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ORNL/TM-6830/P10
Vol. II

District Heating/Cogeneration Application Studies for the Minneapolis–St. Paul Area

St. Paul District Heating System
Conceptual Design Study and Report
Appendix C of
Market Assessment and Economic Analysis
of the St. Paul District Heating
Demonstration Project

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A08 Microfiche A01

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ORNL/TM-6830/P10
Vol. II

Contract No. W-7405-eng-26

ENGINEERING TECHNOLOGY DIVISION
ENERGY DIVISION

ST. PAUL DISTRICT HEATING SYSTEM CONCEPTUAL DESIGN STUDY AND REPORT APPENDIX C OF MARKET ASSESSMENT AND ECONOMIC ANALYSIS OF THE ST. PAUL DISTRICT HEATING DEMONSTRATION PROJECT*

Prepared for the
ST. PAUL DISTRICT HEATING DEVELOPMENT COMPANY

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Date Completed: November 1980

Date Published: January 1982

*Research sponsored by the Division of Utility Coordination and the Division of Buildings and Community Systems, Department of Energy

Research performed under Subcontract No. 7794 with the St. Paul District Heating Development Co., Inc.

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operated by
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for the
DEPARTMENT OF ENERGY

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FOREWORD

This report is one of a series of application studies of district heating/cogeneration for a U.S. metropolitan area. The technical, economic, environmental, and institutional studies in this series established the general feasibility and desirability of a hot water, district heating system using cogenerated thermal energy from utility power plants. St. Paul, Minnesota is proposing to replace a steam district heating system that serves its central business district with a modern hot water district heating system. The St. Paul District Heating Development Company was established to develop an implementation plan for an economically feasible system.

The St. Paul District Heating Development Company, Inc., has been funded by the Department of Energy, the State of Minnesota, the City of St. Paul, and the Northern States Power Company. The Oak Ridge National Laboratory has provided technical management for the Department of Energy as a part of the overall Twin Cities District Heating Application Studies.

PREFACE

The report presented herein describes the results of a conceptual design and feasibility study for a 270 MW hot water district heating system in downtown St. Paul and nearby Capitol Complex. The study was conducted for the St. Paul District Heating Development Company (DHDC) and the report has been prepared primarily for use by the DHDC.

The general areas to be served by the district heating system were specified by the DHDC. The DHDC also provided the Study Team with detailed building heating load data. These data were used by the Study Team in the process of laying out the transmission and distribution network. An effort was also made to identify likely future heating loads. Where such loads could be identified provisions were made for their addition to the system.

Existing thermal sources were also analyzed -- three of them in considerable detail -- to determine their suitability as district heating thermal sources.

In reading this report it should be remembered that, unlike other large projects such as power plants and oil refineries, a district heating system is never "completed". It must be designed to allow for growth and change. Moreover, it is unrealistic to expect such a system -- vulnerable as it is to outside forces and pressures -- to be built exactly as it is originally designed. This fact requires the designer to consider carefully the long-term and to allow for adequate flexibility in the system's design.

The study was conducted by three engineering firms -- KVB, Metcalf & Eddy, and Fjärrvärmebyrån ab -- under the general direction of KVB. It is a good study and we are pleased to submit it to the DHDC for their review and approval.

Dr. Michael H. Barnes

Michael H Barnes

ABSTRACT

The goals of the St. Paul District Heating Demonstration Project are (1) to assess the detailed economic feasibility of a hot water, cogeneration district heating system serving the central business district of St. Paul, Minnesota, and (2) to develop an implementation plan for financing and construction of the first phase of the system over a four-five year time span. This demonstration is being conducted by the St. Paul District Heating Development Co., Inc (DHDC) and is intended to be the nucleus for a large scale district heating system serving the Twin Cities metropolitan area.

This report presents the results of a conceptual design for a 270 MW(t) hot water district heating system serving the central business district of St. Paul and the nearby State Capitol Complex. The system design is based on extensive European hot water design and operating experience provided through the Swedish engineering firm, Fjarrvarmebyran ab. The approach was integrated with U.S. design practices by Metcalf & Eddy, Inc., of Boston, Massachusetts, who also performed the geotechnical analysis of the market area. Conceptual design of existing boiler plants in the area as heat sources plus overall study management was performed by KVB, Inc., of Minneapolis, Minnesota.

The base heat source for the system is the Northern States Power Co. (NSP) High Bridge Power Plant which has three turbines that can be retrofitted to either extraction or back-pressure cogeneration operation. Hot water at 250°F (121°C), produced in steam-to-water heat exchangers, is transported to the St. Paul central business district 0.8 miles (1.3 km) away. This conceptual design includes the supply-and-return transmission

lines from the High Bridge Plant but does not include the design and cost of piping, heat exchangers, pumps, and controls for retrofitting the High Bridge Plant to cogeneration operation.

The system design and construction costs developed in this study are based on the geotechnical analysis of the market area, piping design criteria including code requirements, and piping installation procedures that maximize system reliability and maintainability. The construction cost is developed for a four-five year construction phase based on analyses of the market by the St. Paul DHDC. The total construction cost for the hot water transmission and distribution system in mid-1980 (ENR index = 3200) prices is $29,000,000 including engineering and contingencies. Plant modifications to three power plants for system peaking and reserve requirements are estimated at $4,009,500.

EXECUTIVE SUMMARY

Chapter One
Introduction

Chapter One
Introduction

General

This report presents the engineering data necessary to estimate the overall cost of a 270 MW thermal hot water district heating system in downtown St. Paul and nearby Capitol Complex area. The report delineates the proposed service area for the system, taking into account the need for service reliability and the probable need for future expansion. The system design study identifies pipeline routes and provides pipe specifications and standards. The report also discusses various construction and pipe installation techniques based on investigations of subsurface conditions in the proposed service area. As part of the system design study, an analysis of potential heat sources was also carried out. Preliminary drawings of typical sections of the system are presented herein. The implementation costs for the complete system are estimated on a quarter-by-quarter basis, corresponding to the implementation schedule.

Purpose:

To develop a conceptual design for a hot water district heating system for downtown St. Paul and nearby Capitol Complex incorporating proven European hot water district heating principles and experience.

Objectives:

1. To develop a conceptual system design that minimizes construction costs while assuring a high degree of system reliability and flexibility.

2. To develop a system implementation schedule that will provide sufficient revenue return on invested capital during the system's development.

3. To prepare cost estimates and an expenditure schedule suitable for inclusion in an underwriter's bond prospectus.

4. To develop a conceptual design of the distribution system in sufficient detail to serve as a basis for the preparation of detailed engineering design and construction bid specifications at a later date.

Chapter Two
Study Design, Conclusions & Recommendations

Chapter Two
Study Design, Conclusions & Recommendations

Study Design

A hot water district heating distribution network is quite simple in theory. The network is essentially a large loop: hot water is pumped out of the plant on one side of the loop and is returned on the other. Customers take the hot water, pass it through heat exchangers located on their premises, and return it to the opposite side of the loop. The system may be compared to the circulatory system of the human body. Like the body, the largest diameter outflow and return conduits are located nearest to the pump; there are principal conduits going to, and returning from, all of the major areas served; the system is closed (that is, the same fluid is constantly being recirculated); there are small conduits serving each user; and the conduits get smaller the farther one is away from the pump.

Prior to evaluating alternative configurations for the St. Paul district heating system, the Study Team established certain guidelines to be used in the evaluation. To a large extent these guidelines were based on Swedish experience and practice, but in effect the guidelines are not unlike those that might be applied to any mechanical system.

A district heating system must be designed to deliver hot water to its customers even under the most adverse conditions, and if sections must be shut down for repair, those sections should be short and designed with the appurtenances necessary to permit the lines to be safely and rapidly drained. The system should also be designed with an appropriate level of redundancy so that customers can be served by more than one leg of the system. The ideal system, moreover, should be configured in such a manner as to minimize the total length of the larger diameter pipes and, in general, serve the most customers with the shortest possible runs. Following Swedish practice, the following design criteria were also established:

1. Maximum sendout temperature of 250°F and a peak system pressure of 15 atm (250 psig).

2. Maximum ΔT of 90°F.

3. An ideal bulk flow velocity of 2 m/sec (6.6 ft/sec).

The DHDC provided the Study Team with peak heating load data for each building within the initial service area. That area, also specified by the DHDC, included the downtown business district between Main Street on the west and Wall Street on the east, and between Kellogg Blvd. on the river side and I-94 on the north. In addition to this downtown business district, the initial service area included the State Capitol Complex, Ramsey Hospital, and the Mount Airy housing project. The total peak heating load within this area was estimated to be approximately 240 MW, about 175 MW of which can be attributed to the downtown business district.

The peak heating load for each building was then assigned to each building on a map of the service area. In preparation for laying out preliminary distribution networks, the buildings within the service area were first clustered into blocks -- about 90 blocks plus the Capitol Complex, Ramsey Hospital and Mt. Airy -- which, in turn, were clustered into multi-block units. The aggregate peak heating load for each block and each multi-block unit was recorded in the process. A map showing the multi-block clusters and the peak heating load for each cluster is presented in Figure 2-1. Where significant future growth was expected -- as in Lowertown, for instance -- the future peak heating load was estimated and assigned to the cluster. It was this estimated future heating load that was then used in laying out the distribution system.

Once the multi-block load clusters were established, several distribution networks were laid out, down to 8-inch pipe, serving all identified loads. These rough layouts served the important purpose of allowing for a quick evaluation of alternative network configurations. Using cost estimating factors, each alternative network was priced. The least expensive alternative, which was roughly 15% less than the next most expensive one, was then used as the basis for developing a more refined network.

At this point several other factors were reviewed and assessed for each leg of the system:

1. Street width
2. Pavement conditions
3. Sidewalk width
4. Location of existing utilities and chambers
5. Traffic conditions

It was also necessary to assess the network's flexibility and redundancy, which was accomplished by using specially designed computer programs to analyze pressure drops in the system. The system was designed to accommodate a stable (no-growth) demand in all areas except Lowertown, where future demand was estimated and the system sized to accommodate that demand. At this juncture, the DHDC also supplied the Study Team with information regarding the most likely service entrance for each building.

With this information in hand, the Study Team prepared a modified distribution network, including transmission lines, distribution lines, and service pipes. The locations of chambers on the main pipes were also determined, as were bends and T-pieces on all pipes (Figures 2-2 and 2-3).

Once the distribution network was laid out in detail, the next and final step was to estimate the cost of each section of the system. For estimating purposes, however, it was necessary also to assess the subsurface conditions along each leg of the system and to locate at least the larger lines in each street in order to identify problem construction area. To do this, plan and profile drawings were prepared showing the location of existing utilities and, also, the proposed location of the new distribution lines. The subsurface conditions along each leg of the network were assessed and used to adjust the production rate of the construction crew. The analysis of these subsurface conditions did not dictate any change to the distribution network, although a few potential problem areas were identified. Cost estimates were also prepared for converting three heating plants to supply hot water to the distribution system. The estimated conversion costs for converting these plants were based on engineering reference drawings prepared by the Study Team.

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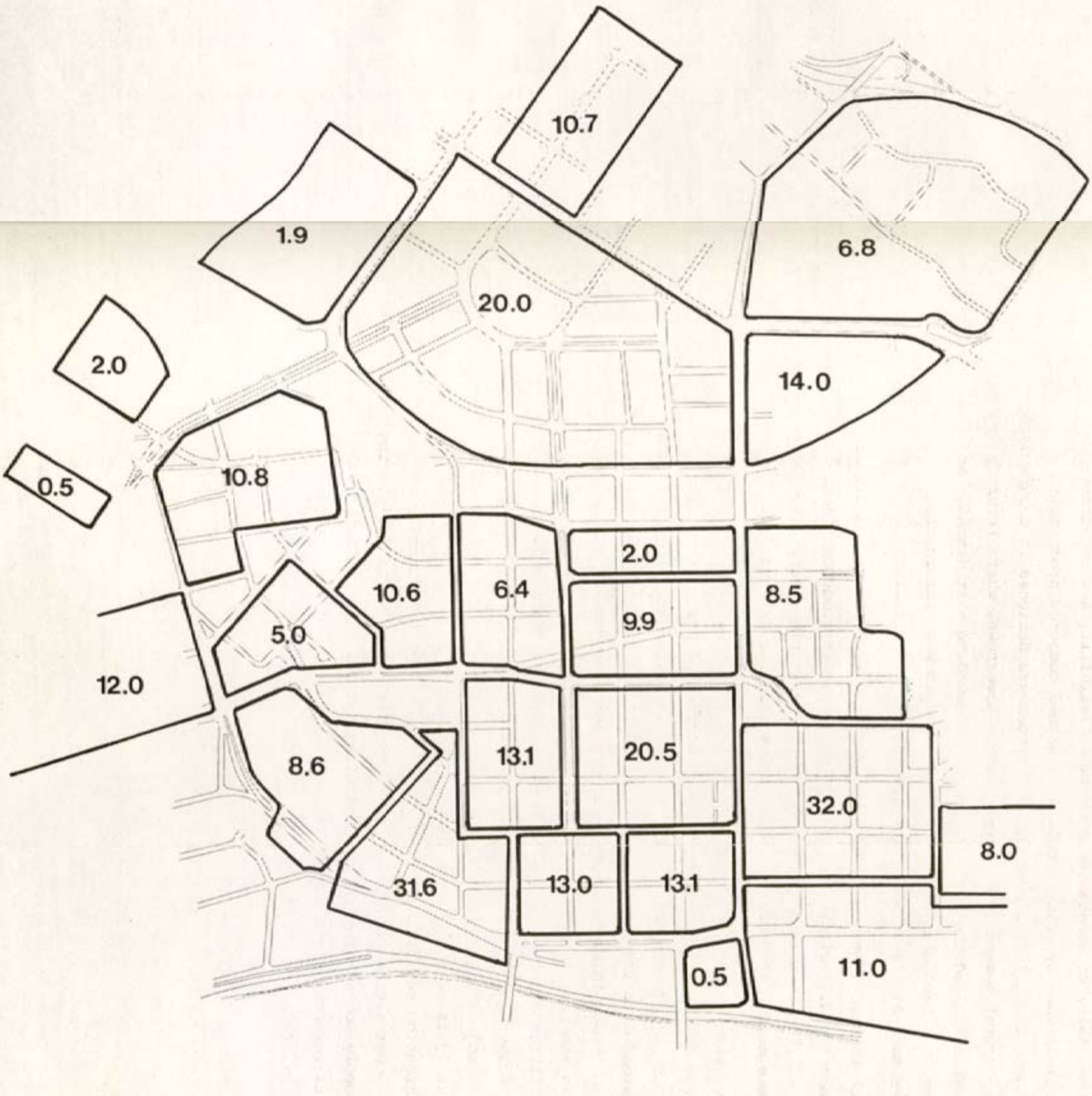


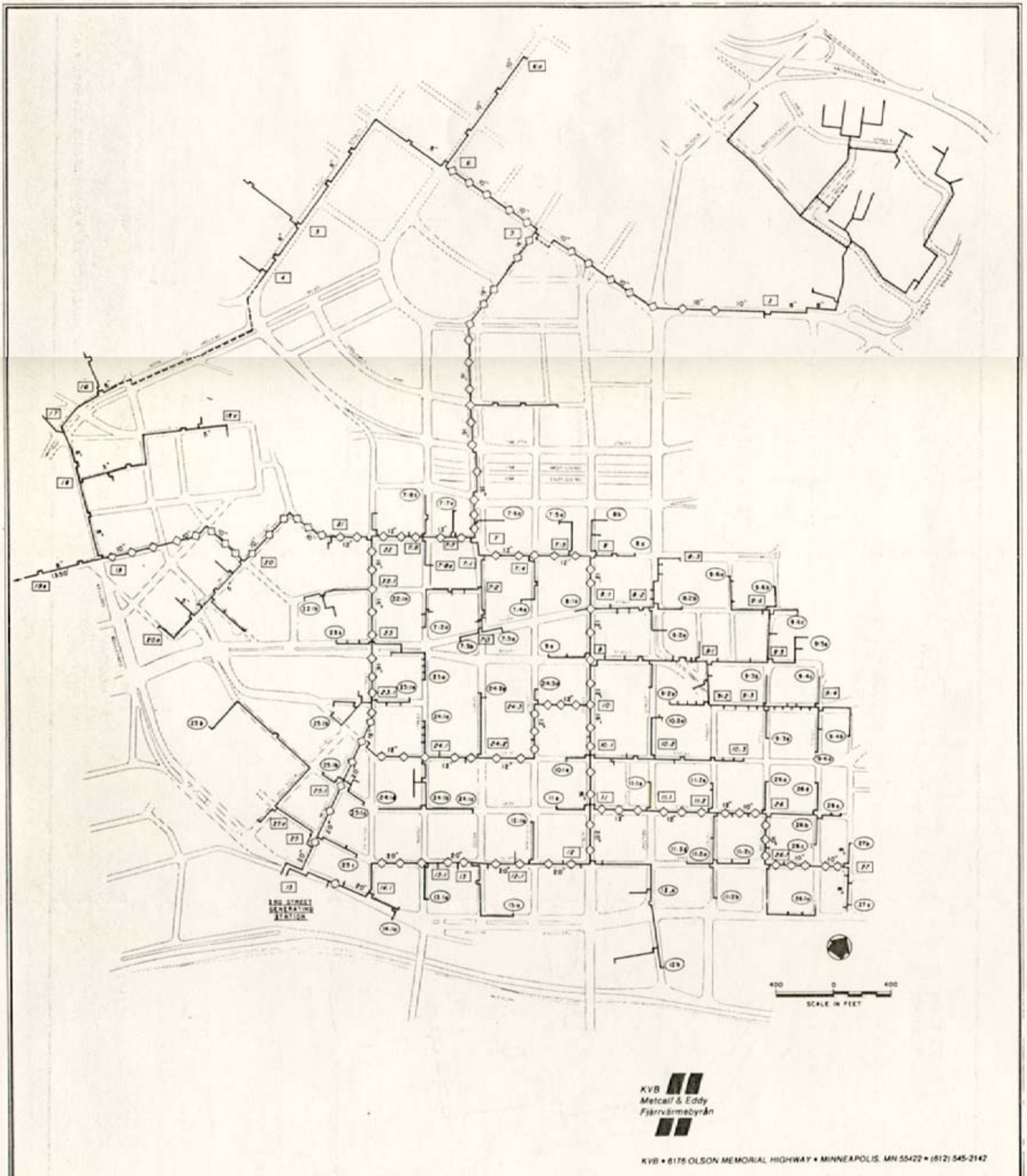
Figure 2-1
Peak Heating Loads (MWt)

KVB
Metcalf & Eddy
Fjärrvärmebyrån

KVB • 6176 OLSON MEMORIAL HIGHWAY • MINNEAPOLIS, MN 55422 • (612) 545-2147

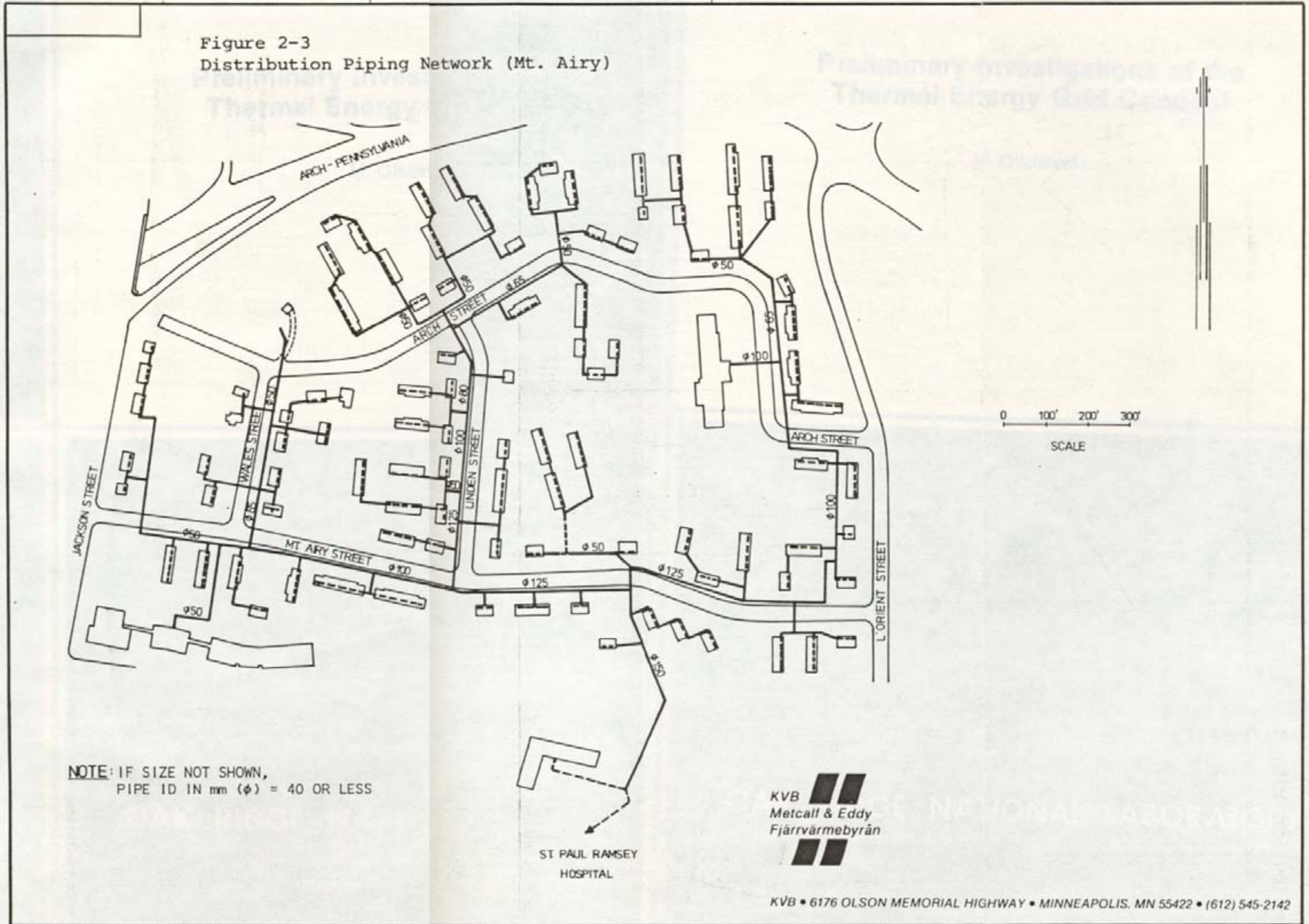
Figure 2-2
Distribution Piping Network

ORNL-DWG 81-23295



ORNL-DWG 81-23296

Figure 2-3
Distribution Piping Network (Mt. Airy)



Conclusions & Recommendations

1. The total estimated project cost of the hot water transmission and distribution network, over a five-year construction period, at current prices (ENR index = 3200), is as follows:

Year	Feet of Pipe**	Estimated Cost**
1	17,080	$ 3,450,000
2	22,820	4,500,000
3	32,510*	7,450,000*
4	58,760	5,500,000
Beyond 4	21,350	2,100,000
Totals	152,520	$23,000,000
Engineering & Contingencies		6,000,000
Total Project Cost		$29,000,000

*Transmission main between the Third St. and High Bridge generating plants include 10,000 ft. of pipe at a cost of $4,000,000.
**Excludes pipe inside buildings.

2. The total estimated project cost of the power plant modifications for district heat is as follows:

Site	Estimated Cost
Third Street Station	$1,938,900*
State Capitol	796,300*
Ramsey Hospital	618,200*
	$3,353,400
Engineering, 12.5%	364,500
Construction Services, 10%	291,600
Total	$4,009,500

*Contingencies (15%) included

3. In general, the installation of pipe within shallow trenches, excavated in the street, was determined to be the most cost-effective technique for all but the very small diameter pipelines. Although a layer of very competent limestone is present at a shallow depth and throughout a widespread

area, the cost of its excavation using mechanical means is estimated to be less than the cost of excavating new tunnels or widening existing tunnels.

4. Installation of the hot water mains within existing utility tunnels would be more expensive than installing the pipelines within entirely new tunnels.

5. The cost of excavating new tunnels within the St. Peter sandstone formation is very expensive for the following reasons.

   A. The required tunnel section is large.

   B. The sandstone deteriorates with exposure to heat and humidity, and is highly erodable by a jet of high pressure water, therefore, measures would have to be taken to protect the new as well as existing adjacent tunnels.

   C. The large chambers required for valving and expansion loops would require an elaborate and expensive support system for the cavern roof.

   D. Adequate clearance from existing tunnels and adequate necessary cover will be difficult to achieve in many congested areas.

6. The route which was selected for study for the transmission mains between the High Bridge and Third Street generating stations appears to have poor soil conditions based on the limited available subsurface data. However, this soil apparently has sufficient bearing capacity to support railroad beds, a roadway subject to heavy truck traffic, and numerous utility pipelines. For purposes of this feasibility study, where the objective is to determine the most likely cost of constructing the transmission system between the two plants, it has been judged that construction of the pipelines along this routing can probably be accomplished provided that certain precautions are taken during design and construction. This presumption should be confirmed by a detailed subsurface investigation.

7. The most economical means of conveying the transmission mains across the Interstate Highway to the Capitol complex area was determined to be the construction of a new pipe carrier bridge.

8. For small diameter pipe, 2½-inch diameter and under, routing from basement-to-basement appears to be practical. Pipe of this diameter could also be economically installed within existing water tunnels in some locations. These savings are indeterminant, and are minor in comparison to the total estimated project cost.

9. Some American-made products, equivalent to those used in European practice, are available.

10. American construction practices can be successfully applied to achieve similar results to those in European practice.

11. Standards more rigorous than those customarily employed in the U.S. in normal fabrication, quality control and construction coordination will need to be enforced.

12. It is recommended that, wherever possible, standardized prefabricated and preassembled components be used to insure quality control, economy and construction efficiency.

13. There are no environmental permit requirements which will unreasonably delay the project.

14. A comprehensive study of environmental factors is currently in progress and will be completed by the Minnesota Energy Agency in October, 1981.

THE REPORT

Chapter Three
Design Criteria for System Components

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Design Criteria for System Components

General

In developing design criteria for the St. Paul hot water district heating system, a vigorous attempt was made to transfer the most recent European district heating technology to the American scene, fully utilizing the engineering background developed in Europe (principally Sweden) and Swedish District Heating Association Standards. Design conditions are based upon use of medium temperature water of 250°F (120°C) at a working pressure of 250 psig (1.7 MPa), which are the common design conditions for Swedish systems.

A review of various products available in Europe has indicated that equivalent American items are available, with some exceptions. As the need for specialized water district heating hardware becomes apparent on the American market place, specialized items will quickly become available here.

Swedish Design Procedures

Pipe. Swedish material standards for steel district heating pipe call for the use of killed or semi-killed steel according to SIS 14 13 12 up to 24-inch diameter (DN600). Above this diameter SIS 14 13 30 steel is utilized. Both longitudinally welded steel pipe, as well as seamless pipe, conform to these standards. Rimming steel is not permitted.

The acceptable American process specification, ASA B31.3, limits steelmaking to electric furnace, open hearth or deoxidized Acid Bessemer steel. However, ASTM A53 permits undeoxidized Bessemer steel. Thus, it is important to emphasize that pipe material meet the ASA B31.3 requirements of having a maximum sulfur and phosphorus content of 0.05 percent and a maximum nitrogen content of 0.009 percent.

A number of ASTM steels are available to meet the SIS requirements, for example ASTM A53, A106, A234, A524 and API 5L. For spiral welded pipe, additional material specifications ASTM A515 and A516 can be used with Specification S18 supplementary requirements. The use of ASTM A-53 Grade B as limited by ASA B3.31 requirements, constitutes the basic pipe material used in estimating pipe costs.

Pipe Thickness

The use of thin-wall pipe is economically desirable provided the pipe can withstand the stresses imposed by pipe expansion, thermal effects, pressure, surface loadings, water hammer, corrosion, fatigue, installation and handling. European pipe wall thicknesses generally are less than American practice. The table below compares applicable U.S. piping standards to normal Swedish piping specifications.

TABLE 3-1

PIPE THICKNESS A53 GRADE B

Nominal Pipe Size Inches	(mm)	Wall Thickness U.S. Standard Schedule	inch	(mm)	Swedish Standard inch	(mm)
2	(50)	Sch 40	.154	(3.91)	.114	(2.9)
6	(150)	Sch 40	.28	(7.11)	.157	(4)
8	(200)	Sch 20	.25	(6.35)	.157	(4)
10	(250)	Sch 20	.25	(6.35)	.177	(4.5)
12	(300)	Sch	.25	(6.35)	.177	(4.5)
16	(400)	Sch	.312	(7.92)	.220	(5.6)
18	(450)	Sch	.312	(7.92)	-	(-)
20	(500)	Sch	.375	(9.52)	.248	(6.3)
24	(600)	Sch	.375	(9.52)	.248	(6.3)
28	(700)		.375	(9.52)	.346	(8.79)

The disparity between pipe wall thicknesses in U.S. and Swedish design practice deserves some discussion here. There are two factors affecting wall thickness: one, mechanical stresses and, two, long-term corrosion. As for the first factor, the thickness of the pipe should be adjusted to take into account the following mechanical stresses:

1. Design pressure loads and overpressures
2. Dynamic pressure loads (water hammer)
3. Mechanical stresses during installation
4. Surface loads
5. Vacuum conditions

6. Thermal stresses
7. Bending and joint loads
8. Settling and soil motion stresses

These stresses represent a complex loading system, but one that has a demonstrated solution in Scandanavian design practice, which has been tested, refined, and proven during the last 30 years.

It should be noted that simple hydrostatic pressure loading is often a minor force in the pipe system, and that even the thinner walled Scandanavian designs are not highly stressed from this source. Moreover, in large pipes the vacuum conditions often determine pipe thickness or require the addition of stiffening bands which contribute to pipe strength. There seems to be general agreement within the U.S. that the thinner Scandanavian pipe designs are acceptable from the standpoint of the mechanical stresses likely to be placed on the pipe.

It is with respect to the second factor -- long-term corrosion -- that there is some difference of opinion between Swedish and U.S. engineers. Corrosion in steel pipe reduces the pipe's strength and may cause perforations if the corrosion is severe. U.S. practice regarding corrosion protection has been based primarily on experience with potable water and steam heating systems in which the pipe has been designed to accept a certain amount of corrosion resulting from exposure, both internal and external, to oxygen and water. The pipe in these systems is designed to accept such corrosion by increasing the thickness of the pipe walls. The thicker walls allow some corrosion to occur without pipe failure.

Scandanavian district heating pipe, on the other hand, is designed to prevent corrosion. Because the district heating water, as well as any makeup water added to the system, is deoxygenated and purified, there is no corrosive attack from within. The steel carrier pipe, moreover, is encased in polyurethane foam, which, in turn, is surrounded by a high density polyethylene jacket that completely isolates the steel carrier pipe from external groundwater and electrolytes. Because the steel carrier pipe is thus isolated from corrosive agents, the pipe walls can be made as thin as mechanical stresses will allow. This thinner pipe is both cheaper and less expensive to install.

Scandanavian design practice has been followed in this study: all pipe, insulation, valves and other appurtenances are based on this proven design practice. At the time the cost estimates were made, standard Swedish pipe and U.S. pipe (thinnest standard grade) were available for the same price, despite the fact that the thinnest available U.S. pipe, as can be seen in Table 3-1, was still thicker walled than its Swedish counterpart. It is not yet known whether or not the slightly thicker U.S. pipe would be suitable. The Swedish pipe has already been proven. We are recommending the use of the Swedish pipe until it can be determined that the slightly thicker U.S. pipe will function at least as well. A final determination of this matter should be made during final system design and the preparation of specifications. Consideration should also be given to the availability of compatible accessories, such as valves, and to the impact of "Buy American" purchasing policies.

Code Requirements

The Minnesota Code for High Pressure Steam Piping and Appurtenances (8MCAR § 1.6312) prescribes minimum requirements for the design, manufacture, testing, and installation of pressurized piping systems for steam generating plants, central heating plants, industrial plants, and district heating. The code has jurisdiction over all the component parts of pressurized piping systems, including pipe, flanges, bolting, gaskets, valves and fittings used in steam or hot water distribution away from a central heating plant "when the pressure exceeds 15 psi gage for steam or 30 psi gage for water and a temperature exceeding 250°F, whether the piping is installed underground or not."

Because the maximum design temperature for the hot water district heating system proposed herein will be ≤250°F, the distribution system can be exempted from the requirements contained in 8MCAR § 1.6312. The code allows such an exception even when the system exceeds design temperatures and pressures for short periods of time, as long as the computed stress in the pipe wall does not exceed the allowable S value for the expected temperature by more than the following allowances for the duration indicated:

1. Up to 15 percent increase above the S value during 10 percent of the operating period.
2. Up to 20 percent increase above the S value during one percent of the operating period.

Pipe Expansion

Pipe thermal expansion provisions will normally be taken care of with pipe bends, pipe loops, or, when necessary, bellows-type expansion joints. The use of bellows axial compensators is common in Europe and gaining more popularity in the U.S. When compensators are necessary, they are generally housed in a culvert box where they are supported and guided.

When compensator systems are installed in chambers as part of the buried pipe network, the insulated and prestressed compensator type is generally of the guided and limited movement type such as the Teddington Max-comp Pressuring rating MC 16 (227 psig), Hyspan type 3502 (300 psig), and Pathway X-Press.

Pipe Insulation and Freeze Protection

District heating requires the use of prefabricated insulated pipe systems. Current European practice is to utilize polyurethane foam insulation capable of operating to 266°F (130°C) when the relative humidity does not exceed 25 percent. The foam is basically a closed cell structure having approximately ten percent open cells. The hard polyurethane foam has a density of 5.62 lbs/ft^3 (90 kg/m^3) and an average thermal conductivity of 0.2016 Btu/ft^2 hr deg. F per inch (0.029 W/mK).

The linear coefficient of expansion for the foam is much less than for the steel pipe. The strong bond between the polyurethane and the pipe, as well as the yield from the foam, prevents adhesive failure. The bond is strong enough to moderate pipe movement when the pipe is directly buried in the ground.

The insulated pipe will have a high density polyethylene jacket surrounding the insulation. This protective jacket varies in thickness from 0.087 inches (2.2 mm) for smaller pipe to 0.59 inches (15 mm) on the larger pipe. The high density polyethylene has high impact strength, good resistance to stress corrosion and ultra-violet radiation deterioration, is easily welded, chemically resistant to most ground effects, and resistant to breakdown at temperatures up to 200°F (90°C).

Several alternate materials may be used for the jacketing material, such as low density polyethylene, PVC (polyvinylchloride), aluminum, steel,

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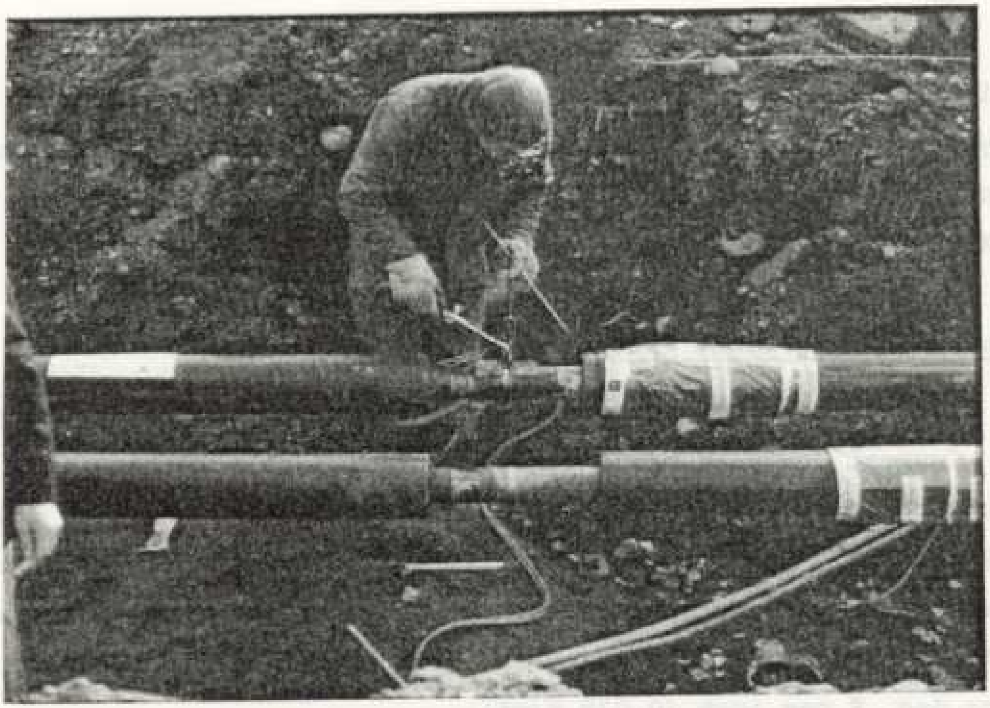

Welding of
Pre-Insulated District Heating Pipe
(Sweden)

FRP (fiber reinforced plastic), and various coatings. In general, while the industry offers several alternatives, the use of high density polyethylene appears to be the most widely accepted.

Foam compressive strength is sufficient to allow the pipe to lay directly in ground trenches. Pipe should not be subject to loadings greater than 60 psi (400 KOa). The depth of cover should vary with surface loading; however, the depth should never be less than 16 inches (40 cm).

Pipelines exposed to the elements above ground are protected by their insulation jackets. However, should water flow be stopped for an extended period in freezing weather, the pipe must be drained.

Within the system numerous culvert box chambers are located to allow access to valves, supports, compensators, and drain systems. Piping and appurtenances within these chambers are insulated, and insulation is applied to the chamber itself.

Valves

The principal requirement for the system valves is bubble-tight closure with the valve pressurized from either side, irrespective of the direction of flow, pressure and temperature. Valves are normally open and not generally used for control purposes. Valves should be furnished with weld ends. The valve must be able to withstand maximum combined axial and bending moment forces by an adequate margin without drip development, or the maneuverability or sealing mechanism being jeopardized.

Swedish District Heating Association standards include, as a guide, a table of possible valve stresses that may be applied through connecting pipes. Portions of this table are presented here in Table 3-2.

It is assumed that the valves are either plug, ball, butterfly, or slide. Valves are to be equipped with a position indicator and include sufficient length of pipe extension to prevent valve packing material damage during welding installation. Valves are to have a packing and packing gland arrangements accessible without disassembly of the valve.

TABLE 3-2

GUIDE FOR POSSIBLE VALVE STRESSES IN WATER DISTRICT HEATING

Pipe Nominal Size Inch	(mm)	Pipe o.d. x x Inch	t Inch	Max Axial Force lbs.	Max Bending Moment lbs. ft.
6	(150)	6.63	.142	11,200	7,400
8	(200)	8.63	.157	22,500	11,000
12	(300)	13	.177	45,000	33,000
16	(400)	16	.220	79,000	55,000
20	(500)	20	.248	112,000	103,000
24	(600)	24	.315	157,000	177,000
28	(700)	28	.346	202,000	266,000
31.4	(800)	32	.346	270,000	332,000

Manual operation of the valves will be accomplished by remote extension rod type adaptors. In ground-buried valves the valve is operated from grade level. For valves within box chambers, the valves may be operated manually either from the grade level (normal) or from within the chamber. Clearance is provided to allow motor driven actuators to be installed at a later date, if so desired.

The type of valve generally used in Europe is the lubricated plug type. In American practice in non-district heating applications, this type of valve has been generally replaced by either the eccentric or the high pressure butterfly type. All valves will meet pressure, temperature, bubble tightness, bi-directional shut-off conditions. Several valve manufacturers were contacted and at least three valve manufacturers can meet the valve requirements cited here. The manufacturing and quality control requirements of

European practice can and are met by the American manufacturers such as Walworth, DeZurik and Jamesbury.

Chamber Installations

Several types of chambers are to be used in the district heating piping system. Openings for pipes are to incorporate water seals to the pipe insulation jacket surface. European practices appear excellent in this regard and elements such as the serrated channel rubber seal are most economical. Packing arrangements with shrink sleeve PVC tubes appear less expensive than the link seal type of closure.

Steel support frames for the pipe are locked into and positioned in the adjacent chamber wall. These frame arrangement may be utilized for guide support or anchors for the pipe. Anchor pipe weldment stops are made in the field after pipe location has been established.

Chambers are vented and have a sump well for low point drainage. Chamber insulation material may be added as needed to protect the wall from excessive temperature or to reduce heat loss. It is noted that piping and appurtenances within the chamber are normally insulated. Manholes are provided large enough to allow access ladders to be inserted. Examples of typical chambers are shown in Figures 3-1 and 3-2.

Draining of Lines

The hot water system is designed to be highly reliable. Should a leak develop which requires immediate attention, isolation and shut-down of a section of the system must be accomplished rapidly, so that repairs can be made and the system put back on line within six hours after shut-down. Criteria call for drain lines of the folowing sizes:

TABLE 3-3

SIZING OF DRAIN LINES

Main Line Diam., in.	Drainage Pipe Diam., in.
20	4
16	3
12	2-1/2
10	2
8	2

The lines are sized to permit complete evacuation of main lines in less than 2 hours. Drain lines, located at pipe line low points, are connected on both sides of each valve and connected to a common manifold. The manifold is in turn valved on its discharge to the precast manhole which in turn discharges to the storm drain. The supply and return lines are all jointed at the manifold. Thus, by proper valving sequence any line may be drained or in turn filled through the manifolding system.

In a similar manner, at pipe line high points, line air relief venting is accomplished.

Cathodic Protection

Two types of cathodic protection were evaluated: one, the placing of expendable and replaceable metal anodes in contact with the steel pipe at each chamber box, or at special small vaults expressly for cathodic protection; the second, reversal of the corrosion cell's current flow by a direct current applied to an anode material that reverses the galvanic flow from the steel to convert the steel into the protected cathode. This latter impressed-current electrode technique is available through Pennwalt Corporation.

Whether or not cathodic protection would be necessary or cost-effective for the distribution system has not yet been determined. Such protection is widely used in the U. S. for potable water distribution systems, but it is not used in Scandanavian hot water district heating systems. The pipe manufactured in Europe for use in hot water district heating systems is designed and fabricated in such a way as to completely isolate the steel carrier pipe from its environment. The cost of cathodic protection has been included in the cost estimates for St. Paul's distribution system, but further examination and analysis may indicate that such protection is not necessary.

Leak Detection

Early detection of a line break or groundwater penetration to the system is an important feature in reducing service disruption and maintenance.

Leakage detection systems commonly in use consist of two sensing wires embedded in the insulation in a horizontal plane, each wire on opposite sides of the steel pipe. Moisture at any location along the wire length will signal an integrated alarm system. Each alarm system will monitor up to 3,000 feet of pipe runs and indicate approximate location of the moisture fault. This detection system is an important tool in the preventive maintenance area, and its cost is included in the estimate.

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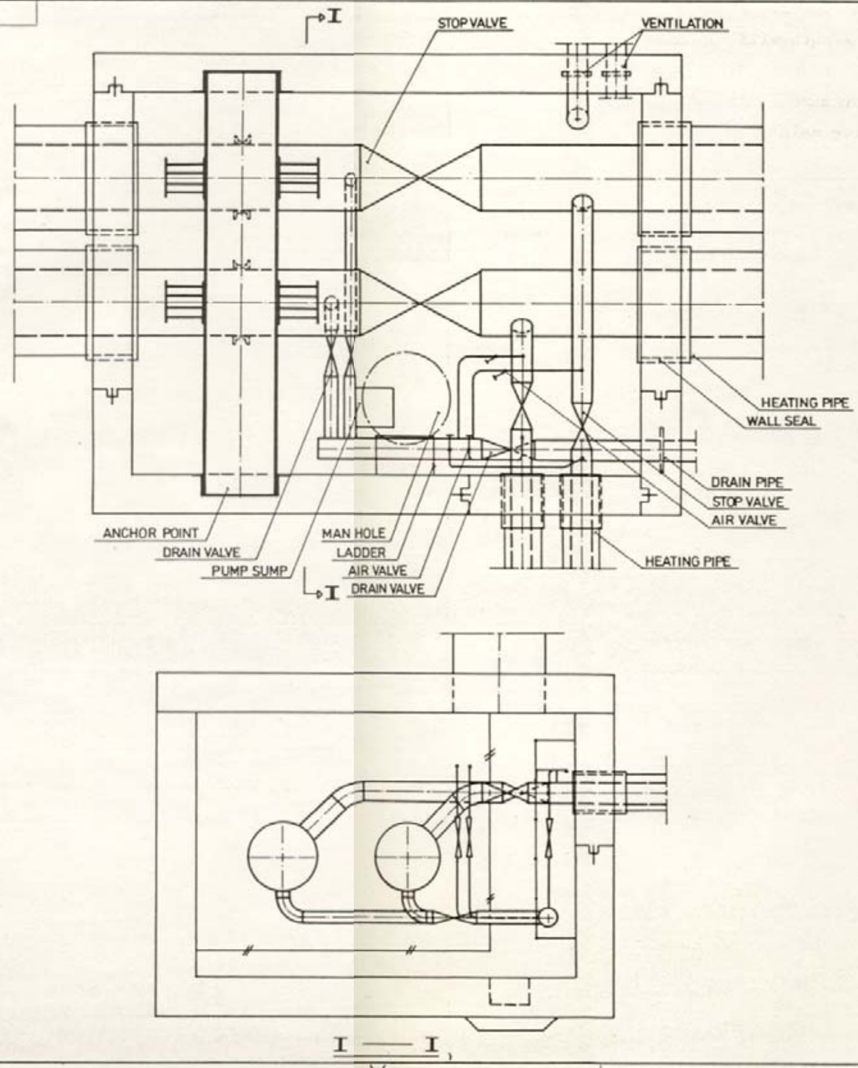

Figure 3-1
Chamber Details

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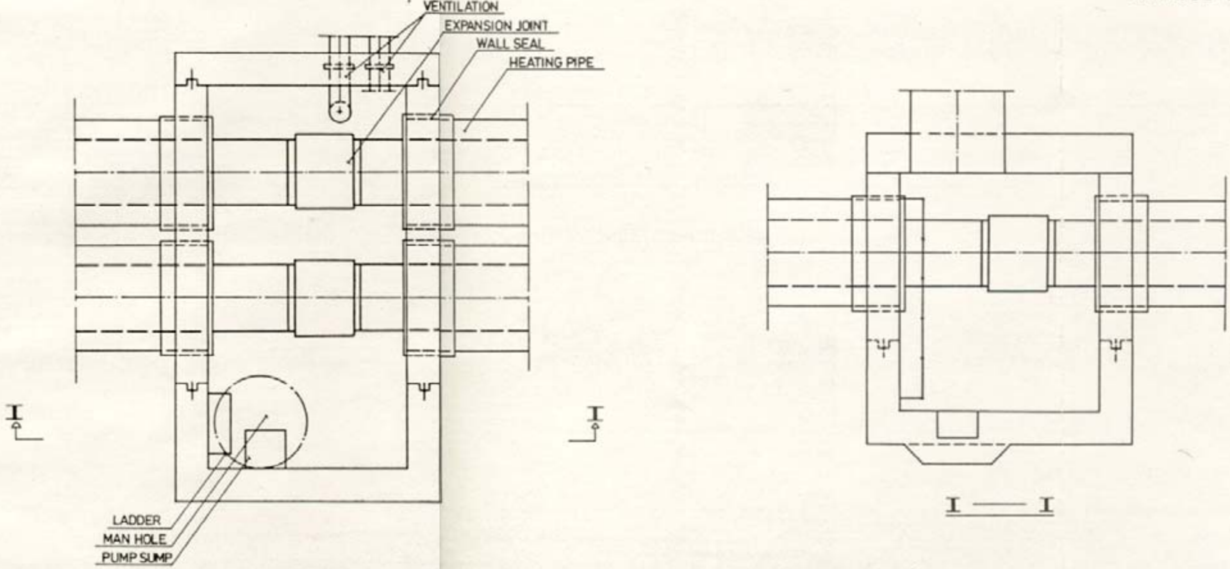
Figure 3-2
Chamber Details



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Chapter Four
Geotechnical Observations

Chapter Four
Geotechnical Observations

General

Prior to discussing pipe installation procedures, it would be useful to review the geological conditions along the proposed pipeline routes since those conditions -- soil, glacial drift and bedrock -- affect the method of pipe installation and, in effect, prohibit the use of certain installation methods in some areas. The geological review conducted by the Study Team, and presented herein, is based on an examination of published information, boring logs, and maps of subsurface conditions. Existing utility tunnels in downtown St. Paul were also visited to supplement and confirm published information.

Soil boring records were obtained from the Minnesota Geological Survey. Sources of the soil boring data include: private boring contractors, well drillers, and public agencies, such as the Minnesota Department of Transportation. The logs of more than 170 borings and wells applicable to the study area were reviewed. This information was supplemented with boring logs obtained from Northern States Power Company and logs plotted on sewer profile sheets furnished by the City of St. Paul Department of Public Works, Sewer Division. After the borings were plotted on a location map, the depths of the various strata were mapped and compared with published information. Applicable boring logs were plotted on profile sheets along most of the main pipeline routes. This information is discussed in general below.

Geological Overview of the Area

During the earlier stages of geological history, marine water flooded Minnesota and an extensive series of sedimentary beds were deposited.[1] The resulting formations that are of particular interest in the St. Paul area include, in ascending order: Shakopee dolomite, St. Peter sandstone, Platteville

[1] Schwartz, G.M. and Thiel, G.A., "Minnesota's Rocks and Waters, A Geological Story", University of Minnesota, Minnesota Geological Survey, Bulletin 37, copyright 1954, 1963.

limestone (including Glenwood shale), and Decorah shale, all of which were deposited in the Ordovician Period. The Shakopee dolomite is the oldest, and consequently the deepest, of these four deposits. The average uneroded thickness of each formation is 100 feet, 125, 30 and 60 feet, respectively. In the St. Paul area, the Platteville beds are remarkably uniform, averaging 30 feet and ranging in thickness between 25 and 35 feet.[2]

Glaciation is a significant factor in the current geology of the St. Paul area. In the Great Ice Age glaciers invaded Minnesota by three different routes at different times. The last glacier, in late Wisconsin time, advanced in a northeasterly direction. Several partially filled preglacial and interglacial valleys, including the Glacial River Warren, join the Mississippi Valley in St. Paul. These ancient valleys restrict tunneling in certain areas. Detailed geological maps delineate the types and thicknesses of deposits and bedrock and are part of a comprehensive geologic and hydrologic study of tunneling in the Twin Cities Area.[3]

Downtown, West of Wabasha Street (Area 3)

In the downtown area enclosed approximately by Wabasha Street, Kellogg Boulevard and Freeway I-94, with a north finger which extends over to about Robert Street, the bedrock terrace is very shallow (Figure 4-1). The logs of about 30 borings were available for this area. The glacial drift (any surficial deposition left behind by glacial activity) in this area is generally less than 5 feet thick overlying the Platteville limestone surface. The eroded limestone ranges between 9 and 11 feet thick. Under the Platteville limestone are 3-5 feet of Glenwood shale. The shale forms a relatively impervious cover for the underlying St. Peter sandstone, minimizing the amount of water seeping downward. The top of the St. Peter sandstone has an average elevation ranging from 772 to768 feet above sea level. This horizontal

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[2]Schwartz, G.M., "The Geology of the Minneapolis-St. Paul Metropolitan Area", University of Minnesota, Minnesota Geological Survey, Bulletin 27, 1936.

[3]Norvitch, R.F. and Walton, M.S. editors, "Geologic and Hydrologic Aspects of Tunneling in the Twin Cities Area, Minnesota", Minnesota Geological Survey and the U.S. Geological Survey in cooperation with the U.S. Department of Transportation, Map 1-1157, 1979.

geological layering of the limestone and sandstone is typical for the Twin Cities area.[4] The sandstone bed averages 125 to 150 feet in thickness[5] and is composed of clean, white well-rounded grains of quartz. It is poorly cemented and has moderate permeability.[6]

Downtown, East of Wabasha Street (Areas 2 and 6)

In the area generally east of Wabasha Street the eroded valley through the limestone and St. Peter sandstone was filled with alluvial terrace deposits from the Glacial River Warren. This area extends northward beyond I-94 to about University Avenue. The logs of about 30 borings were available for this area, but most of the borings are concentrated in three separate subareas. Within this general area, the bedrock has been eroded and exhibits a sudden drop in elevation just east of Wabasha. For example, the bedrock surface drops 70 feet in an easterly direction within a city block along Sixth Street. According to one boring log, the depth to bedrock is about 189 feet below ground surface near Minnesota and 7th Street. Several boring logs along 6th Street revealed bedrock at a depth of about 100 feet. This general area can be subdivided into two subareas: the first subarea between 6th and 8th Streets, and the second between Cedar and Robert Streets. According to one geological map,[7] the first subarea contains fat clay overlying boulder zones, sand and gravelly sand terminating in St. Peter sandstone. According to borings obtained in this subarea, erratic fat clay deposits of varying thickness were encountered to depths of 44 feet. The data on the fat clay

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[4]Nelson, C.R. and Yardley, D.H., "Final Report on Low Cost Tunneling Study for the Twin Cities Area", prepared for the Metropolitan Transit Commission, MTC-73-01, December, 1973.

[5]Schwartz, G.M. and Thiel, G.A., "Minnesota's Rocks and Waters, A Geological Story", University of Minnesota, Minnesota Geological Survey, Bulletin 37, copyright 1954, 1963.

[6]Norvitch, R.F. and Walton, M.S. editors, "Geologic and Hydrologic Aspects of Tunneling in the Twin Cities Area, Minnesota", Minnesota Geological Survey and the U.S. Geological Survey in cooperation with the U.S. Department of Transportation, Map 1-1157, 1979.

[7]Ibid.

deposits are limited, with blow counts ranging generally from 2 to 4 blows per foot by the standard penetration test. This is soft to very soft material, and probably varies in organic content. The clay is generally overlain by a surficial deposit of variable fill.

The second subarea also contains terrace deposits, but with minor amounts of fat clays. Here the terrace deposits consist mainly of layers of silty sand, and sand with some boulder zones and stiff clays.

Mississippi River Flood Plain (Area 1)

The low area bounded by the Mississippi River in the south, the sandstone bluff in the north, High Bridge Station to the west, and the Third Street Station to the east, is flood plain alluvium,[8] varying from sand to clay and overlain by thick fill. The logs of 18 borings were available for this area, although these are mostly located in an area immediately adjacent to the High Bridge Station. The logs indicate a layer of highly variable fill overlying deposits of very loose organic materials, or very soft clays and very loose sands, to depths of about 40 feet below ground surface. Directly below these layers are deposits mostly of sand, increasing in compaction with depth and terminating at depths on the order of 95 feet in limestone bedrock. The maximum depth to bedrock is about 100 feet. There are indications of a significant variation of depth to bedrock -- on the order of 60 to 110 feet -- near Chestnut and Eagle Streets. This large variation is attributed to a canyon eroded into the bedrock surface which descends in a southerly direction.

Capitol Area (Area 5)

In the Capitol area north of I-94, south of Sherburne Ave., east of Pine Street, and west of I-35E, the outwash plain deposits are generally sand and silty sand,[9] but these may be overlain by thin soil deposits of varying composition such as lean clay, claying sand and organics. The glacial drift

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[8]Ibid.

[9]Ibid.

generally varies in thickness from 20 to 120 feet. A total of about 46 borings were obtained for this area. Although the subsurface information in this area is limited, a reasonable distribution of borings was obtained throughout this large area. Available borings show the St. Peter sandstone to be as deep as 136 feet below the present ground surface. The south-eastern quadrant of this area also contains sand and silty sand deposits with boulder zones, but these are lower terrace deposits of the Glacial River Warren.[10]

Interstate Area (Areas 4)

A total of 25 borings for bridges crossing I-94 and I-35E between Wabasha and Jackson Streets were available. This includes the logs of seven borings for the existing Cedar Street Bridge. According to the structural drawings for the Cedar Street Bridge, the abutments and piers are situated on limestone or shale. One boring extended through the limestone, Glenwood shale and about 8 feet into the St. Peter sandstone. The estimated elevation of the top of the sandstone is about 771 feet above sea level, which corresponds to downtown St. Paul.

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[10]Ibid.

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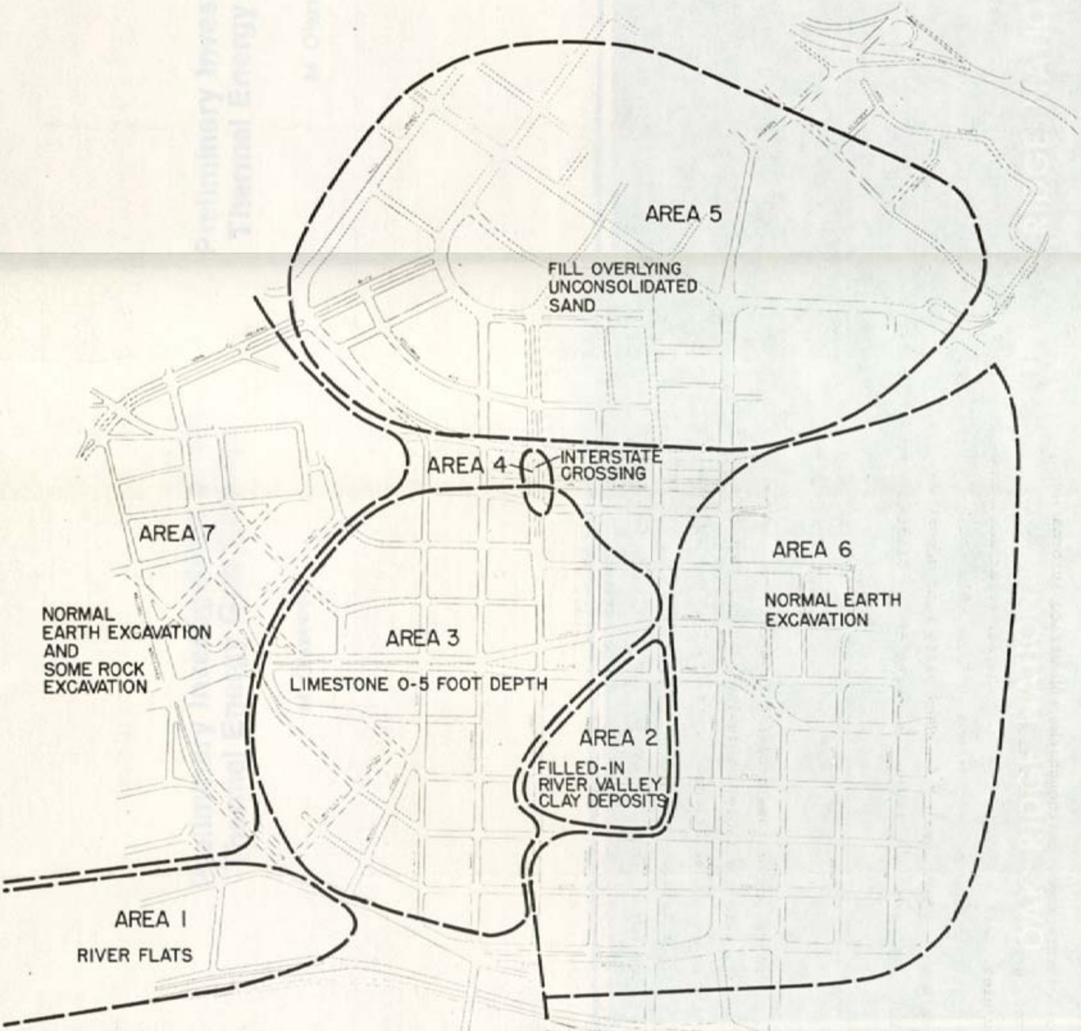
Figure 4-1
Subsurface Conditions



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Chapter Five
Pipe Installation Procedures

Chapter Five
Pipe Installation Procedures

General

After the routes of the principal mains were tentatively selected and the general layout of the network established, the alternative methods of installing the pipe were investigated. These alternatives included: using new or existing tunnels, the use of cut-and-cover in either streets or sidewalks, and the installation of pipe within buildings (basement-to-basement), or combinations of the above. The use of culverts to contain pipes larger than 20 inches in diameter was also examined. Each method was evaluated in light of the geology of the area, the environmental impact of the installation procedure, safety, difficulty in obtaining easements or permits, scheduling of construction, factors affecting installation costs, and other considerations as to the overall practicality of the method. In many cases, certain alternatives could easily be eliminated from serious consideration.

A thorough evaluation of the alternative installation procedures cited above led the Study Team to conclude that the cut-and-cover technique was the most practical and least expensive installation procedure and, in view of available geotechnical information, a procedure that could be employed along most of the pipeline routes. The use of existing or new tunnels in the St. Peter sandstone, while it seemed an attractive alternative at first glance, was, after careful consideration, dismissed as either impractical or unnecessarily complicated. A discussion of each installation procedure is presented below.

Tunnels

Field Observations. One of the unique geological features of downtown St. Paul, west of Wabasha Street, is the relatively shallow bedrock. Consequently, most utilities west of Wabasha are located within tunnels bored through the St. Peter sandstone formation. Some deeper tunnels exist outside this area. For the most part, the shallow tunnels were excavated around the turn of the century. The sandstone, being very friable, was easily removed with simple hand tools. The limestone formation, which overlays the sandstone and is located at, or immediately below ground surface, is a very dense, competent rock which requires blasting, or very heavy mechanical equipment for removal.

Some of the existing shallow tunnels in this area were visited during April, 1980, and measurements and photographs taken. One tour was made of the existing water tunnels, which are reportedly the highest tunnels within the St. Peter sandstone with inverts between El. 762 and 764. These unlined tunnels are small, typically 4+ feet wide at the base, and 6+ feet high, with a "gothic" arch or "tent" form. The tunnels contain a cold water line at the base of one side of the arch. Where a second pipe exists, it is situated at the opposite base of the arch. The effect of heat related ravelling of the sandstone under Market Street is reportedly caused by adjacent steam tunnels. The ravelled sand can be observed on top of the 4-inch pipe and left base of the arch. Similar sized tunnels carry service lines into buildings. These service tunnels are generally referred to as "drifts".

A second tour was made of existing steam and electric tunnels in the area west of Wabasha Street. These tunnels are generally lower than the water tunnels. The tunnels are mostly unlined and vary considerably in width (maximum of 5.5 feet) and height (maximum of 9 feet). It is common for these tunnels to contain both steam and electric lines.

A visit was also made to the Second Street storm drainage tunnel, located in Minneapolis, under construction in the same St. Peter sandstone formation. The large cathedral section tunnel generally was about 9 feet wide by 15.5 feet high. It will be lined with at least 6 inches of unreinforced concrete. The exposed sandstone above the spring line was sprayed with sodium silicate to serve as a temporary liner until the concrete was placed. The sandstone tunnel was excavated with a high pressure water jet and the resulting sand water slurry was removed from the tunnel by pumping. A combination of rock bolts, wire fabric and/or chain link fence with metal strips was used to stabilize the roof for a major portion of the tunnel until the concrete lining could be constructed.

Based on these visits, it is apparent that ravelling of the sandstone is generally prevalent when it is exposed to a prolonged source of heat and/or humidity. The St. Peter sandstone is easy to excavate because the sand particles are only loosely cemented together. This tenuous bond is seriously weakened or destroyed if heat causes the sandstone to dry out. Not only have many of the steam tunnels been seriously affected by heat, but also nearby tunnels, including the normally cool water main tunnels where they are located in proximity to other heated tunnels. While some success has been achieved recently with sprayed-on stabilizing compounds, it is apparent that any new or existing tunnels proposed for inclusion in the hot water system would necessarily have to be concrete lined and insulated since the hot water tunnels will be maintained at a temperature of 167 degrees F. Otherwise, portions of tunnels owned by other utilities might be affected by the heat emanating from the hot water tunnels and become more susceptible to ravelling and dilapidation. Some ravelling of the sandstone must be expected, nevertheless, in a zone immediately around the hot water tunnel. The sandstone, once dry, will eventually act as a cohesionless sand within this zone, placing a structural load on the tunnel lining. The concrete lining and steel reinforcing would have to be designed to resist these long term stresses.

There has been considerable experience with tunneling in the St. Peter sandstone. In fact, Nelson and Yardley report that "more than 100 miles of tunnels have been driven in the upper parts of the sandstone during the past century. [The tunnels] are easily and cheaply excavated, the sand rock stands well with relatively light or even no support and the tunnels can be driven reasonably near the surface."[11] The sandstone is, however, highly erodible, since there is generally little or no cementation. For that reason, a concrete lining is needed to prevent any erosion that might otherwise be caused by a high pressure leak in the hot water pipeline.

As a general rule of thumb in tunnel design, a minimum cover thickness of two tunnel diameters is required to provide adequate arching. In addition, where two or more parallel tunnels are driven, a clear spacing of at least 1 to 1.5 diameters should be maintained to prevent concentrations of excess stresses around the tunnel opening. Similarly, where two tunnels cross one another, a clearance of at least one diameter should be maintained. These are approximate design rules, and may be subject to modification in a final design stage.

The method of tunnel construction in the St. Peter sandstone is documented in the literature. In general, small tunnels (less than 6 feet high by 3 feet wide) were dug by hand. For the large tunnels, a hydraulic lance is frequently used. A high pressure water jet cuts the outline of the section several feet in advance of the lance. Sometimes a second high pressure hose is used to cut and erode the outlined section. A slurry pump is then used to remove muck. In a few cases, a mechanical mole has been used to advance the tunnel in sandstone. If the groundwater is above the tunnel invert, it is generally necessary to dewater the sandstone by a dewatering system, such as deep shafts.

In summary, the following observations may be made about tunnels in the St. Peter sandstone:

1. The sandstone generally has little or no cementation.
2. The sandstone has ravelled when exposed to prolonged heat and/or humidity.
3. The sandstone is highly erodable.
4. Many of the existing utility tunnels are congested.

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[11] Nelson, C. R. and Yardley, D. H., op cit.

5. There is considerable experience with tunneling in the sandstone.

6. Large tunnels in sandstone are frequently constructed by use of a hydraulic lance. Small tunnels have generally been excavated by hand.

7. Tunnels must meet minimum clearance standards.

Tunnel Assessment. The use of existing and/or new tunnels in deploying the hot water distribution system was initially given serious consideration for the following reasons:

1. Much of the pipe located within the downtown area is of large diameter. A wide trench is required to contain the two pipes. In many locations there may not be space available a few feet below street level for this large trench.

2. It is highly desirable to have the pipe visible and readily available for inspection.

3. In the event of shut-down of the system, lines in tunnels would not have to be drained to prevent freezing.

Since bedrock is generally shallow only in the downtown area bounded by Wabasha Street, Kellogg Boulevard and I-94, consideration is given only to tunnels in this area. Within this area, there are a number of existing tunnels within the St. Peter sandstone.

There are design and construction requirements common to both new and existing tunnels:

1. Both will require a reinforced concrete lining. This will prevent erosion of the sandstone in case of hot water leakage and will serve as structural support if the adjacent sandstone becomes hot and ravels.

2. Both will require insulation around the periphery of the concrete tunnel lining. This is to minimize heat flow into adjacent tunnels, thus preventing ravelling of the sandstone. For estimating purposes two layers of styrofoam insulation board were assumed, each 2 inches thick.

3. The location of tunnels must take into consideration adequate ground cover and sufficient clearance from nearby tunnels.

4. Access shafts, ventilation system, lighting system, pipe supports and expansion chambers must be provided.

5. Expansion chambers as large as 40 feet wide and 80 feet long must be installed at intervals of about 750 feet. These chambers will contain U-bends to take up expansion with alignment transverse to the tunnel axis. Since the St. Peter sandstone cannot span wide areas unsupported, these chambers would have to be constructed of reinforced concrete. If the existing tunnels were expanded or if new tunnels were placed directly under the Platteville limestone, it seems likely that the chamber roof would need to be tied together with numerous rock bolts.[12] Even with these design precautions, there is some risk that ground subsidence could occur over chambers with free spans of over 40 to 50 feet and relatively thin limestone cover. Before spans of this width could be considered for expansion chambers, more evaluation and research would need to be done. This would probably require the construction of a test chamber in downtown St. Paul.

6. Since there are numerous existing tunnels at various elevations, the expansion chambers would make clearance with existing tunnels and utilities a major consideration in final design.

7. The usual Swedish practice is to maintain tunnels at 75 deg. C (167 deg. F). Ventilation is provided only to temporarily lower the temperature while workmen are within a tunnel. Continuous ventilation of tunnels to prevent heat buildup has been found to be impractical not only because of the great expense of installing, operating and maintaining the necessary equipment, but also because excessive heat from the pipelines is wasted. Ventilation shafts should be provided which would have to penetrate through the overlying band of Platteville limestone.

8. A relatively large tunnel section is necessary to install and house the hot water pipelines.

Existing Tunnels. Based on a review of the geology, subsurface conditions, condition of existing tunnels and construction practices, consideration was given to laying the hot water lines in existing tunnels. In general, the highest tunnels in the St. Peter sandstone formation are the water main tunnels, which appear to be the most obvious ones to use for district heating.

The water tunnels are at the top of the St. Peter sandstone and would be desirable for use since the tunnels are the least congested of the utility tunnels. It is likely that existing drifts to buildings could also

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[12] Ibid.

be used for the hot water lines. The tunnels are high and will have a protective shale and limestone cap, which is desirable from a structural point of view. However, it is also desirable to maintain an adequate cover over the tunnel. Using the two diameter rule for the enlarged tunnel section shown in Figure 5-1, the cover should be at least 20 feet. Since the existing cover is of order 18 feet in the area west of Wabasha Street, the enlarged tunnel would just meet the minimal cover requirement. In all likelihood, the invert of the enlarged section may also have to be lowered from that shown in Figure 5-1. There are, moreover, some disadvantages to using the existing water tunnels:

1. The existing pipe is relatively old. If it is moved during enlargement of the tunnel, it may be more economical to completely replace it with new pipe. Furthermore, water service has to be continuously maintained to the customers, which will certainly slow construction progress and increase project cost.

2. The best estimate of shape and size of the enlarged water tunnel section shown in Figure 5-1 was compared with the estimated shape and size of a new hot water tunnel as shown in Figure 5-2. Since the cross-sectional area of the new tunnel is less than the cross-sectional area to be excavated for the enlarged tunnel, it is obvious that a new tunnel is more economical.

The use of other existing utility tunnels -- steam and/or electric -- appears to be an even less attractive alternative:

1. Many of the tunnels are congested (on both sides) with a number of steam and/or electric lines. Use of these tunnels would require either temporary relocation of the existing lines during construction, or a very large expanded cross section for the tunnel. Either case would make the cost of these tunnels prohibitive. Furthermore, the existing electric lines would make the use of hydraulic lance impractical for expanding the cross-section. Hand or pneumatic spades could be used to expand the section, but such a technique would be uneconomical.

2. The failure of a hot water line in an electric utility tunnel would have disastrous effects, since some of the lines carry 15,000 volts.

3. Many of the existing steam lines have caused ravelling of the existing tunnels and adjacent tunnels. Some of the deteriorated sections have been lined with brick, block and concrete. In order to expand the cross section area for the hot water lines, these lined sections and cross drifts would have to be removed, and/or rerouted at major expense.

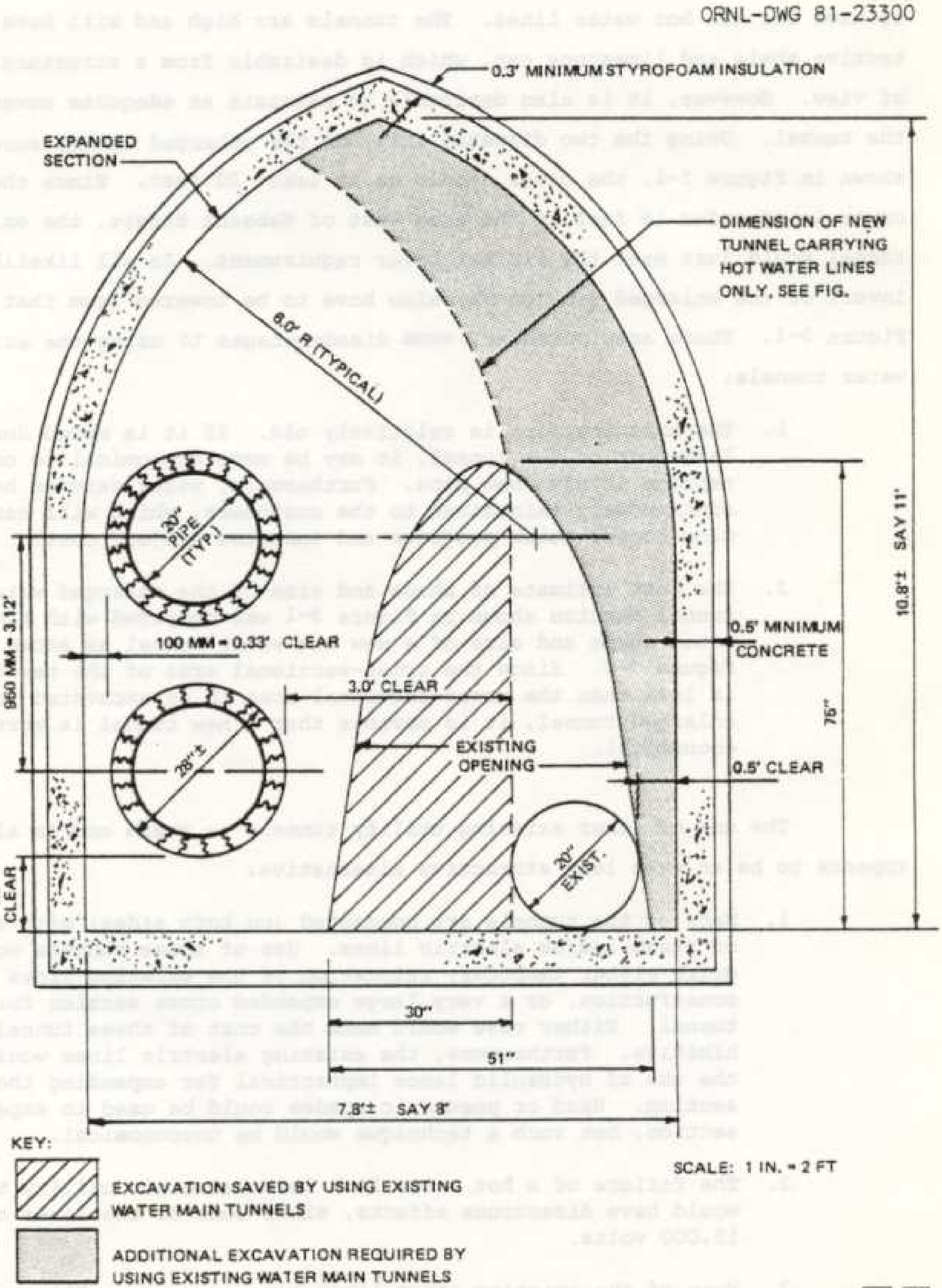

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Figure 5-1
Enlarged Tunnel Section

Figure 5-2
New Tunnel Section

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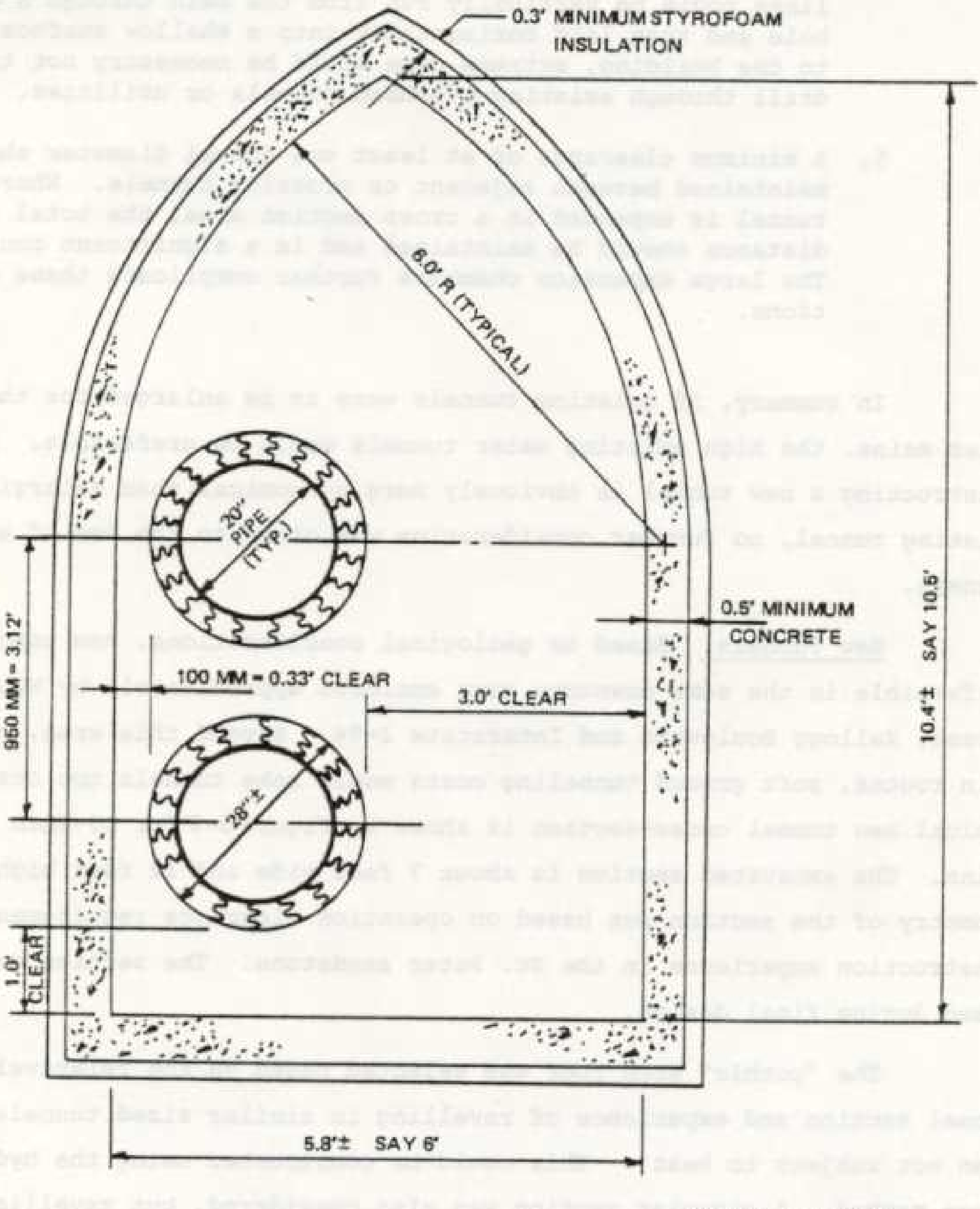

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4. The deeper the tunnel, the more expensive it is to provide service lines from the hot water mains. Assuming service lines could be vertically run from the main through a cored hole and then laid horizontally into a shallow surface trench to the building, extreme care would be necessary not to core or drill through existing overhead tunnels or utilities.

5. A minimum clearance of at least one tunnel diameter should be maintained between adjacent or crossing tunnels. Where a tunnel is expanded in a cross section area, the total clearance distance should be maintained and is a significant consideration. The large expansion chambers further complicate these considerations.

In summary, if existing tunnels were to be enlarged for the hot water mains, the high existing water tunnels would be preferable. But since constructing a new tunnel is obviously more economical than enlarging an existing tunnel, no further consideration was given to the use of existing tunnels.

New Tunnels. Based on geological considerations, new tunnels would be feasible in the same downtown area enclosed approximately by Wabasha Street, Kellogg Boulevard and Interstate I-94. Beyond this area, along the main routes, soft ground tunneling costs would make tunnels too costly. A typical new tunnel cross-section is shown in Figure 5-2 for 20-inch hot water mains. The excavated section is about 7 feet wide and 12 feet high. The geometry of the section was based on operation clearance requirements and construction experience in the St. Peter sandstone. The section may be revised during final design.

The "gothic" arch roof was selected based on the relatively large tunnel section and experience of ravelling in similar sized tunnels (even when not subject to heat). This could be constructed using the hydraulic lance method. A circular section was also considered, but ravelling or cave-in of a circular roof would be likely, unless the tunnel were lined immediately, or supported with steel liner plates, or supported with rock bolts and fencing. Circular sections are usually feasible where a mole can be used on long relatively straight reaches of tunnel. Since the longest run of new tunnel in downtown St. Paul is about 1,500 feet, the mole would not be economically feasible. The single exception to this is the section beneath I-94, where use of a circular tunnel section was considered.

Where pipes smaller than 20-inch diameter are used, the cross-sectional area of the new tunnel is only slightly reduced. Thus, smaller pipes would have a minimal impact on new tunnel costs.

The cost of construction for these new tunnels would be substantial. Besides the normally high costs of tunnel construction, there is the additional cost of insulating the walls with reinforced concrete over some type of insulation to avoid unacceptable safety and maintenance problems resulting from ravelling of the sandstone. In addition, there will be numerous branch service lines that will have to be cored through the limestone to the surface to serve the various buildings. The coring of shafts for service lines will require extensive coordination with existing utility owners.

Cutting new tunnels in the shallow bedrock area would be more economical than expanding existing tunnels, but the combination of substantial costs and technical complexities makes a new tunnel less desirable than a shallow cut-and-cover operation, as discussed later.

There are two locations, nevertheless, where consideration was given to the use of new tunnels: (1) the railroad crossing just west of the north end of the High Bridge and (2) the I-94 crossing at Cedar Street.

<u>Cedar Street I-94 Crossing.</u> Several methods of crossing the freeway were considered, including using the existing bridge, constructing a new bridge, or placing the pipe in a new tunnel. Only the latter alternative will be discussed here. There are a number of borings available for this area, which reveal Platteville limestone and Glenwood shale overlying the St. Peter sandstone. Based on this subsurface information, the alignment of the tunnel should be offset from the bridge and be located in the St. Peter sandstone. Jacking the pipes is not feasible in the sandstone since extremely high frictional forces would resist advancing the casing pipe. The tunnel section should be cut in a circular section and immediately lined with steel liner rings to prevent cave-in of the sandstone roof. A layer of insulation would then be installed and the tunnel finished with a concrete lining. An inside tunnel diameter of 6 feet would allow placement of two 16-inch diameter lines (24-inch outside diameter with insulation), one over the other. The outside diameter would be about 8 feet. Assuming the tunnel would extend outside of the frontage road on one side to out-

side of the frontage road on the other, a total run of 450 feet should be anticipated.

Furthermore, at both ends where these lines rise to the shallow trench, the lines will penetrate as much as 28 feet of the Platteville limestone. Assuming the pits would allow a vertical pipe riser, it would be very expensive to excavate large pits through the limestone down to the tunnel invert in the sandstone. The estimated cost for the pits and tunnel underneath the freeway is $415,000. Since this cost substantially exceeds the cost of alternative crossings, the use of a tunnel here was dropped from further consideration.

Railroad Crossing West of High Bridge. Were the pipeline to be routed to high ground between the High Bridge Plant and the Third Street Station, the pipeline would rise about 80 feet from the river flats near the north end of the High Bridge. This route would require jacking under the railroad tracks, then a tunnel from the north side of the railroad tracks through the St. Peter sandstone to the intersection of Smith and Goodrich Avenues. The tunnel would be about 550 feet long. At the intersection of Smith and Goodrich a vertical shaft would rise about 70 feet and the pipelines then placed in a shallow trench bending eastward.

Cut-and-Cover

Cut-and-cover involves, very simply, digging a trench, then laying pipe, then backfilling the trench and, if necessary, replacing any pavement removed in the process. Because there is no need to bury hot water pipes below the frost line, the trench can be relatively shallow and, depending on the soil conditions, can normally be excavated with a backhoe. This means low excavation costs and fewer interferences with sewer and water lines, which are buried at greater depths.

Depth from surface to trench bottom is normally 3 to 7 feet, with a 2-1/2 foot minimum depth of cover over the crown of the buried pipe when the pipe is laid in city streets. At this trench depth, considerable interference with telephone, electric, Western Union and street traffic signal cables must be expected, but these utilities can be provided with temporary support during construction, and, where required, can be relocated more easily than

ORNL-PHOTO 8598-81

ORNL-PHOTO 8633-81

Typical Cut-and-Cover Trench Construction in an Urban Area
(Minneapolis)

large water or sewer pipes. Gas mains and storm drains present more of a problem, but in most cases the hot water pipelines can be located away from these two utilities.

The two steel water pipes are encased within a polyethylene carrier pipe and the annular space between the pipes is filled with rigid, closed-cell foam polyurethane insulation. The trench contains a perforated concrete underdrain pipe to prevent the buildup of groundwater pressure. Trenches are constructed at a slope of 0.3 to 0.4 percent to permit drainage of the lines at valve chambers.

A compacted coarse grained material must be used for bedding, haunching, and backfill to at least a depth of one-pipe radius above the crown of the carrier pipe. Such bedding conditions will inhibit settlement and will permit an H-20 loading on the pipe at the indicated minimum depth of cover.

As required by the City's Public Works Department, an 8-inch layer of reinforced concrete paving is provided over the backfill, topped with two layers of asphalt paving with a total depth of 3 inches.

Pipe buried in a trench is restrained along its entire length and, therefore, experiences less thermal expansion than does pipe in tunnels or culverts. However, greater stresses are built up within the pipe wall, since it is not free to expand. To take up the expansion which does occur, provision for expansion must be made at adequate intervals.

The normal practice in Sweden is to provide bends in the pipeline (either U, L or Z in shape) for pipe up to 8-inch diameter. Examples of these bends are illustrated in Figure 5-3. At bends, the pipe is encased on three sides by a compressible material. This material permits some pipe movement, but keeps the pipe in general alignment. If insufficient soil bearing capacity is encountered, the encasement can be backed up with concrete as necessary.

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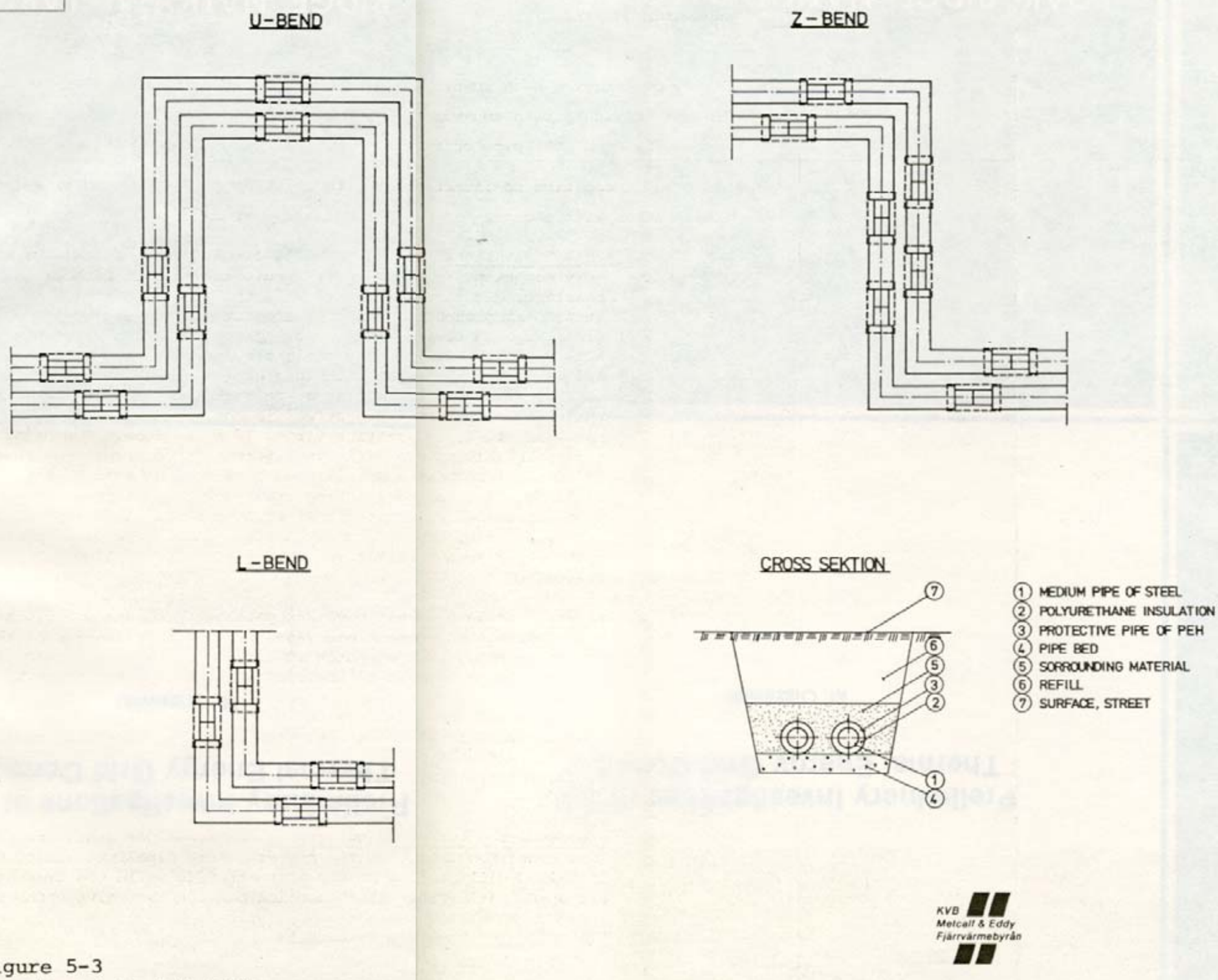

Figure 5-3
Trench and Bend Details

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For the larger diameter pipelines, as well as for smaller pipe where clearances preclude the use of bends, expansion is taken up by bellows expansion joints.

Where a larger diameter pipeline turns through a right angle, a 90-degree bend backed by a compressible material can be used to take up expansion at less cost than an expansion joint. Whichever type of expansion joint or bend is used, the pipe must be anchored between expansion joints.

In addition to interference with existing utilities, the principal difficulties with the cut-and-cover alternative are:

A. Rock Excavation. The Platteville limestone formation is a very competent rock and is difficult to excavate without blasting. As shown on Figure 4-1, the limestone is located at or near ground surface over a considerable part of the area proposed to be served by the district heating system. After interviews with City officials, utility engineers, and several contractors with long experience in installing utilities in the St. Paul area, it became apparent that, while blasting within the street is theoretically and legally possible, it is in practice virtually never done. The major factor inhibiting use of it is difficult to determine whether adjacent structures and utilities have been damaged by the blasting. Instead of blasting, the rock can be broken up from impact by heavy mechanical equipment, or it can be ripped out by powerful excavating equipment. While expensive, this cost is far from prohibitive, especially with shallow trenching.

B. Paving. While the best pavement patching procedures would be used to replace pavement excavated for the installation of the hot water pipelines, no patch is as satisfactory as a complete repaving job. Several of the streets where pipelines are to be installed have only recently been repaved. This is unfortunate but unavoidable with a cut-and-cover operation. The cost included in all cost estimates is for pavement replacement over the width of the trench and the area immediately adjacent to it, not for complete repavement of the entire street width.

C. Inconvenience During Construction. At least one lane, and in most cases two lanes, of the streets where pipelines are to be installed will need to be closed to traffic while the trenches are open. An entire trench section between two valve chambers

ORNL-PHOTO 8599-81

Typical Trench Construction in an Urban Area
(Minneapolis)

must remain open until it is completed and can be pressure tested. In most cases this procedure is expected to require approximately four weeks. The cost estimate includes the expense of removing the soil and rock excavated from the trench, storing the materials to be reused at a remote site, and refilling the trench after completion of the pressure testing. The noise of breaking out rock is a temporary inconvenience which may limit hours of construction in some areas of the City.

One advantage of the cut-and-cover method is that, in areas underlain by limestone, many of the existing utilities are well below the new pipe, so that construction can proceed with very little interference with existing utilities.

Location Beneath Sidewalks. In Sweden, the area beneath sidewalks is considered ideal for the location of district heating pipelines. The principal criteria for depth of cover is to protect the pipelines from heavy traffic loadings. Obviously, this problem is reduced where pipes are located beneath sidewalks. Pipelines thus situated can be installed within culverts, the roof slab of the culvert being the sidewalk. Such installation has the advantage of providing ready access along the entire pipeline route. In St. Paul, it has been the long standing practice for the downtown buildings to make use of the space beneath the sidewalks. For the most part, this has been either for utility vaults, or for elevators to facilitate delivery of materials to the basement of the buildings. While no up-to-date maps showing these vaults exist, the older maps, dating as far back as 1930, show such a profusion of vaults that construction of the district heating mains beneath sidewalks would not be feasible. In addition, in most areas, the electric utility vaults, which are large and numerous, are located beneath the sidewalk on one side of the street. An inspection of those streets where principal mains are proposed indicated that conditions similar to those shown on the old maps still exist, and that construction beneath the sidewalk would not be practical. However, some small pipelines close to consumer services may be routed through basements beneath sidewalks at some reduction in cost. These special cases will be identified during final design.

Location Within Basements. This alternative was not the subject of detailed study because of its complexity: each individual basement is different. It does have the distinct advantage of making use of the heat lost from the district heating pipes to warm basement. It also eases the problem of making connection to the heat exchangers of the customers located on the side of the street where the pipeline runs. It would be extremely difficult, however, to secure easements through each building for large mains. The liability problems in case of a large main break would be difficult to assess. Many of the problems associated with anchoring the pipes and providing for expansion chambers would be even more severe than those associated with the tunnel alternative.

However, the small service pipes from the main in the street can readily be run from building to building along the length of a block. Our calculations indicate that pipe larger than 2½ inch diameter should be installed in trench in the street. Pipes up to 1½ inch diameter can be run from building to building for approximately one-half the cost of the same size pipeline installed beneath the street. Where buildings on both sides of the street are to be served, two sets of pipelines can be installed and the cost of making connections from the street to the buildings is avoided. Pipes of 1½ to 2½ inch diameter installed within buildings are estimated to cost about two-thirds of the price of the same pipes installed in trench in the street. Where all potential customers are located on only one side of the street, piping of this size installed within basements would be more economical.

In general, soil conditions along the hot water main routes consist of glacial drift, frequently covered with shallow fill. Generally the drift is very competent and will provide adequate support for the pipelines. There are a few questionable areas where special foundation preparation might be required but more detailed soil investigations must be carried out first. The areas with special characteristics are discussed below.

1. High Bridge Plant to Third Street Plant

   In this reach of about 4,400 feet along the river flats, a layer of higher variable fill overlies some deposits of very loose organic materials or very soft clays and very loose sands to depths of about 40 feet below ground surface. Occurring directly below these layers are deposits of mostly sand, increasing in density with depth, and terminating at depths of 95 to 110 feet in limestone bedrock. The cost estimates presented in this report are based on floating the hot water pipelines in this area. It will be necessary to take additional borings in this area to confirm soil conditions along the entire route.

2. Localized Downtown Area, (East of Wabasha Street, west and on Robert Street, south of 8th Street and north of 5th Street)

Within this area the bedrock has been eroded with a sudden drop in the surface just east of Wabasha Street. As discussed previously, this locality contains erratic fat clay deposits of varying thickness to depths of 44 feet. It is soft to very soft, and probably varies in organic content. The clay is generally overlain by a surficial deposit of variable fill. Based on this information, the pipelines will be founded directly on soft or very soft deposits of clay or fill deposits overlying the soft clay layers. With this type of material, the precise bearing strength of the foundation is important to determine. For example, if the clay is less than or equal to 2 blows per foot, the pipe should definitely be supported on piles which bypass the compressible clay layers and extend to the sandstone. Where pipe is 6 inches or less, the piles can be deleted. The average pile length in the area is estimated at 50 feet. If the blow counts generally exceed four per foot, it is possible that the lines can be floated if some settlement can be tolerated. The available technical information is relatively limited in this area, and for that reason it is recommended that additional borings and laboratory tests be performed, so that a foundation support system can be recommended with a greater degree of reliability. Depending on economic and other considerations, it may be desirable to relocate the lines outside of this area where the soft clay does not occur: for example, moving the line on Robert Street to Jackson Street.

For purposes of estimating, it is recommended that sheeting be excluded for trenches 5 feet deep or less; for trench depths much greater than 5 feet, permanent timber sheeting is recommended to be at least 5 feet below bottom of trench. The purpose of the sheeting is to prevent shear failure and upheaval of the bottom of the trenches, and settlement of the adjacent soil and utilities. The trench will be left open for a period of time until each reach (between vaults) can be pressure tested. This is unlike normal utility construction where the line is backfilled immediately and then tested. Therefore, it seems even more important that deeper trenches in this area be sheeted to prevent bottom upheaval.

It is recommended that additional borings be taken immediately to ascertain whether or not piles are needed. Consideration may be given to moving the pipe outside of this area, such as Jackson Street instead of Robert Street. The available subsurface data east of Robert Street indicate conventional trenching techniques.

3. Downtown Area, (generally west of Wabasha Street, south of I-94 and north of Kellogg Boulevard, but including a leg out to Robert Street near 10th Street)

   In this area, depth to bedrock is generally 5 feet or less, with some localized depressions of perhaps 10 feet. The bedrock is Platteville limestone, with a thickness in the order of 12 to 16 feet, including several feet of underlying Glenwood shale. Occurring directly below the shale is the St. Peter sandstone with the top of the sandstone varying slightly from El. 772 to 768, and averaging about 770. The existing tunnels are located in the sandstone.

   Since the trenches are relatively shallow, the excavations will extend into only the Platteville limestone. The limestone formation is a very competent rock and is difficult to excavate without blasting. Presplitting has been used to produce clean cuts with little or no overbreak. After interviews with City officials, utility engineers, and several contractors with long experience in installing utilities in the St. Paul area, it became apparent that, while blasting within the street is theoretically and legally possible, it is in practice virtually never done in downtown St. Paul. The major factor inhibiting use of blasting is the liability problem: that indeterminant damage may be done to adjacent structures and utilities, including existing tunnels in the underlying sandstone. The rock, however, can be broken up from impact by heavy mechanical equipment such as a hydrohammer (pneumatic pick). In some cases, where the limestone is weathered, a heavy backhoe with teeth may be used to remove the limestone. It is probable this equipment would need to be used for only a very small portion of the route located in limestone. While expensive, this excavation cost is far from prohibitive, especially with shallow trenching.

   It seems prudent to monitor vibrations transmitted through the ground and/or rock by mechanical equipment to verify that particle velocities are less than allowable values. In addition, existing tunnels would have to be periodically inspected to verify that structural damage, if any, is negligible.

   Within this area, an erratic, perched water table on the Platteville limestone is anticipated, since it serves as relatively impervious cap. Therefore, some dewatering by normal sump pit and pump operations is anticipated.

4. Capitol Area, (north of I-94, south of Sherburne Ave., east of Rice Street, west of I-35)

The available borings in this area taken along the main pipe routes are limited. Generally, bedrock is well below the proposed pipe invert and will have no impact on selection of routes or economics in this area. (One exception to this might be a localized area at the north end of the Cedar Street I-94 crossing where limestone was about 8 feet deep.) The soil profile along the main route can be generalized as fill extending to depths ranging from 1 to 13 feet below present ground surface, and perhaps averaging 6 feet. At some locations the fill is underlain by organic deposits to a maximum thickness of 3 feet. Directly underlying the fill or organic layers are mostly deposits of loose to medium dense sand occasionally interbedded with silt or clay. The base of the trench excavation will be situated mostly in the existing fill, which varies considerably in type of material and density. In order to provide adequate support, it is recommended that the bottom of the excavation be subcut a distance of about 2 feet and backfilled with compacted material. The base of the excavation should be proofrolled where possible to detect any soft zones which should be removed and replaced. This should include a 6-inch layer of concrete fine aggregate to serve as a filter to prevent migration of fines such as clays, silts or organics into the gravel base. Since the ground water is generally well below the base of excavation, only normal sump pit and pumps are anticipated for removal of rain or snow melt during construction.

The above recommendations for cut-and-cover operations are based on the available subsurface information. A number of borings will need to be taken along the main pipe routes during the final design. Based on these borings, some modifications or changes may be necessary, including rerouting the pipelines. In particular, before final design is considered, we recommend that additional borings be taken immediately in two areas, namely: the river flats between the two power plants, and the downtown area near Minnesota and 6th Streets where the deep soft clay deposits were encountered. The existing data for these latter two areas are limited.

It should be understood that analyses and geotechnical recommendations submitted in this report are based upon available information derived from the available soil borings at the indicated locations. Since it is possible that variations in subsurface conditions may exist between boring locations, it should be understood that additional borings are recommended during final design. Depending on actual conditions encountered, some design revisions may be possible.

Crossing of Interstate Route 94 and 35E

The Interstate highway which separates the downtown and Capitol complex areas presents one of the major obstacles along the route of the transmission network. In the area between downtown and the State Capitol Complex, the Interstate is depressed below the grade of the intersecting streets, which are carried over it by means of concrete box girder type bridges. The initial distribution layout called for a crossing to be made at the Robert Street Bridge. After discussions with City and State highway officials, that layout was revised to permit the crossing to be made in the more commodious area at the Cedar Street Bridge.

There are four possible methods of conveying the district heating pipes across the Interstate:

1. Jacking a carrier pipe beneath the road.
2. Constructing a tunnel beneath the Interstate.
3. Constructing a new bridge to carry the line.
4. Making use of an existing bridge.

If properly constructed and drained, a buried line would be a highly reliable means of conveying hot water across the Interstate. However, jacking a carrier pipe was determined to be an impractical undertaking due to the excessive frictional resistance along the walls of the casing pipe. In this respect, tunneling would be preferable to jacking as a means of installing the mains beneath the Interstate. Fortunately, the interface between the sandstone and limestone layers is at an almost ideal depth in this area, permitting the tunnel to be excavated in sandstone, while still leaving a substantial layer of the more competent limestone between the roof of the tunnel and the highway surface. The estimated cost of the tunnel crossing is $415,000, exclusive of engineering and contingencies.

The major disadvantages to either tunneling or jacking, however, are:

1. The necessity of excavating large pits through limestone at either side of the highway.

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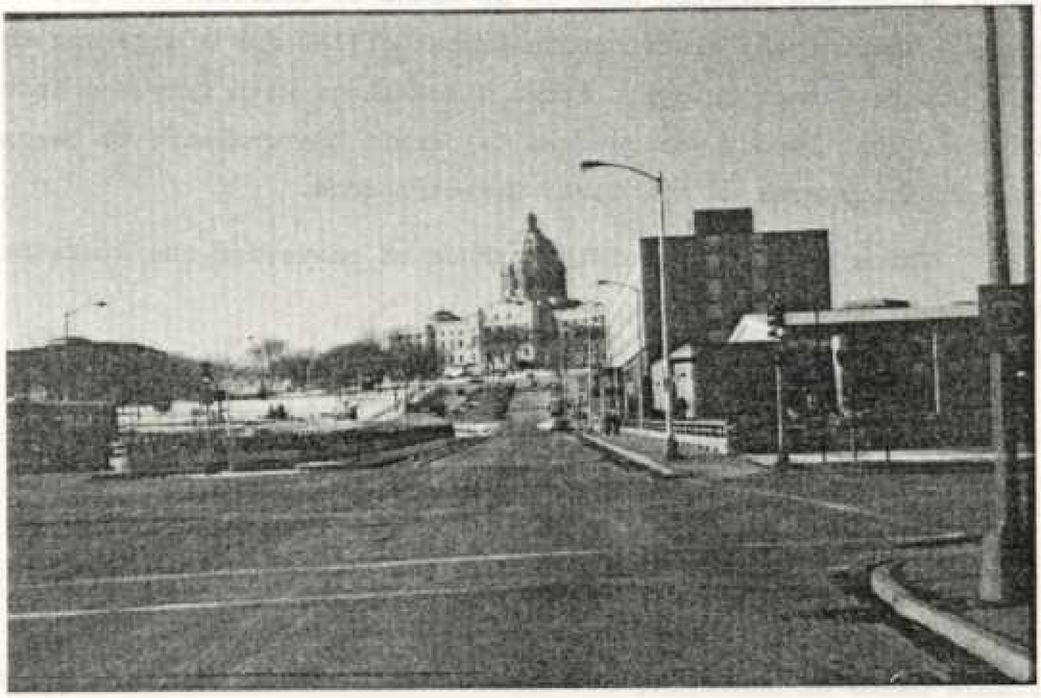

Pipeline Route at the
Interstate 94, 35E Bridge Crossing

2. The difficulties encountered with supporting the pipes at the vertical bends at both shafts to the tunnel.

3. The difficulty of draining lines installed at this low an elevation.

Hanging the proposed pipelines from an existing bridge is potentially the least expensive construction method. The bridges have a center knock-out panel with a single 18-inch diameter opening to permit their use for carrying utilities across the Interstate.

The following criteria have been established for utility crossings of the Interstate via bridges:

1. Pipes must be valved on either side of the bridge and provision for draining the line must be made.

2. The pipe must not reduce the present clearance between the road and the bridge.

3. The utility may not be hung from an exterior beam of the bridge. It must be located between interior beams, where it cannot be seen from, or hit by, vehicles.

4. The utility must not interfere with future painting or maintenance of the bridge.

The proposed hot water mains at the Interstate are 16-inch diameter, encased within a 24-inch diameter steel carrier pipe. The pipes are too large to be installed within the existing 18-inch knock-out utility opening. From our examination of the construction drawings of the bridge, it does not appear practical to install the hot water mains within the existing box beams, because the bridge is constructed with internal concrete diaphrams tied with lateral cables, which would obstruct any conduit larger than 18-inches.

The feasibility of suspending the pipelines from the cantilevered sidewalk sections of the two bridge spans at Cedar Street was subsequently examined. State high officials advised that, on a divided highway where the bridge is constructed to two adjacent spans, the space beneath the sidewalk section between the two spans is considered similar to an interior section of the bridge for purposes of utility installation. Our calculations indicate, however, that the cantilevered sidewalk section does not have the strength required to safely support the hot water piping; and that it cannot be strengthened, or the load of the piping transferred to the main part of the bridge, without lowering the clearance over the highway.

The construction of a new bridge to carry the pipelines was, therefore, studied. The proposed new bridge structure is illustrated in Figure 5-4. It consists of two precast prestressed tee beams with intermediate supports spanning the 237 ft. between the abutments on either side of the interstate highway. Supports, of the same type as those used on the existing bridges, would be provided in line with the existing piers. The existing abutments would not be required to support the proposed pipe bridge. The bridge sections from the piers to the abutments would be supported entirely from the piers. The figure shows the proposed pipe bridge located between the two Cedar Street spans. This location was chosen primarily for aesthetic reasons. There is over 21 feet of clear space between the two existing bridges which will be sufficient to permit construction of the pipe carrier bridge while allowing sufficient space for maintenance of all three structures. The proposed bridge is a completely independent structure, however, and could be located wherever it is most convenient.

Precast concrete members were selected for the new bridge, because the denser concrete used is more weather resistant than cast-in-place concrete, and should require little maintenance. The erection of a precast concrete bridge will take place much more rapidly, minimizing interference with traffic. The use of precast elements also permits a shallower (only 48 in.) section, eliminating clearance difficulties.

The estimated construction cost of the highway crossing using a new pipe bridge is $200,000, which is less than half the cost of tunneling. This new precast concrete bridge has been included in our cost estimates.

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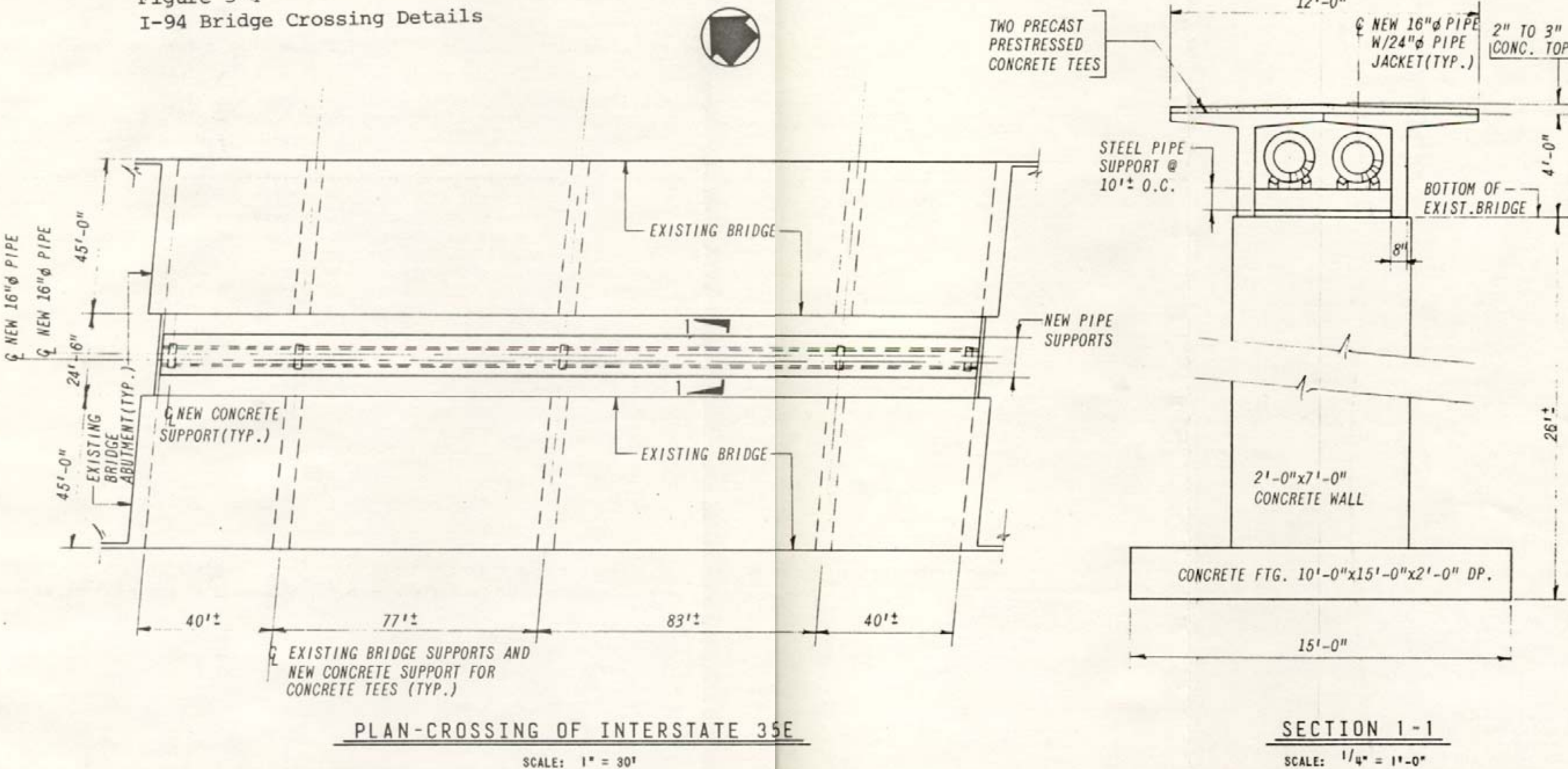
Figure 5-4
I-94 Bridge Crossing Details



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Connection Between High Bridge and Third Street

Recommended Route. The connection between the two power plants is the largest pipeline in the hot water distribution network. It is to be constructed of 700 mm (28 inch) diameter pipe along the route shown in Figure 5-5. The following criteria governing the selection of this route were established:

1. Traverse the shortest possible route between the two stations.
2. Locate the pipe within public rights-of-way where possible.
3. Where the route is to traverse private property, propose easements which run along property lines so as not to divide large parcels of land.
4. Minimize jacking beneath the numerous railroad lines which run between the two plants.
5. Avoid interferences with the major trunk sewers and storm drains which traverse the area.
6. Locate the line on soil with adequate bearing capacity.
7. Avoid running the line within the railroad rights-of-way except for crossings.
8. Avoid locating the line where its construction would seriously disrupt traffic.

The first two criteria cited above are, to an extent, mutually exclusive: the straight-line distance between the two stations traverses a parking lot owned by West Publishing Co., the property of a former barrel cleaning facility, a scrap metal works, railroad rights-of-way, as well as public streets and land owned by Northen States Power. The routes located within public rights-of-way are considerably longer than the straight-line distance.

Routing the mains along Shepherd Road would cause severe traffic disruption during construction, and would make future maintenance problems more difficult. There are other portions (especially in the vicinity of the grain elevators) where clearances are so restricted that construction would be extremely difficult. This space restriction is the principal reason for rejection of the Shepherd Road routing.

Figure 5-5
High Bridge/Third Street
Transmission Pipe Routing

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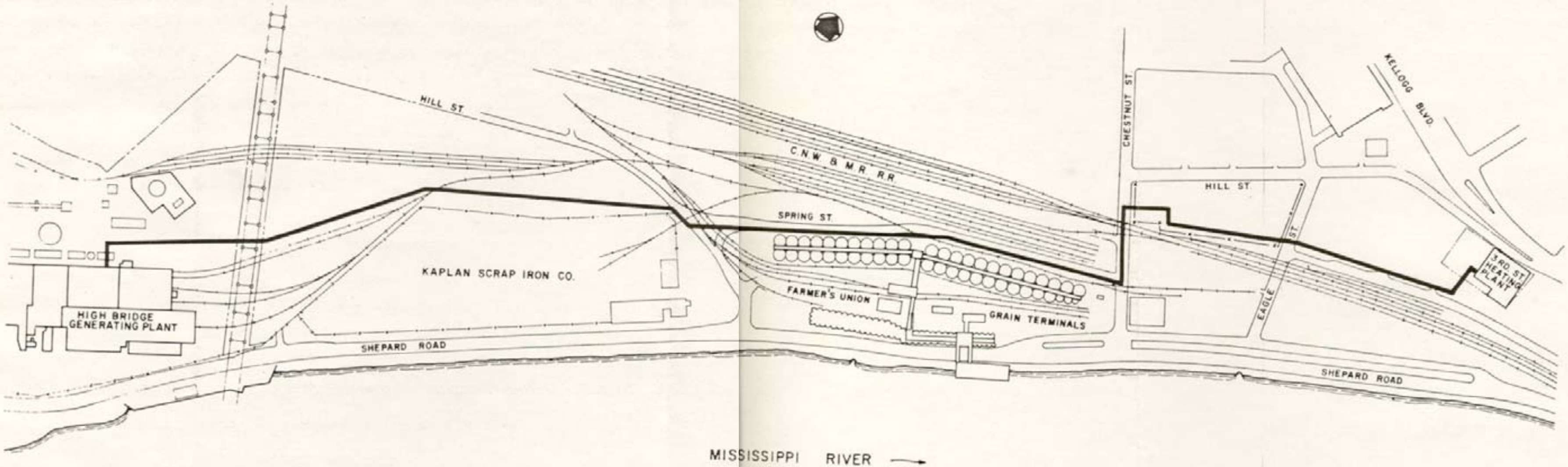

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The route selected for detailed investigation is shown in Figure 5-5. This route is 4,940 feet long, and is as close to the straight line distance between the plants as is practical. Although this routing was selected independently of a study done by the Northern States Power Company for the location of steam lines between the two plants, the resulting routes are almost identical.

The route is located within the flood plain of the Mississippi River, and for much of its length would be within fill areas. Railroad tracks and sidings cover much of the land between the two generating plants. The soil is contaminated with the waste products of the industrial activities which have occupied the site for many years. Many of these products promote corrosion of steel pipe. They may also affect the polyethylene carrier pipe. Testing of the soil should be carried out to determine what protective measures will be required. With normal flow in the river, the groundwater table is only a few feet below ground surface. During floods, the river has briefly risen to cover the proposed route. A positive drainage system is essential if the pipe exterior and insulation are to remain dry. All these problems add to the cost of construction along this route.

With the exception of the power plant property and the West Publishing Company parking lot, the routing is entirely within public streets. It will be necessary to cross a total of nine railroad tracks. The total expense of jacking sleeves beneath railroads is estimated to be under $600,000, exclusive of engineering and contingencies.

There is a surprisingly large number of other utilities in the area, considering the comparitively sparse development. Excellent documentation on their location is available as a result of the earlier NSP study. It is possible to locate chambers, and slope the proposed line, in such a manner that interference with the major sewers and storm drains is almost entirely avoided. The routing does require that 350 feet of 10-inch and 375 feet of 16-inch sewer in Spring Street be relocated to allow clearance for the proposed mains. Several gas mains will have to be lowered as well. These expenses are not major.

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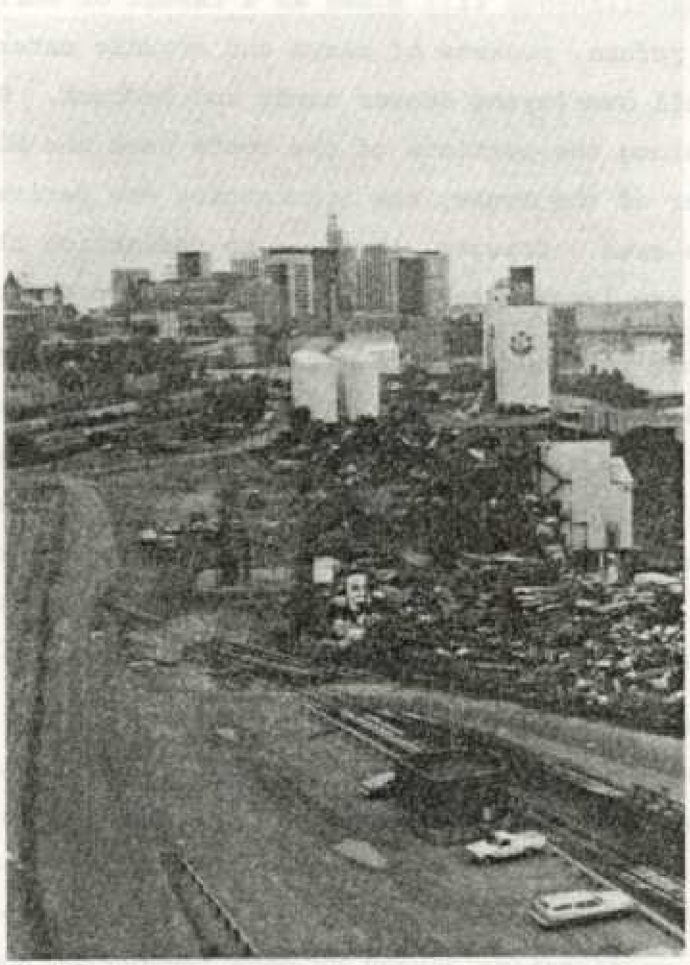


High Bridge to Third Street

Direct Pipeline Route

During the detailed study, it was found that the route has relatively poor soil conditions. Those soil conditions are a cause for some concern. The soil appears to be highly variable, consisting of organic silts deposited by the river, miscellaneous fill added as a result of earlier development and from dumping of refuse, pockets of clays and organic materials within layers of loose sand, all overlaying denser sands and bedrock. Boring logs were available only along the portions of the route near the High Bridge Station. For the remainder of the route, the information was derived from generalized soil maps of the area. However, there is no indication that the soil conditions vary to any large extent from those shown on the boring logs.

There are numerous existing utility pipelines which traverse the area, however, including a 48-inch reinforced concrete storm drain, none of which are known to be supported on piles. There is no unusual settlement of the numerous railroad tracks adjacent to the route, nor failures of the pavements of the roadways which carry the heavily laidened grain trucks to the elevators. Nor was it learned of any unusual maintenance requirements for these facilities as a result of their having been built in this area.

The steel and polyethylene pipelines used in the hot water distribution network are flexible, and are designed to withstand the stresses imposed by substantial differential movement resulting from temperature related expansion of the pipe. With detailed soils information, it would appear likely that the proposed pipelines could be designed to withstand some settlement or flotation caused by poor foundation conditions. Design precautions might include:

1. The design of highly flexible transition sections between fixed points on the line and sections which might be subject to settlement.

2. The use of polyethylene carrier pipe in place of the less flexible precast concrete culvert.

3. Use of bends rather than compensators to adjust for thermal expansion of the pipe.

4. Minimizing the number of chambers.

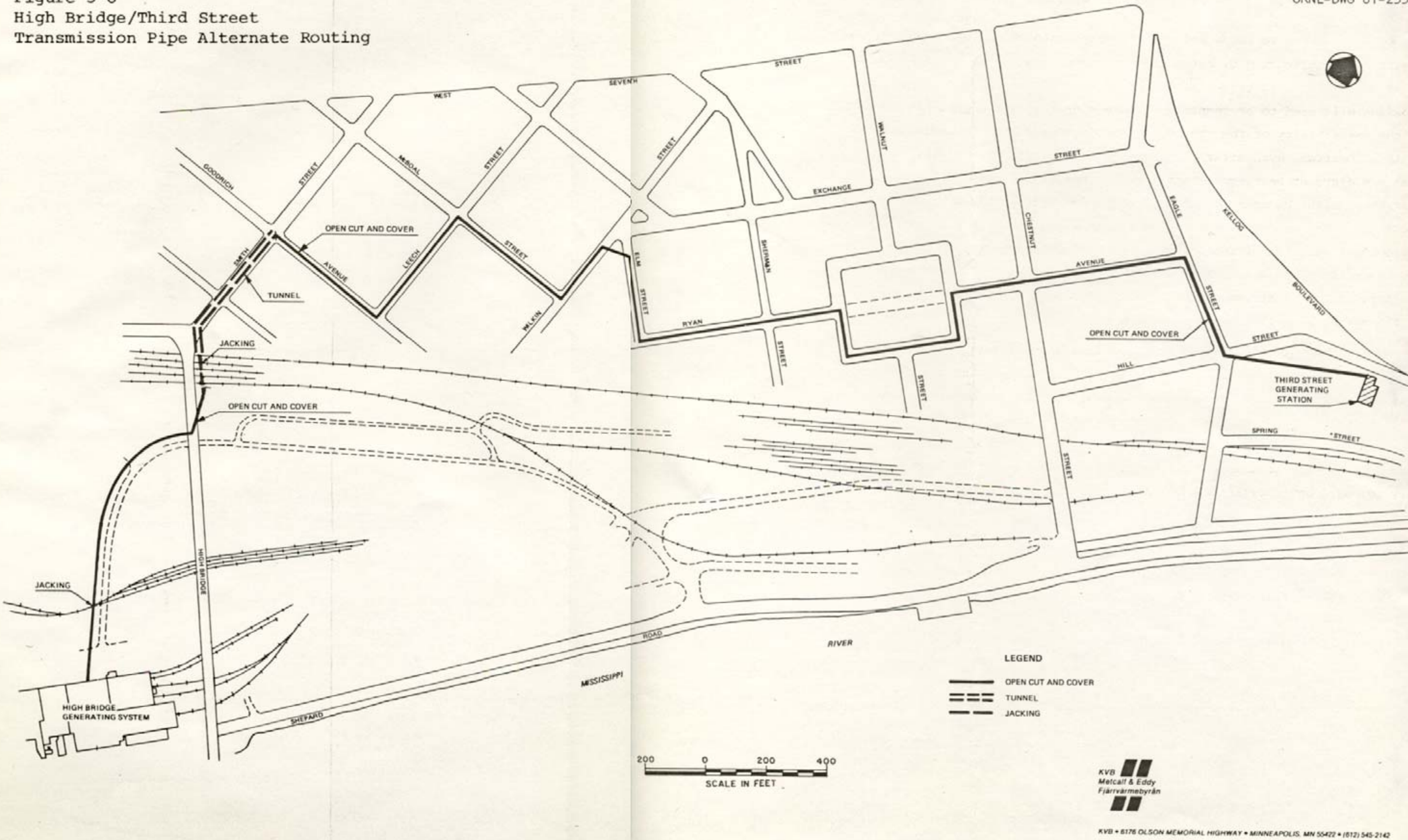
In short, we recommend that the transmission mains between the two stations be constructed by cut-and-cover along this route. However, more detailed soils information will be required, and a preliminary design of the pipeline will need to be completed before a definite judgement can be made on the desirability of the routing. Construction of the transmission main in this location, even after a thorough soils investigation, will require that the district heating utility accept a certain degree of risk: risk that there might be unanticipated construction difficulties, or risk that the lines might present a chronic maintenance problem. In view of the experience of other utilities in this area, it would appear that this risk may be small in comparison to the magnitude of the savings which could be realized by its construction here, as opposed to the cost of construction of the main in an alternative location.

Alternative Route. The cost implications of having to construct all or part of the transmission main, between the generating stations, on pile foundations was investigated. End bearing piles, extending to bedrock, would support precast concrete culvert sections which would contain the pipelines. It was determined that this would add approximately $1,400 per foot of twin pipe to the cost of construction. If it is found to be necessary to build any substantial length of main on piles, it would certainly be preferable to alter the routing.

Figure 5-6 shows a possible alternative routing between the two plants. This alternative was not considered to the same level of detail as was the originally proposed route.

ORNL-DWG 81-23305

Figure 5-6
High Bridge/Third Street
Transmission Pipe Alternate Routing



The proposed alternative route is as follows:

1. From the High Bridge Station north to the bluffs (approximately 900 feet). This section would be constructed of steel pipe within flexible polyethylene conduit.
2. Jacking beneath the railroad tracks with the water pipes installed within 48-inch steel casing pipes.
3. Tunnel horizontally through the bluffs, terminating at a vertical shaft at the intersection of Smith and Goodrich Avenues (approximately 550 feet).
4. Cut-and-cover in existing streets to the Third Street Station (approximately 4,400 feet). This section would be constructed within culverts.

The pipeline to the bluffs would be similar in construction to that described for the original route.

The pipe jacking operation beneath the railroad bed would consist of a 10-foot deep jacking pit, a 10-foot deep receiving pit, two 48-inch diameter pipe sleeves installed beneath the tracks, with the twin 28-inch diameter service pipes installed within them.

A tunnel would be excavated from the receiving pit to a vertical shaft location at Goodrich Avenue. It would consist of steel liner plates, 4-inch of insulation and 6-inch of concrete inner liner. The tunnel has been priced by using historical unit prices for similar operations in the St. Paul area updated to current construction cost indices.

The shaft would be 12 feet in diameter, with the topmost 10 feet of depth excavated in sandstone. A wire mesh liner, attached with 4-foot long rock bolts, 3 feet on center on the horizontal and vertical, would be installed within the shaft. A concrete lining and insulation would also be provided. After installation of the pipe, the top of the shaft would be covered with an 18-inch thick concrete slab suitable for H-20 loading. The pipes within the vertical shaft would be attached to the shaft walls with brackets at 4-foot intervals.

The remaining 4,400 feet of twin pipes would be installed in culverts within the existing streets. Very little interference is expected from other utilities along the route of these lines, and rock excavation is estimated to be only ten percent.

Culverts are used in current European practice to convey pipe above 20 to 24-inch diameter, because at this size range the cost of polyethylene carrier pipe becomes more expensive than the cost of concrete culverts. This relationship holds true in the U.S. as well.

The pipelines are to be constructed within a precast concrete culvert. They would be restricted from lateral movement, but would be free to expand longitudinally along a track system. The culverts would be watertight. An underdrain system would be provided to relieve groundwater. The culvert sections would be sloped toward the valve chambers to permit drainage of the pipes as well as drainage of the culverts with sump pumps, or by gravity to the storm drain system. The culverts would be insulated beneath the roof and panels and insulation would be provided around the pipe. The roof panels of the culvert itself would not have a large enough cross section to permit workmen to traverse it after the pipelines had been installed.

This alternative routing is estimated to have a construction cost of about $2,000,000 more than the route within the flood plain of the river. It has been presented primarily to show the extra cost which would be involved should a detailed soils exploration or a preliminary design indicate that the proposed route near the river is impractical.

Chapter Six
Power Plant Conversions

Chapter Six
Power Plant Conversions

General

Three thermal sources -- Third Street Station, State Capitol Heating Plant, and Ramsey County Hospital -- were analyzed in considerable detail as likely thermal sources for the St. Paul district heating system. Assuming that construction of the system proceeds more or less according to the phasing indicated in Figure 7-1, the first power plant to be modified will be the Third Street Station. During the first year of construction, modification will be made to the Third Street Station to place it on line as the system's base load heat source. At that stage in the system's development, peaking and backup facilities will be provided by temporary mobile boilers (probably leased for this purpose) at sites yet to be determined.

In the second year of construction, the State Capitol heating plant will be modified in conjunction with hooking up the Capitol Complex area of the district heating service area. The State Capitol heating plant will at that time assume the role of peaking and backup for the system, supplanting the mobile boilers. This configuration -- Third Street base loaded with the State Capitol heating plant for peaking and reliability -- will remain the basic operating mode as the system grows.

As the system nears its capacity, modifications to the High Bridge power plant will commence. When those modifications are completed, High Bridge will assume the role of the base loaded heat source. Third Street, in turn, will supply the system's primary peaking and backup requirements. The State Capitol heating plant will become primarily a backup facility, serving only secondarily for peaking purposes. When the Ramsey Hospital heating plant is brought into the system, its role will be similar to that of the State Capitol heating plant.

The NSP High Bridge Station has been the subject of numerous studies relating to its modification to service as a district heating source. These studies have considered steam and hot water as the district heating medium and have been performed and directed by a wide variety of organizations. The general conclusion appears to be that High Bridge can serve as a district heating thermal source for the heating load in St. Paul. We agree with that

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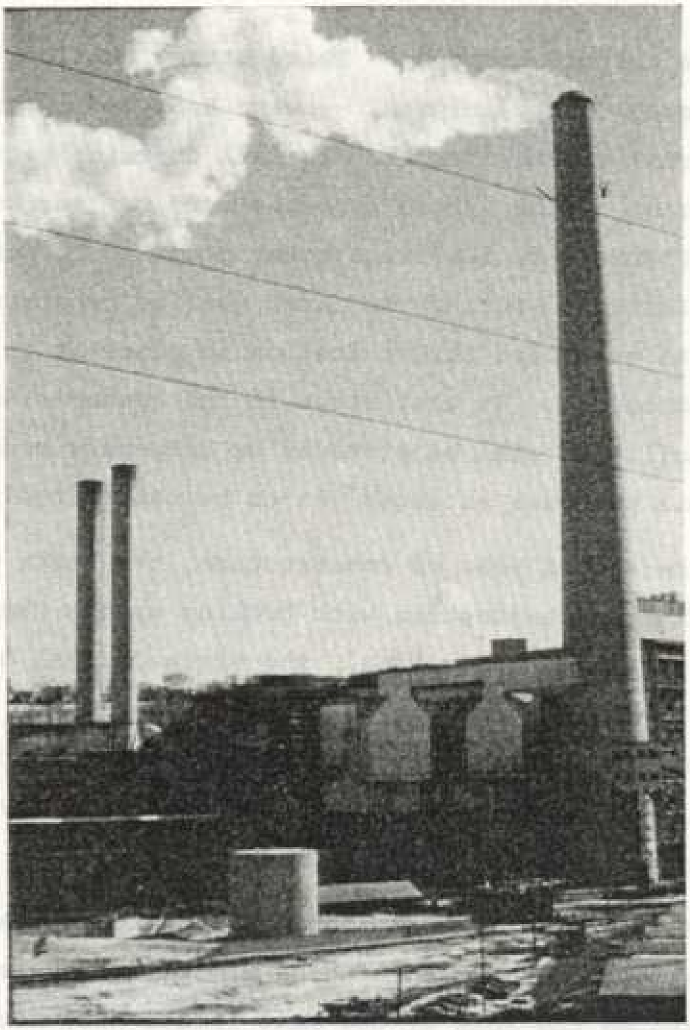


Future Heat Source

NSP's High Bridge Plant

conclusion. Although there exist many possible modes of retrofit for this plant, the district heating equipment, i.e., pumps, pressurizer, water storage, and controls would be essentially the same in any retrofit scheme. The district heating conversion used would be essentially a larger version of that described for the State Capitol heating plant with appropriate modifications depending on the type (if any) of cogeneration scheme selected.

Third Street Station Conversion (140 MWt)

Existing Plant. The Third Street Station has two Bros. boilers and one Riley boiler -- rated at 150,000 lb/hr each -- which were installed in 1962 (Bros.) and 1967 (Riley). The boilers are in good condition but the dust collectors are in need of an overhaul. It appears that all three boilers can meet Minnesota regulations of 0.40 lb/10^6Btu particulates on 80% Kentucky coal and 20% natural gas. The plant also has one gas fired boiler rated at 50,000 lb/hr.

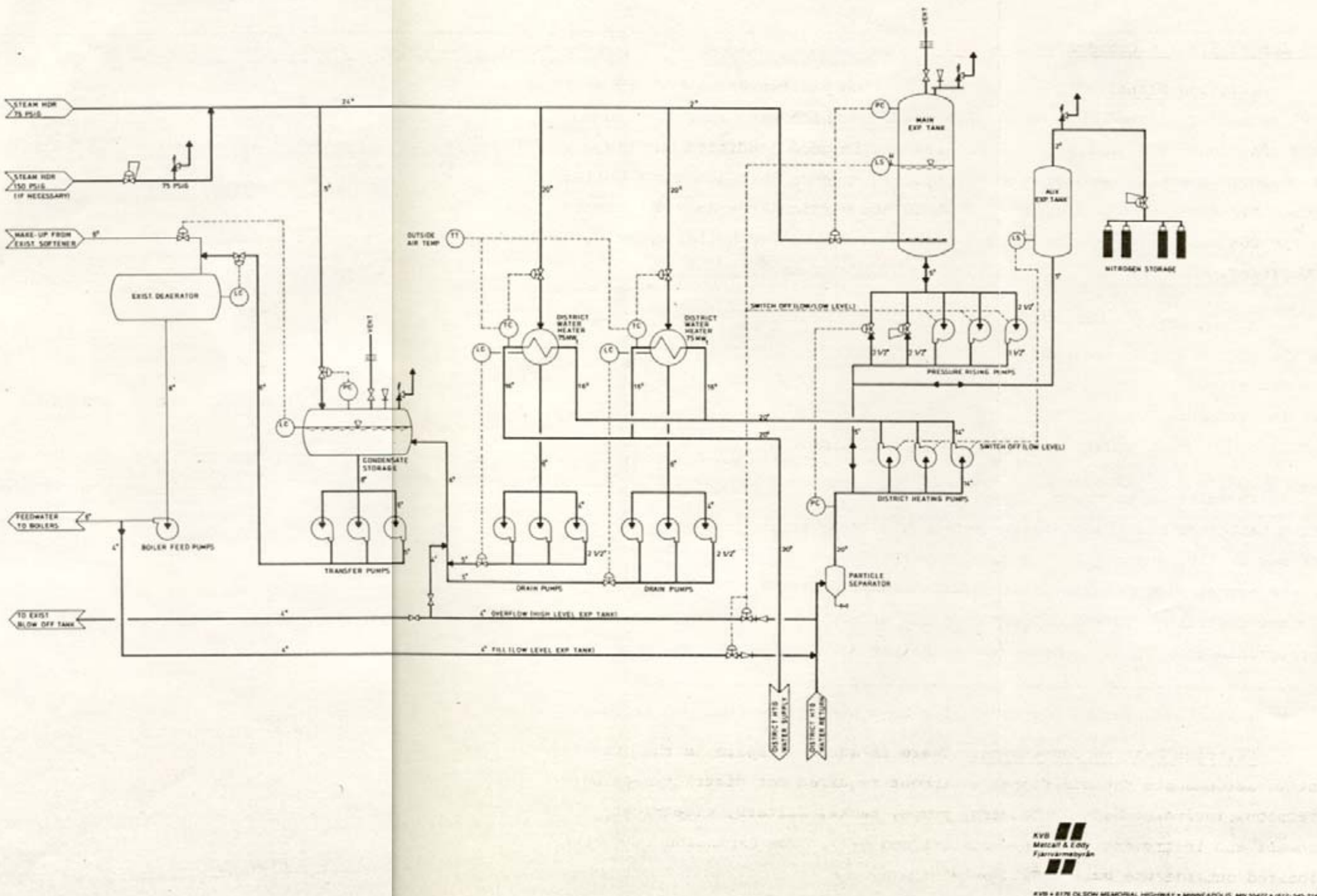
	Boiler No. 2	Boiler No. 3	Boiler No. 4
Make	Bros.	Bros.	Riley
Rated Capacity	150,000 lb/hr	150,000 lb/hr	150,000 lb/hr
Operating Pressure	150 psi	150 psi	150 psi
Fuel	Coal/Natural Gas	Coal/Natural Gas	Coal/Natural Gas

In addition to these three traveling grate stokers, Third Street Station has other boilers of lesser interest. These include several abandoned brick-set boilers and one 50,000 lb/hr gas fired package boiler. This latter unit was not considered as a potential district heating heat source since it could not contribute to either firm capacity or reserve capacity due to its interruptible fuel supply. However, the boiler does feed the common header and could be used during periods of low demand or boiler outage, assuming fuel was available. The boiler could also be converted to fuel oil and gas.

District Heating Conversion. There is adequate space in the existing plant to accommodate the additional equipment required for district heating conversion, including heat exchangers, pumps, tanks, filters, electrical equipment and instrumentation (Figures 6-1 and 6-2). The expansion tank will be located outside the building.

ORNL-DWG 81-23306

Figure 6-1
Third Street
Schematic Flow Diagram



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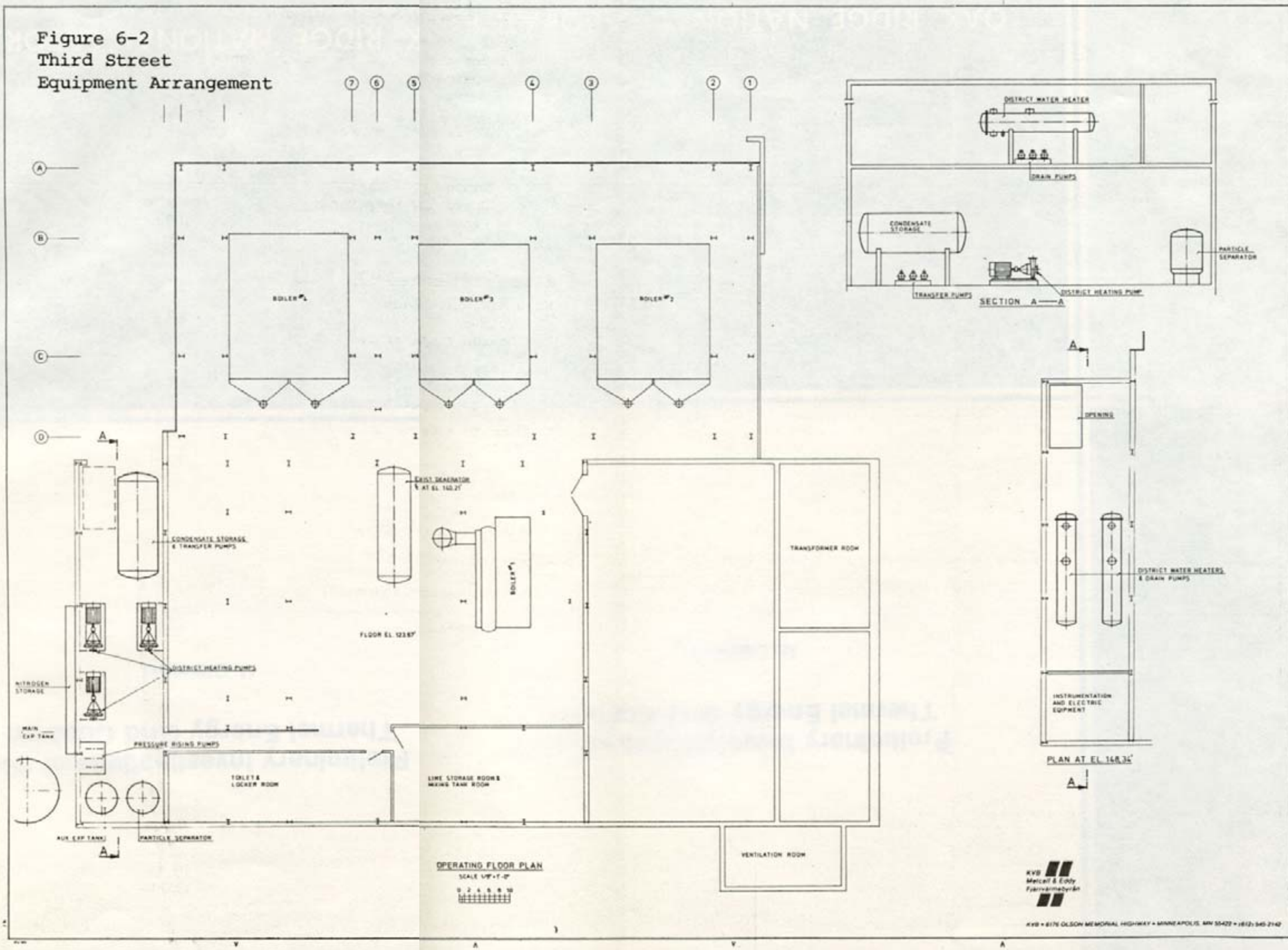


Figure 6-2
Third Street
Equipment Arrangement

Heat Exchangers

District Heating Heat Exchangers

Shell and tube type	
Condensing and drain cooling zones	
Steamside:	
Design pressure	100 psig
Operating pressure	30 psig
Drain temperature	195°F
Flow	230,000 lb/hr
Waterside:	
Design pressure	240 psig
Operating temperature	170/260°F
Flow	2,600,000 lb/hr
Total Capacity	2x70 MWt

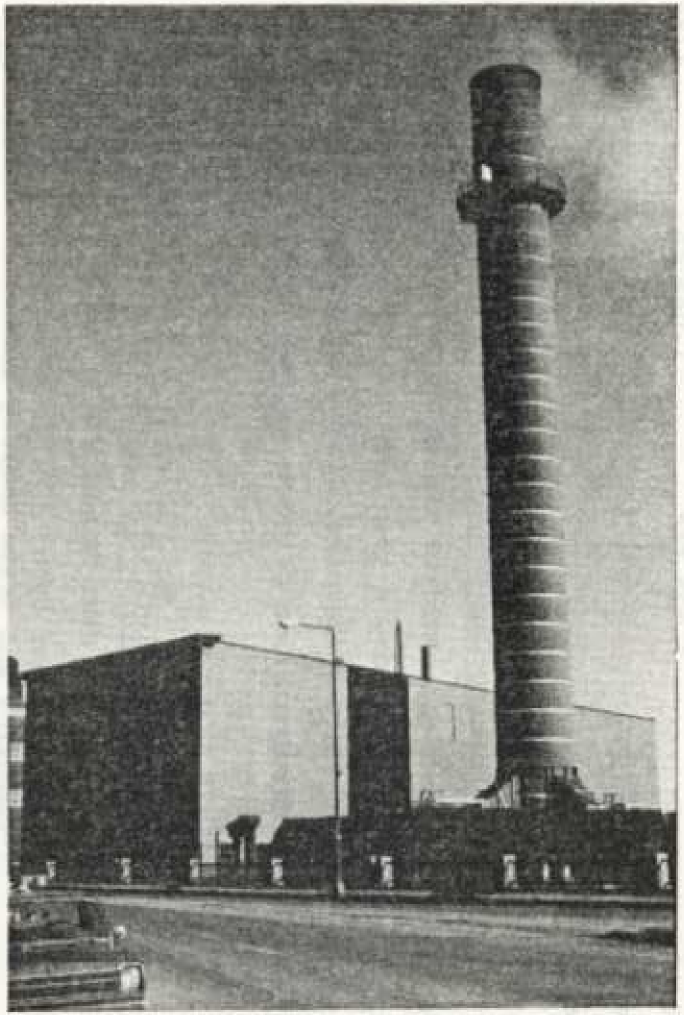
Pressure Vessels, Tanks

Main Expansion Tank	
Volume	53,000 gal.
Design temperature	290°F
Auxiliary Expansion Tank	
Volume	5,300 gal.
Design temperature	270°F
Condensate Storage Tank	
Volume	8,000 gal.
Design temperature	290°F
Filter	
Volume	5,000 gal.
Design temperature	270°F

Pumps

District Heating Pumps (3)	
Capacity	5,500 gpm
Total Head	260 ft
Motor	400 kW
Pressure Rising Pumps (3)	
Capacity	140 gpm
Total Head	200 ft
Motor	11 kW
Heat Exchanger Drain Pumps (6)	
Capacity	240 gpm
Total Head	70 ft
Motor	5.5 kW
Condensate Transfer Pumps (3)	
Capacity	460 gpm
Total Head	70 ft
Motor	11 kW

ORNL-PHOTO 8603-81



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Initial System Heat Sources

Third Street Station and State Capitol Heating Plant

Piping and Valves

Instrumentation and Controls

Accessory Electrical Equipment

State Capitol Heating Plant Conversion (36 MWt)

Existing Plant. The State Capitol heating plant has three Bros. boilers -- two rated at 40,000 lb/hr and one rated at 20,000 lb/hr -- all of which were installed in 1955. The condition of the boilers is quite good. Since emissions tests have never been performed, it was not possible to determine compliance with present emissions standards.

	Boiler No. 1	Boiler No. 2	Boiler No. 3
Make	Bros.	Bros.	Bros.
Rated Capacity	40,000 lb/hr	20,000 lb/hr	40,000 lb/hr
Max AWP	250 psi	250 psi	250 psi
Boiler Heating Surface	4,825 ft^2	2,225 ft^2	4,825 ft^2
Water Wall Heating Surface	1,335 ft^2	1,025 ft^2	1,335 ft^2
Steam Temperature	406°F	408°F	406°F
Fuel	Natural Gas/Oil	Natural Gas/Oil	Natural Gas/Oil

District Heating Conversion. Because there is inadequate space in the existing plant to accommodate the additional equipment required for district heating conversion, a one-level structure will need to be added to the plant to house heat exchangers, pumps, an expansion tank, electrical equipment and instrumentation (Figures 6-3 and 6-4).

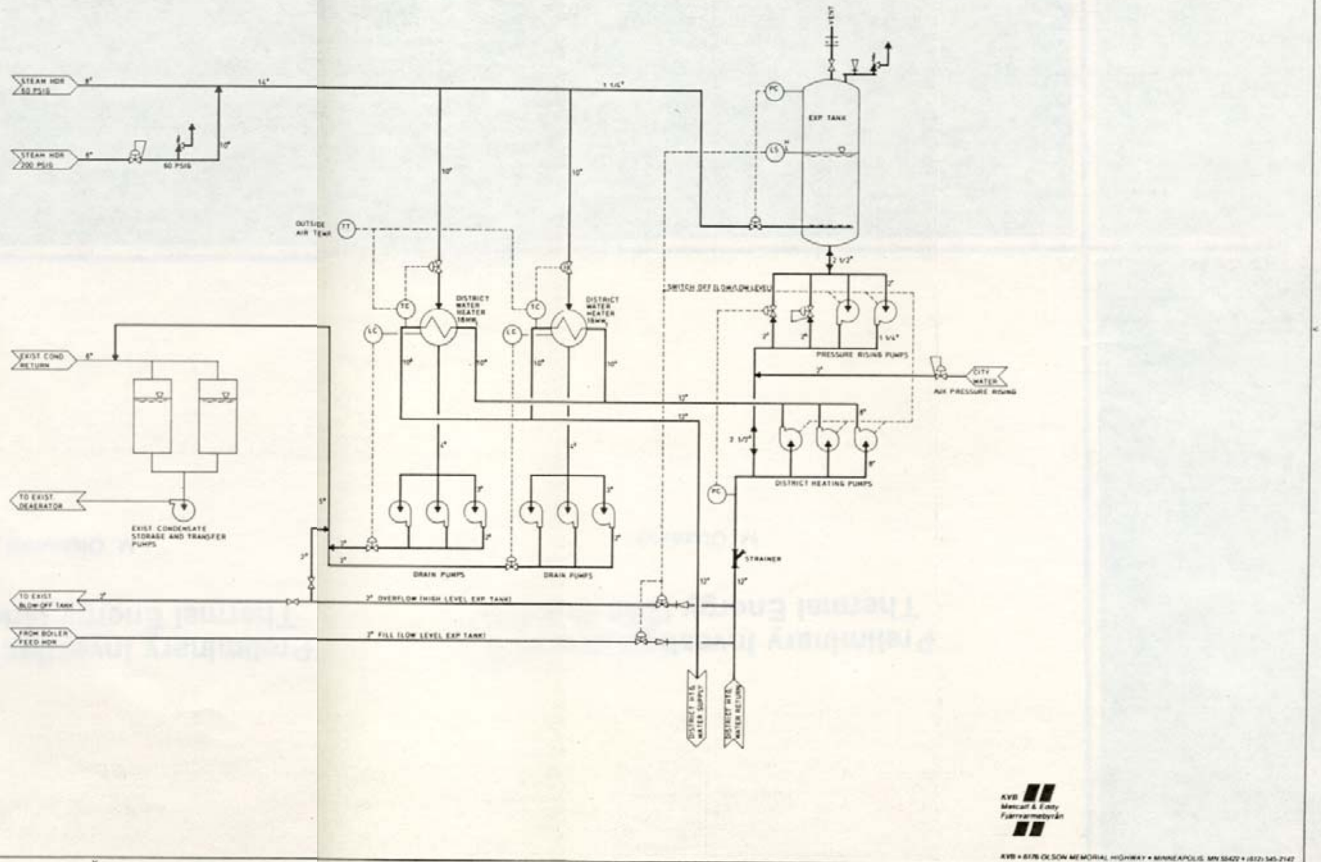
Heat Exchangers (2)

District Heating Heat Exchangers

Shell and tube type
Condensing and drain cooling zones
Steamside:
Design pressure 100 psig

ORNL-DWG 81-23308

Figure 6-3
State Capitol
Schematic Flow Diagram



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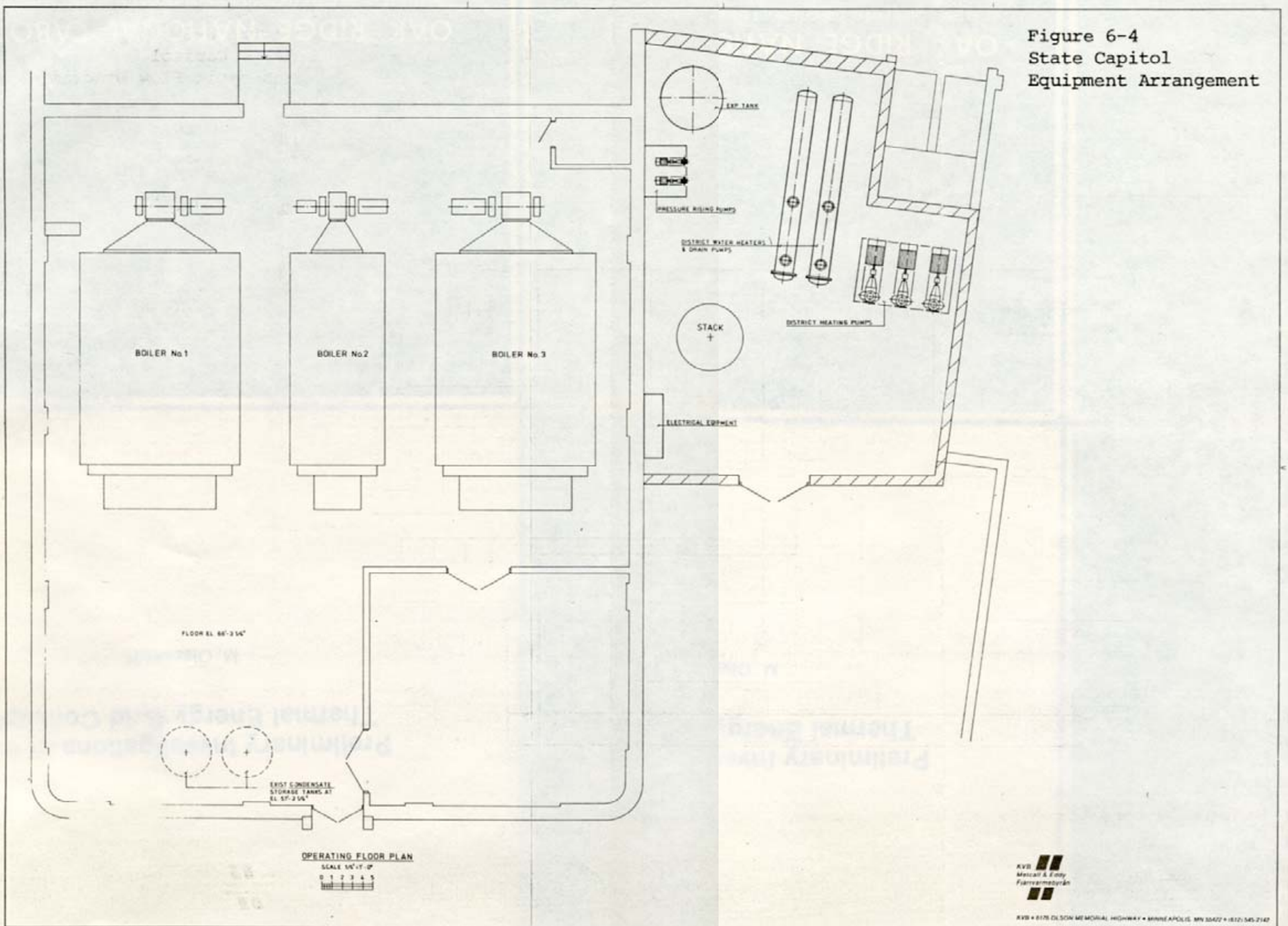

Figure 6-4
State Capitol
Equipment Arrangement

Operating pressure	30 psig
Drain temperature	195°F
Flow	59,000 lb/hr
Waterside:	
Design pressure	240 psig
Operating temperature	170/260°F
Flow	675,000 lb/hr
Total Capacity	2x18 MWt

Pressure Vessels, Tanks

Expansion Tank	
Volume	5,300 gas
Design temperature	290°F

Pumps

District Heating Pumps (3)	
Capacity	1,400 gpm
Total Head	165 ft
Motor	75 kW
Pressure Rising Pumps (2)	
Capacity	60 gpm
Total Head	165 ft
Motor	5.5 kW
Heat Exchanger Drain Pumps (6)	
Capacity	70 gpm
Total Head	70 ft
Motor	2.2 kW

Piping and Valves

Instrumentation and Controls

Accessory Electric Equipment

Ramsey County Hospital Conversion (36 MWt)

Existing Plant. The Ramsey County Hospital heating plant has four Nebraska boilers, each of which has a continuous rated capacity of 30,000 lb/hr. The boilers are in good condition, with the exception of No. 3 which needs to be retubed. Reconditioning work on No. 3 has already been contracted. Since no emissions tests have been performed on the boilers, it was not possible to determine compliance with present emissions regulations.

	Boiler No. 1	Boiler No. 2	Boiler No. 3	Boiler No. 4
Make	Nebraska	Nebraska	Nebraska	Nebraska
Rated Capacity	30,000 lb/hr	30,000 lb/hr	30,000 lb/hr	30,000 lb/hr
Boiler Heating Surface	2645 ft^2	2645 ft^2	2645 ft^2	2923 ft^2
Max AWP	200 psi	200 psi	200 psi	200 psi
Steam Temperature	400°F	400°F	400°F	400°F
Fuel	Oil/Nat Gas	Oil/Nat Gas	Oil/Nat Gas	Oil/Nat Gas

District Heating Conversion. There is adequate space in the existing plant to accommodate the additional equipment required for district heating conversion, including heat exchangers, pumps, tanks, filters, electrical equipment and instrumentation (Figures 6-5 and 6-6). The expansion tank will be located outside the building.

Heat Exchangers

District Heating Heat Exchangers

Shell and tube type
Condensing and drain cooling zones
Steamside:

Design pressure	100 psig
Operating pressure	30 psig
Drain temperature	195°F
Flow	59,000 lb/hr

Waterside:

Design pressure	240 psig
Operating temperature	170/260°F
Flow	675.000 lb/hr
Total Capacity	2x18 MWt

Pressure Vessels, Tanks

Expansion Tank

Volume	5,300 gal.
Design temperature	290°F

Pumps

District Heating Pumps (3)

Capacity	1400 gpm
Total Heat	165 ft
Motor	75 kW

ORNL-DWG 81-23310

Figure 6-5
Ramsey Hospital
Schematic Flow Diagram

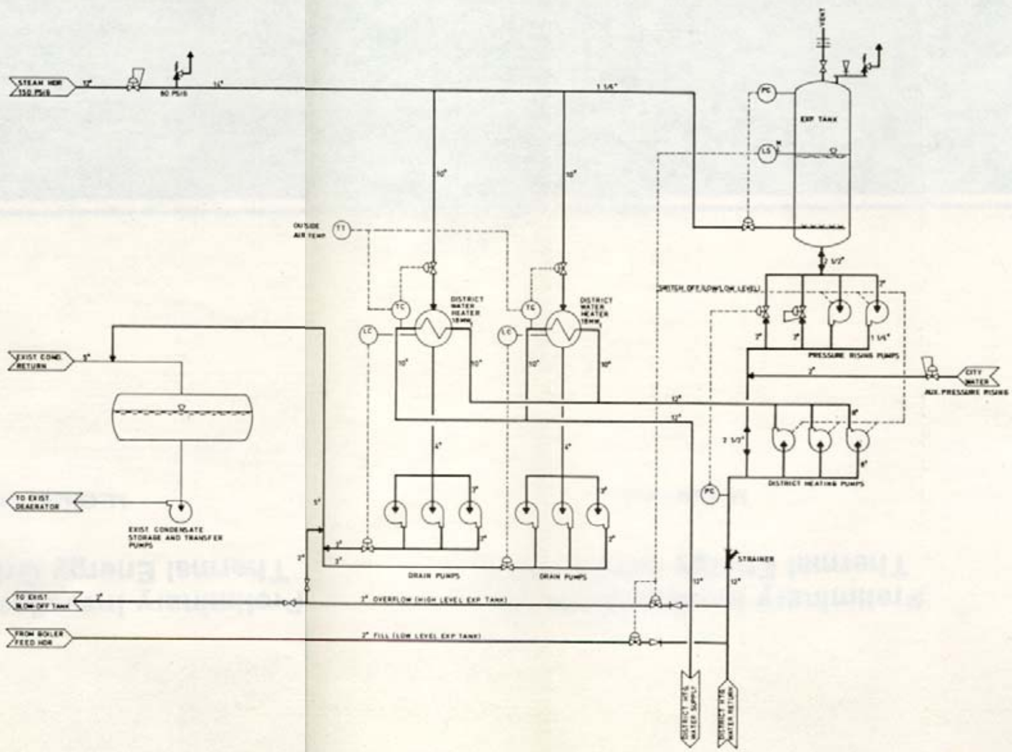

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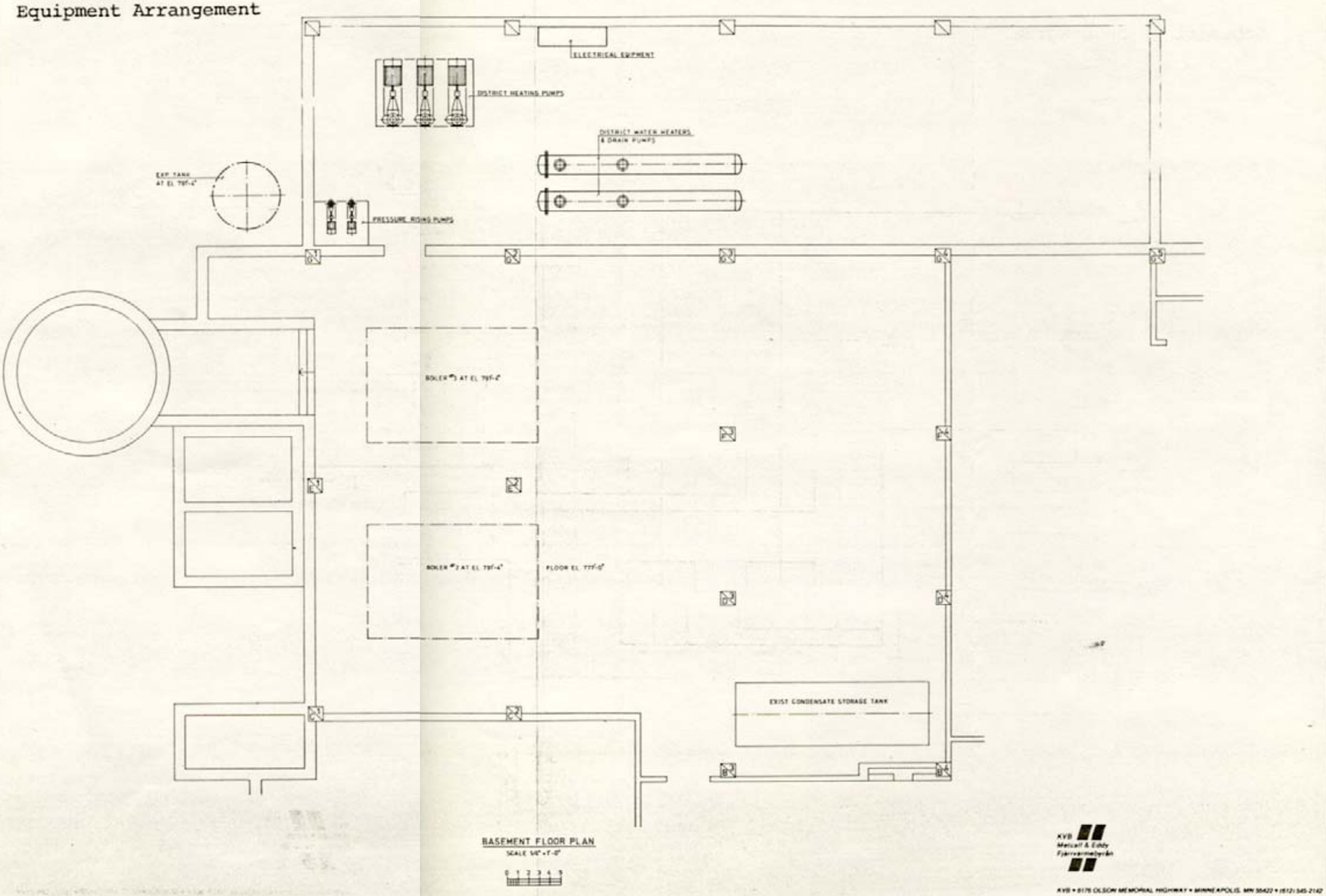
Figure 6-6
Ramsey Hospital
Equipment Arrangement



Pressure Rising Pumps (2)

Capacity	60 gpm
Total Head	165 ft
Motor	5.5 kW

Heat Exchanger Drain Pumps (6)

Capacity	70 gpm
Total Head	70 ft
Motor	2.2 kW

<u>Piping and Valves</u>

<u>Instrumentation and Controls</u>

<u>Accessory Electric Equipment</u>

Chapter Seven
Project Costs

Chapter Seven
Project Costs

Basis for Cost Estimates (Distribution System)

The cost estimate for the St. Paul hot water district heating system was prepared using current cost data -- ENR Construction Cost Index of 3200. The materials selected for use are the American equivalents of products which have a history of successful service in European district heating systems, and which meet the requirements of the Swedish District Heating Association Standards. All substantial material requirements were priced from quotations by suppliers in the St. Paul area, or as delivered to the St. Paul area.

The labor and equipment costs for the construction crew are based on current Minneapolis wage rates and nationally averaged rental rates, as published by Richardson Engineering Services and Associated Equipment Distributors, respectively. An allowance of 25 percent was added to the wage rates to cover various insurance and taxes associated with labor.

All unit costs for labor, equipment and materials include an allowance for contractor's overhead and profit appropriate to a moderately competitive bidding atmosphere.

The cost of installing the various pipe lines was compiled by comparing per diem costs of labor and equipment to a table of production rates. The production rates were established based upon such factors as pipeline diameter, amount of rock excavation, soil conditions, interference with existing utilities, traffic control, etc.

A typical crew consists of a wheeled loader, two backhoes, a dump truck, welding rig, miscellaneous pumps and tools, four operating engineers, three laborers, a welder, a driver and a foreman. One of the backhoes is rigged with a pneumatic powered rock breaker for use in excavating limestone. No blasting is anticipated. Where no rock is anticipated, the rigged backhoe and operator has been accordingly eliminated from the production crew.

The cost of construction is largely dependent on the speed of construction. Several contractors in the St. Paul area were interviewed before typical construction rates were assigned to the various classes of work. For the analysis, four soil conditions were identified ranging from "no rock" to "all rock". Five ranges of pipe sizes were considered. Based on this matrix, twenty typical rates and costs of construction were generated, one for each soil type and pipe size combination (Figure 7-1).

The type of excavation was determined for each street from the study of subsurface conditions. Knowing soil conditions and pipe size, it was possible to determine typical costs of construction in each street. These general costs could then be modified as warranted by other factors, such as interferences with existing utilities specific to each location. Separate costs were estimated for special conditions not covered by the typical cost matrix.

To these daily operating costs for labor and equipment was added the cost of the materials to be installed. A detailed take-off of the number and type of each component was compiled, and appropriate unit prices assigned based upon the cost of the item delivered to St. Paul.

The cost of such standardized items as valve and compensator chambers is largely a function of the cost of the materials used. For example, the cost of installing a 20-inch main line valve is insignificant in comparison to the cost of the valve itself. For items of this type, sketches were prepared. These sketches were adapted from detailed construction drawings or similar structures used on Swedish projects. The construction drawings themselves were used to take off many of the components to be used. Therefore, an accurate material take off combined with computed installation costs, permitted a good degree of precision in the cost estimate of those elements which are not unique to the system proposed for St. Paul.

Installation of the pipe generally involves excavating and placing as simultaneous operations, with excavated material being disposed of out of the area. The trench will be left open and barricaded between chambers until after the pipe has been tested. The trench will then be backfilled and compacted in an acceptable manner to the subgrade of the concrete mat provided below the pavement. The mat, pavement and general restoration and cleanup will then follow to complete the operation.

The chambers are priced as cast-in-place structures, to be built as an on-going process of the general operation, with placing of the pipe prerequisite to their installation. Associated excavation, precast manholes

Figure 7-1
Distribution Piping Network -
Subsurface Conditions

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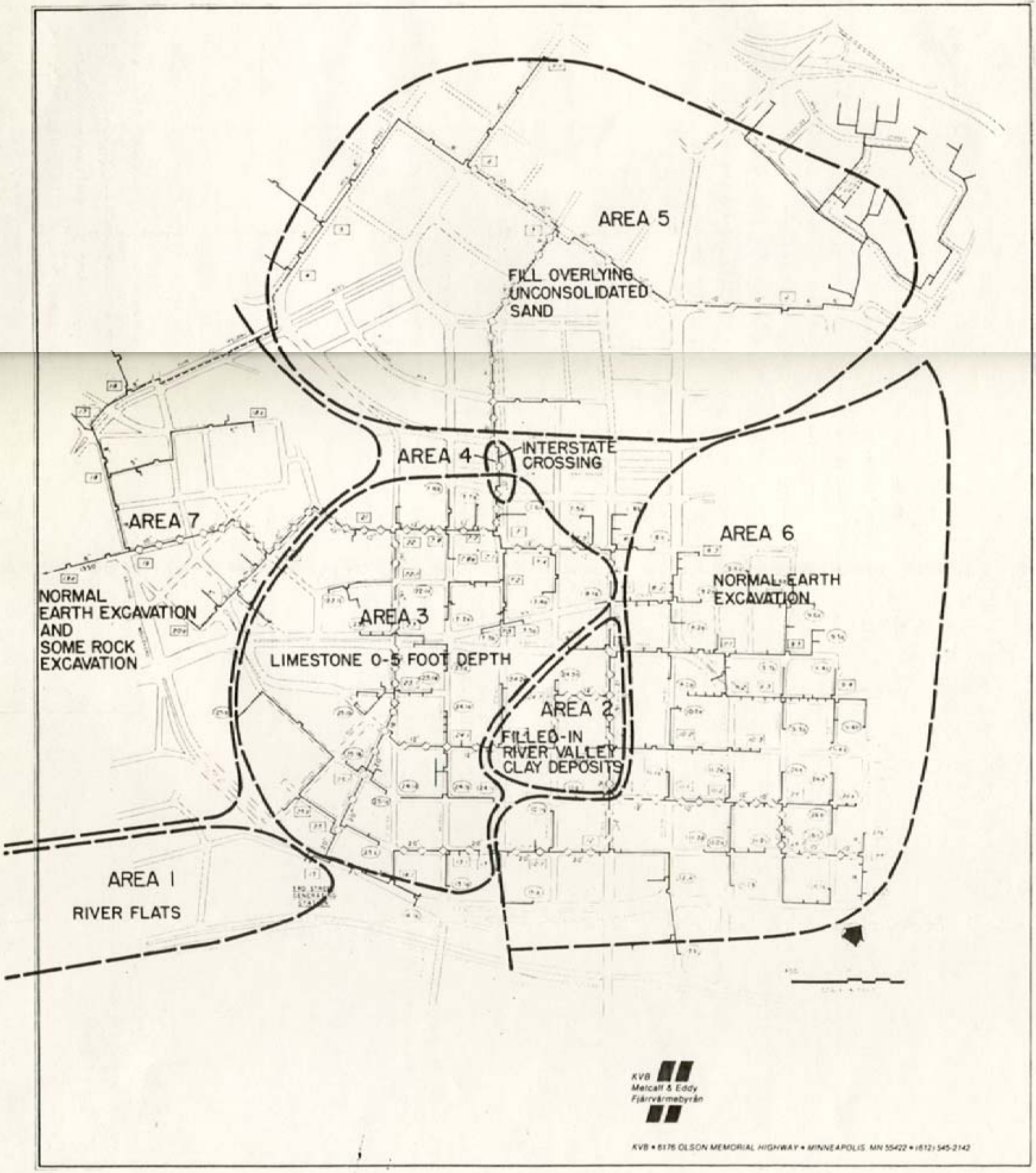


and drains are also to be installed in conjunction with the pipe installation operation.

Although the majority of the cost of the transmission and distribution system consists of pipe in trench plus valving, there are several other major unique components of the system, such as the bridge crossing over the Interstate and pipe jackings beneath railroads. For these items, a conceptual design of the proposed structure was completed to show the size and type of as many of its components as was reasonable. With the structure thus defined, the individual tasks and construction procedures involved in completing its construction were established. The time, number of workers, and equipment necessary to complete each task were computed. The quantities of excavation, and the materials to be used were likewise calculated, and the estimate of the cost of the structure developed.

After all costs of labor and material are summed, an allowance to the total cost is added to cover the additional cost of items such as shop drawing preparation, temporary offices, preparation of schedules, acquisition of permits, bid bonds, and supplemental insurance.

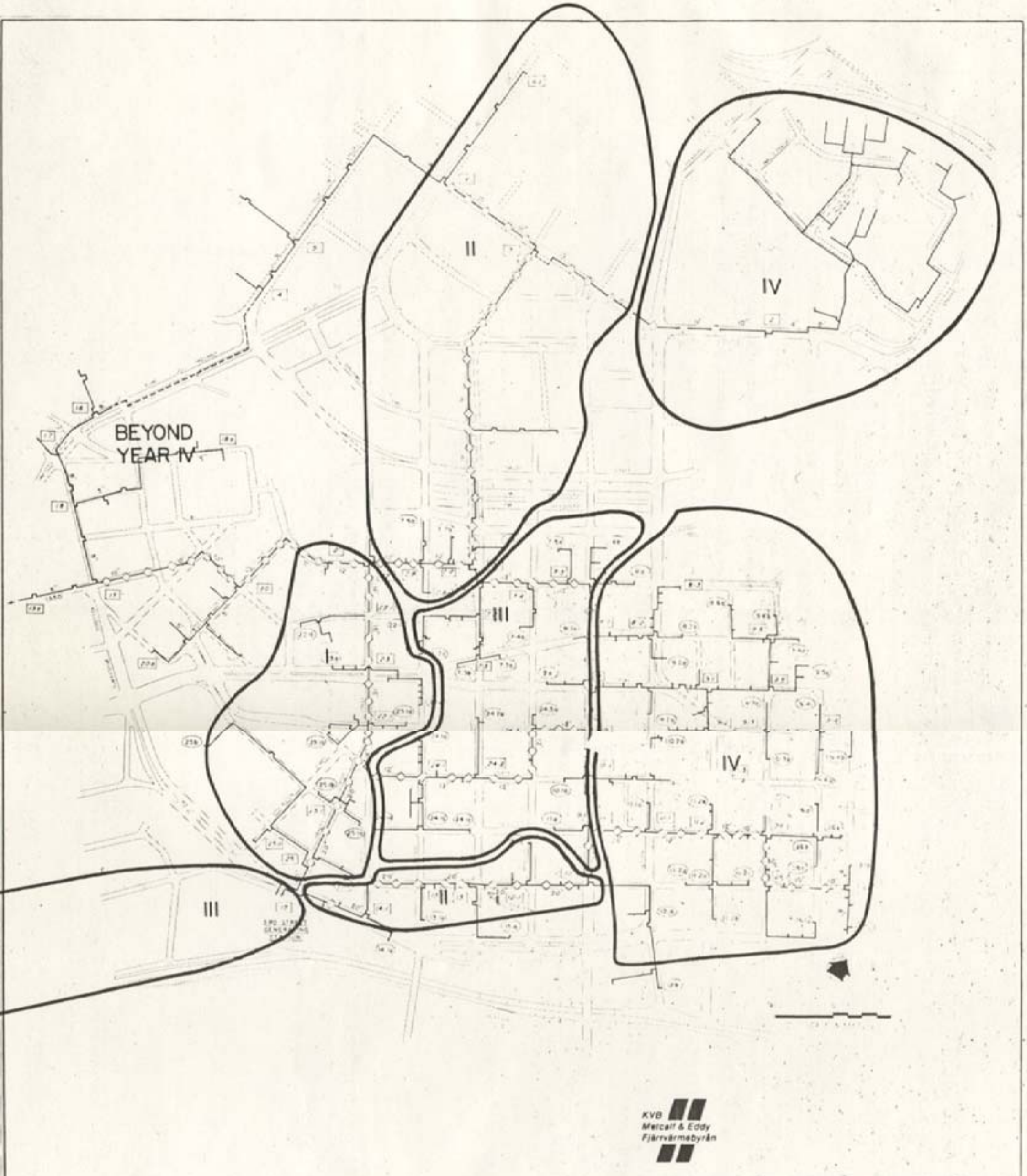
The estimate has been prepared as accurately as possible from the preliminary layout of the proposed district heating transmission and distribution network. Most of the major components of the system can be envisioned at this stage, and their price established. Obviously a detailed design would define more of the minor items which will be required to complete the network. General allowances have been included in this estimate for these items. The costs set forth in this report are adequate to cover construction of the network at present day prices.

The estimated length of pipe, and the number of chambers are shown in Table 7-1. Generalized costs per foot of twin pipe installed are presented in Table 7-2. It must be remembered that these generalized costs are based on completing large segments of work in each yearly contract.

A proposed construction sequence is presented in Figure 7-2 which divides the project into five yearly construction projects. The construction schedule is largely based on common sense and patent economics. The first year's construction will connect large (currently steam) customers in close

Figure 7-2
Distribution Piping Network -
Construction Phases

ORNL-DWG 81-23313



proximity to Third Street Station. The second year's construction will connect the Capitol Complex and Capitol Heating Plant to the district heating system, allowing this heat source to supplant the mobile boilers used for peaking and reserve during the first year. Construction during the third year will connect additional high load density areas downtown and also install transmission lines between High Bridge and Third Street. Once High Bridge is on line, lower load density areas will be connected as the system expands to its full capacity. A detailed cost breakdown for each of these projects is presented in Table 7-3. It can be seen from this table that, while trench excavation is a major cost component, the large amount of rock excavation does not increase the overall cost of the project by more than 10 percent. It can also be seen that materials such as pipe and valves represent a very large proportion of construction cost. This price includes the contractor's usual markup for overhead, handling and profit. If the district heating utility were to prepare purchase specifications for this material, and obtain it directly, some savings should be realized.

Table 7-4 presents a quarterly cash flow projection for constructing the project according to the sequence shown in Figure 7-1 and Tables 7-1 and 7-3. The actual sequence of construction would depend upon such factors as the ease with which potential customers can be attracted to connecting to the district heating system. For the purpose of determining the feasibility of the entire undertaking, this construction schedule has been selected because it represents a logical growth of the network from the design and construction viewpoint. However, the network is designed to be adaptable to other construction scenarios should these be found more desirable.

TABLE 7-1. CONSTRUCTION SUMMARY

Construction Year	Total Pipe Length (Ft) by Size									
	20"	16"	12"	10"	8"	6"	5"	4"	<3"	Chambers
First	2,200	2,800	600		940	1,280	1,300	1,140	6,820	17
Second	4,720	4,600	1,400	1,600	1,840	180	860	1,480	6,140	35
Third*	800	1,400	7,800		460	2,140	240	940	8,730	31
Fourth			1,900	5,700	4,180	4,270	5,440	10,190	27,080	24
Beyond Fourth				3,800	8,500		3,960	650	4,440	14
Grand Total	7,720	8,800	11,700	11,100	15,920	7,870	11,800	14,400	53,210	121

*Third year construction also includes the transmission main between the two generating stations which is 30" pipe, 10,000 feet in length.

TABLE 7-1. CONSTRUCTION SUMMARY (Continued) First Year

Location			Total Pipe Length (Ft) by Size									
Street	From	To	20"	16"	12"	10"	8"	6"	5"	4"	<3"	Chambers
Tenth	St. Peter	Main			600		80					2
W. Exchange	St. Peter	Main									1,320	
Eighth	Wabash	St. Peter									1,740	
E. Ninth	St. Peter	Main									600	
Seventh	Wabash	St. Peter							340		640	
Seventh	St. Peter	Washington									1,080	
Fifth	Market	St. Peter									300	
Fourth	St. Peter	Market					660	400				
Fourth	Market	Washington										
Washington	Fourth	Kellogg									300	
Washington	Fourth	Fifth						400	400	400	140	
Fifth	Washington	E. Ninth						480	560	540	200	
St. Peter	Sixth St.	Tenth		2,800							500	10
Market	Sixth St.	Kellogg	2,200									5
St. Peter	Tenth	Eleventh					200					
Fifth	Market	Washington								200		
		TOTAL	2,200	2,800	600	-	940	1,280	1,300	1,140	6,820	17

TABLE 7-1. CONSTRUCTION SUMMARY (Continued) Second Year

Location			Total Pipe Length (Ft) by Size									
Street	From	To	20"	16"	12"	10"	8"	6"	5"	4"	<3"	Chambers
Cedar	Tenth	University Ave		4,600							1,600	15
Tenth	Cedar	St. Peter			1,400						680	5
University Ave.	Cedar	Park				1,600						5
Park	University	Charles Ave					1,800					
Fourth	Robert	St. Peter	3,000				40	80	40	140	200	9
St. Peter	Fourth	Kellogg	430									
Kellogg	St. Peter	Market	1,290					100	80			1
Wabash	Fourth	Kellogg							500			
Kellogg	St. Peter	Wabash							240	240	140	
Wabash	Tenth	Ninth								460	500	
Cedar	Fourth	Kellogg								640	680	
Columbus Ave.	Cedar	Robert									1,200	
Wabash	Tenth	Eleventh									600	
Minnesota	Fourth	Fifth									540	
		TOTAL	4,720	4,600	1,400	1,600	1,840	180	860	1,480	6,140	35

TABLE 7-1. CONSTRUCTION SUMMARY (Continued)

Third Year

Location			Total Pipe Length (Ft) by Size									
Street	From	To	20"	16"	12"	10"	8"	6"	5"	4"	<3"	Chambers
Tenth	Robert	Cedar			1,800						660	5
Cedar	Tenth	Ninth					460	260	60	100	460	
W. Exchange	Cedar	Wabash								200	580	
Wabash	Ninth	Eighth								200	580	
Ninth	Cedar	Minnesota									250	
Ninth	Cedar	Wabash									300	
Minnesota	Tenth	Ninth									900	
Robert	Tenth	Eleventh									660	
Tenth	Robert	Jackson									720	
Robert	Tenth	Fourth	800	1,400	2,000					240	60	13
Eighth	Robert	Minnesota									220	
Seventh	Robert	Minnesota			600					80	60	3
Minnesota	Seventh	Sixth			600					60	160	3
Sixth	Minnesota	Market			2,800			360		60	220	7
Cedar	Sixth	Seventh						900	140			
Wabash	Sixth	Seventh									820	
Wabash	Sixth	Fifth						360			180	
Fifth	Wabash	St. Peter									540	
Fifth	Wabash	Cedar						260	40		600	
Sixth	Robert	Minnesota									260	
Fifth	Robert	Minnesota									300	
Ninth	Robert	Minnesota									200	
		TOTAL	800	1,400	7,800	-	460	2,140	240	940	8,730	31

TABLE 7-1. CONSTRUCTION SUMMARY (Continued)

Fourth Year

Location			Total Pipe Length (Ft) by Size									
Street	From	To	20"	16"	12"	10"	8"	6"	5"	4"	<3"	Chambers
University Ave.	Robert	I-35E				3,400	1,320				340	7
Jackson	Tenth	Ninth								500	680	
Jackson	Ninth	Eighth									400	
Ninth	Jackson	Robert							460	540	160	
Ninth	Jackson	Temper									400	
Ninth	Wacouta	Sibley								500	200	
Sibley	Ninth	Tenth								500	360	
Wacouta	Ninth	Tenth									460	
Ninth	Wacouta	Wall										
Wacouta	Ninth	Eighth							700		80	
Eighth	Wacouta	Wall									1,040	
Eighth	Wacouta	Sibley					1,700		800	260	120	
Eighth	Sibley	Robert									460	
Sibley	Eighth	Seventh					600				240	
Seventh	Sibley	Jackson									600	
Seventh	Sibley	Wall						750	800		840	
Wacouta	Seventh	Sixth								420	160	
Wacouta	Seventh	Eighth									80	
Wall	Seventh	Sixth								350	270	
Wall	Seventh	Eighth									400	
Broadway	Seventh	Sixth									400	
Seventh	Wall	Broadway								400		
Sixth	Wacouta	Robert			1,900	500		440	500	300	1,200	
Jackson	Sixth	Seventh								600	60	
Fifth	Wall	Robert								640	240	9

TABLE 7-1. CONSTRUCTION SUMMARY (Continued)

Fourth Year (Page 2)

Location			Total Pipe Length (Ft) by Size									
Street	From	To	20"	16"	12"	10"	8"	6"	5"	4"	<3"	Chambers
Jackson	Fifth	Sixth								400	200	
Sibley	Fifth	Sixth									360	
Wacouta	Fifth	Sixth									320	
Wall	Fifth	Sixth									420	
Fifth	Wall	Broadway									400	
Sibley	Fifth	Kellogg						780		560	80	
Wacouta	Fifth	Fourth									180	3
Wall	Fifth	Fourth				600					400	
Fourth	Robert	Jackson						650		20		
Fourth	Sibley	Jackson								400		
Fourth	Sibley	Wacouta									480	
Fourth	Wacouta	Broadway				1,200					120	5
Jackson	Fourth	Warner						650	480	500	600	
Wacouta	Fourth	Kellogg									750	
Kellogg	Wacouta	Wall									830	
Broadway	Fourth	Kellogg					560				280	
Mt. Airy	Jackson	L'Orient						1,000	1,700	1,000	2,800	
	Mt. Airy	Arch St.									2,600	
Wales	Mt. Airy	Arch St.									2,460	
Linden	Mt. Airy	Arch St.								800	1,060	
Arch	Linden	Arch									2,500	
	Arch	Pennsylvania								900	1,050	
Broadway	Fourth	Fifth					400					
L'Orient	Mt. Airy	Arch								600		
		TOTAL	-	-	1,900	5,700	4,580	4,270	5,440	10,190	27,080	24

TABLE 7-1. CONSTRUCTION SUMMARY (Continued) Beyond Fourth Year

Location			Total Pipe Length (Ft) by Size									
Street	From	To	20"	16"	12"	10"	8"	6"	5"	4"	<3"	Chambers
University	Park	Rice					1,800					
Rice	University	Twelfth					2,100				1,000	
John Ireland	Twelfth	W. Kellogg					700			650	1,000	
Anthony	W. Kellogg	Louis										
W. Kellogg	John Ireland	Rice					1,900				240	
Rice	Ninth	Sherman				1,700	2,000					5
Main	Tenth	Fifth				800			1,360		1,300	3
Fifth	Main	W. Kellogg										
Concordia	Main	E. Ninth									700	
Ninth	Main	Smith				500						3
Tenth	Main	St. Peter				800						3
Mulberry	W. Kellogg	Concordia							1,300		100	
Concordia	Mulberry	Summit							300			
Summit	Concordia	Ninth							1,000		100	
		TOTAL	-	-	-	3,800	8,500	-	3,960	650	4,440	14

TABLE 7-2. ST. PAUL DISTRICT HEATING PROJECT
GENERALIZED COSTS

Pipe Diameter, Inch	Estimated Total Cost per Foot of Trench (2 Pipelines)	
	No Rock	All Rock
20	$700	$930
16	610	770
12	500	660
10	340	440
8	225	325
6	200	300
5	175	270
4	155	240
3	135	220
2½ and below	95	155

NOTE: Total costs include average linear cost for manholes, valves, expansion devices, customer take-offs, plus indirect costs for engineering and contingencies.

TABLE 7-3. COST SUMMARY

Operation	Estimated Costs (Thousands of Dollars)						
			Third Year				
	First Year	Second Year	Downtown	High Bridge/ Third Street	Fourth Year	Beyond Fourth Year	Total
Trenching and Installing Pipe	1,000	965	865	237	1,605	420	5,092
Materials, pipe, valves and fittings	1,550	1,900	1,345	2,611	1,960	875	10,241
Backfill	175	190	225	193	440	190	1,413
Paving and restoration	265	370	335	116	775	305	2,166
Chambers	405	750	615	210	575	260	2,815
Railroad Jackings				546			546
Interstate highway crossing		250					250
Anchors				32			32
Cathodic protection, alarms and appurtenances	45	60	50	40	95	35	325
Testing	10	15	15	15	50	15	120
Subtotal	3,450	4,500	3,450	4,000	5,500	2,100	23,000
Engineering and Contingencies	900	1,175	900	1,045	1,430	550	6,000
Total	4,350	5,675	4,350	5,045	6,930	2,650	29,000

TABLE 7-4

QUARTERLY CASH FLOW PROJECTION

Prior to Start of First Year Construction	
Surveys, borings, design, bid & award, purchase specifications, obtain permits	$ 625,000
Year 1 Construction and Engineering	
First quarter	150,000
Second quarter	1,425,000
Third quarter	1,425,000
Fourth quarter	1,250,000
	4,250,000
Year 2 Construction and Engineering	
First quarter	200,000
Second quarter	2,250,000
Third quarter	2,250,000
Fourth quarter	850,000
	5,550,000
Year 3 Construction and Engineering	
First quarter	350,000
Second quarter	3,325,000
Third quarter	3,325,000
Fourth quarter	2,175,000
	9,175,000
Year 4 Construction and Engineering	
First quarter	250,000
Second quarter	2,725,000
Third quarter	2,725,000
Fourth quarter	1,100,000
	6,800,000
Area Outside of First Market Area	
First quarter	100,000
Second quarter	1,025,000
Third quarter	1,025,000
Fourth quarter	450,000
	2,600,000
TOTAL	$29,000,000

Basis for Cost Estimates (Power Plants)

In developing the cost estimates for converting the selected power plants to district heating, a preliminary conversion design was first drawn up for each power plant -- Third Street Station (NSP), State Capitol Heating Plant (State of Minnesota), and Ramsey Hospital (Ramsey County). As a part of developing the conversion designs, schematic flow diagrams were prepared and, eventually, equipment was selected and arranged on plan drawings of each boiler station. These drawings, in turn, were used as a basis for materials and equipment take-offs.

The cost estimates for each power plant conversion, as presented in Tables 7-5 through 7-8, include all materials and equipment required to accomplish the conversion. These items include: structural work, heat exchangers, pressure vessels, tanks, pumps, piping, valves, instrumentation and controls and electrical equipment.

Also included in the cost estimates is the cost of all labor related directly to the conversion.

Additional costs for contingencies (15%), engineering (12.5%), and construction services (10%) have been included, as well, in the cost estimates. Not included in the estimates are costs for startup operations, taxes, or insurance during construction.

TABLE 7-5. COST SUMMARY

Site	MW	Estimated Cost
Third Street Station	70	$1,938,900
State Capitol	36	796,300
Ramsey Hospital	36	618,200
		$3,353,400
Engineering, 12.5%		$ 364,500
Construction Services, 10%		291,600
	Total	$4,009,500

TABLE 7-6. STATE CAPITOL

Item	Estimated Costs
Structures	$138,000
Heat Exchangers	98,400
Pressure Vessels, Tanks	22,800
Pumps	56,400
Piping & Valves	228,000
Instrumentation & Control	120,000
Accessory Electric Equipment	28,800
Contingency 15%	103,900
TOTAL	$796,300

TABLE 7-7. RAMSEY HOSPITAL

Item	Estimated Costs
Structures	$ 19,200
Heat Exchangers	98,400
Pressure Vessels, Tanks	22,800
Pumps	56,400
Piping & Valves	192,000
Instrumentation & Control	120,000
Accessory Electric Equipment	28,800
Contingency 15%	80,600
TOTAL	$618,200

TABLE 7-8. THIRD STREET STATION

Item	Estimated Costs
Structures	$ 91,200
Heat Exchangers	268,800
Pressure Vessels, Tanks	330,000
Pumps	261,600
Piping & Valves	516,000
Instrumentation & Control	156,000
Accessory Electric Equipment	62,400
Contingency 15%	252,900
TOTAL	$1,938,900

Chapter Eight
Permit Requirements

Chapter Eight
Permit Requirements

General

This chapter discusses the environmental and other permits which are likely to be required for the St. Paul hot water district heating transmission and distribution system. The analysis of permit requirements focuses on four major issues:

1. What are the permits required?
2. Do there appear to be any significant adverse impacts or controversy associated with the route selected for the transmission and distribution system?
3. Do there appear to be any significant obstacles to obtaining the required permits?
4. Are there any substantial costs or time requirements involved in obtaining the permits?

The chapter is organized to present the overall findings of the analysis first. The specific permits are then described under the separate headings of Federal, state or local permits. The discussion of specific permits is followed by an estimate of the cost to prepare the permits.

Findings

The major findings from the analysis of permit requirements are as follows:

The Minnesota Energy Agency is currently undertaking a "District Heating Regulatory Study" scheduled for completion October 15, 1981. The study will investigate the environmental requirements for two district heating scenarios, one of which is the proposed St. Paul District Heat Project. The study will develop the detailed information concerning the permit process including permits required, responsible agency, statutory authority, application procedures, estimated time and expense to generate application data, application fees, processing time, public involvement and copies of application forms and instructions. The study will also recommend a strategy or strategies for obtaining the permits in an efficient manner. The analysis of permit requirements presented in this report was coordinated with the Minnesota Energy Agency and is based on the interviews conducted as part of that study. It is recommended that, when the Minnesota Energy Agency study is complete, that study supplement the information presented here and be used as the comprehensive analysis of environmental requirements.

There appear to be no significant adverse impacts or controversy associated with the route selected for the hot water distribution and transmission system. The State of Minnesota environmental review process resulted in a determination that no environmental impact statement was required. It is likely that the Federal environmental review will result in a similar determination. Except for the operating franchise, there appear to be no substantial costs associated with obtaining the permits. It is estimated that approximately eight weeks of consulting engineering effort should be allocated to prepare the required plans and technical information for submission to the agencies. The operating franchise from the City Council to use the streets and other public property for purposes of district heating has significant costs associated with it. The annual fee for this franchise could be on the order of five to eight percent of gross earnings.

There appear to be no major obstacles or delays to obtaining the necessary permits. The key to the process moving smoothly is in careful scheduling of the permits, good coordination with the permit granting agencies and complete submissions.

Federal Permits/Authorizaton

Environmental Review. In accordance with the National Environmental Policy Act (NEPA) of 1969, the U.S. Department of Energy (DOE) is undertaking an environmental review of the St. Paul District Heat Project to determine whether there are any significant adverse effects of the project and mitigation measures. The DOE has engaged Oak Ridge National Laboratory to prepare an environmental assessment of the project and is funding 100 percent of the cost of the study. The assessment will comply with the Council of Environcmental Quality's regulations, published in the Federal Register, November 29, 1978, and the Department of Energy's proposed regulations published in the Federal Register July 18, 1979. The assessment is scheduled for completion in the fall of 1980. It is anticipated that the project will not require an environmental impact statement.

National Pollutant Discharge Elimination System (NPDES) Permit. In accordance with the U.S. Water Pollution Control Act (Public Law No. 95-217), Minnesota Statutes 115 and 116 and Minnesota Rule WPC 36, an NPDES permit will be required for the hydrostatic testing of the hot water pipes due to the direct discharge to the Mississippi River. The application for the permit is submitted to the Minnesota Pollution Control Agency (PCA) who reviews the application, makes a determination as to whether to issue a permit, and issues public notice of the permit application and its determination. It is not anticipated that this project will encounter any problems obtaining a NPDES permit. The permit review process will, however, take approximately three months and the application must be submitted 180 days prior to the date the discharge is to commence.

State Permits/Authorizations

Environmental Review. The Minnesota Environmental Quality Board (MEQB) administers an environmental review program. The environmental review process is complete for the St. Paul District Heating Project. An environmental assessment worksheet (EAW) was filed with the MEQB for this project in May, 1980. The EAW determined that an environmental impact statement was not required for the project. There were no objections to this finding within the 30 day review period and the determination was final.

Utility Permit on Trunk Highway. In accordance with Minnesota Statutes Section 161.45, Order No. 31424, a utility permit is required for construction on, across, or under the right-of-way of any trunk highways. The permit is obtained from the District Office of the Minnesota Department of Transportation (DOT) who reviews the submitted construction sketch for conformance with DOT's regulations (Rules of the Department of Transportation as set forth in Order No. 31424 dated May 3, 1961). For utility construction involving interstate highways, the Federal Highway Administration may also review the permit application if the highway crossing is considered unique or hazardous. In the case of the St. Paul Heat Project FHWA review is likely for the Cedar St. Bridge crossing over Interstate 94 and Interstate 35. Obtaining the necessary utility permits is not expected to be a problem as long as the design is consistent with the DOT's standards. The permit process should take approximately four weeks from submission of the application fees for the utility permit. A surety bond may be required. The cost to the applicant for the bond is minimal.

Critical Area Review. A small portion of the project area (less than five acres)is located within the Mississippi River Corridor Critical Area. St. Paul's Critical Area Plan has not yet been approved and the critical area review is currently conducted by the Minnesota Environmental Quality

Board (MEQB). The project will be reviewed by the MEQB for consistency with the "Interim Development Regulations for the Mississippi River Corridor Critical Area" as well as for compliance with flood plain and shoreland regulations. No problems are anticipated and no application fees are involved. The review process takes approximately one month.

Capital Area Architectural and Planning Board Review. A portion of the project area is within the jurisdiction of the Capital Area Architectural and Planning Board whose authority includes the review of construction proposals affecting any public lands for conformance to the comprehensive use plan for the area. For the St. Paul District Heating Project, a site plan and letter of intent should be submitted to the Board for their review and approval. The review process takes approximately one or two months. No problems are anticipated and no application fees are involved.

Water Appropriation Permit. A water appropriation permit from the Minnesota Department of Natural Resources is required for the hydrostatic testing of the pipes. The application fee is minimal ($15.00) and the time to process the application is on the order of one to three months. No problems are anticipated in obtaining this permit.

Local Permits/Authorizations

Utility Installation Permit. A utility installation permit is necessary to construct the district heat transmission and distribution system. Construction plans and sketches as well as a traffic plan are submitted to the St. Paul Department of Public Works, which internally distributes them to staff in the areas of construction engineering, traffic management, bridge maintenance, etc. No fee is required of the applicant. The time period for approval of the permit is closely related to obtaining the operating franchise. The estimated time to process a utility permit is approximately one month to six weeks. No major problems are anticipated in securing the permit.

Operating Franchise. An operating franchise from the City is necessary in order to use the streets and other public property for purposes of district heating. The franchise is granted by a City Ordinance which contains all the terms and conditions of the franchise, including the rates to be charged by the grantee. Obtaining the franchise can take from two months to one year and often involves substantial negotiations. There is also a major cost associated with the franchise. The annual franchise fee to be paid to the City is required to be at least five percent of gross earning and is usually set at eight percent. Although no major problems are anticipated in obtaining the franchise, the process needs to be carefully handled. With close communications with the City, the franchise can be obtained in two months.

Other. Other permissions involved in constructing the district heat system include easements from private property owners and the railroads. These can be time consuming to obtain and discussions with the affiliated parties should be started when the final route is agreed to and the decision has been made that the project will be built.

Costs. For the most part the technical information required to obtain the permits is information that will be developed and available as part of the final design. There are, therefore, no major costs associated with generating new data. Nevertheless, putting the information in the appropriate form, filling out the applications, responding to questions, and coordinating with the agencies takes time. For the NPDES permit, capitol area planning and architectural review, critical review process, utility installation permit, utility permit on trunk highways and water appropriation permit approximately eight man-weeks of the consulting engineer's time should be budgeted. A successful permitting process also requires an individual at the local level (for example a staff member of the St. Paul District Heating Development Company) to schedule, coordinate, and monitor the process. We estimate that approximately seven man-weeks of this individual's time will be required throughout the project.

The above estimate does not include work associated with the operating franchise, building permits, or easements.

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*U.S. GOVERNMENT PRINTING OFFICE: 1981-546-067/369