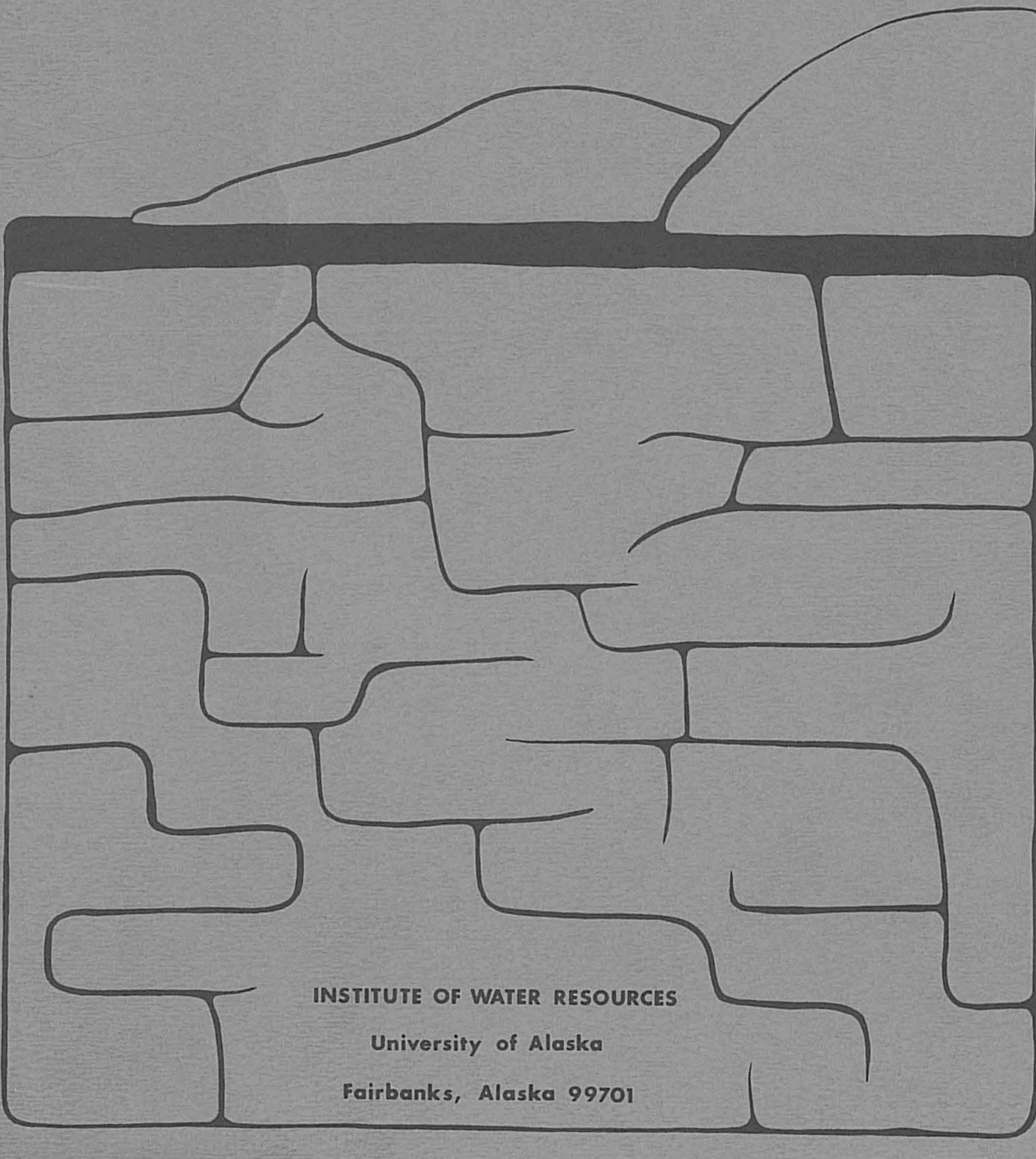
GROUND WATER QUALITY EFFECTS ON DOMESTIC WATER UTILIZATION



INSTITUTE OF WATER RESOURCES

University of Alaska

Fairbanks, Alaska 99701

GROUND WATER QUALITY EFFECTS ON DOMESTIC WATER UTILIZATION

by

Daniel W. Smith, Ph.D.
Assistant Professor of Water Resources
and Environmental Quality Engineering

and

Lawrence A. Casper
Research Chemist

Institute of Water Resources
University of Alaska
Fairbanks, Alaska

IWR-48

March, 1974

ACKNOWLEDGEMENTS

The work upon which this report is based was supported in part by funds (Project A-040-ALAS) provided by the United States Department of the Interior, Office of Water Resources Research, as authorized under the Water Resources Act of 1964, as amended.

The authors would like to acknowledge the assistance of the staff and students of the Institute of Water Resources in preparing and mailing the survey forms. Also, we would like to thank Judith Henshaw for doing the drafing, Mayo Murray for final editing, and H. Mauree Rost and Linda Peifer for suggestions and typing.

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INTRODUCTION

Ground water is the principal source of domestic water supplies in the interior of Alaska. Some consumers have access to municipal or private water systems which pump, heat, treat, and circulate water to their homes. The majority, however, must meet its water needs with private wells or hauled water. The purpose of this study is to examine the quality of ground water in interior Alaska and to determine the costs of alternative methods of meeting water supply needs.

The difficulty in acquiring and maintaining a year-round water supply has always been a serious hindrance to living in cold regions. Surface waters are generally unavailable as a consequence of the severe thermal regimen of the region during a major portion of the year. As a result, requirements for water have been filled by the development of ground water resources. This alternative frequently poses problems since various water quality parameters may be present at concentrations above the drinking water standards recommended by US Public Health Service (1962). The poor quality water coupled with the high cost of well development has led to considerable concern for rural dwellers of Alaska.

OBJECTIVES

The three original objectives of this project were:

1. To examine the areal distribution of various ground water quality characteristics using the rural domestic water users appraisal of the water and a selected number of chemical analyses.

2. To estimate the relative costs of alternative methods of water supply for the rural interior Alaskan consumer.

3. To investigate the possibility of using specific ion electrodes in remote areas.

In evaluating the problems of rural water supply in a large dispersed population, two factors become evident: (1) a means of contacting the individual water user must be developed and (2) a means of evaluating responses is required.

Item 1 was handled by assuming that nearly all of the year-round water-users have electricity. A small per cent of the rural Alaskan population near Fairbanks does not use electricity and was excluded from those contacted. The remainder of the population not served by the Fairbanks Municipal Utilities System was contacted through the use of the Golden Valley Electric Association's subscriber list.

The means of evaluating responses was divided into two methods. First, the responses on returned survey forms were catalogued and coded into a digital format and put on computer cards for quick sorting and evaluation.

The second area of evaluation involved the selection of a geologic cross section of the study area, collecting water samples from those that responded to the survey form, and comparing the responses to the chemical quality of the water.

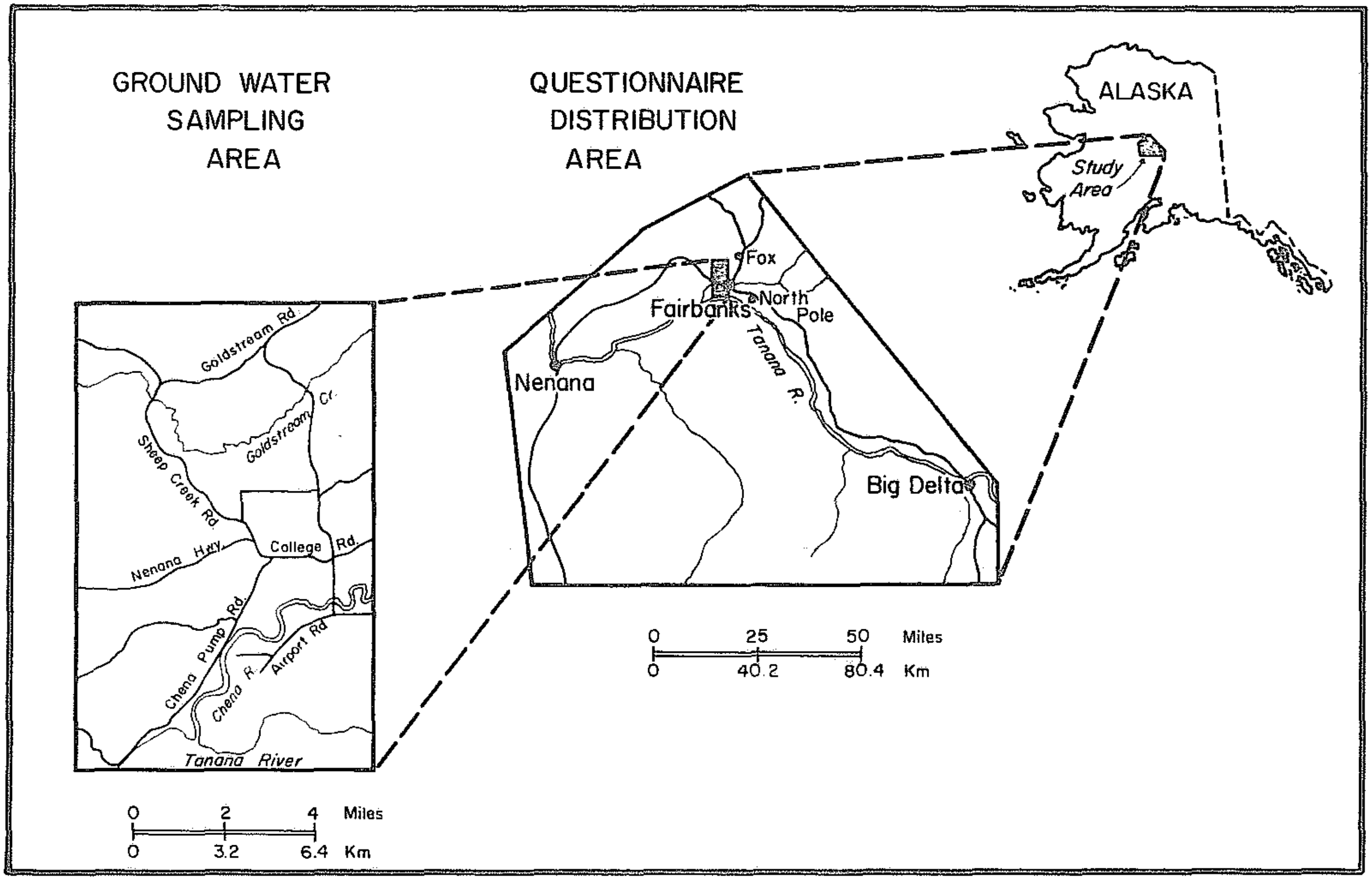

Figure 1: Study Area Location

DESCRIPTION OF STUDY AREA

The population of interior Alaska centers around Fairbanks with population density decreasing rapidly to the north, south and east along the three main highways leading away from the city. The area which was surveyed by the questionnaire included all of the area serviced by the Golden Valley Electric Association, over 8,000 square miles.

The study area lies between 145°50' and 149°20' west longitude and 63°55' and 65°00' north latitude. The communities included in this area are Fairbanks, North Pole, Nenana, Fox, Healy, and Delta Junction. These communities are shown in Figure 1.

The elevation of the study area ranges from 400 feet to over 3,000 feet above sea level northwest of Fairbanks. The area north and west of Fairbanks is hilly with broad valleys filled to depths of 50 to 300 feet with silt, muck and peat over lying beds of coarse gravel 10 to 200 feet thick (Pewe, 1955). The hills are mantled with windblown loess over weathered bedrock (Cederstrom, 1963). The Fairbanks area was not glaciated during the last glacial epoch and is heavily laden with loess. The loess deposits on the north side of the hills are normally shallower and often permanently frozen. The bedrock in these areas consists of well-jointed micaceous schist and isolated masses of granite and basalt. The schist type of bedrock found in several areas of the Tanana-Yukon River basin uplands is termed Birch Creek Schist. It consists of older Precambrian metamorphosed sedimentary rocks of quartzite, quartzite schist, quartz-mica schist, mica schist, feldspathic and chloritic schists, and some carbonaceous and calcereous schist and crystalline limestone (Cederstrom, 1963).

TANANA RIVER VALLEY

The middle Tanana River valley lying between Big Delta to the east and Nenana to the west, is about 50 miles wide and includes an area of about 5,000 square miles. The valley is bordered on the south by the Alaska Range and on the north by rounded hills and ridges. The Tanana River is on the north side of the valley with a wide flood plain subject to annual flooding. From the river to the north the sloping alluvial plain is composed of coalesced silt. The deposits beneath the channels may be unfrozen; however, the alluvium terraces away from the thermal influence of the river are commonly frozen (Williams, 1970). Cederstrom (1963) in evaluating the total ground water resource of the valley, characterized it as "enormous" due to the large storage capacity and high transmissibility of the underlying unfrozen alluvium.

CHENA RIVER VALLEY

The Chena River is located north of the Tanana River and nearly parallel to the Tanana from the confluence to about 25 miles upstream. The Chena River drains an area of about 1,980 square miles. Eielson Air Force Base, Fort Wainwright Army Post, and the City of Fairbanks border the basin. The river originates at an elevation of about 3,600 feet and flows in a westerly direction for approximately 150 miles. The lower 100 miles of the river meander through a broad alluvial valley. The lower materials consist of sand and gravels which are covered by windblown loess. Much of the area is underlain with permafrost (Frey, Muller and Berry, 1970).

GOLDSTREAM CREEK VALLEY

Goldstream Creek is located about 7 miles north of Fairbanks and flows in a westerly direction until it joins the Chatanika River in Minto Flats. The stream is about 70 miles long and drains an area of about 500 square miles with an elevation drop of about 480 feet. The upper one-fifth of Goldstream Creek is included in the study area. The valley is underlain with permafrost and the upper regions have been extensively dredged for gold.

PERMANENTLY FROZEN GROUND

Permafrost is found throughout the study area at varying depths and thickness. Several studies have been conducted examining the distribution of permafrost in the Fairbanks area. The general conclusions concerning permafrost drawn from these studies are as follows:

(1) Frozen ground appears to be thickest in the flat areas: flood plains and at the mouths of creek valleys where ground water movement is minimal and vegetation heavy. It becomes thinner towards the base of south-facing slopes (Pewe, 1955).

(2) South-facing slopes receiving more solar radiation tend to be freer of permanently frozen ground than north-facing slopes.

(3) Areas of low infiltration rates due to silt layers reduce percolation-heating of subsoils and may have more permafrost.

(4) Vegetation in low areas reduces subsurface drainage and returns some moisture to the atmosphere by transpiration.

(5) Downward percolation of snowmelt and summer rains is blocked by permafrost.

(6) Water reaches aquifers only through unfrozen areas that perforate the permafrost (below streams, lakes, summits, slopes of hills, etc.).

Figure 2 is a diagram of the hills and valley areas near Fairbanks. This figure shows locations where water can enter ground water aquifers through unfrozen areas of hills and near streams (Pewe, 1955; Cederstrom, 1963).

HYDROLOGY

The study area has a subarctic, continental climate characterized by long, cold winters with short days and short, warm summers with nearly continuous daylight. Table 1 shows the monthly average, and highest and lowest temperatures recorded for Fairbanks and includes the mean precipitation.

Nearly 70 per cent of the precipitation at Fairbanks occurs as rain during the warmer five months of the year. The average snowfall has been about 70 inches per year between 1951 and 1971. Wind velocities are usually low, averaging about 5 mph out of the north.

TABLE 1: CLIMATOLOGICAL DATA FOR FAIRBANKS, ALASKA*

	Temperature (°F)			Precipitation, inches
Month	Mean 1941-70	Highest Recorded	Lowest Recorded	Mean 1941-70
January	-11.9	47	-66	0.60
February	- 2.5	50	-58	0.53
March	9.5	55	-49	0.48
April	28.9	74	-32	0.33
May	47.3	90	- 1	0.65
June	59.0	96	30	1.42
July	60.7	93	34	1.90
August	55.4	87	23	2.19
September	44.4	84	11	1.08
October	25.2	65	-28	0.73
November	2.8	54	-43	0.66
December	-10.4	58	-62	0.65
Annual	25.7	96	-66	11.22

* From National Oceanic and Atmospheric Administration, Environmental Data Service, 1973.

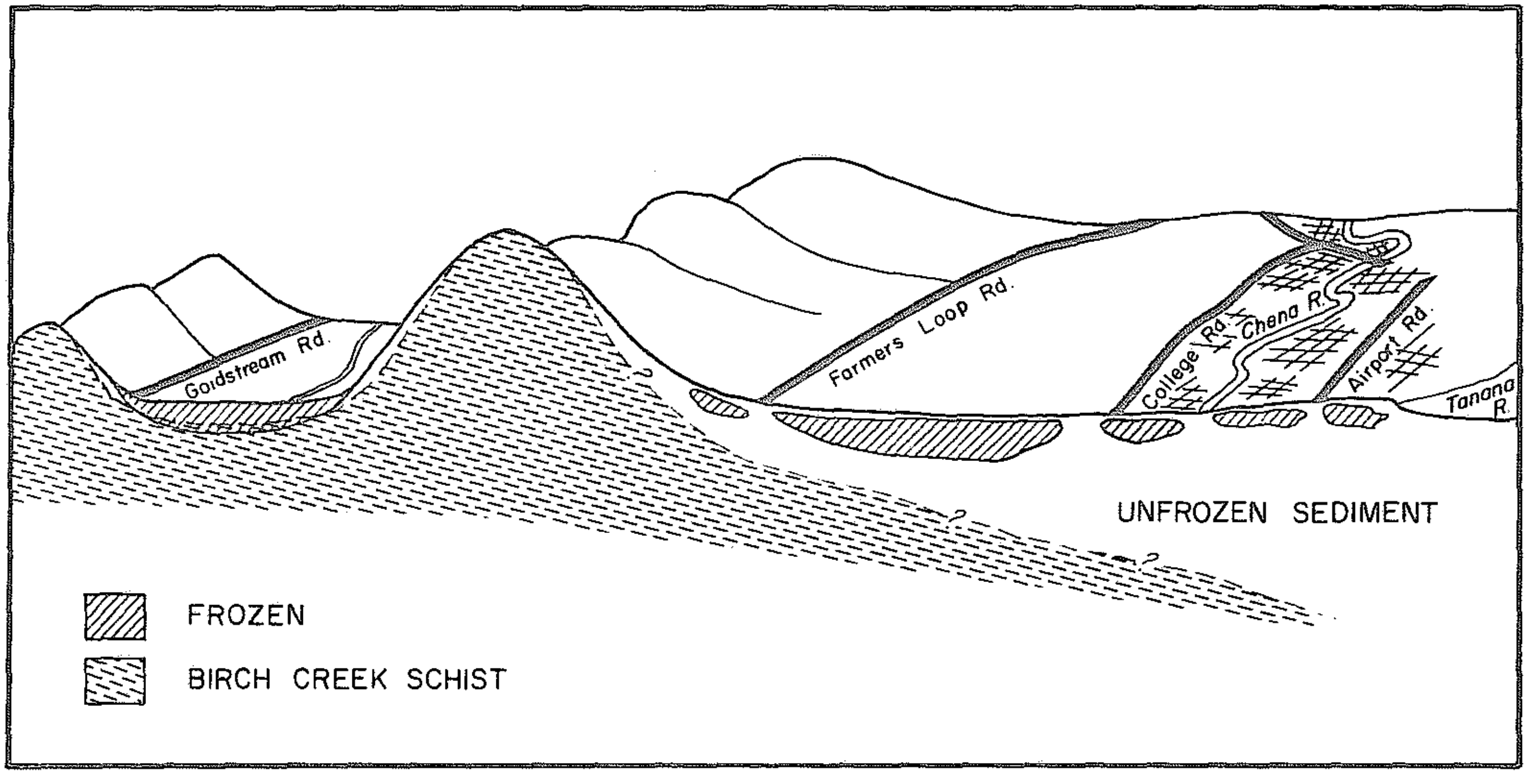

Figure 2: Cross Section of Study Area

Runoff patterns in the interior of Alaska show a peak flow rate in the spring during breakup followed by a decrease in late June and July. In August, high precipitation causes flow to increase in streams and then it gradually declines until the following spring. Snow which has accumulated on frozen ground and runs off during breakup does not usually recharge ground water.

Water which does enter the ground water system can be classified as either suprapermafrost water, that which is perched on an impermeable layer of frozen ground; intrapermafrost water, that which is confined between two frozen layers; and subpermafrost water, that which lies below a permafrost lens. Suprapermafrost water can recharge subpermafrost aquifers by moving to permeable windows in the permafrost. Even after seasonal frost has effectively stopped additions to the suprapermafrost water these waters can continue to recharge low levels. This process is stopped once the seasonal frost reaches the permafrost table.

WATER QUALITY - STREAMS

The water quality in the streams of interior Alaska has been monitored for some time by the U.S. Geological Survey and a number of other investigators including Frey, Mueller, and Berry (1970) and Peterson (1973).

Streams which are glacier-fed, such as the Tanana River, show high turbidity in the summer due to glacial flow and lower turbidity in the fall, winter and early spring. Streams that are not glacier-fed have peak turbidity-loading during breakup. Dissolved materials and conductivity show a pattern which is opposite that of turbidity. The concentration of many of the cations increases through the winter, reaching maximums in February and March (Peterson, 1973; Frey, Mueller, and Berry, 1970). The water making up the winter flows comes from ground water aquifers.

WATER QUALITY - GROUND WATER

Several studies have explored the quality of ground water in permafrost regions. Williams (1965) collected the majority of the information available on ground water in permafrost regions and presented it as an annotated bibliography. Then in 1970, Williams presented a paper discussing what was then known about the ground water in permafrost regions of Alaska. Quality of ground water in the Fairbanks area has been shown to be poor. The U. S. Geological Survey in 1963 published a study of the ground water conditions in the Fairbanks area (Cederstrom, 1963). Data was collected on 417 wells in and around the city and plotted the estimated limits of permafrost underlying the area. Also presented was water quality data on 40 wells. The iron content varied from 0.01 to 43.0 mg/l with an average of 5.97 mg/l. Seventy per cent of the samples exceeded the limits set in the U. S. Public Health Service *Drinking Water Standards* (1962). Manganese was determined in 11 samples and ranged from 0.0 to 4.0 mg/l with an average of 0.9 mg/l. Seventy-three per cent of the samples exceeded the standards. Table 2 summarized the quality data presented by Cederstrom (1965). In 1970, Anderson presented a map of surface and ground water quality in the Tanana River basin. The map included 29 ground water samples showing a general increase in water quality with the distance upstream from Fairbanks.

Loperfido (1968) conducted a study of the dissolved organics in interior Alaskan ground waters using samples collected 4.5 miles north of the Fairbanks area. He stated that the samples of surface runoff water, ground water, and subpermafrost water showed strong similarities among the organics extracted. Based on this similarity, it was hypothesized that dissolved organics in the subpermafrost ground water which he sampled had their origin in the decaying plant and animal material in overlying permafrost-free zones.

TABLE 2

SUMMATION OF ANALYSES OF WATER FROM WELLS IN THE FAIRBANKS AREA (CEDERSTROM, 1965)

	Mean	Maximum	Minimum	USPHS Standards
Depth, ft	119	307	12	*
Silica (SiO_2), mg/l	23	45	10	*
Iron (Fe) (Total), mg/l	5.97	43	.01	0.3
Manganese (Mn) (Total), mg/l	.90	4	0.0	0.3
Calcium (Ca), mg/l	62	144	16	*
Magnesium (Mg), mg/l	21	73	5.1	*
Sodium-Potassium, mg/l	17.6	157	2.6	*
Bicarbonate (HCO_3), mg/l	287	1020	71	*
Sulfate (SO_4), mg/l	46	378	2.7	250
Chloride (Cl), Mg/l	5.8	44	1	250
Fluoride (F), mg/l	.37	1.2	0.0	1.3
Nitrate (NO_3), mg/l	7.2	85	0.0	45
Dissolved Solids ROE @ 180°C, mg/l	318	771	107	500
Hardness ($CaCO_3$), mg/l	273	1220	72	*
Specific conductivity mho @ 25°C	535	2060	159	*
pH	7.2	8.6	6.4	*

*No parameters given for these constituents.

The Fairbanks residents have traditionally used ground water to meet year-round water needs. Historically, ice cut from rivers or lakes or snow was used as a water source during the winter and water hauled from these sources was used during warmer periods. Winter conditions and large ice-flows in the spring effectively prevented the use of surface water as a year-round supply. In 1953, the City of Fairbanks began the installation of a series of wells in the gravel beds under the Chena River (McDonald, 1968). This, couples with a water treatment plant has allowed the city to supply water to its residents on a year-round basis and eliminated the need for individual domestic wells.* The residents in suburban and rural areas still rely on hauled water or wells to meet domestic water needs.

BACKGROUND DATA ON POPULATION

The population of the Fairbanks census division in 1970 was 45,947. The total number of year-round housing units in the division was 12,524, of which 810 or 6.5 % were lacking some plumbing facilities. The census found that 8,309 of the homes were serviced by a public water supply; 3,709 used individual wells; and 519 were using other means of meeting domestic water needs (U. S. Bureau of the Census, 1972). Using census data and adjusting for the area surveyed, 7.2% of the population reported no running water in their homes. In the South Fairbanks area, 12.6% reported no plumbing.

In an opinion poll distributed to the same population considered in this study and also including the population serviced by the Fairbanks Municipal Utilities System the question was asked "Would you be willing to pay more taxes for increases or improvements in city-wide sewer and water systems?" Nearly 43% of those responding to this question were in favor of more taxes for better services. The remaining group indicated they were not willing to pay more for extended services. The areal distribution of responses shown in Table 3 indicates that the majority wanting better services were in or near the larger communities.

* In 1973 the municipal water system served an area of an estimated 2,578 acres with a population of about 17,000 (Linck-Thompson, 1973).

TABLE 3: RESPONSE BY AREA INDICATING WILLINGNESS TO PAY MORE TAXES FOR IMPROVED SEWER AND WATER SYSTEMS

	Fairbanks	North Pole	N. Star Borough	Delta Junction	Nenana	Clear-Anderson	Total
Total Response	1377	66	750	49	50	22	2314
Positive Response	664	16	267	17	17	5	986
Percentage	48	24	36	35	34	23	42.6

(Swanson, Matthews, and Morgan, 1972)

DATA ACQUISITION TECHNIQUES

GROUND WATER SURVEY

Surveys fall into two broad categories; comprehensive surveys designed to check hypotheses which are carefully designed with regard to statistical inference and limited surveys which serve to establish an information base of limited scale and scope (Lansing and Morgan, 1971). This survey was of the latter nature due to the type of information sought as well as budgetary constraints.

The study area was limited to the area outside the Fairbanks Municipal Utilities System which closely correlates with the division between municipal water service and rural areas. The electric association serving the outlying areas graciously provided a mailing list of all residential units in the area which were on the electric service, a total of 6,015 units covering an area of over 8,000 square miles. Since it was feasible to process this number, the complete population was sent survey forms.

The survey form was divided into four sections (see Appendix A). The first section sought information on the source of the water supply. This section asked for information on the method of obtaining domestic water supplies and details with regard to well parameters such as depth and diameter.

The second section dealt with the general acceptability of the water to the consumer. Particular concern in Section 2 was directed toward quality and quantity problems. Section 3 was concerned with the treatment systems being utilized, information on types of treatment units being of prime importance. The last section dealt with the vague area of maintenance costs and a subjective estimation of certain aesthetic values ascribed to the quality of the water.

The information on the returned survey forms was transferred to computer data cards through a coding format. For the purposes of response identification, two coding numbers were assigned to each unit: One an alphabetically sequenced number for individual identification and the other a location number assigned by the Golden Valley Electric Association.

GROUND WATER SAMPLING AND ANALYSES

Time and cost constraints required a reduction in the area considered for well water sampling. Therefore, a portion of the survey area which included the various geological formations shown in Figure 2 was selected for this portion of the study (see Figure 1). Selected respondents to the survey form in the sampling area were contacted and, if they were willing, a water sample was collected from their well. All samples were collected in one-quart containers after flushing the well for several minutes. In most cases, it was unlikely that the aquifer had been adequately pumped to derive a truly fresh sample. Frequently samples were obtained by leaving the container with the resident and arranging to have the sample picked up. Many of the samples were exposed to at least several hours of light and heat before storage in laboratory refrigerators, and therefore, may be somewhat low in value for NO_2/NO_3.

Determination of NO_2/NO_3 was by the hydrazine reduction method as outlined for automated analysis in *EPA Methods for Chemical Analysis of Water and Wastes* (1971). Color was determined by platinum standards as per *Standard Methods* (1971). The high buffering capacity of these waters precluded buffering to a common pH. Consequently, the occurring pH of the centrifuged samples was recorded.

The iron, manganese, calcium and magnesium were determined using atomic adsorption spectrophotometry techniques (*Methods for Chemical Analysis of Water and Wastes*, 1971). Total alkalinity and specific conductance was determined following *Standard Methods* (1971).

RESULTS

The results are presented in five parts. First, the results of the ground water quality survey are presented and discussed. The second section is a discussion of estimated costs of various water supply alternatives and cost of poor water quality. The third section presents the results of the ground water-sampling program that was conducted in the reduced area shown in Figure 1. Next, the responses to the survey form are compared with the chemical analyses of the well waters samples. The last part of the results (Appendix C) is a discussion of the ion specific electrodes for sampling ground water at remote locations.

GROUND WATER SURVEY

For purposes of evaluation and presentation, the study area was divided into 14 subareas. Figure 3 identifies the subareas used for discussing and plotting of the results. Table 4 lists the response to the questionnaire by area. Of the 6,015 survey forms distributed, 20.9% or 1,260 were returned adequately filled out. It is likely that the data obtained was biased since persons having water problems are more likely to have an interest in participating in such a study. Metcalf and Eddy (1972) found a positive correlation between number of responses and mineral content of water.

Other surveys of the mailed form type conducted in the same study area have shown excellent results. The Tanana Valley Opinion Poll (Alaska Cooperative Extension Service, 1972) which surveyed the opinion on community services resulted in a 21.5% return for the same area. Metcalf and Eddy (1972),

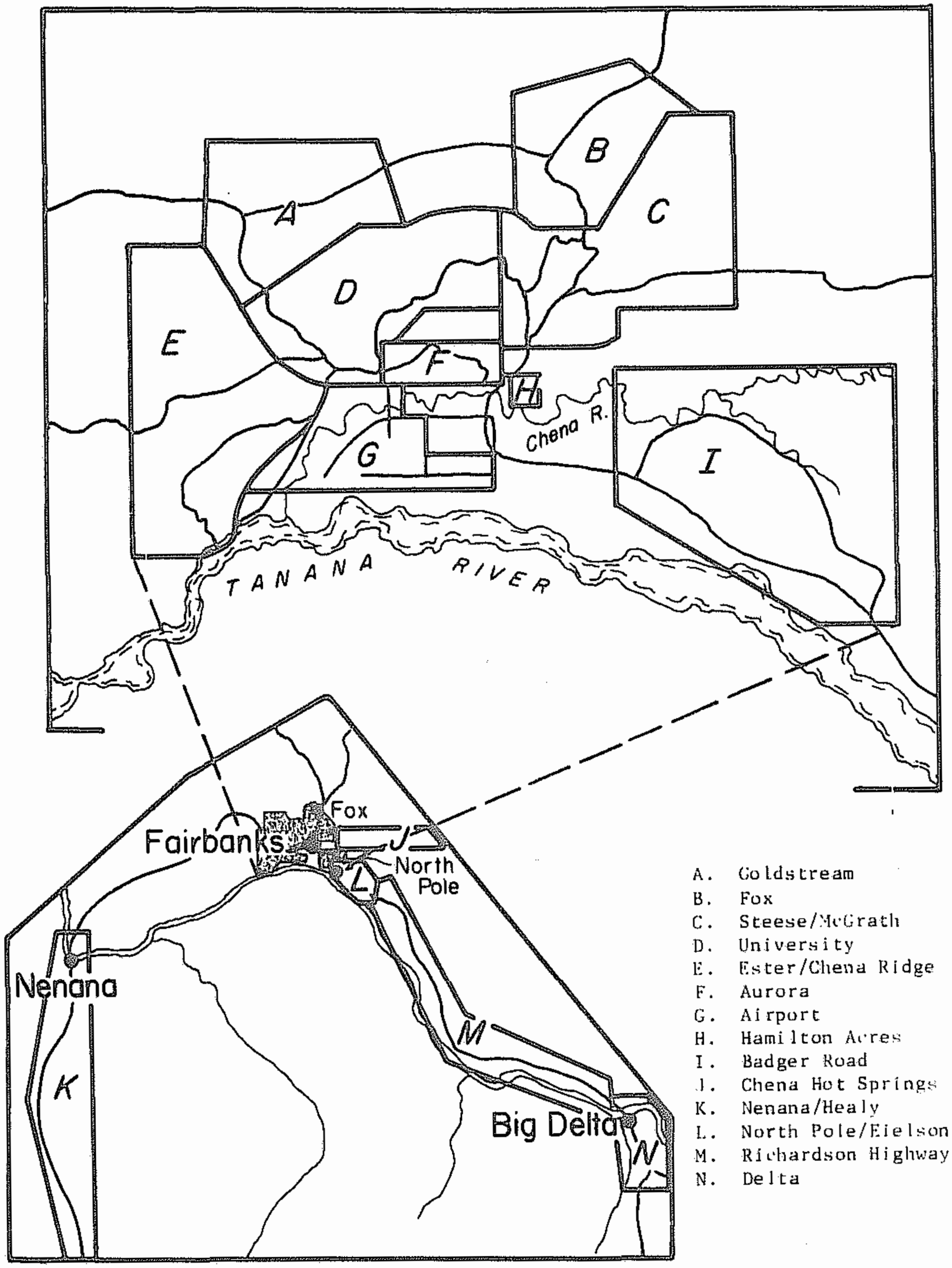

Figure 3: Subarea Identification Map

in a survey directed at the value of water in ten different communities in the contiguous states received responses at the rate of 27% with the range being 13 to 50%.

TABLE 4: AREAL RESPONSE TO GROUND WATER QUALITY QUESTIONNAIRE

Area	Questionnaires Distributed	Questionnaires Received	Per Cent Returned
Airport	1132	203	17.9
Badger Road	507	90	17.7
Chena Hot Springs Road	149	41	27.5
Delta	241	58	24.1
Ester-Chena Ridge	257	78	30.4
Fox	75	11	14.7
Goldstream	81	27	33.3
Hamilton Acres	789	143	18.1
Lemeta-Aurora	913	156	17.1
Nenana-Healy	318	65	20.4
North Pole-Eielson	355	69	19.4
Richardson Highway	346	61	17.6
Steese-McGrath	521	133	25.5
University	331	125	37.8
Totals	6015	1260	Avg. 20.9

The survey results summarized in Table 5 show the areal distribution of response by number returned having wells. Generally, the per cent returned was between 12 and 20. The university subarea was the highest outside this range with nearly 30 per cent return and Hamilton Acres was

TABLE 5: SUMMARY OF RESPONSES TO SURVEY FROM ON GROUND WATER

Subarea Name	Number Of Responses With Wells	Percent Reporting Problem with the Indicated Parameter								Percent Having	
		Quantity	Quality	Iron	Color	Taste	Odor	Suspended Matter	Corrosion	Softener	Filter
Airport	137	9.5	59.9	59.1	32.8	37.2	30.4	13.9	24.1	47.9	45.4
Badger Road	115	0.0	53.1	51.3	22.6	33.9	29.6	15.7	22.6	28.1	31.5
Chena Hot Springs Rd.	35	2.9	17.1	25.7	11.4	14.3	5.7	5.7	2.9	17.1	8.6
Delta	52	2.0	3.8	5.8	0.0	1.9	0.0	3.8	13.5	3.8	1.9
Ester-Chena Ridge	51	5.9	33.3	43.1	11.8	17.6	17.6	7.8	29.4	33.3	43.1
Fox	10	0.0	70.0	60.0	40.0	50.0	50.0	30.0	10.0	50.0	70.0
Goldstream	20	15.0	30.0	20.0	0.0	5.0	5.0	15.0	10.0	35.0	60.0
Hamilton Acres	25	4.0	56.0	56.0	20.0	44.0	36.0	12.0	20.0	44.0	44.0
Lemeta-Aurora	138	11.6	80.4	80.4	57.2	55.8	61.6	23.9	45.6	56.5	56.5
Nenana-Healy	60	8.3	35.0	33.3	25.0	25.0	20.0	8.3	26.7	25.0	10.0
North Pole-Eielson	60	5.0	31.7	33.3	15.0	13.3	13.3	6.7	23.3	13.3	8.3
Richardson Hwy.	45	4.4	31.1	37.7	17.8	17.8	20.0	6.7	22.2	11.1	11.1
Steese-McGrath	98	16.3	27.6	27.6	10.2	12.2	8.2	9.2	10.2	25.5	17.3
University	100	16.0	25.0	22.0	8.0	16.0	7.0	12.0	17.2	30.0	37.0
Hauling	94										
System	220										
Total	1260										

the lowest at 3.1 per cent. The low return in the Hamilton Acres area is related to the high percentage of that area serviced by the city system.

A number of the respondents, 220, indicated that their source of water was either a public or privately operated water system. A total of 23 community water systems were reported in the survey area. Also, 94 respondents reported their water was hauled, either by commerical or private means. This is nearly 7.5% of those responding to the survey. This number corresponds well with the 7.1% reported by the Bureau of Census (1972) for the same general area.

Well Depth and Diameter

The first parameter of interest in discussing the wells in different areas is the relative depth to an acceptable aquifer and the diameter used. Depths of wells reported by those surveyed ranged from 8 to 640 feet. Table 6 summarizes well depth data in increments of 20 feet for the fourteen subareas. Table 9 at the end of this section identifies the figures in Appendix D where detailed information on the well depths reported in each subarea can be found.

Interpretation of the depth information in Table 6 must be tempered by close examination of the figure showing the actual well depths and general topography of the subarea. For example, the Fox subarea includes an extensive region of higher relief and an area of lower, relatively flat valley floor; consequently two separate groups of well depths were reported: one group reporting wells in the range of 60 to 180 feet and the other reporting well depths in the range of 240 to 360 feet. As more information on the transition areas becomes available, some type of relationship between location and depth may be possible. For the present, the applicable figures in the appendix should provide prospective developers and home-owners a means of estimating the well depth needed at various locations in the Interior.

TABLE 6: NUMBER OF WELLS REPORTED AT INDICATED DEPTHS BY SUBAREA

Well Depth Feet \ Subarea name	Airport	Badger Road	Chena Hot Springs Road	Delta	Ester-Chena Ridge	Fox	Goldstream	Hamilton Acres	Lemeta-Aurora	Nenana-Healy	North Pole-Eielson	Richardson Highway	Steese-McGrath	University
0–20	15	14	1	2	1			2	11	19	12	8		
20–40	62	69	4	11				4	54	28	43	22		
40–60	72	7	4	5	2			4	21	2	2	9	1	2
60–80	11	6		4		2		7	10			2	4	9
80–100	13	2	1	2	1	1		2	8				9	6
100–120	7	3	3	7	3	1			4		2	2	9	11
120–140	2		2	5	4			1	3	1			5	9
140–160	2		8	5	2	2	2		3	2			9	12
160–180	2		3	1	4	1			2	1		1	9	6
180–200	1		2	4	5		2						10	2
200–220			1	1	7		2			2			8	6
220–240				1	1		1		1				9	4
240–260		3			3	1	1			1			6	7
260–280			2	3		1	3						4	7
280–300			2	1	5		2		1				2	4
300–320			1					1					3	2
320–340					2		1							4
340–360					2	1	3						1	1
360–380			1				2						1	1
380–400					2								1	3
400–420					2								1	
420–440					1		1						1	
440–460													1	1
460–480														
480–500	1												1	
500+					2				1				1	
Depth Not Reported	14	6	0	0	2			4	19	4	1	1	2	3

The reported well diameters in the subareas are presented in Table 7. The diameter selected is related to the depths needed, the equipment of the driller and the type of subsurface material. Generally, in the valley areas where a very shallow water table exists, the wells are of small diameter. In the outlying areas 1 or 2-inch diameter wells were commonly reported. In the hills 4 and 6-inch wells were more common.

TABLE 7: REPORTED DIAMETER OF WELLS IN SUBAREAS OF SURVEY

Subarea	Well Diameter Reported								
	NR	1"	2"	3"	4"	5"	6"	7"	8"
Airport	25	14	53	7	7	3	27		4
Badger Road	23	9	60	7	5		7		1
Chena Hot Springs Rd.	3	2	3	1	11		14		1
Delta	2		4	2	5	3	35		1
Ester-Chena Ridge	6		4	1	12	2	25		
Fox	1				3	1	4		1
Goldstream					3		16		1
Hamilton Acres	7	1	13	2	1		1		
Lemeta-Aurora	8	10	61	10	6	1	7	1	
Nenana-Healy	11	22	14	3	1	2	7		
North Pole-Eielson	8	14	35	1			1		1
Richardson Highway	5	6	24	5	2		3		
Steese-McGraty	8		5	2	17	4	54		8
University	14	16			29	3	37		1

Quantity

Table 5 shows the per cent of the respondents with wells which did not produce an adequate quantity of water. The per cent by subarea indicating this problem ranged from 0.0 to 16.3. The overall percentage of all those with wells was 8.46. The subareas with the greatest problem were Steese-McGrath, University and Goldstream. These areas are in the higher regions and, generally, have the deepest wells. The aquifers in these areas are relatively undefined and the source of the water being removed from under the higher areas is not understood at present.

Quality

Dissatisfaction with the quality of well water was expressed widely. General quality problems were reported by 43.6% of those responding to the survey. Over 50% of the respondents in five subareas reported a problem with the quality of their ground water supply. Figure 4 shows these subareas with the shaded areas being those reported with a quality problem by over 50% of the respondents. The per cent indicating a quality problem is greater in the valley areas than in the hill areas. The following discussion covers particular quality problems indicated by those responding to the survey.

Iron

The responses show that iron is a very serious problem with interior ground water. The areal per cent indicating a problem with iron was 43.8. The most serious problem was reported by the Lemeta-Aurora subarea with over 80% of the responses indicating an iron problem. Responses from the Airport, Hamilton Acres, and Badger Road subareas indicated that over 50% of the water supplies has an iron problem. The shaded area in Figure 5 indicates the subareas with over 50% reporting an iron problem.

In order to delineate the iron problem more clearly, information was compared between those who reporting iron and also reporting color, taste, and odor. Table 8 summarizes the results by subarea. In general, a response

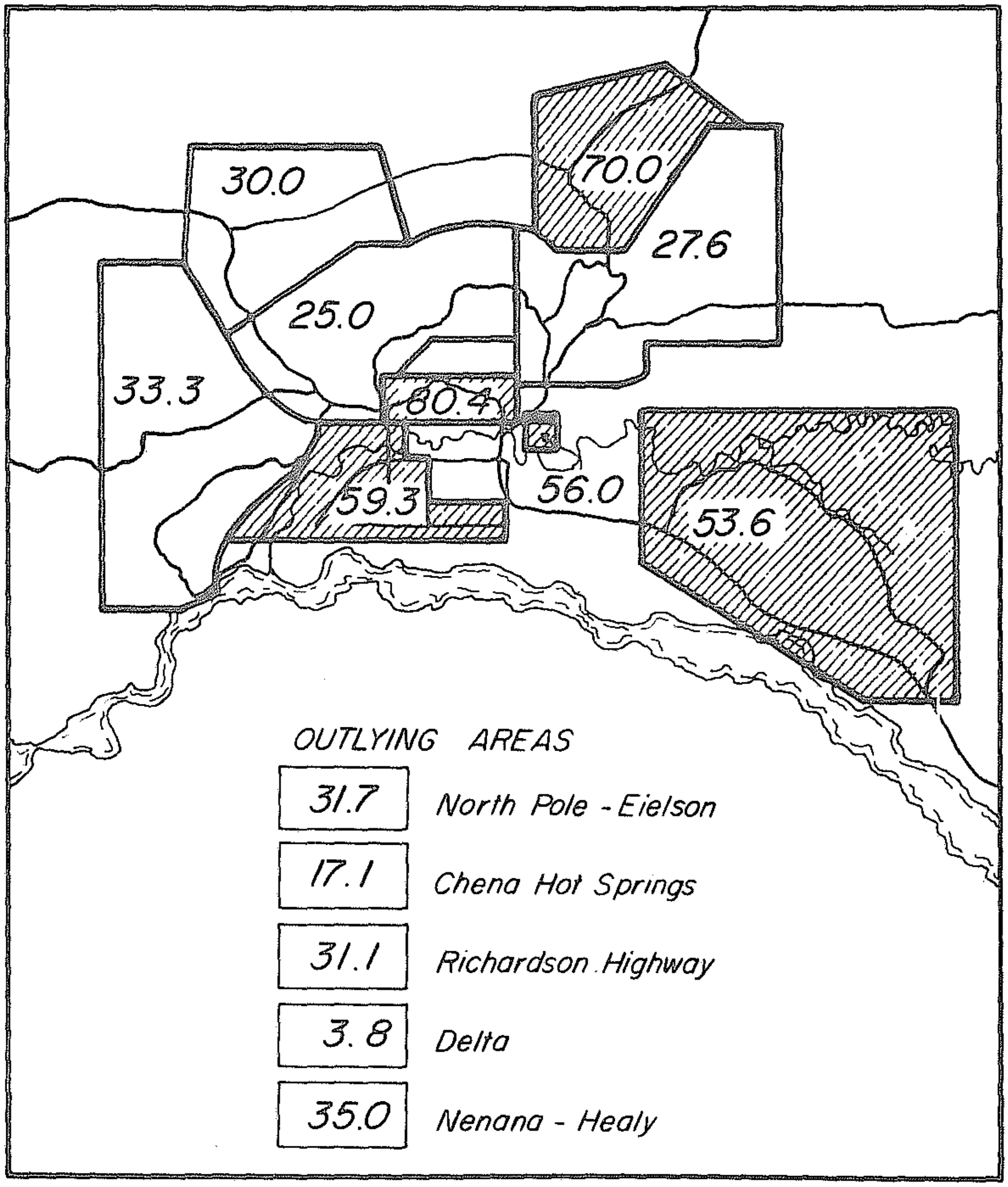

Figure 4: Per Cent of Responses Indicating a Ground Water Quality

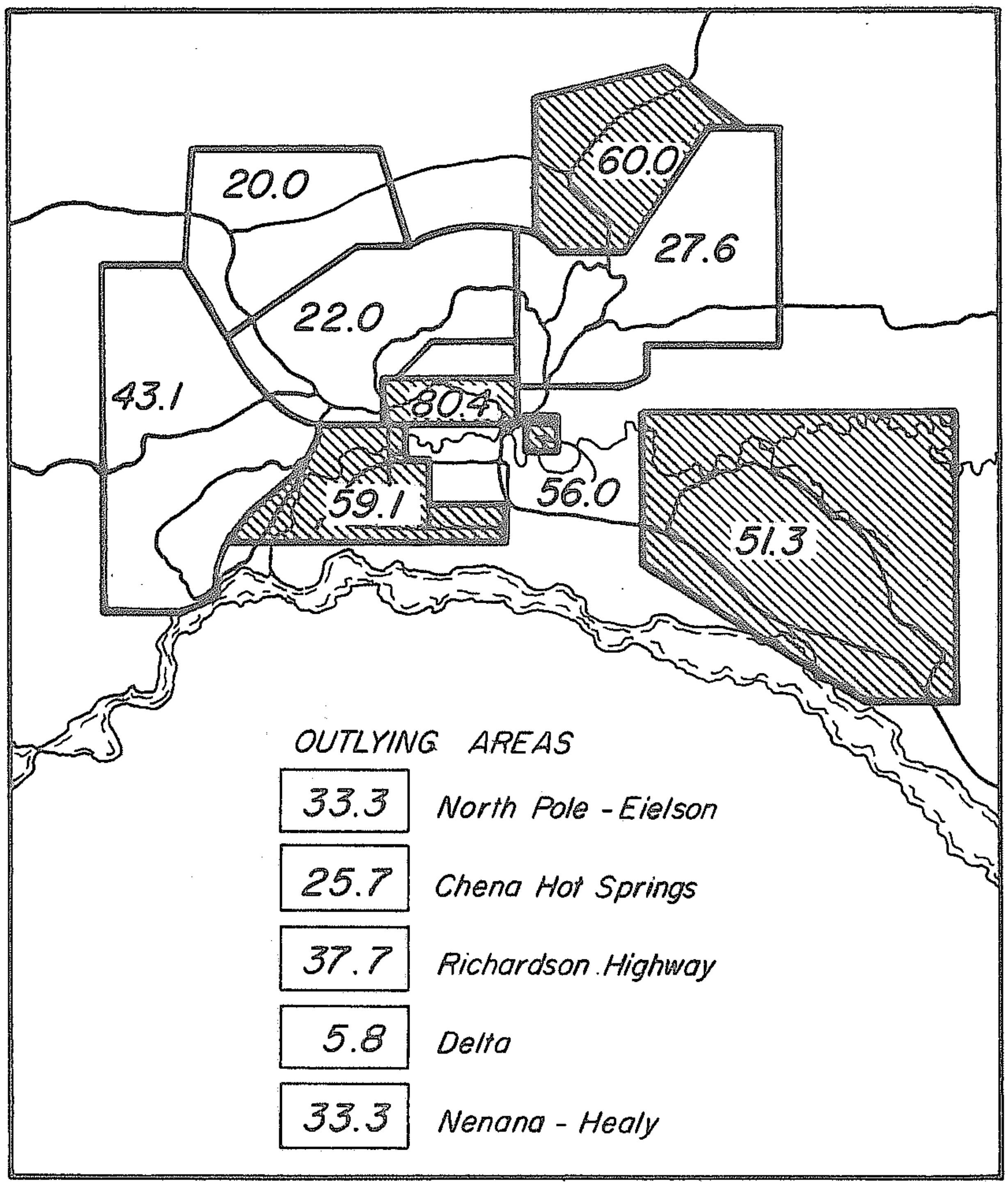

Figure 5: Per Cent of Responses Indicating a Ground Water Quality Problem with Iron.

TABLE 8: PER CENT OF RESPONSES INDICATING A QUALITY PROBLEM WITH TWO PARAMETERS

Subarea	Number Indicating Iron	% Indicating Iron Also Indicating			Number Indicating Color	% Indicating Color Also Indicating			Number Indicating Taste	% Indicating Taste Also Indicating			Number Indicating Odor	% Indicating Odor Also Indicating		
		Color	Odor	Taste		Iron	Odor	Taste		Iron	Color	Odor		Iron	Color	Taste
Airport	81	52.4	50.0	61.7	45	88.9	64.4	75.6	51	98.0	65.4	73.1	43	95.3	67.4	88.4
Badger Road	59	41.4	55.2	56.9	26	92.3	73.1	80.8	39	86.8	55.3	71.1	34	94.1	55.9	79.4
Chena Hot Springs Road	9	44.4	22.2	55.6	4	100.0	50.0	100.0	5	100.0	80.0	40.0	2	100.0	100.0	100.0
Delta	3	0.0	0.0	33.3	0	*	*	*	1	100.0	0.0	0.0	0	**	**	**
Ester-Chena Ridge	22	27.3	40.9	36.4	6	100.0	83.3	83.3	9	88.9	55.6	66.7	9	100.0	55.6	66.7
Fox	6	50.0	66.7	33.3	3	100.0	66.7	66.7	5	40.0	40.0	80.0	5	80.0	40.0	80.0
Goldstream	4	0.0	0.0	0.0	0	*	*	*	1	0.0	0.0	100.0	1	0.0	0.0	100.0
Hamilton Acres	14	28.6	50.0	64.3	5	80.0	80.0	100.0	11	81.8	45.5	72.7	9	77.8	44.4	88.9
Lemeta-Aurora	111	69.4	73.9	67.6	79	97.5	81.0	75.9	77	97.4	77.9	88.3	85	96.5	75.3	80.0
Nenana-Healy	20	75.0	55.0	70.0	15	100.0	60.0	86.7	15	93.3	86.7	66.7	12	91.7	75.0	83.3
North Pole-Eielson	20	35.0	35.0	40.0	9	77.8	33.3	44.4	8	100.0	50.0	62.5	8	87.5	37.5	62.5
Richardson Hwy.	17	35.3	47.1	35.3	8	75.0	62.5	75.0	5	75.0	75.0	87.5	9	88.9	55.6	77.8
Steese-McGrath	27	33.3	25.9	33.3	10	90.0	40.0	50.0	12	75.0	41.7	50.0	8	87.5	50.0	75.0
University	22	36.4	31.8	50.0	8	100.0	75.0	75.0	16	68.8	37.5	37.5	7	100.0	85.7	85.7
Overall Percentage		49.6	52.3	55.9		94.5	69.7	75.7		89.9	64.0	72.9		93.5	65.5	81.0

* Color Not Indicated
** Odor Not Indicated

indicating an iron problem did not necessarily also indicate a color, taste, or odor problem. The percentages for the iron and other constituent problems were near 50%. The areas of Lemeta-Aurora and Nenana-Healy had a significantly higher relationship between an indicated iron problem and a problem with the three other constitutents. The Delta and Goldstream areas had extremely low correlations.

Color

The true color of water and the iron induced or apparent color are often confused by the casual observer. However, apparent color is a very important parameter to the overall potability of water. Table 5 shows that a significant number (23% overall) of the respondents reported color as a problem in their well water supply. Color in the Lemeta-Aurora subarea was reported by 57.2% of the responses from that area. The remainder of the subareas ranged from 0 to 30.1% in reporting color as a problem. Figure 6 shows the per cent of the respondents indicating color by subareas.

Table 8 shows the relationship between those indicating color as a problem and indicating a problem with iron, odor, or taste as well. The correlations between color and iron are very high with an overall rate of 94.5%. The color-odor and color-taste relationships are significant at 69.7 and 75.7%, respectively. These correlations indicate a definite tie between an apparent color problem and an iron problem for the consumer. Also, more responses stated a relation between color, odor, and taste.

Taste and Odor

Taste and odor are, to the consumer, two of the most important characteristics of water. Of those responding to the survey, 24.5% reported an odor problem and 27.2% reported a taste problem. The

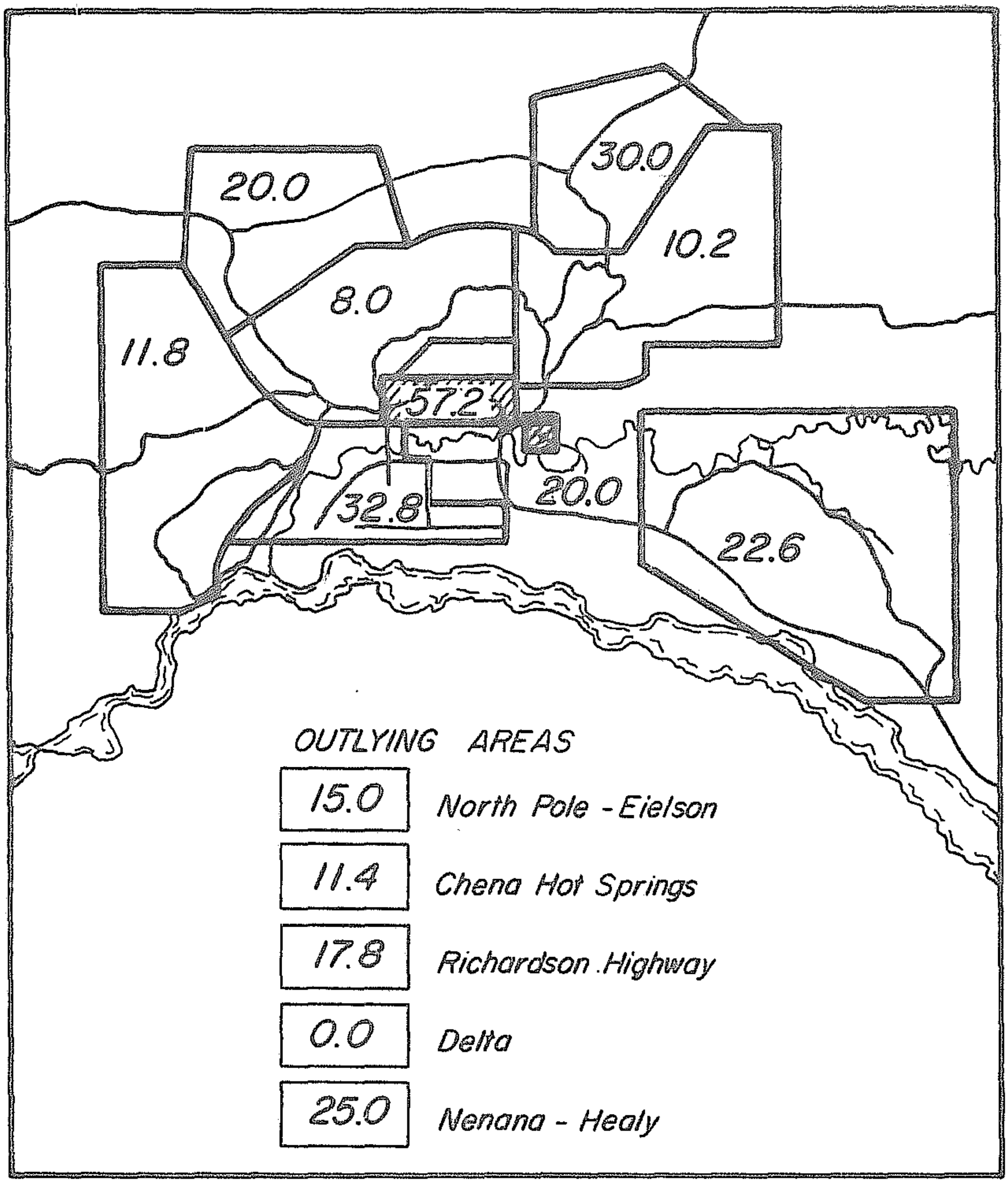

Figure 6: Per Cent of Responses Indicating a Ground Water Quality Problem with Color.

areal distributions of the problems are shown in Figures 7 and 8, respectively. In both cases, the Lemeta-Aurora subarea was the most serious with 61.6% reporting odor and 55.8% reporting taste. Table 8 gives the percentages of those that indicated taste or odor and one of the other constituents. In both cases, the strongest correlation is with iron. The Goldstream and Delta subareas are relatively free of taste and odor problems. Ester-Chena Ridge and the University subareas reported low taste and odor problems; however, those with either a taste or odor problem were very likely to have an iron or color problem.

Suspended Matter

Suspended matter is a much less serious problem than other quality parameters. About 12.7% of the respondents reported the problem. The Fox subarea had suspended matter reported by 30% and in Lemeta-Aurora, by 23.9%. The other areas reported the problems at a rate of 3.8 to 18.0%. In comparing those reporting suspended matter in their water with those reporting an iron problem it was found that 84% of those with suspended matter reported iron as well.

Corrosion

Corrosive water appears to be a relatively serious problem with 23.2% of those responding indicating a problem. However, the exact nature of the corrosion problem was not defined by the survey results. The Lemeta-Aurora area was again the area with the highest per cent, 45.6, reporting the problem. The remaining subareas reported corrosion problems at rates from 10.0 to 29.4%.

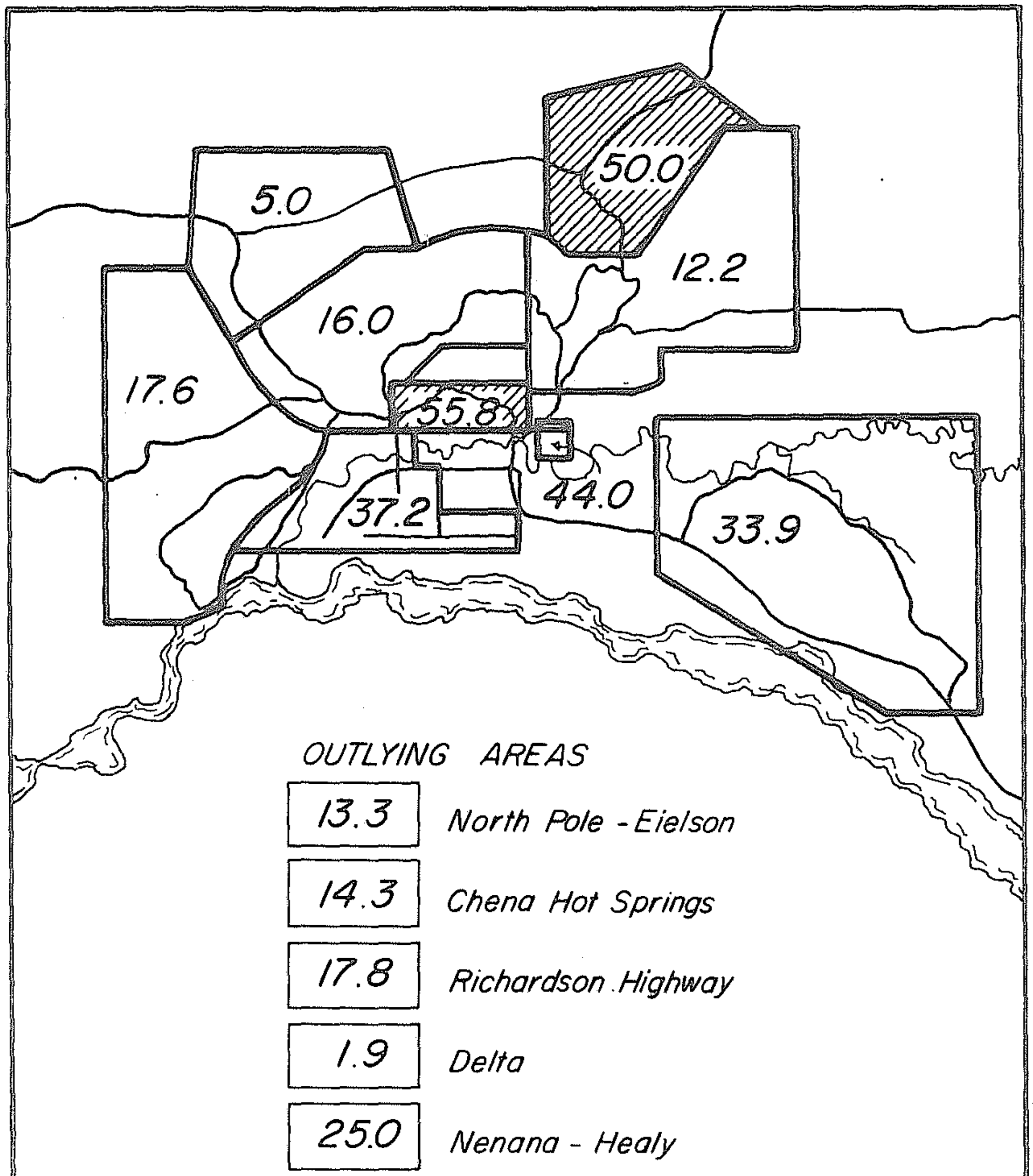

Figure 7: Per Cent of Responses Indicating a Ground Water Quality Problem with Taste.

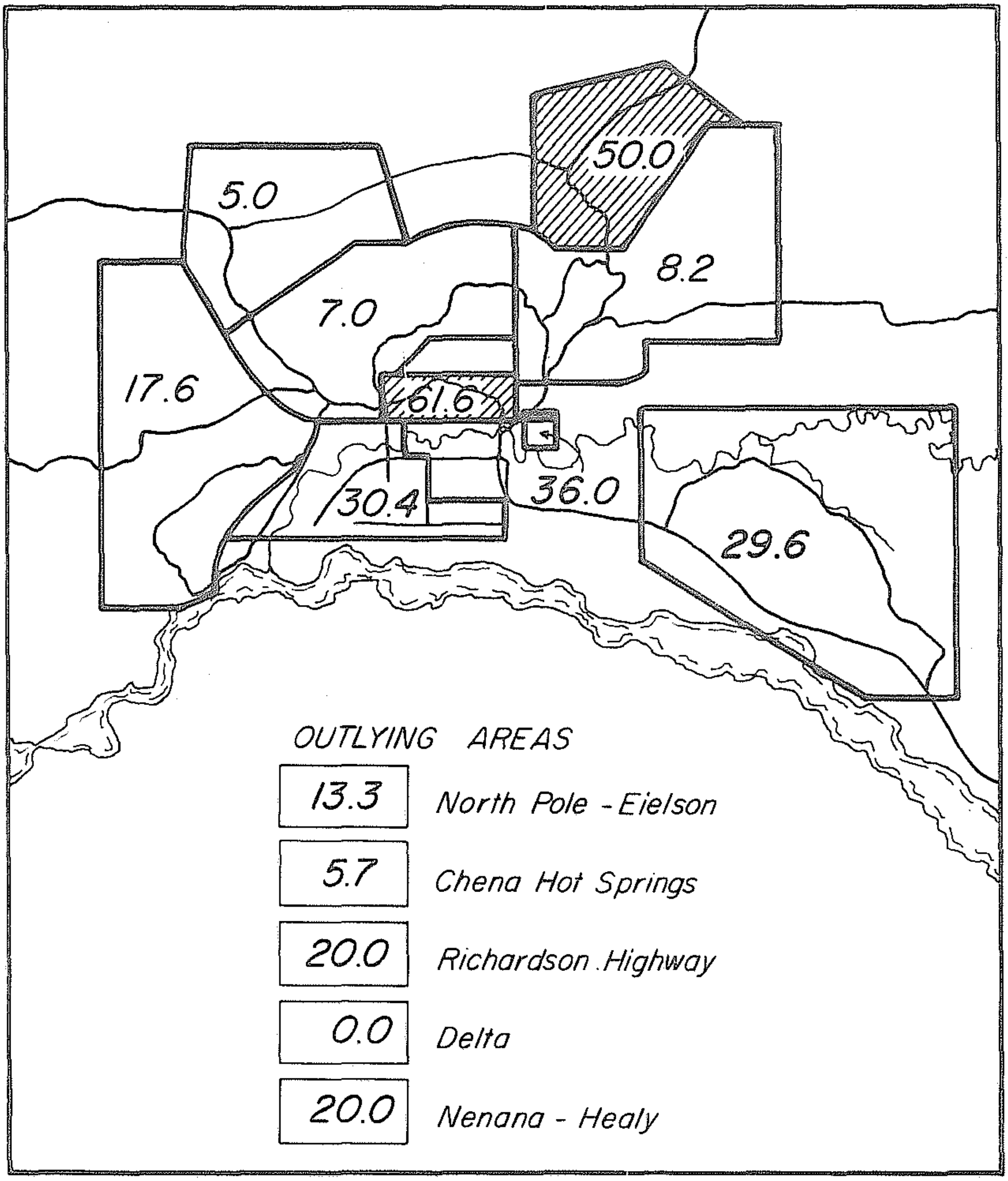

Figure 8: Per Cent of Responses Indicating a Ground Water Quality Problem with Odor.

Softeners and Filters

The quality of ground water in the Fairbanks area is less than ideal with respect to iron and hardness. As a result of this, many home owners have installed softeners for removing hardness and filters for trapping iron. A total of 312 (24.8%) respondents indicated they used a softener and 308 (24.4%) indicated that a filter was used. Table 5 summarizes the responses by subareas. The lower areas reported greater use of home treatment devices than the higher elevations. Generally, the areal concentration of use of these two treatment devices decreases greatly outside of the immediate Fairbanks area as do the reported quality problems.

TABLE 9: DETAILED INFORMATION ON SUBAREAS FIGURE IDENTIFICATION

Subarea	Figure Numbers for				
	Well Depths	Iron	Color	Taste/ Odor	Softeners/ Filters
Airport	14	15	16	17	18
Badger Road	19	20	21	22	23
Chena Hot Springs Rd.*	-	-	-	-	-
Delta*	-	-	-	-	-
Ester-Chena Ridge	24	25	26	27	28
Fox	29	30	31	32	33
Goldstream	34	35	36	37	38
Hamilton Acres	39	40	41	42	43
Lemeta-Aurora	44	45	46	47	48
Nenana-Healy*	-	-	-	-	-
North Pole-Eielson	49	50	51	52	53
Richardson Hwy.*	-	-	-	-	-
Steese-McGrath	54	55	56	57	58
University	59	60	61	62	63

*Not plotted

GROUND WATER ANALYSES

A total of 83 ground water samples were collected in the study area. The topography in the sampling area ranged from the relatively flat flood plain areas near the confluence of the Chena and Tanana Rivers to the higher relief areas of Chena Ridge, the University area and the west side of Goldstream Valley. The location of wells sampled is shown in Figure 9. This region includes the major types of geologic conditions present in the area as shown in Figure 2.

In addition to the samples analysed as part of this project, data from the U. S. Geological Survey and the Arctic Health Research Center were included (see Table 10). The addition of this information brought the total separate wells sampled to 106 with a total of 109 sets of analyses. The following discussion summarizes the quality conditions observed. This information is also graphically presented in Figure 10.

Electrical Conductivity

For 95 samples from the study area, the electrical conductivity ranged from 82 to 2060 micromhos with a mean value of 650 micromhos. These values are within the range normally expected in ground waters. Using an estimated factor of 0.6 (Johnson, 1966) for relating conductance to dissolved solids, the values range from 49 to 1236 mg/l with a mean value about 390 mg/l.

Alkalinity

Alkalinity values ranged from 0 to 1020 mg/l with a mean value of 343. This covers the complete range expected for alkalinity in natural water according to Hem (1970).

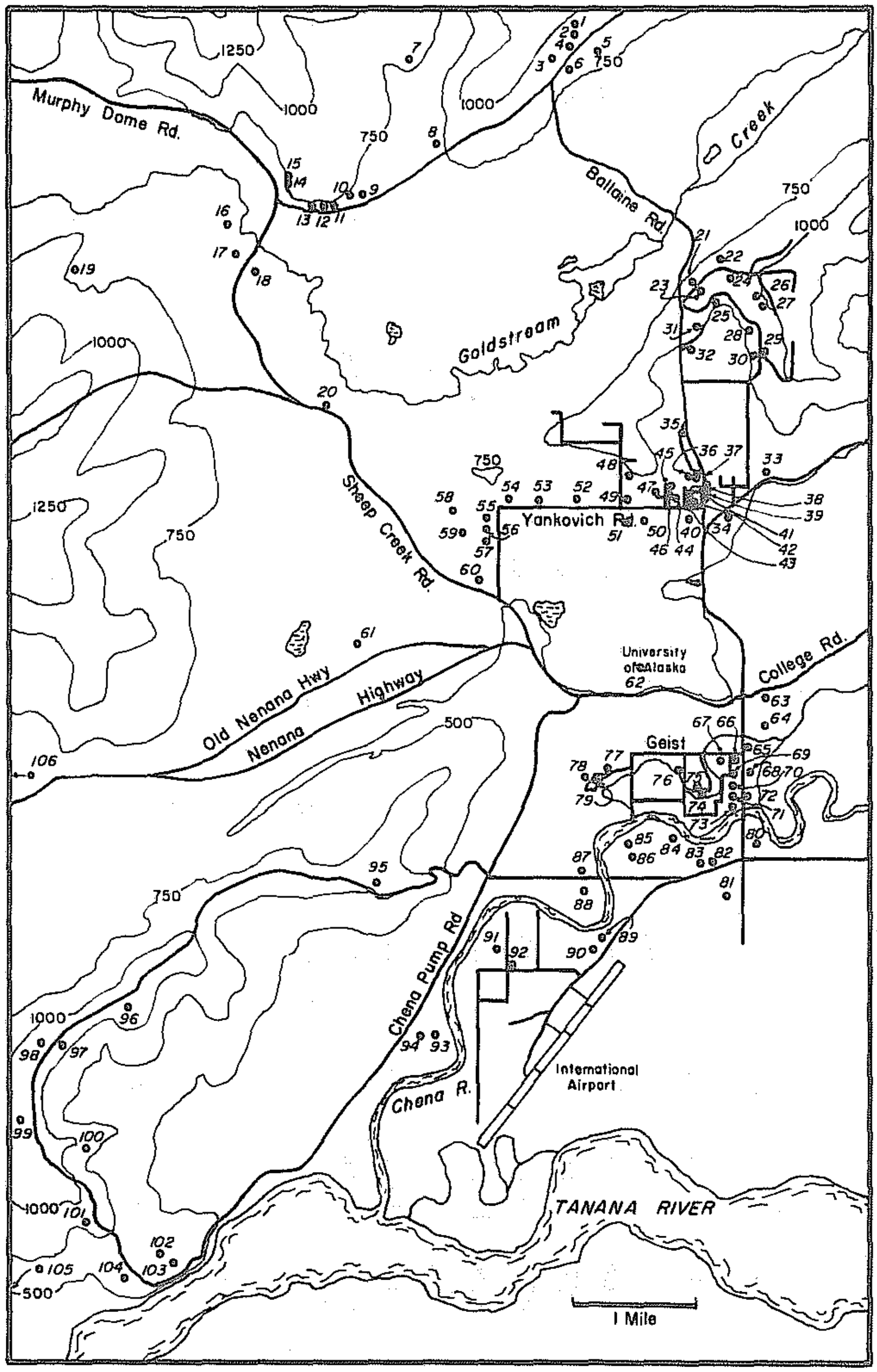

Figure 9: Location and Identification of Wells Sampled.

TABLE 10: ANALYSES OF WELL WATER SAMPLES

Well Number	Data Source	Date	Depth	Alkalinity as HCO_3^- mg/l	EC vmho	Calcium mg/l	Magnesium mg/l	Total Iron mg/l	Manganese mg/l	$NO_2^- + NO_3^-$ as N mg/l	Color
1	IWR	6-73	275	137	248	29	9	0.1	0.0	0.0	0
2	IWR	6-73	345	197	470	54	26	3.1	0.11	0.0	0
3	IWR	10-73	300	442	730	80	44	0.0	0.0	-	0
4	IWR	6-73	160	342	865	74	44	0.0	0.02	15.3	0
	USGS	7-69	-	493	-	95	48	0.60	0.03	44.0	10
5	USGS	9-66	190	274	581	25	47	1.41	-	16.0	0
6	IWR	10-73	-	783	1590	100	2	3.6	0.9	0.8	0
7	IWR	6-73	357	168	780	100	18	0.0	0.4	0.0	0
8	IWR	6-73	202	199	351	53	16	0.1	0.0	0.7	0
	USGS	9-66	-	208	354	44	17	0.25	-	3.1	0
9	IWR	6-73	240	217	392	41	21	15.0	0.50	0.0	0
10	IWR	6-73	150	492	802	89	33	0.0	0.0	0.8	0
11	USGS	9-66	-	524	866	41	90	1.81	-	12.0	0
12	IWR	6-73	185	442	573	98	26	4.1	0.63	0.0	30
13	IWR	6-73	350	93	265	25	10	4.15	0.51	0.0	0
14	IWR	6-73	380	0	209	3.4	5	0.3	0.42	2.2	0
15	IWR	6-73	337	187	-	40	16	0.1	0.0	0.1	70
16	IWR	6-73	254	267	571	56	32	1.8	1.65	1.1	0

TABLE 10: ANALYSES OF WELL WATER SAMPLES (Continued)

Well Number	Data Source	Date	Depth	Alkalinity as HCO_3^- mg/l	EC νmho	Calcium mg/l	Magnesium mg/l	Total Iron mg/l	Manganese mg/l	$NO_2^- + NO_3^-$ as N mg/l	Color
17	IWR	6-73	330	205	783	64	6	6.5	0.25	1.1	0
18	IWR	6-73	150	379	962	136	51	35.0	1.65	0.9	0
19	IWR	6-73	124	0	82	1.6	3	6.6	0.42	0.0	0
20	IWR	6-73	300	436	845	75	54	6.48	0.33	0.0	0
21	IWR	6-73	220	181	298	38	15	0.0	0.05	0.4	-
22	IWR	22-73	240	131	232	20	9	1.5	0.20	0.2	0
23	IWR	10-73	378	62	139	16	6	0.0	0.07	0.4	0
24	IWR	10-73	400	87	291	20	16	19.6	0.69	0.0	0
25	IWR	10-73	125	224	368	46	16	0.0	0.0	1.7	0
26	IWR	6-73	275	193	378	51	12	0.0	0.02	0.3	0
27	IWR	6-73	285	100	155	25	6	0.0	0.0	1.2	0
28	IWR	6-73	74	162	369	39	21	0.0	0.0	0.4	0
	USGS	9-66	-	356	578	69	36	0.25	-	3.0	0
29	IWR	6-73	240	193	638	64	27	12.3	0.07	0.0	0
30	IWR	10-73	290	355	660	114	34	0.0	0.0	1.7	-
31	IWR	6-73	260	281	445	50	22	0.1	0.0	1.1	0
32	USGS	9-66	-	360	538	54	36	0.07	-	15.0	0
33	IWR	6-73	110	410	818	94	40	0.1	0 03	0.9	0
34	USGS	10-48	275	780	1080	144	62	43.0	-	6.1	-
35	IWR	6-73	0	490	819	147	42	5.0	1.76	0.5	0

TABLE 10: ANALYSES OF WELL WATER SAMPLES (Continued)

Well Number	Data Source	Date	Depth	Alkalinity as HCO_3^- mg/l	EC vmho	Calcium mg/l	Magnesium mg/l	Total Iron mg/l	Manganese mg/l	$NO_2^- + NO_3^-$ as N mg/l	Color
36	AHRC	1-71	145	709	-	-	-	1.8	-	123.7	-
37	AHRC	1-71	172	892	-	-	-	1.1	-	51.3	-
38	AHRC	1-71	0	448	-	-	-	20.0	-	0.09	-
39	AHRC	1-71	187	512	-	-	-	12.5	-	0.12	-
40	IWR	6-73	180	523	860	100	55	1.2	0.14	1.1	0
41	AHRC	8-71	-	-	-	-	-	8.19	-	0.7	-
42	USGS	9-66	-	243	362	49	16	0.0	-	7.3	0
43	AHRC	1-71	195	454	-	-	-	15.6	-	0.07	-
44	IWR	6-73	175	329	618	34	44	0.8	0.13	2.2	0
45	AHRC	1-71	-	503	-	-	-	3.0	-	0.42	-
46	IWR	6-73	160	672	1090	122	44	0.0	0.0	3.2	0
47	AHRC	1-71	220	534	-	-	-	1.9	-	2.67	-
48	AHRC	1-71	320	331	-	-	-	0.35	-	1.76	-
49	AHRC	1-71	250	509	-	-	-	2.0	-	5.11	-
50	AHRC	1-71	160	451	-	-	-	2.8	-	0.30	-
51	AHRC	1-71	325	396	-	-	-	0.6	-	4.82	-
52	USGS	9-66	0	282	410	52	22	0.15	-	6.5	0
53	USGS	8-54	203	1020	2060	-	-	9.8	-	0.4	-

TABLE 10: ANALYSES OF WELL WATER SAMPLES (continued)

Well Number	Data Source	Date	Depth	Alkalinity as HCO_3^- mg/l	EC µmho	Calcium mg/l	Magnesium mg/l	Total Iron mg/l	Manganese mg/l	NO_2^- + NO_3^- as N mg/l	Color
54	IWR	10-73	102	492	757	80	37	1.6	0.0	1.7	0
55	IWR	6-73	135	231	339	45	17	0.0	0.1	0.5	0
56	IWR	6-73	140	261	382	53	16	0.0	0.0	1.0	-
57	USGS	7-69	-	327	500	64	24	0.73	0.19	2.9	15
58	USGS	9-66	-	512	1025	40	157	11.55	-	0.32	0
59	IWR	10-73	140	809	1780	15	6	0.0	0.32	28.0	0
60	IWR	10-73	119	777	960	108	39	30.5	0.48	0.0	30
61	IWR	6-73	-	728	1070	117	47	19.8	0.38	7.6	35
62	USGS	10-49	-	333	520	70	25	0.06	-	0.4	-
63	IWR	10-73	160	590	879	100	32	>40.0	1.87	0.2	0
64	IWR	10-73	35	323	541	0	5	0.2	0.01	0.0	5
65	IWR	10-73	-	243	1135	74	15	3.3	0.47	0.0	5
66	IWR	10-73	16	417	783	109	18	0.0	0.0	2.5	0
67	IWR	10-73	45	261	475	66	10	1.5	0.88	0.0	0
68	IWR	6-73	32	293	532	72	12	4.4	1.65	0.0	0
69	IWR	6-73	-	285	1180	60	26	17.6	0.26	0.0	0
70	IWR	10-73	33	287	612	79	13	7.6	1.54	0.0	0
71	IWR	10-73	35	261	522	68	12	3.7	1.32	-	0
72	IWR	10-73	30	293	513	71	10	6.7	1.10	0.0	0
73	IWR	10-73	40	255	509	-	13	> 0.1	0.46	5.6	0

TABLE 10: ANALYSES OF WELL WATER SAMPLES (continued)

Well Number	Data Source	Date	Depth	Alkalinity as HCO_3^- mg/l	EC νmho	Calcium mg/l	Magnesium mg/l	Total Iron mg/l	Manganese mg/l	$NO_2^- + NO_3^-$ as N mg/l	Color
74	IWR	6-73	20	267	504	63	12	4.6	0.63	0.0	0
75	IWR	6-73	70	299	398	60	10	5.5	0.52	0.1	0
76	IWR	10-73	26	479	799	99	12	-	3.08	0.0	0
77	IWR	10-73	65	193	491	53	9	17.6	1.98	0.0	35
78	IWR	10-73	25	311	538	68	17	-	0.77	0.0	0
79	IWR	6-73	20	522	859	105	22	29.9	2.53	0.0	0
80	USGS	3-73	-	282	592	73	18	12.0	1.4	-	50
81	IWR	10-73	300	255	485	1.4	0.4	0.5	0.0	0.0	45
82	IWR	10-73	53	168	301	48	8.0	2.2	1.21	0.0	0
83	IWR	10-73	120	187	321	43	10	4.4	0.46	0.0	0
84	IWR	10-73	90	193	309	40	11	6.1	0.35	0.0	0
85	IWR	10-73	66	181	269	38	10	4.1	0.34	0.0	0
86	IWR	10-73	50	243	381	58	8	8.6	0.77	0.0	0
87	IWR	6-73	-	255	384	51	16	6.59	0.61	0.6	5
88	IWR	6-73	12	193	304	42	10	6.2	0.17	0.9	0
89	IWR	10-73	100	168	338	49	9	34.6	0.03	0.0	0
90	IWR	10-73	100	156	264	38	8	8.6	0.50	0.0	0
91	IWR	10-73	48	647	1635	91	22	27.3	2.42	0.0	5
92	IWR	10-73	87	224	442	55	12	7.6	0.80	0.0	0

TABLE 10: ANALYSES OF WELL WATER SAMPLES (Continued)

Well Number	Data Source	Date	Depth	Alkalinity as HCO_3^- mg/l	EC vmho	Calcium mg/l	Magnesium mg/l	Total Iron mg/l	Manganese mg/l	$NO_2^- + NO_3^-$ as N mg/l	Color
92	IWR	10-73	87	224	442	55	12	7.6	0.80	0.0	0
93	IWR	6-73	25	237	1680	63	27	15.4	0.54	0.0	0
94	IWR	9-73	80	279	412	54	13	10.5	1.10	-	5
95	IWR	10-73	294	187	538	51	22	0.1	0.15	0.0	0
96	IWR	6-73	-	411	583	37	61	0.0	0.0	0.3	0
97	IWR	10-73	160	156	353	44	11	0.1	0.0	0.4	0
98	IWR	6-73	-	261	622	73	17	4.4	0.23	0.0	0
99	IWR	6-73	255	604	2610	55	18	13.0	0.77	0.0	15
100	IWR	6-73	325	273	581	74	22	0.0	0.0	0.4	0
101	IWR	6-73	360	267	581	67	28	0.0	0.0	1.3	0
102	IWR	6-73	385	367	1590	145	100	2.2	0.1	0.1	0
103	IWR	10-73	220	131	226	35	6	0.0	0.0	0.5	0
104	IWR	10-73	460	279	532	54	40	0.0	0.06	0.0	0
105	IWR	6-73	34	273	469	59	21	1.6	0.29	0.0	0
106	IWR	10-73	-	417	810	83	40	0.7	0.0	0.1	0
Mean				343	650	62.4	25.5	5.97	0.51	3.79	
Number				108	95	95	96	107	86	105	

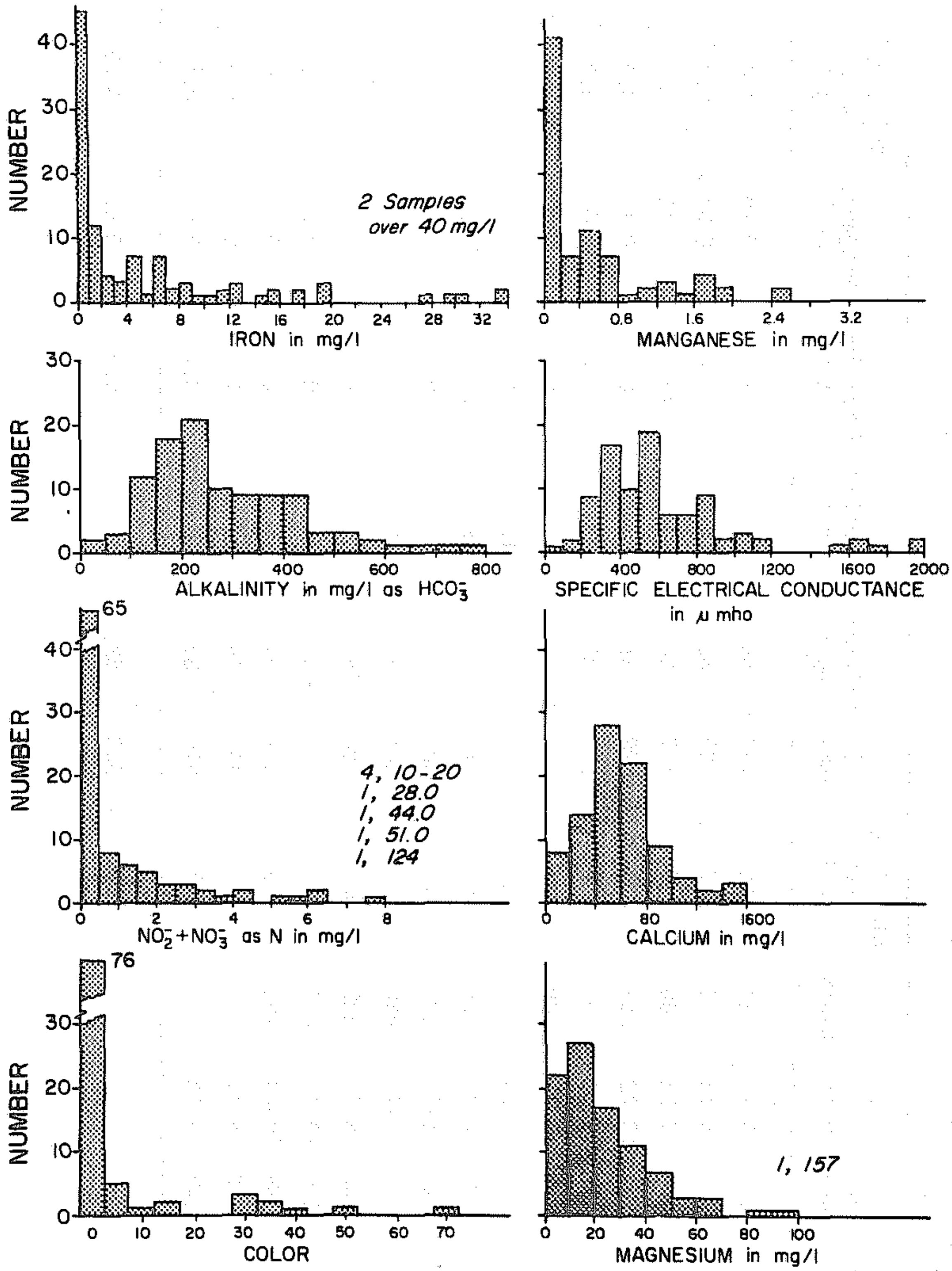

Figure 10: Summary of Ground Water Quality.

Calcium and Magnesium

Both calcium and magnesium are quite prevalent in the ground waters sampled. Calcium concentrations ranged from 0 to 147 mg/l with a mean of 62.4 mg/l. Magnesium ranged from 0.4 to 157 mg/l with a mean of 26 mg/l. Hardness is caused by divalent cations in the water. Normally, calcium and magnesium are considered the primary constituents of hardness, however, with ground water, iron, manganese, and strontium could contribute considerably to the total hardness of the water. In considering only the calcium-magnesium hardness, the waters sampled ranged from 5 to 779 mg/l as $CaCO_3$ with a mean value of 258 mg/l. Water with a hardness of 150 to 300 mg/l is considered hard and over 300 mg/l is considered very hard (Sawyer and McCarty, 1967). The water in the study area would generally be considered hard.

An important indicator of the mineral source of calcium and magnesium in water is the ratio between the two. In general, the ratio was between 0.53 and 8.25. There were two very distinct groups of samples with common calcium magnesium ratios. The low areas between College Road and the International Airport generally had much higher calcium magnesium ratios than the other areas studied, ranging from 2.31 to 8.25 and averaging nearly 5. The higher areas, Farmers Loop Road to Musk Ox Subdivision, had calcium magnesium ratios of 0.77 to 4.25 with a mean of nearly 2.5. The difference in the ratios can be attributed to the differences in the underlying material and a contact time factor. The lowlying areas examined are underlain by deep sediment deposits originating from a variety of sources, *e.g.*, the upper basins of the Chena and Tanana Rivers. These materials appear to have a higher calcium content than the bedrock. The higher elevations are covered with a thin layer of soil over highly fractured Birch Creek schist. The schist contains quartzite mica, feldspathic and chloritic schists and a minor proportion of carbonaceous and calcareous schist and crystalline limestone (Cederstrom, 1963). Except for the last two minerals, these materials are relatively low in calcium and magnesium (Dapples, 1959).

Hem (1959) suggests that calcium magnesium ratios in water of five to one more indicate the water has been in contact with high calcium deposits such as limestone, gypsum, or other high calcium carbonate precipitates. The lower ratios may indicate that magnesium silicate or dolomitic rocks are being dissolved.

Iron and Manganese

No harmful effects to humans have been found relating to drinking water containing iron and manganese. The principle problem comes from the oxidation of these materials forming an aesthetically unacceptable colloidal precipitate. Iron and manganese interfere with laundering operations by staining clothes and tying up detergent, cause difficulties in distribution systems by supporting growths of iron bacteria, and stain plumbing fixtures. Iron ranged from 0.0 to 43.0 mg/l with a mean of 5.97 mg/l. Manganese ranged from 0.0 to 3.08 mg/l with a mean of 0.51 mg/l. The mean values correspond well with those reported by Cederstrom (1963) and indicate a manganese and iron problem that is extensive and serious.

Nitrates and Nitrites

The sum of nitrates and nitrites were found to range from 0 to 126 mg/l as nitrogen. Two of the samples reported actually exceeded the U.S. Public Health Service drinking water standards of 45 mg/l. The occurrence of nitrates has been of considerable concern to the local community (Nicpon, 1972; Holty, 1973). Nitrates are usually associated with wastewater discharges, fertilized agricultural areas, drainage from feedlots, etc. The sampling area should be classified as suburban to rural residential with a noticeable absence of the normal sources of nitrates.

Other sources of nitrate are electrical discharge in the atmosphere or through the combustion process followed by hydrolysis, leaching from nitrate containing minerals, and release by legumes (Hem, 1970).

The group of plants called legumes operating symbiotically with the bacteria on nodules on their roots are able to take nitrogen from the air and fix it in the soil as nitrate (Hem, 1959; Feth, 1966). Petukhov (1969) sampled 509 wells in northern Russia ranging in depth from 9.8 to 49.2 feet (3 to 15 m.) and found a definite relationship between the type of soil and the nitrate concentration in the water. Nearly half of the samples Petukhov examined exceeded drinking water standards. He attributed the high nitrate concentrations to nitrification taking place in the soil when temperatures were suitable. Precipitation then carries the high nitrate water down to the ground water.

Electrical discharges and contaminated air also have been identified as a minor source of nitrates in ground water (Feth, 1966; Petukhov, 1969; Hem, 1959). As for leaching from nitrate-containing minerals, all the nitrate compounds are readily soluble in water, therefore it appears unlikely that nitrates would remain in the undissolved state for long periods of time.

In studying the nitrate problem in interior Alaska, Holty (1973) conducted a sampling program in two regions of known high nitrate ground waters. His analyses brought to light an inverse relationship between nitrate and iron. In plotting the nitrite plus nitrate concentration versus total iron data presented in Table 10, the Figure11 was developed showing the same inverse relationship. Hypotheses for the observed relationship are:

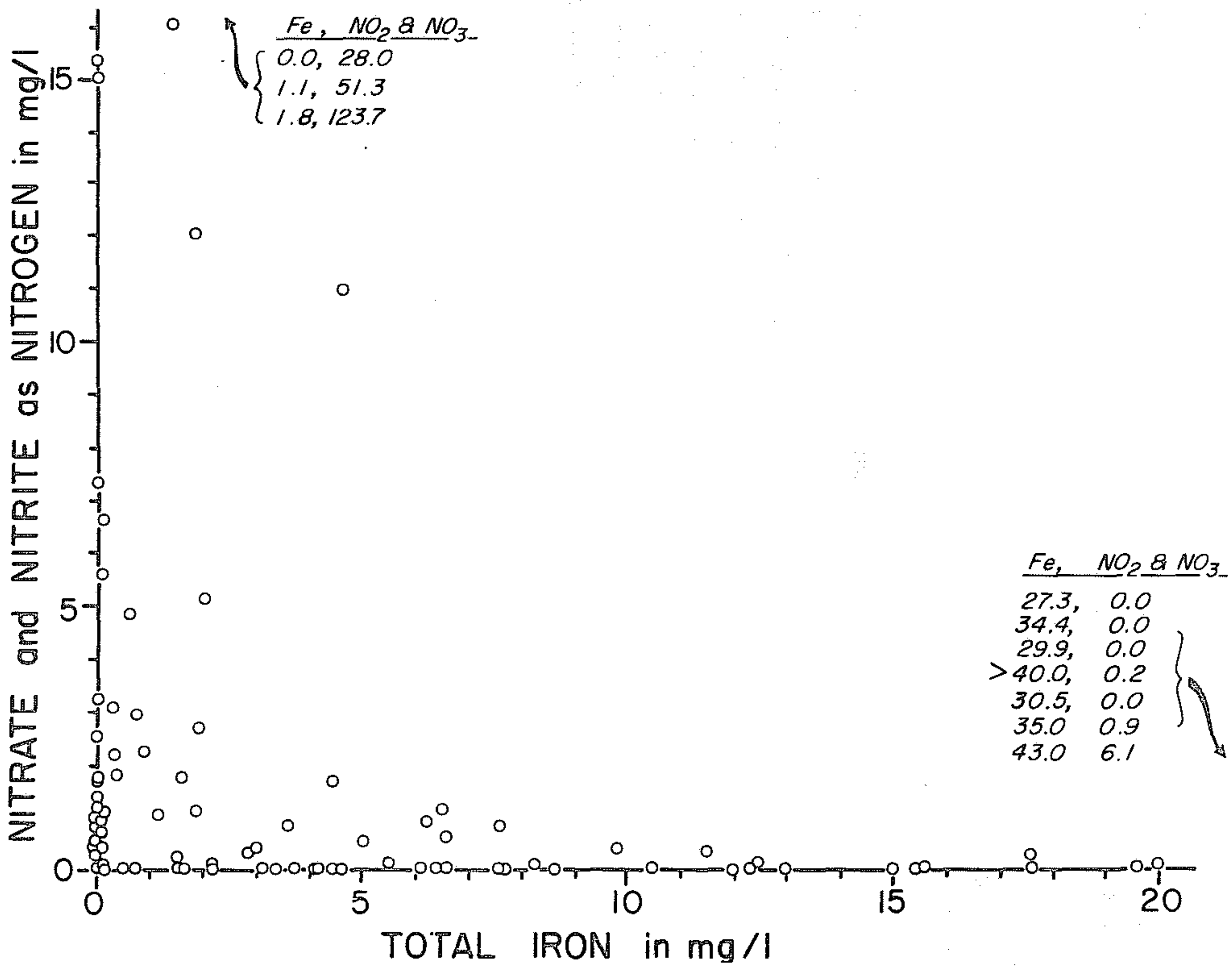

Figure 11. Total Iron versus Nitrate plus Nitrite Concentration

1. Biological populations in the areas of the source waters are different, one involving nitrification and an aerobic environment and the other denitrification in an anaerobic or nearly anaerobic condition.

2. Natural deposits of nitrate compounds occurring sporadically throughout the area cause different equilibriums to be established in the ground water.

3. Differences in percolating patterns may occur with the waters high in nitrates and nitrites being newer to the ground water aquifers than are the waters high in iron.

Considerably more study will be required before the exact mechanisms involved can be identified with assurance.

Color

True color was found in 15 of the 88 samples examined (17%). The values ranged from 0 to 70 color units with the average value of those with color was 24 color units. In general, true color is not serious however those wells with color are likely to have a problem. A pattern for predicting color in the sampling area was not observed.

WATER QUALITY AND SURVEY RESPONSE

In order to relate actual water quality to survey responses, comparisons between the 82 sets of chemical analyses and the actual responses of the water users were made. Iron and color were the key parameters examined. Of the 82 wells sampled, 35 users had indicated an iron problem. However, 50 of the 82 samples had iron concentrations over 0.3 mg/l, the upper limit established by the USPHS *Drinking Water Standards*, and 48 samples had concentrations over 1.0 mg/l of iron. Of those reporting an iron problem, three had actual values less than 0.3 mg/l. Over 91% of those reporting iron actually had a significant problem. Its importnat to note that 36% of those with an iron problem did not report the problem. This probably occurred because the samples were collected directly from the wells and the user's experience was with a treated tap water.

Color problems were reported by the users of 17 of the 82 wells sampled. Six of the samples from wells which had reported color actually had measurable true color after centrifuging. Three of the six samples had color levels which were below the drinking water standards (USPHS, 1962) of 15 units. Color was not reported by four of those with a significant problem. However, all except one of those reporting a color problem did have an iron problem well above standards.

COSTS OF WATER SUPPLY

From the survey results, general interpretations can be made concerning the cost of various water supply alternatives. Data concerning equipment and costs from the survey forms was, in general, insufficient for tabulation. Therefore, the discussion of costs is confined to general information which can be applied to the subareas after consulting the well depth figures in Appendix D.

Studies on the cost of developing ground water supplies have been made for municipal (Cederstrom, 1973; Ackerman, 1969a; and MacDonald, 1968) and domestic systems (Giff, 1971). The basic problems in relating this information to other areas include costs changes with time and with location. Cost indexes are used to adjust for these differences; however, it must be recognized that the use of such indexes give only relative estimates of costs. The main emphasis in this study has been directed at the size and depth of wells needed with the determination of actual costs left to the reader.

Costs of Wells

Cost information was not determined directly for wells. Current costs for drilling and developing a 4 to 6-inch well in the Fairbanks area are usually in the range of \$13-\$15 a lineal foot (personal communication, 1973). By comparison, well cost for a 4-inch sand and gravel well in Illinois would be in the range of \$5 to \$6 per foot and a 6-inch well would cost between \$8 and \$11 per foot (Gibb, 1971). Based on local costs the expenditure necessary for well installation can be estimated for a given area from the data on depths. However, areas characterized by heavy development may exhibit increases in well depth due to localized drawdown of the ground water or mining of water. This is the case particularly in areas of higher elevation where depths required to reach adequate sources are already great. It can be seen, using the depth data, that expenditures of \$3,000 to \$5,000 are not uncommon in some of the elevated areas around Fairbanks. Apart from auxiliary equipment, the basic cost of the well represents a sizeable investment for the homeowner.

Costs of Pumps, Tanks and Associated Equipment

Cost data from the survey for pumps and associated equipment was inadequate since most respondents did not specify pump models, capacity and type. Gibb (1971) made a detailed study of pumping system costs based on a 10 gpm submersible pump, a petless adapter, a pressure tank, and necessary hookups to electric and water systems. An average cost of \$585 was derived for such a system. Using a cost differential index of \$150% for Fairbanks, the current cost would be about \$900 (Moselle, 1970; National Research and Appraisal Company, 1971; and Alaska Division of Personnel, 1972). Costs given in the survey generally ran from \$100 to \$350 for a pump. Jet units, which are less expensive, are being used in many areas of the river basin where the water is being drawn from 20 to 30 feet. More expensive units were reported in elevated areas where submersible units are generally used. Considering the additional cost of a pressure tank ($50-$150) and the necessary labor and parts the $900 figure is reasonable for the system described.

An important part of the cost of well water supplies is the operating and maintenance cost. Ackermann (1969b) presented the following relationship for actual power required in kilowatt-hours for pumping water

$$\text{kw-hr} = 1.88 \times 10^{-4}\ Qht/E_0$$

where Q = flow in gallons per minute, gpm

E_0 = water to water efficiency in per cent

h = total pumping head in feet

t = time in hours

Using this relationship and assuming a 200 ft. total head, an 8 hour pumping period for 1,000 gallons, and an efficiency of 50%, the energy required would be 0.0125 kw-hr. This relationship does not include energy loss due to friction or required for pressurizing the system. Normally, a one-fifth to one and a half horsepower pump is used in domestic wells. For this case the following can be used for estimating the kilowatt hours required:

$$\text{kw-hr} = 0.746\ (\text{Pump horsepower})\ (\text{hours of operation})$$

A second item to be considered is the cost of preventing freeze-up of the well for seven months of below-freezing temperatures. This is normally done by wrapping a heating tape around the pipe. Normally one to five watts per foot of pipe will suffice. Using these two operating cost parameters, estimates can be made of operating cost of a well system. In general these costs are insignificant in comparison to the capital cost of installation.

Maintenance costs include repair of pipe failures and freeze-ups and pump servicing. Data on the frequency of such problems is incomplete; however, these problems are frequent in rural areas.

Hauling

Approximately 7.5% of the respondents reported hauling as the primary source of their water supply. The cost of this water runs about $35 per thousand gallons when hauled commercially. Frequently this is used as a temporary solution to the cost of well construction or may be used to supplement a low quality supply.

Because of the various reasons for utilizing hauling, it was not broken down by area. Such a breakdown would be biased by factors other than water quality.

Hauling is also utilized as a source of high quality water for cooking and drinking. About 6.4% of the respondents indicated that water was hauled in small containers from work or other places on treatment systems. Many of this group reported regular trips to a spring 15 miles north of Fairbanks to obtain water for domestic purposes.

Frequency of hauling was not determined. Generally, households depending wholly on hauled water will take steps to limit consumption such as limiting toilet flushing, bathing and other heavy uses. Frequently such households use privies or chemical toilets rather than water flush toilets. Assuming a 1,000 gallon haul will suffice for about one month, the annual areal cost would be about $200,000. Hauling by hand could approach about 25% of this figure including transportation and time costs.

Water Quality Effects

A major consideration of the project was to determine the indirect costs of water quality in terms of effects on clothing, food, utensils, fixtures and other such water-use related commodities. Such effects may, in the long term, represent a major consideration in determining the real cost of water supplies.

The approach taken here was basically the same taken in the determination of soiling costs due to air pollution by Barrett and Waddell (1973). This method identifyies additional tasks necessitated by the water quality and applies a cost value to these tasks. The cost values used in air pollution soiling were based on average commercial costs for cleaning.

A major domestic use of water is the laundering of clothing. Water quality can effect clothing value through staining, embrittlement and decreased wearability. Studies of the effects of hardness and alkalinity on discoloration and wearability and iron and manganese on staining indicate the effect may be significant (Janecek, 1971; Buckner and Janacek, 1970). Hardness and alkalinity stiffen fibers in fabric through coating and possibly through chemical reaction (calcification) which increases fiber breakage and thus fabric strength and wearability. A quantitative relationship between hardness concentration and wear has not been derived nor has a relation between iron concentrations above .05 ppm and staining problems.

Cost effects on laundering fall into five categories:

(1) Substitution of commercial laundering in order to bypass water quality problems.

(2) Reduced usefulness and durability of apparel due from poor-quality water damage.

(3) Expenditure for special conditioning agents for laundry.

(4) Acquisition of more expensive water systems (*i.e.* treatment) above that needed for other uses.

(5) More frequent replacement of washing machines due to damage caused by poor-quality water and the necessary conditioning agents.

Commercial laundering necessitated by water quality was reported by 8.5% of the respondents. For an average four or five machine loads a week of laundry, the commercial equivalent would be about $20 per week or $1000 per annum. Commercial equivalent based on five loads per week for the average family and 10 pounds per load at the average cost of $0.40 per pound. Self-washing at the laundromats runs about $0.75 per load or $3.75 per week plus detergent, bleach, softeners, time and travel. Any savings on home laundry facilities is assumed to be offset by necessary travel, lost time or nuisance. Assuming the sampling is representative, this would represent an areal cost in excess of $500,000 per annum.

The second factor, reduced wearability or useful life of apparel is more difficult to estimate as this is a value judgement on the part of the user and is highly variable throughout the study area. Damage to laundry due to water quality was indicated by 19.5% of the respondents. The cost of apparel and upkeep for an intermediate standard family budget as reported by Tussing and Thomas (1971) in Alaska Review of Business and Economic Conditions was used as the base of estimated costs for apparel, assumed at $1000 per annum. A reduction of 10% will be assumed to be a conservative estimate. Thus, the reduced wear of apparel would represent an areal cost of greater than $100,000 per annum.

Expenditures for special cleaning agents was not determined in the survey. Metcalf and Eddy (1972) list some costs for cleaning agents which range through $235 per family per annum. This cost is highly effected by personal habits so it would be difficult to quantify.

Costs of Treatment Units

Unit costs for softeners and iron filters were determined from local suppliers. Catalog costs were normalized by adding freight charges and adding an estimated $150 for expenses incurred in installation, including parts and labor. Much of the information was inaccurate and it was not possible to determine a cost. For softening units, there was sufficient data to construct a histogram (Figure 12). This distribution has the hill-shape of the characteristic normal distribution curve with the mean and median costs occurring at about $500 per unit. The majority of the units fall in the $400-600 range with a few cases of costs approaching $1000.

As filters are not as widely used as softeners, there was insufficient data to determine a distribution; however, it was observed that few units were out of the $300 to $400 range.

A major consideration in treatment units is the cost of regenerative chemicals and maintenance. Detailed information was commonly given for this category since most users were dealing with this expense on a weekly basis. A histogram of the softener cost is given in Figure 13. A histogram of $50-interval costs shows a skewed distribution of costs with over two-thirds being under $100 per annum. Some of the higher costs are related to systems having higher daily water requirements or where the units were being operated in areas of high hardness or iron. In some cases, excessive cost may be due to misoperation and excessive regeneration.

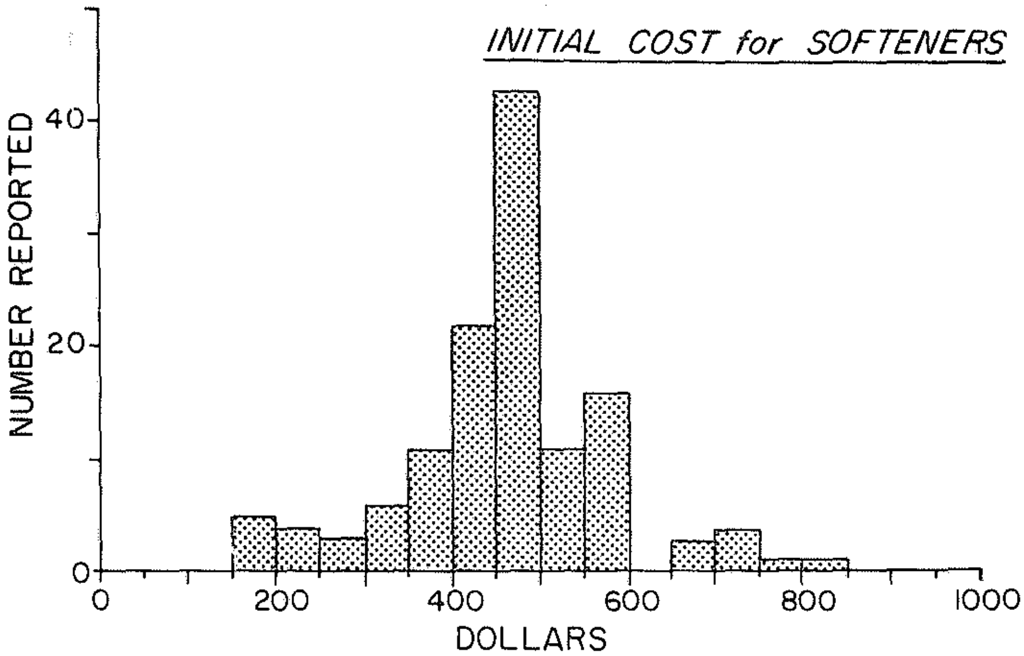

Figure 12: Histogram of Reported Initial Cost of Water Softeners.

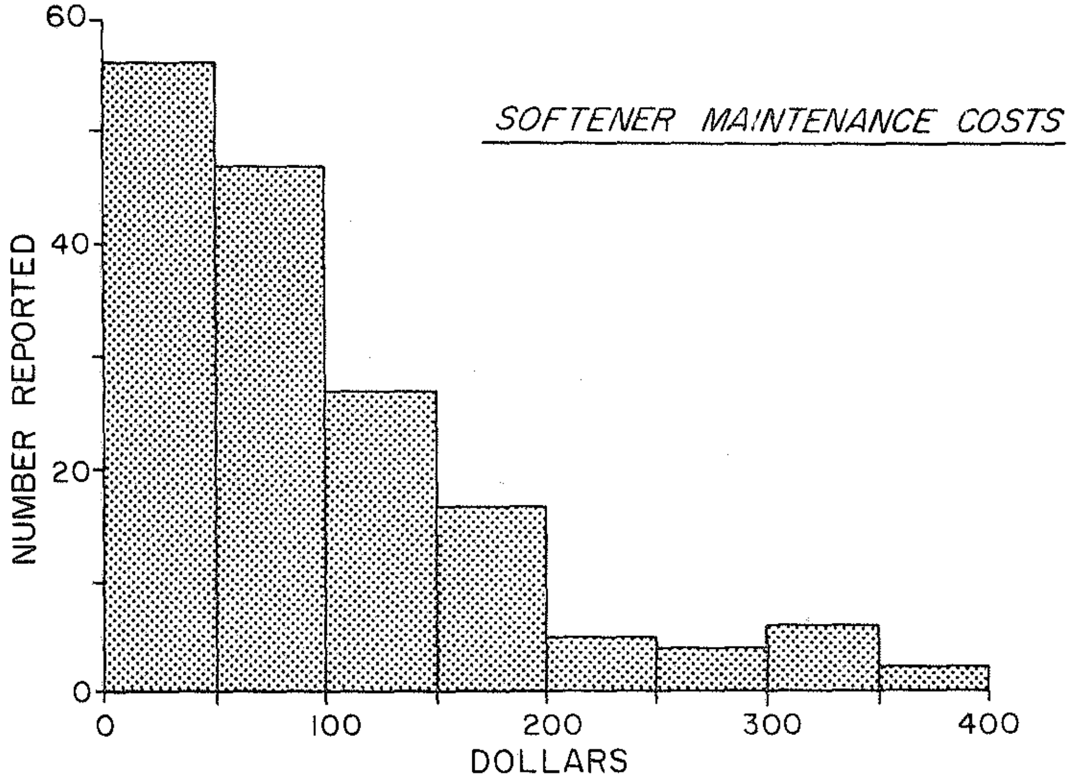

Figure 13: Histogram of Reported Softener Maintenance Cost.

SUMMARY AND CONCLUSIONS

This study of ground water quality in the interior region of Alaska has resulted in the acquisition of considerable information on the domestic water-use problems in the region. The following conclusions can be drawn from the results:

1. The areal cost of low water quality in the Fairbanks area may approach one million dollars per year if treatment costs and quality effects are considered. Unquantified intangibles have not been included but appear to have a high value to a large segment of the statistical population.

This expense warrants full consideration of public water system development where feasible due to residential concentration and proximity to current service areas.

2. Capital costs of wells is a significant economic factor in the cost of rural housing in the Fairbanks area, particularly in elevated locations where deep drilling is necessary for adequate supply. Well costs frequently exceed basic land values and must be considered a constraint on rural residential development. The use of cooperative water systems in subdivisions and residential concentrations could reduce this economic impact while providing the following additional benefits of sound water resource management: reduction in well failure due to aquifer depletion; increase reliability of water supply, improvement of quality through more selective well drilling, and reduction of potential hazards of septic infiltration in developed areas.

3. Quality of well water improves with elevation above the flood plain. Poorest quality is derived from alluvial ground water adjacent to rivers, while improved quality (except for nitrate) is evident in the foothills north of the city. This appears to be a function of penetration to fractured bedrock and utilization of aquifers having more recent recharge.

4. Hauled water as a primary or supplementary supply is a heavily utilized alternative to cost and/or quality problems. The nuisance/aesthetic costs associated with hauling as a primary source are significant since many persons find it feasible to invest several thousand dollars to secure a more desireable water system. Hauling, if used in conjunction with water-saving devices, such as recycling toilets, can be a viable, permanent alternative. The habit of utilizing large quantities of water is a cultural fact which may be difficult to overcome.

Supplementary hauling appears to be a major means of alleviating quality problems for uses involving ingestion. The costs of this have not been estimated but hauling from the Fox spring could include significant expense in terms of time and travel.

5. A large proportion of the water sampled exceeds the recommended USPHS drinking water standards limits. Correlations in the study control area show that the responses listing objectionable qualities do exceed the USPHS standards and this condition may be judged predominant in areal water supplies. Except for nitrate, there is no likely immediate health effects stemming from this problem.

6. Informal collection of information from users indicates a good understanding of ground water supply and a need for wells and treatment units to be upgraded among users.

7. There is an inverse relationship between the occurrence of iron and nitrate plus nitrite in ground water. Nitrate-nitrite occurs in aesthetically pleasing, iron-free water, a condition which can lead to a false sense that the water is potable.

RECOMMENDATIONS

The sources and movement of the ground water in the Fairbanks area are not well defined. Several chemical phenomina also need further study. Based on this study, the following recommendations are made for future study of ground water conditions in the Fairbanks area:

1. A program involving mandatory reporting and logging of wells and a related water quality-testing program should be established in the interior region of Alaska. Such a program will provide a base for understanding ground water movement and quality and allow proper management of ground water resources.

2. A detailed study of the changes in the depth of the ground water aquifer in the hills should be undertaken to establish changes and their causes.

3. Research should be directed toward the observed relationship between iron and nitrate in ground water.

4. For those wells with extremely poor quality or where softening is contraindicated, advanced treatment units employing ozonation, reverse osmosis, or other processes should be studied and developed, with regard to economic feasibility

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APPENDICES

APPENDIX A

SURVEY FORM

INSTITUTE OF WATER RESOURCES

UNIVERSITY OF ALASKA
COLLEGE. ALASKA 99701

Dear Interior Alaskan:

Water supply is a recognized problem in Interior Alaska. In many areas groundwater supplies are very poor in quality, containing iron, hardness, color, odor and other unfavorable characteristics which may render the water unusuable for most domestic needs. Treatment of such water can be costly and troublesome, and in many cases, commercial units are not designed for the low water quality found in this area.

For the homeowner, the cost of developing a well and treatment system may constitute a major part of the cost of home construction. In many cases, the homeowner is unable to determine the cheapest, most effective water system for his home and may be influenced more by unqualified opinions than objective evidence.

As a part of its program in water supply and treatment, the Institute of Water Resources is conducting a cost study of water supply in Interior Alaska. The information you provide on the attached form will provide data for the evaluation of water supply systems now in use. We request you take a few minutes to complete the attached questionnaire. A number of questionnaires will be selected on the basis of water system and location for analysis of water quality. Homeowners selected will be contacted by phone to arrange an appointment for us to pick up a water sample. The results of these tests will be reported to those providing the samples.

Your participation will be of great benefit to this effort.

Sincerely,

Daniel W. Smith

Daniel W. Smith, Ph.D.
Assistant Professor of Water Resources
and Environmental Health Engineering

Lawrence A. Casper

Lawrence A. Casper
Research Chemist

PLEASE REPLY BY AIRMAIL

WATER SUPPLY SURVEY

When completed, please fold, staple, and mail (no postage required)

I Water Source *(circle appropriate answer and fill in blank)*

a. Well: depth and size ________________________________

driller ________________________________

when drilled ________________________________

b. Water System:

1. Municipal

2. Cooperative: Operator ________________________________

c. Delivery: Hauler ________________________________

Cost ________________________________

d. Other: Explain ________________________________

II General *(circle yes or no)*

1. Is your present water supply system completely adequate? yes no

2. Does your system supply sufficient quantity? yes no

If NO, how much of an increase would be an adequate supply?

2X 3X 4X 6X 10X Other ________________

3. Does your system supply acceptable quality? yes no

If NO, indicate what qualities are unacceptable and briefly describe:

a. Iron
b. Odor
c. Color
d. Tast
e. Suspended material
f. Other

4. Is corrosion a problem with your water? yes no

Describe briefly any corrosion problems: ________________________________

____

____

____

III Treatment *(circle appropriate answer and fill in blank giving as complete an answer as possible)*

a. No treatment

b. Treatment supplied by supplier (municipal, hauler, etc.)

c. Chlorination

Mfg., size, model, ______________________________

____

d. Other disinfectors *(explain)*

Mfg., size, model, ______________________________

____

e. Softener

Mfg., size, model, ______________________________

____

f. Filter

Mfg., size, model, ______________________________

____

g. Pump(s)

Mfg., size, model, ______________________________

____

h. Holding Tank(s)

Mfg., size, model, ______________________________

____

i. Other *(explain)* ______________________________

____

IV Maintenance and Nuisance Cost *(circle applicable maintenance and nuisance problems: describe briefly and if available, give actual costs)*

Maintenance

a. Pump(s) ______________________________

____

b. Thawing ______________________________

____

c. Softener ______________________________

____

d. Filter

e. Chemicals (salt, chlorine tablets, etc.)

f. Other (*explain*)

Nuisances (*describe fully*)

a. Damaged laundry

b. Dry Cleaning

c. Commercial laundering necessitated by water quality

d. Damaged porcelain, cookware, etc.

e. Damaged food (from cooking in low quality water)

f. Other (*explain*)

THANK YOU FOR YOUR ASSISTANCE

Please fold, staple and mail. Postage prepaid.

APPENDIX B

COMMENTS ON SURVEY FORMS

COMMENTS ON SURVEY FORMS

The following comments were made on the survey form concerning ground water quality problems:

"Thank you for this service to our city." Mayor, City of Delta Junction.

"More gov't snooping! Go to hell!"

"I was born and raised in western Washington and took good water for granted. I never believed water could be so bad."

"There never seems to be enough water. I have to plan the housework around how much water I have."

"Clothes don't appear clean or smell fresh - material quickly deteriorates."

"Help! I ask the impossible but need simple and permanent solution, cheap."

"I feel that dishwasher, washer, tubs, toilets and sinks are losing life expectancy both from action of deposits and also from use of chemicals almost constantly in order to keep them presentable. We feel the heavy expense of installing and maintaining an effective treatment system is not feasible as our water is potable and not unpleasant for drinking or cooking.

The main complaint is the extra work and annoyance involved. Living day in and day out with brown stains on everything is a rough pain in the neck and is one of my own personal main complaints, as a homemaker, about living in Fairbanks, rated far above the cold and even with the cost of living."

"Backs of dishes in dishwashers get brown stains."

MEASUREMENTS BY ION SELECTIVE ELECTRODES

There has been some interest in recent years in the application of ion selective electrodes to water analysis. These electrode units are advantageous in that they are reasonably compact, rugged and, easily operated.

The nitrate electrode has been investigated by several authors (Langmuir and Jacobsen, 1970; Manahan, 1970) for use in water analysis. The nitrate electrode exhibits interference from bicarbonate and chlorine as well as other less common anions. Such interferences require correction or may be ignored for estimates of nitrate levels. Generally, this electrode works best at fairly high NO_3 concentrations.

A more recent electrode is the ammonia electrode marketed by Orion. An ammonia electrode was procured and it was attempted to run this in parallel with the phenol hypochlorite colorimetric method on the AutoAnalyzer at sub-ppm levels. At these levels the response time of the electrode is fairly long. Values of the response time reported in the literature show that about 4.5 minutes are needed at 1 ppm NH_3-N (Barcia, 1973), and 2 minutes at about 0.6 ppm NH_3. The former value is closer to the times encountered in our trials. More important to continuous analysis was the recovery time, *i.e.*, the time required to return to baseline potential. Periods of up to twenty minutes were encountered at the sub-ppm level. This clearly obviated the applicability to a continuous system as the colorimetric method is much more rapid.

Recently published works (Barcia, 1973; Leblanc and Slinwinski, 1973; Gilbert and Clay, 1973; Thomas and Booth, 1973) have successfully applied the ammonia electrode to monitoring of aquaria, waste water and other high ammonia waters. The electrode has potential in these areas where concentrations are sufficiently high to keep response times within a reasonable period, or where time is not a factor in low level determinations.

The experimental set-up included a Technicon Industry sampler and pump followed by a mixing manifold for addition of NaOH and a debubbler prior to introduction of the sample to the flow-through NH_3 electrode. Readout was by an Orion Model Specific Ion Meter to a Hitachi strip chart recorder.

Application of ion selective electrodes to testing of ground water in remote areas is feasible and a method of choice for NO_3 and NH_3. Use on a local basis is contraindicated due to set-up time and analysis time as well as difficulty of field manipulation where convenient laboratory facilities are available. As an automated analysis alternative the ISE is feasible only at moderately high concentrations or where the continuous analysis is of a single source, such as monitoring of an aquarium.

APPENDIX D

DETAILED SURVEY RESPONSE MAPS

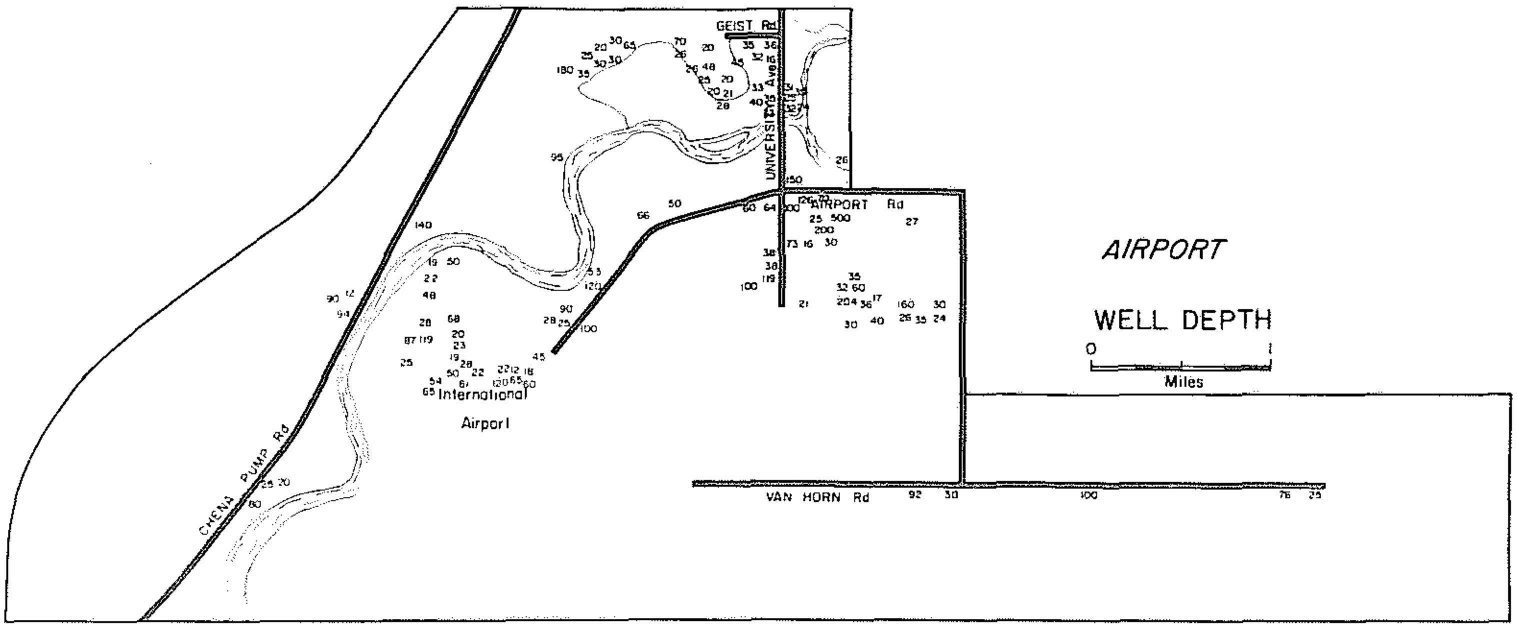

Figure 14: Airport Subarea - Reported Well Depths.

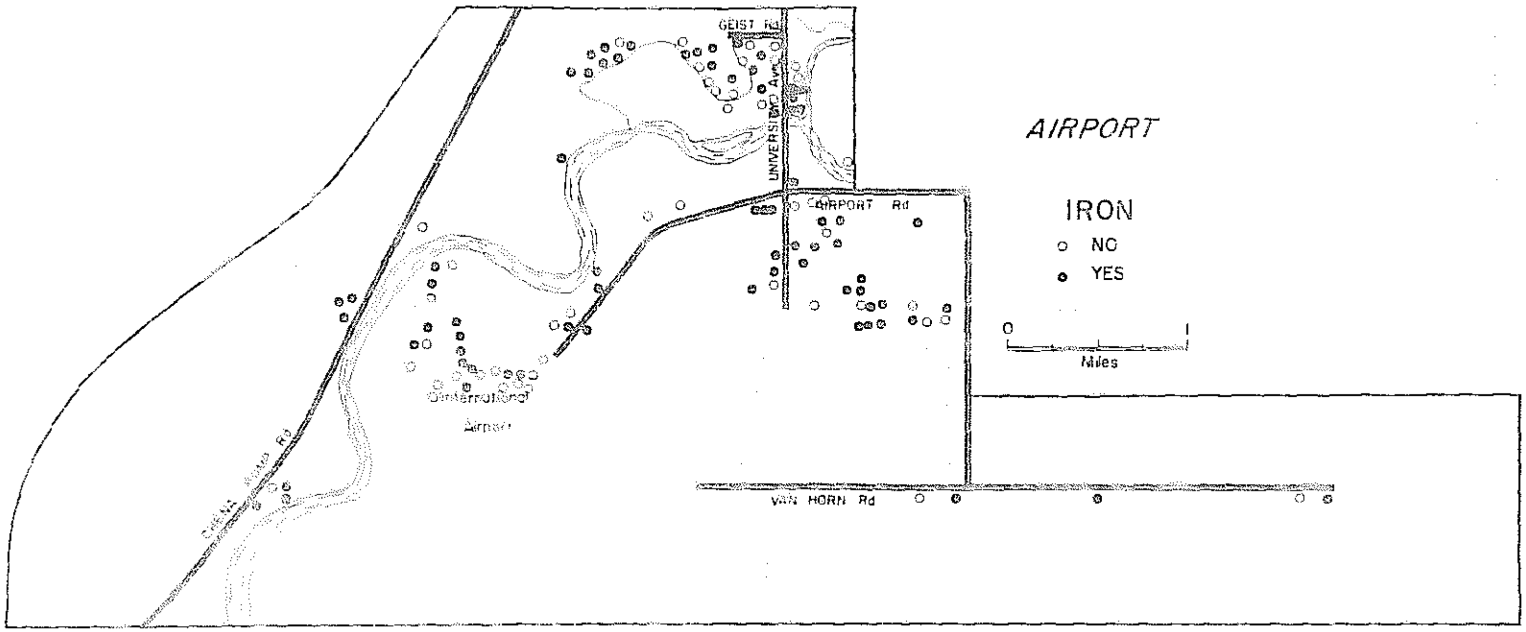

Figure 15: Airport Subarea - Reported Locations of an Iron Problem in the Well Water Supply.

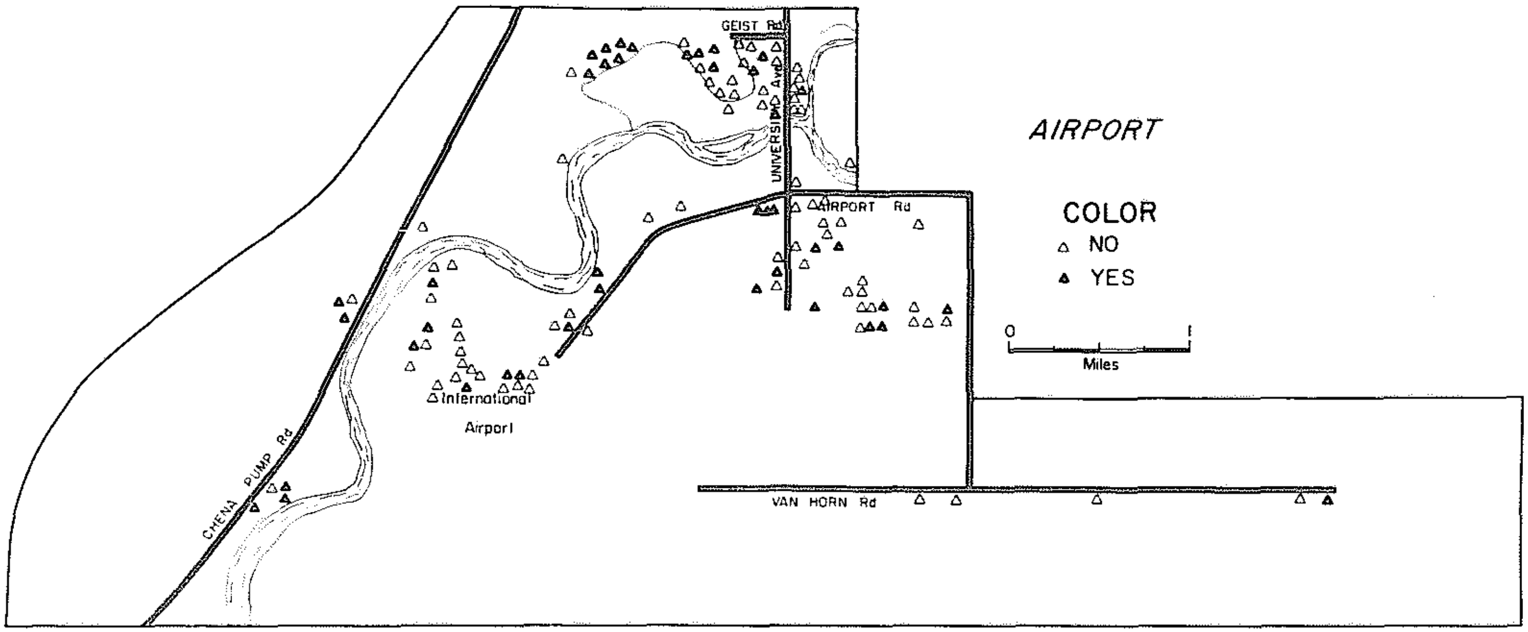

Figure 16: Airport Subarea - Reported Locations of a Color Problem in the Well Water Supply.

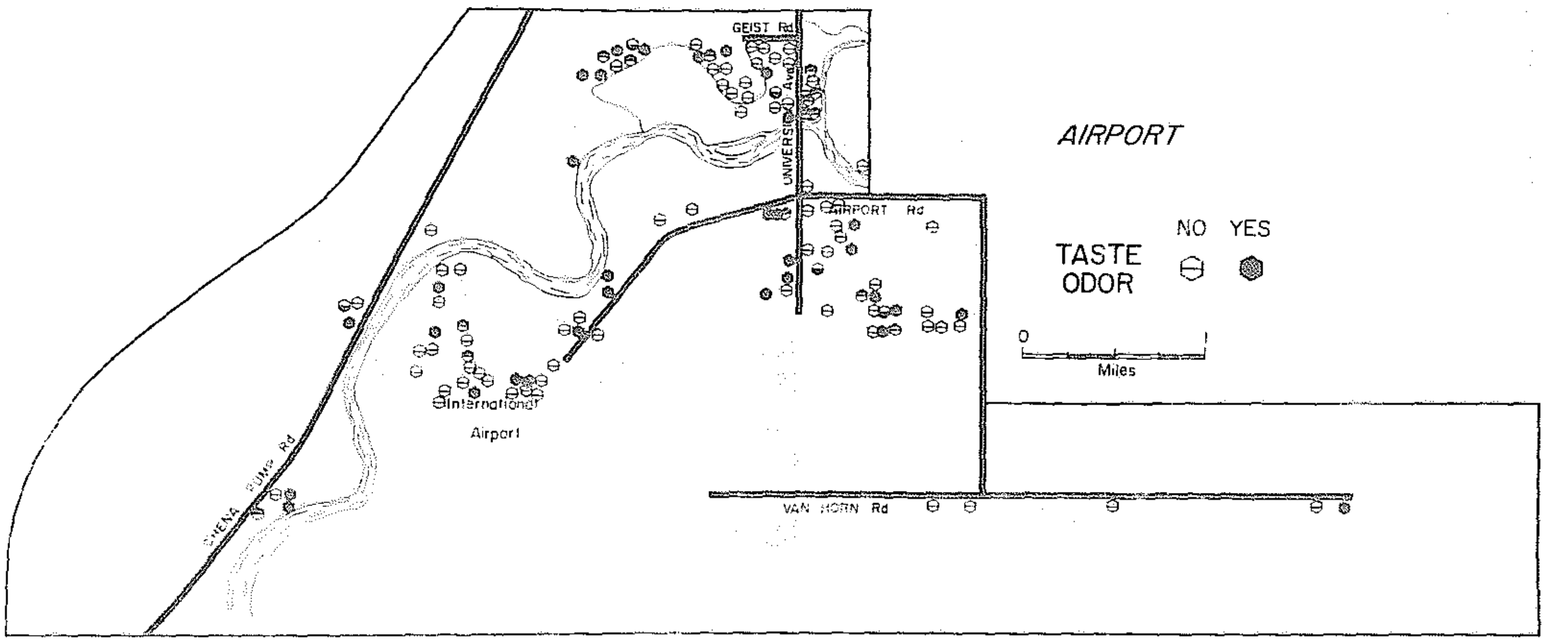

Figure 17: Airport Subarea - Reported Locations of Taste and Odor Problems in the Well Water Supply.

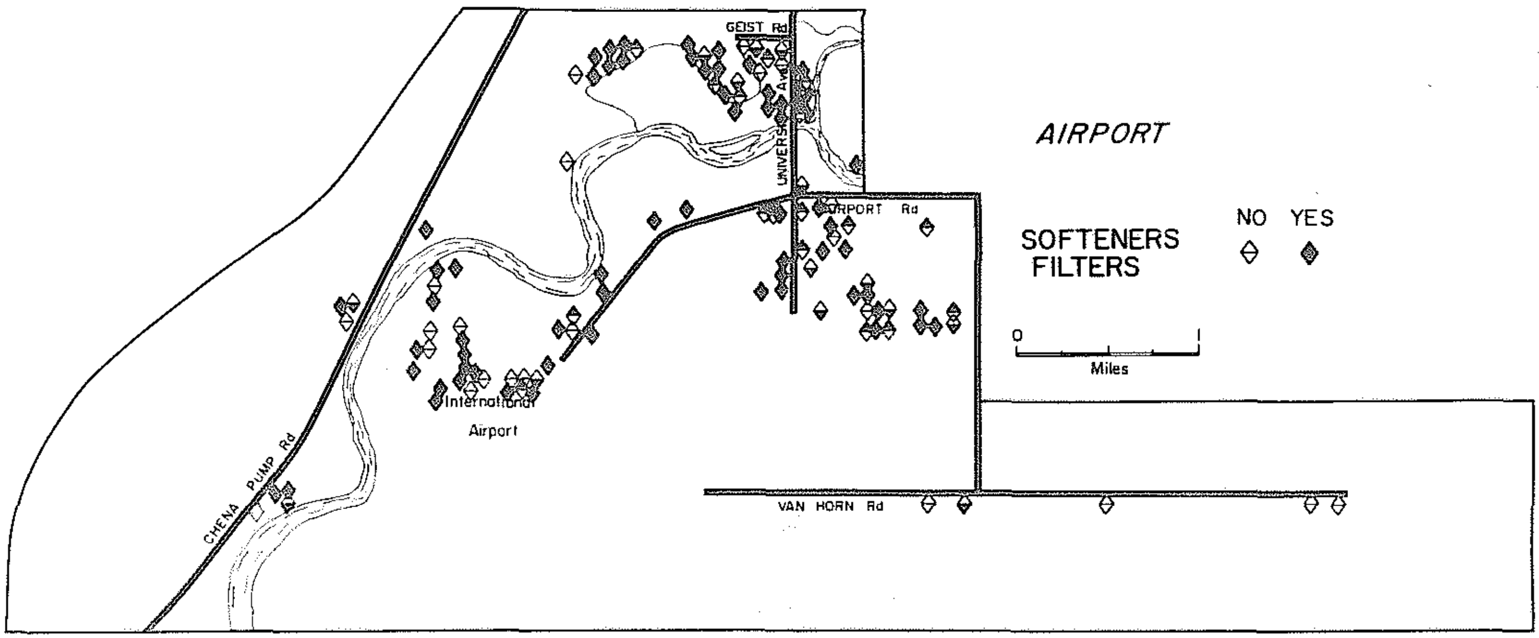

Figure 18: Airport Subarea - Reported Locations of Water Softener and Filter Installations.

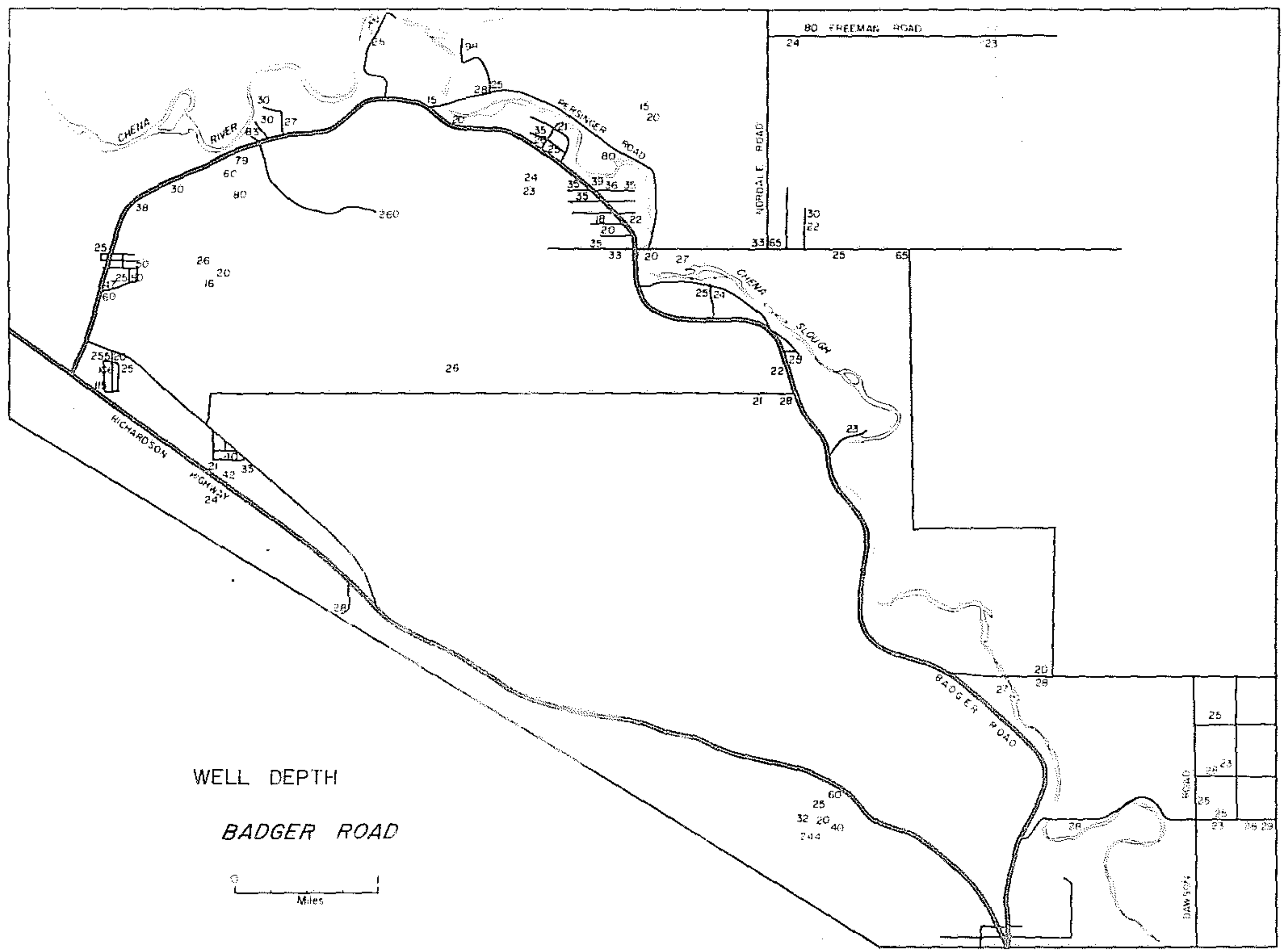

Figure 19: Badger Road Subarea - Reported Well Depths.

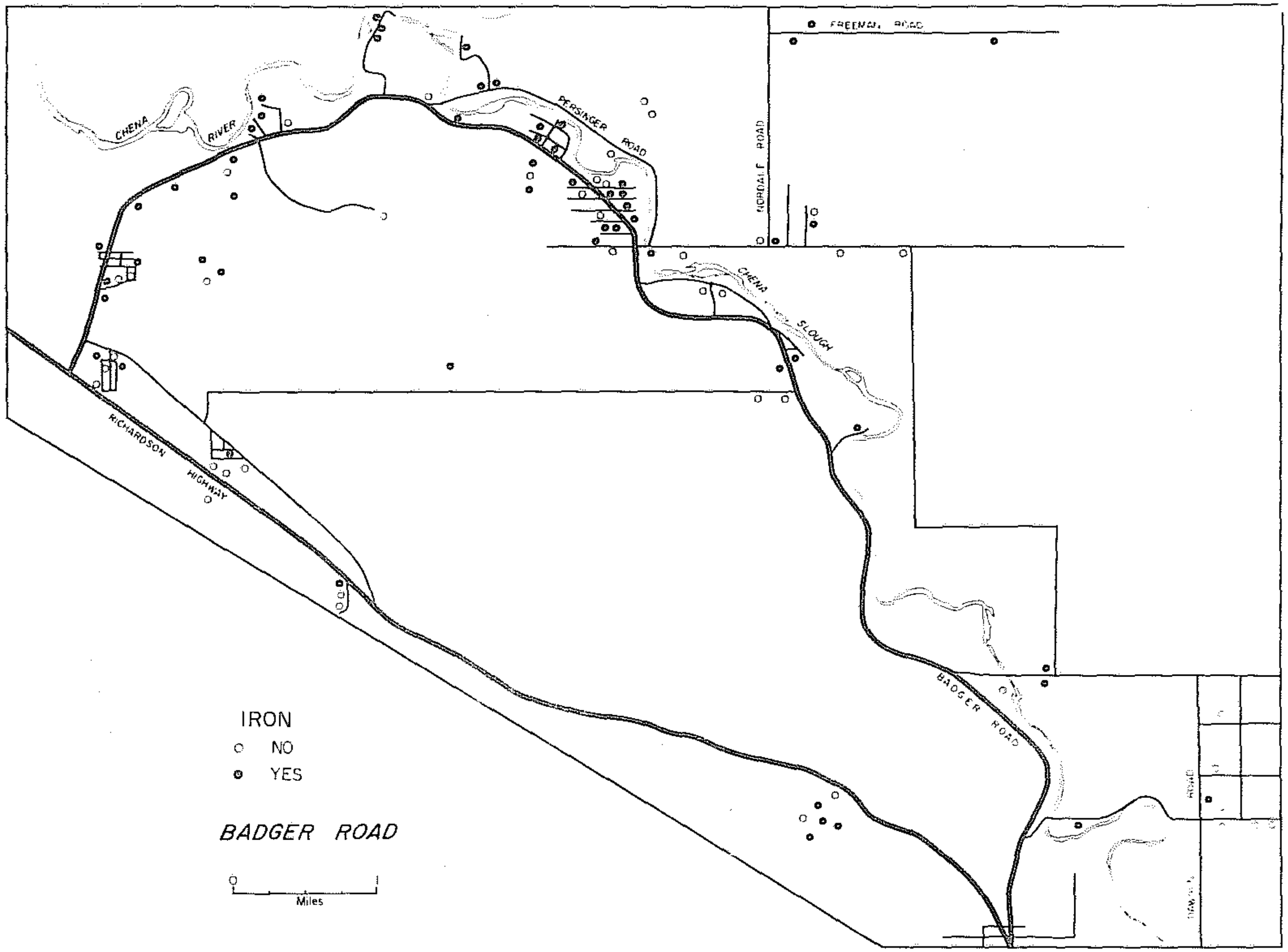

Figure 20: Badger Road Subarea - Reported Locations of an Iron Problem in the Well Water Supply.

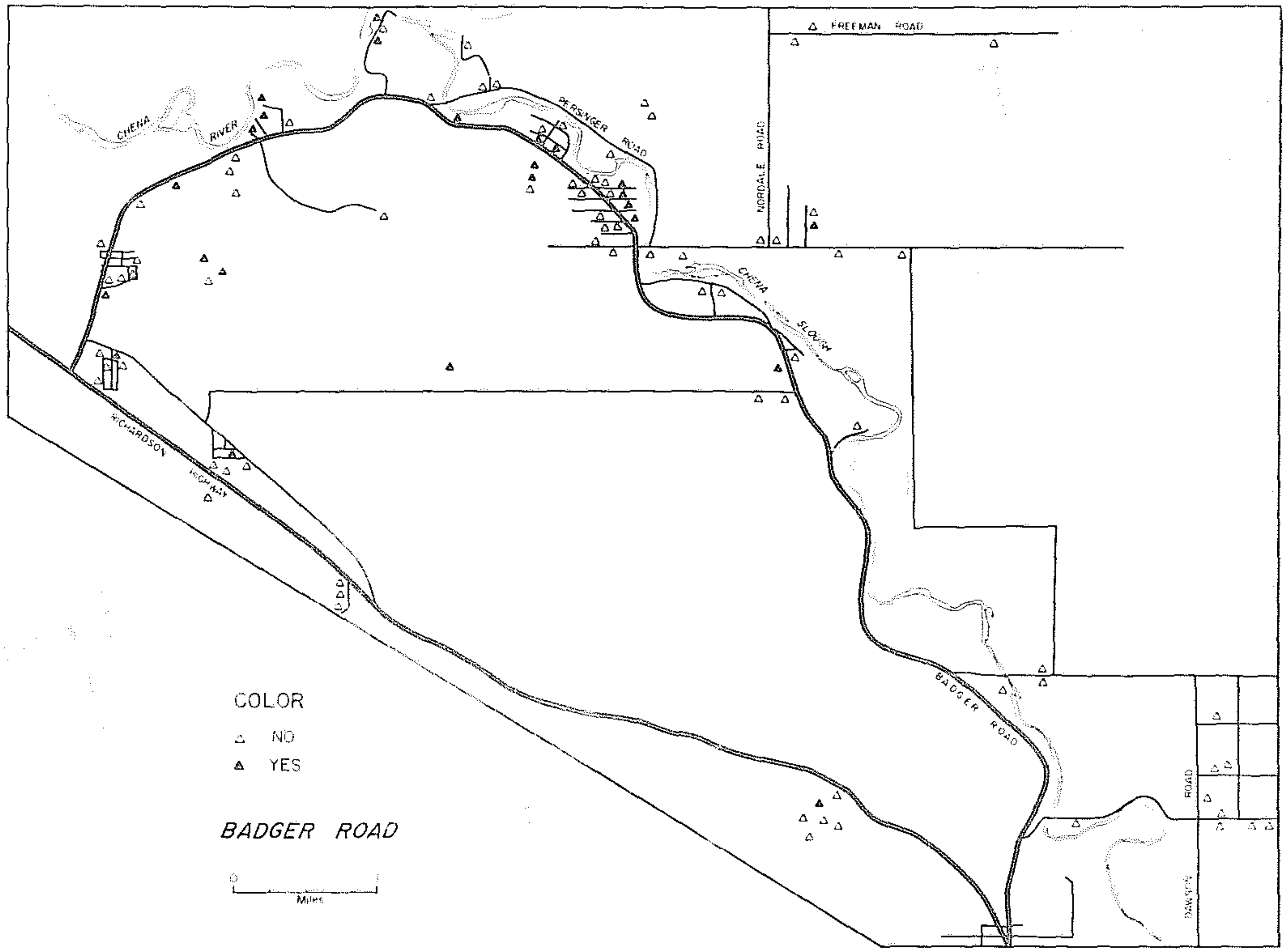

Figure 21: Badger Road Subarea - Reported Locations of a Color Problem in the Well Water Supply.

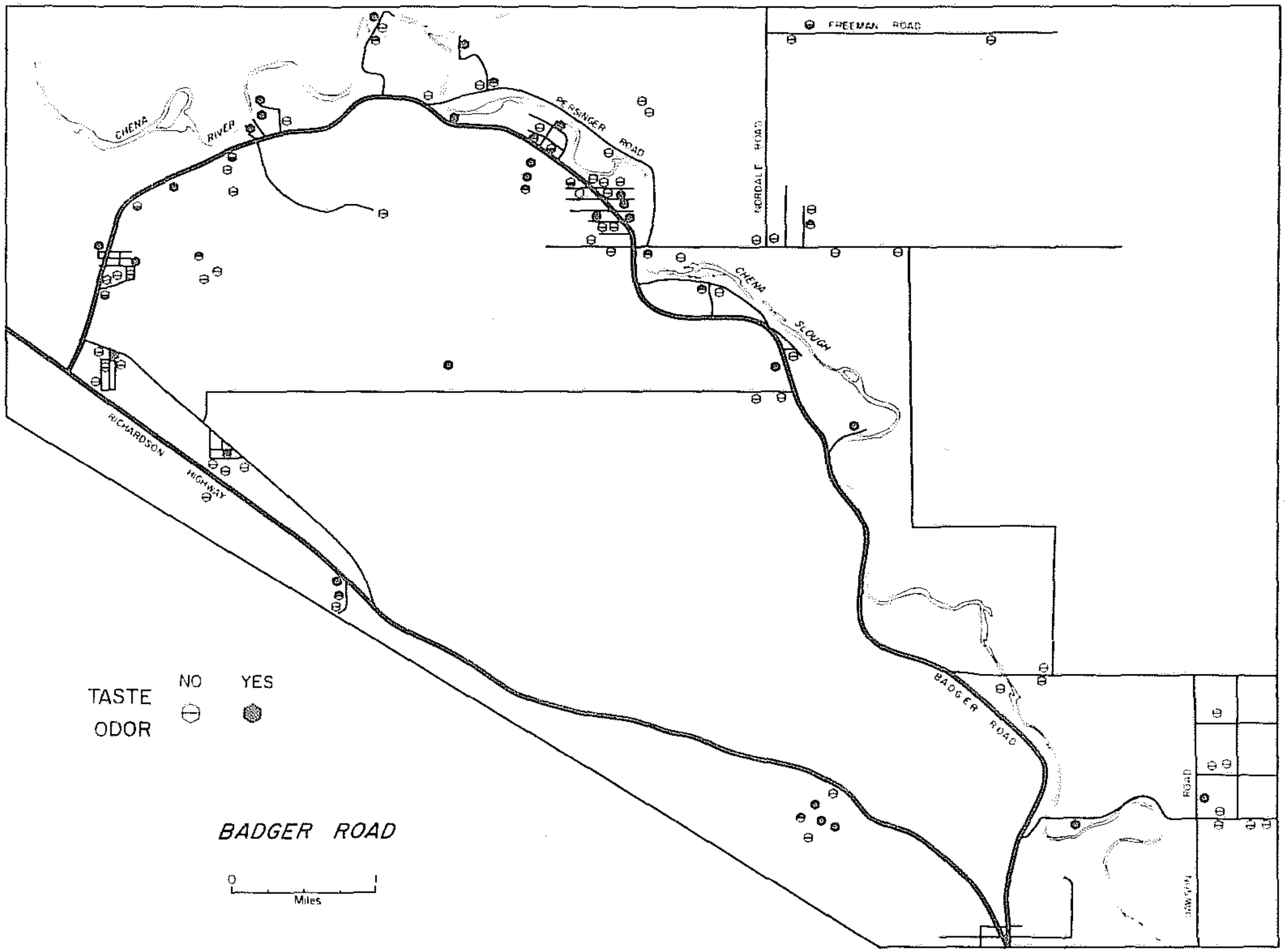

Figure 22: Badger Road Subarea - Reported Locations of Taste and Odor Problems in the Well Water Supply.

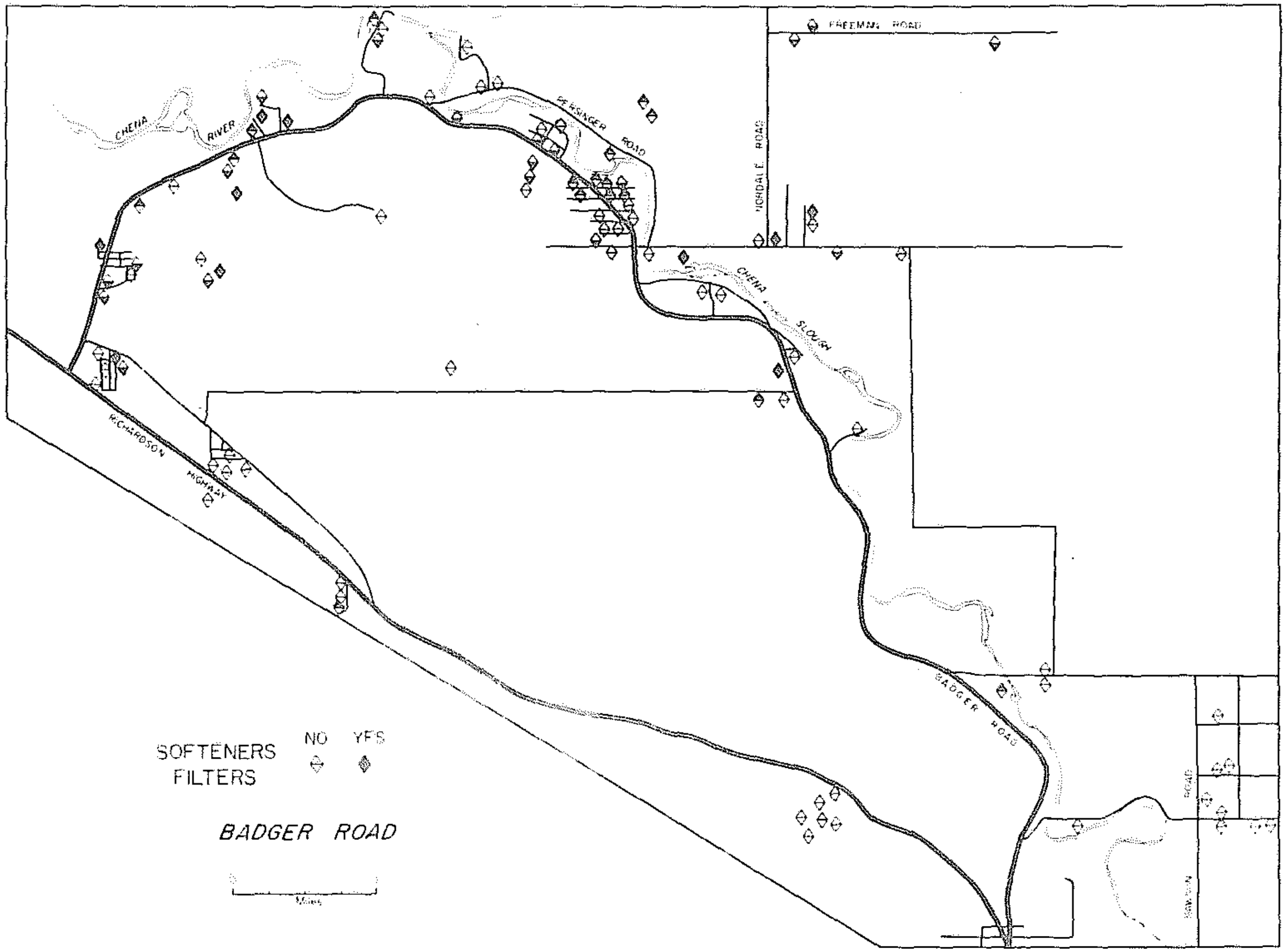

Figure 23: Badger Road Subarea - Reported Locations of Water Softener and Filter Installations.

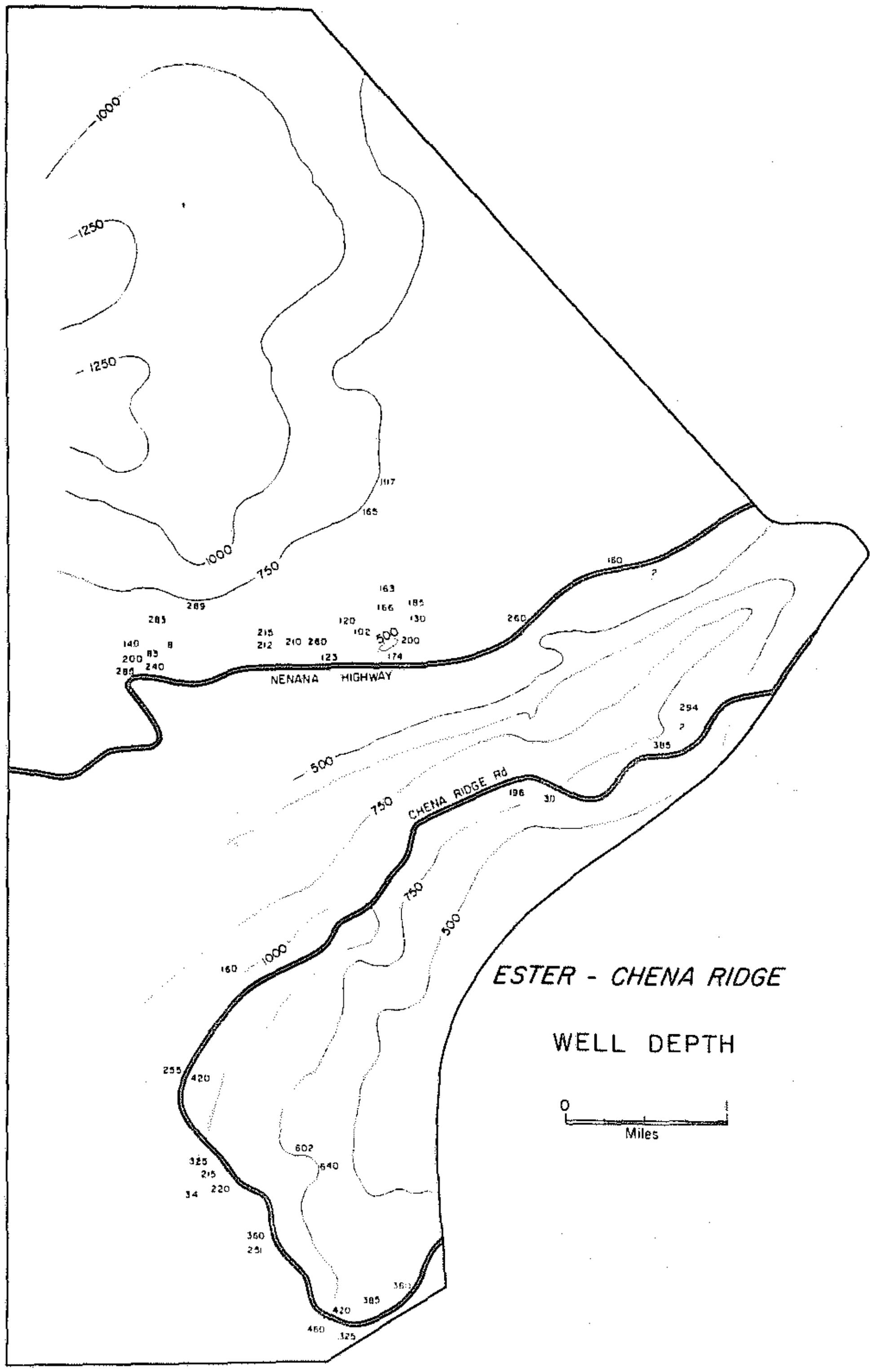

Figure 24: Ester-Chena Ridge Subarea - Reported Well Depths.

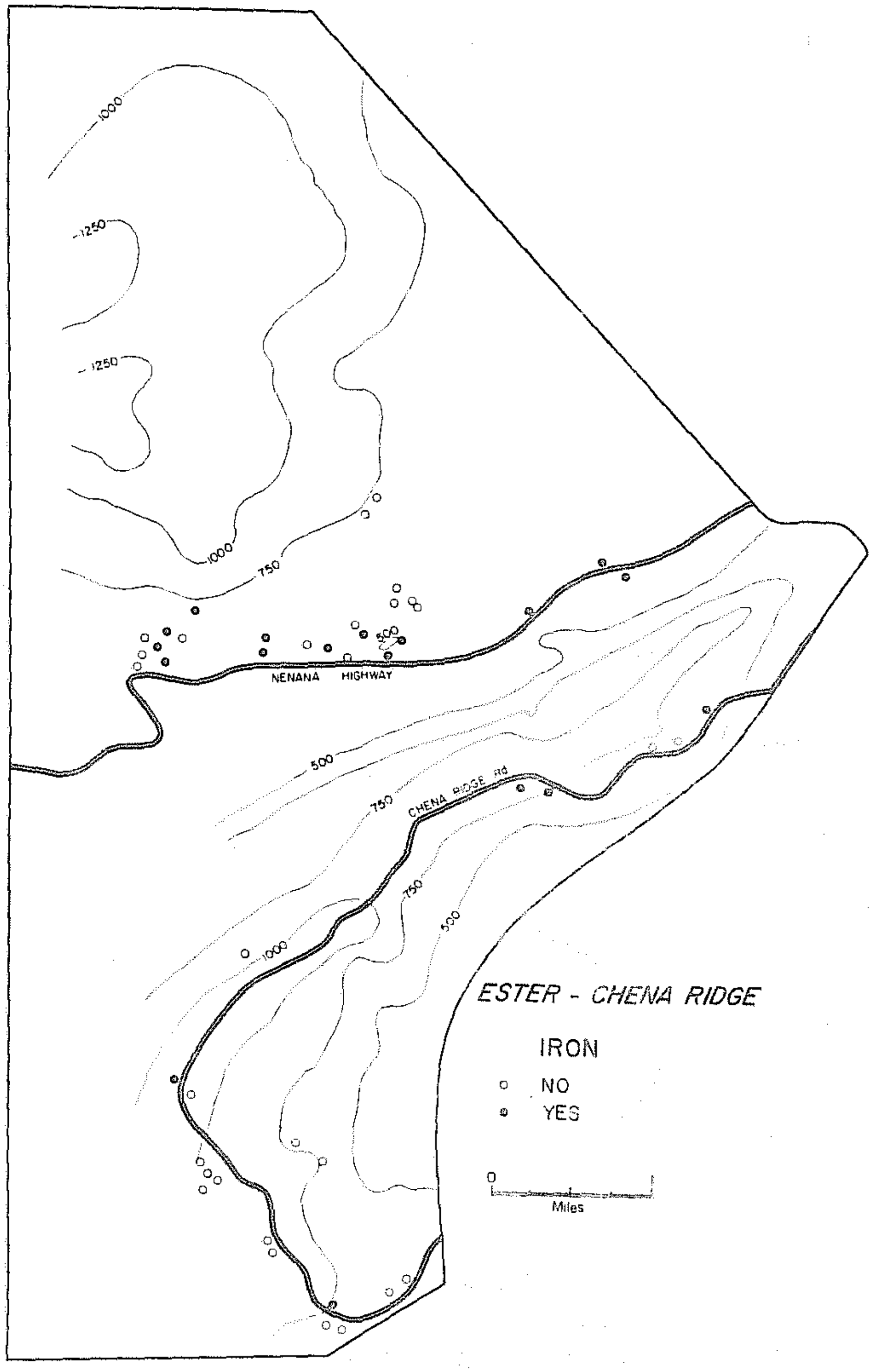

Figure 25: Ester-Chena Ridge Subarea - Reported Locations of an Iron Problem in the Well Water Supply.

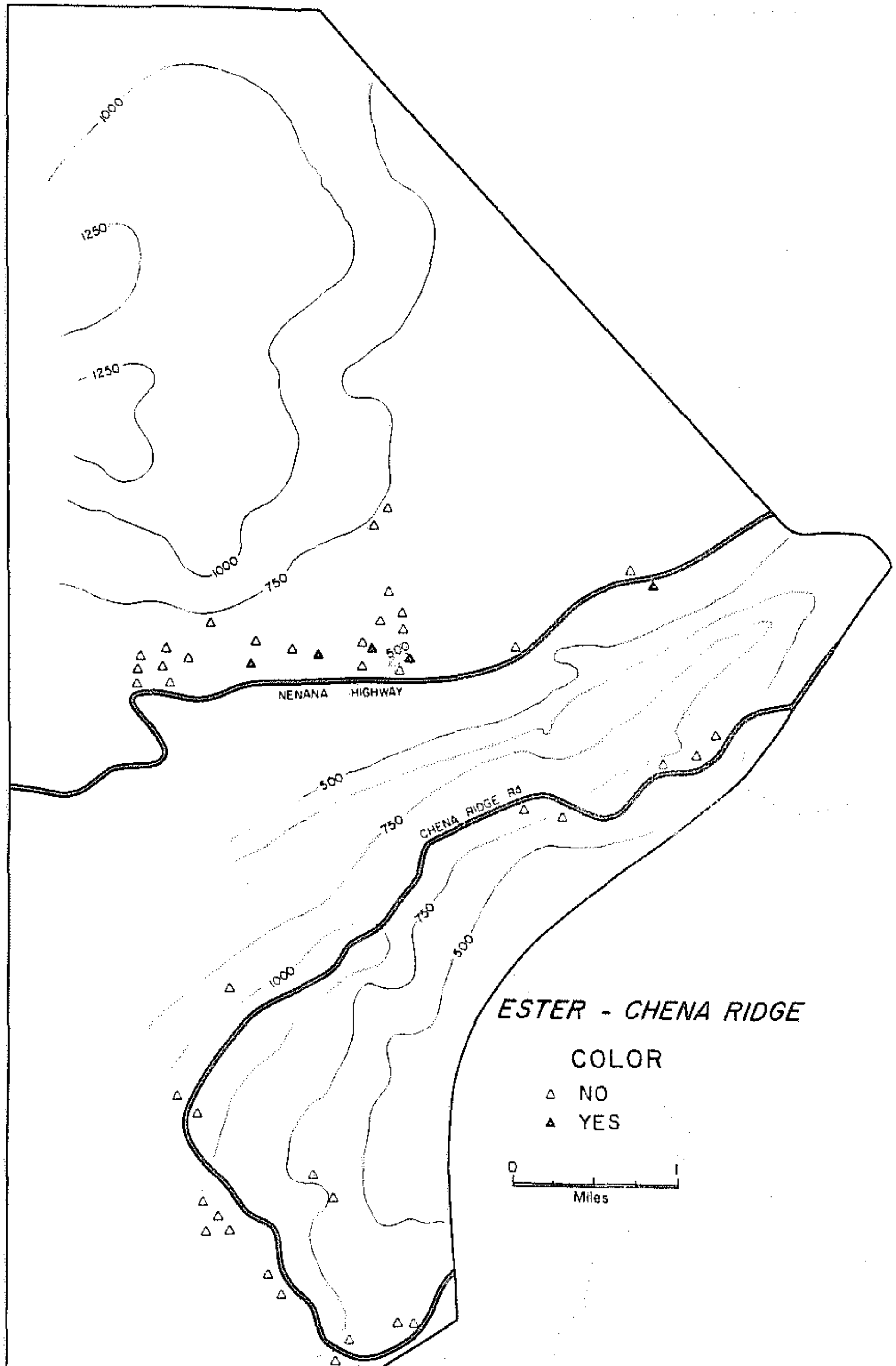

Figure 26: Ester-Chena Ridge Subarea - Reported Locations of a Color Problem in the Well Water Supply.

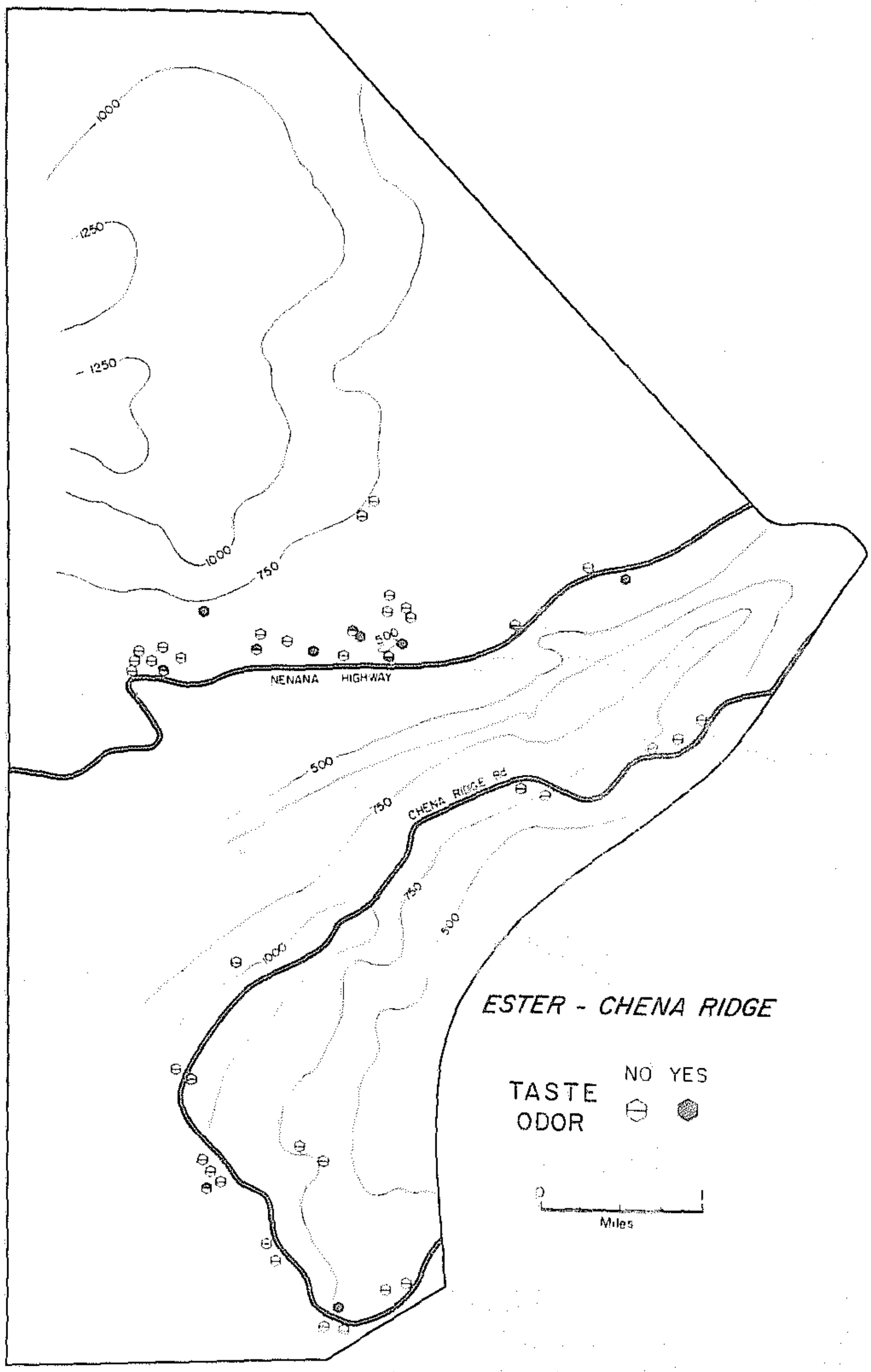

Figure 27: Ester-Chena Ridge Subarea - Reported Locations of Taste and Odor Problems in the Well Water Supply.

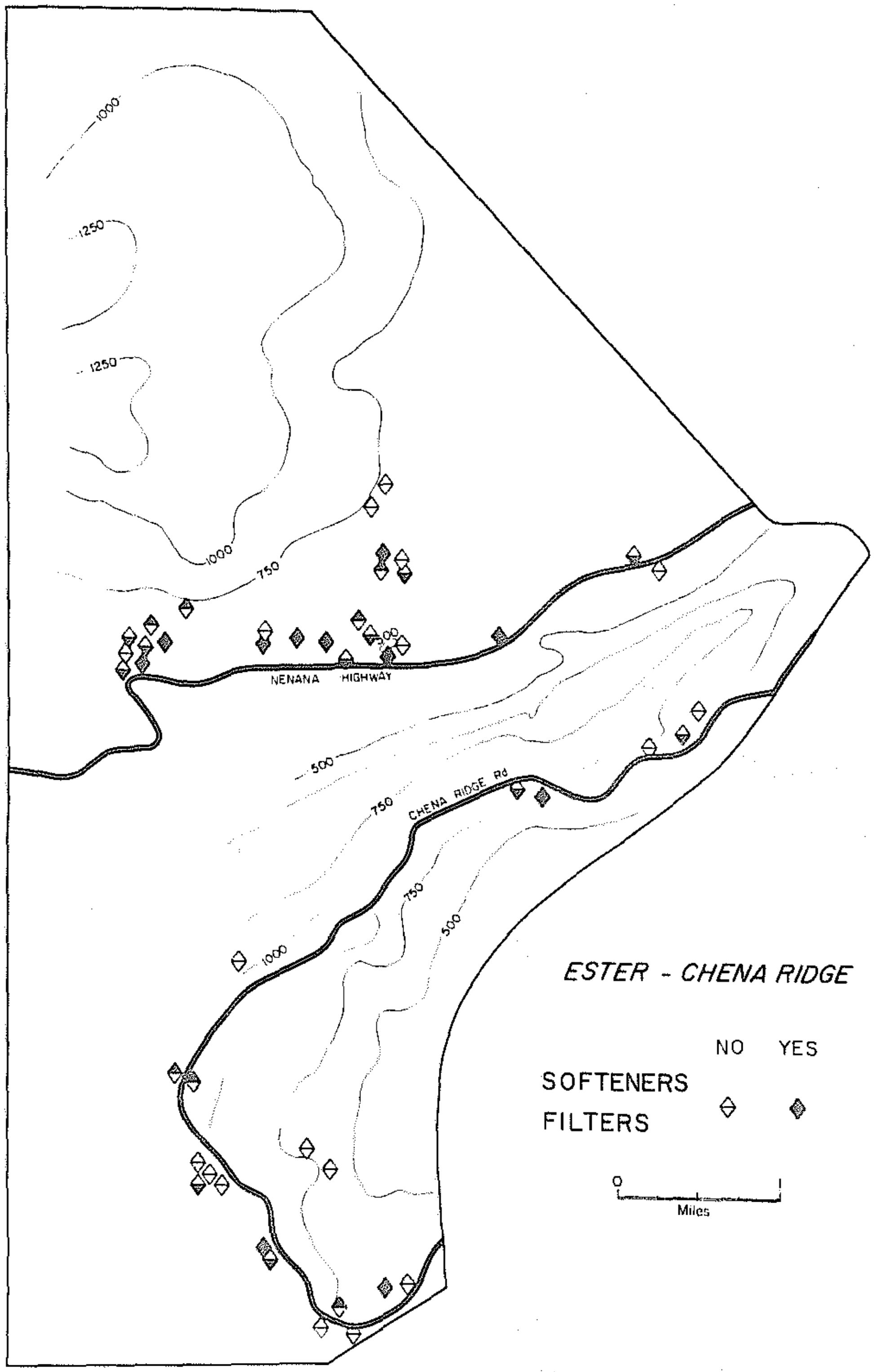

Figure 28: Ester-Chena Ridge Subarea - Reported Locations of Water Softener and Filter Installations.

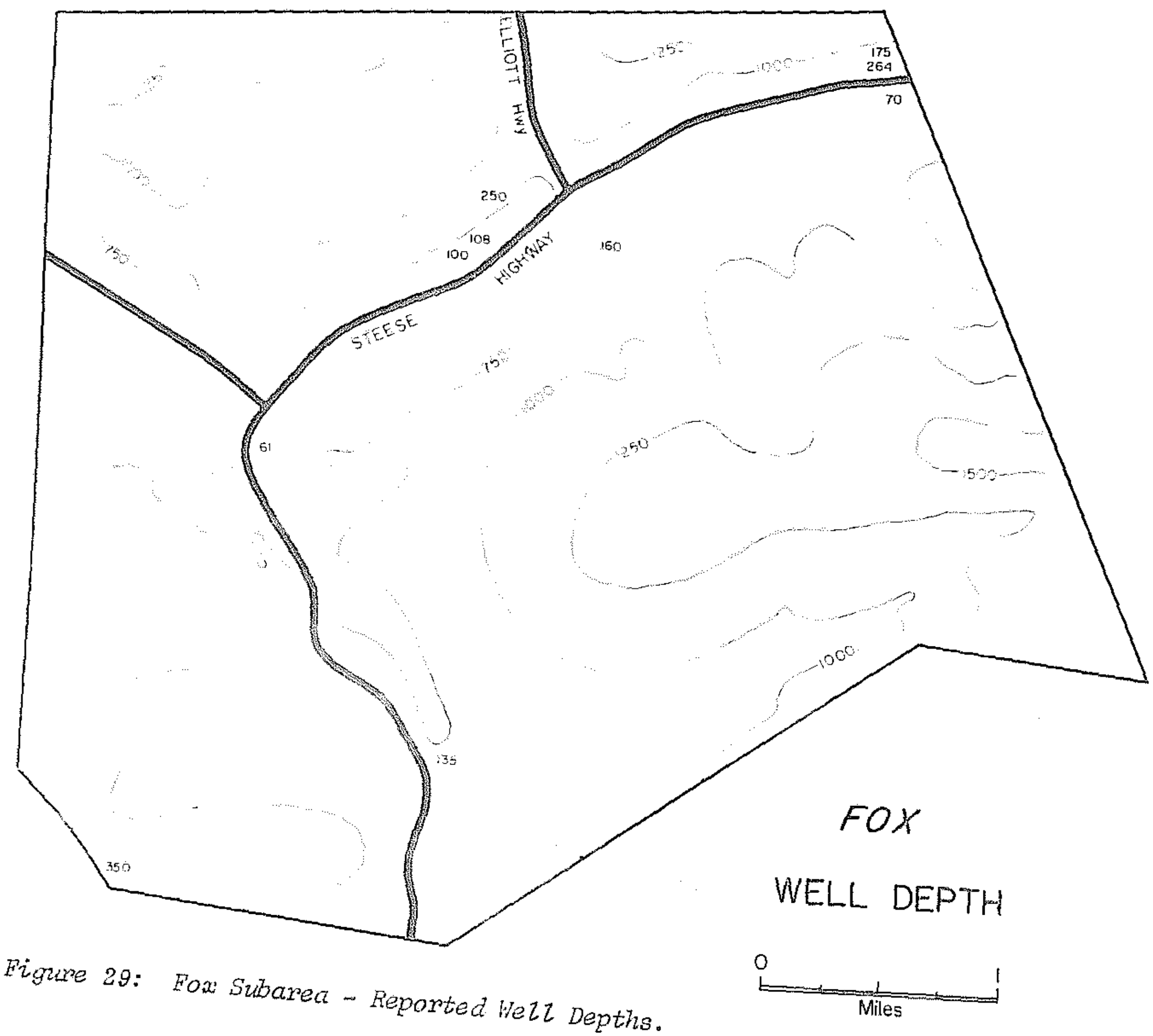

Figure 29: Fox Subarea - Reported Well Depths.

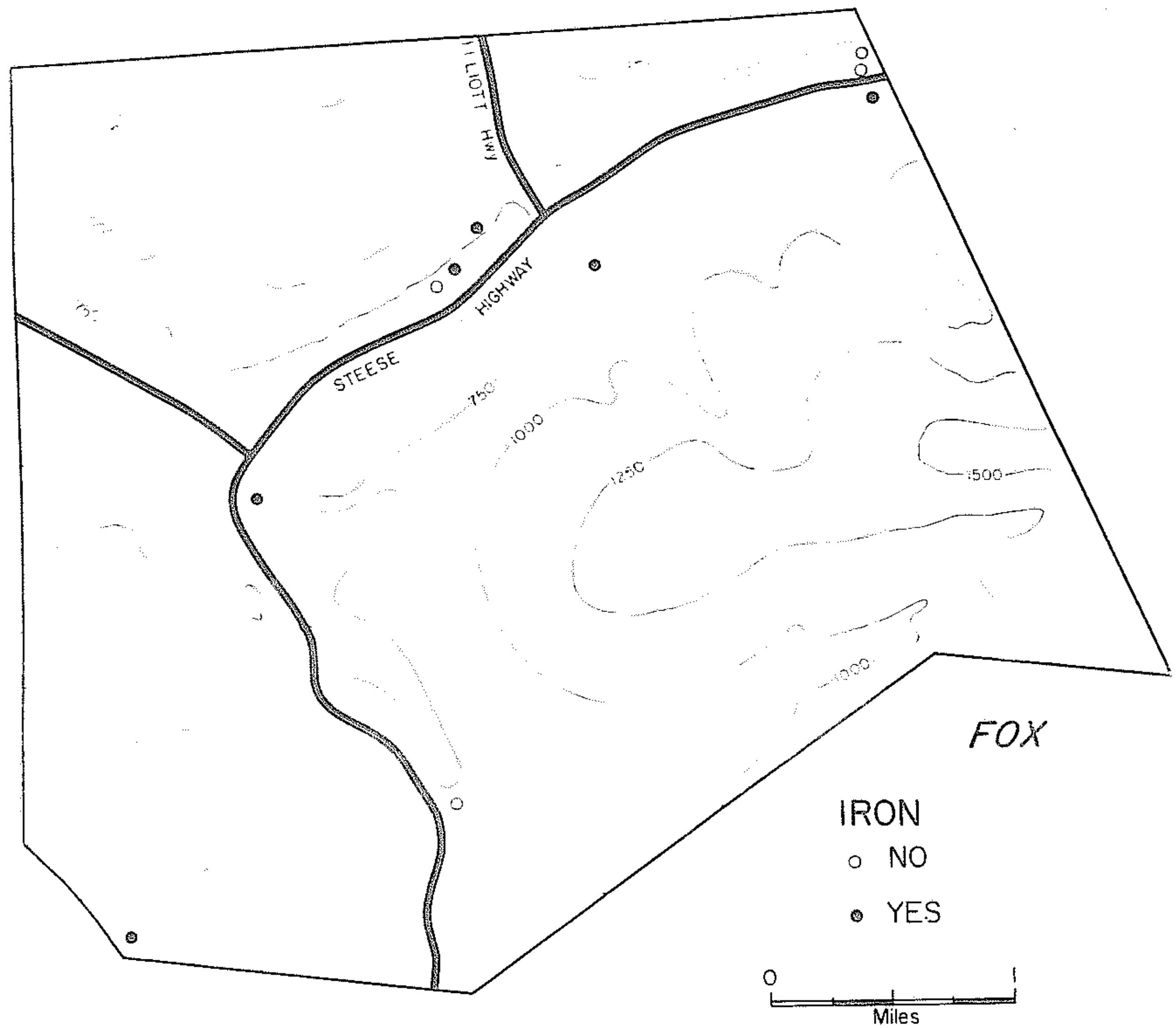

Figure 30: Fox Subarea - Reported Locations of an Iron Problem in the Well Water Supply.

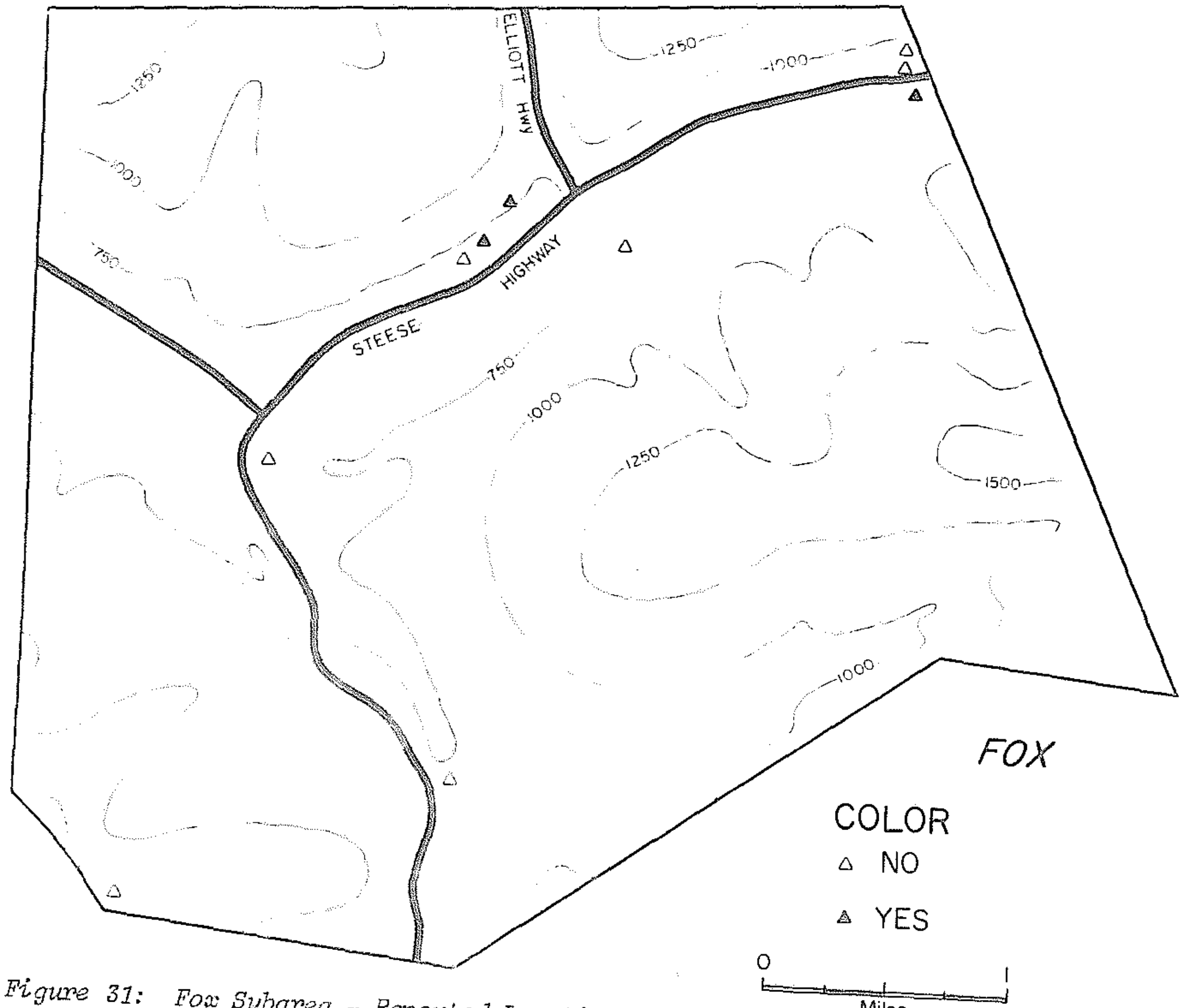

Figure 31: *Fox Subarea - Reported Locations of a Color Problem in the Well Water Supply.*

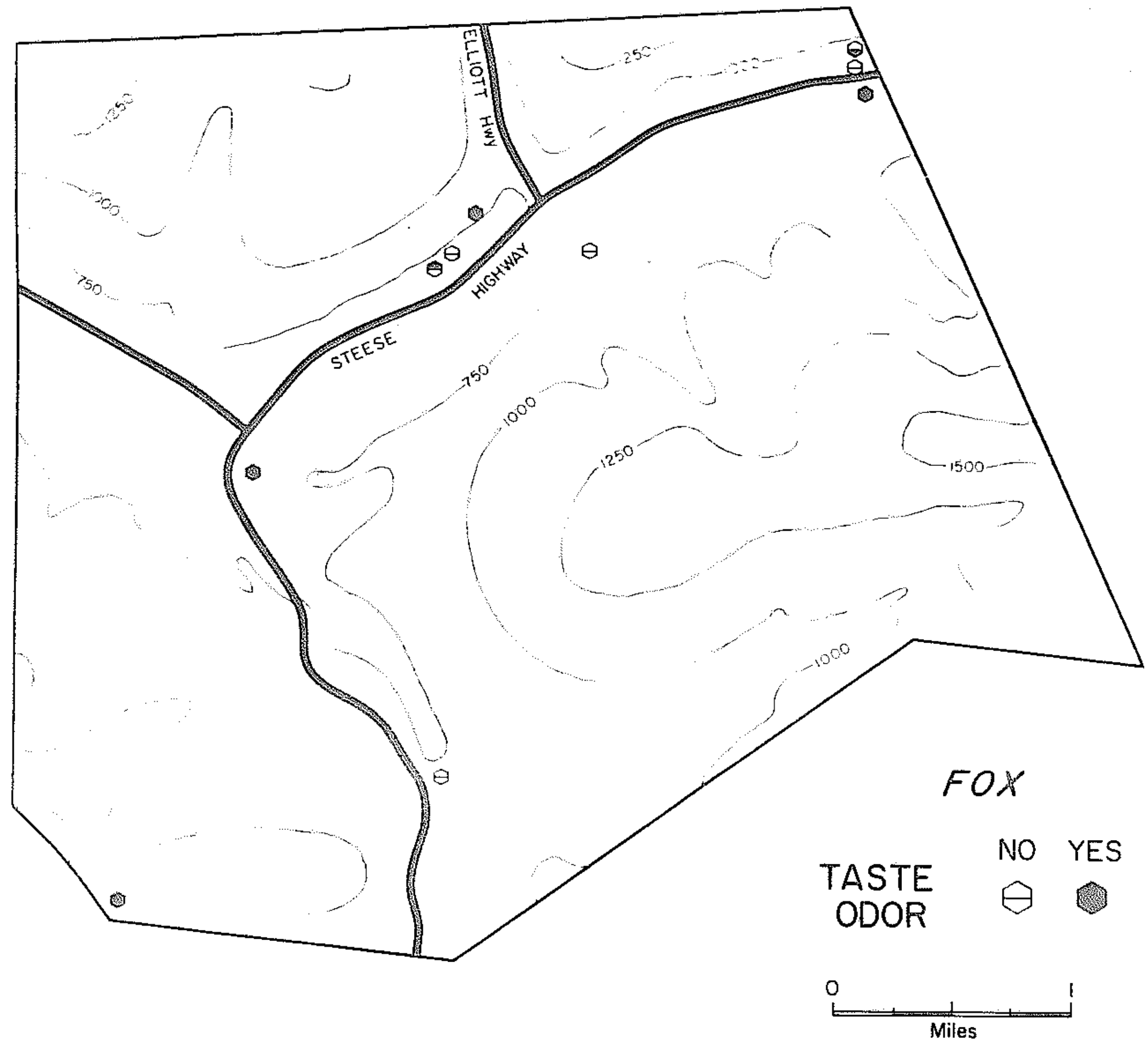

Figure 32: Fox Subarea - Reported Locations of Taste and Odor Problems in the Well Water Supply.

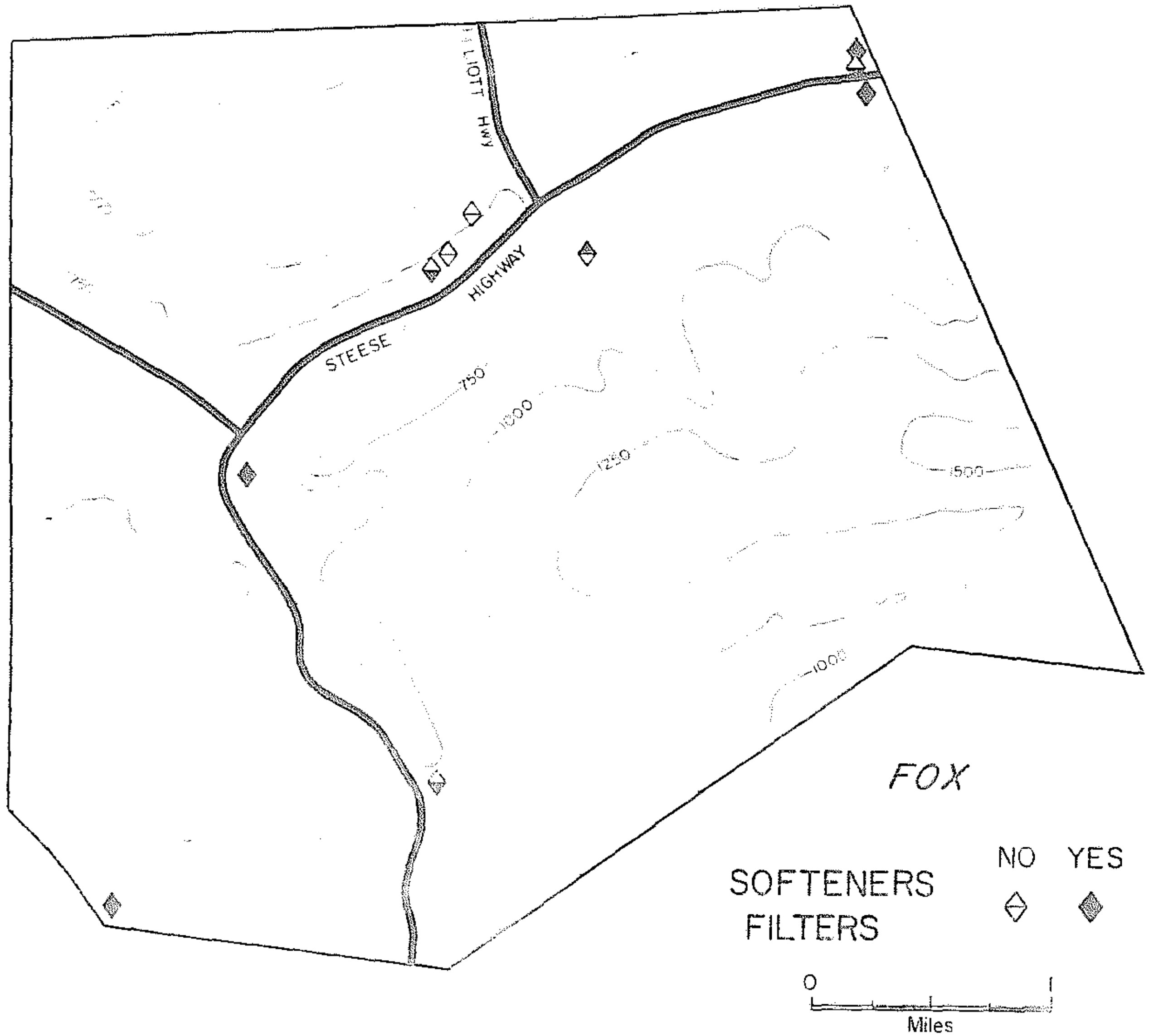

Figure 33: Fox Subarea - Reported Locations of Water Softener and Filter Installations.

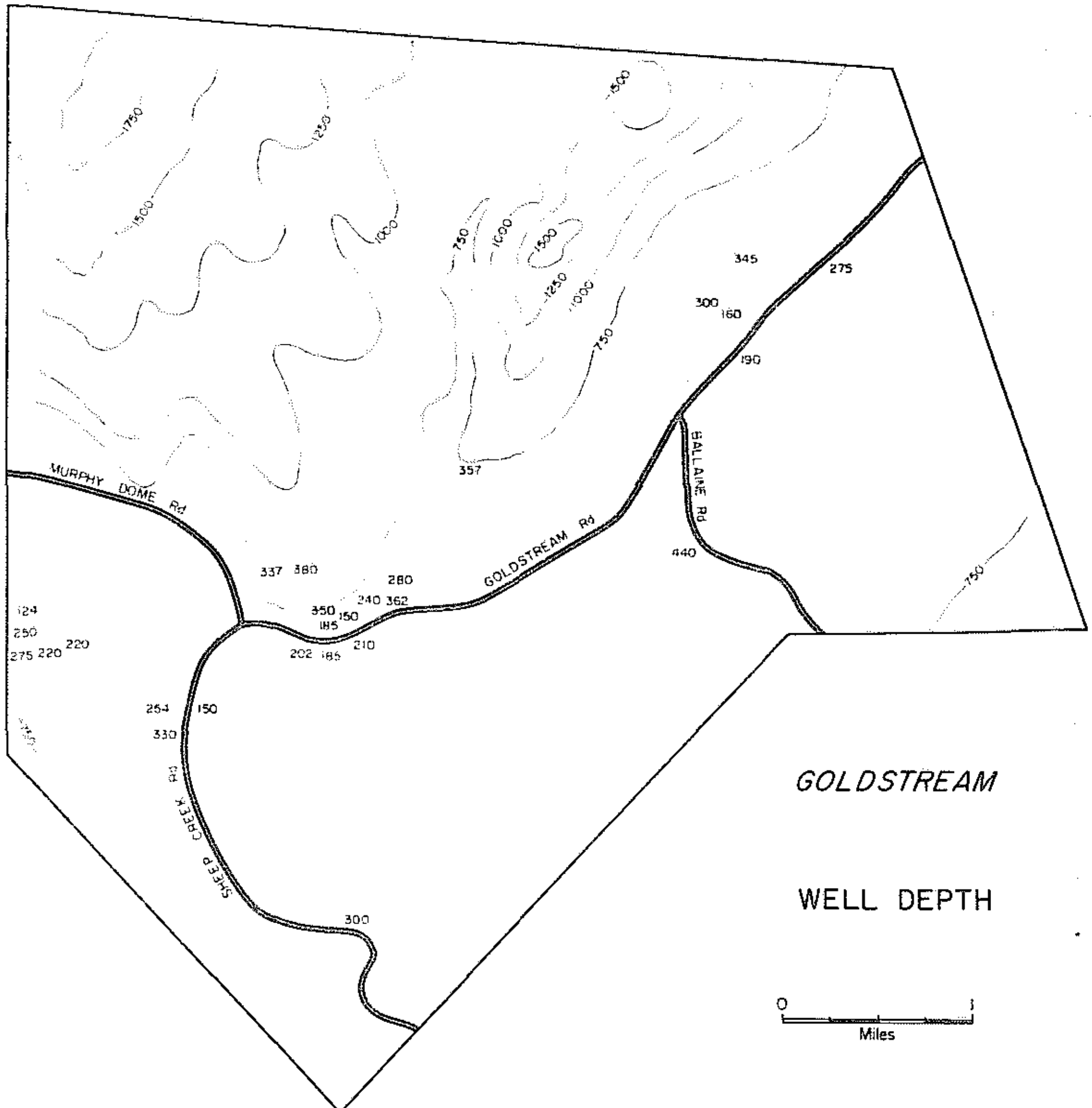

Figure 34: Goldstream Subarea - Reported Well Depths.

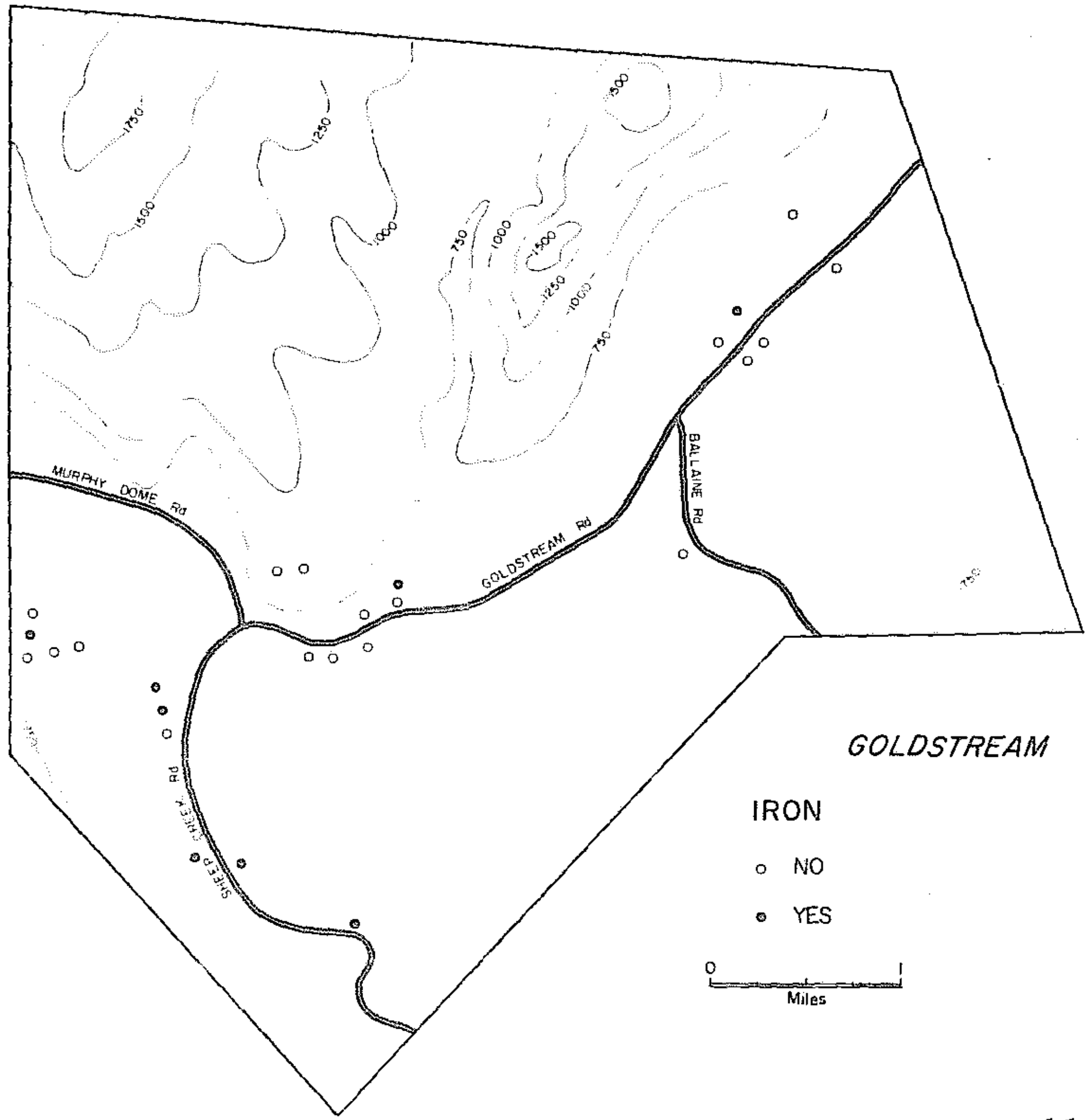

Figure 35: Goldstream Subarea - Reported Locations of an Iron Problem in the Well Water Supply.

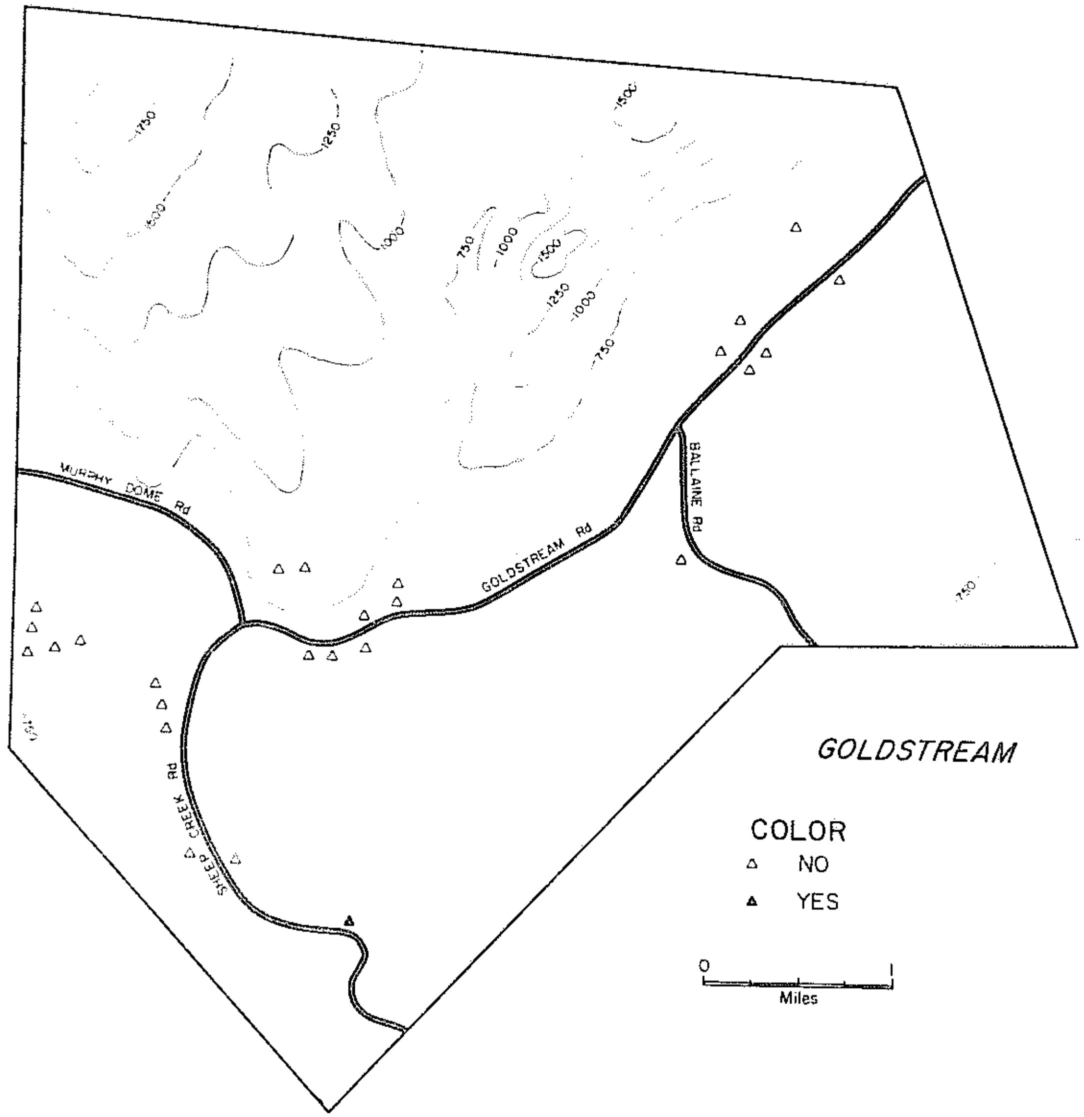

Figure 36: Goldstream Subarea - Reported Locations of a Color Problem in the Well Water Supply.

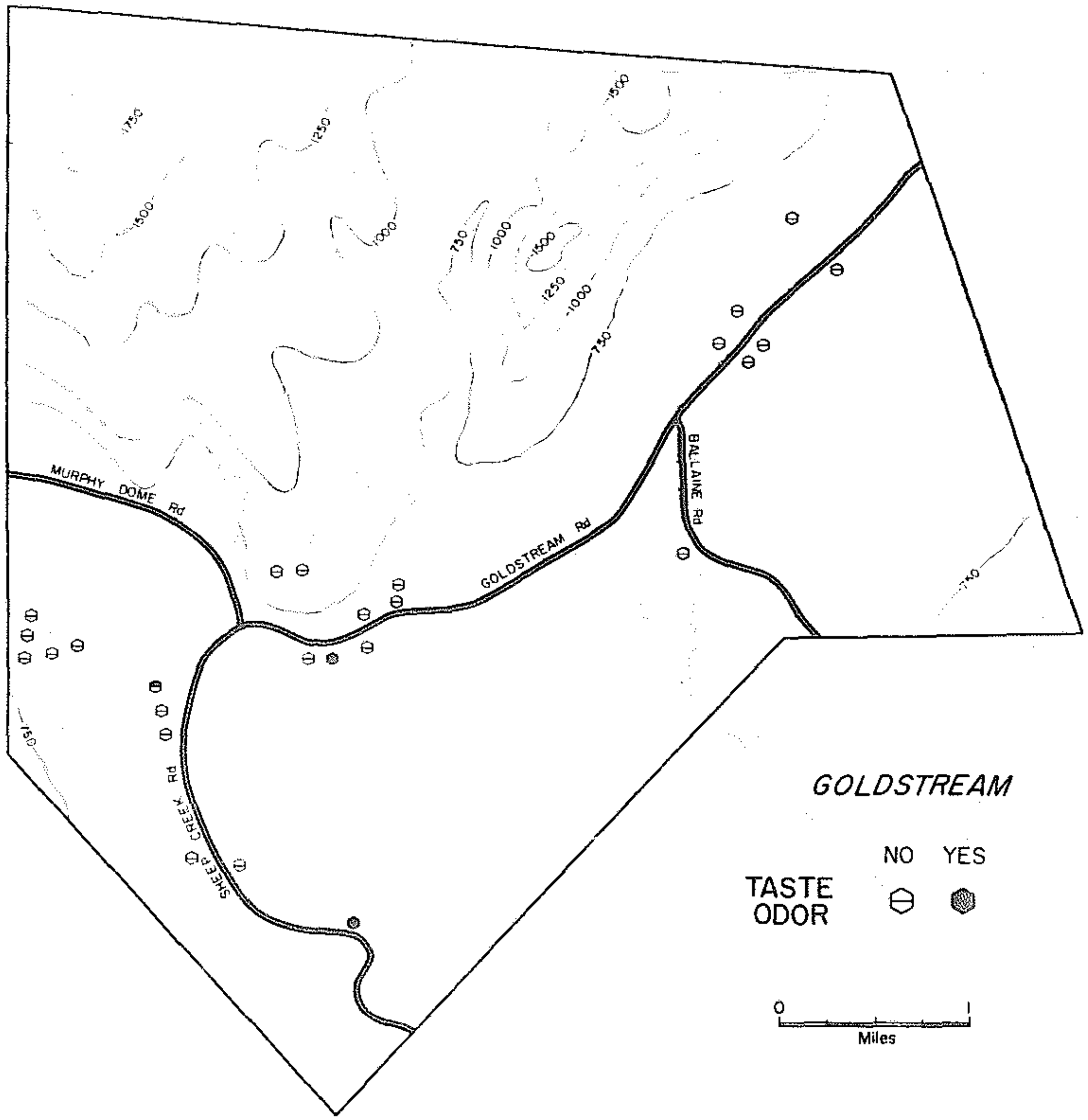

Figure 37: Goldstream Subarea - Reported Locations of Taste and Odor Problems in the Well Water Supply.

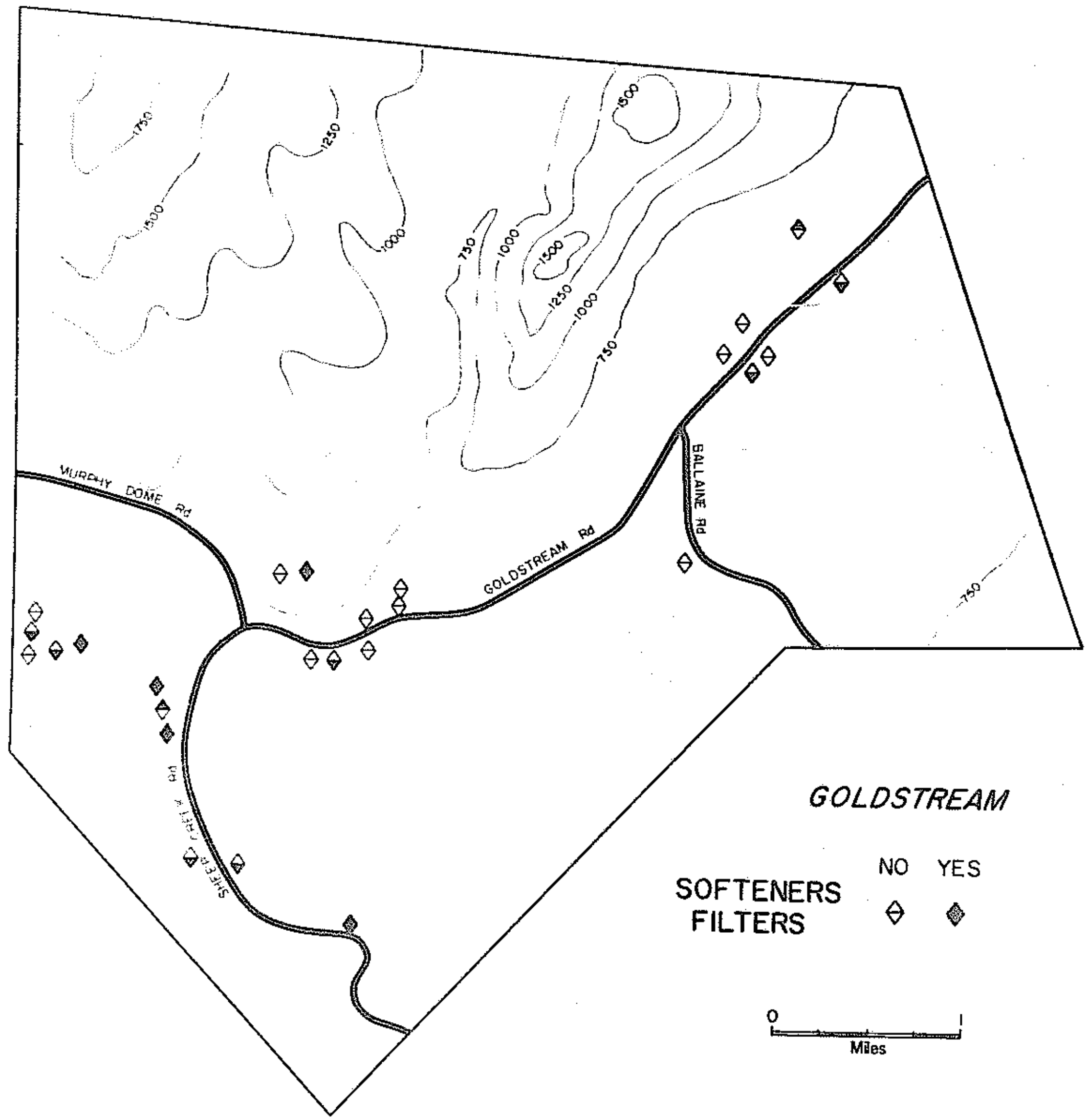

Figure 38: Goldstream Subarea - Reported Locations of Water Softener and Filter Installations.

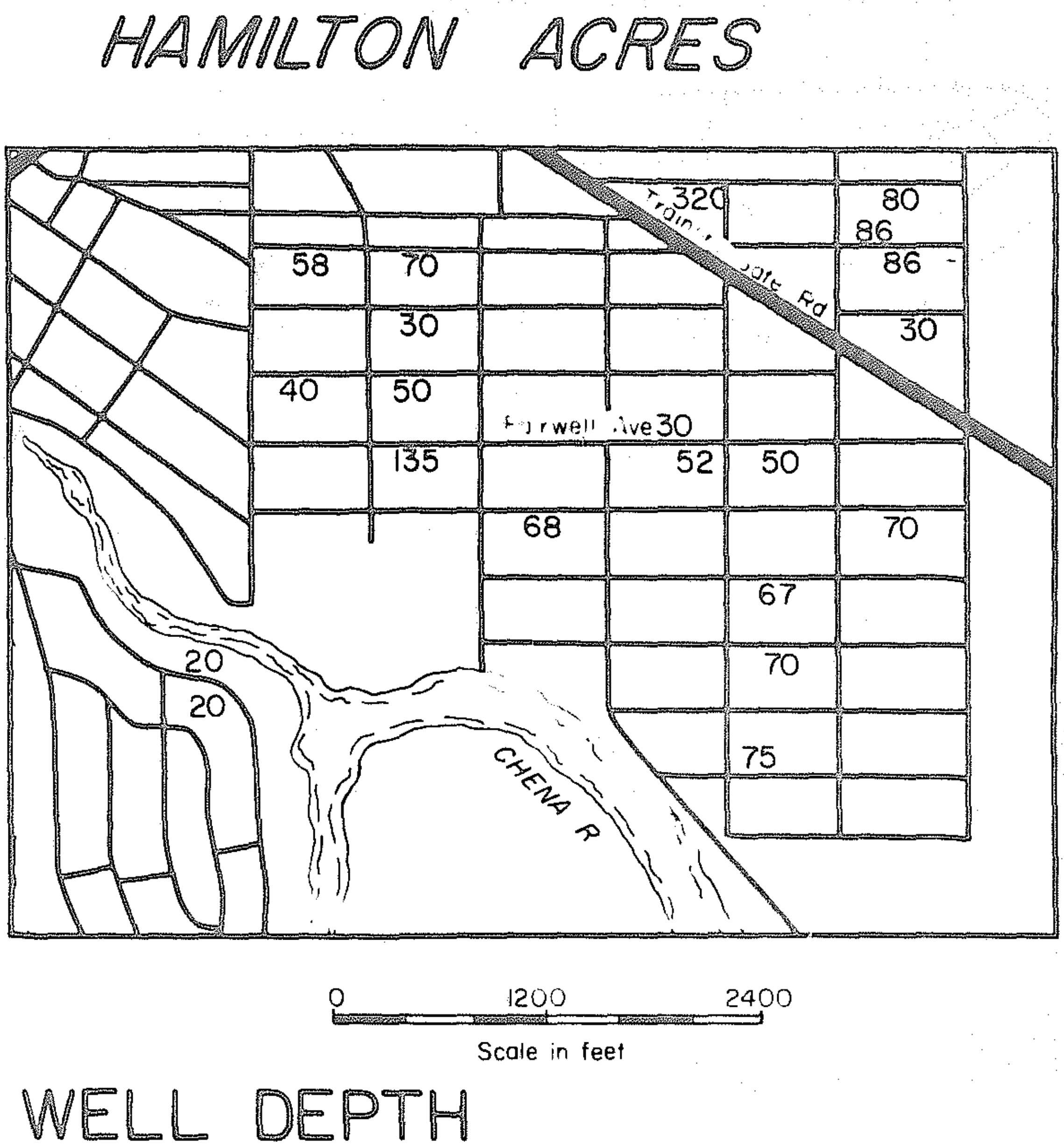

Figure 39: Hamilton Acres Subarea - Reported Well Depths.

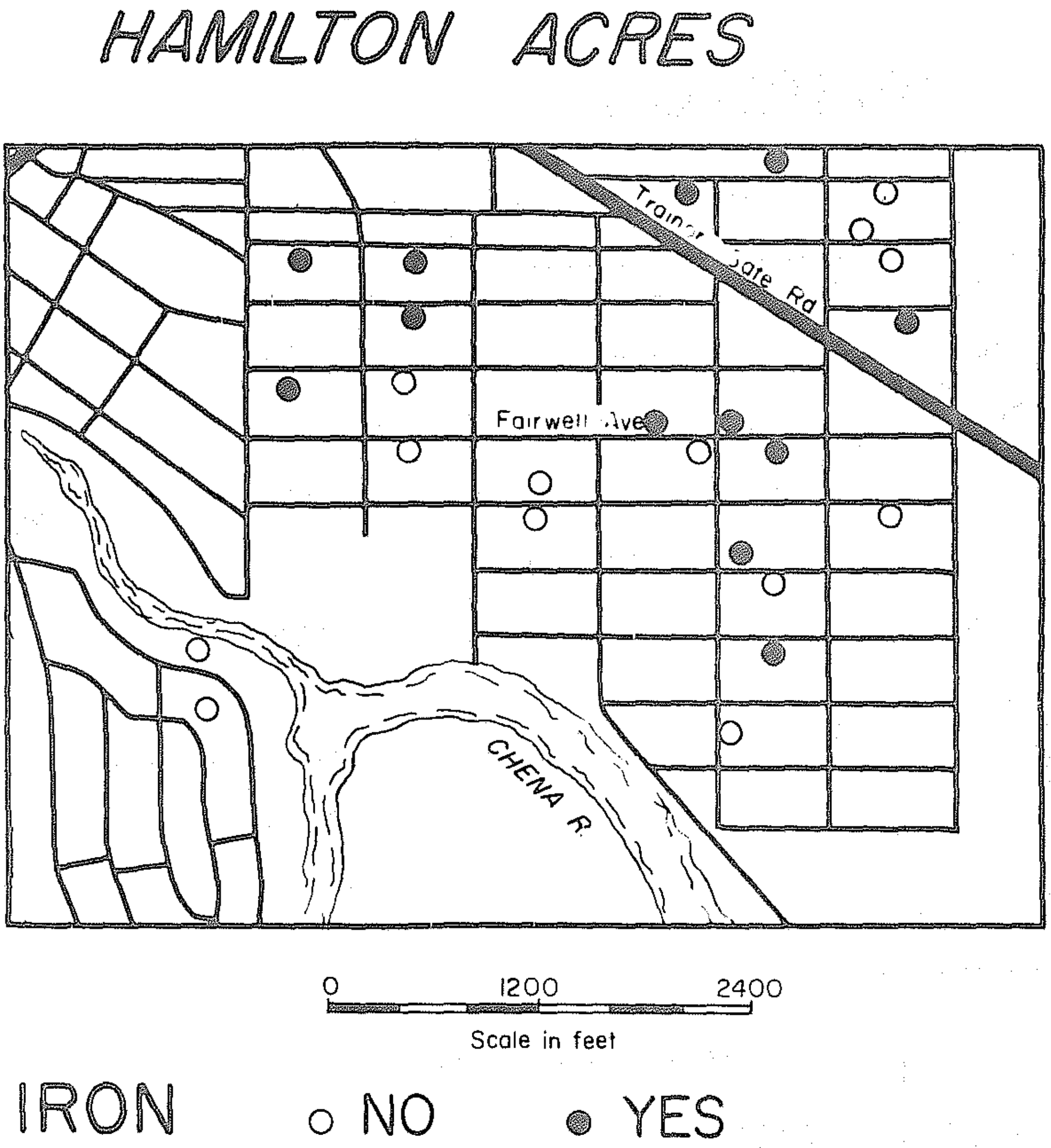

Figure 40: Hamilton Acres Subarea - Reported Locations of an Iron Problem in the Well Water Supply.

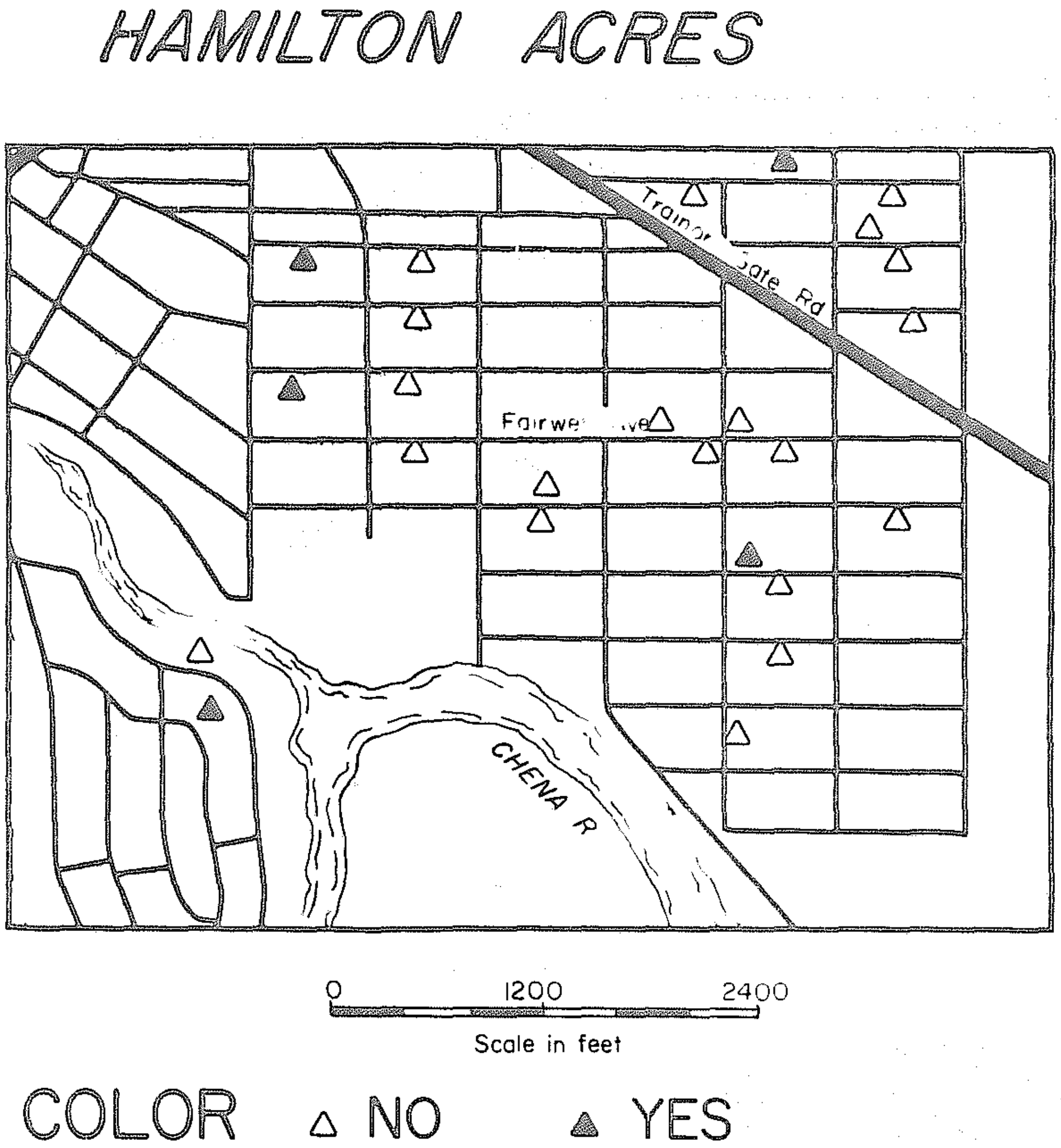

Figure 41: Hamilton Acres Subarea - Reported Locations of a Color Problem in the Well Water Supply.

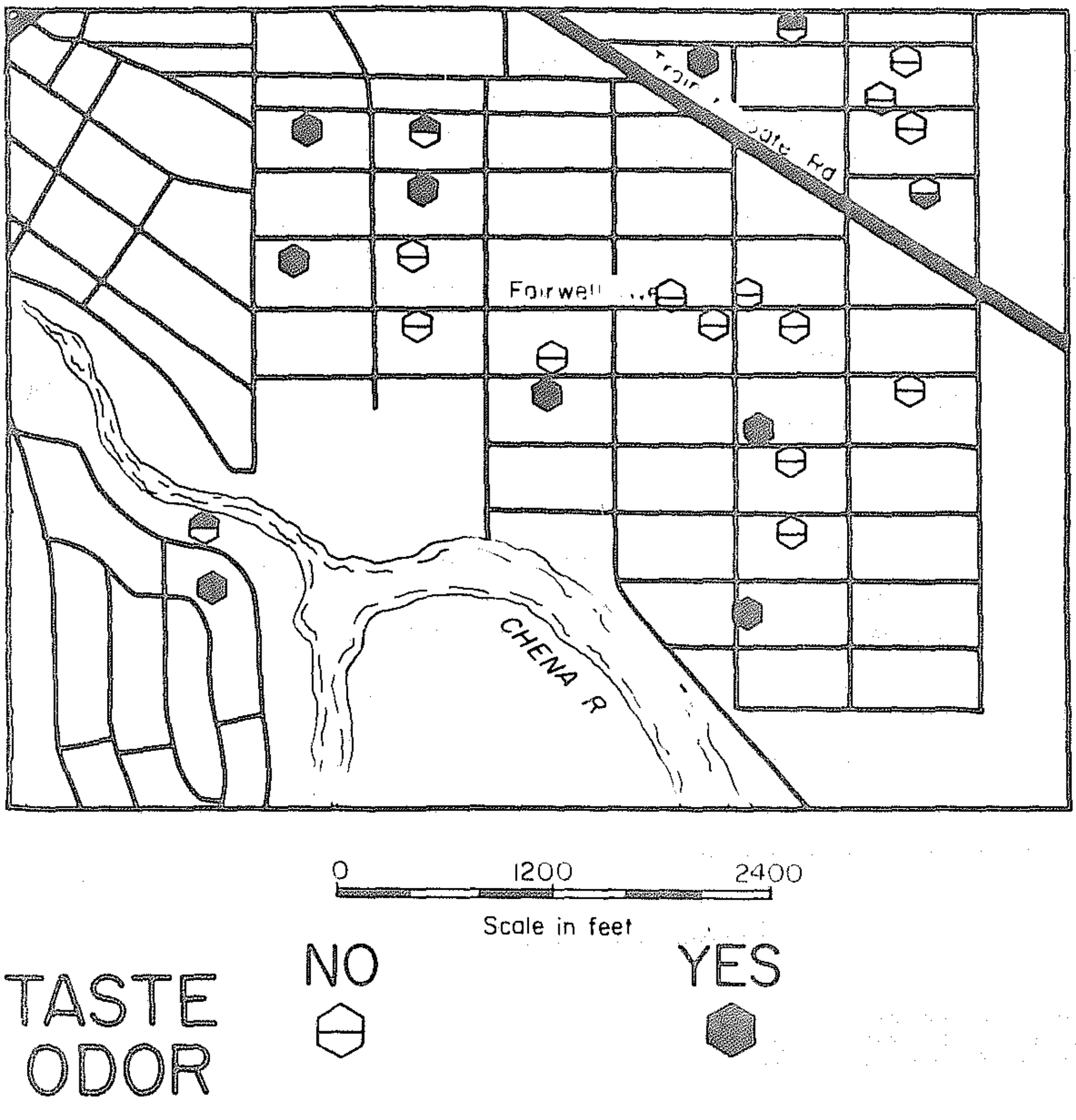

Figure 42: Hamilton Acres Subarea - Reported Locations of Taste and Odor Problems in the Well Water Supply.

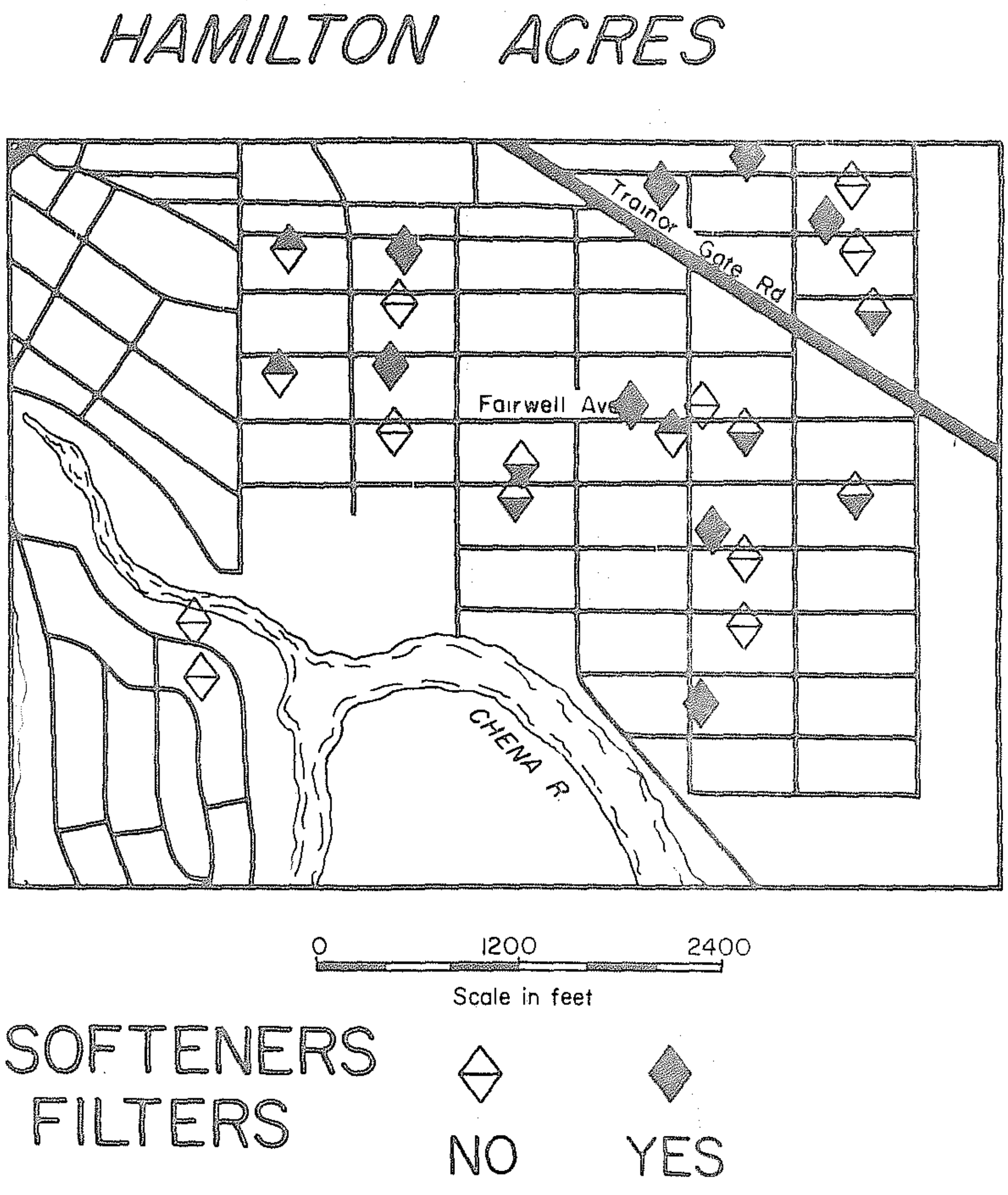

Figure 43: Hamilton Acres Subarea - Reported Locations of Water Softener and Filter Installations.

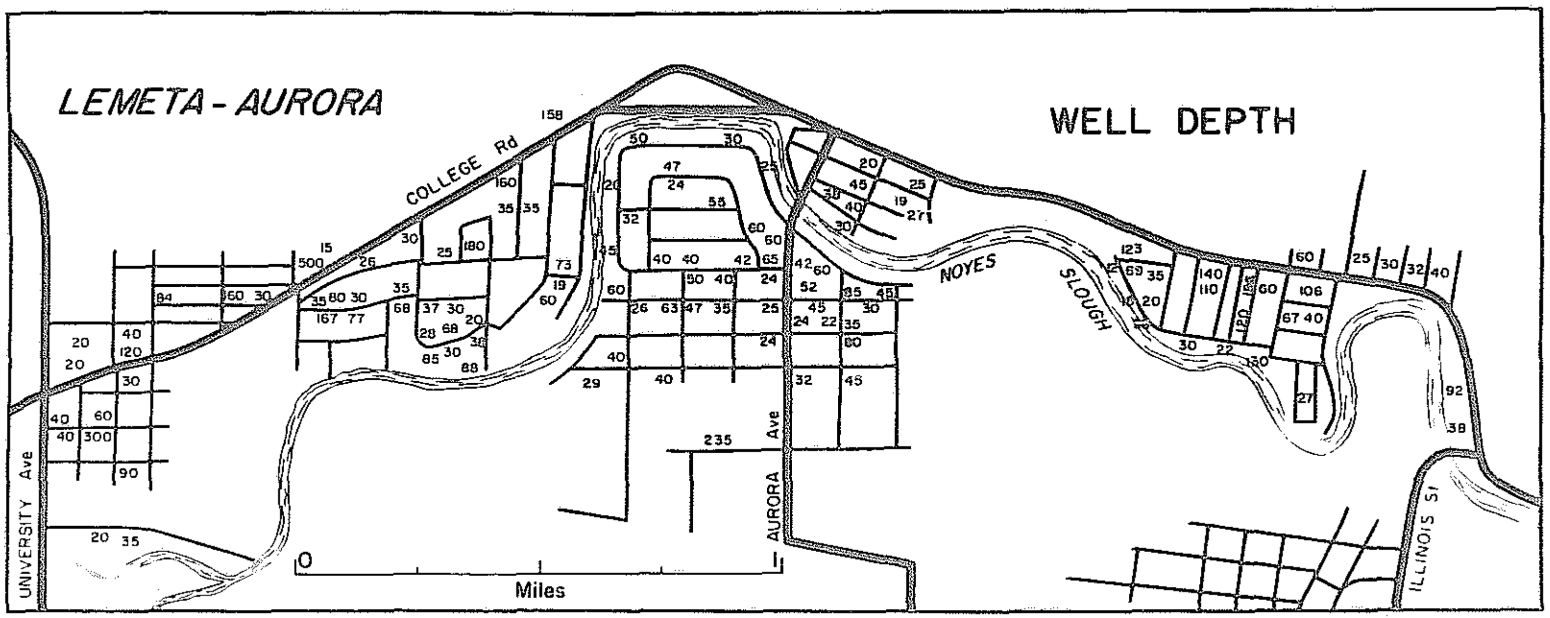

Figure 44: Lemeta-Aurora Subarea - Reported Well Depths.

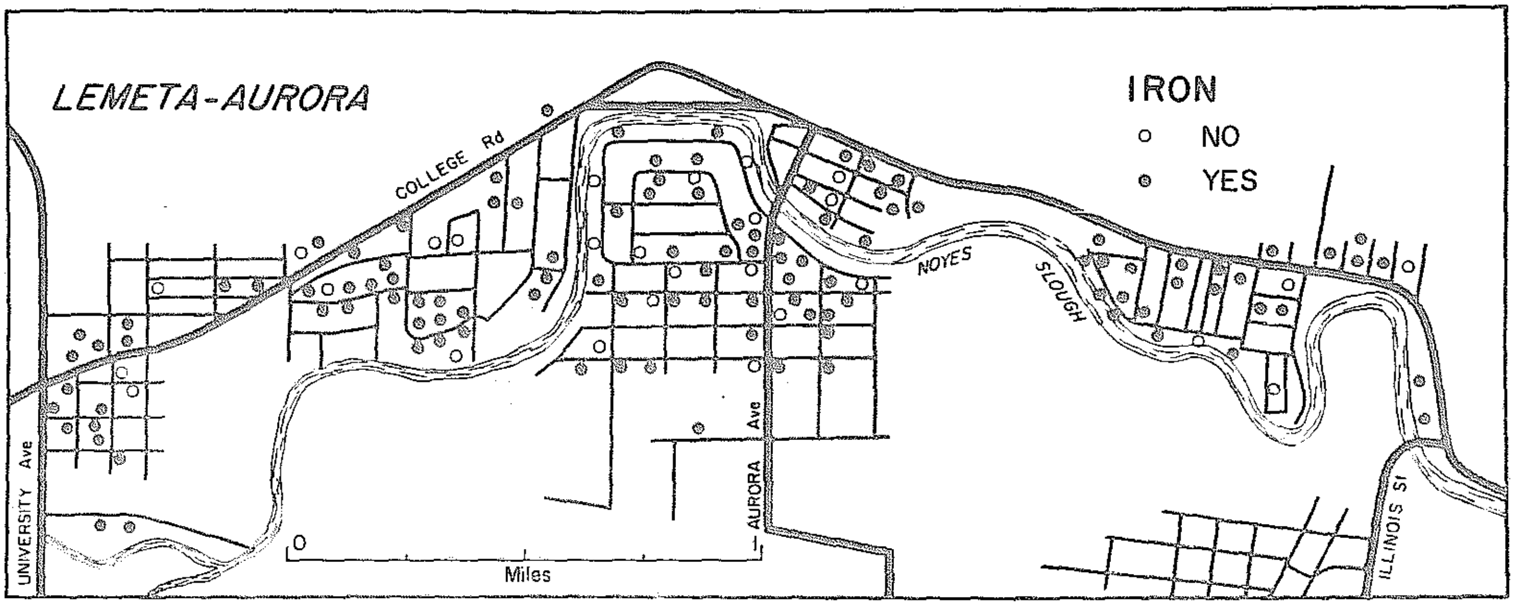

Figure 45: Lemeta-Aurora Subarea - Reported Locations of an Iron Problem in the Well Water Supply.

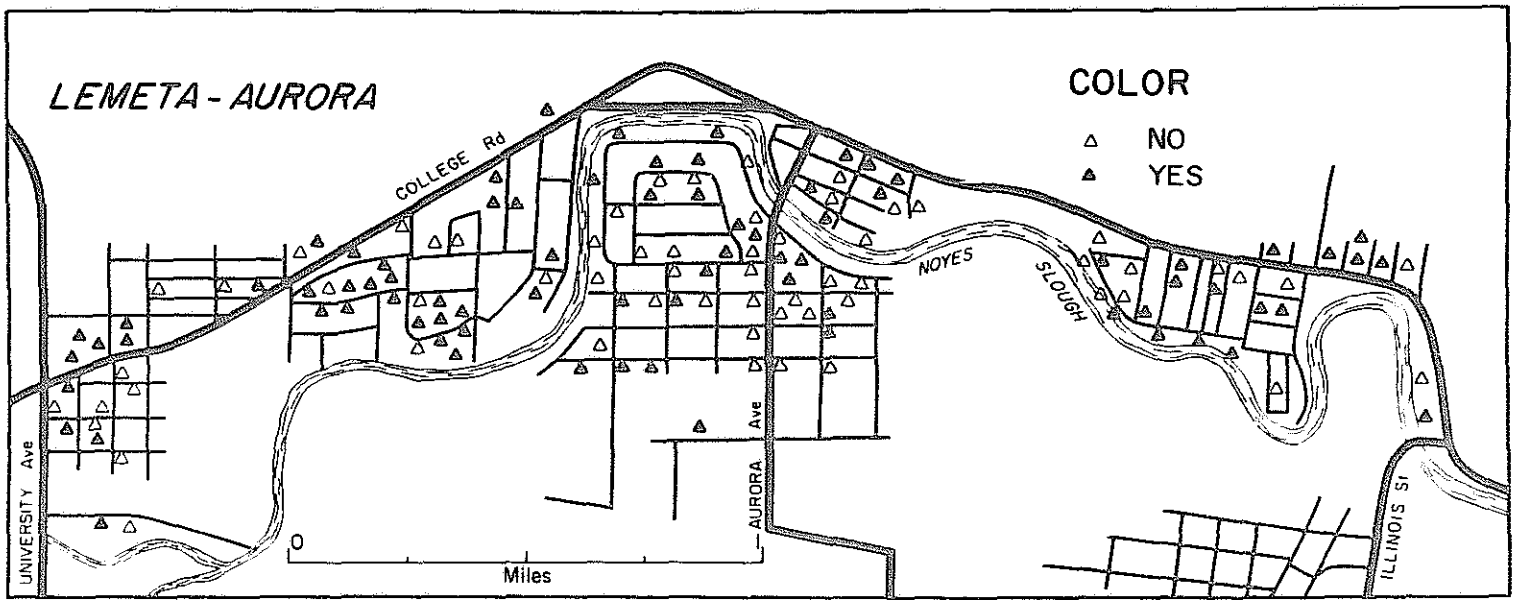

Figure 46: Lemeta-Aurora Subarea - Reported Locations of a Color Problem in the Well Water Supply.

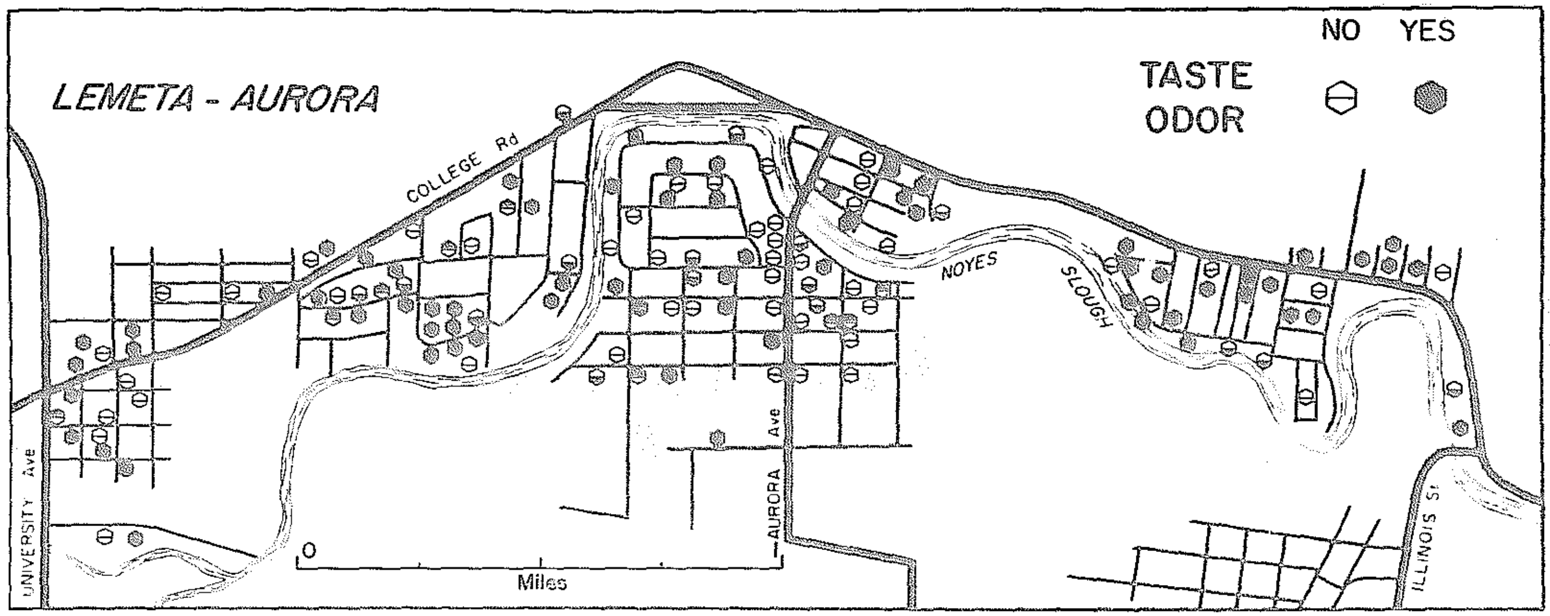

Figure 47: Lemeta-Aurora Subarea - Reported Locations of Taste and Odor Problems in the Well Water Supply.

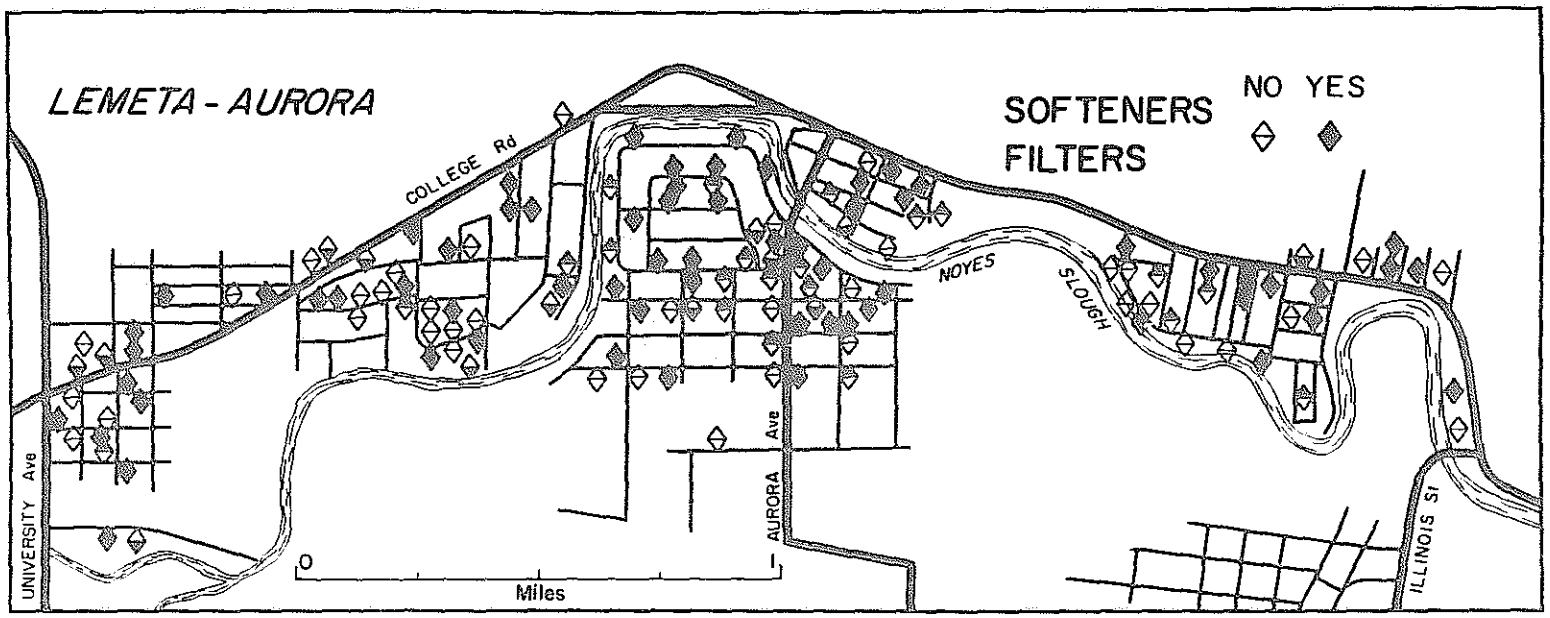

Figure 48: Lemeta-Aurora Subarea - Reported Locations of Water Softener and Filter Installations.

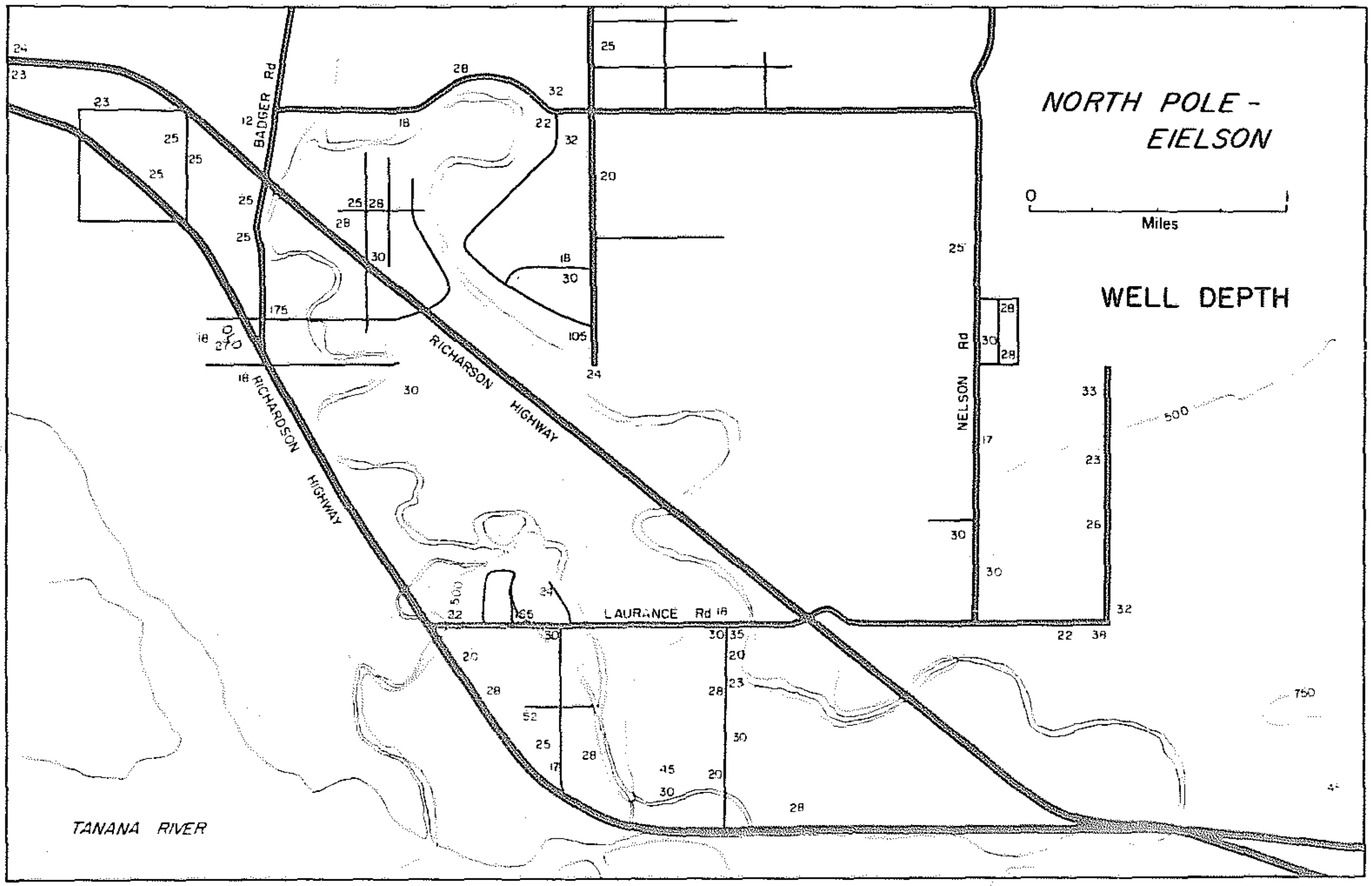

Figure 49: North Pole-Eielson Subarea - Reported Well Depths.

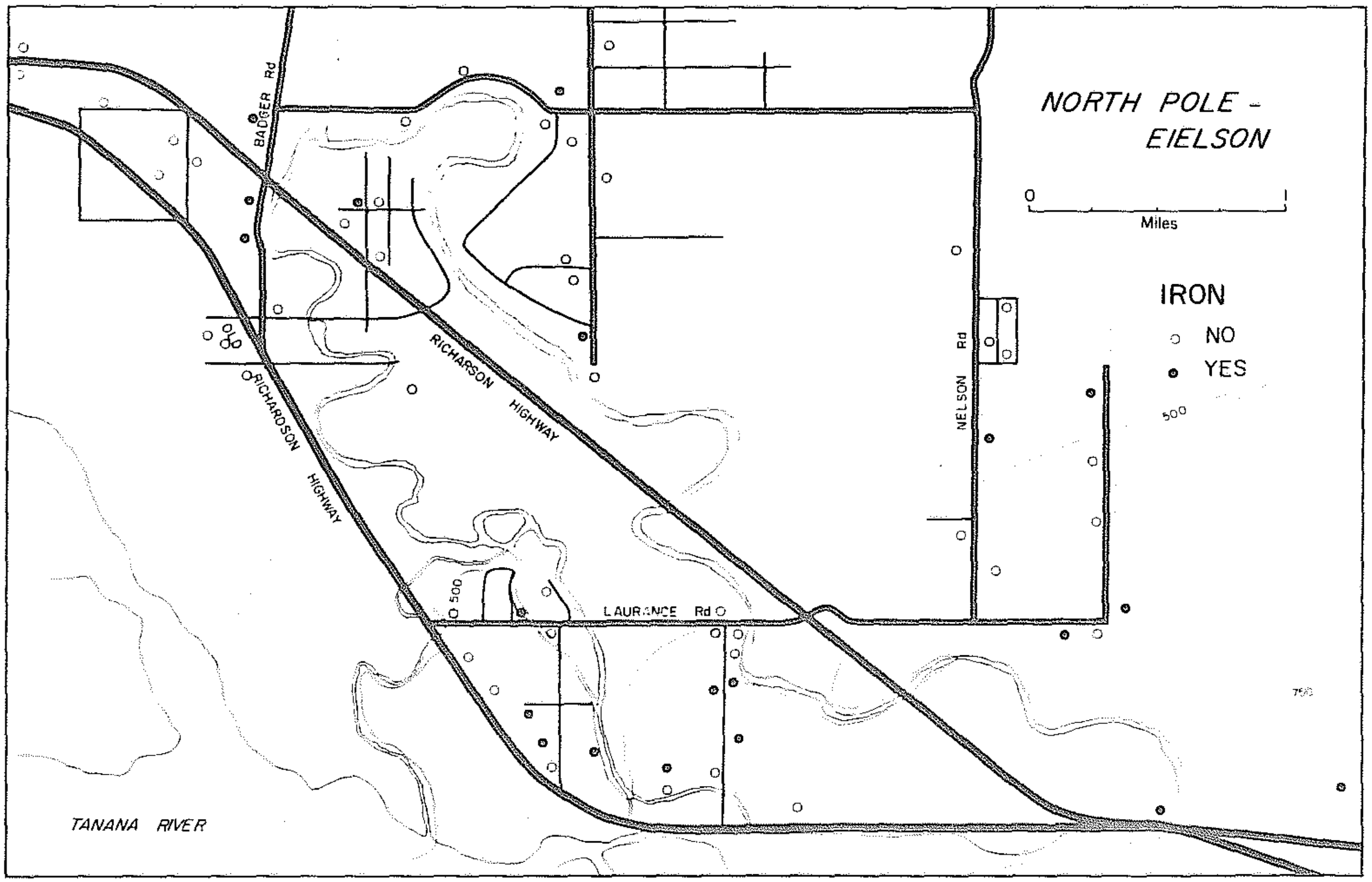

Figure 50: North Pole-Eielson Subarea - Reported Locations of an Iron Problem in the Well Water Supply.

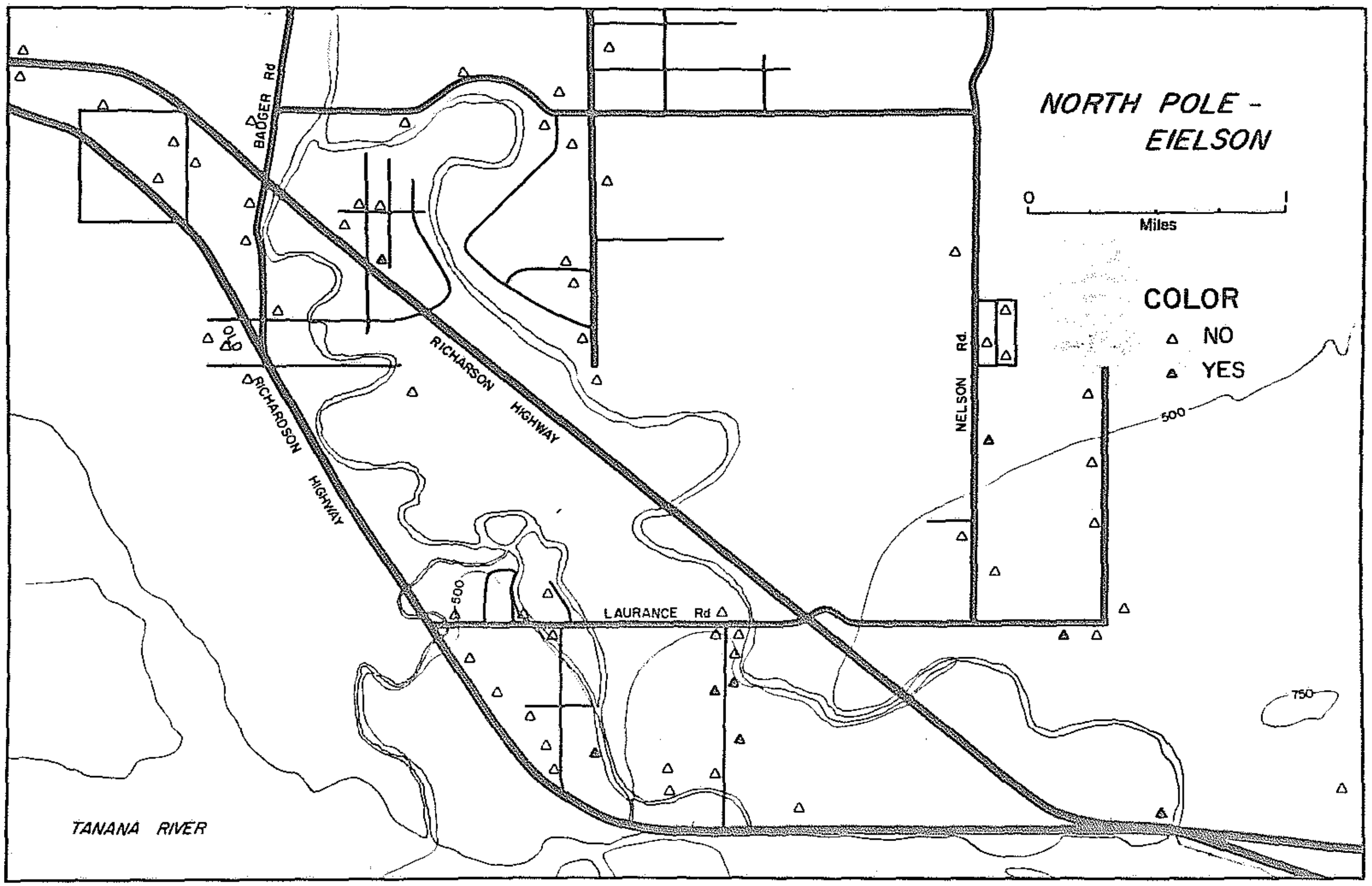

Figure 51: North Pole-Eielson Subarea - Reported Locations of a Color Problem in the Well Water Supply.

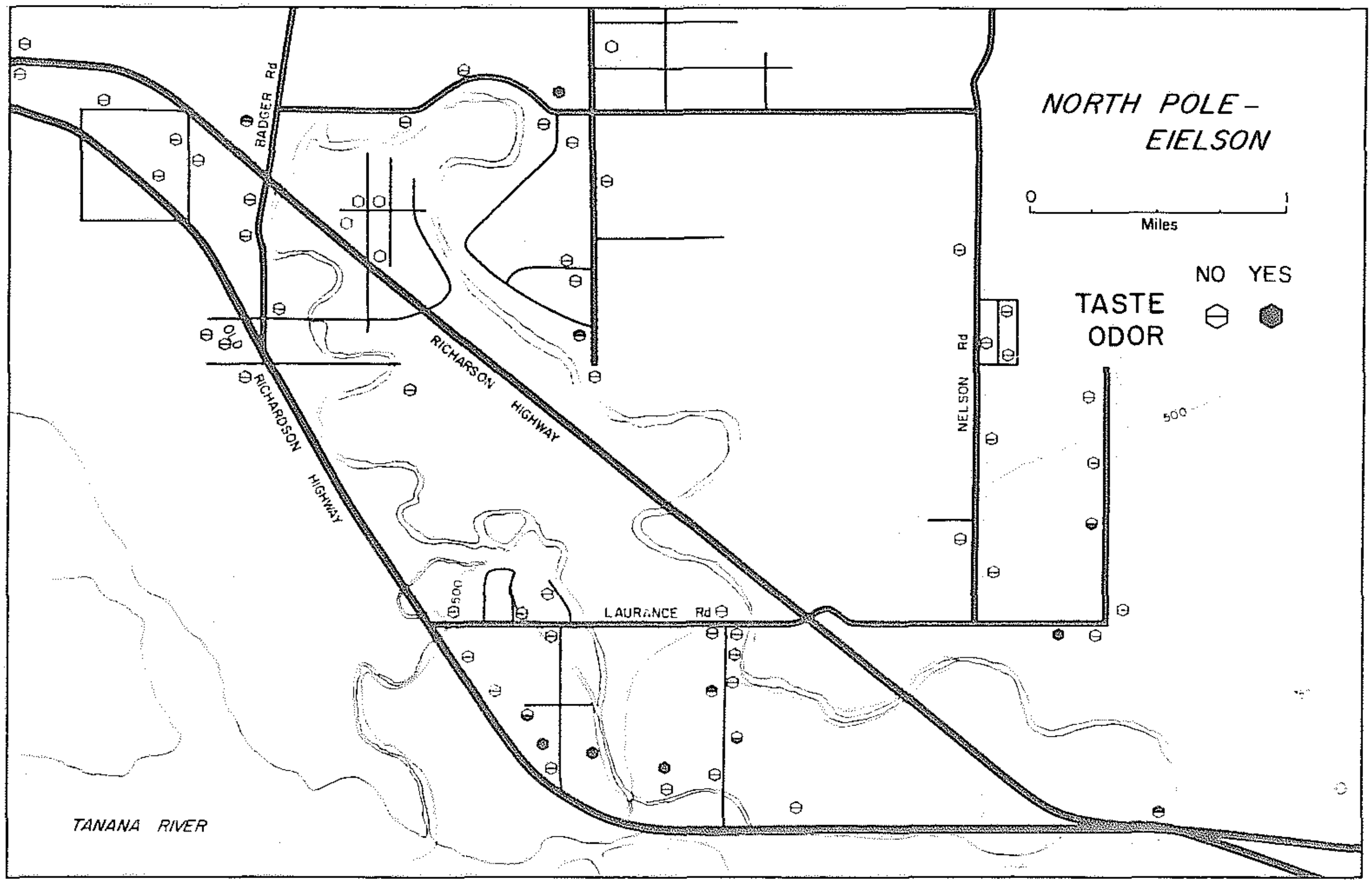

Figure 52: North Pole-Eielson Subarea - Reported Locations of Taste and Odor Problems in the Well Water Supply.

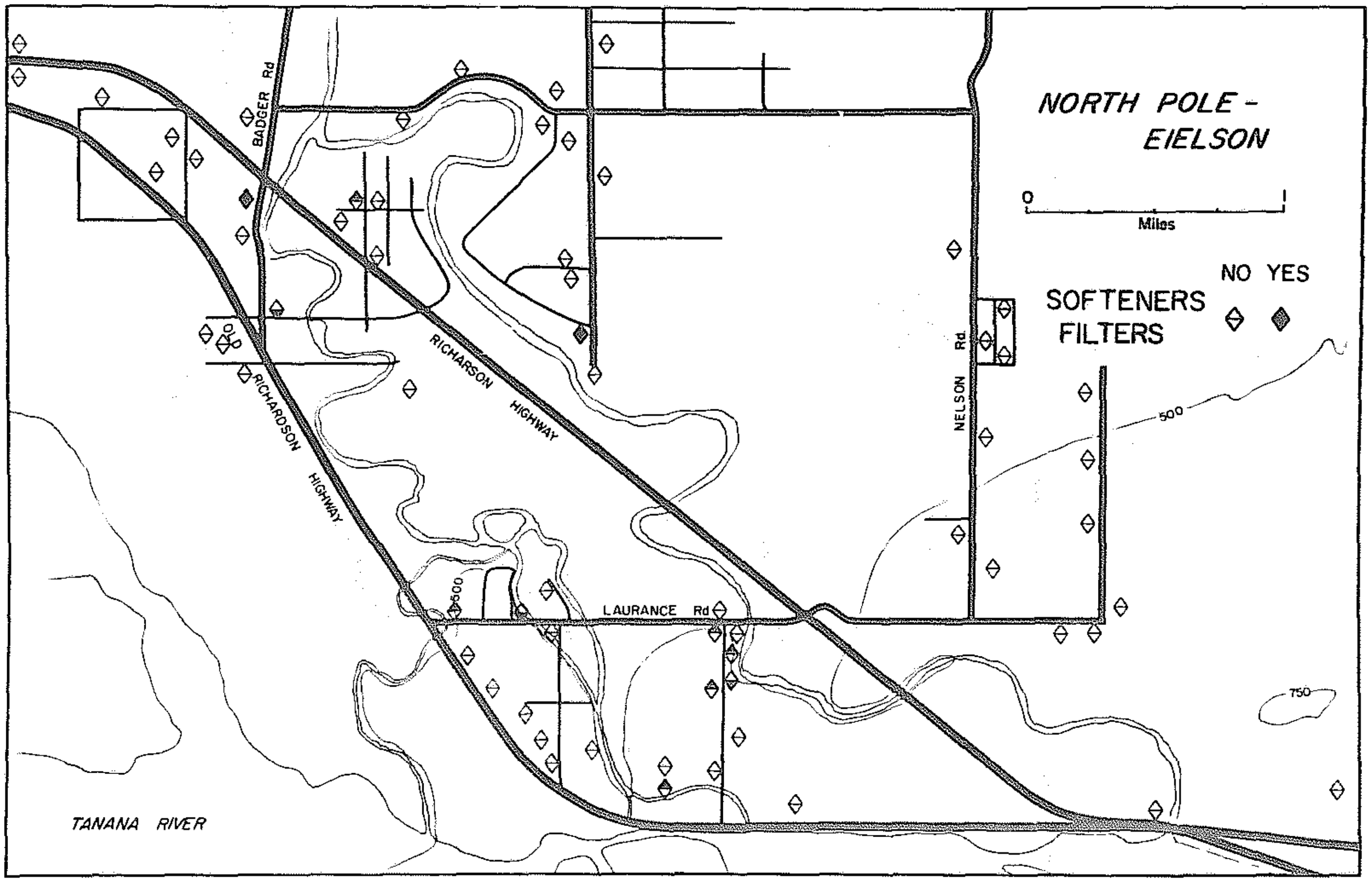

Figure 53: North Pole-Eielson Subarea - Reported Locations of Water Softener and Filter Installations.

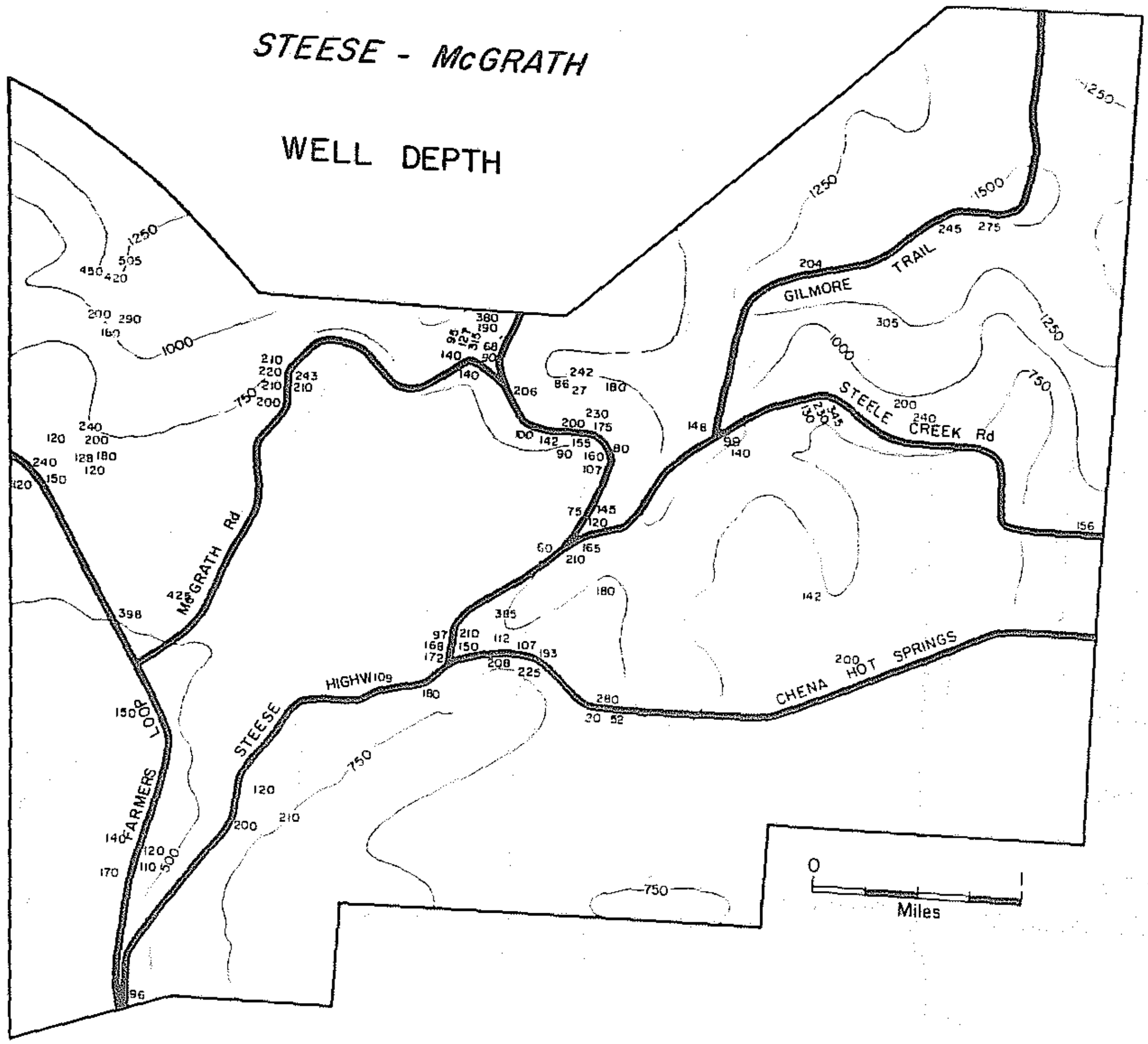

Figure 54: Steese-McGrath Subarea - Reported Well Depths.

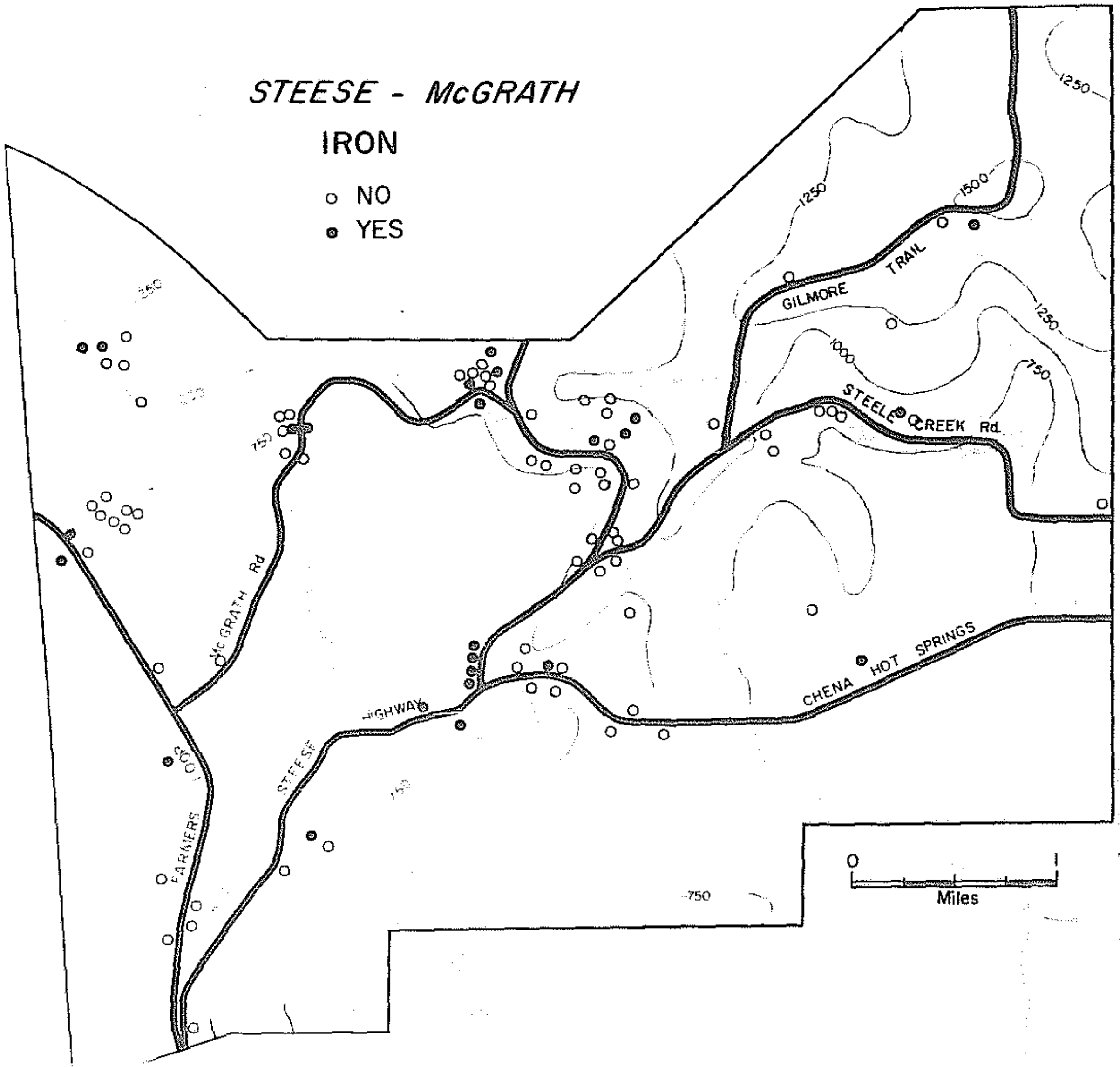

Figure 55: Steese-McGrath Subarea - Reported Locations of an Iron Problem in the Well Water Supply.

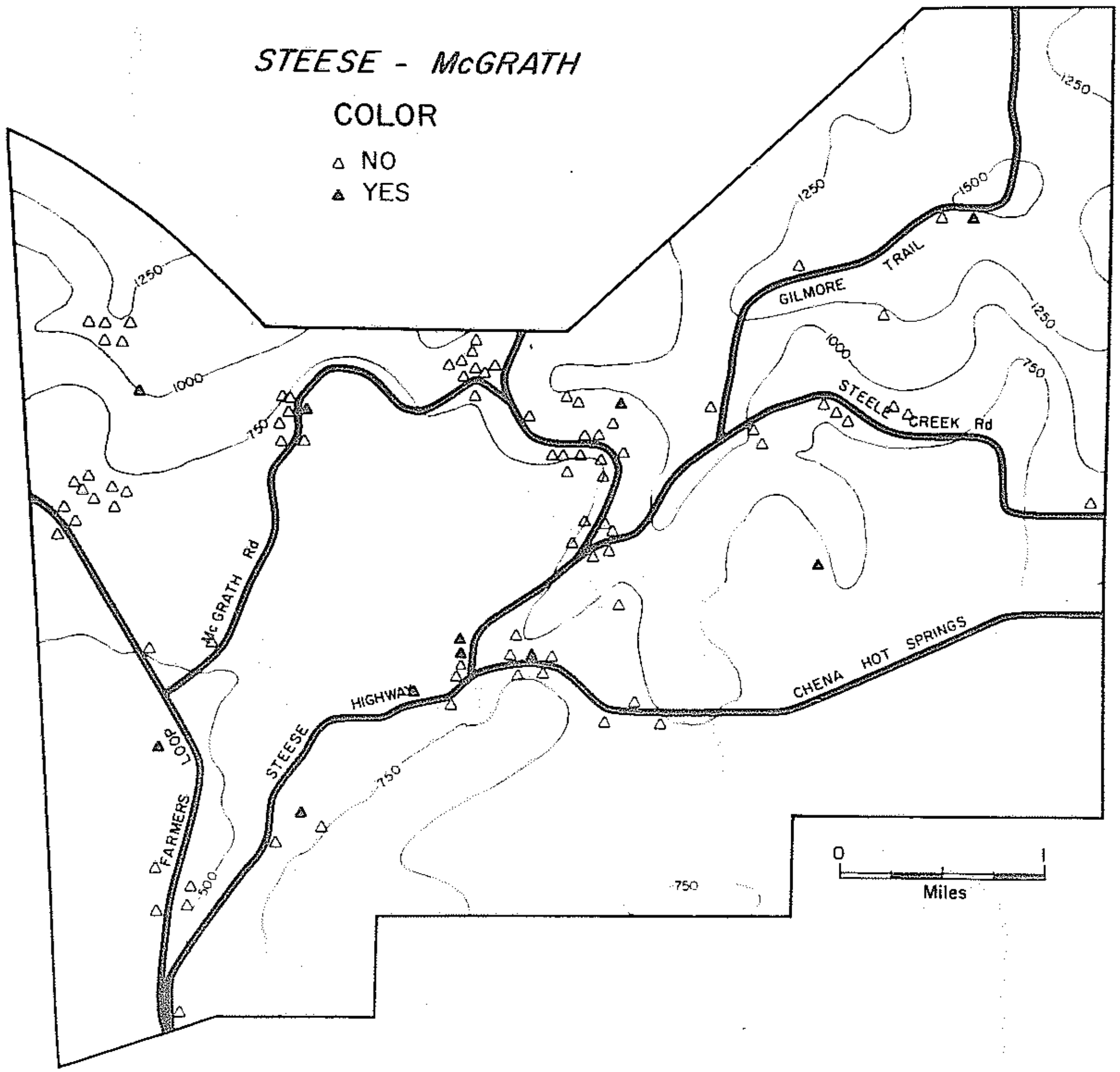

Figure 56: Steese-McGrath Subarea - Reported Locations of a Color Problem in the Well Water Supply.

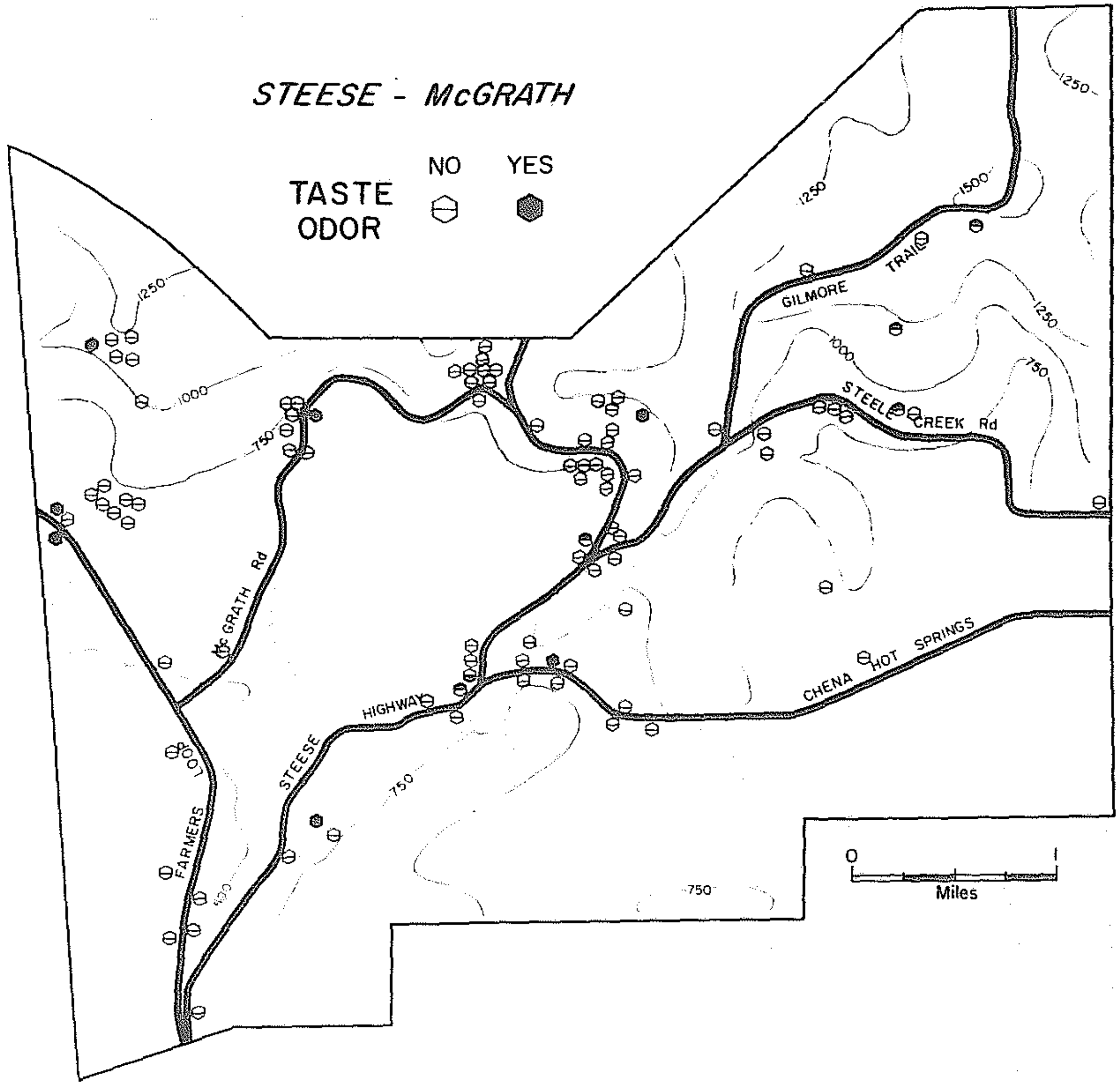

Figure 57: Steese-McGrath Subarea - Reported Locations of Taste and Odor Problems in the Well Water Supply.

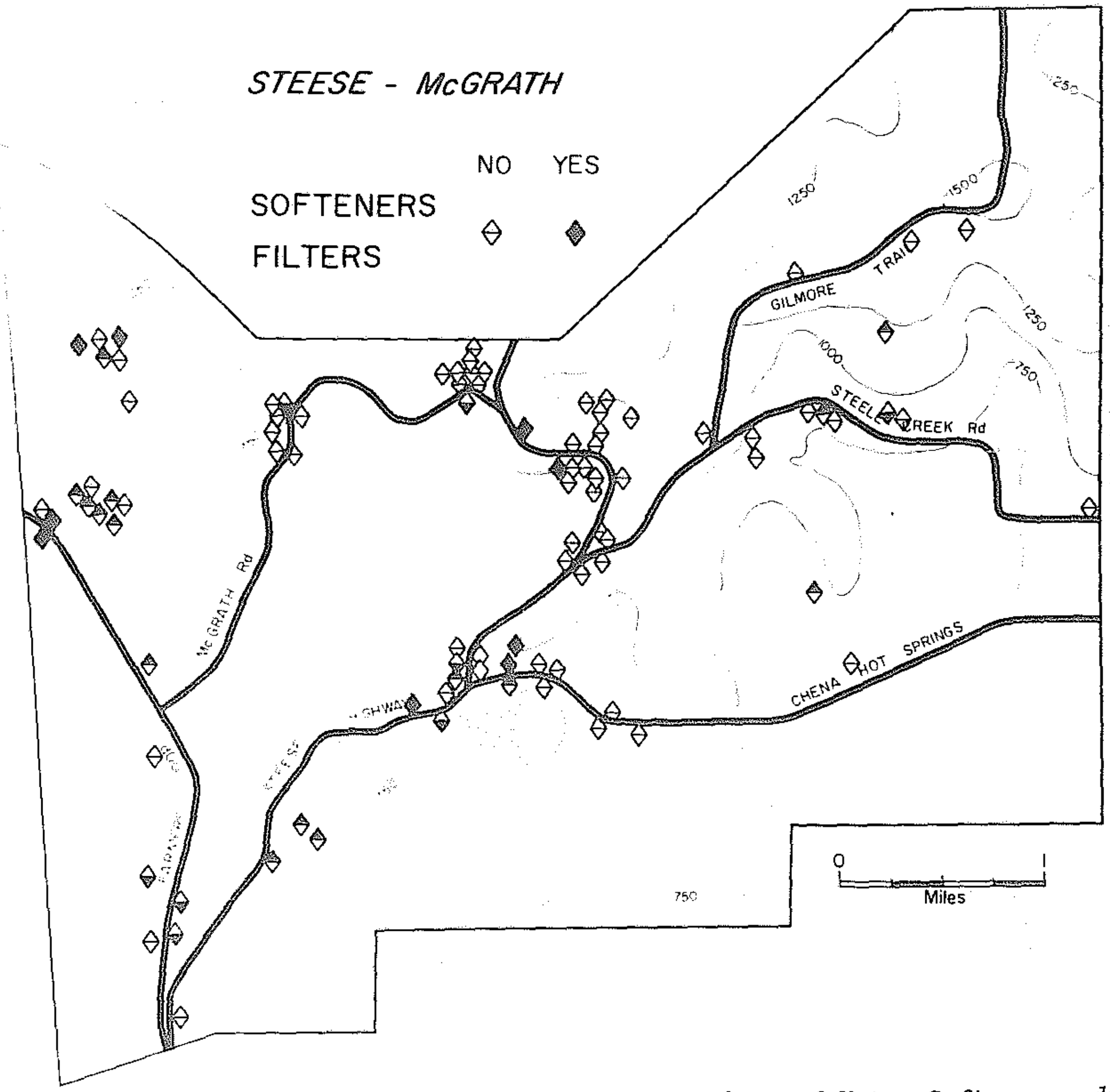

Figure 58: Steese-McGrath Subarea - Reported Locations of Water Softener and Filter Installations.

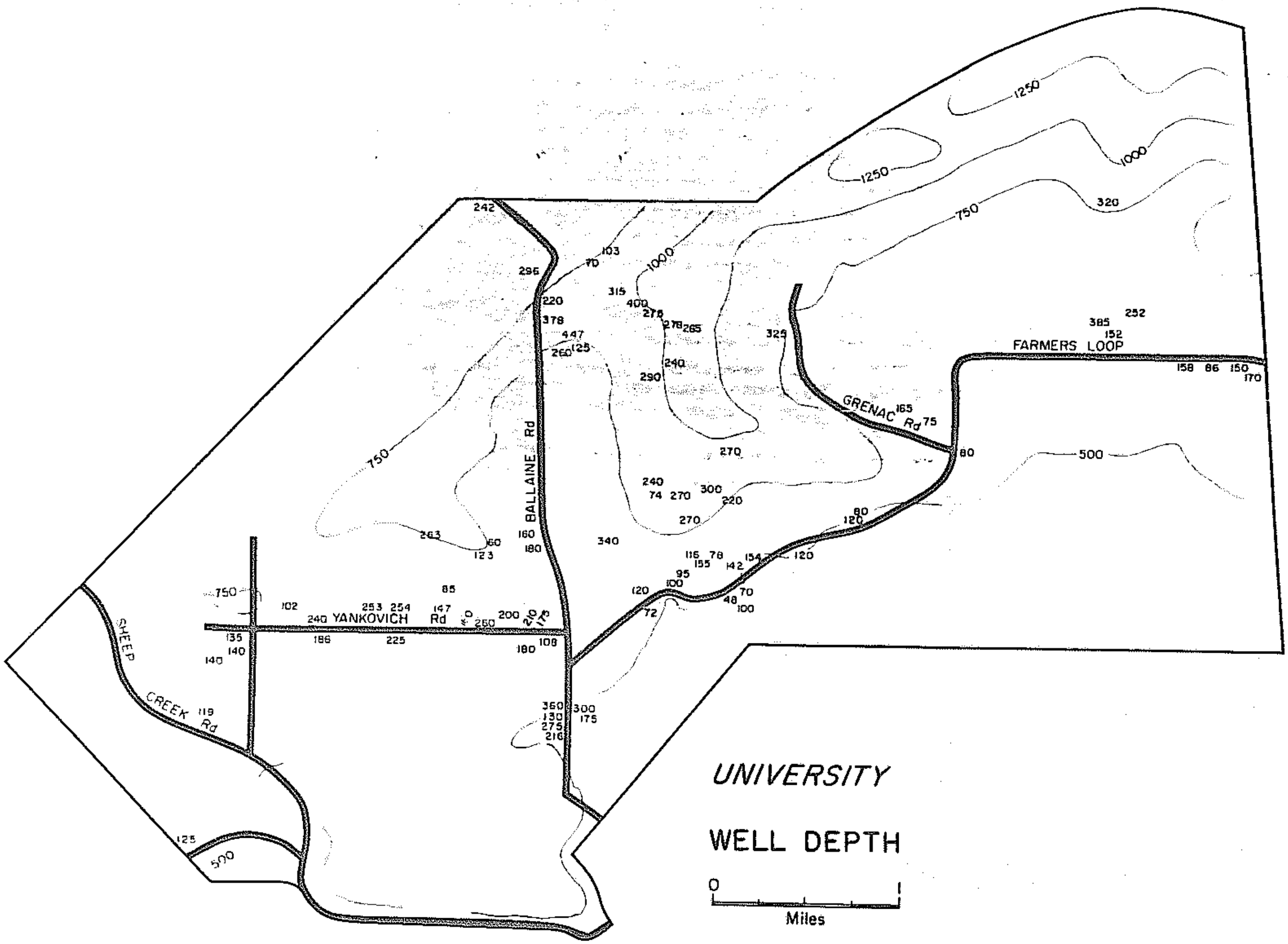

Figure 59: University Subarea - Reported Well Depths.

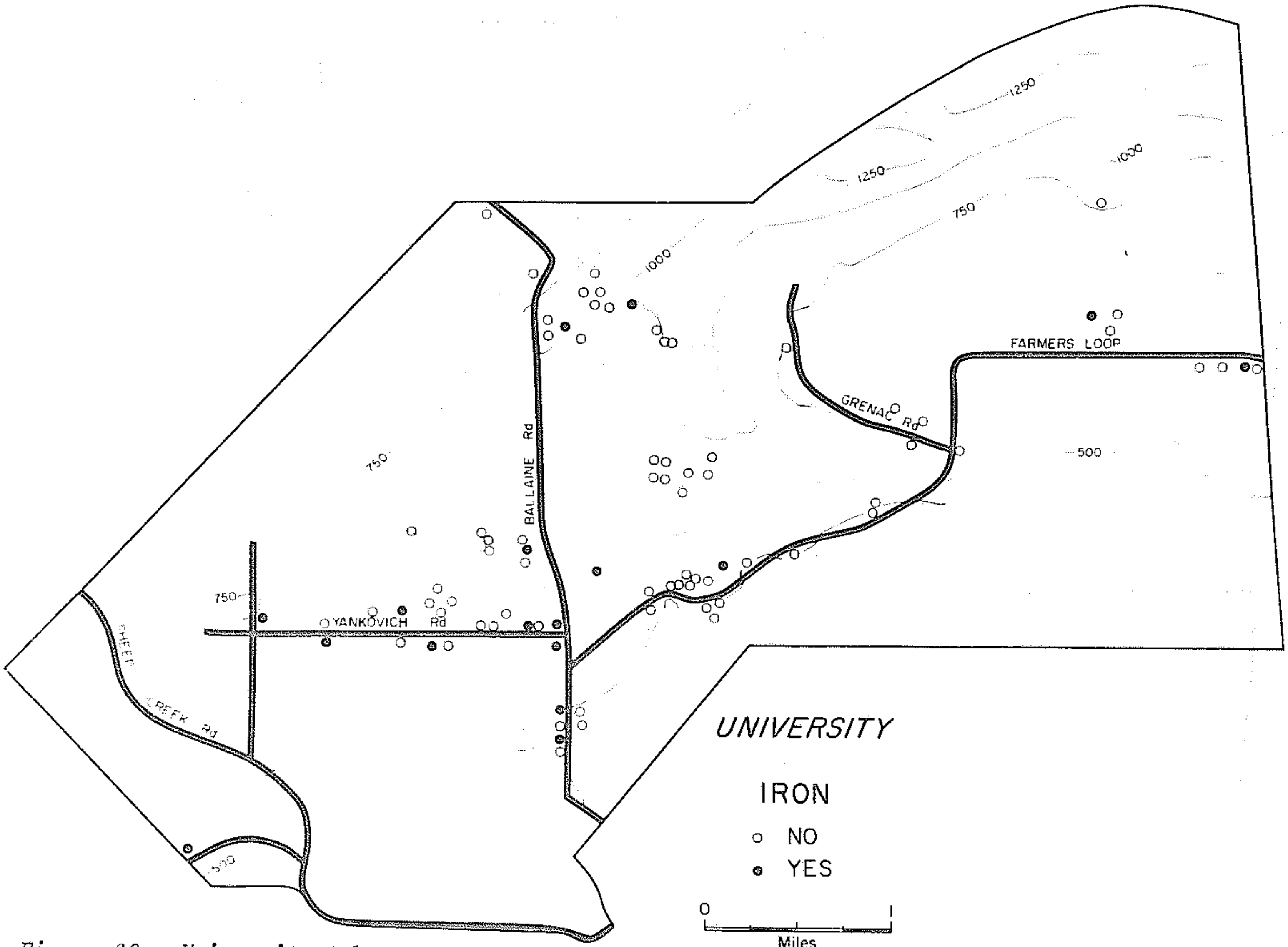

Figure 60: University Subarea - Reported Locations of an Iron Problem in the Well Water Supply.

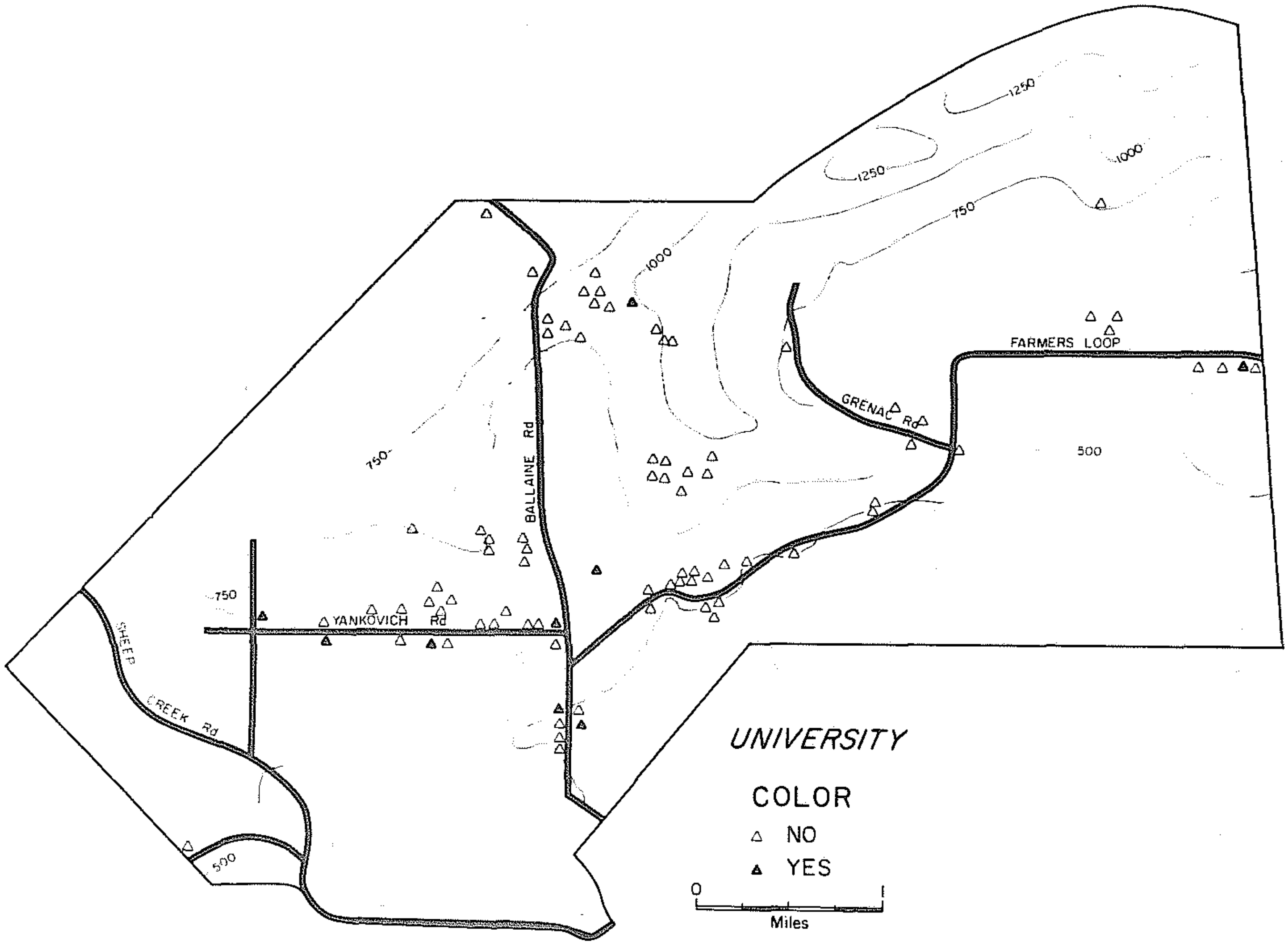

Figure 61: University Subarea - Reported Locations of a Color Problem in the Well Water Supply.

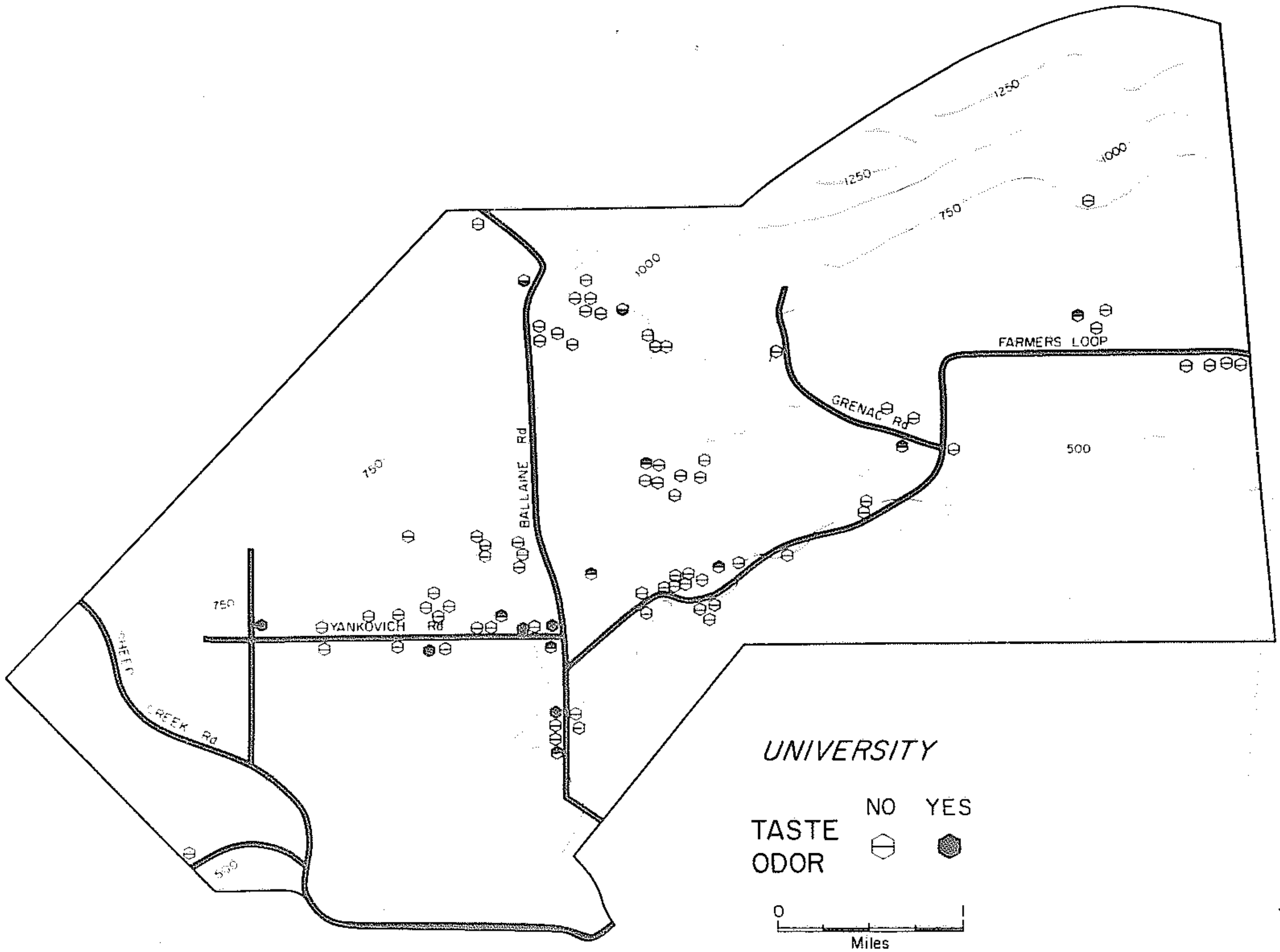

Figure 62: University Subarea - Reported Locations of Taste and Odor Problems in the Well Water Supply.

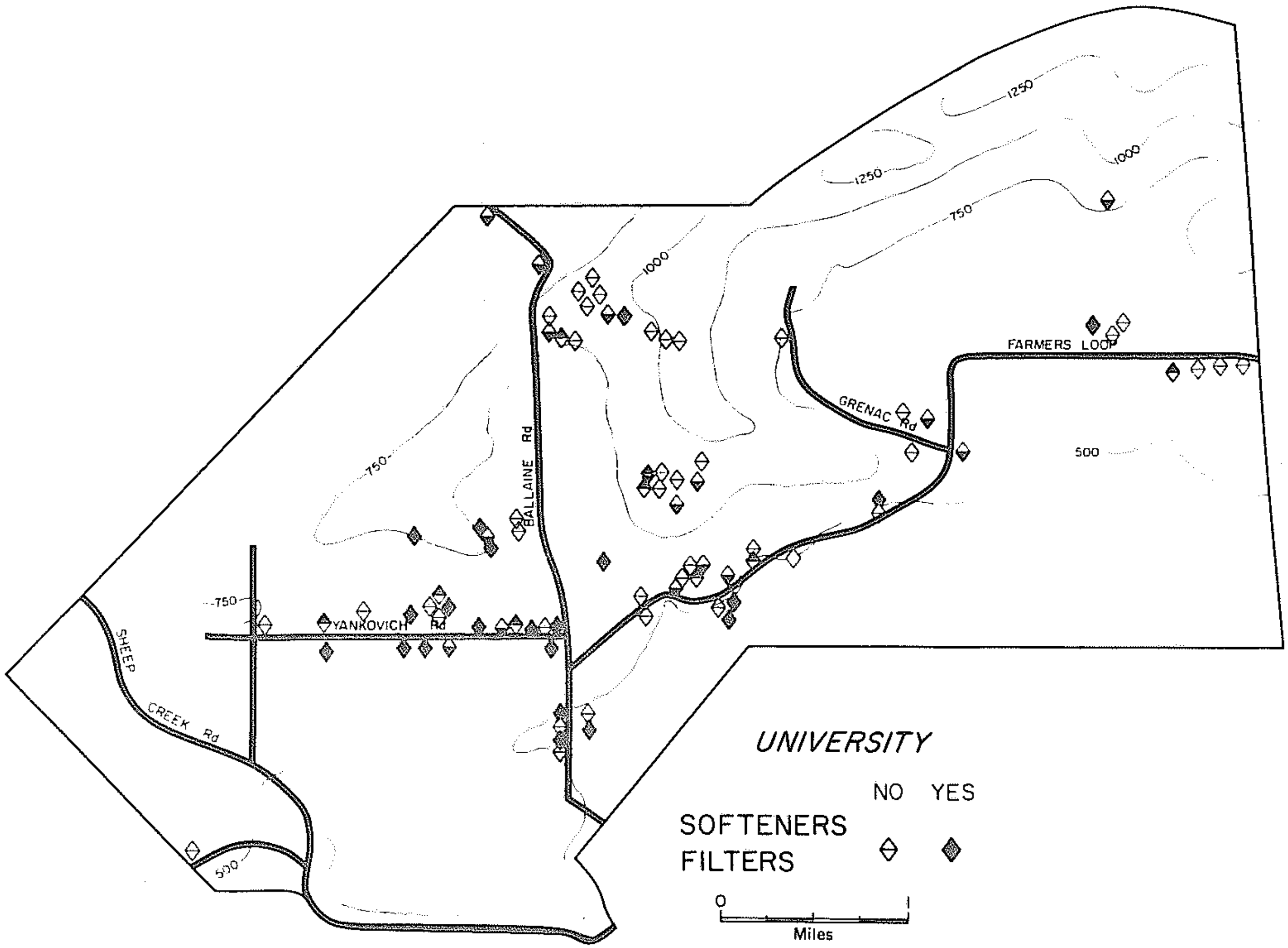

Figure 63: University Subarea - Reported Locations of Water Softener and Filter Installations.