IWR 22

AN ANALYSIS OF THE DEMANDS
FOR WATER FROM THE PRIVATE SECTOR
IN A SUB-ARCTIC URBAN AREA

An analysis of the demands for water from the private sector in a subarctic urban area
Robert C. Haring

by
Robert C. Haring, Ph.D.
(Presently at the University of Arkansas)

INSTITUTE OF WATER RESOURCES
University of Alaska
Fairbanks, Alaska 99701

Report No. IWR-22

April, 1972

PREFACE

This study of demand conditions for water in a sub-arctic community is one of a series of continuing and related research projects. This series has been concerned with the physical and economic environment and urban development and political boundaries have been similar in each of these studies.

The first of these projects were completed in 1965. They are -- Ice Fog: Low Temperature Air Pollution Defined With Fairbanks as the Type Locality, (Geophysical Institute, 1965), and Prices and Costs in the North Star Borough, Alaska, (Institute of Business, Economic and Government Research, 1965). The second portion of the series has been published since 1967. It is represented by Natural Resource Base of the Fairbanks-North Star Borough, Alaska, (Mineral Industries Research Laboratory, 1967); Economic Base of the Fairbanks North Star Borough, Alaska, (Institute of Social Economic and Government Research, 1967), and its supplement Economic Impact of the Fairbanks Flood of August, 1967.

This report was prepared by Institute personnel from an incomplete manuscript left by the author when he terminated his employment at the University of Alaska in 1967. The Institute feels the report fairly describes the work reported by Dr. Haring, since no conceptual changes were made in the content. We feel it to be unfortunate that Dr. Haring refused to cooperate fully with the final phases of this project.

The report is dated as published, but some worthwhile information is included. However, because of the Principal Investigator's lack of cooperation, the Institute is obliged to mention that the contents do not necessarily signify the organization's views or approval, and that the report is published as a means of satisfying contractural requirements.

ACKNOWLEDGEMENTS

The work upon which this report is based was supported by funds (Project B-003-ALAS) provided by the United States Department of the Interior, Office of Water Resources Research, as authorized under the Water Resources Act of 1964, as amended.

Especially useful and timely technical service was contributed by various faculty members, namely Professors Charles E. Behlke, Leo M. Loll and R. Sage Murphy. At various stages in the development of this project research assistants contributed in particular areas, and Mr. Edgar McDonald and Clem Correia deserve special acknowledgement.

Information about construction costs and financing methods of industry and households was obtained principally through personal interviews with executives of financial institutions and public agencies with offices situated in the community. In this respect, Mr. Don Bruce, Mrs. Morris Carpender, Mr. Al Fleetwood, Mr. Cliff Tweedy, Mr. Walter Sczudlo and Mr. Dale Sanner were particularly helpful.

TABLE OF CONTENTS

TABLE OF CONTENTS, Continued

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Manufacturing and domestic uses of water are very important to local communities throughout Alaska, although manufacturing typically represents relatively high levels of consumption in terms of population use equivalents. This study is concerned principally with the present water use practices and associated problems in the private sector of the North Star Borough, Alaska.

PURPOSES AND RESEARCH PROBLEM

The overall research problem concerns estimation of water uses by Fairbanks manufacturers and households, and therefore the purposes of the study are:

(1) To estimate water use characteristics of particular segments of the local economy,

(2) To indicate water quality issues associated with various types of economic utilization, and

(3) To review the pricing and costs associated with various types of water use, and non-pricing regulatory provisions in effect.

The period of study was primarily 1965-1966 although subsequent information was added to update the initial examination of demand conditions.

BACKGROUND

The current investigation of demand conditions for water in the Fairbanks area was significantly affected by the local physical environment and the economic conditions which prevailed up to 1965.

HISTORICAL PATTERN OF LAND USE

The land use patterns and economic organization of the City of Fairbanks in the period 1965-1967 developed from a long series of construction and rebuilding of the downtown district. The lack of and faulty plumbing (water and waste facilities) were major reasons why much of the Fairbanks commercial sector and housing areas were rated dilapidated in 1958 (Bureau of Census, 1963). In large part, those poor condition residences near the downtown core were demolished and replaced with commercial buildings or parking space since that time. Older commercial buildings frequently had gone through a series of repair and modernization efforts. By 1966 commercial and industrial land use had stabilized, and this approximate allocation of industry to land resources remained through mid-1968. Several features of this land use pattern are especially important to a subsequent analysis of utility services and private demand for water. They are:

(1) The relatively sparse and discontinuous density of population (residential structures and commercial enterprises) occurs throughout the urban areas inside and surrounding the City. These conditions, in turn, have been attributable to:

   (a) Consumer choice to reside away from the urban "core",

   (b) Intervening large blocks of public land spread throughout, and control of the more desirable and buildable land in the hands of real estate developers and homesteaders (e.g., near monopoly in the higher income neighborhoods), and

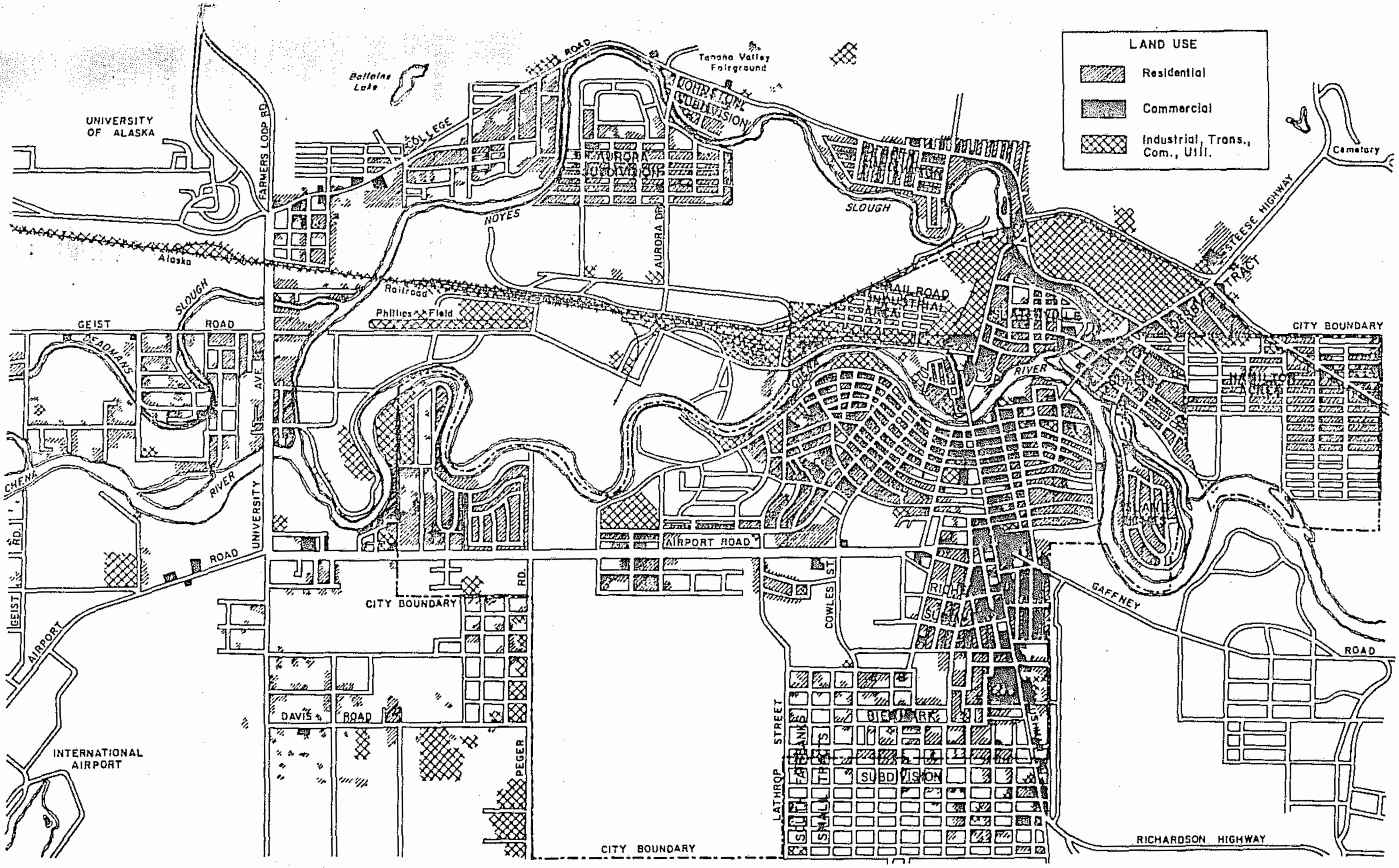
(c) Restrictions in land suitability which stem from the local physical geology of the area, a matter discussed subsequently.

(2) A gradual decentralization of the business district, or splintering of it, is apparent with extension occurring principally southward along Cushman Avenue, and at the College and Lemeta suburban locations. (See Figure 1.)

(3) Erratic spatial development of an industrial complex. Fairbanks industries, such as light manufacturing and prefabrication, forest products manufacturing, construction and equipment-intensive logistics are found scattered here and there on practically every accessible road. From related studies it would appear the following conditions best explain how this came to pass:

(a) The vast proportion of industrial firms grew up locally from small family-owned proprietorships, which were often situated on homesteads or in residential areas.

(b) In the last few years, industrial dependence upon railroad transportation has shifted significantly and allowed these businesses to expand operations based principally on highway and mixed-mode transportation.



FAIRBANKS, ALASKA - 1967, SHOWING CITY BOUNDARIES, SUBDIVISIONS, BUSINESS AND RESIDENTIAL AREAS

Figure 1

(c) Of the industrial and wholesale enterprises which operated in the Fairbanks areas in 1958, an unusually high number of them have lost commercial buildings due to fire, flood and general deterioration. Poor quality design and construction, and poor location probably have hastened these capital losses.

Thus, and in spite of the limited industrial and consumer markets in the Interior Alaska region, Fairbanks industrial areas are several and scattered.

In 1958 city governmental boundaries encompassed practically all of the commercial and industrial sector and much of the residential district. However, by 1966 these boundaries barely confined 30 percent of overall economic activity, although still a very large proportion of retail sales. In this way most new construction, and hence the demand for additional utility services, has occurred principally outside the jurisdiction of the Municipal Utilities System for water supply purposes.

CRITIQUE OF PHYSICAL ENVIRONMENT AFFECTING PRIVATE WATER USES

Surface water is available in ample quantities from the Chena River (including Chena Slough) which has an average discharge of 1,344 cfs. Apparently the use of this surface water as a direct municipal supply has not been seriously considered at the various times additional production facilities were added. Instead the principal source is groundwater of the Tanana floodplain.

The City of Fairbanks is situated on a great aquifer fed by runoff from the north side of the Alaska Range, as well as by local streams. However, the differences between the uplands and the Tanana Valley lowland are of great economic importance in terms of the respective water supply conditions which exist. Wells at any appreciable distance from the valley sides have not penetrated through to the bedrock. Wells drilled close to the bedrock bluffs (as at the University of Alaska) proceed 90 feet or more before striking bedrock. The alluvium of the valley is directly recharged by rain and snow. Taken in perspective Cederstrom described the water supply situation as:

> (It) constitutes a groundwater reservoir of almost limitless capacity. In so far as present and foreseeable needs are concerned, in the area around Fairbanks and Fort Wainwright, the limitations that might be encountered in any well developed plan that might be conceived are those imposed by factors such as economics, mechanics of well construction, and quality of water obtained, rather than those pertaining to permeability, recharge, or storage capacity of the sediments. In the immediate vicinity of Fairbanks, the concept of safe yields is at best of only academic interest.
>
> Practically every well that has been drilled on the floodplain near Fairbanks has a high yield. No failures due to lack of a suitable water bearing formation are known. It appears that exceedingly high yields can be obtained anywhere even from poorly constructed wells that, ordinarily, are less than 250 feet deep. The depth to static, or nonpumping, water level ordinarily is about 10 or 12 feet below the land surface, and it is not known to be more than 16 feet below the land surface anywhere.

Groundwater of the Floodplain

Typical water yields for 2 inch wells from the floodplain range from 30 gpm to as much as 50 gpm. In good highly permeable aquifers, properly developed 6 inch wells can deliver 150 gpm with 22 feet of drawdown. An 18 inch diameter well, owned by the Fairbanks Municipal Utilities, has yielded 3400 gpm. Specific capacities (gpm per foot of drawdown) of 300 and 600 have been reported.

Obviously, the quantity of groundwater in the floodplain is not a pressing problem. There are, however, two factors that introduce serious qualitative difficulties. They are (1) permafrost and (2) poor water quality. Where the permafrost table is below the water table, domestic water might be obtained from shallow wells, although the supply might be somewhat more limited, i.e., as on a perched water table. These sources of water are quite susceptible to contamination. If the level of the water table is only a short distance above permafrost, the potential public health problems are accentuated.

Generally, permafrost is present on the floodplain except near streams or recently abandoned stream channels. Where undisturbed, the depth to the permafrost table ranges from 2 to more than 4 feet. Where the cover has been cleared for many years, the frost table may have receded to considerable depths.

There are a variety of reasons why it may be necessary for domestic wells to penetrate permafrost:

(1) There may not be any ground water above the frost, or too little of it, or

(2) To find better water at a greater depth although there is no assurance that better water will be found.

The thickness of permafrost varies greatly on the floodplain, and depths of 265 feet have been reported. In these cases it may be necessary to institute anti-freezing procedures, such as pouring hot water down the well periodically.

Winter frost is also troublesome to public water systems. The City of Fairbanks, Public Health Service, State Department of Health and Welfare, and local Military installations all have experienced difficulties with water distribution in cold regions. The City of Fairbanks has solved the freezing problem in the following way:

(1) By forcing water to circulate slowly from the main lines into each building and back to the main line stream of water, and

(2) Introducing heat into the water supply. At Fairbanks, the

velocity in the main line is 3 feet/sec., and in distribution lines 0.2 feet/sec., (Huggs, 1963). Water mains are buried about 6 feet deep. Many engineering problems are encountered in installing and operating water and sewage systems in cold climates, (Huggs, 1962).

Poor water quality is a major problem in the Tanana floodplain. For practical purposes, all the water in the Fairbanks area is usable for irrigation and livestock. The quality of water pumped from the Tanana alluvium varies greatly within a short distance, such as 50 feet. This condition is due to the irregular arrangement of lenses of silt, sand and gravel. Organic material will be found at almost any depth. For example, a well drilled several years ago, just downstream from the Cushman Street bridge on the right side of the Chena River, had to be abandoned at a depth in excess of 150 feet. A log had been struck that completely stopped drilling progress. Abandoned slough channels and swales on the surface contain large amounts of other organic material, e.g., decayed grass, moss, and even animal remains. One might encounter this kind of organic matter at any practical depth.

The quality of water from the floodplain is described by Cederstrom as follows:

> The water may be characterized as an alkaline, moderately hard to hard calcium bicarbonate water which ordinarily contains appreciable or objectionable quantities of iron. Objectionable quantities of manganese also were generally associated with the high iron content in the samples analyzed. Sulfate was high in a very few samples. Chloride and fluoride were low. A few samples had a relatively high content of nitrate which suggests possible pollution.
>
> The hardness of the water from the wells rarely is less than 100 ppm and more commonly ranges from 100 to 300 ppm. Only a little of the hardness is of the non-carbonate ('permanent') type, but exceptions may occur; water from well 219 in Fairbanks had a total

hardness of 281 of which 32 ppm was of the non-carbonate type. Most ground water from the floor of the Tanana Valley in Fairbanks and the vicinity is characterized by moderate to high hardness, low sulfate relative to bicarbonate content, and moderate to high iron content. For convenience, water of this type will be referred to as Fairbanks-type water.

The association of iron with organic material is illustrated by the fact that logs exhumed from the alluvium, after drying, are noted to be rust colored. Rain striking such logs washes the color off and often rusty streaks are found downslope from the logs.

Although the water hardness is a troublesome aspect of local ground water supplies, the iron-high content really makes the Fairbanks-type water objectionable. Of course, the presence of H_2S and organic scum, present in some places, are personally objectionable also. "Average" water on the floodplain is reported at 2 - 6 ppm. Water from bedrock sources, though hard, contains amounts of iron sufficiently low to be acceptable under this standard. As might be expected, wells situated on muck or silt areas of the floodplain contain exceptionally "poor" water. Given 0.3 ppm as a permissible maximum standard, iron contents as high as 43 ppm were recorded in Fairbanks.

With heavy and prolonged pumping, a well in a moderate-sized lens of gravel (with relatively good water) gradually exhausts the immediate water supply and draws in water from neighboring silty high-organic areas. In this way, the quality of water from wells deteriorates with use. It is not likely that water quality might improve with well use, and instances of this were not reported. Gravel pits dug in materials penetrated by old wells indicate that iron oxides had precipitated on the surrounding gravel. The clogging of aquifers by iron oxides has been reported for a large capacity industrial well, and its yield dropped from 1800 to 800 gpm in a few years. The high iron content of local water damages wells by rusting, and may partially or completely clog internal screens.

Ground Water of the Uplands

The quality and quantity of ground water away from the floodplain varies greatly and well yields are much lower than found on the floodplain. No wells are found operating in the Fairbanks loess (Qf) and in the muck. Perennially frozen silt, undifferentiated (Qsu), very low permeability, high organic content, and permafrost render the Qsu useless as an aquifer. Reported experience suggests that water obtained from this bedrock is poorer in quality when overlain by silt or muck due to restricted circulation than that obtained from alluvium.

Almost all of the wells drilled in the upland obtain their water from bedrock, even where bedrock is buried beneath a hundred feet or more of muck or silt. The Schist bedrock often is deeply weathered, and it is necessary to drill through the weathered zone or depend on crevices in brittle rock. Where the rock is not brittle, there may be water available. However, the claylike products of decomposition tend to clog the well under these circumstances. Artesian conditions exist on many of the middle slopes, with permafrost forming the cap.

Yields from bedrock sources are much smaller than from alluvium. A great many residential wells yield so little that large storage tanks are maintained inside the homes, and a significant number of wells were reported producing 10-15 gpm. The University of Alaska has obtained its water from sources in the schist bedrock by drilling collector holes laterally from sumps. The sum of these bedrock sources, including 8 wells, yield about 35-40 gpm. The University is the largest local user of ground water from bedrock sources. However, its water consumption has outstripped supply, and water from the alluvium now is mixed with that from the bedrock. As water consumption expands, this trend in lowered quality will continue. In view of the limited supply and uncertain quality of bedrock water sources, additional large-scale water needs must be satisfied from the floodplain alluvium. For example, the annual water requirement of Fort Wainwright is approximately 650 million gallons. This requirement is satisfied by the operation of two independent wells of approximately 150 feet in depth. Although the water table there begins at 15 to 20 feet below surface, its quality is unacceptable. Consequently, water is taken from 100 foot levels. Prior to treatment, the water quality is 9.5 parts iron per million, well in excess of the 0.3 standard.

In Urban Areas

The availability of sufficient quantities of water of suitable quality has been and continues as a major condition restricting commercial and residential building. Notwithstanding the small geographic extent of public water and sewer utility services at present, the local geology and soil conditions limit the areas in which construction might reasonably occur.

These cost and quality barriers to construction are referred to as a rating of "buildability" in Table 1. In it, Area Number 1 represents Fairbanks plus most of the present urban developments near the City. The remaining urban portions of the North Star Borough government unit are designated Area 2, an additional eighty square miles excluding very remote and inaccessible places. Area 1 is assessed as containing approximately 75 percent buildable land, and Area 2 at 60 percent buildable compared with nearly 100 percent rates for mild climate U.S. cities evaluated on a similar basis of comparison. In other words, nearly one-third of the city and adjacent urban land area is unbuildable. This conclusion is attributed directly to permafrost and swamp conditions which directly and adversely affect construction costs and affect water quality. In this respect water quality problems which are dictated by the physical environment of the Fairbanks area, are widespread and inhibit a geographic expansion of the community.

TABLE 1

ESTIMATED SQUARE MILES AND PERCENT OF SELECTED FAIRBANKS-NORTH STAR BOROUGH AREAS CLASSIFIED ACCORDING TO SOIL TYPE AND BUILDABILITY

Soil Classification	Area #1*		Area #2*+		Area #3+	
	Sq. Mi.	Percent	Sq. Mi.	Percent	Sq. Mi.	Percent
Buildable						
1. Floodplain, (except swamp floodplain)	19.0	67.8	18.0	36.7	37.0	48.1
2. Fairbanks Loess	2.1	7.5	10.4	21.2	12.5	16.2
3. Birch Creek Schist	0.3	1.1	1.2	2.4	1.5	1.9
Total Buildable	21.4	76.4	29.6	60.3	51.0	66.2
Unbuildable						
4. Swamp Floodplain+*	1.0	3.6	2.0	4.1	3.0	3.9
5. Silt:						
Silt, n.e.c.	2.0	7.1	15.0	31.0	17.0	22.2
Frozen	0.2	0.7	1.3	2.8	1.5	1.9
Organic	2.8	10.0	0.7	1.4	3.5	4.5
6. Peat	0.6	2.1	0.4	0.8	1.0	1.3
Total Unbuildable	6.6	23.5	19.4	40.1	26.0	33.8
Total All Classifications	28.0	99.9	49.0	100.4	77.0	100.0

(Table 1, continued)

* Area #1 is bounded by the northwest corner of (T1N, R1W, Section 32), the northeast corner of (T1N, R1E, Section 32), the southwest corner of (T1S, R1W, Section 17), and the southeast corner of (T1S, R1E, Section 17).

\+ Area #3 is bounded by the northwest corner of (T1N, R2W, Section 24), the northeast corner of (T1N, R1E, Section 22), the southwest corner of (T1S, R2W, Section 24), and the southeast corner of (T1S, R1E, Section 22).

*+ Area #2 = Area #3 - Area #1

+* The (swamp) floodplain area is included in unbuildable land. Given sufficient investment (drainage and fill), it can be converted readily to a floodplain class.

SOURCE: E. Wolff and R. C. Haring, Natural Resource Base of the Fairbanks-North Star Borough (1967) based on computations from Geological Map of the Fairbanks (D-2) Quadrangle, Alaska by T. L. Pewe, (1958).

Demand for water in the Fairbanks area is derived principally from the nature of economic activity which has developed up to the present. For practical purposes, three features distinguish the region from comparable sized cities elsewhere. They are:

(1) High degree of non-basic and service industries, including a very large government employment sector,

(2) Exceptionally sharp seasonal fluctuations in export-related industries, and

(3) Low community income and employment responses to changes in industry output.

Following several periods of industrial and military expansion and recession, 1950-1963, the Fairbanks economic base shifted heavily into non-military government employment industries, increasing tourist and recreation activity and very limited growth from the traditional basic industries, such as mining, forest products and agriculture.

The prevailing conditions of the physical environment constitute a major concern for industry, urban planners and household water users. They represent a major problem to attracting new industry. Local governmental agencies are directly concerned with offering suitable public utility services, maintaining public health standards and in planning efficient land use. Taken altogether the situation obviously represents a strong case for positive public planning, and outright intervention and regulation of local construction markets far greater than normally practiced.

This kind of public intervention is especially appropriate in governing water supply use and waste disposal. It is especially necessary concerning individuals who are fully capable of directly and adversely affecting the water supply of neighbors and potentially causing grievous health risks to their family and the community at large. Worse yet, these very conditions apparently are known to few persons, and a "reasonable person" (e.g., migrant worker, local resident) could not be expected to be familiar with them.

The implications of this situation are:

(1) Existing soil and water conditions increase construction costs outside city boundaries materially.

(2) Unusual financial risks are borne by those who construct residencies, i.e., likelihood of not locating water, acquiring poor quality water and subsequent difficulties in financing.

(3) Significant amounts of land within the Fairbanks urban area are unbuildable at present. Land so classified corresponds closely with the areas in which water supplies are ample, but likely of poor quality.

(4) The developing and urbanizing portions of the borough contain a larger proportion of unbuildable land than the present urban area. An indirect result of this phenomenon is the necessarily high geographic dispersion of homes as residential areas expand, i.e., low household density per acre of urban land.

(5) Many areas of the Borough might be "upgraded" in terms of buildability. The first major step in this direction is land clearing and draining. These activities should precede construction by several years.

Roughly 40 percent of the acreage neighboring the city is classified unbuildable. That is, acreage immediately surrounding existing commercial and residential areas is generally of progressively poorer quality. High quality land for building purposes is even more scarce than apparent from Table 1 when one considers the following additional factors:

1. Much of the buildable land classified as floodplain probably is also:

   a. very inaccessible, and

   b. exposed to high risk of seasonal flooding

2. Significant portions of areas designated 1 and 2 are in public domain, e.g., Fort Wainwright, University lands; although University lands include sizeable swamp and peat areas.

WATER SUPPLY CONDITIONS AND PRODUCTION

While the Fairbanks area is rated as a dry climate, substantial fluctuations occur in precipitation seasonally and year to year. These water supply variations apparently are coextensive with temperature changes. Thus the natural water flow and supply conditions are highly variable for flood control purposes, and to particular residential wells. However, these same conditions are regular and predictable for purposes of public and commercial wells of 100 ft. or greater depth in the urban floodplain.

IN COLD CLIMATE CONDITIONS

The local cold periods cause several special water supply conditions, and require special purpose water production and distribution facilities. A seasonal decline in economic activity occurs as these problems of seasonal cold (frost heave and freezing) increase in the winter. In other words, at the very time when mechanical problems of water production and distribution are accentuated, the seasonal demands for water supply are materially reduced. For example, the seasonal low in employment is associated with out-migration of transient workers, to the point that the labor force is only 65 percent of its seasonal high. However, reported water consumption patterns change little from season to season.

These reductions in water demand are not apparent from the municipal utility use statistics because changes in water consumption are most prevalent outside of the City boundaries. Also, a high level of water production is maintained due to water requirements in the steam heating plants at Fairbanks and College and the cold weather requirement for nearly continuous operation of facilities.

The cold climate also limits the extent to which water facilities might be spread geographically. For practical purposes, the extent of the water distribution system is limited by:

1. Engineering requirements to circulate warm water in cold ground where remote reheating facilities have not been constructed. In other words, the heat loss factor limits the distance to which water might be pumped from a central water utility supply system prior to freezing.

2. Dramatically increasing financial burden, in turn, attributed to:

   a. Heating cost requirements and additional investment in distributional facilities (as in 1 above),

   b. From the immediate downtown core, residential areas are, by and large, more sparsely settled, and therefore incremental revenues would decline with such an extension of the water system.

A cost and volume allocation of municipal water facilities are shown in the following two tables. Compared with industrial and commercial costs in other U.S. urban areas, the local cost conditions are extremely high. Until very recently the differential between commercial and household water rates, and for "interruptable" versus permanent service, were insignificant. In other words, a developed water rate structure had not been introduced. It is noted that these water rates are significantly higher than comparable water utility prices found in neighboring military reservations.

TABLE 2

WATER PRODUCTION COSTS FOR THE CITY OF FAIRBANKS
1965 - 1967
($ per 000 gal.)

Cost Categories	1967	1966	1965
PRODUCTION:			
Power	0.02	0.04	0.11
Labor	0.02	0.02	0.03
Miscellaneous	0.00	0.01	0.01
TREATMENT:			
Power	0.07	0.05	0.07
Labor	0.21	0.22	0.27
Chemical	0.12	0.10	0.08
Miscellaneous	0.05	0.05	0.06
DISTRIBUTION:			
Labor	0.13	0.19	0.19
Accounting	0.12	0.12	0.13
Sales	0.00	0.00	0.01
Administration & Overhead	0.11	0.08	0.11
Miscellaneous	0.15	0.14	----
FIXED COSTS:			
Depreciation	0.52	0.52	0.50
Franchise Taxes	0.11	0.16	0.17
Social Security & Misc.	----	----	0.02
Interest	0.46	0.50	0.47
TOTAL	2.09*	2.20**	2.26***
TOTAL MAINTENANCE COST (as part of the above)	0.11	0.10	0.11

* Costs are based on a total yearly production of 355,958,000 gallons.

** Costs are based on a total yearly production of 336,260,000 gallons.

*** Costs are based on a total yearly production of 312,518,000 gallons.

SOURCE: Municipal Utilities System, City of Fairbanks, Alaska; Brown, E. S., Feasibility Study of Water Supply Alternatives for the University of Alaska, College; unpublished E.M. Thesis, University of Alaska, 1967.

TABLE 3

SELECTED WATER TREATMENT PLANT PRODUCTION DATA
1965 - 1967

SOURCE	1967	1966	1965
Total Gallons Treated	460,650,000	394,031,000	390,400,000
Water to Distribution System (in gallons)	435,000,000	377,350,000	355,400,000
Water used for Filter Wash (in gallons)	3,250,000	1,728,000	2,150,000
Peak Daily Demand	1,817,000	1,565,000	1,318,000
Minimum Daily Demand	1,022,000	965,000	790,000
Average Daily Demand	1,238,000	1,043,000	971,000
Chemicals Used: (in pounds)			
Lime, Hydrated	457,900	433,500	407,550
Ferric Sulfate	89,865	78,650	83,050
Sodium Silicate	39,750	29,760	57,900
Sodium Silicofluoride	5,041	4,693	4,769
Chlorine	11,235	9,123	11,170
Chemical Costs: (per hundred pounds)			
Lime, Hydrated	$ 3.54		
Ferric Sulfate	6.14		
Sodium Silicate	6.16		
Sodium Silicofluoride	14.71		
Chlorine	13.00		

SOURCE: Municipal Utilities System Water Treatment Plant, City of Fairbanks, Alaska.

In addition to the factors noted earlier, certain special risks and uncertainties are borne in the operation of water utilities in the sub-arctic environment. The operating system during the winter must be maintained and repaired on short notice and at risking severe weather damage to the facilities investment. Although the chance happening of extensive flood damages did occur in 1967, there are recurring operational problems due to:

(1) Frost-heave and allied freezing and,

(2) Chronic earth movements, including earthquakes.

On balance, the degree and frequency to which these special risks and uncertainties have prevailed leads one to reasonably conclude that the geographical extent of the public water supply and waste facilities system ought to be held to a minimum.

PRIVATE UTILITIES

The city boundaries limit the extent which the municipal utilities might expand water supply and waste disposal services. Consequently, various private utility arrangements have arisen beyond those urban boundaries. Some of these arrangements have worked reasonably well, and others lasted only briefly.

Common Property Arrangements

In several housing areas around Fairbanks, such as Ballaine Lake Subdivision, homeowners enjoy common water and also, occasionally, joint waste disposal facilities. In this way, groups of residents have combined together in sharing larger common facilities for an entire subdivision. This common property arrangement is ad hoc in nature, and compares quite favorably with individual water systems in terms of substantial cost savings. In addition, it apparently compares well, cost-wise, with city utility rates. For the more remotely situated, but developing residential areas, this service arrangement is probably the only way that dependable and consistently good quality water facilities might be attained for the vast majority of homeowners. Unfortunately, experimentation along these lines has occurred only recently, and almost no older homes and neighborhoods have participated in these ventures.

University Utilities

The University of Alaska operates its own water supply and waste transfer system at the main campus in College, Alaska. To a large extent "free" water is transferred by many persons working in and around the campus and then in turn to residences where poor water quality is found. In addition, University steam requirements and water demands of student and faculty housing are substantial.

Its water system is independent of surrounding private residential areas. The water supply conditions are not adequate quantity for projected growth of University operations, and a trend in quality deterioration already is apparent.

College Utilities

The College Utilities Company was developed principally as a waste disposal plant under the holding company auspices of the Northern Alaska Development Corporation. In recent years several organizational changes have taken place, and for practical purposes College Utilities serves the University of Alaska and University Park School, with practical connections which might occur to surrounding residential areas. A saleable water supply is not available from the College Utilities Company at present. However, at regular intervals it has been proposed that the City should market water for a wholesale price at the "city line", and a private utility of this type would be the natural "distributor" for this kind of service. The matter of utility jurisdiction, and the sale of utility services beyond the Municipal Utility operating system is discussed subsequently.

Private Versus Public Utilities Debate

The extension of Fairbanks public utilities services has not occurred without political controversy. For practical purposes, these issues have centered recently on matters of:

(1) annexation and urban taxation, and

(2) the sale of utility services beyond the city limits by special arrangement.

The annexation issue is well depicted in reviewing the Hamilton Acres annexation and utility debate of 1965-1966. Following several "false starts" at annexation of this area, a Municipal Utilities System survey of Hamilton Acres residents was conducted. It amounted to the "vote" of residents on the question of whether to connect to public utilities services. A survey taken in the winter of 1965 indicated that approximately 85 percent of respondents favored public sewer, and approximately 75 percent city water. The extension of these utility services would result in direct corollary increases in real estate taxes. As a result of this situation, there was substantial resistance to further annexation of the city beyond its current limits from organized residential areas, and the Municipal Utilities System did not expand its services in one neighboring residential area after another.

Considering the problem in brief historical perspective, it is unfortunate that so few adjacent residential areas were annexed and that extension of public utility services were not extended prior to the flood of August, 1967. Repair and replacement of <u>only</u> public facilities since then obviously would have been much less costly upon individuals and the urban tax rolls.

QUALITY PROBLEMS FOR BUSINESSES AND HOUSEHOLDS

The business and household sectors of the community face special restrictive water supply conditions, most of which are quality in nature. For summary purposes, these problems are listed for two areas:

(1) areas served by the Municipal Utilities System, and

(2) areas served by individual wells, if at all.

Business and residences situated on the Municipal Utilities System are at a distinct advantage in most instances. The drawbacks of city water supply are relatively few, namely;

(1) discoloration which would affect almost no industrial uses, and

(2) taste and odor generally considered less desirable than University or Pioneer Wells quality, but well within minimum public health standards.

In addition, whether residents have public sewer available or not, city water is general insurance against the risks of serious and harmful contamination.

In certain areas, especially Hamilton Acres, selected individual wells once provided water of a higher quality than available from the City. Under these circumstances, mandatory connection regulations initially seem to contradict good sense. For the most part, the benefits of a mandatory utility connections rule far outweigh individual injuries in special circumstances. However, the geographic availability of utility connections in 1966-1967 is nowhere close to providing service to the majority of local residents in recently established residential sections.

Outside of the city limits water supply problems are more severe. An increasing number of commercial enterprises are located in this area, and the largest amount of new residential construction occurs there. In the process of this study, homeowners indicated several major water problems. The principal ones are:

(1) A high proportion of households, in acquiring a water source were forced to purchase;

(a) a well of unknown depth in being drilled, and

(b) make several attempts at locating water, or

(c) a well with poor or unsuitable water flow or quality.

For example, houses constructed prior to locating adequate water often utilized external corridors from a second well to the residence. Many homes remained without an individual operating well of any type five years after initial construction. Approximately one-half of the households visited recently reported serious cost difficulties in one of the above three categories.

(2) Water supply problems represent a serious barrier to real estate financing. With an "adequate" well and its required water quality, long term real estate financing, such as FHA financing is nearly prohibited. In one recent instance, a home was built on a construction loan according to the FHA design and specifications, but a trace of detergent appeared in the well which forbade permanent financing. In many instances reported, residences were sold by escrow (personal mortgage) simply because the real estate could not be marketed at a reasonable price under any other contract terms.

Still worse, several homes visited, which were FHA financed, probably could not be refinanced at any later time unless public utility services would be extended greatly. In examining post-flood reconstruction and S.B.A. recovery financing since August, 1967, special financing was made available. The amount and degree of residence repairs, considering the magnitude of damages, has created a situation much more severe than existed before the flood.

(3) The public health and personal risks in utilizing a private domestic well are potentially quite serious. The very soil and underground conditions which limit water flow and its quality also control the discharge of human wastes. Shallow groundwater wells, frequent in certain established sections of Fairbanks are particularly exposed to these risks. Additional building in developed residential areas not served by public utilities and the continuation of the present situation almost certainly will lead to a progressive worsening of these problems. Urban growth, normally associated with higher population density per acre, will aggravate these conditions. An offsetting factor, which reduces population density, is wide incidence of unbuildable land.

(4) The Fairbanks flood of August, 1967 caused extensive damage to public and private investment in water wells, water distribution facilities and sewer services. A summary of estimated damages is shown in Tables 4 and 5.

TABLE 4

INITIAL* ESTIMATES OF PROPERTY DAMAGE AND LOSS IN THE FAIRBANKS AREA DUE TO THE AUGUST 1967 FLOOD

Category of Flood Damage	Estimated Value (In Millions of Dollars)	Percent of Total
Private Sector:		
Personal Property	134.0	71.6
Real Estate	30.0	16.1
	164.0	87.7
Public Sector:		
Municipal Government Assets	7.8	4.2
Federal at		
Fort Wainwright	15.0	8.0
Eielson Air Force Base	.2	.1
	23.0	12.3
TOTAL	187.0	100.0

* Surveys a year hence may indicate damage and loss which were not apparent initially.

SOURCE: U. S. Army Corps of Engineers estimates.

TABLE 5

PRIVATE SECTOR FLOOD DAMAGE AND LOSS ESTIMATES
IN FAIRBANKS AND SURROUNDING AREAS
FALL, 1967

Flood Loss: by Property Type and Ownership	Estimated Value (In Millions of Dollars	Percent of Total
Residential losses	23.4	34.8
Commercial/industrial losses	5.0	7.5
Tax exempt, trailers, land damage and site damage	.8	1.2
	29.2	43.5
Household goods and personal effects	20.7	31.0
Commercial/industrial, personal property, automobiles, airplanes and trailers	17.2	25.5
	37.9	56.5
Total Real and Personal Property Losses	67.1	100.00

SOURCE: State Compilat'ons from Flood Damage Field Check List, August, 1967; and Flood Damage Questionnaire.

Taken together, the above situation clearly constitutes a variety of public policy problems for local state and federal government. The direct economic implications alone constitute a critical factor inhibiting the growth of this northern urban area. Indirect problems are very widespread, and they obviously detract from the "quality" of environment in Fairbanks at prevailing costs-of-living. Four problem areas, though indirectly generated, appear especially significant.

After a discussion of the flood damage problems with knowledgeable executives of the area's financial institutions, it is the author's opinion that the following conditions prevail and are serious new problems for the Fairbanks area at this time:

(1) Many of the damaged residences have declined in their "marketability." In particular, the houses in residential areas such as Hamilton Acres and Island Homes are of substantially lower market value in 1968 than they were a year prior to the flood. This situation is especially serious when one considers the relatively high amount of total mortgage in relation to present market value. For example, instances were reported where the total amount of first and S.B.A. second morgages actually exceed the expected resale value of the repaired properties. Therefore, one would expect that some of these residences could not be sold to a new owner even without downpayment or by assumption-of-mortgage. In other words, the actual net value of certain properties is practically nothing.

(2) New construction and much of the repair and modernization activities since the flood have occurred at geographically dispersed areas which are situated well beyond the flooded area. Much of the new residential building is taking place outside of the recently flooded residential areas, and a shifting of population favors outlying higher-ground areas. Providing this intra-regional movement continues, certain housing areas

which were extensively flood damaged may come to suffer from long-term low-occupancy rates, or will become predominantly rental properties.

(3) Newly created mortgages have placed many Fairbanks residents in a position of financial tightness in terms of their fixed debt load relative to anticipated monthly income. In other words, the total monthly payments for mortgage and utilities of a significant number of families have risen to a point of near insolvency. In the process of repairing homes, replacement of water and waste facilities often becomes a "last" priority, and remains undone 12 months after the flood. During the fall, 1967, construction starts in Fairbanks increased slightly, but demonstrated that on most occasions repair and modernization work was actually being delayed. In the past ten months, since the flood, construction costs have increased and an associated inflation in housing costs is mounting.

(4) Knowledgeable persons also admit that financial relief available to homeowners has amounted in some cases to legal and contractual discrimination. For example, it is readily apparent that homeowners who had borrowed on F.H.A. and G.I. loans (and who had a large debt outstanding) fared much "better" than persons who had purchased residences by private transaction (e.g., escrow) or by "conventional" mortgage. In other words, the amount of emergency flood protection, whether forbearance or new secondary financing, was very much improved in the case of federally-supported mortgage financing. Obviously, this situation works to the detriment of private financing and favors federal involvement in local mortgage markets. Many homeowners were placed in a no-choice position in new financing, i.e., a no-bargaining position because of the immediate need for housing.

CONSUMPTION AND CONDITIONS INFLUENCING DEMAND

INTRODUCTION

The historical pattern of land use as described has restricted the extent to which possible utility connections might develop within the Fairbanks area. It was noted that even its urban neighborhoods are not densely settled by most standards of comparison. In other words, substantial additional building might occur within the city limits.

Over the decade 1958-1968, the growth in the Fairbanks area and corollary water consumption have increased regularly and dramatically. However, the water supply system, and consequently the demand segments of water users have been highly fragmented.

A FRAGMENTED SUPPLY-DEMAND SYSTEM

Urban areas of the 35,000 population class in other parts of the United States often contain a well-developed and planned water and waste disposal system. By comparison, the Fairbanks area would be characterized as highly fragmented and decentralized. In particular, the central urban supply of water is served by a municipal utilities system; a distinct and separate University water supply system exists; a variety of common facility joint ventures are found in residential subdivisions; and, finally, one observes hundreds of individual wells.

These water supply facilities depend upon a variety of different water sources, and therefore are highly distinct and separable. These facilities represent water sub-systems that are often competing and overlapping, such as individual wells being contaminated by immediate neighbors' sewage and waste disposal. While examples of this sort of conflicting use probably occurred to a limited extent in other urban areas, in Fairbanks its incidence is sufficiently broad to constitute a major public utility and social problem.

The users (or buyers) of water services represent demand for water services which have been committed to very different facilities investments. In other words, the homeowner who has constructed a well has committed himself to an individual system for an extensive period, while in-town homeowners receive municipal water connections. In this respect, the separate markets for water pricing occur in terms of how water utilities and services are bought and financed. In observing recent trends of new residential and commercial construction in Fairbanks, the vast proportion of buildings have appeared outside of the municipal utilities service district. Therefore, the market fragmentation already observed is continuing at an accelerated pace.

TRENDS IN POPULATION AND EMPLOYMENT

The record of population growth in Fairbanks is shown in Table 6. A rapid expansion had occurred since 1950, with regional employment growth slowing since 1960. From this, several conclusions are drawn:

(1) The population of the Fairbanks area increased by 35,000 from 1940 to 1960, and this comprises a major growth trend. However, the trend in population growth was not maintained from 1960 to 1967, and out-migration became a serious economic development problem.

(2) The city's population has increased principally through annexation.

(3) From 1962-1966, the labor force grew more than employment.

This last condition was a major cause of the increased rate of out-migration, and it severely restricts additional population growth.

An analysis of employment statistics clearly indicates several changes in the economic base which appears to govern the longer term development of the area. for summary purposes, the significant changes are:

(1) The relatively large public employment component is shifting away from major dependence upon military expenditures to a greater reliance upon non-military public spending.

(2) The trade and service industries have expanded markedly. This condition is partially attributable to "tourism and recreation" activities, which are increasing in economic importance. The finance-real estate and service sectors of the community will continue to expand.

(3) Even considering the slowing down of population and employment growth since 1963, a gradual expansion of economic activity will continue.

Municipal water consumption and overall use will grow even more rapidly than resident population due to:

(1) Annexation and probably extension of distribution facilities in the city.

(2) Destruction and deterioration of private wells, especially associated with the 1967 flood.

(3) Increasing private well contamination.

The forecast of employment growth for the region would seem to require a growth of 8 to 10 thousand persons in the community in order to provide the 2,500 additional workers for the predicted industry expansion. This initial forecast has been tempered by the housing shortage which has become apparent since the August 1967 flood. Thus, population growth will be restricted by the scarcity of housing, and that is also indirectly manifest in water quality problems. Based on existing per capita water consumption rates and the lack of expansion of basic industry, project water demand conditions would not outstrip existing public facilities in the next 3 to 5 years. For practical purposes, this amounts to a 20 percent increase in municipal and university water production.

TABLE 6

POPULATION OF FAIRBANKS AND THE NINETEENTH ELECTION DISTRICT, 1910-1965
(In Persons)

Census Year	Fairbanks City Limits	Percent Change (annual rate)	Fairbanks District	Percent Change (annual rate)
1910	3,541	-----	11,000 (approx)	-----
1920	1,155	- 6.7	2,182	- 8.0 (approx)
1929	2,101	+ 8.2	3,446	+ 5.8
1939	3,455	+ 6.4	5,692	+ 6.5
1950	5,771	+ 6.7	19,409	+24.1
1960	13,311+	+13.1	43,412	+12.4
1965	17,800 (est)	+ 9.0	45,000 (est)	+ 3.0

*Although the area referred to as the Fairbanks District has not been the same in every Census, the changes have been roughly in accordance with the spread of the settled area and the increase in population in the places already settled. The District figures include the city in each case.

In the 1920 Census the only places in the district which were large enough to be listed were Chena and Fairbanks towns and Chena (native), Garden Island and Graehl villages. The figures in the Censuses of 1929, 1939, and 1950 were for the Fairbanks Recording District. The 1960 figure is for the Election District, but the differences in the boundaries as compared with the figure for 1950 affected only a few small places, and the increase i population is almost entirely accounted for by the growth in Fairbanks itself, in Graehl and Hamilton Acres (since incorporated in the city) and in the large suburbs of College and Lemeta-Johnston.

+The large increase in the city population from 5,771 in 1950 to 13,331 in 1960, is accounted for by a growth of 2,545 (44.1%) in the former area in the city, and the annexation of some suburban areas with a population of 4,995.

SOURCE: Bureau of Census

PRICE AND INCOME ELASTICITIES

The prices charged for Fairbanks utility services (including water rates) have not corresponded to the experience reported for other U.S. cities. In general, the rate structure for the non-water utility services has priced industrial and commerical buyers at higher rates than residential customers. In comparison to the Seattle utility rates (the basis for Alaskan price indexes), the cost of these services to the Fairbanks industrial sector is relatively high and out-of-line with Anchorage and other Alaskan urban areas. A summary of this rate structure is shown in Tables 7, 8, and 9.

One might expect the volume of water utility services consumed to fluctuate directly with the rates charged. In other words, consumption could shift directly with changes in personal income and extent of business operations. In the Fairbanks area these aspects of demand analysis have not been major determinants of consumption over the period of this study. In other words, the need for water utility connections and services has been fairly "absolute," almost irrespective of the prices charged and income changes accruing the users. By and large, increases in metered water consumption stem mainly from a geographic extension of utility connections per household. Moreover, the expansions in business and commercial operations have been slight in recent years. It is readily apparent that an increase in water use will occur as:

(1) Additional employed persons migrate into the Fairbanks city area, i.e., a population change affecting demand; and

(2) Lower quality housing units, represented by some 20 percent of households without water services in 1960 will be upgraded or demolished and replaced as indicated earlier in this report.

TABLE 7

MUNICIPAL ELECTRIC SERVICE FOR FAIRBANKS, ANCHORAGE, KETCHIKAN, AND SEATTLE FOR 1962, BY PERCENTAGE OF KILOWATT HOURS CONSUMED BY INDUSTRIAL AND COMMERCIAL CUSTOMERS (in percent)

	Industrial	Commercial
Fairbanks	11	51
Anchorage	22	40
Ketchikan	--	48
Seattle	24	22

SOURCE: Federal Power Commission, Statistics of Electric Utilities in the United States - 1962.

TABLE 8

MUNICIPAL ELECTRIC SERVICES, OPERATING EXPENSES PER (000) KILOWATT HOUR, 1962, FOR FAIRBANKS, ANCHORAGE, KETCHIKAN AND SEATTLE

	(In Dollars per 000 kwh)	Simple Price Index (Seattle = 100)
Fairbanks	33.00	518
Anchorage	18.91	297
Ketchikan	11.25	177
Seattle	6.37	100

SOURCE: Federal Power Commission, Statistics of Electric Utilities in the United States - 1962.

TABLE 9

MUNICIPAL ELECTRIC SERVICE CHARGES PER THOUSAND KILOWATT HOURS FOR FAIRBANKS, ANCHORAGE, KETCHIKAN, AND SEATTLE ACCORDING TO CLASS OF CUSTOMER, 1962

	Overall	Residential (rates)	Commercial	Industrial
Fairbanks	$ 50.80	$ 54.60	$ 127.68	$ 58.70
Anchorage	25.62	29.78	29.33	23.77
Ketchikan	38.44	19.54	18.63	n.a.
Seattle	9.23	9.53	12.81	5.52

INDEX NUMBERS
(Seattle = 100, by Column)

	Overall	Residential	Commercial	Industrial
Fairbanks	550	573	997	1,063
Anchorage	276	312	229	431
Ketchikan	416	205	145	-----
Seattle	100	100	100	100

SOURCE: Federal Power Commission, Statistics of Electric Utities in the United States - 1962.

POST-FLOOD ADJUSTMENTS

The August 1967 flood in Fairbanks, Alaska, caused considerable damage to public and private water production facilities. However, this natural disaster also altered several conditions influencing the demand for water service and immediately anticipated municipal water use. For summary purposes, these demand-related changes are:

(1) The loss of, or substantial damage to, many private wells and cesspool-septic tank systems. In this way, losses of individual real estate have drastically changed the demand conditions for public utility service connections more strongly than previously.

(2) A significant number of homeowners occupy facilities which cannot be readily repaired, or obtain water from facilities which have been "condemned" for human consumption. In addition, rebuilding original facilities is unlikely or financially impractical.

(3) There has appeared an increasing general awareness of Fairbanksans of the "public need" for an extension of municipal utilities services. In previous periods, individuals in certain neighborhoods were affected by water quality problems, but the recent natural disaster has adversely affected a very large cross-section of the population. As a result the public water supply and waste disposal facilities received an increase in apparent priority for governmental action.

(4) An increasing proportion of new residential starts and building modernization occurs outside the city limits, and this has increased the demand for "fragmented" water systems. New individual wells and separate disposal units will continue to appear at diverse and scattered locations.

The consumer and commercial demands are extremely favorable for a rapid extension of public utilities services to outlying neighborhoods in the Fairbanks area. However, water consumption will be more so affected by the political and jurisdictional decisions of local and state government than by direct demand determinants for water facilities or increasing "need" for utility connections.

CONCLUSIONS

Based on the demand and consumption patterns identified in this chapter, together with information presented in earlier sections of this report, the following conclusions are apparent:

(1) Water used by industry groups and residential users reflect the substantial overall "non-basic" character of the Fairbanks economy. Water consumption by industrial users is very small, and a limited number of conflicting uses exist between users. Natural water supplies, such as used by private wells, have not been materially influenced by industrial development. Instead, individual wells have been significantly affected by:

    (a) Supply problems with the water table, and quality deterioration, e.g., flooding; and

    (b) Highly localized pollution from neighbors.

(2) The orderly programming of water inputs into production is not a systems problem of a conventional type. In other words, existing water supply capacity where municipal connections exist are currently sufficient for commercial and residential demands and anticipated requirements in the near future. An extension of utility boundaries, and increased operation of the local fabricators and commercial enterprises, might occur

without extensive "bottlenecks" arising in the quantity of water available. Water quality problems, other than those already experienced, are not likely to change significantly. In other words, the sufficiency of water is not a major barrier to economic development in the Fairbanks area at the present time.

(3) Water drawn from most natural sources requires treatment for almost all commercial and residential water uses. Treatment costs vary seasonally. Substantial amounts of the water production are devoted to uses such as commercial steam and for cooling. Water quality differs between the flood plain sources and those from bedrock, and quality deterioration of an alarming rate is most apparent among residential wells on the floodplain. Quality changes of commercial wells were reported at a relatively slow but regular pace. Within reasonable cost boundaries, additional treatment costs are a satisfactory short run remedy in these commercial cases.

(4) Considering the very meager industrial expansion which is expected to occur in the Fairbanks area 1970-1975, neither the cost of water or its availability represent major barriers to use. There are seasonal problems superimposed upon this issue, such as difficulties encountered in the winter and typical of the cold climate areas, and the fact that the municipal water distribution system is very limited in geographic extent. Therefore, a principal indirect barrier to industrial and commercial expansion could be the cost availability of commercial land where municipal utility connections are available.

(5) Water and steam are priced in a manner which is not directly based on "separable cost" considerations. The control of utility pricing is accomplished directly by the City Council rather than through a logical pricing system of the utilities

services or to the customer classes concerned. In other words, the prices for utilities service have been "legislated" into existence. Outside of the public utility boundaries, the price of water services is based upon the individual conditions of private well investment and direct cost of operations.

(6) Considering the regulatory situation which exists and the observable problems in allocation of associated public investments, several implications for the efficient development of the Fairbanks regions have been exposed.

SUMMARY AND CONCLUSIONS

SUMMARY

This survey of demand conditions for water in the North Star Borough clearly indicated a gradual expansion of water consumption and requirements for an increased rate of public and private investment in facilities. The water supply systems which exist in urban Fairbanks and populated areas of the Borough are a mixed picture and appear unusually complicated by comparison to reports on other U.S. cities. The major complications stem directly from natural conditions of water supply and associated cold climate problems of distribution, and to utility and water regulation policy problems.

Water Use Characteristics

The Fairbanks area private sector is served principally by the public water system of the Municipal Utilities System and individual residence and small business wells situated at the site of operations. Quite indirectly Pioneer Wells, a private company, and the University of Alaska also supply private persons. An entirely independent water system operates at Ft. Wainwright, Alaska, immediately adjacent to the City.

Taken altogether the water supply facilities, although overbuilt in certain respects and competing in other aspects, are technically sufficient for the present and short run demands of the urban area. More specifically, practically every well that has been drilled on the floodplain near Fairbanks has a high yield. Residences situated on higher ground above the floodplain area face a mixed prospect and higher costs of locating suitable water for domestic consumption.

For the most part, the quantity of groundwater available in the floodplain is not a problem. However, two factors do represent problems to the public and private sector alike. They are:

(1) Permafrost; and

(2) Poor water quality.

The permafrost and ice crystal problems are representative of this cold climate region and principally affect domestic wells. Poor water quality is a more general problem, and with rare exceptions, such as Pioneer Wells and the public spring at Fox.

The quality of public and domestically pumped water varies considerably, and the survey conducted clearly indicates quality varies seasonally and year to year. For practical purposes, most of the groundwater from the floor of the Tanana Valley is characterized by moderate to high hardness, low sulfate to bicarbonate content, and moderate to high iron content. The iron content often is associated with organic materials; rusty colored water and personally offensive odor are typical in several residential areas. The local designation of Fairbanks-type water is not a homogeneous classification for purposes of this report, and economically significant differences in quantity and quality characteristics were apparent.

The vast majority of water supplied to the private sector required moderate levels of treatment. Due to local well contamination and the limited spatial extent of public transmission lines, nearly one-fifth of households interviewed were not using their domestic wells for human consumption purposes.

Trends in water consumption over the period of study and through 1967 indicated gradually increasing water usage of all public facilities at a pace slightly higher than the very meager overall population growth. Changes in private industry during this same period were negligible, and industrial demands are not expected to change markedly in the next several years. New basic industry, should it appear in the area, almost certainly would be situated well beyond the City limits. Groundwater is adequate for direct and untreated use in irrigation and mining operations. Occasional conflicts have and will continue to arise in the area of dredging versus domestic uses in neighboring areas. For the most part, these conflicts will occur far beyond the urban portion of Fairbanks, and its residential areas and traveled highways.

Trends in Consumption and Demand

An expansion in measured consumption will occur gradually with dramatic increases associated with extensions of the existing water distribution system, when that occurs. The 2,500 customer connections of the Municipal Utilities System in 1967 clearly reflects the restricted extent of public "services" in this area.

The price of publicly delivered water (where connections are available) is relatively high by comparison with other Alaskan cities and urban areas in other states. However, the cost of public water remains highly competitive to most local businesses and practically all residences when viewed as an opportunity cost. That is, public water is less costly than installation and operations of domestic wells for most parties, and especially when considered in conjunction with health risks prevalent in shallow wells typical of the older developed neighborhoods. However, several public policy issues are apparent in local government regulation and planning.

Public Policy and Regional Problems

The policy problem which has received the most notice concerns a "mandatory connection rule" of the City. Several conditions have led to its development:

(1) Urban annexation, and hence taxation, has occurred in one neighborhood after another without a corresponding increase in public services. For example, while Hamilton Acres was annexed some years ago, City water is not yet available to all residents of the neighborhood.

(2) Homeowners have constructed domestic wells and domestic

waste facilities in these same areas prior to annexation, and the prospect of receiving timely and comparable public utility services has been very doubtful. Therefore, residents of these areas were forced to purchase initial private water sources, and then subsequently were exposed to mandatory connection rulings. Obviously, the sequence of events has led to substantial public and private waste of financial resources.

(3) Poor water quality and contamination were very real urban problems, in neighborhoods such as Hamilton Acres, throughout 1965-1966. Since the flood of August, 1967, apparently the situation has come to vitally affect two-thirds of residents of several housing areas visited. In particular, the likelihood of deterioration of private domestic water and waste facilities, once difficult to assess, has indeed occurred. It is clearly unwise public policy to allow widespread rebuilding of domestic wells and sewage facilities in these areas.

A less obvious development problem exists in terms of the spatial allocation of Fairbanks industry and residential areas. For example, housing areas such as Lemeta and Johnston Subdivisions reflect fairly low population density and relatively long transmissions distances per residence which might be served. This problem of domestic service is magnified in the subdivisions along College Road and within a 3 mile radius of the University. The planning problem is not unique to Fairbanks: For sparse population densities, public utility service costs increase dramatically. The cost increases are additionally magnified in Fairbanks due to cold climate and permafrost conditions, already discussed.

CONCLUSIONS

Viewed principally from an economic viewpoint, four major conclusions are apparent from this study. They are:

(1) Small Water Consumption Growth, but An Increased Demand for Some Production and Extensive Distributional Facilities.

The population and employment forecasts for the North Star Borough, and associated industry development, would not nearly exhaust present groundwater supplies or production facilities. However, the present water system and organization of economic units in Fairbanks will require in some cases demolition and rebuilding (especially residential service), extension of distributional lines or substantial repair and maintenance of existing domestic service. Therefore, the costs of water utility services are expected to rise more rapidly than recent materials and labor cost increases suggest.

(2) Certain Risks of Health and Financial Losses Due to Well Drilling Uncertainty Are Incorrectly Borne by Households.

Knowledgeable persons have reported at regular intervals that water consumed in certain Fairbanks residential areas is and has been unfit for human consumption. The health risks of this practice are unrealistic on several grounds:

(a) Typical adults are not expected to understand the gravity of their acts as potentially injuring themselves; and

(b) Its continued practice represents a health risk to neighbors, public schools and the community at large.

Obviously, thorough sampling and health standards enforcement are long overdue in this area.

(3) Public and Private Investments in Water Production and Distribution Facilities Overlap in Some Areas and Do Not Exist at All in Others, and Thereby Represent a Mistake in Urban Planning.

Recently annexed neighborhoods in Fairbanks are represented by residences constructed rather recently, i.e., the vast proportion since 1956. Thus, in approximately ten years the urban water system is both inefficient, and in many cases inoperable. Taken in time perspective, a high proportion of homeowners surveyed had paid the "costs" of water facilities which deteriorated fully 10 percent annually. Even without foresight about the 1967 flood, the pattern of residential construction versus distribution of water utility services has operated poorly. The result has been economic discrimination among consumer groups and unduly costly housing considering the services rendered.

(4) Water Quality is a Very Real and Significant Development Problem for Sub-arctic Urban Areas.

The costs of water for human consumption and industrial uses in this northern community are substantial both in direct terms and indirect barriers to development. In order of apparent priority they are:

(a) Water facilities are a substantial and high cost element in housing construction, most of which is now occurring outside of the City limits and public utility boundaries. Risks of not locating suitable water on superficially desirable residential land are uniquely high, and this situation appears typical of interior sub-arctic areas. Malfunction and rapid physical wear and tear of water facilities are widespread.

(b) Water utility services are economically confined to the immediate urban area due to cold climate limitations. Thus, the development of a geographically dispersed community works directly toward creating inefficient water production and distribution.

(c) Enormous financial "trade-offs" have appeared between the short run immediate considerations and satisfactory longer term water facilities investment. In particular, homeowners have repeatedly "settled" for shallow wells in the floodplain where water is first located, yet deterioration of the source and poor water quality are quite likely to occur in a few years. Minimum well standards might have aided this situation, but local government jurisdiction and corresponding ordinances have appeared only recently.

BIBLIOGRAPHY

GOVERNMENT DOCUMENTS

Federal

Advisory Commission on Intergovernmental Relations. Intergovernmental Responsibilities for Water Supply and Sewage Disposal in Metropolitan Areas. Washington: October, 1962.

A. J. Alter. Arctic Sanitary Engineering. Washington: Federal Housing Administration, 1950.

G. M. Arnow and G. L. Hubbs. Characteristics of Surface and Ground Waters in Selected Villages of Alaska, 2 vols. Anchorage: Arctic Health Research Center, Department of Health, Education, and Welfare, 1961.

Bureau of Census. Census of Housing, 1960. Washington: United States Department of Commerce, 1963.

_____. "Finance of Municipalities and Township Governments," Census of Governments, 1962. Washington: United States Department of Commerce, August, 1964.

_____. "Retail Trade - Alaska," 1958 Census of Business. Washington: U. S. Department of Commerce, 1960.

_____. "Retail Trade - Alaska," 1963 Census of Business. Washington: U. S. Department of Commerce, 1964.

_____. "Taxable Property Values," Census of Governments, 1962. Washington: U. S. Department of Commerce, August, 1964.

_____. "Wholesale Trade - Alaska," 1958 Census of Business. Washington: U. S. Department of Commerce, 1960.

_____. "Wholesale Trade - Alaska," 1963 Census of Business. Washington. U. S. Department of Commerce, 1964.

Bureau of Labor Statistics. Indexes of Consumer Prices and Living Costs for Fairbanks, Alaska. Washington: recurring.

D. J. Cederstrom. Ground-water Resources of the Fairbanks Area, Alaska. Washington: U. S. Geological Survey Bulletin 1590, 1963.

_____. "Summary of Ground Water Development in Alaska, 1950." Washington: U. S. Geological Survey Circular 169, 1952.

Cederstrom and Péwé. "Groundwater Data, Fairbanks, Alaska", U. S. Geological Survey Report No. 9, 1960.

"Contributions to the Economic Geology of Alaska," U. S. Geological Survey Bulletin 1155, July 1954.

Corps of Engineers, U. S. Army. Water Resources Development: Alaska. Portland: North Pacific Division, January, 1967.

Covert. "Water Supply of the Fairbanks District, 1907," U. S. Geological Survey Bulletin 345-F, 1908.

Department of Health, Education and Welfare. The Water Quality Act of 1965 (P. L. 89-234). Washington: November, 1965.

Federal Power Commission. "Publicly Owned Systems," Statistics of Electrical Utilities in the United States, 1962. Washington: 1964.

Fuelner. "Galleries and Their Use for Development of Shallow Groundwater Supplies With Special Reference to Alaska." U. S. Geological Survey Water Supply Paper 1809-E, 1964.

Lohr. "Chemical Character of Public Water Supplies of the Larger Cities of Alaska, Hawaii, and Puerto Rico," U. S. Geological Survey Water Supply Paper 1460-A, 1962.

Low Temperature Sanitation. Washington: U. S. Office of Naval Operations, 1954.

T. L. Péwé. "Effect of Permafrost on Cultivated Fields, Fairbanks Area, Alaska," U. S. Geological Survey Bulletin 988-F, 1956.

_____. Geologic Map of the Fairbanks (D-2) Quadrangle, Alaska. Washington: U. S. Geological Survey, T.Q. 110, 1958.

_____. "Origin of the Upland Silt Near Fairbanks, Alaska," Geological Society of America Bulletin, Vol. 67, 1955.

T. L. Péwé and R. A. Paige. "Frost Heaving of Piles with an Example from Fairbanks, Alaska," U. S. Geological Survey Bulletin 111-I, 1963.

President's Science Advisory Committee. Restoring the Quality of Our Environment. Washington: November 1962.

L. M. Prindle and F. J. Katz. "Geology of the Fairbanks District," U. S. Geological Survey Bulletin 525, 1913.

"Quantity and Quality of Surface Waters of Alaska," U. S. Geological Survey Water Supply Papers - 1466 (1950-53), 1486 (1953-56), 1500 (1957), 1570 (1958), 1640 (1959), 1720 (1960).

United States Department of Agriculture. Soil Survey - Fairbanks Area, Alaska. Washington: Soil Conservation Service, September 1963.

United States Geological Survey. Mineral and Water Resources of Alaska. Washington: 1964.

Weather Bureau. Climate of Alaska. Washington: U. S. Department of Commerce, 1959.

Wells and Love. "Compilation of Records of Quantity and Quality of Surface Waters of Alaska Through 1950," Water Supply Paper 1392, U. S. Geological Survey, 1957.

John R. Williams. "Geological Reconnaissance of the Yukon Flats District, Alaska," U. S. Geological Survey Bulletin 1111-H, 1962.

_____. "Groundwater in Permafrost Regions - An Annotated Bibliography," U. S. Geological Survey Water Supply Paper 1792, 1965.

J. R. Williams, T. L. Péwé, and R. A. Paige. Geologic Map of the Fairbanks (D-1) Quadrangle, Alaska. Washington: U. S. Geological Survey map, G. Q. 124, 1959.

State and Local

Alaska Resource Development Board. The Ward Index on Consumer Price in Seven Alaskan Cities. Juneau, Alaska: November, 1958.

City Planning Office of the City of Fairbanks. Fairbanks Neighborhood Analysis. City of Fairbanks, Alaska: 1961.

Richard A. Cooley. Fairbanks, Alaska, A Survey of Progress. Juneau, Alaska: Alaska Development Board, July, 1954.

Department of Economic Development and Planning. A Capital Improvement Program for the State of Alaska. Juneau, Alaska: February, 1963.

_____. A Capital Improvement Plan for the State of Alaska 1963-1969.

Juneau: February, 1963.

Division of Tourist and Economic Development. 1959 Consumer Price Index in Seven Alaskan Cities. Juneau, Alaska: Alaska Resource Development Board, November, 1959.

Robert B. Forbes and Jim Brown. Preliminary Map of the Bedrock Geology of the Fairbanks Mining District, Alaska. Juneau: Alaska Division of Mines and Minerals, 1961.

Highway Planning Board. Greater Fairbanks Master Highway Plan. Fairbanks, Alaska: September, 1958.

Local Affairs Agency, Office of the Governor. Borough Manual Planning, Zoning, and Public Services. Juneau, Alaska: December 30, 1963.

Municipal Utilities System. Annual Report. Fairbanks, Alaska: annual.

Foreign

J. F. J. Thomas. "Water Quality for Some Canadian Military Establishments, 1956-1957," Water Survey Report 12, Canadian Department of Mines and Tech. Survey, Mines Branch, Ottawa: Queen's Printer, 1959.

BOOKS AND REPORTS

G. M. Arnow and G. L. Hubbs. "Characteristics of Surface and Ground Waters in Selected Villages of Alaska," Parts 1 and 2, Arctic Health Research Center Report. Anchorage: 1962.

R. W. Beck and Associates. Annual Engineering Report Municipal Utilities System of the City of Fairbanks, Alaska, as of July 31. Seattle, Washington: annual.

_____. Comprehensive Plan, Fairbanks, Alaska. Seattle, Washington: 1953.

_____. Engineering Report 1954, Extension and Improvement Program Municipal Utilities System of the City of Fairbanks, Alaska. Seattle, Washington: February 1, 1954.

_____. Feasibility Report Financing and Improvement Program Municipal Utilities System of the City of Fairbanks, Alaska. Seattle, Washington: annual.

_____. Inventory and Evaluation, Telephone, Water, and Steam Heat Properties of Municipal Utilities System of the City of Fairbanks, Alaska as of December 31, 1955. Seattle, Washington: June 30, 1956.

_____. Preliminary Feasibility Report Water System Extensions and Improvements Municipal Utilities System of the City of Fairbanks, Alaska. Seattle, Washington: October, 1961.

Carl S. Benson. Ice Fog: Low Temperature Air Pollution. College: Geophysical Institute, University of Alaska, 1965.

Ian Burton and Robert Kates (eds.). Readings in Resource Management and Conservation. Chicago: University of Chicago Press, 1965.

Clark-Coleman & Associates. Central Business District Study for Fairbanks, Alaska. Seattle, Washington: June, 1960.

_____. Comprehensive Plan for Fairbanks, Alaska. Seattle, Washington: October, 1959.

_____. Fairbanks, Alaska Planning Report. Seattle, Washington: 1959.

_____, Industrial Development Study for Fairbanks, Alaska. Seattle, Washington: June, 1960.

Golden Valley Electric Association, Inc. Annual Report. Fairbanks, Alaska: 1962-1965.

Robert C. Haring. Prices and Costs in the North Star Borough, Alaska. College: Institute of Business, Economic and Government Research, University of Alaska, 1965.

Robert H. Haveman. Water Resource Investment and the Public Interest. Nashville: Vanderbuilt University Press, 1965.

Linck, Stevens and Thompson. Report on Water Works Improvements for the City of Fairbanks, Alaska, Prepared for Municipal Utilities System. Portland, Oregon: June 16, 1961.

E. W. Moore. A Summary of Available Data on Quality of Arctic Waters. National Research Council, Committee on Sanitary Engineering and Environment, Division of Medical Science, 1949.

Municipal Utilities System of the City of Fairbanks. Annual Report. Fairbanks, Alaska: annual.

National Acacemy of Sciences. Waste Management and Control. Washington: Committee on Pollution, National Research Council, 1966.

National Research Council. Waste Management and Control. Washington: National Academy of Sciences, Publication 1400, 1966.

National Sanitation Foundation. Resources, Economics and A Quality Environment. Ann Arbor: June, 1966.

North Pacific Consultants. Economic Analysis of Fairbanks and Contiguous Area, Alaska. Fairbanks, Alaska: Golden Valley Electric Association, Inc., January, 1959.

T. L. Péwé. "Permafrost and Its Effect on Life in the North," Arctic

Biology. Corvallis, Oregon: 18th Biology Colloquium, 1957.

Blocher A. Poole. A Report on Quality Problems in the State of Alaska. Juneau: 1961.

Ira M. Robinson. New Industrial Towns on Canada's Resource Frontier. Chicago: Department of Geography, University of Chicago, 1962.

Burton A. Weisbrod. The Economics of Poverty. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1965.

Western Real Estate Research Corporation. Marketability Survey for Central Downtown Area Urban Renewal Project T.A.R.-7 Fairbanks, Alaska. Anchorage, Alaska: Alaska Housing Authority, May 13, 1959.

Howell Williams (ed.). Landscapes of Alaska. Berkeley: University of California Press, 1958.

Ernest Wolff. Handbook for the Alaskan Prospector. College: University of Alaska, 1964.

E. Wolff and R. C. Haring. The Natural Resource Base of the Fairbanks - North Star Borough, Alaska. College: Mineral Industries Research Laboratory, University of Alaska, 1967.

Harold Wolozin (ed.). The Economics of Air Pollution. New York: W. W. Norton and Company, 1966.

PERIODICALS

A. J. Alter. "Alaska Water Pollution Control Investigations," Alaskan Science Conference, (1952).

_____. "Low-temperature Problems in Alaska," Journal of the American

Water Works Association, Vol. 47, No. 8, (1955).

_____. "Relationships of Permafrost to Environmental Sanitation," Alaskan Science Conference, (1952).

_____. "Water Supply in Alaska," Journal of the American Water Works Association, Vol. 42, No. 6, (1950).

_____. "Water Supply Problems in the Arctic," Alaska's Health, Vol. 7, No. 3, (1949).

_____. "Water Supply Problems in Low Temperature Areas," Alaskan Science Conference, (1952).

T. K. Anderson. "Maintaining Water Supply Lines at Zero Temperatures," Water and Sewage Works, Vol. 106, No. 5, (1959).

D. J. Baumgartner. "Water Supply and Waste Disposal Problems at Remote Air Force Sites in Alaska," Alaskan Science Conference, (1960).

C. H. Billings. "Protecting Underground Utilities Located in Arctic Regions," Water and Sewage Works, Vol. 100, No. 11, (1953).

W. L. Boyd and J. W. Boyd. "Water Supply Problems at Point Barrow," Journal of the American Water Works Association, Vol. 51, No. 7, (1959).

Jean C. Brockett. "Index of Living Costs for Alaskan Cities," Monthly Labor Review, (March, 1962).

M. J. Chernyshoff. "Water Services in Regions with Perpetually Frozen Ground," Journal of the American Water Works Association, Vol. 22, No. 7, (1930).

L. K. Clark. "Some Aspects of Sanitation and Water Supply in the Arctic," <u>U. S. Naval Civil Engineering and Research Evaluation Laboratory: Report Symposium Advanced Base Water Supply and Sanitation</u>. Port Hueneme, California: 1954.

L. K. Clark and A. J. Alter. "Water Supply in Arctic Areas: Design Features," <u>American Society of Civil Engineers, Sanitary Engineering Journal</u>, SA2 (Paper 931), Vol. 82, (1956).

Marion Clawson and R. B. Held. "Demand for Rural Resources in the Context of Long-Range National Needs," <u>Journal of Farm Economics</u>, (December, 1963).

S. S. Copp. "Two Water Supply Systems of Northwestern Canada," <u>Alaskan Science Conference</u>, (1952).

S. S. Copp, C. B. Crawford, and J. W. Grainge. "Protection of Utilities against Permafrost in Northern Canada," <u>Journal of the American Water Works Association</u>. Vol. 48, No. 9, (September, 1956).

R. L. Crow. "Cold Weather Public Works," <u>Civil Engineering</u>, Vol. 29, No. 9, (1959).

E. K. Day. "Environmental Sanitation Problems in Alaska and Their Solution," <u>Harvard Public Health Alumni Bulletin</u>, Vol. 9, No. 1, (1952).

"Design of Intake Structures for an Arctic Water Supply," <u>American Concrete Institute Journal</u>, Vol. 22, (1950).

H. B. Dickens. "Water Supply and Sewage Disposal in Permafrost Areas of Northern Canada," <u>Polar Record</u>, Vol. 9, No. 62, (1959).

B. M. Ellis. "A Water Distribution System for the Town of Thompson," <u>Canadian Municipal Utilities</u>, (1962).

J. W. Grainge. "Water and Sewer Facilities in Permafrost Regions," Municipal Utilities Magazine, Vol. 96, No. 10, (1958).

W. A. Hardenberg. "Arctic Sanitation," American Journal of Public Health, Vol. 39, (1949).

R. C. Haring. "Some Water Quality and Air Purity Conditions Which Affect Economic Growth in Subarctic Urban Areas," 1967 Papers of the Regional Science Association: Western Section, Bellingham: Western Washington State College, 1967.

Hostrup, Lyons, and Associates. Study of the Mechanical Engineering Features of Polar Water Supply. U. S. Naval Civil Engineering Research and Evaluation Laboratory, Los Angeles, 1953.

G. B. Hubbs. "Water Supply in Permafrost Areas," Proceedings, Permafrost International Conference. National Acadamy of Sciences - National Research Council, Pub. No. 1287, 1963.

W. L. Hyland, G. M. Reece. "Water Supplies for Army Bases in Alaska," New England Water Works Journal, Vol. 65, No. 1, (1951).

M. F. Hufschmidt. "Field Level Planning of Water Resource Systems," Water Resources Research, Vol. 1, No. 2, (1965).

Institute of Business, Economic and Government Research. Alaska Review of Business and Economic Conditions. College, Alaska: University of Alaska.

Ralph W. Johnson. "Some Myths About Water Shortages," University of Washington Business Review, (October, 1964).

A. V. Kneese. "Economic and Related Problems in Contemporary Water Resources Management," Natural Resources Journal, Vol. 5, No. 2, (October, 1965).

J. V. Krutilla. "Is Public Intervention in Water Resource Development Conducive to Economic Efficiency?" Natural Resources Journal, (January, 1966).

E. W. Lingel. "How Chlorination Helps Water Conditioning at Alaskan Bases," Public Works, Vol. 89, No. 8, (1958).

"Long Hard Winter Takes Toll of Alaska's Water Systems." Alaska's Health, Vol. 8, Nos. 3 and 4, (1950).

M. E. McConnell. "W. E. Engineering for the DEW Line," and "Water and Waste Systems," Western Electric Engineering, Vols. 5 and 11.

J. W. Milliman. "Economic Aspects of Public Water Utility Construction," Journal of American Water Works Association, Vol. 50, No. 7, (July, 1958).

M. Mitchell. "A Continued Search for Small Water Supplies in Alaska," Alaskan Science Conference, (1958).

_____. "Water Supply Management for Alaska," Alaskan Science Conference, (1960).

W. B. Page. "Arctic Sewer and Soil Temperatures," Water and Sewage Works, Vol. 102, No. 8, (1955).

_____. "Design of Water Distribution Systems for Arctic Regions," Alaskan Science Conference, (1952).

_____. "Design of Water Distribution Systems for Service in Arctic Regions: An Experimental Study of the New Dual-main House Service Connection," Water and Sewage Works, Vol. 101, No. 8, (1954).

Frank P. Pauls. "Enteric Diseases in Alaska," Arctic, Vol. 6, No. 3, (1953).

"Problems of Developing Northern Resources." The Current Digest of the Soviet Press, Vol. 43, No. 35, (September, 1966).

Ima M. Reed. "How Dawson Keeps Its Water Mains from Freezing," Pacific Builder, Vol. 49, (1943).

H. G. Rogers. "Investigation of Sanitary Features of Utilidor Construction and Substitutes Therefor in Arctic Installations: Report to the Subcommittee on Waste Disposal," Committee on Sanitary Engineering and Environment Bulletin, National Research Council, 1949.

H. C. Westfall. "Battling Permafrost, Subarctic Weather and Tough Soil to Give Fairbanks Water," Water Works Engineering, Vol. 111, No. 2, (1958).

_____. "Research and Design of a Single-main Recirculating System," Alaskan Science Conference, (1953).

V. F. Zhukov. "Installation of Sanitary Engineering Utilities in Permafrost Regions," Trans. V. A. Institute of Frostology, Vol. 14, Acad. Science U.S.S.R., (1958).

UNPUBLISHED MATERIALS

G. L. Hubbs. Water Supply and Waste Disposal in Northern Canada and Alaska. Geneva: unpublished paper presented at World Health Organization Conference of Medicine and Public Health in the Arctic and Antarctic, September 1, 1962.

_____. "Water Supply Systems in Permafrost Areas," Anchorage: Arctic Health Research Center, Department of Health, Education and Welfare, mimio., 1963.

Lars-Eric Janson. "Water Supply System in Frozen Ground," National Academy of Sciences reprint, mimeo., 1963.