WATER PLACE, WATER POWER

by

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Signature of Author.......................................
Department of Architecture, June 1980

Certified ....
Imre Halasz, Professor of Architecture, Thesis Supervisor

Accepted by.......................................
Professor M[illegible] Smith, Departmental Committee for Graduate Students

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Submitted to the Department of Architecture on May , 1980 in partial fulfillment of the requirements for the Degree of Master of Architecture.

ABSTRACT

The thesis is a projective design of a modest 200 room hotel in Lowell, Mass. which serves as a vehicle for an investigation into some of the possibilities of integrating flowing water and water power into the design of a non-industrial building type. I use some characteristics of the flowing water as a basis for formal decisions and as a source of energy. The design should be understandable as an extension of the water/landscape. By incorporating in the building design an on-site means of production, I believe people who would use such a building could understand and experience the water as an elegant source of power as well as a beautiful element of the environment.

Thesis Supervisor: Imre Halasz

Title: Professor of Architecture

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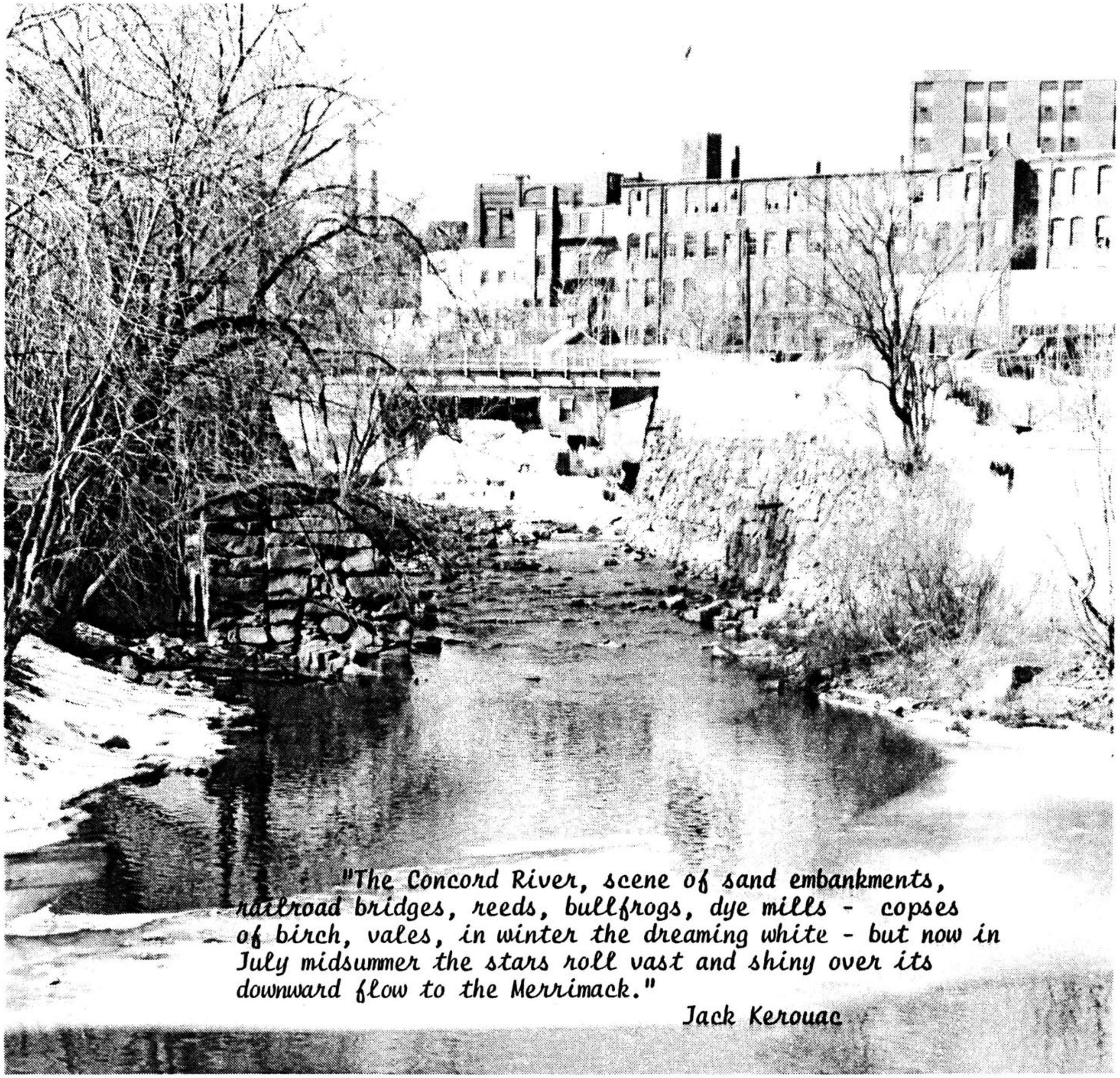
ACKNOWLEDGEMENTS

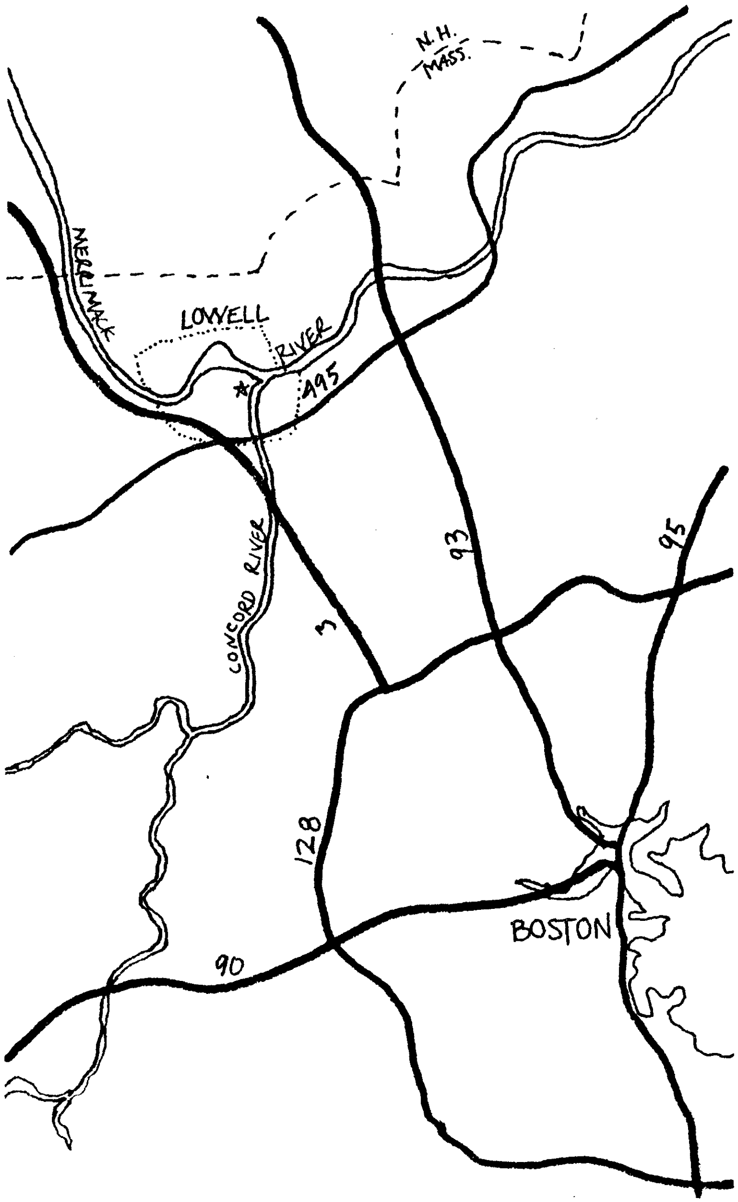
My thanks to my advisor, Imre Halasz; my readers, Sergio Modigliani and Barry Zevin, for their constructive criticism; to the people of the Lowell Division of Planning and Development for ideas, materials, and friendship; to my roommates for making our apartment a home; and especially to my parents and family for their love and support.

PART I

The Problem Setting

1.0 INTRODUCTION





Introduction

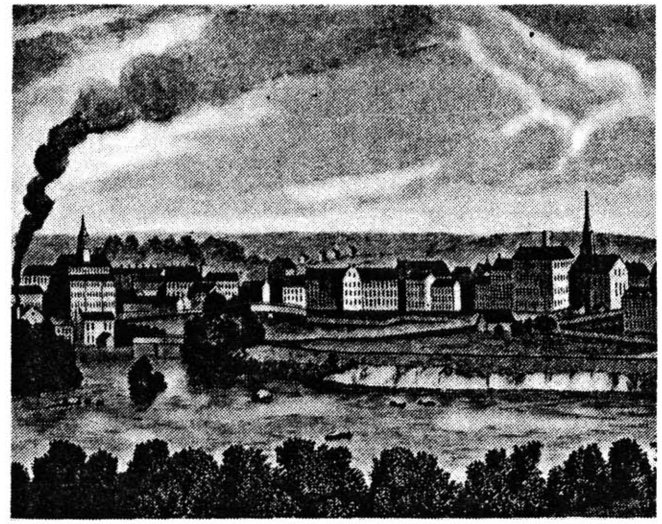
My thesis is that architecture should be integrated with the landscape both formally and physically in order to maximize people's positive association with, and use of, natural and built resources. In this specific application I employ physical and formal properties of flowing water harnessed to produce power. The properties are in some ways general or universal and in other ways particular to the site and the context of Lowell, Massachusetts.

Water power is the raison d'etre for Lowell. It is a city of about 100,000 people located thirty miles northwest of Boston at the confluence of the Merrimack and Concord Rivers. That site was chosen by developers from Boston in 1822 because of a fall of approximately thirty three feet over the Pawtucket Falls which could be used to power textile producing machinery. In addition, there were two existing transportation canals (an important factor in a pre-railroad America). The Pawtucket Canal (1796) ran from just above the falls through four sets of locks to the Concord River so as to bypass the Pawtucket Falls. The Middlesex Canal (1803) was built from just above the Pawtucket Canal to Charlestown in Boston giving access to world markets through the port of Boston.

The Middlesex Canal bankrupted the earlier canal by rerouting goods to Boston instead of Newburyport at the mouth of the Merrimack. The bankrupt canal was easily obtained along with all the water rights to the Merrimack and converted to a main feeder for an extremely complex water power distribution system which eventually extended all the way to the White Mountains of New Hampshire.

Before the invention of electric power the builders of Lowell needed to build a system which could deliver water to many mills at a sufficient height to power textile machinery by direct mechanical energy. This was done at many levels all over the central city and in a large part determined the physical form of the city.

In a very short time Lowell became known as a sophisticated industrial city. Lowell led the way with the most advanced power production machinery, and the development of the modern corporation as well as progressive social movements. Mills in Lowell were famous for the "Lowell System": creating finished goods from raw materials at a single location. In the nineteenth century the city was a national model of efficiency and pride in the place where one lives and works.



The character and physical roots of Lowell lie in the Industrial Revolution. Indeed, Lowell symbolizes the Industrial Revolution in America. It sums up and expresses in physical form the revolutionary impact of industrialization, the enormous change from a basically agricultural world of farms, crops, animal husbandry and small towns to an urban industrial world of mills, factories and cities. Founded in 1822, Lowell was the first attempt on this continent to wed the utopian ideal of a humane, planned community with the harsh realities of the industrial world which were already so unpleasantly vivid in the slums of industrial England.[1]

Above: View of Lowell in 1834
The site is shown on the left

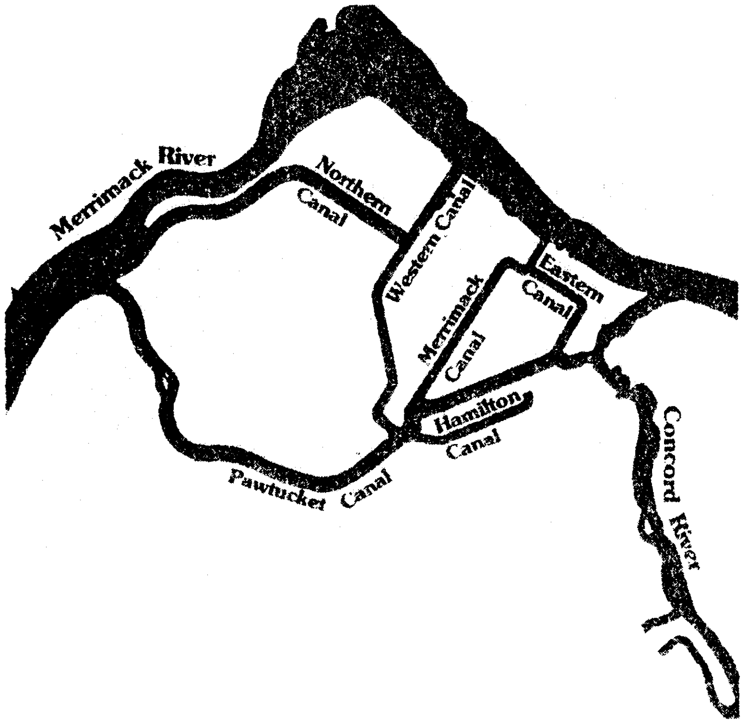


Diagram of major Lowell waterways[2]

Unfortunately, the utopian system broke down under the pressures of greed, competition, immigration, and finally the out migration of the textile industry to the South. By midtwentieth century the mills were largely vacant. Cheap electrical power made the canals obsolete. The economy was so poor that there was no reason to even tear down the obsolete structures. So, luckily, they are preserved today. The canals still generate some power and with increasing fuel costs they have become economically competitive.

The Commonwealth of Massachusetts and the National Park Service have established complementary parks in Lowell. The National Park service is charged with preserving, interpreting and developing the historic and cultural resources of the City to tell the story of the Industrial Revolution.

The State is more involved with developing recreational and green space in several locations around the City. One location, the Rex Lot, is adjacent to the site. The State is also committed to establishing parks and bikeways, etc. along the banks of the Concord River. One of my design goals was to fulfill the ideal that the banks of the River should be accessable to the public. A continuous pedestrian and bicycle path uses the River banks to link the Rex Lot and the downtown commercial and historic districts with recreational and residential zones.

The National Park Service has estimated that the Lowell Park could attract over 700,000 people a year by 1985. The location of the hotel is strategic. It is continuous with the State Park system and adjacent to the National Park intensive use zone which will feature a cross section of a restored nineteenth century Lowell. This restoration will include recycled buildings of all types; barge tours along the canals; restored and operating gatehouses, boat locks, and power generating equipment. Exhibits of all aspects of life in the Industrial Revolution will be housed in corresponding historical buildings.

What Would the Park Be Like? 11

Figure 102 The Boott Mill exhibits explore a range of questions about **working.** Some of the exhibits will be designed to allow visitors to assume duties of early workers, performing certain tasks and gaining some insight into the skills, satisfactions and frustrations that attended mill life.

Figure 103 How is power generated? Water-powered mills will be much more understandable to visitors who are given a chance to operate and control models and devices which describe hydropower.

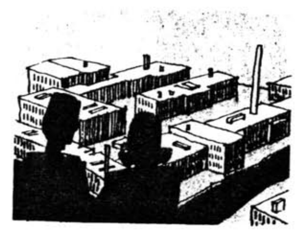


Figure 104 A complete miniature mill will detail the process of textile manufacture as it was conducted more than 100 years ago.

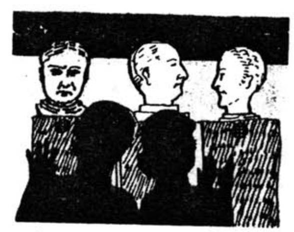
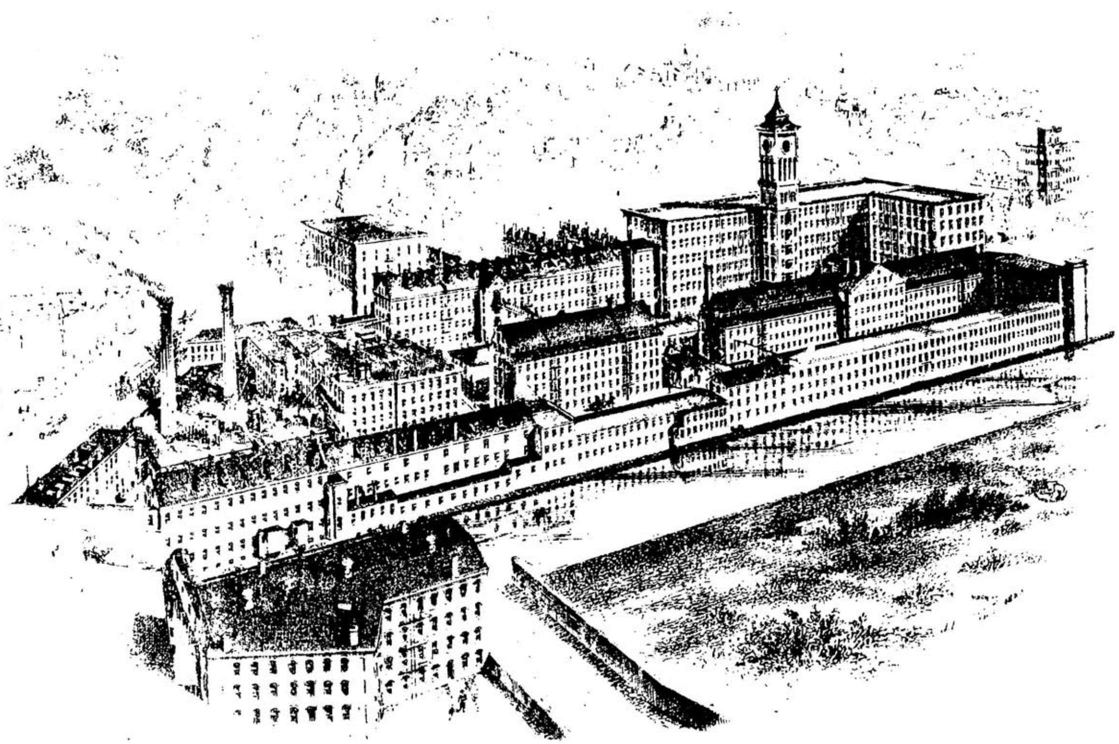


Figure 105 "Why do bosses act that way?" A section of the exhibit will present the ideas of the men who established Lowell, and some of the decisions they faced. Visitors will be given the chance to see how the results of **their** decisions might have turned out, compared to those made 150 years ago.

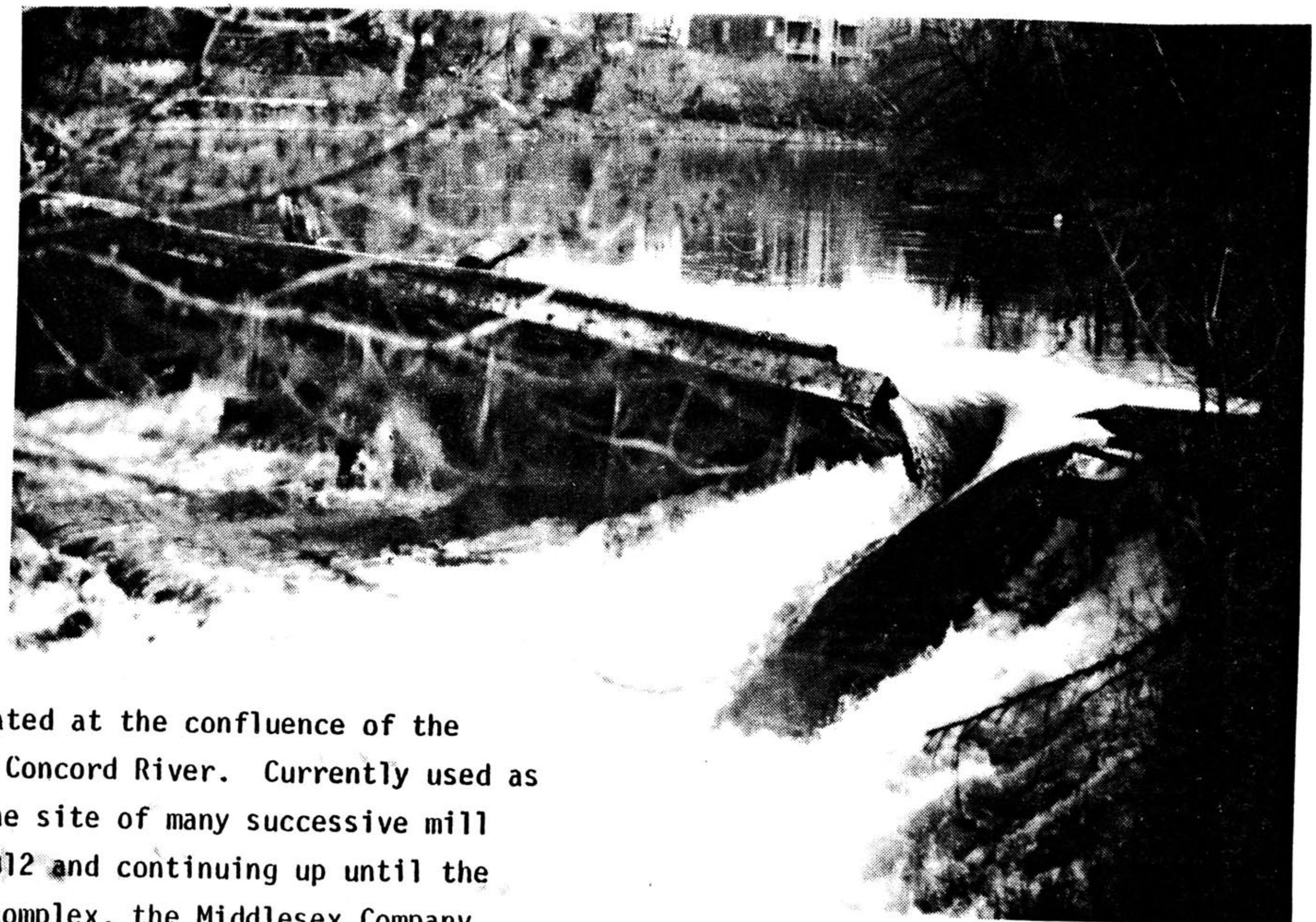
Excerpt from Lowell National Park plan[3]

Although the program for the hotel calls for a primarily business orientated hotel, it is clear that the context is broader. Tourists will stay at the hotel, but more importantly, permanent residents and tourists alike can use, enjoy, and even learn from a design which is generated from the overall concept of this City as the process and product of the Industrial Revolution.

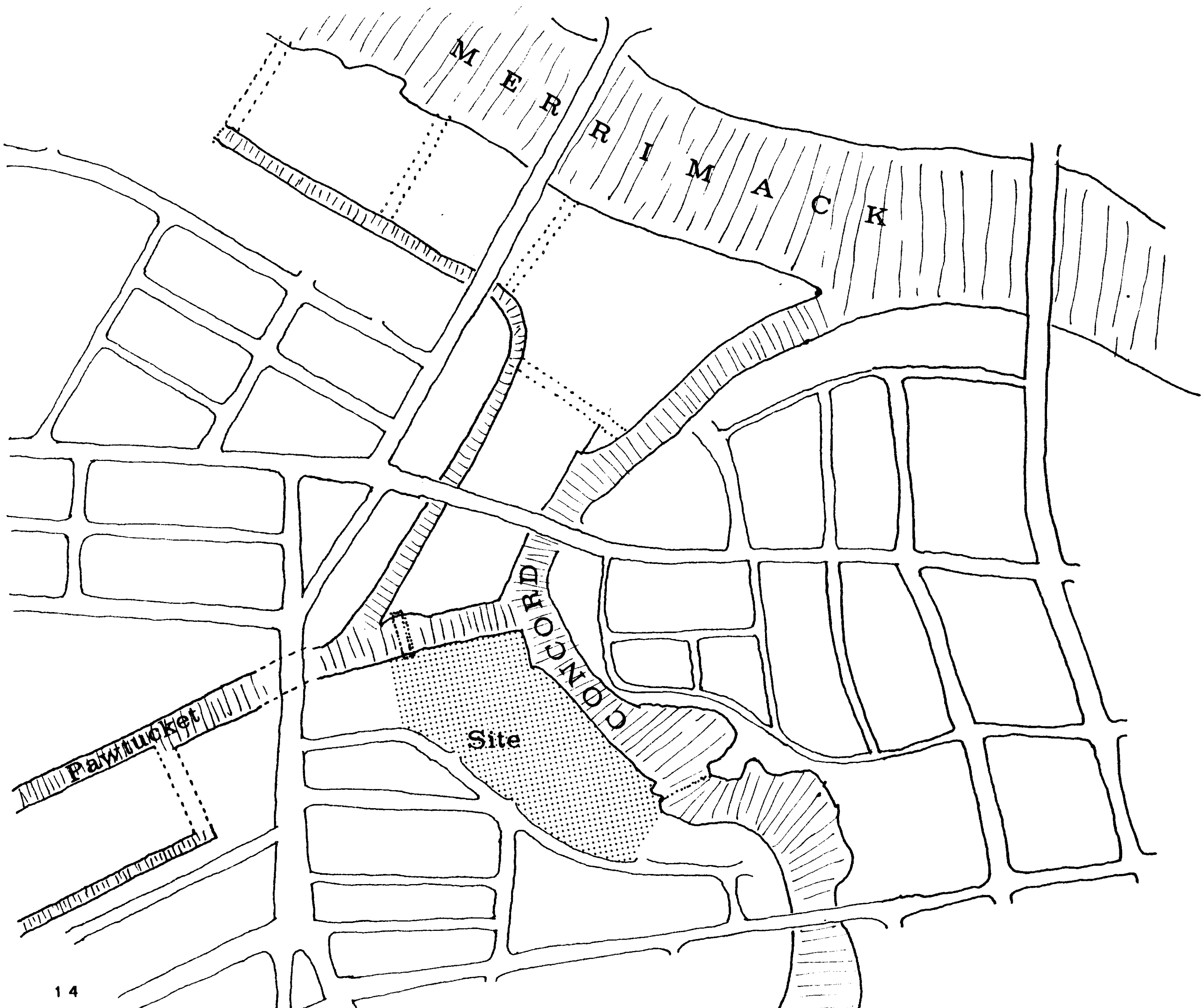


An illustrator's view of the town of Lowell in 1834.

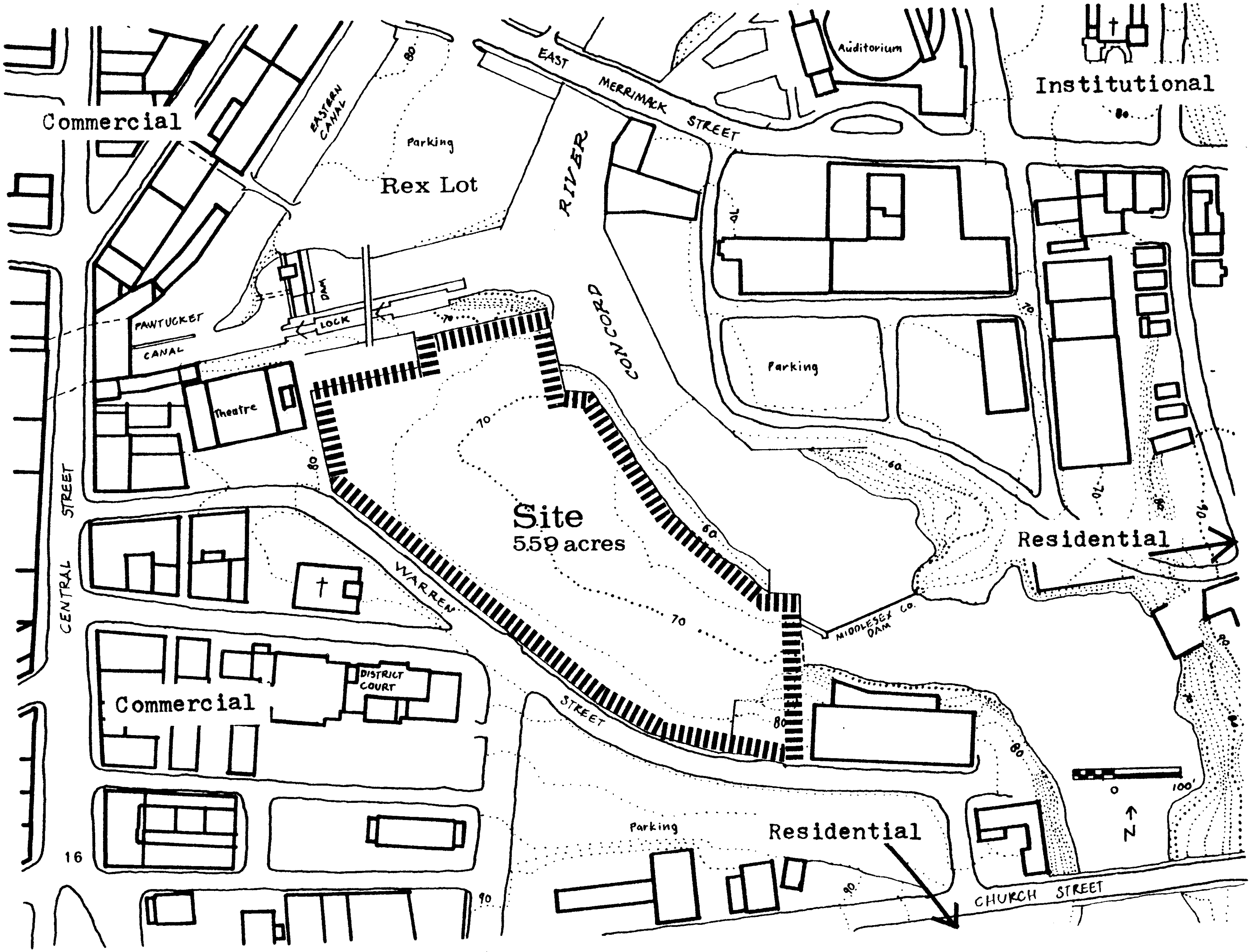
2 Site Description



The site is located at the confluence of the Pawtucket Canal and the Concord River. Currently used as a parking lot, it was the site of many successive mill complexes starting in 1812 and continuing up until the 1950's. The last mill complex, the Middlesex Company, drew water from both the Canal and the River. The Middlesex Company Dam across the Concord has been abandoned and has a large hole in it. The Lower Locks & Dam on the Pawtucket Canal are still owned and operated by Proprietors of Locks and Canals on Merrimack River, the oldest corporation of its type in America.


MERRIMACK
CONCORD
Site
Pawtucket

Much of the foundations of the old mills still survive. The penstocks which served those mills from both waterways are still there albeit decrepit and filled. The tailraces from the former power plants can be clearly seen as portals in the massive granite retaining walls. Some of the walls have fallen down into the river. Foundations and lower walls of the mill buildings can be seen at the street side of the site where they now serve as a retaining wall and boundary for the parking lot. The site drops about ten feet from street grade, slopes gently to the River's edge, and drops another ten feet or so to the River.

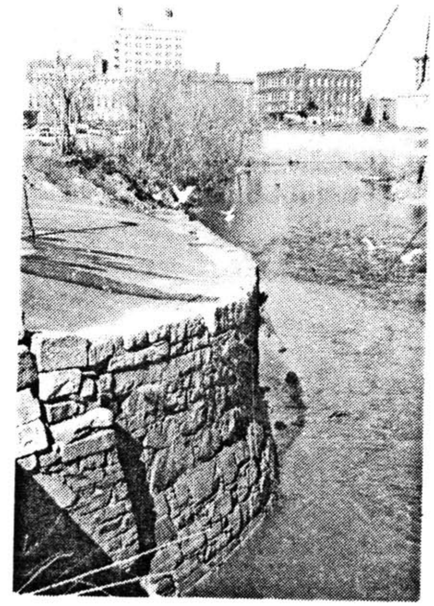

Commercial
EASTERN CANAL
Parking
Rex Lot
EAST MERRIMACK STREET
Auditorium
Institutional
RIVER
CONCORD
DAM
LOCK
PAWTUCKET CANAL
Theatre
Site
5.59 acres
Residential
MIDDLESEX CO. DAM
WARREN STREET
CENTRAL STREET
DISTRICT COURT
Commercial
Parking
Parking
Residential
CHURCH STREET
N

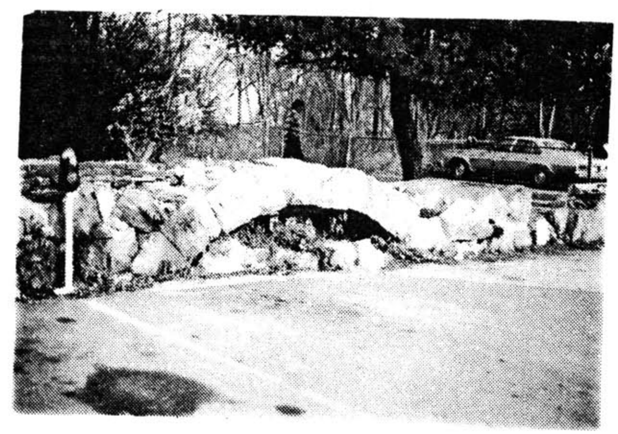
Sewer interceptors and a substation have been installed on the site, but due to the complexity of that work, I have decided not to deal with that issue. In any case, it is reasonable to assume that the power canals could flow over the sewers which are at considerably lower grade than the canals.

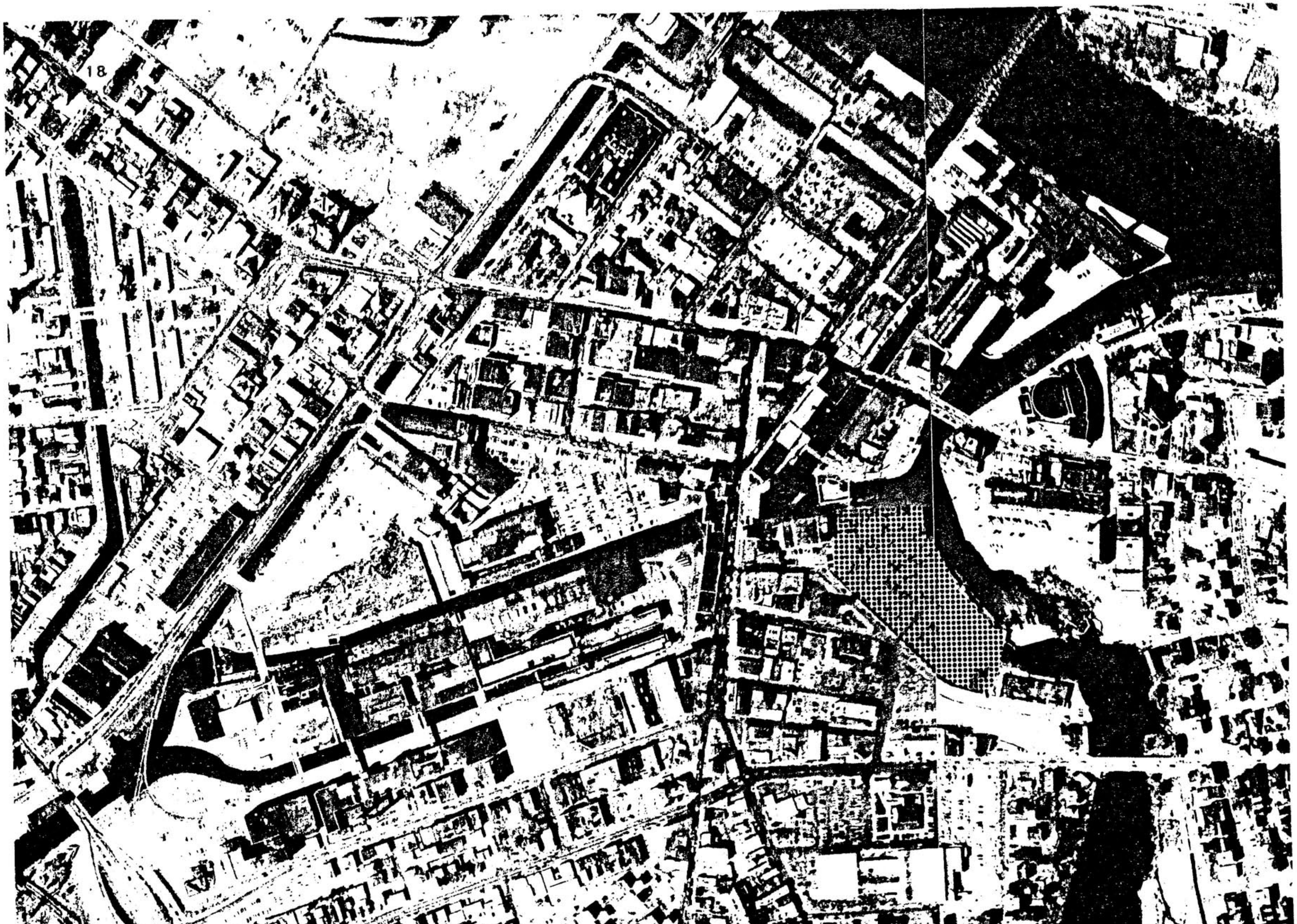
This site is a major joint in the urban fabric of Lowell. To the north and west is located the commercial and historic downtown. Immediately north and linked by a pedestrian bridge is the Rex Lot which in turn is connected to the downtown by another pedestrian bridge over the Eastern Canal.

Arterial access is from Church or Central Street. Warren Street is currently a back street used primarily as a short cut around a busy intersection and as access to the parking lot.

Across the River along East Merrimack Street is an institutional zone including a school, churches, and the City's Memorial Auditorium. Along the long neglected River bank is much open space which has reverted to the natural state. Back from the River's edge and just beyond Church Street are residential neighborhoods making a comeback after many years of decline.






18


19
ST JOHNS HOSPITAL
Parking
RIVER
CONCORD
Parking
Parking
Parking
Parking
STREET
CHURCH
STREET
Dam

3 THE PROGRAM

The program is reprinted from a real project on the same site which is currently in design development[4]. It was used to determine space and user needs and to make some assumptions about the management. The changes I made in applying the program are the substitution of more garaged instead of at grade parking to free up the site; the inclusion of hydropower facilities; and the substitution of natural water for a conventional swimming pool. (Sewer interceptors have been built which will make the water "fishable swimmable" according to the EPA; they were scheduled to come on line in the Fall of 1979.)

Major Design Goals:

1. Formal: emphasize the positive psychological association with the water/landscape.
2. Physical: maximize the use of the water.
3. Social/Political: provide a continuous public way along the river.
4. Economic/Managerial: satisfy the important requirements of the program.
5. Technical: demonstrate hydropower feasibility.

Hotel in Lowell
PROGRAM REPORT

18 May 1979

The program is interpreted freely to accommodate the organization I have chosen, yet the design satisfies all the important functional requirements of the hotel.

INTRODUCTION

This Report serves as the Program for a proposed new hotel to be constructed in downtown Lowell, Massachusetts.

The scope of the project has been developed in a series of meetings involving the Owners and the Architects.

The enclosed Program has been developed in conjunction with the preliminary Project Budget, not included herein.

This Program will be used as a basis for decision making and will be the generator of the conceptual design.

Space programs are included for both 184 room and 200 room hotels. This option will be determined before design.

FUNCTIONAL PROGRAM

GENERAL

This project is intended to be an efficient hotel for businessmen and weekend tourists, located next to, and taking advantage of the scenic features of old Lowell. A meeting place for businessmen, business lunches and conferences, and a new in - town center for an evening out to dinner.

CHARACTER AND MATERIALS

The character and materials should be of a building that is obviously new and up-to-date, but of the Lowell "fabric" -- of the materials and scale of components of fine old Lowell buildings, if possible using some traditional details in brick, etc. A place that appears to be busy without confusion, fresh, light, and "polished", but not "slick". (A building for Lowell, not New York). Spaces exciting enough for curiosity to bring outsiders in. A new "hotel" that might be best thought of as an "inn" in the traditional sense of warmth and hospitality.

This complex should be oriented toward the surrounding natural and historic features, growing from these features, not overpowering them, taking advantage of them without detracting from them.

The structure should appear to be able to withstand the elements, wear and tear, and time as the mill buildings have done so well.

The building should have vantage points at various levels for viewing the natural features and activity below.

The Main Court area should be open enough so that luncheon visitors do not feel like intruders, a fine line between Lobby space and Public space.

Special care should be taken so that the hotel, as viewed from Warren Street, does not appear to simply "straddle a parking lot".

The complex should be planned for expansion, but as built appear complete, with a beginning and an end.

GUEST ROOMS

Guest rooms should be tasteful and portray quality, not through elaborateness, but through simple sturdiness and honest materials. The room layout should work for both the arrangement of one king-size or two twin beds. On the lowest floor, Guest Rooms are to be convertible to conference rooms.

Guest Room Suites are to be two Guest Rooms combined. One Bath Room will be provided at the bedroom area, and a convertible bed provided in the living area. All Suites are to be on the top hotel floor.

MAIN COURT AREA

This area should be designed to be the heart and life of the building.

It should include:

a) A lounge area allowing meeting and greeting of people arriving from the lobby.

b) An area (or areas) for private conversation and discussion with refreshments available.

c) An open bar area.

d) The Restaurant seating.

Level changes and planting should separate functions within the major space. Pedestrian circulation should be allowed and encouraged. The atmosphere should be fresh and airy.

If possible, this space and its planting should carry outdoors toward the canal and may even connect to the planted area at the base of the Lower Locks footbridge.

The pool may or may not be within this space.

TAVERN

This area is to be a separate and enclosed restaurant with a freestanding bar. The area may be adjacent to or overlook the Main Court Area, but is expected to offer a different menu than the other restaurant which is actually in the Main Court Area. The Tavern may on occasion be reserved for a private party.

200 Rooms

Hotel in Lowell
PROGRAM

1. ENTRANCE AREA

Front Lobby and Front Desk		1,000 S.F.
Front Office		200
Women's Room		500
Men's Room		500
Janitor's Closet		50
Telephones		200
Magazine Counter		200
Storage for Magazine Counter		50
Manager's Office		300
Accounting Office		300
Security Office		150
	Sub Total	3,450 S.F.
circulation (x 1.14)		
	Total	3,933 S.F.

2. GUESTROOMS

Standard (2 singles or 1 king size bed)		184 Rms.
Suites (2 room size)	8 (x2)	16
	Total	200 Rms.

200 Rooms @ 360 SF/Rm		72,000 S.F.
Maids' Rooms, 12 @ 60 S.F.		720
Room Service Closets, 8 @ 50 S.F.		400
Ice Rooms, 8 @ 50 S.F.		400
	Sub Total	73,520 S.F.
circulation (x 1.17)		
	TOTAL	86,018 S.F.

3. MAIN COURT AREA

Lobby Lounge		6,000 S.F.
Restaurant - Seat. 130		2,600
Bar Area		1,000
	Sub Total	9,600 S.F.
circulation (x 1.20)		
	TOTAL	10,920 S.F.

4. TAVERN

w/Bar Area - Seat. 80		2,400 S.F.
	Sub Total	2,400 S.F.
circulation (x 1.0)		
	TOTAL	2,400 S.F.

5. BANQUET/MEETING ROOMS

Banquet Room for 400 people, divisible into 2 meeting rooms		4,400 S.F.
Storage Room for Banquet Room		600
Conference Rooms, 3 @ 600 S.F.		1,800
Foyer for Banquet and Conference Rooms		1,000
Toilets for Banquet and Conference Rooms		600
	Sub Total	8,400 S.F.
circulation (x 1.14)		
	TOTAL	9,576 S.F.

6. FOOD SERVICE

Receiving		200 S.F.
Storage		
Cold		250
Ice Cream		150
Day/Dry Stores		300
Non-Food		120
Cocktail Pantry		100
Beverage Storage		500
Food Production		
Preparation		
Cooking		
Baking		
Banquet Kitchen		
Room Service		2,000
Dishwashing		520
Pot Washing		130
Can Wash, Janitorial		155
Garbage		75
Offices		200
Employee Cafeteria		550
Toilets		200
	Sub Total	5,450 S.F.
circulation (x 1.14)		
	TOTAL	6,213 S.F.

7. POOL AREA

Indoor/Outdoor Pool		3,000 S.F.
Jacuzzi Whirlpool		250
Storage - Pool Equipment		150
Storage - Pool Furniture		200
Men's Locker and Steam Room		400
Women's Locker and Steam Room		400
Towel Room		50
Exercise Room		300
Pool Mechanical Equipment		200
	Sub Total	5,050 S.F.
circulation (x 1.14)		
	TOTAL	5,757 S.F.

8. GENERAL SERVICE AREAS

Men Employees' Room		800 S.F.
Women Employees' Room		800
Linens and Uniforms		1,000
Valet		400
Bulk Storage and Receiving		1,500
Maintenance Shop		1,000
Furniture Storage		500
Boiler Room		2,000
Fuel Storage		450
Transformer Vault		250
Telephone Equipment Room		300
	Sub Total	9,000 S.F.
circulation (x 1.15)		
	TOTAL	10,350 S.F.

9. PARKING

Hotel Guests		200 spaces
Restaurant Guests		60
Meeting Room Guests		50 - 100
Employees (80-90 persons)		50
Service and Delivery		5
	Total Parking	365 - 415 spaces

400 spaces @ 350 SF/space =	140,000 S.F.
Max. Area Covered	60,000 S.F.

TOTAL GROSS S.F. (Building only, parking not included)	135,667 S.R.

All room square footages shown represent gross square feet.

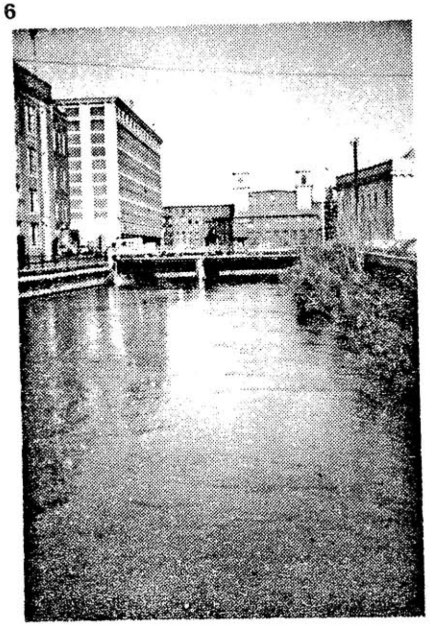
PART II

Hydropower

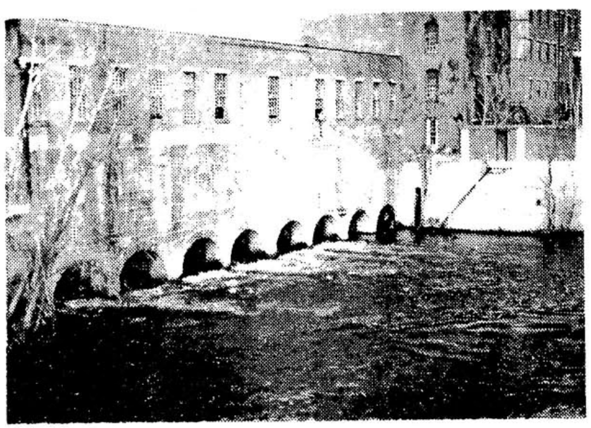
1 HISTORY & CONCEPT

"Perchance, after a few thousands of years, if the fishes will be patient, and pass their summers elsewhere meanwhile, nature will have leveled the Billerica dam, and the Lowell factories, and the Concord River will run clear again..."

Henry David Thoreau



Eastern Canal



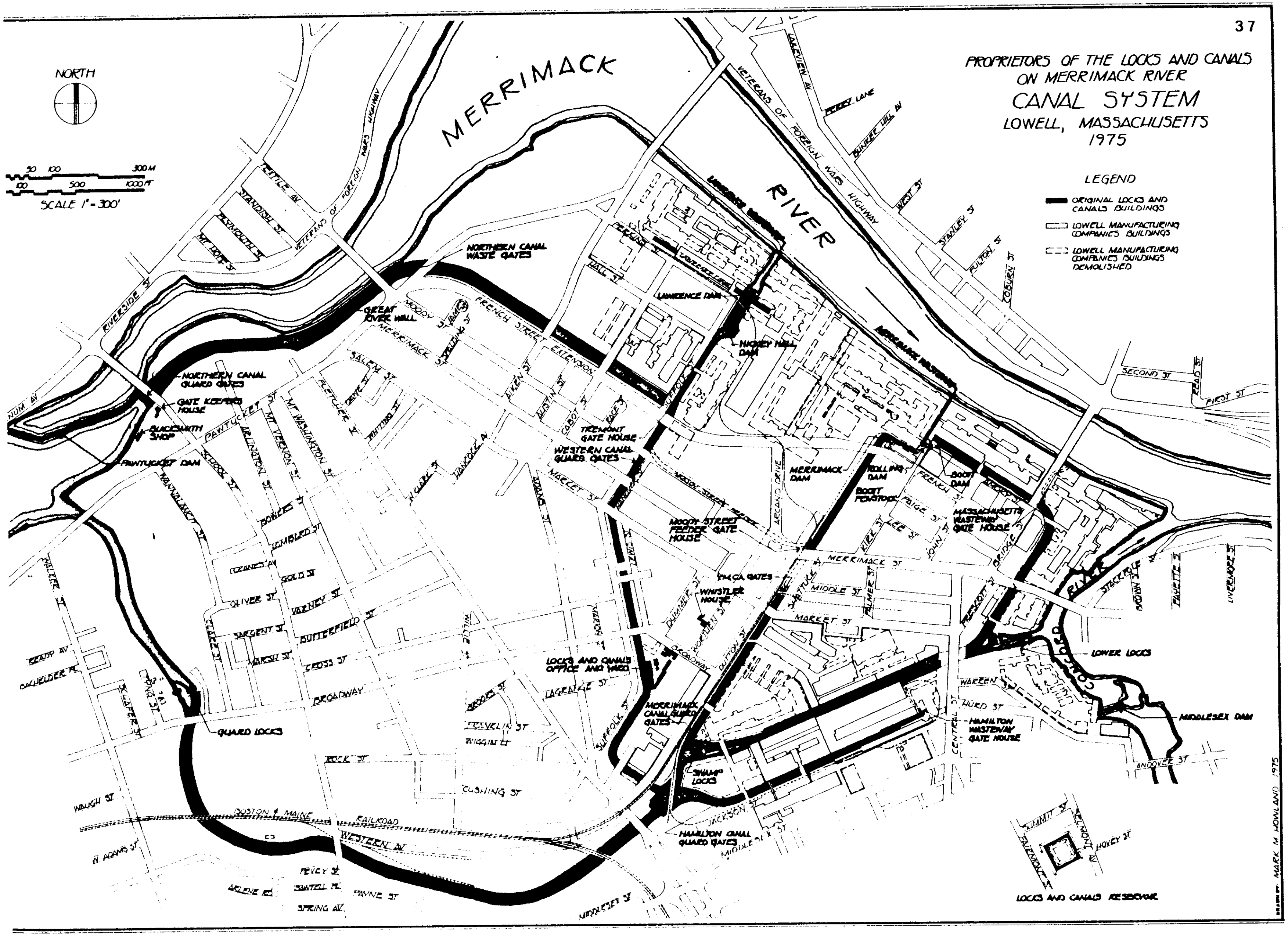
Hydropower Plant

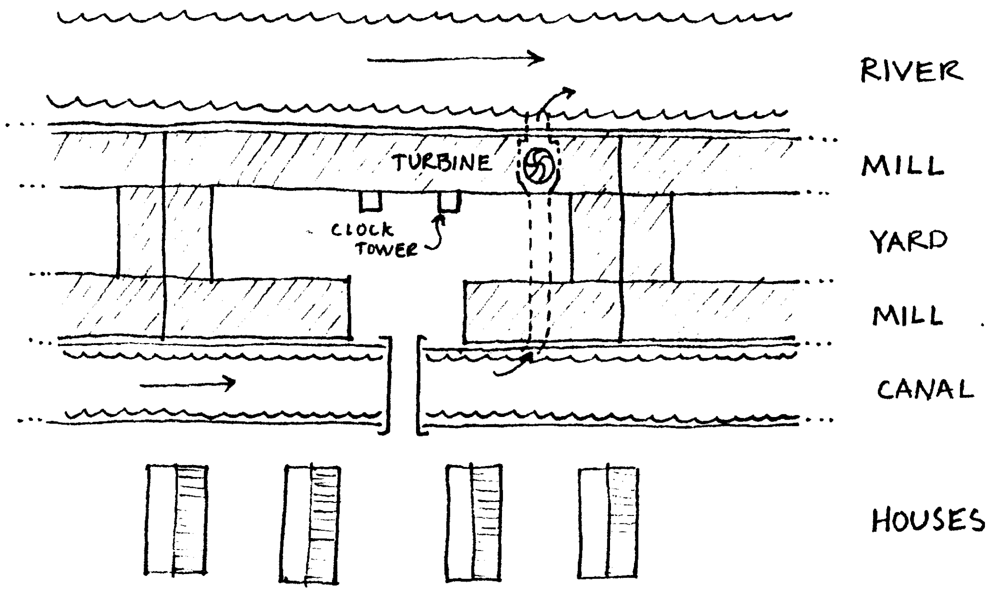
Lowell Textile Mill Complexes and Canal System

The mills and canals were originally built for the very practical purpose of distributing power for the production of cloth. At that time the only available power technology of the proper scale was hydromechanical power. Therefore, the resulting built environment is a direct consequence of the nature of the rivers and the control of those rivers for power production. Examining how the canal system influenced the generation of a city has informed me how to generate a small piece of that city.

Although the builders of the mill complexes intended to model them on the quadrangle scheme of their Alma Mater, Harvard College, there is no mistaking the true nature of the complexes as parallel rows of simple buildings. The closures on the ends of the mill yards were added to control access, define property, etc.

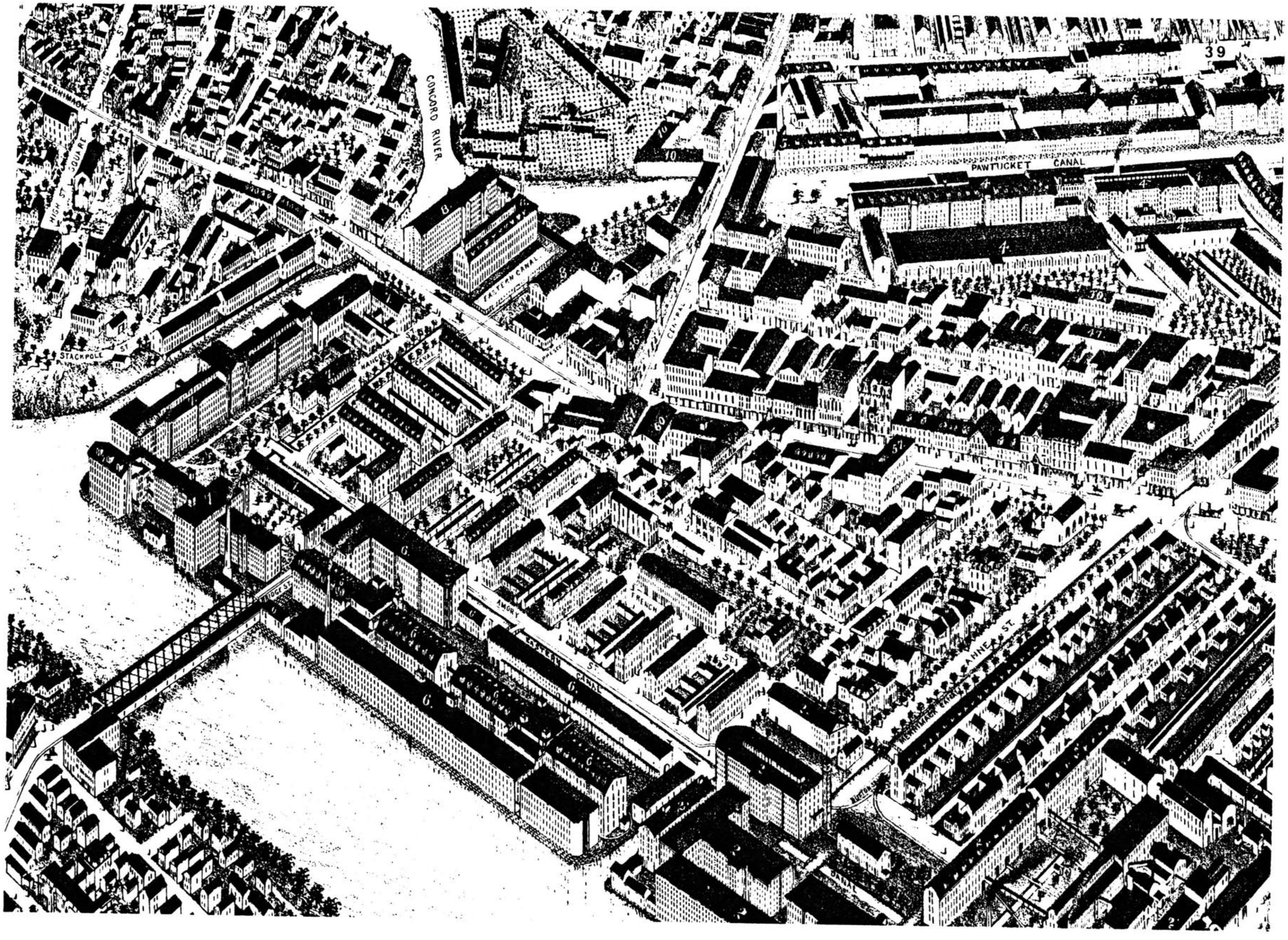
Even though the builder's formal notion was to build rectangular courtyards, the overwhelming necessity of the nature of power production from the flowing water compelled them to build rows of parallel buildings. Later overdevelopment added additional floors and structures which blocked sunlight and filled up the originally beautiful green mill yards.

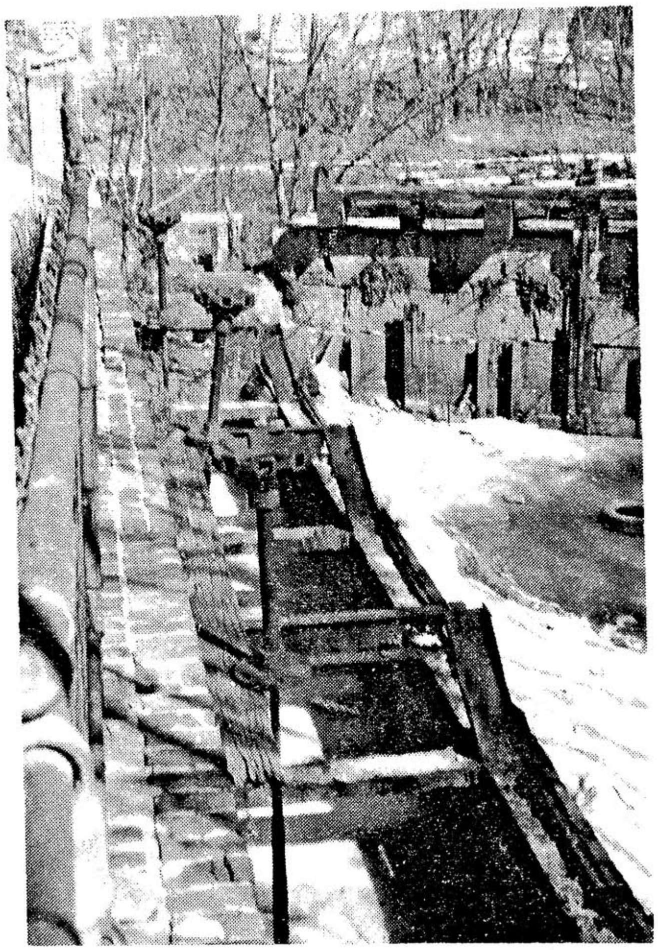

PROPRIETORS OF THE LOCKS AND CANALS
ON MERRIMACK RIVER
CANAL SYSTEM
LOWELL, MASSACHUSETTS
1975
LEGEND
ORIGINAL LOCKS AND CANALS BUILDINGS
LOWELL MANUFACTURING COMPANIES BUILDINGS
LOWELL MANUFACTURING COMPANIES BUILDINGS DEMOLISHED
NORTH
SCALE 1" = 300'
MERRIMACK
RIVER
CONCORD RIVER
NORTHERN CANAL WASTE GATES
GREAT RIVER WALL
NORTHERN CANAL GUARD GATES
GATE KEEPERS HOUSE
BLACKSMITH SHOP
PAWTUCKET DAM
LAWRENCE DAM
HICKEY HALL DAM
TREMONT GATE HOUSE
WESTERN CANAL GUARD GATES
MERRIMACK DAM
ROLLING DAM
BOOTT DAM
BOOTT PENSTOCK
MASSACHUSETTS WASTEWAY GATE HOUSE
MOODY STREET FEEDER GATE HOUSE
SWAMP LOCKS
WHISTLER HOUSE
LOCKS AND CANALS OFFICE AND YARD
MERRIMACK CANAL GUARD GATES
GUARD LOCKS
LOWER LOCKS
MIDDLESEX DAM
HAMILTON WASTEWAY GATE HOUSE
HAMILTON CANAL GUARD GATES
LOCKS AND CANALS RESERVOIR
BOSTON & MAINE RAILROAD
VETERANS OF FOREIGN WARS HIGHWAY
FRENCH STREET EXTENSION
MERRIMACK ST
MARKET ST
MIDDLE ST
BROADWAY
WESTERN AV
PAWTUCKET ST
RIVERSIDE ST
SCHOOL ST
CENTRAL ST
ANDOVER ST
JACKSON ST
SECOND ST
FIRST ST
DRAWN BY: MARK M. HOWLAND 1975



Opposite: View of Lowell in 1876 showing site and mill complexes

Historically, the water was distributed by a branching network of canals, sluices, penstocks, etc. which set up a roughly parallel water/landscape of river, mills, canal, and housing.

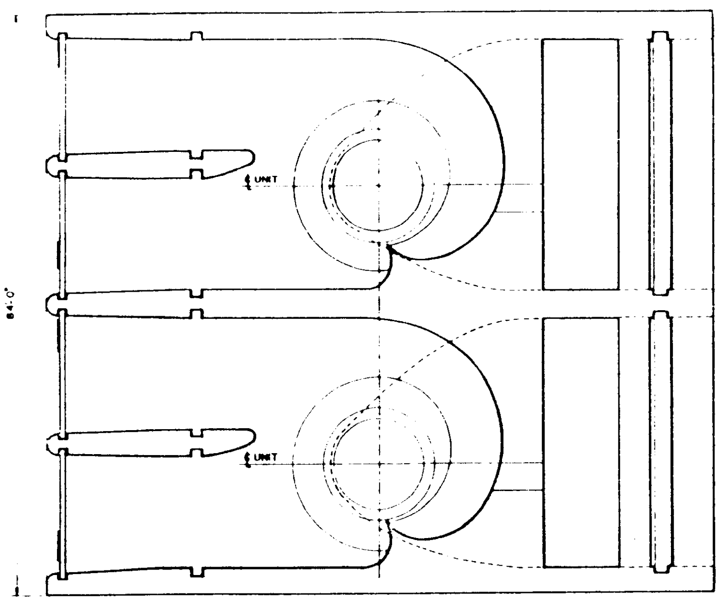

CONCORD RIVER
PAWTUCKET CANAL
STACKPOLE ST
ANNE ST



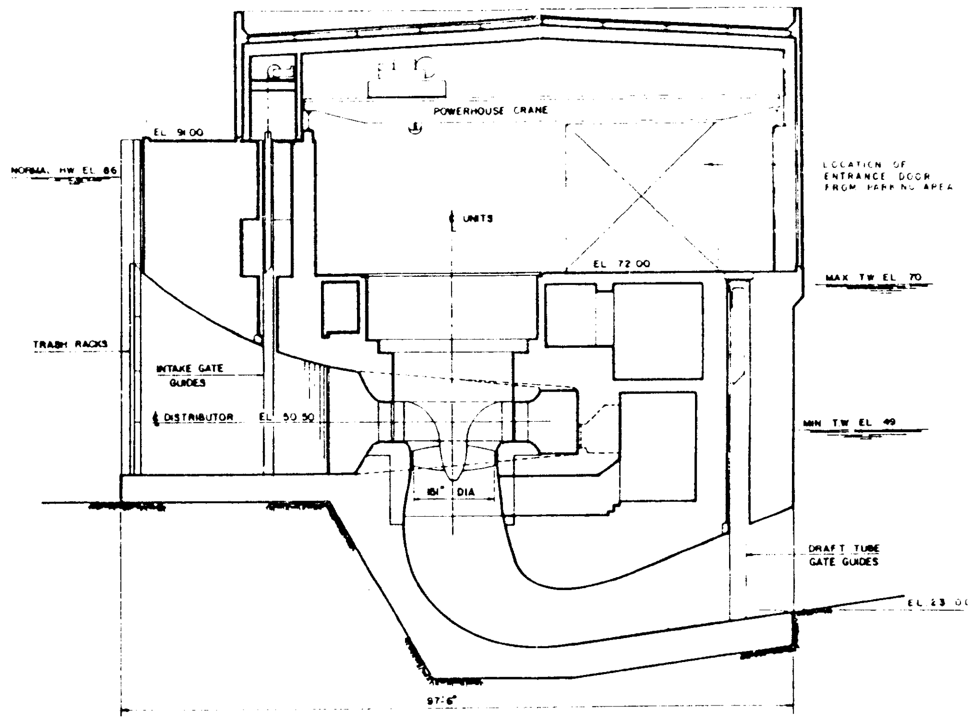
"The ideal way to supply a number of mills with water power is to use a single canal running parallel to a river with a falls. If the canal leaves the river above the falls and re-enters at some distance downstream, then the land between the canal and the river becomes an extended island on which mills can be placed in a line. By keeping the level of water in the canal close to that of the river above the falls, there will be a major difference in water level between the canal and the river at every point below the falls. Water from the canal can enter the mills on the island to drop through power-producing machinery, such as water wheels, and back into the lower river. In this way, the potential energy of the water due to its elevation, or "head", can power manufacturing processes in each mill."*

Controls for the Middlesex Co. penstock gates

*The Lowell Canal System p.7



SECTIONAL PLAN AT ℄ DISTRIBUTOR

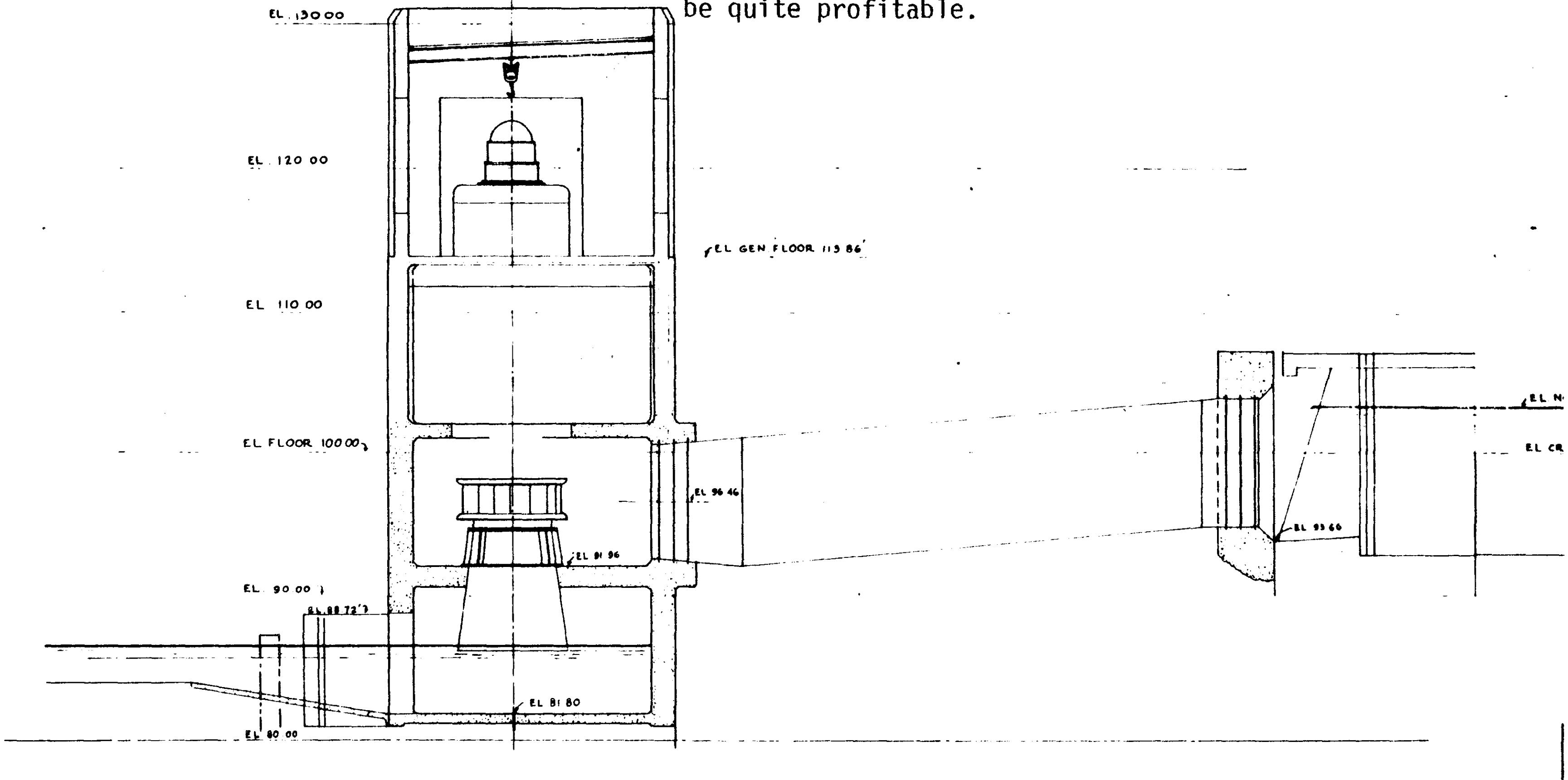


CROSS SECTION AT ℄ UNIT

Integral with the philosophy of formally uniting the water, land and building is the idea of physically uniting the productive use of the environment with everyday human activity. The water is not only the "generator" of the design but the "generator" of electricity to sustain the project.

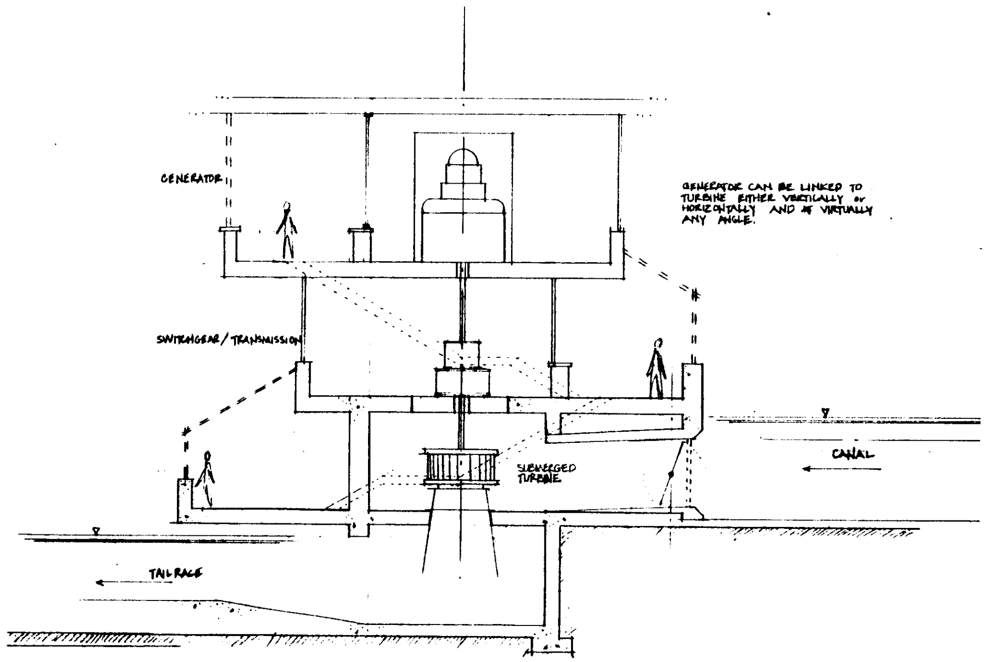
Figure 3-9. 2-7.5 MW Units Fixed Blade Turbine[5]

Two sources of energy are usable: potential energy from the fall of water and the thermal energy from the heat content (enthalpy) of the water. The strategy is to use the potential energy to pump the heat energy out of the water.[6] With increasing energy costs this approach could be quite profitable.



GENERAL SECTION AS SEEN FROM RIVER SIDE

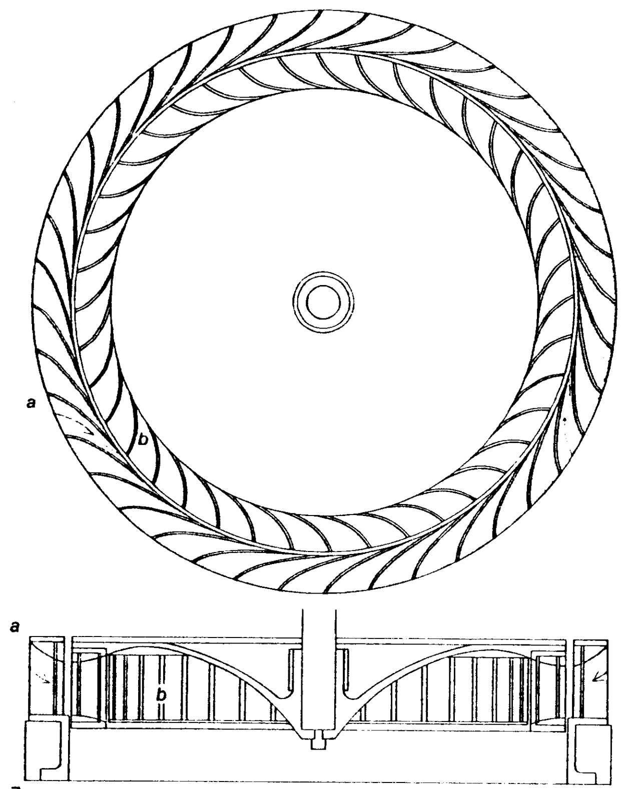
Section of existing turbine in Lowell



Left: Schematic section of turbine house designed for public viewing

Hydraulic or Water Turbines

An hydraulic turbine is a machine which converts the motion of water to mechanical energy in the form of a rotating shaft. There are many types, but in general they run submerged and under pressure so they cannot be viewed under normal operating conditions. In the design for the turbine house I try to convey the idea of the turbine by exhibiting the transmission and generation equipment as much as possible and making the flow of water through the machinery obvious.



7 **INWARD DIRECTION OF FLOW is shown in plan (*top*) and section (*bottom*). The turbine is of the type first proposed by Poncelet in the 1820's and patented in the U.S. in the 1830's. The water enters the motor through an array of fixed blades (*a*) and makes a runner, or central rotor (*b*), spin. The water then enters the race close to the center of the motor. This is a turbine of the kind first built by James B. Francis in 1849 and subsequently installed in Lowell, Mass.**

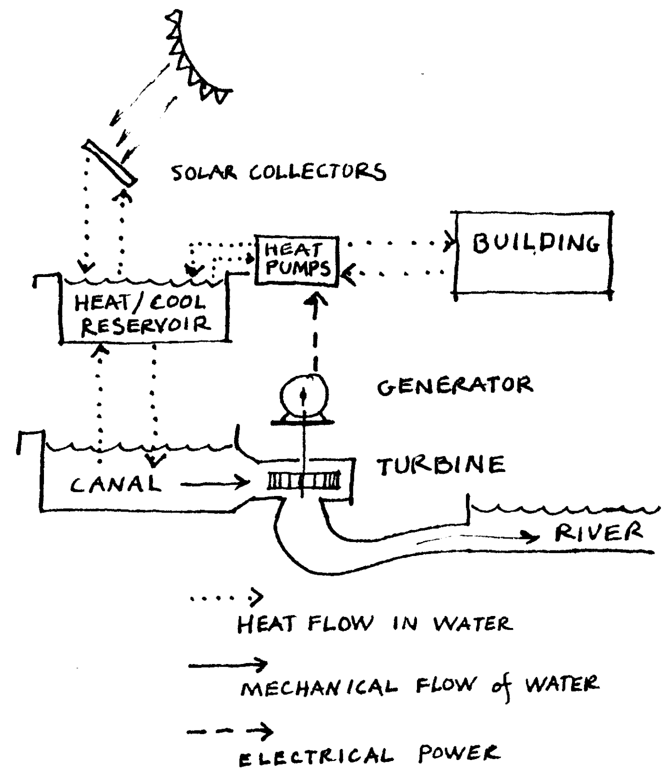
2 Feasibility

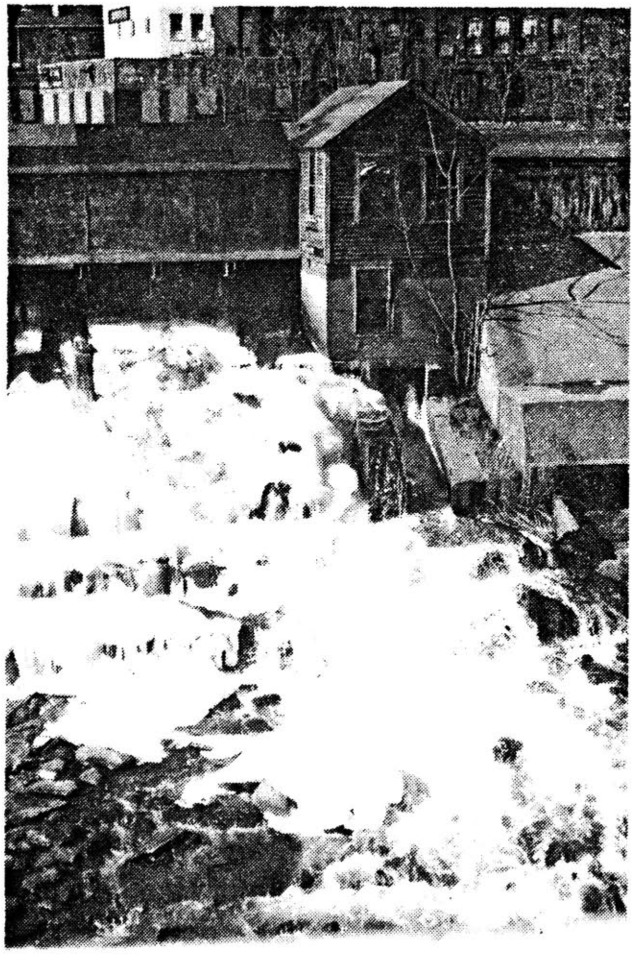
This chapter is a study of the feasibility of using the water of the Concord River and the Pawtucket Canal to supply the energy needs of the hotel project. The feasibility is based on technical considerations only. There is no attempt to make an economic study.

Rather than determine the economic feasibility of the plant, I will demonstrate the technical feasibility of supplying the energy demands of the project. An estimate of the value of the power can be made by simply multiplying total kilowatt hours (KWH) by the average going rate.

Summary

The proposed system is a combined hydro-electric/heat pump scheme. The strategy is to use the fall of the water as a power source to pump heat out of the water. Below is a graph showing that all of the hotel's heating requirements can be met with power to spare. Excess power could be used for domestic hot water, lighting, appliances, or even sold back to the utility grid. The following assumptions and calculations explain the scheme more fully; complete calculations are in an Appendix.



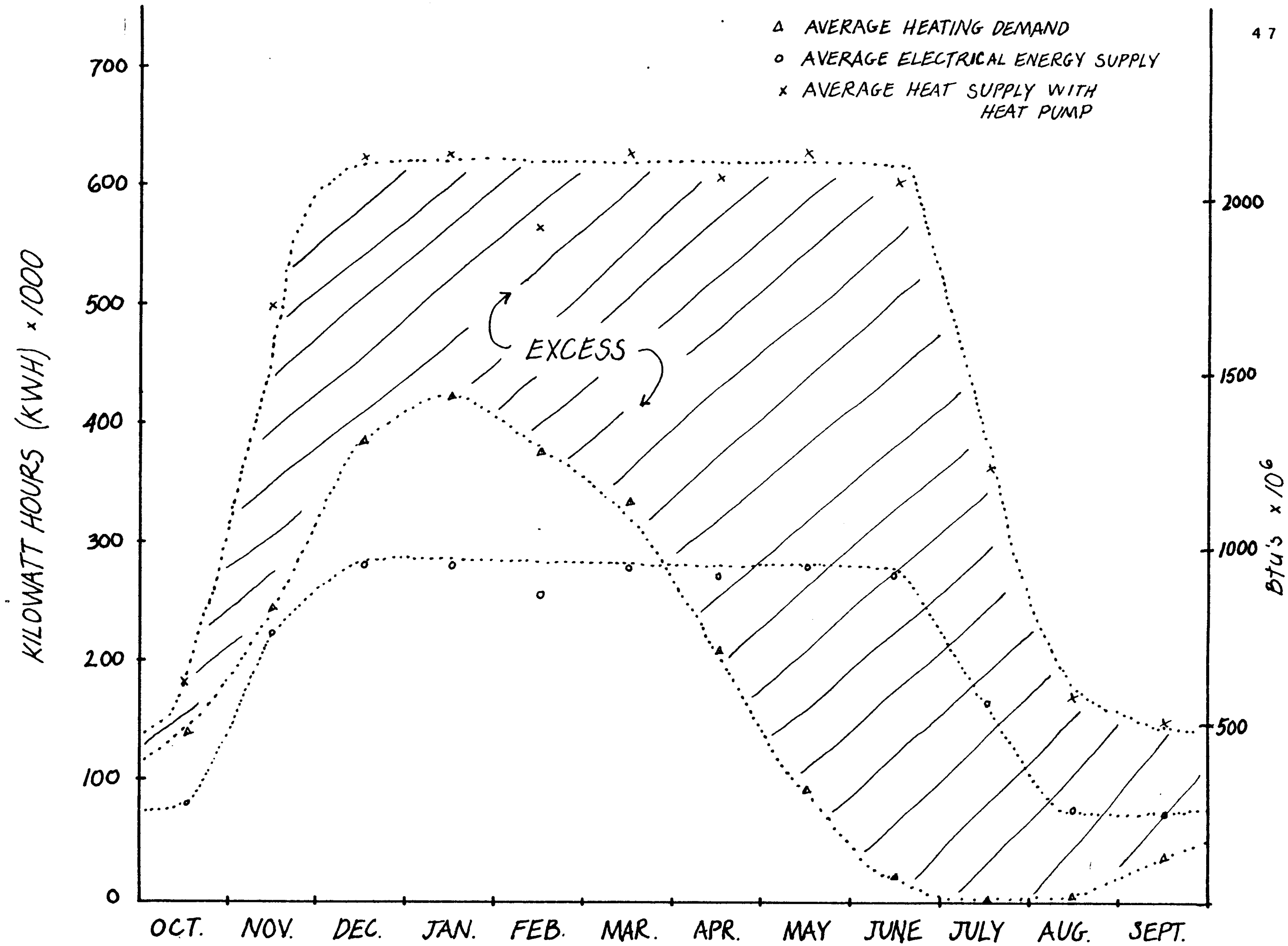


Falls over Lower Locks Dam

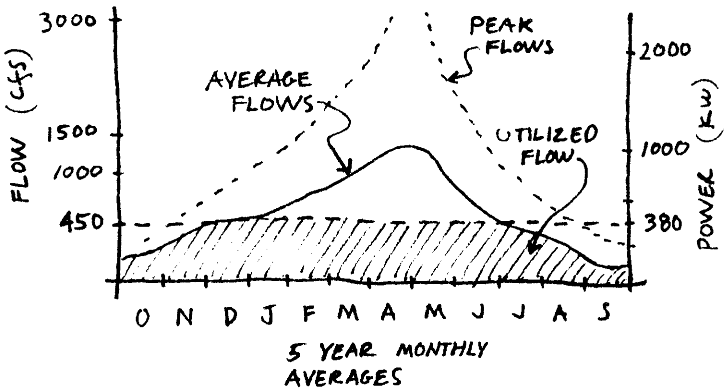
Water

There are two independent sources of water adjacent to the site: The Concord River and the Pawtucket Canal. The Concord River is used in these calculations because it is assumed the owners of the site could gain access to virtually all of the water. Previous owners of the site were responsible for the construction of the existing dam and did have exclusive rights to the water affected only by other mill owners upstream. The Pawtucket canal is part of a very much larger and very complex hydraulic system supplied by the Merrimack River, and although it potentially has even more power available than the Concord, there are too many unknown variables to determine what the actual availability might be. The control of the Pawtucket and the associated system could never be brought under the jurisdiction of the owners of the site.

It is assumed that some flow would be available from the Pawtucket especially during high flow seasons and that this additional flow will be used to augment flow of the Concord, maintain the head of the canals, and provide aesthetic features to the project. Flow rates could be estimated by using historical data. A pre-existing mill on the site did draw water from the Pawtucket as a supplement to the Concord source.



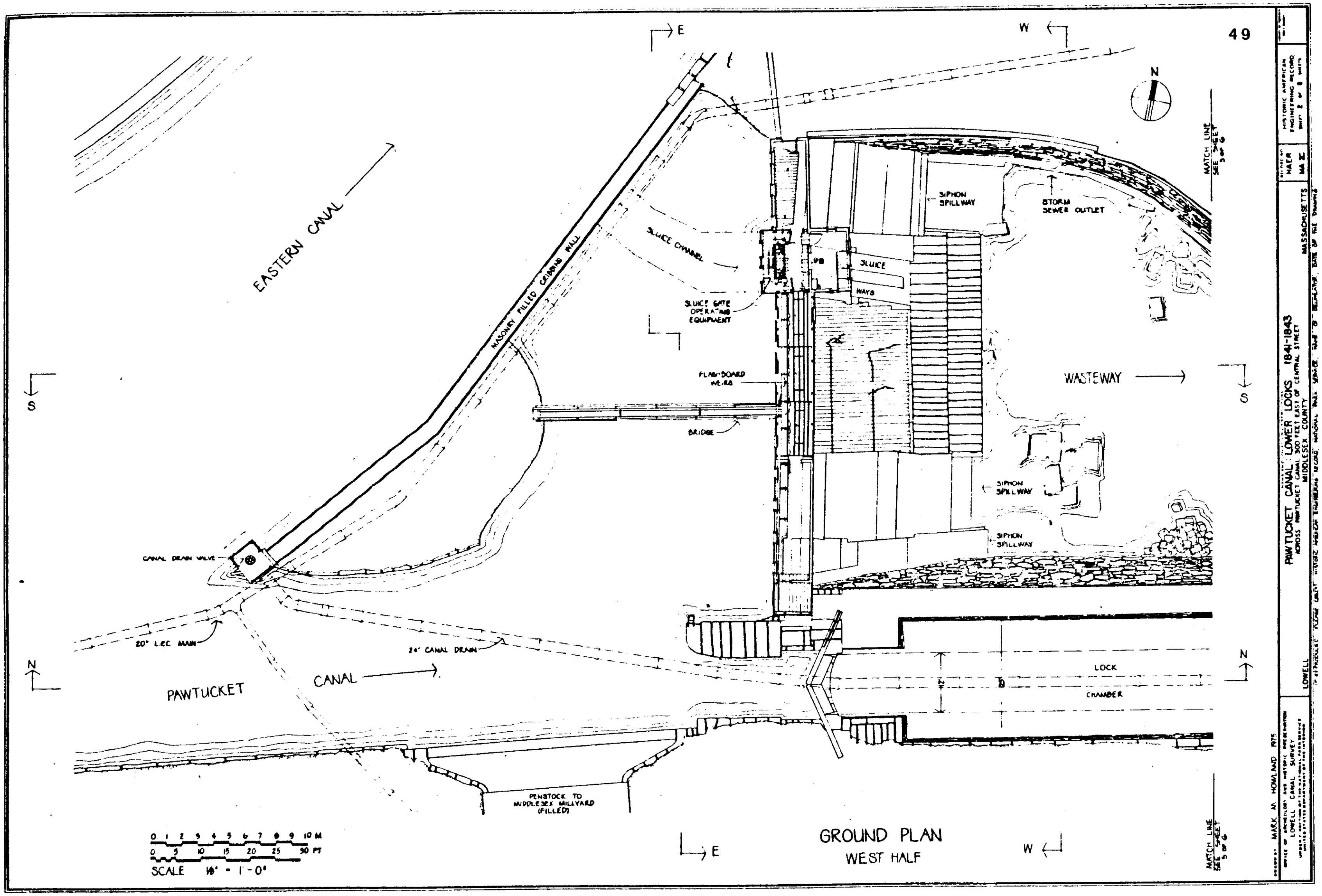
Supply & Demand



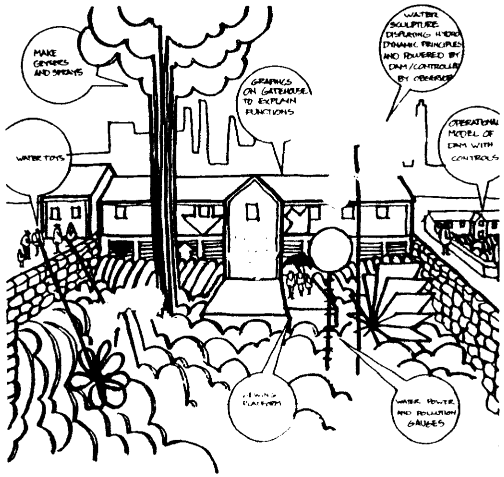
Head

The head of the Concord River is assumed to be ten feet for the feasibility study on the basis of contour maps and site inspection. Since the existing dam is breached and would have to be rebuilt, it is conceivable that the head could be increased to as much as 15 feet based on the contour maps, site inspection and the gage height records of the U.S. Geological Survey. The gage is located 67.41 feet above mean sea level. Records for the five year period 1965-70 show high water levels from 6.09 to 9.16 feet above the gage which represents from 3.5 to 6.57 feet above the design height of 70.0 feet. Caution must be employed because flooding occurred during some of these high flows.

Since the study assumes a head of 10 feet, each additional foot of head represents a possible 10% increase in power. There are many hydraulic devices and techniques available to raise and adjust the head which of course varies with the season. A technique used on the Merrimack River in Lowell is the installation of flashboards during periods of low flow. This technique is rather primative; it requires replacement every year. Rolling dams allow the dam height to be adjusted continuously. Weirs, sluices, flashboards and siphons such as those on the Lower Falls of the Pawtucket Canal adjacent to the site can be used by



Pawtucket Canal: Lower Locks and Dam



water discovery center

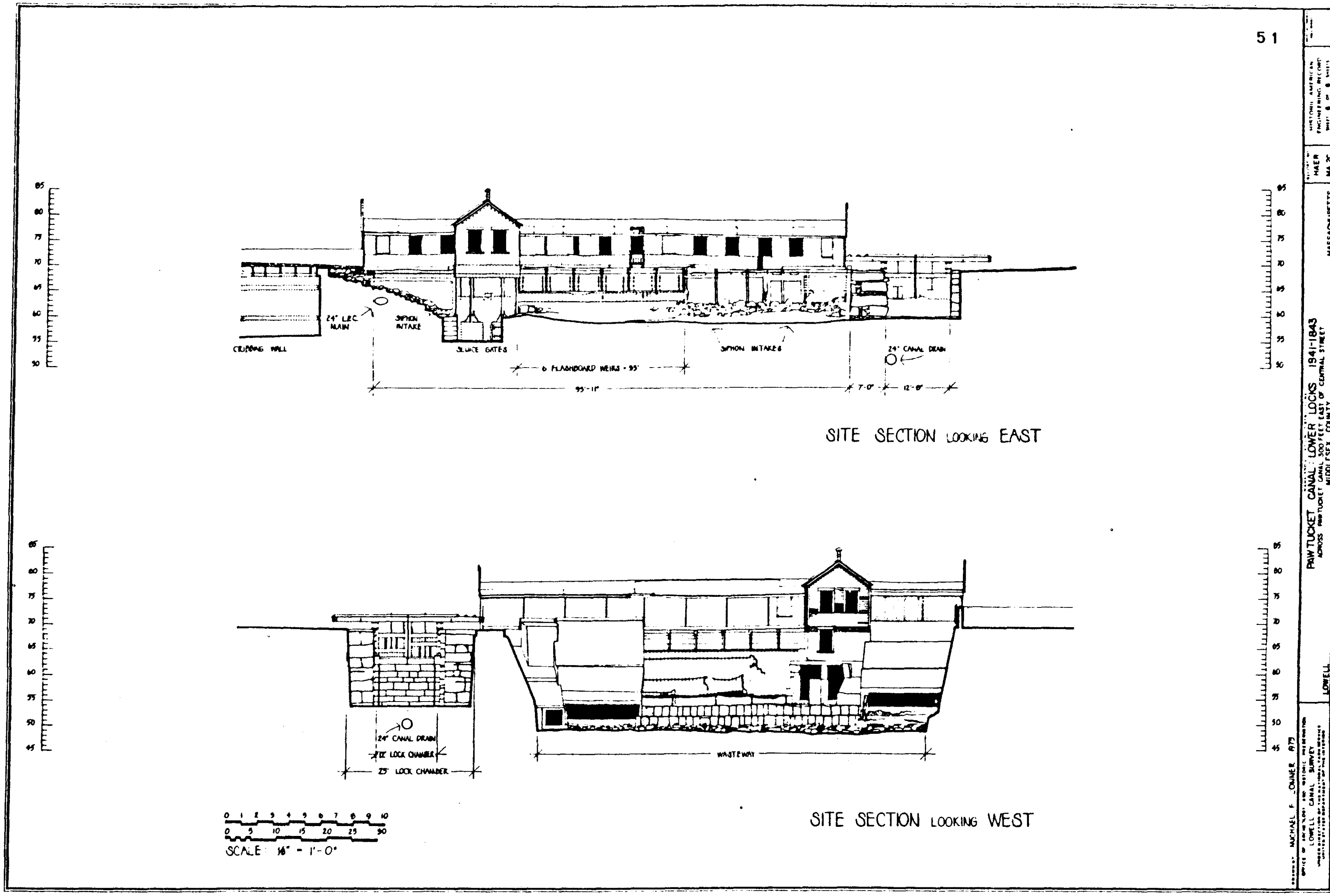
The Lowell Urban National Park proposal is designed to provide a continuous regional open space system centered on the historic canals, including bicycle and pedestrian paths.

The Network proposes numerous "discovery centers" at historic and industrial sites designed to communicate through direct experience the organization of the city and its history, industrial processes and operation of the canal system. These centers are intended as an extension of the school.[1]

[1] Lowell Discovery Network: "An Urban National Park", Model Cities Education Component.

themselves and in combination. All of these options could be integrated into the design of the hydraulic structures and their contribution to the architecture weighed on the basis of how much they contribute to the quality of the environment, i.e. how much they contribute to the ability of people to understand the nature of the water environment; and how much they contribute to the aesthetic quality of the project in addition to the power production.

The head of the Pawtucket Canal is 17 feet. If the water from this canal used to augment the Concord flow is conducted in an open channel 7 feet of head is essentially lost because the turbines are at a lower level to use the 10 foot head of the Concord River. However, if a closed penstrock is used all 17 feet of head could be used. The problem with the closed penstock is that nobody can see and appreciate the flowing water. A compromise which would have both an open and closed channel with the capacity to switch between or run simultaneously is also possible but more expensive. Since the Pawtucket supply is used as a secondary source anyway the strategy is to use the "lost" 7 feet of head for fun and games. An amazing array of fountains, sprays, waterfalls, waterwheels, etc. could be powered by this modest fall because of the relatively large volume of kinetic water obtainable.



Pawtucket Canal: Lower Locks and Dam

<u>Storage</u>

There are two major ways of providing storage. One is by building a large insulated hot water tank to store heat (and cold). The other is to store water behind the dam(s). Both can be used together or separately. Storage behind the Middlesex Co. dam extends to a set of rapids approximately 2000 feet upstream and is about 400,000 square feet (i.e. cubic feet per foot). This is equivalent to about 94 KWH or about 300 KW for 20 minutes (322, 153 BTUs) average for each foot of depth stored. This is very helpful during periods of low flow when turbines can still be turn intermittantly.

Storage in a hot water reservoir has several features: It allows the heat pump to be sized smaller and operate more continuously and efficiently. It is also possible to supplement the heat by adding solar collectors. Since the heat pump's efficiency is dependent on the temperature gradient, the hotter the source, the more efficient the pump.

Design and Sizing Strategy

The design of the system is beyond the scope of this study. However, a graph of total energy versus peak power shows the most efficient point (the maximum point of the curve) to be 1,938,850 KWH at a continuous 380 KW (a flow of 450 cfs). The flow duration curve which shows the percent of time equaled or exceeded by each flow rate shows 450 cfs sustainable 58% of the time. For the purpose of this study flow rates below 100 cfs are considered too slow to be usable. Impoundment behind the sam would allow intermittant operation during periods of less than 100 cfs flow.

A more refined estimate is determined by calculating energy produced month by month based on flow data using 450 cfs as a maximum.

GROSS AVE. POWER = AVE. FLOW x 10' of HEAD x 62.4 lb/ft³ of WATER x 1.356 x 10^{-3} KW/ft·lb/sec

EFFICIENCY FACTORS:

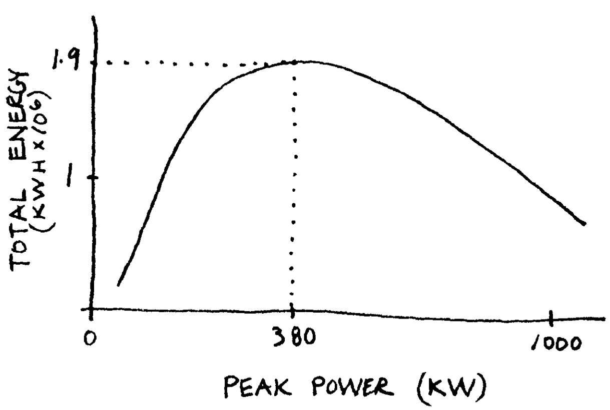
TURBINES LOSSES 10%
MIN. FLOW MAINTENANCE & MISCELLANEOUS LOSSES 5%

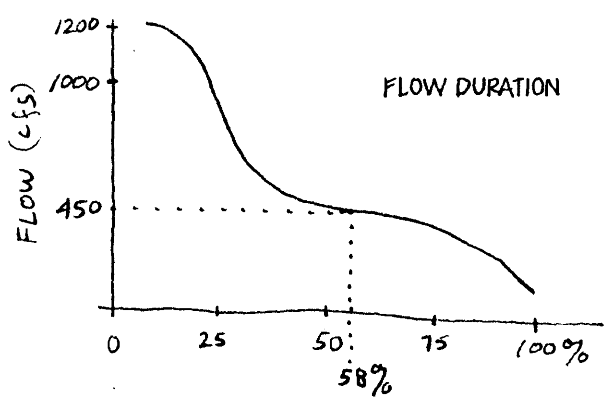
GENERATING EFFICIENCY 85%

380 KW GROSS x .85 = 323 KW NET

SYSTEM LOSSES 20%

ANNUAL NET ENERGY
1,739,122 KWH





ANNUAL HEATING DEMAND:

9 Btu/ft²/Degreeday x
135,667 ft² = 1,775,347,104 Btu/yr.
or 2,278,177 KWH/yr.

NET ANNUAL HEAT SUPPLY:

NET ANNUAL KWH x 3.25 C.O.P. =
5,652,148.8 KWH

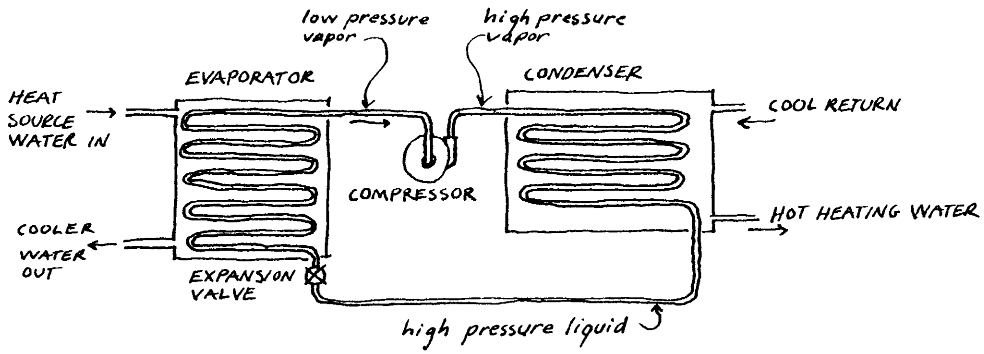
VALUE of ELECTRICITY
@ $0.04/KWH
1,739,122 KWH x $0.04/KWH =
$69,565

VALUE of HEAT N°2 oil @ $1.00/gal
5,652,148.8 KWH x 3.413 x 10³ Btu/KWH
x .75 EFFICIENCY ÷ 141,000 Btu/gal
x $1.00/gal = $102,610

The Turbine(s) could be designed to operate at staged or continuously variable flows which would provide a larger peak power rating; more total energy production; and the ability to use low flows, but at variable efficiencies. For example, one turbine could be designed for the average peak power production while a second smaller turbine could be designed to utilize low flows, provide extra peak power, and provide emergency backup to the main turbine. For the purposes of the feasibility study, average peak rates mentioned above are used.

The Heat Pump

The heat pump is a machine which transfers heat from one medium to another. Heat can be pumped from air to air, air to water, water to air, and water to water. This system uses a water (the River) to water (hydronic heating) system. The thermal properties of water make it the most efficient of common materials for thermal storage and transfer. Heat pumps can be reversed to provide cooling or heating. The way heat is pumped is by the liquification and evaporation of a refrigerant, usually Freon, during which processes it respectively gives off and takes on heat. The heat that it gives off can be circulated to heat the building; the heat that it acquires is drawn out of the River.



SCHEMATIC of COMPRESSIVE REFRIGERATION CYCLE

Freon, a gas at normal temperatures and pressures, must be compressed mechanically and liquified. It is first compressed to a high pressure vapor, then latent heat is extracted from the freon by the heating medium, which condenses it to a liquid. When the high pressure liquid Freon is released through an expansion valve it springs mechanically to gaseous form. In this change of state it must take on latent heat which it does by drawing heat out of the River water. This cycle is known as the "refrigeration cycle" because it is commonly used to pump heat out of refrigerators. Another common example of this machine is the room air conditioner.

The heat pump is run by mechanical power. Conventional units get this power from electric motors. In this scheme mechanical power from the fall of water is used to generate electricity first and then the electricity is used to run a conventional heat pump. Although this extra step might lose a slight amount of efficiency and require more equipment, electrical power is more flexible; it can be used for a variety of purposes in addition to the heat pump if there is a surplus; and maybe most importantly, back-up electrical power from the utility can be used in case of an emergency.

River Temperature

Pumping heat out of the water of the river will cause it to drop in temperature approximately 0.03 degrees Fahrenheit. This small amount should have virtually no effect on the ecology of the river.

The ideal (Carnot) efficiency of a heat pump is

$$T_2/(T_2 - T_1)$$

where

T_1 = absolute temperature of evaporator

T_2 = absolute temperature of condensor.

The actual efficiency of a typical heat pump expressed as a ratio of heat out to work in (coefficient of performance or C.O.P.) is about 50% of the ideal efficiency according to the ASHRAE Equipment Handbook.

Assuming a river temperature of 35°F and a heating medium temperature of 125°F, the C.O.P. is about 3.25. Assuming a river temperature of 35°F is reasonable because the river rarely freezes and has never been known to freeze solid. Defrosting and de-icing equipment can be used, but moving water will not freeze under these situations as shown by 150 years of similar operations in Lowell. In fact, typical water temperature is probably significantly higher. By coupling solar collectors to a heat storage reservoir as mentioned above, the temperature drop could be reduced further, and the efficiency of the heat pumps increased.

Cooling

Heat pumps can be reversed to provide cooling in the summer, but the feasibility of using this hydro-electric system for cooling is beyond the scope of this study. Several factors are encouraging, however: the temperature of the river is very well suited for cooling either directly or by heat pump; the large quantities of water available make evaporative cooling from ponds and fountains very easy; and there is excess hydro-electric power available at least some of the time.

Heat pumps have to be sized to handle the worst condition which is normally during the peak cooling season. Since cooling loads are beyond the scope of this study, the size of the heat pump cannot be determined, but as a strategy several staged and/or phased heat pumps in parallel and/or series would be used in conjunction with a heat storage reservoir to help flatten peak loads. An additional benefit to using heat pumps is that simultaneous heating and cooling can be provided (space cooling and domestic hot water, for instance).

Demand

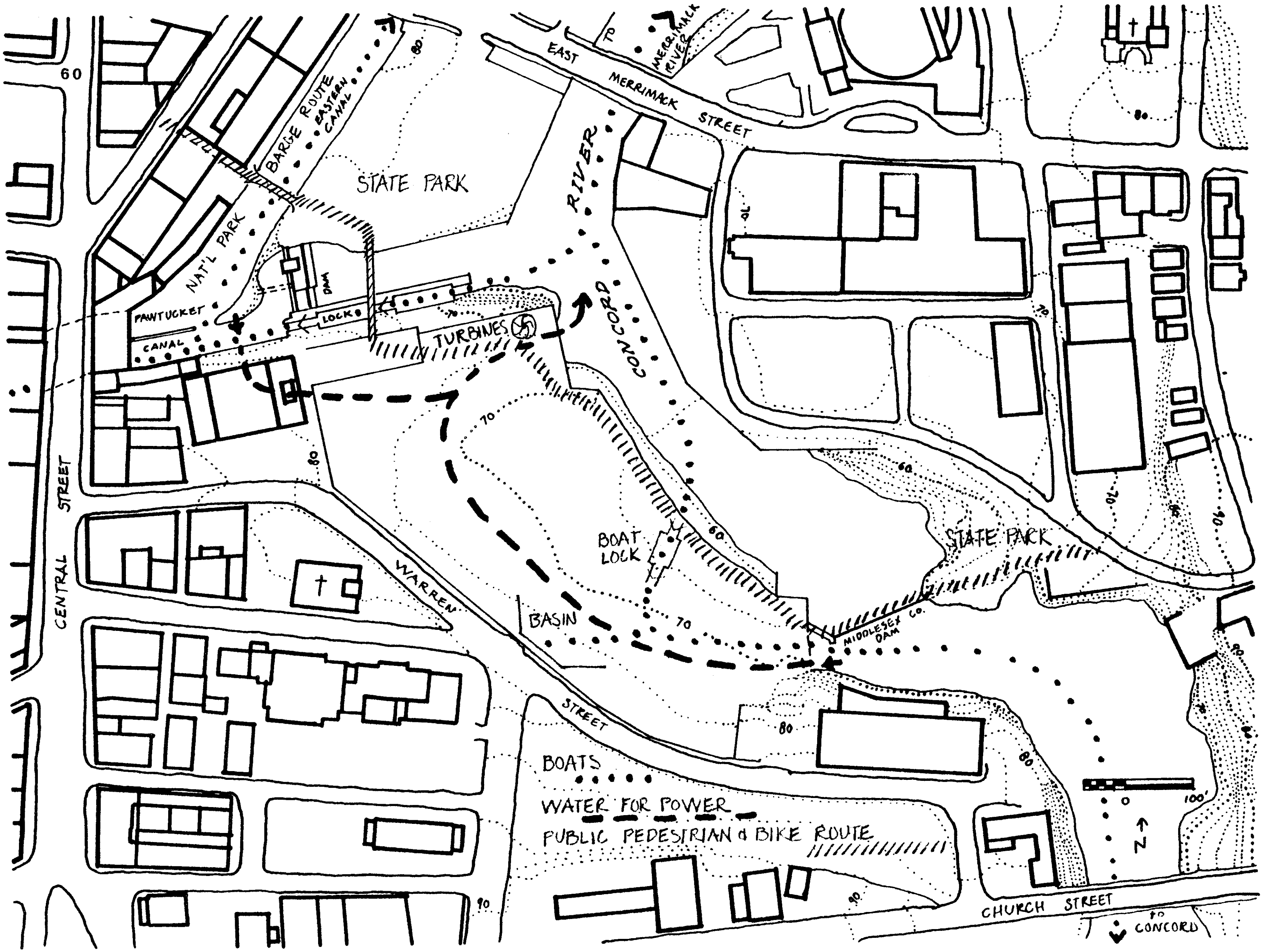
The closest location to the site for weather data on a monthly basis is Blue Hills Observatory which has 6368 total degree days, 5% more than Lowell's 6056 degree days, so the calculations have a built in 5% conservative estimate.[8] Heat loss of seven to nine Btu/square foot per degree day is an attainable goal; the Massachusetts Energy Code allowable maximum is ten to twelve Btu/square foot per degree day and is based on performance of existing inefficient buildings.

Site/Power Organization

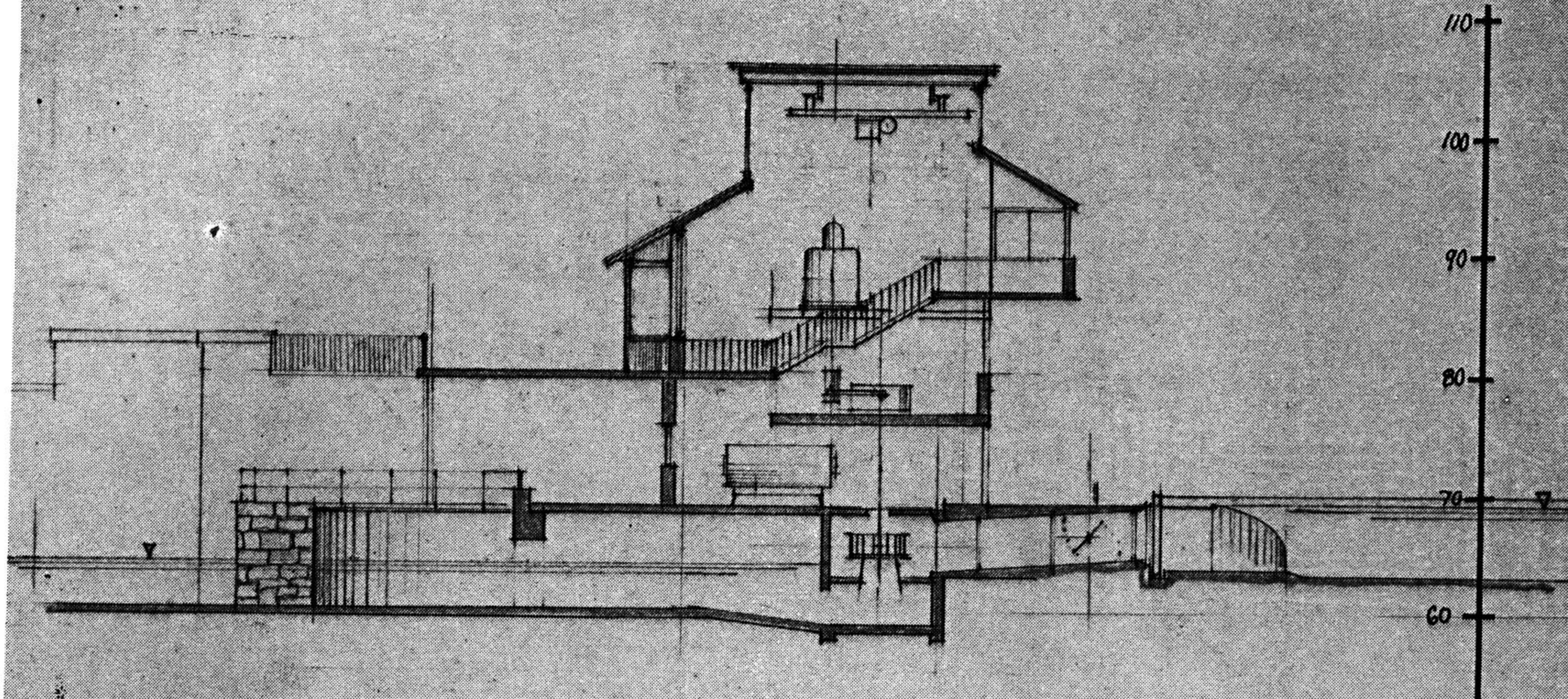
Although I have assumed for the hydropower feasibility study that only the water of the Concord River is available, in the design of the hydraulic system I have made it possible to combine the two sources of waterpower.

The land is situated such that the water sources flow in more or less directly opposite directions, but at different levels. This problem is resolved by employing a ring canal at the height of the River which collects the water from the Pawtucket Canal at a joint where the water drops. The total flow is then available for use by the power plant. This justifies bringing water through the entire site.

The hydraulic system requires wasteways or spillways at any point where it would be necessary to allow excess water to flow out of the canal. The term "wasteway" refers to water wasted as far as power production is concerned and is NOT connected in any way with sewerage. Without wasteways, flooding could occur and an abrupt halt in water flow through the turbines would create a water hammer so large it would destroy any building in the way. Wasteways are controlled by many different devices including weirs, sluices and siphons.

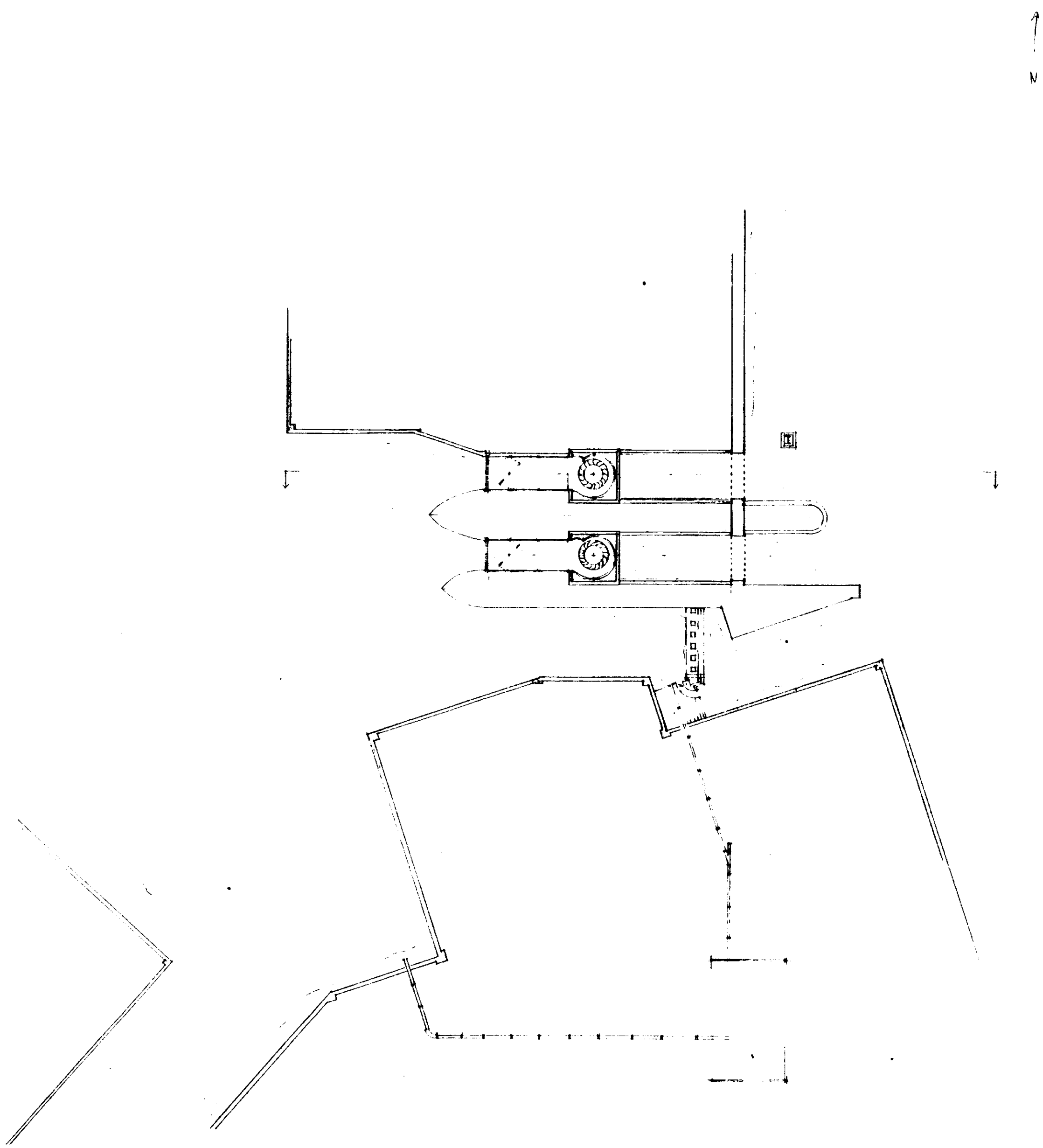


STATE PARK
NAT'L PARK
BARGE ROUTE
EASTERN CANAL
PAWTUCKET
CANAL
LOCK
DAM
TURBINES
EAST MERRIMACK STREET
TO MERRIMACK RIVER
CONCORD RIVER
CENTRAL STREET
WARREN STREET
BOAT LOCK
BASIN
MIDDLESEX CO. DAM
STATE PARK
CHURCH STREET
TO CONCORD
BOATS
WATER FOR POWER
PUBLIC PEDESTRIAN & BIKE ROUTE
0
100'
N
60
70
80
90

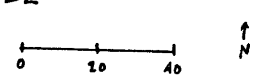


TURBINE HOUSE

SCHEMATIC SECTION



PLAN at WATER/TURBINE LEVEL



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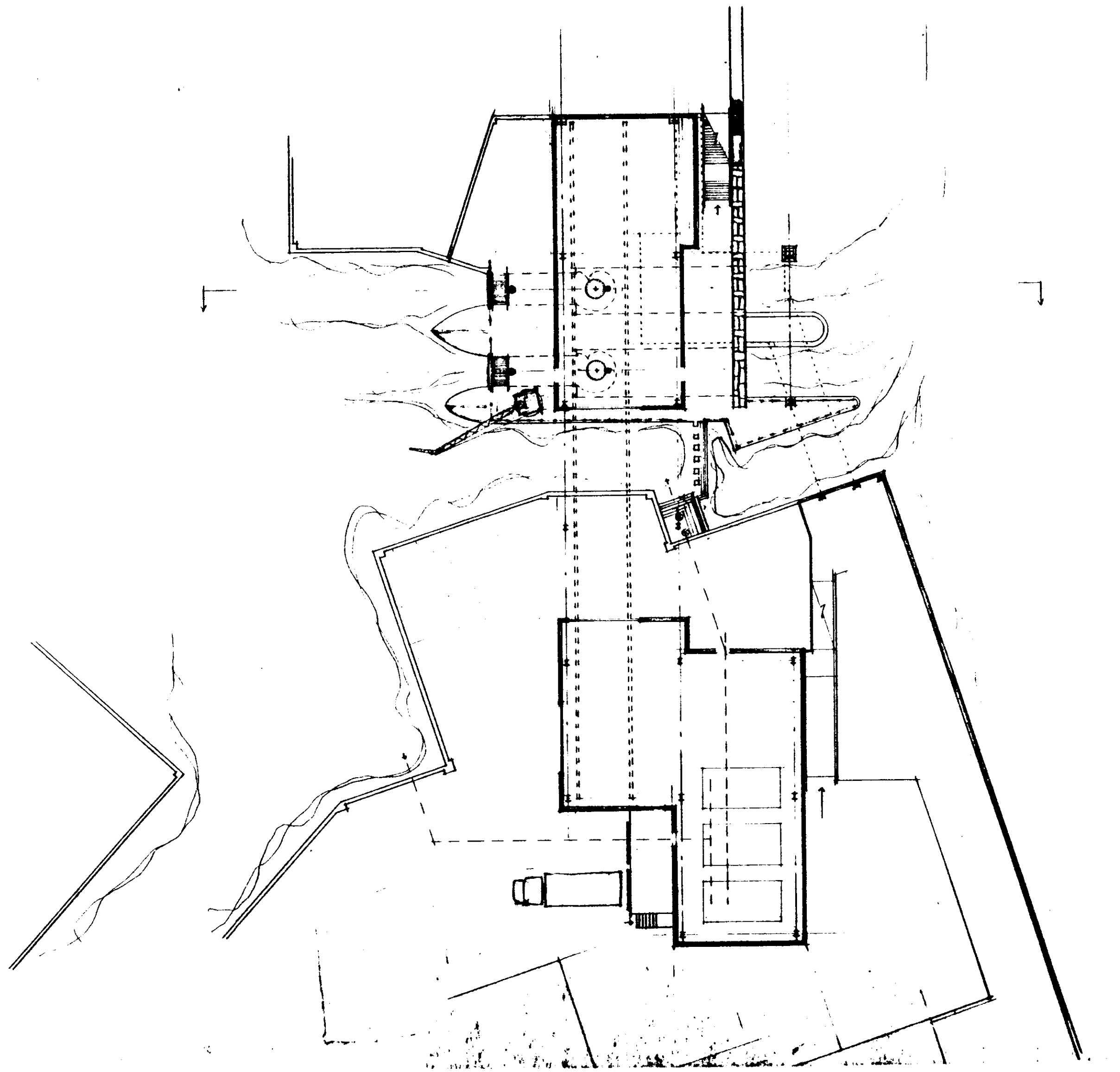
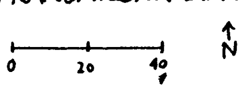
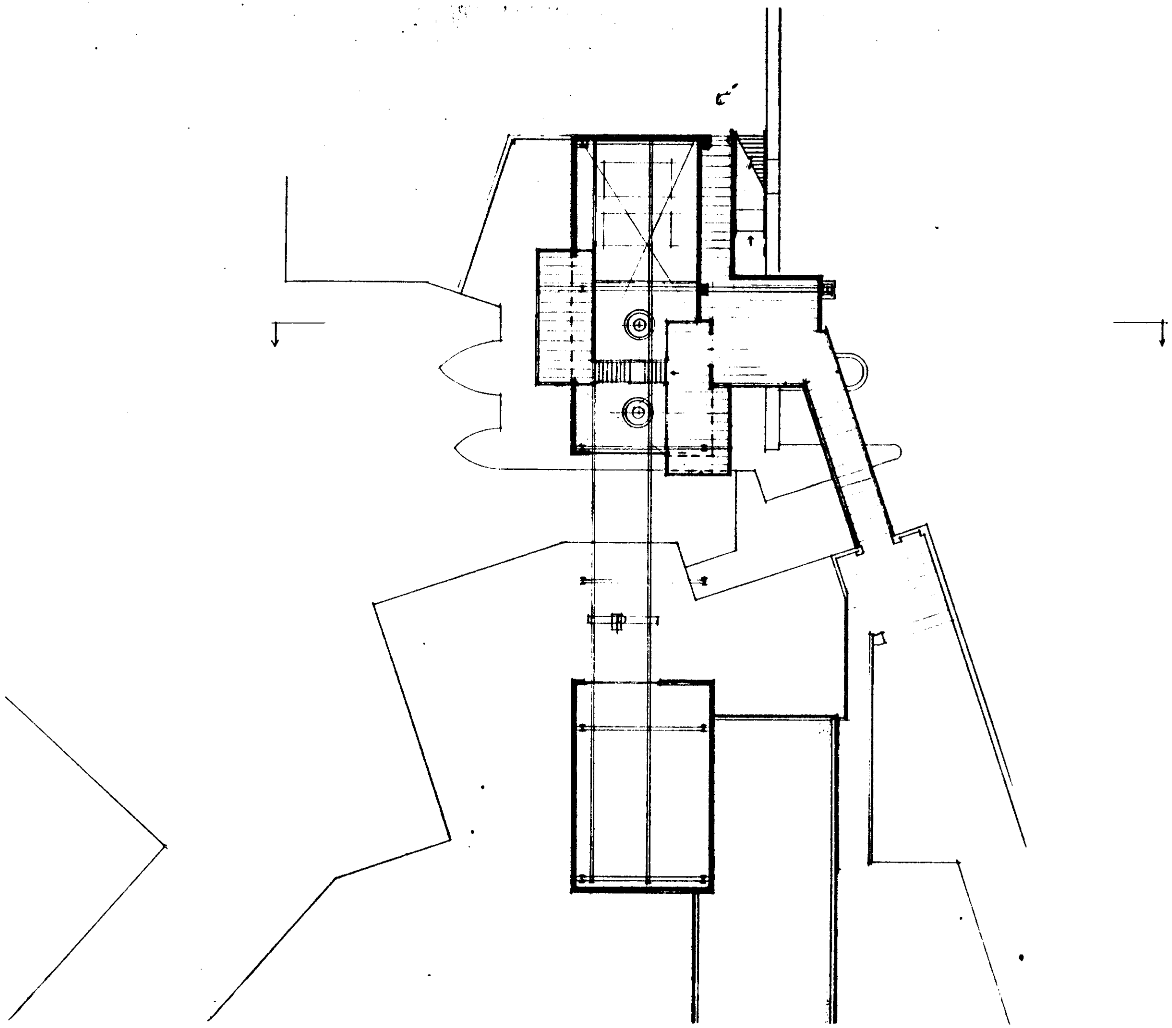


PLAN at GROUND/
TRANSMISSION LEVEL



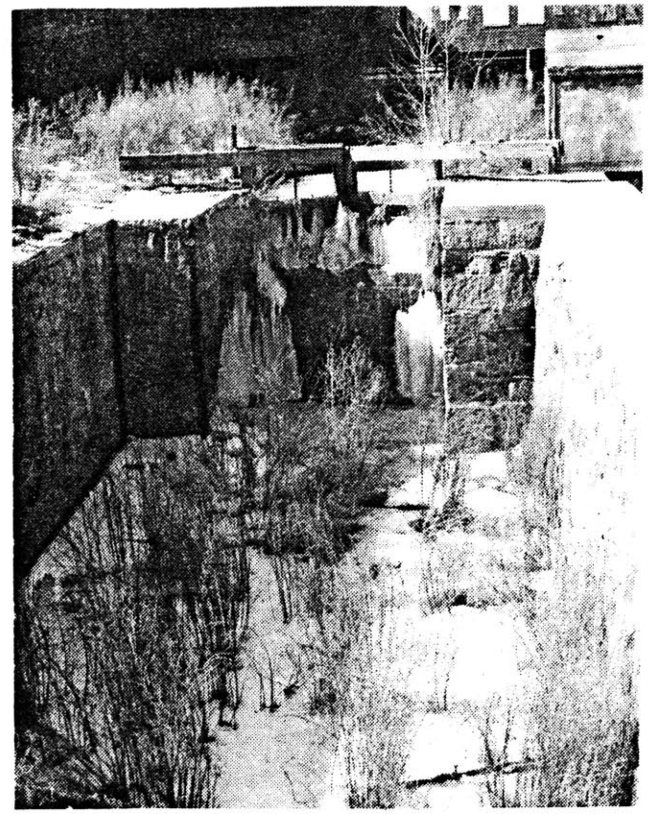


PLAN at MEZZANINE / GENERATOR LEVEL

Recreational use of the water can be separated from power use. The river side of the canal system can be used for recreation, especially boating and possibly swimming. The current in this section of the waterworks could be kept relatively slow by making the channel wide. A boat lock connects the canal back to the River. Boats can then either continue down the River to the Merrimack or re-enter the original canal system via the Lower Locks at the Pawtucket Canal. This way a continuous boat route for National Park tours or for private boats can be made around either dam and avoiding the power plant. The tailraces from the turbines would have to be designed so as to allow safe passage for small boats passing by the gushing water.

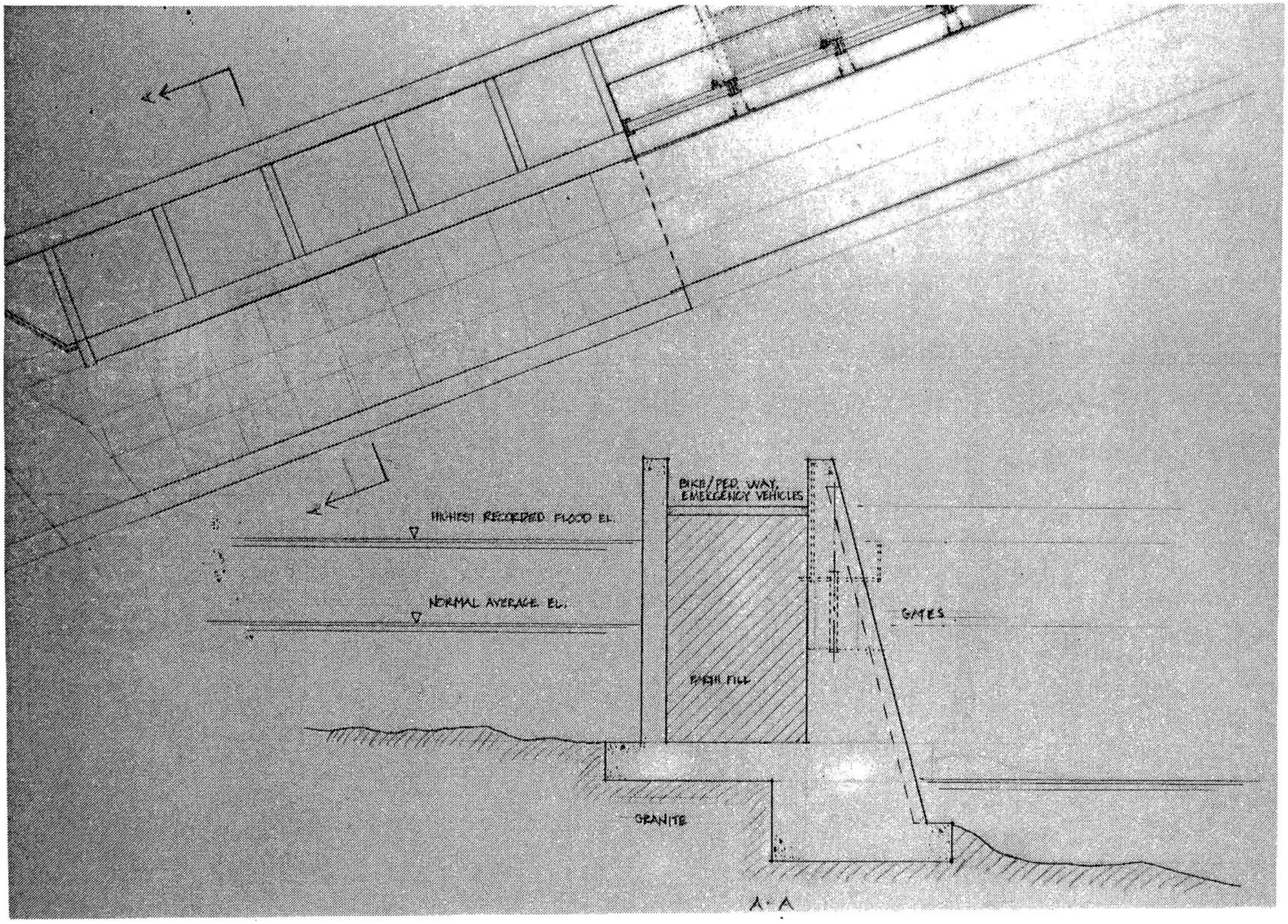
It is conceivable that the water will be clean enough for swimming at some time in the near future due to construction of sewer interceptors which prevent sewerage from entering the River. The currents in the canals are swift, however, so swimming could only occur in sheltered pools off the mainstream canal. The reservoir above the Middlesex Co. Dam is one potential swimming area.

Power canals tend to be shallow and wide in proportion. At a given volumetric flow rate required to supply the power turbines, average current speed is equal to volume divided by cross section.



Boat lock adjacent to site

As the water gets cleaner, fishing will also return. A fish ladder is included in the design of a reconstructed Middlesex Co. Dam.



PART III

The Hotel Design

1

Bending & Branching

"We were uncertain whether the water floated the land, or the land held the water in its bosom."

Thoreau

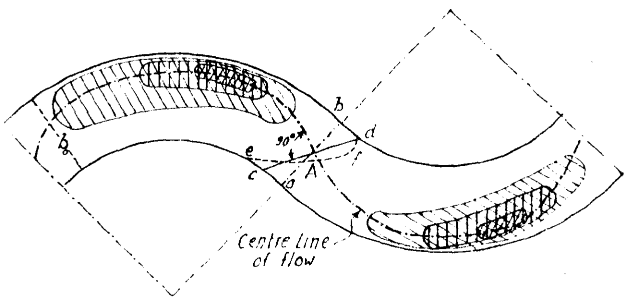
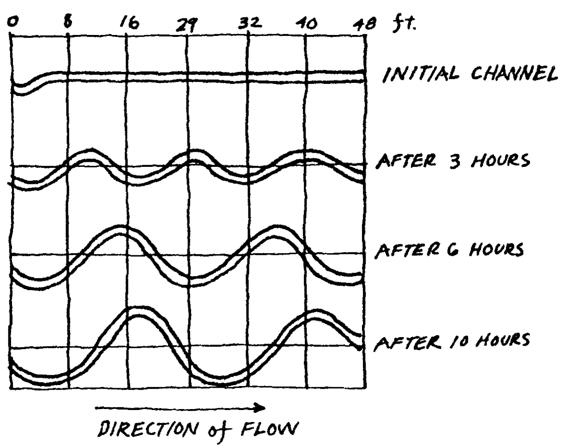


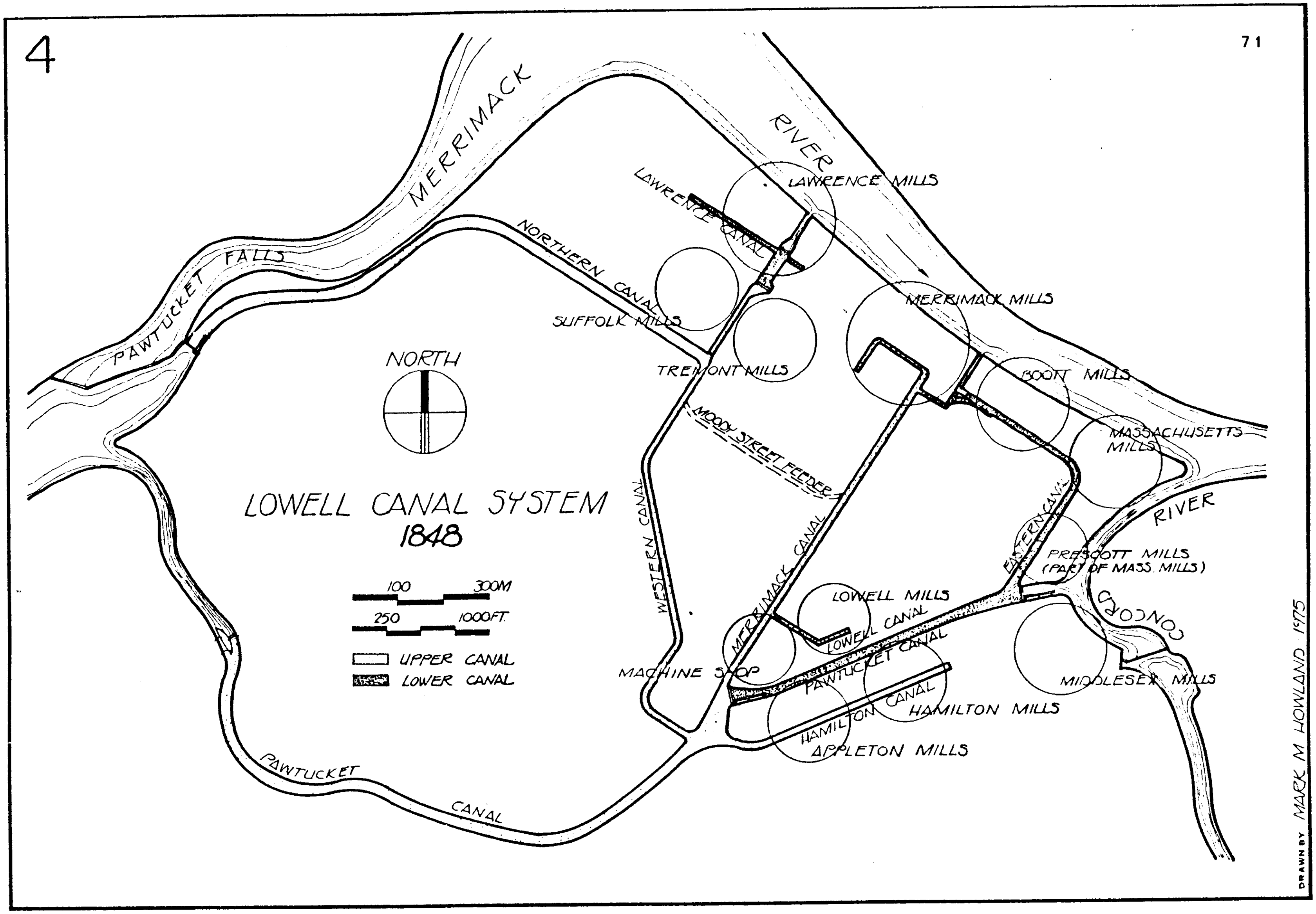
FIG. 39. Diagram of typical meander coil, demonstrating inconsistency of the traditional method of river training, by channel contraction. [10]



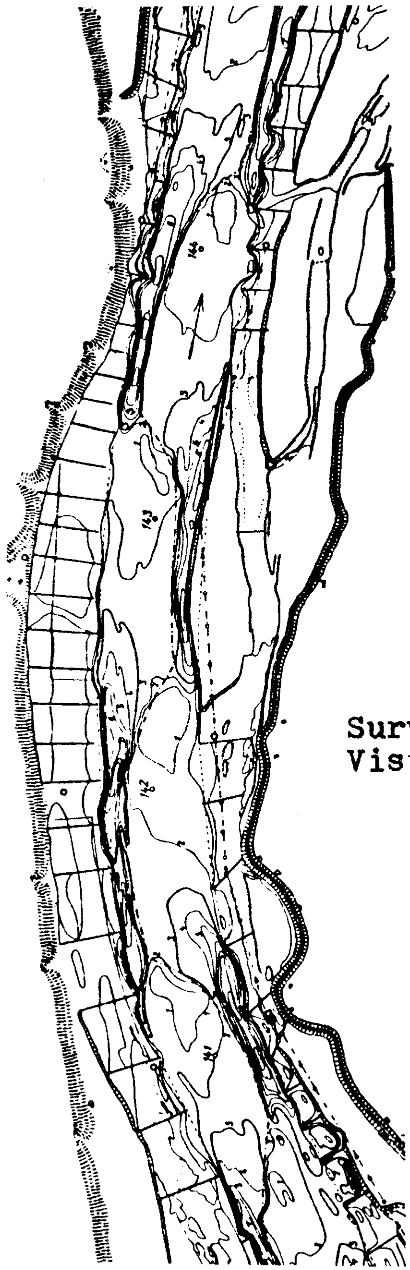
FRIEDKIN'S RIVER MODEL EXPERIMENT which reproduced meander formation [11]

Many studies have shown that under certain conditions rivers naturally tend to "meander"; that is, follow a nearly sinusoidal path.[9] This is due to a complex three dimensional phenomenon depending on the slope of the land and the size of the grain of the soil. In mountainous areas where the grain is course and the slope steep, the flow tends to be straight. In contrast, rivers on flat fertile plains tend to meander. In meandering, a river will create deeps in the concave curves and shoals in the inflextion points between curves. The greater the curve, the deeper the scoured channel beneath them. Contiguous stream lines are neither parallel to each other nor to the banks of the river. River currents are helicoidal or spiral, converging where the river scours and diverging where the channel slits.

Designing with the river implies using a non-parallel geometry. The Merrimack and Concord Rivers sometimes meander, sometimes flow fairly straight, and sometimes drop violently. A natural rhythm of shoal and deep or stream and pond is used to organize the waterways. Metaphorically, this is the alternatively dynamic and contemplative quality of water which people find so attractive, almost magical.



Mark M. Howland HAER - 1975



Survey of Vistula River[12]

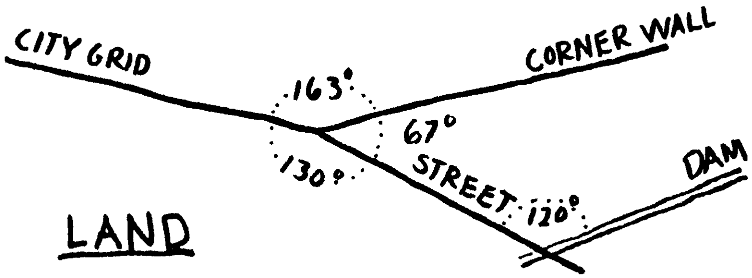
From the meandering of a river, the next level of complexity is the joining of two or more water courses.

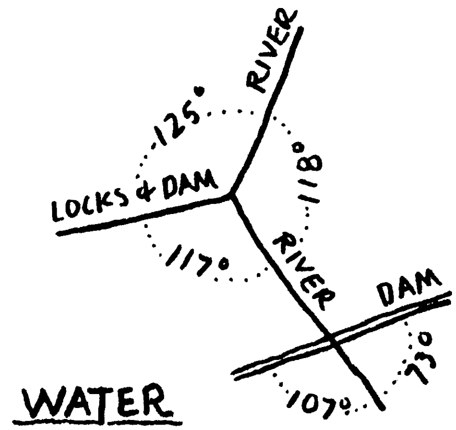
Branching

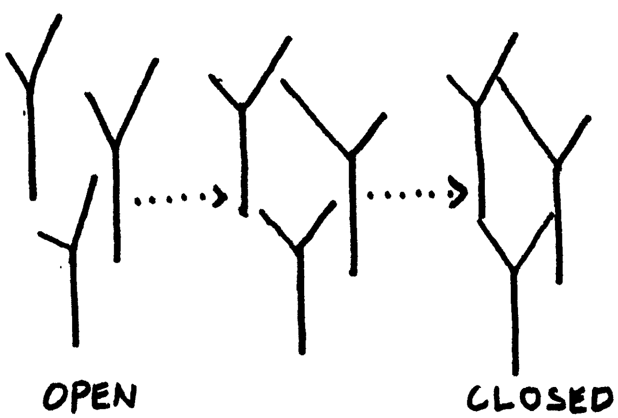
The reasons for branching in the man made canal system were due to the specific site and program:

> *"Unfortunately for the planners of Lowell, the topography of their site and the route of the existing canal were not suitable for implementation of the ideal scheme. The land on the south side of Pawtucket Falls was rocky and rose steeply from the river's edge. The builders of the Pawtucket Canal had avoided high ground by running their channel in a wide arc around the bend in the Merrimack and ending it at the Concord River, close to the junction with the larger stream. Since the builder could not place mills on land higher than the level of the upper river, he had to plan mill sites away from the falls and new canals to reach them. The Pawtucket would have to be reconstructed to feed smaller power canals, but the resulting system would obviously be a complex one, creating far more engineering problems than a single canal. An additional difficulty was the necessity of retaining the original function of the old transportation waterway. Construction supplies, raw materials, and manufactured products would be carried in the Pawtucket Canal for years."*[13]

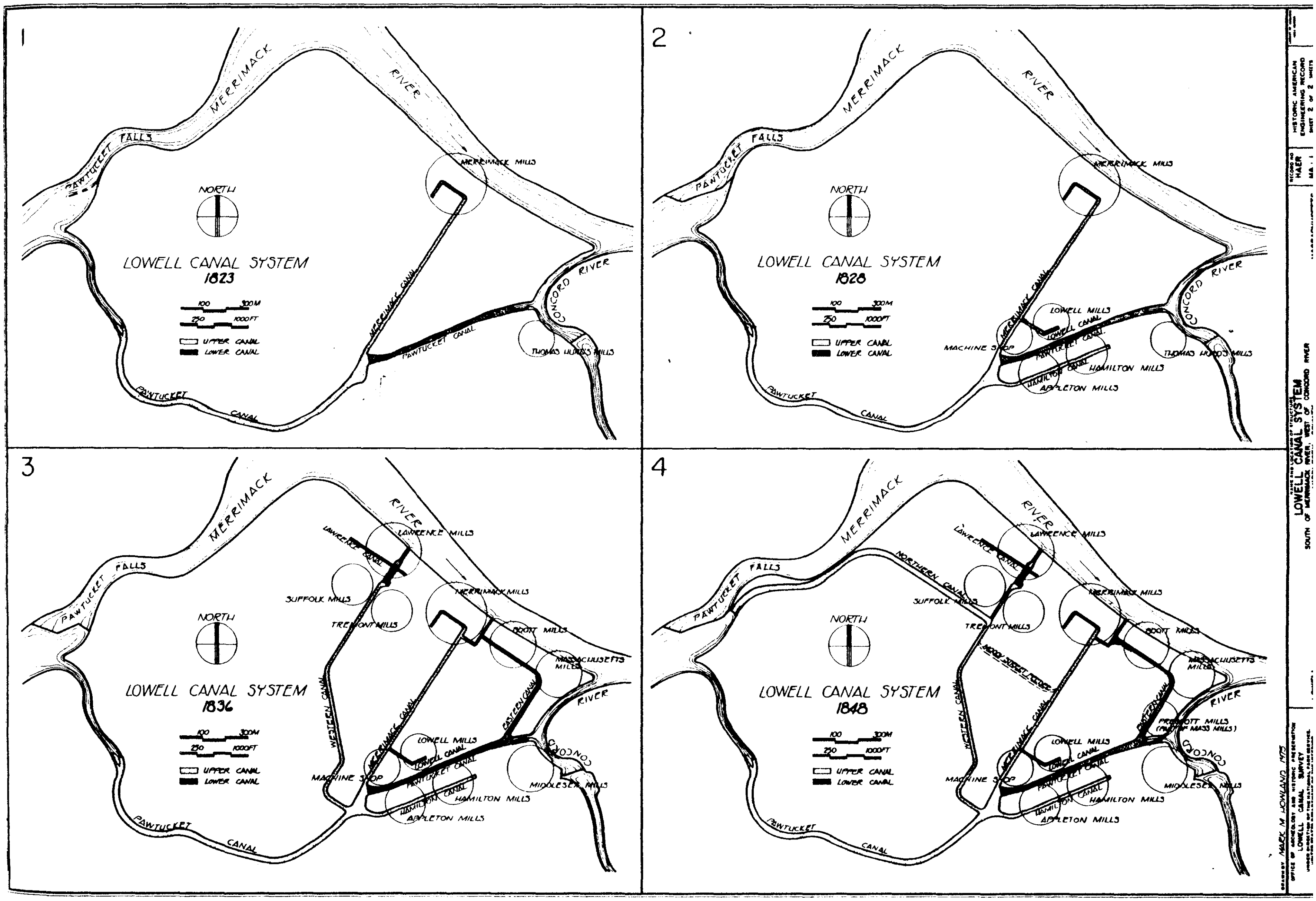
The confluence of two or more water courses form a complex branching water/landscape. Rather than minimize these historical organizational features, I try to maximize their use on the site.





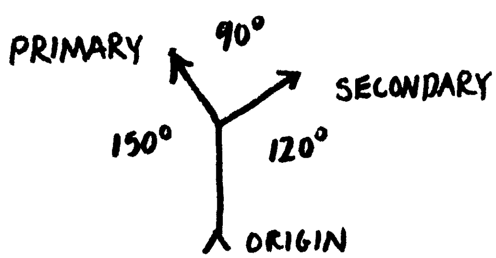


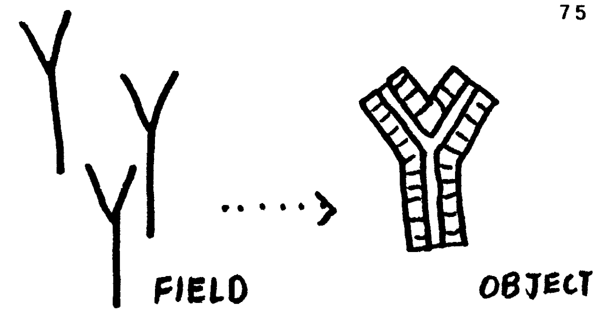
After analyzing the directions of the major features around the site a pattern emerged. The use of a branching organization is derived from the nature and use of flowing water on and near the site. In general, the greater the angle, the more turbulance and friction in a watercourse. Branches are directional and are binary decision points (joints), but are not necessarily uniform or symmetrical. Branching networks can be strictly hierarchical or laterally organized, whereas the figure-ground relationship depends a great deal on the degree of closure. There is a real danger that the organization could become totally closed and the figure would become packed cells. There is also the danger that the field (ground) becomes designed and built as a figure (object).

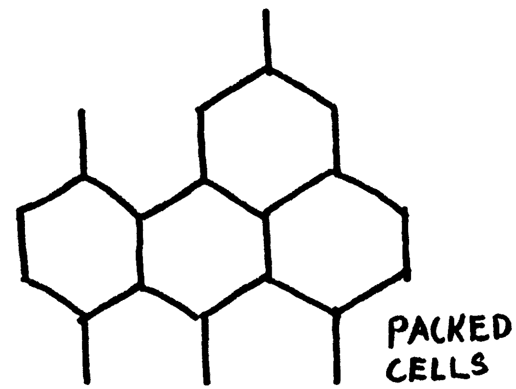

1
MERRIMACK
RIVER
PAWTUCKET FALLS
MERRIMACK MILLS
NORTH
LOWELL CANAL SYSTEM
1823
UPPER CANAL
LOWER CANAL
MERRIMACK CANAL
PAWTUCKET CANAL
CONCORD RIVER
THOMAS HURDS MILLS
2
LOWELL CANAL SYSTEM
1828
LOWELL MILLS
MACHINE SHOP
HAMILTON MILLS
APPLETON MILLS
3
LOWELL CANAL SYSTEM
1836
LAWRENCE MILLS
SUFFOLK MILLS
TREMONT MILLS
BOOTT MILLS
MASSACHUSETTS MILLS
WESTERN CANAL
EASTERN CANAL
MIDDLESEX MILLS
4
LOWELL CANAL SYSTEM
1848
NORTHERN CANAL
PRESCOTT MILLS
HISTORIC AMERICAN ENGINEERING RECORD
SHEET 2 OF 2 SHEETS
RECORD NO HAER
LOWELL CANAL SYSTEM
SOUTH OF MERRIMACK RIVER, WEST OF CONCORD RIVER
DRAWN BY MARK M HOWLAND 1975
OFFICE OF ARCHEOLOGY AND HISTORIC PRESERVATION
LOWELL CANAL SURVEY

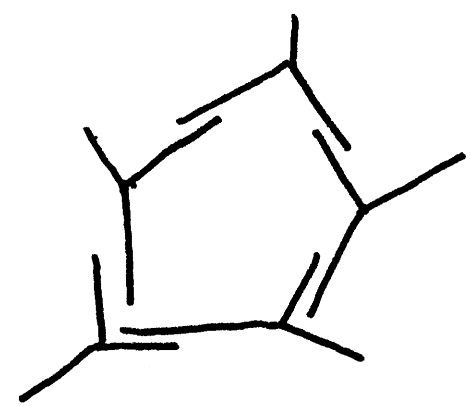
The ideal is to design a reciprocal relationship: figure-ground reversal. Each figure-ground is distinct and unambiguous, yet each contribute equally to the definition of the other so that all spaces are positive and inhabitable or usable. One rule is that the ends of the organizational network should be open joints, not links or closed forms: a dogbone organization. The branching should preferably be highly directional so there is primary and secondary choice both in plan and section. In section down is almost always the primary direction. The configuration of 90° - 120° - 150° avoids the problem of acute angles and is buildable with an orthogonal and/or hexagonal geometry.

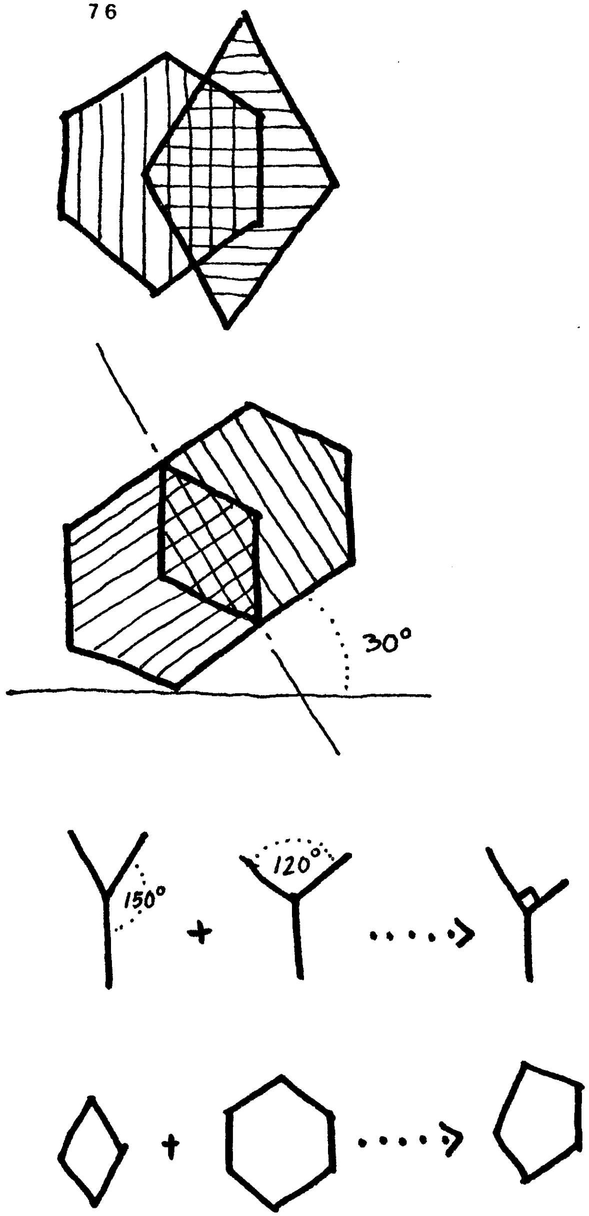
This branching geometry was chosen and applied in a field organization to the site in several schemes and at several scales. The branching figure seemed to imply a ground (or complementary figure) of an irregular pentagon. Because this figure is irregular it will not repeat itself in a packed field; there will be "holes" where another geometry will fill in.





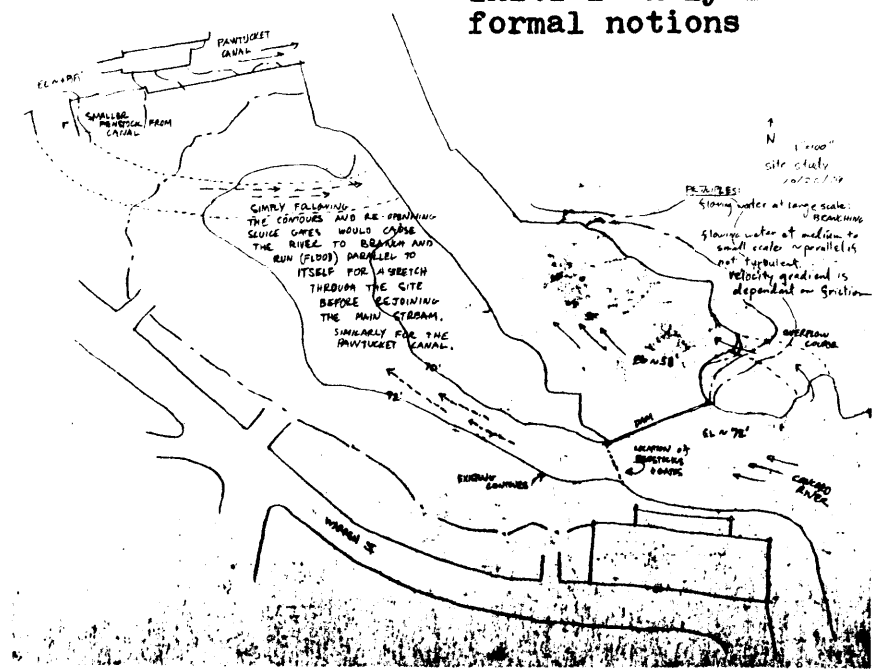




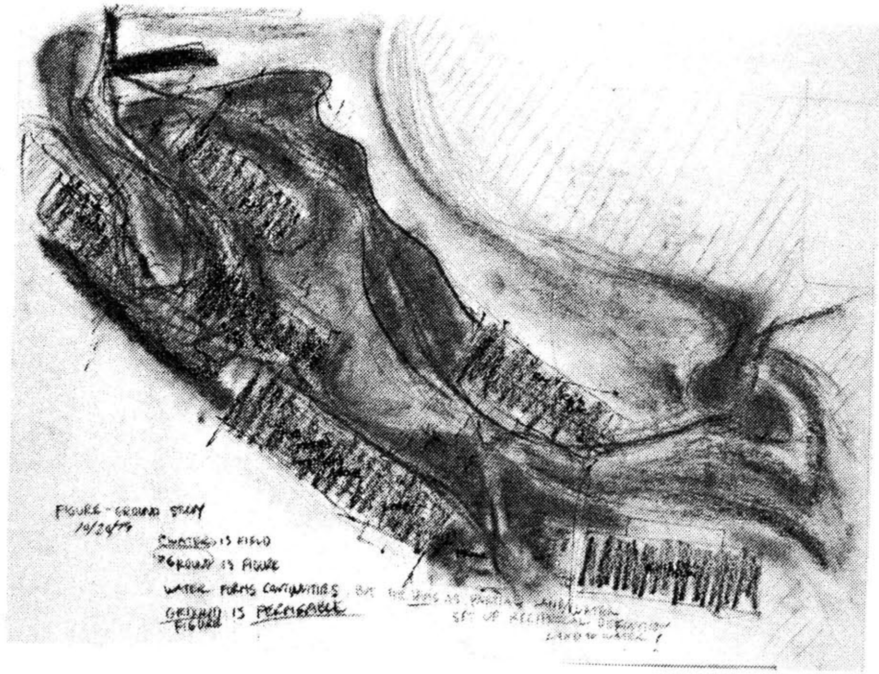


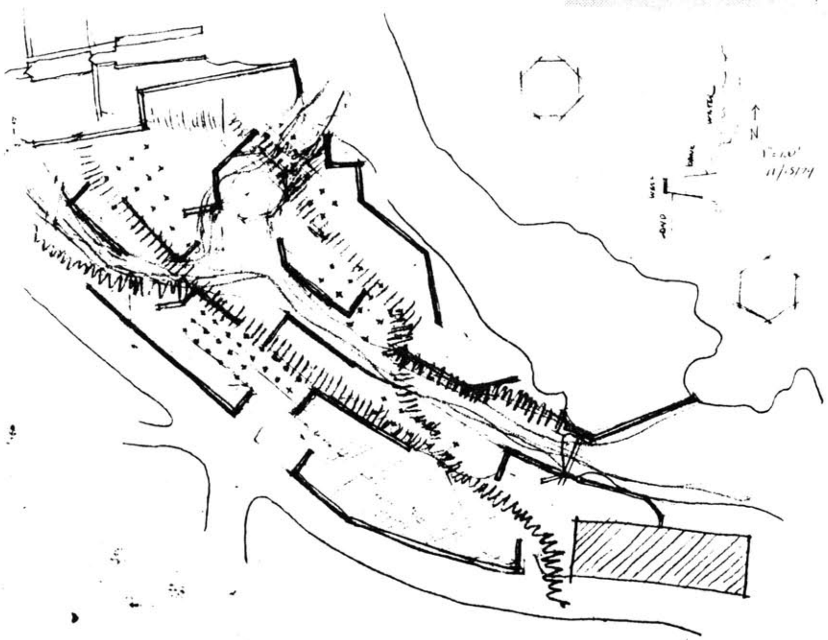
Although this is ideal for a collage of elements in a field organization, it makes composition of a figure-ground relationship more difficult. By further analysis I found the 90° - 120° - 150° geometry reducible to regular geometry. All the directions can be accommodated in a hexagon and diamond rhombus. Both of these are part of the same family rotated 30 degrees. The final site design is based on hexagonal geometry which uses other directions only in special cases.

Initial analysis and formal notions

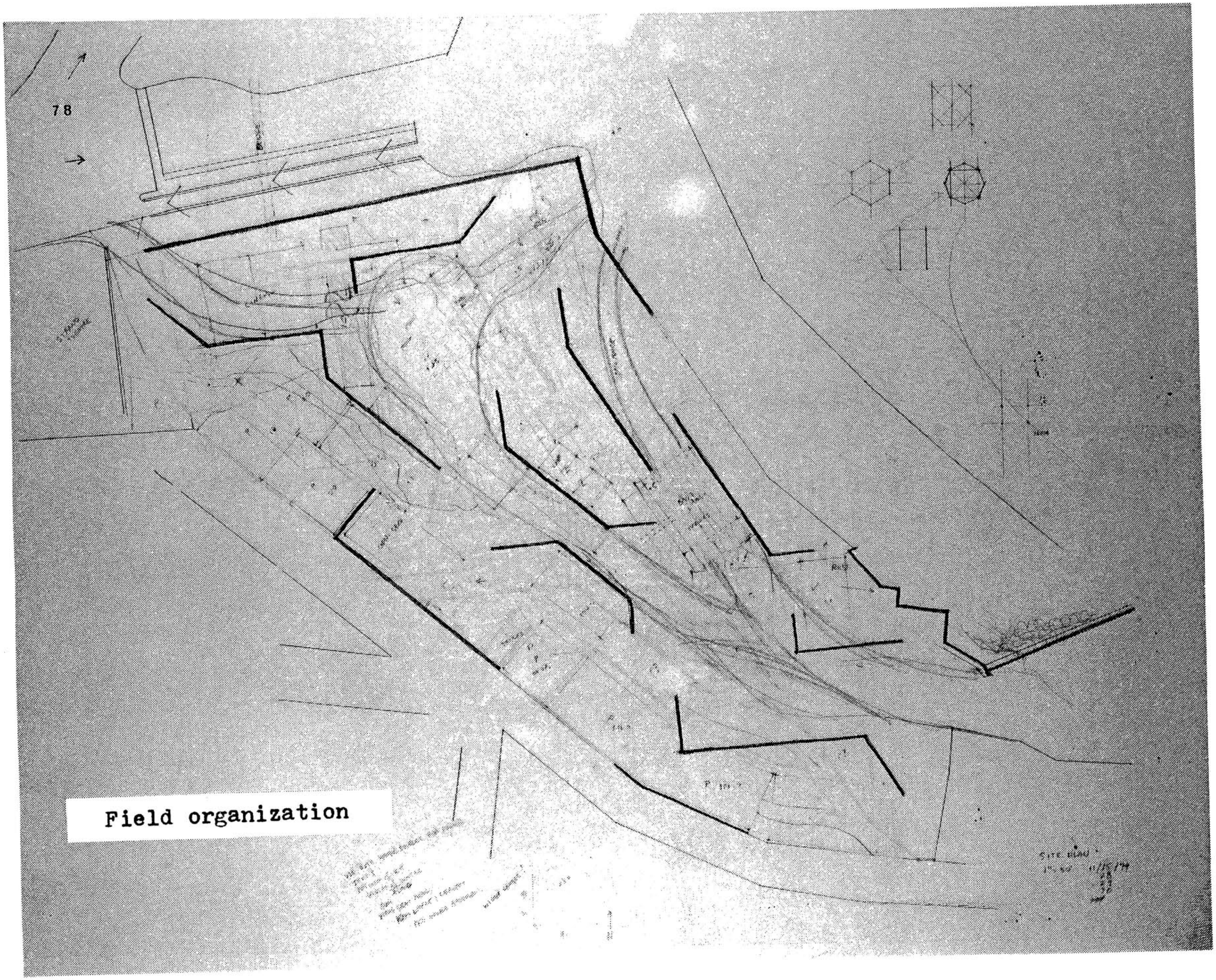


Pastel sketch of site
reciprocity; figure-ground

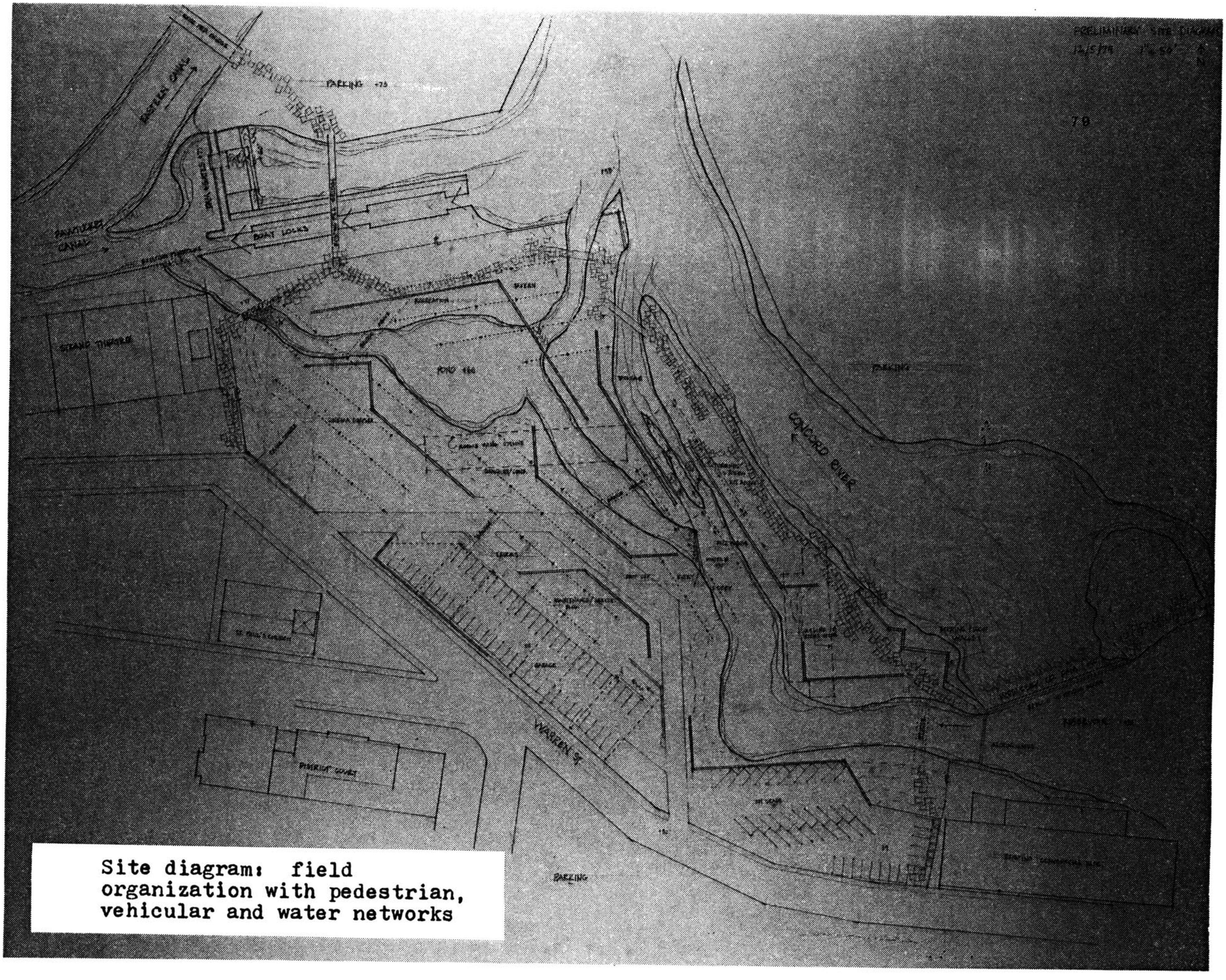




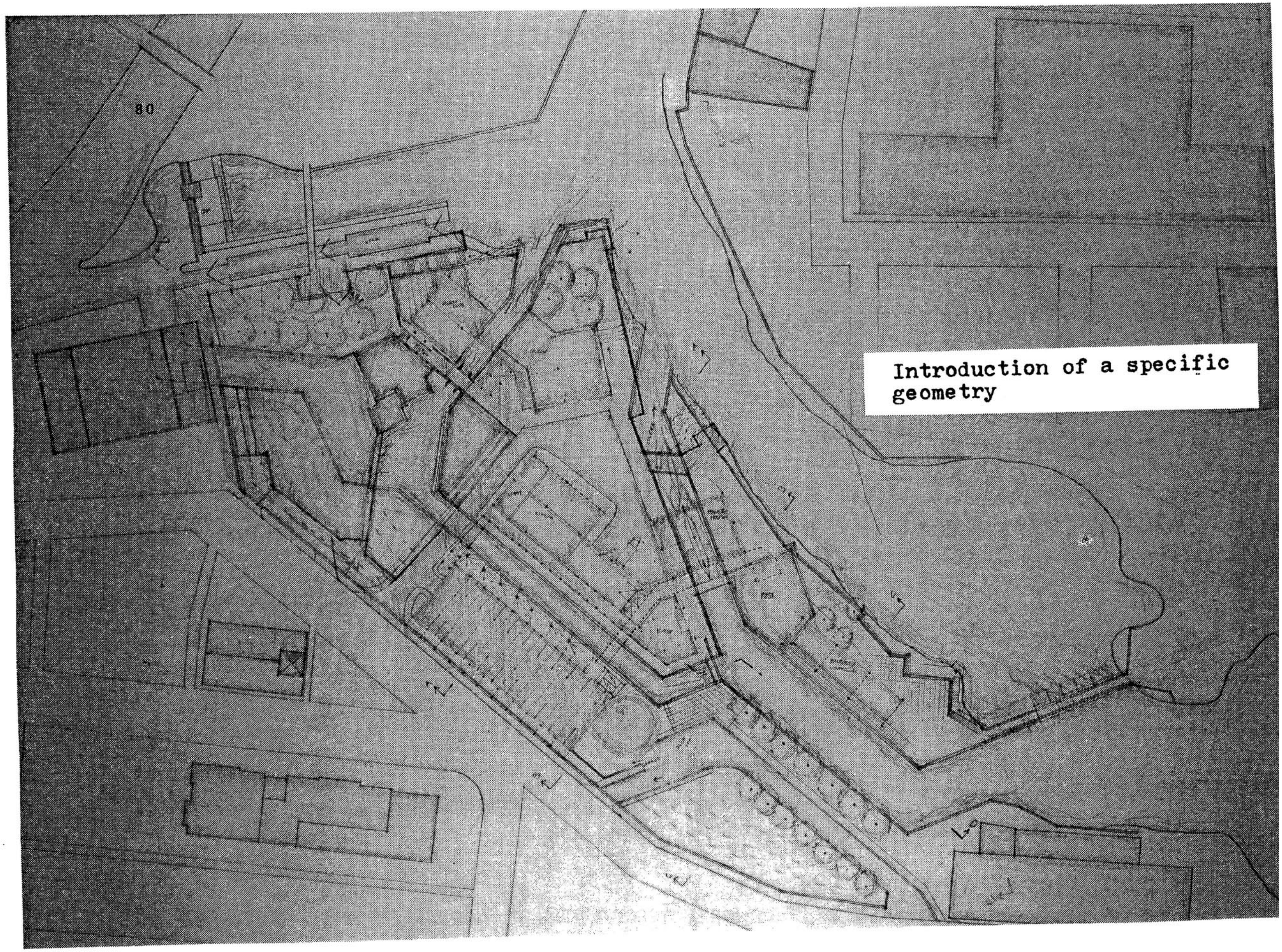
Introduction of a field of
columns and walls



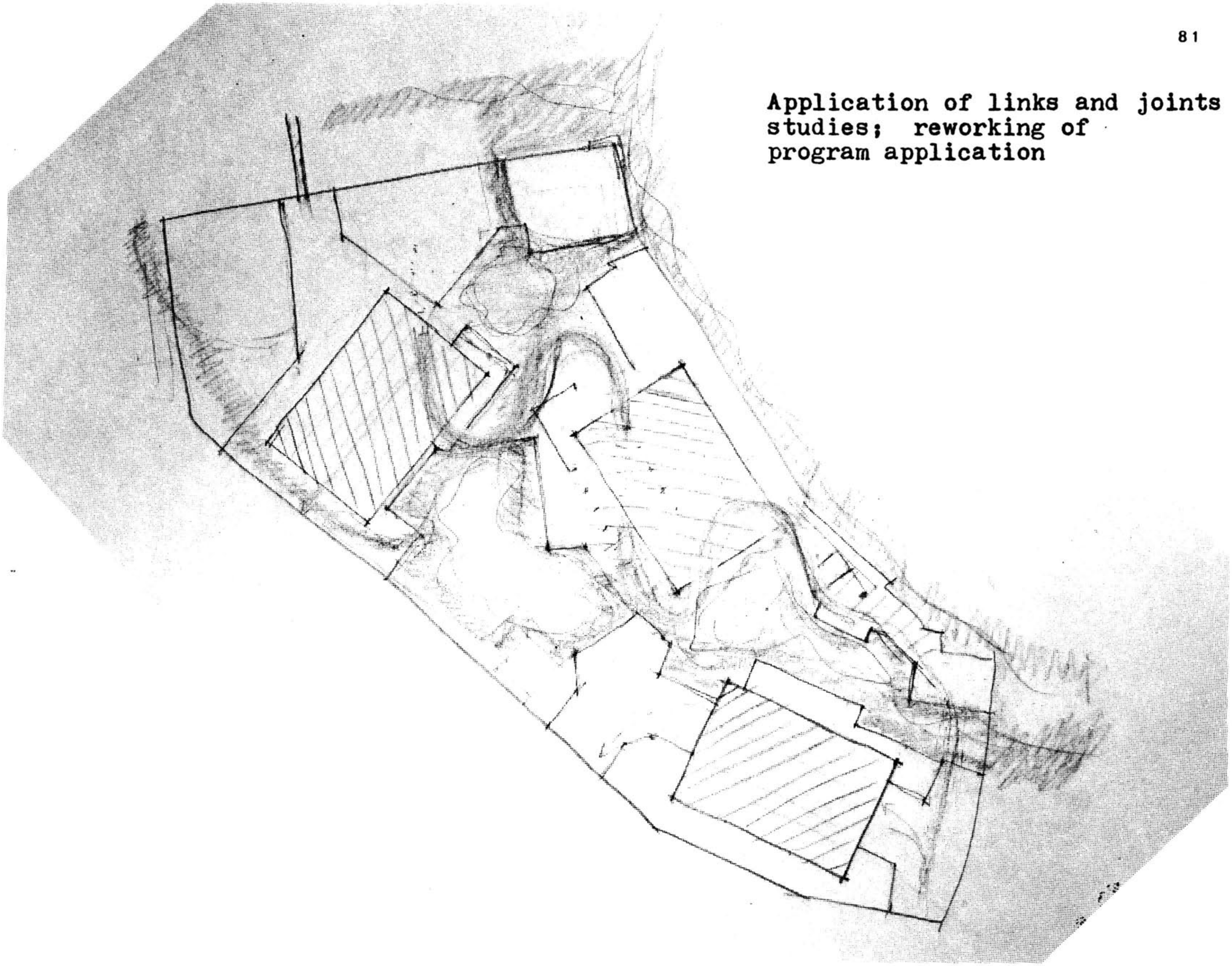
Field organization



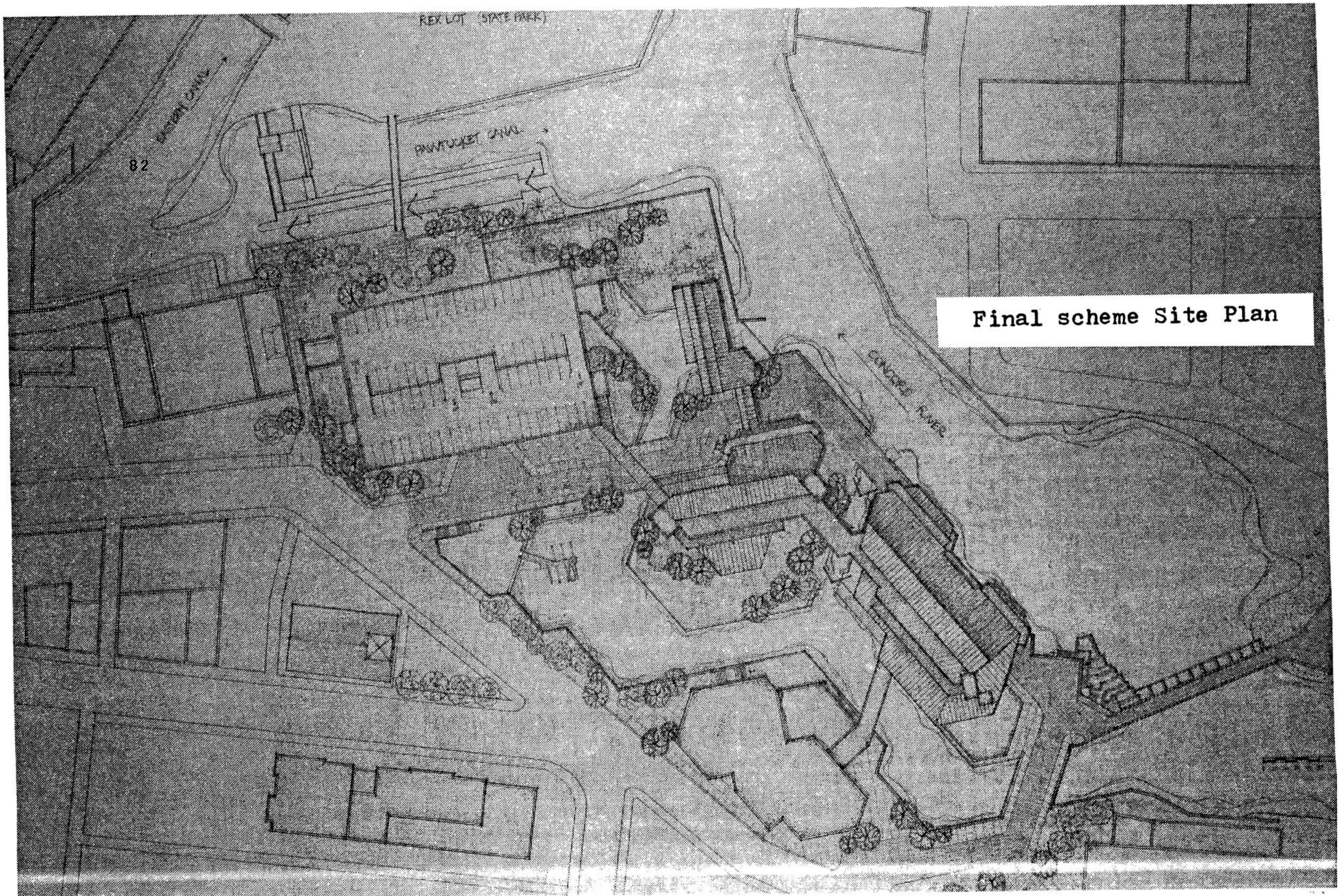
Site diagram: field organization with pedestrian, vehicular and water networks



Introduction of a specific geometry



Application of links and joints studies; reworking of program application



Final scheme Site Plan

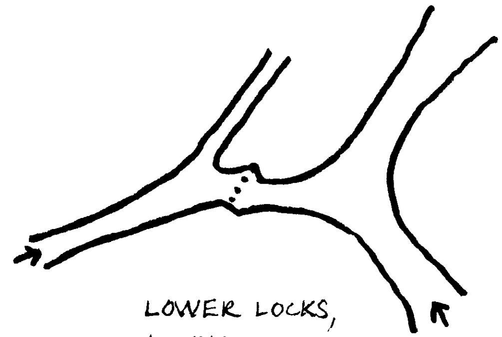
2 LINKS & JOINTS

One way to organize a branching system is through the use of links and joints. There are three separate but interrelated network systems which are consciously organized according to links and joints. The three systems are:

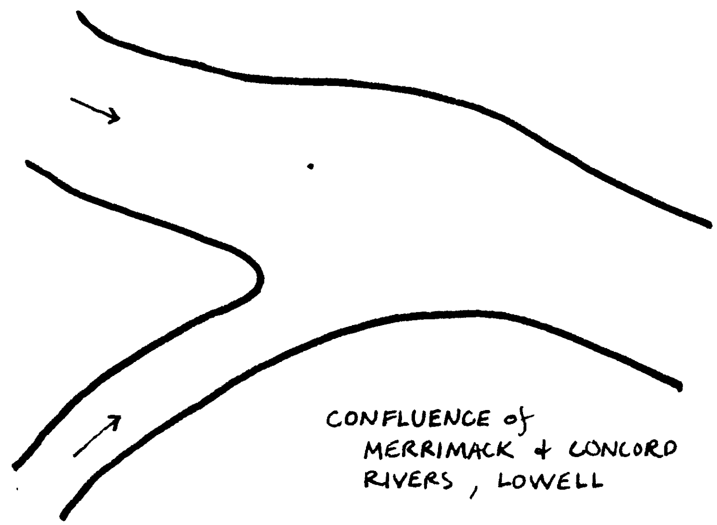
1. the water
2. the land
3. the building(s)

The general terms 'link' and 'joint' take on a more specific meaning on each of these systems.

1. In the water system 'link' means stream or sometimes canal. 'Joint' means pond, or reservoir and enlarged basins which occur at the bends in watercourses.
2. In the land 'link' is an isthmus, a bridge, dam, weir, or a road or street. 'Joint' is a square, plaza, or an island (if it is connected back to the mainland by a link).
3. In the building the links are corridors, arcades, collonades, etc. The joints are lobbies, foyers, lounges, etc.



LOWER LOCKS, LOWELL



CONFLUENCE of MERRIMACK + CONCORD RIVERS, LOWELL

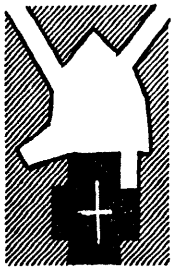


Fig. 39.
Siena:
S. Maria di
Provenzano

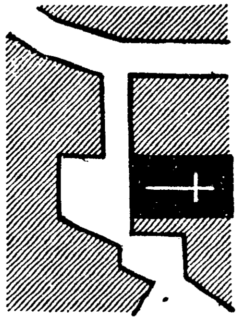


Fig. 40.
Genoa: S. Siro

Fig. 36.
Siena:
S. Pietro alle
Scale

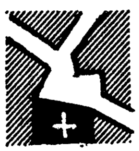


Fig. 37.
Siena:
S. Vigilio

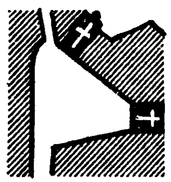


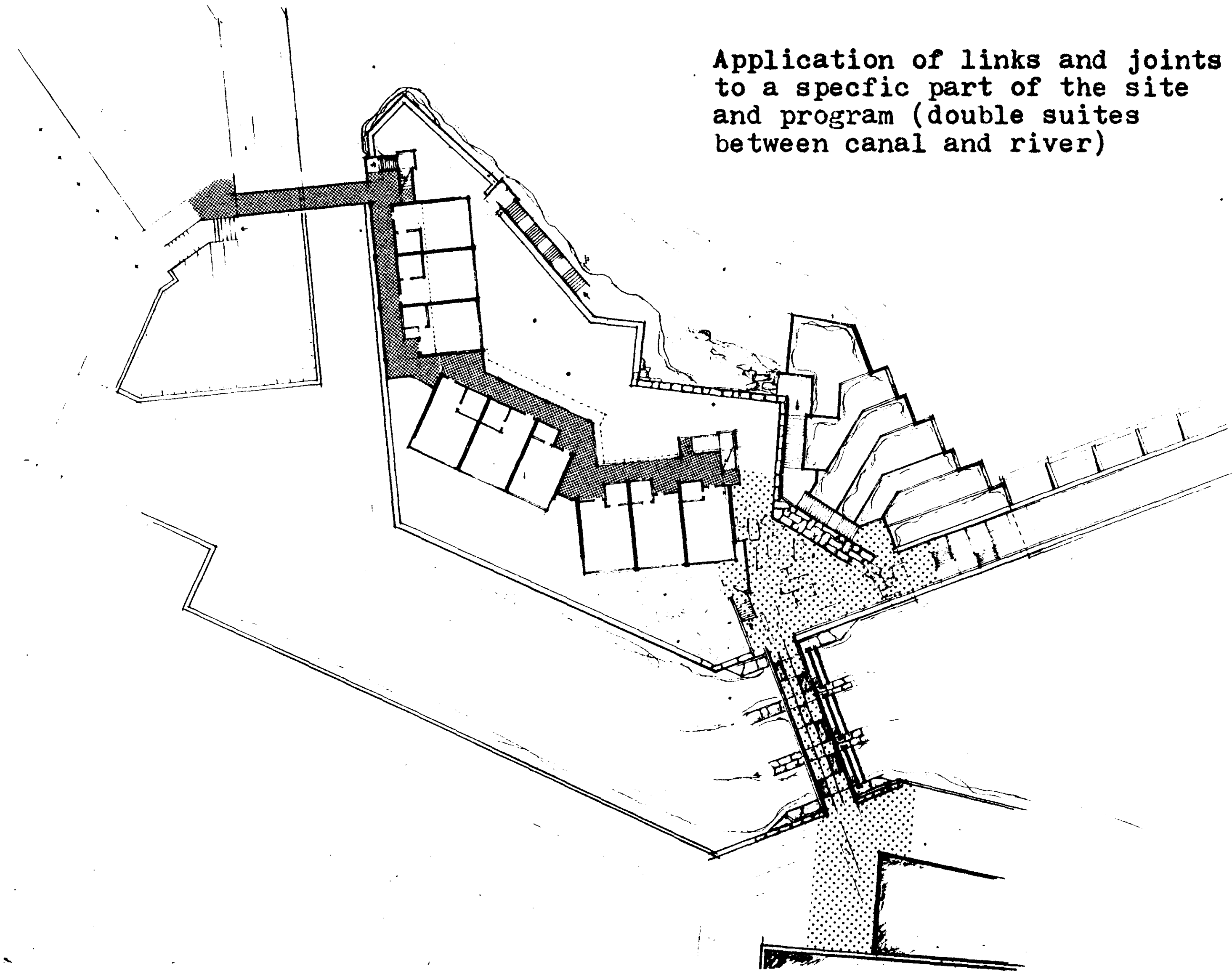
Fig. 38.
Siena: Via
dell'Abbadia

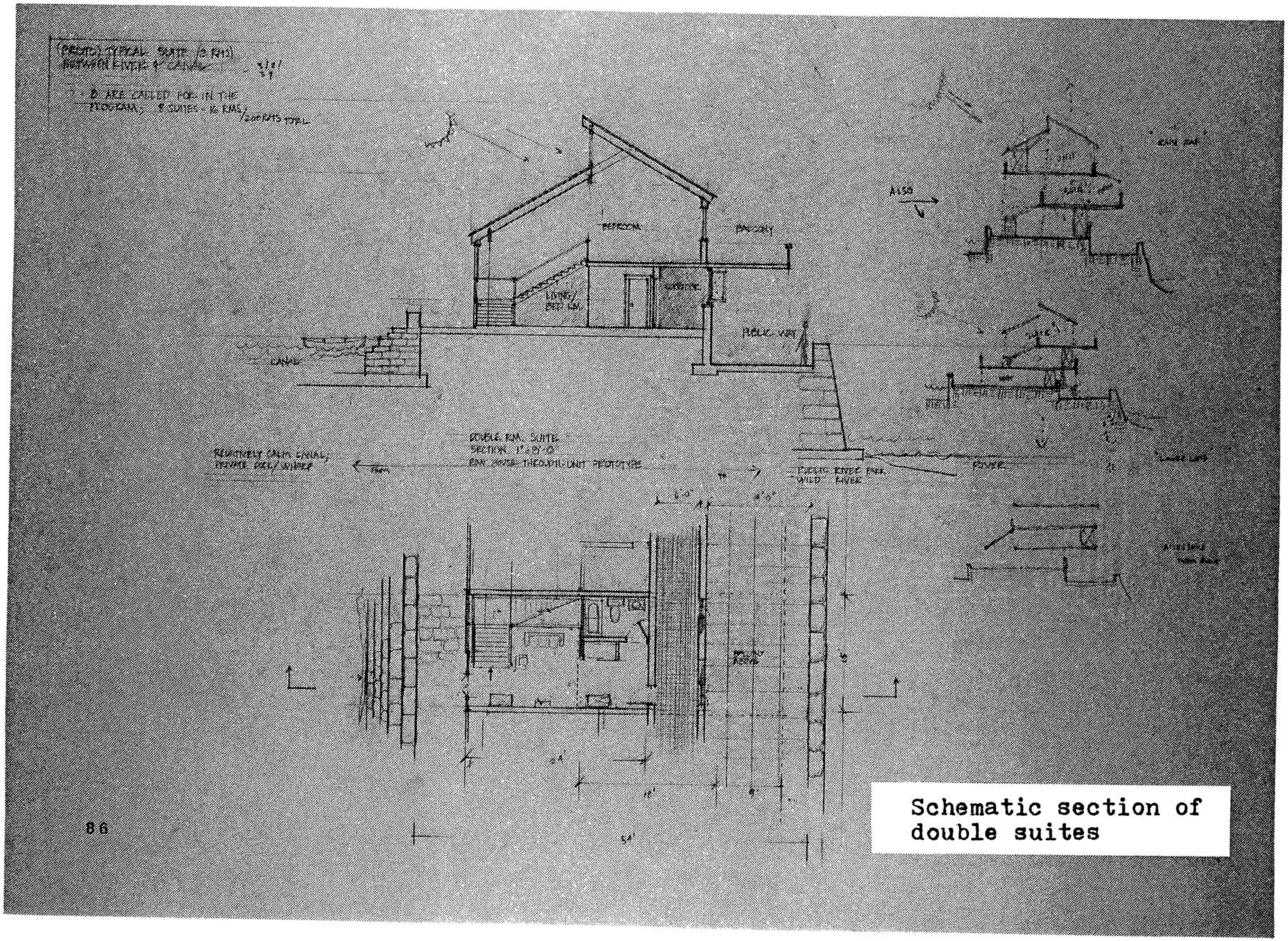
For such systems to work some simple rules are assumed; namely: links always connect to joints, never to other links, but joints can join to other joints (compound joints); and joints should be designed so that a person never has to make a decision among more than three alternatives at any one time. Limiting the choice to two simultaneous alternatives is better still, especially if they are asymetric, i.e. weighted differently so as to aid in the decision making process.

Many of these ideas are beautifully illustrated by Camillo Sitte in his book: City Planning According to Artistic Principles. He sets forth several rules for the design of plazas, which can be thought of as a particular type of joint:

1. Centers of plazas should be open and free
2. Edges should be closed
3. Objects should be placed around edges but not in traffic lanes
4. Traditional traffic lanes must be kept clear and direct.

Application of links and joints to a specfic part of the site and program (double suites between canal and river)

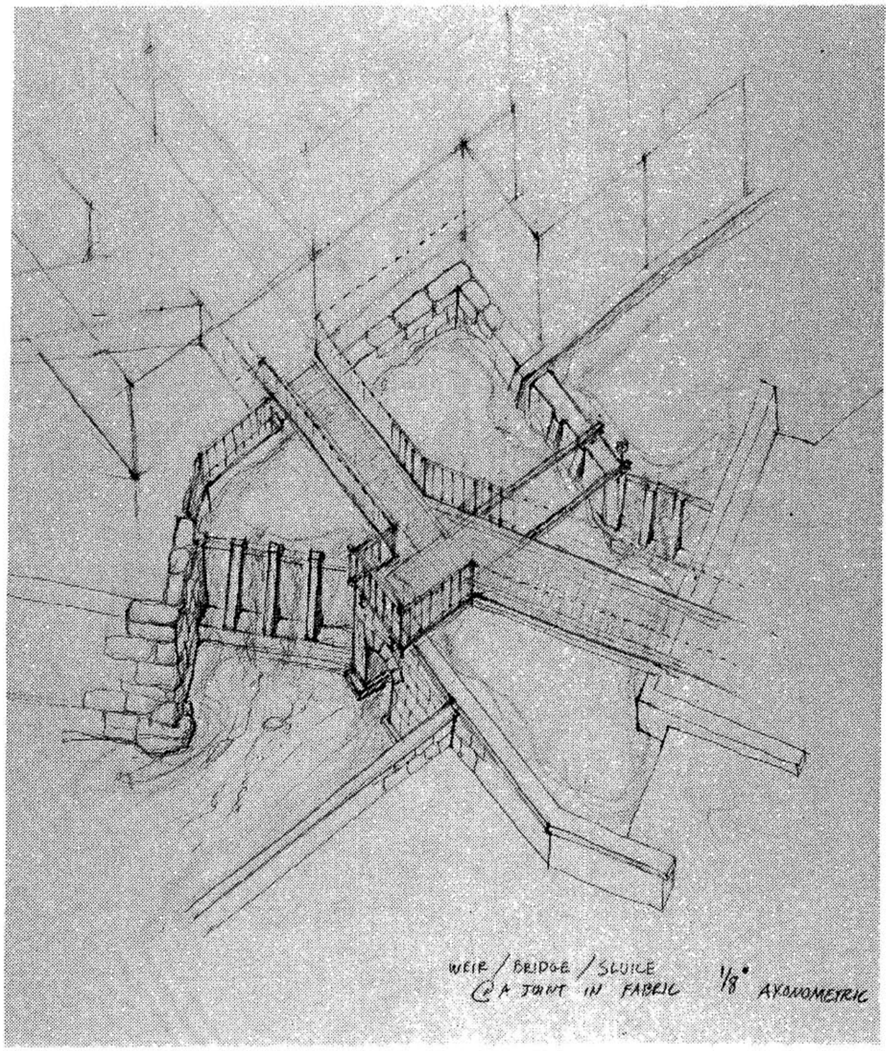


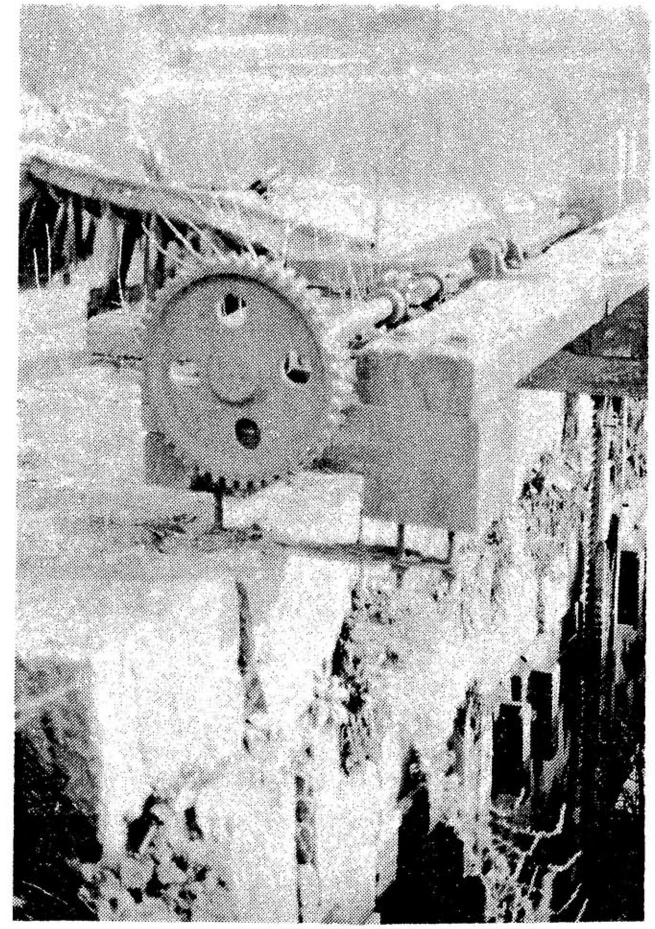


Schematic section of double suites

Middlesex Co. Dam

Application of Links & Joints
to hydraulic works

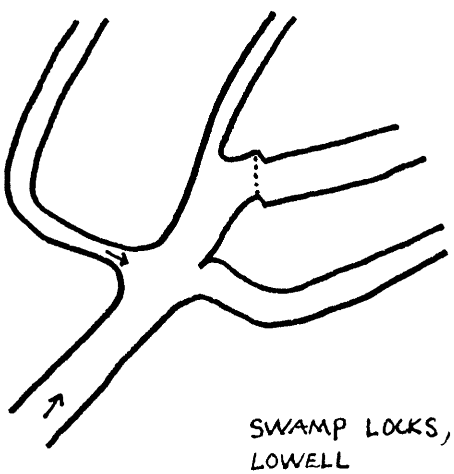


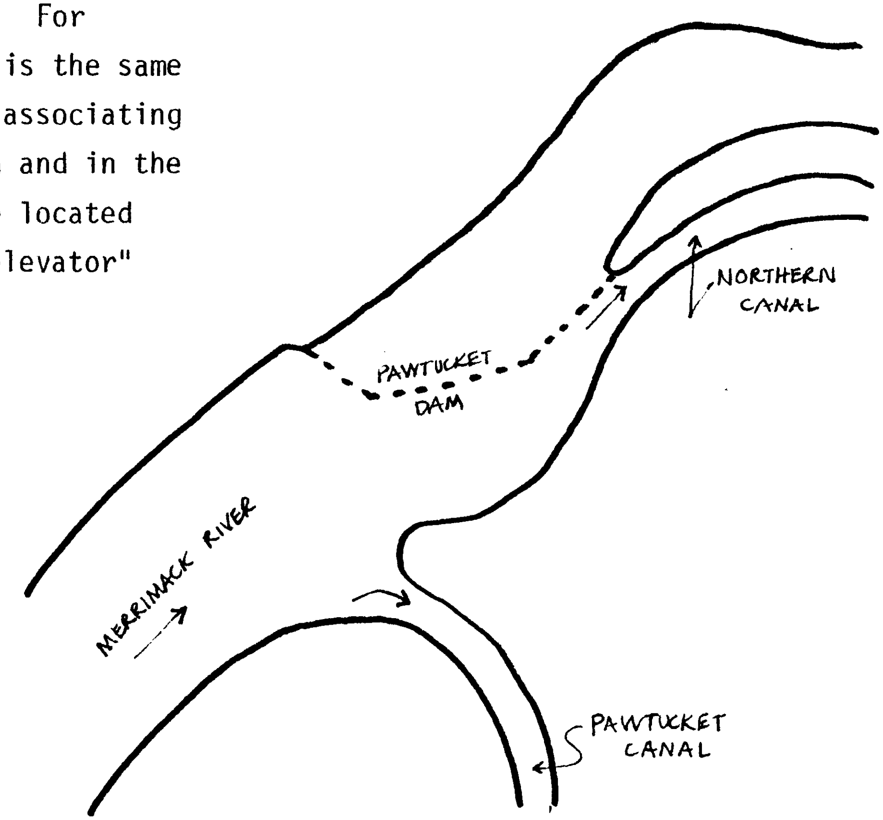


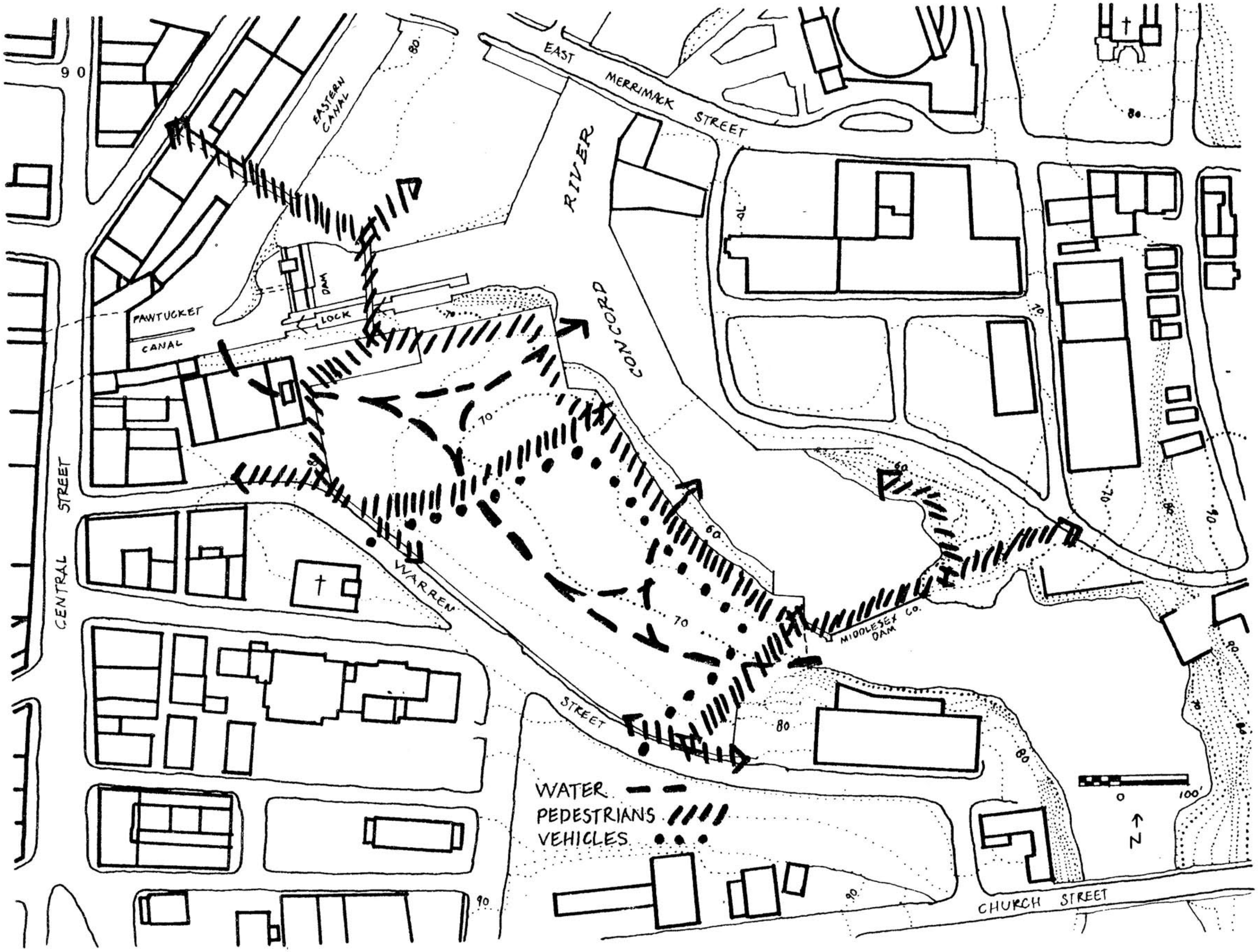
Control gears of
Middlesex Co. penstock

The three systems should be internally consistent as well as consistent between each other. So, a major organizing force is to associate the joints of the major systems to allow people to move from one to the other and to experience several systems simultaneously. For example, the main lobbies are located off plazas which are adjacent to "ponds."

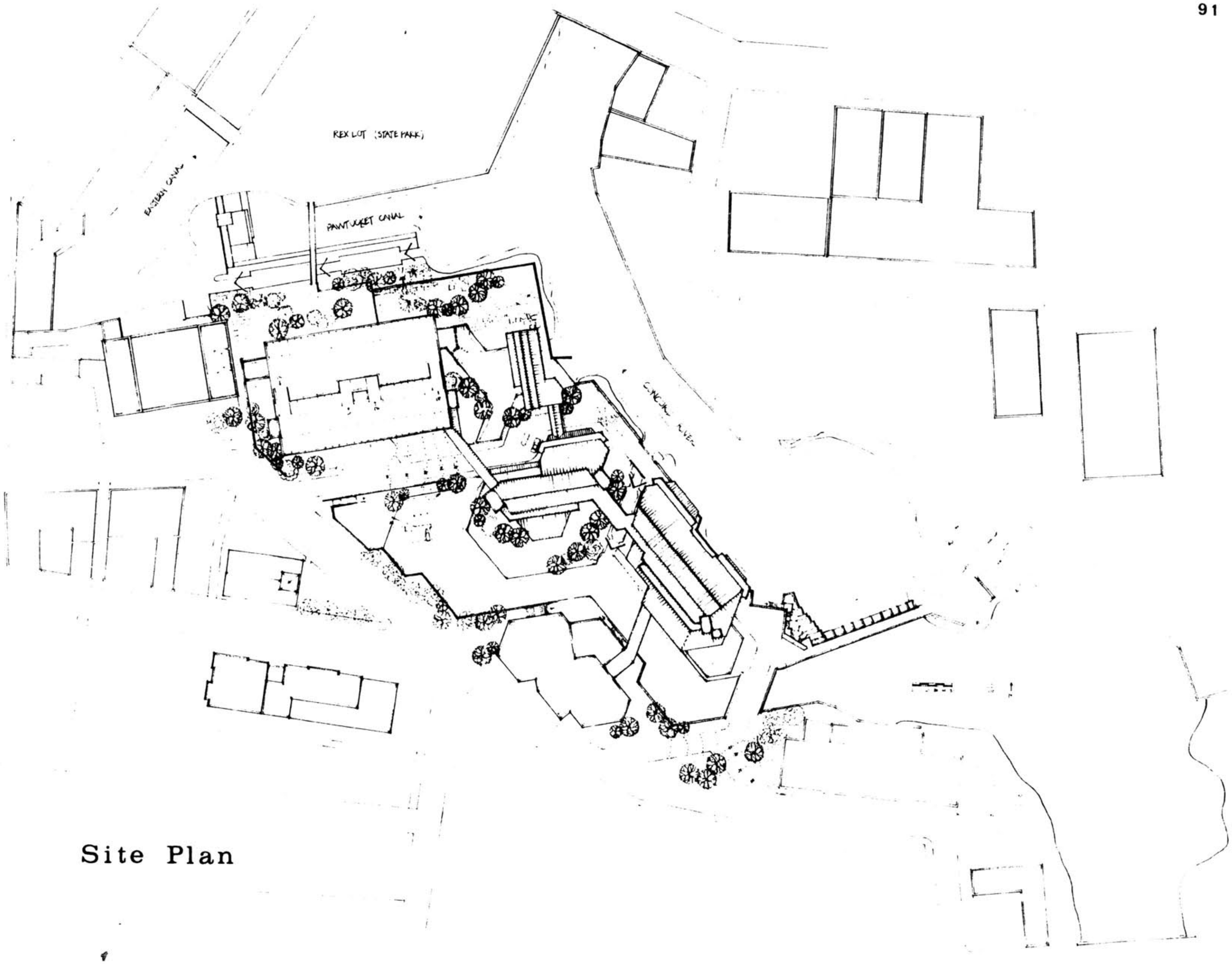
Links, on the other hand, are not necessarily coincident, but are often mutually reinforcing. For example, the direction of movement in the hotel is the same as a public path built along the river's edge, associating the dynamic stream with movement along the path and in the hotel. Vertically, stairs and the elevators are located next to and with a view of the boat lock, an "elevator" for boats.



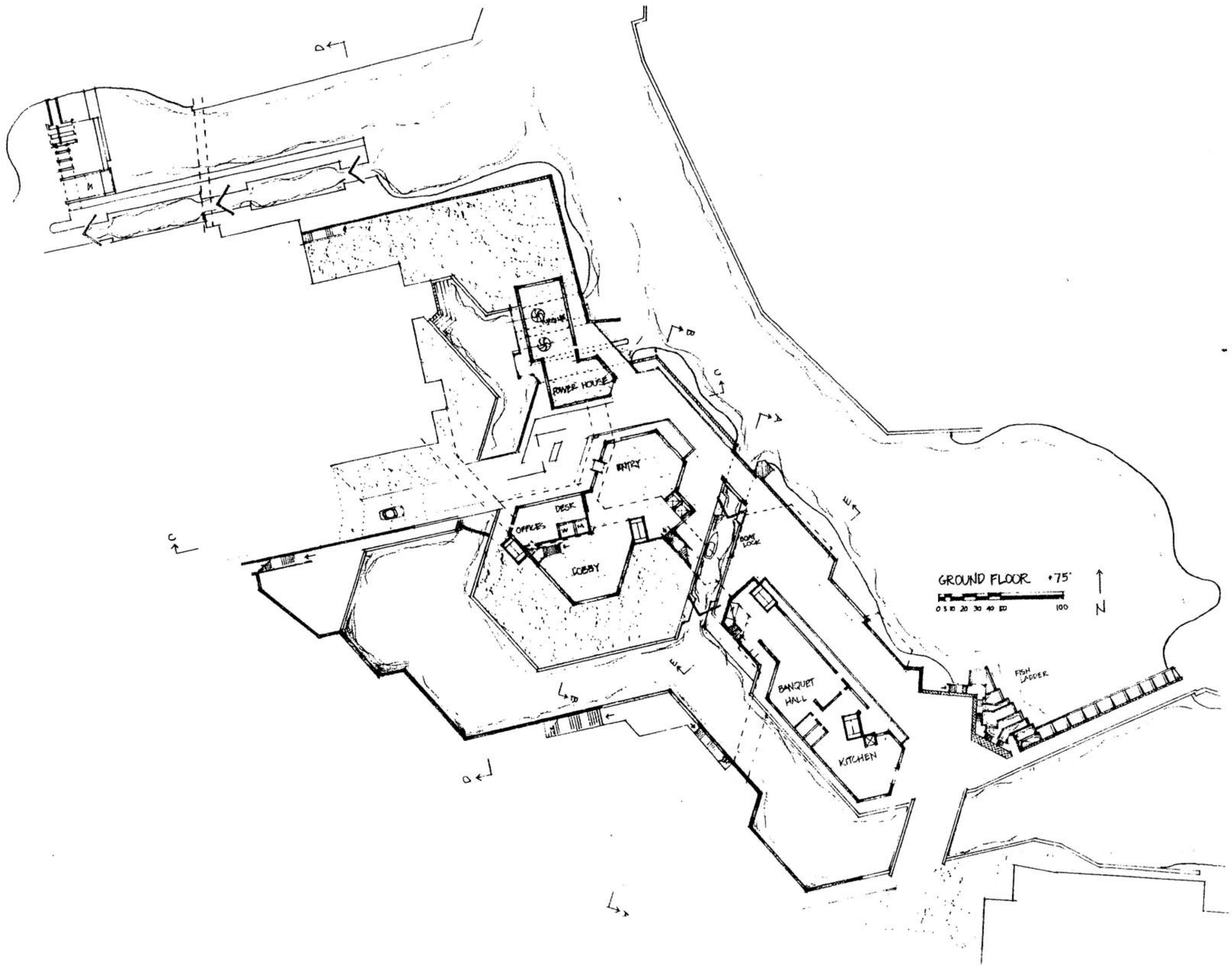


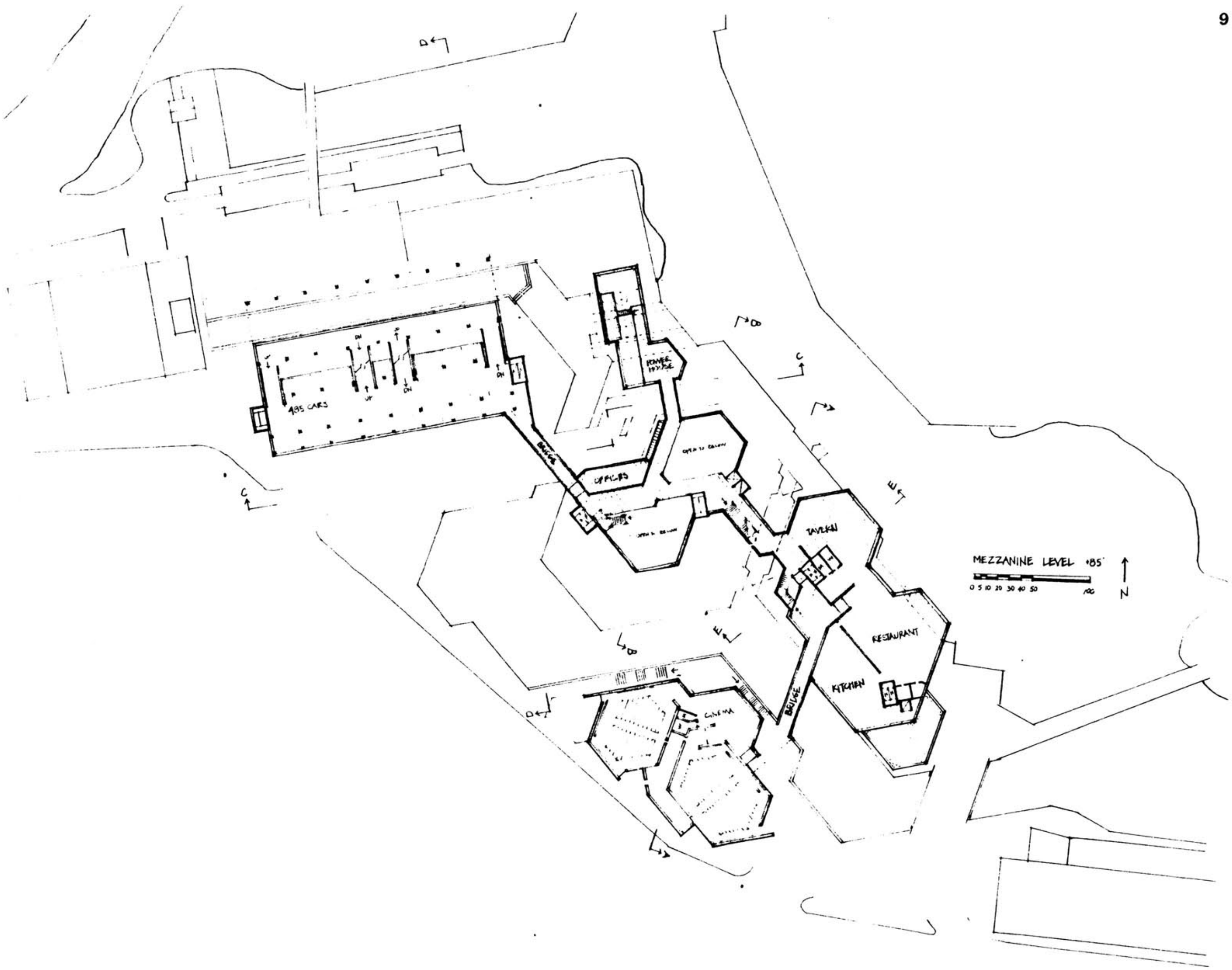


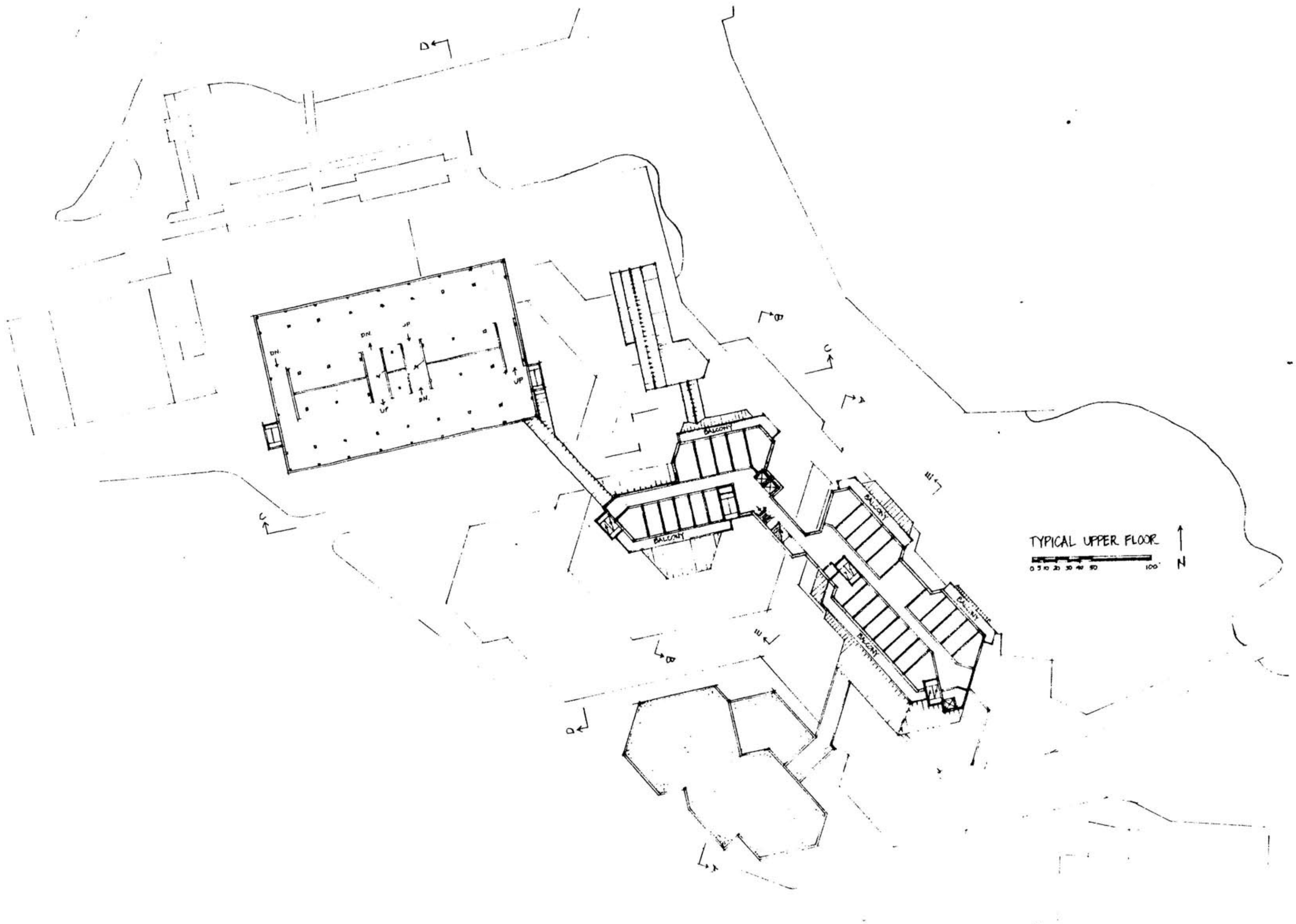
EAST MERRIMACK STREET
EASTERN CANAL
RIVER
CONCORD
DAM
LOCK
PAWTUCKET
CANAL
CENTRAL STREET
WARREN STREET
MIDDLESEX CO. DAM
CHURCH STREET
WATER
PEDESTRIANS
VEHICLES
0
100'
N

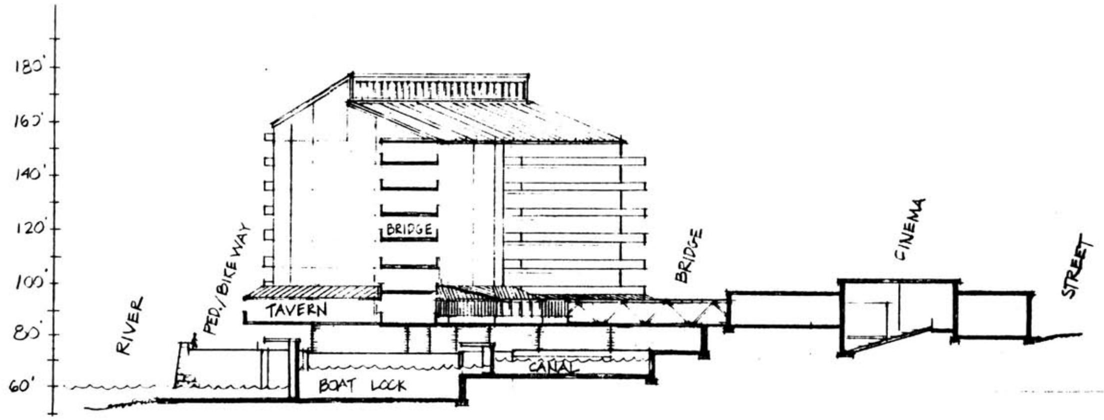


Site Plan

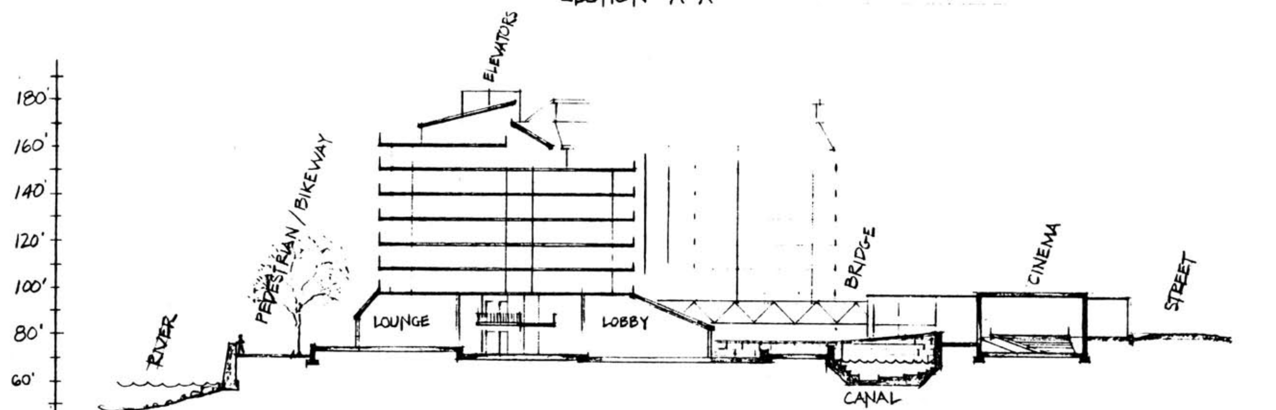

POWER HOUSE
ENTRY
DESK
OFFICES
LOBBY
BOAT LOCK
BANQUET HALL
KITCHEN
FISH LADDER
GROUND FLOOR +75'
0 5 10 20 30 40 50 100
N


MEZZANINE LEVEL +85'
0 5 10 20 30 40 50 100
N
195 CARS
POWER HOUSE
OFFICES
BRIDGE
TAVERN
RESTAURANT
KITCHEN
CINEMA
C
D
E

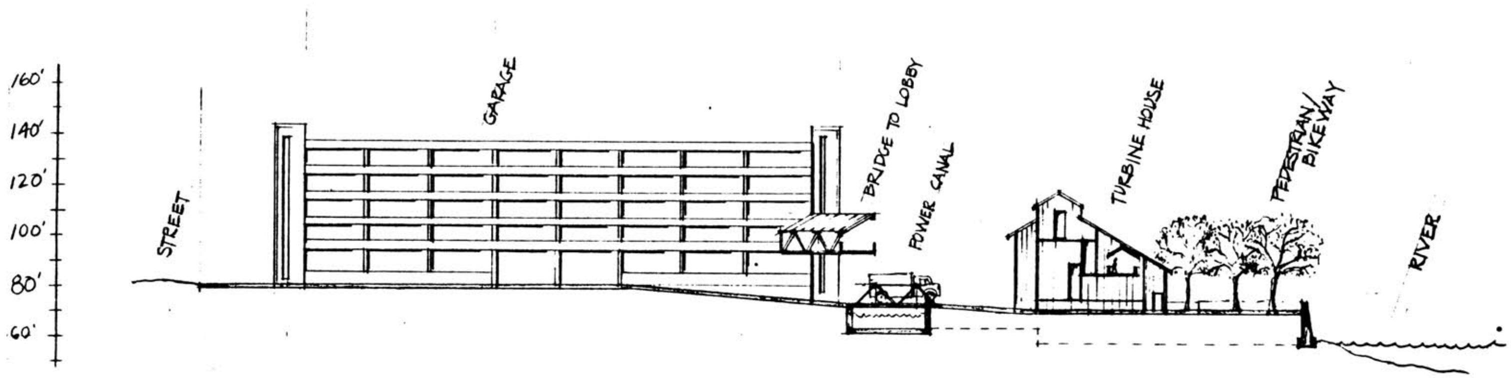

TYPICAL UPPER FLOOR
N
0 5 10 20 30 40 50 100'
BALCONY
DN
UP



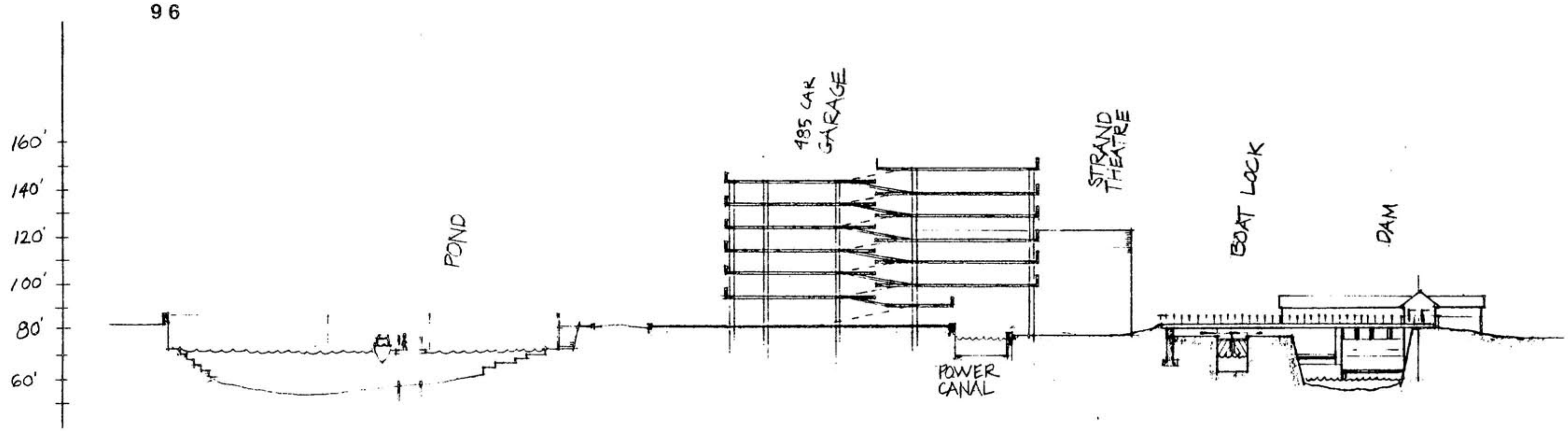
SECTION A-A



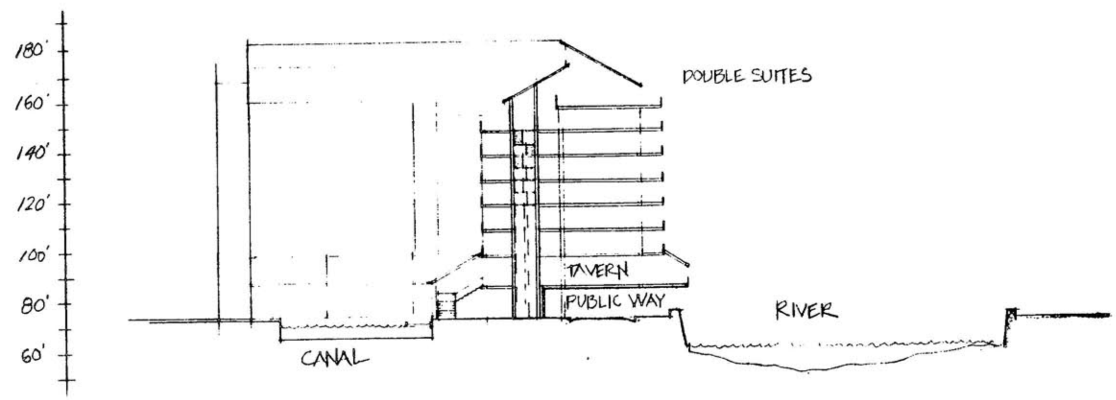
SECTION B-B



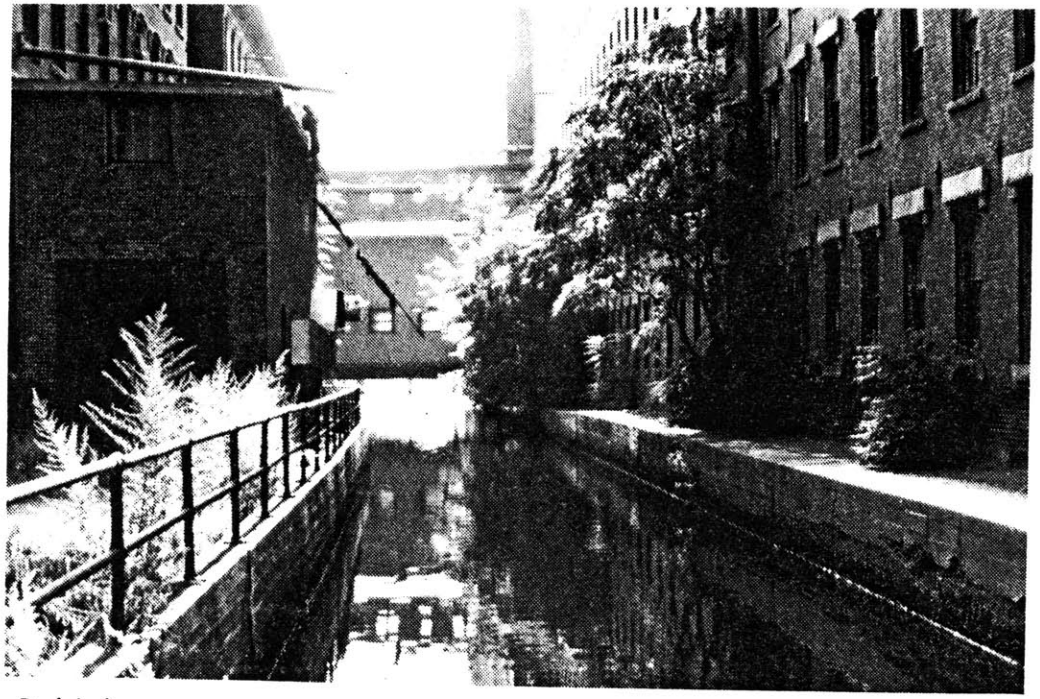
SECTION C-C



SECTION D-D

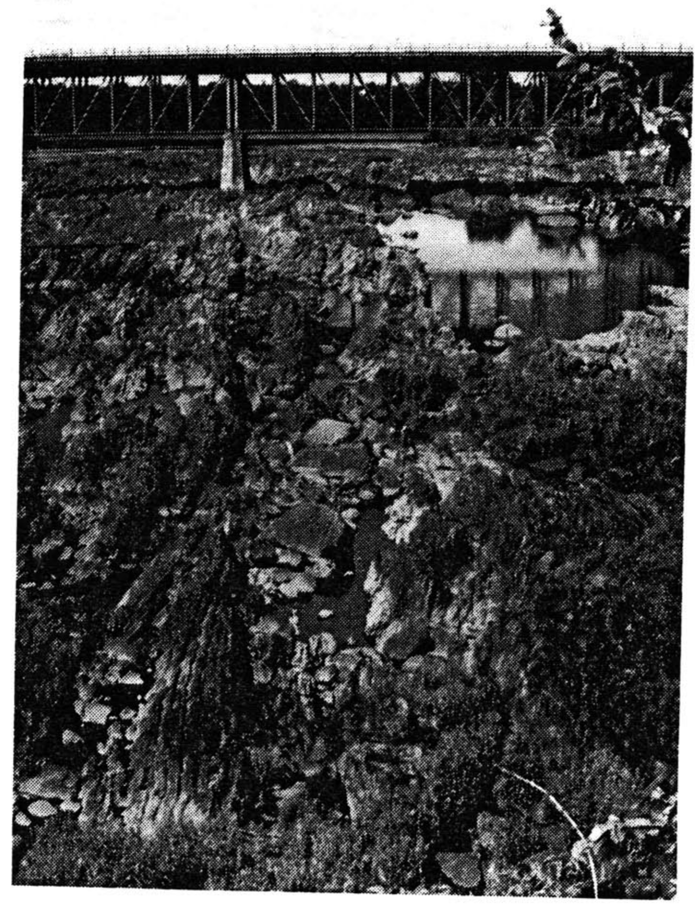


SECTION E·E



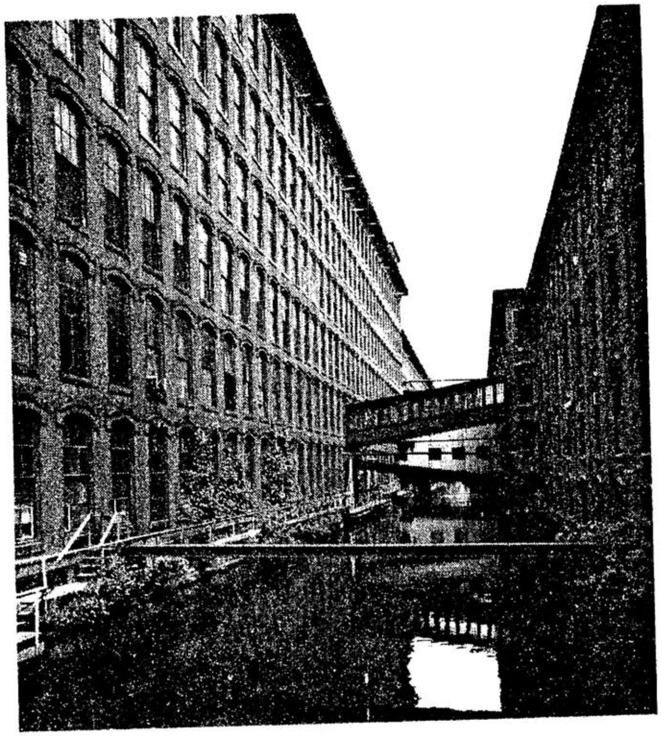
Left: Hamilton Canal

Below: Merrimack River



Bridging

After setting up a very strong parallel mill complex in the early organization of Lowell, it was obvious that people and materials needed to be moved from one parallel to another. The first bridges were built over the canals at ground level because the mills were in effect located on islands. There soon followed bridges from building to building, building to ground, over land and water, and sometimes both, at all levels. The bridges were always built of a different material from the brick mills and were usually wood. The bridges also afforded a view up and down the length of the parallels.

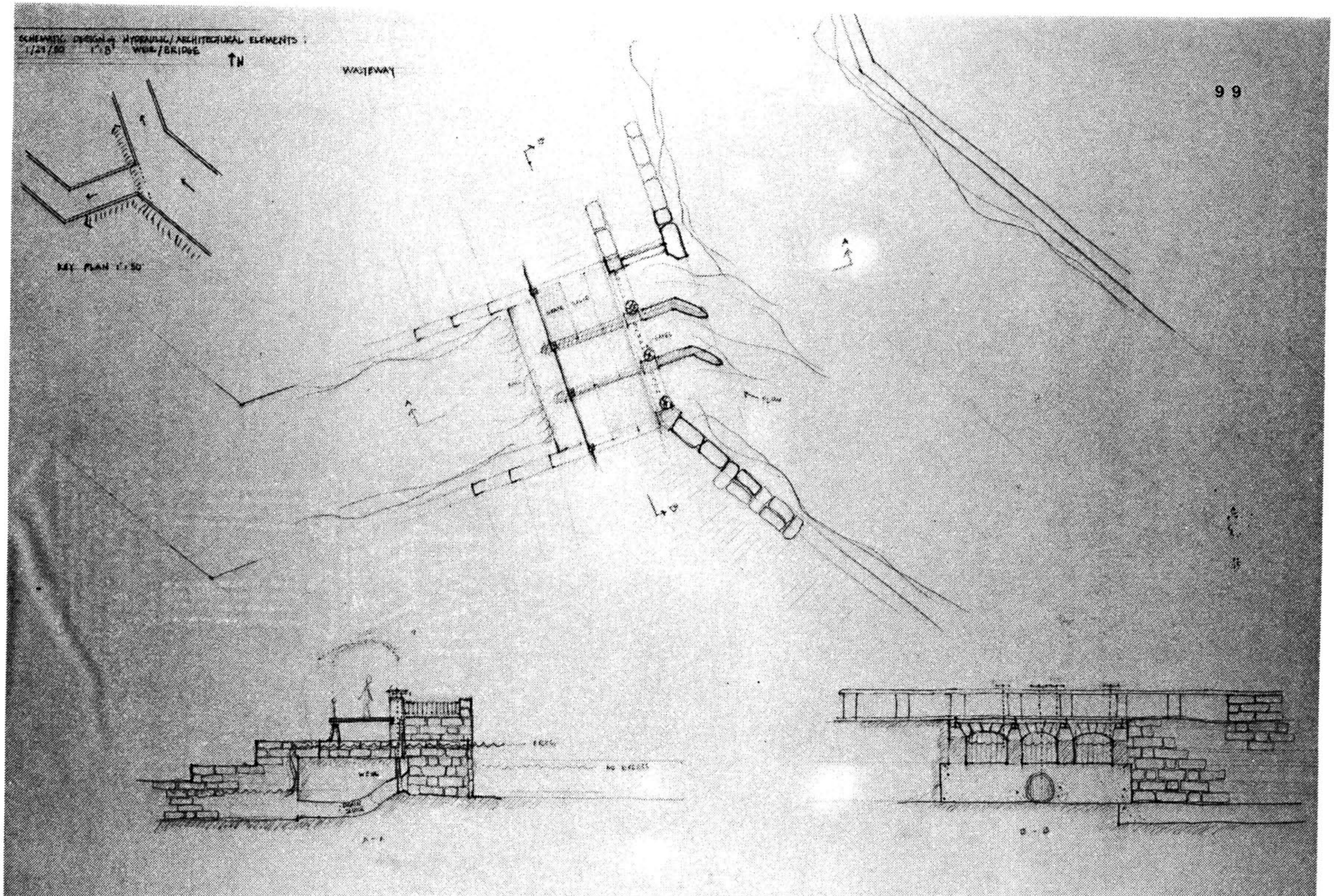


Steve Dunwell

Hamilton and Appleton Mills

Bridging is a type of linking. There are also several types of bridging. A bridge links land to land or building to building; can be enclosed or open; and can even be occupied in a single or double loaded way. A weir on the other hand can be thought of as a water "bridge" linking water from an upper level to a lower level. Depending on the height of the water a weir could be either a land to land link or a water to water link. Interesting changes take place from season to season. Some weirs are adjustible; some are installed and later removed depending on the situation. Functionally, weirs are for measuring or controlling flows, but a weir could be a stepping stone path, Japanese style, across a watercourse. The Lower Locks and Dam on the Pawtucket Canal is a good example of a complex water "bridge". It contains weirs, sluices, siphons, and drains which all have a specific function in controlling the water.

Bridges are used in the design according to specific rules. Bridges should continue the direction of what they are linking. If a bridge is linking two



Schematic design of weir/bridge

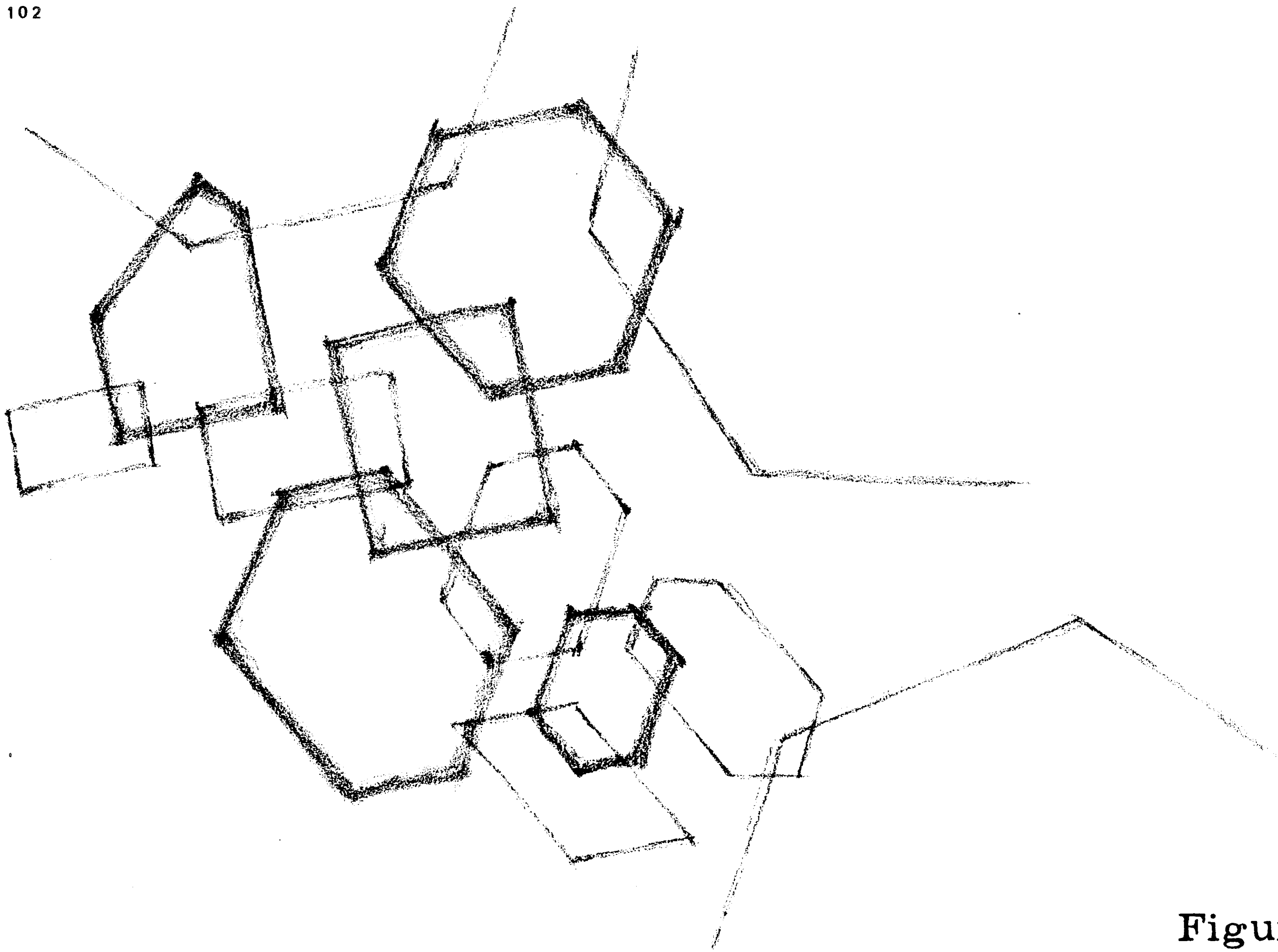
3 FIGURE — GROUND

Figure·Ground

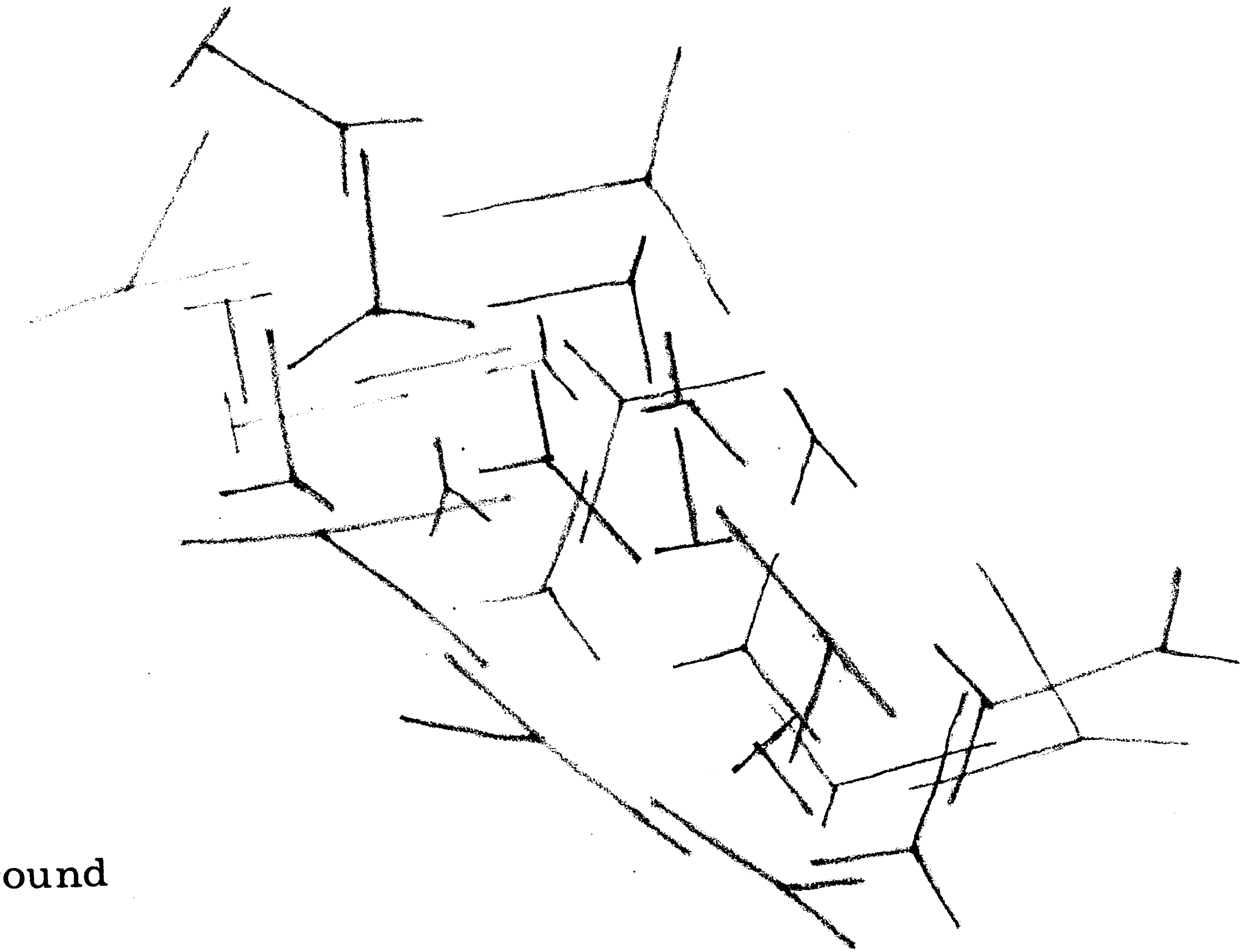
Central to my approach to design is the concept of figure-ground. Design with water/landscope provides a special opportunity to design in a reciprocal way because little else can express what is meant by reciprocal definition better than a shore. The land defines the water; the water defines the land. Using the figure-ground method of working means designing both the figure and the ground which ultimately or ideally leads to figure-ground reversal, i.e. reciprocal definition. This is true for plan, section, and elevation. A totally closed form reads as a figure. If both figure and ground simultaneously achieve a high degree of closure, reversal occurs.

Reversal or reciprocity is not a mere visual or perceptual trick or gimmick. I believe that this simultaneous or near simultaneous perception is what makes people feel at once comfortable in a place and continuous with the environment. There is a deep human psychological need for both continuity and containment; security and freedom.

FIGURE 17 FIGURE-FIGURE Figure, *by Scott E. Kim (1975).*



Figure



Ground

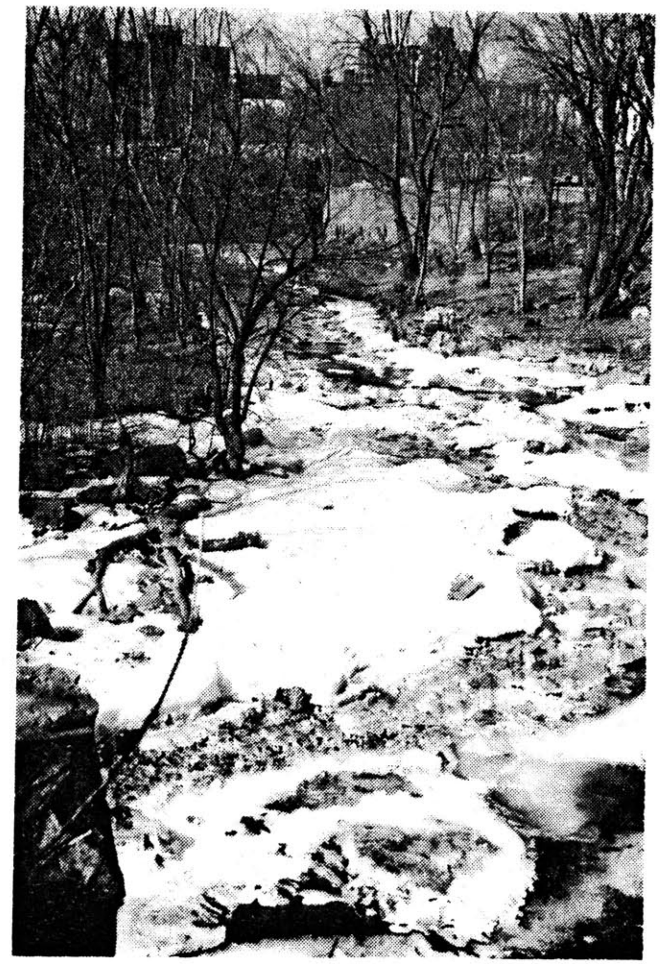
"*It is held by physicists and philosophers and priests that all things depend upon the power of water, for it is the chief requisite for life, for happiness, and for everyday use.*"

Vitruvius

Northern Canal

Conclusion

In the design of the hotel I employed three major organizational metaphors: bending and branching; links and joints; and figure-ground. The first is directly related to the use of surrounding water for inspiration. The second is a general organizational metaphor which is applicable to the land and water in analogous ways. The third is a long time fascination of mine which I find generally applicable to all design and particularly well suited to this one. I found these metaphors were very helpful in conceiving and designing a project which attempted a high degree of physical and formal integration. The process of design did not start with all of these formal conceptions; rather they evolved or were discovered as the design progressed and demanded organizational decisions. However, I continually return to a recursive figure-ground point of view. I used figure-ground to organize the proportions and dimensions of the spaces and their relation to each other; links and joints to organize the movement networks through and between those spaces; and bending and branching to give a specific geometry and direction to the whole.



APPENDIX A

DETAILED HYDROPOWER FEASIBILITY CALCULATIONS

1. Coefficient of Performance (C.O.P.) of Heat Pump

Given:

$$\text{IDEAL(CARNOT) C.O.P.} = T_2/(T_2 - T_1)$$

where

T_1 = absolute temperature of evaporator

T_2 = absolute temperature of condenser

$$\text{ACTUAL C.O.P.} = 50\% \text{ ideal}$$

(From American Society of Heating Refrigeration and Air Conditioning Engineers Equipment Handbook)

Assume:

for evaporator 35°F = 274.8 K

for condenser 110°F = 316.48 K

$$\text{CARNOT C.O.P.} = \frac{316.48}{316.48 - 274.8} = 7.59$$

ACTUAL C.O.P. = 3.8

For a more conservative estimate assume:

for evaporator 35°F = 274.8 K

for condenser 125°F = 324.8 K

$$\text{C.O.P.} = 0.5\left[\frac{324.8}{324.8 - 274.8}\right] = 3.247$$

2. Capacity of Reservoir

Between bridge and upper rapids	2000' × 250'	= 291,666,7	ft.^{2}
Between bridge and dam	200' × 400'		
	+ 150' × 200'	= 110,000	ft.^{2}
	TOTAL	401,667	ft.^{2}

Source: U.S. Geological Survey Maps.

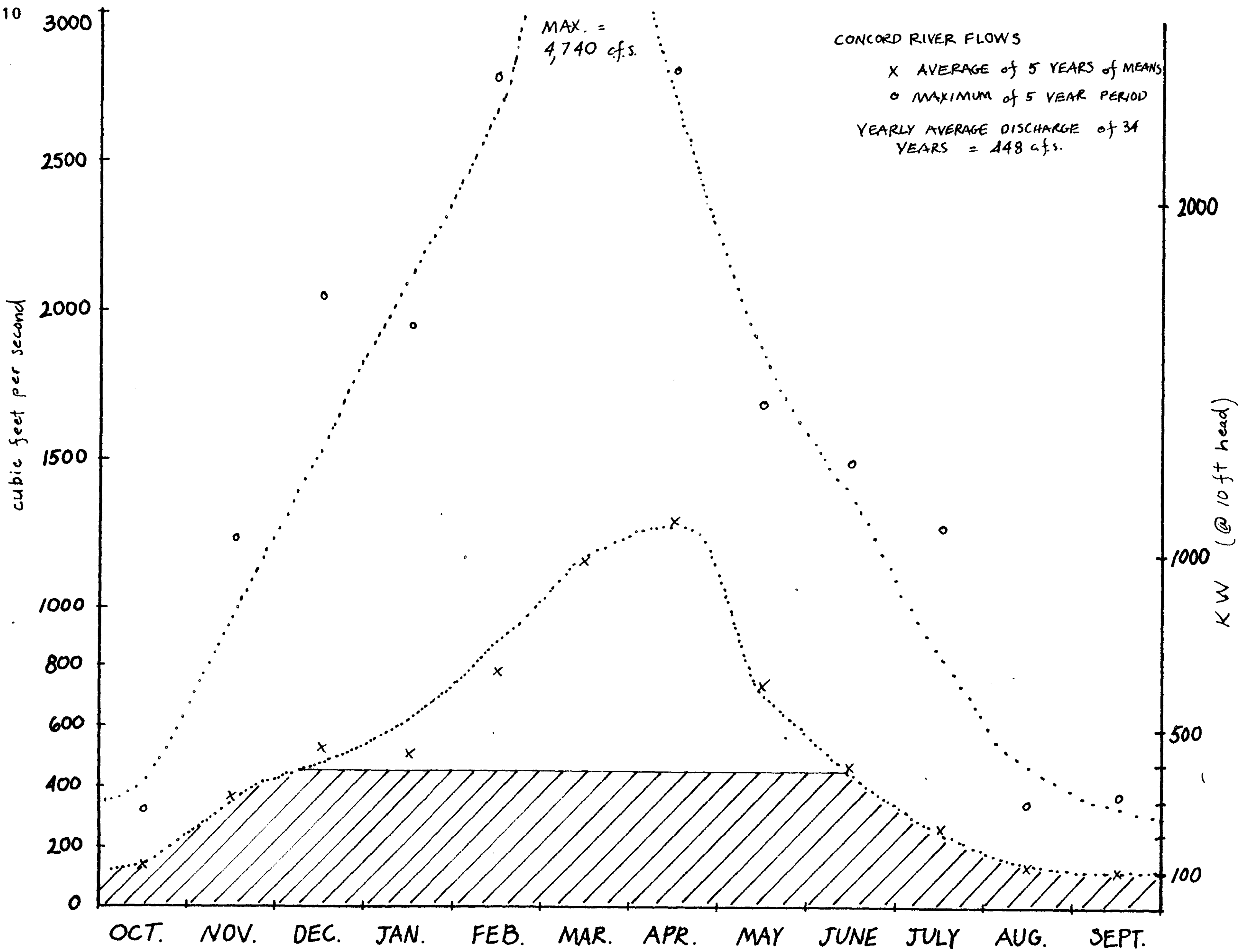
Power

401,667 ft.^{3}/ft. × 10 ft. of head × 62.4#/ft.^{3} = 250,640,208# for each foot of depth stored

= 94.39 KWH

≃ 300 KW for 20 min.

= 322,153 BTUs


CONCORD RIVER FLOWS
X AVERAGE of 5 YEARS of MEANS
o MAXIMUM of 5 YEAR PERIOD
YEARLY AVERAGE DISCHARGE of 34 YEARS = 448 c.f.s.
MAX. = 4,740 c.f.s.
cubic feet per second
KW (@ 10 ft head)
3000
2500
2000
1500
1000
800
600
400
200
0
2000
1000
500
100
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.

3. Energy Supply

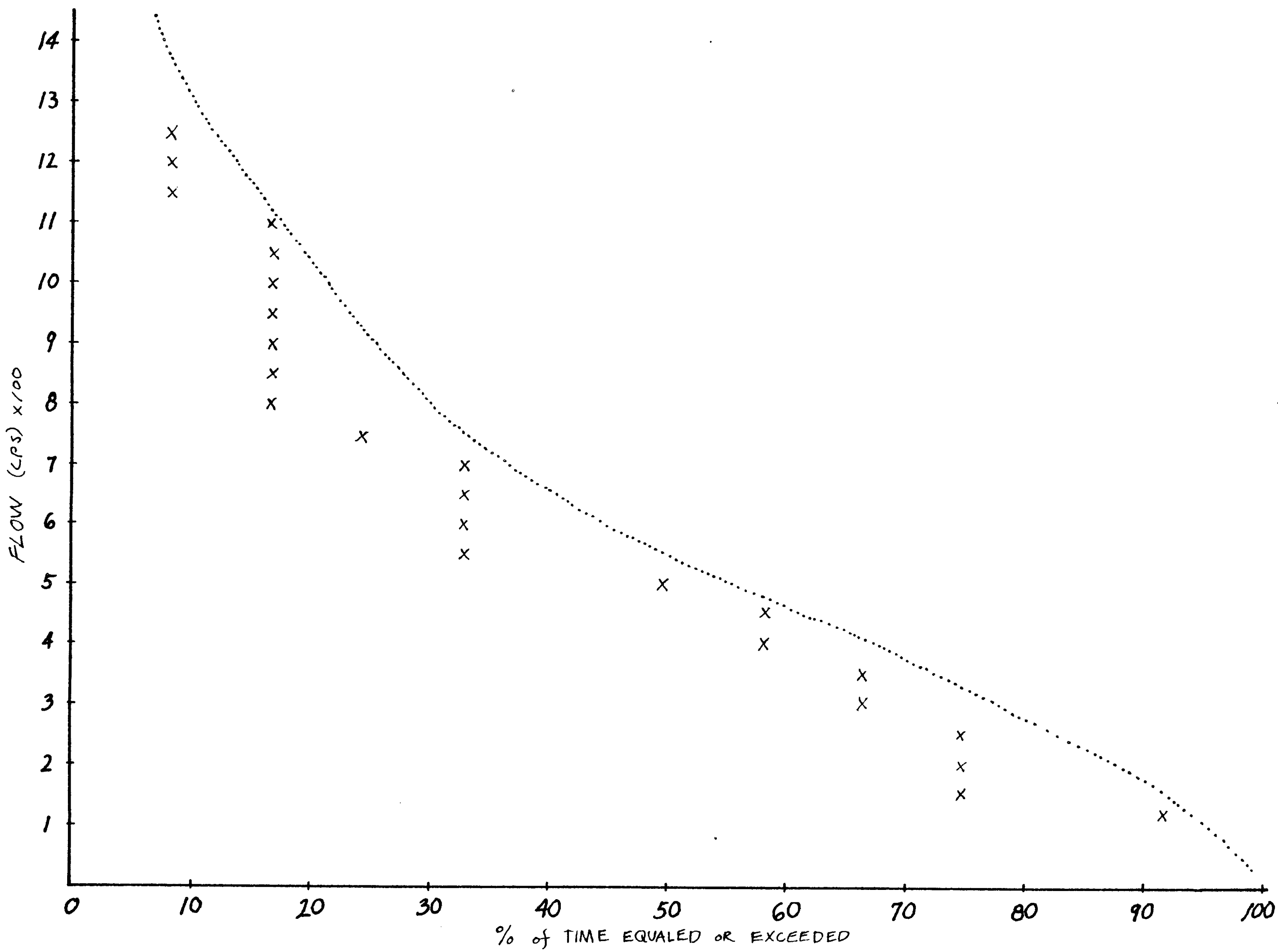
A. Five Year Average Monthly Mean Flow Rate in cubic feet/second (cfs)

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
130.96	370.2	529.6	518.6	780.0	1148.8	1289.0	726.4	468.2	262.3	125.2	113.0

Source: U.S. Geological Survey, Surface Water Supply of the United States 1966-70.

B. Gross Average Power (KW) = Average Flow × 10 feet of head × 62.4#/ft.^{3} of water × 1.356 × 10^{-3} Kilowatts/foot-pounds/second

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
110.8	313.23	448.09	438.79	659.96	972.0	1090.62	614.61	396.14	221.91	105.95	95.61

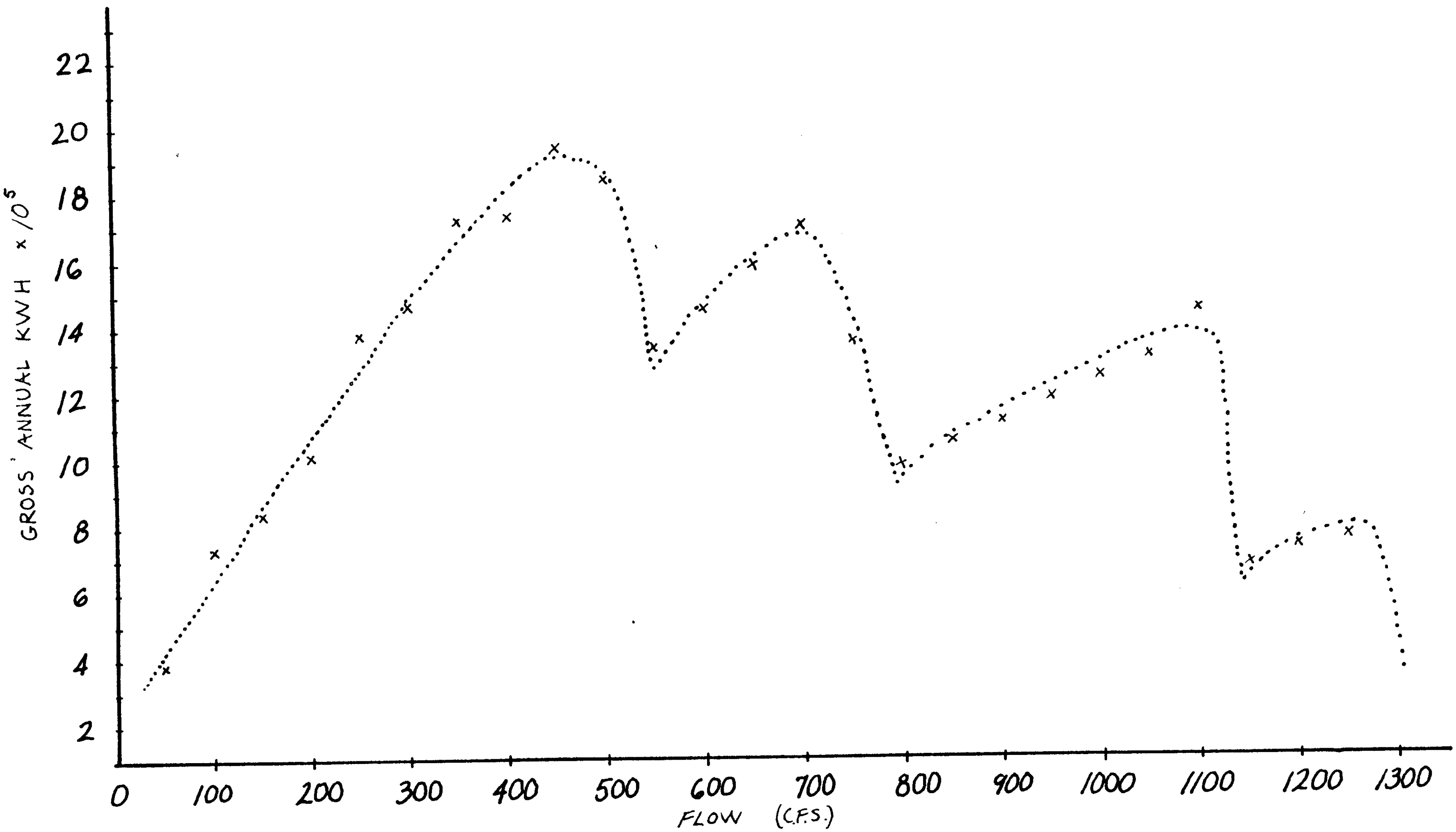

FLOW (CPS) x100
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
80
90
100
% of TIME EQUALED OR EXCEEDED

C. Flow Duration = the percent of time equaled or exceeded by each flow rate

Flow Rate in cfs	% of Time Equalled or Exceeded Annually Based on Average Monthly Flow Rates
100	~ 100%
150	74.82
200	"
250	"
300	66.33
350	"
400	58.13
450	"
500	49.93
550	32.95
600	"
650	"
700	"
750	24.46

Flow Duration (continued)

Flow Rate	% of Time
800	16.79
850	"
900	"
950	"
1000	"
1050	"
1100	"
1150	8.2
1200	"
1250	"
1300	~ 0%


22
20
18
16
14
12
10
8
6
4
2
GROSS ANNUAL KWH × 10^5
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
FLOW (C.F.S.)

D. Gross Energy in Killowatt Hours (KWH) for a Constant Peak Power = power (KW) × duration (in hours)

Flow cfs	KWH
50	370,591.8
100	741,183.6
150	831,830
200	1,109,107
250	1,386,384
300	1,474,881
350	1,720,695
400	1,723,400
450	1,944,495
500	1,850,365
550	1,343,210
600	1,465,320
650	1,587,430
700	1,709,540
750	1,359,701
800	995,558
850	1,057,802
900	1,120,017
950	1,182,225

Gross Energy (continued)

Flow	KWH
1000	1,244,447
1050	1,306,809
1100	1,459,390
1150	698,936
1200	729,310
1250	759,695
1300	~ 0

E. The most efficient size is 450 cfs producing 1,944,495 KWH @ a constant 380 KW, 58% of the time.

F. Net Power = .85 gross power assuming 90% efficiency for turbines and 5% miscellaneous losses, such as maintenance of minimum river flows, fish ladders, etc.

380 KW(.85) = 323 KW

G. Assuming a 20% heating system loss, net annual heat supply = the sum of net KW (by month) × (.80) × duration (in hours by month) × 3.25 C.O.P.

OCT	182,181.8
NOV	498,411.6
DEC	626,036.2
JAN	626,036.2
FEB	565,452.0
MAR	626,036.2
APR	605,841.4
MAY	626,036.2
JUN	605,841.4
JUL	364,856.9
AUG	174,207.2
SEP	151,211.7
	5,652,148.8 KWH (Including less than peak power production)

H. Assuming \$0.04/KWH Rate,

Equivalent \$ Value = Net KWH × \$0.04/KWH

$$1{,}739{,}122.7 \times 0.04 = \$69{,}564.90$$

Alternately, based on N°2 oil heat @\$1.00 Gal.

$$5{,}652{,}148.8 \text{ KWH} \times 3.413\times10^{3}\,\frac{\text{BTU}}{\text{KWH}} \times .75 \text{ efficiency}$$

$$\div\ 141{,}000\,\frac{\text{BTU}}{\text{gal}} \times \$1.00/\text{gal} = \$102{,}610.55$$

4. Energy Demand

A. Assumptions

i. Blue Hills monthly data is close to Lowell and in fact is conservative by 5% if totals are compared.

Blue Hills Total Degree Days (D.D.): 6368

Lowell's Total Degree Days (D.D.): 6056

ii. State bldg. code specifies 10-12 BTU/SF/D.D. limit

iii. Program as given includes 135,667 gross $ft.^2$

iv. Design goal of 30% better than code (7-9 BTU/SF/D.D.) is attainable by proper wall section, site planning, fenestration, etc., especially because state code is based on existing building stock and is not difficult to meet.

B. Demand = Degree Days × 9 BTU/Sq. Ft./Degree Day × 13,667 sq. ft.

Month	Heating Degree Days	BTU/month	KWH/month
OCT	381	465,202,143	136.304.2
NOV	690	842,492,070	246,850.2
DEC	1085	1,324,788,255	388,163.0
JAN	1178	1,438,341,534	421,434.1
FEB	1053	1,285,716,159	376,714.8
MAR	936	1,142,858,808	334,857.6
APR	579	706,960,737	207,139.5
MAY	267	326,007,801	95,520.3
JUN	69	84,249,207	24,685.0
JUL	0	0	0.0
AUG	22	26,862,066	7,870.6
SEP	108	131,868,324	38,637.4
	6368	7,775,347,104	BTU/Year Total
		2,278,176.7	KWH/Year Total

5. Temperature Drop of River

Assume peak flow condition

of 450 cfs

& 380 KW

& C.O.P. = 3.25

BTUs pumped from river:

$$(380\ KW)3.25 - 380\ KW = 855\ KW = 48{,}649.5\ BTU/min$$

Total Heat - Heat from Mechanical Means = Heat from Thermal Capacity of Water

Δt:

$$450\ cfs \times 62.4\#/ft.^3 \times \frac{60\ sec}{min} = 1{,}684{,}800\ \#/min.$$

$$\frac{48{,}649.5\ BTU/min}{1{,}684{,}800\ \#/min} = 0.0289°F\ \Delta T$$

Glossary

Absolute Temperature: Temperature measured from absolute zero, the temperature at which substances contain virtually no energy. Measured in Kelvin $K = °C + 273.15$.

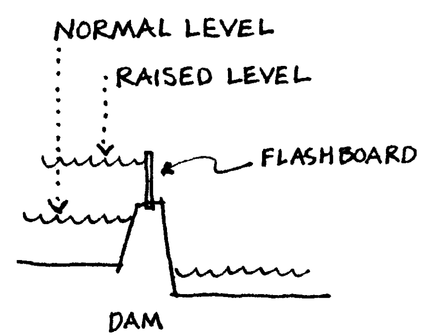
BTU (British Thermal Unit): Measure of heat required to raise one pound of water one degree Fahrenheit. $1 \text{ BTU} = 2.93 \times 10^{-4}$ KWH.

C.O.P. (coefficient of performance): Ratio of energy in, to energy out, of a heat pump.

Degree Day: A measure of heating demand; the number of degree days per annum = 65°F - mean daily temperature for each day summed over the year.

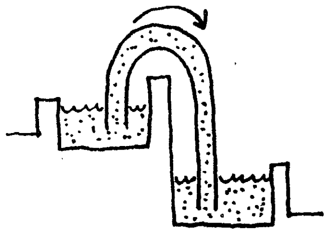
Draft Tube: Closed pipe which conducts outflow from turbine to tailrace.

Flashboards or Flashboard Weir: Boards set vertically at the top of a dam to raise the height of the water.

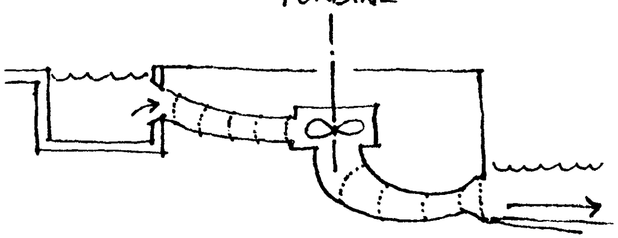


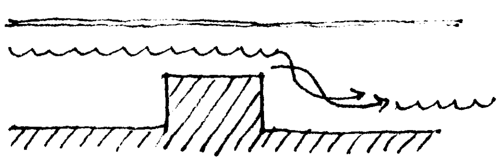
Head: The height water drops over a fall; a measure of potential energy expressed in feet.

Heat Pump: A machine that transfers heat from one medium to another.



SIPHON





WEIR SECTION

Hydro-Electric Plant: A facility which employs a water wheel or turbine to supply mechanical energy to a generator to produce electricity.

Kilowatt (KW): Measure of electrical power. 1000 watts

Kilowatt Hour (KWH): Measure of electrical energy equal to one KW for one hour.

Penstock: Tube or closed channel which conducts water to a turbine.

Siphon: A closed pipe which when filled can conduct water from a high reservoir over a higher barrier to a lower reservoir by atmospheric pressure; used to regulate the head of power canals.

Sluice: Channel which conducts water through a dam, controlled by gates.

Tailrace: Outflow channel from a water turbine.

Turbine: A machine which converts water flow (kinetic energy) to mechanical energy.

Wasteway: Bypass canal around a hydro-power plant to conduct excess flow safely downstream.

Weir: A device placed in a watercourse to raise, divert, regulate, or measure the flow.

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[8]National Oceanic and Atmospheric Administration, Climates of the States, (Detroit, Gale Research Co. 1978)

[9]Leliavsky, Serge, An Introduction to Fluvial Hydraulics,(New york, Dover Publications, 1966) p. 92-147.

[10]*Ibid*. p. 103.

[11]*Ibid*. p. 94.

[12]*Ibid*. p. 131.

[13]Malone. Patrick, *The Lowell Canal System*, monograph, (Lowell, The Lowell Museum, 1974.) p.7.

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