WASTEWATER MOVEMENT NEAR FOUR TREATMENT AND DISPOSAL SITES IN YELLOWSTONE NATIONAL PARK, WYOMING

By Edward R. Cox

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CONVERSION FACTORS

For those readers who prefer to use metric units rather than inch-pound units, conversion factors for terms in this report are listed below:

Multiply	By	To obtain
inch	25.40	millimeter
foot	0.3048	meter
mile	1.609	kilometer
gallon	3.785	liter

Temperatures can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) by the following equations:

$$°F = 9/5(°C) + 32$$

$$°C = 5/9(°F - 32)$$

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ABSTRACT

The U.S. Geological Survey, in cooperation with the National Park Service, studied the effects on nearby streams and lakes of treated wastewater effluents that percolate from sewage lagoons at four sites in Yellowstone National Park. A network of observation wells has been established near the sites; water-level and water-quality data were collected from 1974 through 1982.

Ground-water mounds form under the lagoons as percolation of effluents occurs. The percolating effluents mix with ground water and form plumes of water that contain chemical constituents from the effluents. These plumes move down the hydraulic gradient toward ground-water-discharge areas. The directions of movement of percolating effluents have been determined by measuring the specific conductance of water and by analyzing water samples from wells near the lagoons for chloride and nitrite plus nitrate concentrations. Other constituents and properties also were determined.

Effluent percolating from the Fishing Bridge lagoons probably discharges into the Yellowstone River. The effluent is diluted by ground water and has no discernible effect on the quality of water in the river. Similarly, effluent percolating from the Grant Village lagoons probably discharges into Yellowstone Lake. The effluent also is diluted by ground water and has no discernible effect on the quality of water in the lake.

Effluent percolating from the Old Faithful lagoons discharges into Iron Spring Creek and may increase dissolved constituents, such as chloride, in the stream. Thermal water that is more mineralized than the effluent discharges into the stream and also increases the chloride concentration of water in the stream.

Effluent percolating from the Madison Junction lagoons probably discharges into the Madison River. The effluent is diluted by ground water and has no discernible effect on the quality of water in the river. Thermal water that is more mineralized than the effluent also discharges in the river in the same area as the effluent without appreciably affecting the quality of water in the river.

1.0 INTRODUCTION

1.1 Purpose of study

EVAPORATION-PERCOLATION LAGOONS USED AT FOUR WASTEWATER TREATMENT AND DISPOSAL SITES

The National Park Service, in its mission to protect the environment in the park, needs to know the effects on water quality of the effluents that percolate from the lagoons.

The National Park Service constructed new evaporation-percolation lagoons or enlarged old ones at four wastewater treatment and disposal sites in Yellowstone National Park in 1974-75. A study was begun in July 1974 by the U.S. Geological Survey, in cooperation with the National Park Service, to collect and analyze hydrologic data near wastewater treatment and disposal sites at Fishing Bridge, Grant Village, Old Faithful, and Madison Junction (fig. 1.1). The purpose of the study was to collect and analyze data to determine the effects on nearby streams and lakes of the wastewater effluents that percolate from the lagoons.

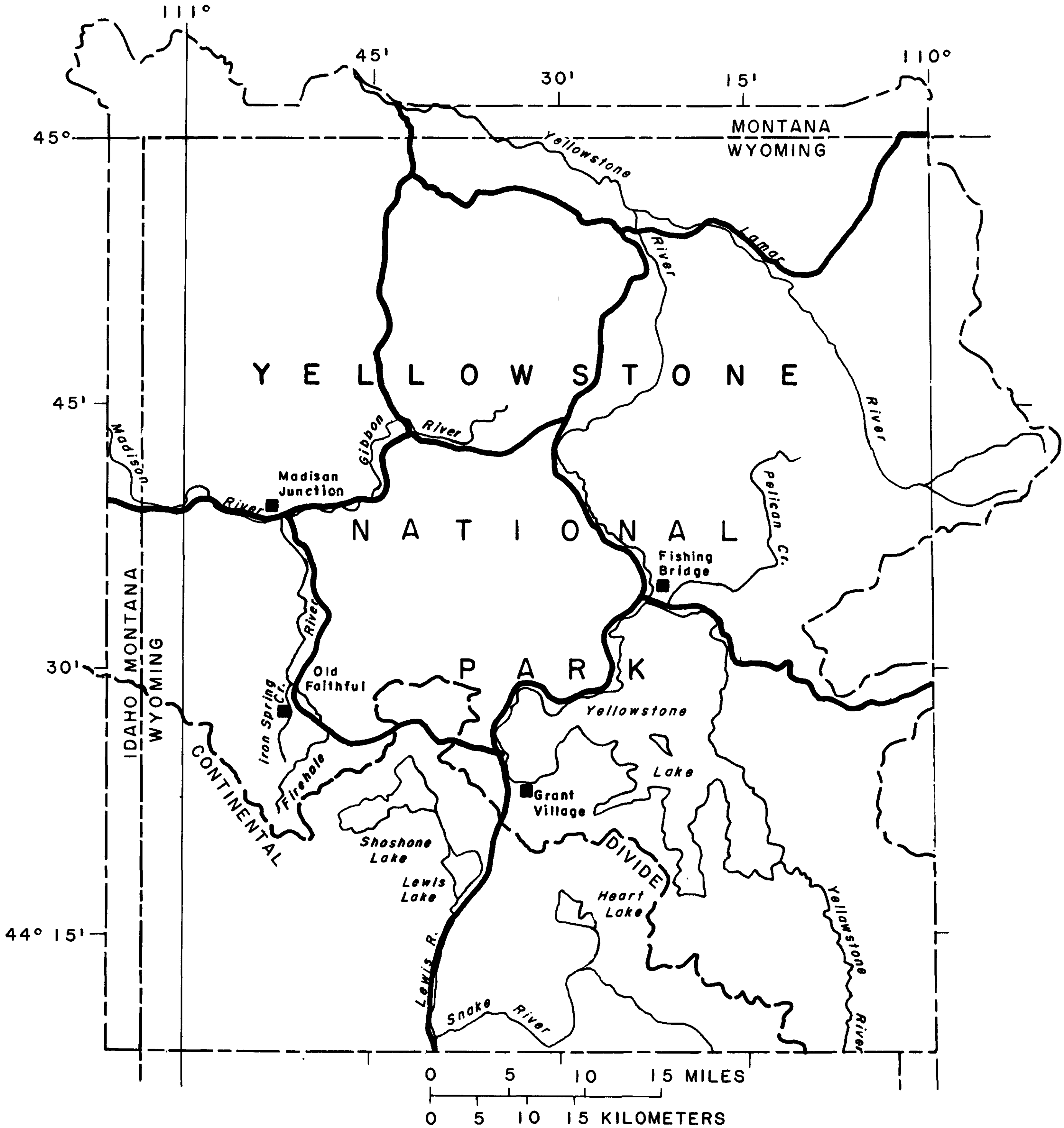


Figure 1.1.--Location of wastewater treatment and disposal sites studied (■).

WASTEWATER TREATMENT AND DISPOSAL SITES ARE WITHIN THE YELLOWSTONE CALDERA

The occurrence of shallow ground water and of discharging thermal water near the wastewater treatment and disposal sites influence the effects of percolating effluents.

The nonthermal shallow ground-water systems move the percolating effluents from the lagoons to nearby lakes and streams at the four sites studied. Some thermal water discharges into streams and probably into shallow aquifers near the Old Faithful and Madison Junction wastewater lagoons.

The wastewater treatment and disposal sites studied in this investigation are located in the plateau area in the central part of the park. The plateau area is underlain by several thousand feet of rhyolite flows and associated tuff of Quaternary age that were deposited during and after the formation of the Yellowstone Caldera (fig. 1.2). North of the plateau are mountains that are faulted and uplifted blocks composed mostly of Precambrian metamorphic rocks and of Paleozoic and Mesozoic sedimentary rocks. East of the plateau is a mountain range composed mostly of andesitic lava flows and breccia of Tertiary age. South of the Plateau are faulted uplands composed of Paleozoic and Mesozoic sedimentary rocks.

All of Yellowstone National Park, except some of the highest mountain peaks, has been glaciated. The resultant deposits of glacial drift cover most of the park, but relatively thick deposits occur chiefly in river valleys and in the basins occupied by the larger lakes. Lacustrine deposits occur not only in the lake basins but also in areas where lakes existed temporarily during and after glaciation.

Alluvial deposits occur along most of the major streams in the park and along many of the tributary streams. Hot-spring deposits are located at many of the thermal areas in the park where hot springs and geysers are tourist attractions.

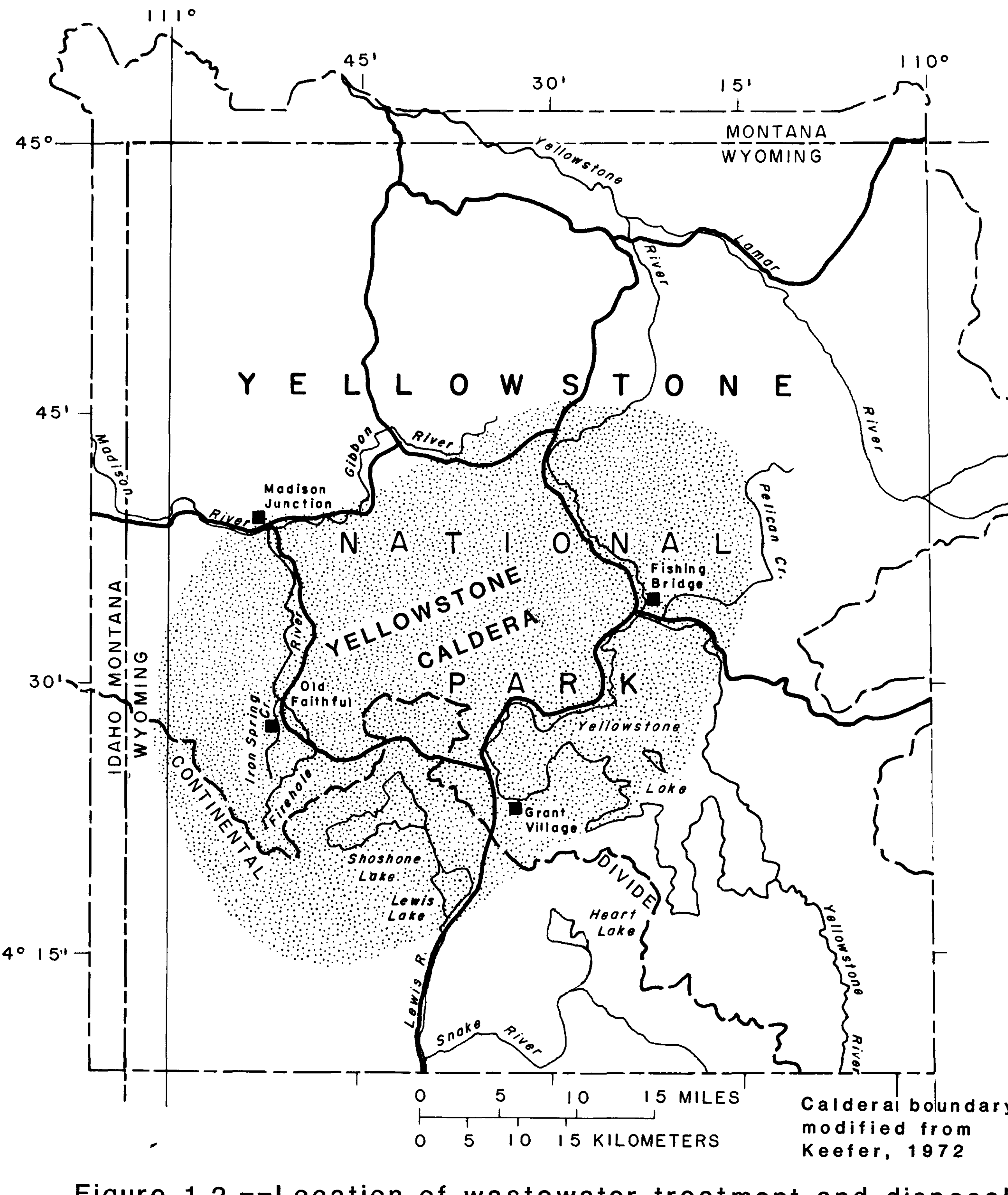


Figure 1.2.--Location of wastewater treatment and disposal sites (■) in relation to the Yellowstone Caldera (shaded).

WASTEWATER TREATED, THEN DIVERTED TO EVAPORATION-PERCOLATION LAGOONS

Wastewater receives primary treatment at Grant Village and Madison Junction and secondary treatment at all facilities; disposal in evaporation-percolation lagoons is considered tertiary treatment.

The Fishing Bridge wastewater treatment facility is an activated-sludge system designed for a flow of 600,000 gallons per day. There are no primary treatment facilities. The secondary treatment process consists of two oxidation ditches operated in parallel and a secondary clarifier. Part of the sludge from the clarifier is pumped to an aerated sludge lagoon and part is pumped back to the oxidation ditches. Digested sludge from the sludge lagoon is transferred to sludge-drying beds. Dried sludge is disposed outside of Yellowstone National Park. Supernatant effluent from the clarifier flows to evaporation-percolation lagoons (fig. 1.3).

During the period of this investigation, the Grant Village wastewater treatment facility consisted of a trickling-filter system designed for a flow of 250,000 gallons per day. The treatment facility has a primary clarifier for primary treatment and a high-rate trickling filter where wastewater passes through a bed of angular stones covered with a biological growth for secondary treatment. Effluent from the trickling filter passes through a secondary clarifier for settling of sludge. Sludge from both the primary and secondary clarifiers is pumped to an anaerobic digester and then is transferred to sludge-drying beds. Dried sludge is disposed outside of Yellowstone National Park. Part of the supernatant effluent from the secondary clarifier is recirculated back to the trickling filter, and part is pumped to evaporation-percolation lagoons (fig. 1.3). This wastewater treatment system was replaced in 1985 with an aerated-lagoon system with a flow of 500,000 gallons per day. The new wastewater treatment system uses evaporation-percolation lagoons in approximately the same location as the old system.

The Old Faithful wastewater treatment facility is an activated-sludge system designed for a flow of 510,000 gallons per day. There are no primary treatment facilities. Wastewater flows to a series of aeration tanks and then to a clarifier for settling of sludge. Part of the sludge from the clarifier is pumped to an aerobic digester, and part is pumped back to aeration tanks. Digested sludge is transferred to sludge-drying beds. Dried sludge is disposed outside of Yellowstone National Park. Supernatant effluent from the clarifier is pumped to evaporation-percolation lagoons (fig. 1.3).

The Madison Junction wastewater treatment facility is a trickling-filter system designed for a flow of 38,600 gallons per day. This system is the same as the old Grant Village trickling-filter system (fig. 1.3).

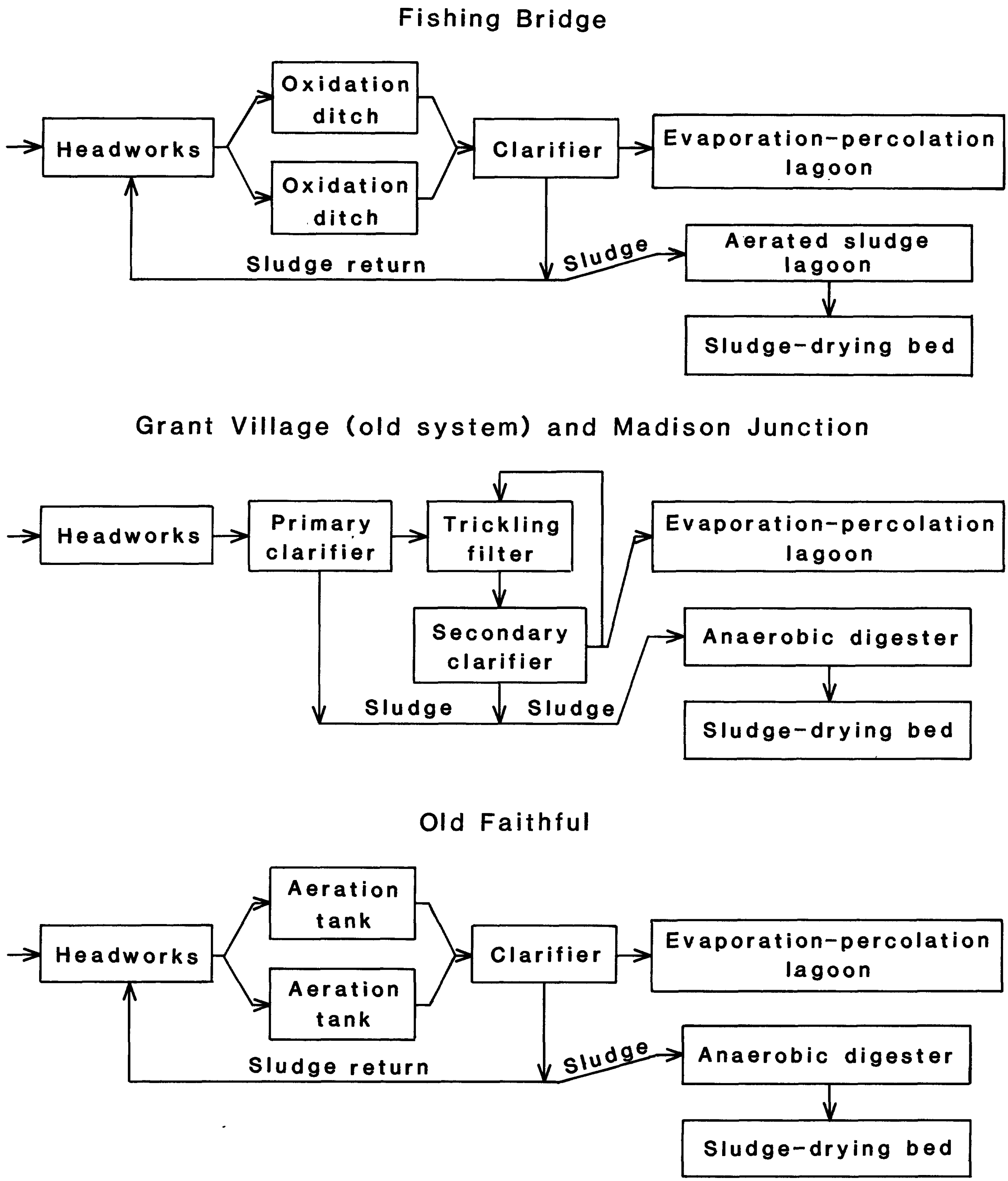


Figure 1.3.--Diagrams of the four wastewater treatment facilities.

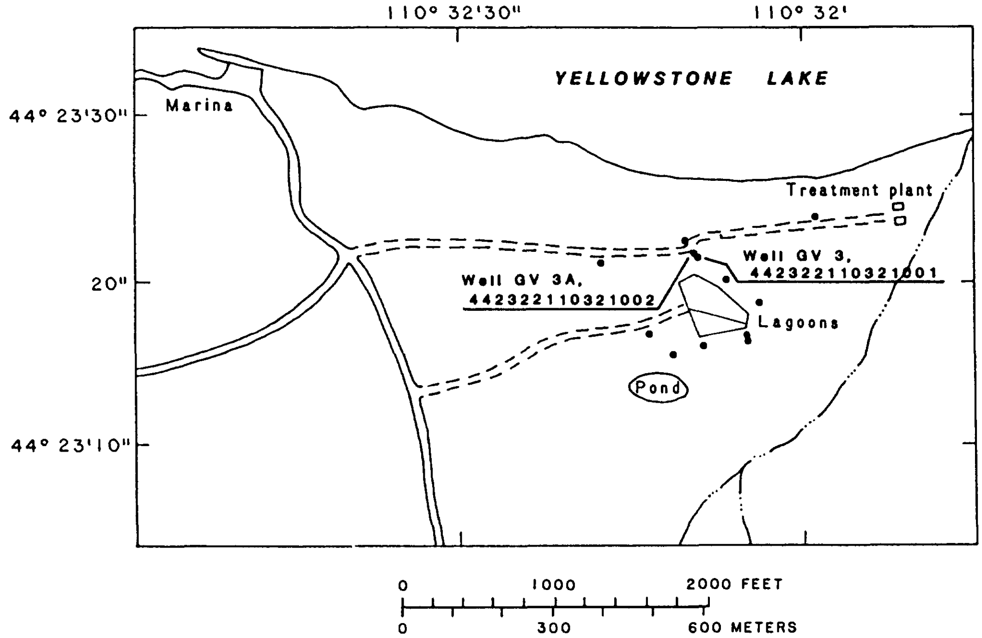
TWO IDENTIFICATION SYSTEMS USED

Abbreviations identify wells in this report, and 15-digit latitude-longitude numbers identify wells and sampling sites on streams; the latitude-longitude numbers are used in the files of the Geological Survey.

The first two letters of the abbreviations are place names near the sites studied--FB, Fishing Bridge; GV, Grant Village; OF, Old Faithful; and MJ, Madison Junction. The number is a sequential number of the wells near a particular site. A letter following the number indicates a satellite well that is located near the well having the same number. For example, well GV 3A is a well about 10 feet from well GV 3, which is the third well near Grant Village (fig. 1.4).

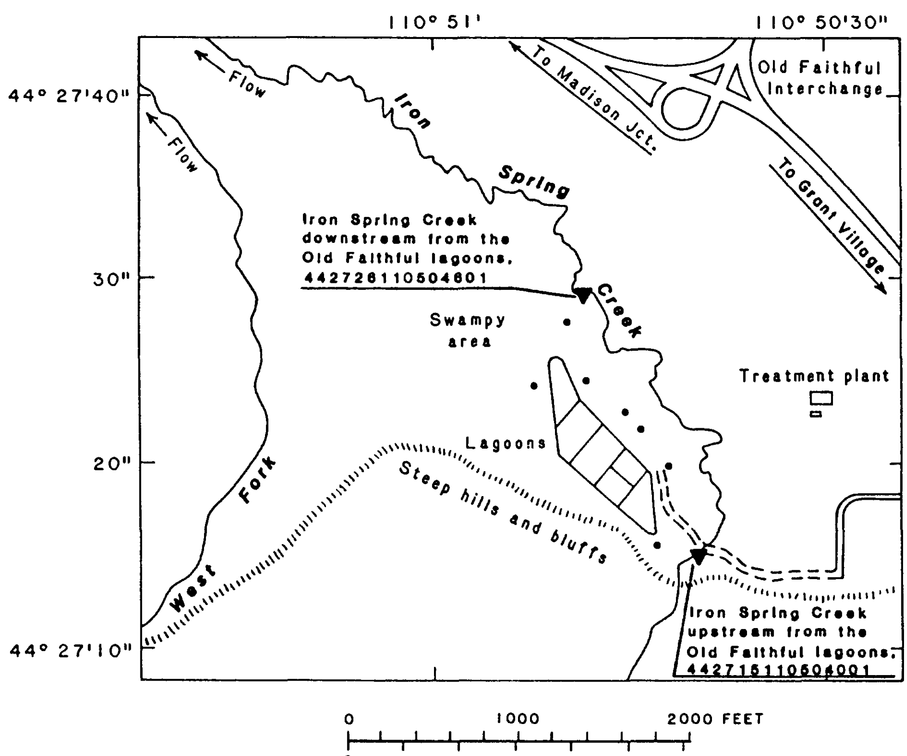
The Geological Survey uses a 15-digit number to identify the location of hydrologic data-collection sites. Such numbers have been assigned to wells and sampling sites on streams used in this study and in this report primarily to enter data into and to retrieve data from computer files (fig. 1.4). The number is based on the universal system of latitude and longitude and a sequential number. The first six digits represent degrees, minutes, and seconds of north latitude; the next seven digits are degrees, minutes, and seconds of west longitude; the last two digits are a sequential number of sites having the same latitude and longitude.

The latitudes and longitudes were determined by using U.S. Geological Survey 1:62,500-scale topographic maps that were prepared before most of the facilities at the wastewater treatment and disposal sites were constructed. In this report the data-collection sites have been located on larger scale maps that show the facilities, but the locations on the larger-scale maps do not necessarily agree with the latitudes and longitudes determined from the topographic maps. The latitudes and longitudes have not been corrected, in order to maintain the continuity of the computer files.



EXPLANATION

• WELL



EXPLANATION

• WELL

▼ SAMPLING SITE ON STREAM

Figure 1.4.--Examples of systems used to identify wells and sampling sites on streams.

GROUND-WATER AND SURFACE-WATER DATA COLLECTED

Hydrologic data consisted mainly of water levels in wells and chemical analyses and specific conductance of water from wells and streams.

Water levels in the wells were measured periodically. Altitudes of the wells were established by spirit leveling. Water samples for chemical analysis were collected from the wells by bailing or by pumping; water samples also were collected at selected sites on streams. Water temperature, specific conductance, and pH were measured at the time the samples were collected. Most of the data were collected when the wells were not covered with snow. However, some data were collected when the wells were covered with snow but could be reached by snowmobile or on snowshoes. Some of the water-level measuring and some of the water-sample collection were done by National Park Service personnel. Location of the data-collection sites near the four wastewater treatment and disposal sites is shown in figure 1.5.

Rhodamine WT dye was injected into selected wells near the Fishing Bridge, Grant Village, and Madison Junction facilities; water samples were collected at varying intervals from nearby wells. Dye also was injected into one of the lagoons at the Old Faithful facility; water samples were collected from one well and from Iron Spring Creek. The samples were analyzed for the presence of dye by using a fluorometer. The dye tests at Fishing Bridge, Grant Village, and Madison Junction were inconclusive because dye apparently was adsorbed on clay and silt and did not move directly from the injection wells to the observation wells. The test at Old Faithful was conclusive. (See section 5.4.)

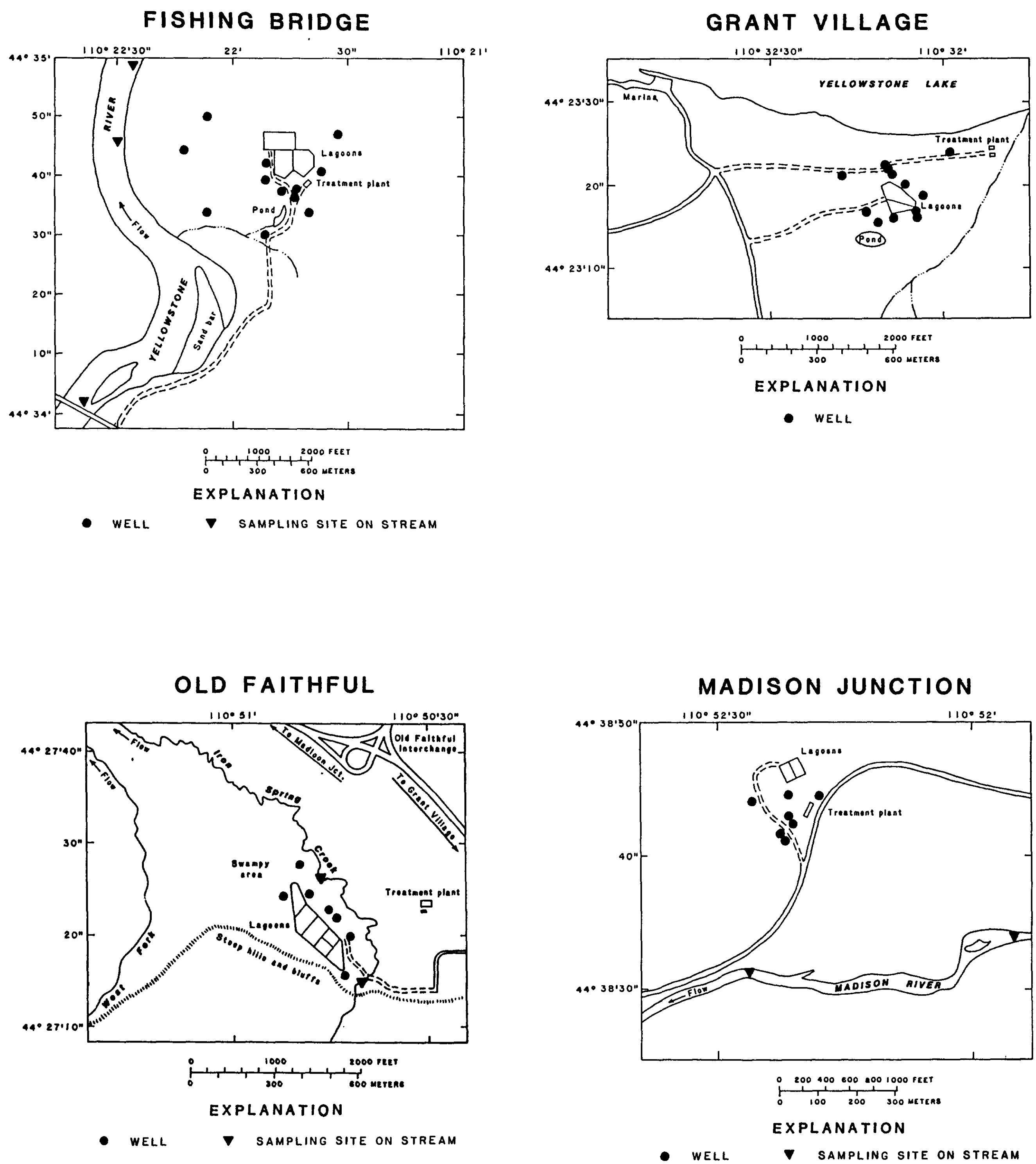


Figure 1.5.--Data-collection sites for studying wastewater movement.

NETWORK OF 47 OBSERVATION WELLS ESTABLISHED

Forty-two test holes were bored with a power-driven auger during July and August 1974; three additional test holes were augered in July 1975; one well was drilled in September 1976, and another was drilled in June 1976.

Wells were established in areas accessible with a truck-mounted augur. The test holes were completed as wells by installing 1.25-inch diameter plastic casing. Selected intervals of the casing were perforated. One well was constructed with a rotary drilling machine and 1.5-inch diameter plastic casing. Another well was established by driving a well point and 1-inch diameter steel pipe. The wells were developed by bailing, by pumping, and by blowing water from the wells with an air compressor. Several wells have been destroyed, including four that were in the area of a new lagoon constructed at the Fishing Bridge site in 1976. Descriptions of wells used for studying wastewater movement near the four wastewater treatment and disposal sites are listed in table 1.5.1.

Table 1.5.1.--Wells used for studying wastewater movement.

Well	Identification number	Well depth (feet)	Well cased (feet)	Interval perforated (feet)	Date completed	Altitude of land surface (feet above sea level)
FB 1	443432110214001	50	48	18-48	7-15-74	7,764.5
FB 2	443437110214601	51	51	21-51	7-15-74	7,762.2
FB 3	443440110215201	50	50	20-50	7-16-74	7,775.3
FB 4	443443110215001	50	49	19-49	7-16-74	7,774.8
FB 5	[1]443446110214801	50	46	16-46	7-16-74	7,770.8
FB 5A	[1]443446110214802	40	35	20-35	7-17-74	7,770.2
FB 5B	[1]443446110214803	36	32	12-32	7-17-74	7,770.5
FB 5C	[1]443446110214804	10	9	4- 9	7-18-74	7,770.8
FB 6	[1]443447110213901	48	48	18-48	7-16-74	7,778.2
FB 7	443448110213101	50	47	17-47	7-16-74	7,783.0
FB 8	443441110213801	50	48	18-48	7-18-74	7,784.0
FB 9	443431110215001	51	51	21-51	7-18-74	7,743.2
FB 10	443452110220401	45	40	10-40	7-17-74	7,764.7
FB 11	443436110214301	50	49	24-49	7-10-75	7,761.4
FB 12	443435110214401	50	50	21-50	7-10-75	7,755.8
FB 13	443435110220401	6	6	5- 6	6-30-76	7,738.8
FB 14	443444110221201	25	25	0-25	9-21-76	7,759.8

Table 1.5.1.--Wells used for studying wastewater movement--Continued

Well	Identification number	Well depth (feet)	Well cased (feet)	Interval perforated (feet)	Date completed	Altitude of land surface (feet above sea level)
GV 1	442324110315701	59	16	11-16	7-19-74	7,773.8
GV 2	442323110321101	65	50	20-50	7-22-74	7,784.0
GV 3	442322110321001	50	50	20-50	7-26-74	7,789.7
GV 3A	442322110321002	38	38	12-38	7-29-74	7,788.6
GV 4	442321110321901	58	58	21-58	7-29-74	7,794.9
GV 5	442319110320401	65	54	38-54	7-23-74	7,819.2
GV 6	442320110320801	72	43	10-43	7-24-74	7,801.3
GV 7	[1]442317110321601	105	105	45-105	7-25-74	7,832.0
GV 7A	[1]442317110321602	45	40	6-40	7-25-74	7,832.2
GV 8	442315110321201	100	97	47-97	7-26-74	7,830.7
GV 8A	442315110321202	52	52	10-52	7-26-74	7,830.9
GV 9	442316110320901	58	58	18-58	7-23-74	7,820.6
GV 10	442318110320301	53	53	37-53	7-22-74	7,816.3
GV 10A	442318110320302	20	20	10-20	7-23-74	7,816.7
OF 1	442717110504601	43	29	9-29	7-30-74	7,340.6
OF 2	442720110504101	50	48	18-48	7-31-74	7,337.8
OF 3	442722110504401	65	65	25-65	7-30-74	7,336.6
OF 4	442723110504601	50	49	19-49	7-30-74	7,334.9
OF 5	442724110504801	50	49	19-49	7-31-74	7,332.3
OF 6	442726110505001	35	35	15-35	8- 1-74	7,323.2
OF 7	[1]442723110505201	35	35	10-35	7-31-74	7,309.5
OF 7A	[1]442723110505202	13	13	5-13	8- 1-74	7,304.8
OF 7B	442723110505202	30	29	7-29	8- 1-74	7,312.6
MJ 1	443844110522501	40	35	14-35	8- 5-74	6,825.7
MJ 2	[2]443844110522201	40	25	15-25	8- 6-74	6,823.6
MJ 3	443844110521901	60	60	20-60	8- 6-74	6,822.1
MJ 4	443843110522101	40	40	20-40	8- 5-74	6,811.0
MJ 5	443842110522201	40	40	20-40	8- 6-74	6,807.2
MJ 6	443842110522101	40	35	15-35	8- 6-74	6,805.5
MJ 7	443843110522001	50	50	18-50	7-11-75	6,809.0

[1] Well destroyed.
[2] Well plugged.

STREAMS SAMPLED NEAR WASTEWATER LAGOONS

Sampling sites were selected on streams at points upstream and downstream from wastewater lagoons at Fishing Bridge, Old Faithful, and Madison Junction.

In order to determine the effects of percolating effluents on water quality of nearby streams, water samples were collected from the streams. The sampling sites were selected at points on the same banks as the lagoons, upstream and downstream from the lagoons, in flowing reaches of the streams. A total of 7 stream sites were sampled, 3 at Fishing Bridge, 2 at Old Faithful, and 2 at Madison Junction. The sampling sites on streams are listed in table 1.5.2.

Table 1.5.2.--Sampling sites on streams used for studying wastewater movement

Sampling site on stream	Identification number
Yellowstone River upstream from the Fishing Bridge lagoons	443403110224801
Yellowstone River downstream from the Fishing Bridge lagoons	443446110223001
Do	443459110222501
Iron Spring Creek upstream from the Old Faithful lagoons	442715110504001
Iron Spring Creek downstream from the Old Faithful lagoons	442726110504801
Madison River upstream from the Madison Junction lagoons	443835110515001
Madison River downstream from the Madison Junction lagoons	443832110522801

2.0 GENERALIZED MOVEMENT OF WATER NEAR LAGOONS

MOUNDS OF GROUND WATER FORM BELOW LAGOONS

The movement of effluents percolating from the lagoons is chiefly vertical in the unsaturated zone; below the water table the effluents move toward areas of ground-water discharge.

Ground-water mounds have formed under the lagoons as percolation of effluents occurred. Ground water probably moves short distances in all directions from the lagoons and then moves down the hydraulic gradient to the area of natural discharge of ground water (fig. 2.0). The percolating effluents may not follow a path of movement directly from the lagoons to the discharge areas but may follow circuitous routes depending on the relative hydraulic conductivities of the materials through which the ground water moves.

The effluents mix with ground water and form plumes of water that contain chemical constituents from the effluents. Each plume tends to move down the hydraulic gradient in a direction generally perpendicular to the water-level contours. The plume may either become larger as it moves through the aquifer owing to dispersion, or it may become smaller owing to dilution by water outside the plume.

Chemical constituents in the plume travel at different apparent velocities. Dissolved chloride, sulfate, and nitrate tend to appear sooner at locations farther from the source than do constituents, such as phosphorus, that may be adsorbed on the surfaces of clay, silt, and sand. Chloride is a conservative ion; that is, it does not interact appreciably with other ions in water or on sediment. Specific conductance, which is a measure of the ability of water to conduct an electrical current, is related to the concentration of dissolved constituents. Therefore, chloride concentration and specific conductance of water from wells are used in this report for interpretations on movement of percolating effluents.

The Fishing Bridge and Grant Village sites did not contain wastewater lagoons prior to July 1975. Data collected before that time at these sites, therefore, represent natural conditions that are useful for comparison with data collected after the lagoons were used. The Old Faithful and Madison Junction sites contained wastewater lagoons prior to 1974, and data were not collected before the lagoons were used.

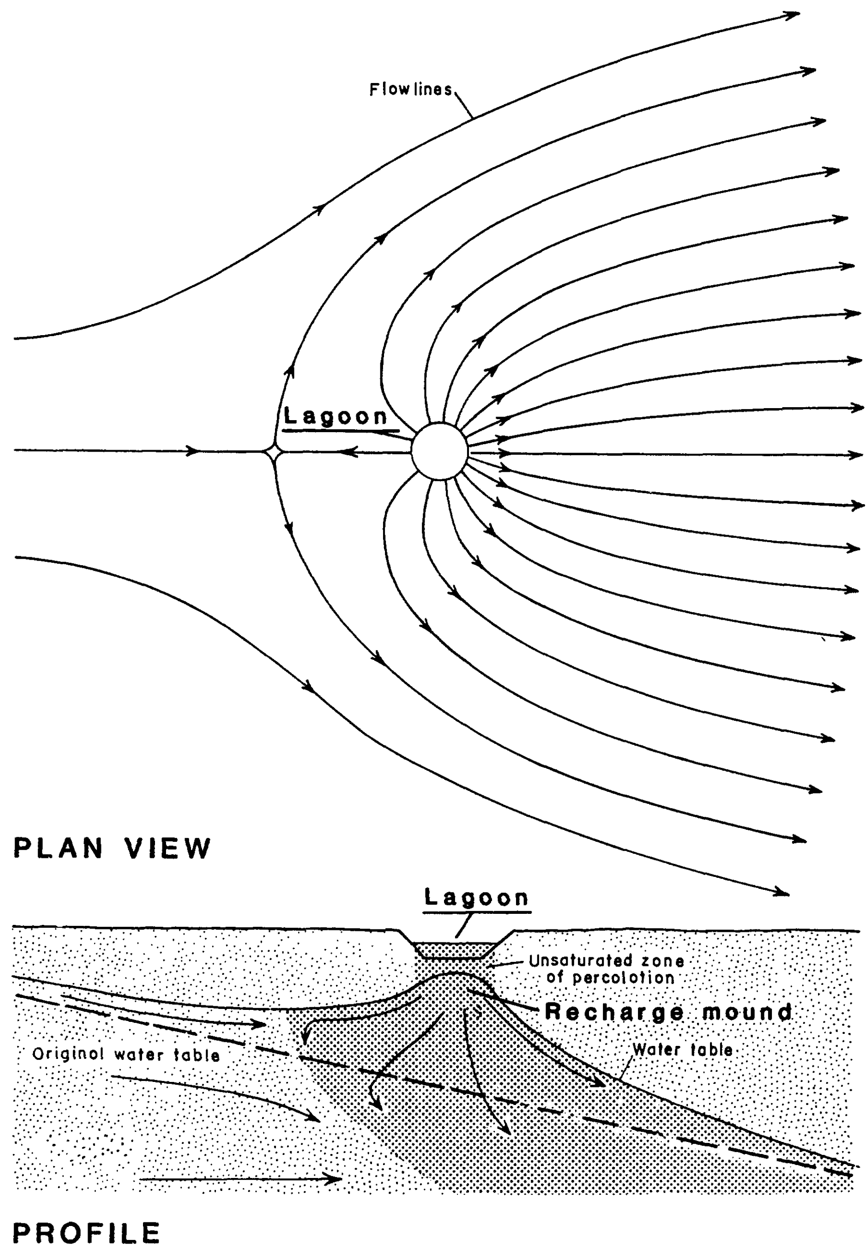


Figure 2.0.--Flow from a recharge mound on a sloping water table. (Modified from Deutsch, 1963.)

3.0 FISHING BRIDGE

3.1 Hydrologic setting

WASTEWATER TREATMENT AND DISPOSAL SITE IS NEAR THE YELLOWSTONE RIVER

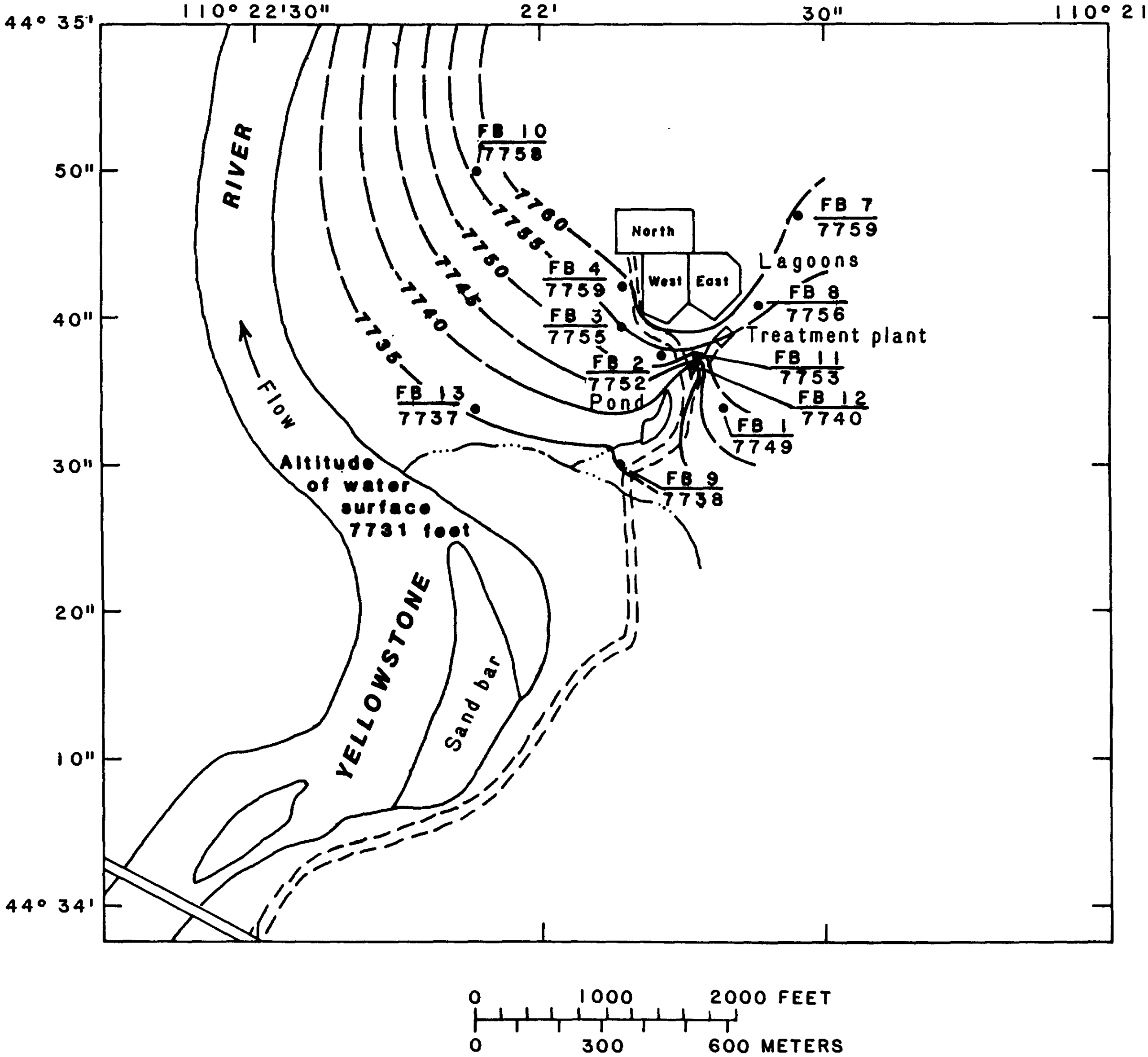
Water-level contours show a hydraulic gradient from the Fishing Bridge wastewater lagoons to the Yellowstone River.

The Fishing Bridge wastewater treatment and disposal site is about a mile northeast of the Fishing Bridge vistor area and the bridge that gives the area its name. The site is underlain by deposits of sand, silt, clay, and gravel that partly fill the basin containing Yellowstone Lake. Wells FB 1 through 12 were augered and well FB 13 was driven in the vicinity of the Fishing Bridge site (fig. 3.1).

The water-level contours indicate the configuration of the water level in August 1978 in the vicinity of the Fishing Bridge site. Although the water levels at other times are different, the changes are not large enough to affect the configuration of the water-level contours appreciably.

Two lagoons (the east lagoon and the west lagoon in this report) were used for disposal of effluent beginning in mid-May 1976. An additional lagoon (the north lagoon) was built north of the west lagoon in September and October 1976. The use of the lagoons for disposal of effluent during 1976-81 is shown in the following table:

Lagoon	1976	1977	1978	1979	1980	1981
East	mid-May through October	mid-May through October	mid-May through October	August through October	mid-May through October	not used
West	mid-May through October	not used	mid-May through October	mid-May through July	not used	mid-May through October
North	---	mid-June through October	mid-May through October	mid-May through October	mid-May through October	July through October



EXPLANATION

——7735—— — WATER-LEVEL CONTOUR--Shows altitude at which water level would have stood in tightly cased wells, August 15-17, 1978. Dashed where approximately located. Contour interval 5 feet. Datum is sea level

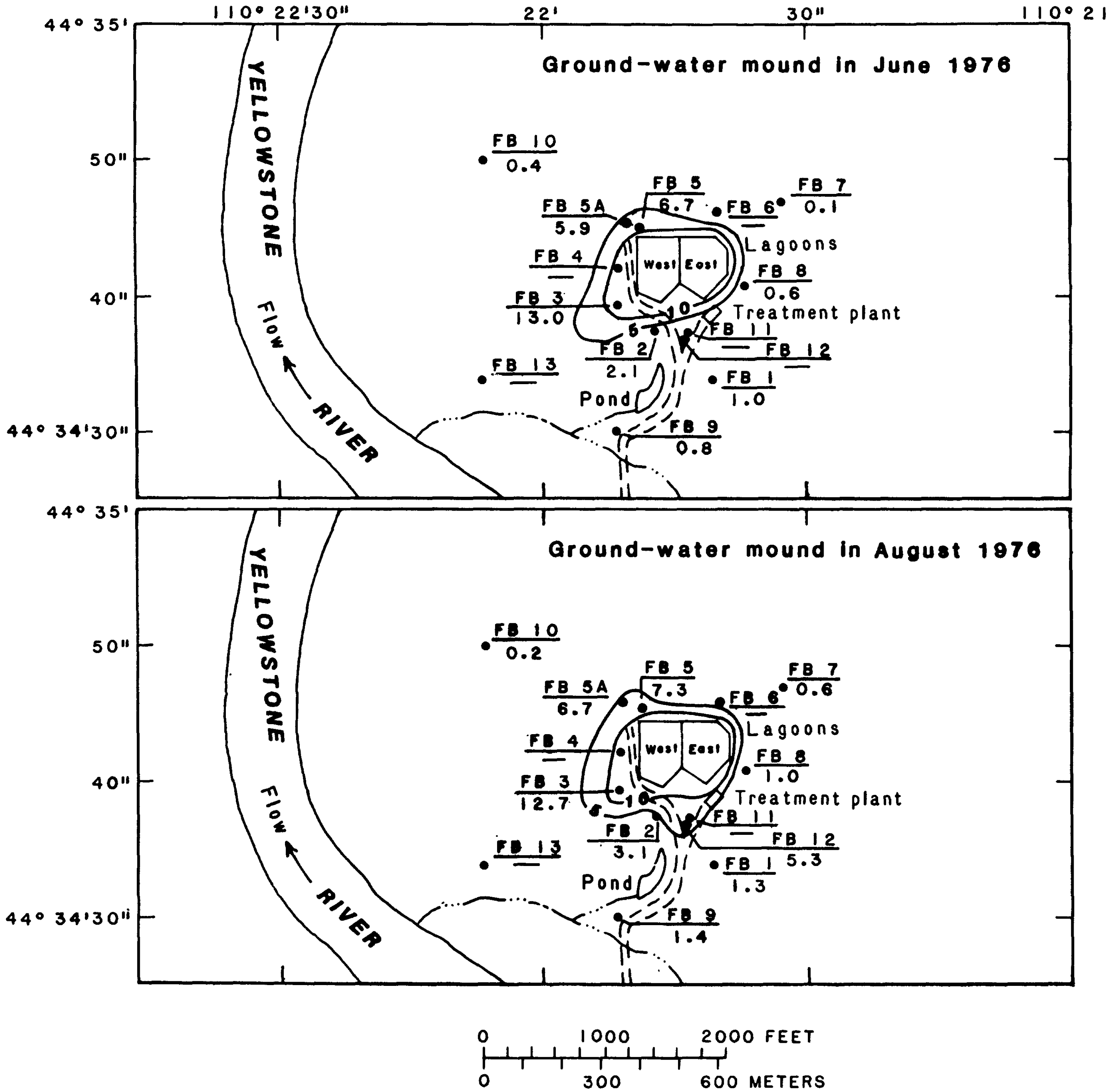
• FB 9 / 7738 — WELL--Upper numeral is well number. Lower numeral is altitude of water level, in feet above sea level, August 15-17, 1978

Figure 3.1.--Location of wells and water-level contours near the Fishing Bridge wastewater lagoons.

GROUND-WATER MOUND FORMS EACH YEAR UNDER LAGOONS

Water levels in wells near the lagoons rise when effluent percolates from the lagoons.

A ground-water mound forms each year under and near the Fishing Bridge lagoons, as indicated by changes in water levels in wells. Water levels in some wells are unaffected by percolation from the lagoons, and rises in water levels in other wells are the result of the ground-water mound near the lagoons. Water levels in wells unaffected by percolation from the lagoons were about the same during a few days of a month in 1976 as they were during the same few days of the same month in 1975. For example, water levels in the unaffected wells were about the same on June 24, 1976, as they were on June 24, 1975, and about the same on August 5, 1976, as they were on August 3, 1975. Most of the differences in water levels were caused by percolation of effluent from the lagoons, and contoured rises indicate the approximate shape of the mound in June 1976 and in August 1976 (fig. 3.2). At both times, the mound was elongated southwest of the lagoons. The shape of the mound cannot be shown similarly in other years because water levels which would be used to determine rises generally were affected by seasonal precipitation and natural recharge. Therefore, the water levels are not comparable as they were in 1975 and 1976.



EXPLANATION

——5—— LINE OF EQUAL RISE IN WATER LEVEL--Interval 5 feet

• FB 9 / 1.4 WELL--Upper numeral is well number. Lower numeral is rise in water level, in feet

Figure 3.2.--Rise in water level June 24, 1975 to June 24, 1976 (upper map), and August 5, 1975 to August 3, 1976 (lower map), in wells near Fishing Bridge wastewater lagoons.

EFFLUENT PROBABLY MOVES TOWARD THE YELLOWSTONE RIVER

The direction of movement of percolating effluent is shown by the rising water levels in wells near the lagoons in response to use of the lagoons for disposal of wastewater.

The movement of percolating effluent at the Fishing Bridge site from lagoons to the Yellowstone River is shown diagrammatically in a section in figure 3.3-1. The forming of a ground-water mound is illustrated by the change in the water level when the lagoon is used.

The water level in well FB 3 rose noticably when the nearby west lagoon was used in 1976, 1978, 1979, and 1981 (fig. 3.3-2). Water level in the well did not rise appreciably in 1977 and 1980 when the west lagoon was not used.

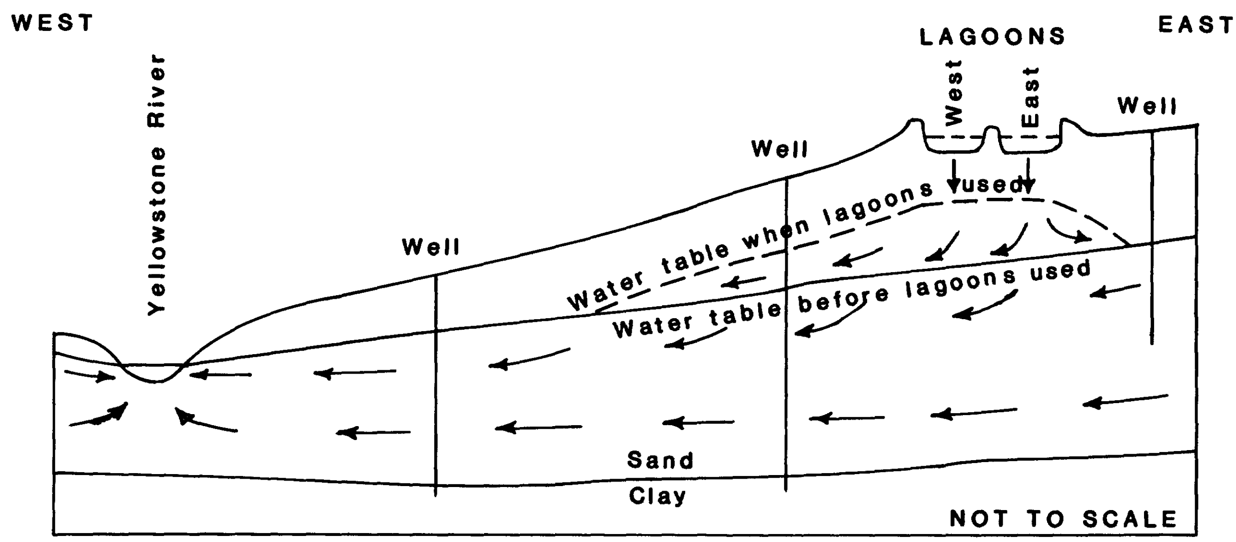


Figure 3.3-1.--Probable movement of ground water (arrows) near the Fishing Bridge wastewater lagoons and the Yellowstone River.

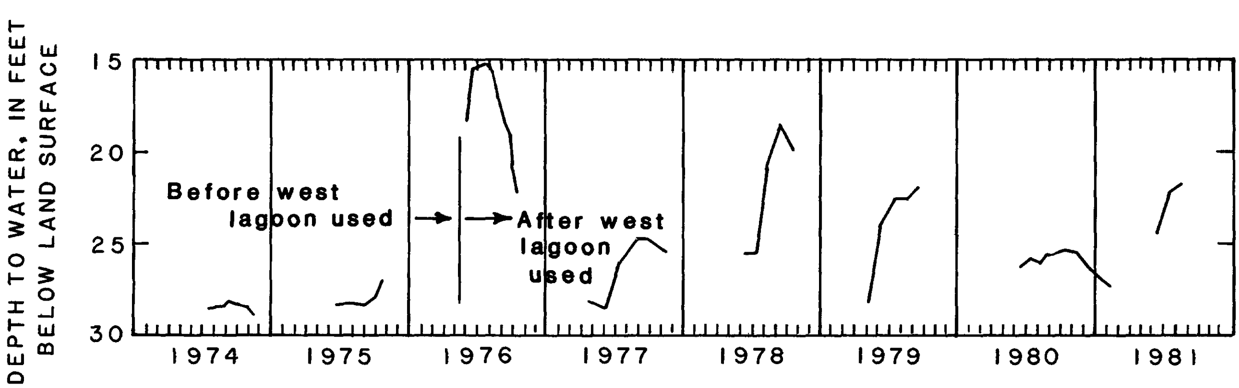


Figure 3.3-2.--Water level in well FB 3.

QUALITY OF GROUND WATER HAS CHANGED

The direction and extent of movement of percolating effluent is indicated by changes in the quality of water in wells since the lagoons have been used.

Most of the wells near the Fishing Bridge lagoons were sampled in 1974 or 1975 before the lagoons were used. Analyses of these samples collected before the lagoons were used provide a background for comparison with analyses of samples collected after the lagoons were used.

The change in quality of water in well FB 3 from 1974 to 1981 is illustrated in figure 3.4 by polygonal diagrams developed by Stiff (1951) of milliequivalents per liter of principal cations and anions. The larger polygons from September 1976 through 1981 indicate an increase in the total ionic concentration. The diagrams of percentage of milliequivalents per liter in figure 3.4 show an increase in percentage of sodium in 1979-80 and a corresponding decrease in percentage of calcium and magnesium in 1979-80. The percentage of chloride increased in September 1976 and in 1978-79. The percentage of nitrite plus nitrate increased in 1980-81. These increases resulted in a corresponding decrease in the percentage of bicarbonate.

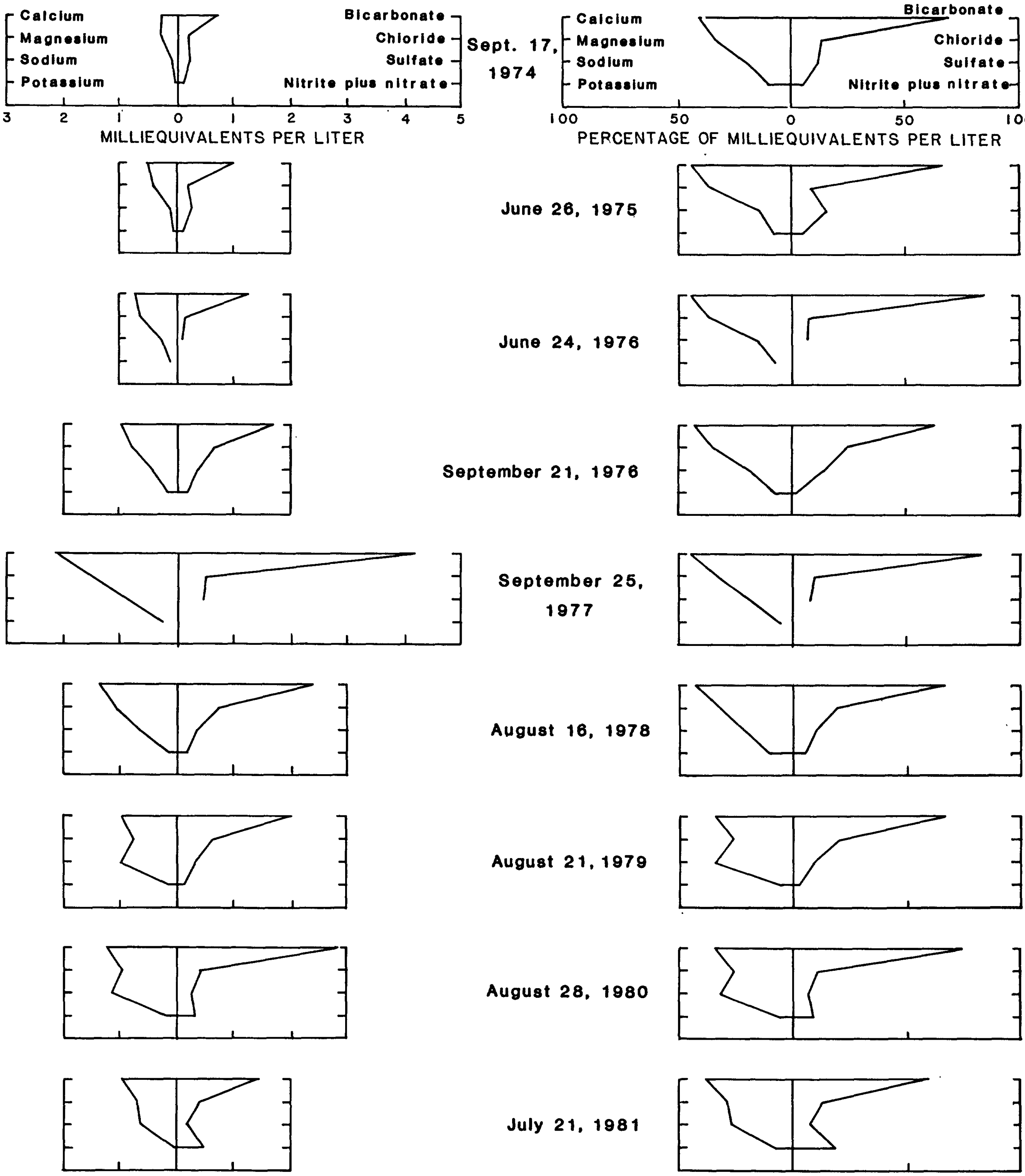


Figure 3.4.--Concentrations of selected dissolved constituents, in milliequivalents per liter and in percentage of milliequivalents per liter, in water in well FB 3.

CHLORIDE CONCENTRATION INDICATES EFFLUENT IN GROUND WATER

The presence of percolating effluent is indicated by changes in chloride concentration of water in wells since the lagoons have been used.

Most of the wells near the Fishing Bridge lagoons were sampled in 1977-79 and were analyzed for chloride. The chloride concentrations are shown in table 3.5. Most of the wells shown in the table were sampled in 1974 or 1975 before the lagoons were used. At that time, chloride concentrations were less than 2 mg/L (milligrams per liter), except in well FB 3, which had a concentration of 4.5 mg/L. Therefore, wells that contained more than 5 mg/L chloride in 1977-79 probably contained percolating effluent at the times the samples were collected.

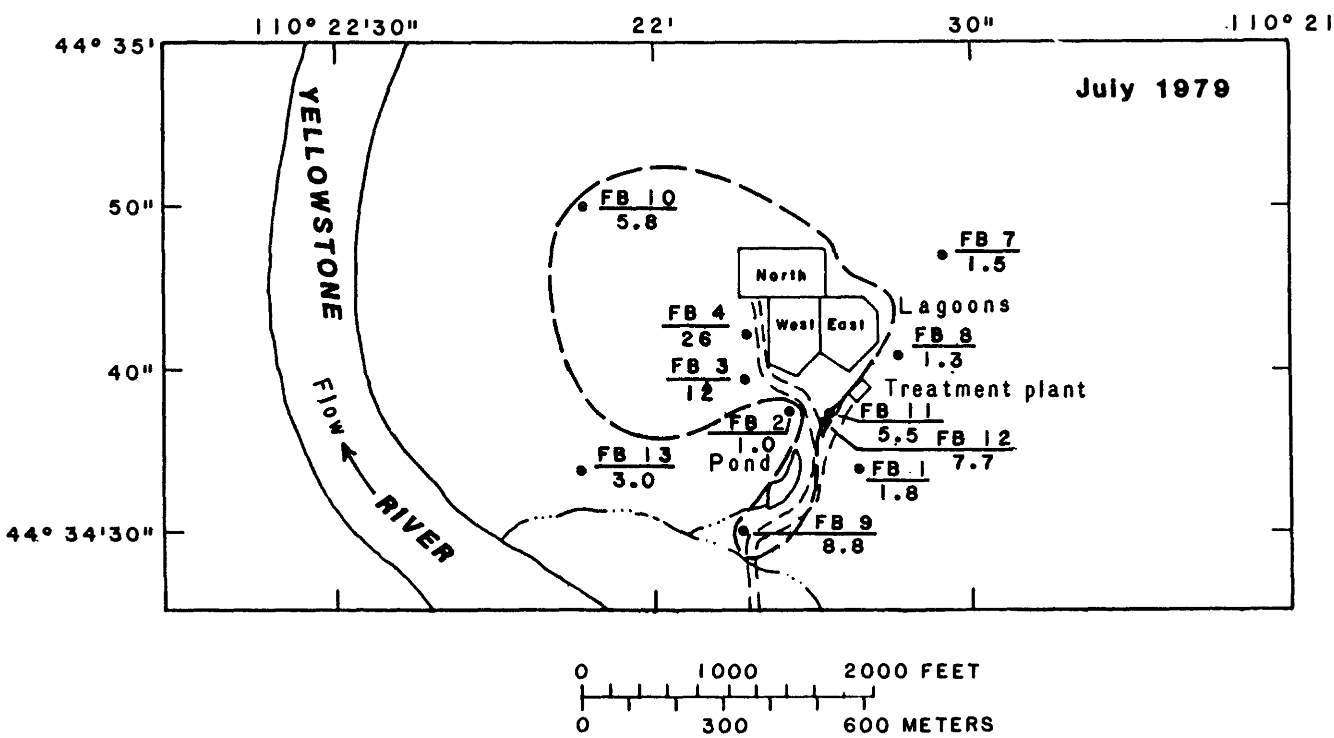
A line of 5 mg/L of chloride in wells in July 1979 is shown in figure 3.5. The area enclosed by the line most likely contained effluent that percolated from the lagoons and represents a plume of effluent moving toward the Yellowstone River.

The shape of the plume also indicates the direction as well as the extent of movement of the percolating effluent. The plume was elongated toward the west, northwest, southwest and south indicating movement of percolating effluent in those directions. The elongated area south of the lagoons around the pond near well FB 9 may have resulted in part from chloride in effluent that was discharged into the pond in August and September 1976. Water flows from the pond only during high stages.

The shapes of plumes at other times during 1977-79 are similar but do have slight differences. The differences in shape probably are due to changes in use of the lagoons or to fluctuations of recharge of ground water by rain and melting snow.

Table 3.5.--Chloride concentrations, in milligrams per liter, in water in wells near the Fishing Bridge wastewater lagoons 1977-79

Well	1977 April	1977 June	1977 July	1977 Aug	1977 Sept	1977 Oct	1978 June	1978 Aug	1978 Oct	1979 May	1979 July	1979 Aug
FB 1	--	--	--	--	0.9	--	2.8	1.1	1.0	1.3	1.8	--
2	0.7	--	1.5	--	.6	1.6	2.1	.8	.8	.9	1.0	1.0
3	16	11	8.9	11	17	18	9.4	23	29	26	12	21
4	4.7	--	--	4.1	12	--	16	17	28	22	26	27
7	--	--	--	--	.9	--	2.2	2.1	1.1	.9	1.5	--
8	--	--	--	--	.9	--	--	1.8	--	1.8	1.3	--
9	--	--	--	--	4.9	--	6.7	6.7	15	10	8.8	--
10	--	--	--	--	2.2	--	7.8	7.9	4.6	3.3	5.8	--
11	--	--	--	--	--	--	2.7	4.6	6.6	8.0	5.5	--
12	--	2.8	--	--	2.6	--	16	7.1	9.0	8.4	7.7	9.7
13	--	--	--	--	.7	--	3.4	.9	1.5	3.3	3.0	--



EXPLANATION

LINE OF CHLORIDE CONCENTRATION OF 5 MILLIGRAMS PER LITER--Dashed where approximately located

FB 9 / 8.8 — WELL--Upper numeral is well number. Lower numeral is chloride concentration, in milligrams per liter

Figure 3.5.--Chloride concentrations in water in wells near the Fishing Bridge wastewater lagoons, July 1979.

SPECIFIC CONDUCTANCE INDICATES EFFLUENT IN GROUND WATER, BUT NOT IN SURFACE WATER

The presence of percolating effluent also is indicated by changes in the specific conductance of water in wells since the lagoons have been used; no change in specific conductance of the Yellowstone River was detected.

Specific conductance of water was measured in most of the wells near the Fishing Bridge lagoons about monthly from June 1980 through August 1981 (table 3.6). Specific conductances of water in the wells before the lagoons were used were less than 100 μS/cm at 25°C (microsiemens per centimeter at 25° Celsius), except in well FB 3, which had a value of 140 μS/cm. Therefore, wells with water that had a specific conductance of more than 100 μS/cm probably contained percolating effluent at the times the samples were collected. Lines of 100 μS/cm of specific conductance of water in wells in February 1981 and June 1982 are shown in figure 3.6.

As with chloride concentrations, the shapes of the plumes indicate the direction of movement of the percolating effluent. The shapes of the plumes at other times in 1980-81 are similar. Slight differences in shape probably are due to changes in use of the lagoons and to fluctuations of recharge of ground water.

Specific conductances of water in the Yellowstone River, tributaries, and nearby springs were less than 100 μS/cm in June 1982 (fig. 3.6).

Table 3.6.--Specific conductance, in microsiemens per centimeter at 25° Celsius, of water in wells near the Fishing Bridge wastewater lagoons 1980-81

Well	1980							1981					
	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Apr	June	July	Aug
FB 1	120	70	70	80	70	70	60	60	50	135	70	70	80
2	80	85	80	90	90	80	90	70	90	185	100	100	100
3	400	360	340	350	355	380	380	370	420	-	380	265	240
4	300	300	290	260	310	280	300	220	240	-	220	215	200
7	60	60	75	70	70	40	70	60	70	-	80	70	70
8	130	130	140	130	140	140	140	130	130	110	180	180	170
9	200	210	200	220	200	210	200	180	220	230	240	210	230
10	110	120	100	110	120	115	100	80	90	-	120	110	120
11	250	190	220	240	250	250	230	220	280	285	300	260	280
12	260	250	240	270	260	265	260	220	280	230	260	240	260
13	160	180	180	110	150	140	120	-	100	245	-	180	170
14	-	-	-	75	100	75	70	70	95	-	80	90	90

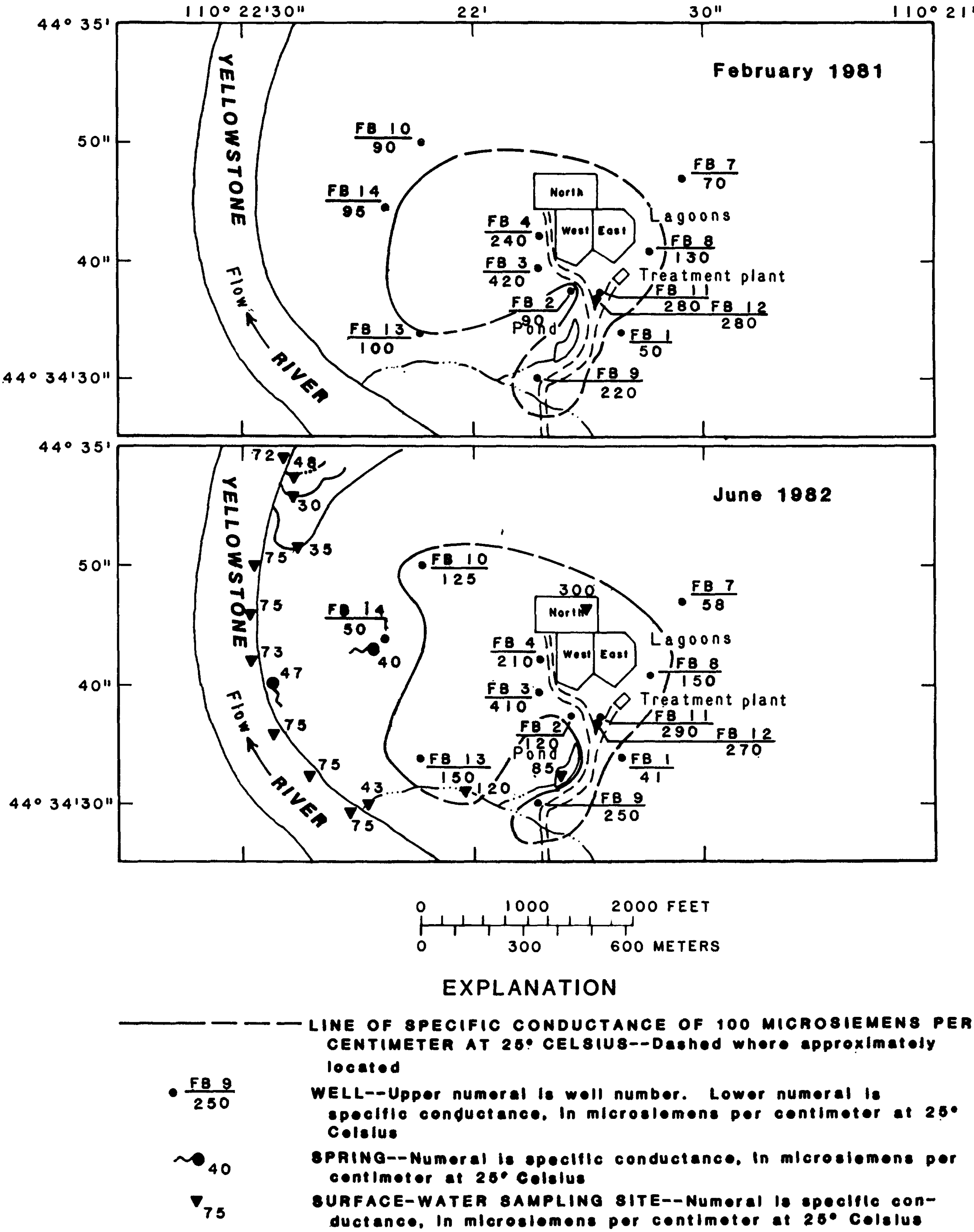


Figure 3.6.--Specific conductance of water in wells, springs, and surface-water sampling sites near the Fishing Bridge wastewater lagoons, February 1981 (upper map) and June 1982 (lower map).

3.7 Change in Quality of Water in the Yellowstone River

NO CHANGE DETECTED IN QUALITY OF WATER

Dissolved constituents in water in the Yellowstone River sampled upstream and downstream from the lagoons show no discernible change during 1976-82.

The Yellowstone River was sampled several times from 1976 through 1982 at three sites, one upstream from the lagoons at the bridge and two considered to be downstream from the lagoons. Results were almost identical for the two sites considered to be downstream from the lagoons. The location of the three sampling sites are shown in figure 3.7.

The only noticable difference in the samples were chloride concentrations of 3.7 mg/L (milligrams per liter) upstream and 7.2 mg/L downstream in August 1980 and nitrite plus nitrate concentrations of 0.11 mg/L upstream and 0.34 mg/L downstream in July 1981. These differences occurred only once in six sets of samples. Therefore, they probably do not indicate a change in quality of water in the river due to percolation of effluent from the lagoons. Analyses of selected constituents are shown in the following tables:

Specific conductance, in microsiemens per centimeter at 25° Celsius:

	9-18-76	8-17-78	8-22-79	8-29-80	7-22-81	8-22-82
Yellowstone River upstream from the Fishing Bridge lagoons	115	85	90	90	85	75
Yellowstone River downstream from the Fishing Bridge lagoons	115	87	90	90	85	80

Chloride concentration, in milligrams per liter:

	9-18-76	8-17-78	8-22-79	8-29-80	7-22-81	8-22-82
Yellowstone River upstream from the Fishing Bridge lagoons	5.3	4.8	5.4	3.7	5.0	4.7
Yellowstone River downstream from the Fishing Bridge lagoons	5.5	4.9	6.2	7.2	5.0	4.7

Nitrite plus nitrate concentration, in milligrams per liter:

	9-18-76	8-17-78	8-22-79	8-29-80	7-22-81	8-22-82
Yellowstone River upstream from the Fishing Bridge lagoons	0.07	0.01	0.03	0.00	0.11	<0.10
Yellowstone River downstream from the Fishing Bridge lagoons	.08	.01	.03	.00	.34	< .10

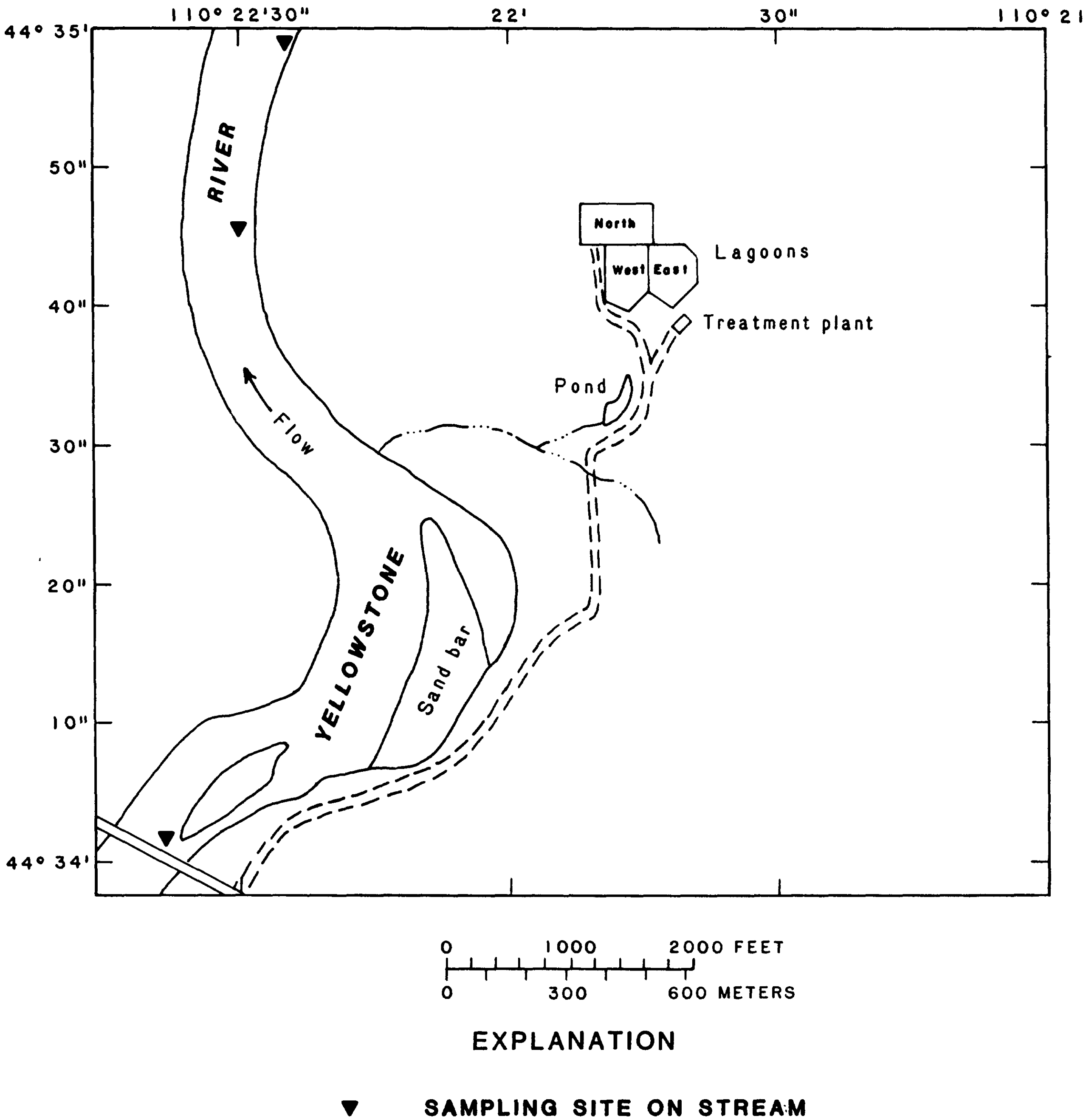


Figure 3.7.--Location of water-sampling sites on the Yellowstone River near the Fishing Bridge wastewater lagoons.

4.0 GRANT VILLAGE

4.1 Hydrologic Setting

WASTEWATER TREATMENT AND DISPOSAL SITE
IS NEAR YELLOWSTONE LAKE

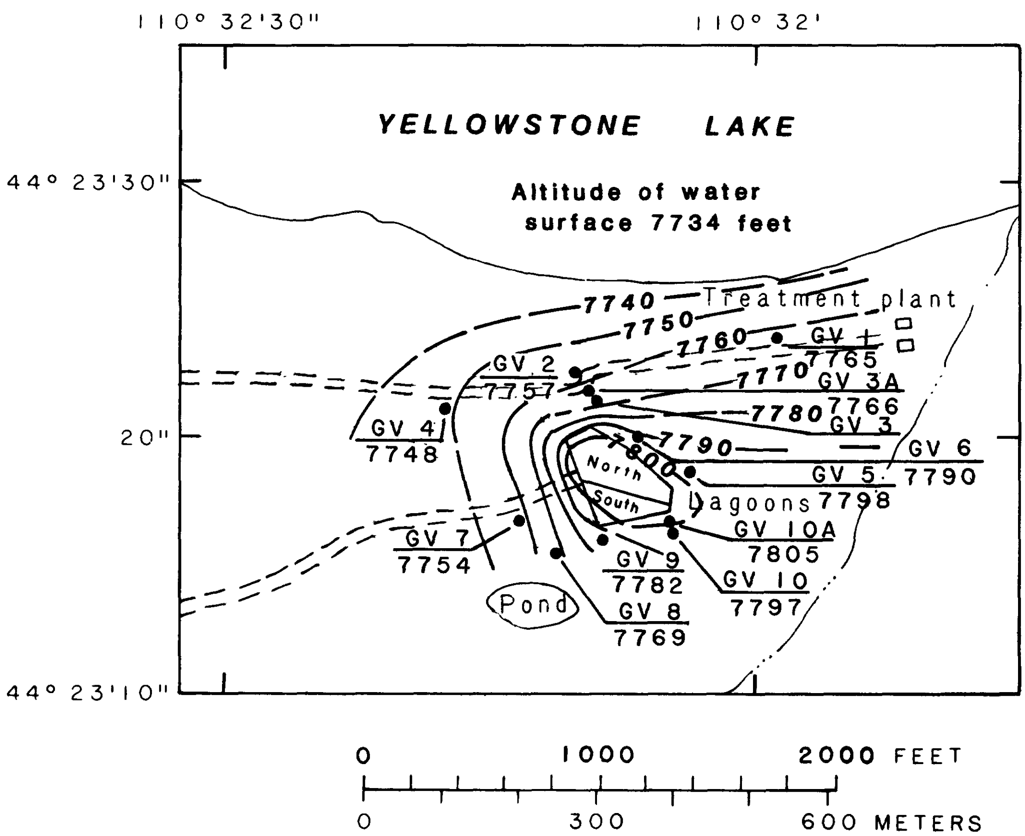
The water table slopes from the Grant Village wastewater lagoons toward Yellowstone Lake.

The Grant Village wastewater treatment and disposal site is about a mile east of Grant Village on a terrace about 100 feet above Yellowstone Lake. The site is underlain by deposits of sand, silt, clay, and gravel that partly fill the basin that contains Yellowstone Lake. Wells GV 1 through 10A were augered in the vicinity of the Grant Village site (fig. 4.1).

The configuration of the water-level contours in August 1978 in the vicinity of the Grant Village site is shown in figure 4.1. The configuration would be similar at other times because the water-level changes would not be large enough to affect the configuration appreciably.

Two lagoons (the north lagoon and the south lagoon in this report) were used for disposal of effluent beginning in September 1975. The lagoons were not used at the same time. Alternate use of the lagoons permitted one to be dried and scraped while the other was being used. The use of the lagoons for disposal of effluent during 1975-81 is shown as follows:

Lagoon	1975	1976	1977	1978	1979	1980	1981
North	September and October	mid-May through October	late June to early September	mid-May to mid-July	mid-July to mid-November	mid-May to mid-August	mid-July through October
South	--	--	mid-May to late June and early September to late October	mid-July through October	mid-May to mid-July	mid-August through October	mid-May through mid-July



EXPLANATION

——7800—— WATER-LEVEL CONTOUR--Shows altitude at which water level would have stood in tightly cased wells, August 18-19, 1978. Dashed where approximately located. Contour interval 10 feet. Datum is sea level

• GV 7 / 7754 WELL--Upper numeral is well number. Lower numeral is altitude of water level, in feet above sea level, August 18-19, 1978

Figure 4.1.--Location of wells and water-level contours near the Grant Village wastewater lagoons.

GROUND-WATER MOUND FORMS EACH YEAR UNDER LAGOONS

Water levels in wells near the lagoons rise when effluent percolates from the lagoons.

A ground-water mound forms under and near the lagoons at the Grant Village site, as indicated by changes in water levels in wells. The rises in water levels in wells near the lagoons from July 1975 to July 1976 and from October 1975 to October 1976 were as much as 11 feet. Most of the differences in water levels were caused by percolation of effluent from the north lagoon, and contoured rises indicate the approximate shape of the mound in July 1976 and in September 1976 (fig. 4.2). The mound was elongated almost north in July 1976 and generally northwest in September 1976. Although not shown in this report, the mound was elongated generally west in October 1976 (Cox, 1978a, fig. 10). The shape of the mound cannot be shown similarly in other years because water levels were affected by varying quantities of natural recharge and are not comparable as they were in 1975 and 1976.

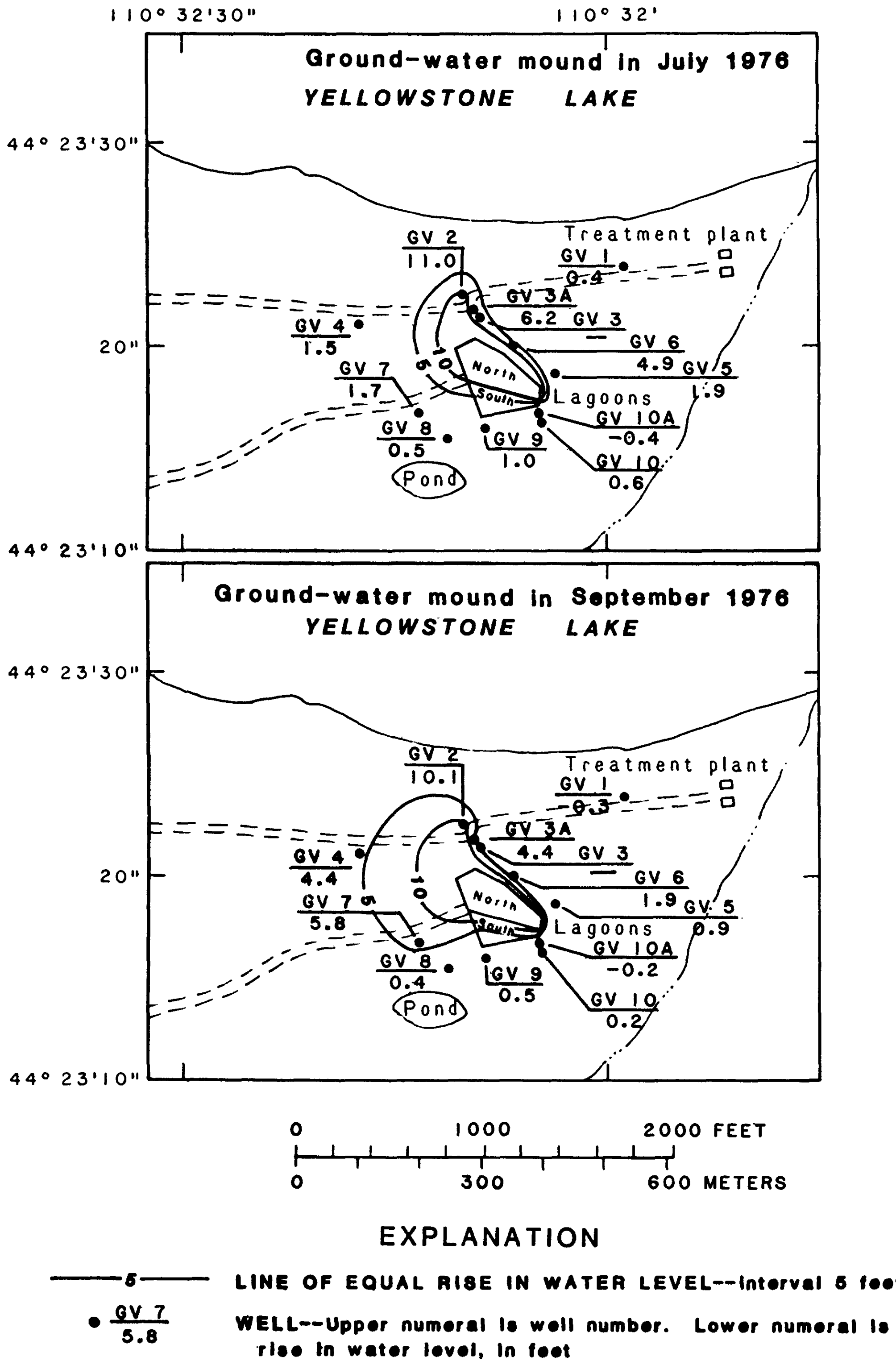


Figure 4.2.--Rise in water level July 12, 1975 to July 14, 1976 (upper map), and September 5, 1975 to September 14, 1976 (lower map) in wells near the Grant Village wastewater lagoons.

WATER LEVELS RESPOND TO USE OF LAGOONS

The water levels in wells near the lagoons rise and decline in response to use of the lagoons for disposal of effluent.

The water levels in wells GV 2 and GV 7 rose each year during the time the lagoons were used for disposal of effluent and declined each year during the time the lagoons were not used (fig. 4.3). The water levels usually were highest in August, when the quantity of effluent pumped to the lagoons was greatest at the peak of the tourist activity.

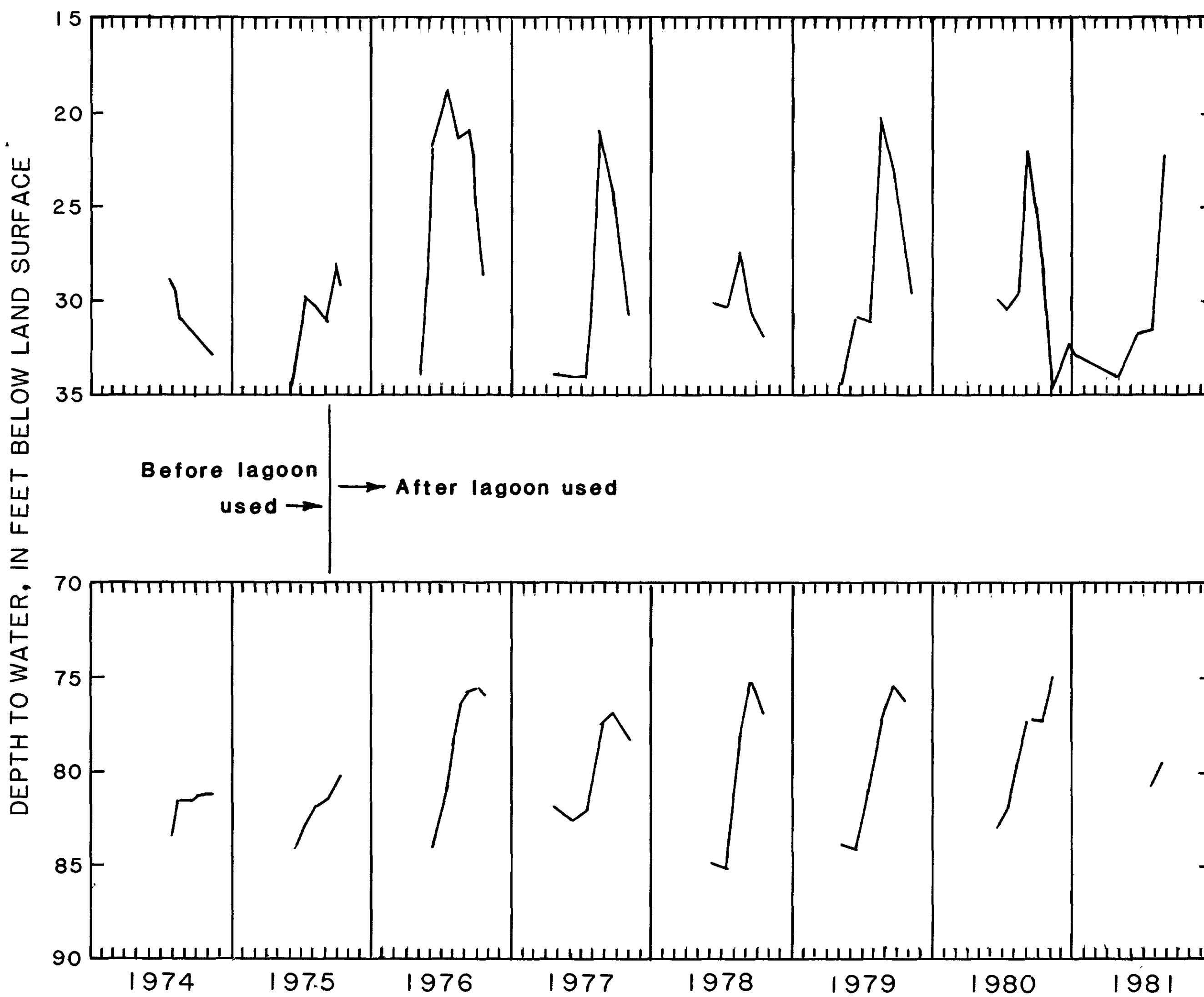


Figure 4.3.--Water levels in wells GV2 (upper graph) and GV 7 (lower graph).

QUALITY OF GROUND WATER HAS CHANGED SINCE THE LAGOONS HAVE BEEN USED

The movement of percolating effluent is indicated by changes in the quality of water in wells as shown by specific conductances before and after the lagoons have been used.

Most of the wells near the Grant Village lagoons (fig. 4.4.1) were sampled in 1974 or 1975 before the lagoons were used. Analyses of these samples collected before the lagoons were used provide a background for comparison with analyses of samples collected after the lagoons were used. Changes in the quality of water in wells since the lagoons have been used are shown by comparing specific conductances of water in wells before the lagoons were used with those after the lagoons were used (table 4.4.1). The north lagoon was used beginning in September 1975, and the south lagoon was used beginning in May 1977. Both lagoons had been used in 1978 before the wells were sampled in August 1978.

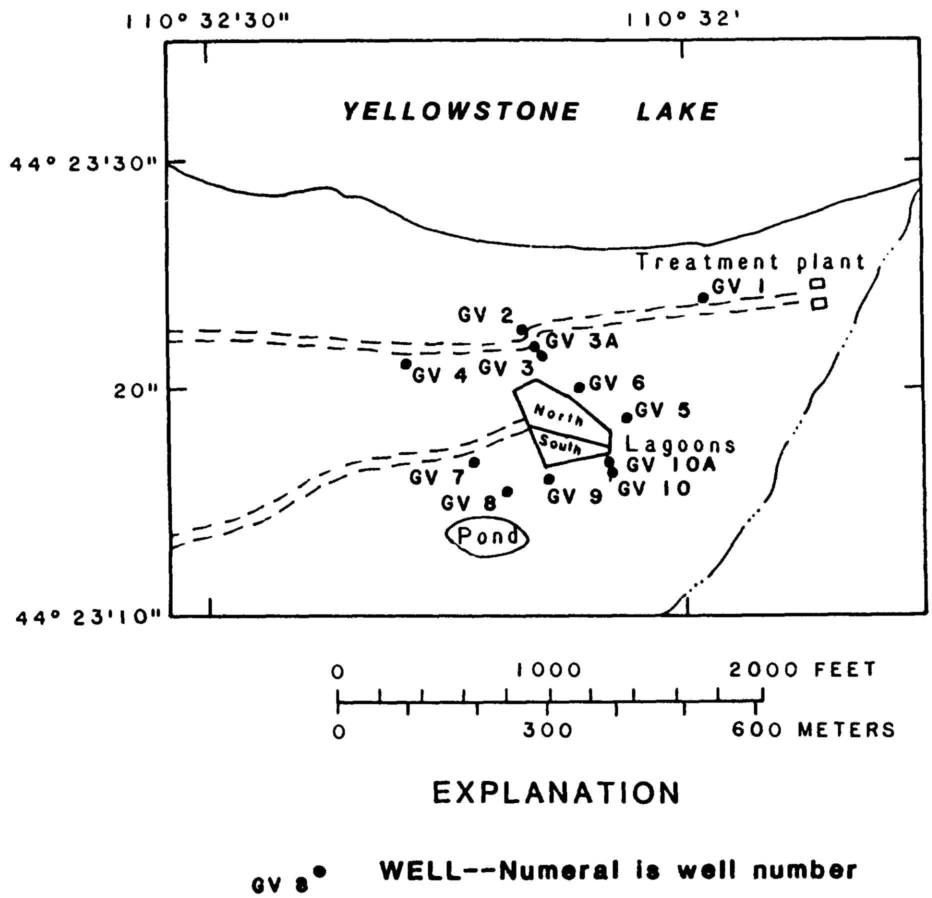


Figure 4.4.1.--Location of wells near the Grant Village wastewater lagoons.

Table 4.4.1.--Specific conductance, in microsiemens per centimeter at 25° Celsius, of water in wells near the Grant Village wastewater lagoons before the lagoons were used and in August 1978

Well	Before lagoons used	August 1978
GV 1	280	160
2	60	[1]140
3	--	--
3A	40	[1]240
4	75	[1]260
5	195	110
6	105	75
7	125	[1]360
8	115	75
9	50	55
10	135	130
10A	--	90

[1] Affected by effluent percolating from lagoons.

4.4.2 Ionic Concentrations near North Lagoon

DIAGRAMS SHOW CHANGES IN WATER QUALITY

The quality of water in wells north of the lagoons is affected by percolation of effluent from the north lagoon.

The change in quality of water in well GV 3A, north of the Grant Village lagoons, from 1975 to 1981 is illustrated in figure 4.4.2 by polygonal diagrams developed by Stiff (1951) of milliequivalents per liter of principal cations and anions. The larger polygons of milliequivalents per liter beginning in October 1976 in figure 4.4.2 indicate an increase in the total ionic concentration as a result of the use of the north lagoon. The smaller polygons in August 1980 and in July 1981 probably resulted from a decrease in percolation from the north lagoon.

The polygonal diagrams of percentage of milliequivalents per liter in figure 4.4.2 show an increase in the percentage of sodium and a corresponding decrease in the percentage of magnesium from 1976 through 1981. The percentage of nitrite plus nitrate increased, and at times the percentage of chloride increased from 1976 through 1981. The percentages of bicarbonate and sulfate decreased at times.

The increases in sodium and chloride concentrations of water in the well from the time the north lagoon was used result from those constituents being in wastewater that percolates from the lagoon. The increase in nitrite plus nitrate probably results from the oxidation of ammonia and organic nitrogen in the wastewater.

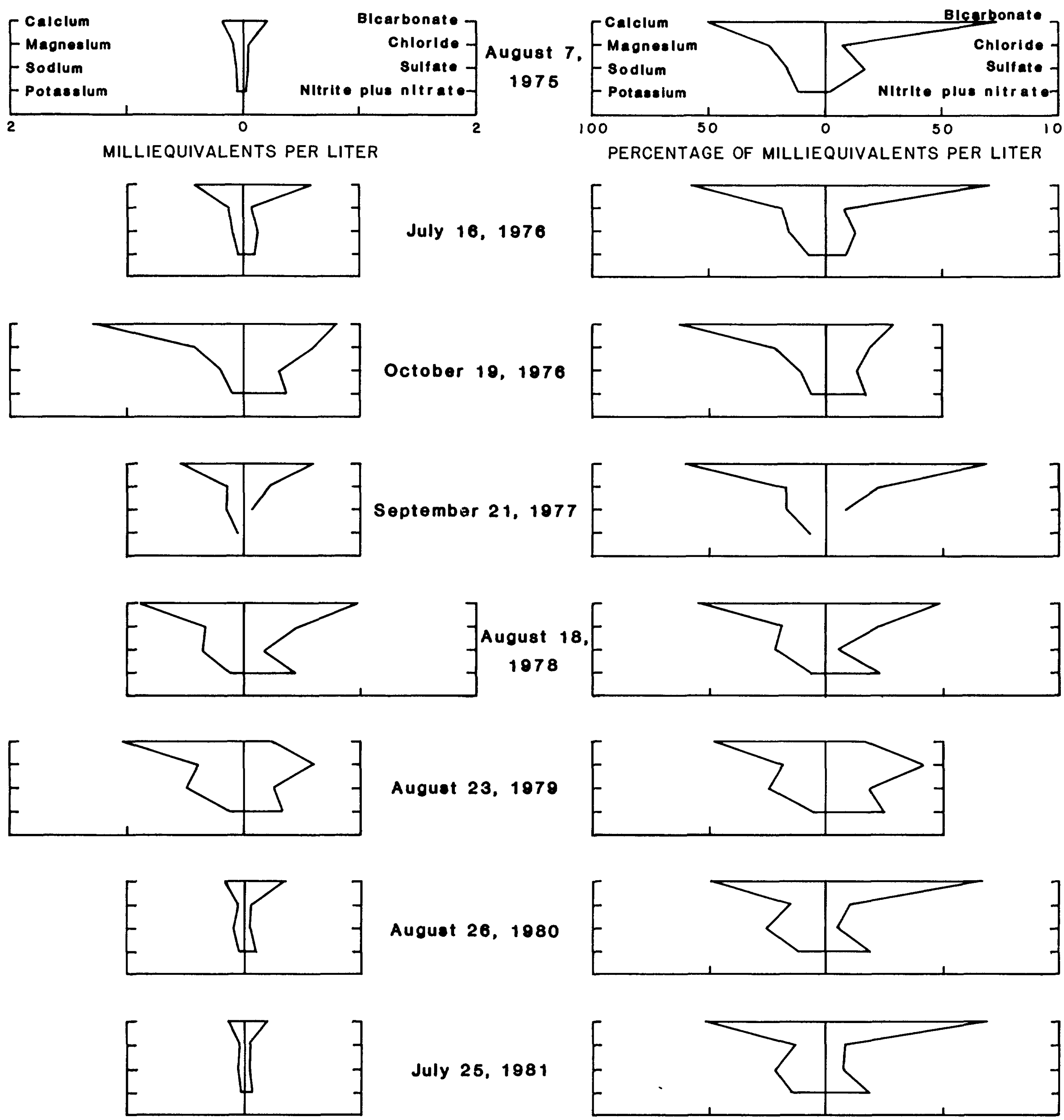


Figure 4.4.2.--Concentrations of selected dissolved constituents, in milliequivalents per liter and in percentage of milliequivalents per liter, in water in well GV 3A.

DIAGRAMS SHOW CHANGES IN WATER QUALITY

The quality of water in a well west of the lagoons is affected by percolation of effluent from the south lagoon.

The change in quality of water in well GV 7, west southwest of the Grant Village lagoons, from 1974 to 1981 is illustrated in figure 4.4.3 by polygonal diagrams developed by Stiff (1951). The larger polygons of milliequivalents per liter beginning in September 1977 indicate an increase in the total ionic concentration as a result of percolation of effluent from the south lagoon.

The percentage of cations did not change appreciably. However, the percentages of chloride and of nitrite plus nitrate increased, whereas the percentages of bicarbonate decreased. The increase in chloride concentration is from chloride in the wastewater that percolates from the lagoon. The increase in nitrite plus nitrate probably results from the oxidation of ammonia and organic nitrogen in the wastewater.

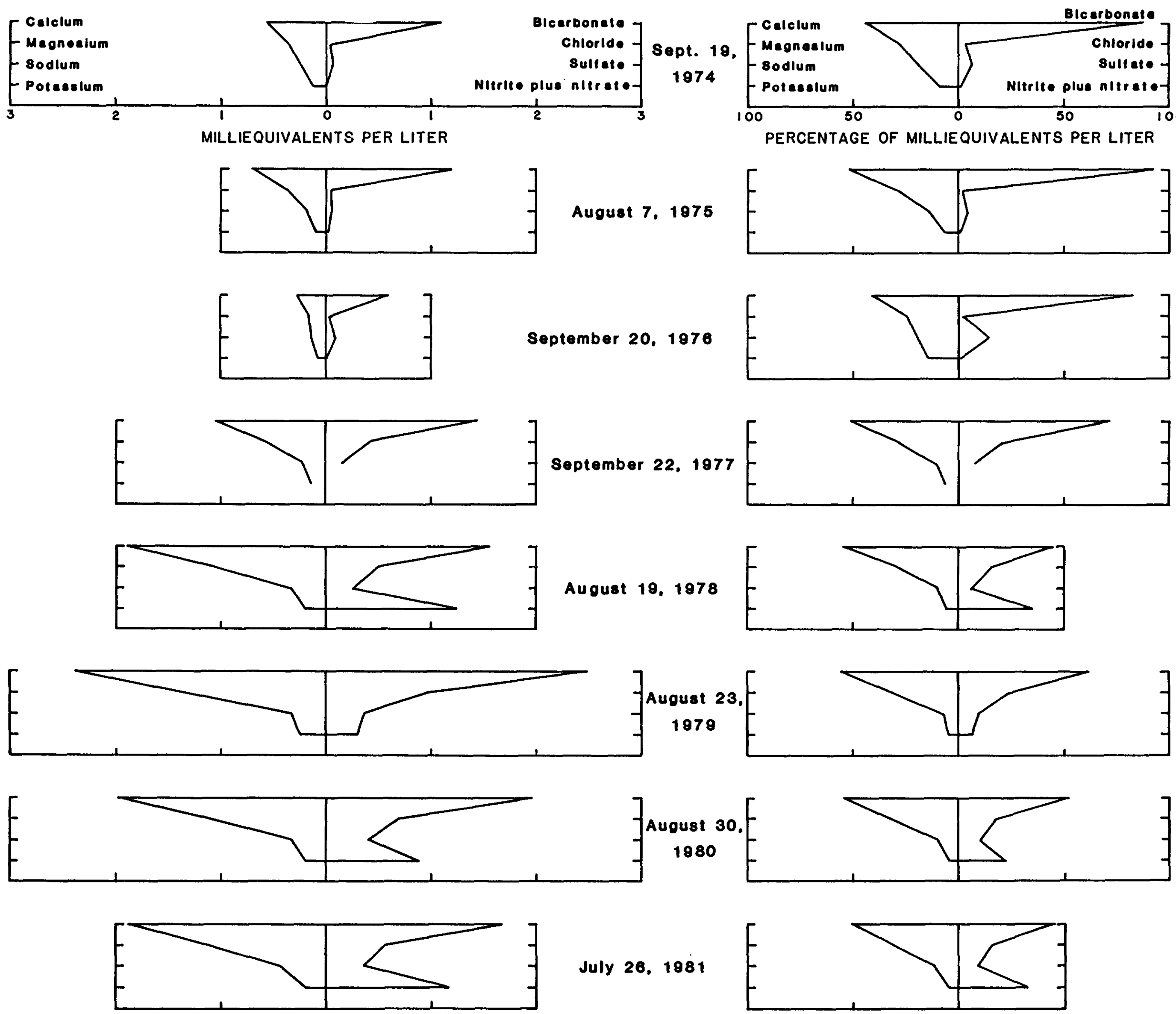


Figure 4.4.3.--Concentrations of selected dissolved constituents, in milliequivalents per liter and in percentage of milliequivalents per liter, in water in well GV 7.

4.5 Chloride Concentrations in Ground Water

4.5.1 Data Collected During 1977-79

CHLORIDE CONCENTRATION INDICATES EFFLUENT IN GROUND WATER

The presence of percolating effluent in ground water is indicated by changes in chloride concentrations of water in wells since the lagoons have been used.

Most of the wells near the Grant Village lagoons were sampled in 1977-79, and the samples were analyzed for chloride. The chloride concentrations are shown in table 4.5.1. Most of the wells shown in the table were sampled in 1974 or 1975 before the lagoons were used. At that time, chloride concentrations were less than 2 mg/L (milligrams per liter), except for concentrations of 3.1 mg/L in well GV 2 and 3.2 mg/L in well GV 9. Wells where the chloride concentration in water exceeded 5 mg/L, therefore, probably contained percolating effluent at the times the samples were collected.

Table 4.5-1.--Chloride concentrations, in milligrams per liter, in water in wells near the Grant Village wastewater lagoons, 1977-79

	1977				1978			1979			
	Apr	June	July	Sept	June	Aug	Oct	May	July	Aug	Nov
GV 1	-	-	-	2.2	2.4	1.9	1.7	1.0	1.7	-	2.6
2	4.8	-	6.0	-	19	15	16	20	15	-	15
3A	6.2	-	-	6.6	1.4	15	5.9	3.6	1.2	21	[1]26
4	23	24	-	2.2	30	15	7.0	26	24	9.7	[1]2.9
5	-	-	-	1.7	1.7	2.0	1.4	1.8	1.5	-	-
6	-	-	-	.7	1.5	1.0	.9	-	1.1	-	-
7	-	2.9	-	14	9.4	17	17	26	31	33	30
8	-	-	-	.9	1.1	.9	1.1	1.8	1.3	-	-
9	-	-	-	.8	6.0	2.1	1.7	1.3	9.7	-	-
10	-	-	-	.6	1.5	2.7	1.1	.9	1.1	-	-
10A	-	-	-	2.8	2.2	5.9	1.7	1.8	1.2	-	-

[1] Sampled October 25, 1979.

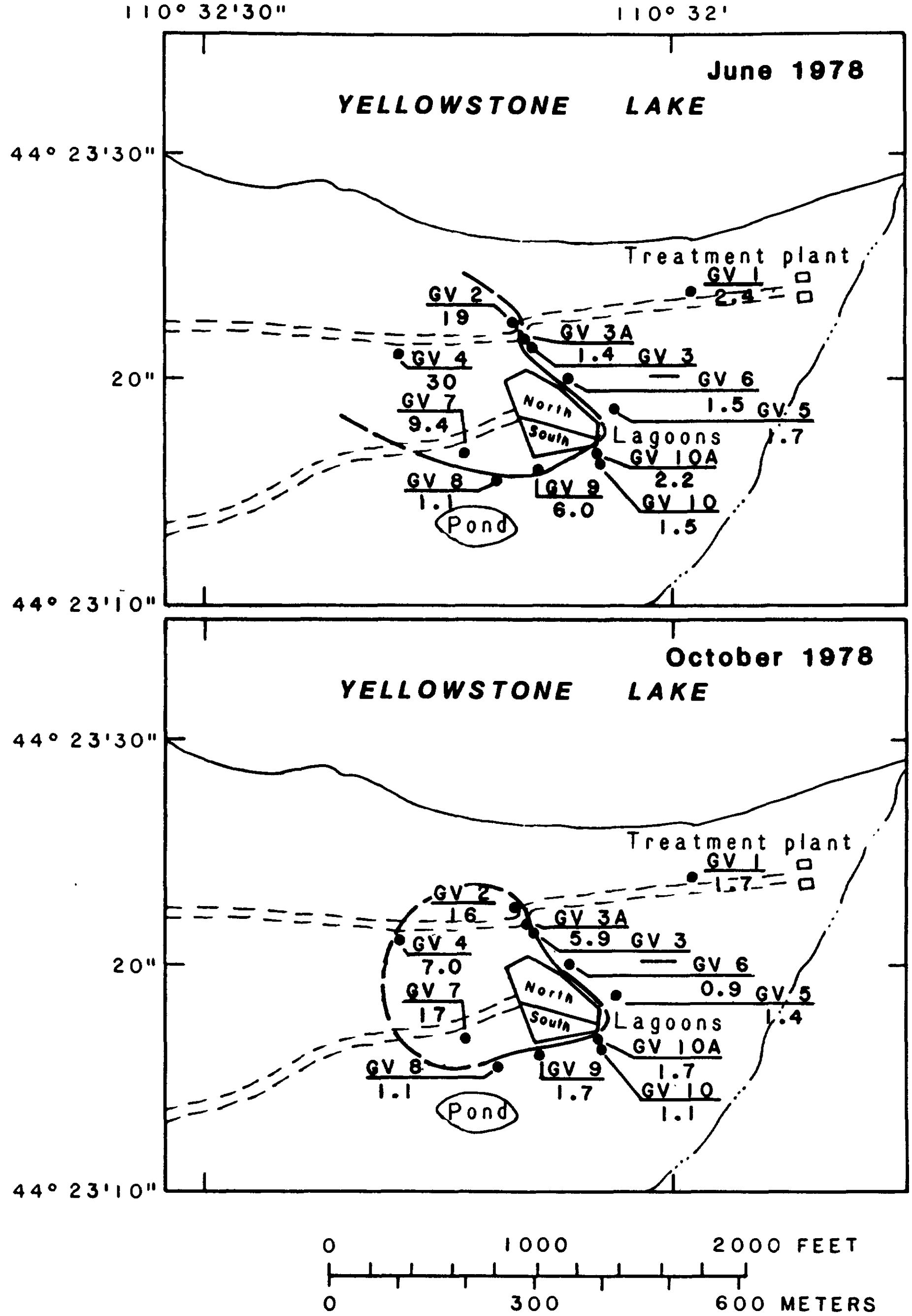
CONCENTRATIONS OF CHLORIDE IN GROUND WATER IN JUNE AND OCTOBER 1978 COMPARED

Lines of 5 milligrams per liter of chloride in water in wells indicate the direction and extent of movement of percolating effluent in June and in October 1978.

The areas enclosed or partly enclosed by lines of 5 milligrams per liter of chloride in water in wells (fig. 4.5.2) most likely contained effluent that percolated from the lagoons and represent plumes of effluent moving toward Yellowstone Lake in June and in October 1978. The elongation of the areas indicates the direction of movement of the percolating effluent.

The direction of movement of percolating effluent seemingly depends on the scheduling of the use of the lagoons. The north lagoon was in use in June 1978 when the apparent direction of movement was northwestward (fig. 4.5.2, upper map). The south lagoon was in use in October 1978 when the apparent direction of movement was westward (fig. 4.5.2, lower map).

The chloride concentration decreased in well GV 4 from June to October 1978. The relatively large chloride concentration of water in this well in June 1978 probably was from effluent that percolated from the lagoons in 1977 rather than from effluent that percolated in 1978. The chloride concentration in well GV 4 in June 1978 was not used in constructing the line of 5 milligrams per liter for the upper map in figure 4.5.2.



EXPLANATION

———— — — — **LINE OF CHLORIDE CONCENTRATION OF 5 MILLIGRAMS PER LITER--Dashed where approximately located**

GV 8 / 1.1 • **WELL--Upper numeral is well number. Lower numeral is chloride concentration, in milligrams per liter**

Figure 4.5.2.--Chloride concentrations in water in wells near the Grant Village wastewater lagoons, June 1978 (upper map) and October 1978 (lower map).

4.0 GRANT VILLAGE--Continued

4.6 Specific Conductance of Ground and Surface Water

4.6.1 Data from Wells and Surface-Water Features, 1980-81

SPECIFIC CONDUCTANCE INDICATES EFFLUENT IN GROUND WATER, BUT NOT IN SURFACE WATER

The presence of percolating effluent in water in wells is indicated by changes in the specific conductance of water in wells since the lagoons have been used; however, specific conductance of water in Yellowstone Lake and in nearby surface-water features has not been affected.

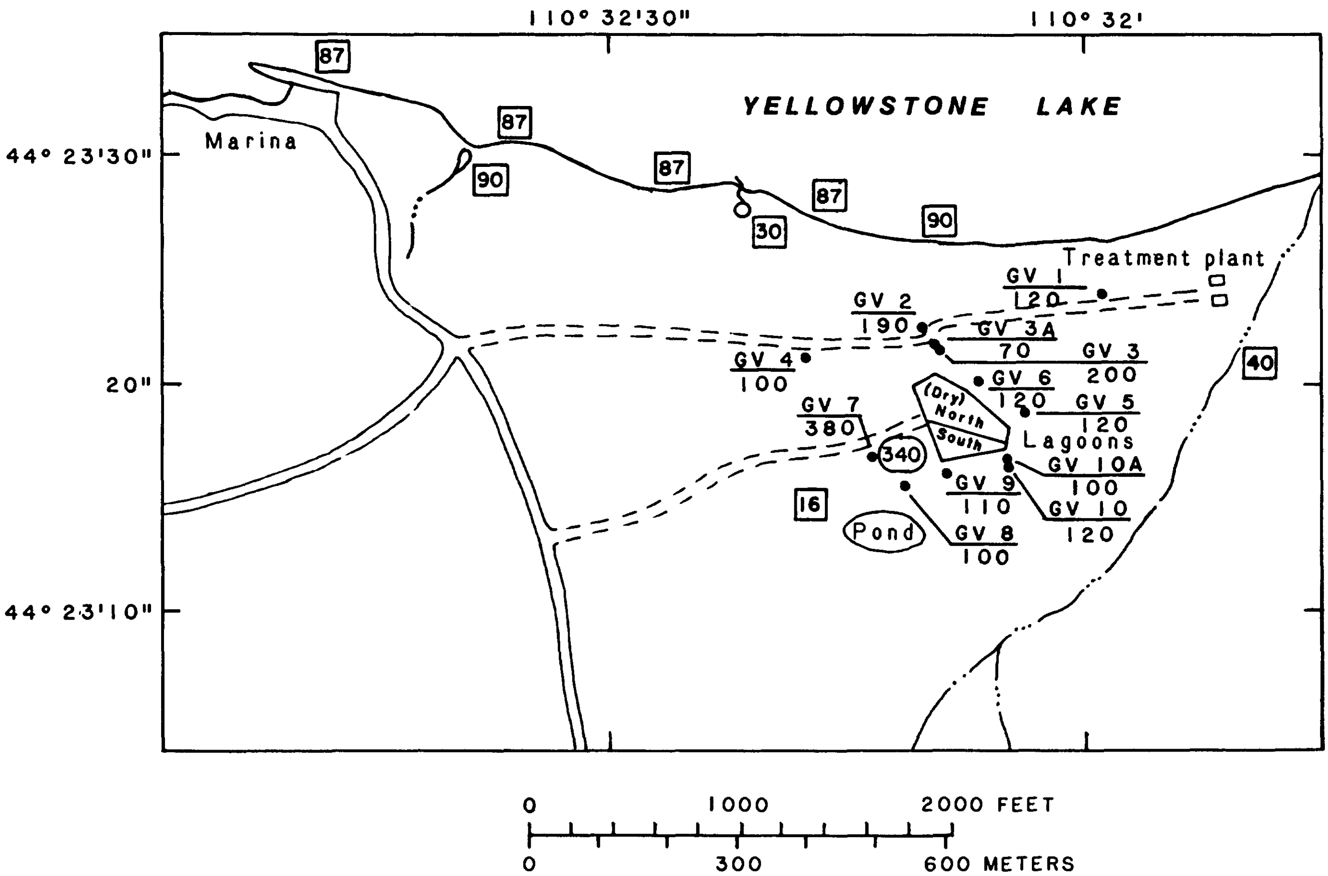
Specific conductance of water was measured in most of the wells near the Grant Village wastewater lagoons about monthly from June 1980 through August 1981 (table 4.6.1). Specific conductance of water in wells before the lagoons were used generally was less than 100 μS/cm (microsiemens per centimeter at 25° Celsius). Therefore, wells with water that had a specific conductance of much more than 100 μS/cm probably contained percolating effluent at the times the samples were collected.

In September 1980, the specific conductance of water in most of the wells was more than 100 μS/cm. At the same time, the specific conductance of water in Yellowstone Lake and nearby surface-water features was less than 100 μS/cm (fig. 4.6.1). The specific conductance of water in Yellowstone Lake and in nearby surface-water features indicates that if effluent discharges at or near these sites, the effluent is diluted sufficiently that the specific conductance of the surface water is not affected.

Table 4.6.1.--Specific conductance, in microsiemens per centimeter at 25° Celsius, of water in wells near the Grant Village wastewater lagoons 1980-81

[<, less than value shown]

	1980							1981					
Well	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Apr	June	July	Aug
GV 1	100	80	100	120	130	135	140	220	280	55	50	60	70
2	280	280	250	190	220	230	200	260	250	280	250	230	140
3	260	<50	50	200	280	260	120	80	100	80	<50	70	140
3A	<50	<50	<50	70	230	140	60	190	100	85	<50	60	<50
4	400	380	390	100	100	120	100	280	380	410	410	390	130
5	180	160	160	120	140	150	120	160	180	160	160	160	140
6	120	110	150	120	110	110	90	110	100	-	120	140	110
7	-	<50	400	380	300	370	-	-	-	-	-	390	330
8	140	80	110	100	80	80	70	80	90	210	100	100	80
9	120	160	110	110	90	100	70	100	90	100	160	130	100
10	120	130	165	120	120	125	100	120	120	110	140	140	120
10A	70	70	105	100	90	100	100	110	110	140	80	100	90



EXPLANATION

• GV 8 / 100 **WELL--Upper numeral is well number, Lower numeral is specific conductance, in microsiemens per centimeter at 25° Celsius, September 2, 1980**

(340) **SPECIFIC CONDUCTANCE OF EFFLUENT, IN MICROSIEMENS PER CENTIMETER AT 25° CELSIUS,--September 2, 1980**

[16] **SPECIFIC CONDUCTANCE OF SELECTED SURFACE-WATER FEATURE, IN MICROSIEMENS PER CENTIMETER AT 25° CELSIUS--September 9, 1980**

Figure 4.6.1.--Specific conductance of water in wells, effluent, and selected surface-water features near the Grant Village wastewater lagoons, September 1980.

4.6.2 Data from Selected Wells, 1980-81

GRAPHS SHOW EFFECTS OF PERCOLATING EFFLUENT

Peaks of specific conductance of water from selected wells are attributed to percolating effluent.

Graphs of specific conductance of water from selected wells that contained percolating effluent in 1980-81 are shown in figure 4.6.2. Peaks on the graphs seemingly correspond to periods of use of the lagoons after varying time lags.

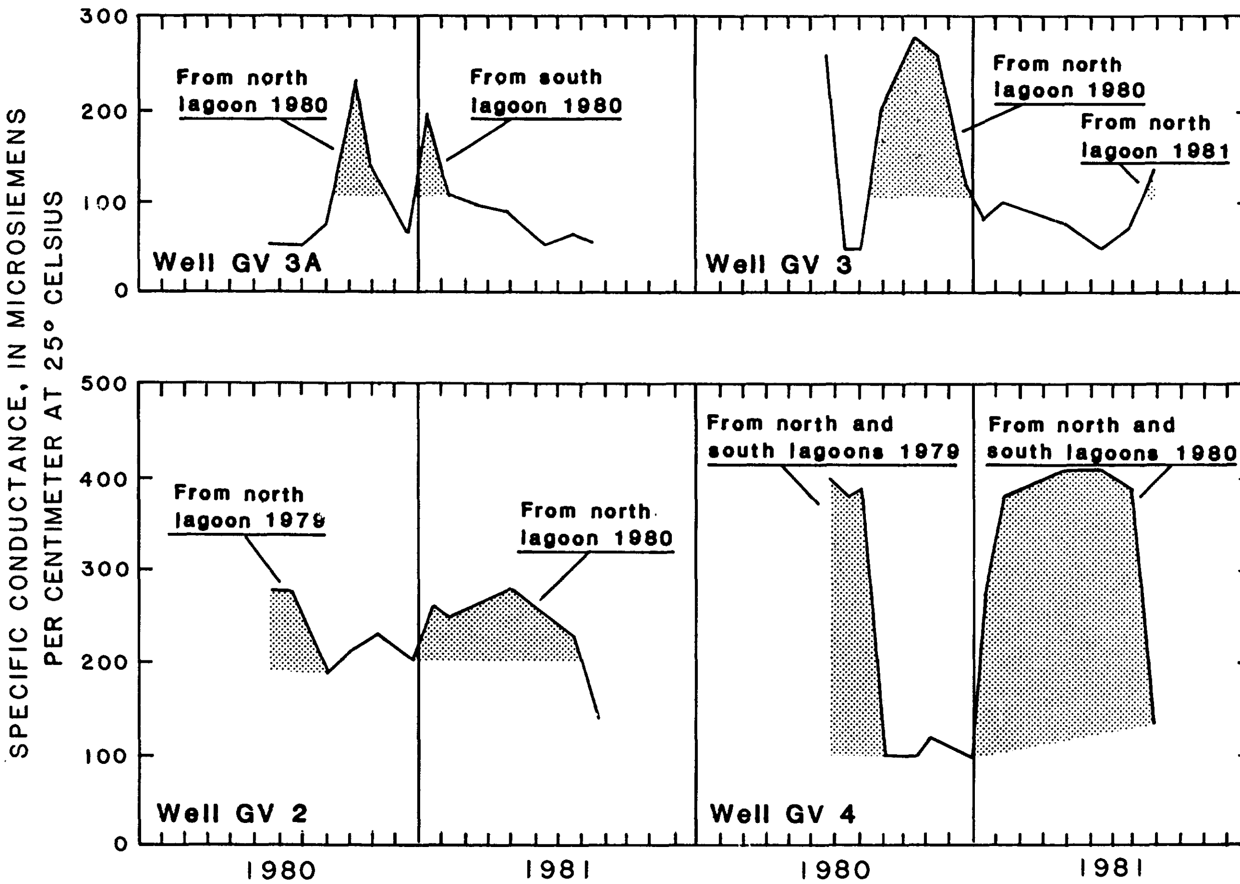
Well GV 3A is a relatively shallow well completed in an upper aquifer north of the lagoons. The larger peak on the graph of well GV 3A is attributed to percolating effluent from the north lagoon, and the smaller peak is attributed to percolating effluent from the south lagoon. The time lags of the peaks are about 2 months after the end of use of the north lagoon and about 2.5 months after the end of use of the south lagoon.

Well GV 3 is a relatively deep well that is completed in a lower aquifer north of the lagoons. A peak on the graph of well GV 3 in 1980 is attributed to use of the north lagoon with a time lag of about 2 months. The graph shows the beginning of a similar peak in 1981.

Well GV 2 also is a relatively deep well that is completed in a lower aquifer north of the lagoons. Peaks on the graph of well GV 2 are not as well defined as those of well GV 3; however, peaks in 1980 and in 1981 probably are the result of use of the north lagoon with a time lag of about 7 months.

Well GV 4 is a relatively deep well generally northwest of the lagoons. A well-defined peak in 1981 is attributed to percolation of effluent from both the north and the south lagoons during 1980. The partial limb of a similar peak in 1980 probably is the result of use of the lagoons in 1979. Time lags of these peaks are about 7 to 9 months.

Data were not collected from well GV 7 during most of the 1980-81 sampling period. Data that were collected show relatively large values of specific conductance in August-November 1980 and in July-August 1981 and small values of specific conductance in July 1980. These data are consistent with other data that indicate the quality of water in well GV 7 is affected by percolation of effluent from the south lagoon but probably not from the north lagoon.



USE OF LAGOONS

Lagoon	1978	1979	1980	1981
North	mid-May to mid-July	mid-July to mid-November	mid-May to mid-August	mid-July through October
South	mid-July throuh October	mid-May to mid-July	mid-August through October	mid-May through mid-July

Figure 4.6.2.--Specific conductance of water in selected wells near the Grant Village wastewater lagoons, 1980-81.

4.7 Nitrite Plus Nitrate Concentrations in Ground Water

NITRITE PLUS NITRATE CONCENTRATION INDICATES EFFLUENT IN GROUND WATER

The presence of percolating effluent in ground water is indicated by relatively large nitrite plus nitrate concentrations in water in wells near the lagoons.

The wells near the Grant Village lagoons were sampled in June and in September 1982, and the samples were analyzed for nitrite plus nitrate concentration (table 4.7). The wells were sampled in 1974 or 1975 before the lagoons were used. At that time, the nitrite plus nitrate concentrations were less than 1 milligram per liter. Wells where the nitrite plus nitrate concentrations exceeded 1 milligram per liter, therefore, probably contained percolating effluent at the time the samples were collected.

Table 4.7--Nitrite plus nitrate concentrations, in milligrams per liter, in water in wells near the Grant Village wastewater lagoons, June and September 1982

[<, less than value shown]

Well	June 18-19, 1982	September 1-2, 1982
GV 1	<0.10	0.13
2	[1]4.3	[1]8.1
3	.11	[1]6.9
3A	.15	[1]1.3
4	[1]16	.54
5	.10	<.10
6	.23	.50
7	[1]15	[1]25
8	.29	.32
9	[1]7.2	[1]5.1
10	<.10	<.10
10A	<.10	.46

[1] Affected by effluent percolating from lagoons.

5.0 OLD FAITHFUL

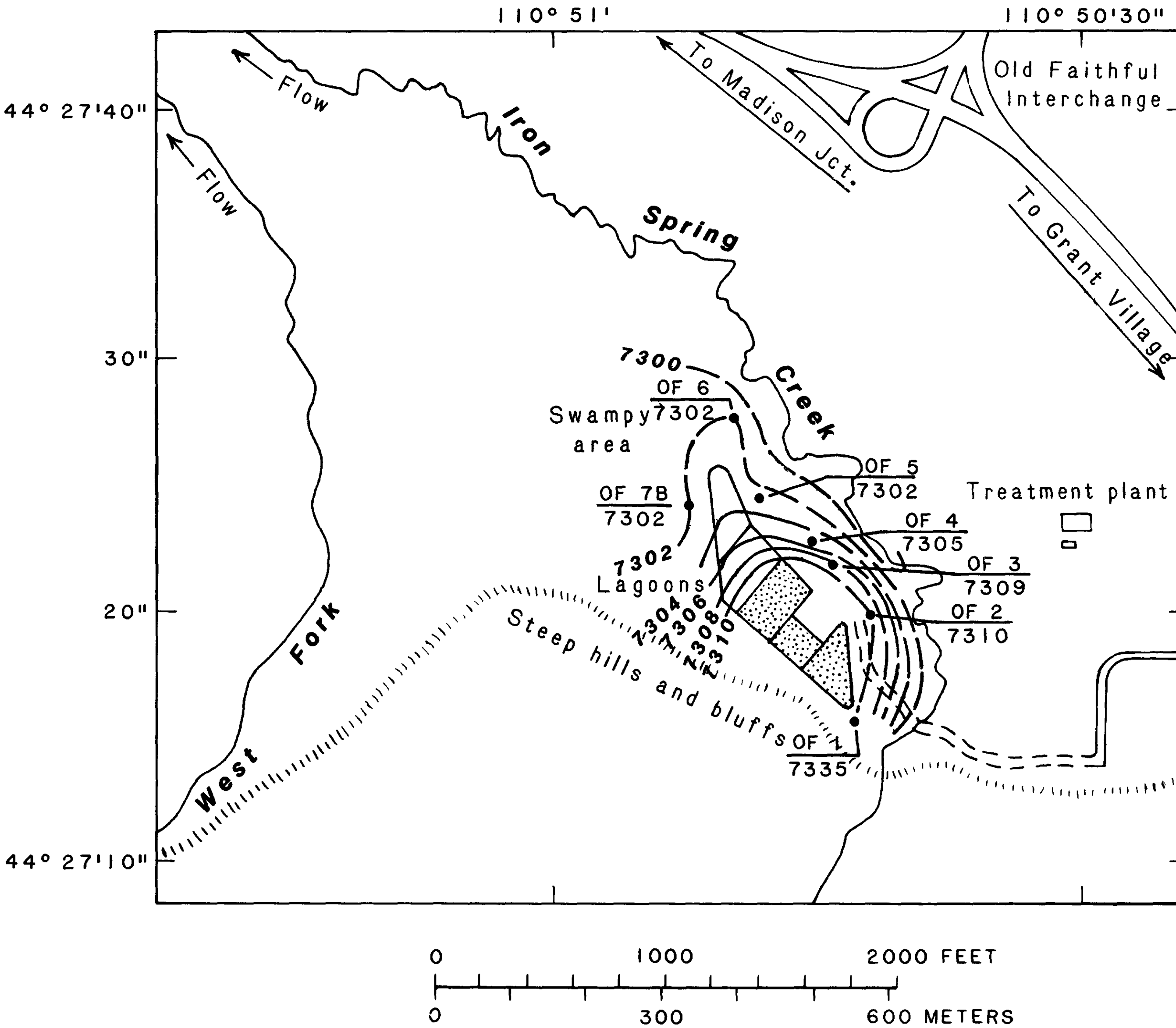
5.1 Hydrologic Setting

WASTEWATER TREATMENT AND DISPOSAL SITE IS NEAR IRON SPRING CREEK

The water table slopes from the Old Faithful wastewater lagoons to Iron Spring Creek.

The Old Faithful wastewater treatment and disposal site is about a mile west of the Old Faithful vistor area on kame-terrace deposits of sand and gravel about 40 feet above Iron Spring Creek, a tributrary of the Firehole River. Wells OF 1 through 7B were augered near the Old Faithful site (fig. 5.1). The lagoons have been used alternately for disposal of effluent. Water levels in wells fluctuate as the lagoons are used and indicate that ground-water mounds form under the lagoons being used.

The water-level contours shown in figure 5.1 indicate the configuration of the water level August 21-22, 1978, in the vicinity of the Old Faithful site. The water level in well OF 1 was not used in constructing the contours because the well apparently is completed in a different aquifer with a considerably higher water level than the other wells. The configuration of the 1978 water level indicates that effluent percolating from the lagoons moves northward and northeastward toward Iron Spring Creek and toward a swampy area between Iron Spring Creek and West Fork northwest of the lagoons. Effluent probably does not move southward or southwestward because of steep hills and bluffs that were formed by rhyolite flows and because of the aquifer with a higher water level.



EXPLANATION

LAGOON USED, 1978

LAGOON NOT USED, 1978

7310 — WATER-LEVEL CONTOUR--Shows altitude at which water level would have stood in tightly cased wells, August 21-22, 1978. Dashed where approximately located. Contour interval 2 feet. Datum is sea level

OF 1 / 7335 • WELL--Upper numeral is well number. Lower numeral is altitude of water level, in feet above sea level, August 21-22, 1978

Figure 5.1.--Location of wells and water-level contours near the Old Faithful wastewater lagoons.

CHLORIDE CONCENTRATIONS INDICATE EFFLUENT PRESENT IN GROUND AND SURFACE WATER

The direction of movement of percolating effluent is indicated by the chloride concentration in water in wells near the lagoons and in Iron Spring Creek.

Wells near the Old Faithful lagoons (fig. 5.2) were sampled in 1977-79, and the samples were analyzed for chloride. The chloride concentrations are listed in table 5.2. Although most of the lagoons had been used for several years before the wells were drilled, the southeasternmost lagoon was constructed after the wells were drilled. Chloride concentrations of water from well OF 2 generally have been less than 10 mg/L (milligrams per liter) either before the southeasternmost lagoon was built or when the lagoon was not being used. Moreover, the chloride concentration of water from well OF 1, apparently not affected by percolation of effluent from the lagoons because of the high water level in the well, always has been less than 5 mg/L. Wells where the chloride concentration exceeded 10 mg/L, therefore, contained percolating effluent at the times the samples were collected.

None of the lagoons were in use in May 1979. However, effluent that percolated from the lagoons in late 1978 was still at wells OF 2, OF 3, and OF 4 and, to a lesser degree, at wells OF 6 and OF 7B.

The chloride concentration of water in Iron Spring Creek in August 1978 was 9.2 mg/L at a sampling site at the road crossing upstream from the lagoons and 20 mg/L at a sampling site downstream from the lagoons (fig. 5.2). The increase in chloride concentration in the stream between the two sites probably was due in part to percolating effluent discharging into the stream. However, the increase also was due in part to chloride ions in thermal water that discharges into the stream between the sampling sites.

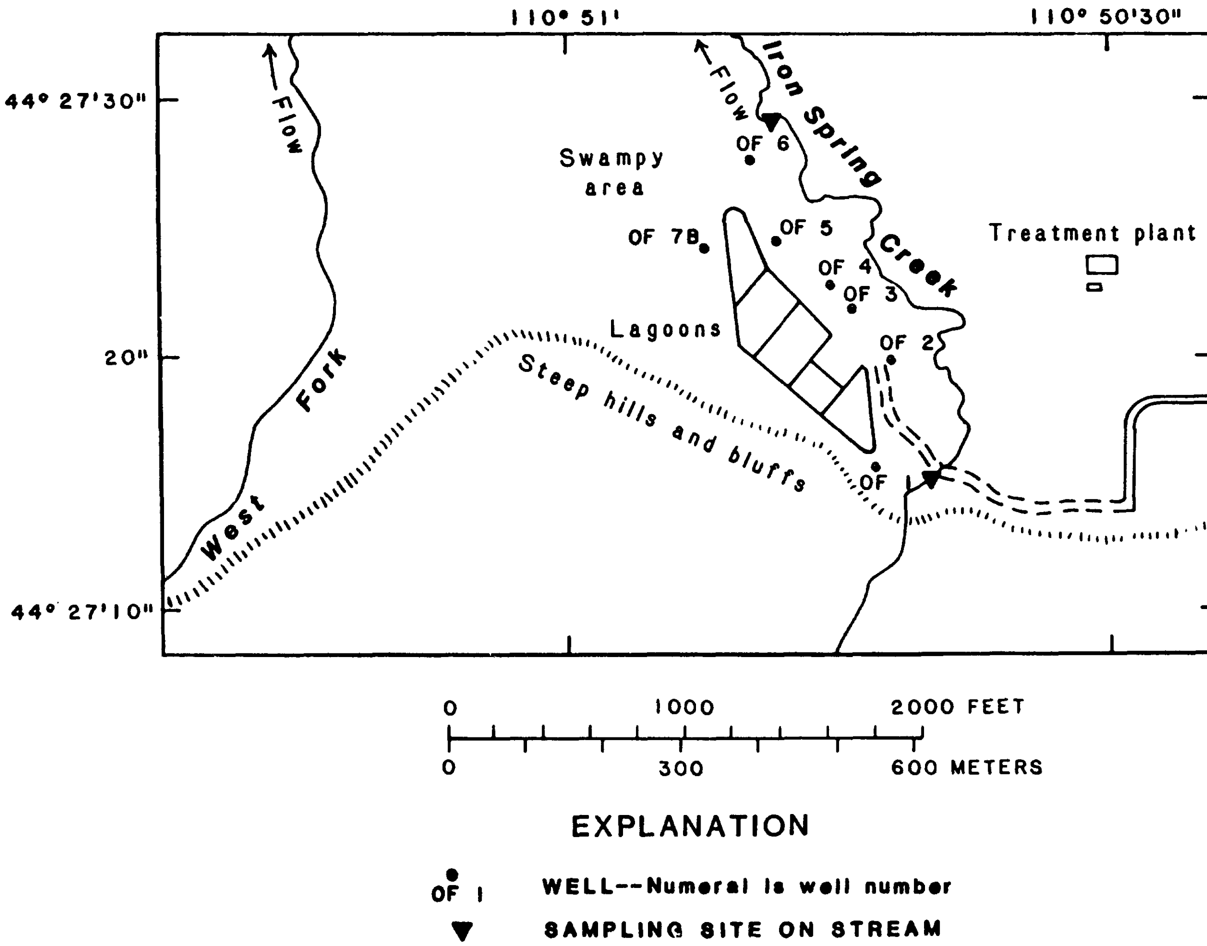


Figure 5.2.--Location of wells and sampling sites on Iron Spring Creek near the Old Faithful wastewater lagoons.

Table 5.2.--Chloride concentrations, in milligrams per liter, in water in wells near the Old Faithful wastewater lagoons, 1977-79

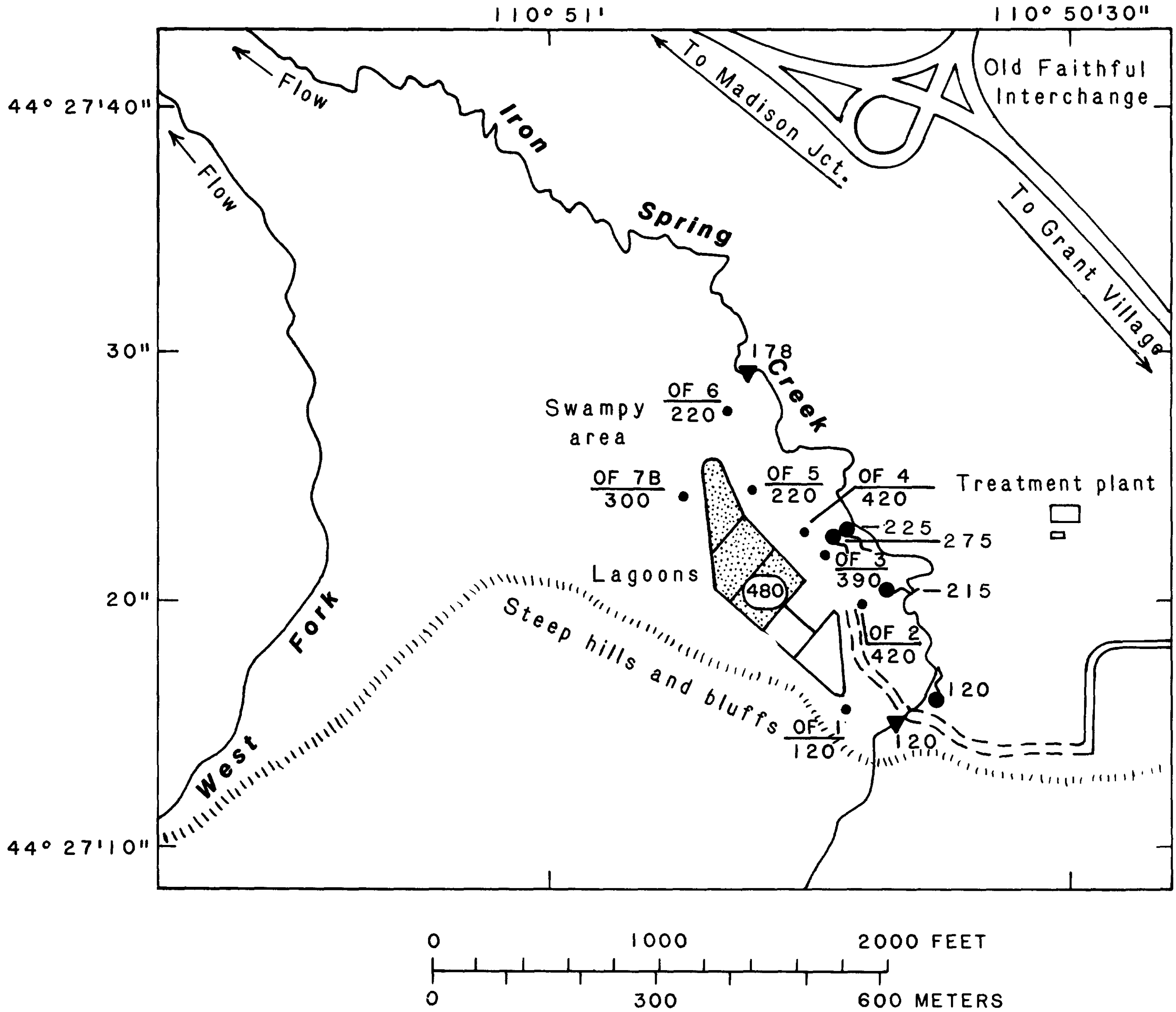
	1977					1978			1979			
Well	June	July	Aug	Sept	Oct	June	Aug	Oct	May	July	Aug	Oct
OF 1	-	-	-	3.4	-	3.8	3.4	3.4	3.5	2.8	-	3.1
2	-	-	-	12	-	8.6	45	34	21	8.6	17	15
3	36	43	45	45	46	38	42	34	30	34	40	39
4	33	41	45	48	47	35	48	35	26	34	40	40
5	-	-	-	49	-	29	39	35	9.2	34	38	37
6	-	-	-	43	-	21	29	17	13	26	-	42
7B	-	-	-	-	-	-	25	42	14	27	-	38

5.3 Specific Conductance of Ground and Surface Water

SPECIFIC CONDUCTANCE INDICATES EFFLUENT IN GROUND AND SURFACE WATER

The direction of movement of percolating effluent and the mixing of effluent and ground and surface water are indicated by specific conductance of more than 120 microsiemens per centimeter at 25° Celsius.

The specific conductances of water in wells, springs, seeps, effluent, and Iron Spring Creek in September 1980 are shown in figure 5.3. The specific conductance of water in well OF 1, Iron Spring Creek upstream from the lagoons, and a nearby spring were all 120 μS/cm (microsiemens per centimeter at 25° Celsius) in September 1980. This value probably is about the specific conductance of the water that does not contain effluent from the lagoons. The specific conductance of the effluent was 480 μS/cm. The specific conductance of the springs and seeps between the lagoons and the stream and of water in the wells are all between 120 and 480 μS/cm. The increase in specific conductance from 120 to 178 μS/cm of Iron Spring Creek in the reach is probably due in part to percolating effluent discharging in the stream and in part to thermal water discharging into the stream.



EXPLANATION

LAGOON USED, SEPTEMBER 1980

LAGOON NOT USED, SEPTEMBER 1980

OF 1 / 120 WELL--Upper numeral is well number. Lower numeral is specific conductance, in microsiemens per centimeter at 25° Celsius, September 3, 1980

120 SPRING OR SEEP--Numeral is specific conductance, in microsiemens per centimeter at 25° Celsius, September 10, 1980

(480) SPECIFIC CONDUCTANCE OF EFFLUENT, IN MICROSIEMENS PER CENTIMETER AT 25° CELSIUS--September 3, 1980

120 SAMPLING SITE ON STREAM--Numeral is specific conductance, in microsiemens per centimeter at 25° Celsius, September 3, 1980

Figure 5.3.--Specific conductance of water in wells, springs, seeps, effluent, and Iron Spring Creek near the Old Faithful wastewater lagoons, September 1980.

PERCOLATING EFFLUENT TRACED WITH DYE

Dye travelled from a lagoon to a nearby well at a velocity of about 2 feet per day.

Rhodamine WT dye was injected in the southeasternmost lagoon on October 1, 1975. Water samples were collected from well OF 2 and from the two sampling sites on Iron Spring Creek about weekly from October 1, 1975, through April 25, 1976. The fluorescence of water in well OF 2 increased to more than the seemingly natural level about October 15, and the peak in fluorescence occurred on November 26, 1975 (fig. 5.4). The fluorescence decreased to the natural level about April 20, 1976. For a curve such as shown in figure 5.4, the center of the mass of the curve that is greater than the natural fluorescence is considered to be the average time of arrival of the dye rather than the peak in fluorescence. The center of the mass of the curve that is greater than the natural fluorescence is shown in the figure by the vertical dashed line on December 5. Therefore, the average traveltime for the dye between the lagoon and the well was about 65 days. The well is about 130 feet from the lagoon; consequently, the velocity of the dye is estimated to be about 2 feet per day.

The dye probably reached Iron Spring Creek between the sampling sites in a very diluted mixture with ground water that discharged into the stream, as indicated by the small increases in fluorescence that is more than the seemingly natural level at the site downstream from the lagoons (fig. 5.4). The small peaks in fluorescence at the sites upstream and downstream from the lagoons during February-April 1976 probably were caused by turbidity of the water in the stream and not by the presence of dye.

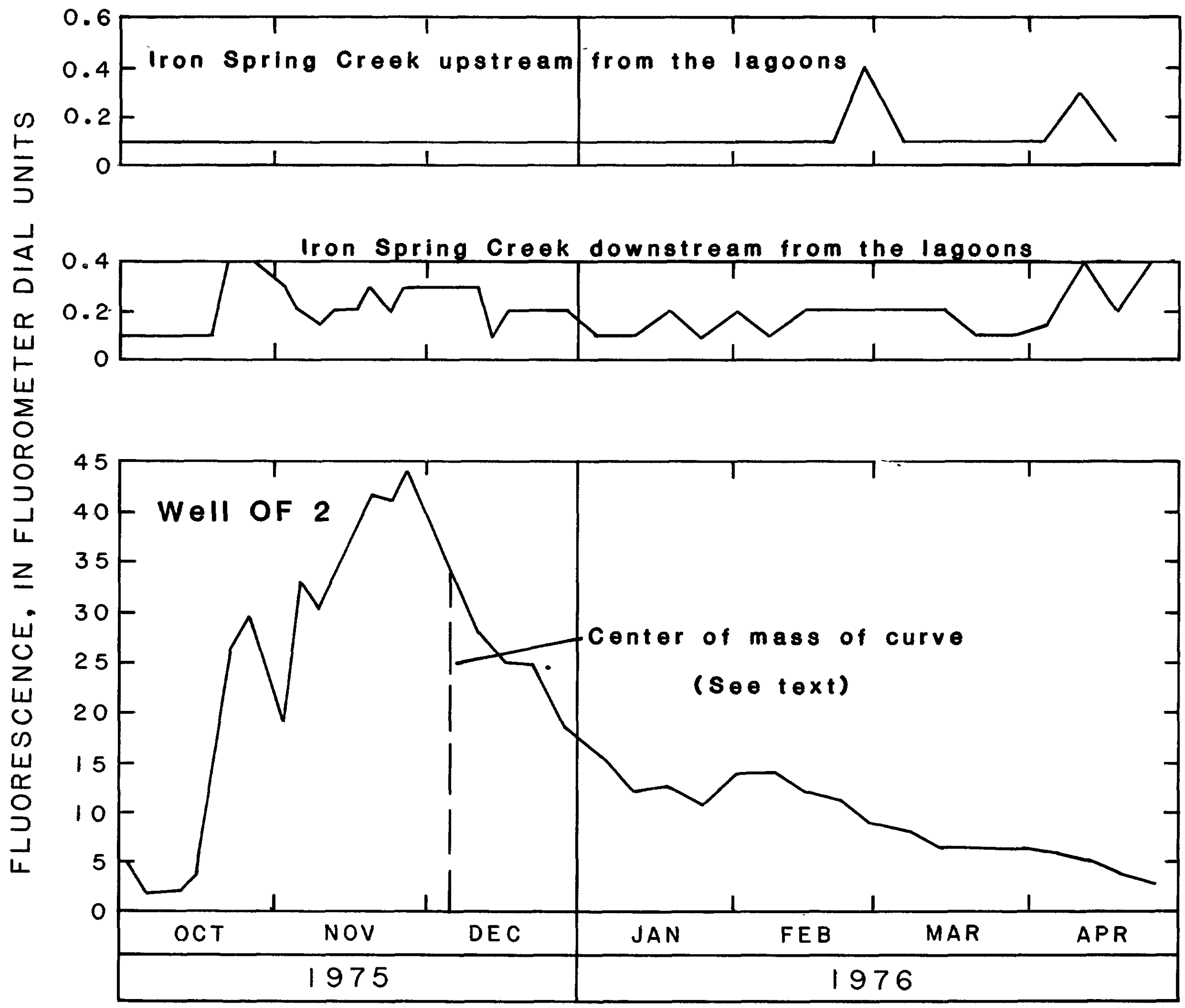


Figure 5.4.--Fluorescence of water in well OF 2 and Iron Spring Creek near the Old Faithful wastewater lagoons.

DISSOLVED-IRON CONCENTRATIONS SIGNIFICANT IN GROUND WATER

Oxidation-reduction reactions triggered by percolating effluent result in large dissolved-iron concentrations at times in water in wells near the lagoons.

Large dissolved-iron concentrations are present at times in water in some of the wells near the Old Faithful lagoons. For example, the concentration of dissolved iron in water in well OF 2 increased from 80 μg/L (micrograms per liter) on August 27, 1974, before the nearby lagoon was used for disposal of effluent, to 17,000 μg/L on October 24, 1974, after the lagoon was used. The effluent contained about 180 μg/L and Iron Spring Creek contained about 20 μg/L of dissolved iron. The reasons for the increase in dissolved iron has been investigated by the author (Cox, 1978b). This study concluded that the large dissolved-iron concentration in water in wells near the Old Faithful wastewater lagoons are a result of oxidation-reduction reactions. Organic carbon, nitrogen, and sulfur in the percolating effluent are oxidized in the unsaturated zone and possibly in the saturated zone as ground water moves through sand and gravel toward Iron Spring Creek. Iron in the sand and gravel below the lagoons simultaneously is reduced from the insoluble ferric phase to the soluble ferrous phase.

Calculated values of the standard potential for both the oxidation and the reduction reactions are positive, indicating that the reactions can occur spontaneously. The oxidation potential was calculated for three chemical analyses having large dissolved-iron concentrations of water from wells by using a method described by Hem (1960, p. 42-51). The analyses have an oxidation potential of 100 millivolts; the same analyses have a pH of 6.9.

An oxidation potential of 100 millivolts and a pH of 6.9 are plotted on a stability-field diagram for aqueous ferric-ferrous solutions that commonly occur in natural waters (fig. 5.5). The plot of oxidation potential and pH occurs in the area of Fe^{+2}, where the ferrous species dominates, and the iron is in solution as ferrous iron. If the oxidation potential increased to more than about 250 millivolts and the pH remained 6.9, the $Fe(OH)_3$ (ferric hydroxide) species would dominate, and the iron would precipitate as the solid phase $Fe(OH)_3$. As the ground water discharges at land surface near the stream, oxygen from the atmosphere increases the oxidation potential and the iron is oxidized to the insoluble ferric phase. Consequently, the iron precipitates as yellowish-brown ferric hydroxide. Ferric hydroxide also precipitates in some of the wells. The iron bacteria *Leptothrix* sp. and other organisms grow in the precipitates.

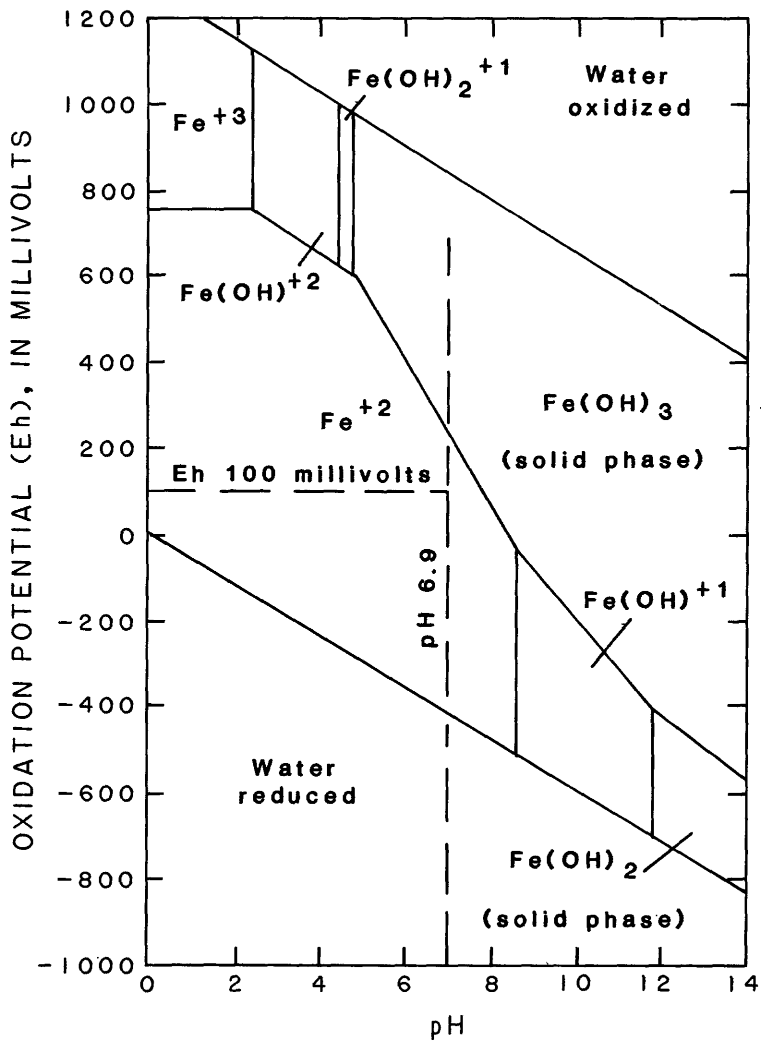


Figure 5.5.--Stability-field diagram for aqueous ferric-ferrous system. (Adapted from Hem and Cropper, 1959.)

6.0 MADISON JUNCTION

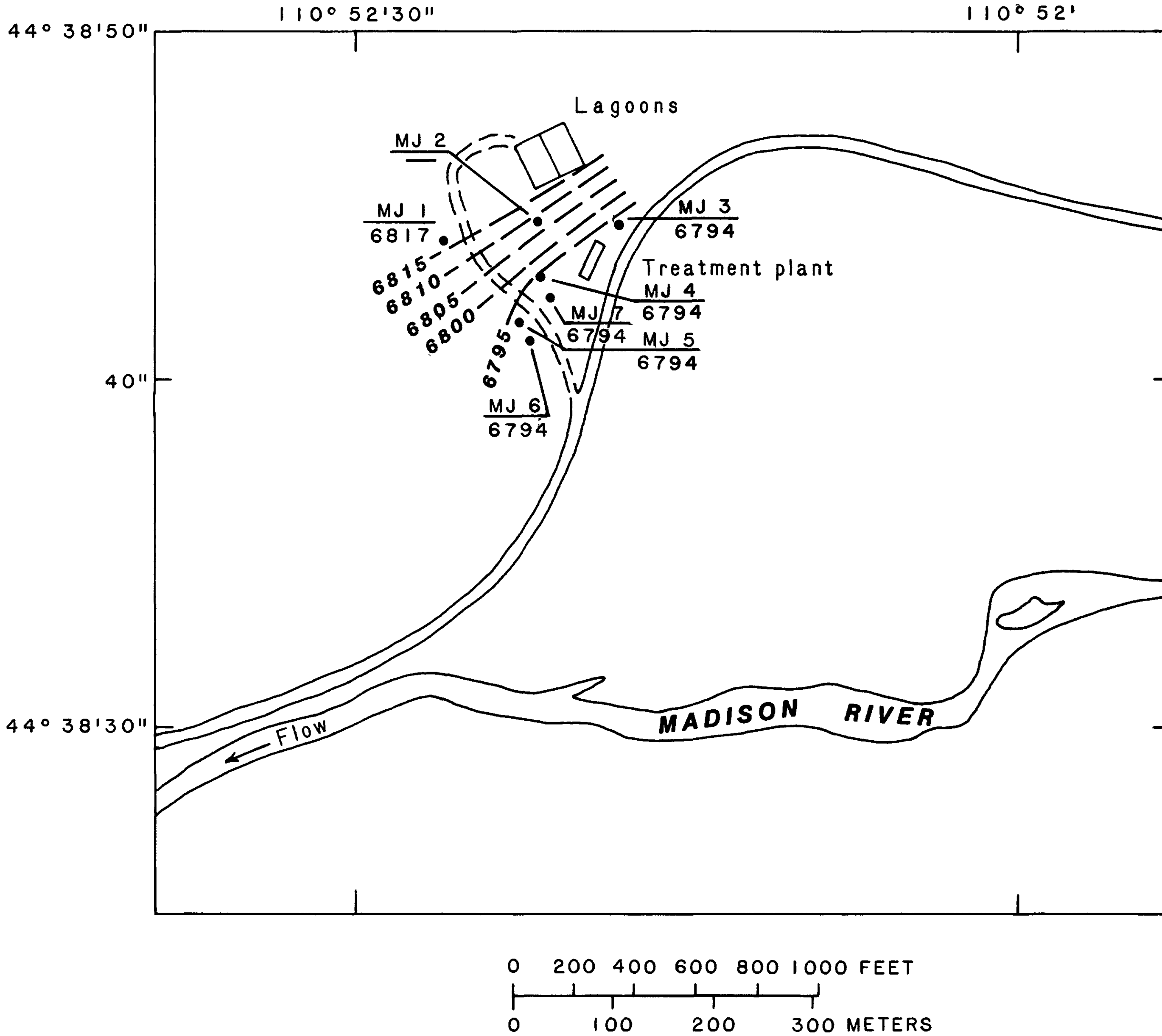
6.1 Hydrologic Setting

WASTEWATER TREATMENT AND DISPOSAL SITE IS NEAR THE MADISON RIVER

The water table slopes from the Madison Junction wastewater lagoons toward the Madison River.

The Madison Junction wastewater treatment and disposal site is about 0.75 mile west of Madison Junction on a terrace about 50 feet above the Madison River. The site is underlain by alluvial deposits of sand, silt, clay, and gravel. Colluvial deposits of cobbles and boulders are present near the site. Wells MJ 1 through 7 were augered near the Madison Junction site (fig. 6.1). The lagoons are used throughout the year for the storage of effluent except when they are frozen in winter.

The water-level contours shown in figure 6.1 indicate the configuration of the water level August 26, 1979, in the vicinity of the Madison Junction site. The configuration would be similar to other times because the water-level changes are not large enough to affect the configuration appreciably.



EXPLANATION

——— 6795 — — — WATER-LEVEL CONTOUR--Shows altitude at which water level would have stood in tightly cased wells, August 26, 1979. Dashed where approximately located. Contour interval 5 feet. Datum is sea level

MJ 6 • / 6794 WELL--Upper numeral is well number. Lower numeral is altitude of water level, in feet above sea level, August 26, 1979

Figure 6.1.--Location of wells and water-level contours near the Madison Junction wastewater lagoons.

CHLORIDE CONCENTRATIONS INDICATE EFFLUENT IN GROUND WATER, BUT NOT IN SURFACE WATER

The presence and direction of movement of percolating effluent are indicated by the chloride concentration of water in wells near the lagoons; chloride concentrations in the Madison River are virtually constant.

Wells near the Madison Junction lagoons (fig. 6.2) were sampled in 1977-79, and the samples were analyzed for chloride. The chloride concentrations are listed in table 6.2. The lagoons had been used for several years before the wells were drilled; therefore, no data are available from the wells before the lagoons were used. However, data from well MJ 1, which is not likely to have percolating effluent because it is not down gradient from the lagoons, indicates that wells not affected by percolating effluent have water with chloride concentrations of less than 10 mg/L (milligrams per liter).

Water in well MJ 3 consistently has chloride concentrations exceeding 10 mg/L, and water in well MJ 7 has chloride concentrations exceeding 10 mg/L most of the time (table 6.2). Well MJ 4 had water with a chloride concentration exceeding 10 mg/L once, in October 1979. None of the other wells had water with chloride concentrations exceeding 10 mg/L. Well MJ 2 became plugged shortly after it was drilled and has not been sampled.

Both lagoons are used continuously except during the winter when effluent is stored in a lined pond. The stored effluent is diverted later to the lagoons.

Water in the Madison River had a chloride concentration of 59 mg/L at both of the sampling sites near the lagoons on August 24, 1978. Chloride concentrations were 65 mg/L at the site upstream from the lagoons and 65 mg/L at the site downstream from the lagoons on August 24, 1979. These and other samples from the river show that the chloride concentrations are the same or nearly the same at the sampling sites upstream and downstream from the lagoons. The chloride concentrations are greater in the river than in the nearby ground water because thermal water containing dissolved minerals discharges into the Firehole and the Gibbon Rivers upstream from the sampling sites. The Firehole and Gibbon Rivers converge to form the Madison River a few hundred feet upstream from the upstream sampling site.

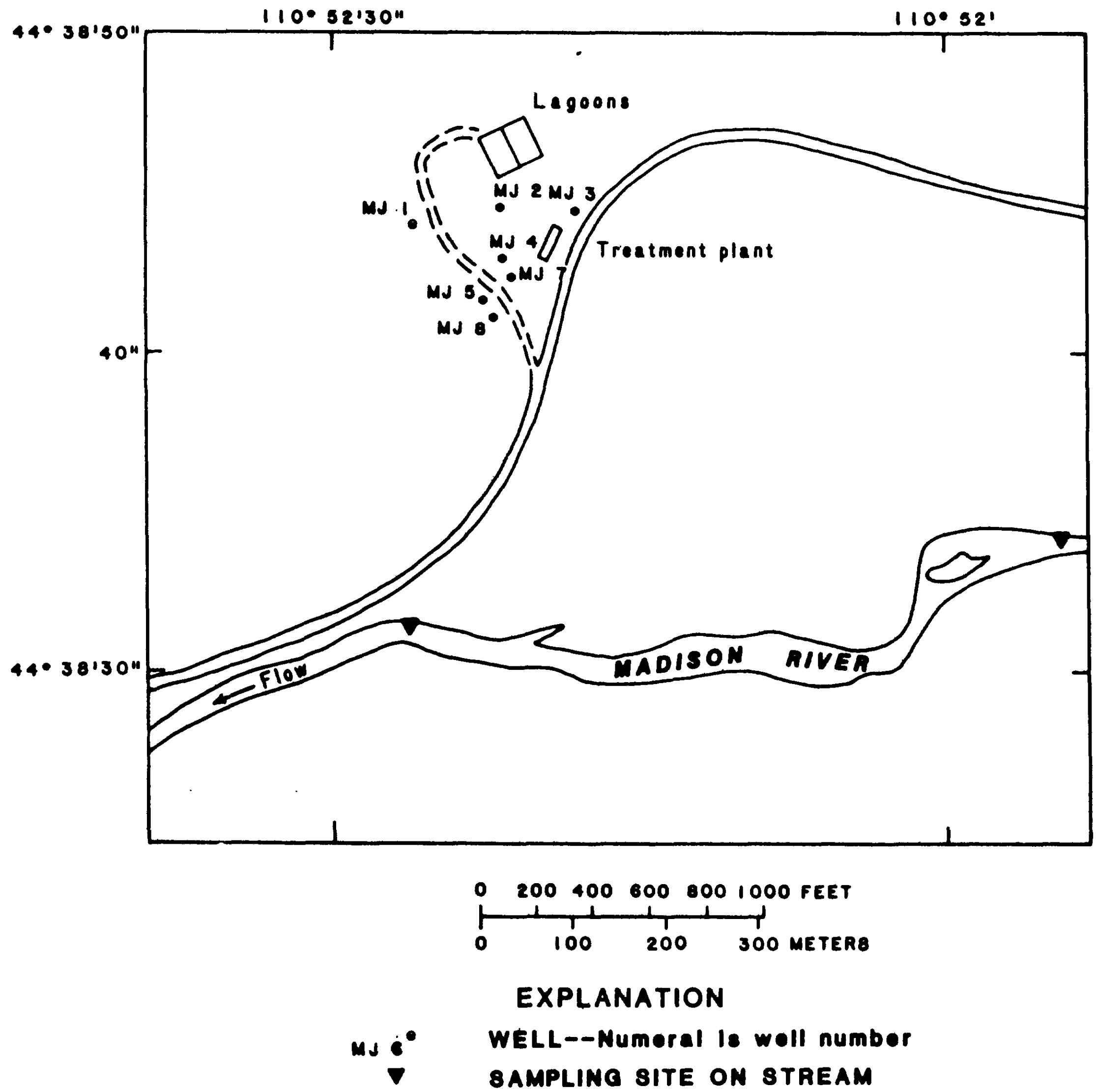


Figure 6.2.--Location of wells and sampling sites on the Madison River near the Madison Junction wastewater lagoons.

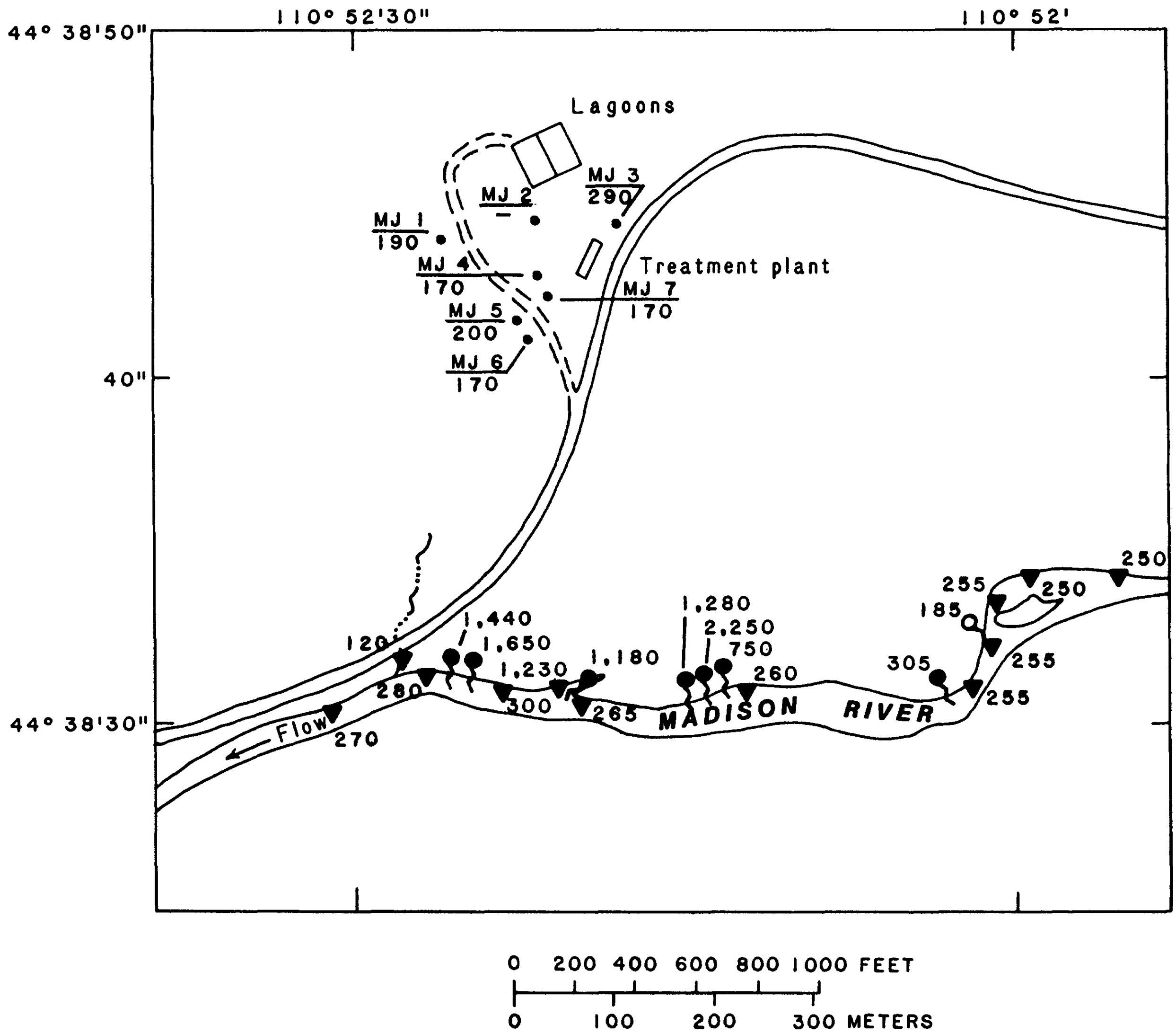
Table 6.2.--Chloride concentrations, in milligrams per liter, in water in wells near the Madison Junction wastewater lagoons, 1977-79

	1977						1978			1979			
Well	June	July	Aug	Sept	Oct	Nov	June	Aug	Oct	May	July	Aug	Oct
MJ 1	-	-	2.3	2.2	-	-	3.3	2.3	2.5	2.1	2.5	-	2.3
3	30	32	25	19	19	17	39	37	18	18	26	19	21
4	-	-	-	-	-	-	-	-	2.7	2.2	2.7	-	14
5	-	2.3	-	2.3	-	2.3	3.5	2.3	2.6	2.1	2.4	2.5	5.3
6	-	-	-	2.6	-	-	4.1	2.8	4.1	2.2	3.1	-	2.8
7	15	-	-	15	20	-	3.9	11	20	13	13	21	22

SPECIFIC CONDUCTANCE INDICATES EFFLUENT IN NONTHERMAL GROUND WATER, BUT NOT IN SURFACE WATER

The direction of movement of percolating effluent is indicated by the specific conductance of water of more than 100 microsiemens per centimeter at 25° Celsius in wells near the lagoons, but thermal springs and seeps near the Madison River have large values of specific conductance.

The specific conductance of water in wells, springs, seeps, and the Madison River in June 1982 are shown in figure 6.3. The specific conductance of 290 μS/cm (microsiemens per centimeter at 25° Celsius) of water in well MJ 3 indicates that percolating effluent was present at that well. Because the water table slopes from the lagoons to the Madison River, the percolating effluent probably eventually discharges into the river. An increase in specific conductance because of discharge of percolating effluent, however, cannot be determined because of thermal springs and seeps in the suspected effluent-discharge area. In addition, the specific conductance of the river at the upstream sampling site was 250 μS/cm, only slightly less than the 290 μS/cm of water at well MJ 3. The quantity of both thermal and nonthermal water discharging in the reach is small compared to the flow of the Madison River.



EXPLANATION

MJ 6 / 170 WELL--Upper numeral is well number. Lower numeral is specific conductance, in microsiemens per centimeter at 25° Celsius, June 5, 1982

1,440 THERMAL SPRING OR SEEP--Temperature is more than 20° Celsius. Numeral is specific conductance, in microsiemens per centimeter at 25° Celsius, June 10, 1982

185 NONTHERMAL SPRING--Temperature is less than 20° Celsius. Numeral is specific conductance, in microsiemens per centimeter at 25° Celsius, June 10, 1982

270 SAMPLING SITE ON STREAM--Numeral is specific conductance, in microsiemens per centimeter at 25° Celsius, June 10, 1982

Figure 6.3.--Specific conductance of water in wells, springs, seeps, and the Madison River near the Madison Junction wastewater lagoons, June 1982.

6.4 Nitrite Plus Nitrate Concentrations in Ground and Surface Water

CONCENTRATIONS OF NITRITE PLUS NITRATE INDICATE EFFLUENT IN GROUND WATER, BUT NOT IN SURFACE WATER

The direction of movement of percolating effluent is indicated by the nitrite plus nitrate concentrations of more than 1 milligram per liter in water in wells near the lagoons; concentrations in the Madison River are less than 0.1 milligram per liter.

The nitrite plus nitrate concentrations of water in wells and the Madison River in June and August 1982 are shown in table 6.4. The values exceeding 1 mg/L (milligram per liter) at wells MJ 3 and MJ 7 (fig. 6.4) at both sampling times and those less than 1 mg/L at the other wells indicate that percolating effluent was at wells MJ 3 and MJ 7 at the times the samples were collected.

The nitrite plus nitrate concentrations of less than 0.1 mg/L at both the sampling sites on the Madison River indicates that the river contains only small concentrations of organic nitrogen or ammonia, substances that are present in wastewater effluent. Thermal water discharging between the sampling sites also may contain only small concentrations of nitrogen, or the thermal-water discharge is too small to affect the concentration at the downstream sampling site.

Table 6.4.--Nitrite plus nitrate concentrations, in milligrams per liter, in water in wells and the Madison River near the Madison Junction wastewater lagoons, June and August 1982

[<, less than value shown]

Sampling site	June 5, 1982	August 31, 1982
Well MJ 1	0.15	0.13
3	8.8	6.6
4	.19	.14
5	.13	.26
6	.32	.17
7	2.1	3.2
Madison River upstream from lagoons	-	<.10
Madison River downstream from lagoons	-	<.10

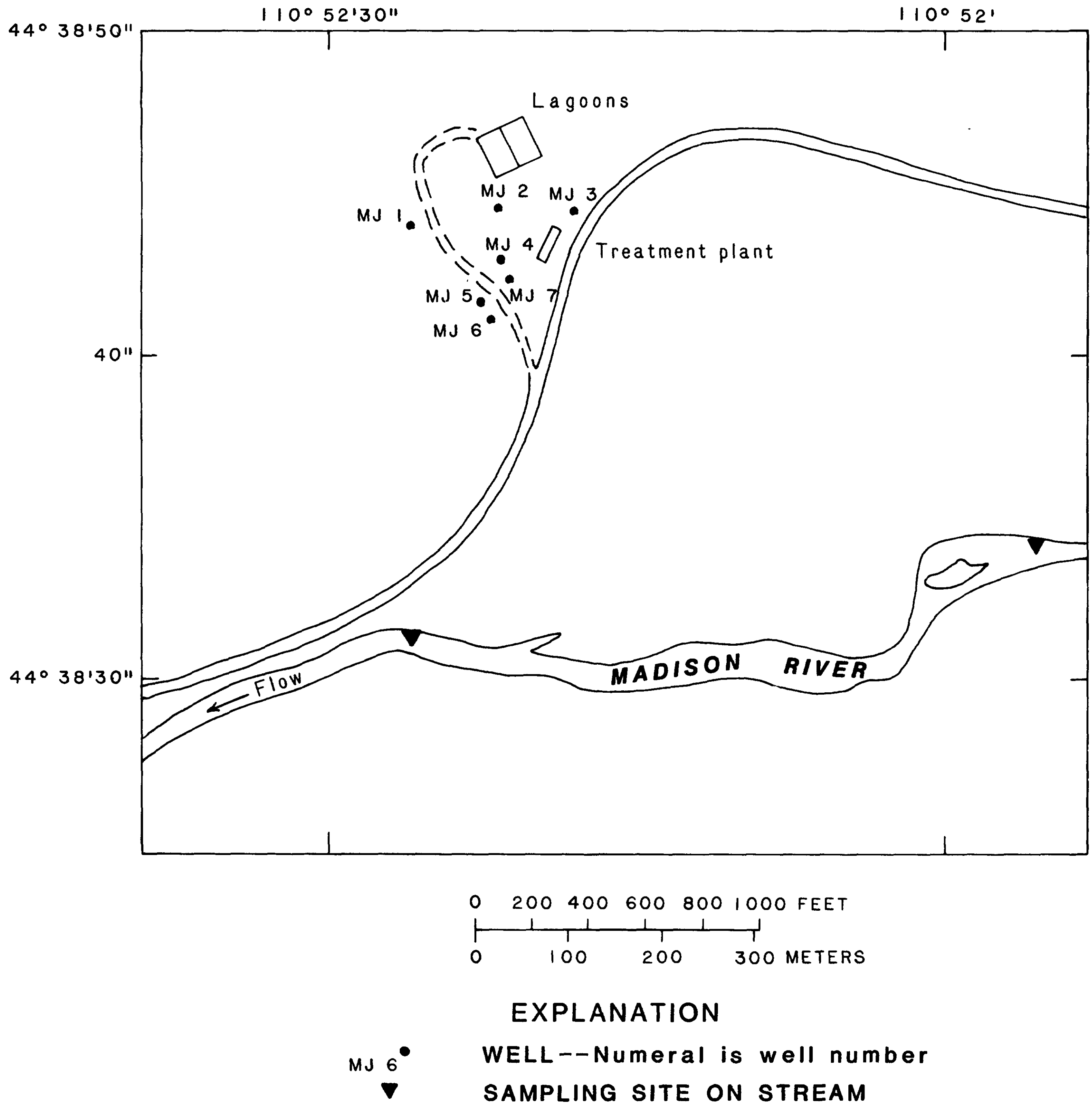


Figure 6.4.--Location of wells and sampling sites on the Madison River near the Madison Junction wastewater lagoons.

7.0 CONCLUSIONS

7.1 Fishing Bridge

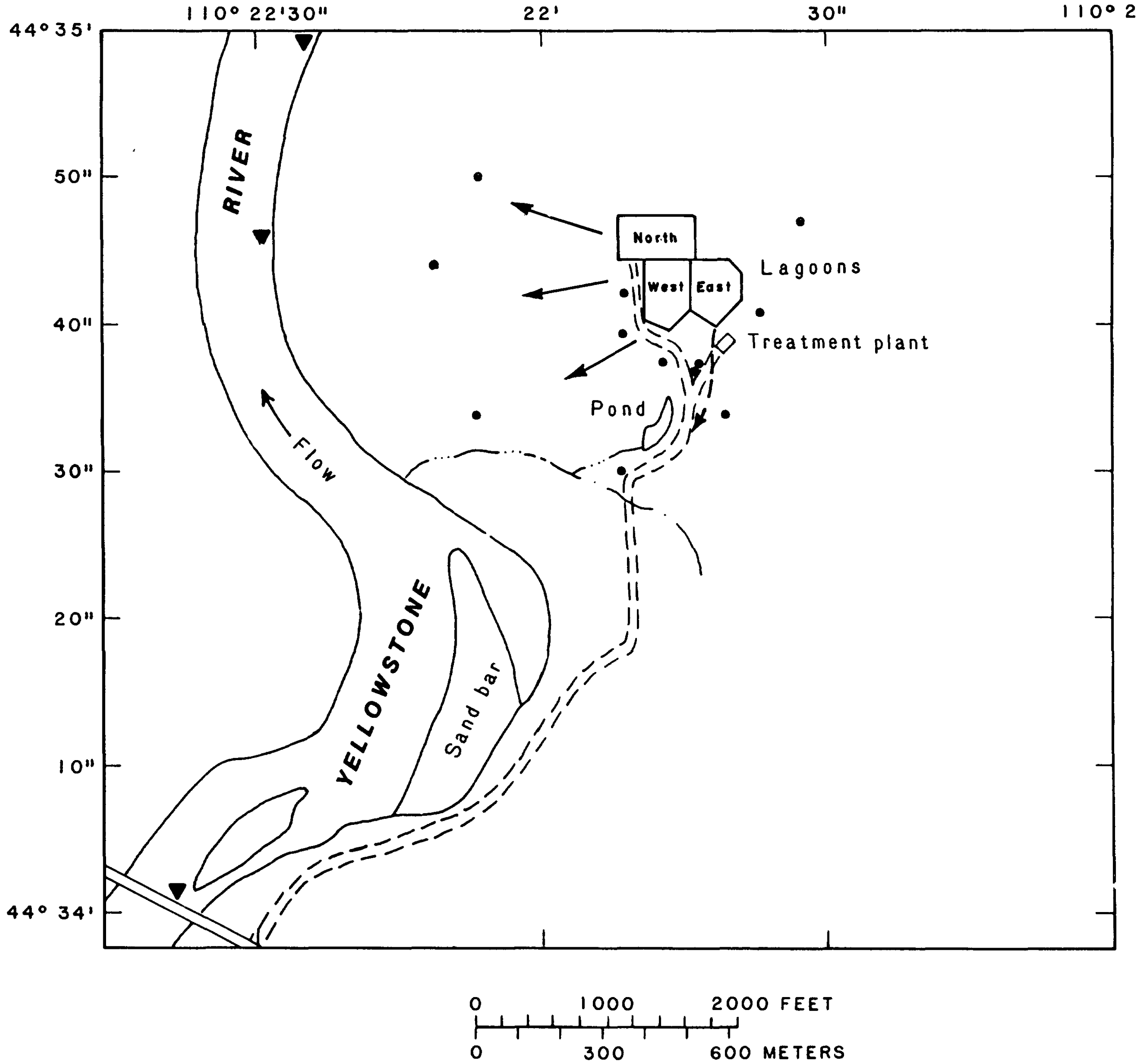
WASTEWATER EFFLUENT MOVES TOWARD THE YELLOWSTONE RIVER

Interpretation of water-level and water-quality data indicates that percolating wastewater effluent from the Fishing Bridge lagoons moves toward and probably discharges into the Yellowstone River without appreciably affecting the quality of water in the river.

Wastewater effluent in the Fishing Bridge lagoons percolates downward to the water table where ground-water mounds form under and adjacent to the lagoons. The percolating effluent mixes with ground water to form a plume of water that contains chemical constituents from the effluent. The plume moves down the hydraulic gradient toward the Yellowstone River in directions shown by the arrows in figure 7.1. The location of the plume has been determined at different times by analyzing water samples from wells near the lagoons (fig. 7.1) for chloride concentration, specific conductance, and nitrite plus nitrate concentration. Other constituents and properties also were determined.

The shape and the direction of movement of the plume depends on which of the three lagoons is used. The plume commonly is elongated northwestward, westward, or southwestward as the north and the west lagoons are used during a typical season of operation from May through October.

Chemical constituents in water have not increased in a reach of the Yellowstone River defined by sampling sites upstream and downstream from the lagoons (fig. 7.1) since the lagoons have been used. Although percolating effluent probably discharges in the reach, the effluent is diluted by ground water and has no discernible effect on the quality of water in the river.



EXPLANATION

← – – DIRECTION OF MOVEMENT OF PERCOLATING EFFLUENT--
Dashed where volume is small

• WELL

▼ SAMPLING SITE ON STREAM

Figure 7.1.--Direction of movement of percolating effluent and location of wells and sampling sites on the Yellowstone River near the Fishing Bridge wastewater lagoons.

WASTEWATER EFFLUENT MOVES TOWARD YELLOWSTONE LAKE

Interpretation of water-level and water-quality data indicates that percolating wastewater effluent from the Grant Village lagoons moves toward and probably discharges into Yellowstone Lake without appreciably affecting the quality of water in the lake.

Wastewater effluent from the Grant Village lagoons percolates downward to the water table where a ground-water mound forms under and adjacent to the lagoon being used. The percolating effluent mixes with ground water to form a plume of water that contains chemical constituents from the effluent. The plume moves down the hydraulic gradient toward Yellowstone Lake depending on which lagoon is used in directions shown by arrows in figure 7.2. The directions of movement of percolating effluent at different times have been determined by analyzing water samples from wells near the lagoons (fig. 7.2) for chloride concentration, specific conductance, and nitrite plus nitrate concentration. Other constituents and properties also were determined.

The direction of movement of percolating effluent depends on which of the two lagoons is used. Percolating effluent generally moves northward and northwestward when the north lagoon is used. The effluent generally moves westward and northwestward when the south lagoon is used. Small volumes of percolating effluent seemingly move northward and southwestward from the south lagoon.

Effluent percolating from the Grant Village lagoons probably discharges into Yellowstone Lake, the logical hydraulic sink for the area. However, the quality of water in the lake along the shoreline north and northwest of the lagoons has not been affected by the percolating effluent. The percolating effluent is diluted by the ground water discharging into the lake and by the water in the lake, so that the percolating effluent has no discernible effect on the quality of water in the lake.

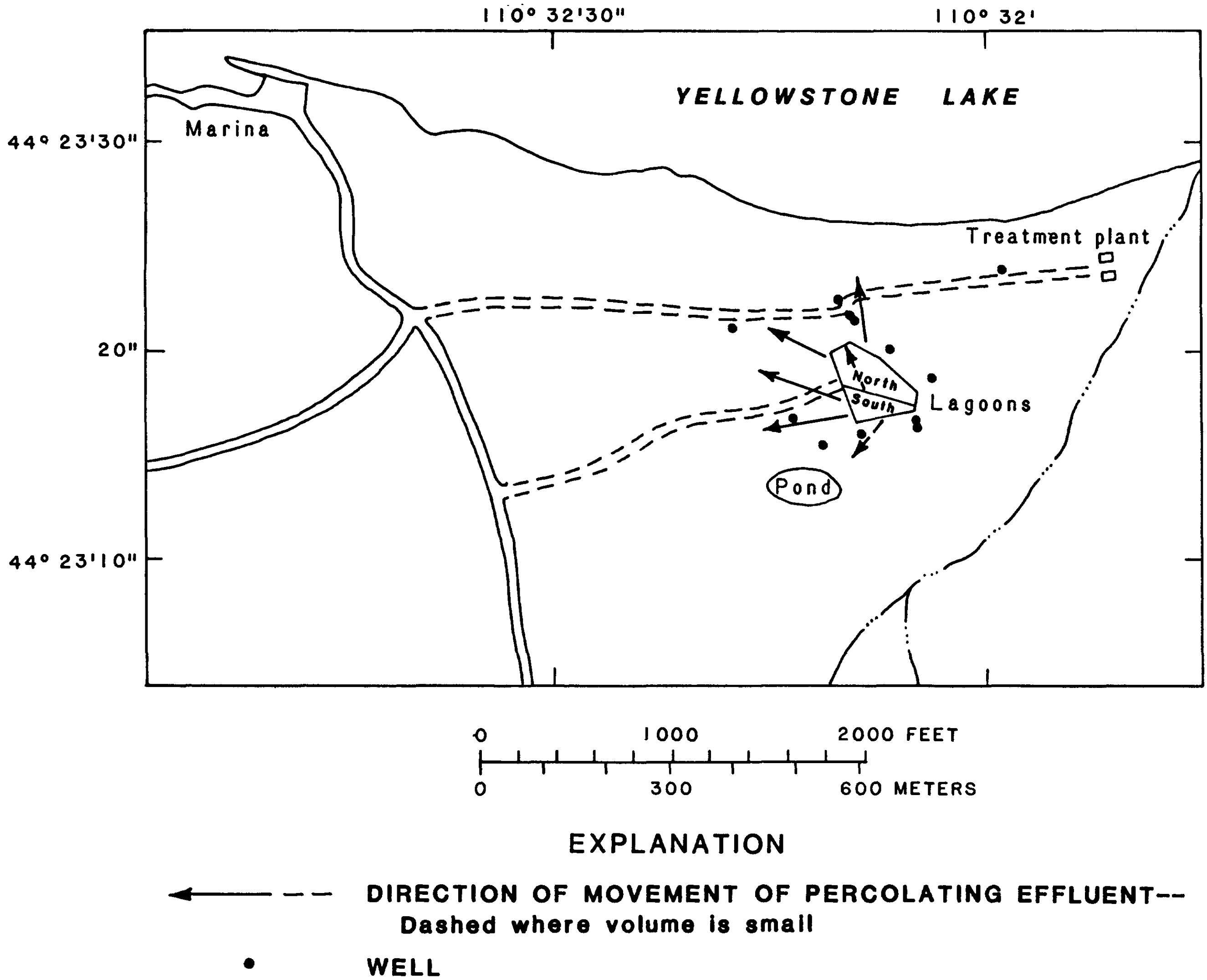


Figure 7.2.--Direction of movement of percolating effluent and location of wells near the Grant Village wastewater lagoons.

WASTEWATER EFFLUENT MOVES TOWARD IRON SPRING CREEK

Interpretation of water-level and water-quality data indicates that percolating wastewater effluent from the Old Faithful lagoons moves toward and discharges into Iron Spring Creek.

Wastewater effluent from the Old Faithful lagoons percolates downward to the water table, mixes with ground water, and moves down the hydraulic gradient to Iron Spring Creek. The directions of movement of the percolating effluent at different times have been determined by analyzing water samples from wells near the lagoons (fig. 7.3) for chloride concentration and specific conductance. Other constituents and properties also were determined.

The direction of movement of percolating effluent depends on which of the lagoons is used. Percolating effluent moves northward and northeastward toward Iron Spring Creek and northwestward toward a swampy area between Iron Spring Creek and West Fork northwest of the lagoons.

As effluent percolates from the lagoons, organic carbon, nitrogen, and sulfur in the effluent are oxidized in the unsaturated zone and possibly in the saturated zone as ground water moves through sand and gravel toward Iron Spring Creek. Iron in the sand and gravel simultaneously is reduced from the insoluble ferric phase to the soluble ferrous phase resulting in large dissolved-iron concentrations. As the ground water discharges at land surface near the stream, the iron is oxidized to the insoluble ferric phase. Consequently, the iron precipitates as ferric hydroxide. Iron bacteria grow in the precipitates.

Chloride concentrations in water increase in a reach of Iron Spring Creek defined by sampling sites upstream and downstream from the lagoons (fig. 7.3). The increase is due in part to percolating effluent discharging into the stream. However, the increase also is due in part to chloride ions in thermal water that discharges into the stream between the sampling sites.

The average traveltime for rhodamine WT dye injected into one of the lagoons to a well 130 feet away was about 65 days. Velocity of the dye, therefore, is estimated to be about 2 feet per day. The dye probably reached Iron Spring Creek between the sampling sites in a very diluted mixture with ground water that discharged into the stream.

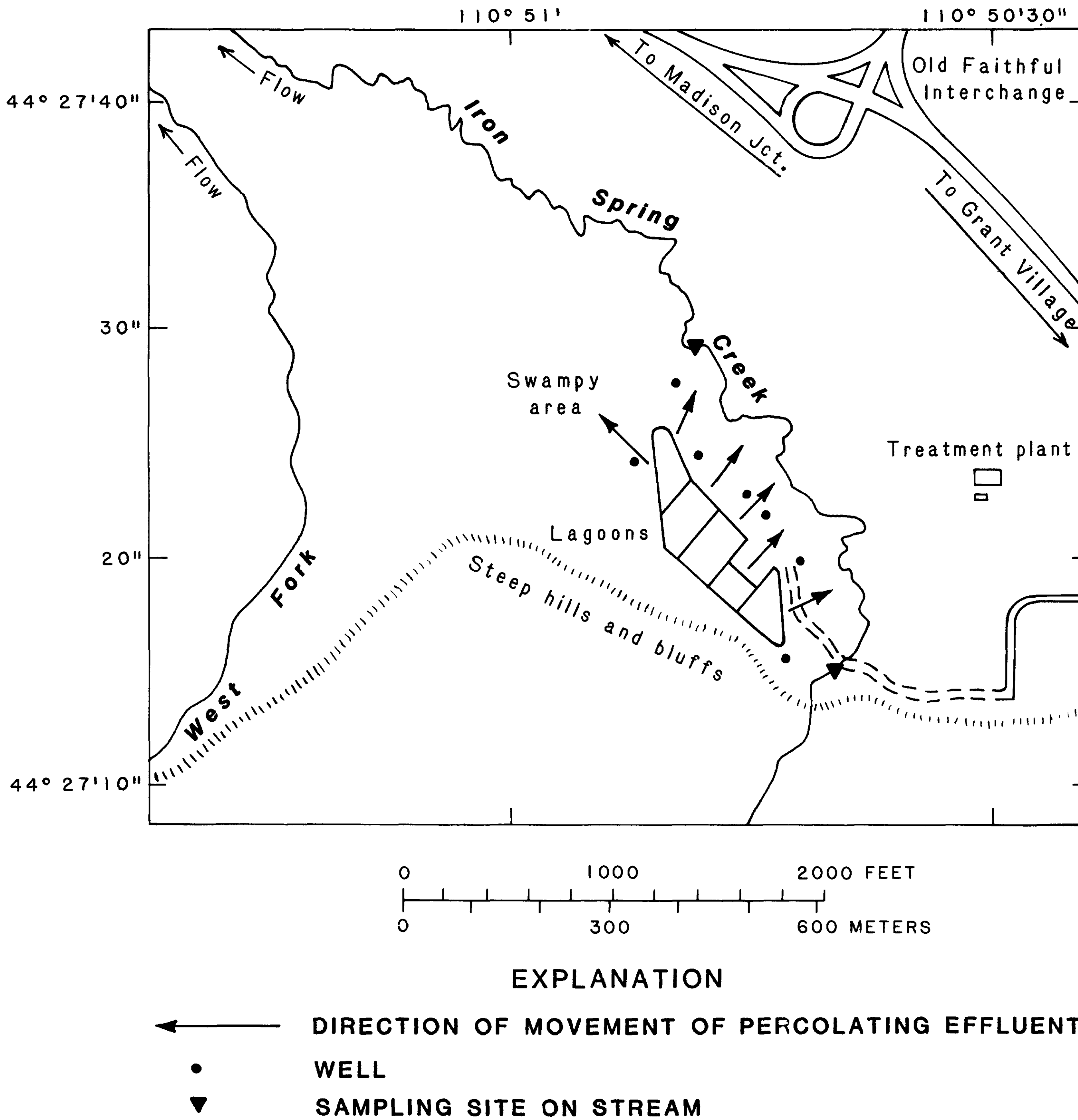


Figure 7.3.--Direction of movement of percolating effluent and location of wells and sampling sites on Iron Spring Creek near the Old Faithful wastewater lagoons.

WASTEWATER EFFLUENT MOVES TOWARD THE MADISON RIVER

Interpretation of water-level and water-quality data indicates that percolating wastewater effluent from the Madison Junction lagoons moves toward and probably discharges into the Madison River without appreciably affecting the quality of water in the river.

Wastewater effluent from the Madison Junction lagoons percolates downward to the water table, mixes with ground water, and moves down the hydraulic gradient toward the Madison River. The directions of movement of percolating effluent have been determined by analyzing water samples from wells near the lagoons (fig. 7.4) for chloride concentration, specific conductance, and nitrite plus nitrate concentration. Other constituents and properties also were determined.

Effluent percolating from the Madison Junction lagoons probably discharges into the Madison River, the logical discharge point for ground water in the area. However, chemical constituents in water have not increased in a reach of the river defined by sampling sites upstream and downstream from the lagoons (fig. 7.4). The effluent is diluted by ground water as it moves toward the river and has no discernible effect on the quality of water in the river. Thermal water that is more mineralized than the effluent discharges into the river in the reach defined by the sampling sites without appreciably affecting the quality of water in the river.

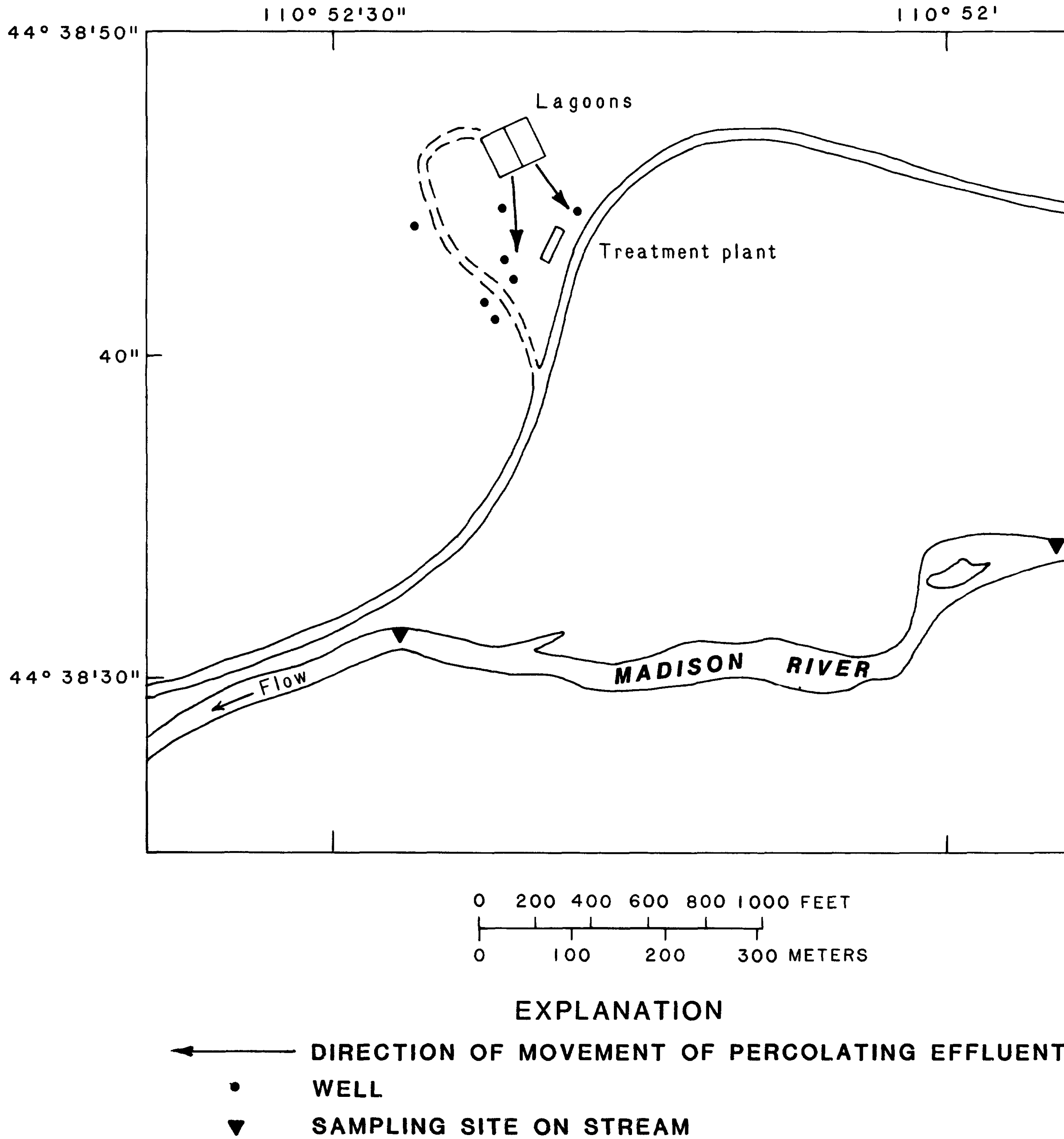


Figure 7.4.--Direction of movement of percolating effluent and location of wells and sampling sites on the Madison River near the Madison Junction wastewater lagoons.

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