MDNR CONSUMPTIVE WATER USE STUDY

FOR THE

MINNESOTA DEPARTMENT OF NATURAL RESOURCES

FEBRUARY, 1990

Consultant's Report prepared for the DNR by Orr-Schelen-Mayeron & Assocs.

Pursuant to 1989 Laws, Chap 326 Article 4, Section 8

MDNR CONSUMPTIVE WATER USE STUDY

FOR THE

MINNESOTA DEPARTMENT OF NATURAL RESOURCES

FEBRUARY, 1990

Prepared By:

ORR-SCHELEN-MAYERON & ASSOCIATES, INC.
2021 East Hennepin Avenue
Suite 238
Minneapolis, MN 55413
(612) 331-8660

OSM Commission #4485

TABLE OF CONTENTS

TABLE OF CONTENTS
Page 2

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

The Minnesota State Legislature, under the Laws of Minnesota 1989 (Chapter 326, Article 4, Section 8), has mandated the Commissioner of Natural Resources to conduct a Study of consumptive water use for "once-through" heating/cooling systems and their impact on existing aquifers. The Minnesota Department of Natural Resources (MDNR), Division of Waters, has contracted Orr-Schelen-Mayeron & Associates, Inc. to prepare the technical portions of the Study relating to current "once-through" environmental comfort applications and to make recommendations for alternatives to these "once-through" well water systems. The following shall be included in this Study:

- Categorization of well water uses in environmental heating and cooling applications,

- Analysis of annual operating costs and capacities for selected "once-through" systems,

- Options for the conversion of "once-through" systems,

- Economic analysis of the alternatives, and

- Ramifications and cost comparisons for conversion to alternative methods.

The MDNR has provided survey information relating to the existing ground water permits in the State. Additional assistance in the preparation of this Report has been provided by the following MDNR personnel:

- David Milles, Supervisor, Permits Unit

- James M. Japs, Program Leader, Water Allocation Programs

- Larry Kramka, Intern

SCOPE OF STUDY

Orr-Schelen-Mayeron & Associates, Inc. has been retained by the Minnesota Department of Natural Resources to provide a technical report and incorporate it in a study of consumptive water use and its impact on existing aquifers. This Report is organized as follows:

1. Review survey results from MDNR on permittees of geo-thermal heating and cooling systems. Tabulate all surveys. Establish basic categories and determine the number of permittees within each category. Select the salient categories of heating and cooling systems based on water use, and identify the representatives of each category for an in-depth Study.

2. Select four (4) existing heating and cooling systems based on results from the MDNR survey and past OSM experience in design. Analyze the annual operating costs and capacities of these facilities based on survey results and supplemental data.

3. Perform life cycle analyses for the following alternative conventional methods:

   - Air-cooled Systems
   - District Heating and Cooling

4. Examine the ramifications and factors in converting "once-through" heating and cooling systems to conventional air-cooled systems or district heating/cooling systems:

   - Consider noise, space, structural capability, maintenance of equipment, and effect on capacity of existing equipment.

- Discuss methods and measures of system improvement for "once-through" applications.

- Compare well water system operating costs with municipal water, air-cooled cooling towers, and district cooling alternatives.

EXECUTIVE SUMMARY

The Minnesota Department of Natural Resources (MDNR) has granted approximately 125 permits for the use of ground water in environmental comfort cooling and heating applications. Water is used as a medium of heat exchange and as a heat source or sink in these applications. The concept of mechanical cooling operates on the principal of energy transfer from a heat source to a heat sink. The atmosphere, the earth, surface water, or ground water are all valid heat sinks in the operation of mechanical cooling equipment. This Study focuses on the ways in which ground water is used in this manner, on the cost of operation for these systems, and on the feasibility & cost of converting to alternative methods.

The Laws of Minnesota 1989 (Chapter 326, Article 4, Section 4, Subdivision 1c) states, "For the purpose of this Subdivision, a once-through cooling system means a cooling or heating system for human comfort that draws a continuous stream of water from a ground water source to remove or add heat for cooling, heating, or refrigeration." The definition of an "environmental" once-through cooling system in this report shall encompass all space cooling or heating which utilizes well water and shall not distinguish between human comfort, Computer Room control, or Process Room environmental control.

The results of a survey conducted by the MDNR reveal four (4) basic categories of water usage in environmental cooling and heating systems. Ground water usage falls into the following basic categories:

A. **Chilled Water.** Well water enters the chiller evaporator, flows through the cooling coils and discharges.

B. **Heat Pump Source/Sink.** Well water acts as a "source" or "sink" for heat pumps.

C. **Condenser Water.** Well water flows through the condenser side of water chillers, condensing units, or other compressorized equipment, and discharges.

D. **Cold Well Water for Cooling Coils.** Well water flows through the cooling coils in a building, and discharges.

Survey results indicate that thirty-seven (37) permit holders use the well water more than once. Only one (1) permittee reinjects the well water back to the aquifer after it has been used.

An example of water which is used more than once is a chilled water application. In this case, well water first flows through the evaporator side of a water chiller for further cooling. It is then circulated through cooling coils, and finally routed through the condenser side of the same chiller. In this operation, the water has been used both as a medium of heat exchange for space cooling and as a heat sink for waste condenser heat. The water may be subsequently used in a process application (where higher water temperatures are acceptable), enabling further utilization of the water for cooling. The well water, so utilized, is not only used more than once, it is used in a mix of environmental and industrial applications.

An appropriate "yardstick" for the efficient use of "once-through" well water would relate the gallons of water appropriated to the end product (energy transferred) and the electrical energy consumed to the end product. When water efficiency (represented by GPM/TON) and electrical efficiency (represented by KW/TON), are plotted on a graph, a relationship between the two efficiencies becomes apparent. An "envelope" of allowable well water usage can be established, where operation within this area meets acceptable standards. This standard would apply to the cooling operation only.

The boundary of this "envelope" (as shown in Figure 1) may be varied, according to the perceived importance of the variables. Utilization of the "envelope" provides two advantages:

1) A straight-forward method of comparing the two efficiencies; and
2) Values for units of measure which are readily obtainable.

Operating cost comparisons of six (6) typical systems with the annual operating cost of an air-cooled open cooling tower reveal that, at 15¢/1000-GAL, condenser applications and cooling coils-to-condenser applications are less expensive to operate. At 12¢/1000-GAL, evaporator-to-coils-to-condenser applications are added to the set of those systems less expensive to operate than cooling towers. The use of well water strictly for cooling coils would have to be excluded specifically, as their electrical efficiency enables them to be less expensive to operate with water fees up to 22.4¢/1000-GAL.

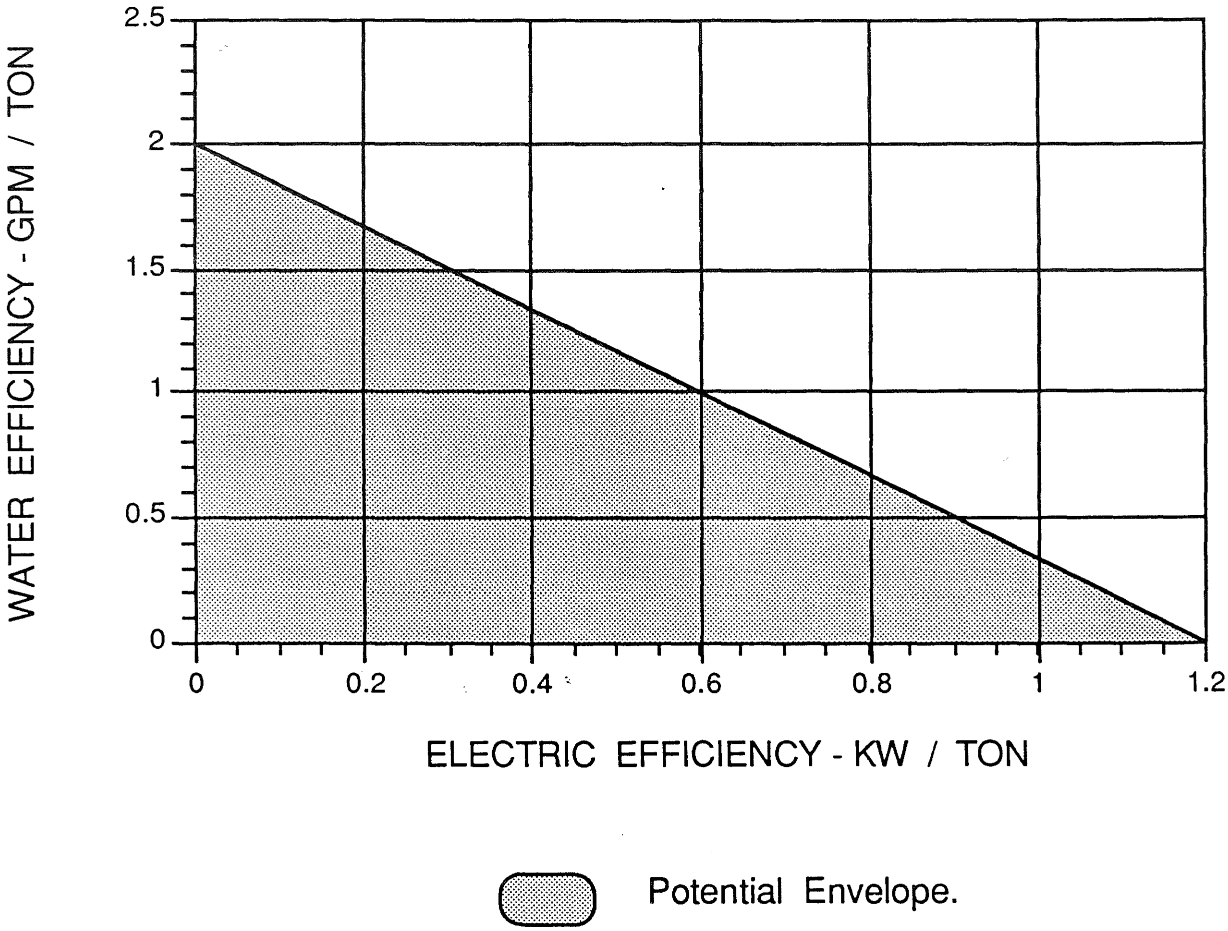


FIGURE 1.0

PROPOSED ENVELOPE METHOD OF
ALLOWABLE WELL WATER USE MEASURE

In the future, if water permits remain in effect, then methods of water conservation will play an important part in system design and operation. Permit holders may be required to meter their well water usage. Such a policy will provide a means of measure and comparison of the relative water efficiency of the usage when coupled with design capacity data. Water conservation practices may encompass the following activities:

-- Installation of well water meters in order to distinguish environmental well water usage and system performance.

-- Installation of 2-way modulating valves.

-- Installation of variable speed/variable volume pumps or utilization of properly-selected constant volume pumps, in conjunction with modulating valves.

-- Installation of facility management system that incorporates multiple setpoint adjustments of water components and airside components to achieve close building control and water/energy conservation.

-- Proper maintenance of water conservation devices.

-- Proper maintenance and optimization of cooling system components.

Those systems which are more water-efficient tend to use water on the condenser side of cooling equipment. By contrast, those systems which circulate well water through cooling coils tend to use water less efficiently. This is due to the higher water flow dictated by the cooling coil requirements. An analysis of conceptual designs reveals that the system which is the most water-efficient (and electrically-efficient) is one which uses well water (first) through cooling coils and (second) through condenser coils.

Cooling towers represent an opportunity to employ water efficiency in the range of 95% - 98%, in terms of water recirculated to total water volume. No other system which utilizes well water or municipal water in an open-loop design is as water-efficient. The cost for such water efficiency is primarily an economic one: conversion cost and higher operating cost. Many permit holders may have equipment near the end of its service life and conversion costs may be offset by this mitigating factor. Conversion provides, in some cases, an opportunity to upgrade existing equipment with more electrically-efficient equipment - even at higher condenser water temperatures. This Study examines one (1) facility where this is the case.

Although technologies exist which utilize air-cooled equipment without open water loops, their electrical efficiency is much lower than water-cooled systems. They are, therefore, cost-prohibitive for large systems (100 tons and above).

Alternatives to "once-through" well water fall into two (2) basic categories. The first alternative is for each user to convert their own system, typically to a cooling tower which is slab-mounted or roof-mounted. In the second alternative, users would purchase cooling from a district cooling source, which operates large air-cooled devices for its central cooling plant.

There are several concerns which effect the feasibility of converting cooling systems from well water-cooled to cooling tower-cooled. The first of these is capacity. Water-cooled chillers which utilize 50-degree Fahrenheit well water in their condensers may typically experience either a decrease in chiller capacity of 10% or a corresponding increase in energy consumption when converting entering/leaving condenser water conditions from 50/80 degrees Fahrenheit to 85/95 degrees Fahrenheit. The ramifications of the decrease in capacity must be anlayzed on an individual basis. In facilities with reserve capacities of equipment, additional equipment may not necessarily be required. Facilities with equipment at the end of its service life are afforded the opportunity to upgrade their equipment in the process of conversion. In one facility studied in this Report, replacement of outdated components resulted in a conversion operating cost that was lower than well water-based operation.

Converting to a cooling-tower-based cooling system may also require modifications to the air-conditioning equipment. Centrifugal chillers often require replacement of the impeller/impeller gear, condenser vessel, or motor to operate at new cooling water conditions. For a 360-ton centrifugal chiller requiring all three changes, the cost could be $35,000. This was verified for one of the facilities studied; however, each machine must be considered individually.

Systems which circulate well water directly through cooling coils would have to convert those systems to chilled water, if a circulated water cooling coil design were re-used. This would require the addition of new equipment (if the existing reserve capacity did not suffice), or the purchase of district chilled water. Piping changes would be inherent in this conversion.

Concerns relating to space, the structural design loads of the roof, and noise must be analyzed on an individual basis.

A comparison of the operating cost differentials for four facilities chosen for further analysis reveals the following:

TABLE 1

FACILITY	ANNUAL OPERATING COST (WELL WATER)	ANNUAL OPER. COST (COOLING TOWERS)	ANNUAL OPER. COST (DISTRICT COOLING)*
General Mills	$ 86,011	$100,862	----
Gaviidae Commons	$ 42,692	$ 48,030	$ 81,000
Honeywell Avionics	$242,870	$387,222	
Methodist Hospital	$204,304	$160,072***	

TABLE 1 - CONTINUED

FACILITY	ANNUAL TON-HOUR	WELL WATER ($/TON-HOUR)	COOLING TOWER ($/TON-HOUR)	DISTRICT COOLING ($/TON-HOUR)*
General Mills	2,529,600 2,355,610**	.0340	.0428	
Gaviidae Commons	689,200	.0619	.0697	.2250
Honeywell Avionics	8,595,159	.0283	.0451	
Methodist Hospital	3,770,750	.0542	.0425	

$/TON-HR FIGURES ARE FOR WELL WATER RELATED COSTS ONLY, NOT INCLUDING CHILLED WATER PUMPING, AIRSIDE OPERATION COSTS, ETC.

* DISTRICT COOLING COSTS ARE PRESENTED WITHOUT HEATING COSTS IN ORDER TO COMPARE EQUITABLY. MAINTENANCE, LABOR AND CAPITOL EQUIPMENT COSTS HAVE BEEN EXCLUDED.

** CONVERSION TO COOLING TOWER

*** DECREASE DUE TO CENTRIFUGAL CHILLER MODIFICATIONS RESULTING IN IMPROVEMENT IN KW/TON

Life Cycle Costs based on a 20-year life (8% discount rate, 5% escalation in energy costs, and 4% increase in water treatment/water waste costs) are shown below. Water tower costs include the conversion first-cost (such as chiller modifications, new cooling towers and cooling tower pumps). These figures are "Present Worth" values in 1989 dollars:

TABLE 2

FACILITY	BASE (EXISTING) LIFE CYCLE COST	WATER TOWER OPERATION LIFE CYCLE COST
General Mills	$1,276,178	$2,998,354
Gaviidae Commons	$ 628,037	$1,044,005 $1,499,338
Honeywell Avionics	$3,631,818	$9,105,832
Methodist Hospital	$3,048,723	$2,728,128

* DISTRICT COOLING LIFE CYCLE COST

The cost ratios associated with well water usage are in the range of 3.0¢/TON-HR to 6.1¢/TON-HR. A conversion from well water usage to an Owner-operated cooling tower may yield costs of 4.3¢/TON-HR to 7.0¢/TON-HR. Converting from well water usage to district cooling (for buildings which could readily switch over to purchased chilled water) would result in annual costs of 22.5¢/TON-HR. [Note that these costs do not include maintenance, service contracts, labor, chilled water pumping or airside delivery costs. They are offered as a means to compare those variables which are sensitive to the source of water or the elimination of water.]

I. WELL WATER USER SURVEY RESULTS

The Minnesota Department of Natural Resources conducted a survey of all permit holders where well water was consumed for environmental heating and cooling purposes. These survey responses were then entered into a database management system, thus allowing manipulation of the data so that meaningful trends in the types of use could be identified and quantified.

Certain categories of use did emerge from the analysis. While Table 3 illustrates these basic types of use, few users fit neatly into one category to the exclusion of other categories. It is quite common for a permittee to use the water in a combination of ways.

TABLE 3
Categories of Well Water Usage
(Total Respondents = 125)
(Total Environmental = 101)

TYPE	PRIMARY USE (NBR PERMITTEES)	ANY USE* (NBR PERMITTEES)
CHILLED WATER	10	14
HEAT PUMP	11	12
CONDENSER	43	73
WELL WATER COIL	37	39
TOTAL	101	138

* "ANY USE" DESIGNATES WELL WATER USED IN SYSTEM DESIGN AS A FIRST USE, SECOND USE OR TERTIARY USE

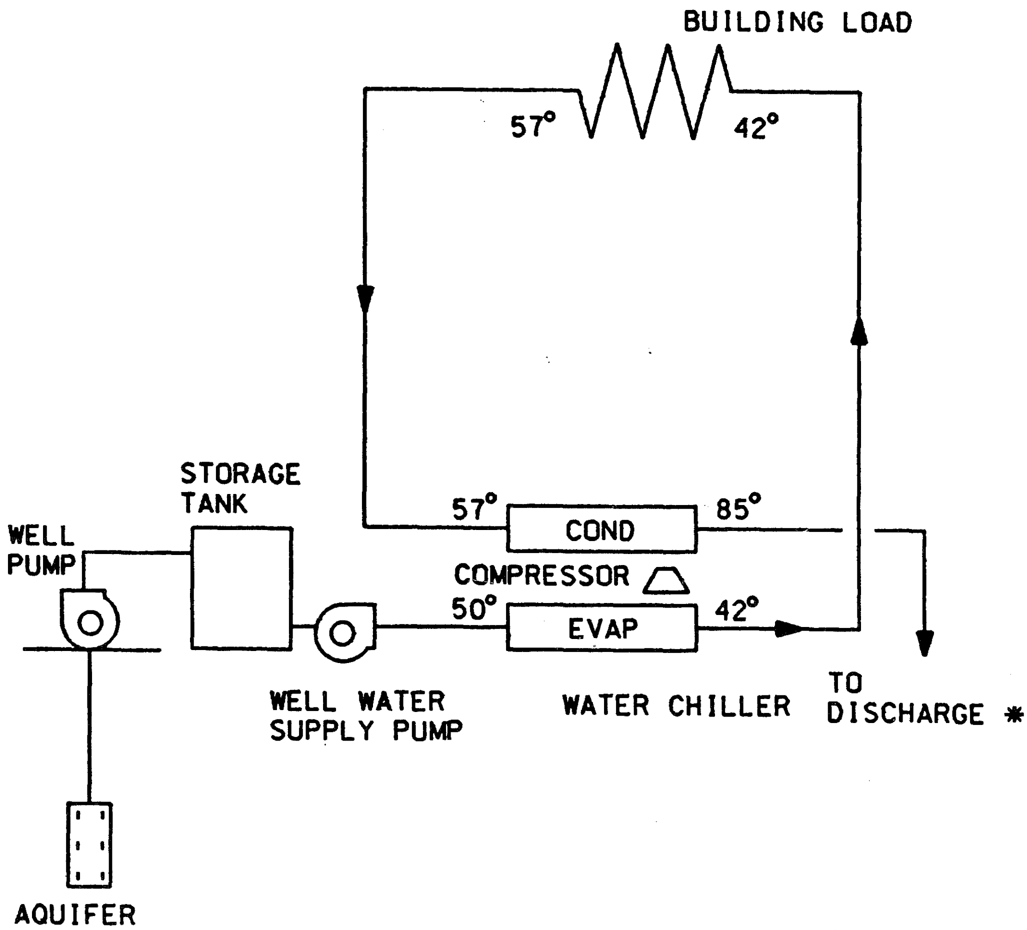
Well water is also used for cooling tower make-up purposes. However, this usage was not considered an environmental usage, since City water is often a substitute source. A total of four (4) Permittees uses well water exclusively for tower make-up. The total number of Permittees using water for the above four (4) categories, plus tower make-up, is 105.

Basic Categories of "Once-Through" Well Water Usage

Chilled Water

Chilled water applications typically route the well water through the evaporator side of a water chiller when it is first drawn from the well. The temperature of well water is usually between 50 and 53 degrees Fahrenheit year-round.

This provides an opportunity to reduce the required cooling capacity or "tonnage" on the machine (where 1 ton equals 12,000 BTU/hr) since return water entering the chiller would otherwise be approximately 54 to 58 degrees Fahrenheit. In other words, the entering water temperature to the evaporator (or "chiller") vessel is lower, thereby, reducing required chiller capacity. The well water provides a portion of the cooling capacity directly. The well water is chilled to approximately 45 degrees Fahrenheit and is then circulated to chilled water coils and other terminal units in the building which take advantage of its cooling effect. Water used in this manner is providing a medium of heat transfer by, first, giving up heat to the refrigerant in the evaporator and, then, by absorbing heat at the terminal units. Upon leaving the terminal units, this water is still relatively cold. For this reason, it is often routed through the condenser side of the chiller, where it acts as a "heat sink", and picks up heat to be rejected to an exterior heat sink. In the case of "once-through" cooling systems, this sink is usually in the form of a pond, stream, river, or storm sewer. This water may also be used to irrigate lawns. Figure 2.0 illustrates this design application.



* NOTE: DISCHARGE MAY CONSTITUTE LAWN IRRIGATION, PROCESS WORK, OR STORM.

Orr Schelen Mayeron & Associates, Inc.
Minneapolis, MN 55413
612-331-8660

MDNR WATER USE STUDY

DRAWING TITLE

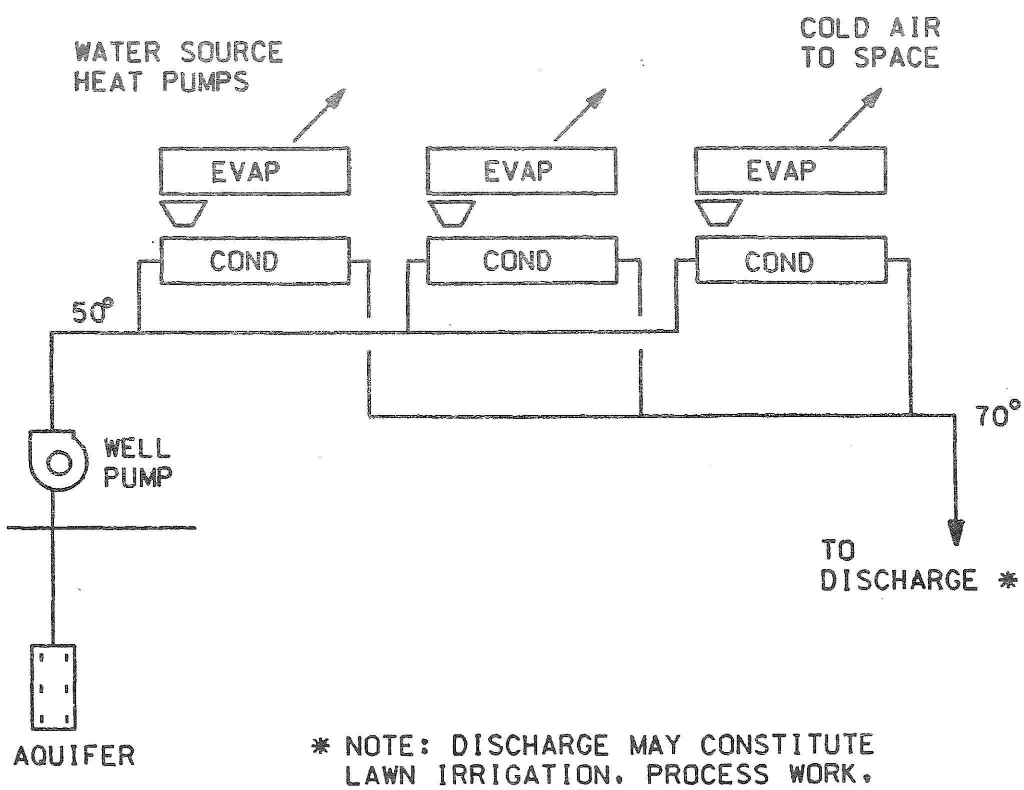
TYPICAL CHILLED WATER APPLICATION

WELL WATER SCHEMATIC

FIG 2.0

Heat Pump Source/Sink

Heat pumps use well water in a method similar to a water chiller. However, these devices are often designed to be "reversible", wherein, they act to produce a cooling effect in one mode and a heating effect when their condenser and evaporator are reversed. Figures 2.1A and 2.1B illustrate the reversible nature of most heat pumps. Depicted in Figures 2.1A and 2.1B is a specific type of heat pump called a "water source" heat pump. During the cooling mode, the well water acts as a "sink" where heat from the space, plus heat from the compressor, is picked up by the water and rejected. In the heating mode, the well water acts as a "heat source" for the heat pump. These units typically have capacities of less than 20 tons each and usually contain their own compressors. This method is referred to as "decentralized" since individual units may operate independently of each other, imparting heat or drawing heat from the source water as the need dictates.



* NOTE: DISCHARGE MAY CONSTITUTE LAWN IRRIGATION, PROCESS WORK, OR STORM.

COOLING MODE
(WELL WATER USED AS SINK)

OSM Orr Schelen Mayeron & Associates, Inc.
Minneapolis, MN 55413
612-331-8660

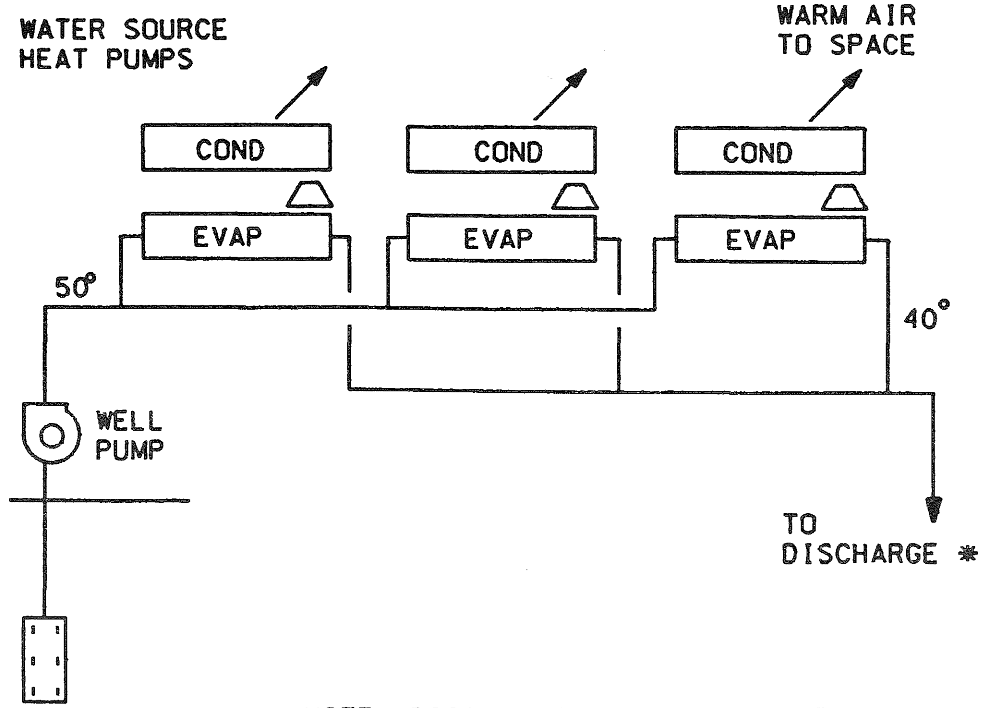
MDNR WATER USE STUDY

DRAWING TITLE

TYPICAL HEAT PUMP APPLICATION

WELL WATER SCHEMATIC

FIG 2.1A



* NOTE: DISCHARGE MAY CONSTITUTE LAWN IRRIGATION, PROCESS WORK, OR STORM.

HEATING MODE
(WELL WATER USED AS SOURCE)

Orr Schelen Mayeron & Associates, Inc.
Minneapolis, MN 55413
612-331-8660

MDNR WATER USE STUDY

DRAWING TITLE

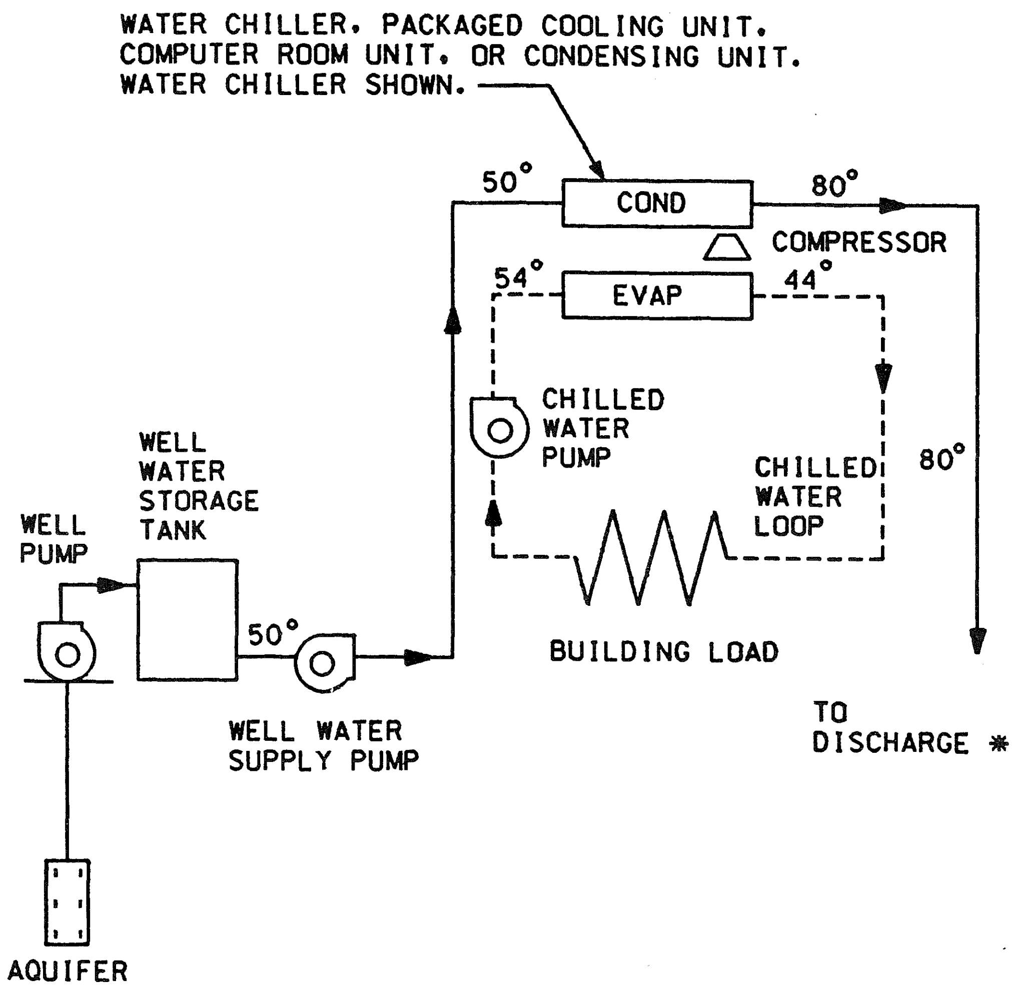
TYPICAL HEAT PUMP APPLICATION

WELL WATER SCHEMATIC

FIG 2.1B

Condenser Water

The most common form of usage for well water is in a "condenser" application. Here, well water is used to pick up heat from the refrigerant, thereby acting as a "sink". It carries the heat away and provides a means for rejecting it. Under a typical air-cooled application, this condenser water enters the condenser vessel at 85 degrees Fahrenheit and leaves at 95 degrees Fahrenheit. Well water which enters at 50 or 55 degrees Fahrenheit provides an opportunity for improving the capacity and efficiency of the machine. Utilization of well water at 50 degrees Fahrenheit provides two (2) benefits to "compressorized" equipment: capacities and efficiencies are increased while pumping costs and water flow volumes are decreased. Figure 2.2 illustrates this application.



* NOTE: DISCHARGE MAY CONSTITUTE LAWN IRRIGATION, PROCESS WORK, OR STORM.

OSM Orr Schelen Mayeron & Associates, Inc.
Minneapolis, MN 55413
612-331-8660

MDNR WATER USE STUDY

DRAWING TITLE

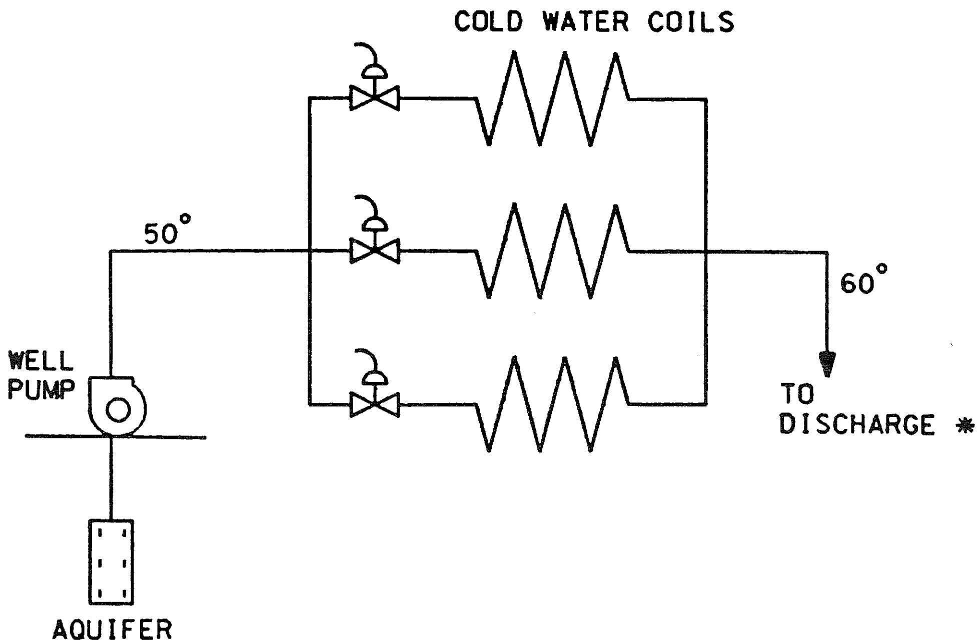
TYPICAL CONDENSER WATER APPLICATION

WELL WATER SCHEMATIC

FIG 2.2

Well Water Coils

The simplest way to utilize well water in environmental cooling is to circulate it directly through air-conditioning water coils. The water is cold enough to provide cooling to the space without being mechanically-cooled to a lower temperature. Environments which require a considerable amount of dehumidification may not be satisfied by 50 or 55 degrees Fahrenheit water. However, when that is the case, ground water is often used to pre-cool incoming air prior to dehumidification by refrigeration coils. The pre-cooling reduces the load on the conventional refrigerant system. Electrical costs in operating conventionally-sized chiller DX systems are reduced. The cooling effect of the ground water is obtained for the mere cost of the pumpage and water treatment. Figure 2.3 illustrates a simple version of direct-cooling with well water.



* NOTE: DISCHARGE MAY CONSTITUTE LAWN IRRIGATION, PROCESS WORK, OR STORM.

Orr Schelen Mayeron & Associates, Inc.
Minneapolis, MN 55413
612-331-8660

MDNR WATER USE STUDY

DRAWING TITLE

TYPICAL WELL WATER COIL APPLICATION

WELL WATER SCHEMATIC

FIG 2.3

Discussion

As stated previously, well water systems may utilize more than one of the above categories in their design. It is important to note that, while the categories described above assist in the understanding of the ways that ground water may be used in environmental cooling or heating, they are by no means all-encompassing. A comprehensive analysis of the full spectrum of well water designs is not within the scope or time frame of this Study. Well water systems and their tendencies to overlap and defy neat categorization can be viewed in the following manipulations of the database:

MINNESOTA DEPT NATURAL RESOURCES
CONSUMPTIVE WATER USE STUDY
ORR-SCHELEN-MAYERON & ASSOC
CHILLER EVAP

PERMIT NBR	NAME	AUTH MGY	AUTH GPM	FIRST USE	USE 2	USE 3	USE 4	NBR A/C USES	REPORTED MGY
74-5231	GENERAL MILLS	650.0	3700	CW COIL	CHILLER	COND		3	581.
60-0131	METRO AIRPORTS COMMISSION	500.0	1850	CHILLER	COND	PROCESS		2	382.
87-6169	BCED MINNESOTA INC. - CONWED TOWER	420.0	833	CHILLER	HEAT PUMP	COND.		3	308.8
64-0643	THS NORTHSTAR ASSOC.	350.0	0	CHILLER	COND.			2	295.7
78-6254	BCED DEVELOPMENT & PROPERTIES, INC.	325.0	2430	CHILLER	COND			2	628.
85-6295	MCC DEVELOPMENT CO., INC.	250.0	2500	HEAT PUMP	CHILLER	COND		3	0.
86-6129	ORDWAY MUSIC THEATER	110.0	750	CHILLER	COND			2	108.
72-0569	APPLETREE ENTERPRISES, INC.	101.0	10	CHILLER	COND			2	127.
85-6011	THE SAINT PAUL HOTEL	70.0	500	CHILLER	COND			2	89.
84-6069	NORTHWEST PUBLICATIONS	65.0	1200	COND.	CHILLER			2	255.
75-6161	THE LEXINGTON COMPANY	65.0	500	CW COIL	CHILLER	COND		3	50.
85-6128	METRO SQUARE PARTNERSHIP	60.0	1000	CHILLER	COND.			2	62.
85-6224	MINNESOTA VETERANS HOME-HASTINGS	40.0	800	CHILLER	COND	PROCESS		2	0.
76-6201	RAMSEY COUNTY SHERIFF'S DEPARTMENT	30.0	360	CHILLER	COND	PROCESS		2	0.
*** Total ***		3036.0	16433					32	2887.

MINNESOTA DEPT NATURAL RESOURCES
CONSUMPTIVE WATER USE STUDY
ORR-SCHELEN-MAYERON & ASSOC
HEAT PUMP APPLICATIONS

PERMIT NBR	NAME	AUTH MGY	AUTH GPM	FIRST USE	USE 2	USE 3	USE 4	NBR A/C USES	REPORTED MGY
82-6002	ST. PAUL PORT AUTHORITY - ENERGY PARK	1386.0	2400	HEAT PUMP				1	1431.8
87-6169	BCED MINNESOTA INC. - CONWED TOWER	420.0	833	CHILLER	HEAT PUMP	COND.		3	308.8
65-1349	IND. SCHOOL DIST. 861	260.0	500	HEAT PUMP				1	33.0
85-6295	MCC DEVELOPMENT CO., INC.	250.0	2500	HEAT PUMP	CHILLER	COND		3	0.0
80-6214	H.B. FULLER COMPANY	185.0	1500	HEAT PUMP	CW COIL			2	0.0
~~80-6201~~	~~U OF MN - ATES~~	~~110.0~~	~~300~~	~~HEAT~~			REINJECT	~~1~~	39.0
66-1196	TOWLE REAL ESTATE - NORWEST CR, ST P.	33.0	1000	HEAT PUMP	COND			2	0.0
86-6178	WILLIAM ULRICH	11.0	100	HEAT PUMP				1	0.0
86-1090	PAMIDA INC.	9.0	35	HEAT PUMP				1	16.0
81-3229	WIDSETH SMITH NOLTING	6.0	16	HEAT PUMP				1	1.3
88-1123	DAVID LUNDEEN	6.0	0	HEAT PUMP				1	3.5
86-2114	JACK WILLIAMS	4.0	20	HEAT PUMP				1	5.0
90-3026	ACROMETAL COMPANIES, INC.	0.0	0	HEAT PUMP				1	0.0
*** Total ***									
		2680.0	9204					18	1838.4

MINNESOTA DEPT NATURAL RESOURCES
CONSUMPTIVE WATER USE STUDY
ORR-SCHELEN-MAYERON & ASSOC
CONDENSER APPLICATIONS

PERMIT NBR	NAME	AUTH MGY	AUTH GPM	FIRST USE	USE 2	USE 3	USE 4	NBR A/C USES	REPORTED MGY
74-5231	GENERAL MILLS	650.0	3700	CW COIL	CHILLER	COND		3	581.0
60-0131	METRO AIRPORTS COMMISSION	500.0	1850	CHILLER	COND	PROCESS		2	382.0
87-6169	BCED MINNESOTA INC. - CONWED TOWER	420.0	833	CHILLER	HEAT PUMP	COND.		3	308.8
63-0519	ST. PAUL - RAMSEY HOSPITAL	385.0	3200	COND.				1	169.7
85-6129	HONEYWELL INC.	380.0	2300	COND.				1	157.0
60-0466	UNITED HOSPITALS	360.0	2625	COND.				1	162.8
64-0643	THS NORTHSTAR ASSOC.	350.0	0	CHILLER	COND.			2	295.7
78-6254	BCED DEVELOPMENT & PROPERTIES, INC.	325.0	2430	CHILLER	COND			2	628.0
85-6227	DAYTON'S - MINNEAPOLIS	300.0	4000	COND.				1	255.0
85-6010	METHODIST HOSPITAL	300.0	1650	CW COIL	COND			2	222.0
66-0906	McCOURTNEY PLASTICS	290.0	550	COND.	PROCESS			1	219.0
85-6267	NORWEST BANK BUILDING CO.	250.0	3000	COND.				1	0.0
69-0707	FEDERAL RESERVE BANK	250.0	2125	COND.				1	485.6
85-6295	MCC_DEVELOPMENT CO., INC.	250.0	2500	HEAT PUMP	CHILLER	COND		3	0.0
85-6140	HFS PROPERTIES	220.0	1000	CW COIL	COND			2	110.5
60-0196	HEITMAN MN MANAGEMENT	200.0	3000	COND.				1	26.0
88-6011	VETERANS ADMINISTRATION	195.0	822	CW COIL	COND			2	119.0
87-6268	MOUNT SIANI MEDICAL CENTER	195.0	650	COND	TOWER			2	40.0
63-0066	ABBOTT NORTHWESTERN HOSPITAL	175.0	2900	COND.				1	342.0
65-0519	RADISSON - ST. PAUL	160.0	700	CW COIL	COND			2	133.3
64-1117	WEBB PUBLISHING CO.	151.0	850	COND.	PROCESS			1	191.6
86-6315	U OF MN - CIVIL/MINERAL ENGRG BLDG	120.0	0	COND.				1	110.4
86-6129	ORDWAY MUSIC THEATER	110.0	750	CHILLER	COND			2	108.0
65-1327	ECO LABS	102.0	1500	CW COIL	COND			2	16.0
75-6268	UNITED PROPERTIES	101.5	0	CW COIL	COND			2	142.0
72-0569	APPLETREE ENTERPRISES, INC.	101.0	10	CHILLER	COND			2	127.0
85-6037	MINNEAPOLIS GRAIN EXCHANGE	100.0	650	COND.				1	45.0
60-0061	THORPE BROTHERS, INC.	100.0	1500	CW COIL	COND			2	5.[illegible]
62-0727	DAYTON'S - ST. PAUL	95.4	1000	CW COIL	COND			2	0.0
85-6073	FAIRVIEW SOUTHDALE HOSPITAL	90.0	3000	COND.				1	229.0

MINNESOTA DEPT NATURAL RESOURCES
CONSUMPTIVE WATER USE STUDY
ORR-SCHELEN-MAYERON & ASSOC
CONDENSER APPLICATIONS

PERMIT NBR	NAME	AUTH MGY	AUTH GPM	FIRST USE	USE 2	USE 3	USE 4	NBR A/C USES	REPOI
62-0138	N.W. BELL - MINNEAPOLIS	74.0	750	COND.				1	[illegible]
87-6193	MINNEAPOLIS ENERGY CENTER INC.	73.0	1200	COND.				1	[illegible]
75-6188	MEDICAL ARTS BUILDING	71.2	1000	COND.				1	[illegible]
59-0896	NORMANDALE PROPERTIES, INC.	70.0	750	CW COIL	COND			2	
85-6011	THE SAINT PAUL HOTEL	70.0	500	CHILLER	COND			2	[illegible]
59-0736	ST. JOSEPH'S HOSPITAL	69.0	950	COND.				1	1
84-6069	NORTHWEST PUBLICATIONS	65.0	1200	COND.	CHILLER			2	2[illegible]
75-6161	THE LEXINGTON COMPANY	65.0	500	CW COIL	CHILLER	COND		3	[illegible]
80-6275	PRUDENTIAL INSURANCE	60.0	1500	CW COIL	COND			2	[illegible]
85-6128	METRO SQUARE PARTNERSHIP	60.0	1000	CHILLER	COND.			2	[illegible]
59-0420	ST. PAUL CIVIC CENTER	60.0	750	COND.				1	[illegible]
85-6081	MINNEAPOLIS ATHLETIC CLUB	60.0	600	COND.				1	[illegible]
58-0243	ROCHESTER AIRPORT CO.	52.0	200	COND.				1	
85-6055	PACIFIC GAMBLE ROBINSON CO.	50.0	200	COND.				1	
61-0320	MARQUETTE BANK - MINNEAPOLIS	45.0	750	COND.				1	
60-0229	DEGREE OF HONOR PROTECTIVE ASSN.	40.0	500	COND.				1	
85-6224	MINNESOTA VETERANS HOME-HASTINGS	40.0	800	CHILLER	COND	PROCESS		2	
65-1258	FARM CREDIT BANKS OF ST. PAUL	36.0	500	CW COIL	COND			2	
63-1113	NW NATIONAL LIFE INSURANCE CO.	35.0	650	CW COIL	COND			2	
66-1196	TOWLE REAL ESTATE - NORWEST CR, ST P.	33.0	1000	HEAT PUMP	COND			2	
59-0771	C.P.S. DEPARTMENT STORES INC.	30.0	350	CW COIL	COND			2	
85-6202	CARSON PIRIE SCOTT - SOUTHDALE	30.0	1000	COND.				1	
85-6226	CITY OF MINNEAPOLIS HEALTH CENTER	30.0	365	COND.				1	
76-6201	RAMSEY COUNTY SHERIFF'S DEPARTMENT	30.0	360	CHILLER	COND	PROCESS		2	
77-6345	ROSEWOOD 5TH & MARQUETTE LIMITED PART	28.0	300	COND.				1	

12/29/89

MINNESOTA DEPT NATURAL RESOURCES
CONSUMPTIVE WATER USE STUDY
ORR-SCHELEN-MAYERON & ASSOC
CONDENSER APPLICATIONS

PERMIT NBR	NAME	AUTH MGY	AUTH GPM	FIRST USE	USE 2	USE 3	USE 4	NBR A/C USES	REPORTED MGY
85-6090	THE 614 COMPANY	20.0	450	COND.				1	11.0
85-6052	WCCO RADIO BUILDING	20.0	400	COND.				1	6.5
59-0760	MIDLAND HILLS COUNTRY CLUB	20.0	0	COND.				1	223.4
79-614B	IND. SCHOOL DIST. 272	12.0	0	CW COIL	COND.	LAWN		2	13.0
85-6051	RAMSEY COUNTY COURTHOUSE	10.0	750	COND.				1	6.9
75-6232	YWCA	10.0	200	COND.				1	6.5
85-6172	ORPHEUM THEATRE	10.0	200	COND.				1	5.0
62-0599	THE ARCHDIOCESE	6.0	100	COND.				1	2.5
78-6257	TRACH PROPERTIES, INC.	5.0	225	COND.				1	3.0
67-0032	JESUIT RETREAT HOUSE	4.3	60	COND.				1	1.3
82-6127	TOWLE REAL ESTATE -METRO BANK BLDG	4.0	525	CW COIL	COND			2	3.9
75-6259	EQUITABLE LIFE ASSURANCE	3.8	145	COND.				1	8.0
64-0014	KENNEDY HIGH SCHOOL	3.6	170	COND.				1	2.0
84-6233	NORWEST BANK - CAMDEN	3.0	50	CW COIL	COND			2	1.6
85-604B	LAKEWOOD CEMETARY ASSN.	1.0	200	COND.				1	0.6
60-0379	LYNDAHL MOTOR COMPANY	1.0	20	COND.				1	0.4
75-6231	HONEYWELL AVIONICS	268.0	694	COND.	CW COIL	PROCESS	DOMESTIC	2	367.9
66-1194	ICI COMPOSITES, INC	0.0	0	COND.	PROCESS			1	149.8
*** Total ***									
		8903.8	70959					~~115~~	7557.8

MINNESOTA DEPT NATURAL RESOURCES
CONSUMPTIVE WATER USE STUDY
ORR-SCHELEN-MAYERON & ASSOC
COLD WATER COIL APPLICATIONS

PERMIT NBR	NAME	AUTH MGY	AUTH GPM	FIRST USE	USE 2	USE 3	USE 4	NBR A/C USES	REPORTED MGY
74-5231	GENERAL MILLS	650.0	3700	CW COIL	CHILLER	COND		3	581.0
85-6010	METHODIST HOSPITAL	300.0	1650	CW COIL	COND			2	222.0
85-6140	HFS PROPERTIES	220.0	1000	CW COIL	COND			2	110.5
88-6011	VETERANS ADMINISTRATION	195.0	822	CW COIL	COND			2	119.0
80-6214	H.B. FULLER COMPANY	185.0	1500	HEAT PUMP	CW COIL			2	0.0
65-0519	RADISSON - ST. PAUL	160.0	700	CW COIL	COND			2	133.3
85-6115	UNISYS	110.0	1000	CW COIL				1	73.5
85-6061	NORTHWESTERN BELL	110.0	0	CW COIL				1	50.6
65-1327	ECO LABS	102.0	1500	CW COIL	COND			2	16.0
75-6268	UNITED PROPERTIES	101.5	0	CW COIL	COND			2	142.0
60-0061	THORPE BROTHERS, INC.	100.0	1500	CW COIL	COND			2	5.0
62-0727	DAYTON'S - ST. PAUL	95.4	1000	CW COIL	COND			2	0.0
89-6129	IDS FINANCIAL SERVICES	89.0	250	CW COIL	TOWER			2	0.0
59-0896	NORMANDALE PROPERTIES, INC.	70.0	750	CW COIL	COND			2	0.0
85-6083	MINNEGASCO	70.0	600	CW COIL				1	102.0
61-0378	PRODUCT DESIGN AND ENGINEERINC, INC.	70.0	200	CW COIL				1	63.0
75-6161	THE LEXINGTON COMPANY	65.0	500	CW COIL	CHILLER	COND		3	50.0
61-0294	JOHN DEERE COMPANY OF MINNEAPOLIS	61.2	600	CW COIL				1	43.0
80-6275	PRUDENTIAL INSURANCE	60.0	1500	CW COIL	COND			2	59.0
75-6206	U OF MN - OFFICE	37.8	500	CW COIL				1	62.6
65-1258	FARM CREDIT BANKS OF ST. PAUL	36.0	500	CW COIL	COND			2	0.0
63-1113	NW NATIONAL LIFE INSURANCE CO.	35.0	650	CW COIL	COND			2	83.0
85-6097	HIGHLAND CENTER, INC.	30.0	350	CW COIL				1	924.0
59-0771	C.P.S. DEPARTMENT STORES INC.	30.0	350	CW COIL	COND			2	0.0
85-6116	UNISYS CORP.	30.0	520	CW COIL				1	15.2
76-6231	HAZELDEN PIONEER HOUSE	20.0	200	CW COIL				1	18.0
86-6003	MINNEAPOLIS PUBLIC LIBRARY	20.0	0	CW COIL				1	32.9
65-0563	BROM MACHINE & FOUNDRY	12.0	250	CW COIL				1	6.2
79-6148	IND. SCHOOL DIST. 272	12.0	0	CW COIL	COND.	LAWN		2	13.0
85-6210	BERWALD INVESTMENT	10.0	200	CW COILS				1	17.2
60-0920	SARGENT INDUSTRIES	9.2	310	CW COIL				1	9.8
61-0538	ECO LABS	8.7	500	CW COIL	TOWER			2	4.9

MINNESOTA DEPT NATURAL RESOURCES
CONSUMPTIVE WATER USE STUDY
ORR-SCHELEN-MAYERON & ASSOC
COLD WATER COIL APPLICATIONS

PERMIT NBR	NAME	AUTH MGY	AUTH GPM	FIRST USE	USE 2	USE 3	USE 4	NBR A/C USES	REPORTED MGY
85-6361	LUNDS, INC.	7.0	60	CW COIL				1	0.0
87-2145	NORTHERN ITASCA HOSPITAL	4.2	65	CW COIL				1	3.4
82-6127	TOWLE REAL ESTATE -METRO BANK BLDG	4.0	525	CW COIL	COND			2	3.9
84-6233	NORWEST BANK - CAMDEN	3.0	50	CW COIL	COND			2	1.6
75-6282	CHURCH OF ST. ANNE	1.2	150	CW COIL				1	0.0
60-0603	GENERAL MILLS	0.0	0	CW COILS	PROCESS	FIRE	LAWN	1	433.6
*** Total ***									
		3124.2	23952						3399.0

12/29/89

MINNESOTA DEPT NATURAL RESOURCES
CONSUMPTIVE WATER USE STUDY
ORR-SCHELEN-MAYERON & ASSOC
NON-ENVIRONMENTAL

PERMIT NBR	NAME	AUTH MGY	AUTH GPM	FIRST USE	USE 2	USE 3	USE 4	NBR A/C USES	REPORTED MGY
75-6269	EQUITABLE -SEE 75-6259 . (DUPLICATE)	0.0	0	0				0	0.0
75-6172	WEST PUBLISHING	34.0	910	DOMESTIC				0	13.7
85-6171	SPECIALTY MANUFACTURING COMPANY	20.0	50	MACHINERY				0	5.0
62-0615	WHITAKER CORP	3.0	200	NONE				0	0.1
66-1060	NORTH STAR STEEL	426.5	800	PROCESS				0	10.5
60-0010	ST. MARY'S HOSP	10.0	450	DOMESTIC				0	0.1
73-1413	CONTROL DATA	30.0	300	PROCESS				0	41.0
75-6252	VANCE PIONEER	14.0	450	NONE				0	0.0
76-6346	DISTRICT HEATING CO	120.0	700	NONE				0	0.0
85-6033	ST. PAUL BURLINGTON LTD PARTNERSHIP	20.0	600	DOMESTIC				0	0.0
*** Total ***		677.5	4460					0	70.4

SURVEY RESULTS

Permittees which utilize ground water for condenser applications outweigh all other uses. 73 out of 101 environmental users utilized well water on the condenser side of compressorized equipment. Ground water was used directly in cooling coils in 39 out of 101 environmental users.

In all cases where well water was used on the evaporator side of a chiller, it was also used on the condenser side. Figure 1.0 is, therefore, typical of all chilled water (evaporator water) applications, except for minor variations. Well water was used an average of 2.3 times in those cases where it was used on the evaporator side. In other words, in those designs where well water was used on the evaporator side, it was always used on the condenser side, accounting for "two uses". In some cases, it was used a third time (such as for pre-cooling air streams).

Heat pump applications tended to use the water only once. This occurred in 8 out of 12 cases.

Well water was used more than once in 33 instances.

It was hoped that numerical data from the survey relating to total capacity, hours of operation and efficiency (EER or COP) could be used to ascertain total tonnage of equipment, tonnage per category, efficiencies, etc. This was not possible due to the nature of the responses. Many surveys did not list the information and many respondents clearly did not have the ability to fill out the questions as intended. Data relating to total Million Gallons per Year (MGY) was also deceiving. For example, General Mills has four (4) wells and reported 581 MGY in 1987. However, an in-depth analysis revealed that Wells #3 and #4 were for environmental usage, while Wells #1 and #2 were for fire protection and domestic use. Honeywell Avionics uses ground water for environmental, process and domestic purposes, in that order. Sixteen (16) man hours of calculations were required to ascertain the portion of their total MGY which was environmental.

CANDIDATES FOR IN-DEPTH ANALYSIS

In order to discuss, with authority, the usage of ground water for environmental benefits and its associated costs, four (4) systems operating in Minnesota were selected for closer analysis. Representatives of each of the four (4) categories above were sought. Database manipulation produced a listing of all permittees based on stated use. An Advisory Committee to the MDNR, meanwhile, provided input to OSM regarding direction and content of the study. Volunteers for in-depth analysis were sought at these monthly Advisory Group meetings. Based on OSM's experience in design, a facility which could easily convert to district cooling was also desired. St. Paul does not have a district cooling facility at the present time, although it does have district heating. A downtown Minneapolis facility was selected which could capitalize on the availability of purchased chilled water from the Minneapolis district cooling facility.

The candidates for an in-depth study and their categories of usage were:

TABLE 4
Candidates for In-Depth Analysis

FACILITY	WELL WATER USAGE	DISCHARGE
General Mills	Chiller Evaporator, Water Coils, and Condenser	Recreation Pond
Gaviidae	Heat Pumps, Condenser, and Chilled Water Pre-Cool	To Storm
Honeywell Avionics	Condenser and Water Coils	Process, Lawn and Storm
Methodist Hospital	Condenser and Water Coils	Recirculated first, to Storm

II. ANALYSIS OF SELECTED "ONCE-THROUGH" SYSTEMS

GENERAL MILLS

General Mills Corporate Headquarters is a 608,900 square foot facility using well water for evaporator chiller water, condenser water and cold water coils (Figure 3.0 illustrates the design). Wells #1 and #2 are primarily used for fire protection and domestic uses, while Wells #3 and #4 are used for environmental cooling almost exclusively. Supplemental pumps "A/C-1" and "A/C-2" operate on system head pressure sensed in the main well water supply line, providing additional water to the system when required. Well pumps #3 and #4 are constant volume pumps. Throughout the system, two-way modulating valves control the flow of well water to the equipment which they serve.

General Mills has six (6) chillers of which Chillers #1, #2 and #3 are 200% redundant. Either one can accommodate the building's peak load. Centrifugal chiller #4 provides chilled water to air handling units #C1, #C5 and #C9 when well water cannot satisfy the load in these spaces. Under normal conditions, this chiller is bypassed and AHU's #C1, #C5 and #C9 are served by well water. Chillers #1 and #2 are centrifugal chillers of 360 full load tons each. At a condensing water temperature of 55/75 degrees Fahrenheit (entering/leaving), the electrical efficiency of each machine is .493 KW/ton.

The condenser pumps which feed the condenser vessels of the six chillers draw their water from a common splash tank (as shown in Figure 4.0). This splash tank collects water from rainwater downspouts as well as return water from the other well water systems. Two-way modulating valves on the inlet sides of the condenser vessels compensate for fluctuations in inlet water temperatures.

Annual operating costs of environmental cooling at the existing facility are estimated at $86,011. This figure excludes the costs which are assumed to remain constant and are not sensitive to well water changes (such as chilled water pumps and air handlers). Annual costs are shown in Table 7. Calculations are shown in the Appendix.

The peak load capacity of the system consists of cold water cooling coil capacity of 401 tons and compressorized equipment capacity of 883 tons. The existing system cost ratio is approximately 3.4¢/TON-HR (not including chilled water pumps or air handling operation equipment).

General Mills - Conversion Costs

General Mills is situated in a suburban location with ample grounds for the addition of slab-mounted equipment. The most feasible alternative to well water cooling is an air-cooled open cooling tower. Assumed operating conditions are 95/85 degrees Fahrenheit water (entering/leaving the tower), 78 degrees Fahrenheit (wet bulb), and 1284 cooling tons. This results in a water flow of 3852 GPM.

Conversion first costs consist of a cooling tower, a tower pump, centrifugal chiller modifications and piping/insulation. Centrifugal chillers #1, #2, #4 and #5 require an impeller (or impeller gear) change due to the increased pressure and temperature required to raise the refrigerant condensing temperature above 95 degrees Fahrenheit. Chillers #1 and #2 also require a condenser vessel change. The chiller data and estimated costs for conversion are shown below:

TABLE 5

CENTRIFUGAL CHILLERS

CHILLER	1	2	4	5
MANUFACTURER	CARRIER	CARRIER	McQUAY	TRANE
<u>EXISTING</u>				
TONS	360	360	150	410
COND EWT	55	55	60	60
COND LWT	75	75	70	80
KW/TON	.493	.493	.686	.646
<u>CONVERSION</u>				
TONS	319	319	127	UNKNOWN
COND EWT	85	85	85	85
COND LWT	93.3	93.3	93.4	95
KW/TON	.603	.603	.755	.710**
<u>CONVERSION COST</u>				
IMPELLER	$ 5,500	$ 5,500	$ -0-	$30,000
GEAR	$ -0-	$ -0-	$15,000	$ -0-
VESSEL	$ 3,800	$ 3,800	$ -0-	$ -0-
MOTOR	<$22,500>*	<$22,500>*	$ -0-	$ -0-

<u>Notes</u>:

* Motor change from Carrier CD to CL would enable the chiller to operate at 360 tons. However, KW/TON would be .61 rather than .603. This option was ruled out, as a less electrically efficient machine would result.

** Assumed.

Conversion costs for a new cooling tower, a tower pump, and piping are shown below. Structural considerations for the installation of the tower were not a problem since it was assumed that the tower and tower pump would be installed on a slab at grade:

TABLE 6
First Costs

EQUIPMENT	COOLING TOWER	TOWER PUMP	PIPING, INSULATION AND INSTALLATION
CAPACITY	1284 TONS	125 HP	---
CONDITIONS	3854 GPM	100′ HD	---
	85/95	1750 RPM	
COST	$68,116	$ 9,010	$347,362

The elimination of well water from the system would mandate the conversion of existing well water cooling coils to chilled water. Piping costs were estimated and included in the conversion first costs. Cost estimates from General Mills for this conversion include the replacement of three (3) chillers for a total cost of $1,500,000. The cost breakdown is $715,942 each (for A/C equipment and installation) and $68,116 (for a cooling tower).

General Mills - Operating Costs (Cooling Tower System)

Annual operating costs for a cooling-tower-based system are $100,862 (as shown in Table 18). The conversion to a cooling tower operating at 95/85 degrees Fahrenheit causes the input KW of the centrifugal chillers to increase dramatically (as shown in the centrifugal chiller table above). The total operating cost ratio for the new system is estimated to be 4.3¢/TON-HR.

The operating cost comparisons for General Mills are:

TABLE 7

ANNUAL TON-HOURS (EST.)	EXISTING (WELL WATER)		CONVERSION (COOLING TOWER)	
2,529,600 2,355,610*	ANNUAL OPERATING COST	$/TON-HR	ANNUAL OPERATING COST	$/TON-HR
	$ 86,011	.0340	$100,862	.0428

* CONVERSION TON-HOURS

<u>General Mills - Life Cycle Cost Comparison</u>

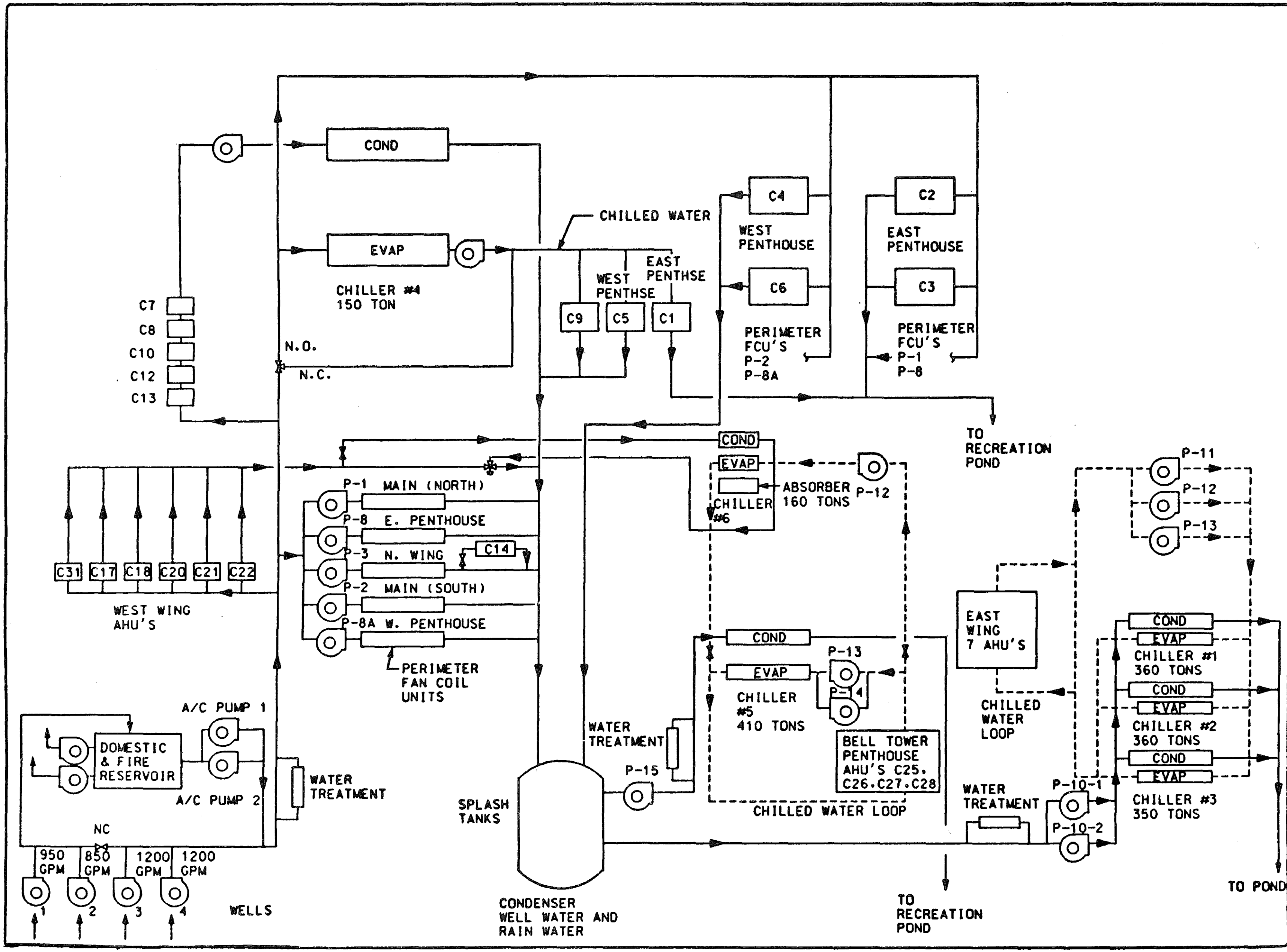
A life cycle cost analysis of the existing system is shown in Table 21. (Note that the age of the existing equipment is not taken into account and replacement costs of existing machinery are not included). The life cycle cost is based on a 20-year life, 8% discount rate, no salvage, 5% fuel escalation, and 4% water treatment cost inflation.

Life cycle costs for a system utilizing a cooling tower to obtain cooling water are shown in Table 22. The first costs for converting to an air-cooled cooling tower appear in the tabulation. The total cost is a "present worth" cost (in 1989 dollars) of a system operating for 20 years. The comparison is as follows:

<u>LIFE CYCLE COST</u>

BASE SYSTEM (WELL WATER) $1,276,178

CONVERSION (COOLING TOWER) $2,998,354



OSM Orr Schelen Mayeron & Associates, Inc.
Minneapolis, MN 55413
612-331-8660

MDNR WATER USE STUDY

DRAWING TITLE

GENERAL MILLS

WELL WATER SCHEMATIC

FIG 4.0

GAVIIDAE COMMONS

Gaviidae Commons is a 125,000 sq. ft. retail facility located in downtown Minneapolis. It utilizes a combination of water source heat pumps, water chillers, and well water heat exchangers in its design. The well water pumped for Gaviidae is also shared with the neighboring Saks Fifth Avenue Building. Of the 1600 GPM flow rate at the well pump, 1000 GPM is dedicated to Gaviidae. This study disregards the Saks portion of the well water (Figure 3.1 illustrates the design), since no information was received from the design engineer.

This facility was chosen for in-depth analysis due to its employment of water source heat pumps and its ability to convert to a purchased chilled water agreement. In fact, the downtown district cooling facility has water pipes that are "stubbed" to supply chilled water to Gaviidae.

There are 105 water source heat pumps currently installed in Gaviidae Commons. They primarily serve the individual tenants in the building. This provides a flexibility of design by enabling the Owner to add more heat pumps to serve new tenants, change sizes as user load profiles change, and provide independent control of each space. A further allowance for expansion to twice the existing capacity is in the design. A heat exchanger provides the well water source/sink required by the heat pumps, which operate at an electrical efficiency of approximately 12.3 BTUH/Watt at 70/85 degrees Fahrenheit (entering/leaving) source water temperature. By contrast, the energy efficiency rating at 85/95 degrees Fahrenheit (entering/leaving) source water temperature is approximately 11.3 BTUH/Watt.

The commons area is served by two (2) centrifugal chillers of 265 tons each. The centrifugal chillers operate at a design efficiency of .414 KW/Ton.

The aforementioned well water heat exchanger serves to pre-cool the chilled water as it returns from the building, prior to being chilled in the evaporator vessel of the water chiller. Approximately 128 tons of cooling are achieved from the well water in this fashion.

Annual environmental cooling operating costs are estimated at $42,692. Annual costs are shown in Table 3. Calculations are shown in the Appendix.

The total peak load of the system consists of a well water heat exchanger at 128 tons, centrifugal water chillers at 500 tons, and water source heat pumps at 284 tons. The existing well water system cost ratio is approximately 6.2¢/TON-HR.

<u>Gaviidae Commons - Conversion Costs</u>
The downtown location of the facility lends itself well to district cooling/heating. Cooling towers would also be feasible; however, space for the new cooling tower could be a problem. Structural costs and considerations for a roof-mounted cooling tower could not be ascertained within the scope of this study.

The building already utilizes district steam heating, and the district cooling chilled water lines are stubbed to receive connections from a future chilled water system from Gaviidae. The water for the water source heat pumps would be heated from a new steam-to-water heat exchanger during the winter season. During the cooling mode, these units could either operate on source water-cooled (by purchased chilled water) or possibly on return water from the chilled water loop for the commons area.

<u>Gaviidae Commons - Conversion Costs (Cooling Tower)</u>
Conversion costs for a cooling tower consist of a cooling tower, a tower pump, centrifugal chiller modifications, piping, and a new reciprocating water chiller of 128 tons (to supplement the 128 tons of well water pre-cooling).

The centrigual chillers would require a gear change to operate at 85/95 degrees Fahrenheit (entering/leaving) condenser water temperatures. The centrifugal chiller data and estimated costs for conversion are shown on the following page.

TABLE 8

CENTRIFUGAL CHILLERS

CHILLER	1	2
MANUFACTURER	YORK	YORK
<u>EXISTING</u>		
TONS	263	263
COND EWT	56	56
COND LWT	70	70
KW/TON	.414	.414
<u>CONVERSION</u>		
TONS	263	263
COND EWT	85	85
COND LWT	94.5	94.5
KW/TON	.673	.673
<u>CONVERSION COST</u>		
GEAR	$25,000	$25,000
VESSEL		

Conversion costs for a new cooling tower, a tower pump, and piping are shown below. Structural re-design and modifications for a roof-mounted system are not included.

EQUIPMENT	COOLING TOWER	TOWER PUMP	PIPING AND MISCELLANEOUS	RECIPROCATING CHILLER
CAPACITY	912 TONS	100 HP	---	128 TONS
CONDITIONS	2736 GPM	100′ HD	---	
	85/95	1750 RPM		
COST	$38,133	$ 7,510	$202,328	$ 84,000

Gaviidae Commons - Conversion Costs (District Cooling)

Conversion costs for district cooling consist of a new steam-to-water heat exchanger for the heat pump source loop, piping, and insulation. Piping changes depend on the method chosen to supply cooling water to the heat pump source loop during its cooling mode.

Conversion costs are estimated to be:

TABLE 9
First Costs

SYSTEM	STEAM HEAT EXCHANGER	PIPING
CAPACITY	3890 LBS/HOUR	----
COST	$26,700	$11,160

Gaviidae Commons - Operating Costs (Cooling Tower System)

Annual operating costs for a cooling-tower-based system are $48,030 (as shown in Table 18). The operating costs on a "$/TON-HR" basis is estimated to be 6.97¢/TON-HR.

Gaviidae Commons - Operating Costs (District Heating/Cooling)

Annual operating costs for a district cooling system and a district heating-supplied heat exchanger are $106,081. Annual operating costs for purchased cooling alone are $112,948 for an estimated 400 tons and 900 Full Load Hours. The actual purchased chilled water operating cost on a "$/TON-HR" basis is estimated to be 31.4¢/TON-HR. For comparison with well water and tower systems, the cost of maintenance, labor and capitol equipment shall be excluded. The resultant comparison cost is 22.5¢/TON-HR. While costs on a "$/TON-HR" basis are high, the building takes advantage of only purchasing the water it needs. The maintenance, labor and unscheduled service costs related to the equipment are borne by the district supplier and not by the Owner. The steam costs are not total building steam costs but, rather, additional steam costs necessary to supply the heating mode heat pump source water which was lost by the elimination of aquifer ground water.

Gaviidae Commons - Cost Comparisons

The operating cost comparisons for Gaviidae Commons are:

TABLE 10

EXISTING (WELL WATER)		CONVERSION (COOLING TOWER)		CONVERSION (DISTRICT COOLING)	
ANNUAL OPERATING COST	ANNUAL $/TON-HR	ANNUAL OPERATING COST	ANNUAL $/TON-HR	ANNUAL OPERATING COST*	ANNUAL $/TON-HR*
$ 42,692	.0619	$ 48,030	.0697	$ 81,000	.2250

Note: * Cooling only for comparison, labor, maintenance and capitol equipment costs excluded.

Gaviidae Commons - Life Cycle Cost Comparison

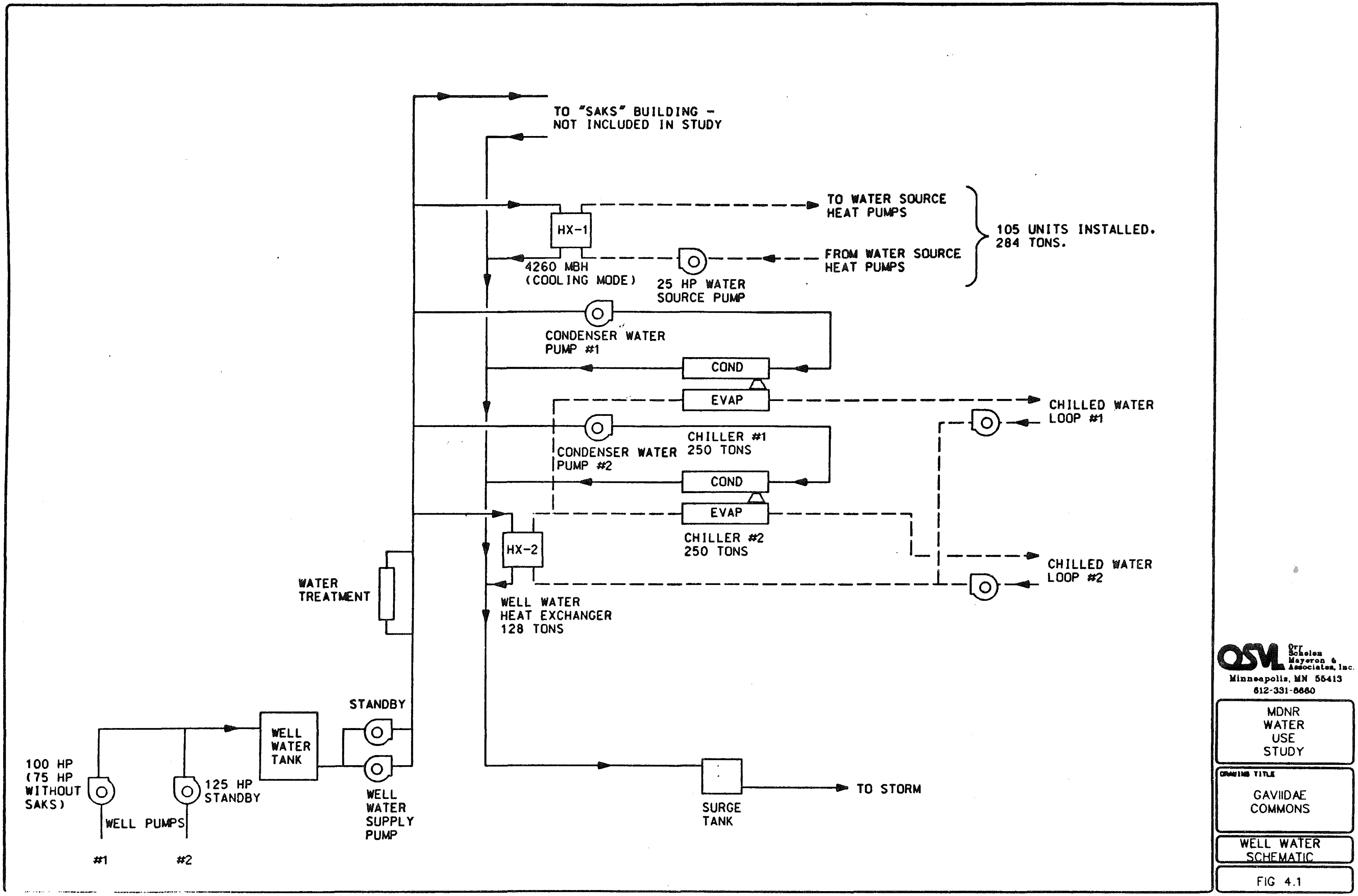
A life cycle cost analysis of the existing system is shown in Table 21. The equipment at Gaviidae is almost new and a 20-year life is expected.

Life cycle costs for a system utilizing a cooling tower to obtain cooling water are shown in Table 22. The total cost is a "present worth" cost (in 1989 dollars) of a system operating for 20 years and includes first costs.

Life cycle costs for a district cooling/heating system are shown in Table 23 and, likewise, include first costs.

LIFE CYCLE COST

BASE SYSTEM (WELL WATER)	$ 628,037
CONVERSION (COOLING TOWER)	1,044,005
CONVERSION (DISTRICT HEATING/COOLING)	1,499,338



TO "SAKS" BUILDING - NOT INCLUDED IN STUDY
TO WATER SOURCE HEAT PUMPS
105 UNITS INSTALLED. 284 TONS.
HX-1
FROM WATER SOURCE HEAT PUMPS
4260 MBH (COOLING MODE)
25 HP WATER SOURCE PUMP
CONDENSER WATER PUMP #1
COND
EVAP
CHILLED WATER LOOP #1
CHILLER #1 250 TONS
CONDENSER WATER PUMP #2
COND
EVAP
HX-2
CHILLER #2 250 TONS
CHILLED WATER LOOP #2
WATER TREATMENT
WELL WATER HEAT EXCHANGER 128 TONS
STANDBY
WELL WATER TANK
100 HP (75 HP WITHOUT SAKS)
125 HP STANDBY
WELL PUMPS
#1
#2
WELL WATER SUPPLY PUMP
SURGE TANK
TO STORM
OSM Orr Schelen Mayeron & Associates, Inc.
Minneapolis, MN 55413
612-331-8660
MDNR WATER USE STUDY
DRAWING TITLE
GAVIIDAE COMMONS
WELL WATER SCHEMATIC
FIG 4.1

HONEYWELL AVIONICS

Honeywell Avionics Division is a 525,000 square foot facility using well water for environmental cooling, process cooling, and domestic purposes. The environmental portion utilizes approximately 85% of the total water appropriated. There are two (2) ground water wells and the system is designed in a parallel fashion so that either well delivers water to all water-cooled equipment. The system is diverse and has expanded as the facility has expanded. The well pumps are constant volume pumps. Two-way modulating valves at the units control the amount of water that they receive.

Due to the complexity of the system, a schedule of equipment will be used to describe the system components. Refer to Schematic Drawing 4.2, Schedule 4.2A and Schedule Notes 4.2B for a complete system description. (Note that the system is more complex than that shown in Schematic Drawing 4.2, but the schematic depicts the salient features).

Annual operating costs of environmental cooling at the existing facility are estimated at $242,870. Annual costs are shown in Table 17. Calculations are shown in the Appendix.

The total peak cooling capacity of the system is estimated at 1507.4 tons. The calculation is shown in Appendix A-5.

Note that the majority of environmental cooling is accommodated by two (2) centrifugal chillers (AC04 and AC05) with capacities of 500 tons and 300 tons, respectively. These units operate ahead of other reciprocating water chillers (such as AC06) which pick up peak loads, as required.

The estimated annual operating cost ratio was derived from the annual operating costs (as shown in Table 17). The portion of that annual cost which is derived from the operation of compressorized equipment is shown in Appendix A-1. The efficiencies of the equipment at 50 degrees Fahrenheit entering condenser water temperature have been taken into account in this analysis. Total hours of operation and estimated loads were provided by Honeywell. The total estimated operating cost ratio of the existing system is $.0283/TON-HR.

Honeywell Avionics - Conversion Costs

The most feasible conversion strategy for Honeywell Avionics is an air-cooled open cooling tower. Assumed operating conditions are 95/85 degrees Fahrenheit water (entering/leaving the tower), 78 degrees Fahrenheit (wet bulb), and 1507 cooling tons. This results in a water flow of 4521 GPM.

Conversion first costs consist of a cooling tower, a tower pump, centrifugal chiller modifications and piping/insulation. No additional chillers would be purchased. Structural estimates for a roof-mounted cooling tower were not conducted. Initial investigations indicate that this may not be a problem.

Conversion costs for the centrifugal chillers and their operating data are shown on the following page.

TABLE 11

CENTRIFUGAL CHILLERS

CHILLER	AC04	AC05
MANUFACTURER	YORK	YORK
EXISTING		
TONS	500	300
COND EWT	55	55
COND LWT	72.8	71
KW/TON	.382	.4133
CONVERSION		
TONS	447	292
COND EWT	85	85
COND LWT	93.4	94.2
KW/TON	.615	.644
CONVERSION COST		
IMPELLER	$ -0-	$ -0-
GEAR	$25,000	$25,000
VESSEL	$ 8,000	$ 8,000

Conversion costs for a new cooling tower, a tower pump, and piping are shown below. Structural costs for the design and construction of new roof loads are not included.

TABLE 12
First Costs

EQUIPMENT	COOLING TOWER	TOWER PUMP	PIPING, INSULATION AND INSTALLATION (CONDENSER PIPING)
CAPACITY	1507 TONS	150 HP	14", 12", 10", 6" AND 4" (DIA.)
CONDITIONS	4521 GPM	100′ HD	---
	85/95	1750 RPM	
COST	$69,996	$ 9,990	$1,303,050

Estimated conversion First Costs for cold water piping and the replacement of reciprocating chillers which are at the end of their service life is $2,500,000.

The operating cost comparisons for Honeywell Avionics are:

TABLE 13
Operating Cost Comparisons

EXISTING (WELL WATER)		CONVERSION (COOLING TOWER)	
ANNUAL OPERATING COST	ANNUAL $/TON-HR	ANNUAL OPERATING COST	ANNUAL $/TON-HR
$256,037	.0298	$387,222	.0451

Honeywell Avionics - Life Cycle Cost Comparison

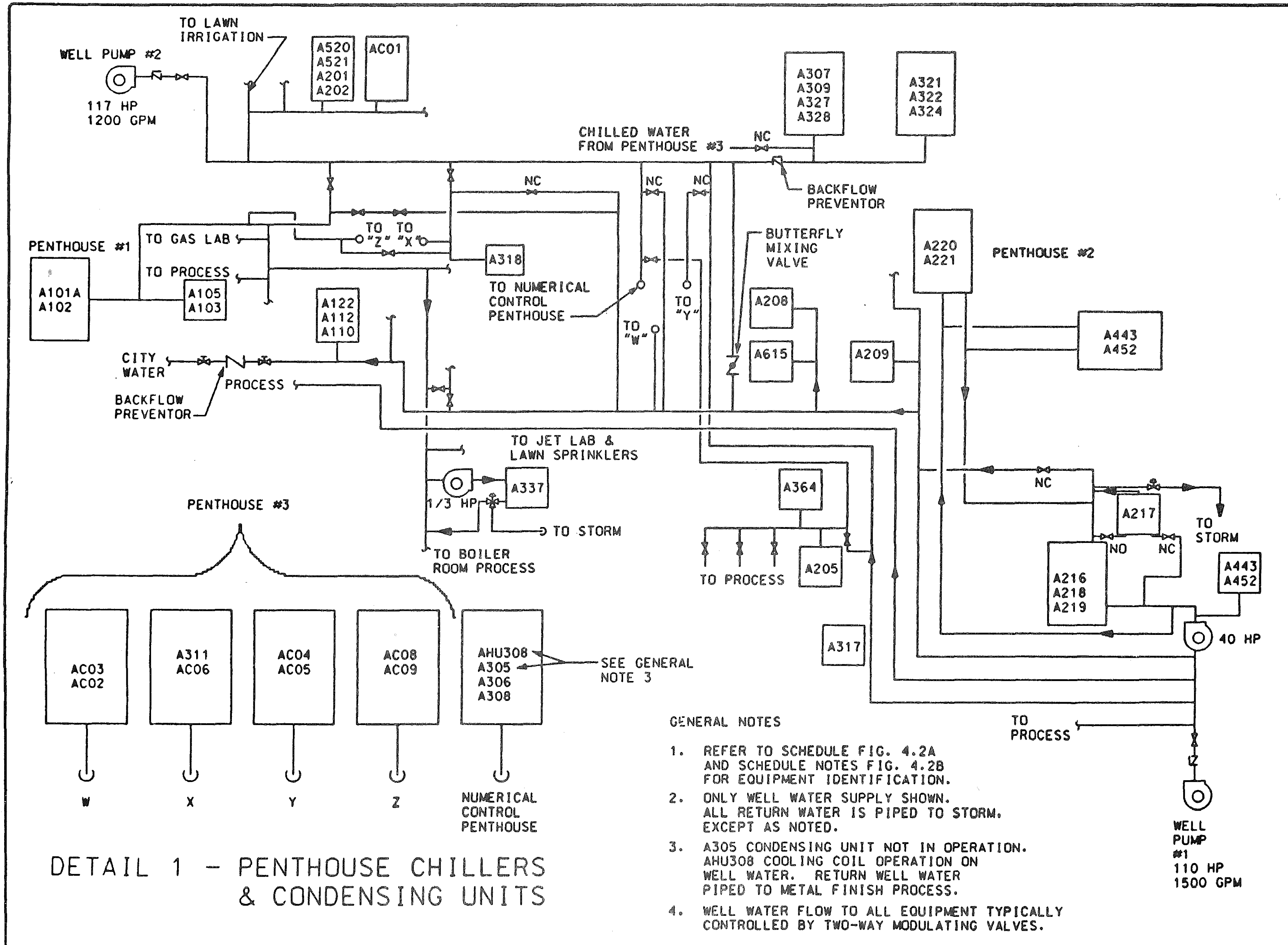
A life cycle cost analysis of the existing system is shown in Table 21. (Note: while the two centrifugal chillers are new, the age of the balance of the equipment was not taken into account). The life cycle cost is based on a 20-year life, 8% discount rate, no salvage, 5% electricity escalation, and 4% water treatment cost inflation.

Life cycle costs for a system utilizing a cooling tower to obtain cooling water are shown in Table 22. The first costs for converting to an air-cooled cooling tower appear in the tabulation. The total cost is a "present worth" cost (in 1989 dollars) of a system operating for 20 years. The comparison is as follows:

LIFE CYCLE COST

BASE SYSTEM (WELL WATER) $3,631,818

CONVERSION (COOLING TOWER) $9,105,832



GENERAL NOTES

1. REFER TO SCHEDULE FIG. 4.2A AND SCHEDULE NOTES FIG. 4.2B FOR EQUIPMENT IDENTIFICATION.
2. ONLY WELL WATER SUPPLY SHOWN. ALL RETURN WATER IS PIPED TO STORM, EXCEPT AS NOTED.
3. A305 CONDENSING UNIT NOT IN OPERATION. AHU308 COOLING COIL OPERATION ON WELL WATER. RETURN WELL WATER PIPED TO METAL FINISH PROCESS.
4. WELL WATER FLOW TO ALL EQUIPMENT TYPICALLY CONTROLLED BY TWO-WAY MODULATING VALVES.

OSM
Orr Schelen Mayeron & Associates, Inc
Minneapolis, MN 55413
612-331 8660

MDNR WATER USE STUDY

DRAWING TITLE

HONEYWELL AVIONICS (SIMPLIFIED SCHEM.)

WELL WATER SCHEMATIC

FIG 4.2

Notes for Well Water Cooled Comfort/Environmental Equipment Schedule

1. Penn Valve: Refrigerant head pressure modulating valve.

2. Control: Space thermostat modulates 2 way pneumatic valve on cooling coil.

3. Liebert self-contained computer room air conditioning unit with well water coil in return air stream. Well water is either diverted thru or past this coil on its way to the condenser. The condenser water flow is head pressure regulated. A 2 way 2 position valve shuts off well water flow thru the unit when the unit is not calling for cooling and/or dehumidification.

4. (Note revised 12-6-89) Unit is controlled by the personnel in the room. Operating schedule unknown.

5. Uses well water thru the cooling coil controlled by a 2 way modulating valve when chilled water is not available. The unit 3 way valve is converted to 2 way action by manually closing a valve in the coil bypass port of the 3 way valve. (Note revised 11-28-89)

6. 3 season operation. Coils are drained in freezing weather.

7. Well water to the coils is pumped. Also, the return water from the coils is either diverted back into the building well water piping or is diverted to the storm drain, depending upon well water pressure. During 1988 and 1989, this system was set to divert the water to the storm sewer. Refer to piping diagram on drawing 100-M 426 . (Note revised 12-6-89)

8. (Note added 11-28-89 and revised 12-6-89). Well water is pumped to this coil thru a 2 way modulating control valve. The return water is either pumped back into the well water line or diverted to a roof drain based upon well water supply temperature. Downstream of this coil, the well water is used for cooling the plant air compressors and for tempering the boiler blowdown.

9. RLG polish clean room well water coil is used only as a backup to the chilled water coil.

10. The chiller is used for peaking and/or for standby for the lead chillers AC04 and AC05.

11. Lead chillers; The condenser well water flow is controlled using head pressure modulated 2 way butterfly valves.

12. Condenser water is also piped to old cooling towers. The towers are in bad condition, probably unusable.

13. AHU A301 has backup DX coils to the chilled water coils.

14. (Note added 11-28-89). This chiller is a backup to the main chilled water loop chillers. If used, this chiller will serve only unit A503 due to the piping configuration.

15. (Note added 11-28-89). This chiller is normally used with cooling towers which are located on the roof of building 7. However in the Spring/Fall changeover period, well water is used in the condenser, controlled by Penn valves.

16. (Note added 11-28-89). Due to mechanical problems, this DX reciprocating compressor/condensing unit (A305) did not operate during the 1989 cooling season. Refer to note 17 for additional information.

17. (Note added 11-28-89). This AHU A305, served by the above DX reciprocating compressor/condensing unit A305, operated during the 1989 cooling season with well water piped thru an existing water coil. The only control that currently exists is a manual shutoff valve. The return water from this coil is piped in such a manner to supply the metal finish well water requirements.

18. (Note added 11-28-89). A discharge air (D. A.) sensor controls the 2 way control valve on the cooling coil.

Well Water [illegible] Environmental Equipment

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	Item tag	Serves	Description	Location	Nominal Capacity	Well Water Usage	Well Water Control	Unit Operating Schedule			Remarks	
3												
4	Building 1 Units - 1st Floor											
5	A1[illegible]3	[illegible] Lab [illegible] Rm	Heat Pump	1-[illegible]-3	1.5-3 Tons (Verify)	Condenser	Penn Valve-Note [illegible]	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Piped to City Water	
6	A1[illegible]	Plant Engineering	Packaged A/C Unit	1-P-3	5 Tons	Condenser	Penn Valve	12 Hrs/Day	6 Days/Wk	52 Wks/Yr	Possibly Piped to City Water	
7	A112	Test Systems Office	Packaged A/C Unit	1-[illegible]-5	5 Tons	Condenser	Penn Valve	16 Hrs/Day	6 Days/Wk	52 Wks/Yr		
8	A110	Test Systems Engr	Packaged A/C Unit	1-R-4	5 Tons	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
9												
10	A122	NW Guard Station	Packaged A/C Unit	1-R-5	7.5 Tons	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
11	A105	Unit 3	DX Recip. Compr/Cond Unit	1-K-5	75 Tons	Condenser	Penn Valve	12.5 Hrs/Day	5 Days/Wk	52 Wks/Yr		
12	A103	[illegible] 3	DX Recip. Compr/Cond Unit	1-K-7	75-100 Tons (Verify)	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	[illegible]	
13	Building 3 Units - 1st Floor											
14	A315	Carpenter Shop	Fan Coil Unit	1-[illegible]-17		Cooling Coil	Space Stat/2 Way Va	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Note 2	
15	A316	[illegible]	Heat Pump	1-D-19	1.5-3 Tons (Verify)	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
16		[illegible] VAX Rm	Heat Pump	1-[illegible]-26	1.5-3 Tons (Verify)	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	To be Relocated (Verify)	
17	A205	Monitor Lab	DX Recip. Compr/Cond Unit	1-E-29	7.5-1[illegible] Tons (Verify)	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
18												
19	A327	DPS-6 Computer Rm	Liebert Glycol Unit	1-P-27	20 Tons	Cool. Coil/Cond	Penn Va/3 Way Va	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Note 3	
20	A307	DPS-6 Computer Rm	Liebert Glycol Unit	1-P-27	20 Tons	Cool. Coil/Cond	Penn Va/3 Way Va	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Note 3	
21	A309	DPS-6 Computer Rm	Liebert Glycol Unit	1-R-26	20 Tons	Cool. Coil/Cond	Penn Va/3 Way Va	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Note 3	
22	A328	Central Comm. Rm	Liebert Glycol Unit	1-Q-28	20 Tons	Cool. Coil/Cond	Penn Va/3 Way Va	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Note 3	
23	A3[illegible]	DPS-8 Computer Rm	Liebert Glycol Unit	1-N-27	[illegible] Tons	Cool. Coil/Cond	Penn Va/3 Way Va	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Note 3	
24												
25	A3[illegible]	DPS-8 Computer Rm	Liebert Glycol Unit	1-N-28	20 Tons	Cool. Coil/Cond	Penn Va/3 Way Va	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Note 3	
26	A324	DPS-8 Computer Rm	Liebert Glycol Unit	1-M-28	20 Tons	Cool. Coil/Cond	Penn Va/3 Way Va	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Note 3	
27	A3[illegible]	[illegible]	Packaged A/C Unit	1-M-25	5-10 Tons (Verify)	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Standby Unit - Note 4	
28	Building 2 & 4 Units - 1st Floor											
29	A202	Optics	DX Recip. Compr/Cond Unit	1-X-30	3 Tons	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
30	A204	Electric Standards Rm	Heat Pump	1-X-33	5 Tons (Verify)	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
31	A206	[illegible] Clean Rm	Liebert Fan Coil Unit	1-U-34	12.5 Tons (Verify)	Cooling Coil	Space Stat/2-3 Way Va	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Note 5	
32	A317	Metrology Tool Crib	Packaged A/C Unit	1-U-30	15 Tons (Verify)	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
33												
34	A207	Tunning	Recip Water Chiller	1-F-35	15 Tons	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
35	A216	Build. 2 & 4 - 1st Fl. S	Air Handling Unit (AHU)	1-M-38		Cooling Coil	D. A. Control/2 Way Va	24 Hrs/Day	7 Days/Wk	26 Wks/Yr	Notes 6,7 & 18	
36	A218	Build. 2 - 2nd Fl. N	Air Handling Unit	1-K-38		Cooling Coil	D. A. Control/2 Way Va	11 Hrs/Day	5 Days/Wk	26 Wks/Yr	Notes 6,7 & 18	
37	A219	Build. 2 & 4 - 2nd Fl. S	Air Handling Unit	1-K-38		Cooling Coil	D. A. Control/2 Way Va	16 Hrs/Day	6 Days/Wk	26 Wks/Yr	Notes 6,7 & 18	
38	A217	AHU A217	DX Recip. Compr/Cond Unit	1-N-37	100 Tons	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	26 Wks/Yr		
39	Building 5 Units - 1st Floor											
40	A520	Old Red Carpet Rm	Packaged A/C Unit	1-G-26	3.5-7.5 Tons (Verify)	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
41	A521	D & E	Packaged A/C Unit	1-T-30	3.5-7.5 Tons (Verify)	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
42	A201	LF Calibration Rm	DX Recip. Compr/Cond Unit	1-X-29	3 Tons	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
43	Building 7 Units - 1st Floor											
44	A6[illegible]5	Building 7	Recip Water Chiller	1-R-37	100 Tons	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	26 Wks/Yr	Note 15	
45	A621	High Bay [illegible] Lab	Packaged A/C Unit	1-W-37	15 Tons (Verify)	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Government Owned Unit	
46	A602	D & E High Bay	DX Recip. Compr/Cond Unit	1-T-41	25-30 Tons (Verify)	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
47	Building 2 & 4 Units - 2nd & 3rd Floors											
48	A250	[illegible] Computer Rm	Liebert Packaged A/C Unit	2-V-36		Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	52 Wks/Yr		
49	A450	Thin Film Computer Rm	Fan Coil Unit	3-D-32	[illegible] Tons (Verify)	Cooling Coil	Space Stat/2 Way Va	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Notes 6 & 7	
50	Building 1 Units - Roof & Penthouse											
51	A1[illegible]A	[illegible] - Trane	DX Recip. Compr/Cond Unit	Penthouse 1	40 Tons	Condenser	Penn Valve	12 Hrs/Day	5 Days/Wk	26 Wks/Yr		
52	A1[illegible]	Unit [illegible] - Carrier	DX Recip. Compr/Cond Unit	Penthouse 1	15 Tons	Condenser	Penn Valve	12 Hrs/Day	5 Days/Wk	26 Wks/Yr		
53	Building 3 Units - Roof & Penthouses											
54	A337	[illegible] Kitchen	Rooftop Make-up Air Unit	Roof-F-18	25 Tons (Verify)	Cooling Coil	See Remarks				Notes 6 & 8	
55	A364	Rug Polish Clean Rm	Air Handling Unit	Roof-H-28	4600 CFM	Cooling Coil	Space Stat/2 Way Va	24 Hrs/Day	7 Days/Wk	52 Wks/Yr	Note 9	
56												
57	A302	Chilled Water Loop C300	Recip Water Chiller (Glycol)	Penthouse 3	75 Tons	Condenser	Penn Valve	---	---	---	Note 10	
58	A303	Chilled Water Loop C300	Recip Water Chiller (Glycol)	Penthouse 3	75 Tons	Condenser	Penn Valve	---	---	---	Note 10	
59	A304	Chilled Water Loop C300	Cent. Water Chiller (Glycol)	Penthouse 3	500 Tons	Condenser	Butterfly Va (Head Press.)	24 Hrs/Day	7 Days/Wk	39 Wks/Yr	Note 11	
60	A305	Chilled Water Loop C300	Cent. Water Chiller (Glycol)	Penthouse 3	500 Tons	Condenser	Butterfly Va (Head Press.)	24 Hrs/Day	7 Days/Wk	39 Wks/Yr	Note 11	
61												
62	A306	Chilled Water Loop C300	Recip Water Chiller (Glycol)	Penthouse 3	100 Tons	Condenser	Penn Valve	---	---	---	Notes 10 & 12	
63	A307	Chilled Water Loop C300	Recip Water Chiller (Glycol)	Penthouse 3	100 Tons	Condenser	Penn Valve	---	---	---	Notes 10 & 12	
64	A308	Chilled Water Loop C300	Recip Water Chiller (Glycol)	Penthouse 3	100 Tons	Condenser	Penn Valve	---	---	---	Note 10	
65	A311	AHU A301 (Clean Rms)	DX Recip. Compr/Cond Unit	Penthouse 3	75 Tons	Condenser	Penn Valve	---	---	---	Note 13	
66												
67	A308	N/C Rm West	Air Handling Unit	N/C Penthouse		Cooling Coil	Manual Shut Off Valve	24 Hrs/Day	7 Days/Wk	26 Wks/Yr	Note 17	
68	A308	AHU A308	DX Recip. Compr/Cond Unit	N/C Penthouse	30 Tons	Condenser	Penn Valve	---	---	---	Note 16	
69	A305	N/C Rm East	Recip Water Chiller	N/C Penthouse	40 Tons	Condenser	Penn Valve	24 Hrs/Day	7 Days/Wk	26 Wks/Yr		
70	A306	Quality	DX Recip. Compr/Cond Unit	N/C Penthouse		Condenser	Penn Valve	---	---	---	Has been abandoned	
71	Building 2 & 4 Units - Roof & Penthouse											
72	A443	Thin Film Clean Rm N	Air Handling Unit	Roof-C-33		Cooling Coil	Space Stat/2 Way Va	24 Hrs/Day	7 Days/Wk	26 Wks/Yr	Notes 6 & 7	
73												
74	A220	Build. 2 - 3rd Fl. N	Air Handling Unit	Penthouse 2		Cooling Coil	D. A. Control/2 Way Va	12 Hrs/Day	5 Days/Wk	26 Wks/Yr	Notes 6,7 & 18	
75	A221	Build. 2 & 4 - 3rd Fl. S	Air Handling Unit	Penthouse 2		Cooling Coil	D. A. Control/2 Way Va	24 Hrs/Day	6 Days/Wk	26 Wks/Yr	Notes 6,7 & 18	
76	Building 5 Units - Roof & Penthouse											
77	A501	AHU A503 (Clean Rms)	Recip Water Chiller (Glycol)	Penthouse 5	130 Tons	Condenser	Penn Valve	---	---	---	Note 14	
78												

METHODIST HOSPITAL

Methodist Hospital is a 549,000 square foot facility using well water for direct circulation through water coils and for condenser cooling of two (2) centrifugal chillers. The system is served by a single variable speed well water pump. One noteworthy feature of the Methodist Hospital design is the recirculated nature of the condenser water serving the chillers. Three-way mixing valves provide 62 degree Fahrenheit water temperature to the condensers, mixing well water temperatures of 51 degrees Fahrenheit with condenser return water temperatures of 72 degrees Fahrenheit. The amount of new well water introduced is matched by the amount of well water which is discharged to a nearby pond.

Annual operating costs of environmental cooling at the existing facility are estimated at $204,304 (excluding costs which are not sensitive to cooling water changes). Annual costs are shown in Table 17. Calculations are shown in the Appendix.

The peak load capacity of the system consists of a cold water cooling coil capacity of 244 tons and a centrifugal chiller capacity of 903 tons. The total peak load is estimated at 1147 tons. The existing system cost ratio is approximately 5.42¢/TON-HR.

Methodist Hospital - Conversion Costs

Methodist Hospital is situated in a suburban location. Air-cooled open cooling towers were deemed the most feasible replacement for well water-sourced cooling water. Assumed operating conditions were 95/85 degrees Fahrenheit water (entering/leaving the tower), 78 degrees Fahrenheit (wet bulb), and 1147 cooling tons. This results in a water flow rate of 3441 GPM.

Conversion first costs consist of a cooling tower, a tower pump, centrifugal chiller modifications, and piping/insulation. The operating data and cost estimates for the two (2) centrifugal chillers are shown below. The existing machines were manufactured with a smooth-tube design in the condenser bundle, as reflected in their high KW/TON. Conversion affords the opportunity to introduce state-of-the-art enhanced tubes, resulting in better electrical efficiencies (as shown below):

TABLE 14

CENTRIFUGAL CHILLERS

CHILLER	1	2
MANUFACTURER	CARRIER	CARRIER
EXISTING		
TONS	650	325
COND EWT	62	62
COND LWT	72	72
KW/TON	.932	.912
CONVERSION		
TONS	650	325
COND EWT	85	85
COND LWT	94.8	94.7
KW/TON	.722	.7385
CONVERSION COST*		
IMPELLER	$17,000	$ -0-
GEAR	$ -0-	$ -0-
VESSEL	$17,500	$17,500

Conversion costs for a new cooling tower, a tower pump, and piping are shown on the following page. The tower was assumed to be installed on a slab at grade.

TABLE 15
First Costs

EQUIPMENT	COOLING TOWER	TOWER PUMP	PIPING, INSULATION AND INSTALLATION
CAPACITY	1147 TONS	125 HP	---
CONDITIONS	3441 GPM	100' HD	---
	85/95	1750 RPM	
COST	$68,116	$ 9,010	$209,202

The elimination of well water from the system would mandate the conversion of existing well water cooling coils to chilled water. Piping costs were estimated and included in the conversion first costs. Analysis of the peak capacity of a third chiller on-site revealed no need for the addition of a new water chiller.

Methodist Hospital - Operating Costs (Cooling Tower System)
Annual operating costs for a cooling-tower-based system are $160,072 (as shown in Table 18). The conversion to a cooling tower operating at 95/85 degrees Fahrenheit has been taken into account in the operating cost of the chillers. The total operating cost ratio for the new system is estimated to be 4.3¢/TON-HR. It is important to note that, due to the introduction of new condenser tube bundles, the electrical efficiency of the two (2) centrifugal chillers was raised from an average of .922 KW/TON to .730 KW/TON. The resultant annual operating cost, even with 85/95 deg. F. tower water, is less than the existing annual operating cost.

Methodist Hospital - Cost Comparisons

The operating cost comparisons for Methodist Hospital are:

TABLE 16
Operating Cost Comparisons

EXISTING (WELL WATER)		CONVERSION (COOLING TOWER)	
ANNUAL OPERATING COST	ANNUAL $/TON-HR	ANNUAL OPERATING COST	ANNUAL $/TON-HR
$204,304	.0542	$160,072	.0425

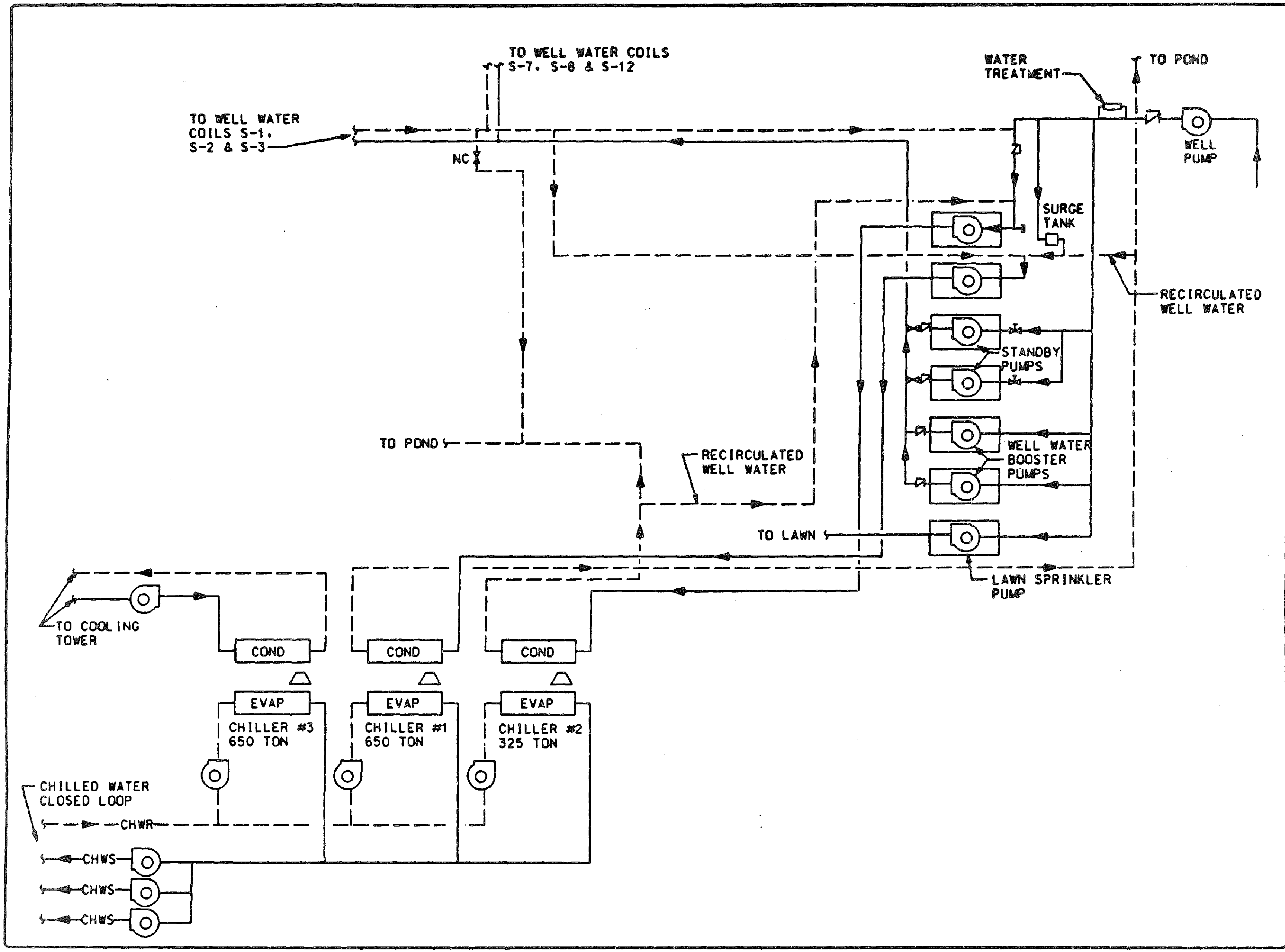
Methodist Hospital - Life Cycle Cost Comparison

A life cycle cost analysis of the existing system is shown in Table 21. (Note that the age of the existing equipment is not taken into account and replacement costs of existing machinery are not included). The life cycle cost is based on a 20-year life, 8% discount rate, no salvage, 5% fuel escalation, and 4% water treatment cost inflation.

Life cycle costs for a system utilizing a cooling tower to obtain cooling water are shown in Table 22. The first costs for converting to an air-cooled cooling tower appear in the tabulation. The total cost is a "present worth" cost (in 1989 dollars) of a system operating for 20 years and includes first costs. Note that the first cost of a cooling tower and condenser tube bundles has been offset by the improved performance of the compressorized machines with the enhanced tubes, as reflected in the conversion life cycle cost below:

LIFE CYCLE COST

BASE SYSTEM (WELL WATER) $3,048,723
CONVERSION (COOLING TOWER) $2,728,128



Orr Schelen Mayeron & Associates, Inc.
Minneapolis, MN 55413
612-331-8660

MDNR
WATER
USE
STUDY

DRAWING TITLE

METHODIST
HOSPITAL

WELL WATER
SCHEMATIC

FIG 4.3

TABLE 17
Annual Operating Costs
Existing Well Water-Cooled Equipment

FACILITY	PUMPING COST	WATER TREATMENT COST	COMPRESS. ELECTRIC COST	MISC. ELECTRIC COST	TOTAL
GENERAL MILLS	$14,907	$15,800	$ 55,304	$ -0-	$ 86,011
GAVIIDAE COMMONS	12,838	12,000	17,854	-0-	42,692
HONEYWELL AVIONICS	31,123	22,856	162,767	26,124	242,870
METHODIST HOSPITAL	53,501	24,145	126,658	-0-	204,304

TABLE 18
Annual Operating Costs
Cooling Tower Conversion

FACILITY	PUMPING COST	WATER TRTMNT COST	CMPRESS ELEC COST	MISC ELEC COST	COOLNG TOWER ELEC COST	MAKE-UP WATER AND SEWER	TOTAL
GENERAL MILLS	$10,192	$4,318	$ 69,689	$ -0-	$ 3,859	$12,804	$100,862
GAVIIDAE COMMONS	$11,078	$2,493	$ 26,205	$ -0-	$ 1,458	$ 6,796	$ 48,030
HONEYWELL AVIONICS	$48,088	$6,959	$233,412	$49,282	$17,220	$32,261	$387,222
METHODIST HOSPITAL	$16,156	$5,245	$120,919	$ -0-	$ 4,948	$12,804	$160,072

TABLE 19
<u>Annual Operating Costs</u>
<u>District Cooling</u>

FACILITY	ANNUAL *		TOTAL
GAVIIDAE COMMONS	$81,000		$81,000

* Based on 360,000 annual TON-HOURS of cooling. Costs are not actual costs, rather they are relative costs for comparison with well water and cooling tower systems. The cost of maintenance, labor and capitol equipment has been excluded. Actual costs are $.3137/TON-HR.

TABLE 20
<u>Annual Operating Costs</u>
<u>District Heating</u>

FACILITY		ANNUAL STEAM	HEAT PUMP CREDIT*	TOTAL
GAVIIDAE COMMONS		$ 25,969	<$888>	$ 25,081

* Heat pumps provide additional capacity due to increased source water temps, compared with well water as a heat source.

TABLE 21
Life Cycle Cost Summary
Base Costs, Existing Operation, No Replacements
(20 Years, 8% Discount, No Salvage)
(5% Fuel Escalation, 4% Water Treatment Inflation)

FACILITY	PUMPING COST	WATER TREATMENT COST	COMPRESS. ELECTRIC COST	MISC. ELECTRIC COST	TOTAL
GENERAL MILLS	$224,738	$217,677	$ 833,763	$ -0-	$1,276,178
GAVIIDAE COMMONS	193,546	165,324	269,167	-0-	628,037
HONEYWELL AVIONICS	469,210	314,887	2,453,875	393,845	3,631,818
METHODIST HOSPITAL	806,581	332,646	1,909,496	-0-	3,048,723

TABLE 22
Life Cycle Cost Summary
Conversion to Air-Cooled Water Tower
(20 Years, 8% Discount, No Salvage)
(5% Fuel Escalation, 4% Water Treatment Inflation)

FACILITY	A/C EQUIPMENT FIRST COST	WATER TOWER FIRST COST	MISC CONSTR FIRST COST*	PUMPING COST	WATER TRTMNT COST	COMPR. ELEC COST
GENERAL MILLS	$ 715,942	$68,116	$ 715,942	$153,655	$59,489	$1,050,631
GAVIIDAE COMMONS	$ 84,000	$38,113	$ 209,838	$167,012	$34,346	$ 395,067
HONEYWELL AVIONICS	$1,316,000	$69,996	$1,993,024	$724,975	$95,874	$3,518,919
METHODIST HOSPITAL	$ 52,000	$68,116	$ 218,212	$243,568	$72,260	$1,822,975

TABLE 22 - CONTINUED

<u>Life Cycle Cost Summary</u>
<u>Conversion to Air-Cooled Water Tower</u>
(20 Years, 8% Discount, No Salvage)
(5% Fuel Escalation, 4% Water Treatment Inflation)

FACILITY	MISC ELECTRIC COST	COOLING TOWER ELECTRIC COST	MAKE-UP WATER & SEWER COST	TOTAL PRESENT WORTH
GENERAL MILLS	$ -0-	$ 58,178	$176,401	$ 2,998,354
GAVIIDAE COMMONS	$ -0-	$ 21,981	$ 93,628	$ 1,044,005
HONEYWELL AVIONICS	$ 742,975	$259,609	$444,460	$ 9,105,832
METHODIST HOSPITAL	$ -0-	$ 74,596	$176,401	$ 2,728,128

TABLE 23
<u>Life Cycle Cost Summary</u>
<u>Conversion to District Cooling</u>
(20 Years, 8% Discount, No Salvage)
(4% Purchased Chilled Water & Steam Inflation)
[Annual Chilled Water Costs: (.2250)$/TON-HR x 400 TONS x 900 FL HRS]
[Annual Steam Costs: $5.51/1000 LBS x 4.72 MMLBS]

FACILITY	HEAT EXCH FIRST COST	PIPING FIRST COST	CHILLED WATER COST	STEAM COST	TOTAL PRESENT WORTH
GAVIIDAE COMMONS	$26,700	$11,160	$1,115,937	$345,541	$ 1,499,338

III. DESIGN ALTERNATIVES TO "ONCE-THROUGH" WELL WATER USAGE

OVERVIEW

The concept of mechanical cooling operates on the principal of energy transfer from a heat source to a heat sink. The atmosphere, the ground, surface water or ground water are all valid heat sinks in the operation of mechanical cooling equipment. Re-stated another way, the environmental cooling of a space requires that there be a means of rejecting that heat. Ground water is one of those means. It can be circulated through a building directly or used to pick up heat from a refrigerant process.

Those applications which currently use ground water for cooling purposes could possibly convert those systems to open-loop water systems, such as conventional, air-cooled, cooling towers. They could also conceivably convert from well water to purchased municipal water, which is primarily surface-water sourced. Although technologies exist which utilize air-cooled equipment without open water loops, their electrical efficiency is much lower than water-cooled systems. These methods are, therefore, cost prohibitive for large systems (100 tons and above).

Of the air-cooled options, the most feasible two (2) are:

1) User owner-and-operated, open cooling towers, and
2) District cooling.

Open Cooling Towers. Inherent in the operation of mechanical cooling equipment is the generation of heat. The most efficient and effective method of rejecting that heat is with water-cooling of the equipment. The component which figures in the conversion from well water, but allows continued usage of water-cooled equipment, is the open, air-cooled, cooling tower. Cooling towers derive their primary cooling effect from the evaporation that takes place when air and water are brought into direct contact . They achieve this effect by exposing the maximum water surface to the maximum flow of air. This is accomplished by introducing a spray of water from the top of the tower. The downward flow of water droplets is countered by the upward flow of air, usually by propeller fans which induce the air draft up. The contact time of the falling water is increased by the introduction of "fill" (or slats) inside the tower which impedes the flow of the water droplets and increases their surface area by breaking them up.

The evaporation of water causes a steady increase in the concentration of total dissolved solids in the circulated water. Control of these undesirable solids in a cooling tower is by continual "blowdown" of a certain amount of water, which is made up with fresh water. Water "make-up" refers to the total amount of water required to make up for evaporative, drift, and blowdown losses. For a system operating at a 10-degree Fahrenheit range of water entering/leaving the cooling tower, and with blowdown requirements allowing a 3:1 ratio contaminant concentration of CIRCULATION water to MAKE-UP water, the percent of MAKE-UP water to CIRCULATION water may range anywhere from 1.22% to 5%. This water can be sourced from municipal water supplies or via well water, depending on the economics and availability.

District Cooling. The feasibility of alternatives available to the user must be analyzed on an individual basis. Downtown users in Minneapolis have an option for purchasing district chilled water which others do not. The development of a district cooling system in downtown St. Paul is under consideration at this time, based on District Energy St. Paul's estimate of twenty (20) potential users. The economics of such a system are currently unknown. By contrast, downtown users may not have the space or the roof structural integrity to accommodate a cooling tower, eliminating that option.

1 JOHN C. HENSLEY, ED., COOLING TOWER FUNDAMENTALS, MARLEY COOLING TOWER CO., MISSION, KANSAS, 1982.

The economic impact on the user for conversion from well water depends on the facility's design. New equipment or modification of existing equipment may be warranted in the conversion. Energy efficiencies and/or capacities may decrease. In isolated cases where outdated equipment is at the end of its service life, conversion affords the opportunity to upgrade this equipment. The analysis of Methodist Hospital in the previous section illustrates an example of improved electrical efficiency even at the higher condenser water temperatures of the conversion. Structural design loads of the roof must be considered for roof-mounted cooling towers.

The ramifications which reach beyond the individual user are the added electrical requirements and environmental costs. Electrical utility suppliers may have an added load, due to the increased electrical consumption. This will have an environmental impact as these utilities consume more natural gas, generate more nuclear energy or burn more coal.

The conversion from well-water-based environmental heating/cooling systems to alternative approaches mandates analyses on an individual basis. Generalizations of alternatives or costs are difficult to ascertain. The ramifications for electrical utility suppliers and the environmental impacts of conversion may warrant further investigation.

METHODS & MEASURES OF SYSTEM PERFORMANCE AND IMPROVEMENT FOR "ONCE-THROUGH" APPLICATIONS

An analysis of the efficient utilization of Minnesota's well water resources for "once-through" environmental heating/cooling requires that measures be developed by which designs can be compared. An appropriate "yardstick" for the efficient use of such water would relate water usage efficiency with electrical efficiency. A system that is highly efficient in electrical usage may not be efficient in terms of the water consumed. An approach which balances the two efficiencies (i.e., judges their relative value and improtances) is desired.

When water efficiency (described in GPM/TON) is plotted against electrical efficiency (described in KW/TON), clear trends appear in the resulting graph. Systems which are efficient on both scales reside within an "envelope" of efficient usage, as illustrated by the shaded area of Figure 5.0. The placement of the "Envelope of Allowable Well Water Usage" may be conducted on the basis of the perceived importance of the two (2) variables.

The advantages of such a measure are two-fold:

1) The proposed "envelope" allows for a method by which the relevant importance of water efficiency versus electrical efficiency may be weighed; and

2) The values for the units of measure are readily obtainable.

The units of measure would be obtained based on the following criteria:

TON: Peak Day Load Cooling Capacity (in Tons) for the System; where Tons = 12,000 BTU/HR. This would be Peak Day Load Tons, not Installed Tons, and would include well water coil capacity.

GPM: Gallons Per Minute; The design GPM of well water required by the System to achieve the Peak Day Load described above. For cooling towers utilizing well water, this would be the make-up GPM of well water.

KW: The KW input required by the System to achieve the Peak Day Load described above. This would be the KW which is sensitive to water temperature or water volume (i.e., well water pumps, condenser water pumps, tower fans, and compressorized equipment). Compressorized equipment would include chillers, heat pumps, condensing units, packaged cooling units, etc. Excluded from the KW value would be chilled water pumps, air handler motors, and any other KW inputs which are not sensitive to well water usage.

The equation for water which relates capacity (BTUH) to GPM and temperature difference is:

$$\text{BTU/H} = 500 \times \text{GPM} \times \text{TD}$$

or, restated:

$$\text{TONS} = \frac{\text{GPM} \times \text{TD}}{24}$$

Hence, a System which culls a high temperature difference from the water results in a low GPM for the same capacity. The well water temperature difference imparted by the System is, thereby, reflected in the unit "GPM/TON".

The unit of measure "KW/TON" describes the electrical efficiency of the System. This can be related to electrical cost by multiplying by the user's local $/KW charge. Usage of KW/TON allows users to be compared based on their electrical efficiency and to be compared on an equitable basis, without regard to the local utility's rates.

TABLE 24:
DETERMINATION OF ELECTRIC AND WATER USAGE
EFFICIENCIES FOR SEVEN COMMON HVAC SYSTEMS

SYSTEM DESCRIPTION

A CHILLED WATER
50 DEG WELL WATER ENTERING EVAPORATOR AND LEAVING AT 45 DEG, THEN FLOWING THROUGH SYSTEM LOAD AND DISCHARGING TO STORM AT 55 DEG.
(NOT USED IN FOUR FACILITIES; FOR EXAMPLE ONLY.)

B HEAT PUMP
50 DEG WELL WATER ACTS AS HEAT SINK FOR HEAT PUMP WHICH DISCHARGES TO STORM AT 85 DEG.

C CONDENSER
50 DEG WELL WATER ENTERING CONDENSER AND DISCHARGING TO STORM AT 80 DEG.

D COOLING COILS
50 DEG WELL WATER ENTERING COOLING COILS AND DISCHARGING TO STORM AT 60 DEG.

E EVAPORATOR TO CHILLED WATER COILS TO CONDENSER
50 DEG WELL WATER ENTERING EVAPORATOR AND LEAVING AT 45 DEG, THEN FLOWING THROUGH COOLING COILS AND LEAVING AT 55 DEG., THEN FLOWING TO CONDENSER AND DISCHARGING TO STORM AT 67.5 DEG.

F COOLING TOWER
50 DEG WELL WATER ENTERING COOLING TOWER AS MAKEUP WATER.

G COOLING COILS TO CONDENSER
50 DEG WELL WATER ENTERING COOLING COILS AND LEAVING AT 60 DEG., THEN FLOWING TO CONDENSER AND DISCHARGING TO STORM AT 85 DEG.

* *

-----> COST FACTOR: $0.045 / KW <-----

SYSTEM	TONS	D.T.	GPM	KW	ELEC COST	GPM/TON	KW/TON
A	100	10.0	240	51.5	$2.32	2.40000	0.51500
B	100	35.0	86	108.6	$4.89	0.85714	1.08640
C	100	30.0	100	45.2	$2.04	1.00000	0.45240
D	100	10.0	240	10.5	$0.47	2.40000	0.10500
E	100	17.5	240	42.5	$1.91	2.40000	0.42500
F	100	10.0	15	82.0	$3.69	0.15000	0.82000
G	150	35.0	120	54.9	$2.47	0.80000	0.36593

NOTE: THESE COSTS DO NOT INCLUDE WATER TREATMENT AND MAKE-UP WATER COSTS, SYSTEM EFFICIENCY LOSSES, ETC., BUT ARE ONLY EXAMPLES OF AFFECT OF WELL-WATER USAGE.

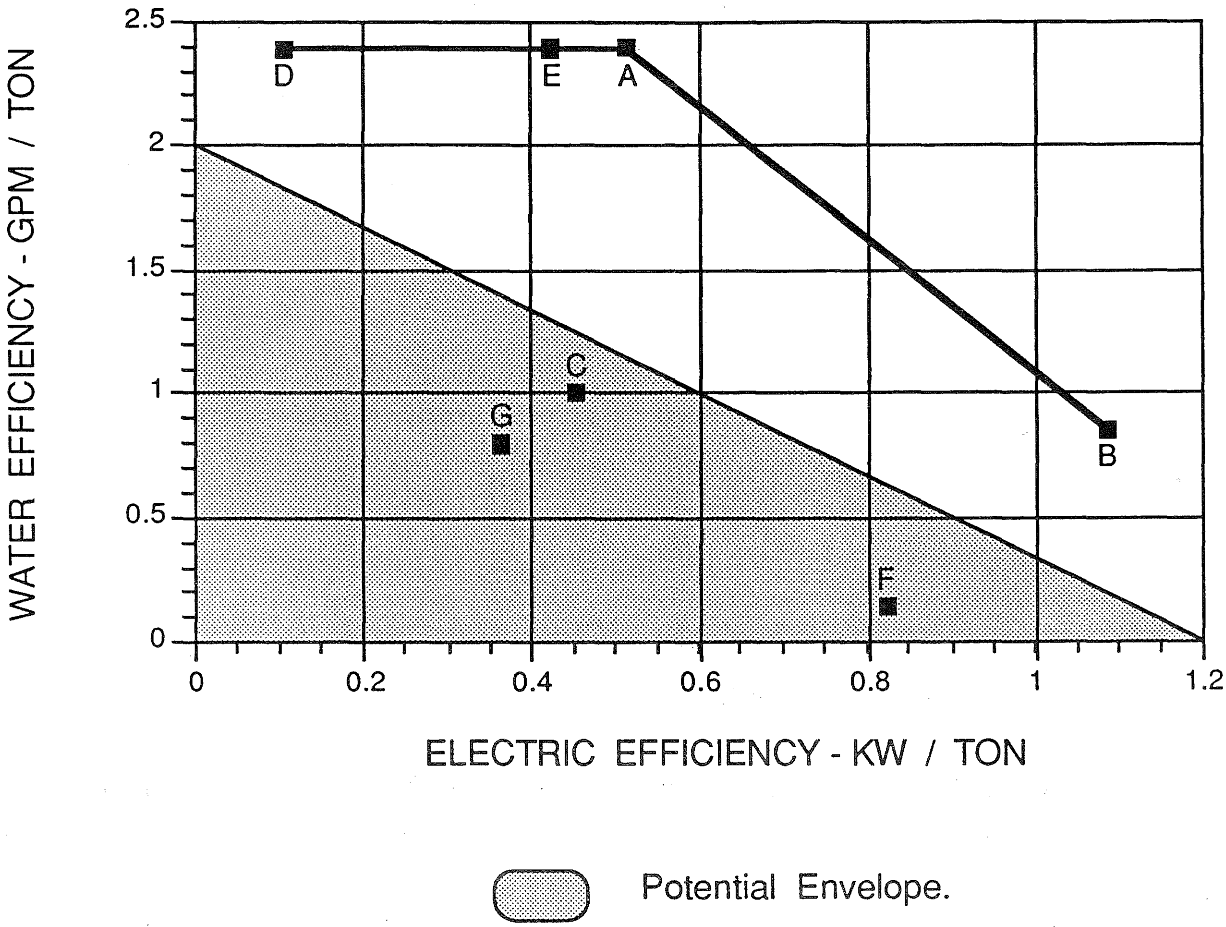


FIGURE 5.0

PROPOSED ENVELOPE METHOD OF
ALLOWABLE WELL WATER USE MEASURE

The systems described in Table 24 provide the basis for comparison of relative efficiencies. They are, however, "pure" systems; whereas, in practice, a combination of approaches may be employed. Analyses of the actual permits issued in the State reveal the following number of permittees whose use adheres to the criteria established in the examples:

TABLE 25
Comparison With (7) Typical Systems

SYSTEM	# OF ACTUAL PERMITTEES
A	0
B	8
C	37
D	16
E	14
G	17

The standard, as proposed in this Section, would be applied based on cooling design capacities only.

A strategy which can serve to increase the water use efficiency of the system is the use of variable volume pumping. The principle thrust in the utilization of variable speed/variable volume pumping is the potential for water and energy savings. A variable volume pumping design requires that there be two-way modulating valves downstream of the pump which automatically apportion the water to the coils or vessels in accordance with their heating or cooling needs. Hence, the user only pumps that quantity of water which the system calls for, achieving a savings in electrical KW consumed and in total gallons per year pumped.

A variation on the use of variable volume pumps is the utilization of constant volume pumps in concert with two-way modulating valves at the coils and vessels as described above. As the valves close, the capacity requirement decreases. Proper care must be taken in the selection and application of constant volume pumps on such a system. The pump curve is described by Total Head (feet) versus Capacity (GPM) and should be "flat" (i.e., allowing larger changes in capacity for a smaller change in head). Flat curve pumps offer a more stable pressure drop ratio as valves close, thereby providing better valve control. The advantage of this type of control is that, as the pump "rides its pump curve", the horsepower requirements change. Thus, an electrical energy savings is achieved as the horsepower decreases. Total pump volume (GPM) likewise decreases as the horsepower decreases, achieving a savings in total gallons per year pumped.

Proper maintenance of the components will promote water efficiency by ensuring that all elements of the system are in good working condition. For example, two-way valves must close properly and cooling tower floats must operate freely. The metering of water use will elevate the importance of the operation and maintenance of the system components and provide a means to measure their condition and effectiveness.

FEASIBILITY AND IMPACT OF CONVERSIONS

Capacity

Water sourced from underground aquifers is typically 50 - 55 degrees Fahrenheit. By contrast, water sourced from open air-cooled towers typically leaves the tower at 85 degrees Fahrenheit. When the cooling water temperature of compressorized mechanical cooling equipment changes from the 50-degree Fahrenheit range to the 85-degree Fahrenheit range, the capacity of the compressors decreases by approximately 10%. This is due to the change in the condensing temperature of the equipment at the higher condenser cooling temperatures, and the resultant decrease in capacity on the "Unit versus Condensing Temperature" curve. The compressors are less efficient at the higher condensing temperatures (i.e., they require more electrical energy input for the same output). However, this effect is mitigated by the fact that the temperature of the cooling water leaving the tower "floats" and can be as low as 60 to 70 degrees Fahrenheit, depending on atmospheric conditions. The efficiency of smaller equipment is measured by its Energy Efficiency Ratio (EER), which is expressed in BTUH/(Output) per Watt (Input). The water source heat pumps used in Gaviidae Commons experience the following cooling EER's at two (2) different source temperatures:

TABLE 26
Water Source Heat Pump EER's

CAPACITY (TONS)	EER @ 70/85 DEG. F. (EWT/LWT)	EER @ 85/95 DEG. F. (EWT/LWT)
1	11.9	11.0
2	12.6	11.7
3	12.3	11.3
4	12.0	11.0
5	12.1	11.2

The electrical efficiency of large equipment is often measured by KW (Input) versus capacity (output) and is expressed in KW/TON. A comparison of reciprocating water chillers at two (2) condenser water temperature levels reveals the following:

TABLE 27
Reciprocating Water Chiller (KW/TON)

50/78 EWT/LWT			85/95 EWT/LWT		
TONS	KW	KW/TON	TONS	KW	KW/TON
16.8	12.5	.744	15.9	13.4	.843
72.3	56.8	.786	68.1	61.5	.903
101.6	80.4	.791	96.7	86.2	.891
136.8	116.8	.853	129.1	125.6	.973

Note: This is catalogued data of a leading manufacturer at 44 degrees Fahrenheit leaving chilled water temperature.

Centrifugal chillers and centrifugal heat pumps experience particular problems when the condenser water temperature is changed. The components of these machines are computer-selected to derive specific performance objectives, based on selected operating conditions. While centrifugal compressor machines are capable of high efficiencies, changes to the condensing water temperature create conditions under which the machine either cannot function or functions at a lower electrical efficiency. A higher condenser water temperature requires a higher refrigerant condensing temperature. Concomitant with a higher condensing temperature is a higher pressure. In order to achieve this, a higher impeller tip speed is required. Based on the design principles of the Manufacturer, a larger impeller diameter or higher speed gear is employed.

These components are machined to very close tolerances and are, therefore, expensive. Quite often condenser vessels must also be changed to accommodate the higher water volume (GPM) of the 85/95 degree Fahrenheit condenser water temperature. The change in condenser vessels can, however, produce a dramatic improvement in system performance if old "smooth tube" designs are replaced with "enhanced fin" designs, as witnessed in the Methodist Hospital scenario discussed in Section II. The age of such equipment is also a factor. Machines that are old enough to have "smooth tube" designs may be near the end of their service life and the entire machine would be replaced with a more electrically-efficient machine. Conversion to a cooling tower system affords the opportunity to upgrade the system. Examples of capacity and electrical efficiency for centrifugal chillers at different condensing temperatures are shown below:

TABLE 28

CENTRIFUGAL CHILLERS (KW/TON)

MACHINE	APPROX. 50/75 DEG. F. EWT/LWT		APPROX. 85/95 DEG. F. EWT/LWT	
	Tons	KW/Ton	Tons	KW/Ton
A	360	.493	319	.603
B	300	.413	292	.644
C	500	.382	447	.615
D	263	.414	263	.673

Facilities which currently utilize well water for circulation through cooling coils would have to convert to chilled water, or DX refrigeration systems. In facilities with reserve capacities of compressorized equipment, the increased operating levels would be called upon to provide the load previously satisfied by the well water coils. If reserve capacities of existing chillers were not available, addditional water chillers or replacement equipment with greater capacities would be required.

Space and Structural Limitations

The space and structural ramifications for the installation of new cooling towers would be different for each specific facility. Cooling towers can be either roof-mounted or slab-mounted at grade. Downtown facilities must usually consider the roof-mounted option. Permittees in downtown St. Paul must embrace this alternative since there currently is no district cooling facility for this area. Roof-mounted equipment not only requires consideration of space, but also consideration of the structural design of the roof. Roof designs that did not anticipate large mechanical equipment in their original design may have been calculated for snow loads only. The design and construction costs for structural re-design would have to be weighed on an individual basis. Those users which utilize large tanks on the roof in their well water designs may, by contrast, experience no structural problems in conversion when those tanks are removed and replaced by cooling towers.

Environmental Concerns

The environmental impact of the conversion from well water to cooling tower water is difficult to ascertain. Environmental concerns derive from the operation of open cooling towers and the increased emissions by the utility company, resulting from the increased KW required.

The impact in terms of utility-derived emissions depends on the estimates of additional wattage that the electrical facility will be required to generate. Estimates range from 5 to 15 MW, additional capacity required. NSP estimates a cost of $2.68 million to construct a 5 MW, gas-fired plant and $6.975 million to construct a 5 MW, coal-fired plant. Emission rate estimates for a coal-fired plant, based on data from NSP and assuming 5 MW annual additional demand, are shown on the following page.

TABLE 29

COAL-FIRED ANNUAL ADDITIONAL EMISSION RATES

SO :	58,867	LBS/YR
NO :	44,150	LBS/YR
PARTICULATES:	2,453	LBS/YR
CO :	3.087 x 10	LBS/YR
THERMAL EFFECTS:	2.87 x 10	BTU TO AIR & WATER/YR

Note that the figures above relate to a 5 MW demand. The range of 5 to 15 MW additional capacity is based on a "worst-case" scenario, wherein all well water systems are converted to alternate technologies. The "Geothermal Survey" data reveals that the "worst-case" scenario results in a 7.33 MW demand, as shown on the following page. Policies which encourage modifications of some well water designs to improve water efficiency would mitigate this effect.

Environmental impacts from the operation of open cooling towers are both technical and aesthetic in nature. The use of cooling tower technologies shifts the medium of heat rejection from water systems to air. Aesthetic concerns relate to the evaporative water loss which may produce a large vapor plume. Open cooling towers produce airborne noise, which may pose design or location problems. A further concern may be the addition of refrigerating machines, as required, to replace the capacity lost from existing systems. These new machines may potentially contribute to the earth's ozone layer depletion resulting from the chlorofluorocarbons used in their design, depending on the refrigerant of the replacement machine.

ECONOMIC IMPACT AND MGY SAVED

The Geothermal survey database was manipulated to investigate the total capacity and total MGY (1987 reported MGY) for each of the categories studied. Estimates of the economic impact for conversion from well water to alternate systems were thereby conducted. The capacity used herein is subject to the accuracy of the input data and is illustrated below:

TABLE 30
Economic Impact and MGY Saved

SYSTEMS ELIMINATED	TONS	KW/TON	INCREASED KW	MGY SAVED	CONVERSION COST	CONVERSION $ PER MGY
TOTAL BAN	47,304	.6	7333	11,158	$70,956,000	6539
CONDENSER	21,778	.45	1960	4,017	$32,667,000	8132
CHILLER	10,500	.43	903	2,001	$15,750,000	7871
COILS	9,143	.11	3565	3,399	$13,714,500	4035
HEAT PUMPS	3,953	1.09	862	1,491	$ 5,929,500	3977

Notes:
- Total Ban KW increase based on the sum of: [TONS x KW/TON x Increased KW Factor] for each respective category
- Increased KW based on TONS x KW/TON x .20 increased KW
- MGY is 1987 reported MGY
- Conversion cost is based on $1500/TON installed cost rule-of-thumb for new systems
- Increased KW for coils is based on (.5-.11) = .39 KW/TON increase

Results indicate that the elimination of Cooling Coil Systems and Heat Pumps Systems have the lowest impact in terms of Conversion Cost per Million Gallons of water saved. The concept of an "envelope of allowable well water use", as proposed in "Methods and Measures", indicates that these are the Systems most likely to be excluded under that scenario.

Analysis of the electrical impact of conversion reveals that the elimination of Cold Water Coil Systems may result in an additional 3.56 megawatts of local utility capacity. This is due to the inherent electrical efficiencies of their existing operation, as all they currently pay for is pumping KW in order to achieve environmental cooling. These systems, which operate at approximately .11 KW/TON, would have to be replaced with systems which require mechanical cooling at .50 KW/TON.

Further investigation reveals that a total ban of all well water-based systems may require an additional 7.3 megawatts of electricity generation over current electrical consumption.

Recommended Time Frame

A recommended time frame for the conversion of well water-based systems to more water-efficient systems might be tied to the estimated remaining life cycle of the system, or components thereof. If a total conversion of all systems is desired by a certain date, this could be accomplished with the introduction of the following requirements:

a) Twenty (20) years as a final date for the conversion of all systems from well water. This would see the current systems through the Year 2010.

b) New or ammended permits would be required, as part of their application, to provide estimates of remaining life cycles of their equipment.

c) The permits would be in effect through the life of the equipment, at which time conversion would be required.

This approach would provide existing Permitees time to assess the latest developments and state-of-the-art technologies in the chlorofluorocarbon (CFC) debate. Such an incremental approach would allow users the opportunity to coordinate their purchases with the develpment of less ozone-depleting refrigerants. Local electrical utilities could likewise approach any increased KW demand in an incremental fashion.

WATER EFFICIENCY COMPARISONS

As discussed in the "Methods and Measures" Section of this Report, the System GPM/TON (as measured on a Peak Design Load basis) provides a means of comparing water efficiencies.

Table 31 compares the GPM/TON for existing well water-based systems with systems converted to cooling towers:

TABLE 31
Water Efficiency Comparisons - Four (4) Facilities

WELL WATER				COOLING TOWER			
FACILITY	GPM	TONS	GPM/TON	FACILITY	GPM*	TONS	GPM/TON
General Mills	2925	1284	2.28	General Mills	58.0	1284	.045
Gaviidae Commons	2740	912	3.00	Gaviidae Commons	36.5	912	.040
Honeywell Avionics	1797	1507	1.19	Honeywell Avionics	61.0	1350	.045
Methodist Hospital	3412	1147	2.97	Methodist Hospital	51.8	1147	.045

* COOLING TOWER MAKE-UP WATER GPM

Note that the make-up water rates above represent estimates of actual field conditions using a Betz Company cooling water calculator. The resulting "water efficiency" of a cooling tower is approximatley 1.5% make-up water as a percent of total water circulated. Another industry manual estimates the make-up water requirements of a cooling tower with a 10-degree Fahrenheit range to be 1.22%. No other system which utilizes open water loops can achieve such water efficiencies.

Table 32 compares the water efficiencies based on GPM/TON for the seven (7) hypothetical systems shown in Figure 5.0 of the "Methods and Measures" Section.

TABLE 32
Water Efficiency Comparisons - Seven (7) Common Systems

SYSTEM	WELLWATER USE	GPM	TON	GPM/TON
A	EVAPORATOR SIDE	240	100	2.40
B	HEAT PUMP	86	100	.86
C	CONDENSER SIDE	100	100	1.00
D	COLD WATER COILS	240	100	2.40
E	EVAP. TO CW COILS TO COND.	240	100	2.40
F	COOLING TOWER	15	100	.15
G	CW COILS TO CONDENSER	120	150	.80

Note that the cooling tower GPM/TON is considerably lower than the GPM/TON for the other systems. Advisory Group statements of an estimated 5% make-up water requirement were used in the calculations. This represents a maximum value of make-up that may be expected.

Table 32 above reveals a particular operating phenomenon that systems utilizing water on the evaporator side of a chiller (such as Systems "A" and "E") require the same GPM as System "D". The operating conditions of the cooling coils in the building determine this GPM. The assumption in all cases was a 10-degree Fahrenheit water temperature difference at the cooling coil. In the case of System "D", the water temperatures are 50/60 degrees Fahrenheit (entering/leaving). If the building does not require a large amount of dehumidification, or if dehumidification is handled by other systems, the same 60-degree Fahrenheit leaving water temperature can be employed in Systems "A" and "E"; thus, achieving a 15-degree Fahrenheit temperature difference and a resultant 1.6 GPM/TON. The ability to rebalance a System to these conditions in order to conserve water must be investigated on an individual basis.

A further analysis reveals that the System which may be the most water-efficient (and electrically-efficient) is one which uses well water through cooling coils (first) and through condenser coils (second). The temperature differences associated with this design are 10 degrees Fahrenheit across the coils and 25 degrees Fahrenheit across the condenser. The condenser dictates the GPM, not the building coils. For a 100-ton chiller, the condenser requires 120 GPM of well water. The well water coils receive 50 tons of cooling effect from the 120 GPM of well water. A separate chilled water loop delivers 100 tons of cooling. The design provides both airside pre-cooling and chilled water for dehumidification. By reducing the coil GPM and utilizing the high temperature difference across the condenser, a total system capacity of 150 tons is obtained at a water usage rate of 0.80 GPM/TON.

OPERATING COST COMPARISONS

Well Water versus Municipal "Surface" Water

There are currently no restrictions on the utilization of large volumes of municipal water. Hence, any well water permittee is free to substitute municipal water for well water in their systems. The water rates for the cities of Minneapolis and St. Paul (as of December, 1989) are:

MINNEAPOLIS	$ .85/750 GALLONS =	$1.133/1000 GALLONS
ST. PAUL	FIRST 37,400 GALLONS =	$1.20 /1000 GALLONS
	NEXT 336,600 GALLONS =	1.173/1000 GALLONS
	OVER 374,000 GALLONS =	1.146/1000 GALLONS

The figures below are for existing well water designs, without conversion to alternate systems. When municipal water is substituted for well water (in the four (4) facilities analyzed in Section II), the annual operating cost ratio comparisons, based on an average $1.14/1000 Gallons for City water, are:

TABLE 33

FACILITY	WELL WATER OPERATION ($/TON-HR)	MUNICIPAL WATER OPERATION ($/TON-HR)*	MGY
General Mills	.0340	.1413	238.0
Gaviidae Commons	.0619	.9313	525.6
Honeywell Avionics	.0283	.0742	346.3
Methodist Hospital	.0542	.1213	222.0

<u>Note</u>: * Annual cost increases due to decreased equipment efficiencies are not included.

The use of municipal water as a replacement for well water in existing well water designs would not be economically feasible for the users examined above.

Well Water versus Air-Cooled Towers

The annual operating cost ratios of well water versus air-cooled cooling towers are:

TABLE 34

FACILITY	WELL WATER OPERATION ($/TON-HR)	COOLING TOWER OPERATION ($/TON-HR) CITY WATER*	COOLING TOWER OPERATION ($/TON-HR) WELL WATER**
General Mills	.0340	.0428	.0394
Gaviidae Commons	.0619	.0697	.0631
Honeywell Avionics	.0283	.0451	.0427
Methodist Hospital	.0542	.0425	.0403

* Operating Costs for Cooling Tower Operation assume a total conversion from Well Water supply to City Water supply for make-up requirements.

** Operating Costs for Cooling Tower Operation assume that Well Water is available as a make-up source. Well Water fees of $.05/1000-Gallon is also assumed.

Well Water versus District Cooling

The annual operating cost ratios of well water versus district cooling (purchased chilled water only) are:

TABLE 35

FACILITY	WELL WATER OPERATION ($/TON-HR)	DISTRICT COOLING OPERATION ($/TON-HR)
Gaviidae Commons	.0619	.2250

* Annual TON-HOURS are estimated to be 360,000 with District Cooling, thereby reducing annual costs as chilled water is purchased to meet actual daily requirements.

FEE STRUCTURES

A water fee is desired that will make well water systems and conversion systems equal in cost. In the analysis that follows, the conversion system to which other systems will be compared shall be an air-cooled, open-cooling tower.

Two (2) costs shall be assessed to each systm:

a) Electric Operating Cost, and
b) Water Usage Cost

Hence, a water fee is desired such that the following equation can be satisfied:

$$\text{ELEC. COST} + \text{WATER COST} = \text{FIXED COST} \qquad \text{EQUATION NUMBER } 1.0$$

where; FIXED COST is the desired base cost to which other systems will be compared.

When each cost is divided by "TONS" (i.e., costs are analyzed on a "per ton" basis), the equation becomes:

$$\text{ELEC}\left[\frac{\$}{\text{TON}}\right] + \text{WATER}\left[\frac{\$}{\text{GAL}} \times \frac{\text{GAL}}{\text{TON}}\right] = \text{FIXED}\left[\frac{\$}{\text{TON}}\right] \qquad \text{EQUATION NUMBER } 2.0$$

Earlier in this Study, the concept of an "envelope" of allowable usage was proposed. This "envelope" was based on seven (7) typical systems, of which cooling towers was one. We shall re-introduce those systems and tabulate their $/TON electric costs and their GAL/TON usage on the following pages.

TABLE 36

"$/TON" AND "GAL/TON" FOR SEVEN SYSTEMS

SYSTEM	DESCRIPTION	$/TON (ELECTRIC)	GAL/TON
A	CHILLED WATER	.0232	144
B	HEAT PUMP	.0489	51.6
C	CONDENSER	.0204	60
D	COOLING COILS	.0047	144
E	EVAP. TO COILS TO COND.	.0191	144
F	COOLING TOWER	.0369	9
G	COILS TO CONDENSER	.0247	48

Equation 2.0 was used to calculate the required $/GAL that makes each of the above systems equal to the cooling tower operation cost of $.0369/TON:

TABLE 37

"$/1000-GAL" - FEE THAT EQUATES WELL SYSTEMS TO COOLING TOWERS

SYSTEM	$/GAL	$/1000-GAL
A	.000095	.095
B	Negative Fee	Negative Fee
C	.000275	.275
D	.0002236	.224
E	.0001236	.124
F	-0	-0-
G	.000254	.254

Tables 38 and 39 illustrate the effect of the State's existing water fee structure on the above systems:

TABLE 38

EFFECT OF WATER FEES AT $.05/1000-GALLON

SYSTEM	[ELECTRIC $/TON] +	[WATER GAL/TON] x	[FEE $/GAL]	= TOTAL $/TON
A	.0232	144.0	.00005	.0304
B	.0489	51.6	.00005	.0515
C	.0204	60.0	.00005	.0234
D	.0047	144.0	.00005	.0119
E	.0191	144.0	.00005	.0263
F	.0369	9.0	.00005	.0374
G	.0247	48.0	.00005	.0271

TABLE 39

EFFECT OF WATER FEES AT $.10 AND $.15/1000-GALLON

SYSTEM	TOTAL @ $.10/1000-GAL	TOTAL @ $.15/1000-GAL	RELATION TO F
A	.0376	.0448	EXCEEDS
B	.0541	.0566	EXCEEDS
C	.0264	.0294	LESS
D	.0191	.0263	LESS
E	.0335	.0407	APPROX. EQUAL
F	.0378	.0383	---
G	.0295	.0319	LESS

Conclusion

Fee structures can be proposed that will provide economic incentives for a user to convert from a well water system to an open cooling tower system. The following synopsis illustrates the water fees required to make comparative systems equal in operating costs to cooling towers:

TABLE 40

FEE SYNOPSIS

SYSTEM	DESCRIPTION	FEE REQUIRED ($/1000-GAL)
A	Chilled Water	.095
B	Heat Pump	NONE
C	Condenser	.275
D	Cooling Coils	.224
E	Evap. to Coils to Cond.	.124
(F)	Cooling Tower	----
G	Coils to Condenser	.254

At a fee of 15¢/1000-GAL, Systems "C" and "G" continue to be less expensive to operate than cooling towers. These systems also fall within the proposed "envelope" of allowable well water usage, as proposed previously in this Study.

At a fee of 10¢ to 12¢/1000-GAL, System "E" is also less expensive to operate than cooling towers and could fall within the allowable "envelope" if the line were raised to include it.

In each of the above examples (15¢ and 12¢/1000-GAL), cooling coils would also be less expensive to operate. A ban would be required to exclude them from operation.

APPENDIX TABLE OF CONTENTS *

* **COPIES AVAILABLE UPON REQUEST**