UTILIZATION OF GEOTHERMAL ENERGY RESOURCES IN RURAL ALASKAN COMMUNITIES

A Feasibility and Planning Study

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TABLE OF CONTENTS

INTRODUCTION

Geothermal Energy in the National Interest

Until the last few years, the United States has not shown much concern or interest in the assessment or development of its geothermal resources. More recently, however, possible worldwide energy shortages, growing pollution problems and the awakening of a national environmental conscience have developed an accelerated interest in geothermal energy. This new cognizance has been reinforced by the Congress, with the passage of the "Geothermal Steam Act of 1970" (84 Stat 1566), which authorizes and delineates geothermal resource "provinces" and "areas," and defines leasing and regulative policies for federal lands.

U.S. Geological Survey Circular 647, *"Classification of Public Lands Valuable for Geothermal Steam and Associated Geothermal Resources"* (Godwin et al., 1971), presents the criteria for determining which federal lands are classifiable as geothermal steam and associated geothermal resources lands, under the Geothermal Steam Act of 1970 (84 Stat 1566). This publication includes a map of Alaska showing lands classified for geothermal resources, as of December 24, 1970 (figure 1).

Alaskan Geothermal Resources

Early Work: The earliest contribution to our knowledge of the geothermal framework of Alaska was G.A. Waring's *"Mineral Springs of Alaska"* (1917), a pioneering work which included data on the geologic setting, chemistry, and thermometry of Alaskan hot springs which were known to the author in 1917. This work, and the accompanying spring location map, was the authoritative reference for over 50 years.

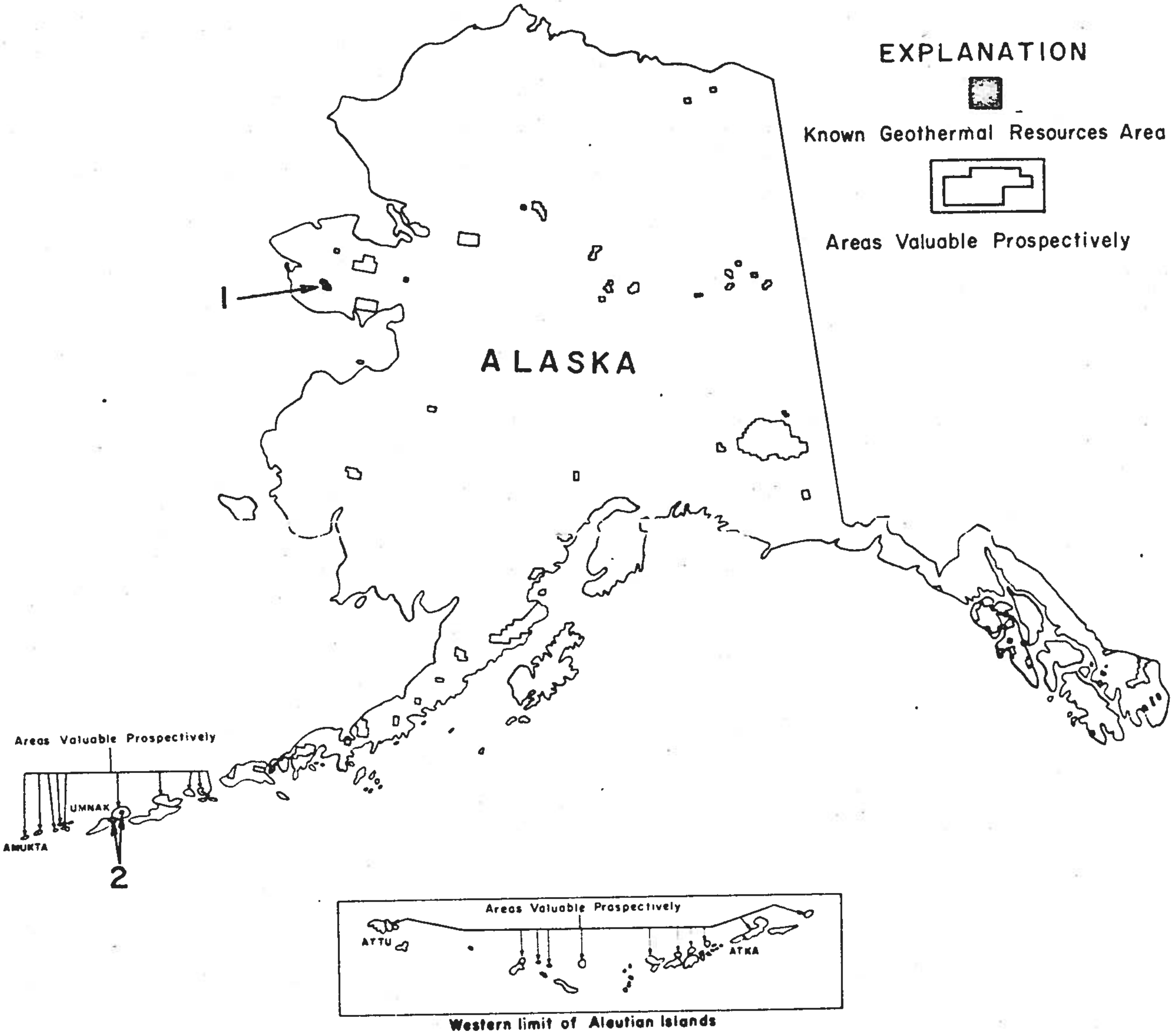


Figure 1. Map of Alaska showing lands classified for geothermal resources effective December 24, 1970. Numbers correspond to localities shown in inset. From U.S. Geological Survey Circular 647, Godwin et al., 1971.

1. Pilgrim Springs
2. Geyser Spring Basin and Okmok Caldera

Recent Thermal Spring Investigations: In 1971, Ms. Norma Biggar, Geophysical Institute, University of Alaska, compiled a revision of Waring's map (figure 2), which showed the location and temperature range of known Alaskan thermal springs. Biggar's map was accompanied by relevant tables of data on spring water temperature and chemistry. Subsequently, T. Miller, Alaskan Branch, U.S.G.S., produced a similar location map which included more recently discovered thermal springs and new chemical and temperature data from the collaborative work of Ivan Barnes, of the U.S.G.S. (1973). A second and complementary open-file report, entitled *"Geologic setting and chemical characteristics of hot springs in Central and Western Alaska"* (Miller et al., 1973), provides additional data on the geothermal potential of Alaskan thermal springs.

Ms. Biggar completed a University of Alaska M.S. dissertation on *"A geological and geophysical study of Chena Hot Springs, Alaska"* in May 1973. The thesis investigation included geomagnetic, microseismic, and soil temperature surveys, in addition to site geology and geochemistry (Biggar, 1973).

Forbes et al. conducted a geophysical reconnaissance of Pilgrim Springs in summer 1974. The data and findings of this study are contained in a separate report which accompanies this study.

Heat Flow and Thermal Gradients: We know very little about the thermal gradient at Alaskan localities other than those located in the petroleum provinces, and there are only a few reliable heat flow measurements reported for Alaska (Lachenbruch and Marshall, 1969; Lachenbruch, personal communication).

According to Lachenbruch (personal communication), no more than ten reliable heat flow measurements have been recorded from Alaskan localities, although down and bottom hole temperature data are available for many holes

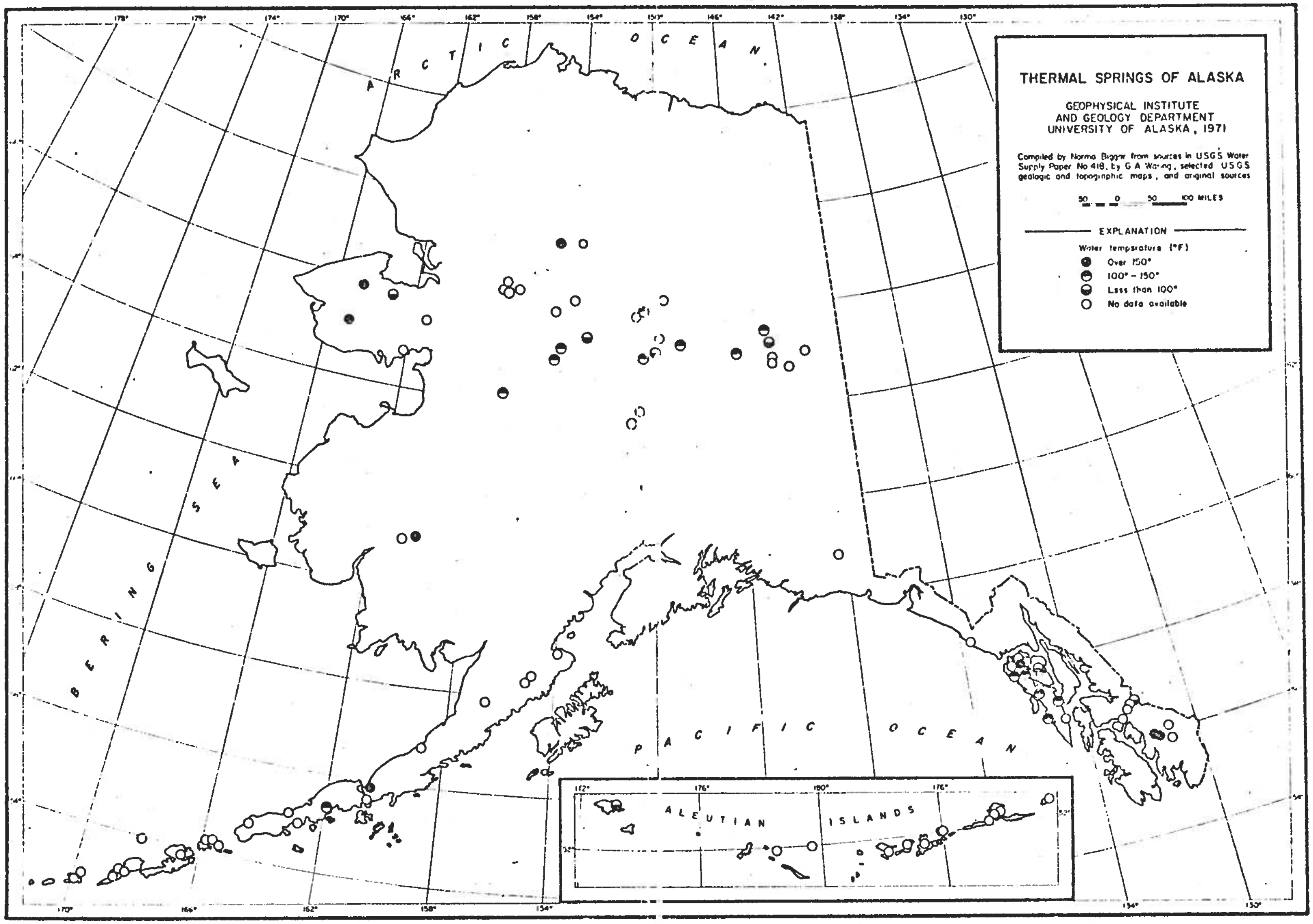


Figure 2. Location map of Alaskan thermal springs as compiled by Ms. Norma Biggar in 1971.

which have been drilled in Alaskan petroleum provinces. Heat flow values calculated from data taken from drill holes near Cape Thompson, Barrow and Umiat (Lachenbruch and Marshall, 1969) were not far from the world average, and low to average values (1.3 microcalories/cm^2/sec.) have been reported by Sass and Munroe (1970) for the Amchitka deep drill holes.

Heat flow data have been taken from other drill holes in the Cook Inlet and Prudhoe Bay areas, but analyses of these data are still in process (Lachenbruch, personal communication). Preliminary data from a deep test hole near Eielson Air Force Base (Fairbanks district), however, indicates that the heat flow is anomalously high at this locality (Lachenbruch, personal communication). Although it is not known at this time whether the anomaly is more than 1.5 times that of the worldwide average of 1.5 microcalories/cm^2/sec., the presence of Chena and Circle Hot Springs, and other thermal springs in the Salcha River drainage, indicates that the Yukon Tanana Uplands deserve additional study.

Geothermal Potential: Currently, optimism toward the geothermal potential of Alaska is chiefly based on the existence of over 40 active volcanoes (figure 3) in the Alaskan segment of the circum-Pacific volcanic belt, and the possibilities offered by thermal spring waters in several districts. To date, however, geochemical studies by the U.S. Geological Survey (Miller et al., 1973) indicate that the reservoir temperatures of analyzed springs are less than the minimum (180° C) which is needed to drive steam turbine generators. In fact, we do not yet know of any documented subsurface two-phase (steam and water) reservoirs in Alaska.

High heat flow and/or geothermal gradients are the characteristic signatures of economically significant geothermal anomalies. Although high heat flow values can be obtained on many active Alaskan volcanoes, published heat flow determinations in drill holes have not exceeded 2.6 hfu (one heat

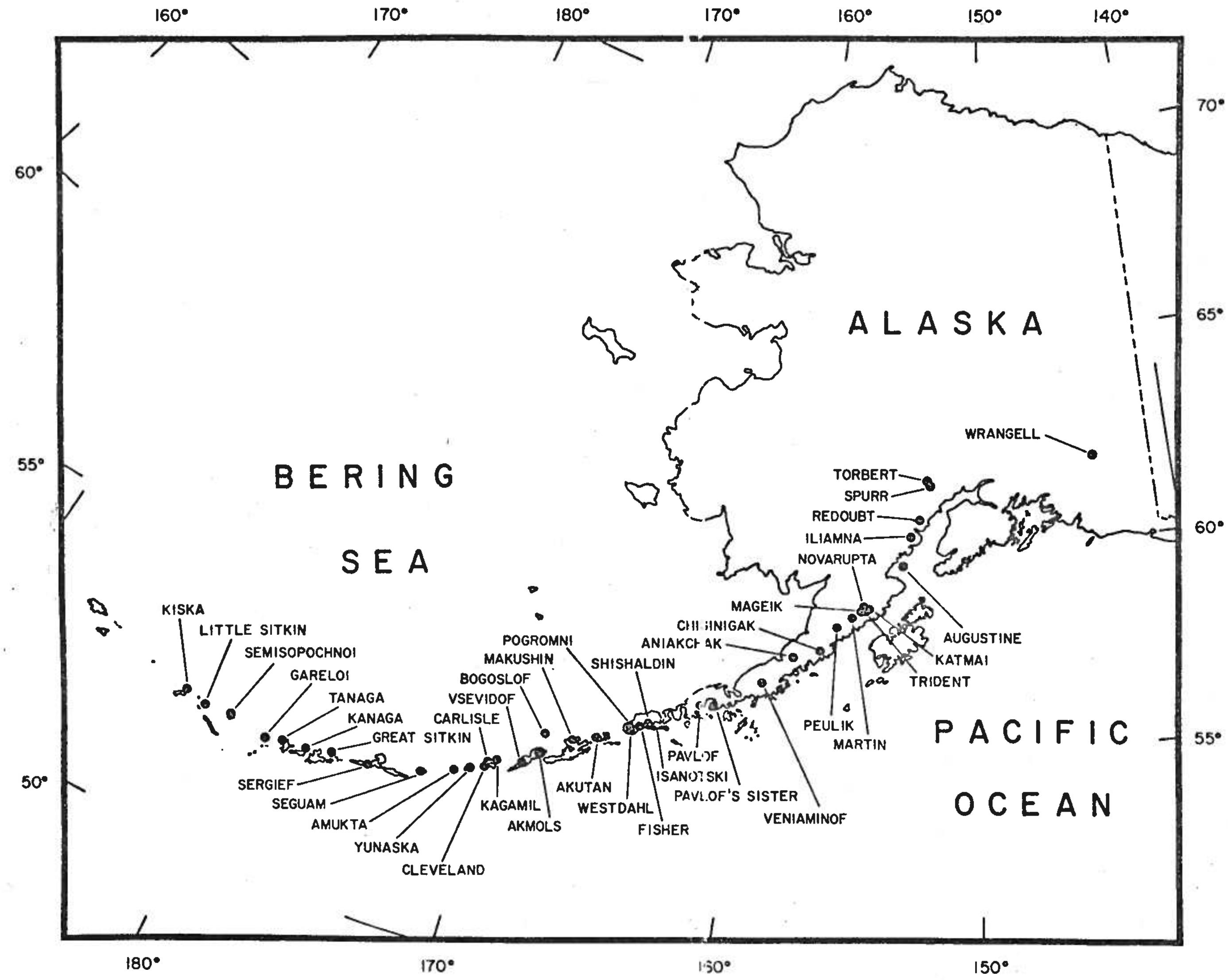


Figure 3. Map showing the location of active Alaskan volcanoes (volcanoes that are known to have erupted in historic time).

flow unit = one microcalorie/centimeter/second). Based on the worldwide average of 1.5 hfu, and the association of heat flow values of 4 hfu and above with meaningful geothermal anomalies, we have not yet discovered any probable targets in Alaska by means of high heat flow values.

Geothermal Exploration: At present, geothermal exploration in Alaska is in its infancy. The U.S. Geological Survey has initiated a helicopter-supported geochemical and geological reconnaissance of thermal springs and volcanoes, which is now into its third field season, and a U.S. Geological Survey geophysicist was obtaining heat flow measurements from available drill holes during the summer of 1974. The University of Alaska is continuing its Augustine and Wrangell Volcano studies, and moving into applications engineering work on thermal springs. To date, there has been little geothermal exploration activity by private industry.

Socio-Economic Framework of Rural Alaska

Alaskan Economic Setting: When considering the geothermal energy potential of Alaska, it is most important to remember that Alaska may have more in common with the developing countries of Africa and Latin America than it does with the forty-nine states. At first hearing, this sounds like an overstatement, but hard facts reinforce this comparison.

Alaska, the largest of the fifty states, has a land area which is equal to about one-fifth the total area of the continental United States. The Alaskan population is around 300,000. Alaska has only three communities which could be classified as cities when compared to other states (Anchorage, Fairbanks, and Juneau).

Over one-half of the Alaskan population lives in or immediately adjacent to these three cities. The residual population is scattered throughout the rest of the state in hundreds of towns, villages, and settlements. Very few of these outlying communities can be conveniently reached by any form of transportation other than air. Modern communications are often limited to a single radio facility located in a Bureau of Indian Affairs, state-operated school, or some other federal or state administrative facility. Traditionally, long transportation routes and high maintenance costs have made the Alaskan cost of living higher than that in other states. Rural communities are at the end of the "logistics pipeline" as emphasized by the cost of fuel oil, for example, which exceeds *$1 per gallon* in many villages.

The Alaskan economy tends to be resource oriented, and most of the revenue is derived from the export of raw materials to other states or countries where they are processed, marketed, and consumed. Fish, timber, metals, and petroleum comprise the major exports. Alaska's small population base, high operating costs, and lack of local markets have discouraged resident processing and manufacturing.

Alaska shares the problems of underdeveloped countries which have become the economic domains of more highly industrialized nations. In common with such countries, a significant portion of Alaska's population (about 20%) lives in poverty. This segment of the population is dominated by Natives which exist for the most part in socio-economic limbo between traditional hunting and fishing economies and the complexities of 20th century civilization. The Native peoples account for a little over one-half of the state's rural population; and it is these Alaskans who suffer the most from the nation's economic problems and continuing inflation. Cross-cultural blocks and the lack of investment capital have left many villages with little cash income other than welfare checks. Few villagers are regularly employed, and if so, the jobs are usually government related. Generally speaking, the economic base of rural Alaska is that provided by federal and state support.

Consumer Prices Versus Income and Earnings: High Alaskan consumer prices have received worldwide attention, dating back to the days of the Klondike and Nome gold stampedes. It does indeed cost more to live in Alaska than elsewhere in the United States. A quotation from a recent report, *"Consumer Prices, Personal Income and Earnings in Alaska,"* by the University of Alaska's Institute of Social, Economic and Government Research (Tussing and Thomas, 1974), summarizes the current economic differential:

> "Almost everything costs more in Alaska than it does in the 'lower forty-eight.' How much more varies widely among places in the state, with the lowest differential occurring in the Anchorage area. The highest differentials occur in the northern and western regions, with costs there sometimes two or three times the national average. Alaska price differentials also vary by commodity. For instance, the costs of housing and all construction in Alaska exceed the U.S. average far more than the costs of such factory-manufactured or processed goods as automobiles, food, or clothing.
>
> "Table I summarizes autumn 1973 family budget costs for three levels of living in Anchorage, relative to the U.S. urban average. Housing accounted for the largest part of the absolute difference between the Anchorage budget and the U.S. urban average: 39 percent of the difference between the budgets of the lower income families and 42 percent in the budgets of intermediate and higher income families.
>
> "Living cost differentials between Alaska and other states *are steeply biased against low income families.* The total cost of a budget for higher income families in Anchorage in 1973 was 26 percent higher than its U.S. average urban counterpart, but the 'lower level' budget was 47 percent higher. Differentials are greatest in the lower income budget level in almost every expenditure category, but as previously stated, the most extreme contrasts are in housing costs. The Anchorage cost of housing for lower level income families was 92 percent higher than the national urban average, but only 45 percent higher for the higher income families."

TABLE 1

Comparison of Anchorage Family Budget Costs
With U.S. Urban Average, Autumn 1973

	Lower Budget	Intermediate Budget	Higher Budget
Total Budget Costs			
Anchorage	$12,010	$16,520	$23,011
U.S. Urban Average	8,181	12,626	18,201
Anchorage Budget Costs (U.S. Urban Avg. = 100)	147	131	126
Total Family Consumption	143	129	123
Food	117	112	109
Housing	192	156	145
Transportation	163	122	111
Clothing	123	118	111
Personal Care	118	133	143
Medical Care	154	154	153
Other Family Consumption	95	95	96
Personal Income Taxes	204	160	148

Source: U.S. Department of Labor, Bureau of Labor Statistics

(Taken from Tussing and Thomas, 1974)

Although Alaskans enjoy a 14% nominal income advantage over "average" United States residents, this advantage does not offset even the Anchorage cost of living differential (+31%) which is probably the lowest of any locality in the state of Alaska, based on the U.S.D.C. Consumer Price Index for 1974. If one compares the per capita income data in Table 2 with the market basket food costs and average annual food expenditures in Tables 3 and 4, respectively, it is painfully apparent that many seasonally employed residents in rural Alaska communities are living at poverty levels.

Rural Alaskan Economics: Although some villages owe their locations to aboriginal subsistence patterns, involving fishing sites, caribou migration

TABLE 2

Per Capita Personal Income and Comparative Ratios for Alaska and the United States, 1969 and 1972

			Ratio to State Total (Alaska=100)		Ratio to U.S. Total (U.S.=100)	
	1969 Census	1972 BEA[a]	1969 Census	1972 BEA	1969 Census	1972 BEA
Aleutian Islands	$3,317	$8,354	88	162	106	186
Anchorage	4,242	5,582	113	109	135	124
Anchorage City	4,741		126		151	
Spenard	4,639		123		148	
Barrow	1,838	10,831	49	211	59	241
Bethel	1,336	2,456	35	48	43	55
Bristol Bay Division	1,637	3,753[b]	97	73	116	84
Bristol Bay Borough	3,641		43		52	
Cordova–McCarthy	4,072	7,189	108	140	130	160
Fairbanks	3,982	5,606	106	109	127	125
Fairbanks City	5,049		134		161	
Haines	3,662	3,906	97	76	117	87
Juneau and Angoon		8,020[b]		156		179
Angoon	516		14		16	
Juneau	5,053		134		161	
Kenai–Cook Inlet	3,806	4,197	101	82	121	93
Ketchikan	3,720	5,606	99	109	119	125
Kobuk	1,527	2,658	41	52	49	59
Kodiak	3,355	5,245	89	102	107	117
Kuskokwim	1,670	3,578	44	73	53	80
Matanuska–Susitna	2,894	4,051	77	79	92	90
Nome	1,992	3,300	53	64	63	73
Outer Ketchikan	2,684	3,091	70	72	84	82
Prince of Wales	4,056	7,470	108	145	129	166
Seward	3,508	4,062	93	79	112	90
Sitka	3,899	5,673	104	110	124	126
Skagway–Yakutat	3,339	4,641	89	90	106	103
Southeast Fairbanks	3,250	3,913	86	76	108	87
Upper Yukon	3,963	4,648	105	90	126	103
Valdez–Chitina–Whittier	4,353	4,279	116	83	139	95
Wade Hampton	1,069	1,877	28	37	34	42
Wrangell–Petersburg	3,376	4,951	90	96	108	110
Yukon–Koyukuk	3,369	3,219	89	63	107	72
State Total	3,765	5,142	100	100	120	114
U.S. Total	3,169	4,492	83	87	100	100

[a] Bureau of Economic Analysis

[b] Because of typographical errors in source tables, BEA figures for "Bristol Bay" and "Juneau and Angoon" were estimated by interpolation between per capita income figures for adjacent ranked census divisions, SMSA's or counties.

Source: U.S. Department of Commerce, Bureau of the Census, *1970 Census of Population, General Social and Economic Characteristics, Alaska and United States Summary*, and *Survey of Current Business, May 1974.*

(Taken from Tussing and Thomas, 1974)

TABLE 3

Market Basket Food Costs[a] in Selected Alaska Cities and Seattle, Washington, 1963-1974

	1963	1964	1965[b]	1966	1967	1968	1969	1970	1971	1972	1973	1974 (March)	1974 (June)
Anchorage	$22.67	$22.68	$20.80	$22.26	$22.03	$22.00	$23.05	$22.97	$24.32	$25.03	$23.43	$34.32	$34.04
Bethel	N/A	N/A	N/A	N/A	N/A	32.19	33.79	35.69	37.24	38.40	41.19	45.02	45.84
Fairbanks	25.26	25.13	23.34	24.45	23.93	24.44	25.82	26.35	26.71	27.01	30.83	35.55	35.57
Juneau	21.11	21.54	20.67	21.40	21.19	21.90	22.76	22.63	23.78	24.99	29.01	32.99	33.17
Kenai–Soldotna	N/A	N/A	N/A	N/A	N/A	23.42	24.36	24.32	25.01	26.47	30.53	33.90	37.09
Ketchikan	20.40	20.85	19.89	10.75	20.85	21.62	22.73	23.24	23.54	24.62	27.92	30.86	31.78
Kodiak	22.91	22.82	21.43	22.33	22.33	23.25	24.47	25.96	26.79	27.96	31.67	34.77	36.12
Nome	28.91	29.55	28.70	28.96	29.45	30.28	31.66	33.20	35.03	36.59	39.97	45.40	49.17
Palmer	21.85	21.85	21.14	21.91	21.23	21.65	23.13	23.65	24.21	24.89	28.60	33.03	34.53
Petersburg	21.12	21.46	21.24	22.02	22.17	23.01	24.03	24.29	25.43	27.11	30.92	33.79	35.88
Seward	22.50	22.25	21.77	22.36	21.91	23.05	24.08	24.73	25.44	26.80	31.57	36.41	37.75
Sitka	21.61	22.20	21.82	22.70	22.41	23.23	24.02	24.90	25.42	26.32	29.62	33.17	32.54
Valdez	N/A	N/A	N/A	24.60	24.50	25.31	26.67	28.42	28.52	29.03	34.02	38.49	39.17
Seattle	17.70	17.90	N/A	N/A	16.69	17.36	18.45	19.08	19.63	20.71	23.69	26.81	27.45

[a] At home food costs.

[b] Change in combination of forty-five food items used in market basket.

Source: "Retail Prices of 45 Food Items in Thirteen Alaska Cities," Palmer: Alaska Agricultural Experiment Station.

(Taken from Tussing and Thomas, 1974)

TABLE 4

Average Annual Food Expenditures for Twenty-four Alaska Communities (October 1972 Survey) and Comparisons with Anchorage Data

Alaska Community	Expenditures Per Household	% of Anchorage Food Expenditures Per Household	Expenditures Per Person	% of Anchorage Food Expenditures Per Person
Anchorage	$2,960	100	$ 971	100
Barrow	3,878	131	954	98
Bethel	4,156	140	950	98
Cold Bay	3,083	104	1,178	121
Cordova	3,175	107	1,006	104
Dillingham	4,420	149	1,319	136
Emmonak	3,103	105	601	62
Fairbanks	3,206	108	1,035	107
Fort Yukon	4,426	150	1,070	110
Haines	3,858	130	1,024	105
Juneau	2,879	97	920	95
Kenai	3,436	116	987	102
Ketchikan	3,625	122	731	75
Kodiak	3,862	130	1,163	120
Kotzebue	4,484	151	1,030	106
Nenana	4,129	139	1,214	125
Nome	3,406	115	902	93
Palmer	3,388	114	942	97
Seward	3,244	110	884	91
Sitka	4,150	140	1,145	118
Tanana	5,340	180	951	98
Valdez	3,369	114	1,193	123
Wrangell	2,653	90	884	91
Yakutat	4,255	144	1,324	136
Summary — All locations	3,185	108	978	101

Source: State of Alaska, Division of Personnel, *Survey of Salaries and Benefits, Housing and Food Costs and Salary Recommendations; Part III Housing and Food Costs*, December 1972

(Taken from Tussing and Thomas, 1974)

routes and various animal populations, others are situated according to more recent developments including gold camps, river transportation routes, and airstrips. In some cases, the present location of settlements and villages reflects old patterns or activities which no longer exist; and in others, natural and/or man-made changes have created a hostile environment for village life.

Poverty is said to be a state of mind. Although both native and white rural Alaskans do not think of themselves in those terms, living conditions in most rural areas would be equated with poverty based on inadequate lighting, the lack of central heating or plumbing, and fresh fruits and vegetables. According to Tussing and Thomas (1974), the lowest per capita incomes were found in rural divisions with predominantly native populations (e.g., Angoon, Wade Hampton, Bethel, Kobuk).

Poverty in rural Alaska is related to high import costs and little or no local cash income. A dollar expended for a gallon of fuel oil or a head of lettuce, leaves the village....never to return. Under current conditions, there is very little cash flow within the village communities.

Energy Problems in Villages and Remote Areas: To most Americans, the energy crisis is something new. To rural Alaskans, it is a way of life. Isolation, high transportation costs, and unforgiving winters have equated energy conservation with survival. Inflation and the recent "energy crisis" have brought an added increment of economic hardship.

Heat is a precious commodity in the Alaskan Arctic. Small communities in the more isolated areas are forced to import expensive fossil fuels to maintain adequate communications and living standards. Most of the fresh produce consumed by such villages is also imported. Electricity, where present, is generated by gasoline- or diesel-powered generators, resulting in an additional fossil fuel demand....and a dependence on exterior supply.

The high cost of imported fossil fuels in the outlying communities restricts improvements and depresses the standard of living. The high cost of fresh and canned vegetables creates an additional economic stress on these communities, and is a source of dietary problems in the more isolated populations during the winter.

Petroleum Impact: Recently, there has been much in the news about the feasibility of petrochemical and other oil-related industries in Alaska. To date, however, Alaska has only one petrochemical plant which is located on the Kenai Peninsula, and most producers consider it more advisable to ship the crude outside to areas with lower labor and manufacturing costs. In fact, manufacturing and raw material processing in Alaska is becoming less attractive economically with increasing fuel and transportation costs.

The recent North Slope petroleum discoveries and subsequent construction of a trans-Alaskan pipeline, which are heralded as Alaskan bonanzas, will stimulate the economy of a few communities adjacent to the pipeline corridor. But the majority of our rural Alaskan residents will experience indirect rather than direct benefits from the petroleum boom, based on royalties and tax revenue which will be received by the State of Alaska.

The Alaska Native Claims Settlement Act: Stewart French (1972) has conducted an excellent analysis of the Native Claims Settlement Act. French's introductory statement introduces the reader to the social and economic impact of the Act on the peoples of Alaska:

> "No event since the 1968 Prudhoe Bay oil discovery, and perhaps even Statehood in 1958, has had as great a potential social and economic impact on the people of Alaska -- both Native and non-Native -- as has enactment of the Alaska Native Claims Settlement Act (Public Law 92-203, 85 Stat. 688). The Act is a complex legislative resolution of a 104-year old question and a source of conflict that have been bars to full achievement of the social and economic aspirations of Natives, non-Natives, and the State."

The Native Claims Settlement Act provides that the Native peoples of Alaska will receive,

(1) legal title to 40 million acres of land together with mineral estate, plus nearly a billion dollars from federal appropriations and shared revenue from state and federal mineral leases;

(2) membership in regional (profit) and village (profit or non-profit) stockholder corporations;

(3) an Alaskan Native Fund, totaling $462.5 million in federal monies, to be paid over 11 years; and $500 million derived from 2% of the revenues acquired from mineral leases on state and federal lands.

Among many other benefits, new mechanisms and sources of support for village improvement will become available, including help from the respective regional corporations. The potential now exists for cooperative village development programs and economic experiments, as joint enterprises between Native and federal and/or state agencies.

Geothermal Resources Applied to Alaskan Needs

Assessment of Available Geothermal Resources: A comprehensive assessment of potential Alaskan geothermal resources or targets must consider the following:

1. Surface Resources
    a. Thermal springs
2. Subsurface Resources
    a. Two phase reservoir systems (steam and water)
    b. One phase reservoir systems (hot water)
    c. Hot dry rock
        (1) Potential reservoir rocks; water injected from surface

(2) Impermeable rocks; reservoir space must be artificially created by hydrofracture or explosives.

d. Hot dry rock in volcanic piles adjacent to subsurface magma bodies, or recently extruded plugs or domes.

e. Subsurface magma tap

In an earlier section, we mentioned the primitive state of knowledge of the geothermal framework of Alaska, and the lack of confirmed local or regional zones of high heat flow, other than those associated with active volcanoes or thermal springs. Although the probability of future discoveries seems to be high, we do not know of any subsurface targets that have been defined by geochemical and geophysical prospecting methods other than Pilgrim Springs, which will be discussed later on in this report.

Considering the high cost of geothermal prospecting in Alaska, and the absence of promising targets in other geologic settings, it seems prudent to exploit those geothermal resources that are already defined and accessible at the surface (e.g. thermal springs and volcanoes). Alaska has more to gain than any other state, from the eventual tapping of volcanic energy; and the development of a technology for extracting energy from volcanic systems deserves a very high priority in Alaskan geothermal investigations.

A direct magma tap to extract thermal energy from subsurface magma reservoirs is a new concept in the geothermal energy field. The Sandia Laboratories, Albuquerque, N.M., which is presently pioneering magma tap research, estimates that one cubic mile (4 km^3) of 1000°C magma contains enough energy to drive several 1000 MW electrical plants for a hundred years. Vast quantities of thermal energy are dissipated by passive and active volcanoes throughout the world. Table 5 is a compilation of energy released in historic volcanic eruptions. The energy yields are impressive. The Krakatoa eruption of 1883, for example, released about 10^{25} ergs of energy, which compares to the

TABLE 5

Total Energy Released in Volcanic Eruptions

Volcano	Year	Energy Released	Volcano	Year	Energy Released
Tambora[1]	1815	8.4×10^{26}	Una-Una[1]	1898	1.8×10^{22}
Sukurajima[1]	1914	4.6×10^{25}	Mihara[1]	1954	1.3×10^{22}
Bezymianny[1]	1955-1966	2.2×10^{25}	Adatarasan[1]	1900	6.4×10^{21}
Krakatoa[1]	1883	ca. 1.0×10^{25}	Asama[1]	1938	4.0×10^{21}
Asama[1]	1783	8.8×10^{24}	Mihara[1]	1912	6.3×10^{20}
Fuji[1]	1707	7.1×10^{24}	Tokachidake[1]	1926	2.8×10^{20}
Sakurajima[1]	1946	2.1×10^{24}	Kusatsu-Shirane[1]	1932	1.6×10^{13}
Torishima[1]	1939	9.7×10^{23}	Showa Sin-San[1]	1944	1.4×10^{20}
Komagatake[1]	1929	5.6×10^{23}	Capelinhos[1]	1957	4.0×10^{24}
Miyakeshima[1]	1940	4.8×10^{23}	Arenal[1]	1968	1.0×10^{22}
Bandaisan[1]	1888	ca. 1.0×10^{23}	Kilauea[2]	1952	1.8×10^{24}
Pematang Bata[1]	1933	4.5×10^{22}	Nyamlagira[3]	1938-1940	8.4×10^{25}

[1] After Yokayama (1957) with additions.
[2] After MacDonald (1972).
[3] After Verhoogen (1948).
After Verhoogen (1948).

(As prepared by Kienle, 1974)

total power consumption in the U.S. in 1970. The 1952 eruption of Kilauea, for example, represents a value of 350 million dollars if converted to commercial electrical power today! Volcanoes represent a very high-grade energy source if we could somehow tap them. Lava lakes also dissipate large amounts of energy (Table 6), which represents but a fraction of the energy stored in the depths of the volcanoes.

In the last few decades, the production of geothermal power has experienced a very slow growth, based on the discovery and development of vapor phase reservoirs. New concepts, such as artificially induced reservoirs in hot-dry rock and the direct magma tap, offer new avenues for the exploitation of geothermal energy. Two approaches seem to offer the most promise for the direct extraction of volcanic energy:

1) Extraction and packaging of magmatic gases (such as hydrogen).
2) Generation of electricity by heat transfer from a magma to a conventional power plant on the surface via a heat exchanger immersed in the magma (an approach under investigation by Sandia Laboratories).

The problem, however, is to locate a suitable shallow magma reservoir, which is amenable to such an experiment. Very little is known about the physical characteristics of magma reservoirs and the internal plumbing of volcanoes. It is not certain that molten lava pools exist at depth. The geophysical evidence for magma at depth is highly speculative and inferential.

The depths of the magma chambers discussed in the literature range from about 4 km to greater than 60 km. Unfortunately, we do not know of one proven shallow magma reservoir in the U.S. or Alaska, apart from temporal lava lakes.

TABLE 6

Heat Energy Released from Lava Lakes

Volcano	Year	Energy Released (ergs/sec)	Remarks
Halemaumau (Kilauea)	during 1909	9.6×10^{15}	As heat energy (R.A. Daly, 1911).
Nyiragongo	during 1959	9.3×10^{15}	As heat energy in the form of radiation and conduction away from the surface by convecting air (Bonnet, 1960).
Nyiragongo	during August 1959	3.6×10^{19}	Total heat output by radiation, transport outward by gases and conduction into surrounding rocks (Delsemme, 1960).

(As prepared by Kienle, 1974)

Urban Versus Rural Power Needs: Although this report focuses on non-electric applications of geothermal energy, the relative importance of geothermally-generated electricity in rural areas cannot be disregarded. Many non-electric geothermal applications could be enhanced, if small amounts of electricity were also generated.

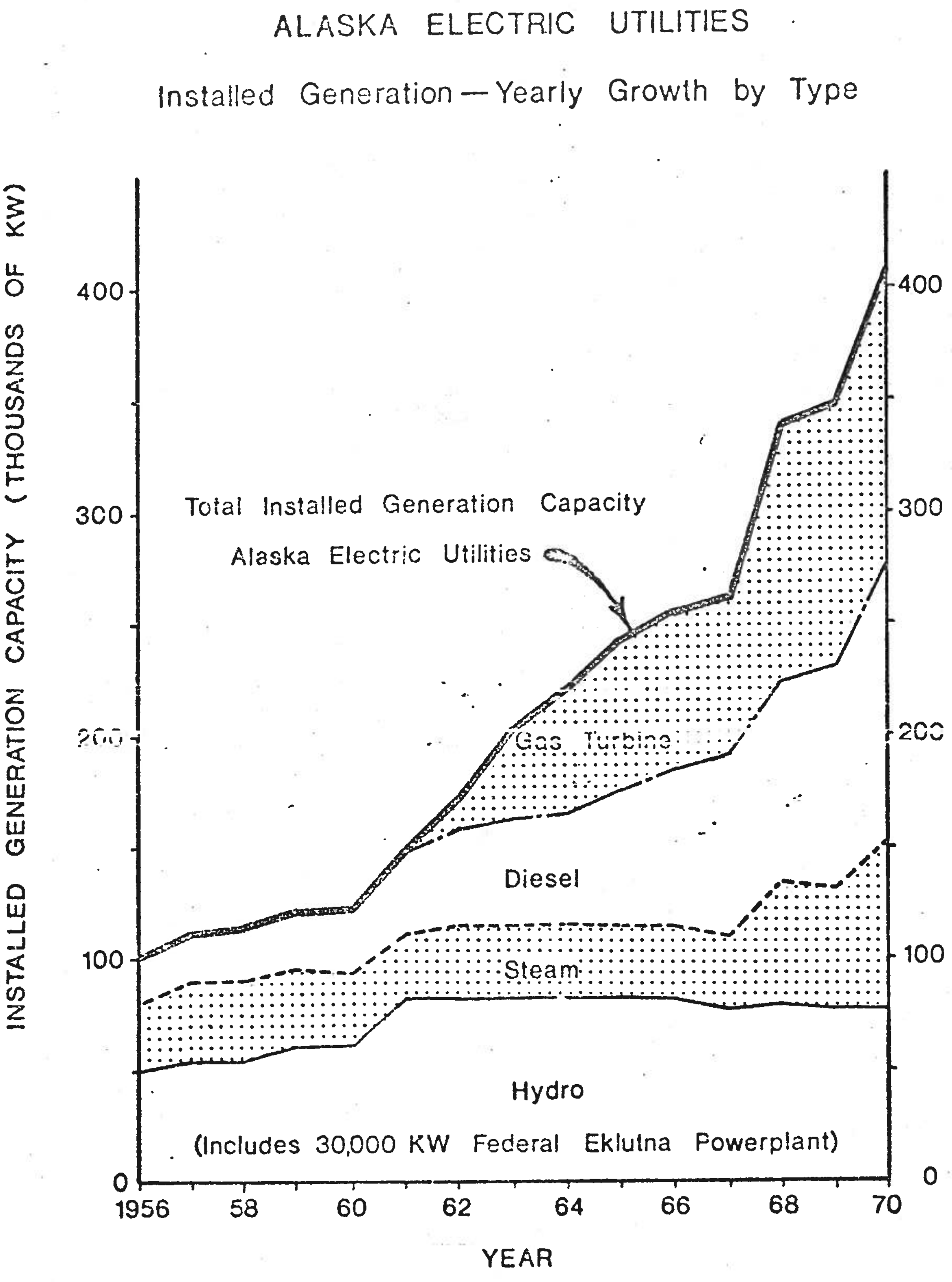
Statewide Requirements

The electric utilities operations in the State of Alaska bear little resemblance to the complex systems of the lower 48 states. Although Alaskan generation and transmission equipment is modern and efficient, the great distances between population centers prohibit grid system interties, and there is no long-range service to outlying rural communities. The Alaskan power scene is much like that which existed in the United States before the rural electrification drive which took place in the early 1930's.

Alaskan electricity is derived from several sources including hydroelectric, oil-fired and coal-fired steam, gas turbine, and diesel-generating systems (figure 4). Figure 4 shows the relatively large contribution of diesel-electric power plants. The increasing use of diesel-electric power is creating a problem in Alaska which geothermal energy sources could help to alleviate. Although the portability and relatively low capital cost of diesel-electric plants has brought electricity to many communities in rural Alaska, the high cost of fuel and accompanying maintenance problems are escalating the cost of electricity in remote areas.

Urban Electricity

Anchorage, Fairbanks, Juneau, and Ketchikan have electric utility systems comparable to those in small cities in the other states.



(Taken from Alaska Electric Power Statistics 1960-1970.)

Figure 4. Diagram showing cumulative and individual growth curves for electric generating plants (by type) in Alaska.

(without the interties with larger systems). In 1970, these systems were providing electricity to homes in Alaska at an average rate of 3.01¢ per kwh, as compared to 2.10¢ per kwh for the rest of the nation. This is a small differential considering the higher cost of living in Alaska, and the absence of power sharing with larger systems. As of 1970, the electric power consumed by the urban communities (which include unusually large peripheral suburban areas) accounted for 75% of the yearly electricity consumed in the State of Alaska.

The success of urban power systems and the related abundance of accessible fossil fuels indicates that the bulk of the State's electrical power requirements can be met by such facilities. The large natural gas reserves and relatively untouched hydroelectric potential of the south-central region should insure an adequate supply of low-cost electricity to the Anchorage area for many years to come. The coal resources of Interior Alaska coupled with access to crude from the trans-Alaska pipeline should more than meet power requirements of the Fairbanks area, the second largest urban area in the State. The Juneau area is presently supplied with hydroelectric power, and the hydroelectric potential of the area is more than adequate to meet projected needs over the next 50 years. It is unlikely that geothermally-produced electricity could be economically competitive with the present systems in these cities in the foreseeable future.

Rural Electric Power

As mentioned previously, the lack of interties between urban electric utility systems prevents power distribution from larger systems to remote areas. There are many communities of less than 1000 people throughout the State, which must produce their own power.

The agency which has had the most experience in such systems, is the Alaska Village Electric Cooperative, Inc. This non-profit power co-op was formed in 1967, and received its initial operating capital from the Rural Electrification Administration of the U.S. Department of Agriculture. Since its formation, "AVEC" has installed power systems in 48 Alaskan villages, which previously had little or no electricity. These systems range in size from 100 kw at Shaktoolik, a small Eskimo village on Norton Sound, to the 450 kw plant at Savoonga on St. Lawrence Island in the Bering Sea.

Due to the small power needs of these villages, diesel-electric generators have been installed. But the high diesel fuel and maintenance costs in these remote areas have resulted in power costs up to 20¢ per kwh. This rate is highly damaging to the village consumer, as it is roughly six times the cost of electricity in other parts of Alaska, and the average annual cash income of rural residents is far below that of the urban population; thus imposing the highest cost on those least able to pay.

The Case for Rural Geothermal Priorities and the Total Energy Concept:

The above factors suggest that highest priority should be assigned to the potential development of geothermal resources in rural Alaska, rather than the cities. In addition to the previously mentioned economic constraints, none of the geothermal targets are located in the immediate vicinity of the cities (Ref. Map). There are, however, potential geothermal resources which are located in or closely adjacent to villages in the outlying areas. The need is also most acute in the rural areas, and the development of any resource which can reduce the dependence on expensive fossil fuels and/or help establish local industry on any scale would be highly desirable.

In our discussion of rural Alaskan economics, we pointed out the difference between Alaskan needs and priorities and those of the other forty-nine states. It follows that the utilization and economic potential of geothermal energy resources will be based on special criteria related to Alaskan problems and needs. One of these requirements concerns the utilization of the electric potential of geothermal energy as well as the non-electric applications. There are two basic reasons for this. First, in many areas of rural Alaska, electricity is not continuously available in any form at the present time, and it would not be sensible to develop a geothermal resource exclusively for non-electric applications under such conditions. Secondly, the amount of electricity under consideration ranges from 2 to 250 kw....quantities which are substantially below the levels considered feasible for large-scale developments in other parts of the nation. Since economic competition with other forms of power generation does not exist in many parts of rural Alaska, it makes good sense to consider generating small quantities of electricity geothermally, where possible.

We have reached a point in time when many rural areas could benefit greatly from geothermal resources, if we begin now to develop a technology which is compatible with environmental considerations and the cultural needs of the people. Capital to invest in such an enterprise may be available from two resources. The Alaska Native Claims Act of 1971 has given the Native people the economic leverage to undertake development of geothermal energy. However, these monies are restricted by act of Congress to profit-making ventures by the regional and village corporations; and research and development expenditures on geothermal resources are not permissible. The State of Alaska will have excess oil and gas revenues which could be used to develop geothermal resources in rural areas; these revenues will not accrue until the completion of the trans-Alaskan pipeline which is scheduled for 1980. Research and pilot plant experiments must be initiated as soon as possible to insure that the technology is ready when the funds become available.

TOTAL ENERGY UTILIZATION OF SELECTED
ALASKAN THERMAL SPRINGS

Origin and Geologic Setting of Alaskan Thermal Springs

Origin of Thermal Spring Water: Just a few years ago, most of the steam and/or water that was erupted by thermal springs and/or fumaroles was thought to be primary or magmatic water. More recently, however, based on oxygen and hydrogen isotope studies and other evidence, we have learned that less than five percent of this water is of magmatic origin and that about 95 percent is recirculated groundwater (figure 5).

Vapor Dominated Versus Hot Water Systems: Geothermal systems, as discussed by White, Muffler, and Truesdell (1971), have been subdivided into two types:

(1) Hot water systems, and

(2) Vapor dominated (dry steam systems).

Hot water systems appear to be about 20 times as common as the vapor dominated type (White, 1970).

In hot water systems, only a small part of the volume is steam, and the water and steam are separated mechanically before the steam is routed to the turbine system. If heat exchange systems utilizing low boiling point fluids such as freon or isobutane are proved feasible, this will increase the number of hot water systems which can be used for the generation of electricity. Producing geothermal fields of this type include the New Zealand fields and more recent discoveries in Mexico and the Salton Sea.

The vapor dominated systems produce superheated steam with subordinate amounts of CO_2 and H_2S. Only three commercial vapor dominated systems are in production today, including those at Lardello, Italy, (since 1904); the Geysers, California; and a field at Matsukawa, Japan.

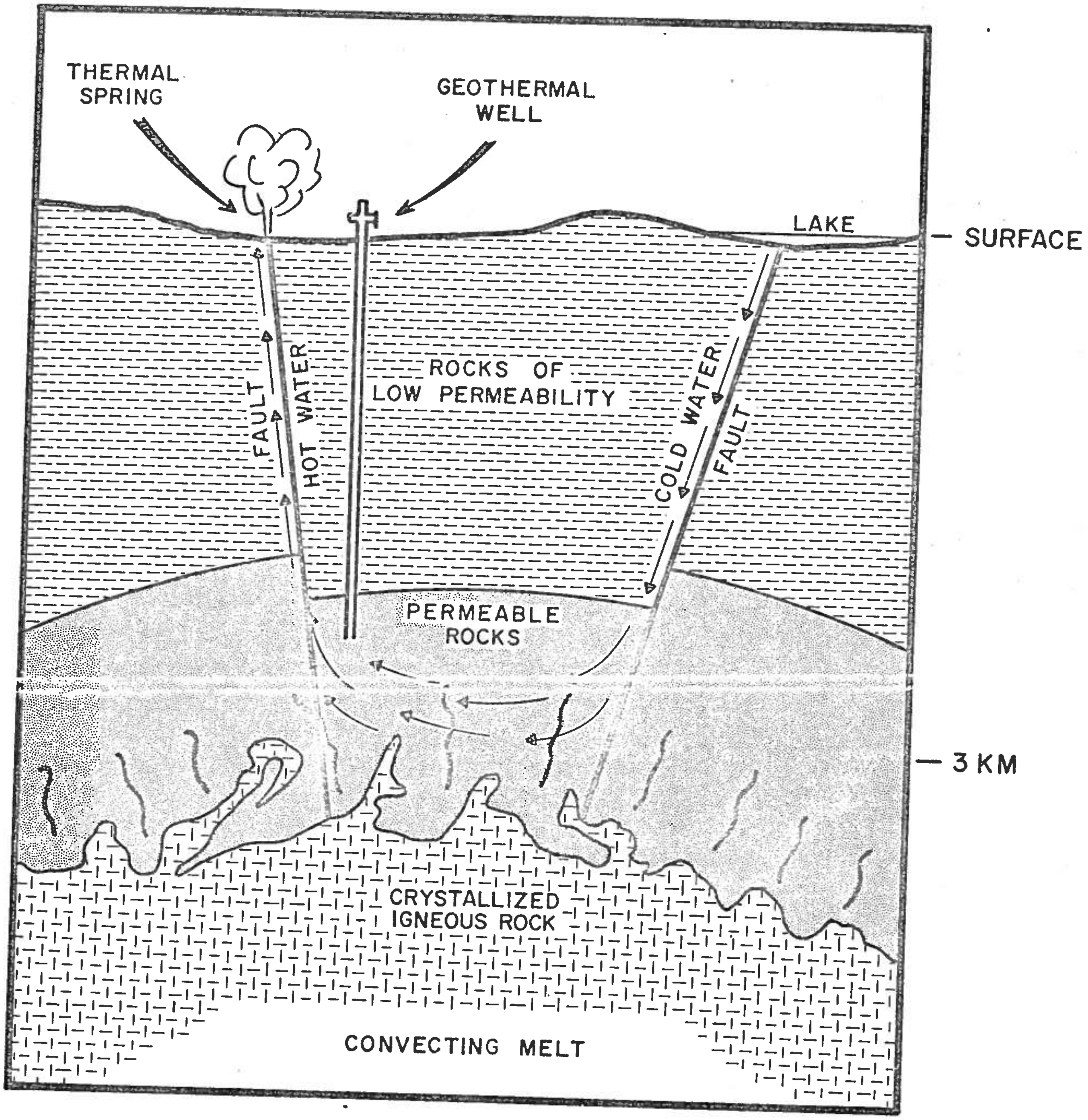


Figure 5. Diagram showing a hypothetical vapor-dominated, two-phase geothermal system as driven by convecting melt at depth. Meteoric (cold) water descends along fault line to hot permeable reservoir rock where it is heated by the cooling melt. Due to lowbed density, the hot water ascends along another fault system to emerge at the surface as a thermal spring. A geothermal well has been driven into the reservoir rocks. In vapor-dominated systems, boiling will begin before the water reaches the surface.

Geothermometry: Subsurface reservoir temperatures of thermal systems can be estimated through the use of geochemical techniques. Various geothermometers have been developed based on analyzed concentrations and ratios of the dissolved mineral constituents. The more commonly used indicators are the SiO_2 (figure 6) content, the Na-K ratio (figure 7), the Mg content and Mg-Ca ratio, and the Na-Ca and Cl-F ratios.

The assumptions involved in the use of geothermometers have been outlined by White (1970). These include (1) the availability of constituents from the reservoir rocks; (2) the equilibration of water-rock reactions at the reservoir temperature; (3) the rapid flow of water from the reservoir to the surface to eliminate reactions in transit at lower temperatures and to retain the composition of reservoir temperatures; and (4) a lack of mixing with other waters at intermediate levels.

If equilibrium has been obtained in the subsurface waters, the Na/K geothermometer should be in general agreement with estimated reservoir temperatures determined from dissolved SiO_2.

Thermal springs which have a high dissolved SiO_2 content, and/or those which deposit silicious sinter at the surface, are probably related to high temperature subsurface reservoirs. Geysers are also a favorable indication of high temperatures at depth.

The Na/K geothermometer is based on the temperature dependent base exchange or partitioning of alkalies between solution and solid phases. Discussion of the sodium-potassium equilibria generally applies to systems with temperatures above 175°-200°C, as the alumino-silicate equilibria at lower temperatures are uncertain (Ellis, 1970).

Factors limiting the possible use of this method are the dilution effects of the deeper water as it rises to the surface, the effect of different mineral suites as source rocks, the effect of continual base exchanges as the waters move toward the surface, and the formation of

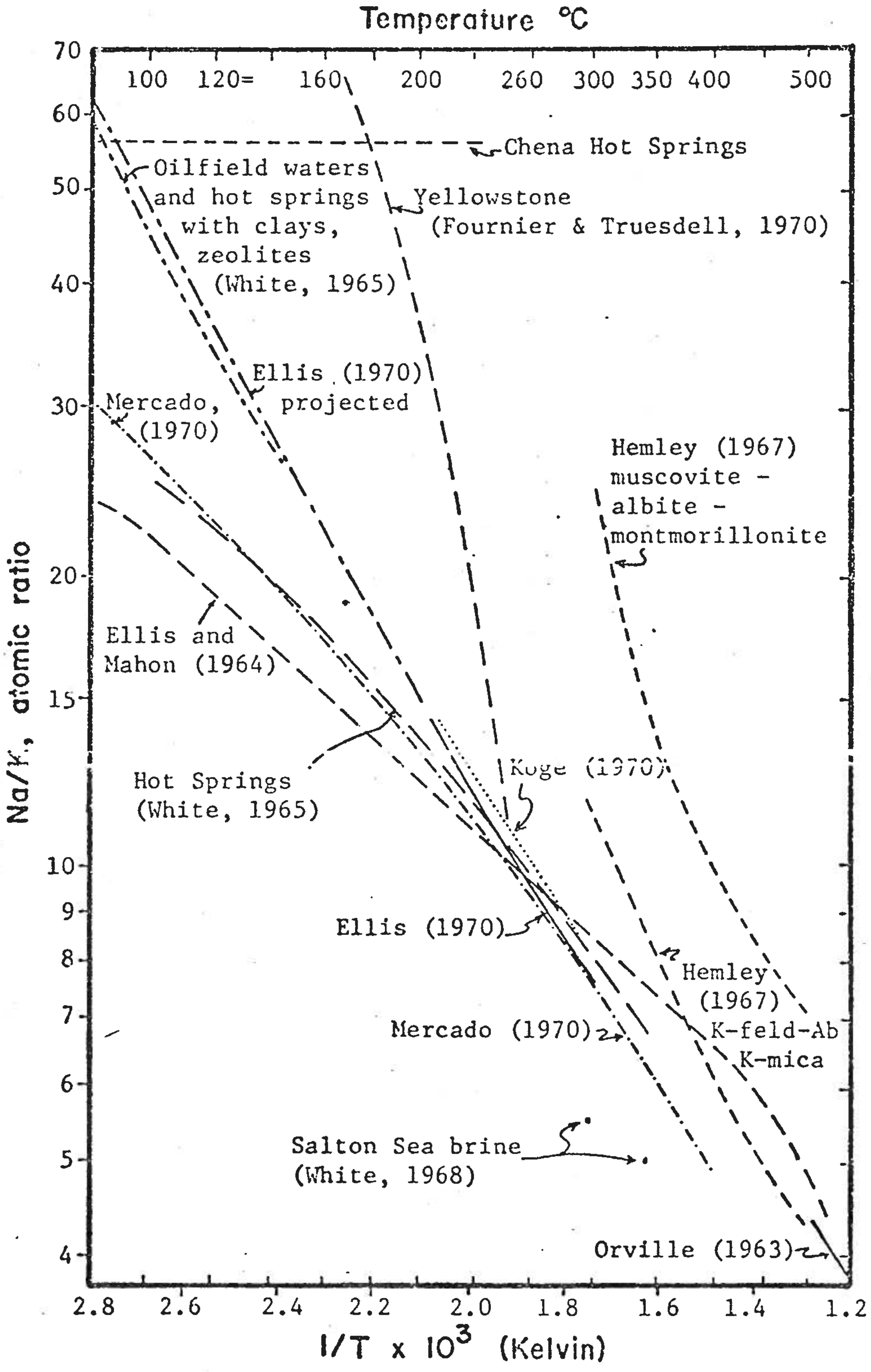


Figure 6. Atomic Na/K ratios versus temperature, showing experimental and empirical curves (White, 1970).

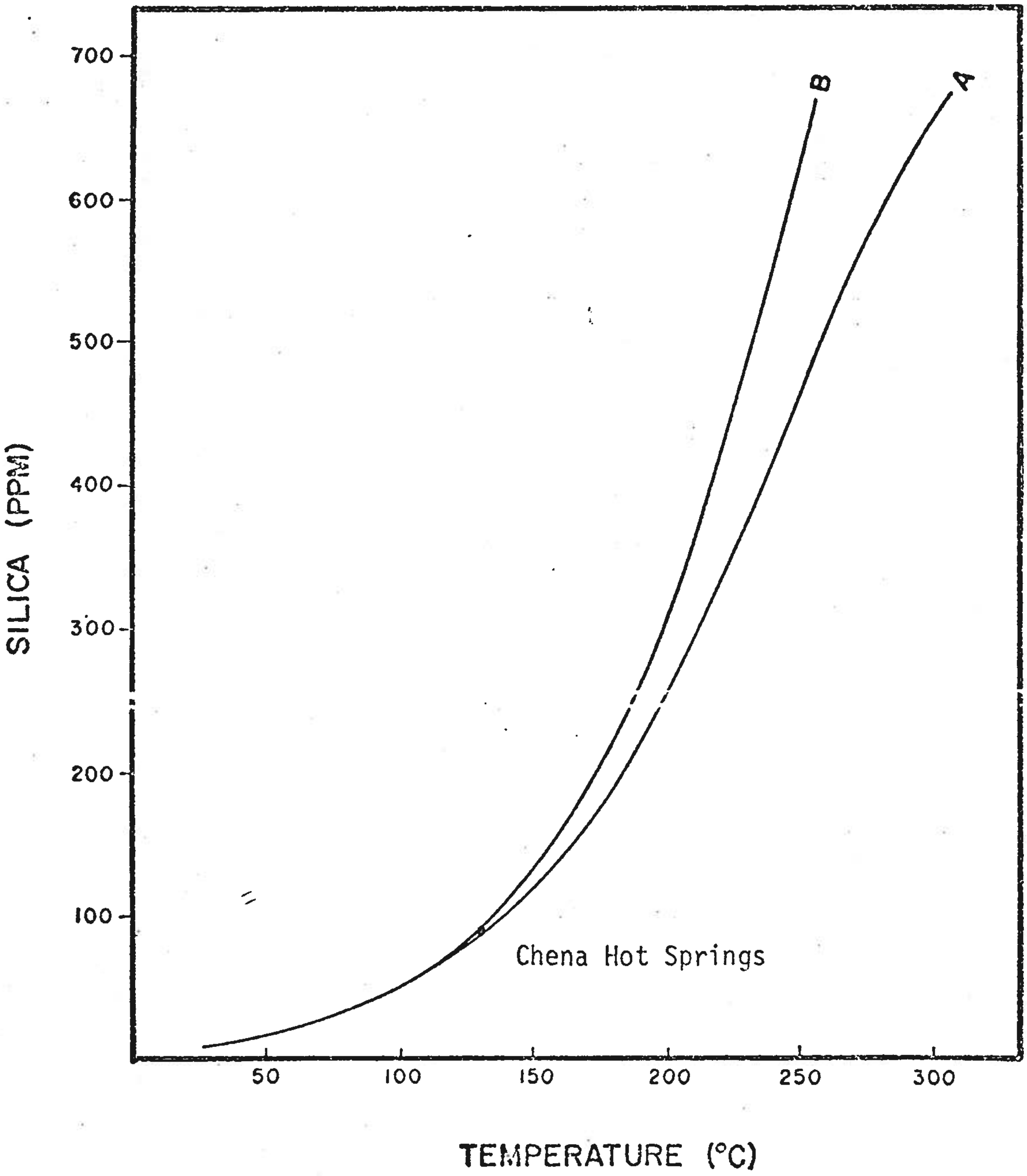


Figure 7. Silica concentration in geothermal water versus estimated temperature of last equilibration. Curve A applies to waters cooled entirely by heat conduction. Curve B applies to waters cooled entirely by adiabatic expansion at constant enthalpy (from Fournier and Truesdell, 1970).

complex ions. These factors are discussed in greater detail by Fournier and Truesdell (1970).

Geologic Setting of Alaskan Thermal Springs: According to the compilation by Biggar (1973) and the later work of Miller et al. (1973), there are about 95 recognized Alaskan thermal springs. The geographical distribution patterns indicate that the thermal springs occur in three tectonic settings or geologic associations (see Plate I, map pocket):

(1) Adjacent to Quaternary volcanoes (i.e. Aleutian Archipelago, Alaska Peninsula, Wrangell Mountains)

(2) In a broad east-west trending zone in northcentral Alaska associated with late Cretaceous or Tertiary granitic plutons

(3) In southeastern Alaska, south of the Chatham Strait Fault, in a zone which may be involved in a transform fault system

Quaternary Volcanic Belts

Some thermal springs in the Aleutian Islands exhibit relatively high temperatures (close to 100°C) and occur near Quaternary volcanoes. The Aleutian arc also shows evidence of extensive mid-Tertiary intrusive activity (Cameron and Stone, 1970), and is believed to be a consuming plate margin between the Pacific and North American plates.

Many of the Aleutian Islands have not been mapped in detail, and it is probable that there are more thermal springs in the Aleutian Archipelago than those recognized to date.

Southeastern Alaska

The occurrences of thermal springs on the south side of the Chatham Strait Fault appear to be located along a trend which can be projected underneath the continental block from the North Pacific Rise, where it appears to plunge under the Southeastern Alaskan Archipelago. Quaternary volcanic eruptive centers are also located along this same trend in the Canadian Coast Ranges (see Plate I, in map pocket).

In plate tectonic terms, this area appears to be essentially a transform fault system that connects the actively spreading Explorer and Juan de Fuca Ridges, and the Gorda Rise with the Aleutian Arc system.

Central Alaska

This belt of thermal springs forms a broad zone which extends from the Yukon-Tanana Uplands to the Seward Peninsula. These springs are often located on or near the contacts between late Cretaceous or early Tertiary granitic plutons. Portions of this belt may also be underlain by zones of high heat flow.

Spring Water Temperatures, Chemistry, and Estimated Reservoir Temperatures:

Maximum Surface Water Temperatures

The hottest water temperatures discovered in Alaska have been measured in thermal springs or hot lakes or pools associated with volcanoes on the Alaska Peninsula or in the Aleutian Islands (e.g. 102°C, Hot Springs Cove, Umnak Island). Water temperatures up to 88°C have been measured in the waters of Bailey Bay Hot Springs, southeastern Alaska.

Estimated Reservoir Temperatures

Based on geochemical data reported by Waring (1917), Byers and Brannock (1949), and Miller (1973a), and the reservoir temperature estimates given by Miller et al. (1973b), based on quartz solubility and Na-Ca-K geothermometers, thermal springs in western and central Alaska are associated with subsurface systems of the hot water type. Maximum estimated reservoir temperatures, for 10 springs, were 137°C and 161°C respectively, as determined by the quartz and Na-Ca-K geothermometers.

Both of these maximum temperatures are below the minimum temperature of 180°C which is required to drive steam turbine generators, according to Muffler (1973) and others. However, hot water systems, with adequate flow capacities, can be used to generate electricity with turbine systems incorporating heat exchanges and low boiling point working fluids.

Reservoir and Conduit Systems

Over 90 percent of the thermal springs in central Alaska are located near the contact of late Cretaceous and early Tertiary granitic plutons with the surrounding country rock. In many cases, the country rocks are crystalline schists, with relatively no intersticial porosity, and very poor permeability other than that associated with fractures and faults (figure 8a). In such settings, the probability of large reservoirs at depth is very low. Considering the low estimated reservoir temperatures there, the prognosis is poor for the discovery of large vapor dominated geothermal systems in such settings. A few springs occur in westcentral Alaska near the margins of plutons which have been emplaced in Jr-K sediments (figure 8b). The probabilities of finding large hot water reservoirs are higher in such terranes.

Flow Rates

Flow rates of Alaskan thermal springs have been observed which range from slow seepage to rates as high as an estimated 400 gpm at Clear Creek Hot Springs (page 68). In some cases, such as that at Pilgrim Springs (page 73), spring water flow rates are difficult to determine due to lateral flow, convective circulation and mixing with ground water. Potential electric and non-electric applications of hot water systems are constrained by flow rates, and whether or not such rates can be improved by subsurface drilling.

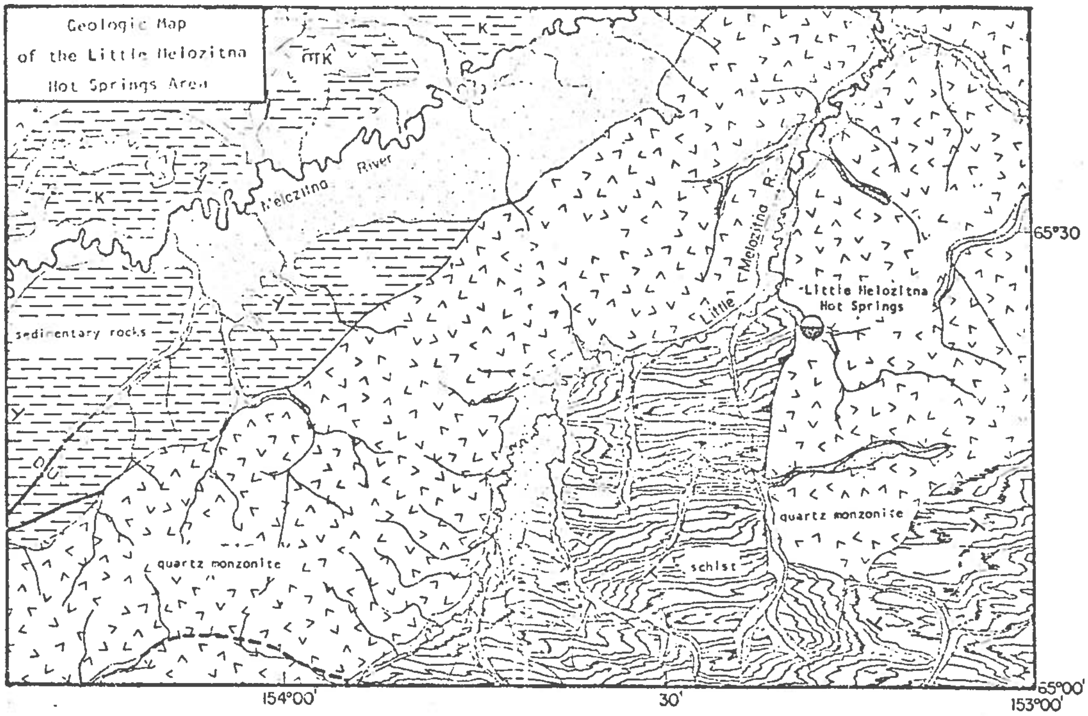


Figure 8a. Geologic map of the Little Melozitna Hot Springs Area.

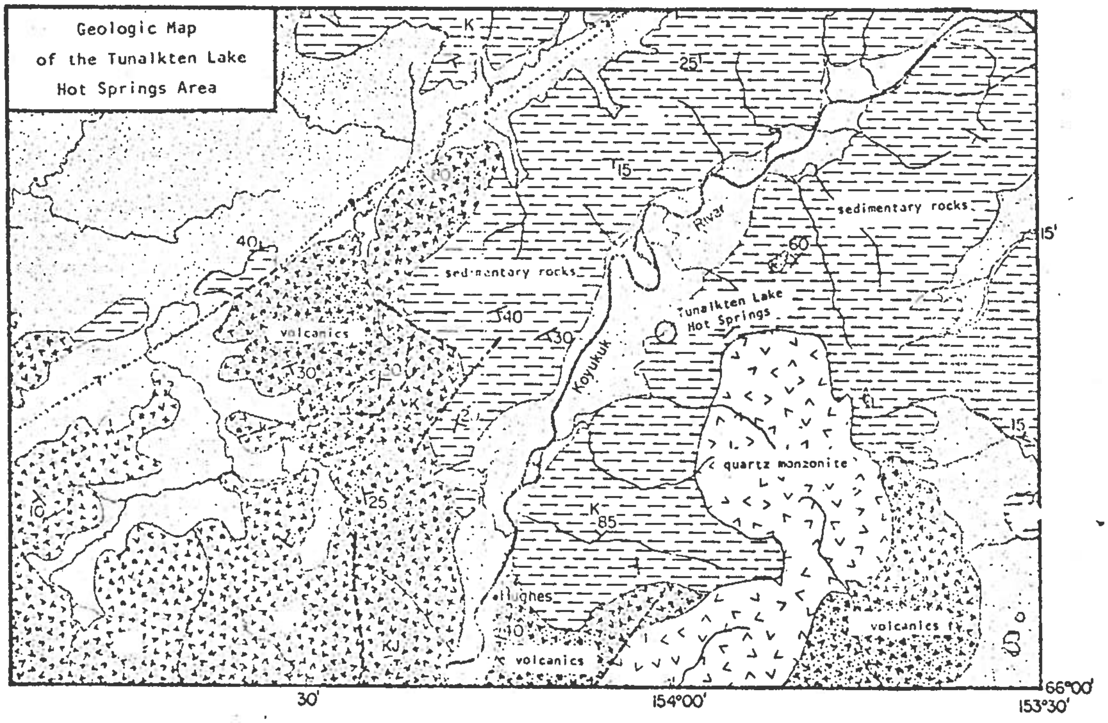


Figure 8b. Geologic map of the Tunalkten Lake Hot Springs Area.

The potential application of drilling techniques to these systems is an unknown area, as the geometry and reservoir mechanics of the conduits and reservoirs are not understood.

Saline Springs

Four saline springs are known in central and western Alaska including Pilgrim, Serpentine, Kwiniuk and Tolovana (Plate I). These springs are characterized by high concentrations of Cl, Na, Ca, and K. Pilgrim and Serpentine Springs are the most saline (Pilgrim: Na=1450 ppm/Cl=3346 ppm. Serpentine: Na=800 ppm/Cl=1450 ppm.)

Both of these springs exceed the salinity threshold of acceptable potable water, and are potentially troublesome in terms of corrosion of casing, pipe, and other hardware.

Utilization of Alaskan Thermal Springs

The thermal springs of Alaska were first utilized and developed by early stampeders and entrepreneurs. For example, Circle and Chena Hot Springs, in the Fairbanks District, were used by early prospectors for bathing and recreation; and subsequently, roadhouses and small settlements appeared. In these early cases, primitive engineering techniques were used, the applications were limited to bathing pools, hot tap water, and space heating, using hot water convectors. At Manley Hot Springs, the utilization of thermal waters was more advanced, as spring water was used to heat greenhouses, animal barns, and a 60-room hotel in addition to that used in the bathing pools and the hot water system. Agriculture also became an important part of the activity at Pilgrim Springs, during the Nome gold rush in the early 1900's.

These early attempts to utilize the energy of thermal springs passed with the wave of gold seekers, but the energy remains. If properly utilized, such energy sources could play an important part in the economic and cultural life of many rural communities.

The ideal utilization of a geothermal resource in a rural Alaskan community would provide the following:

(1) Heat and electricity for the entire community, to reduce and perhaps eliminate the dependence on imported fossil fuels.

(2) Energy for local industries which would aid the economy with minimum impact to village culture and lifestyle.

The following sections discuss the more promising applications of thermal spring resources to rural needs.

Electricity: There are many techniques for producing electric power from geothermal resources. Unfortunately, most of these are very complex and require vapor phase reservoirs or high temperature waters which can only be reached by deep drilling. Such techniques are not economically feasible, if very small amounts of power are needed, as in the case of a small Alaskan village.

We must then find techniques to produce relatively small amounts of electricity from geothermal resources with as little impact on the environment as possible. The most promising of these resources in Alaska are the thermal springs. We have been investigating a method which might be used to produce electricity directly from hot spring water, which utilizes the organic Rankine cycle, and the temperature difference between the spring water and the ambient air. An experimental plant, utilizing this technique is now operating at Paratunka, Kamchatka, USSR, which is using water at a temperature of 81.5°C (Facca, 1970).

We have been working informally with Ormat Turbines Ltd. of Israel, to determine whether or not one of their organic Rankine cycle turbines could be coupled to thermal spring water as an energy source. "Ormat" has determined that one of their units could be so adapted, and that useful but small amounts of power could be produced from waters with temperatures as low as 60°C; a temperature which is obtainable in many Alaskan hot springs. Shallow drilling to minimize dilution by ground water could increase the water temperature and enhance the efficiency of the Ormat turbine. Such drilling would not be cost prohibitive, and could be easily accomplished by small rigs in remote locations.

Ormat engineers estimate overall efficiencies of approximately 5-1/2 percent which would require about 40 gpm of 60°C thermal spring water to produce 5 kw of continuous power. This efficiency would, of course, be increased if the temperature of the input water were greater. A schematic diagram illustrating the Ormat system as applied to a thermal spring source is shown in figure 9.

The electrical system of the Ormat turbine produces a high frequency voltage at the generator which is rectified to DC, thus eliminating the need for costly speed control equipment. The DC output can then be inverted to AC, or it can be used to charge batteries. Such a system would be integratable with wind-generating equipment and circuitry. The combined use of alternate energy sources such as wind power and geothermal energy is especially attractive, and should be evaluated in demonstration experiments.

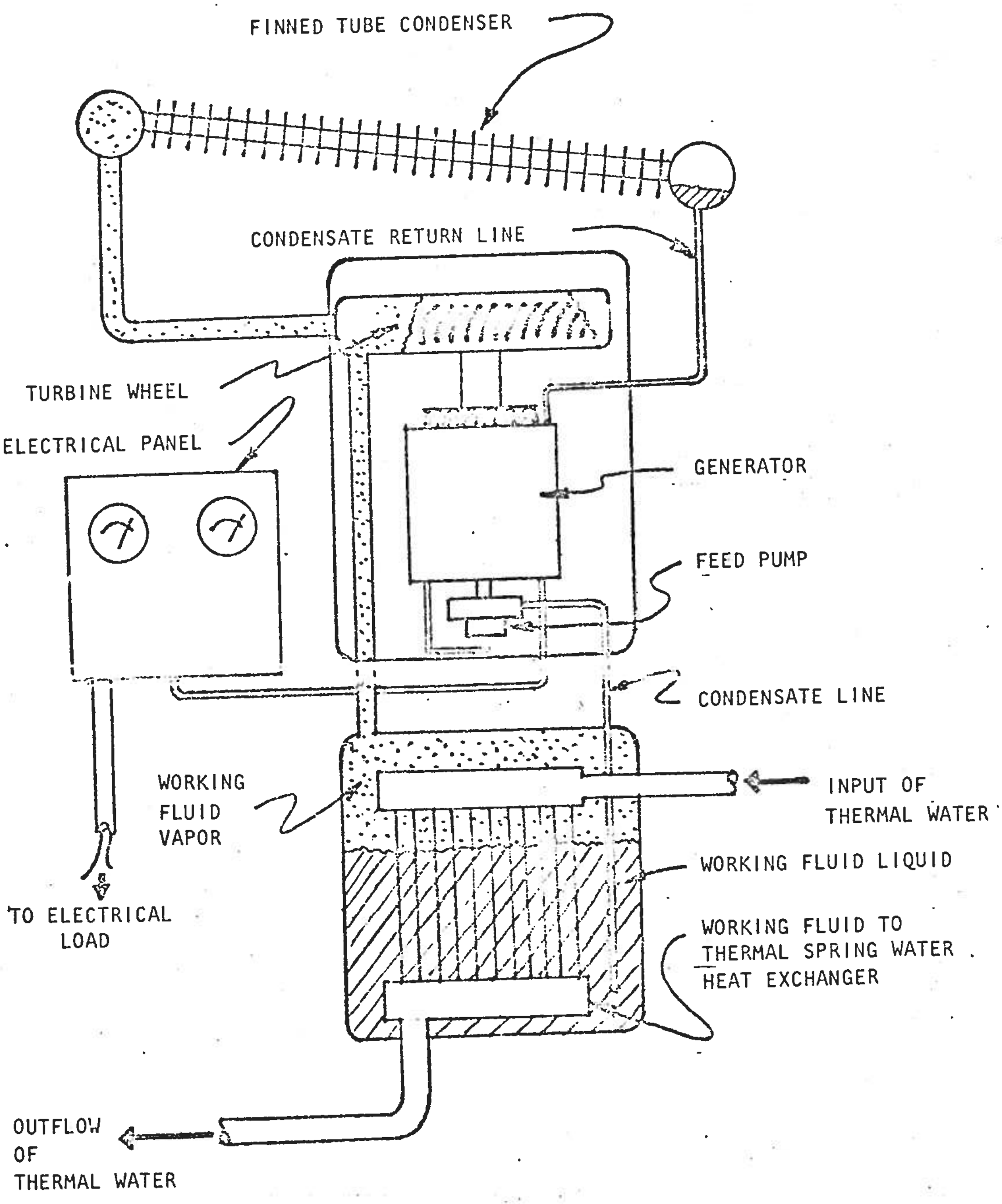


Figure 9. Diagram of Ormat system applied to thermal spring heat source.

While Rankine cycle power generation at small temperature differences is not very efficient, compared to conventional steam plants, the continuous free supply of the geothermal "fuel" makes it attractive. But in addition to fuel savings, the Ormat turbine has advantages which make it well adapted to use in remote regions:

(1) The synthetic organic working fluid allows for low working pressures and temperatures. This results in the elimination of sophisticated pressure vessels and the need for elaborate safety equipment.

(2) The entire vapor system is closed, eliminating the need for constant monitoring of the working fluid.

(3) The only moving part is the common, turbine-generator shaft. Lubrication is provided by the working fluid which contains a lubrication agent.

(4) The working fluid-air condenser is of the free convection type which makes cooling fans and similar devices unnecessary.

(5) The turbo-generating system is hermetically sealed and Ormat claims a 20-year operating life without maintenance.

All of these factors, as well as the previous experience of Ormat Turbines Ltd. in manufacturing organic Rankine cycle systems for the communications industry in other arctic and subarctic areas, make the Ormat system ideally suited for rural Alaska. If an optimum system for a rural Alaskan village could be found, it would be one in which:

(1) A local fuel could provide the basic energy input.

(2) No maintenance was necessary, and the system could operate unattended for extended periods.

(3) The system would be simple enough to be operated by personnel with basic technical skills, and without extensive formal training.

(4) Low cost.

An Ormat type system appears to meet most of these criteria, but the system has not been demonstrated in the field. If a successful demonstration is achieved, cost factors will fall with increased demand. To date, the largest Ormat unit of this type is a 15 kw unit. However, Ormat engineers are now working on a 100 kw system. Hopefully, the production of this size unit could coincide with the final phase of a successful small-scale feasibility demonstration of a geothermally-powered Ormat turbine.

Ormat Turbines has agreed to work with the Geophysical Institute on a co-sponsored research and development investigation. Ormat has agreed to design and construct a 2500 w test unit with a hot water to working fluid heat exchanger suitable for the experiment.

Space Heating: The cost of home heating in Alaska is high. In many rural villages without local fuels such as wood- or coal-imported fuel, oil is the only source of heat. Presently, No. 1 stove oil costs are as high as $1 per gallon in some remote villages and recently has risen to over 50¢ per gallon in many Alaskan cities. At this rate, $900 would be an annual cost for home heating that many village residents can expect to pay this year. With the typical head of a household making less than $3000 per year, the heating bill alone would constitute about 30 percent of the family's annual income. Under these conditions, the burden of heating costs alone can seriously depress the potential for economic growth of rural communities.

The heating of buildings with thermal spring waters is one of the oldest and most basic applications of geothermal energy. In areas where thermal springs exist, obvious benefits could be realized by the construction of a geothermally-powered municipal heating system. Figure 10a shows a simple system in which thermal waters from the spring would be directly circulated through convectors in homes. Since many thermal springs contain dissolved salts and other minerals which are corrosive to piping, binary systems as shown in figure 10b could be constructed which would limit the corrosive effects to a heat exchanger which could be built of stainless steel, or other non-corrosive material.

Various methods could be employed to circulate the thermal spring water. Thermal siphons could help reduce the required pump work. This particular method was used at Pilgrim Hot Springs, Alaska, during the 1930's when the waters of the spring were used to heat buildings at the Catholic mission school.

Space heating techniques are not new and probably do not require further experimental development. A careful literature and design investigation should be made, however, to gain full advantage of existing equipment which could be applied to Alaskan needs.

Refrigeration: Several villages such as Elim and Mary's Igloo on the Seward Peninsula, and Manley in Interior Alaska, could benefit greatly from low-cost refrigeration systems. Small coastal villages cannot presently take full advantage of commercial fishing opportunities due to the lack of cold storage facilities. The reindeer industry is another example of the need for cold storage or freezer facilities as such facilities could eliminate the need for immediate sale and shipment of meat after the reindeer are harvested.

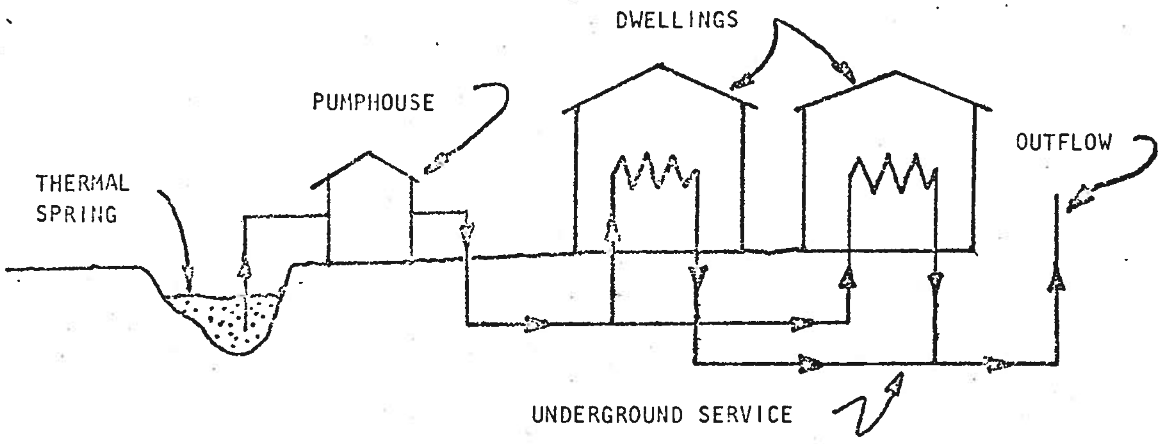


Figure 10a. Primary space heating system.

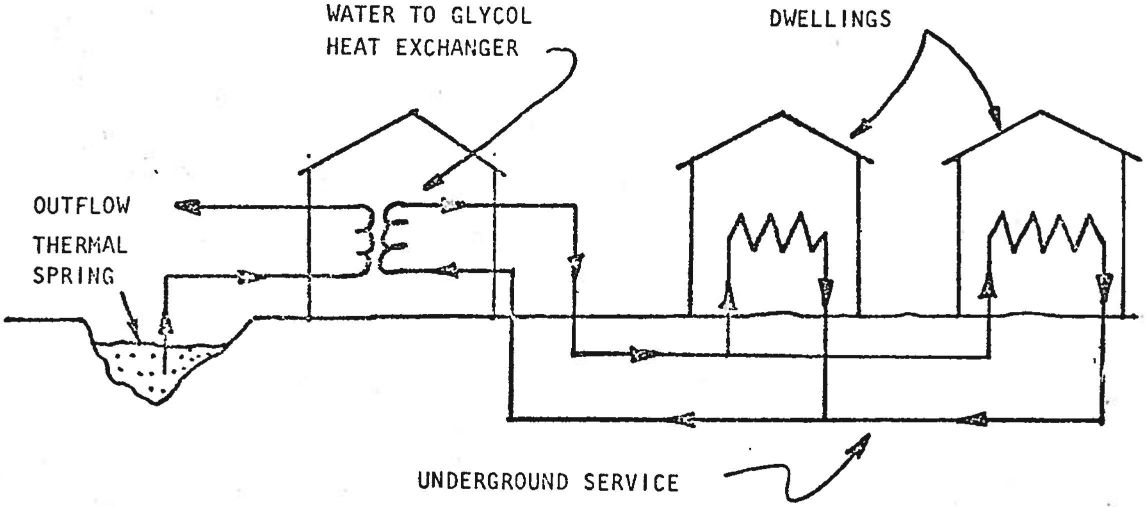


Figure 10b. Binary space heating system.

Fuel and electrical costs associated with conventional refrigeration equipment are highly restrictive. If thermal springs could be used as an energy source for rural refrigeration plants, some of the marginal industries could be made profitable.

A study should be made to determine how organic fluid refrigeration systems could be adapted to geothermal energy sources. Hybrid systems using geothermal and natural refrigeration systems which utilize partially frozen brines as described by Johnson (1971) should also be evaluated.

Agriculture:

Alaskan Agriculture and the Energy Problem

Alaska, one-fifth the size of the 48 contiguous states, produces a relatively small amount of the vegetables consumed by its own population because commercial production is limited by the short growing season.

Alaska is a prime location for the development of a technology suited to total energy utilization. Increasing Alaskan and world population will inevitably require utilization of northern areas and development of new methods for food production in these northern areas. There is an abundant availability of fossil fuels, and there is need for such maximal production. Anticipated development of various natural resources (particularly in the petroleum industry) indicate future social and economic development of Alaska. Also, the Native Land Claims Settlement, the Rural Development Act of 1972, and the continuing industrialization of Alaska's cities will stimulate development of the State. The world situation that puts agricultural products on the world market will certainly create expanding demand for U.S. agricultural products and inhibit the development of surplus.

Fuel price increases will undoubtedly have a great effect on the cost of foods shipped to Alaska and on the cost of producing foods in the southern latitudes. Estimates show that as much as 15 percent of the fuel will be expended to transport farm products from the arctic to markets in the south. At least another 15 percent will be needed to ship food products back to Alaska. If the cost of moving the food to Alaskan markets is coupled with the investment of public and private funds in transportation modes, it is obvious that a large amount of energy is being consumed for these purposes.

Controlled Environment Plant Systems

Although vegetables are grown during the relatively short summer growing season in many rural areas and communities, only a very small portion of the summer crop can be preserved for consumption during the other months of the year. The high cost of fuel and electricity has prohibited large-scale greenhouse operations, and hydroponic gardening has not yet been attempted in the rural areas for the same reasons.

Controlled environment experiments at the University of Arizona's Environmental Research Laboratory, and the Phyto-Engineering Laboratory of the Agricultural Research Service at Beltsville, Maryland, have demonstrated that certain plants are capable of growing up to 10 to 50 times faster under controlled environments than by conventional growing means, and that the yields in tons per acre can be greatly increased.

Accelerated growth rates and vastly increased yields per unit acre are being developed through the application of several techniques including:

(1) High CO_2, humidity and temperature

(2) Artificial solar radiation (controlled periodicity).

(3) Chemically controlled nutrients, utilizing a gravel, sand or peat matrix, with trickle or flood sub-irrigation techniques.

Hydroponically-grown and sub-irrigation grown lettuce and tomatoes already bring premium prices because of their quality and year-round availability. The yields of such premium produce would be greater under ideal controlled environment conditions. Premium hydroponically-grown tomatoes are now being grown and marketed in Anchorage, with considerable success by Mosesian Farms.

Recent experiments conducted by Donald H. Dinkel of the Institute of Agricultural Science, University of Alaska, on the Fairbanks campus, have shown that controlled environment facilities have excellent potential for producing year-round salad vegetable crops in northern Alaska.

Thermal springs are uniquely valuable energy sources for controlled environment experiments, as they can provide hot water, warm and permafrost-free ground, and small amounts of electricity from a common energy source, at very little expense.

Open Plot and Controlled Environment Gardening on Geothermally-Heated Ground

Some Alaskan thermal springs are surrounded by rather large areas of warm ground, which remain frost-free throughout the year. Perennially warm ground around Manley, Chena and Pilgrim Springs has been used for vegetable crop gardening since the arrival of the first white settlers. The Pilgrim garden plots produced vegetables in commercial quantities for miners during the Nome gold rush period; and the Manley Hot Springs commercial vegetable crops have continued from the early 1900's to the present day .... as exemplified by Mr. Charles Dart's presently successful greenhouse operation (to be described in more detail in the next section).

Warm, frost-free soil is of great potential value in the arctic environment and should be utilized in a total energy applications system. A soil temperature survey similar to that conducted by N. Biggar (1973) at Chena Hot Springs (figure 11), can determine those areas which are optimum for vegetable crops.

Controlled environment enclosures could be located on selected plots of hot ground, adjacent to thermal springs, and require no other source of heat to maintain adequate soil and ambient air temperatures.

Growing seasons could be lengthened and plant maturation time could be accelerated through the use of garden plots which are heated by hot springs water circulated through networks of plastic pipe, buried at shallow depths in the soil.

Sewage Disposal: The disposal of human and animal waste in arctic rural areas underlain by permafrost is a critical problem. Buried sewer lines tend to freeze, without a continuing flow of +0°C water, and biodegredation processes are difficult to maintain in sewage processing plants and sanitary landfills.

The skillful use of thermal springs water in creatively-engineered sewage and refuse disposal systems, could improve the quality of life in rural communities.

Fish Farming and Hatchery Operations: Thermal springs water may have potential value for the creation of community-operated, year-round fish (char, trout, etc.) farms (mixed thermal spring and surface water).

Recent findings of the salmon fisheries research program at the University of Washington include the discovery that the homing instinct of spawning salmon is imprinted by the trace chemistry of the parent stream water, and that as little as 48 hours immersion is enough to

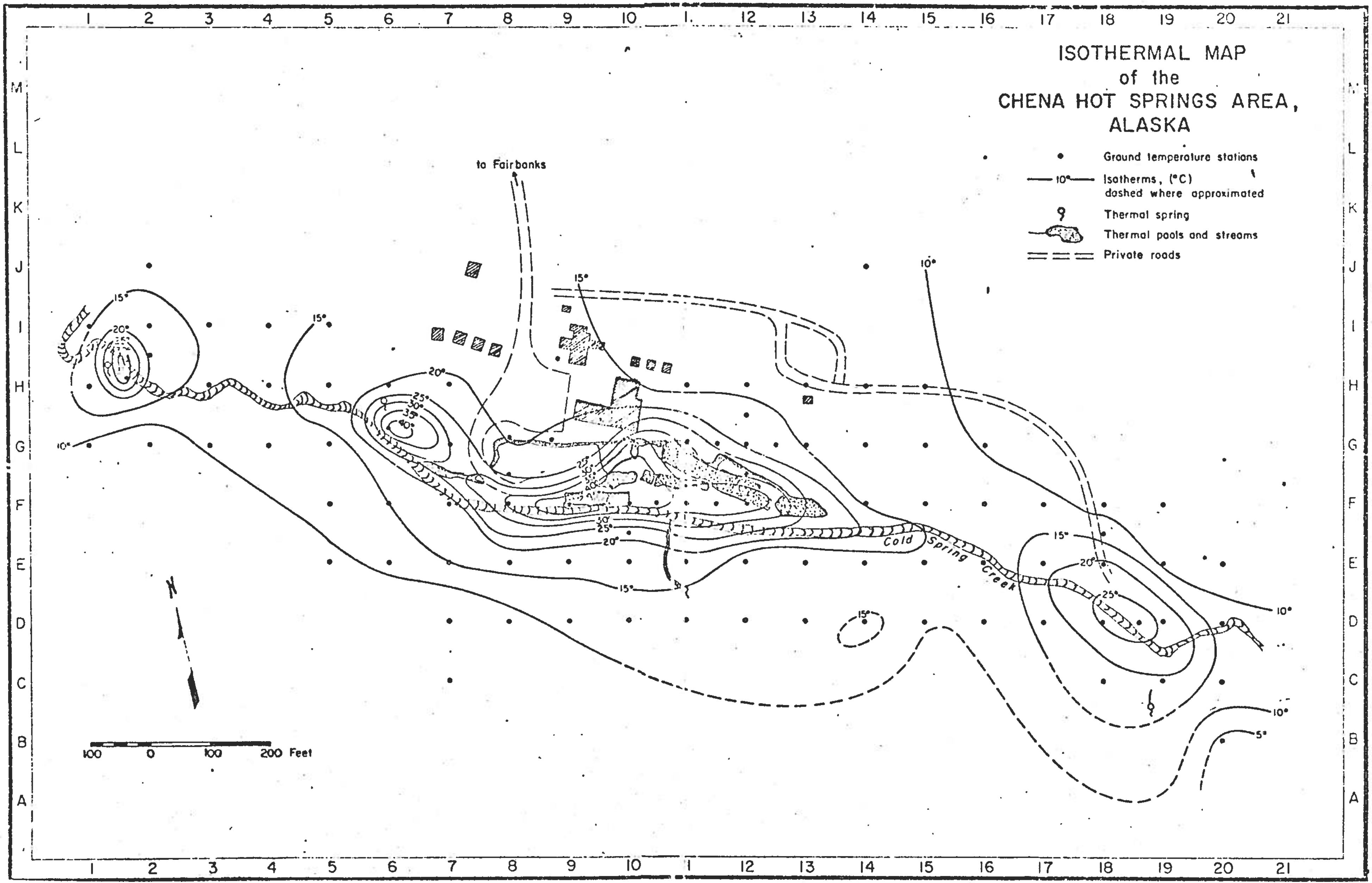


Figure 11. Isothermal map of soil temperatures in the Chena Hot Springs Area (Biggar, 1973).

imprint salmon smolt before they travel down the stream to the sea. Hatchery-raised fry can be transferred to desired streams at the critical development stage, with a subsequent high rate of return of the adult salmon to the same stream two to four years later.

The mortality rate of salmon fry before the outbound trip to the sea is inevitably high, but it is often increased by unusually hard winters, low water levels, and other hazards, both natural and man-made.

Native village cooperatives might well consider the establishment of hatchery operations for the rehabilitation of salmon streams in their aboriginal fishing grounds. Thermal springs could play an essential role in the winter husbandry of salmon fry.

Transmission of Geothermal Energy

Since geothermal resources often exist in areas which are some distance from the location where they could be best utilized, the transmission of this energy becomes an applications engineering problem. If electricity was the only concern, it could be transmitted from the generating site to the users by the usual transmission lines. But since we are also concerned with non-electric applications and the total utilization of the available energy, the problem is more complex.

High Temperature Pipelines: To date, no large reservoir geothermal systems have been discovered in Alaska; thus we are not immediately concerned with the transmission of large quantities of energy. If such a discovery should be made, however, pipeline transmission of hot water might present formidable problems. The Icelandic operations are the most valuable model that we currently have for hot water transmission technology. The Alaskan climate is more extreme, however, and hot water pipelines will face the same environmental problems that confronted the trans-Alaska oil pipeline. High moisture content permafrost is a costly handicap, and non-stable soil problems can offer many challenges to pipeline engineers. This report does not contain a complete economic analysis of hot water pipelines in Alaska, but we believe that the cost would be highly prohibitive, unless a great number of people could be served and there was a large magnitude energy potential.

Low Temperature Pipelines: Low temperature waters such as those emitted by many thermal springs, offer similar transmission problems to those which would be encountered by high temperature water pipelines, with the added hazard of lower outflow temperatures, due to heat loss.

Pipeline transmission of low temperature thermal waters (60°C or lower) is not practical in permafrost terrane for distances over two or three miles. Where low temperature springs are to be utilized, it is more feasible to move the user to the source, than to attempt pipeline transmission of the water.

Selection of Demonstration and Study Sites

Proposed Sites: Three sites have been selected for proposed geothermal demonstrations and experiments, to evaluate the feasibility of the total energy extraction concept, as applied to thermal springs in the rural Alaskan environment. The recommended sites (figure 12) are:

(1) Manley Hot Springs (90 miles northwest of Fairbanks)

(2) Pilgrim Springs (40 miles north of Nome)

(3) Clear Creek Springs (15 miles north of Elim, on the southeastern coast of the Seward Peninsula)

Manley Hot Springs: The thermal springs at Manley are privately owned and operated by Mr. Charles Dart. There are three major springs at the Manley site: One has a temperature of 64°C and an estimated flow rate of 20-25 gal/min; the second spring has a temperature of 51°C and an estimated flow rate of 200 plus gal/min; and the third has a temperature of 55°C and an estimated flow rate of 30 gal/min.

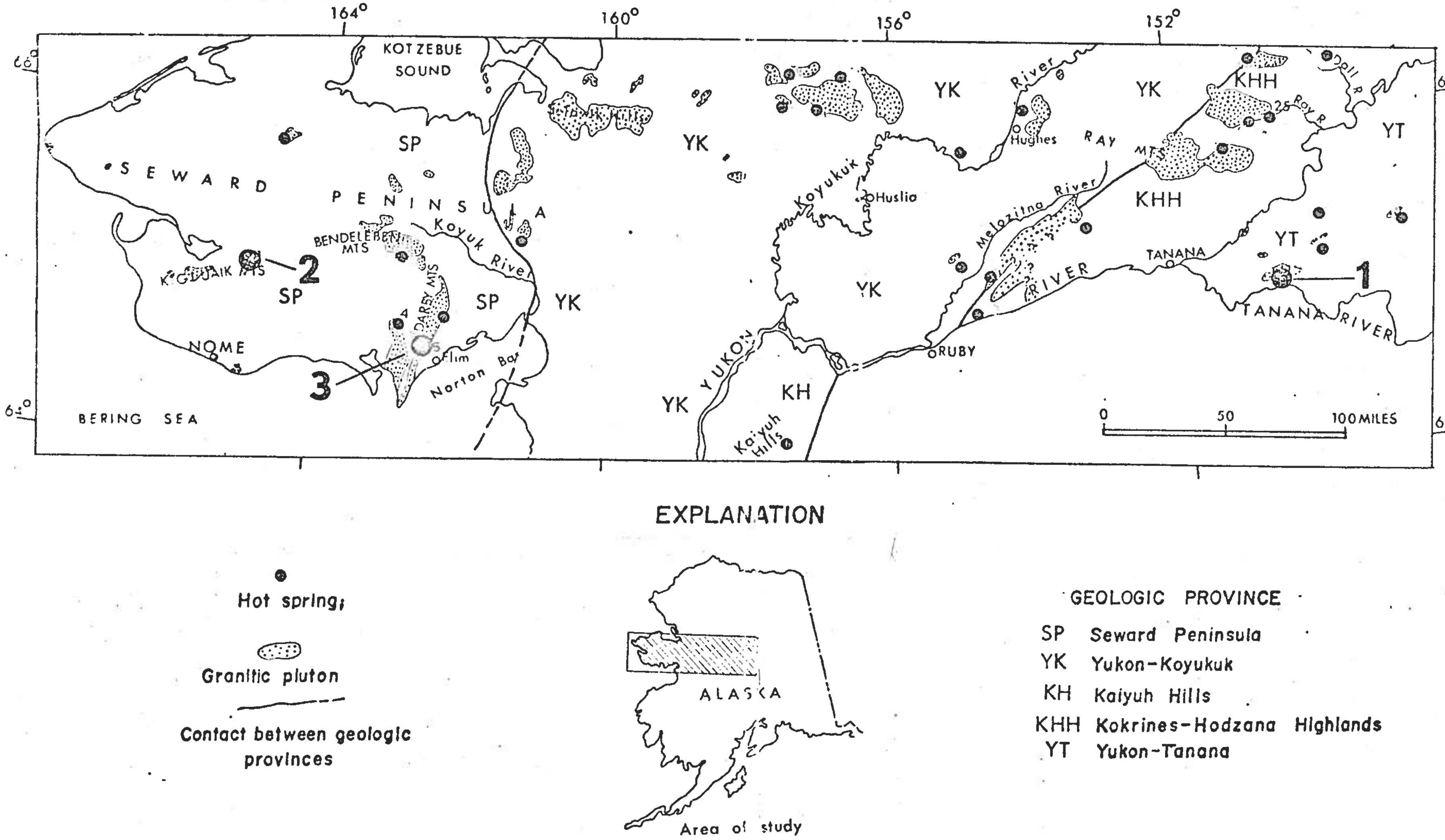


Figure 12. Geologic sketch map showing location and geological setting of thermal springs in central and westcentral Alaska (taken from Miller et al., 1973). Manley, Pilgrim, and Clear Creek Springs are shown as locality numbers 1, 2, and 3, respectively.

Manley is accessible from Fairbanks, via an all-weather road and by commercial air transportation. The Manley Springs are presently utilized for greenhouse operations, space heating, and bathing. Mr. Dart has offered his facilities and support for the proposed project.

Pilgrim Springs: Pilgrim Springs are owned by the Catholic church, and under lease to Mr. C.J. Phillips of Nome. Based on temperature measurements by earlier workers, maximum spring water temperatures were thought to be about 68°C. Shallow subsurface thermal probes (8 ft.) recorded temperatures up to 80°C during fieldwork conducted in summer 1974.

Although the site was formerly occupied by a Catholic Mission school until 1942, it is now abandoned. A small airstrip is accessible to light aircraft, via a short flight from Nome.

Mr. Phillips enthusiastically endorses the proposed program, and has given his permission for on-site demonstrations and experiments.

Clear Creek Hot Springs: The Clear Creek Thermal Springs are about 15 miles north of the village of Elim, on the southeastern coast of the Seward Peninsula. There are three springs, and one of these flows at an estimated rate of 450 gal/minute at a temperature of 68°C -- one of the largest estimated flow rates of known Alaskan thermal springs.

Although there are no residents near the Clear Creek Springs, the village of Elim is located on the coastline about 15 miles due south of the springs. Moses Point, another community, is located about 5 miles east of Elim.

Elim is a native village with an estimated population of 150-200 residents. Local industries include fishing, hunting, reindeer herding, and a potential lumber industry. Elim is currently served by an AVEC 100 kw diesel power system. Diesel oil must be lightered ashore from offshore anchorages. The peak power consumption during winter 1972-73 was 63 kw.

PROPOSED RESEARCH PROGRAMS

Manley Hot Springs Project

Background:

The Manley Community

The village of Manley has about 69 permanent residents. Approximately 30 percent are Athabascan Indians, and 70 percent are Caucasians. During the summer months, the population increases to about 100, as many Fairbanks residents occupy summer homes in the village.

Manley has no local government. There is a one-room school operated by the State of Alaska. There is no high school, and children of that age must attend boarding school in Fairbanks.

Traditionally, Manley was not a Native village, though it has been recently classified as such following land selection requests arising from the Alaska Native Claims Settlement Act. Manley was founded in 1901, when a prospector named Karshner discovered the hot springs. In that year, he staked the land surrounding the springs, and took up residence on the homestead. At that time, there were no other people known to be living at the springs; but a year or so later, gold strikes at Tofty and Eureka brought thousands of miners to the region.

One of the new miners was a man who called himself "Frank Manley." It is said that "Frank Manley" was fresh from the Cleary Creek diggings with several hundred thousand dollars in his pockets. In a few short years, "Frank Manley's" capital turned the Karshner homestead into the agricultural marvel of Alaska, and the first (and to date, the only) large-scale Alaskan geothermal project.

Many acres of land were cleared, and a 60-room hotel was built with the logs (figure 13). The hotel was heated entirely by the thermal waters of the spring, piped for a distance of one-helf mile in a 4-inch galvanized pipe. Behind the hotel were enclosed bathing pools of differing temperatures to appeal to the tastes of the most discriminating guests. A dairy farm was also established, with hay and feed grain crops covering the rolling hills which flanked the spring. Figure 14 shows the hot spring area and the nearby poultry and hog barns which were also heated by water from the spring. The photos also show buried aquaducts and rows of garden vegetables. Many varieties of fruits and vegetables were also grown in a large greenhouse that was heated by the spring. Potatoes were apparently the largest crop. Waring (1917) reports that in 1910, the Manley-Karshner operation shipped 150 tons of potatoes down river to the Iditarod mining district. Waring's map of the hot springs area, as it existed in 1915, is shown as figure 15.

[1]"Frank Manley's" geothermal experiment was to be short-lived. By 1913, placer mining began to decline. In April of that same year, the hotel burned to the ground, never to be rebuilt; and the farm began to deteriorate.

The final patent for the land was issued to Karshner's widow in 1915, and the land has had several owners in subsequent years.

In 1955, the property was purchased by Charles Dart, the present owner. Today a small portion of the land is still under cultivation, and tomatoes, cucumbers, and melons are raised in a 72- by 120-foot greenhouse which is heated by the springs.

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[1] Later it was discovered that "Frank Manley" was actually Willard Beaumont from Texas, a residence "from which he had hastily taken leave." Years later, he returned to Texas to stand trial for horse theft, where he was acquitted.

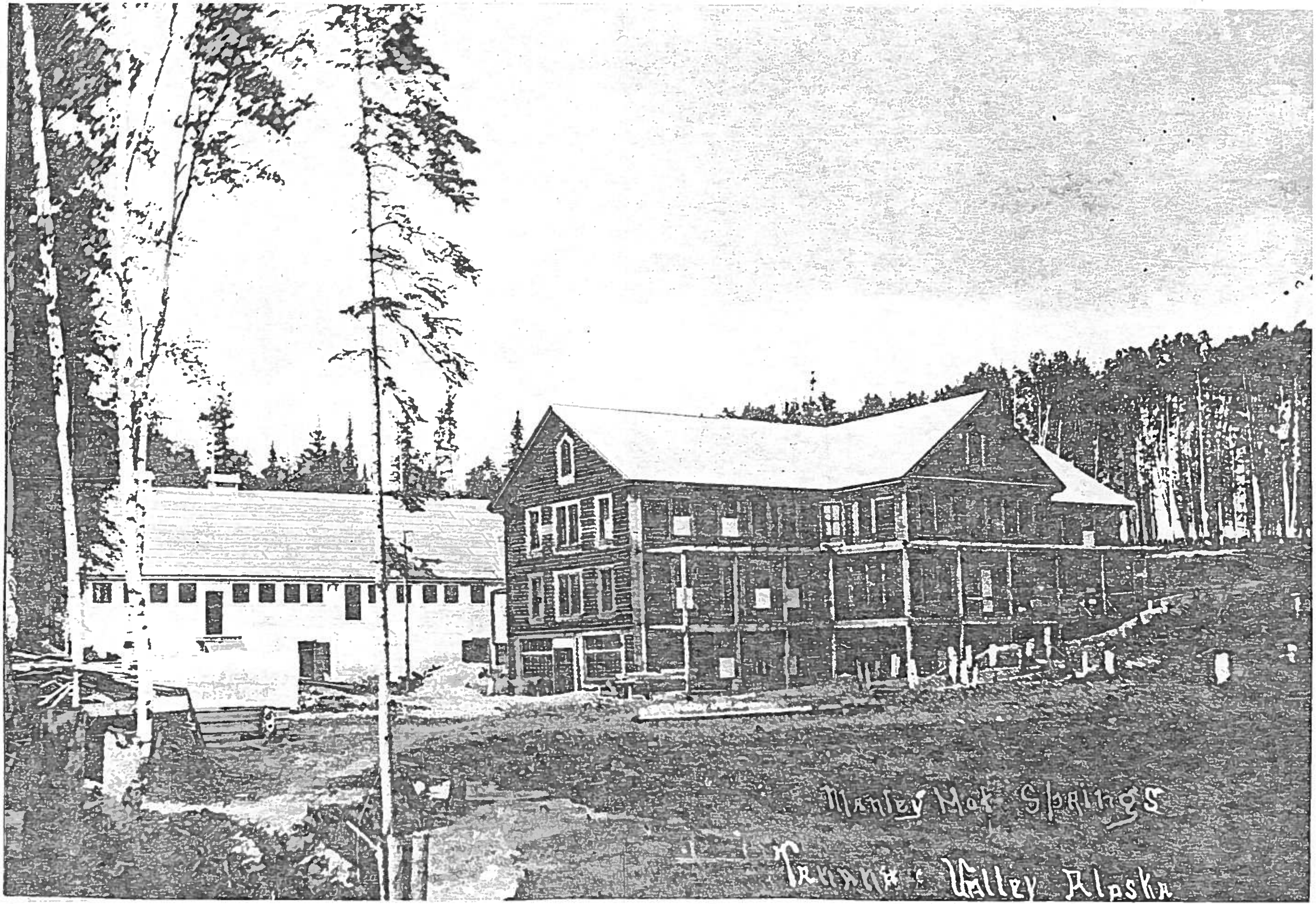

Figure 13. Manley Hot Springs Hotel buildings, area 1910.

(Photo from University of Alaska
Archives, Charles Bunnell Collection)

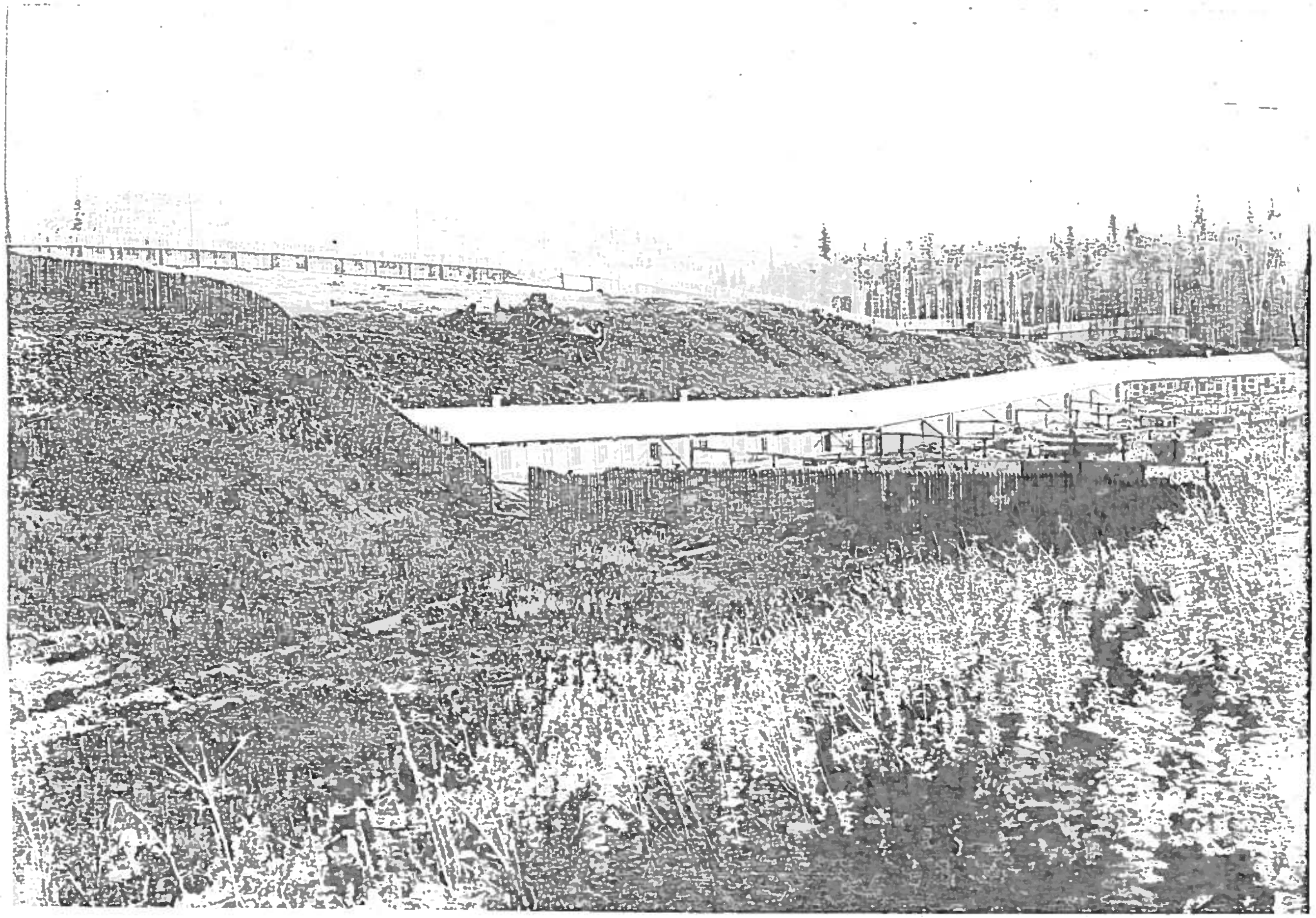

Figure 14. Poultry and hog barns near Manley Hot Springs, area 1910. Barns were heated by water from the thermal springs.

(Photo from University of Alaska Archives, Charles Bunnell Collection)

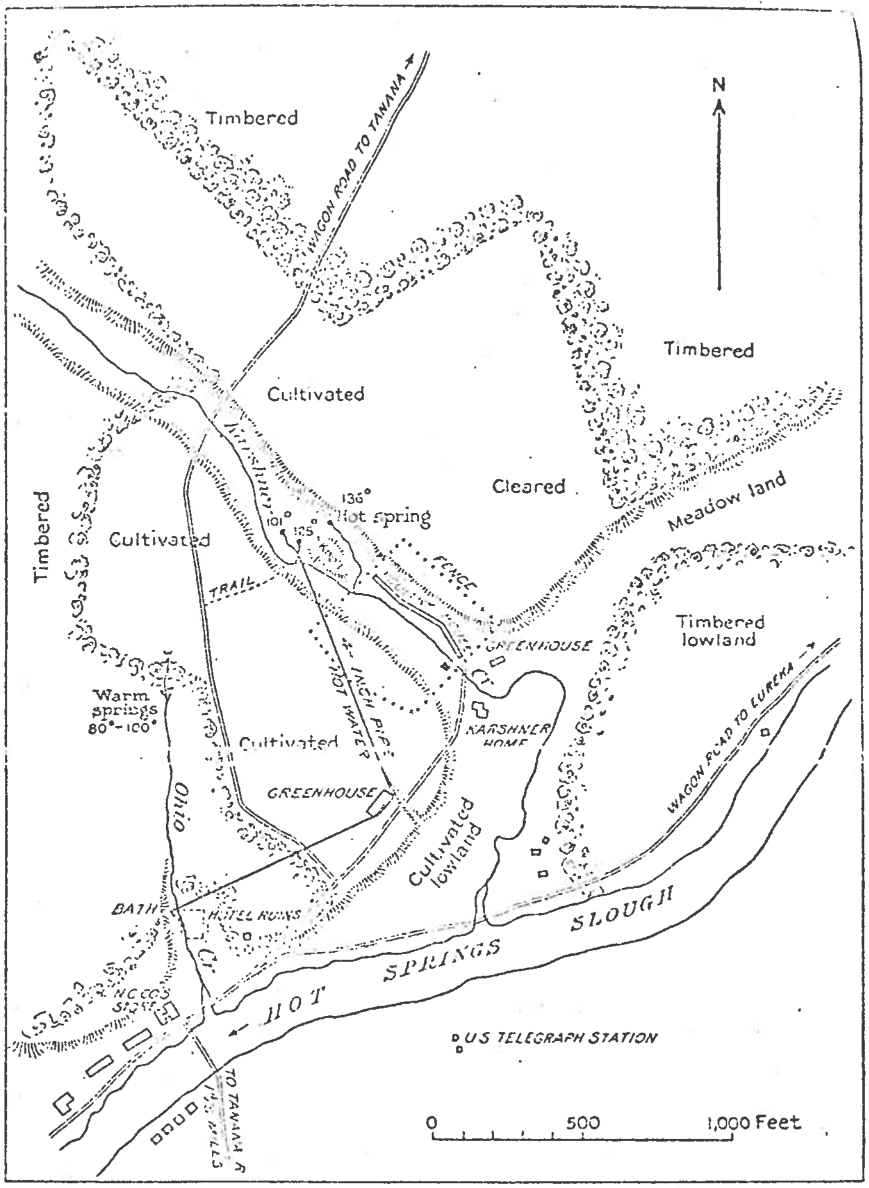

Figure 15. Sketch map of Manley Hot Springs as it appeared to Waring in 1915.

Geologic and Geochemical Setting: The springs are located near the contact between the quartz monzonite of the Hot Springs Dome Pluton (age = 60 m.y.) and the surrounding Jurassic or Cretaceous sedimentary rocks (shales and siltstones).

The resource consists of principal springs and several seeps near the confluence of the valley of Karshner Creek and Hot Springs Slough. The springs and seeps are surrounded by about 20 acres of warm ground that remains unfrozen and snow-free throughout the year (figure 16). Upper Karshner Creek is fed by highland tributaries and springs, however, and has an average summer temperature of about 6°C.

Chemical analyses of spring water have been reported by Waring (1917), and more recently by Miller et al., as shown below in Table 7.

TABLE 7

Chemical Analyses of Water from Manley Hot Springs (taken from Miller et al., 1973)

	(1)	(2)
SiO_2	65.	65.
Al	0.046	0.016
Fe	--	--
Ca	6.8	4.
Mg	2.9	1.
Na	130.	130.
K	4.8	4.5
Li	0.28	0.28
NH_3	0.5	4.9
HCO_3	90.7	89.6
CO_3	--	--
SO_4	51.	54.
Cl	132.	134.
F	8.2	8.5
Br	--	--
B	1.2	1.3
PH =	7.7	7.72
T =	59°C	56°C

Figure 16. Snow-free and thawed ground at the confluence of Karshner Creek and Hot Springs Slough, surrounding Manley Hot Springs and associated seeps. The two greenhouses operated by the Dart family are located in the upper part of the area. Spring water is also piped to buildings at the base of the hill for household use and in commercial and public baths.

(Photo courtesy of C. Dart)

Subsurface Reservoirs (?) and Estimated Temperatures

Estimated subsurface reservoir temperatures, based on the quartz conductive and Na-K-Ca geothermometers are 78 and 137°C respectively, as calculated by Miller et al. (1973). These temperatures are too low for commercial vapor phase reservoirs. The probability of large steam or hot water subsurface reservoirs is also low, based on the presence of hornfelsed argillaceous rocks about one-half mile above the springs, which suggests that the country rock has been too highly recrystallized to retain desired porosity and permeability. However, the three-dimensional subsurface geometry of the pluton and the contact aureole is unknown.

Although the prospects do not seem to favor deep drilling for subsurface reservoirs, shallow drilling near the site might provide higher temperature spring water than that which issues from the two major springs.

This recommendation is based on the premise that some mixing of the waters from Karshner Creek and the spring conduit system is occurring at shallow depth under the site.

Plan of Research:

Scope of Research

We propose a three-year investigative program including a one-year engineering evaluation of a Rankine-cycle generating system; a three-year agricultural application-space heating study; and a geochemical program to monitor the temperatures and chemistry of the thermal spring waters, and ground temperature variation during the experiments.

Rankine-Cycle Turbine Evaluation

Ormat Turbines Ltd. has agreed to collaborate with the University of Alaska in a project to evaluate the feasibility of producing electric power at Manley, using thermal spring water as an energy source. Ormat has agreed to supply a 2.5 kw organic Rankine-cycle turbine for field tests at Manley. This unit is to be equipped with a newly designed spring water-working fluid heat exchanger to extract heat from the thermal spring water. University of Alaska personnel would prepare the site, install the unit, and monitor the performance and output efficiency after installation.

The lead time prior to delivery and installation is estimated to be from 6 to 9 months. During the site construction phase, several shallow holes will be drilled to evaluate the possibility of obtaining hotter water in the shallow subsurface. If hotter water cannot be obtained, however, water from the hottest spring (54°C) will be used. If this temperature proves too low, the input water temperature can be raised by supplemental heating to the minimum temperature which is required by the system, and the value of the demonstration can be maintained. A one-year evaluation period is planned to monitor sustained performance characteristics and the effect of possible variations in water temperature and flow rate.

Present estimates indicate that a 20 gpm flow rate would be required for the evaluation. Outflow temperatures from the generator would be approximately 47°C. The outflow water will be returned to the agricultural and space heating systems for the extraction of additional energy.

The electricity produced by the experiment will be consumed by other Manley experiments, including lighting for the instrument hut and water pumps required by the gardening experiments. These applications will also aid in evaluating the generator performance under varying loads.

If this small scale power demonstration proves successful, Ormat Turbines Ltd. will collaborate with the University of Alaska in the construction and installation of a larger pilot plant at another thermal spring (Clear Creek Springs).

Space Heating Studies

Space heating experiments will constitute a significant part of the Manley engineering studies. Two structures are to be built at the site. A laboratory hut with accommodations for two investigators, which will also serve as a test enclosure for space heating experiments. The agricultural experiments will also require a building which will include a greenhouse and a controlled environment module which will need continuous heat.

Water delivery, regulation, and convector systems will be designed and tested. Whenever possible, commercially available equipment will be used. This work will concentrate on the optimization of existing equipment and systems, rather than attempts to develop new and radical techniques. Applications engineering studies will document the effects of fluctuations in flow rate and temperature of input water on heating systems.

Agricultural Applications and Experiments

Building on the past and present Manley agricultural successes, we propose a series of experiments and engineering application studies to determine the optimum methodology and economic feasibility of utilizing energy from thermal springs for the production of large-scale vegetable crops in controlled environment modules, greenhouses, and heated garden plots.

Controlled Environment Experiment

The major objective in this study is to determine economically optimum environmental controls and methods which could lead to large-scale vegetable farming at Alaskan hot springs. These experiments will require a specially designed and constructed agricultural laboratory. This structure would be composed of three modules, including a greenhouse unit, a hydroponic section, and a controlled total environment module.

The greenhouse would be operated during extended summer growing seasons and heated by thermal spring water and radiant heat from the warm ground. The intermediate section will function as a greenhouse or hydroponic unit, as controlled by detachable insulated panels which would overlie the basic glass frame enclosure.

The controlled total environment unit is to be a completely enclosed insulated module, heated by radiant heat from the warm ground, thermal spring water, and radiant heat from solar lamps powered by electricity generated by the 2.5 kw Ormat energy converter. Environmental controls will include solar radiation, ambient air and substrate temperature, CO_2 content (in air), and nutrient supply and chemistry.

Heated Garden Plot Experiments

There are extensive areas of warm ground adjacent to Manley Hot Springs (figure 16). The average root depth soil temperatures in Interior Alaska are about 13°C during most of the growing season. In June 1974, soil temperatures up to 45°C were measured at root depths near the hottest of the Manley Springs as compared to soil temperatures of 11°C, 300 meters distant. Soil temperatures averaged 25°C within the thermally disturbed zone, which included a surface area of about 6.7 acres. Based on recent studies by Dinkel (1974) and others, the potential yield of such acreage, when farmed with the new techniques, is much greater than that of arable land with the usual Interior Alaskan soil temperatures.

Planned experiments include preliminary soil temperature grid surveys and the compilation of detailed isothermal contour maps. Garden plots would then be located in planned temperature zones, and crops would be planted according to optimum root temperature requirements. Additional garden plots would be heated by networks of subsurface pipe (PVE, copper, steel) carrying thermal spring water, and surface irrigation with warm spring water would also be evaluated. Early planting and transplant techniques are to be explored, including the use of temporary plastic shelters. The yields per unit area, growth time, and quality versus cost would be compared to those of control garden plots farmed with standard agricultural methods.

Geochemical and Geophysical Studies

Very little is known about the annual and/or seasonal variation in chemistry, temperature, and flow rate of thermal springs in general, and Alaskan springs in particular. Such variations, if large, could be very troublesome. A drop of a few degrees in water temperature could seriously reduce the performance and efficiency of binary type generating systems, and changes in flow rate would pose additional regulation problems. Variation in water chemistry, including relative increases in the concentration of alkalies, silica, calcium, and fluorine could be hazardous to agriculture, if the spring water is used for irrigation and/or for nutrient solutions.

As mentioned in an earlier section, it is now known that thermal spring waters are composed of at least 95% recirculated meteoric water. We do not know, however, what the turn-around time is in such systems;

and the problem is complicated by mixing with water from the local water tables, before emergence. Continuing geochemical data should be acquired during the program, to be applied to several problems and studies including:

(1) Short and long-term variation in the chemistry, temperature, and flow rate of spring water.

(2) Correlation of the above variations with local precipitation, break-up chronology, water table level, and barometric pressure.

(3) Turn-around time (surface reservoir surface) of water in the thermal spring system, with the aid of tritium and oxygen isotope analyses.

(4) Identification of the factors which control the mixing of ground and spring water in the subsurface, and the effect on the chemistry of the spring water.

The chemical monitoring system would be centralized in the laboratory module to be constructed on the site. Continuous temperature and flow rate data would be registered on recorders in the laboratory, and daily water samples would be analyzed with the aid of flame photometric and atomic absorption analytical equipment in the same laboratory.

Tritium and oxygen isotope analyses of spring water will be done at outside laboratores by separate contract, on weekly samples.

Clear Creek Springs Project

Socio-Economic Framework of Elim

Background: The village of Elim, which is located about 15 miles from Clear Creek Springs had a population of 170 people in 1970 when it became a fourth-class city. The population is Eskimo, with the exception of resident Bureau of Indian Affairs school teachers.

Elim was apparently an ancestral Eskimo village prior to the coming of the white man. A Covenant Church Mission was established in the village in 1914 by L.E. Ost. Elim received a post office in 1943.

Apparently the Elim people and adjacent villages paid little attention to Clear Creek Spring, although remnants of hunting camps can be found in the area.

There is no major industry in the village of Elim at present. The residents make their living from subsistence hunting and fishing, commercial fishing, trapping, reindeer herding, and a locally-owned cooperative store. Other sources of employment are mainly government related.

In recent years, the State Rural Development Agency has awarded several small grants to the village to perform public works projects, which have totaled about $2000 per year in resident wages.

The 1970 census showed the average individual income in Elim to be between $500 and $1000 per annum. At that time, skills possessed by unemployed villagers included:

a) grocery clerks
b) diesel mechanics
c) carpenters
d) dredge winchmen
e) heavy equipment oilers
f) truck and jitney drivers
g) reindeer herders
h) dozer operators
i) fishermen

Elim has a council which governs village affairs including law enforcement. There are two health aids in the village, but there is no sanitation aid, and no mechanized fire department.

Elim residences are mostly old log structures of one or two rooms. There are a few frame houses. Generally, the condition of the houses is poor, and most are in need of repair.

The only utility system in Elim is the Alaska Village Electric Cooperative power system. This system consists of two 50 kw diesel generators. The peak load in the winter of 1972-73 was 25 kw with an expected peak for 1974-75 estimated at 44 kw. There are no sewer or water systems.

Organized activities in Elim consist of:

a) Boy Scouts
b) 4-H Club
c) weekly movies
d) Sewing Circle
e) Covenant Church activities
f) Dog Race Committee

There are no community indoor or outdoor recreation facilities.

The geothermal potential of Clear Creek Springs offers interesting opportunities for the village of Elim. However, careful planning is necessary to insure that proposed developments and applications are compatible with the wishes and lifestyle of the Elim people. Preliminary discussions should be held with the villagers to determine what electric and/or non-electric applications are best suited to the needs and desires of the community.

Geologic and Geochemical Setting: The geologic setting of Clear Creek Springs has been described by Miller et al. as follows:

> "Hot springs on either side of east-flowing tributary of Clear Creek. Spring south of tributary has large flow estimated at several hundred gal/m and is about 400 ft above Clear Creek valley floor. A temperature of 63°C. was measured in 1970. Two hot spring areas occur north of tributary. The upper spring is inaccessible by helicopter; the lower one has a smaller flow than the spring to the south and a temperature of 67°C. Chemical analysis available.
>
> "Springs are in quartz monzonite of Darby pluton less than 1/4 mi from contact with Devonian limestone. Pluton-limestone contact is inferred to be major fault (Miller and others, 1972) trending N.18°E."

A partial chemical analysis of water from Clear Creek Hot Springs has been reported by Miller et al. (1973) (Table 8).

According to the Na-K-Ca geothermometer, the reservoir temperature for this spring water is estimated to be 111°C. The springs emerge from fractures in quartz monzonite, and this setting, along with the probable low reservoir temperature, argues against the presence of large subsurface geothermal steam reservoirs. However, Clear Creek Springs have excellent resource potential due to the large (400 gal/min or greater) flow rate of one of the springs, and a location which is 400 vertical feet above the valley floor.

Plan of Research: The high cost of food, heat and power in Elim, and the proximity of the village to Clear Creek Springs, constitute an optimum setting for a village demonstration project, involving the total energy concept as applied to the most acute energy needs of an isolated arctic community.

Socio-Economic Assessment

At the outset, the needs and wishes of the Elim people must be determined, and a program should be developed which has a reasonable

TABLE 8

Partial Chemical Analysis of Water from Clear Creek Hot Springs (Miller et al., 1973)

SiO_2	--
Al	--
Fe	--
Ca	5.6
Mg	0.06
Na	54.
K	1.4
Li	--
NH_3	--
HCO_3	34.
CO_3	34.
SO_4	25.
Cl	4.9
F	--
Br	--
B	.02

PH = 9.43

T = 67°C

probability of answering these needs without disrupting village life, as idealized and desired by the residents.

We suggest that a small group of villagers, selected by the Village Council, be brought to Manley in the early stages of the project, to observe the pilot studies and experiments, and that the details of the Elim-Clear Creek program be finalized at an Elim-University of Alaska workshop, following the Manley visit.

Clear Creek Experiment

Calculations show that a 50 kw binary generating system could be driven by the 400 plus gal/min inflow of Clear Creek Springs water. The outflow temperature would be about 55°C. Considering the flow rate, the residual energy potential of the water is impressive. A 400-foot fall to the valley floor offers an additional hydroelectric inducement.

The Clear Creek experiment, subject to conferal with the Elim Council, would include the following:

(1) Installation of a 50 kw binary generating system.

(2) Construction of an electric transmission line to Elim.

(3) Possible development of a new community at the Clear Creek Springs site, utilizing the total energy of the springs, for:

  (a) Generation of electricity

  (b) Space heating

  (c) Controlled agriculture environment

  (d) Salmon hatchery operations

Pilgrim Springs Project

Background: Pilgrim Springs is located approximately 40 miles north of Nome, in the southwest corner of the Bendeleben (A-6) Quadrangle (figure 12).

Before the arrival of the white man, the Eskimo name for Pilgrim Springs was Kruzgamepa. During the height of early gold mining activity, the Springs served as a resort for residents of Nome, Solomon, Council, and other mining communities, and vegetables were also raised at the springs for local markets.

Subsequently, the Catholic Church established a mission school for native children at Pilgrim Springs which was closed in 1942. At present, the springs are leased from the Catholic Church by C.J. Phillips of Nome.

Geologic and Geochemical Setting: The Pilgrim River Valley is mantled by alluvial fill. Precambrian gneisses and biotite schists are exposed on Hen and Chickens Mountain, four miles north of the springs, and Cretaceous granitic intrusives cut Precambrian gneisses and schists in the hills to the south and east (Sainsbury, 1974). Miller et al., (1972), have suggested that an extension of the Bendeleben Range front fault may underlie the alluvium of the Pilgrim River Valley, and that Pilgrim Springs may be related to this fault system.

Serpentine Hot Springs is located approximately 50 miles north of Pilgrim Springs waters, and is characterized by high salinity of the NaCl type (Table 9). The saline character of the Pilgrim Spring water has aroused speculation on a possible marine origin.

To the northeast, a large lowland area centered on Imuruk Lake is covered by a very young basaltic volcanic field which ranges in age from

TABLE 9

Chemical Analyses of Pilgrim and Serpentine Spring Water (taken from Miller et al., 1973)

Component	Pilgrim	Serpentine	
SiO_2	100.0	100.0	*ppm
Al	0.044	0.083	
Fe	----	----	
Ca	530.0	47.0	
Mg	1.4	0.48	
Na	1450.0	730.0	
K	61.0	40.0	
Li	4.0	4.7	
NH_3	----	----	
HCO_3	30.1	64.5	
CO_3	----	----	
SO_3	24.0	29.0	
Cl	3346.0	1480.0	
F	4.7	6.4	
Br	----	----	
pH	6.75	7.91	

* parts per million

3.5 million year old basal volcanics to very young flows which may have been erupted as recently as a few hundred years ago (D.M. Hopkins, unpublished data).

The larger springs and associated seeps emerge from channel sands and silts in an abandoned meander loop of the Pilgrim River. However, other seeps and patches of warm ground occur in the adjacent area as shown by snow-free ground and bright green vegetation in winter versus summer aerial photographs (see "A Geophysical Reconnaissance of Pilgrim Springs," included as a separate report).

Based on the apparent lack of subsidence and tilting of the mission buildings (with the exception of damage of uncertain origin to the greenhouse) and the absence of thermokarst pits in the cleared fields, the Pilgrim Springs area appears to be free of permafrost. The three dimensional geometry and areal extent of the thawed zone are not known.

Pilgrim Springs as a Potential Geothermal Resource

Although Pilgrim Springs has a previous agricultural and resort history, it has excited more recent interest as an indicator of a possible subsurface geothermal stream or hot-water reservoir.

Based on the silica, potassium-sodium and sodium-potassium-calcium thermometers (White, 1970), (Fournier and Truesdell, 1970), (Fournier and Truesdell, 1973), estimates of the sub-subsurface reservoir temperature of Pilgrim Springs have ranged from 120° to 137°C (Miller et al., 1973). Previous estimates of spring water flow rates have ranged from 8 to 20 gal/min (Table 9). However, data reported in this study show that earlier temperature and flow measurements must be treated with caution due to the high permeability of the surrounding channel sands, and the mixing of spring and ground water.

Geophysical Survey

In an attempt to refine previous estimates of the geothermal potential of Pilgrim Springs, we applied several geophysical survey techniques including:

(1) Seismic refraction profiling

(2) Geomagnetic profiling

(3) Microseismic background recordings

(4) Surface and subsurface water temperature measurements in springs and seeps

The results of the survey and recommendations for further work are summarized below.

(1) Shallow subsurface water temperatures in zones of maximum upwelling reach 80°C a few inches below the bottom sediment.

(2) Pilgrim Springs waters are diluted by mixing and convection with local ground water, and water temperatures and salinities will increase in the subsurface.

(3) A 9060/5540 ft/sec discontinuity is located approximately 208 feet below the springs, which is believed to be Tertiary sediments or hydrothermally-cemented glacio-fluvial gravels. The sedimentary section, if present, may be up to 400 feet thick.

(4) Tertiary sediments, such as those which occur to the northeast, contain permeable rock units which could make good geothermal reservoirs; and a hydrothermally-cemented conglomerate cap would offer an interesting target, if it does indeed exist.

(5) The negative magnetic anomaly over the springs is most satisfactorily explained by a zone of hydrothermal leaching along the conduit system, which has a lower magnetic susceptibility.

(6) Subsurface spring waters will be more saline at depth, and with increasing temperature will constitute a serious corrosion problem in respect to drilling and application engineering.

(7) Although the observation period was dangerously short, the absence of microseismic activity during the two recording periods minimizes the probability of vapor phase reservoirs.

Plan of Research:

(1) An extended seismic refraction profile should be completed which includes deeper penetration and north-south step-outs. Objectives include the definition of Tertiary rocks versus hydrothermally-cemented gravels, and the Nome Group basement discontinuity.

(2) Based on a refined seismic profile, a shallow drilling program should be initiated which will accomplish the following objectives:

  (a) A drill hole which penetrates the 208-foot discontinuity under Pilgrim Springs. The upper part of the hole will be in water-saturated sand, and effective drilling techniques will require driving casing ahead of the bit, and up-hole circulation to remove the unconsolidated and water-saturated sediment.

  (b) The drilling program should include several halts in drilling activity to allow the development of a reasonably good thermocline in the water column in the cased hole, to allow meaningful gradient measurements.

  (c) The casing should contain a corrosion resistant plastic liner.

(d) If shallow (100 feet) subsurface temperatures approach 100°C, drilling should be suspended until blow-out prevention equipment is installed at the well head.

(e) Draw-down and pumping tests should be conducted after each cycle of down-hole temperature measurements. This is the only method which will supply meaningful flow rate and capacity data in terms of large-scale geothermal applications.

(3) An agricultural experimental program should be activated at Pilgrim Springs which would evaluate the feasibility of the following:

(a) Shallow subsurface heating of agricultural plots by thermal spring water circulated through networks of plastic pipe.

(b) Heating of hydroponic and greenhouse facility by thermal waters from Pilgrim Springs.

(c) Heating of local residences by thermal spring waters.

(d) Desalinization of spring waters to provide potable water.

ENVIRONMENTAL HAZARDS AND PROTECTION

Environmental Hazards

Chemical Pollution: Steam brought up from subsurface reservoirs contains about 0.5-5% noncondensible gas which is principally carbon dioxide with varying amounts of hydrogen sulfide, methane, and ammonia.

These gases are released directly from the condensate in cooling towers. Condensates usually contain trace amounts of boron, arsenic, and other volatile elements which can be hazardous in excessive concentrations. Hydrogen sulfide is a dense gaseous pollutant which can be dangerous to human and animal life.

Most geothermal steam fields are the wet rather than the dry type (vapor dominated) and contain approximately 80% water at the well head. The water often contains higher concentrations of trace elements than the steam. The most common dissolved constituents include carbonate, silica, and sodium chloride.

Some of the liquid-dominated reservoirs contain brines as the fluid phase which contain very high concentrations of sodium, potassium, bromine, and heavy metals. Such brines are extremely corrosive, and potentially hazardous to plant and animal life if released into the environment without treatment.

Noise Pollution: When superheated water flashes to steam, an intense roar is produced which is very offensive to workers, residents, and nearby communities.

Thermal Pollution: Hot water which is wasted from geothermal power plants and other uses is potentially troublesome if it is allowed to flow into streams, rivers, lakes or ground water tables. The chemical effect on the ecosystem may be far less in some cases than the thermal shock created by the inflow of hot water.

Anti-Pollution Measures

In the case of steam fields, water and condensates may be reinjected into another drill hole. Acoustic problems from flashing steam can be solved with silencers.

In the next few years, a technology will no doubt be developed for desalinization systems which will extract valuable salts and metals from brines after steam has been extracted for the turbines, with a useful outflow of potable water (figure 17).

Environmental Vulnerability of Alaskan Thermal Springs

The utilization of thermal waters emitted from springs, is not beset by some of the hazards associated with geothermal steam operations. Thermal waters which well up from the springs flow into streams which are part of the same ecosystem. The chemical composition of the spring waters should not be greatly changed by the planned demonstrations and experiments, as only the heat will be extracted....and concentrations of dissolved constituents are not high enough to cause accelerated precipitation during the cooling process. The water can be rechanneled into the same outflow streams with relatively little environmental impact.

If shallow drilling at Pilgrim Springs should indicate a possible geothermal steam reservoir, with more highly concentrated brines as the liquid phase, adequate protection measures will have to be taken before proceeding to demonstrations involving deeper drilling and the possible release of steam and condensates at the well head.

Some concern has been voiced for thermal springs and the adjacent terrain as possible island ecosystems surrounded by a hostile arctic environment. It has been suggested, for example, that such ecosystems

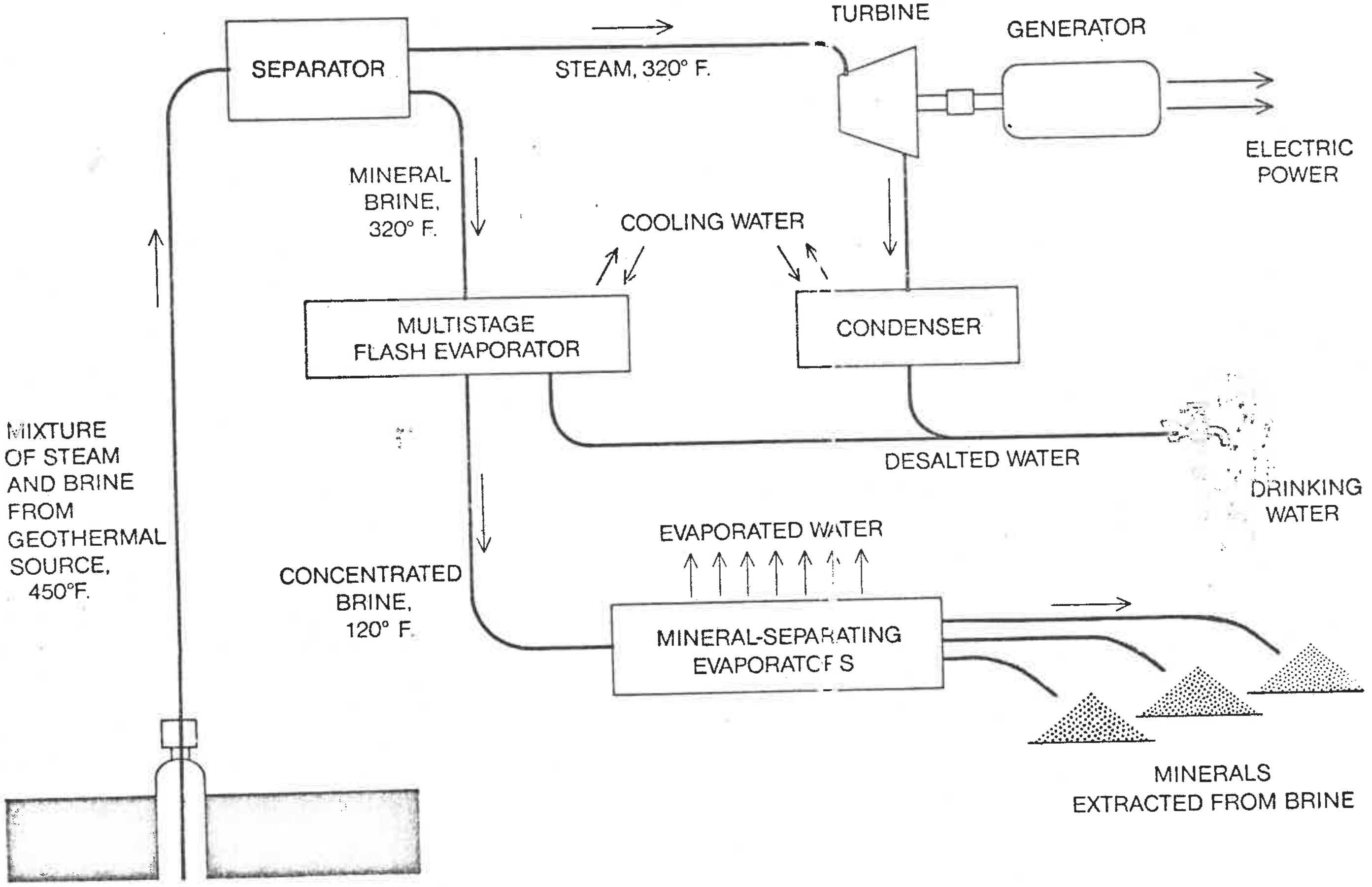

Figure 17. Multipurpose geothermal system, as designed by the UN and the Government of Chile. From "Geothermal Power" by Joseph Barnea. Copyright January 1972 by Scientific American, Inc. All rights reserved.

and the accompanying microenvironment (unless destroyed by man) may contain relict biological populations which have survived the glacial maxima, dating back to Pliocene time. Although this hypothesis remains to be proved, the presence of a vigorous earthworm population in the warm soil around Pilgrim Springs is of more than passing interest....even though the earthworms may have arrived via plants which were imported during the Nome gold rush.

Manley and Pilgrim Springs have been thoroughly overprinted by the works of man. Channelways, pools, and seeps have been reworked and altered by several generations of residents. Indeed, it would be difficult, or perhaps impossible, to reconstruct the original setting. Nevertheless, each of these microenvironments should be carefully assessed and evaluated, so that future developments can be accompanied by attempts to restore the former biological equilibrium, if possible.

Clear Creek Springs will be a more sensitive site, as it has not been obviously altered or disturbed by the white man. It would be prudent to conduct a thorough biological assessment of these particular springs and the surrounding terrain during the reconnaissance studies scheduled for 1975.

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