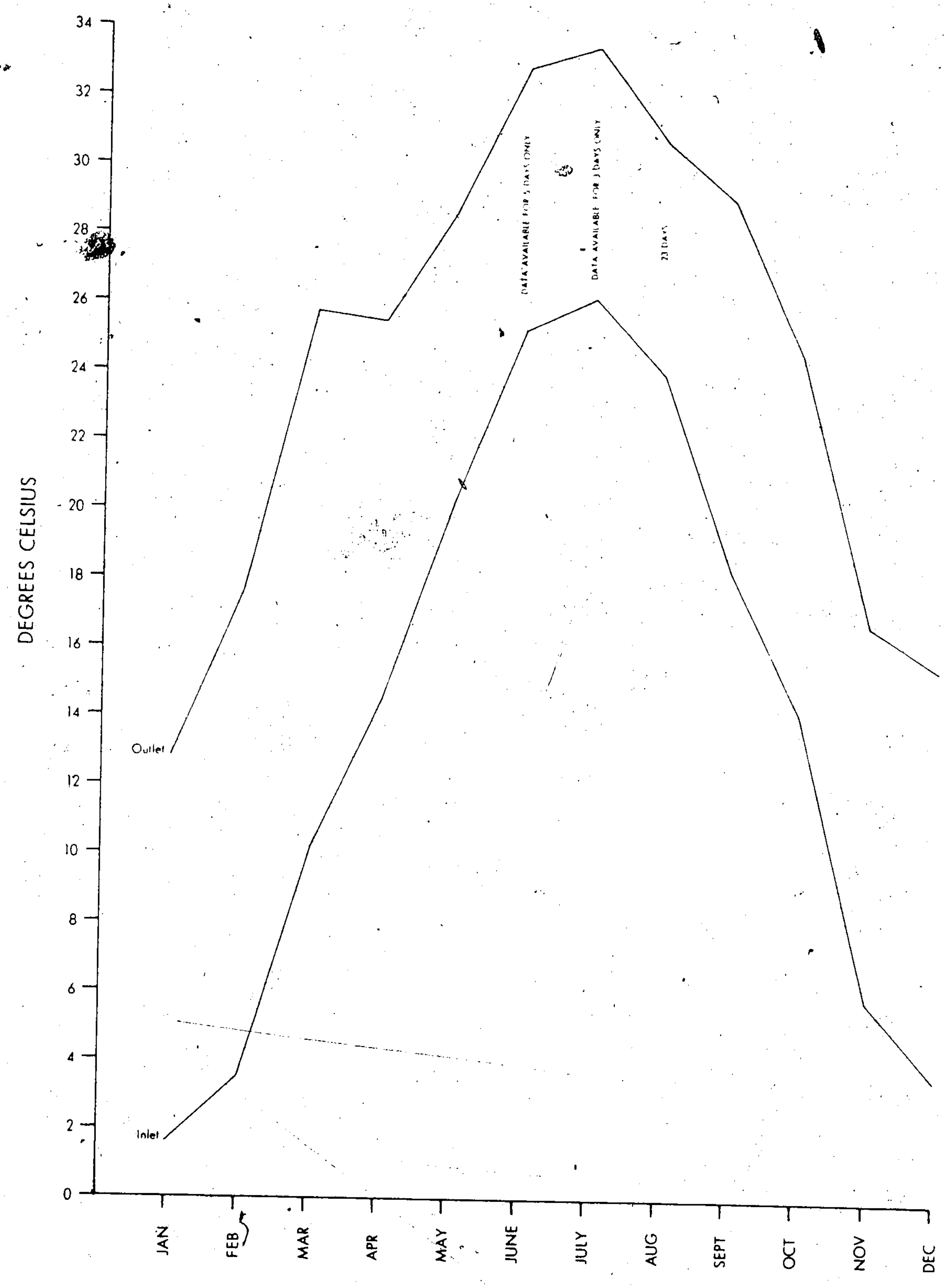
SUNDANCE 1978 MONTHLY HEAT REJECTED IN COOLING WATER



Source: 1978 Production Statistics Provided by Calgary Power Ltd.

Figure 2:12

SUNDANCE 1978 MONTHLY AVERAGE INLET AND OUTLET WATER TEMPERATURES



Source: 1978 Production Statistics Provided by Calgary Power Ltd.

completed, the quantity of water circulated through the condensers could reach 1818 x 10^9 litres per year (400 x 10^9 Imperial gallons per year).

An even more startling figure is the total amount of heat rejected from the Sundance plant in 1978, more than 40 x 10^{12} BTU's (Figure 2:11). The inlet and outlet water temperatures graph (Figure 2:12) illustrates that the outlet temperatures are relatively high during the coldest months of the year, about 12.8C (55F) in January and 15.5C (60F) in December. During the summer months, the outlet water temperatures are very high, 28.7 to 31.8C (83.5 to 89.2F). These temperatures can be expected to increase only slightly after the final unit is commissioned.

Make-up water for the cooling pond is obtained from the North Saskatchewan River via a 106.7 cm (42 in) diameter pipeline (J. Railton, Calgary Power Ltd., personal communication, January 1979). Blowdown from the reservoir is returned to the North Saskatchewan River in a 61 cm (24 in) diameter pipeline. Make-up and blowdown pumping are maintained in such a manner that the pond water concentrations do not exceed one and one-half times the concentrations of the North Saskatchewan River. In order to meet this criterion, the make-up and blowdown pumps are started up every four months and allowed to continue running until the desired concentrations are reached (J. Railton, personal communication, January 15, 1979). The make-up water flows are approximately 1.9 m^3/s (25,000 IGPM) while the blowdown water rates are in the order of 0.36 m^3/s (5,000 IGPM).

Data on the cooling pond water quality have been provided by Calgary Power. The results of tests conducted on the cooling pond water in December 1976 are presented in Table 2:1. When compared with the results of tests conducted on the North Saskatchewan River at Devon just downstream from the point of withdrawal (Table 2:2), the cooling pond water is found to have several parameters exceeding those of the river water. This is to be expected however, as the pond water concentrations can be quite high due to losses from evaporation and consumptive usages within the plant. At the time of these tests, the Sundance plant had only four units in operation (1350 MW). When the plant has reached a total capacity of 2100 MW in 1980, the evaporative and consumptive losses can be expected to be much higher, with the result that make-up and blowdown pumping will have to be increased.

Calgary Power contracted International Environmental Consultants in 1976 to conduct a study of the cooling

Table 2:1

SUNDANCE COOLING POND WATER QUALITY

PARAMETER		Inlet Canal (mg/l)	Discharge Canal (mg/l)
pH		8.15	7.95
Alkalinity-T	$CaCO_3$	168	168
Conductivity	umhos	440	470
Turbidity	FTU	0.55	0.84
Colour	APHA	5	5
Total Dissolved Solids		254	240
Sulphate	SO_4	59	62
Chloride	Cl	4.3	4.4
Silica	SiO_2	5.4	5.4
Calcium	Ca	44	44
Magnesium	Mg	9.5	8.3
Sodium	Na	37	37
Potassium	K	6.3	6.5
Total Hardness EDTA	$CaCO_3$	150	145
Phosphate - Total	P	0.012	0.014
Nitrate - Total	N	0.03	0.03
Ammonia	N	0.052	0.040
HEAVY METALS (EXTRACTABLE)			
Iron	Fe	0.01	0.01
Copper	Cu	0.01	0.01
Zinc	Zn	0.004	0.008
Manganese	Mn	0.010	0.010
Lead	Pb	L0.02	L0.02
Mercury	ug/l Hg	0.14	0.09
Nickel	Ni	0.01	0.01
Cadmium	Cd	0.001	0.002
Cobalt	Co	L0.01	L0.01

Source: Data provided by Calgary Power Ltd.

Table 2:2

LONG TERM NORTH SASKATCHEWAN RIVER WATER QUALITY DATA AT DEVON

PARAMETER		mg/l
pH		8.14
Alkalinity-T	$CaCO_3$	139
Conductivity	umhos	349
Turbidity	FTU	29
Colour	APHA	13
Total Dissolved Solids		265.7
Sulphate	SO_4	48
Chloride	Cl	1
Silica	SiO_2	4.6
Calcium	Ca	47.6
Magnesium	Mg	13.9
Sodium	Na	5
Potassium	K	1
Total Hardness EDTA	$CaCO_3$	176
Phosphate - Total	P	0.2
Nitrate - Total	N	0.15
Ammonia	N	0.3
HEAVY METALS (EXTRACTABLE)		
Iron	Fe	0.15
Copper	Cu	0.004
Zinc	Zn	0.021
Manganese	Mn	0.016
Lead	Pb	0.010
Mercury	ug/l Hg	0.0004
Nickel	Ni	0.010
Cadmium	Cd	0.001
Cobalt	Co	0.003

Source: Calgary Power Ltd. Application to the Energy Resources Conservation Board for Approval to Construct, Connect and Operate the South Sundance Plant. Calgary: November 1976, Tables 2-6 & 2-7, pp. 2-15 & 2-16.

pond and its associated aquatic biota. As part of this study, submerged vegetation observations at seven different locations within the pond were made throughout the year. The results indicated that of the macrophytes found, *Elodea canadensis* was the dominant species at all locations but this weed never represented more than 30 percent of the bottom cover (International Environmental Consultants, 1977). At all locations tested, the proportion of the bottom covered with aquatic vegetation ranged from only 5 to 40 percent. These results are presented in Table 2:3.

During the course of this study, no direct evidence was obtained during minnow seining, diving or profiling to suggest the presence of forage fish in the pond. Many waterfowl species were observed feeding in the cooling pond but these birds may have been attracted by benthic organisms abundantly present in the pond. However, recent sampling by Alberta Fish and Wildlife netted thirty suckers and six perch in only two hours at the cooling pond (A. Chamberlain, Alberta Fish and Wildlife, personal communication, June 1979). This suggests that some species of fish are being introduced into the cooling pond through the make-up water pipeline.

Table 2:3

SUBMERGED VEGETATION OBSERVATIONS AT SUNDANCE COOLING POND
25 AUGUST 1977

Species, % of Bottom Cover

Station	Elodea canadensis	Potomageton richardsonii	Potomageton sp.	Myriophyllum sp.	Filamentous green algae	Bare	Depth (m)	Bottom Type
1	15	5	3		1	76	1.5	mud
2	30	5	1	1	1	62	1.5-2.0	mud
3	30	5	1	3	1	60	2.0-3.0	mud
4	20	10	3	1	1	65	2.0-3.0	mud
5	20	5			1	74	1.0-1.5	mud
6	10	1		4	1	80	2.0-3.0	mud
7	1	2		1	1	95	2.0-3.0	mud

Source: International Environmental Consultants. 1976 Report on the Environmental Management Program for Sundance Cooling Pond. Prepared for Calgary Power Ltd., 1977.

FORESTBURG

General Plant Description and Operating Statistics

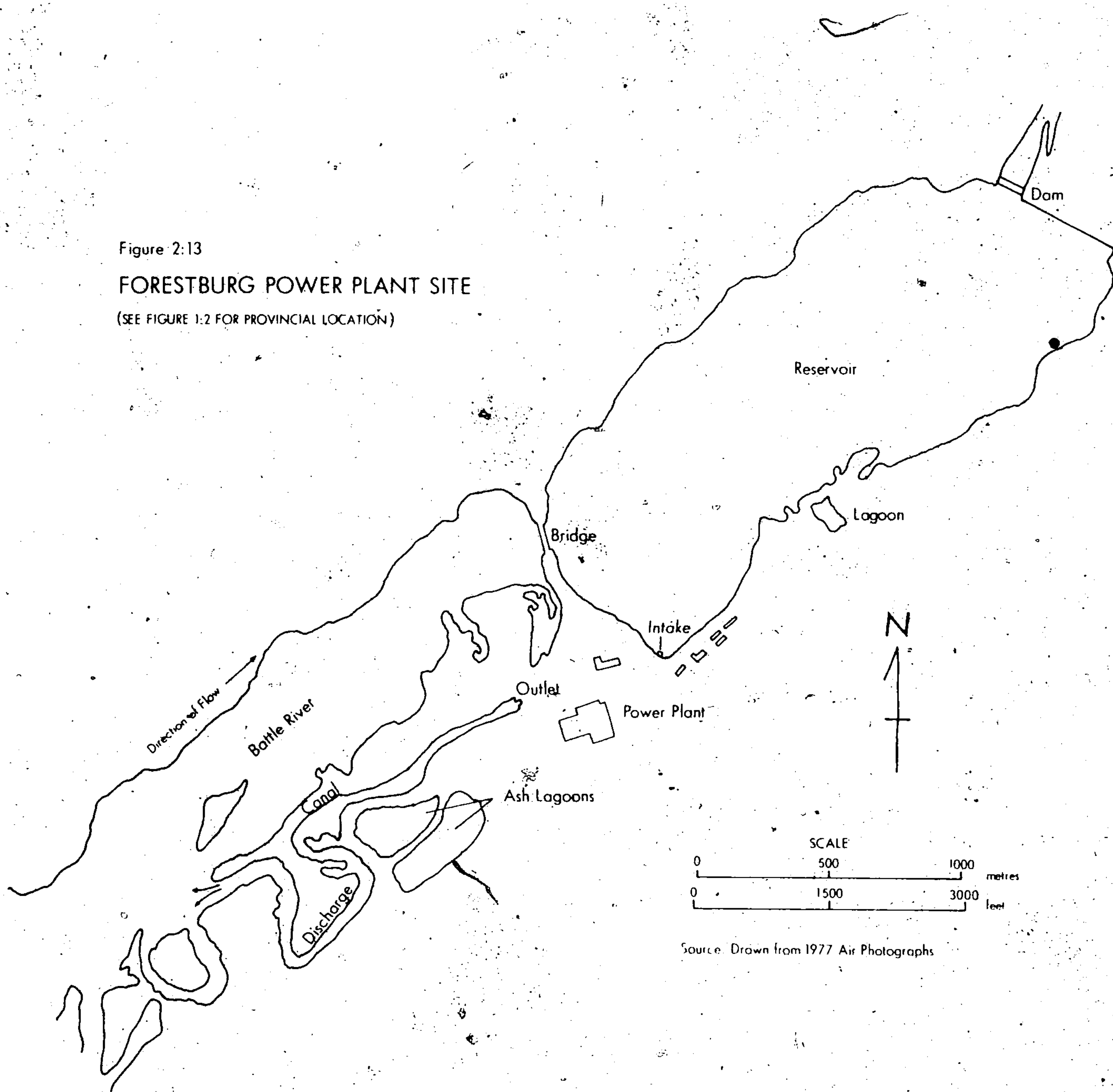
This 360 MW, coal-fired thermal power plant, owned and operated by Alberta Power Ltd., is located on the Battle River approximately 190 km (120 mi) southeast of Edmonton (Figure 2:13). The plant first began commercial production of electricity in 1956 with the commissioning of a 30 MW unit (W. Peel, Alberta Power Ltd., personal communication, November 1978). The station was expanded to 60 MW in 1964 while a 150 mw unit was added in 1969. An additional 150 MW unit was commissioned in 1975. Currently, construction is in progress to complete a 375 MW unit, scheduled for commissioning in 1981. This will bring the total station capacity to 735 MW.

Coal for the Forestburg power plant is obtained from surface mines located immediately north and south of the river, on the plains area. In 1977, the plant coal consumption was approximately 1,260,000 million tonnes (1,400,000 million tons, W. Peel, personal communication, November 1978). The monthly mean gross generation figures

Figure 2:13

FORESTBURG POWER PLANT SITE

(SEE FIGURE 1:2 FOR PROVINCIAL LOCATION)



Source: Drawn from 1977 Air Photographs

for the Forestburg generating station are presented in Figure 2:14. This graph reveals that a fluctuating demand for electricity from the plant occurred during 1978 with the monthly average production ranging from 186.6 MWH/H in June to 325.6 MWH/H in December. These figures represent 52 percent and 90 percent respectively, of the total station capacity. In 1978, 2,358,139 MWH of electricity were produced at the Forestburg power plant, representing about 75 percent of the station's capacity.

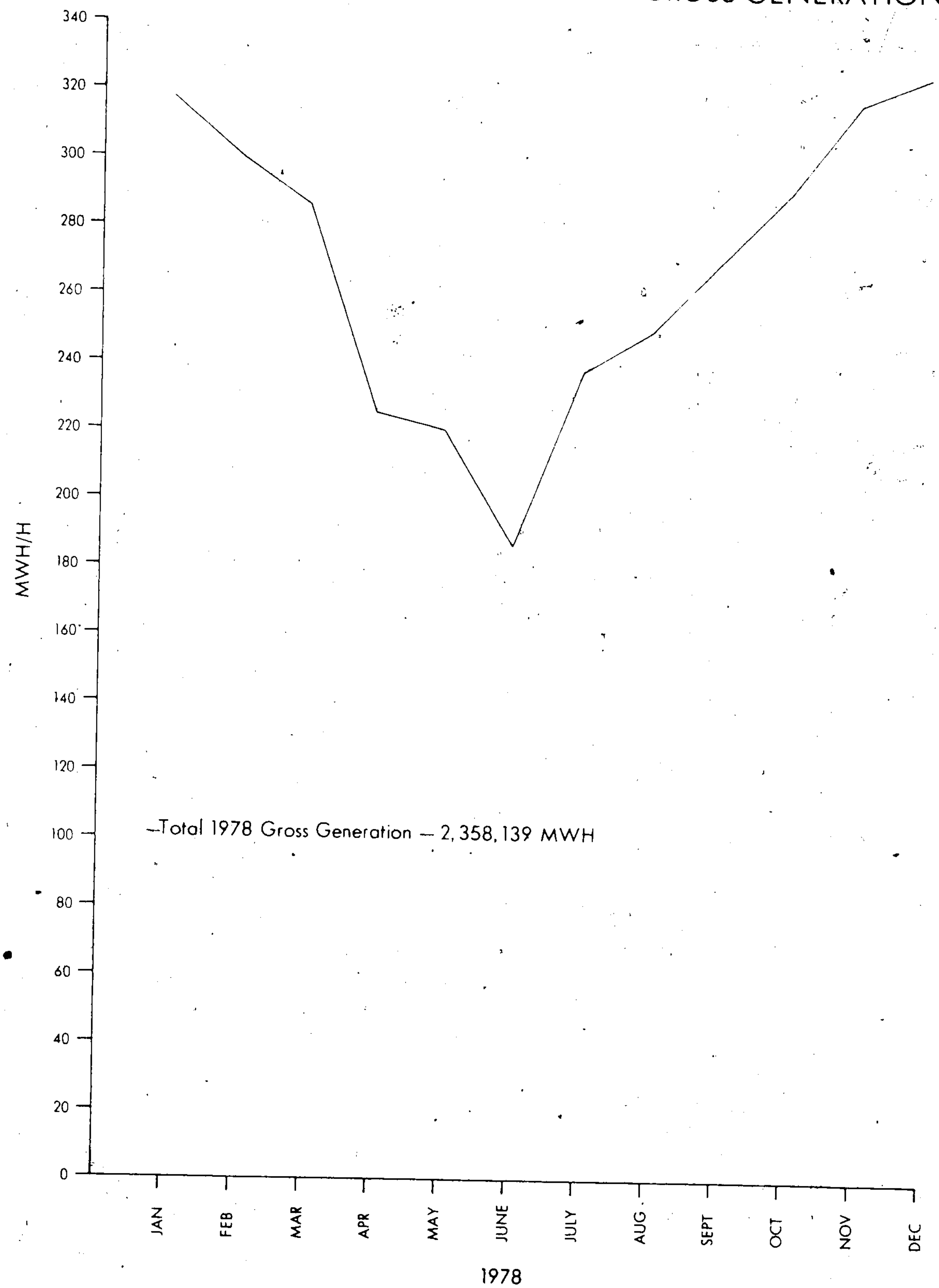
Physical Characteristics of the Plant Site

The Forestburg thermal power plant is located on the valley floor of the Battle River (Figure 2:15). The area adjacent to the river is a young, stream eroded plain with a maximum relief of approximately 53.4 m (175 ft, Canada Department of Energy, Mines and Natural Resources, NTS Map 83 A/8, 1975). Most of this relief is concentrated in the slope of the valley walls. The topography of the plain is level and undulating (Bowser et al, 1951).

Surficial materials of the plain are lacustrine clays and sands that are underlain by the sandstones and shales of the Edmonton Geological Formation (Le Breton, 1971). The soils throughout the plant area are loams from the Thin Black and Dark Brown soil groups. These soils are

Figure 2:14

FORESTBURG 1978 MEAN MONTHLY GROSS GENERATION



Source: 1978 Production Statistics Provided by Alberta Power Ltd.

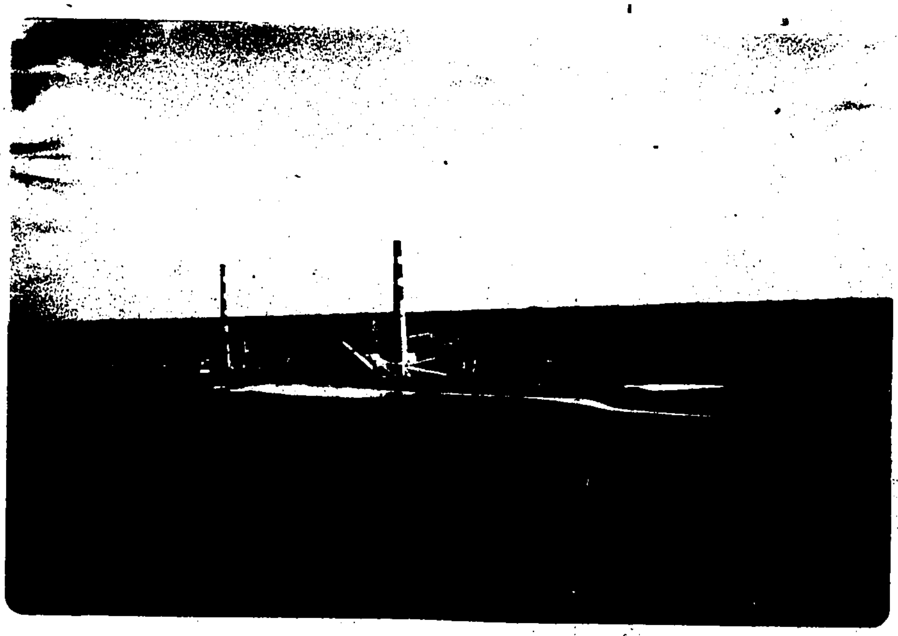


Figure 2:15 The Forestburg power plant on the Battle River in June 1978. A portion of the discharge canal and an ash lagoon can be seen in the middle right of the photo with the reservoir in the foreground. This photo illustrates the lack of flat land in the immediate plant vicinity.

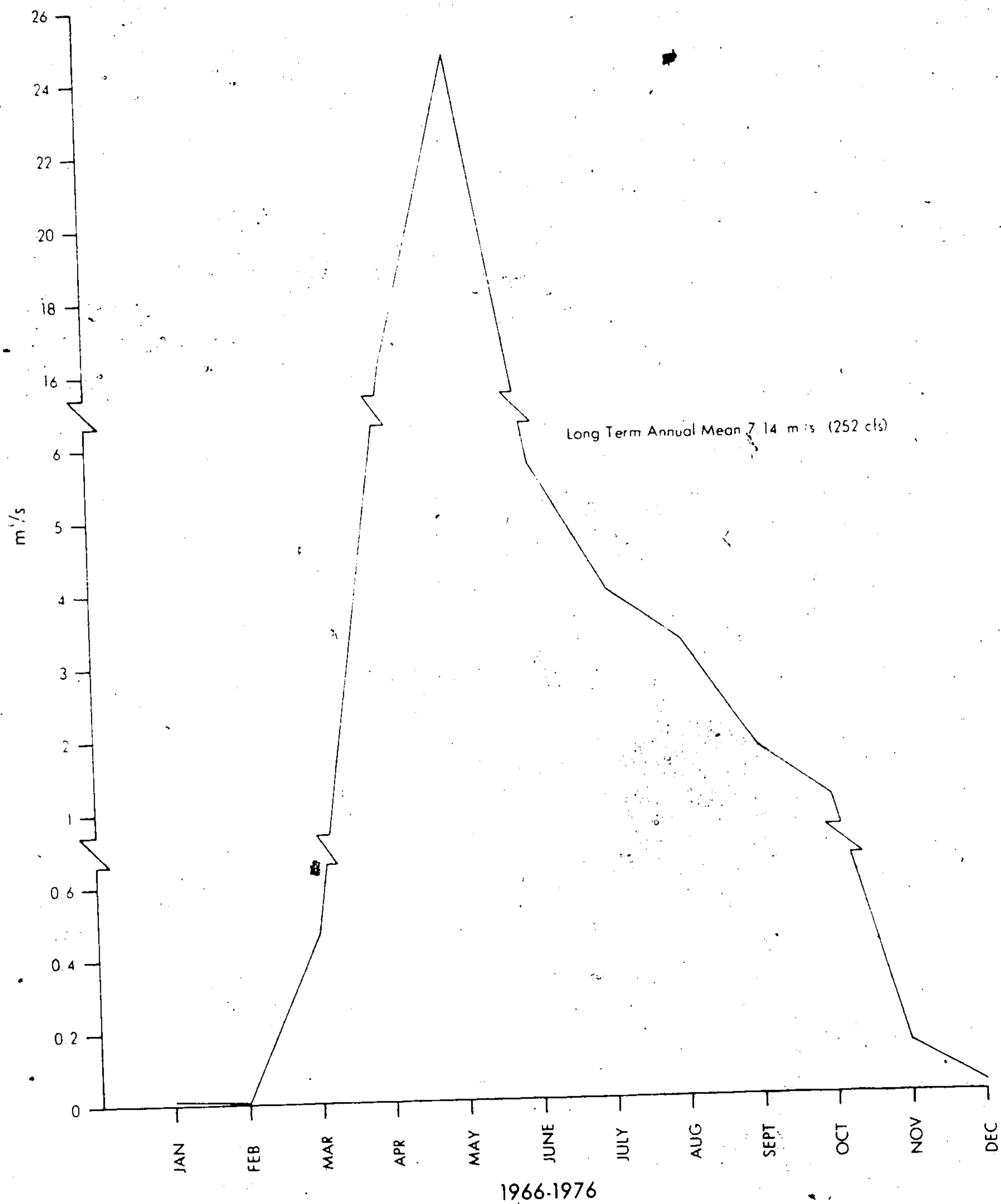
rated fair to good for agriculture (Bowser et al, 1951).

The only major water resource within the plant area is the Battle River. This resource is limited in quantity as evident in Figure 2:16. This long term hydrograph of the Battle River near Forestburg indicates near zero and zero flows are common occurrences during the winter months while the discharge during the spring thaw is very high in comparison. The annual mean discharge recorded for the ten year period, 1966 to 1976, is 3.7 m^3/s (132 cfs) while an extreme discharge of 243.0 m^3/s (8580 cfs) was recorded on April 30, 1974 (Fisheries and Environment Canada, 1977, p. 12). The common occurrence of zero flows on the Battle River may be partially attributed to small storage facilities located upstream at Coal and Driedmeat Lakes. Accurate water quality data of the Battle River cannot be reported here. Water quality studies of the river have been commissioned by Alberta Power in the past but the results of these studies are not available to the public from either the utility or the Alberta Department of Environment.

The groundwater in the plant area is generally poor in terms of quantity and quality. The water table in the mine area is shallow, about 15.2 m (50 ft) below the surface

Figure 2:16

LONG TERM MONTHLY MEAN DISCHARGE OF THE BATTLE RIVER NEAR FORESTBURG



Source: Fisheries and Environment Canada. Historical Streamflow Summary: Alberta to 1976. Ottawa: Inland Waters Directorate, 1977, p. 12.

and the probable well yields are in the order of 4.5 to 22.7 litres per minute (1 to 5 IGPM, Le Breton, 1971). The main chemical constituents are sodium, potassium, carbonate and bicarbonate with some chloride present. The total dissolved solids are in the range of 1500 to 2000 mg/l while the iron content is from 0.5 to 2.0 mg/l (Le Breton, 1971).

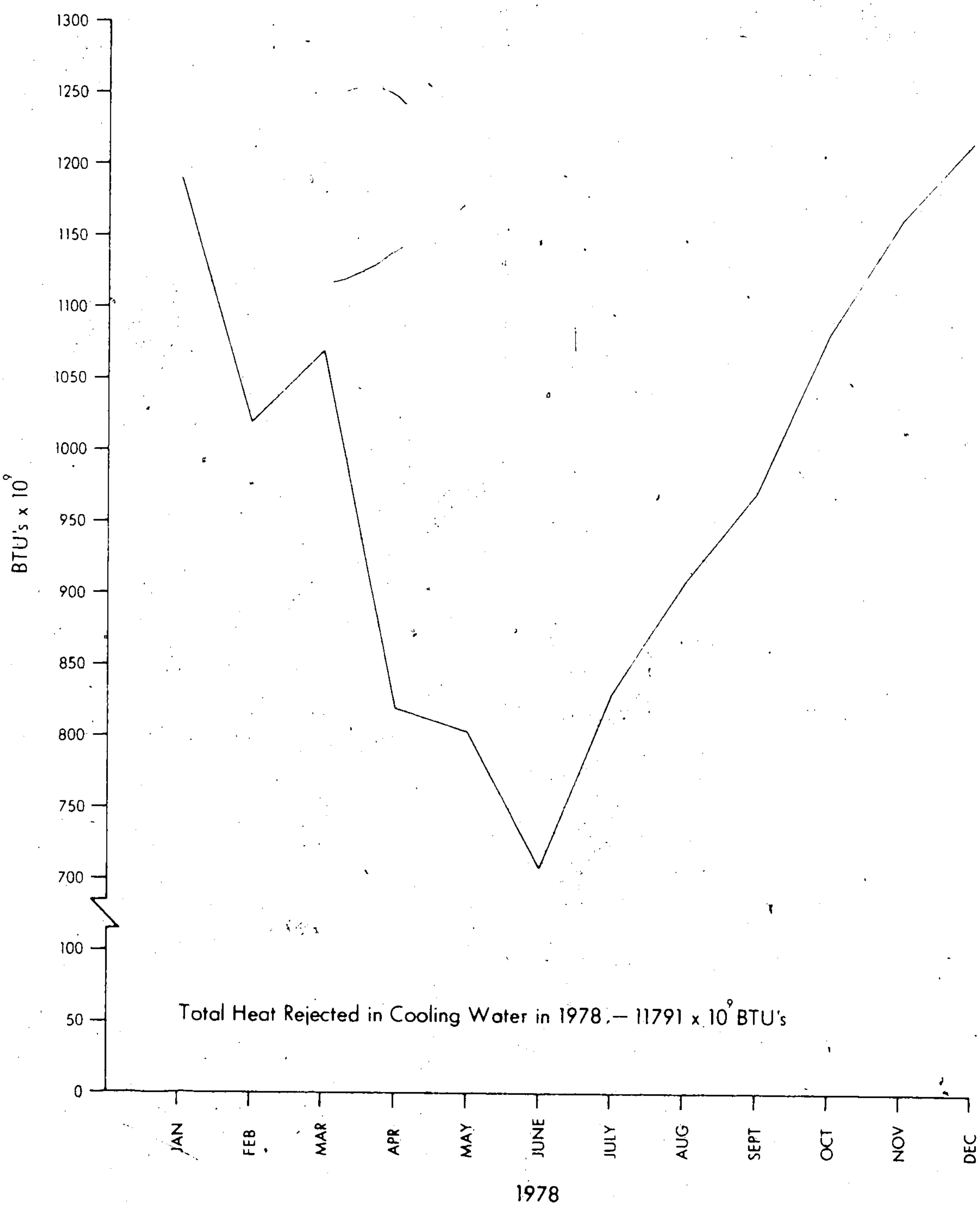
Condenser Cooling

The Forestburg thermal power plant employs a once-through cooling system, drawing water from, and returning water to the Battle River. To ensure an adequate supply of water for this cooling method during the winter months, when river flows are near zero, a dam was constructed on the river below the plant in 1956 (W. Peel, Alberta Power Ltd., personal communication, November 1978). This control structure resulted in the formation of a 300 hectare (750 acres) reservoir from which the plant draws water. The dam is outfitted with a syphon which allows approximately 2 cfs (0.06 m^3/s) of water to pass below the dam when the river level is below that of the structure (Harvey, 1978). The intake pumphouse is located below the plant while the thermal effluent is discharged in the old stream channel above the station (Figure 2:13). Alberta Power recently constructed a dyke along the southern edge of the reservoir above the plant so as to lengthen the discharge canal and provide more surface area to aid in the heat dissipation processes.

The condenser circulating water flows are not monitored at the Forestburg generating station and thus are not available. The heat rejection rates and the monthly average inlet and outlet water temperatures are monitored however, and these data for 1978 are presented in Figures 2:17 and 2:18 respectively. The total heat rejected in the condenser cooling water from the Forestburg plant in 1978 was greater than 11 x 10^{12} BTU's. The outlet water temperatures for the station in 1978 were quite high, particularly in the latter months of the year. The outlet water temperatures for the last five months averaged 27C (80.6F), considerably above the ambient conditions.

Figure 2:17

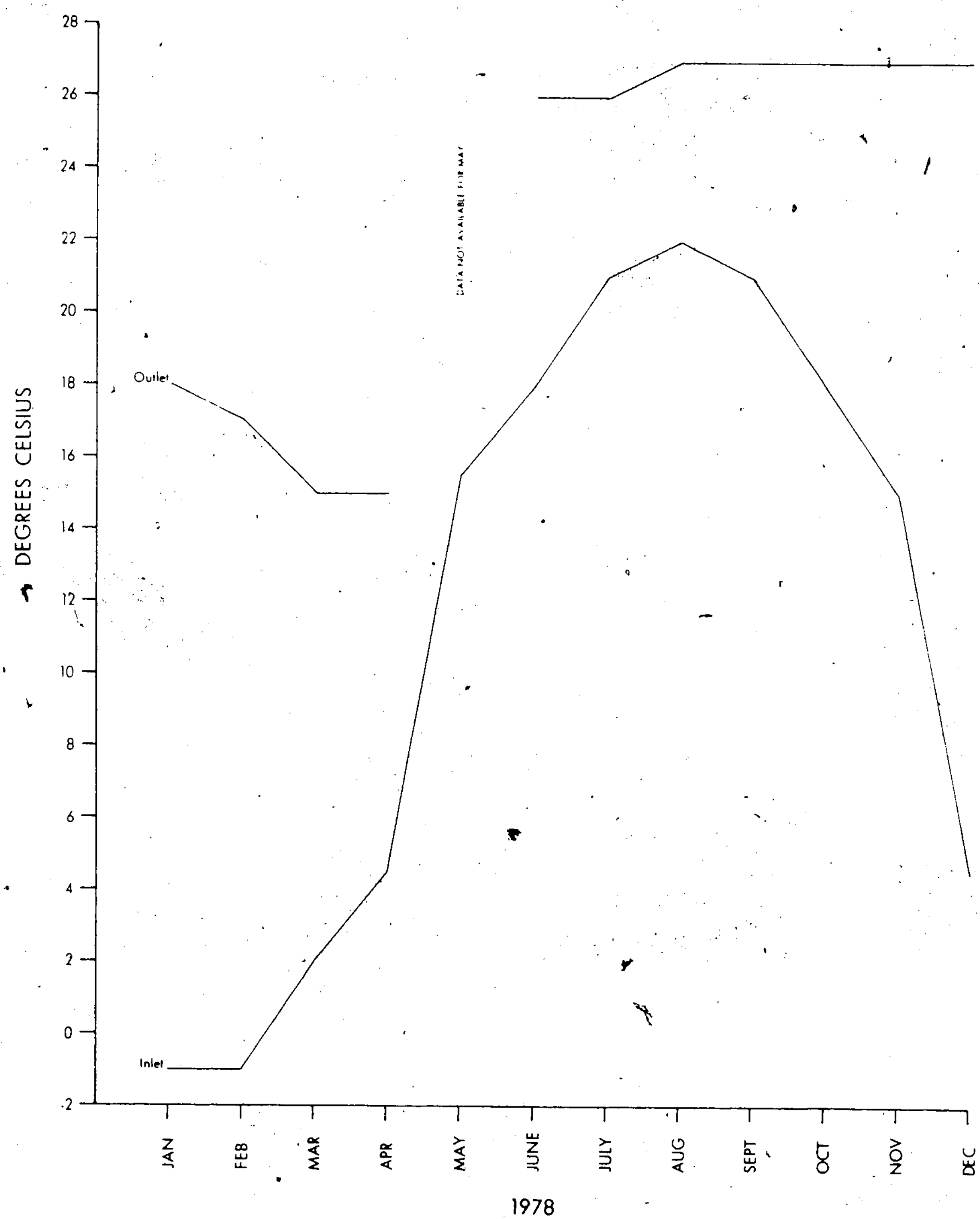
FORESTBURG 1978 MONTHLY HEAT REJECTED IN COOLING WATER



Source: 1978 Production Statistics Provided by Alberta Power Ltd

Figure 2:18

FORESTBURG 1978 MONTHLY AVERAGE INLET AND OUTLET WATER TEMPERATURES



Source : 1978 Production Statistics Provided by Alberta Power Ltd.

ROSSDALE AND CLOVER BAR

General Plant Descriptions and Operating Statistics

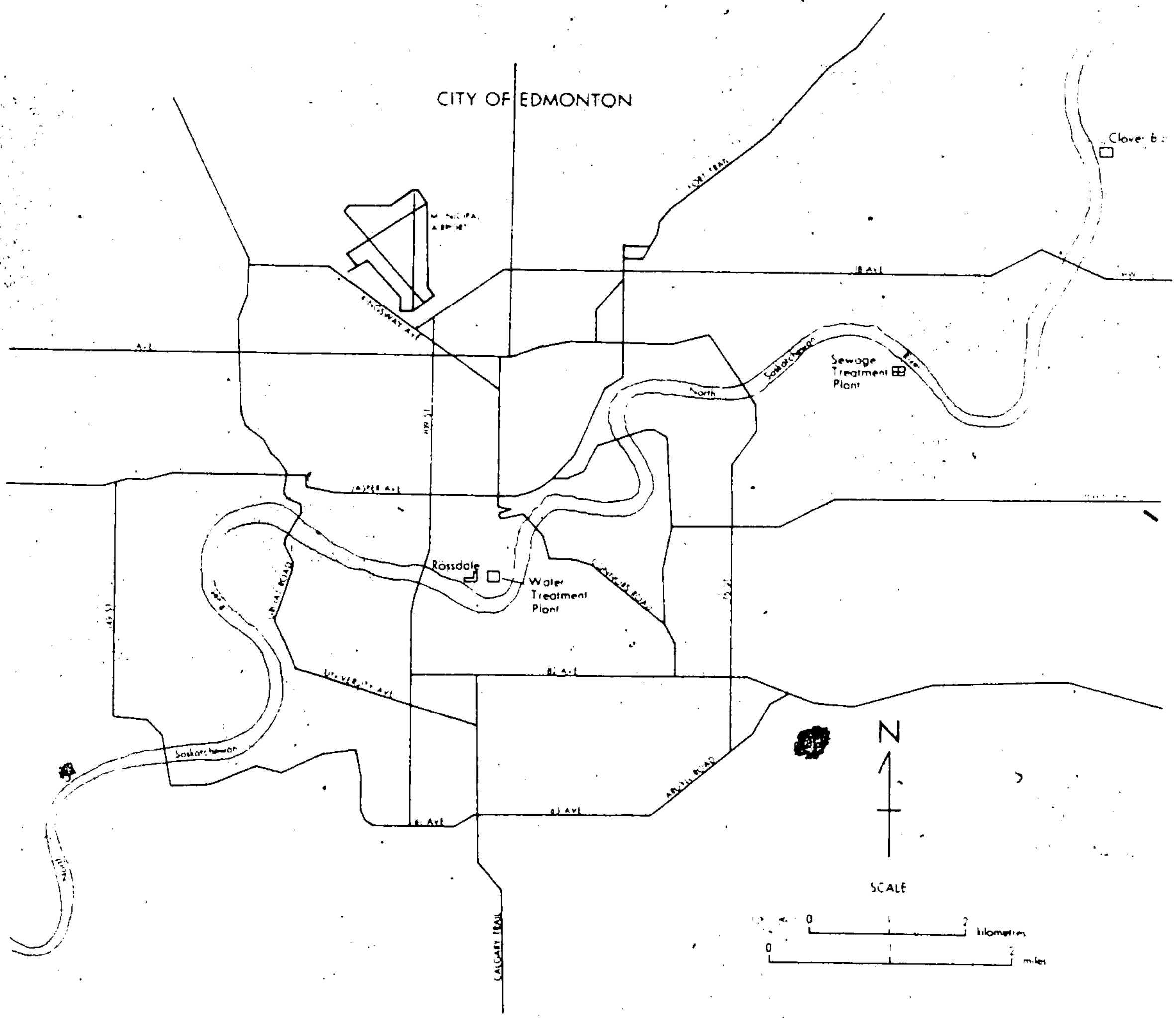
These two natural gas-fired thermal generating stations are owned by the City of Edmonton and operated by Edmonton Power. The two plants are located adjacent to the North Saskatchewan River in the city. The Rossdale station is situated close to the city core on the north shore of the river while the Clover Bar plant is located on the east bank further downstream in the Clover Bar industrial sector of the city (Figure 2:19).

The Rossdale generating station origin dates back to 1891 when it was privately owned and situated near the river on what is now 101 street (Edmonton Power, 1971). In 1904 the plant was taken over by the City and relocated to its present site one year later. Over the years the Rossdale plant has undergone considerable expansion to its present capacity of 405 MW. This consists of three different types of generating units; a low pressure, steam turbine plant; a gas turbine plant; and a high pressure plant.

Figure 2.19

ROSSDALE AND CLOVER BAR POWER PLANT SITES

(SEE FIGURE 1.2 FOR PROVINCIAL LOCATION.)



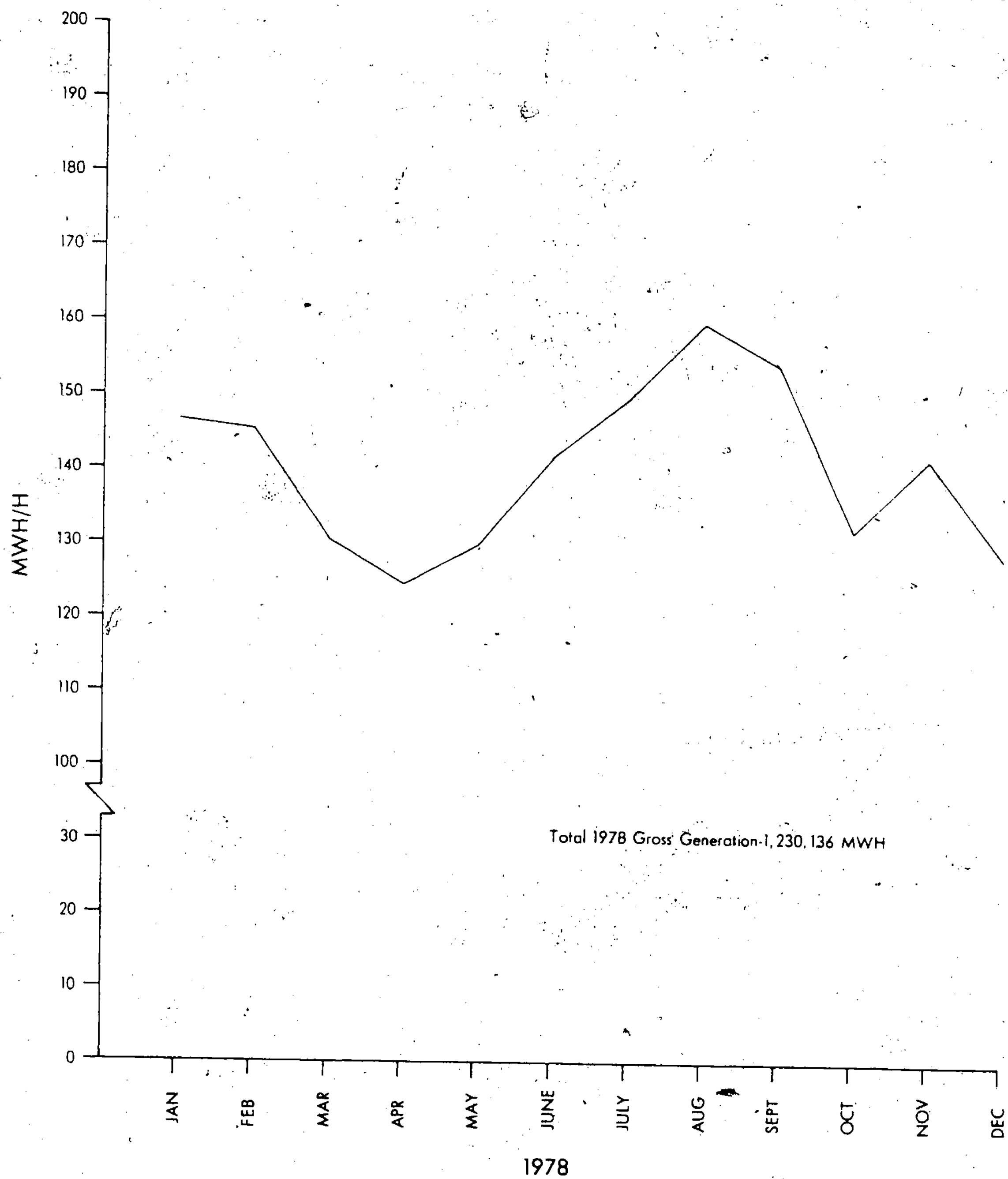
The low pressure plant has a total generating capacity of 120 MW with five turbines and seven boilers. The five turbines consist of two turbo generators rated at 15 MW each and three turbo generators rated at 30 MW each. The gas turbine plant also consists of two 30 MW generating units. The high pressure plant has a total capacity of 225 MW with three 75 MW turbines.

The Clover Bar thermal generating station is considerably more modern than the Rossdale plant. The first unit of this plant, rated at 165 MW, was commissioned in 1970 (Edmonton Power, 1971)., Since then, two additional 165 MW units have been commissioned in 1972 and 1977 with a fourth 165 MW unit scheduled to begin commercial production of electricity in 1979 (R. Johnston, Edmonton Power, personal communication, November 1978). This will provide the plant with a total capacity of 660 MW. Although the Clover Bar station is a natural gas-fired plant, there are provisions on Units 1 and 2 to burn oil.

The 1978 monthly mean gross generation statistics for the two plants are presented in Figures 2:20 and 2:21. The graph of the Rossdale production (Figure 2:20) indicates that two periods of high electricity demand occurred in 1978. The first was in January and February when the demand

Figure 2:20

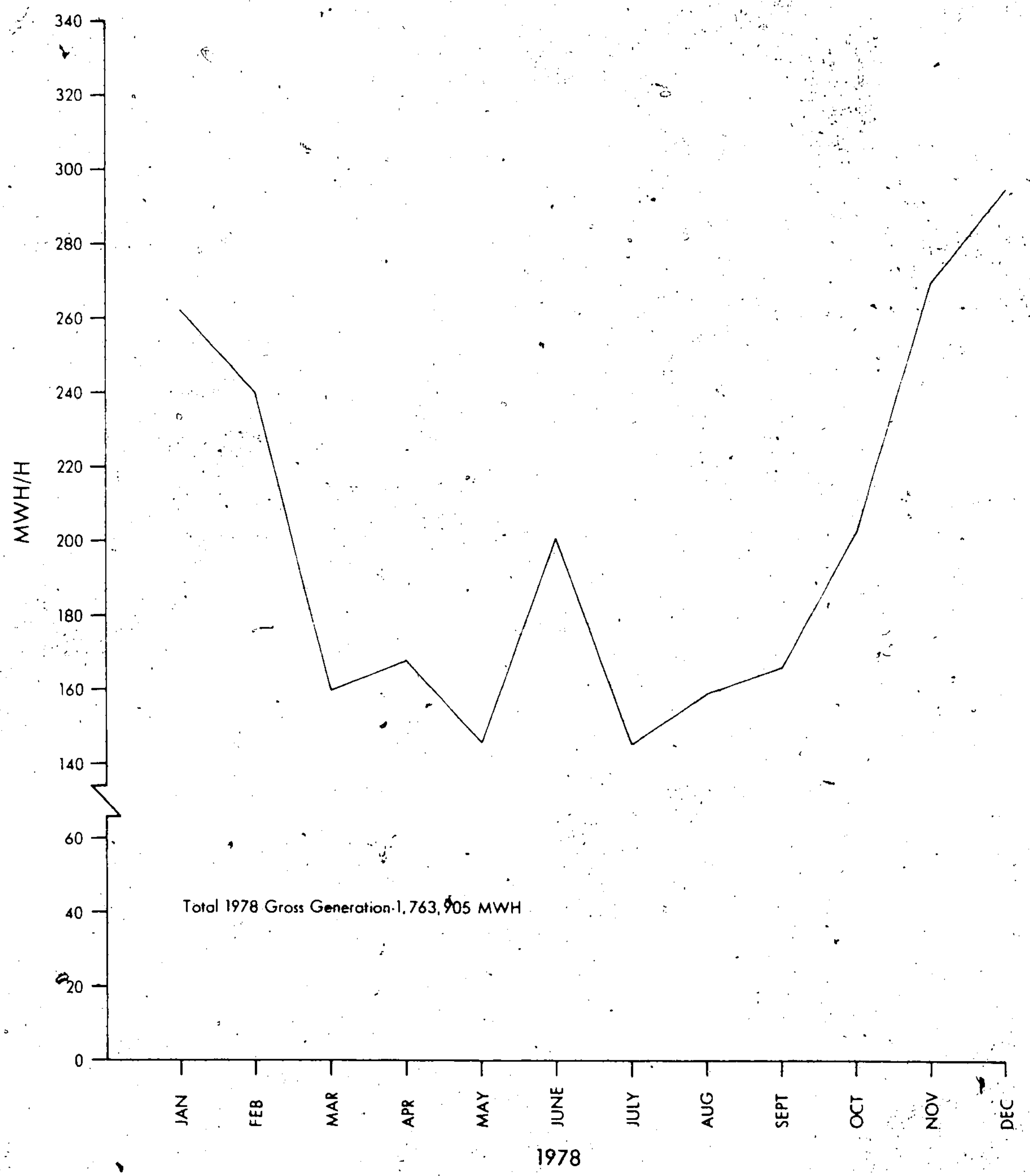
ROSSDALE 1978 MEAN MONTHLY GROSS GENERATION



Source: 1978 Production Statistics Provided by Edmonton Power

Figure 2:21

CLOVER BAR 1978 MEAN MONTHLY GROSS GENERATION



Source: 1978 Production Statistics Provided by Edmonton Power

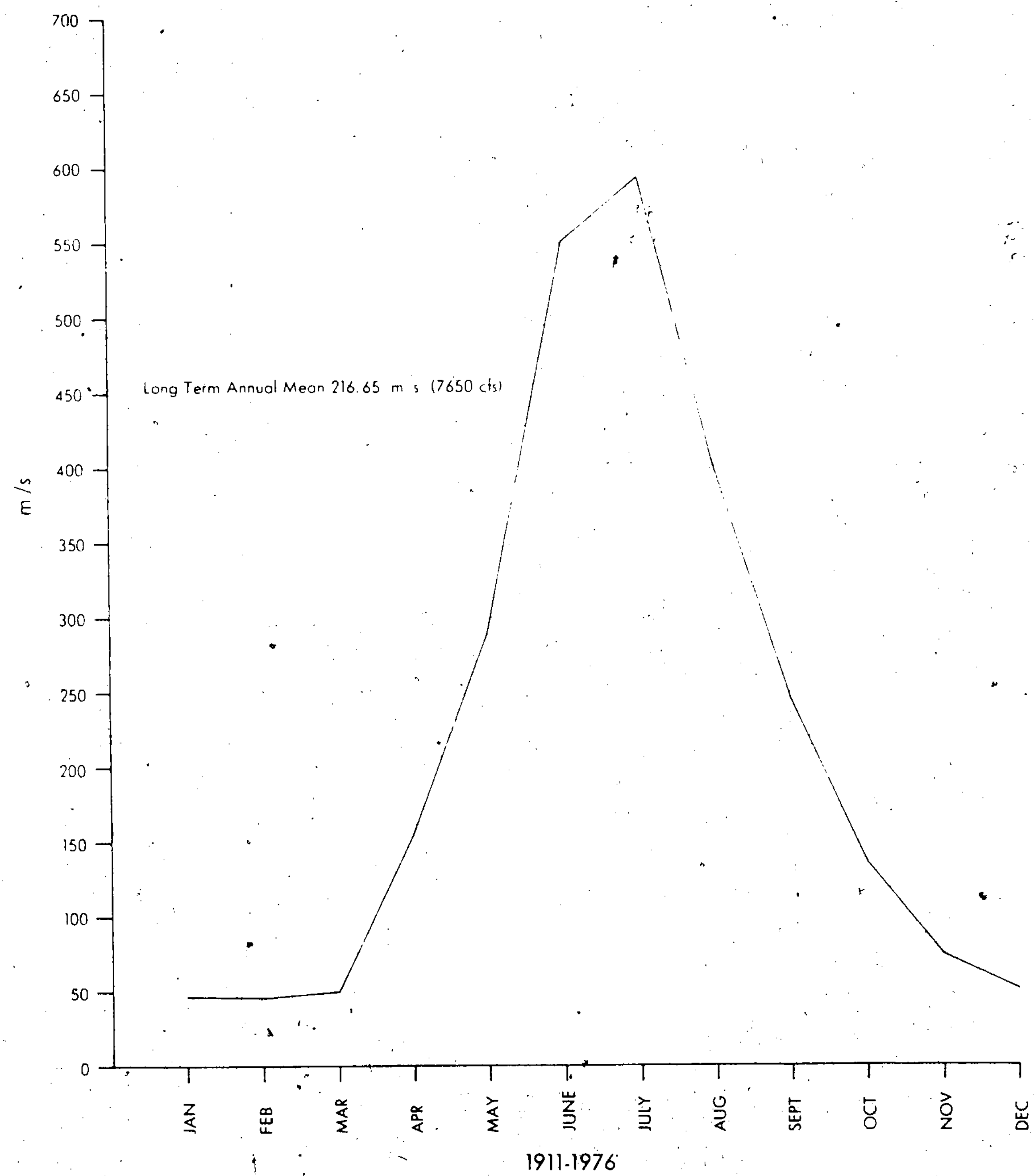
for electricity is traditionally quite high due to cold weather conditions and longer periods of darkness. This trend is also evident in the Clover Bar 1978 output (Figure 2:21). The second peak occurred in July, August and September. This high output was probably necessary to makeup for lost production, due to scheduled maintenance, at the Clover Bar plant during the same period. Overall, the Rossdale station operated at only about 35 percent of total capacity in 1978. The Clover Bar plant operated at a somewhat higher rate of capacity in 1978, approximately 41 percent.

Condenser Cooling

The Rossdale and Clover Bar plants employ once-through cooling systems with the North Saskatchewan River providing the source of water for both plants. A hydrograph indicating the long term mean monthly discharge of the North Saskatchewan River at Edmonton is presented in Figure 2:22. Although the condenser circulating water flows are not monitored at either plant, Dunsmore (Edmonton Power, personal communication, December 1978) reports that even the minimum flows of the river are sufficient to meet the cooling water demands of the two stations. This may be partially attributed to low flow supplementation provided by the Brazeau and Bighorn dams upstream. One interesting aspect of the

Figure 2:22

LONG TERM MONTHLY MEAN DISCHARGE OF THE NORTH SASKATCHEWAN RIVER AT EDMONTON



Source: Fisheries and Environment Canada. <u>Historical Streamflow Summary: Alberta to 1976</u>. Ottawa: Inland Waters Directorate, 1977, p. 219.

Rossdale condenser cooling water is that a considerable portion of the heated effluent is used by the adjacent municipal water treatment plant. The warm water is used as a preventive measure against water main breaks. This aspect will be discussed in more detail in Chapter VI.

The heat rejection rates at the two plants are not monitored as well. The inlet and outlet water temperatures are recorded at the Clover Bar station on an hourly basis but these data are not condensed into a concise report. Therefore, it is impractical to attempt a calculation of the monthly average temperatures. The inlet water temperatures at the Rossdale station are monitored but not recorded.

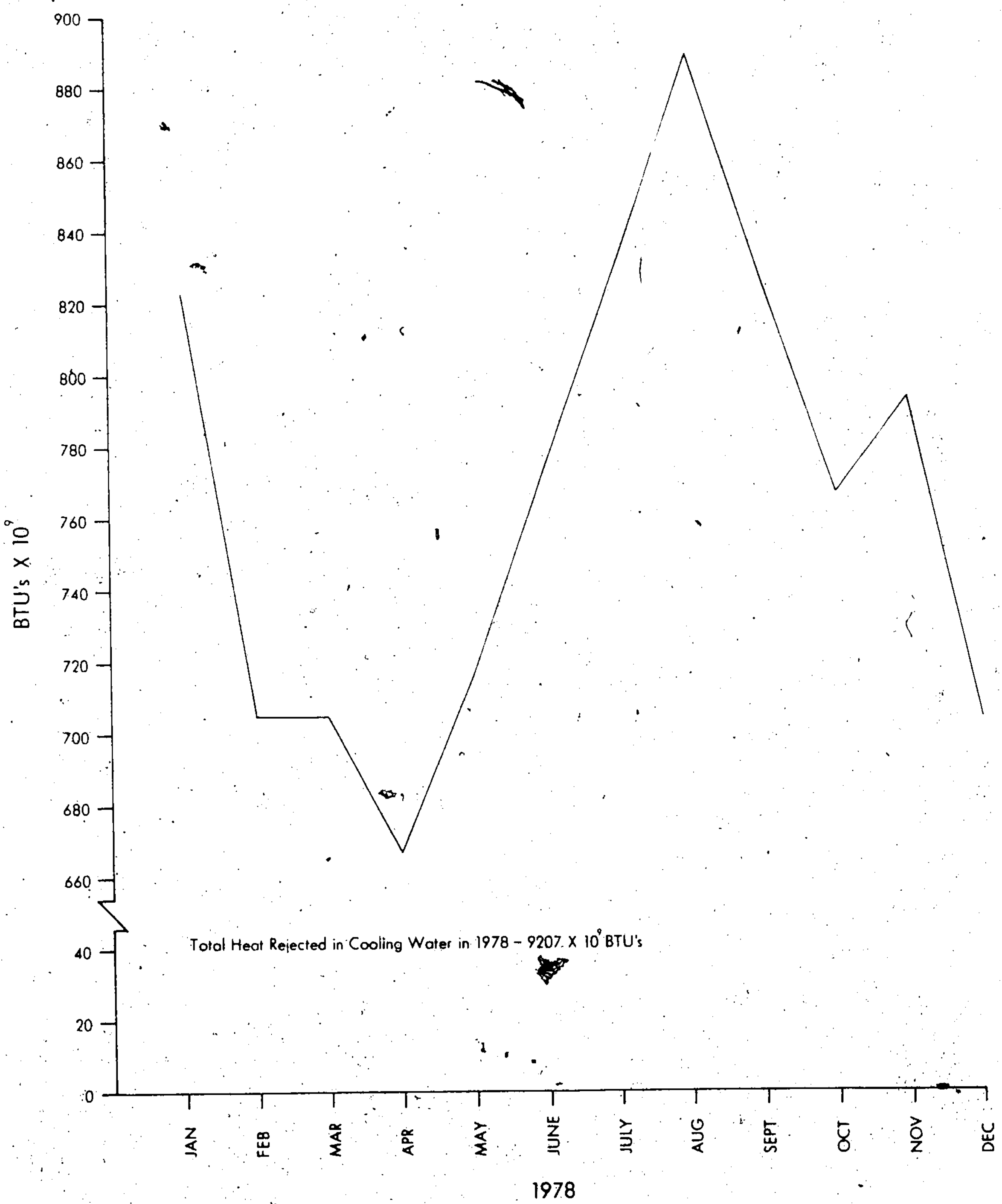
Although the heat rejected in the condenser cooling water at the two plants is not monitored, an approximate figure can be determined for the annual rates of heat energy lost in the water. This is possible because the net thermal efficiencies of the Rossdale and Clover Bar stations are known; 27 percent and 32 percent respectively (R. Johnston, Edmonton Power, personal communication, January 1979). Of the 73 percent and 68 percent input energy lost at the two plants, 10 percent is lost via the stacks. Therefore, approximately 63 percent of the input energy at the Rossdale station is lost to the condensers while this figure for

Clover Bar is 58 percent. Furthermore, the amount of gas burned per kilowatt hour (kWh) of electricity produced (measured in BTU's) is available from Edmonton Power in the form of operating statistics for the two plants. Therefore, by the simple process of multiplication, a very rough figure for the amount of heat rejected in the condenser cooling water at the Rossdale and Clover Bar power plants can be determined.

The monthly heat rejection rates for these two plants are presented in Figures 2:23 and 2:24. The patterns apparent in these graphs closely resemble those for the monthly average gross generation at the two stations. The total heat rejected in 1978 was approximately 9207 x 10^9 BTU's for Rossdale and about 10132 x 10^9 BTU's for Clover Bar. These figures are comparable to those for the other power plants previously described in this chapter.

Figure 2:23

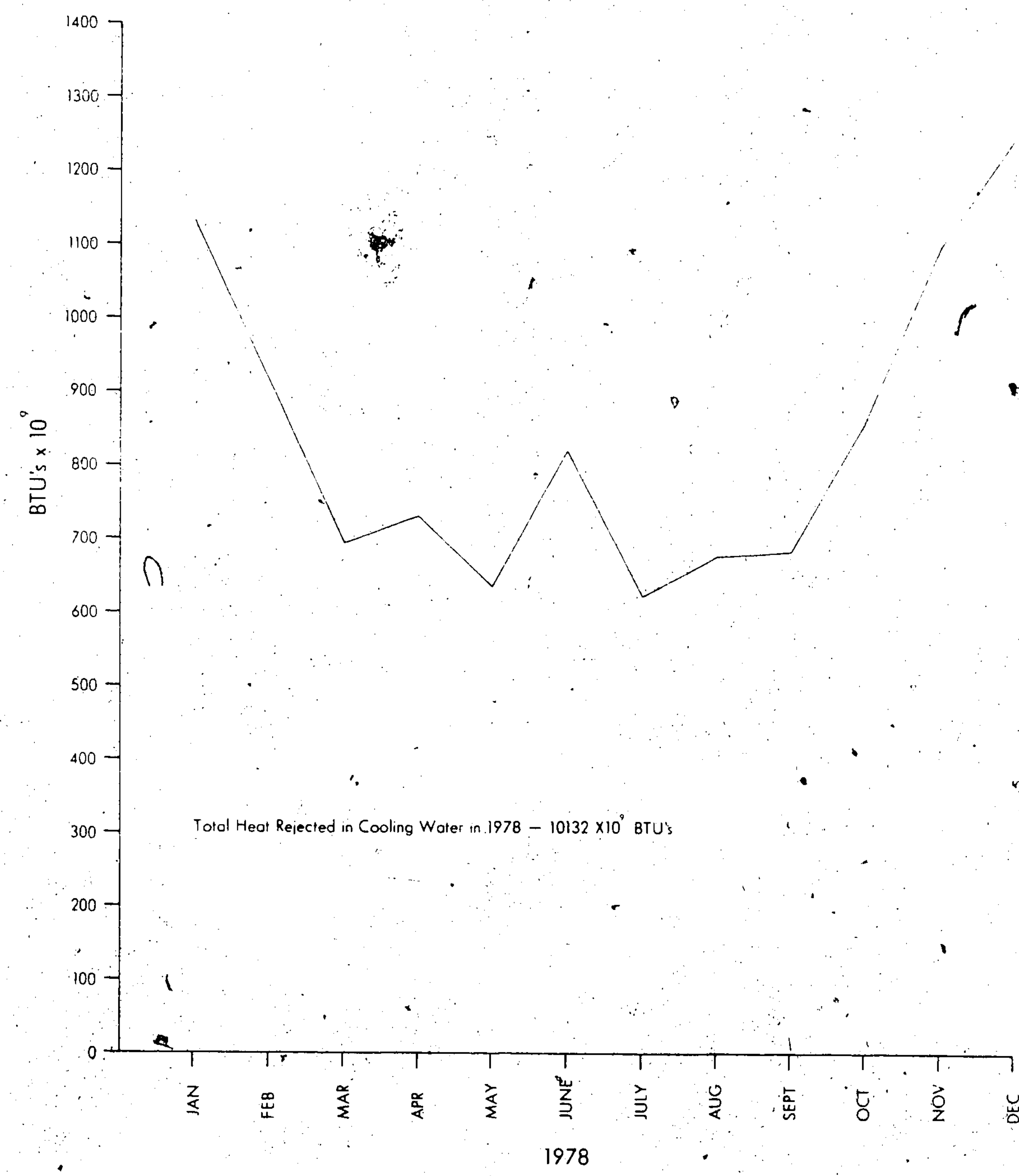
ROSSDALE 1978 MONTHLY HEAT REJECTED IN COOLING WATER



Source: 1978 Production Statistics Provided by Edmonton Power

Figure 2:24

CLOVER BAR 1978 MONTHLY HEAT REJECTED IN COOLING WATER



Source: 1978 Production Statistics Provided by Edmonton Power

KEEPHILLS[1]

General Plant Description

The Keephills plant, which was originally named the South Sundance plant, will be located approximately 10 km (6 mi) to the southeast of the Sundance plant (Figure 2:25). It will be a nominal 750 MW coal-fired station, supplied with coal from an extension to the Highvale Mine. The plant is to be constructed and operated by Calgary Power Ltd. at a total capital cost of $371 million (1976 dollars), including an allowance for funds used during construction. This cost is expected to escalate to $510 million by 1983 when the plant is expected to be completed. A breakdown of the capital costs (excluding an allowance for funds used during construction) is presented in Table 2:4.

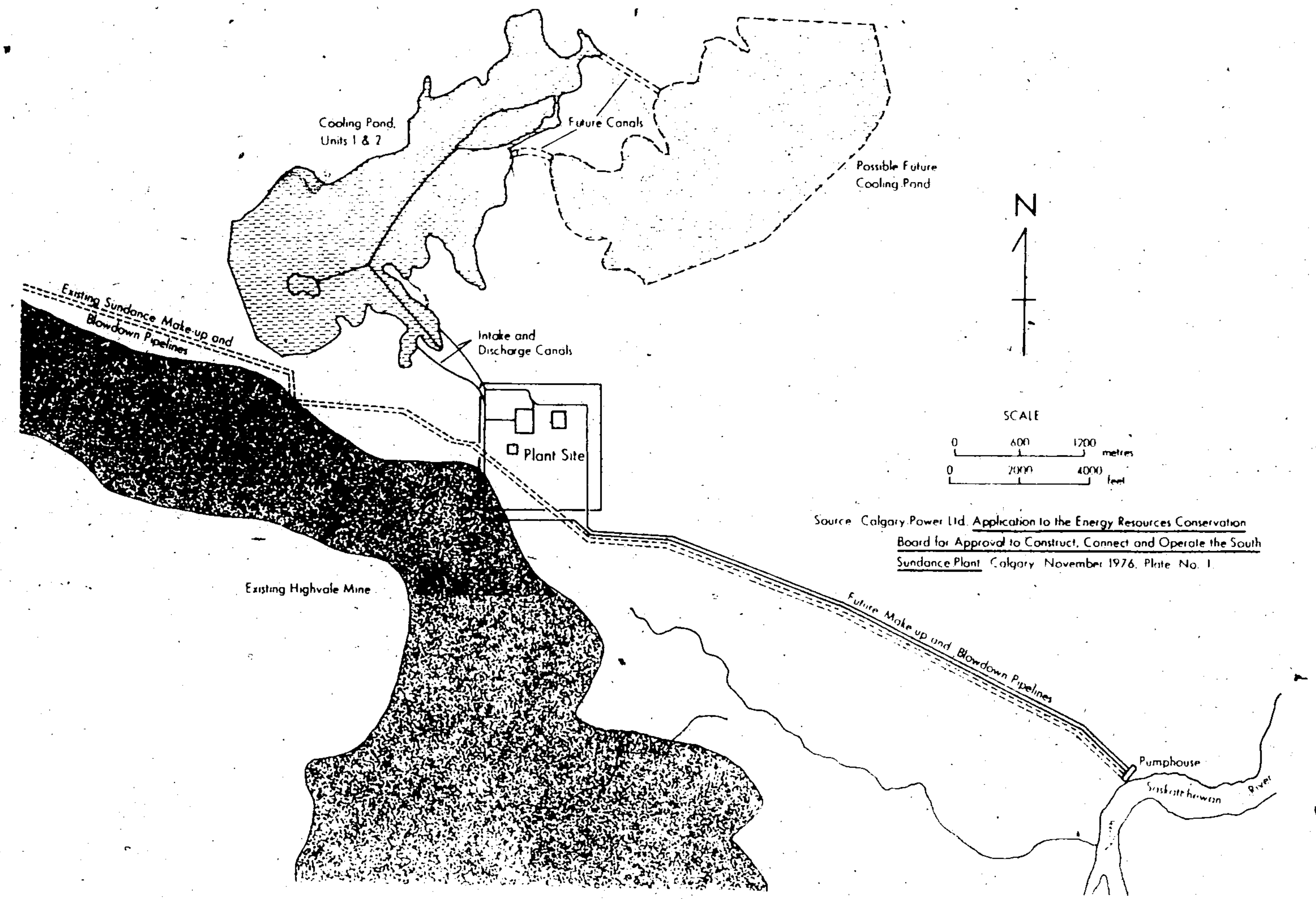
The power plant will initially consist of two, 375 MW generating units. Unit 1 is scheduled for commissioning

[1] The information used in this section was obtained, unless otherwise noted, from the following source:
Clagary Power Ltd. Application to the Energy Resources Conservation Board for Approval to Construct, Connect and Operate the South Sundance Plant. Calgary: November 1976.

Figure 2:25

KEEPHILLS POWER PLANT SITE

(SEE FIGURE 1.2 FOR PROVINCIAL LOCATION)



Source: Calgary Power Ltd. Application to the Energy Resources Conservation Board for Approval to Construct, Connect and Operate the South Sundance Plant. Calgary. November 1976. Plate No. 1

Table 2:4

KEEPHILLS PRELIMINARY PLANT COST ESTIMATE

(1976 Dollars)

DESCRIPTION	UNIT 1 375 MW	UNIT 2 375 MW	TOTAL
Land	1,864,000	-	1,864,000
Structures & Improvements	21,867,000	13,175,000	35,042,000
Water Supply Systems	9,236,000	3,485,000	12,721,000
Boiler Plant Equipment	66,706,000	50,972,000	117,678,000
Turbine Generator	28,188,000	26,118,000	54,306,000
Accessory Electrical Equipment	7,389,000	3,626,000	11,015,000
Miscellaneous Plant	1,985,000	302,000	2,287,000
Generator Transformers	1,244,000	1,244,000	2,488,000
Undistributed Overhead	39,419,000	21,042,000	60,461,000
Total	177,898,000	119,964,000	297,862,000
$ PER NET KW	489	330	409

ASSOCIATED SUBSTATIONS
PRELIMINARY COST ESTIMATE

(1976 Dollars)

DESCRIPTION	UNIT 1 375 MW	UNIT 2 375 MW	TOTAL
Substation	6,761,000	3,192,000	9,953,000
Undistributed Overhead	325,000	155,000	480,000
Total			10,433,000

Source: Calgary Power Ltd. Application to the Energy Resources Conservation Board for Approval to Construct, Connect and Operate the South Sundance Plant. Calgary: November 1976, Table 3-1, p. 3-2.

in October 1982 with Unit 2 scheduled for comm..ssioning one year later. Provisions have been included in the plant design for at least 750 MW of additional capacity. Current plans are that this additional capacity will be commissioned within two or three years of the commissioning of Unit 2. Furthermore, there are apparently sufficient coal reserves in the area to support further expansion of the Keephills plant beyond 1500 MW at a later date. With two units fully operational, the annual coal consumption will be approximately 2,888 x 10^6 kilograms (3,184,000 tons).

Data relating to the plant energy balance are presented in Table 2:5. These figures indicate that the boiler efficiency is expected to be 85 percent but the net electrical output, or the plant net thermal efficiency, will be only 34.66 percent. Of the total input energy, 48.05 percent will be rejected to the condensers.

Physical Characteristics of the Plant Site

The site selected for the generating station is in an area that is characterized by undulating to hilly topography. Maximum relief in the project area ranges from 76.2 to 91.4 m (250 to 300 ft, Canada Department of Energy, Mines and Natural Resources, NTS Map 83 G/8, 1970). Surficial

Table 2:5

KEEPHILLS PLANT ENERGY
BALANCE TWO 375 MW UNIT

	10^6 BTU/hr	%
1. Input		
Coal input to furnace 414,000 kg/h (912,800 lb/hr)	7,156	100.00
2. Distribution		
a. Steam Generator Losses	1,072	15.00
b. Net heat available to turbine and auxiliaries	6,084	85.00
c. Gross electrical output	2,644	36.95
d. Auxiliaries consumption and cooling pond pumping	164	2.29
e. Net electrical output	2,480	34.66
f. Heat rejected to condensers	3,440	48.05

Source: Calgary Power Ltd. Application to the Energy Resources Conservation Board for Approval to Construct, Connect and Operate the South Sundance Plant. Calgary: November 1976, Table 2-3, p. 2-7.

materials in the area consist of glacially derived sands, silts and clays. The soil is of the grey wooded variety from the Podzolic soil group. This soil is rated fair to fairly good for agriculture (Lindsay et al, 1968).

Presently, 56 percent of the area to be directly affected by the Keephills project is devoted to agricultural production, principally coarse grains. The remaining 44 percent consists of water bodies or wetlands, native grass lands, treed areas, recreational land, farmsteads and road allowances. Approximately forty-three families residing within the area will be displaced by the project.

The major water resources in the immediate vicinity of the plant area are Lake Wabamun to the northwest and the North Saskatchewan River to the east. The North Saskatchewan River is to be the source of make-up water for the plant as it is for the Sundance station. The only complete data available for North Saskatchewan River flows near the plant site are for Rocky Mountain House and Edmonton stations. The point of withdrawal of water for the power plant will be at the Sundance make-up water pumphouse, a location intermediary between the two flow recording stations. Hydrographs indicating the long term monthly mean discharges of the river at these two locations are presented in Figures

2:26 and 2:22. Monthly water quality data for the North Saskatchewan River at Devon, just downstream from the withdrawal point, are presented in Table 2:2

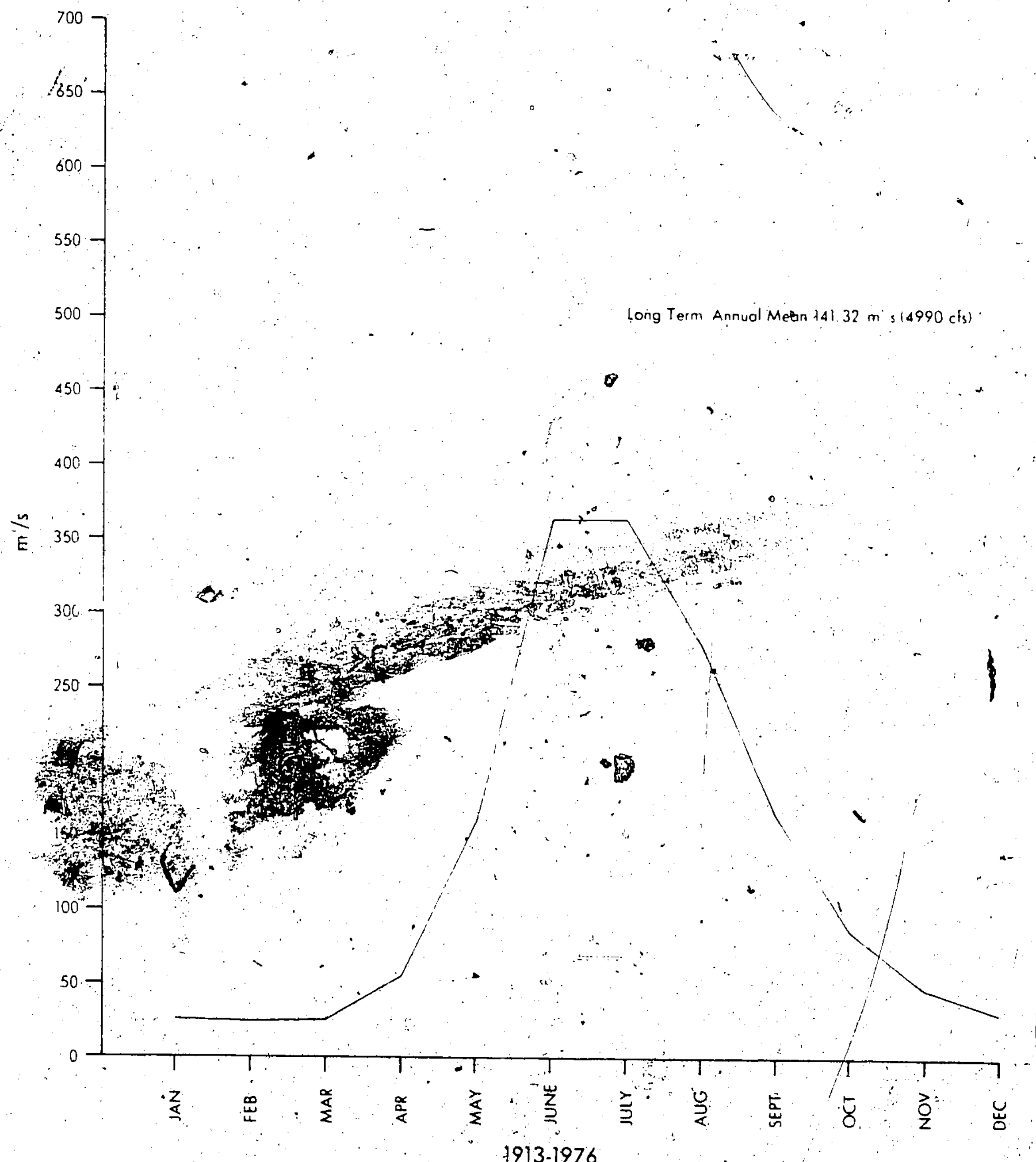
The groundwater quality in the project area is fairly good. Test drillings conducted by the Research Council of Alberta (1970) in the Keephills plant area indicate that the water table is approximately 30.5 m (100 ft) below the surface with probable well yields of 22.7 to 113.6 litres per minute (5 to 25 IGPM). The total dissolved solids range from 1000 to 1500 mg/l while sodium, potassium, carbonate and bicarbonate constitute the chemical characteristics of the groundwater. Some undesirable calcium and sulphates are present as well however.

Condenser Cooling

Condenser cooling for the Keephills plant will be provided by a semi-closed, cooling pond facility. This reservoir will be constructed adjacent to the plant (Figure 2:25) and will be sized at 0.4 hectare (1 acre) effective surface area per MW of initial station capacity. The estimated capital cost for a 300 hectare (750 acre) cooling pond is approximately $12 million, excluding land costs. Alternative cooling systems were considered either imprac-

Figure 2:26

LONG TERM MONTHLY MEAN DISCHARGE OF THE NORTH SASKATCHEWAN RIVER AT ROCKY MOUNTAIN HOUSE



Source: Fisheries and Environment Canada, Historical Streamflow Summary: Alberta to 1976. Ottawa: Inland Waters Directorate, 1977. p. 225.

tical or uneconomical. The topographical conditions in the immediate plant area are also favourable for an extension of the pond to serve future generating units.

Water to fill the pond, and make-up water for the first unit, will be obtained via the existing pipeline from the North Saskatchewan River to the Sundance plant. This pipeline passes just south of the new plant site. Blowdown from the first unit will be incorporated into the existing Sundance blowdown line with additional pumping equipment required. The blowdown is returned to the North Saskatchewan River at a point below the withdrawal pumphouse. Make-up and blowdown pipelines and pumps will be provided for the second unit. These pipelines are to be sized at 610 mm (24 in) and 457 mm (18 in) respectively. The make-up water supply requirements will be approximately 0.97 m^3/s (34 cfs) for a 750 MW station. The blowdown pumphouse will initially have a capacity of 0.48 m^3/s (17 cfs) with the assumption that make-up and blowdown will be required for eight months out of the year.

Calgary Power proposes that the quality of the cooling pond water, and therefore its discharge, will be maintained so that the concentrations will not exceed twice those of the water source. The predicted composition of blowdown concentrations for the cooling pond water are presented in Table 2:6. With most parameters, these figures are simply doublings of the data presented in Table 2:2, the water quality of the North Saskatchewan River at Devon.

The estimated cooling water flow for each 375 MW unit is 14.5 m^3/s (230,000 USGPM) with a temperature rise across the condensers of approximately 8.3C (15F). The heat rejected to the pond will result in a maximum pond temperature of about 32C (89F) during the summer months when the plant is fully operational. The anticipated annual variation in the cooling pond water temperatures is presented in Figure 2:27. By employing the heat rejection rate of 3440×10^6 BTU's per hour lost to the condensers as listed in Table 2:5, a very rough annual figure of 30×10^{12} BTU's can be expected to be rejected in the condenser cooling water at the Keephills power plant when it is operating at maximum capacity.

Table 2:6

KEEPHILLS COOLING WATER POND COMPOSITION OF BLOWDOWN*

GENERAL CHEMICAL

PARAMETER		mg/l
pH		7.9
Alkalinity - P	$CaCO_3$	
Alkalinity - T	$CaCO_3$	200
Conductivity	umhos	
Turbidity	FTU	10
Colour	APHA	20
Total Dissolved Solids	ppm	450
Sulphate	SO_4	185
Chloride	Cl	2
Silica	SiO_2	9.2
Calcium	Ca	96
Magnesium	Mg	28
Sodium	Na	10
Potassium	K	2
Total Hardness EDTA	$CaCO_3$	355

METALS

	mg/l
Iron	0.3
Manganese	0.02 - 0.03
Cadmium	0.002
Chromium	0.004
Cobalt	0.006
Copper	0.02
Lead	0.02
Mercury	0.001- 0.001
Molybdenum	0.014
Nickel	0.020
Silver	0.002
Selenium	0.02
Tin	0.05
Zinc	0.02 - 0.04

NUTRIENTS

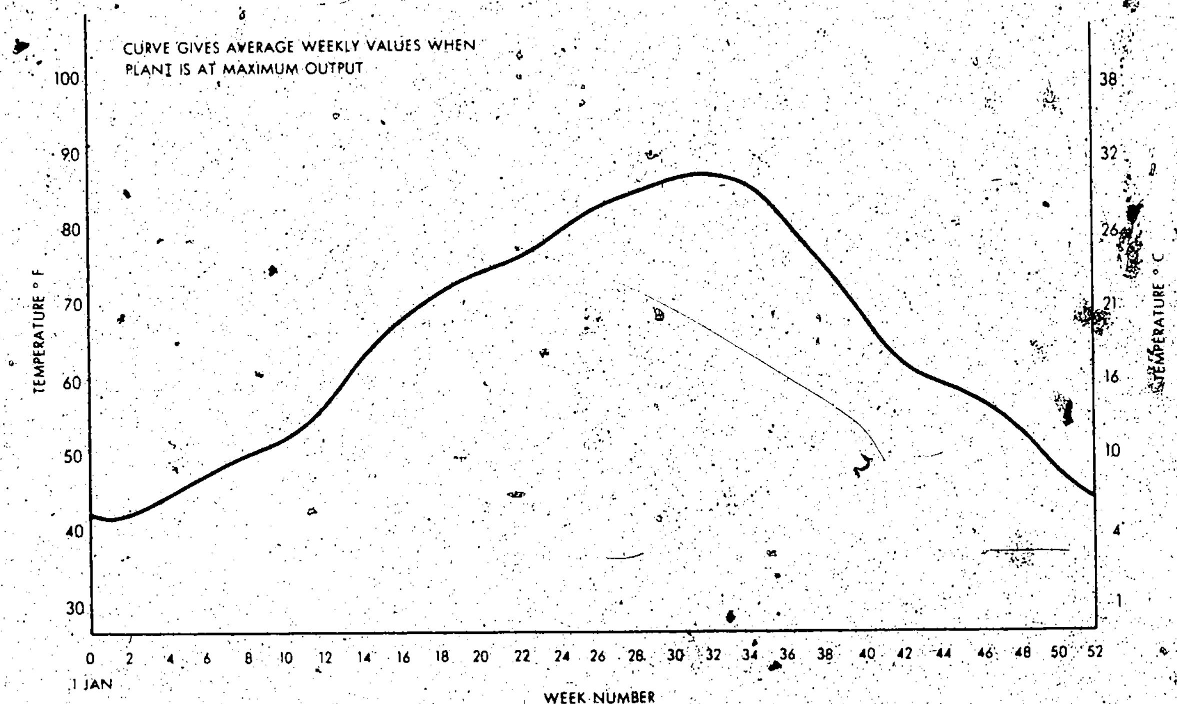
Phosphate-Total	P	0.4
Nitrate-Total	N	0.3
Ammonia	N	0.6
B.O.D.	O_2	2.5

* Assumed that source of cooling water is the North Saskatchewan River at Devon, that the cooling pond will be operated at an average two cycles of concentration and that sulphuric acid will be used to prevent scale formation in the power plant equipment.

Source: Calgary Power Ltd. Application to the Energy Resources Conservation Board for Approval to Construct, Connect and Operate the South Sundance Plant. Calgary: November 1976, Table 2-8, p. 2-17.

Figure 2:27

KEEPHILLS PLANT COOLING POND PROJECTED ANNUAL TEMPERATURE VARIATION



Source: Calgary Power Ltd. Application to the Energy Resources Conservation Board for Approval to Construct, Connect and Operate the South Sundance Plant. Calgary, November 1976, Plate No. 8.

SHEERNESS[1]

General Plant Description

The proposed Sheerness power plant site is situated just south of the municipality of Hanna approximately 280 km (174 mi) S.S.E. of Edmonton and 195 km (121 mi) E.N.E. of Calgary (Figure 2:28). The plant, which is to be constructed and operated by Alberta Power Ltd., will be a mine-mouth, coal-fired generating station. Coal for the plant will be obtained from the Sheerness coal field which underlies the area and is centered 7 km (4.2 mi) northeast of the plant site.

The Sheerness generating station will initially

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[1] The information used in this section was obtained, unless otherwise noted, from the following sources:

Alberta Power Ltd. Sheerness Power Development. Amendment of Application No. 9759 to ERCB to Construct and Operate. Edmonton: Vols. I & II, August 1977.

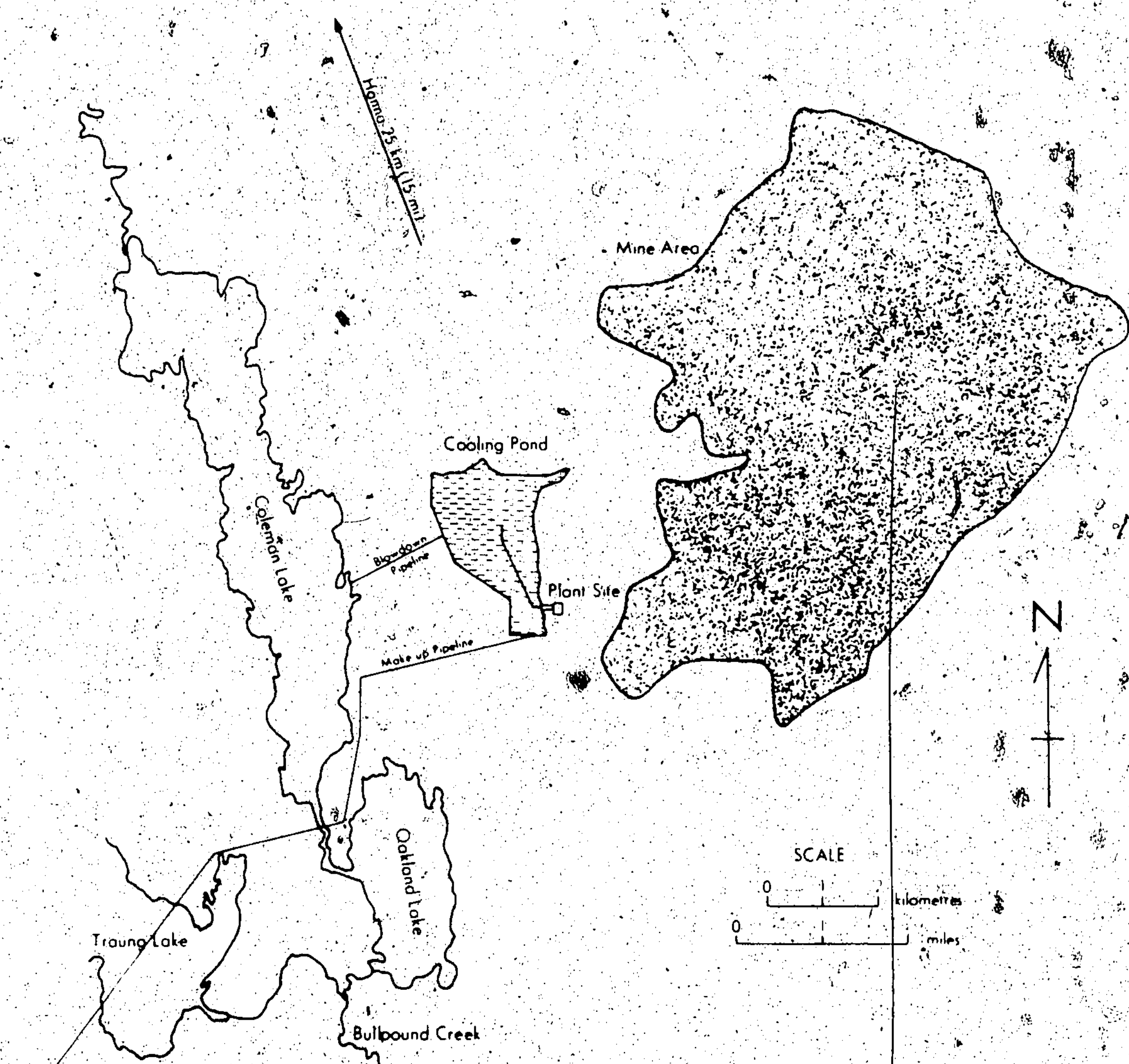
Alberta Power Ltd. Sheerness Power Development. Supplementary Information in Respect of Application No. 9759 to ERCB. Edmonton: Aug. 1977.

Alberta Power Ltd. Sheerness Power Development. Supplementary Information in Respect of Application No. 9759 to ERCB. Edmonton: April 1978.

Figure 2.28

SHEERNESS POWER PLANT SITE

(SEE FIGURE 1.2 FOR PROVINCIAL LOCATION)



Source: Alberta Power Ltd. Sheerness Power Development. Amendment of Application No. 9759 to Energy Resources Conservation Board to Construct and Operate. Edmonton. Vol. 1. August 1977.

consist of two, 375 MW units with space allotted in the plant layout for two additional 375 MW units. The station energy balance with two units is presented in Table 2:7. The anticipated boiler efficiency is listed as 83 percent. The net electrical output, or the overall plant net thermal efficiency, is expected to be only 33.8 percent. This is very similar to the anticipated net thermal efficiency of the Keephills plant. The principal cause of lost energy is the heat rejected to the condensers, 46.9 percent, or 3438 x 10^6 BTU's per hour.

The scheduled commissioning dates for the two units were originally set at July 1, 1983 and July 1, 1984 but the application to construct and operate the Sheerness plant was delayed final approval by the Energy Resources Conservation Board. The commissioning date of the first unit is now expected to be sometime in 1985. The estimated capital cost of the project is $347.1 million (1976 dollars). A more detailed breakdown of the capital costs is presented in Table 2:8.

Physical Characteristics of the Plant Site

The terrain in the area to be developed is gently undulating with local relief seldom exceeding 61 m (200 ft). The surficial materials consist of glacially derived sands

Table 2:7

SHEERNESS PLANT ENERGY
BALANCE TWO 375 MW UNIT

	10^6 BTU/hr	%
1. INPUT		
Coal Input to Furnace 503,800 kg/h (1,110,600 lb/hr)	7,330	100.0
2. DISTRIBUTION		
a. Steam Generator Losses	1,246	17.0
b. Net Heat Available to Turbine and Auxiliaries	6,084	83.0
c. Gross Electrical Output	2,646	36.1
d. Auxiliaries Consumption and Cooling Pond Pumping	166	2.3
e. Net Electrical Output	2,480	33.8
f. Heat Rejection to Condensers	3,438	46.9

Source: Alberta Power Ltd. Sheerness Power Development. Amendment of Application No. 9759 to ERCB to Construct and Operate. Edmonton: August 1977, Vol. 11, Table 5-3, p. 5-8.

Table 2:8

SHEERNESS PRELIMINARY PLANT COST ESTIMATE

(1976 Dollars)

DESCRIPTION	UNIT 1 375 MW	UNIT 2 375 MW	TOTAL
Land	871,000	-	871,000
Structures & Improvements	22,607,000	13,067,000	35,674,000
Water Supply Systems	27,809,000	250,000	28,059,000
Boiler Plant Equipment	73,505,000	57,135,000	130,640,000
Turbine Generator	28,702,000	23,588,000	52,290,000
Accessory Electrical Equipment	7,230,000	3,625,000	10,855,000
Miscellaneous Plant	2,206,000	302,000	2,508,000
Generator Transformers	1,244,000	1,244,000	2,488,000
Undistributed Overhead*	49,914,000	24,873,000	74,787,000
(*2/3 Unit #1, 1/3 Unit #2)			
TOTAL	214,088,000	124,074,000	338,172,000
$ per Net KW	590	342	466

ASSOCIATED SUBSTATIONS
PRELIMINARY COST ESTIMATES

(1976 Dollars)

DESCRIPTION	UNIT 1 375 MW	UNIT 2 375 MW	TOTAL
Substation	7,196,000	1,774,000	8,970,000

Source: Alberta Power Ltd. Sheerness Power Development. Amendment of Application No. 9759 to ERCB to Construct and Operate. Edmonton: August 1977, Vol. 11, Table 6-1, p. 6-3.

and clays which are underlain by the Edmonton Bedrock Formation (Canada Department of Energy, Mines and Natural Resources, 1967). The soils in the area are primarily loam which contain various proportions of clay, silt, sand and gravel. This soil is relatively fertile and has the capacity to retain relatively large quantities of moisture that may be used by [illegible]s in periods of low precipitation (Wyatt & Newton, 1927).

There are some deeply eroded badland areas in the region while numerous small natural and man-made sloughs, ponds and dugouts dot the landscape. The important drainage features include the Red Deer River, located south and west of the Sheerness area, and two of its tributaries, Bullpound Creek and Berry Creek. The significant surface water bodies in the area are Coleman Lake, Oakland Lake and Traung Lake, all reservoirs on local creeks. Land use in the area is as follows:

Pasture	56 percent
Cultivation (wheat)	30 "
Seasonal wetland depressions	8 "
Mined land	4 "
Gullies	1 "
Buildings and environs	1 "

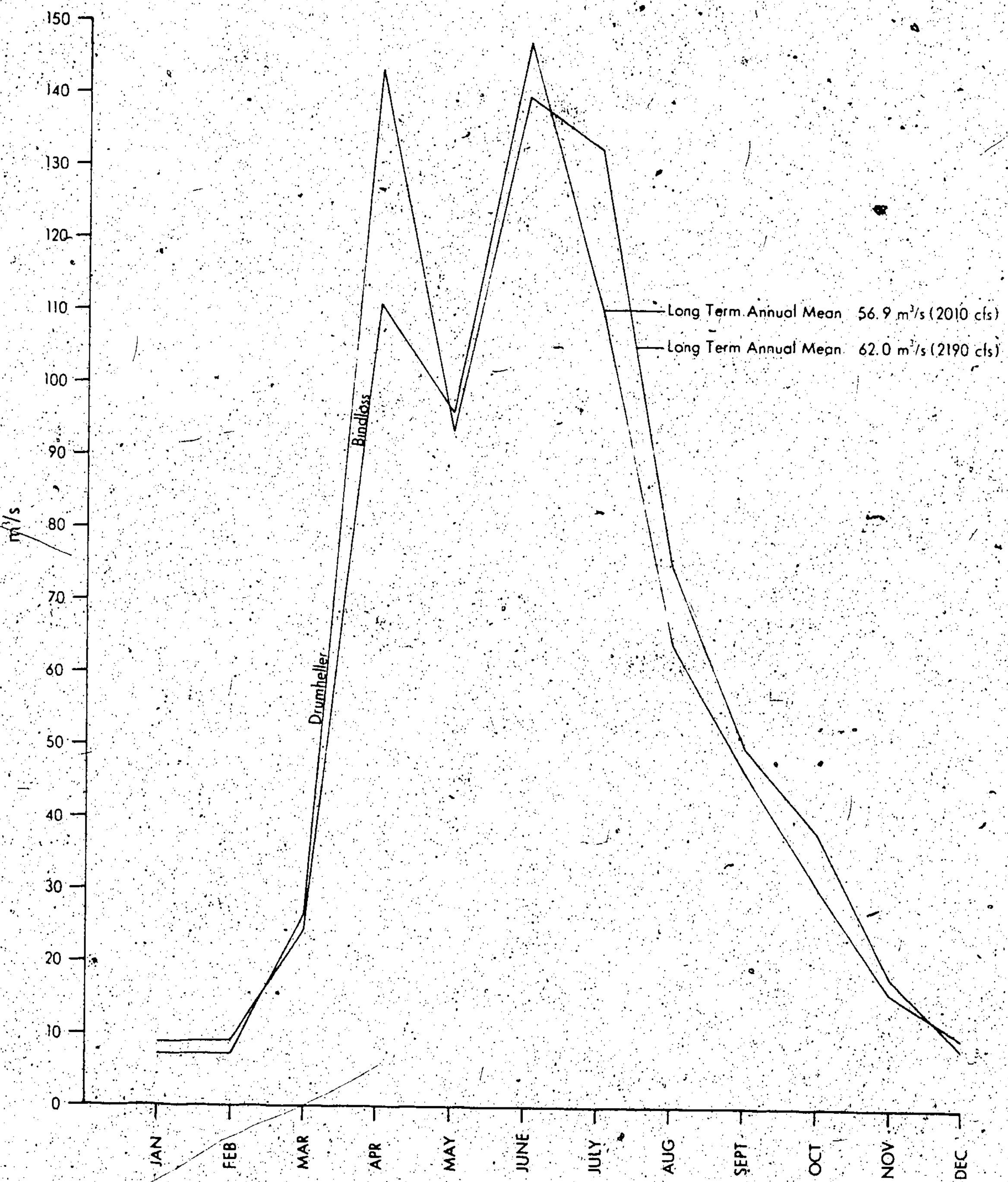
The water resources in the Sheerness plant area are limited in both quantity and quality. The Red Deer River is the major source of water in the area but it is characterized by low yields in the winter and high sediment loads in the spring and summer. The long term mean monthly flows of the Red Deer River at Drumheller and Bindloss are illustrated in Figure 2:29. The proposed point of withdrawal for the plant water supply is located between these two stations on the river. A summary of water quality measurements is presented in Table 2:9 while the suspended residue levels at Bindloss and Drumheller are illustrated in Figure 2:30.

The stream flow data presented in Figure 2:29 demonstrate the extreme variation in the Red Deer River annual yields. The variation between the highest and lowest months is close to 141.6 m^3/s (5000 cfs). In addition, Fisheries and Environment Canada (1977, p. 263 & 266) lists the minimum daily discharge at Drumheller and Bindloss as 1.8 m^3/s (64 cfs, Dec.7, 1922) and 2.5 m^3/s (88 cfs, Dec. 21, 1961). This large variation is expected to be alleviated in the near future with the construction of a dam on the Red Deer River upstream from Red Deer. The primary objective of this dam is to regulate the streamflow with a desired minimum discharge of between 17.1 and 21.9 m^3/s (605 to 775 cfs) (Alberta Environment, 1975, p. 50).

The water quality data presented in Table 2:9, and

Figure 2:29

LONG TERM MONTHLY MEAN DISCHARGE OF THE RED DEER RIVER AT DRUMHELLER AND BINDLOSS



1915-1976 (Drumheller) 1960-1976 (Bindloss)

Source: Fisheries and Environment Canada. Historical Streamflow Summary: Alberta to 1976. Ottawa: Inland Waters Directorate, 1977, p. 262, 266.

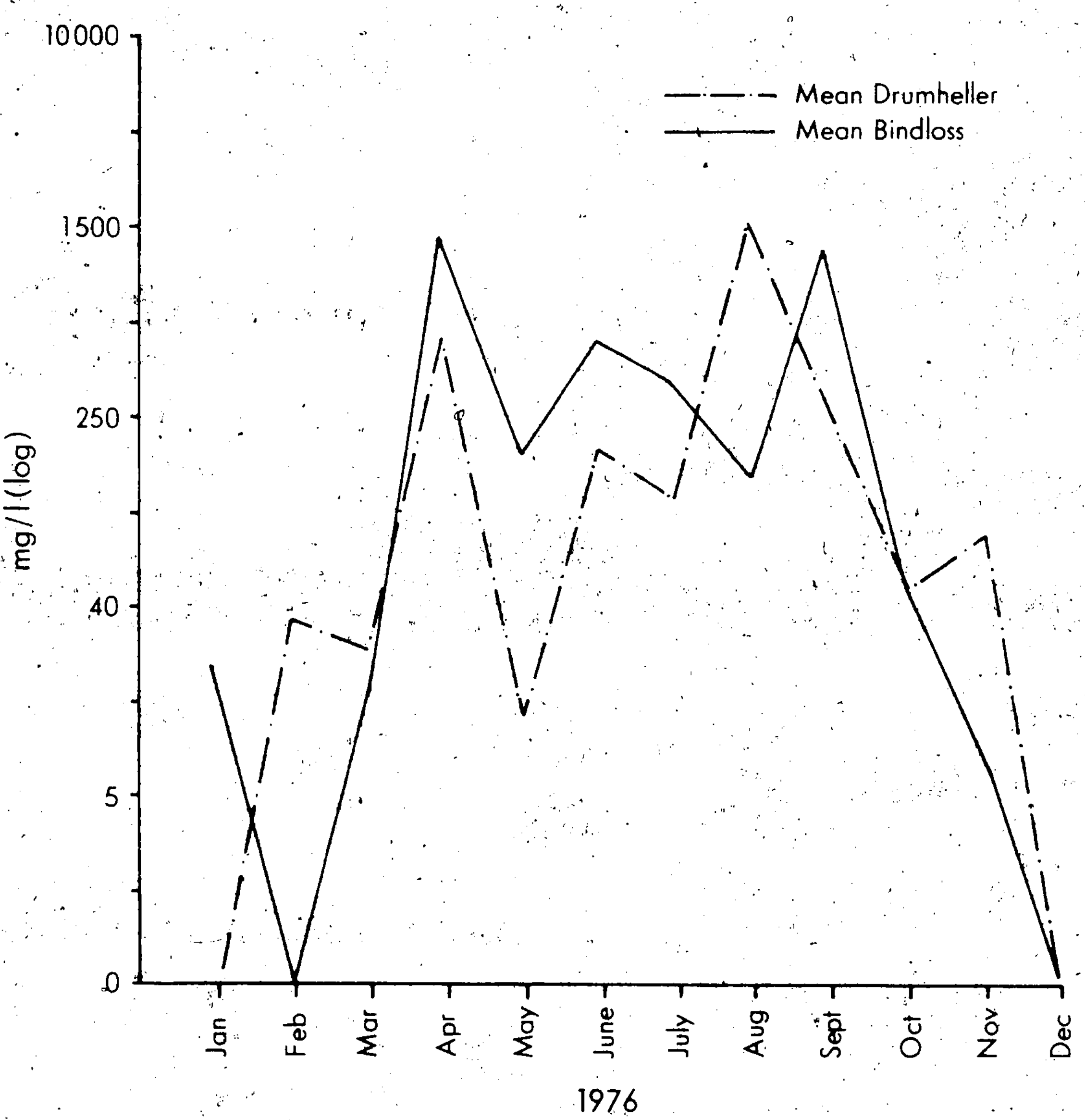
Table 2:9
WATER QUALITY SUMMARY OF RED DEER RIVER AT DRUMHELLER AND BINDLOSS (1976)

PARAMETER	PROVINCIAL SURFACE WATER QUALITY	(OCT TO MAR) DRUM-HELLER mg/l	BIND-LOSS mg/l	(APRIL TO SEPT) DRUM-HELLER mg/l	BIND-LOSS mg/l
Total Alkalinity	-	214	249	146	143
Chemical Oxygen Demand	-	-	-	-	-
Chloride	-	2.1	6.3	1.7	3.2
Apparent Color	30 above natural	11	8	24	38
Fluoride	1.5	0.18	0.17	0.17	0.17
Hardness	-	240	289	155	156
Ammonia Nitrogen	-	-	-	-	-
Nitrate & Nitrite Nitrogen	1.0[4]	0.30	0.30	0.27	0.37
Oil & Grease	no iridescent sheen				
pH	6.5-8.5	8.1	8.0	8.0	8.2
Total Phosphate Phosphorus	0.15	0.009	0.11	0.082	0.19
Dissolved Residue	-	282	318	210	241
Suspended Residue	-	45	15	482	784
Total Residue	-	-	-	-	-
Sulfate	-	52	84	37	58
Turbidity	25 JTU over natural	15	13	166	137
Arsenic	0.01	0.005	0.007	0.0061	0.0010
Cadmium	0.01	0.009	0.002	0.0001	0.001
Chromium	0.05	0.015	0.015	0.015	0.015
Cobalt	-	0.002	0.001	0.012	0.007
Copper	0.02	0.003	0.002	0.013	0.012
Iron	0.3	0.22	0.16	1.5	3.4
Lead	0.05	0.001	0.001	0.007	0.005
Manganese	0.05	0.012	0.021	0.16	0.20
Mercury	0.0001	0.05	0.05	0.05	0.05
Nickel	-	0.004	0.003	0.030	0.015
Selenium	0.01	0.0005	0.0005	0.0006	0.0007
Zinc	0.05	0.005	0.004	0.063	0.020

Source: Alberta Power Ltd. Sheerness Power Development. Amendment of Application No. 9759 to ERCB to Construct & Operate. Edmonton: Vol. 1, August 1977, p. 4.6-16.

Figure 2:30

RED DEER RIVER SUSPENDED RESIDUE LEVELS AT DRUMHELLER AND BINDLOSS



Source: Alberta Power Ltd. Sheerness Power Development. Amendment of Application No. 9759 to Energy Resources Conservation Board to Construct and Operate. Edmonton: Vol. 1, August 1977, p. 4.6-35.

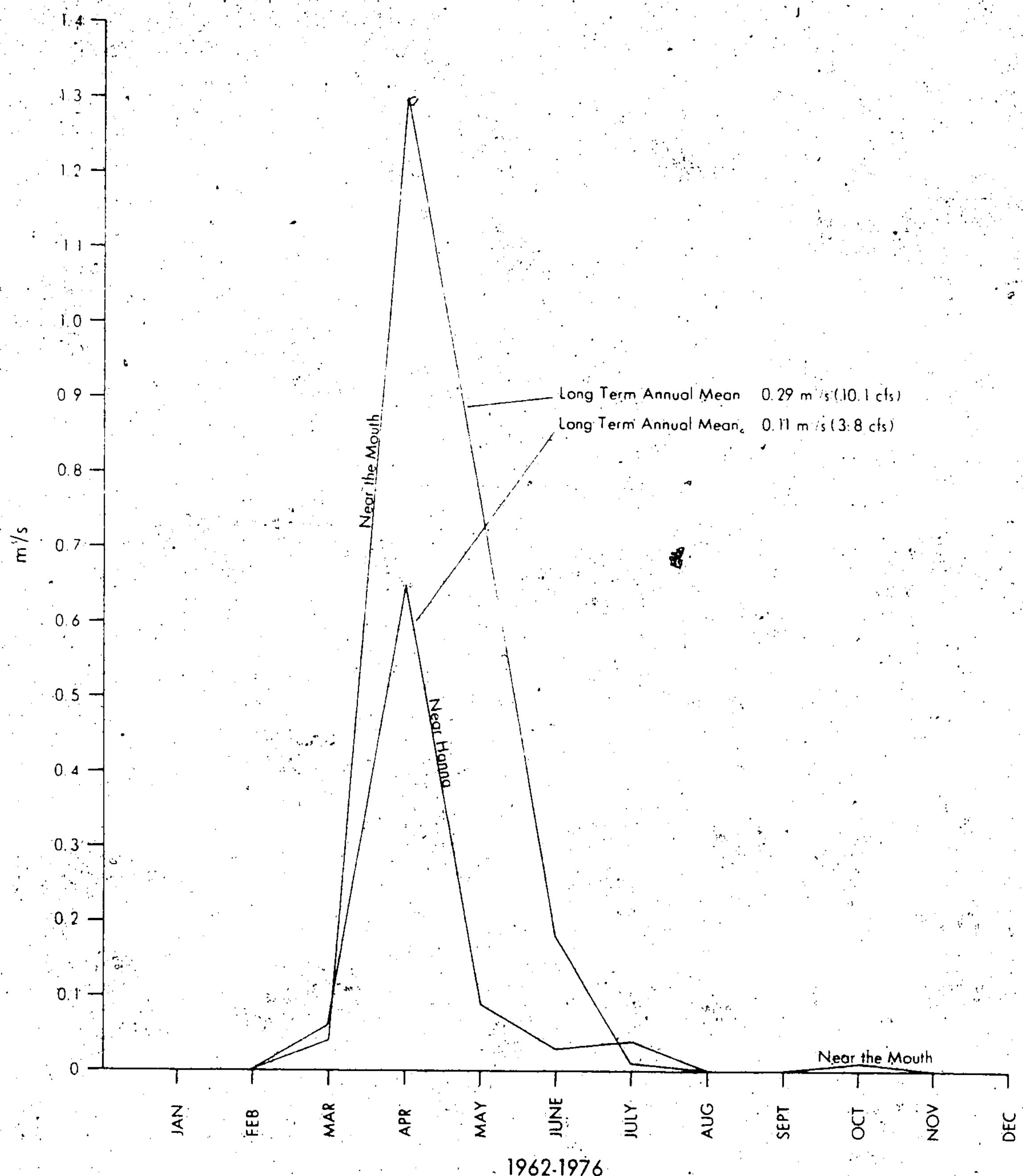
the suspended residue levels illustrated in Figure 2:30, are also very significant. A review of the water quality data reveals that several parameters have been found to exceed the Provincial Surface Water Quality Criteria, especially total phosphate phosphorous and several of the heavy metals. The suspended residue levels are also very high during the periods of peak discharge.

A similar situation exists for Bullpound Creek as evident in Figure 2:31. This hydrograph demonstrates that zero flows are exhibited by the creek during the winter months. Table 2:10 is a summary of water quality test results conducted on Bullpound Creek and an almost identical situation as that for the Red Deer River is noted.

The groundwater found in the Sheerness Power Development area is of very poor quality. It is also very difficult to extract from wells because of low aquifer permeability. Consequently, groundwater recharge is extremely slow and occurs largely as point recharge under ponded surface water. The quality of the groundwater is often outside the limits designated for human consumption. Chemical analyses have indicated very high values of iron, sodium, sulphate, chlorides and, in general, all total dissolved solids. As a result of this poor quality, there are very few users of

Figure 2:31

LONG TERM MONTHLY MEAN DISCHARGE OF BULLPOUND CREEK NEAR THE MOUTH AND NEAR HANNA



Source: Fisheries and Environment Canada. Historical Streamflow Summary: Alberta to 1976. Ottawa: Inland Waters Directorate, 1977, p. 54, 55.

Table 2:10

WATER QUALITY OF BULLPOUND CREEK NEAR THE MOUTH (1976)

PARAMETER	SURFACE WATER QUALITY CRITERIA mg/l	BULLPOUND CREEK mg/l
Total Alkalinity		318
Chemical Oxygen Demand		52
Chloride		9.7
True Color	30 above natural	40
Fluoride	1.5	0.23
Hardness		174
Ammonia Nitrogen		0.09
Nitrate & Nitrite Nitrogen	1.0[3]	0.02
pH	6.5 to 8.5	8.2
Total Phosphate Phosphorus	0.15	0.74
Dissolved Residue		588
Suspended Residue		7
Total Residue		595
Sulfate		120
Turbidity	25 JTU over natural	3.5
Arsenic	0.01	0.005
Cadmium	0.01	0.005
Chromium	0.05	0.005
Cobalt		0.01
Copper	0.02	0.005
Iron	0.3	0.30
Lead	0.05	0.01
Manganese	0.05	0.072
Mercury	0.0001	0.001
Nickel		0.005
Zinc	0.05	0.005

Source: Alberta Power Ltd. Sheerness Power Development. Amendment of Application No. 9759 to ERCB to Construct and Operate. Edmonton: Vol. 1, August 1977, p. 4.6-19.

groundwater within the study area with only the local farmers and the municipality of Sheerness utilizing this resource. The town of Hanna withdraws its water from local surface water sources.

Condenser Cooling

The proposed method of condenser cooling at the Sheerness power plant is a semi-closed, cooling pond system. This pond will be 300 hectares (750 acres) in size. The cooling pond will be located to the west of the power plant and will be formed by erecting a dyke across the mouth of a natural depression (Figure 2:28). The temperature rise across the condensers is anticipated to be about 8.3C (15F) and the maximum pond temperature will be approximately 30C (86F) in the summer at full load. The decision to employ a cooling pond system was based strictly on economics. There are insufficient water resources in the project area to warrant a once-through cooling system. A comparison of costs for constructing cooling towers, as opposed to a cooling pond, is presented in Table 2:11. These data indicate that the capital cost of constructing a cooling pond is high relative to a mechanical draft cooling tower or an air-cooled condenser, but this higher cost is offset by the high operating costs of the other systems.

Table 2:11

SUMMARY OF ALTERNATIVE COOLING SYSTEMS FOR SHEERNESS PLANT

(1976 Dollars)

	COOLING POND	WET COOLING TOWERS MECHANICAL DRAFT	NATURAL DRAFT
Capital Cost[1]	\$37,038,000	\$33,617,000	\$45,000,000
Water Make-up Capacity (6 months pumping)	$1.22 m^3/s$	$1.0 m^3/s$	$1.0 m^3/s$
Auxiliary Power:			
Capacity (KW)	6,900	11,360	9,960
Energy (MWH/yr)	31,850	63,910	57,890
Present Worth[2] of Power and Operating and Maintenance			
Power:			
Capacity (\$150/KW)	\$1,035,000	\$1,704,000	\$1,494,000
Energy (2.9mills/KWH)	\$1,271,000	\$2,551,000	\$2,311,000
Operating and Maintenance (excluding Power	\$3,100,000	\$5,800,000	\$4,800,000
Total Investment	\$42,444,000	\$43,672,000	\$53,605,000
Relative Cost Estimate[3]	1	1.03	1.26

1 Including pumping equipment and piping.
2 Thirty years of operation at 6 percent discount.
3 The relative cost estimates for mechanical draft and natural draft dry cooling towers are 1.25 and 1.30 respectively.

Source: Alberta Power Ltd. Sheerness Power Development. Supplementary Information in Respect of Application No. 9759 to ERCB. Edmonton: August 1977, p. 8.

Make-up water for the cooling pond will be obtained via a 914 mm (36 in) diameter steel pipeline from the Red Deer River some 40 km (25 mi) to the southwest. The point of withdrawal will be located approximately 15 km (9.3 mi) upstream from the confluence of Bullpound Creek and the Red Deer River. After the reservoir has been filled, water will be pumped in sufficient quantity to provide for twice the yearly evaporation and inplant consumptive usage losses. Simultaneously, water will be discharged to compensate for evaporative concentration effects over the annual period. The annual withdrawal volumes will be approximately 19,736,000 m^3 (16,000 acre feet) and total volume of the pond will be approximately 21,426,000 m^3 (17,370 acre feet).

The proposed withdrawal of make-up water from the Red Deer River is scheduled for the summer months only because of flow regime constraints. The rate of withdrawal will be constant over a six month period (April to September): 1.2 m^3/s (43.0 cfs). It is anticipated that the high sediment load of the Red Deer River during this period could pose problems of pipeline abrasion and could also be detrimental to inplant uses. If this becomes the case, Alberta Power proposes shortening the period of withdrawal to include only the months of May to September or shift the period of withdrawal to the months of May to October. It is also proposed that withdrawal could be halted during periods of exceedingly high suspended residues levels such as occur during thunderstorm activity. However, this scheduling may be unnecessary upon completion of the Red Deer River dam.

Blowdown from the cooling pond will be directed into the Bullpound Creek system via Coleman Lake, with eventual discharge back into the Red Deer River. The schedule for discharge will be coincident with withdrawal of make-up water. The annual blowdown volumes will be in the range of 9,868,000 m^3 (8,000 acre feet). The flow at the point of discharge will be approximately 0.61 m^3/s (21.5 cfs) over the six month period. This will be transmitted through a 610 mm (24 in) diameter steel pipeline.

It is proposed by Alberta Power that the cooling pond water system will be designed to ensure that the pond water, and therefore its discharge, will exhibit chemical characteristics between those of the Red Deer River and twice the concentrations exhibited by that same river. The predicted maximum concentrations of the cooling pond discharge are simply doublings of the Red Deer River concentrations (Table 2:9). This results in several parameters exceeding the Alberta Surface Water Quality Criteria. The rationale employed by Alberta Power for allowing these concentrations to be returned to the Red Deer River is that the river itself exceeds many of these parameters.

In addition to the condenser circulating water, effluent from a sewage lagoon will be discharged into the cooling pond. Inplant sources of this effluent include boiler blowdown, boiler cleaning, domestic sewage, bottom ash sluice water discharge, water treatment plant, station services, yard and plant discharge, coal storage drainage and spent lubricants. The estimated flow from the lagoon to the cooling pond will be about 23,680,000 litres per day (5,209,067 IGPD). The lagoon outflow will be monitored to ensure that discharges from the lagoon will not impair the water quality of the cooling pond discharge.

Environmental Concerns

There are several environmental concerns associated with the Sheerness Power Development proposal. The potential effects of the cooling pond discharge on Coleman Lake and Bullpound Creek are not specifically known. It is proposed that this water be either temporarily stored in the lake or released to cause an increased flow in Bullpound Creek. The hydrological effects on Coleman Lake remain to be quantitatively evaluated. The lake is controlled by a spillway, therefore one major hydrological effect anticipated is an increase in the flushing rate of the lake, and an increased period of active flow in Bullpound Creek will almost certainly increase erosion of the stream bed and banks. This is difficult to quantify but Alberta Power feels the potential stream erosion in Bullpound Creeek would be minimal because natural flows as high as 14.2 m^3/s (500 cfs, daily means) are not uncommon in the creek. They anticipate the lower blowdown flows of 0.61 m^3/s (21.5 cfs) will have an even smaller effect. A continuous flow of even 0.61 m^3/s (21.5 cfs) may increase stream erosion over present values during periods of near zero and zero flows but this would be minimal in comparison to that which occurs during periods of peak natural flows.

The water quality of the cooling pond blowdown is also a potential problem area. The water quality of Bullpound Creek (Table 2:10) is similar to that anticipated for the pond discharge but with several notable exceptions. Nitrogen, suspended residue, turbidity, iron, manganese, nickel, arsenic copper and zinc will all be higher in the cooling pond discharge than in Bullpound Creek. The increased spring flushing of Coleman Lake could also result in increased levels of various parameters, especially metals which had previously settled on the bottom of the lake.

Furthermore, natural and forced evaporation in Coleman Lake will cause some constituents to become more concentrated than in the make-up water from the Red Deer River. Additional concentrations may arise from higher flushing rates of the lake.

A further environmental concern is the potential for seepage of water from the cooling pond or blowdown in Bullpound Creek into local groundwater aquifers. A major aquifer channel has been identified in the area which traverses in the direction of Bullpound Creek passing under Oakland and Coleman Lakes. It generally appears that the quality of the cooling pond water will be better than that of the groundwater, therefore, no adverse effects are anticipated. In addition, it appears that there is little interplay between the lakes and the aquifer channel, based on test results which have indicated that there are substantial differences between the water quality of the aquifer and the lakes.

The aquatic biota could be adversely affected by two sources: increased water temperatures and re-introduction of metals from increased flushing of Coleman and Oakland Lakes. Increased temperatures and nitrogen levels will probably result in increased productivity. However, Bullpound Creek, Coleman Lake and Oakland Lake have very little value for recreational fishing due to poor habitat conditions (high total dissolved solids and low dissolved oxygen levels) and extensive damming on the upper reaches of Bullpound Creek for agricultural purposes produces intermittent flows which effectively eliminate fish from these areas. Low flows of near zero and zero for much of the time in the drier years must also inhibit fish presence.

One secondary benefit that could arise from the Sheerness Power Development is the supplementation of the Hanna water supply. With development of the Sheerness power plant, residential and commercial expansion in Hanna could necessitate the acquisition of a new water supply. This could possibly be met by pumping water from the power plant cooling pond.

GENESEE

General Plant Description

The Genesee thermal generating station is to be a nominal 750 MW, mine-mouth, coal-fired plant supplied by the Genesee coal field. The power plant is to be constructed and operated by Edmonton Power at a total capital cost of $400 million (1977 dollars) including interest accrued during construction (Edmonton Power, 1977a). The mining equipment is expected to cost an additional $43.5 million while the substation and transmission line costs will add a further $1.88 million to the total cost of the facility. A breakdown of the capital costs is presented in Table 2:12.

The Genesee power plant will initially consist of two 375 MW units (Edmonton Power, 1977a). The commissioning dates for the two units were originally scheduled for 1985 and 1986 but the Energy Resources Conservation Board has yet to approve the application. Therefore, these dates will probably be deferred by at least one year each. As with the Keephills and Sheerness power plants, provision is to be included in the Genesee plant design for an

Table 2:12

GENESEE PRELIMINARY PLANT COST ESTIMATE

(1977 Dollars)

DESCRIPTION	UNIT 1 375 MW	UNIT 2 375 MW	TOTAL
Land	1,520,000	-	1,520,000
Structures & Improvements	19,250,000	10,980,000	30,230,000
Water Supply Systems	7,865,000	-	7,865,000
Boiler Plant Equipment	60,465,000	45,800,000	106,265,000
Turbine Generator	35,000,000	27,720,000	62,720,000
Accessory Electrical Equipment	6,010,000	5,750,000	11,760,000
Miscellaneous Plant	2,180,000	380,000	2,560,000
Undistributed Overhead	55,460,000	33,140,000	88,600,000
Total	187,750,000	123,770,000	311,520,000
$ Per Net KW	516	340	428

ASSOCIATED SUBSTATIONS
PRELIMINARY COST ESTIMATE

(1977 Dollars)

DESCRIPTION	UNIT 1 375 MW	UNIT 2 375 MW	TOTAL
Substation	900,000	590,000	1,490,000
Undistributed Overhead	235,000	155,000	390,000
Total	1,135,000	745,000	1,880,000

Source: Edmonton Power. Application to the Energy Resources Conservation Board for Approval to Construct, Connect and Operate the Genesee Thermal Power Plant and Mine, Vol. 111, Power Plant Evaluation. Edmonton: December 1977, p. 8-3.

additional 750 MW of capacity. The annual coal requirements of the plant when operating at 80 percent of capacity will be approximately 2.7 million tonnes (3.0 million tons, Edmonton Power, 1977b). Edmonton Power estimates that there is a recoverable coal reserve of about 180 million tonnes (200 million tons) in the area which is sufficient to supply 1500 MW for thirty years.

Data relating to the plant energy balance with the two units in operation are presented in Table 2:13. These figures are almost identical to the expected plant energy balances for the Keephills (Table 2:5) and the Sheerness (Table 2:7) plants. At Genesee, the expected boiler efficiencies are 85 percent but the total plant net thermal efficiency will be only about 37 percent (Edmonton Power, 1977a). Of the in-plant energy losses, the heat rejected to the condensers represents the largest proportion, 46 percent of the input energy.

Physical Description of the Plant Site

The Genesee power project will be located approximately 50 km (31 mi) W.S.W. of Edmonton and south of the North Saskatchewan River near the town of Warburg (Figure 2:32). The total area affected by the project will be about 1200 hectares (3000 acres, Edmonton Power, 1977a).

Table 2:13

GENESEE PLANT ENERGY
BALANCE TWO 375 MW UNITS

	10^6BTU's/hr	%
A. Heat in Fuel Burnt	7,161	100.0
B. Steam Generator Losses	1,072	15.0
C. Heat to Turbo-Generator and Auxiliaries	6,087	85.0
D. Heat Rejected to Condersers	3,302	46.1
E. Heat Equivalent of Electricity Generated	2,645	36.94
F. Auxiliary Power (including C.W. Make-up and Blowdown Pumping)	162	2.26
G. Heat Equivalent of Net Electricity Generated	2,483	34.68

Source: Edmonton Power. Application to the Energy Resources Conservation Board for Approval to Construct, Connect and Operate the Genesee Thermal Power Plant and Mine, Vol. 1, Application. Edmonton: December 1977, p. 1-6.

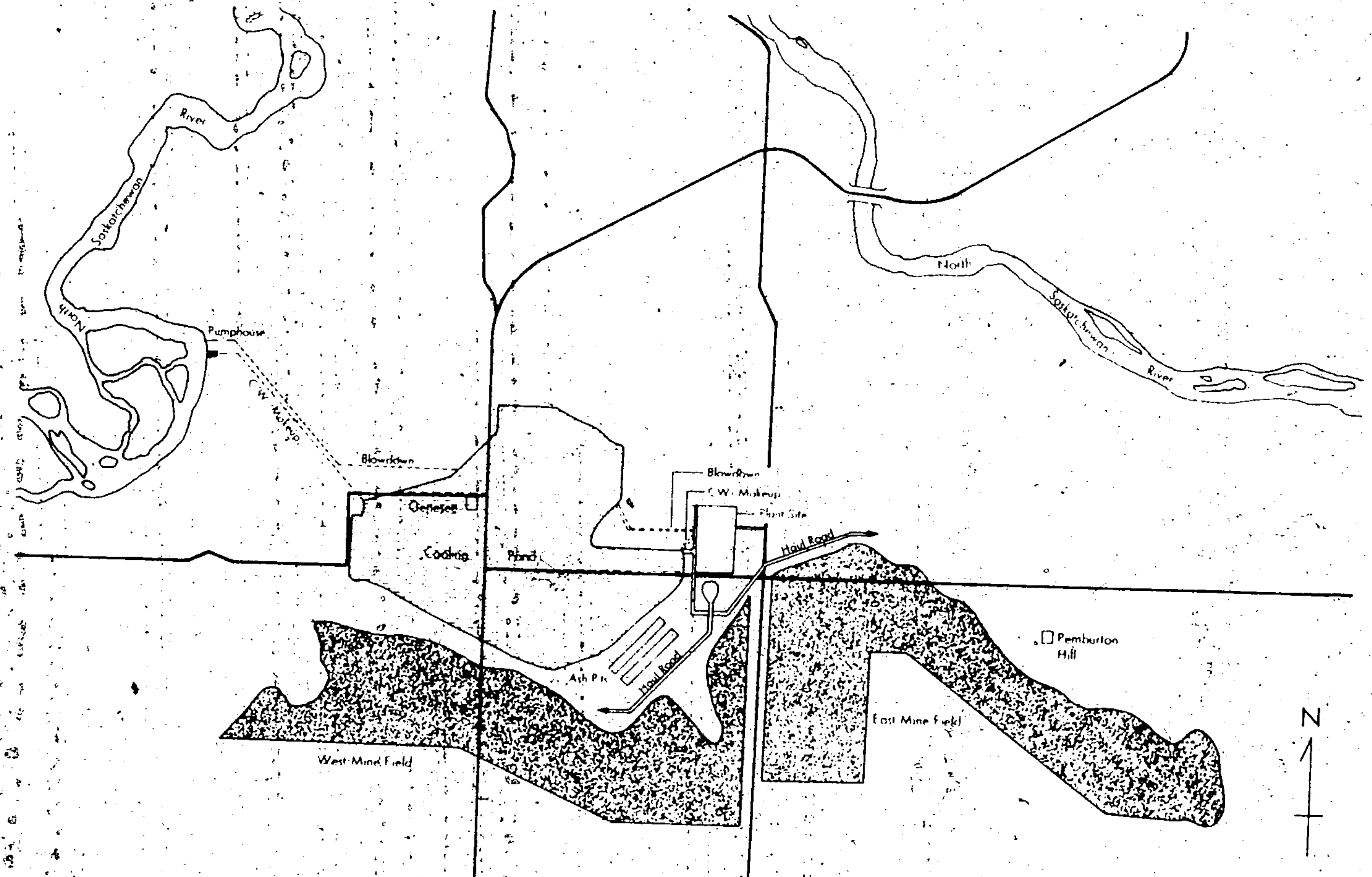


Figure 2:32

PROPOSED GENESEE THERMAL
POWER PLANT SITE LAYOUT (SEE FIGURE 1.2 FOR PROVINCIAL LOCATION)

Source: Edmonton Power. Application to the Energy Resources Conservation Board for Approval to Construct, Connect and Operate the Genesee Thermal Power Plant and Mine Vol I. Application. Edmonton. December 1977. Figure 2.1.

The topography of this area in the province varies from gently rolling to flat (Edmonton Power, 1977e). The maximum relief in the project area ranges from 45.7 to 61.0 m (150 to 200 ft, Canada Department of Energy, Mines and Natural Resources, NTS Map 83 G/8, 1970).

The surficial materials in the area consist of clay and till with lesser amounts of sand and gravel outwash (Edmonton Power, 1977e). These deposits overlie the sandstones and shales of the Edmonton Bedrock Formation. The soils are predominantly Orthic Dark Grey Wooded and Orthic Grey Wooded from the Podzolic soil group (Lindsay et al, 1968). Some Solonetzic and Organic soils are also found in the project area. In general, these soils are rated from fair to good for agriculture by Lindsay et al (1968).

The relative amounts of forested and cultivated land in the plant site area are presented in Table 2:14. These figures reveal that a considerable portion of the area to be developed is under cultivation. Forested land represents very little of the total area. The soil ratings for the area, plus the large amount of land under cultivation, indicate that the Genesee power plant will be disrupting an area that is good for agriculture.

The major water resource in the region is the North

Table 2:14

RELATIVE AMOUNTS OF FORESTED AND CULTIVATED LAND AT THE PROPOSED GENESEE PLANT SITE

Vegetation Cover	Cooling Pond ha	Cooling Pond %	West Mining Area ha	West Mining Area %	East Mining Area ha	East Mining Area %
Cultivated/ cleared	541	76	613	81	658	88
Mixed Wood	21	3	12	2	-	-
Black Spruce	62	8	-	-	-	-
Poplar Wood	91	13	127	16	89	12
Bog Birch-willow	-	-	6	1	-	-
TOTAL	715		758		747	

Source: Edmonton Power. Application to the Energy Resources Conservation Board for Approval to Construct, Connect and Operate the Genesee Thermal Power Plant Mine, Vol. IV (Part 2), Environmental Impact Assessment Draft Report. Edmonton: December 1977, p. 3-69.

Saskatchewan River which bounds the plant site on the east, north and west. The mean monthly discharge of the river at the two closest recording stations for which long term data are available were presented earlier in Figures 2:26 and 2:22. There are also some natural sloughs and marshy depressions in the plant site area.

The groundwater, according to the Research Council of Alberta (1970), is similar to that found in the Sundance and Keephills plant ares. That is, carbonate and bicarbonate constitute the major proportion of total anions while sodium and potassium constitute the major proportion of total cations. The total dissolved solids are in the order of 1500 mg/l while some sulphates and calcium are also found. The water table is quite shallow, about 30.5 m (100 ft) below the surface, and the probable well yields are only in the order of 4.5 to 22.7 litres per minute (1 to 5 IGPM). Investigations of the groundwater in the area by Edmonton Power (1977e) revealed that there is very poor recharge of groundwater resources because of low permeability.

Condenser Cooling

A 600 hectare (1500 acre) cooling pond is the proposed system of condenser cooling to be employed at the Genesee power plant (Edmonton Power, 1977c). The site selected for this reservoir is to the west of the plant in a natural depression that is largely marshland (Figure 2:32). The decision to construct a 600 hectare pond, rather than a 300 hectare pond, was based on the land topography which will allow for a minimum of dyking. A 600 hectare pond would be only marginally more expensive and would provide sufficient surface area for two more units at no additional cost (Edmonton Power, 1977c).

A cooling pond is considered by Edmonton Power to be the most practical method for condenser cooling at the Genesee thermal power plant. Dry cooling towers would cost \$29 to \$31 million more to construct than a cooling pond and would also result in a slightly lower plant net thermal efficiency (Edmonton Power, 1977c). Wet cooling towers are also very capital intensive, about \$9.11 million more than a cooling pond. The annual operating costs of wet cooling towers are also very high; estimated to be upwards of 10 percent per year of the installed cost (Edmonton Power, 1977c). There are several other problems inherent in wet cooling tower systems. Fogging problems, high noise levels and a generally undesirable visual effect are usually associated with wet cooling towers. The towers also require chemical treatment to preserve the structure. This would result in the discharge of certain undesirable chemicals, primarily zinc and chromium. A further problem associated with wet cooling towers is that make-up cannot be used at times of high river turbidity and an emergency reservoir of some 150 hectares (375 acres) would have to be constructed. These factors, in addition to the favourable land topography at the site, result in a cooling pond being the only practical solution for condenser cooling at the Genesee power plant.

The buildup of excessive concentrations in the cooling pond will be controlled by the introduction of make-up water from the North Saskatchewan River, some 4 km (2.4 mi) to the northwest. An average rate of 0.62 m^3/s (21.9 cfs) will be conveyed via a 762 mm (30 in) pipeline for make-up water requirements (Edmonton Power, 1977c). Simultaneously, blowdown from the pond will average 0.23 m^3/s (0.2 cfs) and be conveyed via a pipeline sized at 610 mm (24 in). Make-up and blowdown pumping will be halted during periods when river water suspended solids become excessively high. This period may be as long as eight weeks. The cooling water flows for each generating unit will be approximately 14.5 m^3/s (513 cfs) and the design temperature rise across the condensers is 8C (14.4F). The expected maximum and minimum temperatures of the pond water are 28C (82F) and 5C (41F) at full load.

In addition to the condenser cooling water, several plant waste effluents, after treatment, will be discharged to the cooling pond and represent a considerable volume, approximately 1,931 m^3/day (68,193 ft^3/day, Edmonton Power, 1977d). The estimated water quality of the cooling pond blowdown, like that for the Keephills and Sheerness cooling ponds, is simply a doubling of the river concentrations, in this case, the North Saskatchewan River at Devon (Table 2:2).

CONCLUSION

Several interesting, but disturbing, facts are evident in the foregoing description of the five thermal power plants operating in the province and the three stations proposed for development. The amounted of energy rejected by these plants on an annual basis is of a considerable magnitude. During 1978, the total heat rejected by these five power plants amounted to more than 85 x 10^{12} BTU's. Considering that it takes approximately 10,000 BTU's to produce one kWh of electricity in Alberta (A. Pettican, Edmonton Power, personal communication, June 1979), this total is equivalent to the energy required to produce 8.5 million MWH. When the Keephills, Sheerness and Genesee plants are finally constructed and operating at near capacity, this figure will approximately double.

Another disturbing fact revealed in this description of the eight power plants is the unusually large requirement for cooling water. Fortunately, this is not a consumptive use of water but problems are common nevertheless. The environmental concerns experienced at Lake Wabamun are a prime example of this. This has resulted in considerable expense for Calgary Power. The ongoing study at Lake Wabamun by Beak Consultants Ltd. has cost the utility about $2 million to date (Crosby-Diewold & Railton, 1978). If the results of this study are not acceptable to the Energy Resources Conservation Board, Calgary Power could be faced with seeking alternative cooling systems which might cost upwards of $40 million for a plant that is being operated as a peak load facility.

As is evident from the proposals for the construction of the Keephills, Sheerness and Genesee power plants, the utilities are moving to cooling pond systems as the only viable method for condenser cooling in this province. The main problem associated with this method is the quality of the pond discharge. It is proposed by the three utilities that the quality of this discharge will not exceed twice the concentrations of the pond make-up water source. A disturbing consequence of this is the potential effects on the receiving water body. At the Sheerness power development, the Red Deer River quality already exceeds several of the Provincial Water Quality Criteria parameters and a considerable volume of water, at twice the river concentrations, will be discharged into the river. A very serious problem could arise with the North Saskatchewan River. In this case, there will be three large thermal power plants discharging cooling pond blowdown to the river within a very short stretch of the river. Furthermore, the Keephills and Genesee plants will probably be doubling their capacities by the mid 1990's which means that a large quantity of cooling pond discharge, exhibiting twice the concentrations of the river water, will be released on almost a continuous basis to the North Saskatchewan River. The accumulated totals of this discharge will result in some decline in quality but it is difficult to determine whether this will have any detrimental effects on downstream users, if indeed there will be any effects.

Another problem associated with condenser cooling at thermal power plants is the quantity of electricity required to pump water through the condensers. The predicted energy balances for the Keephills (Table 2:5), Sheerness (Table 2:7) and Genesee (Table 2:13) plants indicate that approximately 2 percent of the input energy will be devoted to circulating water for the condensers. This represents a significant amount of electricity over an annual period.

Although this grossly inefficient use of energy is a serious problem, solutions are not easily attainable. It is highly unlikely that a technological solution can be developed to substantially increase the plant net thermal efficiencies. Nuclear power is not a solution as these plants are even less efficient than fossil fueled power plants. Nuclear power plants require much larger circulating water flows as well. Hydro electric power is not likely to continue meeting increased demands for electricity as the majority of favourable sites are already developed. A reduction in the demand for electricity is unlikely to occur for several decades and constant stress will be placed on the utilities to continue increasing the supply of electrical power. More efficient uses of power and a conserver society approach might complement plant development and slow down the rate of growth but this is not likely to occur in Alberta for some time because of the abundant supply of coal. Basically, the only short term solution to the problem would appear to be some concerted efforts to beneficially utilize this reject heat. Some of the applications which have the potential to partially achieve this solution are discussed in the following chapters.

CHAPTER III

GREENHOUSE HEATING

Introduction

Heating greenhouses with waste heat from thermal power plants has been conceptualized for a number of years. Utilizing power plant reject heat in this manner was considered as one potential method of thermal pollution reduction. This has since been rejected as a viable technique of dissipating reject heat from power plant condensers for two reasons. Firstly, vast acreages of greenhouses would be required to utilize all the waste heat from a single plant. Secondly, greenhouses would not utilize the reject heat during the summer months. Furthermore, in two separate greenhouse heating demonstration projects (Shaw et al, 1977; Ashley, 1978), it was observed that the temperature of the thermal effluent, after passing through the greenhouse heat exchange system, had been reduced by only approximately 4.5C (7 to 8F).

Although the concept of utilizing greenhouses as heat sinks for the reject heat from thermal power plants has been rejected as a viable alternative to conventional heat dissipation methods, the recent rapid escalation in energy costs has created a renewed interest in heating greenhouses with waste heat. The Canadian greenhouse industry has experienced soaring energy costs in the past five or six years. This has occurred despite efforts to improve the efficiency of greenhouse operations with respect to energy use. The current situation in the Canadian greenhouse industry is that the balance between viability and survival is precariously small because of a rapid increase in fuel costs particularly, but also labour and capital investment costs. Agriculture Canada (1978) reports that fuel, the major cost item for the industry, increased 21 percent in 1976. During the same period, the costs of materials and labour rose by 16 percent and 11 percent respectively. Alberta greenhouse growers are experiencing similar cost escalations, especially fuel costs, although in some parts of the province they remain the lowest in North America (Alberta Agriculture, 1978).

Despite these problems, the industry has continued to expand with an estimated 13,935 m^2 (150,000 ft^2) of greenhouse acreages started in Alberta in 1977 (Alberta Agriculture, 1978). In Canada, the total area devoted to greenhouses increased at an average annual rate of approximately

9.5 percent from 1974 to 1977 (Agriculture Canada, 1978). This growth indicates a continuing viability in the industry but the rapid escalation of costs is increasingly eroding this viability and is bound to have a detrimental effect on the industry's growth in the near future.

Canada's, and Alberta's deficit balance of trade in horticultural and floricultural crops, especially those that are commonly grown in greenhouses, is another cause for concern in the Canadian greenhouse industry. With an ever increasing demand for fresh vegetables by consumers, the greenhouse industry must continue to expand to prevent the deficit from increasing. This trade balance will be analyzed in detail in Chapter VII but if the greenhouse production of fresh vegetables and floral crops is to be increased substantially in Canada, the industry will have to maintain a distinct competitive advantage over imports. Without direct subsidization of the industry, or the imposition of additional customs and excise taxes and/or quotas on imports, this can only be accomplished if costs associated with the industry can be stabilized. Utilizing waste heat from steam electric generating stations as an energy source is potentially one method of stabilizing, or even marginally decreasing, fuel costs in greenhouse operations.

Based upon an increasing concern for more efficient uses of energy, numerous feasibility studies have been undertaken in Canada and the U.S. to investigate the potential for heating greenhouses with thermal power plant waste heat. Several demonstration projects have also been attempted, but two of these, the Lake Wabamun Thermal Water Use Project (Shaw et al, 1977) and the Sherco Greenhouse Project (Ashley, 1978), deserve particular attention. The Sherco project in Becker, Minnesota is probably the most successful greenhouse heating project of its kind in North America. The Lake Wabamun project, on the other hand, was a similar but less successful effort for reasons that will be discussed later in this chapter. Additional attempts at demonstrating the economic and technical feasibility of heating greenhouses with waste heat have been in regions experiencing moderate climates in comparison to Alberta's. For example, greenhouse heating projects have been established in Mexico, Tennessee, New York, Oregon, and Abu Dhabi (Beall & Yarosh, 1973). This chapter, therefore, will be a review of the Sherco and Lake Wabamun projects only and based upon the knowledge gained from these efforts, as well as information available in the literature, some basic conceptual designs for a future prototype greenhouse in Alberta will be presented.

THE SHERCO GREENHOUSE PROJECT

Project Origin

The Sherco Greenhouse Project was initially conceived in the early 1970's by the Northern States Power Company and evolved into a cooperative effort of the utility, the U.S. Environmental Protection Agency, and the University of Minnesota (Northern States Power Co., 1977). Prior to construction of the greenhouse on which this project is based, Northern States Power tested the concept of greenhouse heating with waste heat in a small 180 m^2 (2,000 ft^2) commercial greenhouse in 1974 and 1975 (Boyd et al, 1977). This research effort proved very successful and led to an award of $250,000 from the U.S. Environmental Protection Agency to demonstrate the technical and economic feasibility of utilizing power plant waste heat in a 0.2 hectare (0.5 acre) greenhouse. This grant was later increased to $340,000 (J. Hietala, Northern States Power Co., personal communication, August 1978).

The greenhouse, constructed in 1975, is located adjacent to the coal-fired Sherburne County power plant in

Becker, Minnesota 72.4 km (45 mi) northwest of Minneapolis. During the winter of 1975/76 the greenhouse was heated with simulated waste heat because the power plant remained under construction but since that time has been heated solely with reject heat from the generating station.

Greenhouse Structure

The greenhouse is a conventional gutter connected style, oriented on a north-south axis, with a double layer of air-inflated polyethylene roof and sidewalls (Figure 3:1). A north-south orientation was selected because it was felt to be superior to an east-west orientation at the latitude of the area. A gutter connected design was selected over several structures including quonset, air-inflated, and fully air-supported styles. The quonset design was rejected because of its increased surface area per coverage area and a fully air-supported structure was not considered because of potential collapse under heavy snow conditions (J. Hietala, Northern States Power Co., personal communication, August 1978). Double layer polyethylene was chosen as a covering material over conventional glass or fiberglass because it has a greater resistance to heat transfer and a lower capital cost (Boyd et al, 1977). Furthermore, double layer poly is becoming very popular with growers and the project coordi-

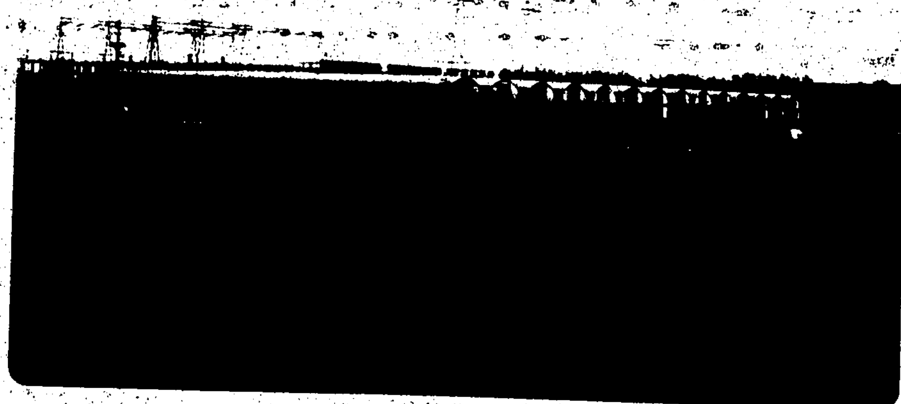


Figure 3:1 The Sherco greenhouse in Becker, Minnesota. Exhaust fans are evident in the ends of each bay while some of the power plant cooling towers can be seen just beyond the greenhouse under the transmission lines.

nators wanted to demonstrate a facility that is commercially acceptable (J. Hietala, Northern States Power Co., personal communication, August 1978). The one disadvantage of plastic, even though it is considerably less expensive than glass or fiberglass, is that it requires replacement every one or two years. Conventional covering materials cost upwards of six to eight times as much as polyethylene (McCullagh, 1978). At the Sherco project, the covering material has been replaced every year to avoid an embarassing failure despite the fact that most growers in the area get two years of use from it (J. Hietala, Northern States Power Co., personal communication, August 1978).

The greenhouse consists of fourteen gutter connected bays, each 5.2 m wide by 29.3 m long (17 ft x 96 ft, Ashley, 1978, p. 3). This provides a total enclosed ground area of 2,123 m^2 (22,848 ft^2). The height from the ground to the gutters is 2.4 m (8 ft). A headhouse has been provided at the north end of the greenhouse and measures 12.2 m by 18.3 m (40 ft x 60 ft). This contains a production area, boiler room, data acquisition and control room, and two offices and a restroom.

Heating and Cooling Systems

Heating requirements for the facility were based upon a minimum winter condenser water temperature of 29.5C (85F), a minimum outside design air temperature of -34.5C (-30F), and a design inside air temperature of 10C (50F, Ashley, 1978, p. 3). These design criteria resulted in the calculation of a design heat loss from the structure of 2.2 million BTU's per hour. To meet this heating requirement, each bay in the greenhouse is supplied by warm air from a commercially available packaged fan-coil air handling unit. The air handlers have fin tube heat exchangers estimated to transfer 145,000 BTU's per hour from 29.5C (85F) entering water to 10C (50F) entering air (Boyd et al, 1977, p. 4). The air handlers are powered by 3 horsepower electric motors designed to deliver 3.3 m^3/s (7000 cfm) of air. The design water flow rate for each unit is 0.0018 m^3/s (29 USGPM) for a total flow of 0.0256 m^3/s (406 USGPM).

Warm air from the heat exchange units is distributed the length of each bay through a 0.76 m (30 in) diameter perforated polyethylene duct (Figure 3:2, Boyd et al, 1977, p. 4). This heating system is completely closed with all supply air being recirculated through the heat exchange system. The system has provisions for drawing in outside air but this is used only periodically during the day as a horticultural tool (J. Hietala, Northern States Power Co., personal communication, August 1978). A schematic diagram

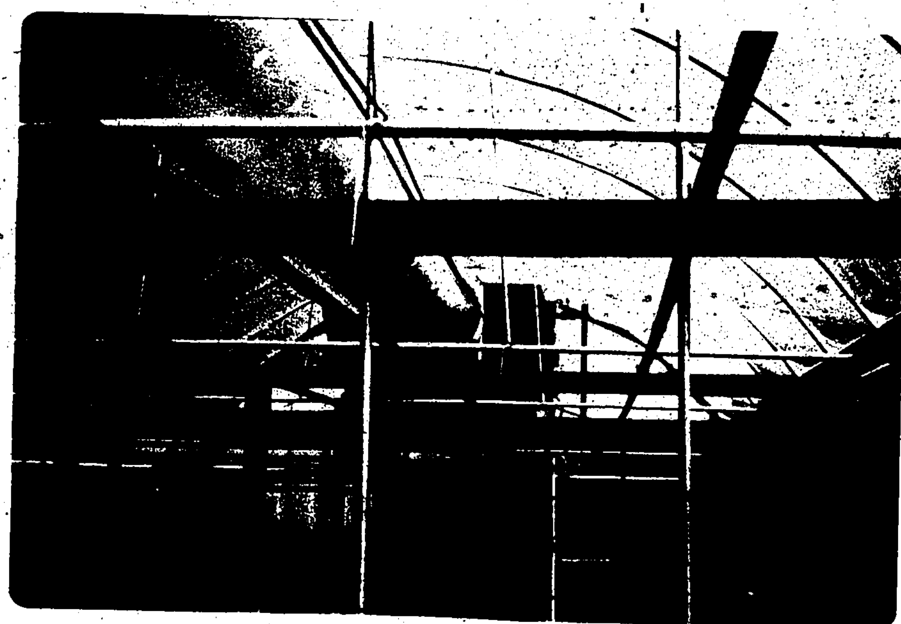


Figure 3:2 One of the perforated polyethylene air distribution ducts that run the full length of each bay in the Sherco greenhouse. The supply air fan and mixing chamber are enclosed at the end of the duct.

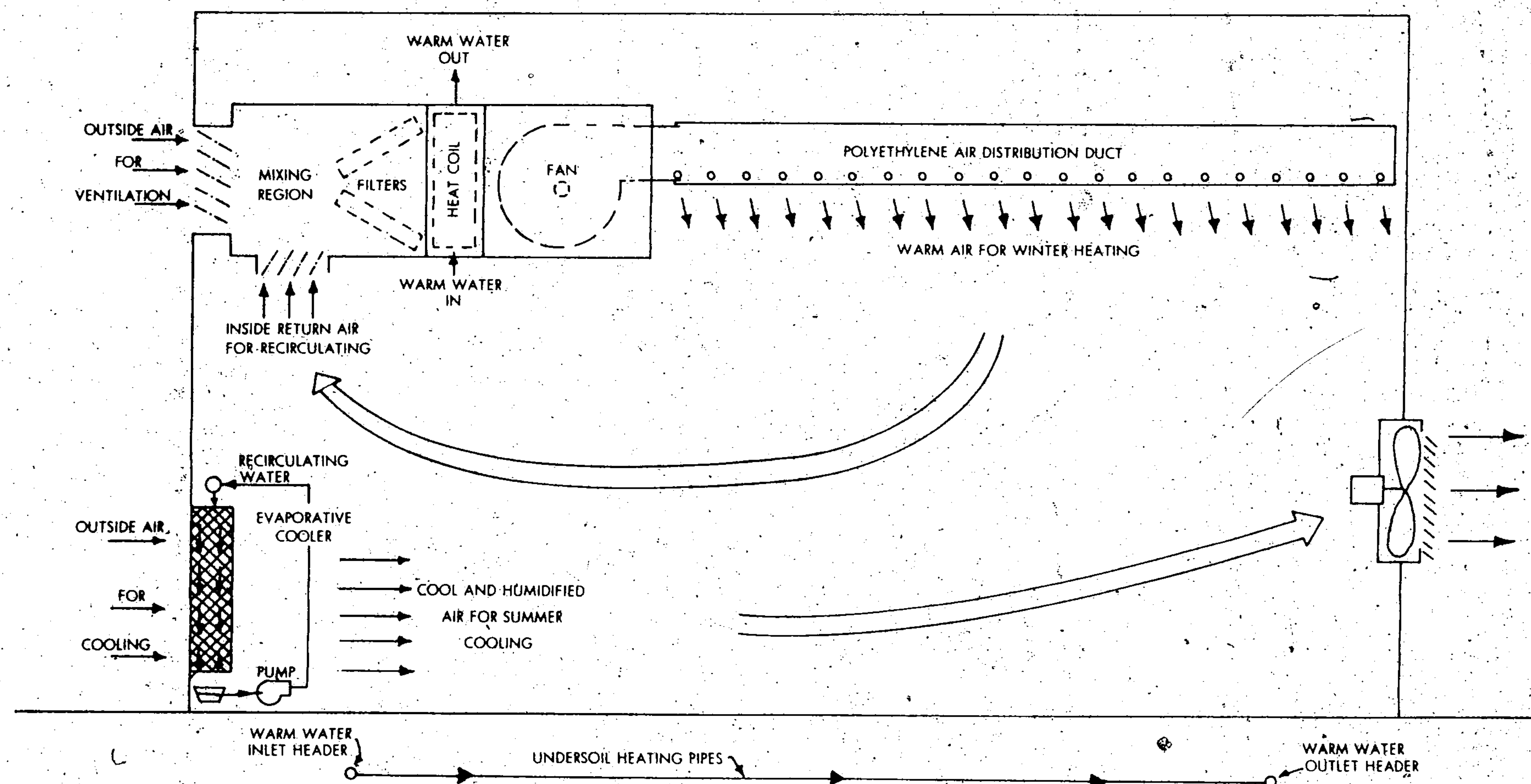
of the air heating system is provided in Figure 3.3.

In addition to the air heating system, a soil heating system was also installed in the greenhouse. This consists of 2.54 cm (1 in) diameter polyethylene pipe spaced 0.61 m (24 in) on centres and buried 30.5 cm (12 in) below the soil surface (Boyd et al, 1977, p. 4). Warm effluent is circulated through these pipes at a rate of about 0.0071 m^3/s (112 USGPM) with a design temperature drop of 5.6C (10F). This was based upon a 10C (50F) soil temperature and a desired root zone temperature of 15.6C (60F). The soil heating system was installed primarily as a horticultural tool to increase crop yields but there is some evidence to indicate that it may be contributing up to 5 percent of the greenhouse heating requirements (J. Hietala, Northern States Power Co., personal communication, August 1978).

Thermal effluent for the greenhouse air and soil heating systems is taken from two cooling tower riser pipes prior to entering the power plant mechanical draft cooling towers. The distance from the riser pipes to the greenhouse is approximately 1070 m (3500 ft) and the water is transmitted via an underground, uninsulated pipe that is buried to a depth of 1.52 m (5 ft, Ashley & Hietala, 1977, p. 4). The water flow capacity of this pipeline is 0.10 m^3/s (1600

Figure 3:3

SHERCO GREENHOUSE HEATING AND COOLING SYSTEM SCHEMATIC



Source: Ashley, 1978, p. 12.

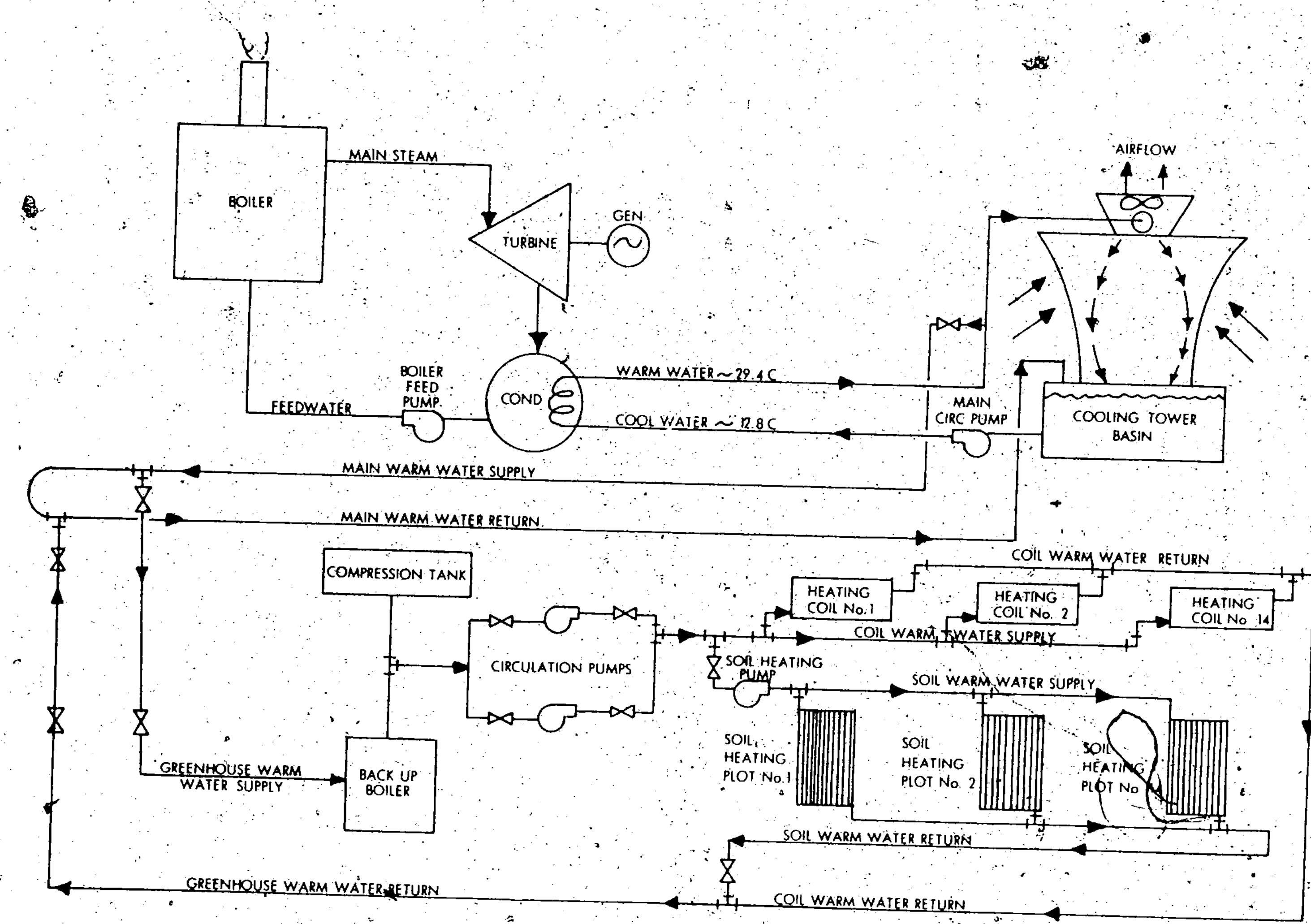
USGPM). Return flows from the greenhouse are transmitted back to the cooling towers by another 1070 m (3500 ft) pipe-line. A schematic illustration of the system is presented in Figure 3:4.

A cooling system designed to offset solar influx gains during the summer months has also been installed in the greenhouse. It is a standard evaporative cooling system comprised of 0.91 m (36 in) high evaporative pads that run along the entire north wall of the greenhouse (Figure 3:5). Supply water for this system is obtained from a well and is allowed to drip over and through the pads at a rate of 0.0076 m^3/s (120 USGPM, Boyd et al, 1977, p. 5). Exhaust fans located in each bay draw cooled air through the wetted pads at a design airflow rate of 84.5 m^3/s (179,000 cfm).

In addition to these systems, the greenhouse is equiped with emergency standby heaters and a standby electric generator. The backup heating source consists of two 390 kW electric hot water boilers. If a power outage occurs, six 102,575 watt propane-fired forced air heaters are available while a 10 kW propane-fired electric generator provides electricity for the heaters and lights for the facility (Boyd ét al, 1977, p. 6).

Figure 3:4

SCHEMATIC DIAGRAM OF SHERCO GREENHOUSE COOLING WATER SYSTEM



Source: Boyd et al, 1977, p. 12.

Figure 3:5 Part of the evaporative pad cooling system employed at the Sherco greenhouse for summer cooling. This system uses cool well water and runs along the entire north wall of the greenhouse. Deflated air distribution ducts can be seen in the upper middle portion of the photo.

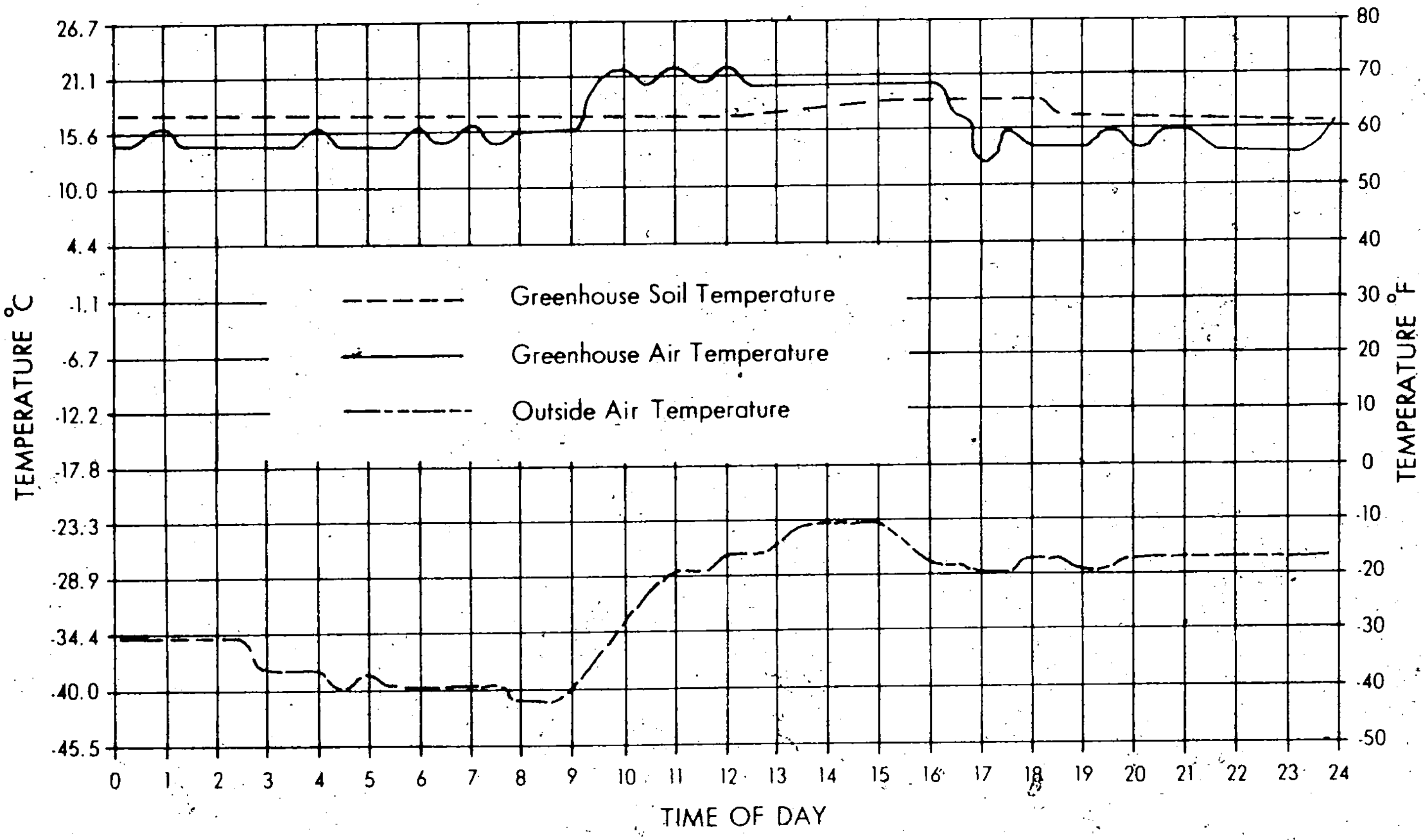
Operation Experience

The operation of the Sherco greenhouse has been very successful to date. The 1976/77 heating season, when the greenhouse was first heated solely with waste heat, was the second coldest winter on record in the Becker area. The coldest day of that winter was January 9 when the outside air temperature dropped to -41.4C (-42.6F). The inside air temperature at this time was maintained at 14.4C (58F) or greater (Boyd et al, 1977, p. 7). The performance of the greenhouse and heating system on this date is illustrated in Figure 3:6. As indicated in the graph, the average ambient air temperature for that day was -31.0C (-23.8F) while the average inside air temperature was 15.3C (59.5F, Ashley, 1978, p. 6).

The primary reason for the maintenance of a favourable greenhouse inside air temperature was the relatively high supply water temperatures that were available. When the outside air temperature dropped to -41.4C on January 9, 1977, the temperature of the supply water was 32.7C (90.9F). To their advantage, it has been found that the supply water temperatures are highest (32.2C to 37.8C) during the most severe weather. There are two reasons for this. First, during extremely cold weather, the demand for electricity

Figure 3:6

PERFORMANCE OF THE SHERCO GREENHOUSE HEATING SYSTEM DURING THE COLDEST 24 HOUR PERIOD OF THE 1976/77 HEATING SEASON (JANUARY 9, 1977)



Source: Boyd et al, 1977 p. 17.

is very high requiring high output from the generators. Second, when ambient air temperatures drop to -28.9C (-20F) to -34.4C (-30F), the power plant operators increase the condenser discharge water temperature to prevent localized ice formation in the cooling towers (J. Hietala, Northern States Power Co., personal communication, August 1978).

Crop Production

A wide variety of vegetable and floricultural crops have been produced in the greenhouse. During the first heating season, started in January 1976, roses, tomatoes, and peppers were planted. The roses produced well but the tomatoes and peppers were disappointing in terms of yield and also because of local wholesale price levels in terms of economic returns (Ashley, 1978, p. 8). These crops were replaced with lettuce and snapdragons from August 1976 through January 1977. The lettuce showed little promise because of high labour input compared to returns but the snapdragons achieved fairly promising yields in terms of economic return with limited labour input.

The 1977 season began in February with tomatoes once again being planted. This time better yields were achieved because of the previous year's experience and the addition of a carbon dioxide enrichment system. After the tomatoes were harvested, snapdragons, freesia, cineraria and geraniums were planted so that the whole greenhouse was devoted to floral production. It was felt that the overall vegetable crop production experience did not indicate that tomatoes, or others, were unacceptable, but market conditions prevailing were such that the floral production was much more valuable (Ashley, 1978).

Problems Encountered

Two problems were encountered during the first years of operation at the greenhouse. The most troublesome problem was the fouling of heat exchangers and associated piping with organic and silt materials. Deposition thicknesses of up to 3.2 mm (1/8 in) were noted on sections of a 15.2 cm (6 in) pipeline. The main 30.5 cm (12 in) supply pipeline's capacity was reduced from 0.10 m^3/s (1600 USGPM) to 0.0631 m^3/s (1000 USGPM). To overcome this problem, a chlorine injection system was introduced in the supply pipeline (J. Hietala, Northern States Power Co., personal communication, August 1978).

A less serious problem encountered was plume shading. Cooling tower vapour plumes have caused a shading effect over the greenhouse. It is felt, however, that this will not cause any serious lighting problems with the particular location of the greenhouse site.

Adoption

Due to the success of this demonstration project, Northern States Power was approached by commercial greenhouse operators in the Spring of 1977 and asked to provide a site and warm water service to a 0.4 hectare (1 acre) commercial floral operation and to a 0.08 hectare (0.2 acre) commercial vegetable operation. These requests were granted and construction of both facilities began in the summer of 1977. Warm water was first delivered to the floral operation in November of that year while the vegetable operation did not require warm water service until February 1978. The floral operator has devoted his whole facility to rose production after initially growing chrysanthemums and roses. Lettuce and spinach were the first crops grown in the other facility (Ashley, 1978).

The floral operator's greenhouse is identical in design and covering material to the Sherco greenhouse but it has seventeen gutter connected bays measuring 5.25 m wide by 43.2 m long (17.2 ft x 141.7 ft) for a total enclosed area of 3855.5 m^2 (41,500 ft^2). The heating system for this facility includes both air and soil warming, similar to that used in the Sherco greenhouse. The vegetable grower's facility consists of two quonset style greenhouses that are covered with a double layer of polyethylene. Each structure measures 9 m wide by 45 m long (29.5 ft x 147.6 ft). The heating system is basically the same as that employed at the two other greenhouses except the air distribution system is under the growing beds. This operator is using a hydroponic culture method.

In order to allow for future expansion of greenhouse operations at the power plant, as well as providing a more reliable warm water service, Northern States Power made an interconnection between the two generating units so that waste heat could be provided from either of the units. This was accomplished by tying into the second unit riser pipe at the cooling tower and a cast iron pipeline was constructed to interconnect with the previously existing pipeline. This uninsulated pipeline is sized at 45 cm (18 in) in diameter and buried to a depth of about 1.5 m (5 ft). This additional pipeline provides the utility with the capability of delivering sufficient warm water to heat up to fourteen acres of greenhouses at the site.

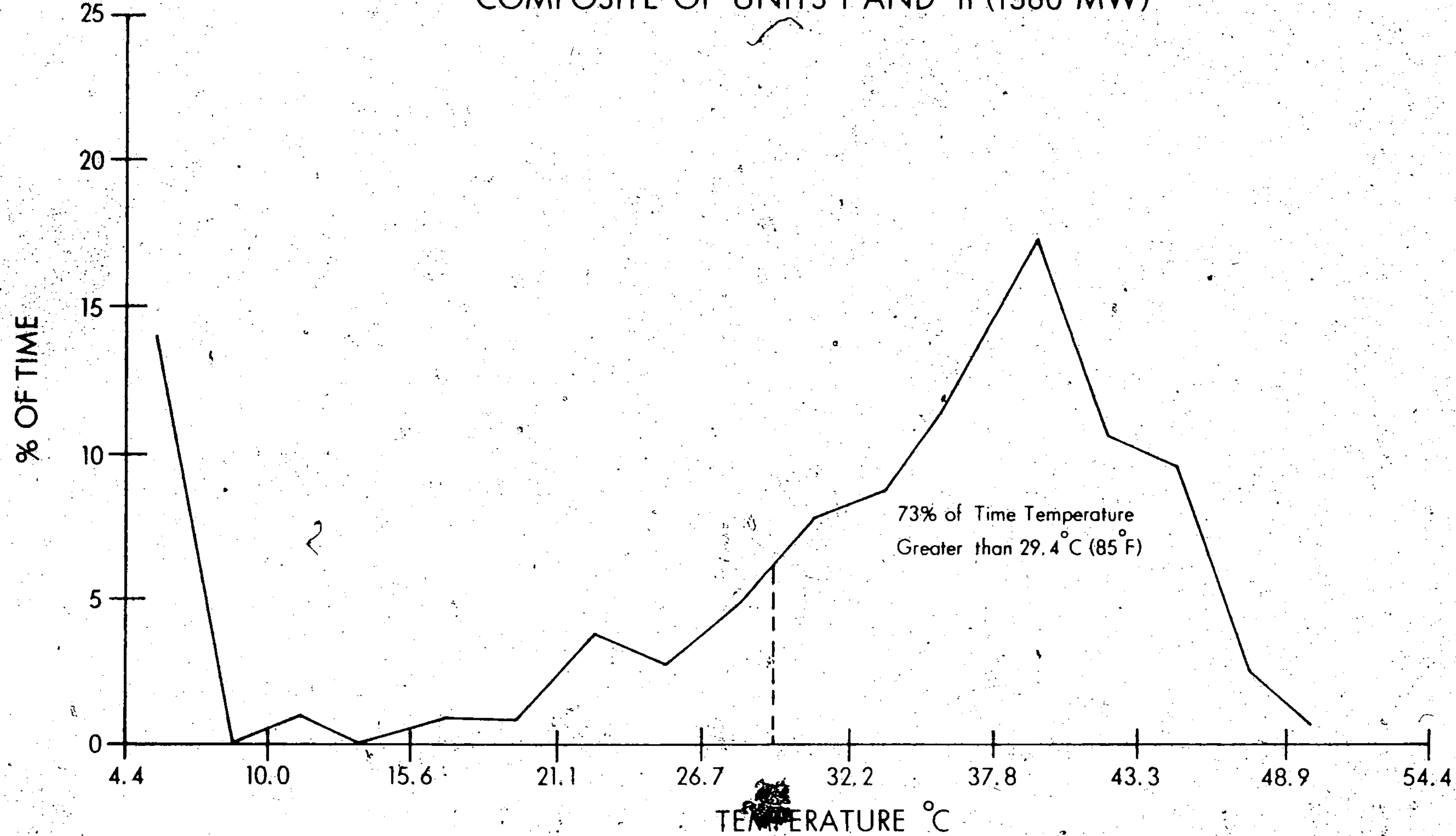
The reliability of the warm water service has been very good. During the first heating season that warm water service became commercially available (November 2, 1977 to the end of May 1978), the overall availability of the warm water was 96.6 percent (Ashley, 1978, p. 7). During this thirty week period, there were only four weeks when warm water was unavailable for part of the time. This was caused primarily by pipeline failures, reductions in electrical load over night, and to some extent, frozen coal pile problems experienced at the power plant. Although warm water service was available 96.6 percent of the time during the heating season, it was not always available at temperatures high enough for maintaining a greenhouse environment desired by the operators. Warm water over 29.4C (85F) was available 73 percent of the time during the first heating season. Supplemental heat for the remaining 27 percent of the time was provided by the propane-fired backup heating systems in the commercial greenhouses. The overall reliability of warm water at the site during the 1977/78 heating season is illustrated in Figure 3:7. It is expected that in the future the operating availability of the pipeline system will improve and the supplemental and standby heat energy requirements will be diminished (Ashley, 1978).

Economics

Based on operating experience at the Sherco Greenhouse Project, it has been found that conditions are such

Figure 3:7

SHERCO GREENHOUSE SUPPLY WATER TEMPERATURE DISTRIBUTION, JANUARY 1978
COMPOSITE OF UNITS I AND II (1360 MW)



Source: Ashley et al, 1978, p. 10.

that the concept appears economically feasible. There are four basic costs associated with this facility:

1) capital cost of the equipment,
2) electricity costs,
3) warm water delivery costs, and
4) the cost for standby propane.

Ashley (1978) reports that for the Minnesota climatic conditions, the estimated installed cost of a complete 0.4 hectare (1 acre) warm water heating system including controls, electrical work, and a backup heating system is about $85,000 (1978 U.S. dollars). This consists of $60,000 for materials and $25,000 for union craft labour. This compares to conventional greenhouse heating systems that, on the same basis, might cost anywhere from $25,000 to $50,000 per acre in Minnesota. It is felt that an individual operator could install the heating system himself for considerably less than $85,000.

The electricity costs associated with a project of this nature are quite high because a significant amount of electrical energy is required by the fans and pumps to produce the desired heat transfer rate. For example, the total electric power consumption for circulating water pumps and heat exchanger fans in the Sherco greenhouse was 73,786 kWH for the period October 1, 1976 to March 1, 1977 (Ashley & Hietala, 1977, p. 13). The estimated operating cost for electricity on a per acre year basis at the Sherco site is $8,000 (Ashley, 1978, p. 9).

Northern States Power has maintained the position that there is no energy value placed on the waste heat but a charge for the costs associated with pumping the water and the overall operation and maintenance of the pipeline has been fixed at roughly one cent per 3785 litres (1000 USG) of water delivered. At this rate, a typical one acre greenhouse operation would realize an operating cost of about $1,500 per year (Ashley, 1978, p. 9). This is in addition to an approximate capital cost of $6,500 per acre for installation of the pipeline. This is relatively expensive but Northern States Power has adopted a policy of offering the commercial growers long-term, fixed-price contracts to pay for costs. In this manner, the commercial operators are assessed their portion of the cost of the pipeline network and are then allowed to pay for it over a period of twenty years (Ashley, 1978).

The fourth basic cost associated with a greenhouse of this nature is the cost for standby propane. This has been estimated to be approximately $2,000 per acre year. This results in a total operating cost on a per acre year basis of $18,000. A comparison of the operating costs of a waste heat system versus a conventional system is presented in Table 3.1. This indicates an apparent savings of $8,000 per acre year by utilizing a waste heat system. Extrapolated to the year 1998, this savings increases to $42,000 per acre year. To date, operating experience of the commercial growers at the Sherco site has indicated that the warm water system fell short of the projected annual savings but there is optimism these projected values will be achieved in the forthcoming years (Ashley, 1978).

Table 3:1

COMPARATIVE OPERATING COSTS OF WASTE HEAT VERSUS CONVENTIONAL HEATING AT THE SHERCO PROJECT

(1978 U.S. DOLLARS)

	1978 Costs		1998	
	Waste Heat	Conventional	Waste Heat	Conventional
Fuel Cost				
Standby Propane	$2,000	-	$6,000	-
#2 Fuel Oil	-	$25,000	-	$80,000
Electricity	$8,000	$1,000	$26,000	$4,000
Waste Heat Cost	$8,000	-	$10,000	-
Total Per Acre Per Year	$18,000	$26,000	$42,000	$84,000

Basis: #2 Fuel Oil @ $0.45/gal.
Propane Cost @ $0.43/gal.
Electricity Cost @ 3.5¢/kwh.
Future Fuel and Utilities Escalate @ 6%/year.

Source: Ashley, 1978, p. 10.

THE LAKE WABAMUN THERMAL WATER USE PROJECT

Background Information

As previously mentioned, the Sherco Greenhouse Project is probably the most successful of its kind in North America. In contrast however, the Lake Wabamun Thermal Water Use Project was probably one of the least successful of its kind on this continent. This poorly planned effort was a cooperative venture of Alberta Agriculture, Calgary Power Ltd., Alberta Government Services, Alberta Business Development and Tourism, and Alberta Environment. It consisted of a 30.48 m by 9.75 m (100 ft x 32 ft) fiberglass covered, arch type greenhouse located adjacent to the Wabamun power plant discharge canal. The objectives of this project were "to determine the operational parameters of a specific system to utilize beneficially otherwise waste heat in a viable agricultural enterprise" (Shaw et al, 1977, p. 2). In other words, it was an attempt to heat a greenhouse with reject heat from the Wabamun power plant.

Heating System

The heat exchange system used in this greenhouse consisted of a stack of precisely spaced polypropylene monofilament, wound on a redwood frame. Warm water from the discharge canal was pumped into the greenhouse and allowed to cascade down through the monofilament medium while two fans drew outside air through the stack. Two exhaust fans were installed in the opposite end of the greenhouse to balance the air intake system. The average supply water flow was 27.66 litres per minute (365 IGPM) during the project period. Return flows were discharged back into the canal. Soil heating was attempted in metal and wooden boxes and beneath a small area of the greenhouse.

Operation Experience

The environment created by the heat exchange unit was evaluated for its suitability to crop production. For this purpose, a variety of vegetable and ornamental crops were grown including tomatoes, cucumbers, radishes, broccoli, geraniums, and hardwood cuttings of several tree species.

The project was beset with problems from the start. The heat exchange system created very high relative humidity levels in the greenhouse. This caused several problems as the inside air was effectively saturated at all times. Free water on plants, conducive to fungus growth, occurred whenever the dew point was reached. The dripping of condensation from the structure onto the plants fostered rot and tissue breakdown. This dripping also saturated the soil and delayed soil preparation and planting.

The high humidity levels and cold winter air led to several mechanical failures. Icing of fans and freezing of the heat exchange medium were two very serious problems encountered. Ice accumulation on the blades of the supply air fan caused both a decrease in fan output and overloaded the fan motor. This situation also occurred on the exhaust fans and required frequent supervision during cold weather. On the lower surface of the heat exchange unit, where cold outside air was in direct contact with the heat exchange medium, many of the filaments were broken as was the wooden frame on one occasion. This also required close supervision and frequent stoppages of the fans to remove the ice.

Algae accumulation in the heat exchange unit resulted in the total clogging of several spray nozzles. This problem occurred even though all water supplied to the system was passed through a self-cleaning mechanical strainer.

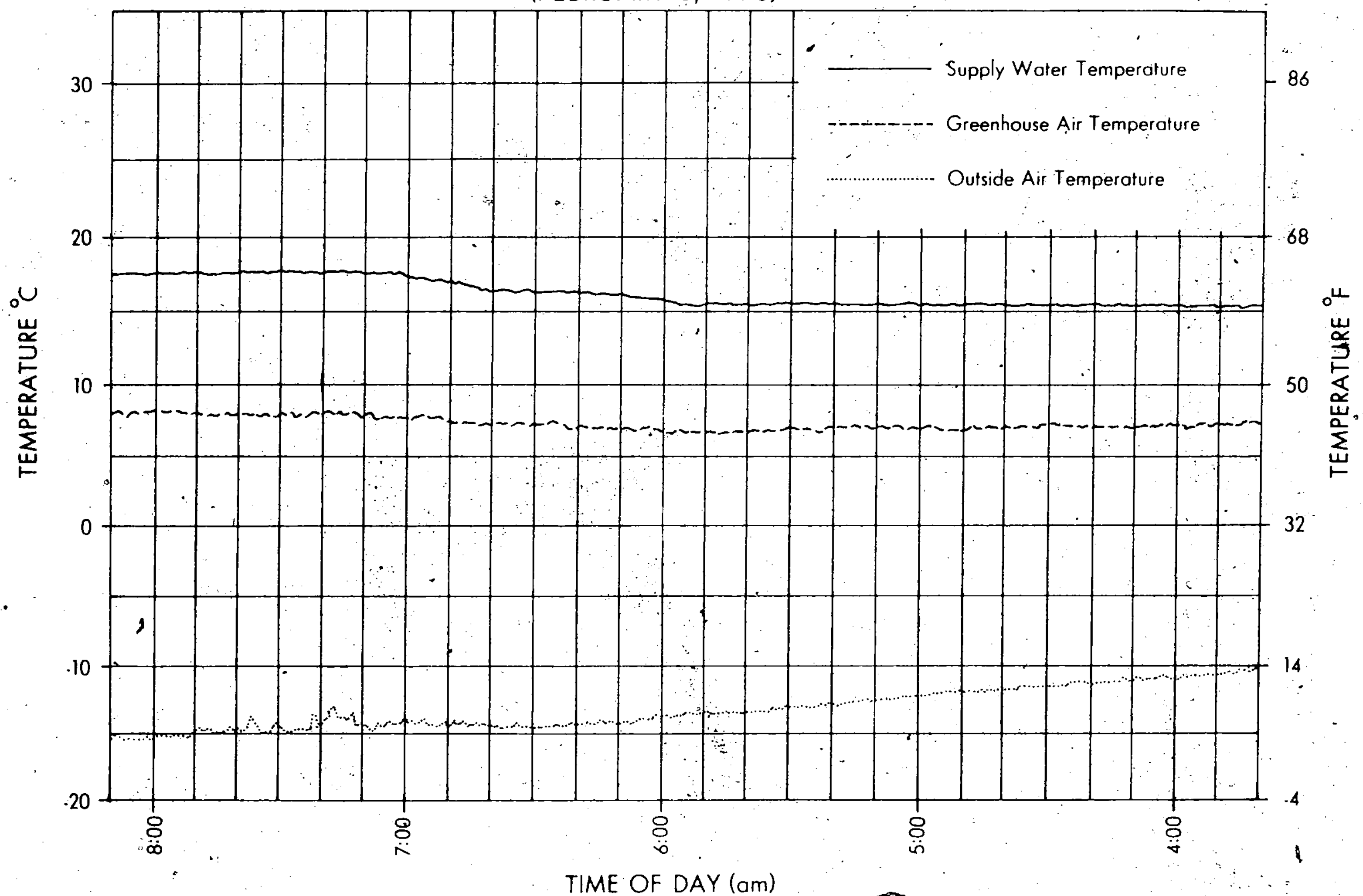
Mitigative measures intended to control this problem included shutting down the unit to disassemble and clean the nozzles. Algaecide was not employed because of the potential damage to the plants and the hazard of discharging the material to the lake in the return water.

A further problem associated with the high relative humidity levels was the buildup of heavy frost on the inside of the fiberglass. This frost formation reached up to 35 mm (1.4 in) in thickness and reduced light levels within the greenhouse to about 25 percent of outdoor illumination. Normally, 85 to 90 percent light transmission would be expected through the fiberglass of the type used in this project (Shaw et al, 1977, p. 22).

Although these failings caused innumerable difficulties, by far the greatest problem experienced in this project was low inside air temperatures. This was caused largely by low supply water temperatures. Furthermore, the long-term effluent temperatures are directly proportional to the long-term outside air temperatures so that the colder the ambient air, the colder the supply water. Figure 3:8 illustrates the low air and water temperature problems encountered, especially when compared to a similar graph for the Sherco greenhouse (Figure 3:6). Over a nineteen week

Figure 3:8

PERFORMANCE OF THE WABAMUN GREENHOUSE DURING NORMAL OPERATION (FEBRUARY 3, 1976)



Source: Shaw et al, 1977, p. 11.

period beginning November 24, 1975 and ending April 4, 1976, the difference between the greenhouse air temperature and the supply water temperatures averaged only 5.6C (10F). The resulting inside air temperatures during this period ranged from only 7.1C (44.8F) to 16.5C (61.7F). Consequently, the greenhouse air temperatures were relatively low in comparison to the growing requirements of most crops during this period of the year. This was reflected in the crop production as poor plant growth was observed beginning in the fall and continued throughout the winter. Late planted crops did not develop and rooting trials with most species gave little success.

The low supply water temperatures were the primary cause of the cool inside air temperatures and the resultant poor crop production as the heat exchange system proved to be very efficient within the constraints of the water temperatures available. The authors indicate that a minimum supply water temperature of 27C (80.6F) is necessary for the maintenance of optimal greenhouse temperatures, employing a similar system to that used in this project. Although 27C would have been the desired water temperature, minimum monthly average effluent temperatures at the point of withdrawal were frequently in the 13C to 14C (55.4F to 57.2F) range during the winter.

The main conclusion drawn from the results of operation of this pilot project was that the energy costs of the experimental system were 300 to 800 percent that of a conventional greenhouse in terms of heating capital and operating costs. Therefore, the authors state that, on the basis of the experimental results, the energy recovery system tested cannot be recommended as a method of commercial greenhouse heating. It is also suggested however, that modifications to the test system and future changes in energy costs may alter the economics of the system. Three recommendations are proposed to improve the system's efficiency and economic viability:

1) using water directly from the plant discharge rather than from the canal to provide higher temperature supply water,
2) reducing the lift distance of this water, and
3) sealing the greenhouse to prevent excessive air loss.

Project Analysis

In comparison to the Sherco Greenhouse Project, the Lake Wabamun Thermal Water Use Project was a dismal failure, even though the objectives of both projects were basically similar. The reasons for this can only be in the initial planning and design of the Wabamun project and a thorough analysis of the effort reveals this to be the case.

The first oversight was the greenhouse structure and the fiberglass covering material. There is considerable debate over the proper orientation for greenhouses but it is now conceded that greenhouses located at latitudes above 35 N should be oriented on an east-west axis to optimize solar gains (Mastalerz, 1977, p. 70). The structure was constructed with a high arch, to prevent snow accumulation, but this necessitated the use of additional wooden struts for support which intercepted solar radiation and provided a surface for the formation of condensation. The size of the greenhouse also contributed to the poor results. According to Shaw (Greenhouse Specialist, Brooks Horticulture Research Station, personal communication, July 1978), only a very small greenhouse could be constructed because of budget restrictions. A larger structure would have benefited from improved efficiencies and economies of scale.

The selection of fiberglass was a poor choice of a covering material for this particular application. It was very poorly sealed and allowed for excessive infiltration. This is evident in the fact that heat loss and temperature drop in the greenhouse were as much as 40 percent greater than predicted (Shaw et al, 1977, p. 24). A covering material of double layer polyethylene would have been more practical as this material provides a very tight seal (Blom et al, 1978, p. 4). In addition, double layer poly as a covering material can increase heat savings by up to 40 percent over conventional materials such as glass and fiberglass (D. Shaw, Greenhouse Specialist, Brooks Horticulture Research Station, personal communication, July 1978). The use of polyethylene would also have eliminated the problem of ice accumulation on the inside of the greenhouse. Obviously, the designers of the greenhouse had a very poor knowledge of optimum greenhouse designs for areas experiencing cold climates.

The choice of an indirect heat exchange system, such as that selected for the Sherco greenhouse, would have eliminated the humidity related problems. For numerous reasons, there was absolutely no justification for choosing a direct contact, evaporative type heating system. First, an identical heat exchange system had been previously tested at the Brooks Horticulture Research Station and found to create excessive humidity levels, especially during cooler periods (D. Shaw, Greenhouse Specialist, Brooks Horticulture Research Station, personal communication, July 1978). Second, there is documented evidence, predating the project (e.g., Boersma & Rykbost, 1973; Beall, 1973), that direct contact evaporative pad heat exchangers create high humidity levels, especially during colder weather. Finally, as outlined in their list of alternative techniques that were considered for the purpose of this project, the project coordinators recognized beforehand the potential humidity problems that could be expected. One of these alternative techniques is listed: "mass transfer system - either a pad and fan system or a Filacell device would require large air flows through the house and, unless reheat facilities were included, excessive humidity would result" (Shaw et al, 1977, p. 2). Furthermore, on page three of that report, the Filacell heat exchange system is described as being unique in that it "... cannot function as a heat exchange medium without the flow of water; hence, air handled by this system is essentially saturated." This clearly indicates that high relative humidity levels were expected in the greenhouse but dry contact systems were not even considered as an alternative technique. Therefore, the only logical explanation for having selected this heating system is that it was the least expensive.

Another apparent serious ommission in the initial design of the Wabamun project was the decision to neglect soil heating throughout the greenhouse. This decision was also apparently a result of budgetary restrictions (D. Shaw, Greenhouse Specialist, Brooks Horticulture Research Station, personal communication, July 1978). This is unfortunate because soil heating probably would have supplemented the air heating requirements as well as providing a horticultural tool. Soil heating at the Sherco greenhouse was thought to contribute up to 5 percent of that greenhouse's make up heat requirements. Conestoga-Rovers and Associates (1977, p. II-47) report, in their study on waste heat utilization at the Bruce Nuclear Power Development in Ontario, that soil heating would contribute approximately 5 percent to the heat requirements of a greenhouse. Boersma & Rykbost (1975, p. 29) found that soil heating in a double layer polyethylene covered greenhouse resulted in inside air temperatures 3.5C (6F) above the ambient night temperatures. The results of experiments with soil heating in Oregon (Berry & Miller, 1974, p. 149) indicated that greenhouse minimum air temperatures averaged 4.8C (8.2F) higher than ambient minimums for the March 1972 through March 1973 period.

With respect to the low supply water temperatures being the primary cause of the low inside air temperatures at the Wabamun project, there is once again absolutely no justification for not having recognized this problem beforehand. The outlet water temperatures at the Wabamun plant are recorded and a simple review of previous years records would have clearly indicated the water temperatures that could be expected. In addition, the point of supply water withdrawal was totally inadequate because it was mid-way down the discharge canal. By the time the effluent reaches this point it has already cooled somewhat. The optimum withdrawal point would have been at the condenser outlet where the water temperatures are much higher. Another method for providing warmer inside air temperatures would have been to recirculate the air within the greenhouse, rather than heating outside air that often dropped to -25C (-13F), with 15C (59F) supply water.

The conclusion that the greenhouse energy costs were 300 percent to 800 percent that of a conventional greenhouse is not open to debate. The operating costs of this project were exorbitant however, and a review of these expenditures reveals considerable room for improvement.

The major factor contributing to the energy costs at the Wabamun greenhouse was an extremely high consumption of electricity. The net power consumption of the project averaged about 840 kWH per day which corresponded to an electricity cost of $25.20 per day. This was 1.7 times as much electricity consumed as that at the Sherco greenhouse which has 7 times the enclosed area. The authors have also projected this cost to that which could be expected for a one acre greenhouse by estimating that a ten-fold increase in area would increase the operating costs by a factor of eight. On this basis, the power costs for a one acre greenhouse would be $6,048 per month. This is considerably more than the estimated cost of $8,000 per year for electricity and $1,500 for waste heat delivery for a one acre greenhouse at the Sherco site.

The extremely high power consumption rates at the Wabamun project are attributed to two factors. First, the largest consumers of electricity in the greenhouse were the two supply air fans and the two exhaust fans. These fans represented approximately 43.5 percent and 18.8 percent respectively, of the total greenhouse electricity load. This corresponds to about 21.5 kW of the total 35 kW of input power in the greenhouse operation. The reason for this was a unique characteristic of the heat exchange system. That is, the demand for power is nearly constant throughout the year, regardless of outdoor conditions. Therefore, the consumption of electricity remains the same, winter or summer. The power costs could have been reduced if an air recirculation system had been employed in the greenhouse. This would have eliminated the need to operate exhaust fans on a continuous basis.

The second factor that contributed to the high power consumption was the pumping of supply water to the heat exchange unit. This required approximately 36 percent, or 12.6 kW, of the total greenhouse electricity load. The primary reason so much electricity was used for pumping water is that the lift distance was approximately 10.2 m (30 ft, D. Shaw, Greenhouse Specialist, Brooks Horticulture Research Station, personal communication, July 1978). A direct connection of the supply water pipeline to the condenser outlet would have substantially reduced this lift distance and correspondingly, the power consumption.

The methods employed by the authors of this project for estimating the capital cost of a one acre greenhouse with an identical heating system are also suspect. They report that the capital cost for the mechanical system used at the Wabamun greenhouse was $40,000. The authors have once again taken the simplistic approach of predicting that a ten-fold increase in area to one acre would increase the capital cost by a factor of eight. This would result in a capital cost of $320,000 for a one acre facility. This is considerably more than the estimated capital cost for a one acre greenhouse heating system at the Sherco site. Furthermore, the $320,000 does not include standby heating and soil heating.

This foregoing discussion of the Lake Wabamun Thermal Water Use Project demonstrates the poor planning and mismanagement associated with the operation. The project was obviously a classic "white elephant." The effort suffered from poor quality engineering and poor teamwork. In addition, there was apparently very poor communication between the various people involved in the project and little support from the upper management (D. Shaw, Greenhouse Specialist, Brooks Horticulture Research Station, personal communication, July 1978). The budget restrictions did not allow for any recommendations to be taken into account, such as altering the supply water withdrawal point.

The accumulated effects of this project have been more detrimental than beneficial, especially since the evidence seems to indicate that the project was destined to fail from the start. The poor results attained have simply provided ammunition for those opposed to attempting the utilization of waste heat from thermal power plants in Alberta. Because of this, the hurdles to overcome in establishing a future prototype study of this nature in Alberta have become even greater and will make the task even more difficult that it already is. Obviously, the Lake Wabamun project should never have been allowed to proceed in the manner in which it was designed.

CONCEPTUAL DESIGNS FOR A FUTURE PROTOTYPE GREENHOUSE

Optimum Location

The Sundance power plant, of the existing power plants in this province, is the optimum site for developing a future prototype greenhouse heated with waste heat. The remaining plants, for various reasons, would not be suitable locations for this purpose. The Wabamun plant is now being operated on a peak load basis which results in a totally unreliable source of warm water. In addition, there is a lack of available land in the vicinity of this plant. To the east of the station is the hamlet of Wabamun, to the south is the lake, and ash lagoons and coal stockpiles are situated on the west and north sides of the station. Similarly, the Forestburg power plant has very little land near the plant on which to develop greenhouse heating on a large scale without pumping the water a lift distance of about 53.3 m (175 ft) up out of the river valley. The Rossdale station would not be a practical site because of its urban location while the flats north of the Clover Bar plant have only marginal potential for this application.

The Sundance plant is the largest thermal power plant in Alberta and is operated on a base load basis. There will be six generating units when the station is completed which will ensure that thermal effluent is readily available at a reasonable temperature. According to Way (Calgary Power Ltd., personal communication, March 1979), there is only about a 2 percent chance of two units at the Sundance plant being shut down at any one time for unscheduled maintenance. The value for three units is less than 1 percent.

There is also ample land available immediately to the west of the plant in the reclaimed mine area. The slope of the land here is relatively flat thus minimizing water pumping requirements. Furthermore, with the prevailing winds generally from the north and northwest, this site is on the windward side of the plant which will minimize the potential for plume shading from the plant stacks. The generating station is also close to a major market, about 80 km (50 mi) from Edmonton, with good transportation facilities to the city.

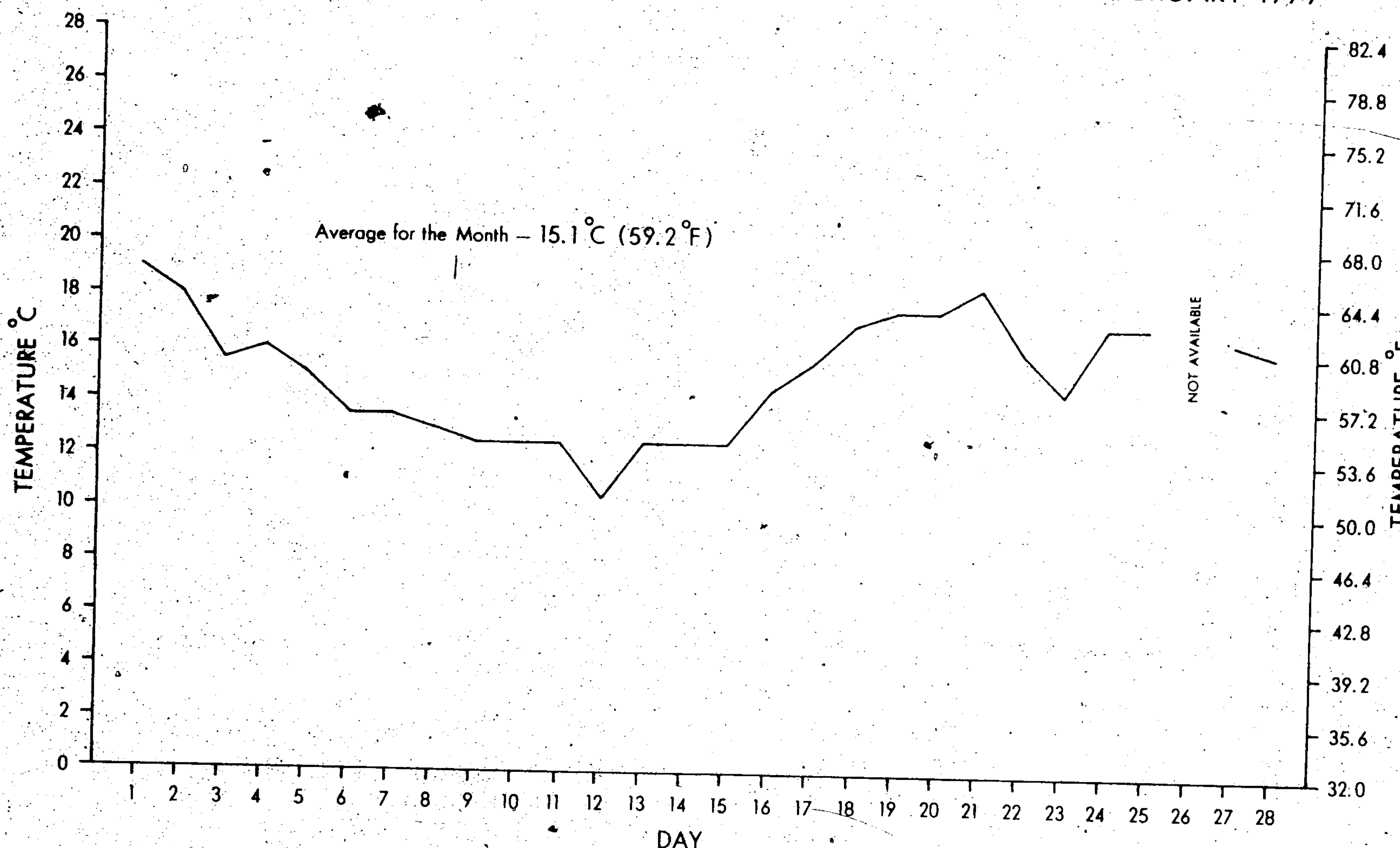
Greenhouse heating should be seriously considered for development at the Keephills, Sheerness and Genesee power plants. The primary reason for this is that provisions can be made now, in the initial plant designs, for the necessary pipework and other modifications that would be required to establish this application. This would substantially reduce the capital costs of the project, a saving that is not available when having to retrofit an existing plant. Of these three power plants, the Sheerness station will have the best location for greenhouse heating. The more southerly location of this plant will mean a somewhat milder winter but, more importantly, considerably more sunshine hours during the winter months.

Supply Water Temperatures

In order to avoid a repeat of the Lake Wabamun project results, a future greenhouse heating study will have to be very carefully planned and designed. This will require a marriage of various energy conservation techniques; that have recently been developed in the greenhouse industry, because of the low supply water temperatures available and the cold winter climate in Alberta. For example, Figure 3:9 is a graph of the daily average outlet water temperatures at the Sundance plant for February 1979. February had the lowest mean monthly temperature of the 1978/79 winter in Alberta. This graph reveals, on the one hand, that the average outlet water temperature recorded for the month was about 15C (27F) less than the minimum desired

Figure 3:9

SUNDANCE DAILY AVERAGE OUTLET WATER TEMPERATURES FOR FEBRUARY 1979



Source: 1979 Production Statistics Provided by Calgary Power Ltd.

water temperature of 29.4C (85F) at the Sherco greenhouse. On the other hand, the maximum daily average outlet water temperature recorded during the month was only about 10C (19F) below this value. The large daily fluctuations in the outlet water temperatures are also very apparent in this diagram.

The supply water temperatures are obviously not sufficient to provide the sole energy source for a greenhouse heating system. Nor are there any practical methods available for upgrading this heat source. One potential method would be to decrease the condenser circulating water flows. This would increase the outlet water temperatures but would also reduce the station net thermal efficiency. According to Forest (Department of Mechanical Engineering, University of Alberta, personal communication, June 1979), in order to increase the winter outlet water temperatures by approximately 10C in this manner, the resultant loss in station net thermal efficiency would be about 1/2 percent. This corresponds to a loss of approximately 10 MW in electricity production at the Sundance plant with its current capacity. Therefore, to compensate for the low supply water temperatures, extensive energy conservation techniques, incorporated in the greenhouse, will definitely be required.

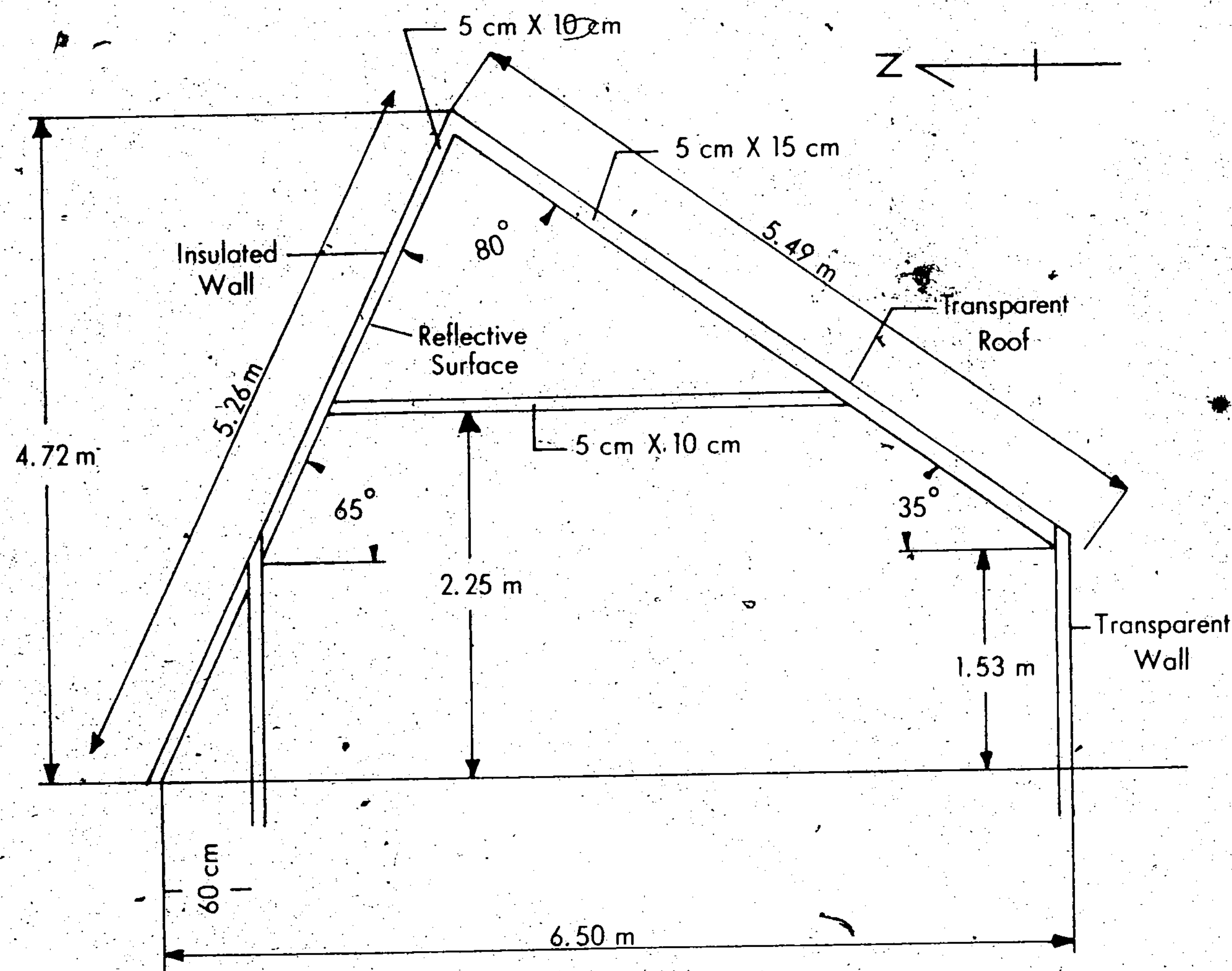
Greenhouse Designs

The greenhouse structure is a very crucial factor and would have to be designed with the greatest thermal efficiency that is technically feasible. There are several different approaches documented in the literature that could be applied in the initial design of the structure. A greenhouse designed to optimize the use of solar energy has been developed at the Brace Research Institute of McGill University in Montreal (Lawand et al, 1975). The greenhouse configuration they have designed and tested is somewhat different than conventional designs in that it is oriented on an east-west axis with the north wall insulated with masonite. The justification being that little radiation gain comes from the north and, in addition, it reduces heat loss from this surface. The inner surface of the north wall is also covered with a reflective coating which redirects incident solar radiation onto the plant canopy. Insulating the north wall has the further advantage of acting as an effective windbreak.

A cross-sectional sketch of this greenhouse is illustrated in Figure 3:10. The slopes of the south facing wall (double layer poly) and the north facing wall were computer optimized to permit the maximum penetration of

Figure 3:10

SECTION VIEW OF THE BRACE GREENHOUSE



Source: Lawand et al, 1975, p. 308.

incident solar radiation into the greenhouse as well as allowing for an even distribution of reflected radiation on the plant canopy. The range of values were calculated as 60 to 75 degrees to the horizontal for the north wall and 40 to 70 degrees to the horizontal for the south wall. The angles selected were 65 degrees for the north wall and 35 degrees for the south roof. Thirty-five degrees was selected for the south roof in order to meet standard size construction materials. The few degrees off the optimum range were not expected to significantly affect the transmission of radiant energy into the greenhouse. For an Alberta context, McCullagh (1978, p. 17) reports that a simple rule of thumb for determining the optimum south roof angle at various latitudes is to add 20 degrees to the latitude at the proposed greenhouse location. This would result in a 73 degree angle for the Sundance area.

Preliminary results from operation of this greenhouse have indicated that a reduction in heating requirements of between 30 and 40 percent can be expected over conventional greenhouse designs (Lawand et al, 1975, p. 311). Clearly, the actual reduction in the heating requirements is directly proportional to the number of sunshine hours during the winter. There are additional limitations associated with this design. First, the farther north the greenhouse site, the greater the optimum angle for the south roof. This results in an increasing roof height unless the height of the vertical support for the south wall is increased or the angle for the north wall is reduced. Second, expansion of a greenhouse with this design can only be linear as widening the structure would result in an unrealistically high arch and substantially increase the surface area.

If this design is considered impractical for these or other reasons, a gutter connected, air inflated double layer polyethylene configuration is a proven design. This design has been adopted by at least two waste heat projects; the Sherco greenhouse and the Princess Greenhouse Project in Princess, Alberta (Dunn & Hesje, 1978). The Sherco greenhouse has proven to be very efficient with the actual heat loss being within 10 percent of the design heat loss (J. Hietala, Northern States Power Co., personal communication, August 1978). The Princess greenhouse is the same design as that at the Sherco site and is heated with exhaust gases from a gas compressor station. This waste heat is of a considerably higher quality than condenser cooling water, being in the range of 370C (700F, Dunn & Hesje, 1978, p. 4). The greenhouse consists of eighteen gutter connected bays with a total enclosed area of 3,864 m^2 (0.95 acre). The roof of this greenhouse is covered with a double layer of polyethylene while the walls are a single layer of ribbed translucent fiberglass.

There are several other greenhouse designs that are effective for optimizing thermal efficiencies. These include spherical dome, hyperbolic paraboloid, gothic arch, and gable even span shapes. These will not be described here but Mastalerz (1977) provides an adequate discussion of solar greenhouse designs.

Covering Materials

The optimum covering material, in terms of energy conservation, for a greenhouse located in Alberta, would appear to be air-inflated, double layer polyethylene. Among the advantages of plastic over conventional glass and fiber-glass are: lower capital and installation costs (Conestoga-Rovers & Associates, 1977, Appendix C); it provides a more tightly sealed house; and it has a greater resistance to heat transfer (Boyd et al, 1977). The main disadvantage associated with this material is that it requires replacement every one to two years. The space between the two layers of poly can be inflated to provide an insulating layer of stagnant air. At the Sherco greenhouse, seven 1/16 horsepower fans maintain a certain inflation pressure between the two layers. These fans consume a trivial amount of electricity and are therefore a valuable asset.

Design Heat Loss Calculations

Once a greenhouse design and covering material have been selected, the anticipated heat loss rate from the greenhouse can be calculated. There are several methods of accomplishing this but a formula described in the "ASHRAE Handbook of Fundamentals" (1977, p. 379) appears to be the most widely accepted procedure. The formula is as follows:

$$H_t = AU(t_i - t_o)$$

where: H_t = heat loss transmitted through the greenhouse structure, BTU's/hr
A = total exposed surfaces, ft^2
U = coefficient of transmission, air-to-air, BTU's/hr/ft^2/^oF temperature
t_i = desired indoor temperature
t_o = minimum outdoor temperature expected

The coefficient of transmission (U) varies for individual covering materials and is usually listed with the material specifications. A wind factor, designed to take into account the average prevailing winds at the greenhouse site, can also be incorporated in the equation. Similarly, a construction factor, designed to account for the construction and type of greenhouse, can also be employed.

Thermal Curtains

Greenhouse thermal efficiencies can be drastically improved with the addition of thermal curtains on the interior roof and/or walls of the structure. Sixty percent of the heat loss in a greenhouse is through the roof and 30 percent through the sidewalls (Blom et al, 1978). Further, 60 to 80 percent of this heat loss occurs at night. Therefore, it would seem logical to consider the use of thermal blankets that can be opened or closed when desired. Rebuck et al (1977) report that a 50 percent reduction in energy use is possible through the use of a curtain material of porous five ounce polyester, aluminum foil hybrid fabric in a glass covered greenhouse. These curtains have the further advantage in that they can be drawn during the day to control the photoperiods of the plants.

There are certain disadvantages associated with thermal curtains. Because they are usually drawn across the roof of the greenhouse, the curtains may impede the heat delivery system. A second problem is one of storage during the daytime. This is especially true of small structures where the curtains may cause shading of the plant canopy and interfere with the daily operation of the greenhouse. Thermal curtains are also relatively expensive. Blom et al (1978) estimate that the cost of installation ranges from $0.50 to $2.00 per square foot but the energy savings that can be achieved with the use of interior blankets more than offsets this high cost in the long term.

Two other techniques for improving greenhouse thermal efficiencies are possible; utilizing solar reflectors on the roof and providing some form of heat storage inside the greenhouse. Solar reflectors would simply consist of panels covered with a reflective material that would re-direct solar radiation into the greenhouse. These panels can also be used to provide nighttime insulation. Heat storage in the greenhouse is possible through the use of water filled plastic bottles or metal drums. These could be placed along the north wall. These techniques are des-cribed by McCullagh (1978).

Heating Systems

The choice of an air heating system is equally as important as the selection of a proper greenhouse design and covering material. Iverson et al (1976), in a feasibility study on waste heat utilization, have considered four types of heat exchange systems:

1) dry heat exchange employing forced air circulation over a finned tube heat exchanger,
2) dry heat exchange employing natural convection air heaters,
3) contact heat exchange between the greenhouse air and warm water in an evaporative pad with forced air circulation, and

4) heat pumps in conjunction with dry heat exchange.

Of these systems, contact heat exchange would appear to be the least practical, even though it is the least expensive (Iverson et al, 1976). The problems encountered with the contact heat exchange unit at the Lake Wabamun project are further justification for not considering this system in the future.

A contact heat exchange system that reportedly does not create excessive humidity levels has been tested in waste heat utilization projects by the Oak Ridge National Laboratory in Oak Ridge, Tennessee and found to be quite acceptable (Olszewski et al, 1977; Olszewski, 1977; Furlong et al, 1973; Beall, 1973). This unit consists of an evaporative pad and fan system with finned-tube coils downstream of the pad. In this system, warm water drips down through a fibrous material in the pad while air flows horizontally through it. Because this method causes rapid saturation of the air, the bank of finned-tube coils is employed as a dehumidification device. Warm water is also pumped through these coils and the addition of sensible heat from the fins heats and dries the air coming from the pads. This system is designed to lower the relative humidity from 100 percent to 80 percent (Bond et al, 1975). A further benefit of this system is that it can be used for summer cooling.

There are disadvantages associated with this system as well. Boersma et al (1975) report that the Oak Ridge system still suffers from high humidity as well as requiring large heat exchangers and a continual exposure of the warm water to greenhouse or outside air. In addition, there are increased capital costs for the finned-tube coils and increased pumping costs associated with supplying water to the finned-tubes. For these reasons, a direct contact heat exchange system, with or without reheat facilities, would not be acceptable for use in a prototype greenhouse study in this province.

With respect to heat pumps as an air heating system, Iverson et al (1976) conclude that they are not practical because of very high capital costs. Furthermore, Ashley (1978) reports that the heating system selected for the Sherco greenhouse was more than three times as efficient as a heat pump system because it used one-third as much electricity.

Of the remaining two systems, Iverson et al (1976) contend that the forced air circulation system is the best of the two dry contact systems. First, a forced air system can be designed to meet the greenhouse heating and cooling requirements. This combination of fan duties results in a reduced capital expenditure but it is not possible in a natural convection heating system. Second, even heat distribution, constant air movement, for carbon dioxide dispersion, good control of humidity, and freedom from pipes in the growing area are horticultural advantages offered by the forced air system. The forced air circulation, dry contact system is recommended by Boersma (1975) and Conestoga-Rovers & Associates (1977). It has also been a proven system for heat exchange in the Sherco greenhouse. Therefore, a prototype greenhouse in Alberta should employ a forced air circulation, dry contact heat exchange system as the method for air heating.

The most practical method for distributing the warm air throughout the greenhouse is probably that employed at the Sherco greenhouse. This system of perforated poly tubes running the length of the greenhouse is also employed at the Princess greenhouse and therefore appears to be an accepted technique. This method is also recommended by Conestoga-Rovers & Associates (1977) and Iverson et al (1976).

Subsurface soil heating should be seriously considered as a technique for increasing plant growth and as a supplement to the air heating. Numerous studies have documented the potential for increasing yields with soil heating. Boersma (1970) observed that plants grown on heated soil plots exhibited much faster growth and doubling of total dry matter production in some instances in comparison to identical plants grown on unheated plots. Berry & Miller (1975, p. xxiv) note that "... warm water use for underground soil heating, in open fields and under greenhouses, shows significant potential for profitable use with selected crops which demonstrated increased yields." Ormrod (1975) estimates that open field soil heating in Ontario using condenser cooling water could advance the time of maturity of some crops by one to two weeks and result in yield increases of 30 to 40 percent or more. Boersma et al (1975) are of the opinion that the value of installing a soil heating system is doubtful when only heating requirements are considered, however, field trials indicate large yield increases resulting from such an installation. Conestoga-Rovers & Associates (1977) also support this conclusion.

Therefore, soil heating would appear to be justified on the basis of the increased yields that can be expected. This system does not seem to be justifiable solely as a supplement to the air heating requirements, because of the additional costs involved, but the 5 percent it can contribute to the air heating could be essential in cold climatic areas such as Alberta.

Miscellaneous Subsystems

The remaining systems that require consideration are standby heating and electricity generation, summer cooling, and horticultural systems such as irrigation and fertilization. Standby heating and electricity generation would be absolutely essential for a successful prototype study. Cooling is generally required during the summer months because of the rapid accumulation of heat within the greenhouse resulting from solar radiation. However, a cooling system might not be required in regions of northern latitudes if sufficient air movement through the greenhouse can be provided by exhaust fans. It should be noted that it was deemed necessary to include a summer cooling system in the Princess greenhouse. This particular system is identical to the one used at the Sherco greenhouse. This requires a source of cool water which could be a problem at some of the power plant sites in Alberta. For example, the water flow rate for the cooling system at the Sherco greenhouse is approximately 454.2 litres per minute (120

USGPM) while the Princess system uses about 899.1 litres per minute (232 USGPM). As discussed in the previous chapter, the groundwater yields in the majority of areas where power plants are located in Alberta are generally in the range of 4.5 to 113.6 litres per minute (1 to 25 IGPM).

The irrigation systems in a demonstration greenhouse would also require a separate source of water as the chemical constituents of the condenser cooling water preclude its use. It was found at the Sherco project, for example, that the condenser water was pH adjusted with acid injection and also contained chlorine and quite high levels of dissolved solids which together would be detrimental to the plants. This aspect would have to be investigated at each power plant individually.

CONCLUSION

In summary, the recent escalation of fuel costs in the greenhouse industry has sparked interest in seeking alternative energy sources for heating. One of the alternatives considered is the utilization of reject heat from thermal power plants. This application of waste heat utilization has been successfully demonstrated at the Sherco Greenhouse Project in Becker, Minnesota. It was also attempted, but with considerably less success, at the Wabamun power plant. Unfortunately, due to the manner in which it was planned and designed, the Wabamun effort did more harm than good for future attempts in this province to utilize power plant waste heat.

The knowledge gained from the Sherco project, in conjunction with recent developments in energy conservation techniques in the greenhouse industry, would seem to indicate that a similar prototype study could be equally successful at the Sundance power plant. The outlet water temperatures at the Sundance plant are about 15C (27F) lower than the desired minimum supply water temperatures at the

Sherco greenhouse. However, utilizing several solar heating techniques in the greenhouse, such as altering the structural design, insulating the north wall, placing solar reflectors on the roof, and utilizing thermal curtains and heat storage systems, could offset the low water temperatures. Nevertheless, much research remains to be undertaken in order to determine whether this application is technically and economically feasible in Alberta.

CHAPTER IV

THERMAL AQUACULTURE

Introduction

The utilization of condenser cooling water as a medium in which to raise commercially acceptable species of fish is gaining wide recognition in the U.S. and Canada as the most practical application for the heat rejected from steam electric generating stations. Consequently, aquaculture facilities are being developed and tested at numerous thermal power plants throughout the U.S. There has been considerable research conducted in Canada on thermal aquaculture, in the form of feasibility studies, but this country has lagged behind the U.S. in the development of facilities. Nevertheless, there is evidence that this application is receiving increased attention in Canada as there are currently thermal aquaculture projects in Alberta and New Brunswick. The literature concerning thermal aquaculture operations outside of North America is scarce and outdated but it appears that this waste heat use has become a common and accepted practice in Great Britain, Eastern

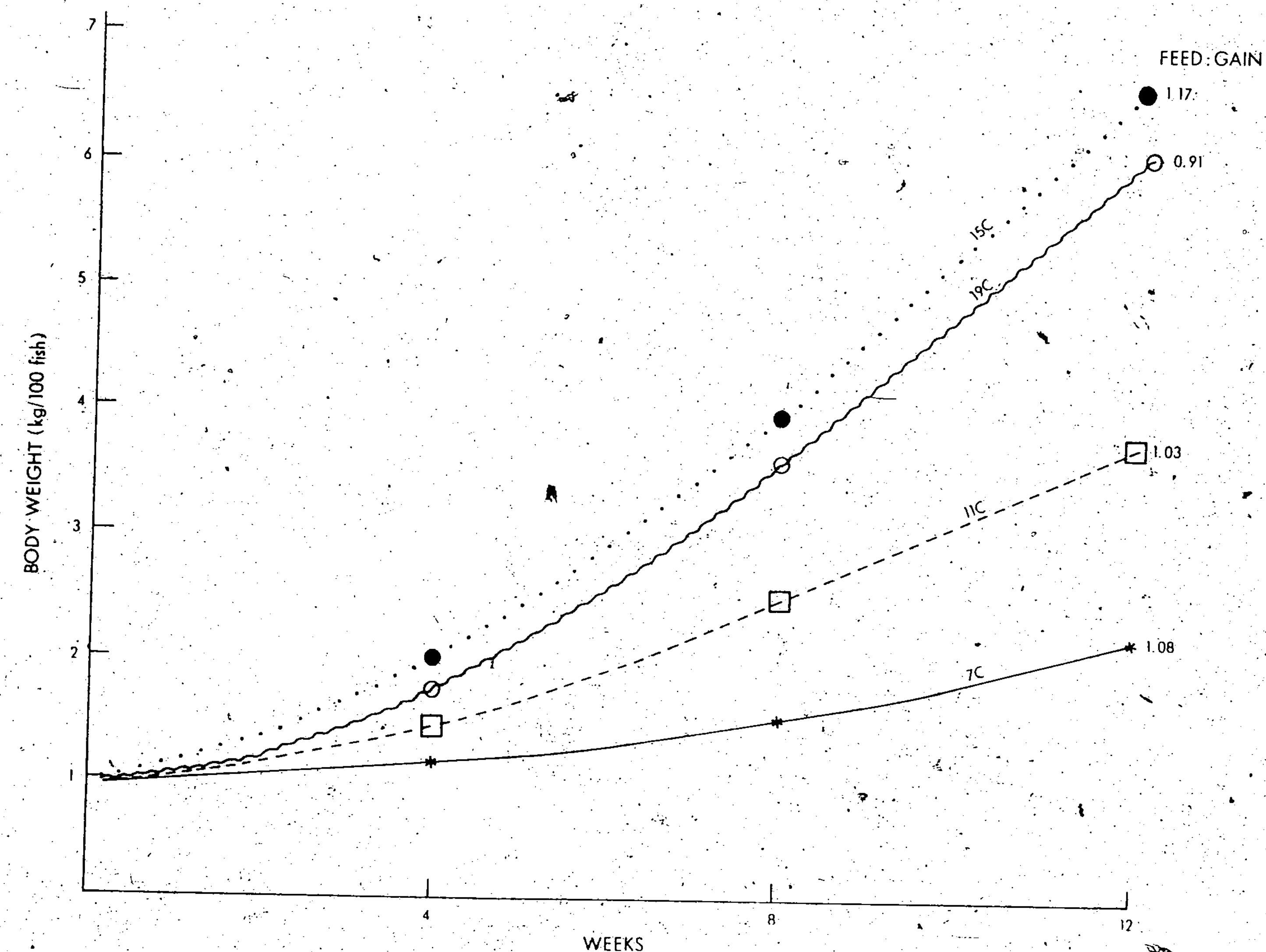
Europe, Russia, and Japan (e.g., see Bowers, 1970; Guthrie et al, 1975; Nash, 1970a & b; The Commercial Fish Farmer & Aquaculture News, September 1974; Yee, 1972; & Yee, 1974).

The concept of raising fish in condenser cooling water is based on the fact that water temperature is one of the most important fish growth parameters (Sylvester, 1975, p. 1). Water temperature is extremely important because the metabolic activity, hence growth rate, is directly related to the water temperatures. Furthermore, the optimum water temperatures for most commercially acceptable species of fish are usually in the range exhibited by condenser cooling water during the winter months. Therefore, by culturing fish during the winter in thermal effluents, growth rates can be increased significantly over those experienced in ambient water conditions. This has the further advantage of shortening the time required to produce a marketable product.

The actual increase in the growth rate that can be expected is dependent on a number of variables. Some sources, such as Henderson (1975) in a feasibility study in New Brunswick, report that for most species, winter growth can be maintained at five times or more the rate without artificial heat. Figure 4:1, for example, illustrates the

Figure 4:1

GROWTH OF RAINBOW TROUT AT DIFFERENT WATER TEMPERATURES



Source: Slinger and Cho, 1978, p. 15.

growth rates of rainbow trout at different water temperatures with all other conditions being equal. These optimum conditions tend to be limited in reality however, as water flowrates, water quality, method of culture, diseases, and parasites are also important parameters. These will be elaborated upon later in this chapter.

Thermal aquaculture is also attractive because extensive heat extraction systems, as required in other waste heat applications, are not necessary. Cages, for containing the fish, can be placed directly in the discharge canal of a power plant or a small portion of the effluent can be redirected through raceways, tanks, or ponds in which the fish can be grown. This also eliminates the need for expensive retrofitting, as would be required with greenhouse heating, for example.

The foregoing discussion provides an indication of the apparent simplicity of this waste heat application. Practical experience with thermal aquaculture has proven otherwise however, as will be outlined in this chapter which is a brief review of the state of the art in Canada and the U.S. Particular attention will be focussed on a thermal aquaculture project in Trenton, New Jersey where fish are grown year round in the thermal effluent of a power plant.

This state of the art review will be followed by a discussion of the environmental and technical constraints that will play a major role in the success or failure of a prototype aquaculture project in Alberta. This should clearly indicate the feasibility of this waste heat application, especially for future development in Alberta.

Miscellaneous Facilities

There are a large number of facilities in the U.S which are actively utilizing thermal effluents for aquacultural purposes. Some of these are commercial enterprises, while the rest are pilot projects with the intention of becoming commercialized in the near future. The different varieties of fish that are being raised are almost as numerous as the facilities but catfish appears to be the most widely cultured species in condenser cooling water in the U.S. This is due to a considerable amount of existing knowledge on the raising of catfish under hatchery conditions, a large demand for this fish on the consumer market (especially in the southern states), and the high optimum temperature of the species, about 27C to 29C (80.6F to 84.2F, Pickering, 1970). In addition to catfish; rainbow trout, shrimp, freshwater prawns, lobsters, oysters, striped bass, eels, pompano, striped mullet, and mosquitofish are some of the other species grown in thermal effluents in the U.S.

There are at least five thermal power plants in the U.S. where catfish are raised:

1) TVA's Gallatin Steam Electric Plant at Gallatin, Tennessee,

2) the Trinidad Steam Electric Station near Athens, Texas,

3) the Texas Electric Service Company at Lake Colorado, Texas,

4) the Mississippi Power and Light Company at Jackson, Mississippi, and

5) the Freemont Municipal Generating Station in Freemont, Nebraska.

The Gallatin thermal aquaculture project was developed by the Tennessee Valley Authority (TVA) in conjunction with the Cal-Main Company on the Cumberland River in Tennessee (Hicks, 1975). The facility was first built in 1970 and consists of ten, 15.24 m long, 1.22 m wide and 1.22 m deep (50 ft x 4 ft x 4 ft) concrete troughs (Beall & Yarosh, 1973). Condenser cooling water is drawn from the discharge canal at the rate of approximately 7,570.7 litres per minute (2,000 USGPM) and allowed to flow through the raceways (757.1 litres per minute per raceway).

The first crop of catfish was harvested in 1971 and was the basis for projected yields of several hundred thousand kilograms of fish per hectare year (Beall & Yarosh, 1973). However, in June of the following year, an interruption of electrical power caused by a storm resulted in the killing of the entire stock of 30,844 kg (68,000 lbs) of fish. The electrical outage was only a fractional interruption but the circulating water pumps lost their prime and it was several hours before they could be restarted. One month later, 105,000 fish were stocked in the channels but these were discovered to be diseased and 40 percent of the stock were lost. In March 1973, 5443 kg (12,000 lbs) of catfish fingerlings were stocked and 36,287 kg (80,000 lbs) were harvested in December of that year (Hicks, 1975). This was a production equivalent to that normally achieved in 16 to 24 hectares (40 to 60 acres) of farm ponds (The Commercial Fish Farmer & Aquaculture News, September 1974). Based upon these optimistic results, the Cal-Main Company was planning to expand the facility to 230 channels which would have a capacity for 27,215 kg (60,000 lbs) of dressed catfish per week (Yee, 1974). The current status of this enterprise is unknown.

Near Athens, Texas, the Texas Power and Light Company has been working in conjunction with scientists from Texas A & M University to develop techniques for the most efficient methods of raising catfish (Murrell, 1973). A total of 149 cages have been placed in a 3716 m^2 (40,000 ft^2) area of the Trinidad generating station's discharge canal. Results have indicated that marketable catfish (about

700 gm) can be grown from egg in only ten months compared to eighteen months in waters with cooler average temperatures (The American Fish Farmer & Aquaculture News, March 1972). Furthermore, when beginning with 12.7 cm (5 in) fingerlings, only four months of growth are required.

The Lake Colorado City project in Texas is a very successful commercial enterprise. Catfish are cultured in 105 cages which are placed in the discharge canal of the power plant. Annual production has been in the range of 22,680 to 27,215 kg (50,000 to 60,000 lbs, The Commercial Fish Farmer & Aquaculture News, September, 1974). Eventual capacity of this facility is projected to be 453,590 kg (1 million lbs) of fish per year (Beall & Yarosh, 1973).

The Jackson, Mississippi project has been largely experimental and has involved the cage culture of catfish in a 152 hectare (380 acre) cooling pond (Pickering, 1970). In Freemont, Nebraska, a private firm is raising catfish in 365.8 m (1,200 ft) long raceways which receive 37,853 litres per minute (10,000 USGPM) of discharge water from the municipal generating plant (Beall & Yarosh, 1973). They plan on raising between four and ten million fish in the present discharge canals which occupy approximately 3.2 hectares (8 acres) of land.

Elsewhere in the U.S., shrimp are being raised at power plants in Florida by Ralston Purina, Armour, and United Fruit Companies (Yee, 1974); International Shellfish Industries has been growing oysters and clams in thermal effluents near Santa Cruz, California (Beall & Yarosh, 1973); San Diego State University has been experimenting with lobster culture at two power plants in California (Olszewski, 1977); and Texas A & M University has been experimenting with several species, including striped mullet and pompano, in the thermal effluent of a power plant near Baytown, Texas (Luebke, 1973). There is also considerable documentation about the raising of oysters by the Long Island Oyster Farms Company in Long Island, New York. However, problems with fluctuating water temperatures have no longer made the venture feasible (R. Pitman, Long Island Oyster Farms Inc., personal communication, August 1978). A thermal aquaculture operation at Wiscasset, Maine has also gained some popularity because coho salmon were being raised in the discharge canal of a local power plant (Meth, 1976). This venture has also ceased operating however, because of severe problems with gas bubble disease and a general lack of management expertise in aquacultural techniques (E. Sawyer, Sea Run Inc., Kennebunkport, Maine, personal communication, August 1978).

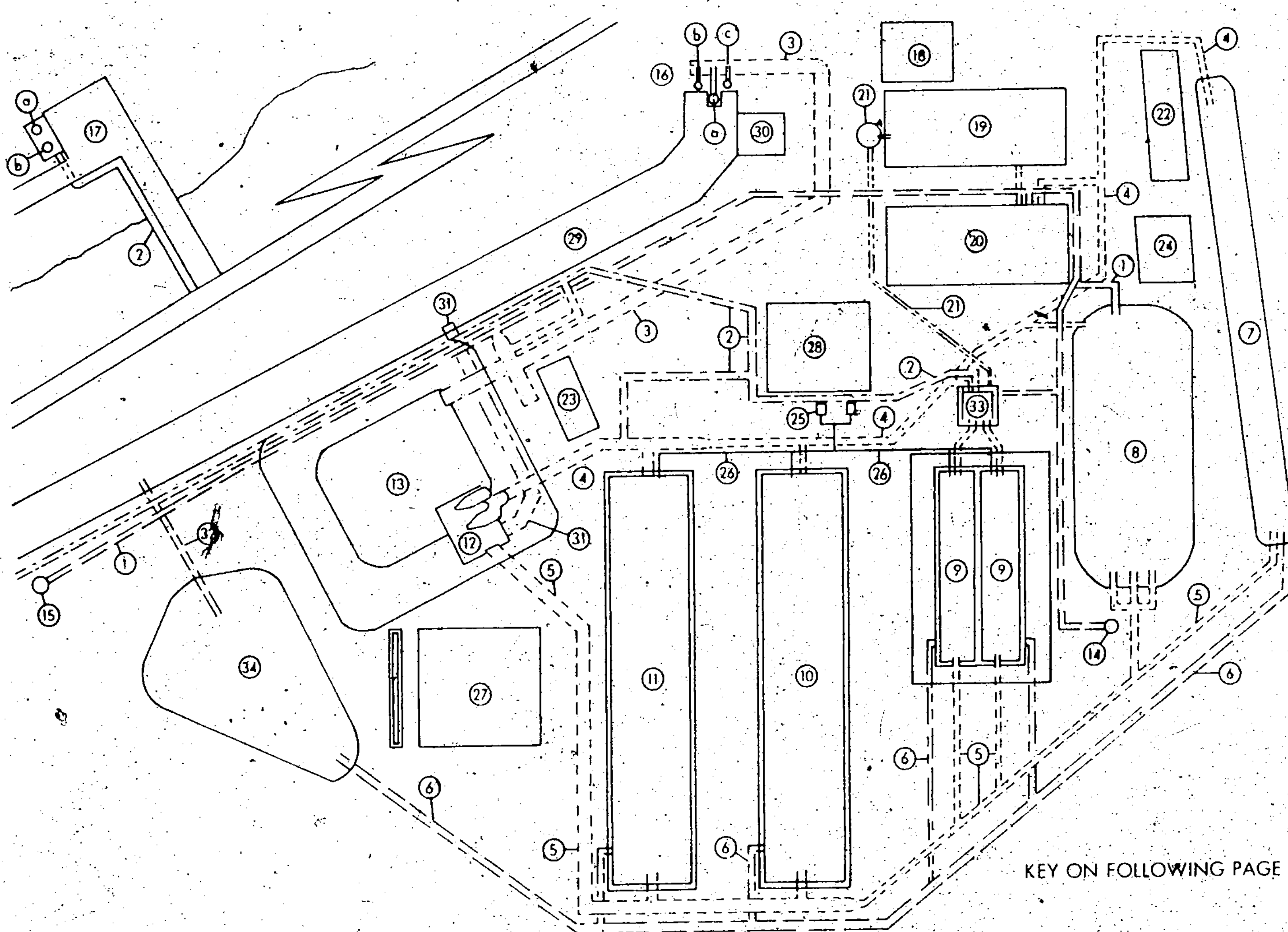
Trenton, New Jersey

The last project to be discussed in this section is probably the most innovative of all thermal aquaculture operations in the U.S. The project is a joint research effort of the Public Service Electric and Gas Company, Rutgers University, and Trenton State College (Guerra et al, 1977) and was visited by the author in August 1978. It is located at the Mercer generating station on the Delaware River in Trenton, New Jersey. The study was initiated in 1973 by the utility with the primary objective of evaluating the biological feasibility of rearing the freshwater shrimp (Macrobrachium rosenbergii) and rainbow trout in the thermal effluent of a fossil-fueled generating station. The rationale for attempting to culture two different species is based on the large annual variations in the thermal effluent temperatures. Rainbow trout is a cold water species while the freshwater shrimp have a high optimum temperature. These two species, therefore, are being raised on a semiannual basis, the trout during the winter and the prawns during the summer.

A general layout of the facility is presented in Figure 4:2. This diagram illustrates the extent of the project as there are five separate raceways and one pond

Figure 4:2

TRENTON, N.J. AQUACULTURE FACILITY LAYOUT



Source: Guerra et al. 1978, p. 153.

FIGURE 4:2 KEY

1. Lines from Wells 1 and 2 to laboratories and raceways
2. Line from Delaware River to aquaculture system
3. Line from Mercer station discharge canal to temperature moderation pond
4. Line from recirculation chamber to raceways and labs
5. Line from raceways to recirculation chamber
6. Line from raceways to waste settling pond
7. Raceway #I
8. Pond #I
9. Enclosed raceways A & B
10. Raceway #II
11. Raceway #III
12. Recirculation chamber
13. Temperature moderation pond
14. Well #1
15. Well #2
16. Pumps for Mercer station discharge canal to aquaculture system
    - a - 5,700 litres per minute (1,500 USGPM)
    - b - 3,000 litres per minute (800 USGPM)
    - c - 3,000 litres per minute (800 USGPM)
17. Delaware River pump station
    - a - 1,900 litres per minute (500 USGPM)
    - b - 1,900 litres per minute (500 USGPM)
18. Maintenance building - also houses alarm system
19. Laboratory #1
20. Laboratory #2
21. Line from laboratory #1 to mixing chamber for enclosed raceways
22. Office - laboratory trailer
23. Office trailer
24. Food storage shed
25. Compressed air blowers
26. Air lines for compressed air
27. Greenhouse
28. Mercer station transformer
29. Mercer station discharge canal
30. Mercer station fire house
31. Drainage Line from recirculation chamber to Mercer station discharge canal
32. Line from waste settling pond to discharge canal
33. Mixing chamber for enclosed raceways
34. Waste settling pond

(Figures 4:3, 4:4, & 4:5) as well as several buildings for laboratory and office space. The method of operation is quite simple. Process water can be obtained from three different sources: wells, river water, and heated discharge water (Guerra et al, 1978). Because these differ substantially in quality, temperature, and quantity, and because the capability to blend these sources in varying ratios is desired, a tempering pond was constructed into which these waters flow. From this pond, an overflow structure carries the water by gravity to the various components of the facility. Return flows from the raceways are collected and routed through underground piping to the plant discharge canal and then to the Delaware River.

To avoid toxic levels of chlorine in the process water, caused by periodic batch chlorination of the cooling water by the power plant, a unique recirculation device was designed for the facility. It was felt that the only method of avoiding the chlorine problem was to cease pumping of the discharge water altogether when chlorination was taking place (Guerra et al, 1978). However, the suspension of pumping was feared might create toxic levels of dissolved oxygen depletion and ammonia accumulation therefore recirculation was considered a desired feature. Furthermore, to increase the reliability of the unit against possible break-

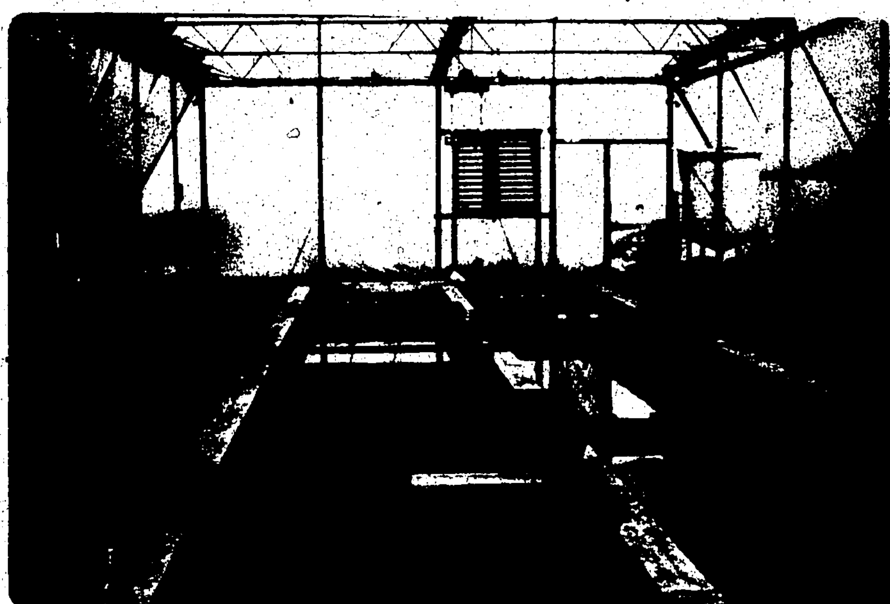


Figure 4:3 The two enclosed concrete raceways at the Trenton, New Jersey aquaculture facility. These are number 9 in Figure 4:2. At the time of this photo (August 1978) American eels were being raised in these raceways.

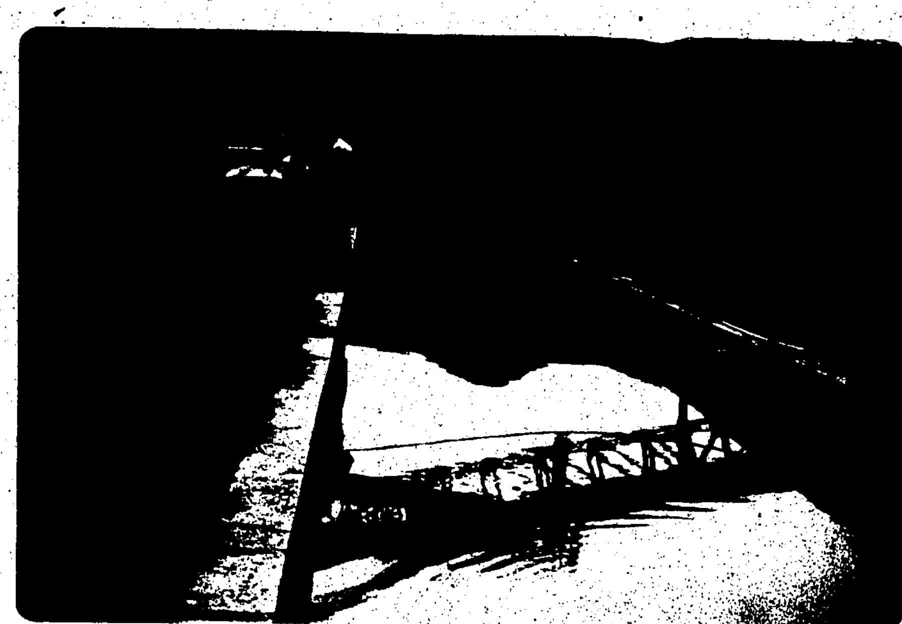


Figure 4:4 One of the three exterior concrete raceways (# 11 in Figure 4:2) at Trenton, N.J. Catfish were being raised in this raceway when this photo was taken in August 1978.

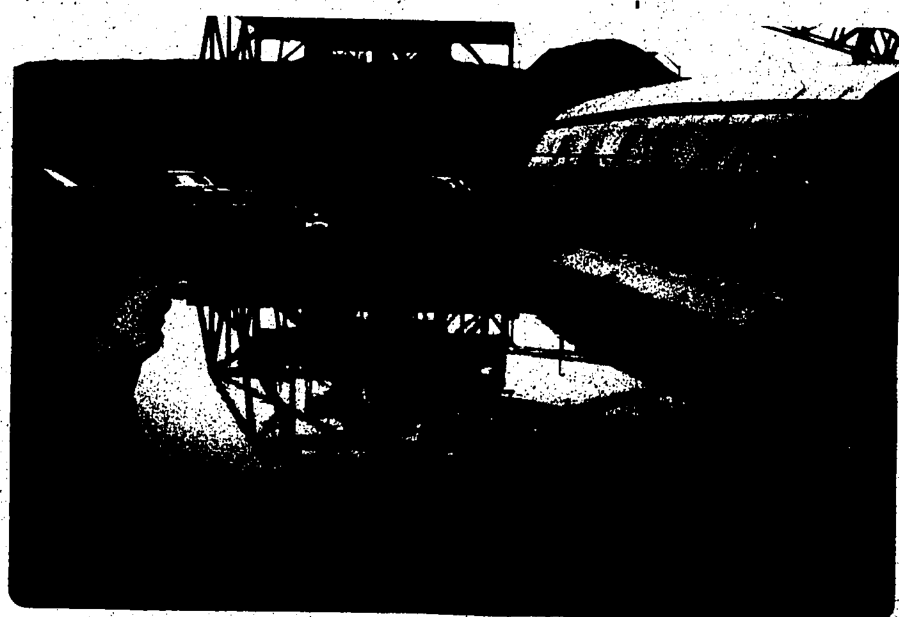


Figure 4:5 The small culture pond (# 8 in Figure 4:2) at Trenton, N.J. It is simply a dugout with a plastic liner. It is used for freshwater prawns.

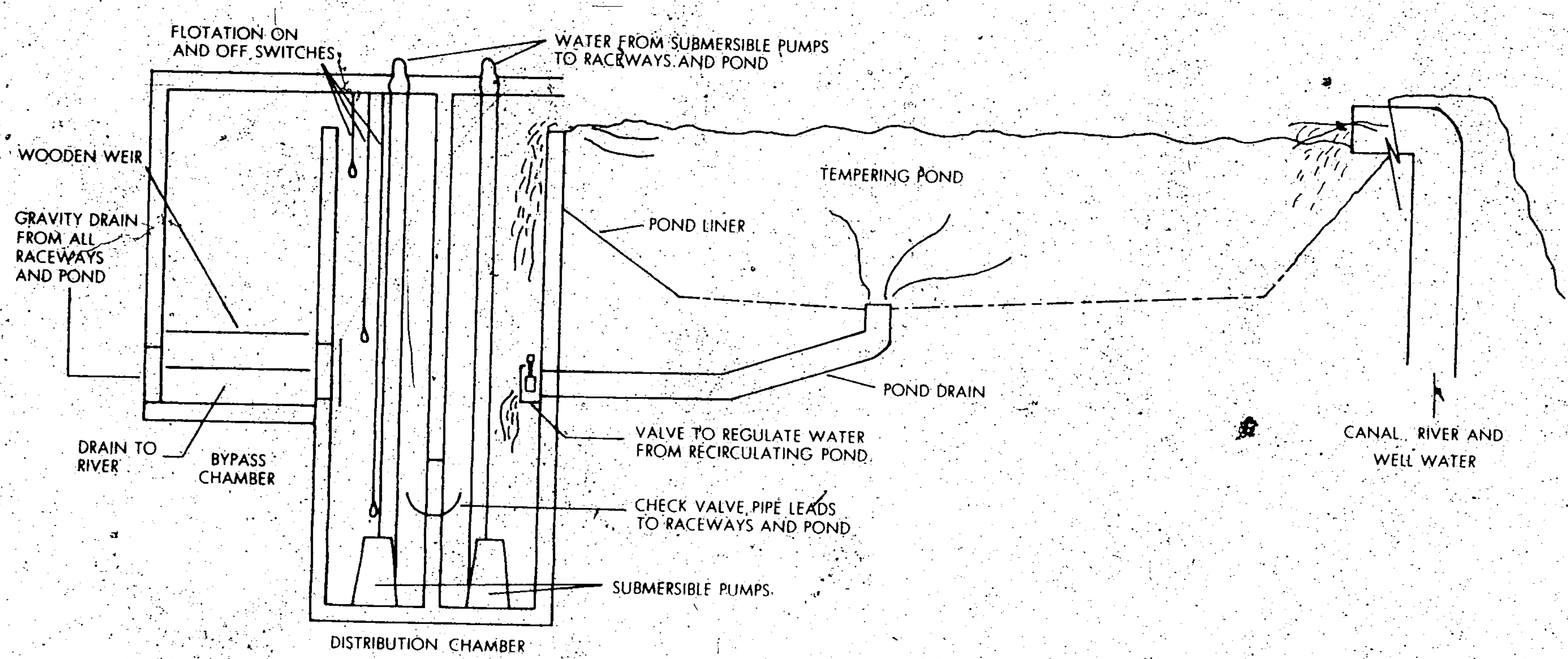
downs elsewhere in the pumping system, no mechanical or electrical devices and no interlocking or interconnecting devices between well and discharge canal pumps were desired.

A schematic diagram of the recirculation unit is presented in Figure 4:6. Under normal conditions, two pumps in the discharge canal supply heated effluent to the tempering pond. Overflow from the pond passes over a weir into a pumping chamber. The pumping chamber is separated into two parts by a concrete wall which contains a check valve. Water from the pond is distributed from one section of the chamber to the raceways. Return water from the raceways flows into the other section of the chamber and then into the discharge canal.

The two water supply pumps in the discharge canal are electrically connected to the plant chlorination mechanism so that when chlorination begins the pumps will stop. In this manner, water from the tempering pond will cease overflowing into the pumping chamber and the level of the water in that chamber will gradually drop. Before the level of this water reaches the same elevation of the water in the raceways, a switch is activated which starts up two submersible pumps in the chamber. These pumps rapidly reduce the level of the water in the chamber causing the check valve

Figure A:6

RECIRCULATION CHAMBER SYSTEM — TRENTON, N.J. FACILITY



Source: Guerra et al, 1978, p.18.

between the two chambers to open. This causes the waste water from the raceways to flow into the supply chamber rather than returning to the discharge canal. In this fashion, the water is continuously recirculated until chlorination is completed. Dissolved oxygen levels of the water are maintained by the water flowing over weirs placed at the end of each raceway and also by the supply of some tempering pond water through a 25.4 cm (10 in) pipeline that enters the chamber. Upon completion of chlorination, the discharge water supply pumps are started up and the process returns to normal operating conditions.

The fish wastes and uneaten food particles are treated separately from the process water flows. The effluent that flows over the weirs at the end of the raceways is of suitable quality for discharge to the Delaware River according to State of New Jersey regulations (M. Evans, Trenton State College, personal communication, August 1978). The suspended solids (metabolic wastes and food particles) that are flushed off the bottom of the raceways have to be settled in a pond for twenty-four hours. This is conducted by means of bottom flushing drains that are located on the downstream side of each raceway. The suspended solids are collected in a large settling pond located at the facility and the water from this pond is returned to the Delaware

River. According to Evans (Trenton State College, personal communication, August 1978), the state regulations are quite lenient because the project is operated under the utility's licence to operate. The amount of wastes that are produced are not quantifiable but Evans reports that they are considerable in relative terms.

The research project has been very successful in culturing both the rainbow trout and the freshwater shrimp. Eble (1977, p. 1) reports: "it has been unequivocally demonstrated that all life-cycle stages of the tropical freshwater prawn, (Macrobrachium rosenbergii), can be successfully cultured using waste heat effluents ..." Further, "rainbow trout, (Salmo gairdneri), culture has also been successfully demonstrated utilizing the waste heat discharges ..., animals can be reared at the same densities (1.7 kg/litre/minute) presently used in commercial systems: indeed, evidence suggests that even this density may be successfully exceeded due to high volumes of water flow possible with generating stations."

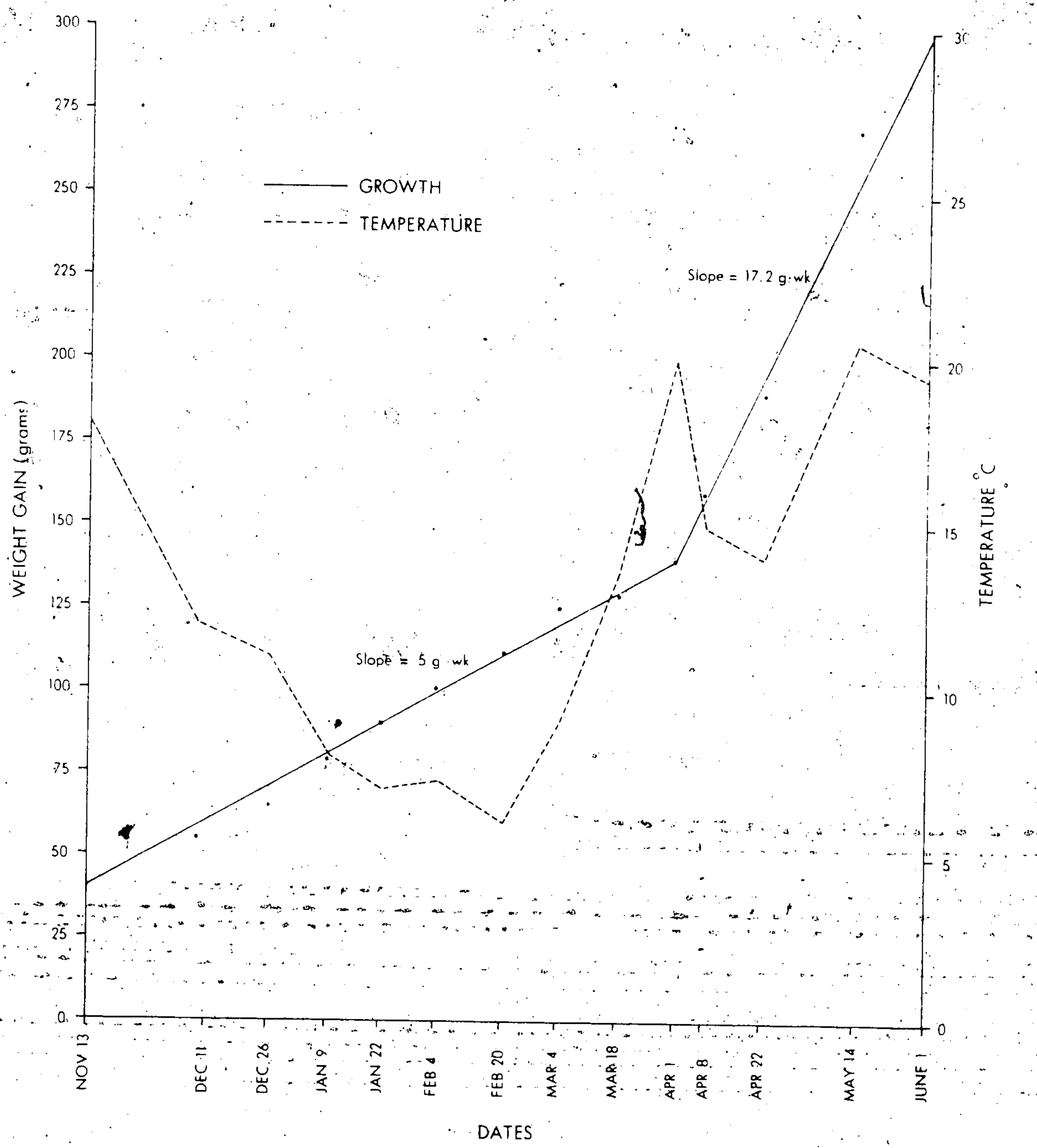
The first trout growing season during the winter of 1974/75 saw a very high mortality of 75 to 80 percent of the crop due to lethal levels of chlorine (Eble, 1977). The remaining fish grew from 65 gm to 190 gm (2.3 oz to 6.7 oz) (average weights) and exhibited an average growth of 7.6 cm (3.0 in) in length over a four month period. The food conversion ratio achieved was 1.4 and the water flowrate through the raceway was adjusted at 1,500 litres per minute (396.3 USGPM).

The following winter the flowrate was adjusted at between 1,500 and 1,900 litres per minute (396.3 to 501.9 USGPM) in the raceways (Eble, 1977). By this time, the water recirculation system had been installed and no chlorine related problems were encountered. The trout experienced slow growth from January to March when the water temperatures were below 15C (59F) but growth increased rapidly in early April when the water temperatures increased (Figure 4:7). The food conversion ratio was slightly higher than the previous year, 1.91. Data for the last two growing seasons are not completely available but equally high success rates, as in the two previous years, were achieved (M. Evans, Trenton State College, personal communication, August 1978).

The prawns have proven to be very hardy and virtually disease free. They can survive in water at temperatures up to 37.5C (99.5F) and dissolved oxygen levels as low as 2 mg/l (Farmanfarmian, 1977). However, a major difficulty with the prawn culture has been encountered in

Figure 4.7

RAINBOW TROUT GROWTH RATE AT TRENTON, N.J. (NOV. 13/75 TO JUNE 1/76)



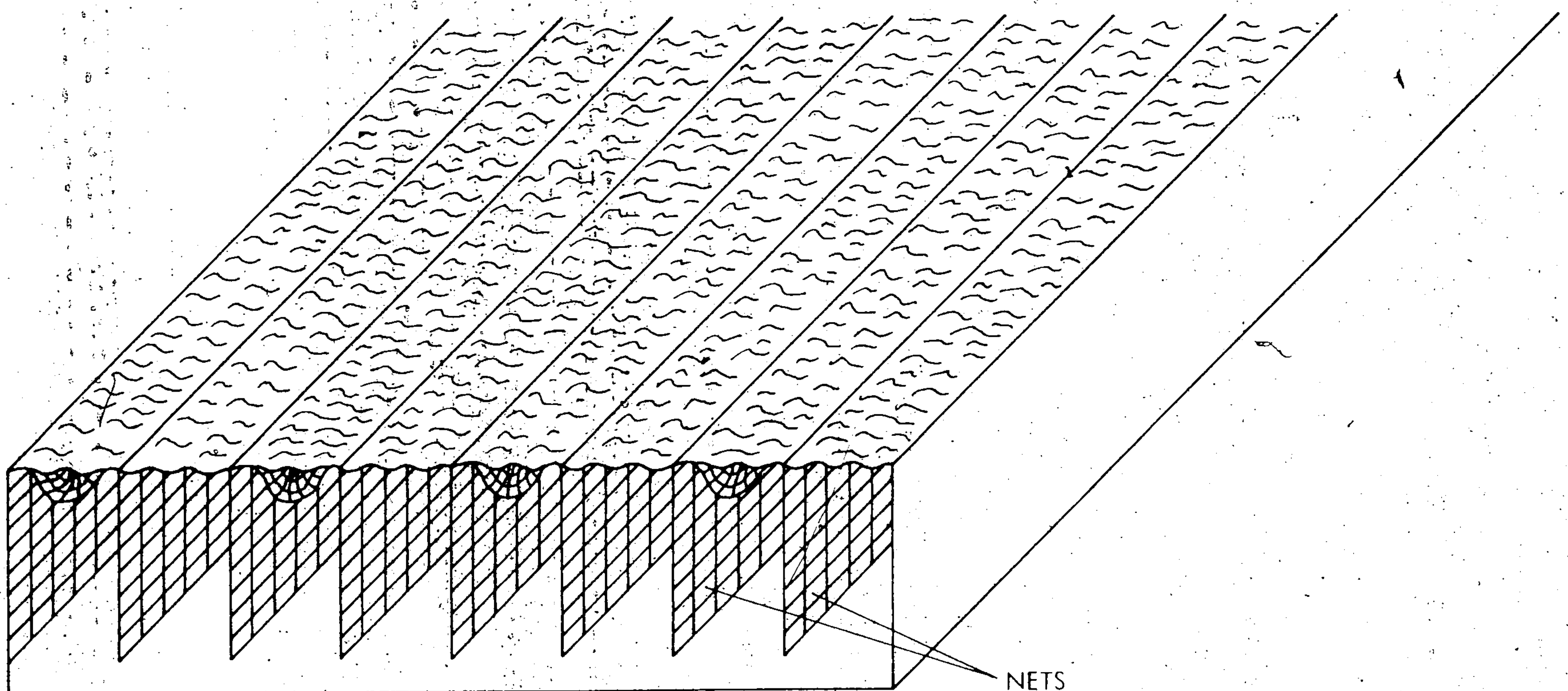
Source: Eble, 1977, p. 75.

the stocking densities. They tend to exhibit stress and cannibalism under crowded conditions. For example, 2 gm (.07 oz) animals stocked at $243/m^2$ of water suffered a 69 percent mortality in two momths (Guerra et al, 1977). When the density was reduced to $11/m^2$, the mortality rate dropped drastically to only 9.8 percent. A further experiment with a stocking density of between 35 and $54/m^2$ was attempted with the use of a vertical substrate (Figure 4:8) to provide an increased surface area on which the shrimp could maintain a position. This resulted in a mortality rate of 41 percent. An experiment to overcome this problem tested the feasibility of growing prawns in closed cells. The cells were basically rectangular shaped compartments that measured 10 cm x 10 cm x 15 cm (3.9 in x 3.9 in x 5.9 in, Figure 4:9, Guerra et al, 1977). The results from this experiment indicated that the production per unit area can be increased by a factor of six. However, although survival has been good with this system, growth has been poor.

This problem with stocking densities has led to the search for alternative warm water species for culture at the facility. Three species have been cultured for this purpose; channel catfish (<u>Ictalurus punctatus</u>), American eel (<u>Anguilla rostrata</u>), and striped bass (<u>Morone saxatilis</u>). This stage of the research is not yet completed but prelim-

Figure 4.8

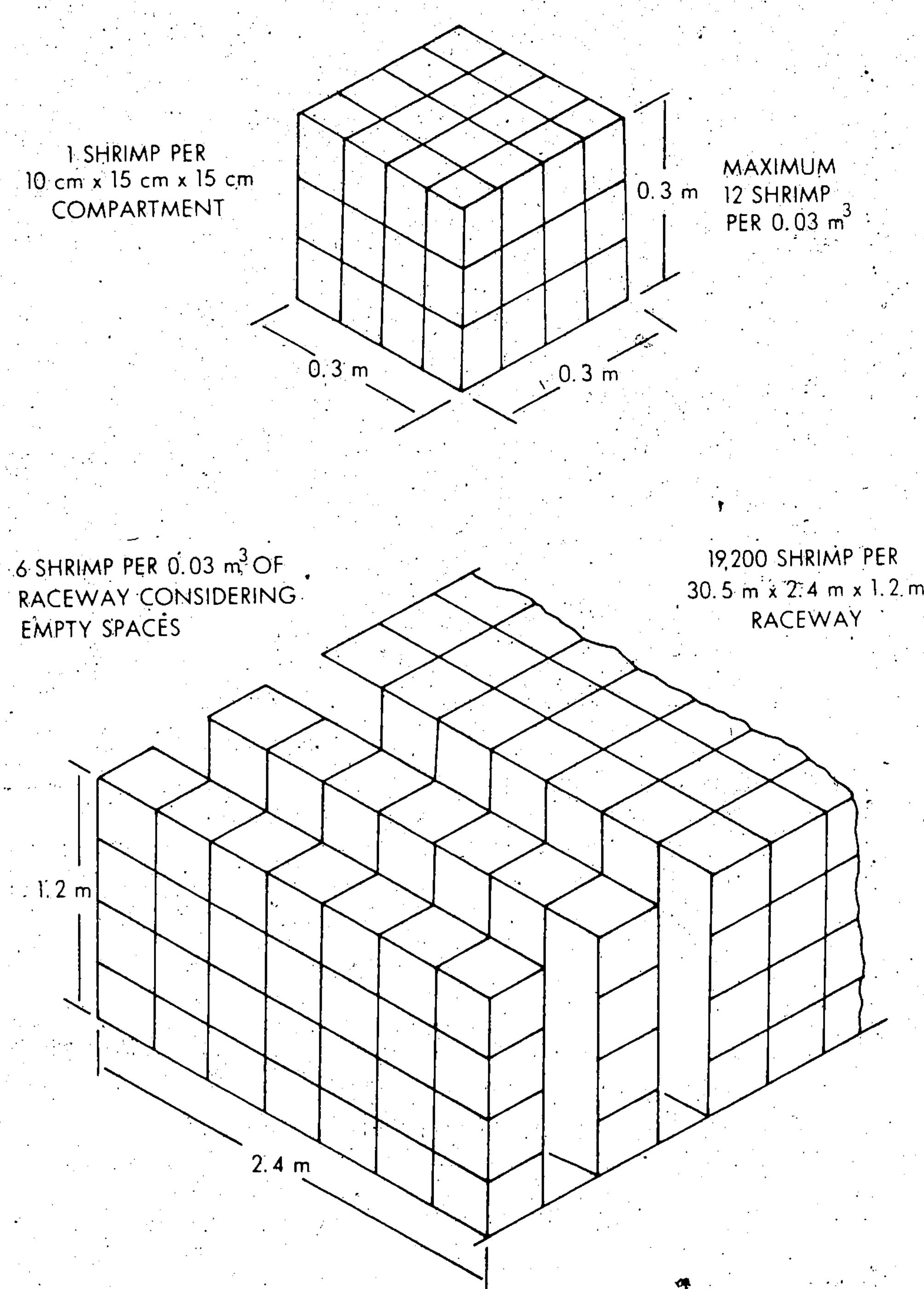
SCHEMATIC DIAGRAM OF ARRANGEMENT OF DRAPED NETTING USED IN PONDS FOR PRAWN CULTURE AT TRENTON, N.J.



Source: Eble, 1977, p. 43.

Figure 4:9

SCHEMATIC OF PRAWN GROW OUT CAPACITY (TRENTON, N.J. FACILITY)



Source: Guerra et al, 1977, p. 21.

inary results have indicated a high degree of success in raising the eels (M. Evans, Trenton State College, personal communication, August 1978). Unfortunately, the Orient is the only market that exists for this product. The catfish and striped bass have not proven to be amenable to intensive culture as yet.

Two aspects of this research project are very encouraging. One is the success that has been achieved to date with the culture of aquatic species in the thermal effluents of a power plant. The second is the degree of involvement on the part of the Public Service Electric and Gas Company. This has demonstrated that cooperation from the utility is an essential part of a project of this nature.

CANADA

Background Information

Despite the rapid growth of aquaculture facilities at numerous power plants in the U.S., Canada has been very slow in recognizing the potential of this waste heat application. The concept has been thoroughly investigated, as evident in the large number of feasibility studies which have been undertaken in this country[1], but the development of commercial operations, or even pilot projects, has been virtually nonexistent. Currently, there are only two thermal aquaculture projects in Canada, both of which are very small scale. One of these has been developed by the New Brunswick Department of Natural Resources at Grand Lake, New Brunswick while the other is a privately operated venture at the Sundance power plant in Alberta.

[1] For example, see Conestoga-Rovers & Associates, "Feasibility Analysis of Moderator Heat for Agricultural and Aquacultural Purposes. Bruce Nuclear Power Development. Final Report." Prepared for the Government of Ontario, Dec. 1977; Guthrie, J.E. et al, "An Assessment of Nuclear Power Plant Waste Heat Utilization for Freshwater Fish Farming," Pinawa, Manitoba: Atomic Energy of Canada Ltd., AECL-4924, May 1975; Underwood McLellan & Associates Ltd., "Feasibility Study on the Use of Low-Grade Heat Effluent in Aquaculture," Prepared for Environment Canada, 1975.

Elsewhere in this country, plans to develop aquaculture facilities have been undertaken at the Holyrood generating station in Newfoundland and the Lennox power plant near Kingston, Ontario but these projects were never constructed (Meth, 1976). At the Holyrood station, it was found that the projected rate of increase in electrical load demand did not materialize and the power plant was being operated on an intermittent basis only. A lack of funding has been cited as the reason for not proceeding with the aquaculture facility at the Lennox plant (Meth, 1976). A major investigation on the feasibility of developing a thermal aquaculture facility at a coal-fired power plant in Lorneville, New Brunswick was conducted for the New Brunswick Department of Fisheries and Environment (MacLaren Atlantic, 1974). This was followed up with the formation of a steering committee and the publication of a prospectus by the New Brunswick Department of Fisheries (1976) to encourage the development of a private aquaculture enterprise at the plant site. Unfortunately, the steering committee failed to generate interest among entrepreneurs and a general lack of capital funds in the area has been blamed for this (K.A. Wilson, Chairman, Lorneville Aquaculture Steering Committee, personal communication, August 1978). Presently, individuals are expressing interest in establishing small scale operations at the plant but nothing has been developed to date.

Grand Lake, New Brunswick

The thermal aquaculture project at Grand Lake, New Brunswick was the first attempt in Canada to utilize the waste heat from power plants in this fashion. This facility was also visited by the author in August 1978. The project was initiated in 1975 as part of a program to develop the sport fishing industry in the Grand Lake area. Fingerling sized brook trout are raised during the winter in the thermal effluent of the New Brunswick Electric and Power Commission's coal-fired generating station on Grand Lake approximately 56 km (35 mi) northeast of Fredricton. In the spring, the fish are transferred to the numerous surface coal mine ponds which dot the area. The quality of this pond water tends to be very acidic but hydrated lime is applied to alleviate this problem.

The brook trout are cultured in a complex of ten wooden cages which are lowered in the ice free area of the power plant discharge canal (Figure 4:10). The cages are 3.7 m x 3.7 m x 2.3 m (12 ft x 12 ft x 7.5 ft) in size and are covered with plastic Vexlar mesh (Figure 4:11, Stocek, 1978). A box net, conforming to the general dimensions of the cages, is suspended in each cage to protect against

Figure 4:10 The discharge canal of the small coal-fired power plant at Grand Lake, New Brunswick. Several cages used for raising brook trout, are seen suspended in the water. The fish are only placed in these cages during the winter.

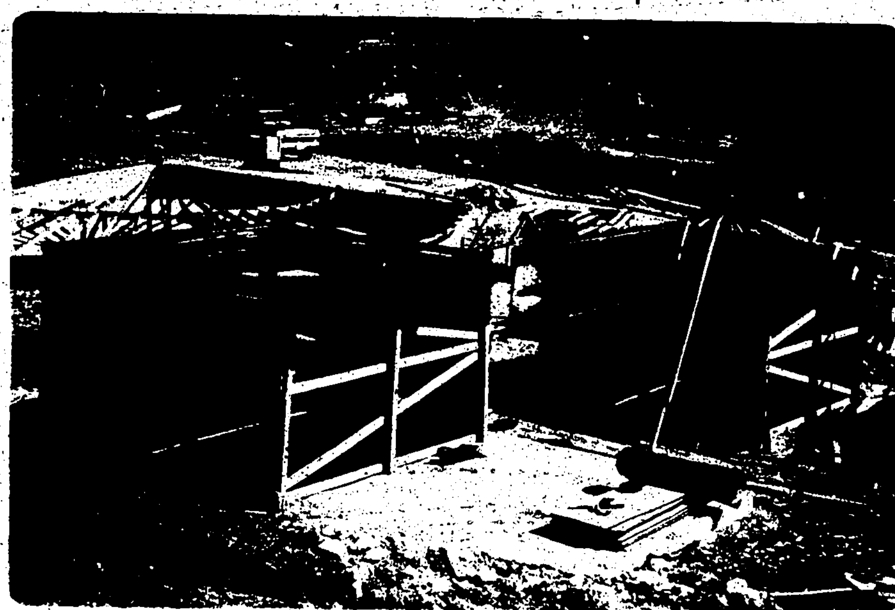


Figure 4:11 Two of the cages used for fish culture at Grand Lake, N.B. They are covered with a non-abrasive plastic Vexlar mesh.

aquatic predators and fish escapement and to facilitate fish removal. Plastic mesh lids are locked on all cages to prevent bird predation and theft.

The operation has enjoyed varying degrees of success. Originally, lake trout were also cultured but high mortalities were encountered and it was found that this species was not a good candidate for intensive culture (Hooper et al, 1977). Three major problems have also been encountered at the facility. These were gas supersaturation, low pH levels, and fluctuating water temperatures. Total gas saturation levels of 106 percent were frequently recorded while nitrogen saturation varied between 101 and 117 percent (Stocek, 1978). Efforts to alleviate this problem were restricted to the construction of a small weir in the discharge canal in an attempt to dissipate some of the dissolved gas in the water (W. Hooper, New Brunswick Department of Natural Resources, personal communication, August 1978).

Large fish mortalities were attributed to low pH levels as well. In late October 1977, the discharge water was found to have a pH reading of 4.7 (Stocek, 1978). The source of this problem was discovered to be surface runoff into the lake from an adjacent coal pile. The fluctating water temperature problem was a result of the station operation. The power plant has a capacity of only 100 MW and various units in the plant are frequently shut down and started up.

These problems resulted in a total natural mortality of about 30 percent for the entire brook trout stock in the winter of 1977/78 (Stocek, 1978). This was very high in comparison to the previous year when the natural mortality rate was about 1 percent (Hooper et al, 1977). The growth rates, on the other hand, have been quite spectacular. In the winter of 1977/78, the fish increased in weight by 175 percent in four months whereas the weight increase over four months in 1976/77 was about 100 percent. The body length growth rate has been about 1.3 cm (1/2 in) per month. The food conversion rates for the 1976/77 and 1977/78 growing seasons were 2.01 and 2.9 respectively.

As well as demonstrating the biological feasibility of raising brook trout in thermal effluents, the project has also proven to be economically viable. The cost of raising 37,000 fish for a seven and one-half month period in the winter of 1977/78 amounted to $11,927 (Stocek, 1978, p. 10). This includes both operational and capital expenditures. The operating cost amounted to $5,738 and included the wages of one part time labourer. The total expenditure resulted in a cost per pound of $4.83 to raise the trout in the winter of 1977/78. The fish were sized at approximately four per 1/2 kg (1 lb).

These costs have been compared to the economic returns generated by the increased sport fishing and found that substantial benefits are being realized. The New Brunswick Department of Natural Resources has determined that each fish produced generates 0.25 angler days recreation which in turn generates an angler gross expenditure of $12.00 per day (Hooper et al, 1977). Secondary net benefits to local communities have been calculated to be approximately $1.20 per angler day. These figures greatly overbalance the cost of rearing the fish in the thermal effluents.

Sundance Aquaculture Project

In contrast, the thermal aquaculture project at the Sundance power plant in Alberta has been considerably less successful in its operations to date. This venture is privately owned and was established in the summer of 1978 by Mr. D. Bilowus. His primary goal was to raise fingerling size rainbow trout during the winter in warm water from the power plant cooling pond (D. Bilowus, Sundance Aquafarms Ltd., personal communication, October 1978). Mr. Bilowus anticipated marketing the fish in the spring to the numerous private fish farmers in the province but problems with extremely low water temperatures in early January 1979 caused high mortalities and the remaining fish had to be released into the cooling pond.

The principal cause of this problem was the poor choice of a location for the project as the design of the facility is basically sound. A building containing ten circular tanks was constructed immediately below the cooling pond dyke on the southeast side of the pond. Water from the reservoir was fed to the building by gravity flow through a plastic, uninsulated pipeline at the rate of approximately 2,273 litres per minute (500 IGPM, Figure 4:12, D. Bilowus, Sundance Aquafarms Ltd., personal communication, October 1978). Upon reaching the facility, the water was directed to the tanks (Figure 4:13) where it entered through the side, creating a circular flow in the tanks, and draining in the middle. The return water from each tank was directed to a trough in the floor of the building which in turn drained into a settling pond adjacent to the structure. From there, the water was pumped back into the cooling pond.

Approximately 430,000 rainbow trout fingerlings were purchased in the late fall from the Spring Creek Hatchery in Lewiston, Montana at a cost of about $16,000

Figure 4:12 This photo was taken from the top of the Sundance cooling pond dyke in October 1978 and shows the pipeline installed by Bilowus to supply his aquaculture facility (central building).

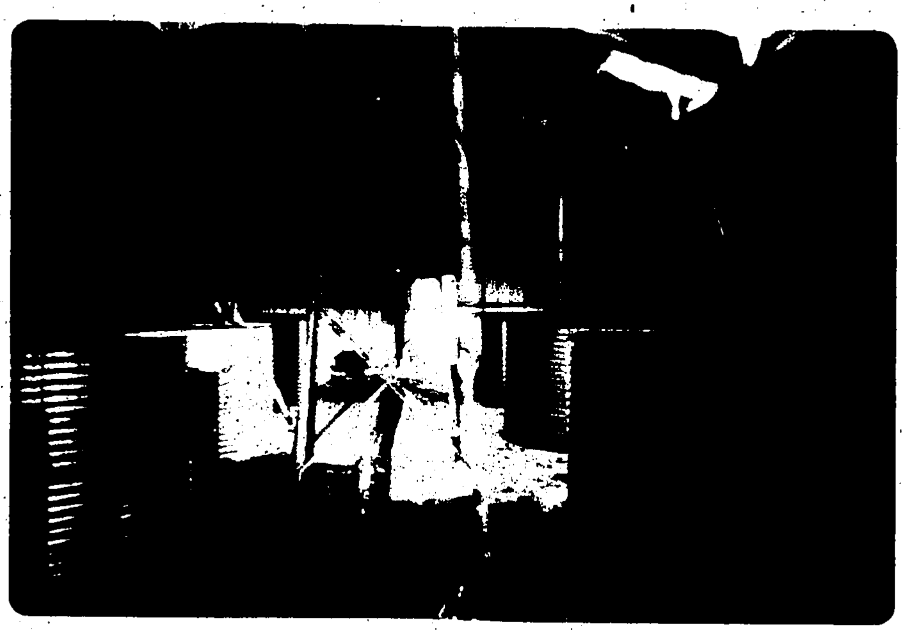


Figure 4:13 Interior view of Bilowus' main building. Water from the cooling pond flowed into the tank placed on stilts. From there it was directed to the circular tanks where the fish were placed. The return flows from these circular tanks entered the trough in the middle of the floor which drained into a small settling basin outside the building.

(D. Bilowus, Sundance Aquafarms Ltd., personal communication, October 1978). The fish were fed EWOS fish food and mortalities, although not recorded, were quite high. In the first week of January, severe cold weather, coupled with strong westerly winds and the unscheduled shutdown of three generating units, caused the cooling pond water temperatures at the point of withdrawal to drop to freezing. Slush and ice formation in the system resulted and, rather than allowing all the fish to die, Bilowus was forced to let approximately 200,000 free in the cooling pond.

Since that time, the fish have been observed on a few occasions but there are fears that they will not be able to survive in the pond. Only two rainbow trout have been discovered on the trash screens over the power plant intakes and no dead fish have been observed on the shore of the cooling pond. However, recent sampling with a net caught sixty suckers and six perch in only two hours (A. Chamberlain, Alberta Fish and Wildlife, personal communication, June 1979). Perch are natural predators of rainbow trout and therefore may have substantially reduced the trout population in the pond. An attempt to harvest the remaining trout will be conducted in mid July but the size of the cooling pond is expected to hinder this operation.

The solution to the low water temperature problem is clearly the selection of an alternative site that is closer to the cooling water outlet. The water temperature in this area would never approach freezing unless all the units in the power plant were to shut down, which is highly unlikely to occur. Having recognized this obvious solution, Bilowus has now arranged to lease a small portion of land from Calgary Power that is located adjacent to the intake ring canal. Water will be obtained, by gravity flow, from the discharge canal via an insulated pipeline to a new facility he plans to construct. Return flows will be directed into the ring canal by gravity flow as well. Currently, Mr. Bilowus is awaiting the acceptance of an application he submitted for financial assistance before he proceeds further.

The chances of success with this new location are much improved. Furthermore, the Alberta Fish and Wildlife Division has been actively assisting Mr. Bilowus in planning his new facilities and fully intend to continue this assistance throughout the forthcoming winter. Hopefully, no serious problems will arise that might cause a repeat of the previous year's experience. If the project fails once again, many people will be left with a false impression about the feasibility of a project of this nature and it would probably be some time, if ever, before another attempt was made at this application. This would be unfortunate as thermal aquaculture can definitely be feasible, as proven at Trenton, New Jersey and Grand Lake, New Brunswick.

TECHNICAL DISCUSSION

Candidate Species

The culturing of fish in thermal effluents is much more complicated than simply dropping a cage in the discharge canal of a power plant, or diverting some of the effluent through a tank or raceway system. Aquaculture by itself is a very complex process because the slightest disruption can result in a total loss of the stock. The use of thermal effluents only further complicates the process. Thus, prior to the establishment of a thermal aquaculture enterprise, a great deal of site specific research is required before the design and construction of the operation can proceed.

The first factor that has to be decided upon is the species of fish that is to be raised. A number of parameters will affect the final decision in this case, including marketability of the product, supply of fingerlings, and acceptability for culture. In Alberta, the optimum species for culture is rainbow trout. There are several reasons for this. One, rainbow trout is one of the most widely cultured fish in North America and the biology of the fish is understood in considerable detail (Guthrie et al, 1975). The rainbow trout has also been cultured for some time and, as a result, semi-domesticated strains have been developed (Waldrop, 1976). This makes the species particularly amenable for intensive culture. Evans (Trenton State College, personal communication, August 1978) reports that the stocking densities which can be achieved with rainbow trout are virtually unlimited provided sufficient oxygen is available. There are very few species of fish that can survive under intensive culture systems of this nature.

Secondly, rainbow trout is a highly desirable fish for human consumption and sport fishing and there appears to be a very substantial market for it in Alberta. This will be discussed in more detail in Chapter VII. Thirdly, rainbow trout would be an excellent candidate for culture in power plant effluents in Alberta because the range of temperatures exhibited by these discharges during the winter is about the optimum temperature for that species (15C, see Figure 3:8). Finally, several other feasibility studies on thermal aquaculture (e.g., Guthrie et al, 1975; Waldrop, 1976; Conestoga-Rovers & Associates, 1977) have all reached the same conclusion that rainbow trout is the most desirable species for culture.

The selection of rainbow trout as the optimum species precludes its culture during the summer months when the water temperatures are too warm unless a reliable source of cold water is available for blending with the thermal effluent. The only potential source of cold water for this purpose would be groundwater but both the quantity and quality of the groundwater in the area of the power plants in Alberta, as discussed in Chapter II, rules out its use. Therefore, if year round use of the warm water is desired for this application, a dual species approach, similar to that employed in Trenton, New Jersey, will have to be considered.

Summer culture of fish in thermal effluents will require the selection of a warm water species but this could prove to be an irksome task. Freshwater prawns would appear to be an acceptable species for this purpose because it has a high optimum temperature of about 30C (86F, The Commercial Fish Farmer & Aquaculture News, January 1977) and it is highly desirable for human consumption. The prawn is not particularly amenable to intensive culture but research, as that being conducted in Trenton, New Jersey, is continuing on methods of raising this species under intensive conditions. If they cannot be raised intensively, there is considerable land around the Sundance power plant where the prawns could be cultured extensively in a large pond. There might even be potential for raising this species in the cooling pond itself provided it does not interfere with the operation of the power plant.

A major problem that would be associated with attempting to culture freshwater prawns in Alberta is that the species is not indigenous to Alberta waters. Thus, in order to introduce an exotic species of this nature into the province, a detailed proposal is required by the government (A. Chamberlain, Alberta Fish and Wildlife, personal communication, June 1979). This should include all aspects of the species' life cycle as well as its potential diseases and host parasites. It is not anticipated that prawns would pose any problems to native species because they are very hardy and virtually disease free (M. Evans, Trenton State College, personal communication, August 1978). Furthermore, they would be cultured under controlled conditions and if any escaped to the natural environment it is highly unlikely they could survive the colder waters. Even so, if prawns meet all the conditions for introduction into Alberta, there is still no guarantee the government would approve such an introduction.

Another potential warm water species that could be cultured is largemouth bass (<u>Micropterus salmonides</u>). This species has a high optimum temperature level, about 30C (86F, Coutant, 1977), and it has been cultured in the past in Ontario (MacCrimmon et al, 1974). It is doubtful, however, whether a retail market exists in Alberta for this product but it would probably be very acceptable as a sport fish. The other problem with largemouth bass is that they also are nonindigenous to Alberta waters. They have been introduced into Lake Wabamun in the past but there is no evidence that reproduction or survival occurred (Paetz & Nelson, 1970).

The remaining possible choices of warm water fish for culture in Alberta are limited. Carp is one fish that is cultured in many areas of Europe and Asia and is a very desirable species for human consumption in that part of the world. However, North American society has yet to accept this fish as a food item and there is virtually no market for it in Alberta. Eels, similar to those currently being cultured in Trenton, New Jersey, do not enjoy a very large demand in Alberta but they apparently command a very high price in the Orient (M. Evans, Trenton State College, personal communication, August 1978). It is not known whether it would be economically feasible to culture this species in Alberta for sale in Japan. The marketability of catfish is also suspect and thus are not considered a likely candidate for culture in Alberta.

Water Quality

A second crucial factor to be considered prior to the establishment of a thermal aquaculture enterprise is the quality of the water source. This includes the daily fluctuations in the temperature of that water. In general, lethal limits for most species are a function of acclimation temperatures and exposure times, and usually increase with temperatures and exposure times up to a species specific level (Sylvester, 1975). In other words, fish can usually withstand a fairly large variation in water temperatures so long as the variations do not occur over a very short period of time. This is an important consideration for intensive culture facilities because of the fluctuating nature in which most power plants are operated and because the fish will have little scope for movement within the thermal gradients due to confinement in enclosures and hence will have little opportunity to engage in temperature selection behaviour.

The other major water quality parameters that will determine the feasibility of a thermal aquaculture project are chlorine, oxygen, and nitrogen levels. Most power plants periodically chlorinate their cooling water to prevent corrosion and to inhibit the growth of algae and fungi in the condensers and associated piping. Chlorine is a very toxic substance for fish. For example, the lethal limit of chlorine for rainbow trout is from 0.01 mg/l to 0.08 mg/l (Waldrop, 1976). For this reason, chlorine concentrations would have to be very carefully monitored or a system would have to be developed where pumping is halted during periods of chlorination, such as that employed at Trenton, New Jersey. This would eliminate the feasibility of cage culture in the discharge canal.

The oxygen and nitrogen level problems that can be anticipated are related to the fact that an increase in water temperature results in less gas (both oxygen and nitrogen) that can be dissolved in the water. For example, a 10C (18F) rise in temperature will increase the saturation of oxygen and nitrogen from 100 percent to 125 percent (Holmberg, 1976). If the solution is not equilibrated with the atmosphere there will be gas supersaturation. Nitrogen supersaturation will cause "gas bubble" disease, or embolisms, in the blood vessels of fish, which can have lethal effects. This problem, as previously mentioned, has been encountered at the Grand Lake, New Brunswick and Wiscasset, Maine thermal aquaculture projects. At Wiscasset, it was one of the principal reasons for that operation to fold. In general, this problem should not arise if the water has sufficient time to equilibrate with the atmosphere. This can be done if the culture system is located an adequate distance from the outlet.

An increase in water temperature also reduces the concentration of dissolved oxygen and increases the respiration rate of fish. The desired dissolved oxygen level for rainbow trout is 7 to 8 mg/l (Guthrie et al, 1975), and the oxygen content should not be allowed to drop below this level for any length of time. Aeration would probably be a desired feature in the culture of rainbow trout in any event because the stocking density of this fish can be increased tremendously if sufficient oxygen is provided. For example, at Trenton, New Jersey, the present stocking densities being achieved with rainbow trout are approximately 1.8 kg/0.028 m^3 (4 lbs/ft^3) of water (M. Evans, Trenton State College, personal communication, August 1978). To increase this density, they are purchasing an oxygen injection system that will introduce water, with dissolved oxygen levels of up to 75 mg/l, into the raceways. With this system, the stocking densities can be increased to 5.4 kg/ m^3 (12 lbs/ft^3) of water. Therefore, if the crop can be increased by as much as a factor of three, a system of artificially aerating the water would be a good investment.

Fish Wastes

Another factor to be considered in an aquaculture project, and particularly an operation utilizing thermal effluents, is the metabolic wastes generated by the fish. These wastes, principally ammonia and urea, will have lethal effects if allowed to accumulate in the system. Water flowing through the system would remove this problem but the effluent would probably require treatment prior to release to the environment.

The degree of treatment that will be required for metabolic fish wastes will be dependent upon government regulations and, in the case of generating stations with closed cycle cooling systems, restrictions imposed by the utility. There are no specific regulations in Alberta governing the discharge of fish wastes (Waldrop, 1976) but Bilowus was required to install a settling pond for the return flows from his facility. Initially, he hoped to allow the return flow to enter a creek adjacent to his facility which drains into Lake Wabamun but the Alberta Department of Environment would not allow him to do this (D. Bilowus, Sundance Aquafarms Ltd., personal communication, October 1978). He had to construct a settling basin and pump the water from this back into the cooling pond. Calgary Power did not express any concerns about the quality of this water but this could be a factor if the size of the operation were to be substantially increased.

Culture Systems and Water Flowrates

The remaining important factors that would be specific to a thermal aquaculture enterprise are the type of culture system to be used and the water flowrates that will be required. The type of culture system is basically a choice between extensive and intensive methods where an example of an extensive method would be a pond or dugout while intensive methods include cages, raceways, and tanks. Extensive methods are only practical for raising fish that exhibit stress and cannibalism under crowded conditions. Otherwise, this method usually requires a significant amount of land and does not lend itself to ease of harvesting. Intensive methods, on the other hand, require considerably less space, allow for the control of environmental factors, and facilitate harvesting. The flowrates are important because they must flush wastes and remove nuisance growths of algae and fungi, they must be sufficient to maintain dissolved oxygen levels, and the flowrates have to be high enough to maintain temperature control of the water stream.

The least expensive of the various intensive methods is cage culture in the discharge canal. This method also allows relatively high stocking densities but artificial aeration, if desired, is difficult. Furthermore, no control over the water flowrate can be maintained. This aspect is very important because the flowrate must not be so great that the fish expend significant food energy swimming to retain their positions. Of the remaining two intensive methods, circular tanks would appear to be favoured because a circular flow can be maintained which does not allow for the accumulation of fish and food wastes in corners as may occur in raceways. The optimum flowrate to be used in these systems will depend on the species being cultured and the desired stocking densities. At Trenton, New Jersey, rainbow trout stocked at about 1.8 kg/0.028 m^3 (4 lbs/ ft^3) of water require approximately 1,500 litres per minute (396.3 USGPM) of water flow (Eble, 1977).

Miscellaneous Factors

There are several other considerations that have to be investigated prior to the establishment of an aquaculture project but they are not necessarily specific to an operation utilizing thermal effluents. Some of these include feed and nutrition, diseases and parasites, and predator control (both animal and human). A reliable source of feed is essential as is knowledge of the various controls for outbreaks of diseases. This is especially true for intensive systems where the fish are closely spaced and diseases can spread very rapidly. One unique problem that has been encountered at some thermal aquaculture projects is termed "cold water disease." This occurs when the fish surface to feed and the dorsal fin becomes exposed to the air. If the facility is not heated, these fins will freeze and fall off and the bases will eventually become infected causing death (M. Evans, Trenton State College, personal communication, August 1978). The use of sinking feed removes this problem. Predator control usually implies the installation of locked covers over the culture systems.

CONCLUSION

In summary, the process of raising fish in power plant thermal effluents has been demonstrated to be technically feasible and is gaining widespread popularity in the U.S. A number of aquaculture facilities have been established at power plants in that country, on both a commercial and research oriented basis. An equally large number of species of fish are also being raised at these facilities in the U.S. The most innovative of these enterprises is probably the ongoing research project at Trenton, New Jersey. This effort was initiated by the Public Service Electric and Gas Company and has successfully demonstrated the feasibility of raising rainbow trout in thermal effluents during the winter months. Research at this project is now being concentrated on determining the optimum species for culture during the summer months when the water temperatures are much warmer. To this end, two species, freshwater prawns and American eels, have been successfully cultured in the summer. Unfortunately, the prawns have been found to require low stocking densities to survive and this has resulted in the cost of raising them to exceed the revenue.

Eels are amenable to intensive culture but there is a very limited market for this product in North America.

In Canada, this application of power plant waste heat has been very slow in getting off the drawing boards as there is only one successful thermal aquaculture operation in place at the present time. Even so, that effort is only designed for the culture of fish destined for the sport fishing industry. The only other known attempt at raising fish in thermal effluents in this country has been disappointing to date, largely because of factors beyond control of the operator but subject to correction with better planning and development, and the future of this project is subject to optimism.

It is difficult to understand why more attempts have not been made at utilizing thermal effluents in this manner in Canada. There has been some promotion, of this application, conducted by the public utilities in Ontario and New Brunswick but they have not made any financial commitments to establish any ventures. In Alberta, the private utilities have adopted the position of considering an application of waste heat to be a nuisance to their operations. The extent of their support is usually in the form of moral support only. Clearly, if this sort of venture is to succeed in Alberta, better cooperation from the utilities will be required. The degree of cooperation from the utilities will essentially dictate the feasibility of a thermal aquaculture project.

The other possible reason why more thermal aquaculture projects have not been established in Canada may be an unwillingness on the part of individuals to assume the risk of investing capital in a venture of this nature. This may be due to a lack of demonstrated economic feasibility and this should be thoroughly investigated. Unfortunately, it appears that a prototype study will have to establish the technical and economic feasibility of this waste heat application before individuals will seriously consider it as a viable commercial enterprise.

A prototype thermal aquaculture study in Alberta could take several different approaches. Assuming that rainbow trout is the desired species for winter propagation and that the previously discussed water quality parameters can be met, a variety of systems could be established at a power plant in this province. An inexpensive system of cage culture in a discharge canal could be established or a more intensive culture system involving tanks or raceways could be considered. The market that is being catered to will dictate the size of the fish that has to be raised. If fish for the sport fishing industry or the local private fish farmers is desired, a project could begin in the late fall with small fingerlings and grow them out to 7.6 cm to 10.2 cm (3 to 4 in) during the winter. This would reduce the cost of the fingerlings. If a table market is the desired final destination for the product, larger fingerlings will have to be used to start the growing season. The cost of fingerlings in this case would be higher but the returns from sales of the product to a retail or restaurant market would also be greater. The operating costs of such an operation and the revenues that could be expected should be carefully investigated beforehand.

In the future, after some experience has been gained in the propagation of the fish, it would be in the best interests to establish a hatchery facility. This would greatly reduce the cost of purchasing fingerlings. Two problems are envisaged with this however. First, growing out the fish from eggs would increase the length of time required to produce a marketable product. Secondly, extreme caution, in the form of environmental controls, would be required with the hatchery process. This includes water temperature which would probably require control by means of blending cool water with the effluent to achieve the exact desired water temperature. This will also increase the operating costs.

If year round use of the thermal effluent is desired, and there is no reason why it should not be, an alternative, warm water species will have to be the candidate for culture. Unfortunately, no species that meet the thermal, market, and culture requirements for such a venture exist in Alberta. Therefore, an exotic species would have to be introduced into the province. Freshwater prawns could be the ideal species for this purpose. They are very hardy and virtually disease free, popular on the consumer market, and command a high price on the retail market. The only problem with culturing prawns is their resistance to intensive culture techniques. However, research is ongoing in the hopes of solving this problem and a breakthrough can be expected eventually. If they are grown extensively, a large tract of land would be required for a pond in which the prawns could be placed. Another alternative might be enclosing an area of the Sundance cooling pond with netting or some other means for this purpose. This could be the most practical solution and should be investigated.

The other warm water species that might have potential for culture in Alberta is largemouth bass. A substantial table market does not exist for this product in the province but it should be acceptable for sport fishing. If stocking this fish in local streams is not desirable, after grow out in the thermal effluent, the bass might be allowed to remain in the cooling pond of the Sundance plant or those of the Sheerness and Keephills plants in the future. Sport fishing could then be encouraged at the ponds. The remaining species that can be cultured during the summer do not enjoy any portion of the market in Alberta and it is not considered feasible, for this reason, to raise them in thermal effluents in this province. These species include catfish, striped bass, and eels.

Finally, the concept of culturing fish in power plant thermal effluents is a complicated, but technically feasible process. It enjoys an advantage over other waste heat applications in that the warm water can normally be utilized as is and no heat extraction systems are required. Whether the process could be economically feasible in Alberta remains to be demonstrated. Bilowus apparently considered this waste heat application economically viable before he invested a great deal of money in it. It is this author's opinion that a prototype study should be established in this province to prove that the concept is technically and economically feasible. This would hopefully lead to a large scale operation to effectively utilize power plant reject heat.

CHAPTER V

DISTRICT HEATING

Introduction

The heating of large urban areas with waste heat from thermal power plants can be accomplished by two separate methods. The first is utilizing condenser cooling water as a heat source for heat pumps that are located in individual buildings and houses. The second method is often termed co-generation where both electricity and heat are produced by the generating station. This method does not involve the direct utilization of heat rejected from a power plant but it does increase the station thermal efficiency and thus reduces the amount of energy that is wasted.

The objective of the author in this chapter is to discuss the basic principles of both of these district heating methods. Heat pump operation will be outlined along with the criteria that have been established to evaluate its economic feasibility. Co-generation, although considered to be somewhat beyond the scope of this thesis, is gaining increased attention in North America as the most practical method for improving energy utilization in steam electric generating stations. Therefore, the various methods that can be employed for co-generation will be discussed and some of the proposed studies which have been conducted on this subject in the U.S. and Canada will be reviewed.

HEAT PUMPS

The most common example of a heat pump is the household refrigerator except in reverse. As with this familiar appliance, a heat pump is a mechanical device that extracts heat from one medium at a lower temeprature, such as air or water, and transfers this heat to another medium for delivery at a higher temperature. An efficient heat pump will provide three or four units of heat energy output for each unit of energy input (Sector, 1977). A heat pump has the further advantage in that it's cycle can be reversed to provide cooling (air conditioning).

There are four basic heat pumps for space heating and cooling (Ambrose, 1966). These employ:

1) air as the heat source/sink and air as the heating and cooling medium,

2) air as the heat source/sink and water as the heating and cooling medium,

3) water as the heat source/sink and air as the heating and cooling medium, and

4) water as the heat source/sink and water as the heating and cooling medium.

Because this study is dealing with thermal effluents, only the heat pump designs employing water as the heat source/sink will be considered here.

The principal components of a water source heat pump are illustrated in Figure 5:1. This diagram demonstrates the cycle for a water sink heat pump but an air sink system would simply involve the substitution of a fan driven coil for the radiators. The operation of this heat pump is very basic. During the heating cycle, the refrigerant (e.g. Freon) extracts heat from the water, in this case thermal effluent, at the evaporator (Step 4-1, Figure 5:1). This heat is delivered by the condenser (Step 2-3, Figure 5:1) to the heat sink, in this case a building. During the cooling cycle, the refrigerant flow is simply reversed.

The efficiency of a heat pump, and also the key for determining its economic feasibility, is measured as the coefficient of performance (CP) where:

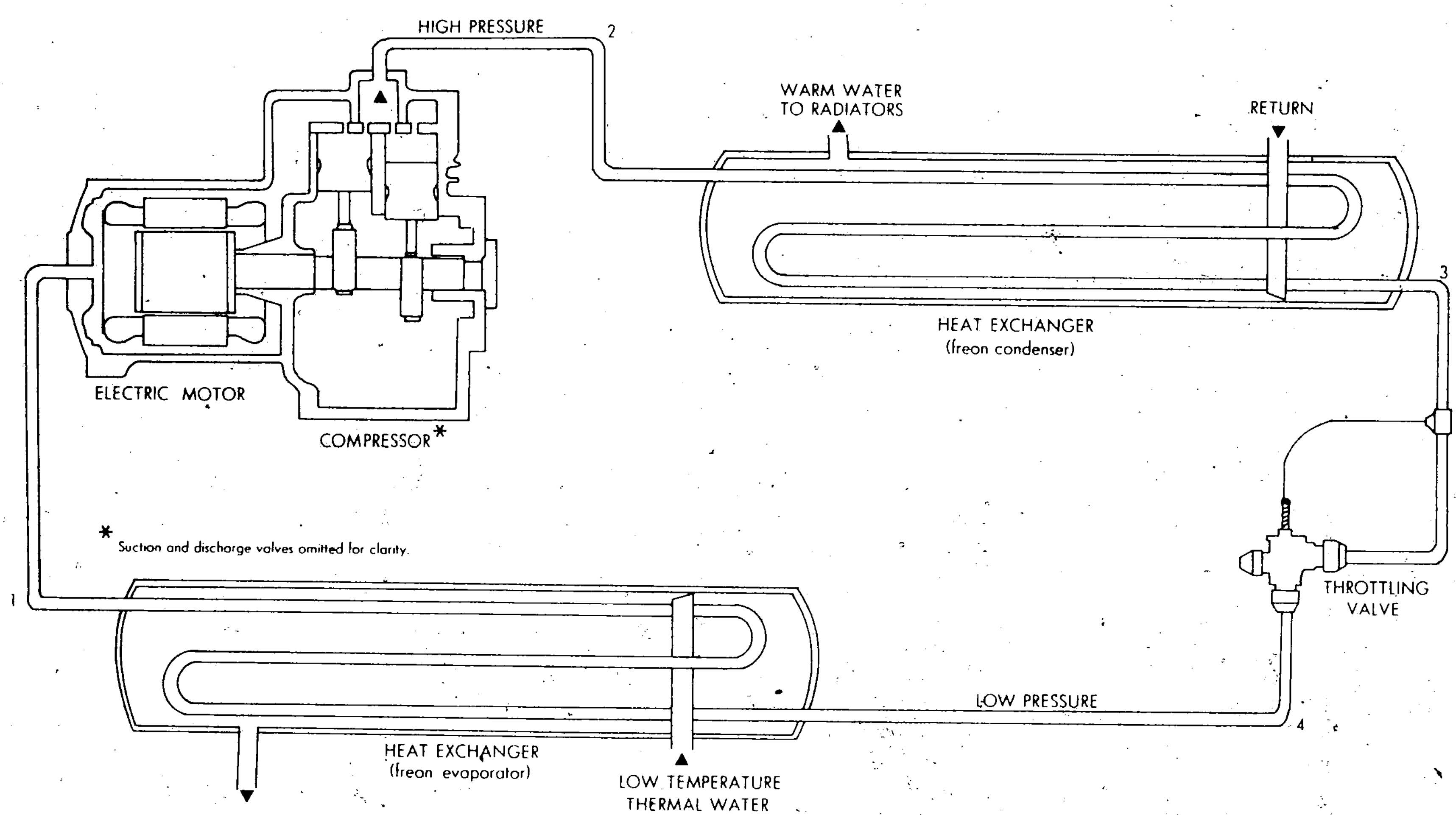
$$CP = \frac{\text{useful heat output}}{\text{energy input for compressor work}}$$

This equation applies to the heating mode and the value is dimensionless (Aamot, 1977a).

The energy input in a heat pump is usually in the form of electricity. In the U.S., the Corps of Engineers has calculated that 11,600 BTU's are required to produce and

Figure 5:1

THE PRINCIPAL COMPONENTS OF A WATER SOURCE/SINK HEAT PUMP



* Suction and discharge valves omitted for clarity.

Source: Aamot, 1977a, p.24.

transmit electricity per kWh (Aamot, 1977a). This is equal to 3.4 in coherent units and means that 3.4 units of fuel energy produce one unit of delivered electric energy. In other words, an electrically powered heat pump is energy efficient if it produces 3.4 units of thermal energy for every unit of electric energy used; i.e., CP= 3.4. In Canada, Bradley (1976) reports that the CP of an electrically powered heat pump should be 3.7 in order to break even.

There are a number of factors that will affect a heat pump's performance. Ambrose (1966, p. 7) states that:

> "in an actual heat pump system the CP varies directly as the compressor suction pressure and inversely as the condensing pressure. The suction pressure, in turn, is determined by the temperature of the heat source, so that the lower the heat source temperature the lower the compressor suction pressure. Similarly, the head pressure or condensing pressure is determined by the heat sink temperature or the temperature of the medium being circulated to the conditioned space."

In other words, the greater the temperature difference between the heat source and the heat delivery, the lower the CP. For this reason, it is desirable to use the highest temperature heat source possible and to use the lowest practical delivery temperature (Aamot, 1977a). Based on this fact, power plant thermal effluent, at 10 to 20C (50 to 68F), is an ideal heat source for heat pumps.

The other factors that influence the CP are inherent in the heat pump itself. These include the effectiveness of the heat exchangers (the evaporators and the condensers), the efficiency of the compressor and motor, and the choice of the refrigerant (Aamot, 1977a). The question of partial load operation also concerns the overall efficiency. Performance measurements are usually made under steady state operating conditions but frequent on-off cycling will reduce the overall efficiency. The efficiency is also lower during the starting period. Therefore, the heat pump should be closely matched to the load requirements, not significantly oversized.

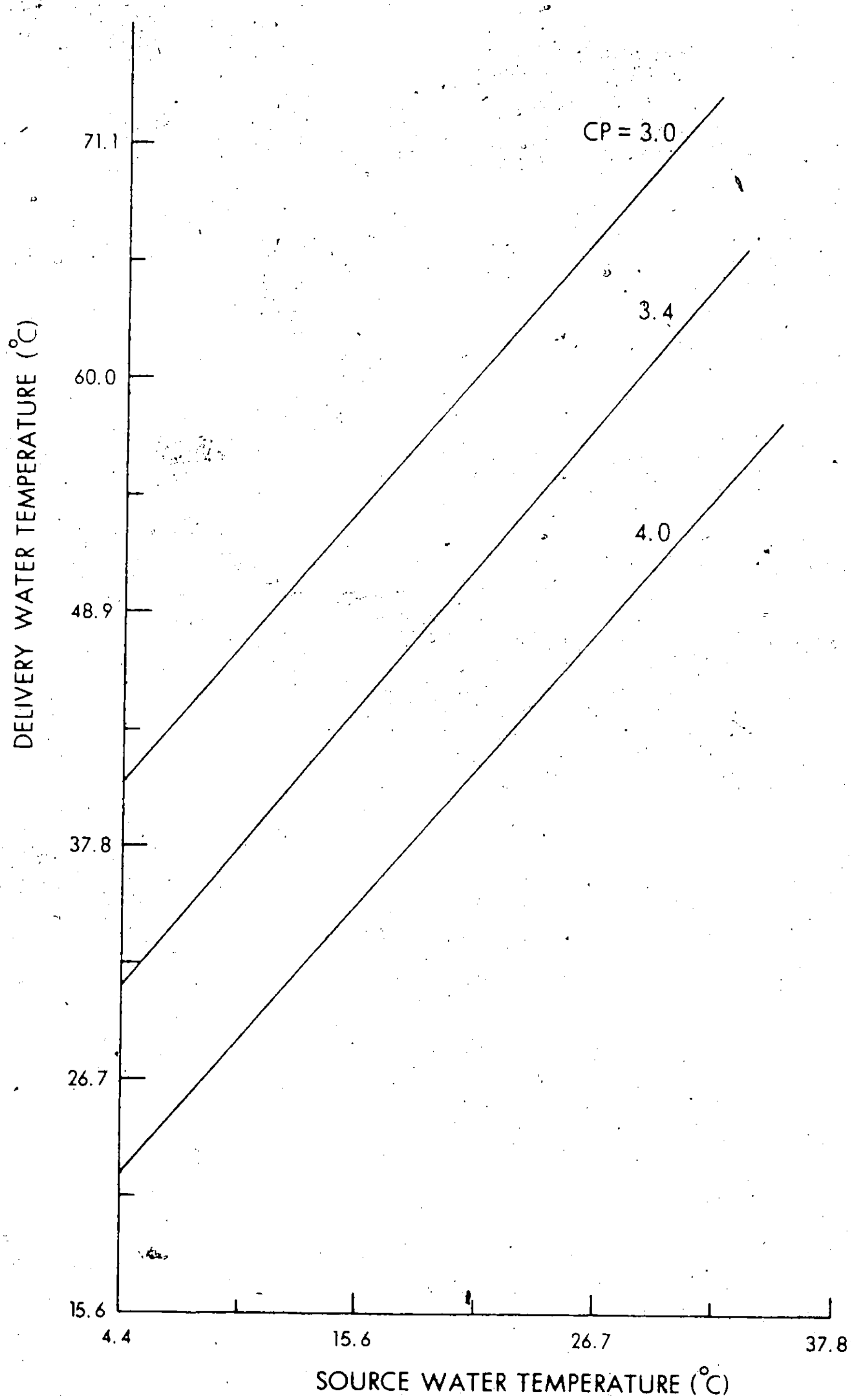
Possibly the most crucial factor affecting the overall feasibility of utilizing heat pumps for district heating with thermal effluents is the cost of distributing the warm water to the individual buildings. For this reason, only those generating stations located in close proximity to urban areas can be considered for this application. This rules out the majority of power plants in Alberta with the exception of the Rossdale and Clover Bar plants in the City of Edmonton. The remaining generating stations in Alberta are located at sufficient distances from urban areas to greatly reduce the overall efficiency of a heat pump system. Of course, the power plant satellite communities housing plant employees could be heated in this fashion.

With these facts in mind, Aamot (1977a) has calculated the expected CP of a heat pump with a supply water temperature of 57.2C (135F) to be 3.4. This assumes a relative cycle efficiency of 85 percent and a compressor/motor efficiency of 65 percent. The CP values for different water source and delivery temperatures have also been calculated and are presented in Figure 5:2. This diagram simply indicates that which was previously mentioned; i.e., the greater the temperature difference between the supply water and the delivery water, the lower the CP.

From the available literature there does not appear to be any urban area in North America heated by heat pumps using power plant thermal effluents as the heat source. Furthermore, the feasibility of implementing such a system has not been widely investigated. The one group that appears to be the most intensively involved in research of this nature is the U.S. Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire. This group has sponsored a feasibility study on district heating in Fairbanks, Alaska (Aamot, 1974). They have also been heating a building at their laboratory complex in Hanover with a heat pump using waste heat from a large refrigeration unit (Aamot, 1977b; Aamot & Sector, 1977; Sector, 1977).

Figure 5:2

COEFFICIENT OF PERFORMANCE VALUES THAT CAN BE EXPECTED FOR GIVEN WATER SUPPLY AND DELIVERY TEMPERATURES FOR A WATER SOURCE/SINK HEAT PUMP



Source: Aamot, 1977a, p. 28.

Electricity for the City of Fairbanks is supplied by the municipal coal-fired power plant that is centrally located on the bank of the Chena River which flows through the city. Operation of this generating station has resulted in air pollution and winter fogging problems for the city and, for these reasons, it was decided to investigate the feasibility of installing heat pumps in the homes of Fairbanks to utilize the thermal effluents from the plant (Aamot, 1974). It was felt this would have the further advantage of reducing home heating costs as well as reduce the air pollution from individual home furnaces.

The proposed system is basically a closed loop cooling water system connecting the power plant with all the homes in one part of the city. It has been determined that the waste heat available is sufficient to heat about 1,500 homes at -45.6C (-50F, Aamot, 1974, p. 104). In other words, all the water from the condensers would be used. The electric power required to drive the heat pumps would be 11.2 to 14 MW, assuming a CP of 3.0 to 3.5. The cooling water would be supplied at 15C (59F) and returned at approximately 3C (37.4F), representing a temperature drop of 12C (21.6F) through the system.

The economic feasibility of this system has been determined by comparing the annual operating and financing costs of a heat pump to oil-fired furnaces, electric resistance, and district heating. The results of this evaluation are presented in Table 5:1. In order to determine the annual financing costs, an interest rate of 9 percent over a twenty year amortization period was calculated on the estimated total capital cost of $4,000 (1974 U.S. dollars) for a heat pump. This represents $2,500 for the heat pump and $1,500 for connection to the distribution system.

As evident in Table 5:1, heat pumps, with the exception of district steam, show a definite advantage, in terms of annual costs, over the conventional home heating systems. The heat pump has several other advantages. For example, the conversion of 1,500 homes to heat pump systems would result in a significant reduction in furnace oil consumption. Aamot (1974) has calculated that a reduction of 20.8 percent would occur in the amount of waste heat discharged to the river from the power plant. Finally, there would be the further benefit of reducing air pollution by removing 1,500 chimneys from service. Unfortunately, despite these apparent advantages, the proposed system has yet to be implemented and its current status is unknown (G. Phetteplace, CRREL, personal communication, August 1978).

Table 5:1

SUMMARY OF THE ANNUAL OPERATING AND ANNUAL FINANCING COSTS OF FOUR DIFFERENT HEATING METHODS IN FAIRBANKS

(1974 U.S. Dollars)

	Operating	Financing	Total
Heat Pump System	$819	$440	$1259
Oil Fired Boiler	1285	176	1571
District Steam	1119	3	1122
Electric Resistance	2458	–	2458

Source: Aamot, 1974, p. 117.

At the CRREL laboratory in Hanover, a large ice engineering facility was recently constructed for conducting research on such problems as ice jams on rivers, navigation in sea ice, and sea ice forces on off-shore platforms (Aamot, 1977b). Part of this facility includes a large refrigeration unit that rejects 1.2 million BTU's per hour of waste heat in condenser cooling water at the rate of 0.03 m^3/s (450 to 500 USGPM) and at a nearly constant temperature of 12.8C (55F, Sector, 1977). In an effort to utilize this resource, it was decided to heat a large equipment storage and fabrication building with a heat pump using the cooling water as a heat source. The heat pump selected for this purpose is a conventional industrial package chiller similar to those which provide air conditioning for small office buildings. The unit is rated at 52,800 BTU's per hour of heat removal (cooling) for 5.7 kW of electrical power consumption. The heating capacity of this unit is therefore 72,249 BTU's per hour where there are 3,412 BTU's/kWh and 5.7 kW of electrical input. The heat pump extracts heat from the 12.8C (55F) entering water and transfers it to air which is blown into the building at about 30C (86F).

To date tests only have been performed on the system in operation. The results of five of these tests indicated an average CP of 3.8 (Sector, 1977). The minimum acceptable CP for this situation is 2.8 which represents a 25 percent reduction in cost compared to heating with oil (Sector, 1977). However, as previously mentioned, the U.S. Army Corps of Engineers has calculated that the practical minimum CP for a heat pump to be energy conservative is 3.4. This reduces the savings that can be achieved with this particular heat pump system although it still remains less costly to operate. The system is apparently in full operation at the present time (G. Phetteplace, CRREL, personal communication, August 1978).

There has been one feasibility study conducted in Canada on the potential of utilizing thermal effluents for heat pumps in a district heating scheme (McLoughlin & Reinbergs, 1977). This study has proposed taking condenser cooling water from the Pickering nuclear station east of Toronto and upgrading the water temperature to about 29.3C (84.7F) by blending it with moderator cooling water from that power plant. This water would then be distributed to Toronto homes through the municipal water system. Return flows would be directed into the storm sewer system in this proposal.

The rationale for using the municipal water system as a transmission network is based on the high cost of installing a new distribution network. Furthermore, winter demand for potable water in Toronto is about half that for the summer period. Thus, there exists excess water capacity in the system during the winter months that can be used without incurring additional capital costs.

The excess capacity that exists has been calculated to be sufficient to supply 20 percent of Toronto's population (approximately 500,000 people) with warm water from the power plant. The authors have also developed a scenario where condenser cooling water at only 18.3C (64.9F) would be used in the same distribution system. In this case, only 10 percent of the population could be served because of the additional heat requirements that would result.

The economics of this system are quite favourable. The heating system would be marginally less expensive than conventional systems and the payback period would run anywhere from three to thirteen years. This excludes the savings that would accrue from the reduction in furnace oil and natural gas consumption. The homes with electric resistance heating would also realize a reduction in their electricity consumption.

Although the system appears to be technically and economically viable, there is one major problem that could prevent its implementation. That is the proposal to distribute cooling water from a nuclear power station through a municipal water system. The authors recognize this as a problem in that there would be psychological and/or aesthetic reluctance on the part of the population to use this water even though it would be perfectly safe to do so. For this reason, it is extremely doubtful that this proposed scheme will ever be implemented.

CO-GENERATION

Co-generation, implying the production of both electricity and heat for practical purposes, can be achieved in steam electric generating stations by either of two methods:

1) employing an extraction turbine from which a portion of the steam that enters is removed after it has produced considerable electricity, or

2) employing a back-pressure turbine to remove all the steam after it reaches a temperature such as 121C (250F).

Miller (1972) has calculated that the first of these two methods would reduce the heat rejected to the condensers from 60 percent to 30 percent. The corresponding reduction in electricity generating efficiency in this case would be 5 percent, to about 35 percent, for an improved station net thermal efficiency of approximately 70 percent. The second method, although resulting in a reduction in the efficiency of electricity production from about 40 percent to 30 percent, would increase the total energy use to about 100 percent of that supplied to the turbine if all of the back-pressure heat were used.

Of these two methods, backpressuring is the most desirable for several reasons. The first is the greater improvement in station efficiency. Secondly, by increasing the back-pressure to about one atmosphere the steam condenses at 100C (212F) which is sufficiently hot for economical transport and for use in both space and water heating applications (Karkheck & Powell, 1977). Extracting steam, although providing additional heat, is more than twice as expensive at its source than hot water (Karkheck & Powell, 1977). Finally, the volume density of heat in hot water at 100C (212F) is greater, by more than a factor of ten, than in steam available from extraction. This means that much greater volumes of steam must be transported to satisfy a given demand. This is particularly uneconomical for transport over extended distances.

Sweden is one of the leading countries in the world in co-generation and district heating. The first plans for co-generation of heat and electricity in Sweden began shortly after World War II and there are now some thirty-five towns in that country with district heating (Acres Shawinigan, 1976). Currently, the total installed co-generation capacity in Sweden is about 10,000 MW heat with 1,600 MW electricity produced (Hambraeus & Stillesjö, 1977). Present plans for that country envisage a thermal power rating of 18,000 MW in the 1980's for a simultaneous production of 3,000 MW electricity.

In the U.S., district heating from co-generation has been in use for a number of years. Substantial segments of the downtown areas of New York, Boston, Philadelphia, and Detroit are heated with steam extracted from condensing steam turbines (Acres Shawinigan, 1976). The downtown areas of several other American cities are also centrally heated but they are relatively small and employ boiler plants only.

Escalating fuel costs and the development of numerous nuclear power plants in the U.S. has led to the procreation of several studies on co-generation and district heating in that country (e.g., Beall & Miller, 1972; Ileri et al, 1976; Karkheck & Powell, 1977; Lusby & Somers, 1972; Miller et al, 1971). These studies, rather than investigating the potential of retrofitting an existing power plant for co-generation, have all assumed the technical feasibility of this process and have attempted to apply it to hypothetical model cities. This has involved the calculation of anticipated total heat requirements for the model and outlining the distribution network that would be required. In two studies, Karkheck & Powell (1977) and Miller et al (1971), attempts have been made to estimate the total cost of servicing a large urban area with district heat and the savings that could be realized by implementing such a system. In both cases, it has been found that co-generation for district heating would be competitive with conventional home heating systems and current district heating systems in place in the U.S. There would also be the annual savings of millions of barrels of oil.

The current situation in Canada with respect to district heating is very similar to that in the U.S. Portions of Winnipeg, Vancouver, London, Toronto, and Ottawa are served by district heating systems (Acres Shawinigan, 1976). In each case however, the heat is distributed as steam directly from central boilers without any power generation. The potential for implementing district heating from co-generation in Canada has been studied for the Pickering nuclear station (Acres Shawinigan, 1976) and a small thermal plant in Halifax (Shawinigan Engineering, 1977). In addition to these studies, Edmonton Power is currently investigating the feasibility of retrofitting their Rossdale power plant for co-generation and district heating of a large portion of downtown Edmonton (R. Johnston, Edmonton Power, personal communication, March 1979).

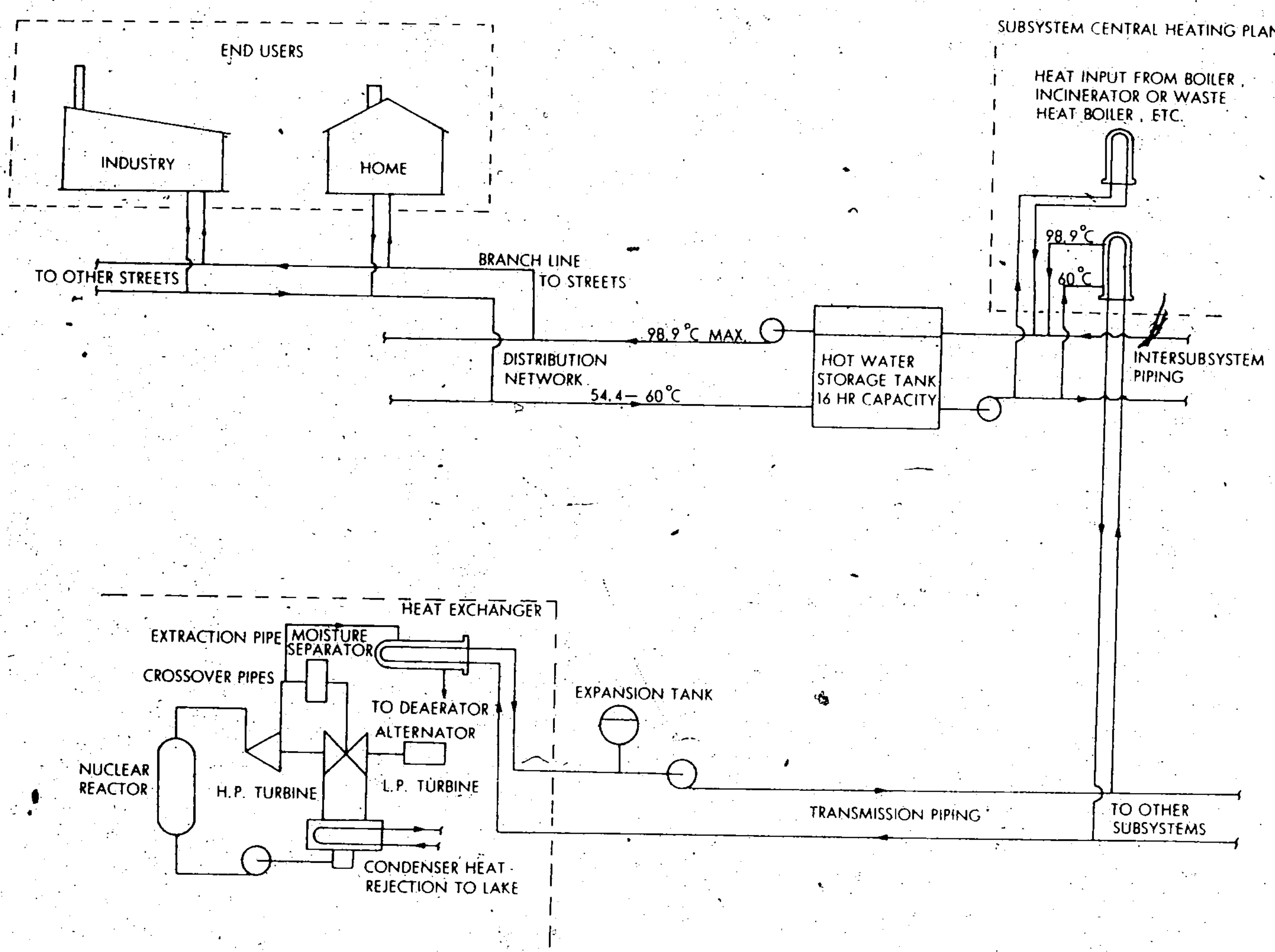
The Pickering study diverges somewhat from conventional co-generation schemes in that, rather than extracting steam or hot water, it proposes supplying hot water from the Pickering B nuclear station (under construction) for up to eight hours a night during the electrical off-peak period. Only hot water and no electricity would be produced during this period. The water would be supplied to a large underground storage tank that will have sufficient capacity to supply the model town of North Pickering for twenty-four hours. When electrical demand begins to increase in the early morning hours, the station will revert to the production of electricity only. A schematic representation of the proposed system is presented in Figure 5:3.

The scheme has several attractions, particularly as a means of keeping the nuclear reactors in continuous operation. The savings in fuel oil would be an estimated 2 million barrels per year over conventional home heating systems. The resultant reduction in air pollution is also cited as a benefit. The efficiency of the nuclear station would only be increased from 30 percent to 33 percent with this scheme however.

Two problems are inherent in the design as well. First, the technology for a large storage tank of the nature envisaged for this scheme is not readily available at a reasonable cost. Secondly, because of the high costs of

Figure 5:3

SCHEMATIC OF PROPOSED PICKERING DISTRICT HEATING PLAN



Source: Acres Shawinigan Ltd., 1976, p.20a.

this heat storage system and the transmission pipeline from the power plant to the new town, the scheme would not show an overall price advantage over conventional heating systems for approximately fourteen to eighteen years. For these reasons, the proposal has been indefinitely shelved.

In contrast, the Halifax district heating study reached much more positive conclusions. The objective of this study was to investigate the feasibility of converting the centrally located Wall Street generating plant to co-generation for heating buildings in the Halifax downtown area. Two alternative methods are considered for this purpose. The first alternative is to equip an existing 20 MW unit with a back-pressure turbine for extracting low pressure steam. The second alternative would involve converting this same 20 MW unit to a pure back-pressure unit. This would provide hot water at approximately 110C (230F).

The feasibility of the proposed system from an economic standpoint is very favourable. Both the steam system and the hot water system would be competitive with individual building heating. This does not include the annual fuel savings of between 2.8 and 3.6 million Imperial gallons that would result from implementation of the scheme. Furthermore, the steam system would break even after only four years of operation while the water system would require six years before a return on investment would occur. This is despite the fact that pipeline installation costs would be very high because of the need for extensive excavation in bedrock. In any event, this study also appears destined for a long shelf life as the Nova Scotia Power Corporation has refused to invest any new capital in the generating station citing the old age of the plant as the primary reason for this decision (R. Johnston, Edmonton Power, personal communication, March 1979).

The Edmonton district heating study is only partially completed at this time. As conceived, the plan would involve the removal of some blading from the low pressure section of the turbines in the high pressure section of the Rossdale power plant (R. Johnston, Edmonton Power, personal communication, March 1979). New condensers for the turbines would be installed to allow for back-pressuring. This would provide hot water at approximately 100C (212F). This water would be distributed to a large portion of the downtown core. No water storage would be required because the pipeline network would be sufficiently long to provide a twelve hour supply.

To date only the marketing research has been completed to determine the potential clients. The results from this research have been very positive with the majority of building managers contacted expressing a keen interest in the proposed system. There has been no problem selling the concept to potential users (R. Johnston, Edmonton Power, personal communication, March 1979). The remaining research that is required relates to the expected costs of retrofitting the plant and the installation of the transmission and return pipelines.

Hopefully, the findings of this study will indicate a significant reduction in building heating costs will occur if the system is installed. A major benefit would be the increased efficiency of the Rossdale power plant to about 85 percent. The one major obstacle, if the scheme proves to be economically viable, could be raising the necessary capital funds as the project would most certainly cost millions of dollars. The proper authorities would also have to be convinced of the need and viability of such a scheme.

CONCLUSION

Of the two district heating alternatives outlined in this chapter, co-generation is obviously the most practical, primarily because of the large increases in station net efficiency that result from this technique. Heat pumps are attractive from the viewpoint that no major alterations to the power plant are required as the thermal effluents can be utilized at their existing temperatures. On the other hand, the economic feasibility of a heat pump system rests solely on the somewhat precarious coefficient of performance. It appears that a heat pump can operate within an effective CP only if the conditions are ideal. For this reason, any additional electrical costs, such as those for transmitting the supply water through an extensive distribution network, would probably play havoc with the CP. Even so, the secondary benefits to be incurred with the conversion of an urban area to a heat pump system might outweigh a CP that is slightly lower than the accepted minimum.

The technical and economic feasibility of co-generation for district heating is a very appealing alternative and it is difficult to understand why this application has not been in use for several years in Canada. The answer, of course, is that in previous years this country has been "blessed" with cheap energy sources. The only obstacles blocking the development of co-generation for district heating in Canada and Alberta are administrative and the distant locations of most thermal power plants from urban areas. This former stumbling block will eventually be overcome as energy becomes more expensive. It is difficult to predict when this threshold will occur however.

The problem of remotely located power plants is currently being investigated in Sweden. In that country, research is ongoing on the development of new pipe technologies for transporting hot water over long distances without a subsequent major heat loss (Margen, 1976). In this regard, inner protective layers and new pipe materials, such as glassfibre armoured plastic, are being tested. Their results have indicated that transmission distances of up to 100 km (62 mi) can be justified if the heat rates transmitted are sufficiently large. This means that very large areas in a city have to be heated by the system.

If this is possible, the two power plants at Lake Wabamun, in addition to the Rossdale and Clover Bar plants in Edmonton, might be considered for providing district heat to Edmonton. It is unlikely however, that this possibility would be less expensive than conventional home heating systems. In the meantime, there is a strong possibility that the ongoing district heating study in Edmonton will find this alternative to be very attractive economically and will be Canada's first demonstration of this application.

The final consideration is that co-generation does not necessarily need to be designed for district heating. There are a variety of industrial processes that require hot water or steam and these could benefit from heat supplied by co-generation. For the isolated power plants, co-generation could provide sufficient heat for vast acreages of greenhouses. In fact, in Romania, approximately 1,200 hectares (3,000 acres) of greenhouses are heated in this manner (D. Haycock, Conestoga-Rovers & Associates, personal communication, August 1978). The options for utilizing heat from co-generation are much greater than those for utilizing condenser cooling water.

CHAPTER VI

MISCELLANEOUS APPLICATIONS

Introduction

The applications reviewed in the three previous chapters are often heralded as having the greatest potential for utilizing thermal power plant reject heat. The two primary reasons for this are the apparent ease of adaptation of these well established industries to a waste heat energy source and, greenhouse heating, thermal aquaculture, and district heating can all generate economic returns that are easily measured. In fact, the feasibility of these applications is usually based solely on the amount of these returns as the technology is readily available for employment of a waste heat energy source by these three industries.

There are however, several other potential applications that do not necessarily provide direct benefits in the form of economic returns but do, nevertheless, generate benefits that cannot be easily quantified in monetary terms. For the most part, these applications, which include municipal water heating, wastewater heating, warm water irrigation and open field soil warming, will increase productivity through improved efficiencies. One application, waterfowl habitat enhancement, has been more accidental in its occurrence than the result of any efforts to pre-plan this waste heat use, even though there could be deliberate sanctuary development in areas receiving thermal discharges. There are also potential recreational uses with respect to condenser cooling water and cooling ponds.

This chapter is a brief discussion of the forementioned applications and their potential for development in Alberta. In the case of municipal water heating, the cities of Edmonton and Saskatoon have been employing thermal effluents in this manner for some time and thus only a cursory description of their use of waste heat will be provided. There is very little documentation available on waterfowl habitat enhancement through the use of waste heat and therefore the discussion of this application will also be quite brief. Some suggestions on how to expand this use of thermal effluents will be presented as well.

MUNICIPAL WATER HEATING

The use of waste heat for municipal water heating has a good potential for power plants that are centrally located in cities and towns experiencing cold winter climates. With the onset of winter and below freezing temperatures, condenser cooling water can be mixed with pretreated potable water to prevent frost damage and water main breaks in municipal distribution systems. Increased chemical efficiencies in the treatment process are also accrued when the water is warmer than under normal conditions. There is a further benefit in that consumers do not require as much energy to heat slightly warmed water as they would require for water exhibiting near freezing temperatures.

Two Canadian cities are currently employing this technique; Saskatoon and Edmonton. In Saskatoon, condenser cooling water from a central power plant is pumped to the municipal water treatment plant. There, it is mixed with raw river water, treated for consumption, and distributed at a temperature of approximately 14C (57.3F, D. Kelly, Saskatoon Water and Pollution Control Department, personal communication, June 1978). Approximately 68 million litres per day (15 million IGPD) of condenser cooling water are used in this manner from November to April, depending upon the weather conditions.

In Edmonton, condenser cooling water from the Rossdale power plant is pumped to the adjacent municipal water treatment plant (Figure 2:19). This cooling water is carefully blended with river water (source of potable water for the city) to achieve a mix at exactly 11.1C (52F, L. Gyurek, Edmonton Department of Water and Sanitation, personal communication, April 1979). After several years of operating experience, it is felt that the maximum benefits from this application are accrued when the water temperature is 11.1C (52F). Because of the widely varying winter temperatures and demand for potable water, the water flows from the power plant to the treatment facility vary substantially on a daily basis. No accurate records of these flows are maintained.

One interesting aspect of the Edmonton system is that the water treatment plant is assessed a user fee for the waste heat. The reason for this is that the Rossdale plant has to generate sufficient electricity to produce the required amounts of warm water. This has resulted in the

Rossdale station assuming a portion of the base load demand that would normally be generated at the Clover Bar plant, which is more efficient in terms of electricity production. The calorific value of this lost efficiency is charged to the water treatment facility and amounts to approximately $400,000 for five months (L. Gyurek, Edmonton Department of Water and Sanitation, personal communication, April 1979). However, the benefits, which are difficult to quantify, are obviously in excess of this fee for them to continue operating in this fashion.

Unfortunately, the city's new water treatment plant, which is currently under construction upstream in southwest Edmonton, will not be utilizing condenser cooling water in this manner. This new facility is designed to supply future demands for potable water in south Edmonton and thus will not replace the existing water treatment plant which will continue to utilize the Rossdale cooling water.

Northern communities especially could benefit from this use of power plant waste heat. In some areas, such as Yellowknife, the water faucets are allowed to continue running in cold periods in order to avoid the freezing of lines. This application should be integrated into the original design of power plants that are located near towns as it has been demonstrated to be a benefit in Edmonton and Saskatoon.

WASTEWATER TREATMENT

The use of additional heat in wastewater treatment involves the utilization of thermal power plant condenser cooling water to increase the efficiency of municipal sewage treatment facilities. The efficiency of these systems can be improved by simply increasing the temperature of the wastewater, especially during colder winter periods. This use of waste heat has been investigated by numerous sources (e.g., Agardy et al, 1973; Fazzolare & Sierka, 1974; Oswald, 1973; Sierka & Fazzolare, 1973; Tobin & Trax, 1974) and found to be both technically feasible and economically attractive. For example, Table 6:1 is a summary of findings documented by Tobin & Trax (1974). These results indicate that wastewater treatment efficiencies can be improved significantly by only a 10C (18F) increase (from 20C to 30C, 68F to 86F) in the water temperature. This increase in efficiency has the further advantage of reducing the size of the unit required in treating the wastewater.

Increasing the water temperature has a significant effect upon both the physical and chemical processes com-

Table 6:1

SUMMARY OF UNITS SIZE AND EFFICIENCY CHANGES
DUE TO 10°C TEMPERATURE INCREASE (20°C to 30°C)

Unit Operation	Change Due to Temperature Increase: % Change in Unit Size	% Change in Unit Efficiency
Grit Chamber	16.5	13
Primary Clarifier	20	13
Aeration Basin	10	12
Trickling Filter	68	30
Stabilization Pond	48	15
Aerated Basin	52	8
Final Clarifier	20	-
Chlorine Contact Tank	28	-
Thickener	20.5	-
Anaerobic Digestor	38.5	8.2
Vacuum Filter	14	9
Centrifuge	20	25
Filtration (Strat.)	19	20
Rapid Sand	-	60
Backwash Rate	-	-16
Activated Carbon	-8	29
Foam Separation	-	-5
Nitrification	27	65
Denitrification (A.S.)	92	47
Ammonia Stripping	50	14
Anaerobic Column (Nitrogen Removal)	-	28
Pure O_2 Activated Sludge	-	114
Coagulation	-	50

Note: Minus sign indicates an increase in unit size or a decrease in efficiency. No sign indicates a decrease in unit size or an increase in efficiency.

Source: Compilied by Tobin & Trax, 1974, p. 112.

monly employed in waste treatment. The physical processes, which include grit removal, clarification, thickening, sludge dewatering, and flotation, involve a separation of solid material from water. The efficiency of this process is chiefly a function of the fluid viscosity. Therefore, decreasing the viscosity of the fluid by increasing its temperature will improve the efficiency of separation (Tobin & Trax, 1974).

In the chemical processes, various chemicals are employed as an aid in the separation processes as well as for disinfection, phosphorous removal, and biological denitrification. The chemical reaction rates in these processes can be enhanced by elevating the water temperatures. In general, the efficiencies of the physical and chemical processes will improve with elevated temperatures up to a threshold of about 50C (122F, Tobin & Trax, 1974).

Increased water temperatures can also improve the efficiencies of biological processes used in waste treatment systems. Biological treatment is a process wherein active bacteria are mixed with a waste. Provided sufficient dissolved oxygen is available, the bacteria reduce the waste to a more stable form through BOD removal. The speed at which this process will operate is dependent upon the water temperature and the amount of dissolved oxygen present. By increasing both these parameters, the process becomes much more efficient in terms of BOD removal. The degree of improvement with increased temperature is illustrated in Table 6:2. These figures indicate that the amount of BOD removal increases from 35 percent at 10C (50F) to 55 percent at 20C (68F). The optimum temperature for biological reactions depends upon the type of process and ranges from 30C to 52C (86F to 125.6F, Tobin & Trax, 1974).

The major problem associated with this waste heat application is transferring the heat from the cooling water to the wastewater. There have been several alternatives proposed for dealing with this problem. Agardy et al (1973) discuss the possibility of utilizing direct and indirect contact systems. With direct contact systems, the cooling water is mixed directly with the wastewater to be treated. Indirect contact would involve separation of the two fluids by a physical barrier such as a shell and tube heat exchanger. The advantage of these systems is that the water could be returned to the condensers for cooling in a closed loop system.

Oswald (1973) proposed the establishment of a waste treatment ponding system located adjacent to a power plant.

Table 6:2

EFFECT OF TEMPERATURE CHANGES
ON BOD REMOVAL

Temperature (^{o}C)	Suspended Solids (% removed)	BOD (% removed)
10	45	35
12.5	55	40
15	65	45
17.5	75	53
20	85	55

Source: Compiled by Agardy et al, 1973, Table 4, p. 36.

All municipal wastes would be directed to the ponds which would also serve as cooling reservoirs for the power plant. A byproduct of this system, according to Oswald, would be the production of methane gas and usable algae. A similar proposal is advocated by Zahradnik et al (1976).

Sierka & Fazzolare (1973) propose that raw sewage, after primary settling to remove large particles, be passed through a special condenser in the power plant in order to heat the water to 43C (109.4F). The back-pressure of the turbine in this case would be adjusted to allow for this higher temperature and would result in only a minor loss of thermal efficiency in the power plant.

Tobin & Trax (1974) propose the construction of an elaborate, integrated power, water and wastewater utility complex on Long Island, New York. The process will involve the utilization of process steam from a 1000 MW nuclear power plant for a water distillation plant. Spent steam from the final stage of the distillation process is to be used to elevate the temperature of wastewater from a local municipality. This will enhance the primary and secondary treatment processes. The secondary treated water will then act as a feed for the distillation process. The distilled water will be directed into the municipal potable water system.

In addition to these proposed schemes, there is a thermal power plant in Great Britain where treated wastewater is used for condenser cooling. The Croydon power station has been employing this system for twenty years and has reduced costs and improved efficiencies in the sewage treatment (Wood, 1976). The station has the advantage of being located on top of the sewage works and thus a circulating water system did not involve any exceptional pipework. Recent construction of another unit at the power plant resulted in heavy fouling of the condenser tubes but this was alleviated by chlorination.

Any such system in Alberta would only be practical in Edmonton with its two centrally located power plants. Wastewater treatment facilities for the city are located on the southbank of the North Saskatchewan River about midway between the Rossdale and Clover Bar stations (Figure 2:19). Even so, the Rossdale station would have to be ruled out as the source of cooling water because of its commitments to the municipal water treatment plant and also because of the possibility of conversion of the power plant for district heating. It also provides open water in the river during the winter months. This allows for oxygen to be dissolved in the water thus improving the natural aerobic processes in the river. Pumping water from the Clover Bar plant would be expensive. This generating station also provides for some natural sewage treatment in the river by maintaining an ice free area during the winter months.

OPEN FIELD SOIL WARMING

The benefits of soil warming with condenser cooling water in greenhouses were discussed in Chapter III. In general, this application has been found to have significant effects on the maturity and yield of several crops in greenhouse conditions. Similar results are also reported for tests conducted on open field soil warming with condenser cooling water and with other heating devices such as buried cables.

In a report on the effect of soil temperature on plant growth, Yang (1970) states that the minimum soil temperature for germination of cucumber, snap beans, sweet corn, and tomato is between 11C and 18C (51.8F to 64.4F) Below 11C (51.8F), no production of seed were observed while the optimum temperatures are 18C to 25C (64.4F to 77F) for tomato and 25C to 30C (77F to 86F) for cucumber, snap beans, and sweet corn. The actual growth of tomatoes, cucumbers, snap beans, and sweet corn can be increased significantly through ~~the~~ use of soil heating according to Yang.

Experiments on soil warming with heating devices designed to simulate condenser cooling water have been reported by the Tennessee Valley Authority (TVA, Mays, 1975), the University of Minnesota (Allred et al, 1975), and Oregon State University (Rykbost et al, 1974). At the TVA's laboratories in Muscle Shoals, Alabama, summer squash, string beans, and sweet corn were planted on heated and unheated soil plots in early spring of 1971 and 1972. The soil temperature of the heated plot was maintained at 9C to 10C (48.2F to 50F) above ambient soil temperatures up to a maximum of 29.4C (85F). With all crops, emergence was hastened by three to four days, early growth was greater, and the crop matured a few days earlier on heated than on unheated soil. When averaged over two years, soil warming markedly increased vegetable yields (Table 6:3) both with and without irrigation. Follow up crops planted in midsummer showed little response to soil warming although this might depend on the ambient summer temperatures.

The Minnesota experiment compared potato yields on heated and unheated soil plots during the 1973 and 1974 growing seasons. Soil temperatures within the heated plot were controlled by the circulation of warm water (35C to 40.5C, 95F to 104.9F) through an underground network of copper pipe. The results of maturity and yield observations for the 1973

Table 6:3

VEGETABLE YIELDS AS AFFECTED BY SOIL HEATING AND IRRIGATION AT THE TVA, 1971-1972

Treatment	Total Yields, tonnes/hectare(tons/acre)		
	Sweet Corn	String Beans	Summer Squash
Heat + Irrigation	19.9 (8.7)	18.6 (8.3)	68.5 (30.6)
Irrigation only	11.2 (5.0)	12.5 (5.6)	49.5 (22.1)
Heat only	11.6 (5.2)	12.8 (5.7)	41.2 (18.4)
No Treatment	5.4 (2.4)	6.7 (3.0)	29.8 (13.3)

Source: Mays, 1975, Table 1, p. 88.

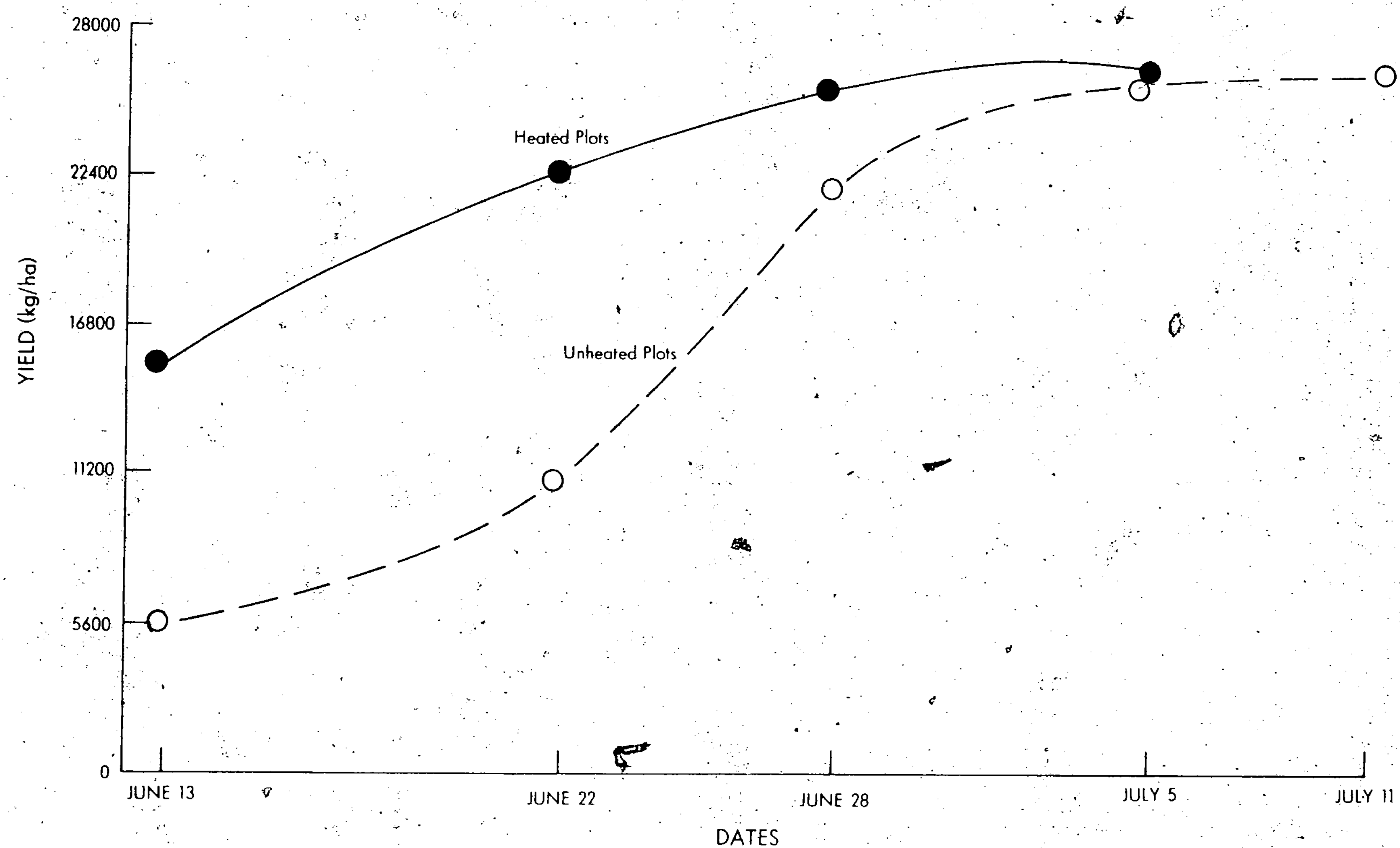
growing season are presented in Figure 6:1. This graph depicts the potato yields on the heated and unheated soil plots for five different harvesting dates and indicates that yields on heated plots were much higher on the earlier harvesting dates. After July 5, the yields on the two plots were similar. No conclusive results were obtained for the 1974 growing season because of adverse climatic conditions. This experiment also demonstrated that soil warming provided frost protection for plants less than 7.6 cm (3 in) above the soil surface but only until air temperatures dropped to -2.8C (27F), which is very significant.

In Oregon, Rykbost et al (1974) describe an experiment with open field soil warming that was conducted from 1969 to 1972. In this experiment, electrical cables were buried to a depth of 92 cm (3 ft) with 183 cm (6 ft) lateral spacing. Several crops, including strawberries, bush beans, broccoli, peppers, and tomatoes, in addition to a number of forage crops, were planted.

A wide range in yield response to soil heating was observed for different crops and for some crops in different years. In general, the bush beans (except for soybeans), tomatoes, broccoli, and peppers all demonstrated marked increases in yield due to soil warming, by as much as a

Figure 6:1

POTATO YIELDS ON HEATED AND UNHEATED SOIL PLOTS IN MINNESOTA



Source: Allred et al, 1975, p. 95.

factor of two in the case of broccoli. The forage crops growth rates were substantially increased during the winter but suffered from soil heating in the summer. The authors conclude that, in general, soil warming will not be economically feasible for low value crops but high value crops, such as vegetables, may be profitably grown with soil warming methods even if the producer is assessed a user fee for the warm water.

Perhaps the most extensive research effort on open field soil warming is reported by Berry & Miller (1974). This research was part of a five year study in Oregon to determine the feasibility of utilizing thermal effluents in agricultural applications. The source of the warm water in this case was effluent from a pulp and paper mill. Temperatures of this water were about 37.8C (100F). Approximately 0.8 hectares (2 acres) of land was heated by 6.3 cm (2.5 in) diameter polyvinylchloride (PVC) pipe buried about 66 cm (2 ft) deep and 152 cm (5 ft) off center. Tomato, sweet corn, asparagus, and squash were the crops tested.

The results from this experiment are similar to those reported by Mays (1975), Allred et al (1975) and Rykbost et al (1974) with the exception that soil heating did not influence tomato yields. The remaining crops demonstrated early emergence and maturity on heated soil and significantly higher yields than those crops grown on control plots. On a number basis; ungraded, graded and immature ears of corn were increased by 36, 23 and 129 percent respectively by heated soil while the weight of asparagus ferns and stalks from soil heated plots averaged 95 percent more than those from unheated plots. The soil heated block of squash produced 24 percent more fruit by number and 13 percent more fruit by weight than the nonheated block.

The findings reported from the forementioned experiments would appear to indicate that this particular application of waste heat could prove to be very beneficial to Alberta farmers, especially those producing vegetable crops. This use of waste heat is particularly attractive because of the rural locations of most thermal power plants. Special consideration should possibly be given to the potential of establishing a prototype study utilizing thermal effluents in this manner.

WARM WATER IRRIGATION

The only reported study of this application is that by Berry & Miller (1974) in Oregon. The primary objective in their study of this application was to determine if protection against frost in orchards is possible through sprinkler irrigation of thermally enriched water. Some frost protection was achieved on fruit trees and other plants although it was not demonstrated that using warm water rather than normal temperature water gave additional frost protection. Some crops gave greater protection and earlier yields.

Although the findings of this particular study were not very positive, there might be potential for developing some aspect of this application in Alberta. There are very few orchards in the province but warm water irrigation could provide an aid for sugar beet production. Cold irrigation water in the southern portion of Alberta is a factor in slowing the growth of several other crops as well.

WATERFOWL HABITAT ENHANCEMENT

There is very little published material on this aspect of waste heat utilization. Nevertheless, it appears that many waterfowl and other migratory birds are overwintering in the ice free areas of lakes and rivers where thermal discharges are released. This has been reported at the Wascana Park in Regina, Saskatchewan (R. Prach, Canadian Wildlife Service, personal communication, April 1979), Lake Wabamun (Prach & Surrendi, 1978) and the Battle River at the Forestburg power plant (W. Peel, Alberta Power Ltd., personal communication, June 1978).

At the Wascana Park in Regina, a small thermal generating station has been discharging cooling water into Wascana Lake for a number of years. Large numbers of waterfowl have been overwintering in the ice free area created by the thermal discharge and there has even been some encouragement, in the form of artificial feeding, for them to do so. However, the power plant was scheduled to close down in 1978 and there was some concern expressed about the plight of the birds. This proved unnecessary as many birds remained during the winter without the benefit of open water although feed was provided by park authorities.

At Lake Wabamun, Prach & Surrendi (1978) have undertaken a study to determine the ecology of waterfowl overwintering on open water created by the release of thermal effluents from the Wabamun generating station. The study is not yet completed but preliminary results indicate that during the winter of 1976/77 and 1977/78 more than 4,600 and 2,800 birds respectively overwintered at Lake Wabamun. Forty-two different species were observed during these two winters. Winter mortality of the birds at Lake Wabamun is about 25 percent. A similar situation is reported to be occurring at the Forestburg power plant but no studies have been undertaken in this regard.

Attempts to develop and manage this resource could be met with several problems. One, the birds present potential hazards to aircraft. However, with the exception of the two Edmonton power plants, there are no major airports in the vicinity of the generating stations under study in this thesis. Secondly, the birds can cause severe damage to cereal grain. There are management techniques to control this problem however, such as lure feeding and scaring programs. Finally, the number and condition of waterfowl overwintering on an open body of water is directly affected by the available food supply. If feeding programs are established, more waterfowl will be attracted to the area creating difficulties in controlling the large populations.

The two major opportunities that exist for management of this resource are hunting and viewing of the birds. The only waterfowl hunting available after freezeup in Alberta is in these areas of open water while the variety of waterfowl provides an excellent opportunity for bird watching. Thermal discharge into a lake or river provides a rich and productive winter habitat for migratory birds and should be exploited for this purpose in the future in this province. A program of this nature would be much easier to control if planned and managed than one that is neither.

RECREATIONAL USES

As with warm water irrigation and waterfowl habitat enhancement, there is virtually no available literature on the potential of utilizing condenser cooling water for recreational purposes. Nevertheless, several possibilities may be developed. Certainly waterfowl hunting and viewing are recreational activities. Apparently a number of people take advantage of the open water at Lake Wabamun for ice fishing. Cooling ponds could be particularly attractive features for recreational activities. These include sport fishing, boating, swimming, and perhaps even water skiing. The possibilities would seem limitless but many would require a great deal of cooperation and encouragement from the utilities.

CONCLUSION

Although greenhouse heating, thermal aquaculture and district heating command the most attention in the literature as methods of utilizing thermal power plant waste heat, there are several other potential applications of this resource. Some of these have been outlined in this chapter and all, with possibly the exception of warm water irrigation, would appear practical for development in Alberta. Municipal water heating has been in use in Edmonton for a number of years which further exemplifies the forward thinking of Edmonton Power in their attitudes towards improving generating station thermal efficiencies.

There are potentially several other applications of condenser cooling water in addition to those discussed in this thesis. The integrated food complex, in various forms, has been proposed by several authors (e.g., Beall, 1973; Boersma & Rykbost, 1973; Boersma et al, 1974; Hirst, 1973). This system would involve a complex of greenhouse heating, soil warming, animal shelter heating, a food processing plant, and treatment of the animal and processing wastes from the complex with the aid of condenser cooling water. Jaske et al (1970) propose the development of a canal lake system to supplement inter-regional water supply. It has also been suggested that thermal effluents be utilized to increase the shipping seasons in major waterways, such as the St. Lawrence Seaway, by delaying freezeup (Biggs, 1968).

There are clearly numerous methods of utilizing power plant waste heat depending upon the needs and desires of those wishing to take advantage of this resource. All it would require to develop some aspect of power plant waste heat utilization in Alberta is a little initiative on the part of individuals or the utilities. Perhaps the public is not fully aware of this resource and thus do not comprehend the apparent potential of utilizing this waste energy.

CHAPTER VII

THE MARKET POTENTIAL FOR SOME FRESH VEGETABLES, FLORICULTURAL CROPS, AND FISH IN ALBERTA

Introduction

In an effort to partially determine the economic feasibility of greenhouse heating and thermal aquaculture, a market analysis was attempted for the products that would be produced in these two industries. These include the vegetables that are commonly grown in greenhouses such as tomatoes, cucumbers, and lettuce as well as cut flowers, bedding plants, and potted plants. For thermal aquaculture, only rainbow trout and shrimp were considered.

The method originally envisaged for conducting this analysis was that of comparing the total imports of these products into Alberta versus the provincial production of these same products. This would provide an indication of the total supply that is produced locally and aid in determining if there is indeed a substantial market for more domestically produced fresh vegetables, floral crops, and fish. Unfortunately, the information required to follow this routine was either very fragmented or simply not available and only the analysis of fresh vegetables follows the above mentioned methodology. The general paucity of literature on the subject necessitated a large number of interviews with individuals throughout the province who are directly involved in the production and/or importation of these products. This yielded some information but the final results in most cases are either incomplete or inconclusive. This will be discussed in more detail in the following analysis.

FRESH VEGETABLES

The fresh vegetables considered for this section are beans, broccoli, brussel sprouts, carrots, cauliflower, celery, cucumbers, lettuce, peppers, spinach, and tomatoes. Cucumbers and tomatoes are the two crops most commonly associated with greenhouse production but the other crops listed above can also be grown in greenhouses. In addition, the majority of these crops were grown in the Lake Wabamun greenhouse project.

Data on imports for these crops were obtained from the 1977 annual unload report of fresh vegetables that is published by Agriculture Canada (1978a). This report only lists those unloads at the Calgary and Edmonton markets while data on shipments made directly to other markets in the province are not available. Nevertheless, these figures represent about 90 percent of the total imports into the province (S. Bryant, Agriculture Canada, personal communication, January 1979). The monetary values assigned to the foreign imports are average prices derived from the total value, by commodity, of imports into the four western provinces in 1977 (Alberta Treasury, 1979). The monetary values assigned to imports of Canadian origin are the 1977 average Canadian farm prices as listed by Agriculture Canada (1978b).

The only domestic, commercial field production of note is with carrots and cucumbers. The remaining vegetables are not grown on a commercial scale in Alberta. Some production of these vegetables takes place in market and private home gardens and can be substantial but this is difficult to quantify. The figures for carrots and cucumbers were obtained from the Statistics Branch of Alberta Agriculture and are simply the total number of acres in the province devoted to these crops multiplied by the average yields per acre. The monetary values of the carrots and cucumbers are the 1977 average Canadian farm prices similar to those mentioned above.

It appears that only cucumbers and some tomatoes are produced in greenhouses in this province. Although tomatoes were once a predominant greenhouse vegetable crop in Alberta, growers are now switching to cucumbers and floral crops because of the higher returns available with these products and the much greater labour requirements for tomatoes (B. Cantin, Alberta Agriculture, personal communication, January 1979). No Alberta government agency collects data on the greenhouse production of fresh vegetables in the province but Statistics Canada publishes an annual report on the Canadian greenhouse industry which lists the individual vegetable production by province (Statistics Canada, 1978). This report is based on the results of a questionnaire distributed to all known greenhouse growers in the country. Response to this questionnaire was performed on a voluntary basis and Statistics Canada does not report on the percentage of nonrespondents. However, they do state that it is believed almost all the industry is covered in the report. The number of respondents from Alberta is not listed for confidential purposes and is only included in the Canadian total. The average value of the crops is provided in this report and was used to calculate the value of the greenhouse production.

The summary data are presented in Tables 7:1 to 7:11. Several interesting disclosures are revealed in these results. The most disconcerting feature is the large deficit balance of trade for these eleven fresh vegetables in 1977. The total deficit amounts to more than $13.5 million. The data for 1978 are not yet available but it is reasonably safe to assume that the deficit in that year was probably similar to that of 1977, or perhaps even larger. The deval-

Table 7:1

THE 1977 COMMERCIAL SUPPLY AND VALUE OF BEANS IN ALBERTA

	kg.	dollars
Imports (foreign origin)	142,427	84,174 (.591/kg)
Imports (Canadian origin)	24,251	10,598 (.437/kg)
Total Imports	166,678	94,772
Domestic Field Production	–	–
Domestic Greenhouse Production	–	–
Total Supply	166,678	94,772
Exports	–	–
Net Trade	(166,678)	(94,772)

Table 7:2

THE 1977 COMMERCIAL SUPPLY AND VALUE OF BROCCOLI IN ALBERTA

	kg.	dollars
Imports (foreign origin)	1,650,617	683,355 (.414/kg)
Imports (Canadian origin)	–	–
Total Imports	1,650,617	683,355
Domestic Field Production	–	–
Domestic Greenhouse Production	–	–
Total Supply	1,650,617	683,355
Exports	–	–
Net Trade	(1,650,617)	(683,355)

Table 7:3

THE 1977 COMMERCIAL SUPPLY AND VALUE OF BRUSSEL SPROUTS IN ALBERTA

	kg.	dollars
Imports (foreign origin)	208,651	132,493 (.635/kg.)
Imports (Canadian origin)	10,886	6,913 (.635/kg.)
Total Imports	219,537	139,406
Domestic Field Production	-	-
Domestic Greenhouse Production	-	-
Total Supply	219,537	139,406
Exports	-	-
Net Trade	(219,537)	(139,406)

Table 7:4

THE 1977 COMMERCIAL SUPPLY AND VALUE OF CARROTS IN ALBERTA

	kg.	dollars
Imports (foreign origin)	2,616,307	664,542 (.254/kg.)
Imports (Canadian origin)	446,333	42,848 (.096/kg.)
Total Imports	3,062,640	707,390
Domestic Field Production	5,096,000	489,216 (.096/kg.)
Domestic Greenhouse Production	-	-
Total Supply	8,158,640	1,196,606
Exports	-	-
Net Trade	(3,062,640)	(707,390)

Table 7:5

THE 1977 COMMERCIAL SUPPLY AND VALUE OF CAULIFLOWER IN ALBERTA

	kg.	dollars	
Imports (foreign origin)	1,592,555	801,055	(.503/kg.)
Imports (Canadian origin)	297,101	78,732	(.265/kg.)
Total Imports	1,889,656	879,787	
Domestic Field Production	–	–	
Domestic Greenhouse Production	–	–	
Total Supply	1,889,656	879,787	
Exports	–	–	
Net Trade	(1,889,656)	(879,787)	

Table 7:6

THE 1977 COMMERCIAL SUPPLY AND VALUE OF CELERY IN ALBERTA

	kg.	dollars	
Imports (foreign origin)	6,029,583	1,989,762	(.33/kg.)
Imports (Canadian origin)	206,837	32,473	(.157/kg.)
Total Imports	6,236,420	2,022,235	
Domestic Field Production	–	–	
Domestic Greenhouse Production	–	–	
Total Supply	6,236,420	2,022,235	
Exports	–	–	
Net Trade	(6,236,420)	(2,022,235)	

Table 7:7

THE 1977 COMMERCIAL SUPPLY AND
VALUE OF CUCUMBERS IN ALBERTA

	kg.	dollars
Imports (foreign origin	3,029,074	939,013 (.31/kg.)
Imports (Canadian origin)	218,177	41,672 (.191/kg.)
Total Imports	3,247,251	980,685
Domestic Field Production	188,683	36,040 (.191/kg.)
Domestic Greenhouse Production	232,280 doz[1]	825,774 (3.56/doz)
Total Supply	5,235,944	1,842,499
Exports	-	-
Net Trade	(3,247,251)	(980,685)

[1]This is approximately 1,800,000 kg.

Table 7:8

THE 1977 COMMERCIAL SUPPLY AND
VALUE OF LETTUCE IN ALBERTA

	kg.	dollars
Imports (foreign origin)	17,030,944	3,406,189 (.20/kg.)
Imports (Canadian origin)	936,210	184,433 (.197/kg.)
Total Imports	17,967,154	3,590,622
Domestic Field Production	-	-
Domestic Greenhouse Production	-	-
Total Supply	17,967,154	3,590,622
Exports	-	-
Net Trade	(17,967,154)	(3,590,622)

Table 7:9

THE 1977 COMMERCIAL SUPPLY AND VALUE OF PEPPERS IN ALBERTA

	kg.	dollars
Imports (foreign origin)	1,880,130	1,165,681 (.62/kg.)
Imports (Canadian origin)	47,173	29,247 (.62/kg.)[1]
Total Imports	1,927,303	1,194,928
Domestic Field Production	-	-
Domestic Greenhouse Production	-	-
Total Supply	1,927,303	1,194,928
Exports	-	-
Net Trade	(1,927,303)	(1,194,928)

[1]There is no average farm price for peppers that is readily available, therefore the import value rates have been used.

Table 7:10

THE 1977 COMMERCIAL SUPPLY AND VALUE OF SPINACH IN ALBERTA

	kg.	dollars
Imports (foreign origin)	125,644	39,075 (.311/kg.)
Imports (Canadian origin)	-	-
Total Imports	125,644	39,075
Domestic Field Production	-	-
Domestic Greenhouse Production	-	-
Total Supply	125,644	39,075
Exports	-	-
Net Trade	(125,644)	(39,075)

Table 7:11

THE 1977 COMMERCIAL SUPPLY AND VALUE OF TOMATOES IN ALBERTA

	kg.	dollars
Imports (foreign origin)	6,344,363	3,362,512 (.53/kg.)
Imports (Canadian origin)	97,975	35,663 (.364/kg.)
Total Imports	6,442,338	3,398,175
Domestic Field Production	-	-
Domestic Greenhouse Production	103,006	101,048 (.99/kg.)
Total Supply	6,545,344	3,500,123
Exports	-	
Net Trade	(6,442,338)	(3,398,175)

uation of the Canadian dollar over the past year may also add at least 15 percent to this deficit.

A second disturbing fact, as previously mentioned, is the almost total absence of domestically produced commercial fresh vegetables, both in field and greenhouse production. Of the eleven vegetables analyzed, only carrots (Table 7:4) and cucumbers (Table 7:7) are produced locally in open fields while cucumbers and tomatoes (Table 7:11) are the only vegetables grown in greenhouses in this province. More carrots are produced in Alberta than are imported but the values of foreign imports are greater because of the higher prices thus resulting in a deficit. The domestic greenhouse and field production of cucumbers represents only about 38 percent of the total supply of this vegetable in Alberta. The domestic production of tomatoes represents less than 2 percent of the total provincial supply.

A further distressing facet of this analysis is the large proportion of foreign imports to those imports of Canadian origin. In terms of quantity, the proportion of foreign imports represented about 94.5 percent of the total imports into Alberta. The majority of these imports of foreign origin come from the states of California, Arizona, and Texas while a substantial portion also comes from Mexico.

Virtually all the fresh vegetable imports into Alberta from Canadian provinces originate in British Columbia with some coming from Ontario and Manitoba.

In summary, these data on fresh vegetables are not quite complete but they are as accurate as possible with the existing information. Despite this, the information presented above is conclusive and partially quantifies the large deficit balance of trade that exists in Alberta with respect to most fresh vegetables.

FLORICULTURAL CROPS

The only information available on floral crops is on domestic greenhouse production as reported by Statistics Canada (1978). The varieties of flowers and plants that were produced in 1977 are too numerous to list but the total value of ornamental and plant sales for the Alberta greenhouse industry was $8,116,388 (Statistics Canada, 1978, p.21). This total is derived from sixty-two respondents of the questionnaire that is the basis for this report. Of the cut flower, carnations, chrysanthemums, and roses represented by far the largest proportion of the total flowers produced in Alberta in 1977. Geraniums, tropical foliage, and green plants were the predominant potted plants grown in the province during 1977. Bedding plants and vegetable plants were the most commonly produced rooted cuttings.

The only available information on the quantity of floral crop imports into Alberta is provided by Alberta Treasury (1979). However, these data are only for the port of clearance, not the final destination, and are therefore meaningless. Agriculture Canada has only recently begun collecting data on the unloads of floricultural crops in the major Canadian markets and no information is available for Alberta points at this time (S. Bryant, Agriculture Canada, personal communication, January 1979). The Statistics Branch of Alberta Agriculture maintains no records whatsoever of these imports preferring to rely on Agriculture Canada for this information (C. Sterling, Alberta Agriculture, personal communication, January 1979). Therefore, a market analysis following the prescribed procedure could not be conducted and only generalities may be concluded.

In the past, of all the floricultural crops, cut flowers were the primary crop produced by greenhouse growers in the province. Now, foreign suppliers of cut flowers are gradually capturing the market (E. Toop, Department of Plant Science, University of Alberta, personal communication, February 1979). Agriculture Canada (1978b) reports that the imports of cut flowers into Canada for the period ending August 31, 1978 had increased by 16.5 percent over a similar period in the previous year. These imports originated primarily in the U.S., Colombia, and the Netherlands. During the same period, the Canadian production of tulips, carnations, and gladioli decreased by 5, 9, and 48 percent respectively according to Agriculture Canada (1978b). These declines were partially offset by gains in the production of roses.

To make up for the market losses in cut flowers, local growers are changing over to bedding and potted plant production (E. Toop, Department of Plant Science, University of Alberta, personal communication, February 1979). In Alberta, increased marketing of bedding plants and potted plants are reported for 1977 and the projected increase for 1978 was 14.7 percent for these products (Alberta Agriculture, 1978, p. 21). It is unknown whether or not this projection was achieved. According to Toop (personal communication, February 1979) however, there is speculation that the recent increased popularity in house plants will level off and the market for these products may experience a period of slow growth in the future.

In summary, the total lack of information on the imports of floricultural crops into Alberta makes a proper market analysis impossible. There is evidence however, which indicates that foreign competition in cut flowers is capturing the local market. To this end, Alberta growers are producing more bedding and potted plants to satisfy an increasing demand for these crops but this increasing demand may only last for a short period in the near future.

FISH

For a market analysis of fish, only two species were considered; rainbow trout and shrimp, or freshwater prawns. The shrimp and freshwater prawns are considered similar products and sold as such on the retail and institutional markets. Only rainbow trout and shrimp were considered for this market analysis because they are the most likely candidates for a thermal aquaculture operation in Alberta. This is especially true of rainbow trout.

Three different markets exist in Alberta for rainbow trout. They are the retail, institutional, and fish farming markets. The retail market includes the local groceries, the major supermarkets, butcher shops, etc. while the institutional markets are specialty markets, particularly restaurants. The fish farming markets are local private and commercial game fish farmers who grow rainbow trout in sloughs and dugouts on their property. Only the retail and institutional markets exist for freshwater prawns in this province.

As with floricultural crops, there are virtually no data available on the quantities of these two products imported into the province. The Fish and Wildlife Division of Alberta Recreation, Parks and Wildlife does not collect this information and it relies upon the Fisheries Department of the federal government for these data (A. Chamberlain, Alberta Fish and Wildlife, personal communication, January 1979). The federal Fisheries Department has data only on the foreign imports that come directly into Alberta destined for Alberta markets. In 1978, there were approximately 15,000 kg (33,069 lbs) of rainbow trout imported directly into Alberta from the U.S. (G. Parrot, Fisheries and Environment Canada, personal communication, March 1979). According to Parrot however, this represents only about 10 percent of the total supply. The balance apparently is imported from Japan into British Columbia from where it is distributed by a large number of suppliers. The exact quantities of rainbow trout that are distributed to Alberta markets in this manner are unknown.

In an effort to determine these import quantities, one large British Columbia distributor, B.C. Packers Ltd., in addition to several local retail and wholesale suppliers of rainbow trout, including Safeway and Woodwards, were contacted. It is generally conceded that B.C. Packers Ltd., who distribute their product under the Prince Rupert brand name, maintain the largest share of the retail market (G. Parrot, Fisheries and Environment Canada, personal communication, March 1979). The proportion of the market that is supplied by the Prince Rupert brand is unknown however (J. Ferrenci, B.C. Packers Ltd., Edmonton, personal communication, March 1979). Neither Woodwards, nor any of the small local retail outlets, would release any information on their annual sales of rainbow trout. Several of the small retail suppliers did volunteer information to the effect that there is a fairly large demand for rainbow trout in Alberta but this product is frequently unavailable.

According to Green (B.C. Packers Ltd., Vancouver, personal communication, March 1979), B.C. Packers supplied Alberta with approximately 11,500 kg (25,353 lbs) of rainbow trout for the retail market in 1978. Hunter (MacDonald's Consolidated Ltd., Safeway Distribution Warehouse, personal communication, March 1979) claims that Safeway sells approximately 8,000 kg (17,637 lbs) of rainbow trout a year, at most, on the Edmonton retail market. Thus, by taking these figures, in addition to the quantity imported directly into Alberta from the U.S., it may be inferred that the total supply of rainbow trout for the Alberta retail market approaches 45,000 kg (99,208 lbs) a year. It must be emphasized however, that this is a very rough estimate at best.

The total supply of rainbow trout for the institutional market appears to be at least twice as large as that for the retail market. This is based on information provided by Coral Keys Seafoods Ltd. (personal communication, March 1979) that approximately 225,000 kg (496,042 lbs) of rainbow trout are sold for the restaurant market trade only over an annual period in Alberta. Green (B.C. Packers Ltd., Vancouver, personal communication, March 1979) also reports that B.C. Packers supplied Alberta with approximately 28,000 kg (61,730 lbs) of rainbow trout for the institutional market in 1978. This figure is almost three times as large as the quantity supplied by B.C. Packers for the retail market in 1978. This discrepancy in the total supplies for the two markets is difficult to understand as the product is identical. That is, there are about 4.4 fish per kilogram (2/lb) and they are imported from Japan packaged and frozen.

Information on the total supply of rainbow trout for the local fish farmers was obtained from a report published by Alberta Recreation, Parks and Wildlife (Wood, 1978). This report is based on the results of a questionnaire distributed to all licenced private and commercial game fish farmers in Alberta in 1977. Of the 1,569 questionnaires issued, 807 were returned for a response rate of 51.4 percent.

The results indicate that an estimated 411,044 rainbow trout fingerlings were stocked in 1977 in Alberta. Although only twenty-one commercial game fish farmers responded to the questionnaire, they accounted for 87,750 (21.3 percent) of the total fish stocked in 1977. The remaining 78.7 percent were planted by private game fish farmers. The majority of the fingerlings stocked originated from hatcheries in the U.S. while a small number of fish were supplied by two commercial operators in Alberta. The average cost per fingerling was $0.58.

The estimated total number of fish harvested was 151,709 or only 36.9 percent of those stocked. Mortalities were attributed to summerkill resulting from the presence of abundant algae and to predation. The most popular method of harvesting was angling followed by the use of gill nets. The questionnaire did not contain information on marketing procedures, therefore it is unknown what proportion of the total number of fish harvested were supplied to the consumer markets although it is suspected to be quite small.

Two interesting facts are revealed in this report.

Firstly, the total number of first time fish farmers who responded to the questionnaire represented 43.2 percent of the total return. However, a similar report produced for the 1975 growing season claims that 51 percent of the respondents for that year were also first time fish farmers (Barton, 1976). This indicates that there is a large turnover in the people who raise game fish, especially the private fish farmers.

Secondly, 11.5 percent of the respondents encountered difficulties in obtaining fingerlings. This resulted mainly from the demand exceeding the available supply. This problem is also described by Chamberlain (Alberta Fish and Wildlife, personal communication, March 1979) who reports that fish farmers in Alberta have to place their orders for fingerlings as early as December for deliveries in the following spring. Two reasons are offered in explanation of this short supply. One, there are very few suppliers of rainbow trout fingerlings in Canada, especially Alberta. Secondly, the U.S. suppliers have to be certified by the Canadian government to ensure that disease free fish only are transported across the border. The regulations imposed by the federal government are becoming very stringent and costing the U.S. hatcheries up to $5,000 to implement (F. Kehoe, Alberta Agriculture, personal communication, June

1979). This has resulted in many U.S. hatcheries not taking the trouble to apply for approval to ship rainbow trout fingerlings to Canadian buyers. Therefore, there currently exists a relatively healthy market in Alberta for rainbow trout fingerlings. This should be a definite asset for Bilowus.

The total supply of shrimp and freshwater prawns in Alberta is also very difficult to determine. The federal Fisheries Department does not collect data on the total quantity of imports but Parrot (Fisheries and Environment Canada, personal communication, June 1979) reports that about 113,398 kg (1/4 million lbs) were imported directly into Alberta in 1978. However, a similar situation occurs with shrimp as that for rainbow trout in that a large portion of the total supply enters the country through ports in other provinces from where it is distributed. Parrot further claims that the demand for this product is fairly healthy.

CONCLUSION

The information employed to determine the market potential in Alberta for eleven fresh vegetables was obtained from a variety of sources. Thus, the results presented in Tables 7:1 to 7:11 are somewhat incomplete. However, indications are that virtually all the fresh vegetables consumed in Alberta originate from outside the province, particularly the U.S. These imports resulted in a deficit balance of trade of at least $13 million in 1977.

Two reasons are offered for causing this deficit. Firstly, the climatic conditions in Alberta preclude extensive field production of fresh vegetables. Secondly, the greenhouse growers are producing the crops which generate the highest returns. Unfortunately, these crops, except for cucumbers, do not include fresh vegetables. However, recent problems in obtaining produce from the U.S. because of transport problems relating to oil shortages and the devaluation of the Canadian dollar are anticipated to increase the returns that can be expected from fresh vegetable production in Alberta. It is not known if growers will take advantage of this situation however.

There is insufficient information available to conduct a proper market analysis for floricultural crops as only the domestic production is available. The imports are unknown but Agriculture Canada is now realizing the importance of these data and has begun recording this information. Nevertheless, it would appear that the market for domestically produced cut flowers is declining because of foreign competition. It is unknown what effect the devalued dollar is having on this market however. There is a fairly healthy market for bedding plants and potted plants in this province and projections indicate an increased demand for these products will continue in the near future.

There is a large demand for rainbow trout and freshwater prawns in Alberta as well. The retail and institutional markets account for approximately 270,000 kg (595,250 lbs) of rainbow trout and probably at least that much of shrimp being imported into the province annually. Imports are required because of the almost total absence of a domestic supply. Rainbow trout fingerlings are in very high demand in Alberta by the numerous game fish farmers. It is further anticipated that the total number of these fish farmers will substantially increase if there is an adequate supply of fingerlings.

In conclusion, almost all of the total supply of the products considered for the foregoing analysis originate from foreign suppliers. This is largely due to a lack of domestically produced commodities. The conclusion that may be derived therefore, is that there is a substantial market for the products that would be produced from greenhouse heating and thermal aquaculture.

CHAPTER VIII

CONCLUSION

Thermal power plants in Alberta are rejecting tremendous quantities of energy to the environment. In relation to the total input energy used to produce electricity in steam electric generating stations, approximately 50 percent is rejected in condenser cooling water. In 1978, the Wabamun, Sundance, Forestburg, Rossdale and Clover Bar plants released more than 85 x 10^{12} BTU's of heat energy to the environment in condenser cooling water. Considering that it takes approximately 10,000 BTU's to produce one kWh of electricity in Alberta power plants, this total is the equivalent of the energy required to produce 8.5 million MWH of electricity. When the Keephills, Sheerness and Genesee power plants are commissioned in the 1980's, this figure can be expected to double.

This inefficient use of energy by thermal power plants is not expected to improve in the foreseeable future because they are operating within the constraints of thermodynamic principles given existing technology. The only conceivable method of improving the inplant thermal efficiencies is to operate at higher steam temperatures and pressures but the materials required to handle and transport steam under these conditions are not readily available at a reasonable cost. Even if these materials were available, the station net thermal efficiency would show only a marginal improvement.

A more practical method of improving power plant net thermal efficiencies is to utilize the waste heat for beneficial purposes. This can take various forms, including greenhouse heating, thermal aquaculture, district heating, wastewater treatment, open field soil warming, and waterfowl habitat enhancement, all of which have been discussed in this thesis. There are several other applications of power plant waste heat proposed in the literature but they are not considered feasible for development in Alberta. These include fog dispersion, airport runway de-icing, and lenghtening the shipping season in seaway transportation.

Heating greenhouses with condenser cooling water has been successfully demonstrated at the Sherco Greenhouse Project in Becker, Minnesota. Heating a greenhouse with power plant reject heat was also attempted at the Wabamun plant, but with considerably less success than in the Sherco project. The primary reason for this, excluding the extremely poor planning of the Wabamun project, is that the available water temperatures are significantly higher at the Sherco project, in the order of 29.4C to 32.2C (85F to 90F). The maximum temperature of the thermal effluent at the Wabamun plant during the coldest weather was about 16C (61F).

A future attempt to heat greenhouses in Alberta with power plant reject heat could offset the lower available water temperatures by employing several solar heating techniques. These include a better greenhouse design, thermal blankets, solar reflectors, and heat storage. These methods would optimize the use of available solar radiation and minimize heat losses from the greenhouse.

Of the existing power plants in Alberta, the Sundance and possibly the Clover Bar plants exhibit the necessary prerequisites for greenhouse heating, for reasons outlined in Chapter III. This would require extensive retrofitting to these plants which could be costly. Therefore, if it is considered desirable to establish a prototype greenhouse heating study in this province, it should be incorporated into the initial plant design of the Sheerness power plant preferably. The Sheerness plant will be better suited for solar heating with its more southerly location.

A considerable research and technical effort, particularly in the U.S., has been devoted to developing the feasibility of thermal aquaculture. A wide variety of species of fish is successfully being cultured in power plant thermal effluents in the U.S. To date, the only successful demonstration of this application in Canada is at Grand Lake, New Brunswick where brook trout are raised in the discharge canal of a small power plant. A small, privately operated aquaculture facility has been developed at the Sundance power plant in the past year but several problems have to be worked out before this operation becomes profitable.

Thermal aquaculture appears to be the most practical application for utilizing power plant reject heat in this province. There are many reasons for this. Firstly, aquaculture can be easily adapted to the use of thermal effluents as a culture medium. Secondly, extensive systems for extracting heat from the warm water are not required. Thirdly, this application can be developed to varying degrees. A relatively inexpensive system of suspending cages in the thermal effluent is possible or a more intensive system utilizing separate facilities, such as raceways or tanks, is also possible. A sizeable market also exists in this province for certain species of fish that can be raised in thermal effluents. Finally, thermal aquaculture, although by necessity required to operate in close proximity to the power plant, would be physically removed from the station and would not pose a nuisance to the normal operation of the plant. This holds true for greenhouse heating as well.

Rainbow trout is clearly the most desirable candidate for culture in a thermal aquaculture operation for reasons that were described in Chapter IV. The only drawback associated with culturing rainbow trout is that it is a cold water species and would be amenable for culture in the winter months only. To this end, it would be advisable to conduct additional research into the practicability of raising alternative, warm water species in the thermal effluent during the summer months. At the present time, only freshwater prawns have been successfully cultured in warmer thermal effluents. There is a substantial market for this product in Alberta but problems might arise in attempts to introduce prawns into this province for aquacultural purposes. Largemouth bass is another species that could be cultured during the summer months but only for the sport fishing industry. There is no substantial retail market for this fish in Alberta.

Thermal aquaculture could be developed at both the Sundance and Forestburg power plants. The Wabamun plant would not be a suitable location because the heat supply is unreliable while the Rossdale plant has to be ruled out because of its urban location. Aquaculture facilities could possibly be developed at the Clover Bar plant as well. The Sundance plant, with its cooling pond, is a particularly attractive site for the development of thermal aquaculture. A wide variety of aquacultural methods might be developed for this large body of water. The pond could even be stocked with fish for sport fishing purposes. The Forestburg plant operated at close to capacity in 1978 and it thus offers a very reliable source of warm water, a requirement that is essential for the success of a thermal aquaculture project. It does suffer from the disadvantage of being located somewhat distant from a major market.

The Keephills, Sheerness and Genesee power plants will also have the prerequisites for thermal aquaculture. As with greenhouse heating, now is the time to plan for this application at these power plants in order to avoid costly retrofitting. This point cannot be overemphasized. Evans (Trenton State College, personal communication, August 1978) reports that the only method of obtaining condenser cooling water from the Mercer generating station in Trenton, New Jersey was to pump it from the discharge canal, a lift distance of about 6.1 m (20 ft). The pumping costs associated with this system are apparently the one item that could result in the operation not being economic, according to Evans. Therefore, thermal aquaculture operations should be included in the initial design of a power plant whenever possible if such facilities are to be developed.

The development of a more advanced aquaculture project in Alberta, involving the production of trout and prawns for sale to the consumer market, should be postponed for at least one year until the outcome of Bilowus' second growing season is known. If he enjoys considerably more success in the upcoming winter and is able to turn over a profit, this could be all the stimulus required to attract other thermal aquaculture developments. However, if the project fails once again this year it is highly unlikely Bilowus will be able, for financial reasons, to continue his operation for a third year. If this should occur and no other individuals express an interest in establishing a separate facility, a prototype study should be developed to demonstrate the economic and technical feasibility of this waste heat application. It is this author's opinion that this demonstration is all that is required to attract private entrepreneurs.

With district heating, the most plausible method is the co-generation of heat and electricity. Although not a direct utilization of condenser cooling water, it is a very effective technique for improving power plant net thermal efficiencies. It has the further advantage of reducing furnace oil and gas consumption as well as reducing the air pollution caused by individual home and building heating systems.

In Alberta, only the Rossdale and Clover Bar power plants are practical sources of heat for heating large urban areas. The remaining generating stations could only provide heat for satellite communities housing plant employees. The potential for widespread space heating in Edmonton has already been recognized by Edmonton Power as is evident by their on-going study to convert the Rossdale Station into a co-generation plant for heating a large portion of the city center. However, the costs involved in having to retrofit the plant and construct a distribution network are factors that will determine the feasibility of this application. Hopefully, a large enough market exists for the heat to make this use economically attractive. If this proves to be an economical venture, perhaps a similar study could be initiated to investigate converting the Clover Bar station into a co-generation plant. There is potentially a demand for heat in both the residential and industrial sectors in the area of the city where this power plant is located.

Co-generation could prove to be an attractive source of heat for heating greenhouses and for industrial applications. The large demand for domestically produced fresh vegetables in Alberta, coupled with recent problems in assuring supplies of produce from the U.S., oil price increases by O.P.E.C., and the devaluation of the Canadian dollar, demonstrate that local production of fresh vegetables should be drastically increased. Because of unfavourable climatic conditions in most of the province, fresh vegetable production will have to be increased in greenhouses if the demand is to be supplied from local sources. The heat available from one power plant in Alberta is sufficient to heat all the greenhouses required to make up for the deficit balance of trade currently experienced in this province with respect to fresh vegetables.

Wastewater treatment is another potential application that might benefit from the use of thermal effluents originating from either the Rossdale or Clover Bar stations. Several studies in the U.S. have indicated that by slightly warming the wastewater, the efficiencies of treatment can be substantially improved. This remains to be clearly demonstrated in actual practice in North America however.

There is ample evidence to support the feasibility of open field soil warming. This is especially true for the production of fresh vegetables where both maturity and yields can be increased by warming the soil. All experimentation with this application has been conducted in the U.S. unfortunately, but there does not appear to be any reason why the results cannot be extrapolated to an Alberta context. This can be easily demonstrated in a simple prototype study in this province and could prove to be even more beneficial considering the colder climate that prevails here.

It is obvious that several applications are available for utilizing thermal power plant reject heat. Why, therefore, have the utilities in this province not made greater efforts to utilize this resource? Edmonton Power has been pumping thermal effluents from the Rossdale station to the adjacent municipal water treatment plant for a number of years and is currently studying the feasibility of district heating with heat produced at the Rossdale plant. This is largely due to convenience because of the power plant's central location in the city as Edmonton Power has no plans to develop any waste heat applications at either the Clover Bar or Genesee power plants.

Clearly, the answer is lack of incentives and initiative on the part of the utilities. Many times during the course of this study the author was confronted with the response "... we are in the business of producing electricity only ..." It is unfortunate that this sole corporate policy is not changed to utilize energy in the most efficient manner possible. The utilities consider reject heat an annoyance that comes with thermal power production. Thus, any other means of dealing with the thermal effluents, rather than the conventional methods of reject heat dissipation, are unjustifiably considered a nuisance to the operation of a power plant in this province.

Another perplexing aspect of this situation is the contrast between the U.S. and Canadian utilities in their attitudes towards the utilization of waste heat. In the U.S., the majority of power plants where various applications of reject heat are being developed are privately owned. In Canada, the opposite is true with the publicly owned utilities taking the initiative in this field; e.g., Ontario Hydro and the New Brunswick Power Commission. The primary reason most utilities are becoming involved in waste heat utilization is a concern for their public images. Do the Alberta utilities enjoy such good public images that they do not require enhancement?

Our system for producing and distributing electric energy works on the basis of financial incentives. There are no significant incentives for utility companies to utilize waste heat in Canada, including Alberta, even though such action would generate economic returns and secondary benefits from improved public relations. Obviously, significant efforts will be required to overcome the institutional constraints which mitigate against power plant waste heat utilization.

There are several options available in Alberta for the government and/or utilities to make positive moves relating to the better use of waste heat:

1) strong encouragement through promotion or legislation changes,
2) trade-offs, e.g., company action in return for concessions in other areas,
3) support the construction of, and operate, prototype operations, (e.g., the Princess Greenhouse),
4) support the construction of, and lease, prototype operations, and/or
5) instigate a publicity program to encourage private entrepreneurs.

The last two options listed are clearly the most acceptable in this province. Legislation changes and trade-offs would exceed present government practice in dealing with private firms. Supporting the consruction of a prototype operation and operating it may also be beyond the present perceptions concerning the role of government. The fourth option would involve a prior canvas of firms that might be interested in greenhouse, aquacultural, or other operations. This option might include, within its acceptable range, a direct government or contract pilot model study program. The participation of the power companies would still be voluntary but the publicity plus government involvement would tend to invite a higher degree of cooperation than at present.

There is every reason to believe that waste heat use development is a part of a long term trend and that Albertans have special advantages in becoming leaders in this field. These include good research funding, a rapidly expanding development of new thermal power plants, and relative isolation from alternative sources of supply thus assuring some competitive advantage. However, it appears that the feasibility (technical and economic) of waste heat uses will have to be demonstrated beforehand in well designed and well developed prototype programs if private development is to be encouraged and initiated. It is anticipated that subsequent development will then be rapid and little additional support will be needed.

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