Selenium in Waters in and Adjacent to the Kendrick Project, Natrona County, Wyoming

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2023

Prepared in cooperation with the Wyoming State Engineer, City of Casper Board of Public Utilities, Wyoming Game and Fish Commission, Wyoming Department of Health

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By MARVIN A. CRIST

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1974

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 73-600303

For sale by the Superintendent of Documents, U.S. Government Printing Office
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Stock Number 2401-02551

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By Marvin A. Crist

ABSTRACT

Selenium in concentrations exceeding the maximum limit, 0.01 milligrams per liter or 10 micrograms per liter, recommended by the U.S. Public Health Service in "Drinking-Water Standards, 1962," Public Health Pub. 956, is present in waters in areas near Casper, Wyo. Some streams containing selenium flow into the North Platte River upstream from several municipalities that obtain water from the river and the alluvium along the river.

The area of this investigation includes about 725 square miles in Natrona County in central Wyoming. Study effort was most intensive within the area bounded by the North Platte River, Casper Creek, and Casper Canal, the approximate boundaries of the Kendrick irrigation project.

Geologic formations in the area contain selenium that may have been derived from deposits of seleniferous material or from volcanic emanations brought down by rain. Formations older than Cretaceous age were not considered as important sources of selenium in waters of the area, because no irrigation water is applied to areas underlain by these rocks. The selenium concentration in 82 samples of Cretaceous rocks ranged from less than 10 to 4,200 μg/kg (micrograms per kilogram of sample); no correlation was found between selenium concentration and the depth at which the sample was collected. Of four samples of Tertiary rocks analyzed, three contained no selenium and one had a selenium concentration of 40 μg/kg. The selenium concentration in 93 samples of Quaternary rocks ranged from less than 10 to 520 μg/kg, and the highest selenium concentration was generally found at depths less than 4 feet. No geologic formation has consistently high concentrations of selenium, but high concentrations were found at points throughout the study area. Probably the rocks in any locality could be the source of selenium in the water in the surrounding vicinity.

The selenium concentration in water from some wells fluctuates widely. It is concluded that the selenium concentrations in the ground water in these areas have not reached a state of equilibrium in the aquifer. It is possible that such nonequilibrium conditions exist in aquifers throughout much of the area. If so, statements in this report concerning trends of selenium concentration in ground water are somewhat speculative.

Poison Spring Creek, Poison Spider Creek, Oregon Trail Drain, and Casper Creek are the principal tributaries that contribute selenium to the North Platte River. The selenium load, expressed in pounds per day, in Poison Spring Creek and Poison Spider Creek decreased slightly during the first year of sampling and increased slightly during the second year of sampling. The selenium load in Oregon Trail Drain is greatest in late winter and early spring during the period of low flow; the selenium load in Casper Creek varies, but shows no correlation with season and little correlation with stream discharge. The North Platte River above and below the irrigation project had consistently low selenium concentrations, 10μg/l (micrograms per liter) or less, in the period April 1968 through June 1969. The total selenium load contributed to the North Platte River from tributaries in the study area is almost undetectable after mixing with the river water.

From the fall of 1968 to the spring of 1969, results of water sampling in areas influenced by irrigation show that the selenium concentration increased at 29 percent of the locations (average net increase of 640 μg/l), decreased at 34 percent of the locations (average net decrease of 80μg/l), and had little (10 μg/l or less) or no change at 37 percent of the locations. As a comparison, results of water sampling in areas not influenced by irrigation showed that the selenium concentration increased at 2 percent of the locations (average net increase of 30 μg/l), decreased at 26 percent of the locations (average net decrease of 30μg/l), and had little or no change at 72 percent of the locations. It is not possible to make a general statement that would be applicable to the entire Kendrick Project concerning the effects of irrigation on the selenium concentration in waters of the area; however, irrigation undoubtedly has accelerated movement of selenium within and from the irrigated areas.

INTRODUCTION

PROBLEM

Selenium in concentrations exceeding the maximum limit, 10 micrograms per liter, recommended by the U.S. Public Health Service (1962) is present in waters in areas near Casper, Wyo. Some streams containing selenium flow into the North Platte River upstream from several municipalities that obtain water supplies from the river and the alluvium along the river. The principal tributaries drain land that is irrigated with water diverted from the North Platte River at Alcova Reservoir. The irrigation water contains little or no selenium; however, the water is applied to some soils that contain soluble selenium.

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of this investigation is to determine the source, extent, and movement of selenium in water in the area. Recharge from surface-water irrigation affects the chemical quality of ground water in parts of the area; therefore, it is necessary to determine whether or not the recharge water is leaching selenium and depositing it in the ground-water system and if the streams contain greater concentrations of selenium during the irrigation season than during the nonirrigation season.

The investigation was started in April 1968 as a cooperative program of the U.S. Geological Survey with the City of Casper Board of Public Utilities, Wyoming Game and Fish Commission, Wyoming Department of Health, and the Wyoming State Engineer.

LOCATION AND EXTENT OF THE AREA

The area of this investigation, shown in figure 1, includes about 725 square miles in Natrona County in central Wyoming. Study effort was concentrated within the area bounded by the North Platte River and Casper Creek on the east and Casper Canal on the west (pl. 2). These features mark the approximate boundaries of the Kendrick Project, an irrigation project that extends from about 2 miles north of Alcova to about 15 miles northwest of Casper. This project contains about 24,000 acres of irregularly spotted irrigable land (U.S. Bur. Reclamation, 1964, p. 5). The boundary of the area of investigation is an arbitrary line drawn about 5 miles outside the approximate boundaries of the Kendrick Project.

PREVIOUS INVESTIGATIONS

Crist and Lowry (1972) made a reconnaissance study of the ground-water resources of Natrona County. Selenium analyses in that report showed that some ground water within the Kendrick Project contained as much as 1.1 mg/l (milligrams per liter), which is equivalent to 1,100 μg/l (micrograms per liter). That report led to the present investigation.

Whitcomb and Lowry (1968) made a reconnaissance of the geology and of the ground-water resources of the Wind River Basin; their study area included the southwestern part of the area in this report. Two other reports have been prepared (Larsen, 1951; Wilson, 1951) on ground-water investigations in the Kendrick Project.

WELL-NUMBERING SYSTEM

Water wells, springs, and test holes cited in this report are numbered according to the Federal system of land subdivision in Wyoming (fig. 2). The first number indicates the township, the

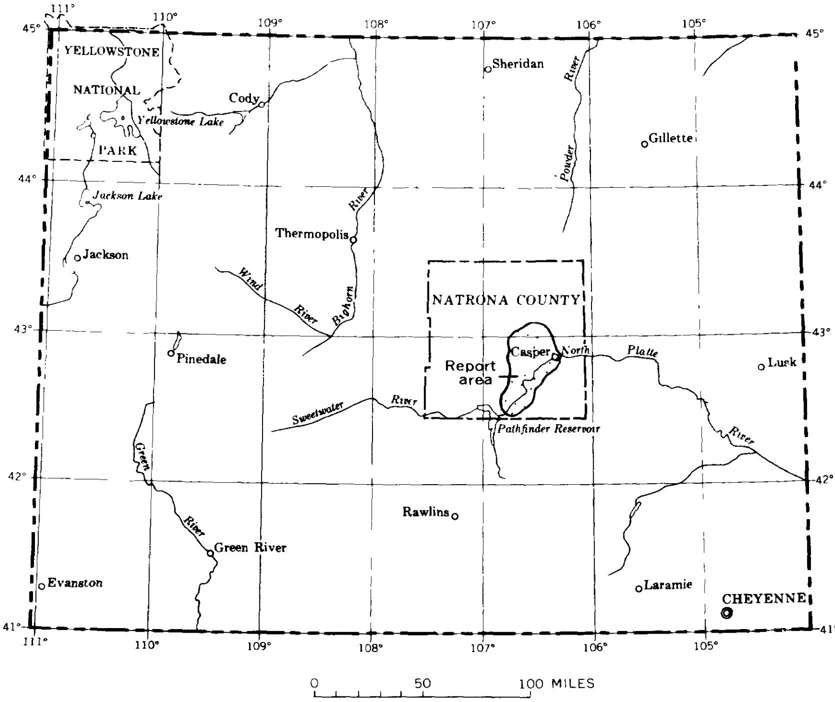

FIGURE 1.—Location of the area studied in this report.

second the range, the third the section in which the well, spring, or test hole is located. Lowercase letters following the section number indicate the position of the well in the section. The first letter denotes the quarter section, the second letter the quarter-quarter section, and the third letter the quarter-quarter-quarter section (10 acre tract). The subdivisions of a section are lettered a, b, c, and d in counterclockwise direction, starting in the northeast quarter. If more than one well is found in a 10-acre tract, consecutive numbers starting with 1 follow the last lowercase letter of the well number.

ACKNOWLEDGMENTS

The author appreciates the cooperation of the many residents in the area who contributed information for this report, especially those landowners that permitted test holes to be drilled on their property. The U.S. Bureau of Reclamation supplied streamflow data during the irrigation season and permitted the U.S. Geological Survey to operate three of their stream gages during the nonirrigation season. Information provided by the Casper-Alcova

Irrigation District is appreciated, especially information obtained from Mr. Arthur Hay, whose personal knowledge of the area was very helpful.

PRESENT DEVELOPMENT AND WATER USE

The North Platte River and the alluvium along the river are the sources of many private domestic water supplies as well as

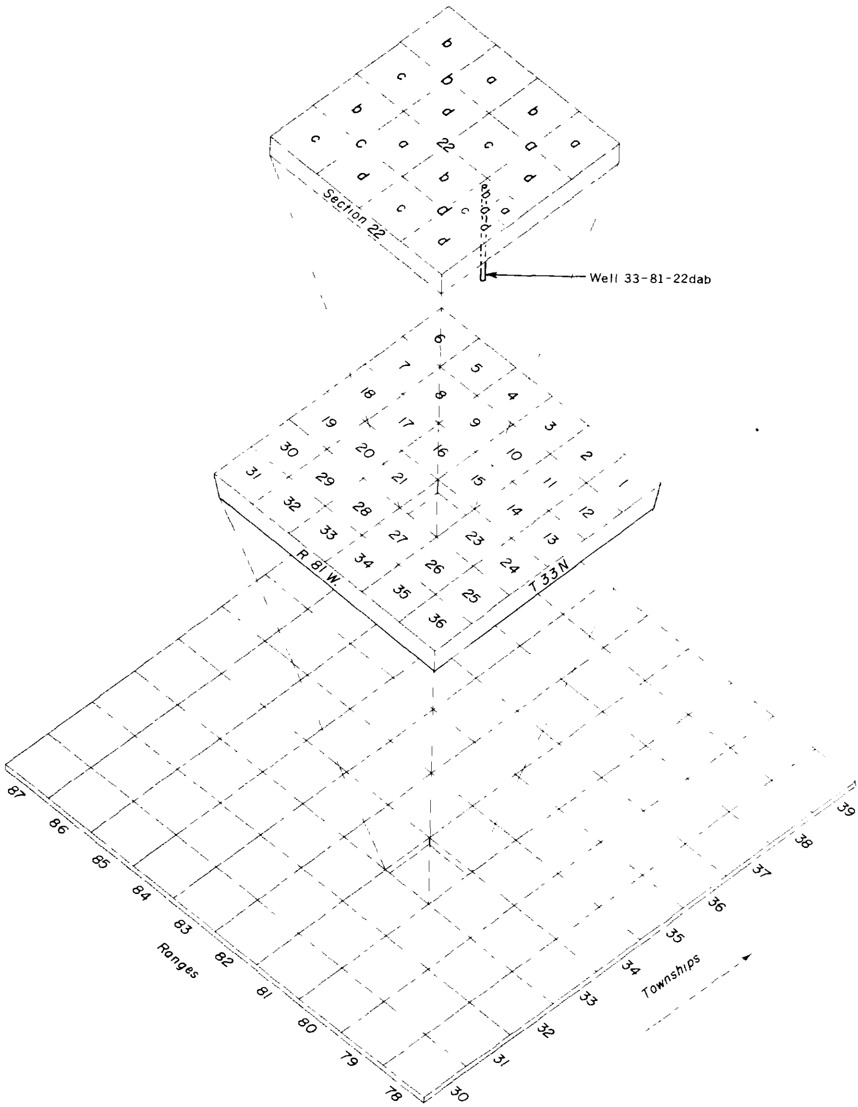

Figure 2.—System of numbering wells, springs, and test holes.

municipal water supplies for Red Butte, Paradise Valley, Casper, Mills, and Evansville. Midwest, a town about 40 miles north of Casper, also obtains its water supply from the North Platte River. Several industries including three refineries obtain water from the alluvium along the river.

Much of the ground water in the area is too highly mineralized for domestic use. As a result, many of the farmers and ranchers carry their drinking water from Casper. Ground water suitable for domestic use has been developed in some alluvial terrace deposits, primarily in the terrace southeast of the Natrona County Airport. Ground water containing less than 500 mg/l total dissolved solids is available in the alluvium along the North Platte River and in at least one area in the alluvium along Bates Creek (sec. 9, T. 31 N., R. 81 W.). The alluvium along Poison Spider Creek contains ground water which in places has as much as 4,000 mg/l total dissolved solids. In places along Poison Spider Creek domestic water supplies have been developed where the dissolved-solids content is about 1,500 mg/l. Livestock drink water from most of the creeks in the area, and in many places this is the only water available for them. Ground water suitable for livestock has been developed at depths of less than 100 feet in most of the area that is irrigated.

Sufficient ground water for irrigation has been developed in the alluvium along Bates Creek; one well (in 1969) used solely for irrigation yields about 1,300 gpm (gallons per minute). One other well (33–81–36aad) is used primarily for irrigation. It was drilled as a test for oil but was completed as a water well. The well flows about 360 gpm from the Amsden Formation of Late Mississippian and Pennsylvanian age and the Tensleep Sandstone of Pennsylvanian age. These two wells are the only ones in the area which produce significant quantities of ground water for irrigation. Goose Egg Spring (32–81–15bad) flows about 17 cfs (cubic feet per second) of excellent quality water, part of which is diverted by the Wyoming Game and Fish Department to the Dan Speas Fish Rearing Station. Water from the spring is also used for domestic supply and for irrigation.

The principal development of surface water in the area of investigation is the Kendrick Project. Water is diverted from the North Platte River at Alcova Reservoir for irrigation on the project. Approximately 56,780 and 65,840 acre-feet of water were diverted during 1968 and 1969, respectively.

Reservoirs and (or) diversions are also constructed on Poison Spider Creek, Casper Creek, Bates Creek, and some of the smaller creeks on the north side of Casper Mountain. The diverted water is used primarily for irrigation.

SELENIUM

Selenium has been the subject of many publications; therefore, its occurrence and toxicity will be discussed only briefly here. Selenium is an element that is found in minute quantities in the earth's crust. Compounds of this element occur naturally in some soils. The principal origins of selenium are believed by many to be volcanic emanations and volcanic and sedimentary sulfide deposits; the selenium may be redistributed by erosion or weathering (Lakin, 1961, p. 5). The selenium found in the soil and rocks in this investigation is believed to have been derived (1) from material weathered from underlying parent rock, (2) from wind- or water-deposited seleniferous material, or (3) from volcanic emanations brought down by rain. Selenium is reported to be less abundant throughout the earth's crust than gold (U.S. Dept. Agr., 1968, p. 363), but in Wyoming selenium in trace quantities is quite common. Beath (1946) stated that critical seleniferous areas are correlative with the available, or water soluble, form of selenium.

Selenium is believed to be highly toxic to humans although little proof is available to demonstrate how harmful it actually is. Definite symptoms of selenium poisoning have not been identified, but it has been stated (Kehoe and others, 1944) that the symptoms are similar to those associated with arsenic poisoning.

Animals are also susceptible to selenium poisoning. Selenium is the toxic factor in the animal disease called "alkali disease" sometimes referred to as "blind staggers"; however, this element in trace quantities appears to be essential for nutrition to both humans and animals (McKee and Wolf, 1963, p. 253). It has been found that selenium is beneficial in prevention of muscular dystrophy (white muscle disease) in sheep (Thacker, 1961, p. 52).

Toxicity of selenium in water is such that the U.S. Public Health Service (1962) has stated that concentrations of selenium in excess of 0.01 mg/1 (equal to 10 micrograms per liter) are grounds for rejection of the supply for drinking. As a comparison, the maximum permissible concentration of arsenic in drinking water is not to exceed 0.05 mg/l (U.S. Public Health Service, 1962, p. 8).

No limits have been established for selenium concentration in irrigation water. Dr. O. A. Beath is credited by Miller (1956) with suggesting the following tentative limits of selenium in water for irrigation:

Irrigation class	*Selenium (ppm[1])*	*Remarks*
1, low	0.00–0.10	No plant toxicity anticipated.
2, medium	0.11–0.20	Usable but with possible long-term accumulations under particular conditions.
3, high	0.21–0.50	Use doubtful. Probable toxic accumulation in plants except under especially favorable conditions.
4, very high	>0.50	Nonusable under any conditions.

[1] Parts per million are considered in this report to be equivalent to milligrams per liter.

METHOD OF INVESTIGATION

An auger was used to drill 126 test holes, averaging about 35 feet deep; 181 rock samples were collected with a split spoon sampler during the augering. The U.S. Geological Survey laboratory in Worland, Wyo., analyzed 179 of the samples for selenium content. (One sample was accidentally destroyed during analysis, and one sample, a granite boulder, was not analyzed.) The water-soluble selenium was extracted from the rock samples according to the method given in Methods of Soil Analysis (American Society of Agronomy and American Society for Testing and Materials, 1965). The extracts were then analyzed for selenium using the procedure given in the Standard Methods (American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1965). Because of problems in reproduction of analytical results, the concentrations of selenium in the rock samples ranging from 0 to 100 $\mu g/kg$ (micrograms per kilogram of sample) are reported to the nearest 10 $\mu g/kg$; above 100 $\mu g/kg$, the concentrations are listed to two significant figures. Sampling spots were selected where it was known that surface-water irrigation was applied. Other spots were selected where there was no irrigation and it was known that irrigation could not affect the composition of the soil and underlying rocks. Samples were collected at various depths but, generally, were collected at or near land surface, at a depth of about 3 feet, and at other depths where there were distinct changes in lithology.

Plastic pipe, 1½ inches in diameter was installed in 62 of the test holes, and steel pipe, 4 inches in diameter, was installed in four test holes for periodic water-level measurements and water sampling. Location of the test holes is shown on the geohydrologic map (pl. 1) along with wells and springs inventoried in the area.

Ground-water levels were measured in 22 wells from June 1968 through June 1969, and the water was sampled monthly. Location of the wells is shown on plate 2. After collecting data at the 22 stations for 1 year, it was decided that changes of selenium concentration in ground water could be monitored with 10 stations from July 1969 through June 1970. The decision to stop sampling at a station was based on one or more of the following reasons:

1. The selenium concentration remained fairly constant throughout the year.
2. The selenium concentration remained low (generally less than 20 μg/l) throughout the year.
3. A nearby station was effectively monitoring the changes in selenium content.
4. The station was outside the influence of irrigation; thus, the selenium concentration probably would not change radically from season to season.
5. Water in the well may not be representative of water in the formation because irrigation water possibly could get into the well directly from the land surface.

The water was obtained by pumping the wells with an air lift. In addition to sampling for selenium analysis, the water level and specific conductance were also measured monthly at these stations. The specific conductance of water is a measure of the ability of water to conduct an electric current and is related to the amount of dissolved solids. An increase in specific conductance indicates an increase in the dissolved-solids content of the water. The specific conductance does not necessarily indicate anything about the selenium content but is used to determine if there is correlation between selenium concentration and the amount of total dissolved solids.

The water samples were analyzed by the U.S. Geological Survey laboratory in Worland, Wyo., using the method described by Magin, Thatcher, Rettig, and Levine (1960). The accuracy of the determination is somewhat sensitive to interference from other minerals at high concentrations of total dissolved solids. Therefore, the concentrations of selenium in water ranging from 0 to 100 μg/l are given in this report to the nearest 10μg/l; above 100 μg/l the concentrations are given to two significant figures.

At three separate locations (31–82–27cdd, 33–81–16bcb, and 34–80–33ccc), two test wells were drilled near each other but were cased to different depths. This arrangement enabled the sampling of water from different depths in an aquifer at the same location.

Samples of surface water from 11 stations were collected monthly for 15 months. However, beginning July 1970, the decision was made to monitor only four surface-water stations; these stations were monitored monthly until June 1970 when sampling ended.

An inventory was made of approximately 200 wells and springs (part of inventory is shown on pl. 1) to obtain data for mass sampling of water in the area. In addition to the monthly sampling of ground and surface water, samples were collected from many other wells, test holes, springs, and streams (referred to as mass sampling) in August and September following the 1968 irrigation season. Mass sampling was done again in April and May prior to the start of the 1969 irrigation season. By sampling in this way, the selenium content of water during the irrigation season could be compared with that of the water during the nonirrigation season. Water was sampled in areas not influenced by irrigation (in the 5-mile-wide area outside the Kendrick Project) to determine if there was a natural seasonal variation in selenium content.

SELENIUM IN ROCKS

Samples of material collected for selenium analysis, including soil, bedrock, and other unclassified rock material, are referred to in this report as rock samples. Results of the selenium analyses of the rock samples are given in table 1. Rocks in the area have been grouped according to age, pre-Cretaceous, Cretaceous, Tertiary, and Quaternary.

ROCKS OF PRE-CRETACEOUS AGE

Significant amounts of water are not applied to soils derived from formations older than Cretaceous age; therefore, rocks of pre-Cretaceous age were not sampled and were not considered important sources of selenium in waters in the area. These formations crop out only in the areas of Casper Mountain and Alcova Reservoir. Generally, these are areas of rugged terrain used primarily for pasturing livestock.

ROCKS OF CRETACEOUS AGE

Most of the soils on the Kendrick Project are derived from formations of marine origin of Late Cretaceous age. The Cody Shale and its equivalents (Steele Shale and Niobrara Formation) are the most prevalent bedrock units in the area and probably contribute more selenium to waters in the area than any of the other Cretaceous formations; most of the rock samples of Cretaceous age were collected from the Cody Shale. Each Cretaceous formation sampled shows a wide range of selenium concentrations (table 1). A plot of the selenium concentration versus depth of sample for Cretaceous rocks (fig. 3) shows no correlation between the selenium concentration and the depth at which the sample was collected.

ROCKS OF TERTIARY AGE

Of four samples collected from Tertiary rocks, three samples contained less than 10μg/kg (micrograms per kilogram of sample), and one sample had a concentration of 40μg/kg. Because no irrigated areas are underlain by formations of Tertiary age, probably little selenium is contributed to water in the study area from these rocks.

ROCKS OF QUATERNARY AGE

Formations of Quaternary age underlie most of the irrigable lands and are mostly within the area shown as alluvium on the geohydrologic map. The alluvium on the map includes terrace deposits and flood-plain deposits and consists of lenticular beds of clastic material ranging in size from clay to boulders.

The plot of the selenium concentration versus depth sampled for the Quaternary rocks (fig. 3) shows that the samples containing the highest concentration of selenium were generally found at depths of less than 4 feet. It should be noted that most of the Quaternary samples (about 83 percent) were collected from depths of less than 4 feet. There is wide variation of selenium concentration (fig. 3) in the surface material (depths of less than 9 inches).

DISTRIBUTION OF SELENIUM IN ROCKS

The areal distribution of the samples collected above the water table (pl. 2) shows that selenium occurs throughout the area. The range of concentrations given in table 1 show that no particular geologic formation has consistently high concentrations of selenium; instead, high concentrations were found at points throughout the study area. The rocks in any locality probably

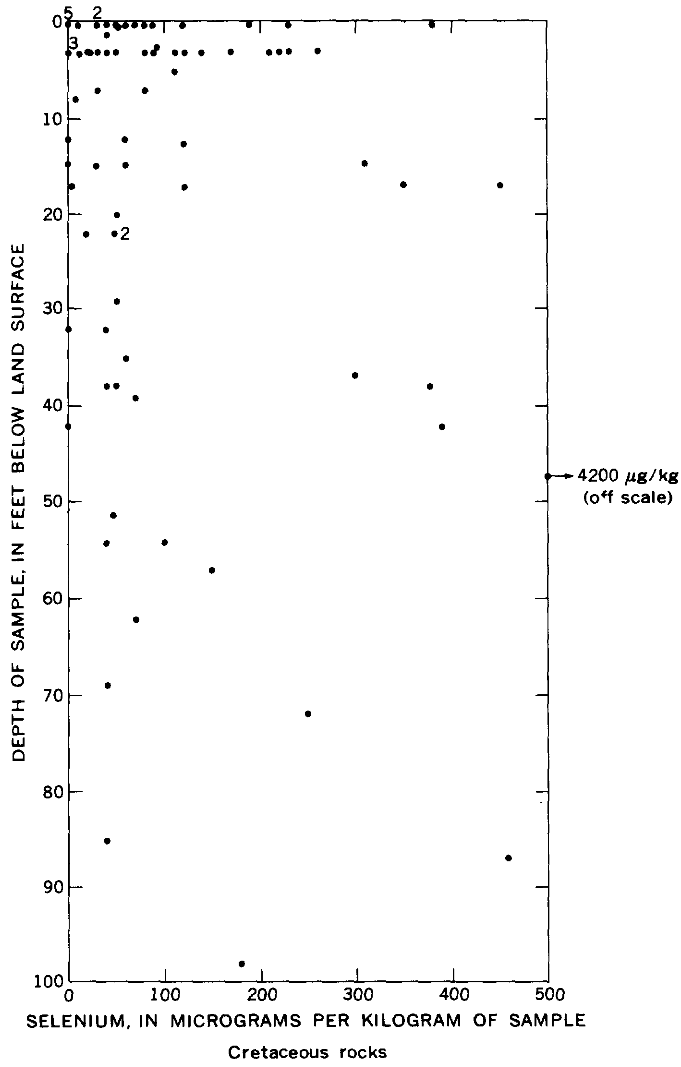

FIGURE 3.—Selenium concentration in rock samples versus depth of sample for Cretaceous and Quaternary rocks. The number near a point is the number of samples represented by that point.

could be the source of selenium in the water in the surrounding vicinity.

Similar random distribution of high selenium concentrations in rocks has been found elsewhere. In South Dakota it was found that a soil containing 0.5 ppm (parts per million) selenium could lie between soils containing 5 and 8 ppm (Lakin, 1961, p. 27).

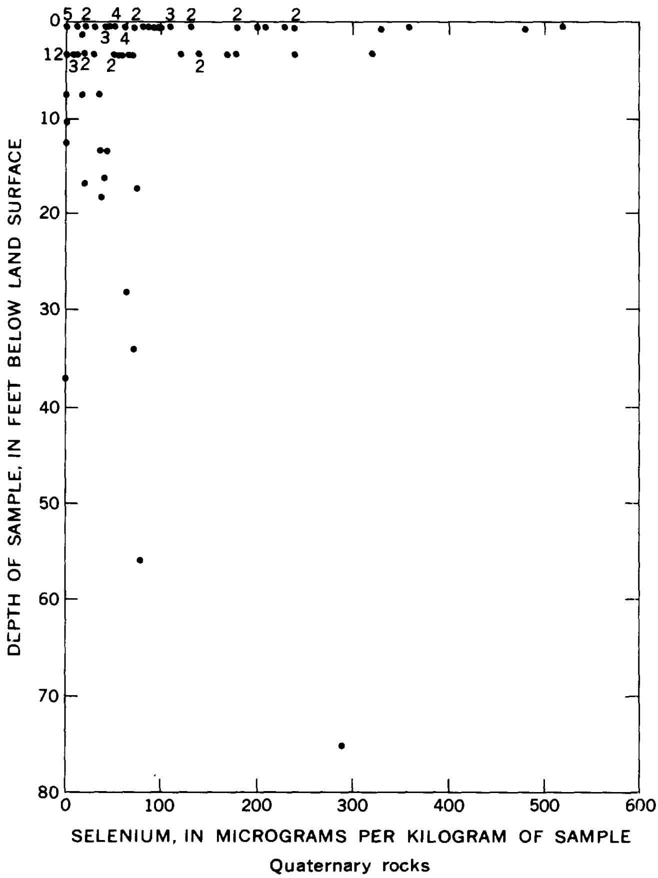

FIGURE 3.—(See explanation on facing page.)

SELENIUM IN WATER

GROUND WATER

The quality of ground water in the Kendrick Project is influenced by irrigation water brought from Alcova Reservoir via the Casper Canal. This water is of good quality and contains less dissolved solids than most of the ground water in the project area. Only in some localities does the leaching of some of the minerals from the soil and rocks by downward percolation of irrigation water cause an increase in mineralization of the ground water and deterioration of the ground-water quality. In most localities, recharge to aquifers (water-bearing strata) from irrigation improves the quality of the ground water by dilution.

The quantity of ground water within the project has increased

TABLE 1.—*Selenium analyses of rock samples from test holes in and near the Kendrick Project*

Location: See description of well-numbering system in text.
Depth to water: Data given in feet below land surface.
Geologic formation: Kmt, Mowry and Thermopolis Shales: Kf, Frontier Formation; Kc, Cody Shale; Ks, Steele Shale; Kn, Niobrara Formation; Kmv, Mesaverde Formation; Kl, Lance Formation; Twdr, Wind River Formation; Twrl, lower member of White River Formation; Qal, flood-plain deposits; Qt, alluvial terrace deposits; Qs, windblown sand.
Sampled interval: Data given in feet below land surface.
Selenium: Concentration of selenium given in micrograms per kilogram of sample.

Location	Depth to water (ft)	Land irrigated	Geologic formation	Sampled interval (ft)	Selenium (µg/kg)	Remarks
30–81– 5dbb	Dry	No	Qal	0.25– 0.75	240	
			Qal	3.00– 3.50	240	
			Kn	35.00–35.50	60	
7ccb	Dry	No	Kn	.25– .75	30	
			Kn	3.00– 3.50	210	
30–82– 9baa	36	Yes	Qt	.17– .42	40	
			Qt	3.00– 3.25	70	
			Kn	55.00–55.50	40	Shale at 54 feet.
26ddc	Dry	No	Kf	.25– .75	380	
			Kf	3.00– 3.50	220	
			Kf	12.00–12.50	60	
31–81– 6dcd	Dry	No	Qt	.17– .56	20	
			Kc	38.00–38.50	380	Shale at 37 feet.
7bdc	------	Yes	Qal	.25– .75	240	
			Qal	3.00– 3.50	320	
			Kc	17.00–17.50	120	Shale at 15 feet.
9ada	16	Yes	Qal	.17– .50	60	
			Qal	3.00– 3.25	20	
			Kc	39.00–39.50	70	Shale at 38 feet.
17abb	27	Yes	Qal	.17– .42	<10	
			Qal	3.00– 3.25	<10	
			Kc	98.00–98.50	180	Shale at 97 feet.
20daa	Dry	No	Kc	.17– .42	<10	
			Kc	3.00– 3.25	230	
31–82– 2aca	33	No	Qal	.17– .42	<10	
			Kc	85.00–85.50	40	Shale at 82 feet.
14baa	26	No	Qal	.17– 42	180	
			Qal	3.00– 3.25	<10	
23ccc	14	Yes	Qt	.17– .50	110	
			Ks	32.00–32.50	<10	Shale at 30 feet.
25aba1	Dry	No	Qal	.25– .75	200	
			Ks	17.00–17.50	350	Shale at 15 feet.
27cdd1	20	Yes	Qt	.17– .42	80	
			Qt	3.00– 3.25	50	
			Qt	37.00–37.50	<10	
			Ks	55.00–55.50	100	Shale at 53 feet.
28daa	7	Yes	Qt	.17– 50	70	
			Qt	3.00– 3.33	<10	Shale at 27 feet.
			Ks	37.00	40	Sample at 37 feet taken from bit.
31–83– 2aca	4	No	Qal	.17– .42	<10	
			Twdr	3.00 3.25	40	
			Twdr	12.00–12.50	<10	
3dcc	Dry	No	Twrl	.17– .42	<10	
			Twrl	3.00– 3.33	<10	
32–80–31cbd	16	No	Kmt	.17– .50	40	
			Kmt	3.00– 3.25	260	
32–81– 3ddb	10	Yes	Qal	.25– .75	50	
			Qal	3.00– 3.50	10	Shale at 40 feet.
			Kc	42.00	<10	Sample at 42 feet taken from bit.
7ccc	15	Yes	Kc	.25– .75	<10	
			Kc	3.00– 3.50	90	
			Kc	28.00–28.50	130	
8bbb	5	Yes	Kc	.25– .75	50	
			Kc	3.00– 3.50	40	
			Kc	17.00–17.50	450	
29bca	43	Yes	Qt	.17– .42	30	
			Qt	3.00– 3.25	170	Shale at 68 feet.
			Kc	69.00	40	Sample at 69 feet taken from bit.

TABLE 1.—*Selenium analyses of rock samples from test holes in and near the Kendrick Project*—Continued

Location	Depth to water (ft)	Land irrigated	Geologic formation	Sampled interval (ft)	Selenium (µg/kg)	Remarks
32-82-16ddb ----	Dry--	No--	Kmv	0.17- 0.42	<10	
			Kmv	3.00- 3.25	50	
21aca -----	12	No--	Kl	.17- .42	30	
			Kl	3.00- 3.25	170	
			Kl	32.00	40	Sample at 32 feet taken from bit.
23cad ----	5	No--	Qal	.17- .42	20	
			Qal	3.00- 3.25	<10	Shale at 37 feet.
			Kc	38.00	50	Sample at 38 feet taken from bit.
29aba ----	16	No--	Qal	.17- .42	130	
			Qal	3.00- 3.25	<10	
33-79-28bab ----	Dry--	No--	Pediment deposits of Quaternary age.	.17- .67	90	
			--do----	3.00- 3.50	<10	
			Kc	12.00-12.50	<10	Shale at 11 feet.
33-80- 3ccb -----	11	Yes-	Qt	.50- .75	480	
			Qt	3.00- 3.33	<10	
			Kc	12.50-13.00	120	Shale at 9 feet.
5ddd ----	12	Yes-	Qt	.17- .42	60	
			Qt	3.00- 3.25	<10	Shale at 10 feet.
			Kc	15.00	<10	Sample at 15 feet taken from bit.
7ada ----	4	Yes-	Kf	.17- .67	60	
			Kf	3.00- 3.25	140	
			Kf	22.00-22.50	20	
11acc ----	Dry--	No--	Qt	.17- .42	210	
			Kc	15.00-15.50	310	Shale at 13 feet.
12dbb ----	47	No--	Qt	.17- .42	40	
			Kc	62.00-62.50	70	Shale at 61 feet.
16bbb ----	Dry--	No--	Kf	.17- .42	<10	
			Kf	3.00- 3.25	<10	
22ddb ----	-----	No--	Qal	.17- .42	<10	
			Qal	3.00- 3.25	<10	
			Kc	47.50-48.00	4,200	Shale at 47 feet.
33bcd ----	-----	No--	Kc	.25- .75	230	
			Kc	3.00- 3.50	<10	
33-81- 3aaa ----	6	No--	Kc	.25- .75	80	
			Kc	3.00- 3.50	20	
			Kf	17.00-17.50	<10	
16bcb1 ---	13 .	Yes-	Qal	.25- .50	<10	
			Qal	75.00-75.50	290	Shale at 84 feet.
			Kc	87.00	460	Sample at 87 feet taken from bit.
19daa ----	13	No--	Qal	.25- .75	60	
			Kf	3.00- 3.50	80	
20ddd ----	7	Yes-	Qt	.25- .75	50	
			Qt	3.00- 3.50	180	
			Qt	7.00- 7.50	<10	
			Kc	22.00-22.50	50	Shale at 21 feet.
33bab ----	Estimated 10.	Yes-	Kc	.25- .75	10	Test holes 33-81-33bab and -33bbb are representative of possible effects of leaching by irrigation. Test holes are about 1,400 feet apart.
			Kc	3.00- 3.50	<10	
			Kc	15.00-15.50	60	
33bbb ----	Dry--	No--	Kc	1.25- 1.75	40	See above.
			Kc	3.00- 3.50	30	
			Kc	15.00-15.50	30	
33-82-16dcb ----	16	No--	Qal	.25- .75	180	
			Kf	8.00- 8.50	10	
34-79-29abc ----	31	No--	Qs	.17- .42	130	
			Kc	29.00-29.50	50	Shale at 24 feet.
31add ----	Dry--	No--	Qs	.17- .42	<10	
			Kc	20.00-20.50	50	

TABLE 1.—*Selenium analyses of rock samples from test holes in and near the Kendrick Project*—Continued

Location	Depth to water (ft)	Land irrigated	Geologic formation	Sampled interval (ft)	Selenium (µg/kg)	Remarks
34–80– 5aba ----	6	Yes_	Qt	0.25– 0.75	100	
			Qt	3.00– 3.50	120	
			Qt	7.00– 7.50	20	Shale at 13 feet.
8cad1 ---	10	Yes_	Qt	.25– .75	520	
			Qt	3.00– 3.50	70	
			Qt	10.00–10.50	<10	Shale at 17 feet.
19abb ----	13	Yes_	Qt	.17– .67	50	
			Qt	3.00– 3.33	<10	
			Qt	12.00–12.50	<10	
			Kc	22.00–22.50	50	Shale at 19 feet.
21ccd1 ---	27	Yes_	Qt	.25– .75	330	
			Qt	3.00– 3.50	<10	
			Qt	13.00–13.50	40	
			Qt	28.00–28.50	60	Shale at 50 feet.
32aaa2 ---	26	Yes_	Qt	.25– .50	40	
			Qt	3.00– 3.25	10	
			Qt	56.00–56.50	80	
			Kc	72.00	250	Sample at 72 feet taken from bit.
33aaa1 ---	6	Yes_	Qt	.50– .75	100	
			Qt	3.00– 3.25	140	
			Qt	7.00– 7.50	30	Shale at 55 feet.
			Kc	57.00	150	Sample at 57 feet taken from bit.
33ccc1 ---	8	Yes_	Qt	.50– .83	70	
			Qt	3.00– 3.50	10	
			Qt	18.00–18.50	40	
			Kc	37.00–37.50	300	Shale at 30 feet.
34–81– 1aaa ----	Dry--	No--	Kc	.25– .50	190	
			Kc	3.00– 3.25	110	
12ccc ----	Dry--	No--	Kc	2.50– 3.00	90	
			Kc	5.00– 5.50	110	
25bbb ----	5	Yes_	Qal	.17– .67	10	
			Qal	3.00– 3.33	50	
			Kc	42.00–42.50	390	
35–80–30 bcc ----	10	Yes_	Qal	.17– .67	50	
			Qal	3.00– 3.50	60	
			Qal	34.00–34.50	70	
30ccc ----	Dry--	Yes_	Qt	.25– .75	60	
			Qt	3.00– 3.50	10	
			Kc	7.00–7.50	30	Shale at 5 feet.
35–81– 2aad ----	Dry--	No--	Qal	.25– .50	110	
			Qal	3.00– 3.50	<10	
			Qal	16.00–16.50	40	
			Qal	16.50–17.00	20	Shale at 17 feet.
7bbb ----	11	No--	Qal	.25– .50	110	
			Qal	3.00– 3.50	140	
			Qal	13.00–13.50	40	Shale at 47 feet.
13ddd ----	4	Yes_	Qt	.25– .75	360	
			Qt	3.00– 3.50	30	Shale at 9 feet.
30ccc ----	5	No--	Qal	00– .50	230	
			Kc	7.00– 7.50	80	Shale at 5 feet.
31ccc -----	Dry--	No--	Kc	.00– .50	70	
32dda ----	Dry--	No--	Kc	.17– .67	80	
			Kc	3.00– 3.50	120	
34ddd ----	Dry--	Yes--	Kc	.17– .67	<10	Test hole is adjacent Johnson Lateral. Shale was wet to 13 feet but dry at 17 feet.
			Kc	3.00– 3.33	20	
35–82–13ddc ----	Dry--	No--	Kc	.25– .75	50	
36–81–20aca ----	11	No--	Qal	.50– .83	80	
24cba ----	21	No--	Qal	.25– .50	50	
			Qal	3.00– 3.25	60	
			Qal	17.00–17.33	70	Estimate shale at 34 feet.
27aad ----	Dry--	No--	Kc	.25– .50	120	
			Kc	3.50– 3.75	10	
31dcc ----	Dry--	No--	Qs	1.00– 1.33	20	
			Kc	51.00–51.50	50	Shale at 50 feet.

because of recharge from surface-water irrigation. Some rock strata have become saturated at shallow depths and shallow aquifers now exist in many places where previously there were none. The ground-water level has risen as much as 20 feet in places since 1950. Generally, water levels in many wells on the Kendrick Project change in response to infiltration of irrigation water, rising in June after the start of the irrigation season, reaching maximum level in August or September, then declining until the following spring. The increase in ground-water storage and ground-water movement undoubtedly has caused an increase in the movement of selenium from the rocks.

GROUND-WATER SAMPLING

Selenium concentration, water level, and specific conductance data are given in table 2 for all the ground-water sampling sites. These data for the monthly sampling sites are shown graphically on plate 3. For convenience, the data for a particular month are plotted at the end of the month.

Analyses of the selenium data for the observation wells with 2 years of record are as follows:

Well 30–82–9baa (pl. 3).—The overall trend of selenium concentration appears to be slightly upward since late 1968.

Well 32–81–7ccc (pl. 3).—This water contains the highest concentration of selenium of any of the observation wells, but the wide fluctuation of the concentration masks any trend that might be present.

Well 33–80–12dbb (pl. 3).—A trend of the selenium concentration in this well is not defined; however, the specific conductance of the water has increased steadily since early in 1969.

Well 33–81–16bcb1 (pl. 3).—There is wide fluctuation of the selenium concentration in this well, but the overall trend appears to be slightly upward for the period of record. A similar upward trend is noted in the specific conductance of the water.

Well 33–81–16bcb2 (pl. 3).—This well is about 50 feet east of well 33–81–16bcb1 and penetrates about 2 feet into the saturated zone. The selenium concentration in this well appears to trend slightly upward since early 1969. The specific conductance of the water is lowest during the winter.

Well 34–80–5aba (pl. 3).—The selenium concentration increases with a decline in the water level, which indicates that irrigation water probably dilutes the concentration in the ground water. No overall trend of selenium concentration is recognized. The lower

TABLE 2.—*Data for wells and springs where ground water was analyzed for selenium, in and near the Kendrick Project*

Location: See description of well-numberin system in text.
Geologic source: PPta, Tensleep Sandstone; PPc, Casper Formation; ₹c, Chugwater Group; KJcm, Cloverly and Morrison Formations; Kmt, Mowry and Thermopolis Shales; Kf, Frontier Formation; Kc, Cody Shale; Kmv, Mesaverde Formation; Kl, Lance Formation; Tfu, Fort Union Formation; Twdr, Wind River Formation; Qal, flood-plain deposits; Qt, alluvial terrace deposits; Qs, windblown sand; Qc, colluvium.
Well depth: Depth is given in feet below land surface.
Casing interval open: Perforated or screened interval, given in feet below land surface.
Water level: Measured depths to water level given in feet and tenths; reported or estimated depths are given in feet.

Location	Geologic source	Well depth (ft)	Casing interval open (ft)	Date	Depth to water below land surface (ft)	Selenuim (μg/l)	Specific conductance (micromhos per cm at 25°C)
30-81- 4ddb ---	KJcm	310	290-310	8-28-68	Flowing --	20	--------
				4-29-69	Flowing --	<10	2,100
30-82- 3bdd[1] --	Qt	42	-------	5- 1-69	28.3	10	3,700
9baa[1] --	Qt	55	50-52	6-10-68	36.6	210	>8,000
				7-30-68	34.1	300	>8,000
				8-19-68	33.9	310	>8,000
				9-24-68	32.4	120	>8,000
				10-28-68	33.1	50	>8,000
				11-20-68	33.5	60	>8,000
				12-17-68	34.1	100	>8,000
				1-27-69	34.9	30	>8,000
				2-25-69	35.4	200	>8,000
				3-18-69	35.8	80	>8,200
				4-22-69	36.2	210	>8,000
				5-26-69	36.5	100	>8,000
				6-23-69	35.5	50	>8,000
				7-24-69	37.1	90	>8,000
				8-19-69	32.9	<10	>8,000
				9-25-69	32.7	300	>8,000
				11- 6-69	33.7	60	>8,000
				12- 1-69	34.2	280	>8,000
				12-30-69	34.8	350	8,000
				1-20-70	35 1	40	>8,000
				2-19-70	35.2	280	>8,000
				3-16-70	36.0	250	>8,000
				4-20-70	35.0	80	>8,000
				5-20-70	36.7	90	>8,000
				6-25-70	34.8	190	>8,000
18ada ---	Qal	20	5-20	8-28-68	10	10	--------
				4-29-69	10	<10	1,320
18cbb ---	Qal	38	-------	8-28-68	10	10	--------
				4-29-69	10	<10	1,400
19bcc1 --	Qal	41	-------	8-28-68	31	20	--------
				4-29-69	31	<10	1,000
19cbd ---	Qal	49	-------	8-28-68	15	10	--------
				4-29-69	15	<10	2,200
30-83-13ddc2 --	Qal	90	-------	8-28-68	29.8	20	--------
				4-29-69	31.5	<10	930
15bda ---	₹c	132	100-130	8-28-68	50	20	450
				4-29-69	50	<10	470
24dda2 ---	PPta	---	-------	8-28 68	Flowing --	20	--------
				4-29-69	Flowing --	<10	1,300
31-81- 7abb ---	Qt	35	-------	8-27-68	26.8	50	1,900
				4-29-69	30.3	<10	1,640
9ada[1] --	Qal	39	37-39	6-10-68	15.2	<10	--------
				7-30-68	16.6	70	900
				8-19-68	16.9	70	750
				9-24-68	17.6	10	740
				10-28-68	17.9	<10	720
				11-20-68	16.5	<10	750
				12-17-68	17.4	<10	850
				1-27-69	18 5	<10	950
				2-25-69	19.3	10	870
				3-18-69	19.8	<10	850
				4-22-69	17.5	<10	870
				5-26-69	16.5	<10	840
				6-23-69	16.9	<10	830
17abb[1] --	Qal	98	73-98	8-26-68	27.2	90	2,100
				4-28-69	27.9	20	1,750

TABLE 2.—*Data for wells and springs where ground water was analyzed for selenium, in and near the Kendrick Project*—Continued

Location	Geologic source	Well depth (ft)	Casing interval open (ft)	Date	Depth to water below land surface (ft)	Selenuim (µg/l)	Specific conductance (micromhos per cm at 25°C)
31–82– 2aca	Qal	85	50–85	8–23–68	33.0	20	4,500
				4–28–69	37.9	20	4,000
12acb[1]	Qt	66	-------	8–27–68	31.0	<10	2,000
				4–29–69	37.2	<10	1,350
14baa	Kl	29	26–29	6– 5–68	26.5	40	--------
				8–23–68	21.9	10	1,450
				4–28–69	23.7	20	1,700
23ccc[1]	Qt	32	32	8–26–68	14.2	20	1,800
				4–28–69	18.6	40	1,990
24bdc	Qal	25	32	4–29–69	11.9	<10	990
27cba[1]	Qal	19	-------	8–27–68	6.5	90	--------
				4–29–69	14.1	<10	5,500
27cdd1[1]	Qt	55	34–52	6–10–68	20.8	20	--------
				7–30–68	17.8	10	2,350
				8–19–68	16.5	30	2,350
				9–24–68	16.9	10	2,250
				10–28–68	17.3	10	2,300
				11–20–68	17.9	10	2,500
				12–17–68	18.2	10	2,600
				1–27–69	18.8	<10	2,500
				2–25–69	19.0	10	2,200
				3–18–69	19.4	20	2,200
				4–29–69	19.9	<10	2,000
				5–26–69	20.3	<10	2,100
				6–23–69	19.9	10	2,100
27cdd2[1]	Qt	40	38–40	6–10–68	21.0	10	1,300
				7–30–68	18.0	20	1,300
				8–19–68	16.7	10	1,340
				9–24–68	16.9	30	1,400
				10–28–68	17.3	10	1,340
				11–20–68	18.0	10	1,250
				12–17–68	18.3	<10	1,300
				1–27–69	19.0	<10	1,300
				2–25–69	19.2	20	1,300
				3–18–69	19.6	20	1,200
				4–22–69	20.1	20	1,210
				5–26–69	20.5	130	1,400
				6–23–69	20.0	20	1,400
28add[1]	Qal	13	-------	4–29–69	7.4	<10	1,280
32ddb	Qal	28	-------	8–27–68	8.6	10	2,100
				4–29–69	9	<10	1,900
34dbb[1]	Qt	58	-------	8–27–68	20.2	<10	2,700
35bcd[1]	Qal	12	-------	8–27–68	2.5	10	2,400
				4–29–69	3.1	<10	1,750
35dcd	Qal	11	-------	8–28–68	9	<10	650
				4–29–69	9	<10	600
31–83– 2aca	Qal,Twdr	22	20–22	6– 8–68	3.8	<10	--------
				8–28–68	4.3	10	860
				4–28–69	2.5	<10	790
32–80–31cbd	Kmt	28	Open hole	6– 5–68	16	10	--------
32–81– 2dcb[1]	Qal	43	32–42	8–19–68	7.9	20	2,000
				4–22–69	11.6	<10	1,980
3ddb[1]	Qal	42	40–42	8–19–68	10.2	10	750
				4–22–69	15.2	<10	740
4aaa[1]	Qt	80	48–75	8–23–68	47.6	360	>8,000
				4–22–69	48.0	80	>8,000
32–81– 7ccc[1]	Kc	28	26–28	6–11–68	15.6	750	>8,000
				7–30–68	13.2	130	>8,000
				8–20–68	13.3	600	>8,000
				9–26–68	13.8	2,100	>8,000
				10–29–68	14.3	1,800	>8,000
				11–20–68	14.6	2,900	>8,000
				12–17–68	14.6	1,400	>8,000
				1–28–69	14.8	400	>8,000
				2–25–69	14.7	160	>8,000
				3–18–69	15.0	770	>8,000
				4–22–69	15.0	710	>8,000
				5–26–69	15.3	940	>8,000

TABLE 2.—*Data for wells and springs where ground water was analyzed for selenium, in and near the Kendrick Project*—Continued

Location	Geologic source	Well depth (ft)	Casing interval open (ft)	Date	Depth to water below land surface (ft)	Selenuim (µg/l)	Specific conductance (micromhos per cm at 25°C)
32-81- 7ccc[1]—Con.							
				6-24-69	13.1	2,700	>8,000
				7-24-69	13.4	720	>8,000
				8-19-69	12.5	610	>8,000
				9-25-69	12.6	1,500	>8,000
				11- 6-69	12.9	330	>8,000
				12- 1-69	13.3	1,600	>8,000
				12-30-69	13.7	1,700	>8,000
				1-20-70	13.8	[2]180	8,320
				1-20-70	--------	[3]610	8,620
				2-19-70	14.0	1,800	8,000
				3-16-70	13.9	2,000	>8,000
				4-20-70	13.8	500	>8,000
				5-27-70	13.9	540	7,000
				6-25-70	12.9	860	8,000
8bbb[1] --	Kc	18	18	8-23-68	5.0	1,600	>8,000
				4-25-69	6.9	3,000	>8,000
9bab[1] --	Kc	42	24-42	8-23-68	16.8	100	>8,000
				4-22-69	23.6	20	>8,000
15bad ---	P₽c	Spring-	-------	8-27-68	Flowing --	<10	760
				4-25-69	Flowing --	<10	710
15abb ---	Kf	870	-------	8-27-68	60	20	3,100
				4-25-69	60	<10	2,500
29bca[1] --	Qt	69	66-68	6-11-68	43.5	<10	--------
				7-30-68	24.9	30	4,400
				8-20-68	33.6	10	4,400
				9-26-68	37.2	20	4,100
				10-28-68	39.3	10	3,900
				11-20-68	40.5	10	3,700
				12-17-68	41.6	10	3,500
				1-28-69	42.8	10	3,400
				2-25-69	43.4	10	3,300
				3-18-69	43.8	<10	3,300
				4-22-69	44.0	20	3,600
				5-26-69	43.7	20	3,900
				6-24-69	40.8	40	4,000
32bbb[1] --	Qal	50	-------	8-28-68	8	60	3,700
				5- 1-69	6.9	280	3,100
32bcb ---	Qal	50	-------	8-28-68	10	<10	770
				5- 1-69	10	<10	690
32-82-21aca ---	Kl	32	26-32	8-26-68	12.4	40	>8,000
				4-28-69	12.6	30	>8,000
23cad ---	Qal	38	36-38	8-23-68	4.8	10	6,000
				4-28-69	5.8	10	5,100
29aba ---	Tfu	28	26-28	8-26-68	15.9	10	2,500
				4-24-69	15.2	10	2,400
33-79- 3abb ---	Qal	29	-------	2- 6-68	8	<10	--------
18[4] -----	Qal	---	-------	3-29-68	--------	[4]10	--------
18bcc1 --	Qal	37	12-30	7-30-68	8.2	10	940
				8-21-68	7.8	10	910
				9-26-68	7.7	<10	970
				10-30-68	8.8	<10	900
				11-19-68	7.8	10	940
				12-18-68	8.4	<10	910
				1-29-69	5.4	<10	910
				2-25-69	6.1	<10	930
				3-18-69	7.3	<10	940
				4-23-69	8.0	<10	880
				5-26-69	8.0	<10	870
				6-25-69	7.1	<10	970
18cab ---	Qal	33	14-33	2- 8-68	8	10	--------
31ddd ---	Qc	Spring-	-------	9-20-68	Flowing --	<10	280
				5- 1-69	Flowing --	<10	320
33-80- 3baa3[1] -	Qt	35	-------	8- 9-68	8.2	10	870
				4-30-69	12.7	<10	1,290
3bcb[1] --	Qt	30	-------	8-29-68	7.9	<10	880
				4-30-69	10.7	10	1,000
3cad[1] --	Qt	37	-------	8-28-68	17.1	100	4,400
3cbbl[1] -	Qt	31	-------	8-21-68	4.6	100	1,980
				4-29-69	6.3	<10	1,610

TABLE 2.—*Data for wells and springs where ground water was analyzed for selenium, in and near the Kendrick Project*—Continued

Location	Geologic source	Well depth (ft)	Casing interval open (ft)	Date	Depth to water below land surface (ft)	Selenuim (µg/l)	Specific conductance (micromhos per cm at 25°C)
33-80- 3ccb[1]	Qt	17	-------	8-22-68	5.9	20	1,700
				4-24-69	11.6	150	4,200
4cbb[1]	Qt	59	-------	8-22-68	6.2	230	4,200
				4-24-69	6.5	320	3,700
5bcd	Kf	140	-------	8-29-68	Flowing	20	6,000
				4-30-69	Flowing	<10	5,500
5ddd[1]	Qt	15	10-15	6-12-68	11.8	<10	--------
6aaa[1]	Kc	25	15-25	8-22-68	Flowing	90	>8,000
				4-24-69	.1	280	>8,000
6cbc	Kf	204	-------	8-28-68	Flowing	10	2,590
				4-25-69	Flowing	<10	2,400
7ada[1]	Kf	22	20-22	6-12-68	4.5	20	--------
				7-29-68	4.4	<10	5,000
				8-20-68	3.3	10	5,000
				9-26-68	Flowing	30	5,000
				10-29-68	Flowing	30	4,700
				11-20-68	Flowing	20	5,000
				1-28-69	4.3	40	4,800
				2-25-69	1.0	20	4,900
				3-18-69	1.5	40	4,900
				4-21-69	2.2	80	4,600
				5-26-69	3.3	20	5,000
				6-24-69	.3	10	5,900
7dda	Kf	98	-------	8-28-68	30	<10	3,900
				4-30-69	30	<10	3,500
8aad1	Kf	128	-------	6-13-67	29	20	3,670
				8-28-68	29	10	4,100
				5- 1-69	28	<10	3,400
8bcc[1]	Kf	135	-------	8-28-68	13	10	5,000
				4-25-69	8	<10	--------
10add[1]	Kc	42	10-42	8-22-68	16.9	300	4,800
				4-24-69	19.1	220	4,000
12bbb[1]	Qt	62	59-61	6-10-68	46.8	40	--------
				7-30-68	46.6	40	1,270
				8-21-68	46.5	120	1,190
				9-26-68	46.4	100	1,200
				10-30-68	47.4	30	1,200
				11-19-68	46.5	40	1,150
				12-18-68	46.4	10	1,150
				1-29-69	46.4	10	1,200
				2-25-69	46.4	60	1,190
				3-18-69	46.5	60	1,200
				4-23-69	46.7	70	1,220
				5-26-69	46.8	20	1,220
				6-25-69	46.7	10	1,320
				7-24-69	46.7	30	1,500
				8-20-69	46.7	30	1,320
				9-25-69	46.6	90	1,400
				11- 6-69	46.5	40	1,420
				12- 1-69	46.5	100	1,400
				12-31-69	46.6	40	1,300
				1-20-70	46.5	20	1,300
				2-19-70	46.4	70	1,520
				3-16-70	46.7	90	1,400
				4-20-70	46.8	40	1,500
				5-27-70	46.8	50	1,850
				6-25-70	46.8	40	1,600
12dda2	Qal	34	-------	2- 6-68	7	20	--------
14daa	Qal	44	-------	8-27-68	15	20	1,150
				5- 2-69	15	<10	--------
27bbb2	Kc	220	120-220	8-29-68	30	10	1,950
				4-29-69	30	<10	1,800
31baa	Kmt	Spring	-------	9-19-68	Flowing	<10	1,610
				4-29-69	Flowing	<10	1,600
33-81- 2cca	Kf	180	-------	8-28-68	Flowing	10	>8,000
				4-30-69	Flowing	10	6,000
3aaa	Kf	17	11-17	6- 9-68	7.7	<10	>8,000
				8-22-68	6.0	50	>8,000
				4-24-69	4.8	20	>8,000

TABLE 2.—*Data for wells and springs where ground water was analyzed for selenium, in and near the Kendrick Project*—Continued

Location	Geologic source	Well depth (ft)	Casing interval open (ft)	Date	Depth to water below land surface (ft)	Selenuim (µg/l)	Specific conductance (micromhos per cm at 25°C)
33–81– 7caa[1] --	Qal	16	-------	8–27–68	6.5	10	1,900
				4–30–69	7.9	<10	1,900
10cbc ---	Kmt	Spring-	-------	8–27–68	Flowing --	10	1,590
				4–30–69	Flowing --	<10	1,400
16bcb1[1] -	Qal	87	76–78	6– 9–68	13.3	740	--------
				7–30–68	14.0	10	7,000
				8–20–68	14.2	650	6,500
				9–26–68	14.2	500	7,000
				10–29–68	14.2	350	7,000
				11–19–68	14.3	300	6,500
				12–17–68	14.2	820	7,500
				1–28–69	14.4	150	6,800
				2–24–69	14.6	220	6,500
				3–18–69	14.5	460	6,200
				4–21–69	14.1	350	6,200
				5–26–69	14.1	860	6,100
				6–24–69	13.9	220	7,400
				7–23–69	14.0	180	6,800
				8–19–69	14.0	20	7,500
				9–25–69	14.3	1,100	7,500
				11– 6–69	14.1	220	8,000
				12– 1–69	14.1	360	7,000
				12–30–69	14.2	130	>8,000
				1–20–70	14.3	[2]210	8,420
				1–20–70	--------	[3]130	7,700
				2–19–70	14.3	550	8,000
				3–16–70	14.4	1,200	>8,000
				4–20–70	13.6	1,300	>8,000
				5–27–70	13.3	860	>8,000
				6–26–70	15.6	320	>8,000
16bcb2[1] -	Qal	18	16–18	6– 9–68	15.2	60	--------
				7–30–68	15.7	40	2,800
				8–20–68	15.8	20	2,700
				9–26–68	15.8	60	2,500
				10–29–68	15.7	90	3,000
				11–19–68	15.7	40	2,500
				12–17–68	15.5	20	2,400
				1–28–69	15.8	30	2,300
				2–24–69	15.6	50	2,250
				3–18–69	16.3	60	2,400
				4–21–69	15.9	<10	2,400
				5–26–69	16.0	30	2,600
				6–24–69	15.7	50	2,900
				7–23–69	15.8	50	2,850
				8–19–69	16	90	3,200
				9–25–69	16.1	190	3,100
				11– 6–69	15.9	20	2,900
				12– 1–69	15.9	40	2,950
				12–30–69	15.9	120	2,600
				1–20–70	16.0	20	2,600
				2–19–70	16.2	70	2,900
				3–16–70	16.0	100	3,000
				4–20–70	15.5	90	3,000
				5–27–70	15.0	40	3,000
				6–26–70	14.9	120	2,820
19daa[1] --	Qal	52	50–52	6–12–68	8.8	10	--------
				7–30–68	11.6	120	2,250
				8–20–68	11.4	60	2,300
				9–26–68	12.4	10	2,200
				10–29–68	12.7	10	2,200
				11–20–68	13.2	10	2,250
				12–17–68	13.7	20	2,350
				1–28–69	13.2	10	2,400
				2–25–69	13.3	10	2,400
				3–18–69	13.6	<10	2,500
				4–22–69	13.3	<10	2,600
				5–26–69	14.6	30	2,900
				6–24–69	12.0	<10	3,000
20bba[1] --	Kc	12	-------	8–28–68	4.0	<10	2,350
				4–30–69	7.2	<10	2,800

TABLE 2.—*Data for wells and springs where ground water was analyzed for selenium, in and near the Kendrick Project*—Continued

Location	Geologic source	Well depth (ft)	Casing interval open (ft)	Date	Depth to water below land surface (ft)	Selenuim (μg/l)	Specific con- d ıctance (micromhos pe- cm at 25°C)
33-81-20dac[1]	Qt	20	-------	8-27-68	3.7	20	1,410
				4-30-69	7.6	10	2,200
20ddd[1]	Qt	22	10-22	8-23-68	5.9	50	7,900
				4-22-69	8.8	80	>8,000
22cbb[1]	Qt	57	42-57	8-22-68	41.8	70	5,500
				4-22-69	41.4	50	4,900
27cbb[1]	Qt	55	-------	8-29-68	46.0	10	1,390
				4-30-69	46	<10	1,950
28dad[1]	Qal	9	-------	8-27-68	2.3	20	2,600
				4-25-69	4.2	10	2,500
32dda[1]	Qal	70	-------	8-26-68	20.3	160	7,000
				4-30-69	20.8	40	6,000
32ddd[1]	Kc	68	50-68	8-22-68	22.6	50	>8,000
				4-22-69	23.6	930	>8,000
33dda[1]	Qal	42	-------	8-28-69	11.8	120	7,500
				4-25-69	7.4	130	7,200
36aad	PIPta	3,600	-------	4-29-69	Flowing --	10	3,900
33-82- 8aab	Kf	540	-------	8-28-68	Flowing --	20	1,850
				4-30-69	Flowing --	<10	1,800
16dcd	Kf	22	20-22	6- 9-68	16.4	20	--------
				7-30-68	16.5	<10	4,500
				8-20-68	16.6	60	4,900
				9-26-68	17.0	20	4,500
				10-29-68	17.2	10	4,400
				11-19-68	17.3	20	4,400
				12-17-68	17.3	10	4,300
				1-28-69	17.2	30	4,000
				2-25-69	17.5	40	4,000
				3-18-69	17.3	10	4,000
				4-21-69	17.0	10	4,000
				5-26-69	17.0	40	5,000
				6-24-69	17.0	30	5,000
25ddd[1]	Kc	22	12-22	8-27-68	7.1	890	>8,000
				4-24-69	6.3	6,500	>8,000
36ddd[1]	Qs	17	8-17	4-28-69	7.5	180	6,500
34-79- 5cca	Kmv	115	-------	9-18-68	80	<10	5,500
				5- 2-69	87.3	30	5,000
17baa	Kc	200	35-200	9-18-68	55	<10	6,100
				5- 1-69	32.5	10	6,200
17dba	Kc	405	385-405	6-12-67	30	10	4,840
				5- 2-68	30	10	--------
				5- 2-69	30	10	5,000
29cac	Qs	23	-------	9-18-68	14.5	10	1,750
				5- 1-69	15.0	10	2,100
34—80- 5aba[1]	Qt	17	8-10	6- 9-68	5.5	190	--------
				7-31-68	3.2	50	1,850
				8-21-68	2.5	30	1,360
				9-26-68	3.0	10	1,850
				10-30-68	4.6	20	2,800
				11-21-68	5.2	140	5,000
				12-18-68	5.6	100	8,000
				1-29-69	6.0	280	>8,000
				2-26-69	6.2	170	>8,000
				3-19-69	6.4	130	>8,000
				4-23-69	6.3	180	>8,000
				5-27-69	6.4	150	>8,000
				6-25-69	2.2	<10	1,420
				7-23-69	1.9	<10	1,800
				8-20-69	1.2	10	1,700
				9-26-69	2.3	20	1,290
				11- 7-69	4.2	50	1,600
				12- 2-69	4.7	10	2,400
				12-31-69	5.2	130	4,600
				1-20-70	5.6	30	6,000
				2-20-70	5.7	130	>8,000
				3-17-70	5.8	240	8,000
				4-21-70	5.7	110	8,000
				5-28-70	6.0	130	8,000
				6-26-70	2.2	120	3,500

TABLE 2.—*Data for wells and springs where ground water was analyzed for selenium, in and near the Kendrick Project*—Continued

Location	Geologic source	Well depth (ft)	Casing interval open (ft)	Date	Depth to water below land surface (ft)	Selenuim (µg/l)	Specific conductance (micromhos per cm at 25°C)
34-80-33aaa2[1]	Qt	25	17-19	6- 7-68	5.9	30	--------
				7-29-68	5.1	20	4,000
				8-20-68	5.6	50	4,100
				9-26-68	4.1	40	4,000
				10-29-68	5.1	30	3,900
				11-20-68	5.6	50	4,000
				12-19-68	5.7	<10	4,000
				1-29-69	5.9	10	4,000
				2-26-69	6.1	20	3,900
				3-18-69	6.1	20	3,900
				4-21-69	6.2	20	3,800
				5-26-69	6.3	20	4,100
				6-25-69	2.8	30	4,200
				7-24-69	1.9	<10	4,800
				8-19-69	3.8	<10	4,800
				9-26-69	4.7	40	5,000
				11- 6-69	2.1	10	5,000
				12- 2-69	4.9	20	5,000
				12-30-69	5.2	40	5,000
				1-20-70	5.3	20	5,000
				2-19-70	5 5	60	5,000
				3-16-70	5.3	30	4,500
				4-21-70	5.1	60	5,000
				5-28-70	5.1	<10	5,000
				6-26-70	3.9	50	4,460
33cccl[1]	Qt	37	30-32	7-29-68	7.2	700	6,100
				8-20-68	5.7	140	6,100
				9-26-68	7.0	1,100	6,000
				10-29-68	7.7	270	6,000
				11-20-68	8.1	200	6,000
				12-19-68	8.1	130	6,000
				1-28-69	8.2	250	6,000
				2-25-69	8.3	560	6,000
				3-18-69	8.5	230	5,700
				4-21-69	8.6	120	5,600
				5-26-69	8.4	150	6,000
				6-25-69	7.5	180	6,100
				7-23-69	7.2	1,100	6,500
				8-20-69	7.7	100	6,300
				9-26-69	7.7	1,800	6,800
				11- 6-69	8.3	220	6,800
				12- 2-69	8.7	190	7,000
				12-30-69	8.7	1,800	7,000
				1-20-70	8.8	120	6,000
				2-19-70	9.1	560	7,000
				3-16-70	8.7	990	7,000
				4-21-70	8.8	870	7,000
				5-27-70	8.4	790	7,000
				6-26-70	8.4	370	--------
33ccc2[1]	Qt	18	15-17	7-29-68	7.7	400	5,000
				8-20-68	7.0	200	5,000
				9-26-68	7.4	390	4,900
				10-29-68	7.9	220	5,000
				11-20-68	8 5	120	5,000
				12-19-68	8.4	130	5,000
				1-28-69	8.6	220	5,000
				2-25-69	8.6	450	4,900
				3-18-69	8.9	420	4,900
				4-21-69	9.0	180	4,600
				5-26-69	8.8	260	4,800
				6-25-69	8.0	180	4,900
36ccc[1]	Qal	53	30-53	8-21-68	20.0	260	2,200
				4-23-69	24 5	130	1,850
8cadl[1]	Qt	19	14-19	6-11-68	9.1	10	--------
				7-31-68	.7	30	2,800
				8-21-68	3.3	50	3,500
				9-26-68	5.3	10	3,600
				10-30-68	6.3	40	4,200
				11-21-68	7.0	10	4,200

TABLE 2.—*Data for wells and springs where ground water was analyzed for selenium, in and near the Kendrick Project*—Continued

Location	Geologic source	Well depth (ft)	Casing interval open (ft)	Date	Depth to water below land surface (ft)	Selenuim (µg/l)	Specific conductance (micromhos per cm at 25°C)
34–80– 8cad1[1]—Con.							
				12–18–68	7.5	30	4,250
				1–29–69	8.0	30	4,400
				2–26–69	8.3	60	4,300
				3–19–69	8.6	20	4,400
				4–23–69	8.8	50	4,000
				5–27–69	9.1	60	4,900
				6–25–69	3.1	40	4,800
				7–23–69	3.9	50	6,800
				8–20–69	5.3	40	6,000
				9–26–69	6.6	140	5,000
				11– 7–69	7.3	50	5,200
				12– 2–69	7.7	40	4,000
				12–31–69	7.9	60	4,100
				1–20–70	8.1	20	3,800
				2–20–70	8.5	30	4,500
				3–17–70	8.6	40	4,500
				4–21–70	8.5	80	4,200
				5–28–70	8.6	10	5,200
				6–26–70	8.5	150	8,000
8cad2[1]	Qt	13	11–13	5–12–68	9.6	10	--------
19abb[1]	Qt	22	9–22	8–21–68	8.9	20	2,400
				4–23–69	11.8	70	2,400
21cad	KJcm	3,100	-------	9–17–68	--------	<10	485
				4–23–69	--------	<10	480
21ccd2[1]	Qt	50	27–42	6– 7–68	25.6	200	--------
				8–21–68	26.3	120	3,900
				4–23–69	25.5	120	3,600
25aaa	Qt	69	-------	8–27–68	34.8	20	2,900
				4–24–69	37.7	<10	2,800
29aac[1]	Qt	Spring	-------	6–13–67	Flowing	100	3,590
				8–29–68	Flowing	50	3,600
				4–25–69	Flowing	30	3,500
30add[1]	Qt	11	-------	6–13–67	6.1	30	1,740
				8–28–68	7.2	10	1,650
				4–30–69	8.5	10	1,650
30bcc[1]	Qal	32	12–32	8–22–68	3.1	20	>8,000
				4–24–69	2.0	<10	8,000
31dcd[1]	Kc	22	-------	8–28–68	5.9	<10	6,000
				4–25–69	4.1	<10	4,200
32aaa1[1]	Qt	68	-------	8–29–68	26.0	10	1,300
				4–25–69	25.9	20	1,170
32cbc2	Kf	735	250–735	5–25–67	Flowing	20	2,830
				5– 2–68	Flowing	<10	--------
33aaa1[1]	Qt	57	24–41	6– 7–68	7.9	90	4,300
34–81–13ccb[1]	Qal	47	21–46	8–20–68	4.5	370	6,000
				4–23–69	3.4	640	7,000
23cbb[1]	Qs	18	6–16	8–22–68	4.9	80	6,900
				4–24–69	5.9	400	3,800
23ddd3[1]	Qal	48	-------	5–24–67	6	1,100	7,180
				5– 2–68	6	540	--------
				5–27–68	6	630	--------
25bbb[1]	Qal	44	23–43	6–12–68	5.3	190	--------
				7–29–68	3.0	210	6,400
				8–20–68	2.9	140	6,000
				9–26–68	4.1	560	6,000
				10–29–68	4.5	850	6,100
				11–21–68	5.0	90	6,000
				12–18–68	4.7	550	6,000
				1–29–69	4.8	270	6,000
				2–26–69	5.0	260	5,900
				3–19–69	5.3	300	5,900
				4–23–69	4.8	800	5,500
				5–27–69	4.5	120	6,200
				6–25–69	3.1	180	6,200
				7–23–69	3.3	220	6,800
				8–20–69	3.7	90	6,500
				9–26–69	4.7	840	6,400
				11– 7–69	4.7	220	6,400
				12– 2–69	4.9	320	6,300

TABLE 2.—*Data for wells and springs where ground water was analyzed for selenium, in and near the Kendrick Project*—Continued

Location	Geologic source	Well depth (ft)	Casing interval open (ft)	Date	Depth to water below land surface (ft)	Selenuim (µg/l)	Specific con-ductance (micromhos per cm at 25°C)
34-81-25bbb[1]—Con.							
				12-31-69	5.1	890	6,500
				1-20-70	5.2	350	6,000
				2-20-70	5.7	220	7,000
				3-17-70	5.0	350	7,000
				4-21-70	4.7	530	6,500
				5-28-70	4.5	720	7,000
				6-26-70	4.1	1,300	>8,000
26bbb[1] --	Qs	39	-------	8-29-68	18.1	540	5,900
				4-30-69	17.9	1,800	5,000
36ccb[1] --	Kc	32	-------	8-22-68	2.8	<10	6,000
				4-24-69	1.3	<10	5,000
35-80-30bcc[1] --	Qal	34	17-32	8-22-68	12.2	10	5,600
				4-23-69	12.9	30	4,900
35-81- 7bbb ---	Qal	49	40-42	6- 9-68	10.5	20	--------
				7-31-68	11.0	20	4,900
				8-21-68	11.2	10	5,000
				9-26-68	11.4	20	5,000
				10-29-68	11.3	20	4,600
				11-21-68	11.3	10	4,500
				2-18-68	11.2	<10	4,500
				1-29-69	11.1	<10	4,500
				2-26-69	11.1	10	4,200
				3-19-69	11.1	<10	4,200
				4-23-69	11.0	10	4,100
				5-27-69	11.0	10	4,500
				6-25-69	10.8	<10	4,600
13ddd[1] --	Qt	17	4-6	8-21-68	3.5	40	5,000
				4-23-69	3.1	20	--------
35-81-30ccc ---	Qal	28	23-25	6- 9-68	4.6	60	--------
				7-31-68	5.0	60	>8,000
				8-21-68	6.1	110	>8,000
				9-26-68	6.3	70	>8,000
				10-29-68	5.9	30	>8,000
				11-21-68	6.1	80	>8,000
				12-18-68	5.6	<10	>8,000
				1-29-69	5.4	10	>8,000
				2-26-69	5.4	30	>8,000
				3-19-69	5.5	10	8,200
				4-23-69	5.0	70	>8,000
				5-27-69	3.4	40	>8,000
				6-25-69	4.4	<10	>8,000
36ccc[1] --	Kc	23	-------	8-22-68	4.9	220	>8,000
				4-23-69	3.7	1,000	>8,000
36-81-20aca --	Qal	25	15-21	6- 9-68	7.1	30	--------
				8-21-68	9.8	10	4,600
				9-26-68	10.1	30	4,400
				10-29-68	10.1	20	3,600
				11-21-68	10.5	10	3,500
				12-18-68	10.5	10	3,500
				1-29-69	10.7	10	3,500
				2-26-69	10.9	10	3,300
				3-19-69	11.1	10	3,300
				4-23-69	10.5	<10	3,300
				5-27-69	11.0	<10	3,600
				6-25-69	10.7	10	3,900

[1] Ground water at this location probably receives recharge from irrigation water.
[2] Water sample bailed from well prior to pumping
[3] Water sample collected after pumping well 40 minutes with air.
[4] Tap water collected at Casper municipal pump station.

specific conductances during the irrigation season indicate that recharge from irrigation water improves the quality of the ground water.

Well 34–80–8cad1 (pl. 3).—There appears to be a slight upward trend of the selenium concentration in this well during the period of record. Apparently, there is no seasonal variation in the concentration of selenium. The specific conductance of the water was higher each year during the irrigation season.

Well 34–80–33aaa2 (pl. 3).—There is some fluctuation of the selenium concentrations in this well, but no definite trend is apparent. There was a significant increase in the specific conductance after April 1969.

Well 34–80–33ccc1 (pl. 3).—Fluctuation of the selenium concentration makes it difficult to recognize an overall trend, but it appears there is a slight upward trend after late 1968. The specific conductance of the water has been increasing since early 1969.

Well 34–81–25bbb (pl. 3).—Fluctuations of the selenium concentration in this well prohibit defining a trend for the period of record. A definite increase in the specific conductance is indicated.

It is evident from plate 3 that the quality of the water (indicated by specific conductances) and selenium concentration vary at different depths in the same aquifer. In fact, it was found that the specific conductance and selenium concentration in the water produced from one open interval in a well can vary over a short period of time.

On November 3, 1970, water was produced from well 32–81–7ccc with a centrifugal pump for about one-half hour, then with air for another 2½ hours. Water samples were collected periodically with the following results:

Sample	Hour	Temperature (°C)	Specific conductance (micromhos per cm at 25° C)	Selenium (μg/l)	Remarks
--	0900	---	-----	----	Started producing with centrifugal pump.
--	0905	---	7,400	----	
1	0915	10.5	7,400	900	Samples 1 and 2 were identical samples collected with a centrifugal pump; sample 2 was aerated, and sample 1 was not.
2	0915	10.5	7,400	840	
3	0930	9.0	12,500	1,900	Collected with centrifugal pump.
--	1100	8.5	13,000	----	Started pumping with air at 1045.
4	1240	10.0	10,500	2,100	
5	1315	10.0	9,600	2,100	

The water samples were probably composite samples of the saturated interval from 13 to 28 feet below land surface even though the well screen is from 26 to 28 feet. The selenium concentrations in the rock samples from this well ranged from less than 10 to 130 μg/kg (table 1). The highest concentration was found in the rock sample taken below the water table.

Well 33–81–16bcb1 was also sampled repeatedly November 3, 1970. Air was used to pump the well for 2¼ hours. The results of the sampling are as follows:

Sample	Hour	Temperature (°C)	Specific conductance (micromhos per cm at 25°C)	Selenium (μg/l)	Remarks
--	1435	9.5	7,250	----	Started pumping with air at 1430.
--	1437	9.5	7,200	----	Color: yellow.
6	1440	8.5	7,200	1,400	Do.
--	1442	9.0	7,300	----	Color: clear.
--	1445	9.5	7,200	----	
--	1500	9.5	7,200	----	
--	1515	9.5	7,200	----	
7	1525	9.5	7,100	960	
--	1535	9.5	6,900	----	
--	1630	9.75	7,200	----	
--	1635	9.5	7,100	----	Specific conductance measured after surging the well.
8	1645	9.5	7,200	1,000	

The selenium concentration and specific conductance of the water in well 33–81–16bcb1 vary but to a lesser degree than in well 32–81–7ccc. Well 33–81–16bcb1 along Poison Spider Creek is completed in alluvium, and permeable sand and gravel allow good mixing of water before it reaches the well screen set about 60–62 feet below the water level. The water samples are probably representative of the water moving in the lower part of the saturated section. Nearby well 33–81–16bcb2, about 50 feet east of well 33–81–16bcb1 penetrates about 2 feet into the saturated zone. The specific conductance of water from well 33–81–16bcb2 has never exceeded 3,400 micromhos per centimeter (pl. 3), and the selenium concentration has never been more than 190 μg/l during the period of record.

The changes in selenium content and specific conductance noted when pumping wells 32–81–7ccc and 33–81–16bcb1 for a short period of time indicate that the water in the aquifer is not in chemical equilibrium. A similar lack of chemical equilibrium in other areas could account for the wide range of selenium content and specific conductance found in the water from some wells. Long-term records of frequent sampling would be required to predict accurately the trend of selenium concentration throughout much of the study area. Because of the possibility that nonequilibrium conditions exist throughout much of the area, conclusions in this report about selenium trends are somewhat speculative.

Of the 17 observation wells in areas where chemical quality is influenced by irrigation, five of the wells are in areas that indicate a trend of increasing selenium concentration in the ground water; five of the wells are in areas where the trend of selenium concentration is masked by fluctuating concentrations; and seven of the wells are in areas that have consistently low selenium concentration (generally 10 μg/l or less), where there is no change in trend.

Of the five observation wells outside the influence of irrigation, four wells are in areas where the ground water has low concentrations of selenium (generally 10μg/l or less), and no change in trend was indicated. The selenium concentration was higher in the other well, but the period of record was too short to detect a trend.

SURFACE WATER

The North Platte River is the principal stream in the area. Between Alcova Reservoir and the eastern boundary of the study area, the North Platte River is fed by many small tributaries and drainage ditches. Facing downstream, the principal tributaries from the right are Bates Creek, Matheson Creek, Webb Draw, Squaw Creek, Wolf Creek, and Garden Creek; from the left are Lone Tree Gulch, Poison Spring Creek, Poison Spider Creek, Oregon Trail Drain, and Casper Creek. Of the streams flowing from the right, only the quantity and quality of water flowing in Bates Creek would be appreciably affected by irrigation. Surface water used for irrigation along Bates Creek is diverted from Bates Creek and not the North Platte River. All the principal tributaries from the left are influenced by irrigation from Casper Canal, as most of their flow is drainage from irrigation on the Kendrick Project.

SURFACE-WATER SAMPLING

Surface-water sampling on a monthly basis was started in

April 1968 at 11 locations (pl. 2) and continued through June 1969. After June 1969, seven stations were discontinued. These stations were on streams that generally showed low concentrations of selenium (10 μg/l or less) and no indication of change in trend.

The results of the streamflow and selenium data for the stations sampled on a monthly basis are given in table 3 and are shown graphically on plate 3. These graphs are intended to illustrate fluctuations and possible trends. For convenience, the data for a particular month are plotted at the end of the month. It was found that Poison Spring Creek, Poison Spider Creek, Oregon Trail Drain, and Casper Creek are the principal tributaries which contribute selenium to the North Platte River in the study area.

Discharge measurements at Poison Spring Creek (pl. 3) indicate a relatively constant streamflow rate except in April 1968. The high discharge at that time was caused by precipitation runoff. Surface runoff could be the cause of the high concentration of selenium during the high flow. No other correlation is apparent between discharge and selenium concentration during the period of record. The selenium load that was being transported by the stream at the time each sample was collected was calculated and is given in pounds per day (pl. 3). The selenium load appears to trend slightly downward (pl. 3) during approximately the first year of sampling and slightly upward during the second year.

There is no apparent correlation between discharge and selenium concentration at Poison Spider Creek near Goose Egg (pl. 3). Generally, the highest discharges are during the irrigation season. The selenium load appears to have had a decreasing trend during the first year of sampling and an increasing trend during the last year of sampling.

The highest discharges from Oregon Trail Drain (pl. 3) occur during the irrigation season. Generally, selenium concentration decreases during periods of high discharge and increases during low periods of discharge. Although no conclusion can be drawn from such a short record, it appears that the most selenium is being transported in late winter and early spring during the period of low flows.

The discharge from Casper Creek at Casper (pl. 3) fluctuates considerably. The changes generally correlate with the irrigation practices; discharge increases in summer and decreases in winter. There is little correlation between discharge and selenium concentration.

Selenium concentrations are consistently low in the North Platte River at Alcova (pl. 3) and below Casper (pl. 3), which are

TABLE 3.—*Selenium analyses of surface water at selected sites in and near the Kendrick Project*

Station No.: See plate 2 for location of station.
Discharge: Streamflow at time sample collected indicates estimated discharge (E).

Station	Stream	Date	Discharge (cfs)	Water temperature (°C)	Selenium (µg/l)
6-6420.00	North Platte River at Alcova	11-27-67	1,200	---	<10
		2- 6-68	845	3	<10
		4-11-68	1,320	3	10
		5-21-68	952	12	<10
		6-21-68	1,190	8	<10
		7-23-68	1,910	---	<10
		8-19-68	2,040	16	10
		9-18-68	1,950	16	<10
		10-18-68	935	16	<10
		11-18-68	1,010	7	<10
		12-23-68	888	2	<10
		1-17-69	800	2	<10
		2-17-69	944	1	<10
		3-18-69	900	2	<10
		4-19-69	1,160	6	<10
		5-19-69	1,560	8.5	<10
		6-18-69	2,430	12.5	<10
Mile 0.54	Casper Canal Near Alcova	8-26-68	227	17	[1]10
Mile 12.50	Casper Canal near Alcova	8-26-68	150(E)	17	[1]10
Mile 34.44	Casper Canal near Mills	8-27-68	159	18	[1]10
At 15 ft weir.	Johnson Lateral near Bishop	8-27-68	82.7	19	[1]<10
At weir	Lateral 328 near Illco	8-27-68	9.3	19	[1]10
6-6420.10	Pete's Draw near Alcova[2]	5- 1-69	.02	16	750
6-6420.60	Lone Tree Gulch near Alcova[2]	10-16-67	1(E)	14	80
		11-27-67	.5	---	50
		2- 6-68	.37	4	60
		4-11-68	1.28	14	20
		5-21-68	.42	14	10
		6-21-68	3.32	16	10
		7-23-68	2.98	21	10
		8-27-68	2.60	18	20
		9-24-68	1.03	12	20
		10-31-68	.91	9	10
		11-26-68	1.11	2	50
		12-23-68	.69	5	10
		1-20-69	.68	5	40
		2-24-69	.37	8	10
		3-25-69	.50	4	10
		4-21-69	.38	13	20
		5-22-69	.28	14.5	10
		6-23-69	.28	21.5	10
6-6430.00	Bates Creek near Alvoca[2]	2- 6-68	12.3	2	10
		4-11-68	43.3	10	<10
		5-21-68	53.0	9	10
		6-18-68	.76	24	10
		7-23-68	.42	24	<10
		8-27-68	.88	16	<10
		9-24-68	10.9	8	<10
		10-31-68	12.5	9	<10
		11-26-68	20.9	1	<10
		12-26-68	18.3	0	<10
		1-20-69	22.1	3	<10
		2-25-69	18.5	6	10
		3-25-69	14.5	4	<10
		4-21-69	20.1	11	<10
		5-23-69	.06	20.5	10
		6-23-69	.04	18	10
6-6430.60	Poison Spring Creek at Casper Canal near Alcova.[2]	5- 1-69	.26	13	<10
6-6430.75	Poison Spring Creek tributary below Rasmus Lee Lake near Alcova [2]	4-22-69	.03	17	<10
6-6431.00	Poison Spring Creek near Alcova.[2]	10-16-67	.05	11	180
		11-27-67	.5	---	220
		2- 5-68	1(E)	3	230
		4- 9-68	8.97	14	60
		5-22-68	.94	17	140
		6-18-68	.98	16	80
		7-24-68	1.10	14	100
		8-26-68	.75	17	140

TABLE 3.—*Selenium analyses of surface water at selected sites in and near the Kendrick Project*—Continued

Station	Stream	Date	Discharge (cfs)	Water temperature (°C)	Selenium (µg/l)
6-6431.00—Con.					
		9-25-68	.93	7	30
		10-31-68	1.33	9	80
		11-26-68	.77	1	180
		12-26-68	.95	2	30
		1-20-69	1 53	6	200
		2-24-69	.98	6	60
		3-25-69	1.31	4	30
		4-21-69	.91	14	130
		5-23-69	.61	21	40
		6-24-69	.91	17.5	80
		7-24-69	.55	20.5	10
		8-19-69	1.30	21.5	10
		9-25-69	.69	16.5	260
		11- 6-69	1.04	6	70
		12- 1-69	1.02	3.5	10
		12-30-69	.81	1.5	290
		1-19-70	1.14	3.5	40
		2-19-70	.90	---	50
		3-16-70	1.14	9.5	140
		4-20-70	1.27	7.0	270
		5-27-70	.79	21	260
		6-25-70	2.36	22	70
6-6439.00	Poison Spider Creek near Mills	4- 9-68	8.66	9	20
		5-20-68	3.71	17	<10
		6-18-68	1 37	19	10
		7-24-68	.11	22	<10
		8-26-68	.09	18	<10
		9-25-68	.13	12	10
		10-31-68	.47	9	<10
		11-25-68	.81	1	10
		12-26-68	0	---	---
		1-20-69	.95	0	<10
		2-25-69	.98	0	10
		3-26-69	3.32	8	<10
		4-21-69	.52	21	10
		5-23-69	.30	25.5	10
		6-24-69	.09	17.5	20
6-6439.55	Poison Spider Creek above Clevidence Draw near Mills.[2]	4-23-69	1.42	22	10
6-6439.70	Poison Spider Creek below Clevidence Draw near Goose Egg.[2]	4-23-69	1.95	21	20
6-6439 80	Poison Cpider Creek above Iron Creek near Goose Egg.[2]	4-23-69	2.51	18	<10
6-6439.90	Iron Creek near Goose Egg[2]	4-23-69	.02	22	30
6-6440.00	Poison Spider Creek near Goose Egg.[2]	7-21-67	11	24	60
		11-27-67	4	---	160
		2- 5-68	7.16	6	120
		4- 9-68	14.9	13	40
		5-20-68	8.99	17	100
		6-18-68	10.9	14	50
		7-24-68	12.6	14	20
		8-26-68	13.4	20	70
		9-24-68	9.21	15	120
		10-31-68	8.41	11	20
		11-26-68	7.38	1	100
		12-26-68	7 85	1	30
		1-20-69	8.13	8	30
		2-25-69	6.53	7	30
		3-26-69	7.64	8	<10
		4-22-69	6.22	21	<10
		5-23-69	7.78	19	20
		6-24-69	10.2	14.5	110
		7-23-69	13.3	25	30
		8-19-69	13 5	20.5	20
		9-25-69	8.77	15.5	170
		11- 6-69	8.82	10	50
		12- 1-69	8.14	6	40
		12-31-69	7 36	3.5	200
		1-19-70	7.15	5.5	30
		2-19-70	6.98	4.0	90
		3-16-70	7.89	8.0	170
		4-20-70	9.55	8.0	170

TABLE 3.—*Selenium analyses of surface water at selected sites in and near the Kendrick Project*—Continued

Station	Stream	Date	Discharge (cfs)	Water temperature (°C)	Selenium (µg/l)
6–6440.00—Con.		5–27–70	16.0	8.0	90
		6–25–70	10.8	18.5	40
6–6440.10	Matheson Creek at Goose Egg	8–28–68	.18	12	10
		4–22–69	.15	14	<10
6–6440.20	North Platte River tributary near Goose Egg.	9–19–68	.12	8	<10
		4–22–69	.09	22	<10
6–6440.25	Webb Draw near Goose Egg	8–27–68	.04	18	10
		4–22–69	.08	21	<10
6–6440.30	North Platte River tributary near Mills.	2– 6–68	.05	0	<10
		4–11–68	.86	14	10
		5–22–68	.25	21	<10
		6–18–68	.05	28	<10
		7–24–68	0	---	---
		8–26–68	.21	21	10
		9–24–68	0	---	---
		10–31–68	<.10	2	<10
		11–26–68	0	---	---
		12–23–68	0	---	---
		1–20–69	.21	1	<10
		2–25–69	.22	7	<10
		3–25–69	.13	1	<10
		4–22–69	.03	20	<10
		5–23–69	.03	11	<10
		6–23–69	0	---	---
6–6440.34	Oregon Trail Drain at Poison Spider Road near Mills [2]	4–23–69	.01	21	10
6–6440.37	Lovelace-Meyer Drain near Mills.[2]	4–24–69	.10	13	300
6–6440.40	Oregon Trail Drain near Goose Egg.[2]	10–17–67	1(E)	2	540
		11–27–67	2	---	940
		2– 5–68	.24	0	810
		4– 9–68	2.84	2	(2)
		5–20–68	.54	12	800
		6–17–68	4.13	19	340
		7–24–68	5 41	---	80
		8–26–68	11.1	13	20
		9–25–68	3.23	11	50
		10–31–68	1.66	6	280
		11–25–68	1.56	0	<10
		12–23–68	.82	0	10
		1–21–69	3.41	0	190
		2–24–69	1.83	0	950
		3–26–69	3.50	1	200
		4–24–69	.37	17	390
		5–22–69	1.87	25	210
		6–26–69	7.25	10.5	40
		7–24–69	9.18	25	10
		8–20–69	12.1	22	<10
		9–26–69	4.33	15	150
		11– 7–69	1.53	7	120
		12– 2–69	1.50	0	130
		12–31–69	.24	0	700
		1–19–70	.33	.5	110
		2–20–70	3.03	0	160
		3–17–70	1.52	.5	300
		4–21–70	1.46	16.5	910
		5–28–70	10.1	14	230
		6–26–70	9.98	26	50
6–6440.50	Squaw Creek near Casper	9–18–68	.01	13	<10
		4–22–69	.05	13	<10
6–6440.60	Wolf Creek near Casper	9–18–68	.76	14	10
		4–22–69	1.29	12	<10
6–6440.80	Garden Creek at Casper	9–18–68	.27	14.5	10
		4–22–69	2.82	8	<10
6–6441.20	Middle Fork Casper Creek near Bucknum.	4– 9–68	4.37	3	<10
		5–20–68	.20	16	<10
		6–17–68	.86	18	10
		7–24–68	0	---	---
		8–26–68	0	---	---
		9–25–68	0	---	---
		10–31–68	.03	8	<10
		11–25–68	.07	2	<10

TABLE 3.—*Selenium analyses of surface water at selected sites in and near the Kendrick Project*—Continued

Station	Stream	Date	Discharge (cfs)	Water temperature (°C)	Selenium (µg/l)
6–6441.20—Con.					
		12–23–68	0	---	---
		1–21–69	.34	1	<10
		2–24–69	.02	0	<10
		3–26–69	.31	1	<10
		4–21–69	.12	13	10
		5–22–69	.11	21	10
		6–25–69	.41	17	10
6–6441.30	Middle Fork Casper Creek near Illco.	4–25–69	.01	4	<10
6–6444.20	Casper Creek near Bishop[2] ------	4–30–69	2.66	21	80
6–6444.40	Johnson Reservoir No. 2 drain near Bishop.[2]	4–30–69	.36	21	80
6–6444.50	Casper Creek above Sixmile Draw near Mills.[2]	4–30–69	3.08	14	30
6–6444.70	Sixmile Draw tributary near Mills.[2]	4–30–69	.01	16	90
6–6444.80	Sixmile Draw above Johnson Lateral near Mills.[2]	4–30–69	.50	21	1,200
6–6444.90	Sixmile Draw near Mills[2] -----	4–24–69	1.24	13	190
6–6445.00	Casper Creek at Casper[2] ------	10–17–67	10(E)	3	200
		11–27–67	4	---	240
		2– 5–68	10.9	4	210
		4– 9–68	11.6	2	([3])
		5–20–68	6.30	9	240
		6–17–68	14.4	---	130
		7–23–68	9.56	29	30
		8–26–68	15.3	12	20
		9–25–68	8.82	16	50
		10–31–68	7.56	6	60
		11–25–68	8.62	1	120
		12–23–68	5.26	0	50
		1–21–69	13.9	2	60
		2–24–69	11 7	1	110
		3–26–69	9.19	1	20
		4–24–69	6.03	13	20
		5–22–69	10.1	23	80
		6–26–69	21.3	13	30
		7–24–69	24.7	29.5	20
		8–20–69	12.0	24.5	10
		9–25–69	9.65	11.5	90
		11– 7–69	8.33	9	20
		12– 2–69	7.81	0	30
		12–31–69	4.64	0	50
		1–20–70	5.39	5.5	60
		2–20–70	18.4	3.5	30
		3–17–70	11.8	2.0	390
		4–21–70	20.1	15.5	190
		5–28–70	50.0	16	30
		6–26–70	19.4	30	60
	North Platte River diversion recharge water).[2]	10–17–67	--------	7	20
		8–29–68	--------	17	<10
		4–23–69	--------	13	<10
	North Platte River at American Oil Refinery.[2]	11–27–67	1,200	---	10
	North Platte River at Casper municipal pump station.[2]	3–29–68	--------	---	20
6–6450.00	North Platte River below Casper[2]	5– 3–68	1,143	9	10
		5–29–68	877	14	<10
		6–17–68	618	19	10
		7–19–68	1,990	19	<10
		9– 9–68	2,080	---	10
		10–15–68	1,760	12	<10
		11–27–68	1,080	1	10
		12–23–68	1,000(E)	0	<10
		1–22–69	1,070	1	<10
		2–26–69	1,090	3	<10
		3–21–69	1,030	6	<10
		4– 9–69	1,410	6	10
		6– 2–69	1,910	14	<10
		6–13–69	2,450	9	<10

[1] Water sampled is irrigation water before being used on croplands.
[2] Water quantity and quality influenced by drainage from irrigation.
[3] Sample accidentally destroyed.

stations above and below the irrigation project. The high concentrations of selenium entering the North Platte from tributaries in the study area are diluted to low concentrations by the larger flow in the river; thus, the selenium contributed by tributaries is almost undetectable after mixing with water in the North Platte.

MASS WATER SAMPLING

Mass water sampling was done in August and September 1968, at the end of the irrigation season. The samples, 106 ground water and 23 surface water, including Casper Canal, were analyzed for selenium. The analyses are given in tables 2 and 3 along with other selenium analyses obtained since 1967.

Water-level measurements made in wells at the time of the mass sampling were used to prepare a contour map of the water-level surface of much of the area. (See pl. 1.) The direction of ground-water movement was determined from the contours. The location of hydrologic boundaries, formed by ground-water divides and streams, was interpreted from the contour map (pl. 1). These boundaries are shown on plate 2. This information was used as a guide for the mass sampling done in the spring of 1969 before irrigation started.

In total, 110 ground-water samples and 34 surface-water samples were collected in April and May 1969. Where possible, surface-water samples were collected near the hydrologic boundaries (pl. 2). These samples indicate the changes, if any, of selenium concentration in the stream caused by ground-water contributions. Some of the streams were sampled only at points where most or all of the water in the stream was return flow from irrigation.

Water samples from 123 locations were collected both in the fall (August and September) of 1968 and in the spring of 1969 (April and May) during the mass sampling. These included 105 samples of ground water and 18 samples of surface water. These samples were separated into two categories: Category A includes those samples of water that were probably influenced by surface-water irrigation, and category B includes those samples that were not influenced by irrigation.

Comparison of the changes in selenium concentration by categories is given in the table on page 36.

Slightly more than half (57 percent) of the samples were collected from areas influenced by irrigation. The remaining sam-

Category A (samples influenced by irrigation)

Change in selenium concentration from the fall of 1968 to the spring of 1969		Number of ground-water locations	Average net change	Number of surface-water locations	Average net change	Total locations	Percent
Increase	>10 µg/l	19	640 µg/l	1	370 µg/l	20	29
Decrease	>10 µg/l	23	80 µg/l	1	70 µg/l	24	34
Change	≤10 µg/l	20	-------	6	-------	26	37
		62	-------	8	-------	70	------

Category B (samples not influenced by irrigation)

Change in selenium concentration from the fall of 1968 to the spring of 1969		Number of ground-water locations	Average net change	Number of surface-water locations	Average net change	Total locations	Percent
Increase	>10 µg/l	1	30 µg/l	0	-------	1	2
Decrease	>10 µg/l	14	30 µg/l	0	-------	14	26
Change	≤10 µg/l	28	-------	10	-------	38	72
		43	-------	10	-------	53	-------

ples (43 percent) were collected from areas not influenced by irrigation.

In category A, approximately the same number of locations showed an increase, a decrease, and little (10 µg/l or less) or no change in selenium concentration in the ground water. Most of the locations where surface water was sampled showed little or no change from fall to spring. In category B, the water at 72 percent of all the locations showed little (10 µg/l or less) or no change between the two seasons.

It may be important to note the high average net changes in selenium concentrations in areas influenced by irrigation. Of those locations where the ground water showed an increase in selenium concentration, there was an average net increase of 640 µg/l, and, of those locations where the ground water showed a decrease in selenium concentration, there was an average net decrease of 80 µg/l. By comparison, ground water sampled in areas not influenced by irrigation had much smaller net changes.

The results of the mass sampling show that irrigation is affecting the selenium content of some waters in the area, but it is difficult to sort out definite effects of irrigation on the occurrence and movement of selenium in the area, for the selenium concentration in water at locations in category A increased at 29 percent of the locations, decreased at 34 percent of the locations, and had little or no change at 37 percent of the locations. The changes of selenium concentrations caused by irrigation are probably local and thus differ from location to location. A single general statement cannot be made that would be applicable to the entire irrigated area concerning the effects of irrigation on the selenium concentration in waters of the area. Irrigation undoubtedly has accelerated the movement of selenium within and from the irrigated area.

SUMMARY AND CONCLUSIONS

Selenium in concentrations exceeding the maximum limit recommended by the U.S. Public Health Service is present in some waters in areas near Casper, Wyo. Surface water brought into the area for irrigation does not contain significant amounts of selenium, but the water is applied to some land containing soluble selenium. The result is that some of the selenium is taken into solution and carried to the ground-water system, thence into the streams.

No geologic formation or area consistently contains high concentrations of selenium, but high concentrations were found at points throughout the area. Probably, the rocks in any locality could be the source of selenium in the water in the surrounding vicinity.

The quality and quantity of ground water within the Kendrick Project are influenced by irrigation water. In some areas irrigation causes increased mineralization of the ground water because of minerals leached from the soil. In other areas, recharge to aquifers from irrigation improves the quality of the ground water. The quantity of ground water in storage has increased because recharge by surface-water irrigation has saturated some rocks that were previously unsaturated.

The water in some aquifers has not reached chemical equilibrium, which could account for the wide range of selenium concentrations found in the water from some wells. Frequent sampling over a long period of time would be required to predict accurately the trend of selenium concentrations in much of the study area. It is possible that nonequilibrium conditions exist in aquifers throughout much of the area; therefore, the statements in this report about trends in selenium concentrations are somewhat speculative.

Poison Spring Creek, Poison Spider Creek, Oregon Trail Drain, and Casper Creek are the principal tributaries that contribute selenium to the North Platte River. The selenium load transported in Poison Spring Creek and Poison Spider Creek decreased slightly during the first year and increased slightly during the second year of sampling. The selenium load transported in Oregon Trail Drain is greatest in late winter and early spring during the period of low flow. The selenium load in Casper Creek fluctuates, but there is little correlation between stream discharge and selenium concentration. The selenium concentration was consistently low (10 μg/l or less) in the North Platte River above and below the irrigation project during the period April 1968 through June 1969. The total selenium load contributed to the North Platte River within the study area is almost undetectable after mixing with the river water.

Irrigation practices cause changes in the selenium concentration in some waters of the area. The selenium concentration in waters from areas influenced by irrigation increased at 29 percent of the locations (average net increase of 640 μg/l), decreased at 34 percent of the locations (average net decrease of 80 μg/l), and had little (10 μg/l or less) or no net change at 37 percent of the locations from the fall of 1968 to the spring of 1969. As a comparison, the selenium concentration in waters from areas not influenced by irrigation increased at 2 percent of the locations (average net increase of 30 μg/l), decreased at 26 percent of the locations (average net decrease of 30μg/l), and had little or no net change at 72 percent of the locations from the fall of 1968 to the spring of 1969. It is not possible to make a general statement that would be applicable to the entire Kendrick Project concerning the effects of irrigation on the selenium concentration in waters of the area; however, irrigation undoubtedly has accelerated movement of selenium within and from the irrigated areas.

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UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
WYOMING STATE ENGINEER
CITY OF CASPER BOARD OF PUBLIC UTILITIES
WYOMING GAME AND FISH COMMISSION
WYOMING DEPARTMENT OF HEALTH

WATER-SUPPLY PAPER 2023
PLATE 1

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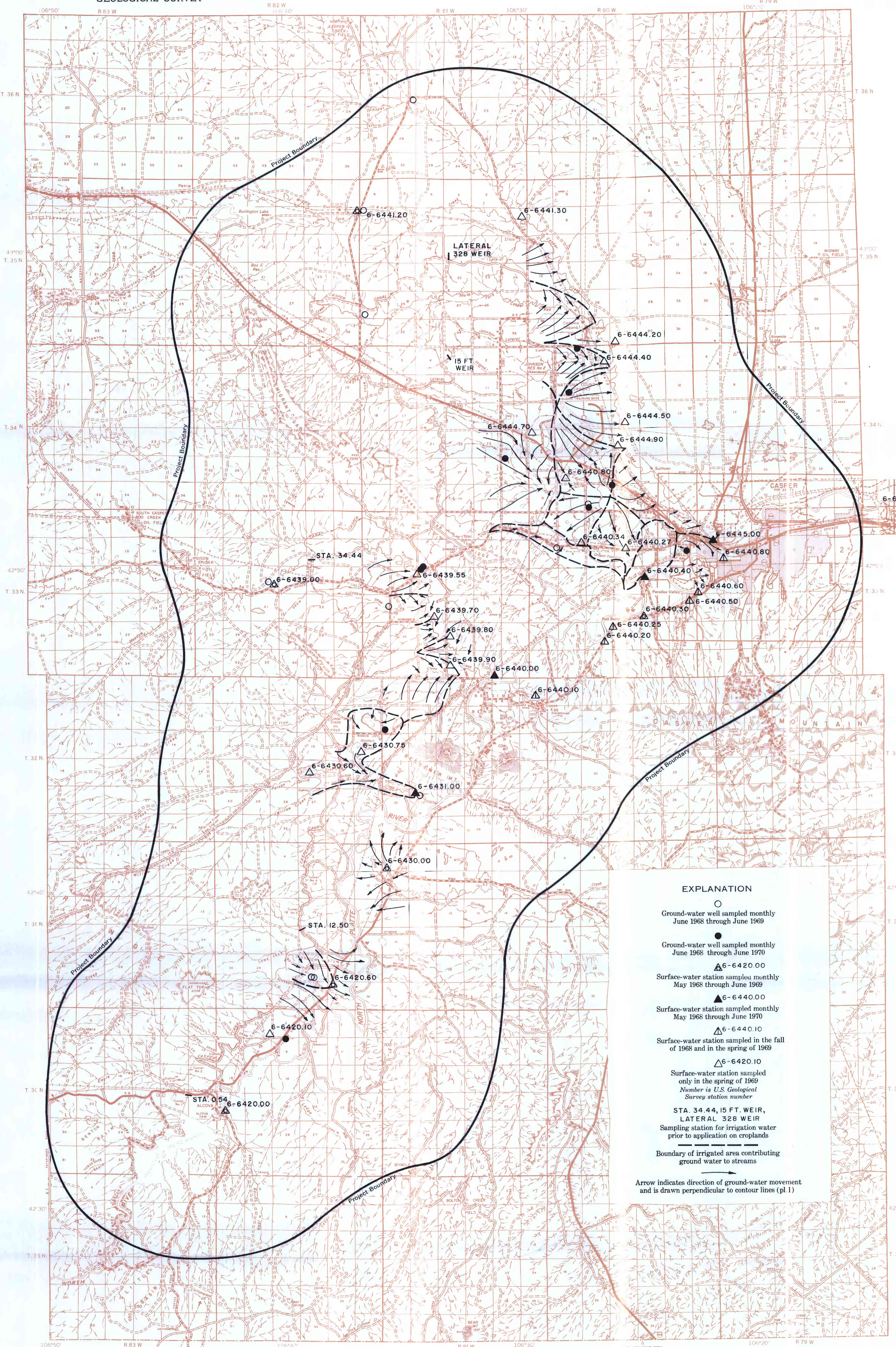
Hydrology by Marvin A. Crist, 1971
Geology adapted from published sources indicated on index map

GEOHYDROLOGIC MAP OF THE AREA OF SELENIUM INVESTIGATION IN NATRONA COUNTY, WYOMING

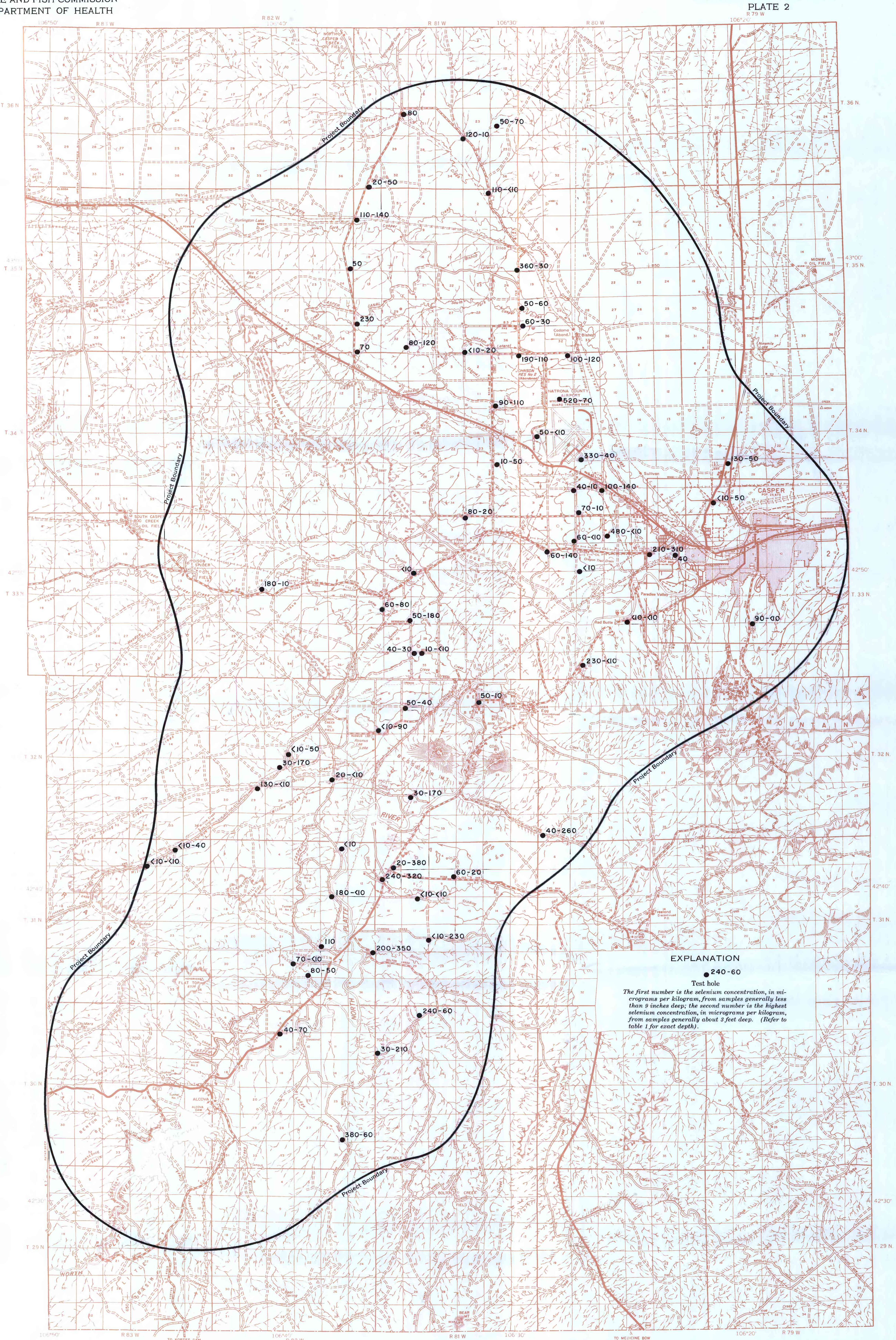
PREPARED IN COOPERATION WITH THE
WYOMING STATE ENGINEER
CITY OF CASPER BOARD OF PUBLIC UTILITIES
WYOMING GAME AND FISH COMMISSION
WYOMING DEPARTMENT OF HEALTH



Base map prepared and copyrighted by the Wyoming Highway Department, 1956, with all rights reserved: published with permission

A. LOCATION OF SELECTED SAMPLING STATIONS USED FOR SELENIUM ANALYSIS OF GROUND AND SURFACE WATER

Hydrology by Marvin A. Crist, 1971



B. DISTRIBUTION AND RANGES OF SELENIUM CONCENTRATION IN ROCK SAMPLES ABOVE THE WATER TABLE

Prepared by Marvin A. Crist, 1971

SCALE 1:125 000

2 0 2 4 6 8 10 MILES

2 0 2 4 6 8 10 KILOMETERS

HYDROLOGIC MAPS OF THE AREA OF SELENIUM INVESTIGATION IN NATRONA COUNTY, WYOMING

U.S. GOVERNMENT PRINTING OFFICE: 1974 O—585-468/10

PREPARED IN COOPERATION WITH THE
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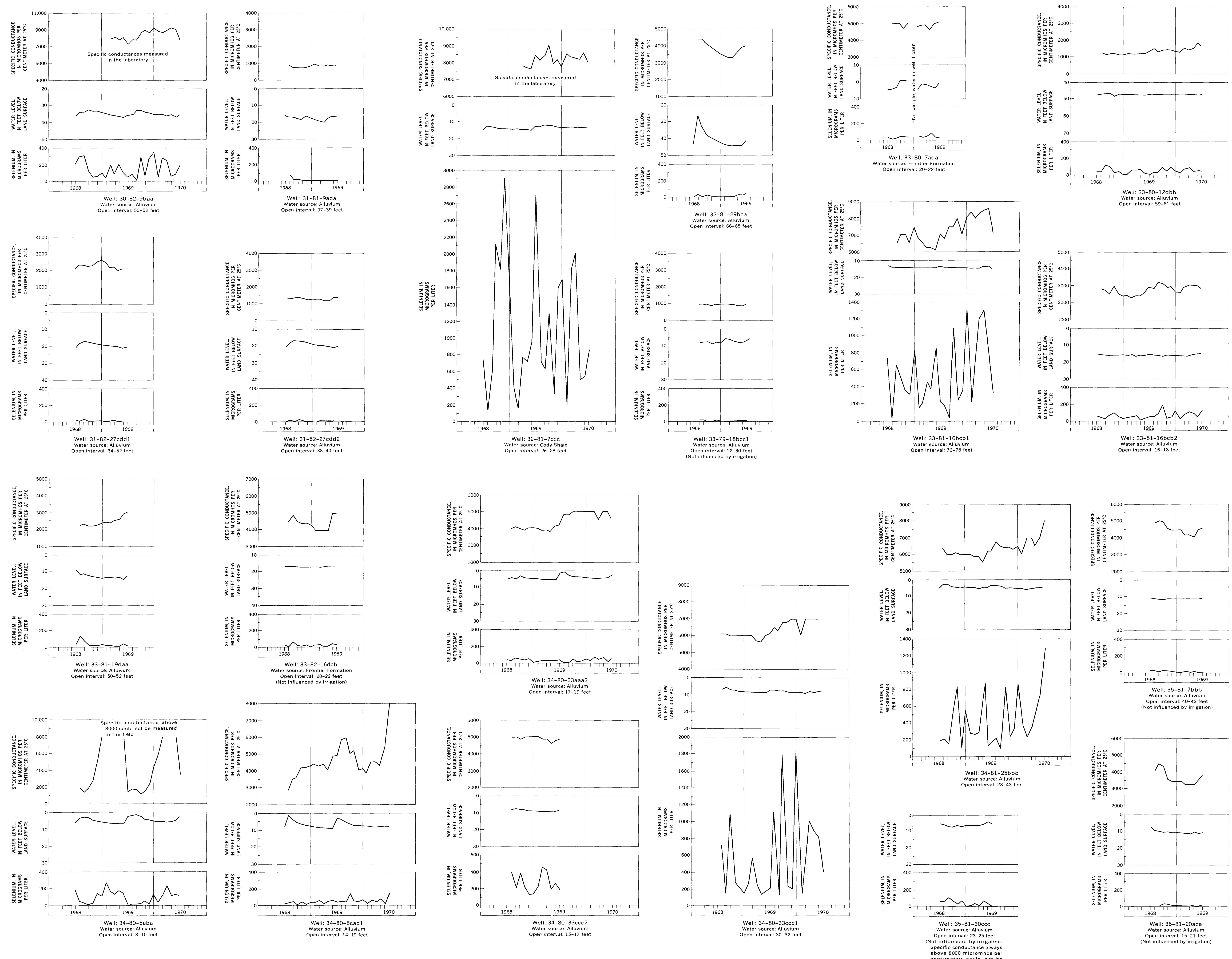
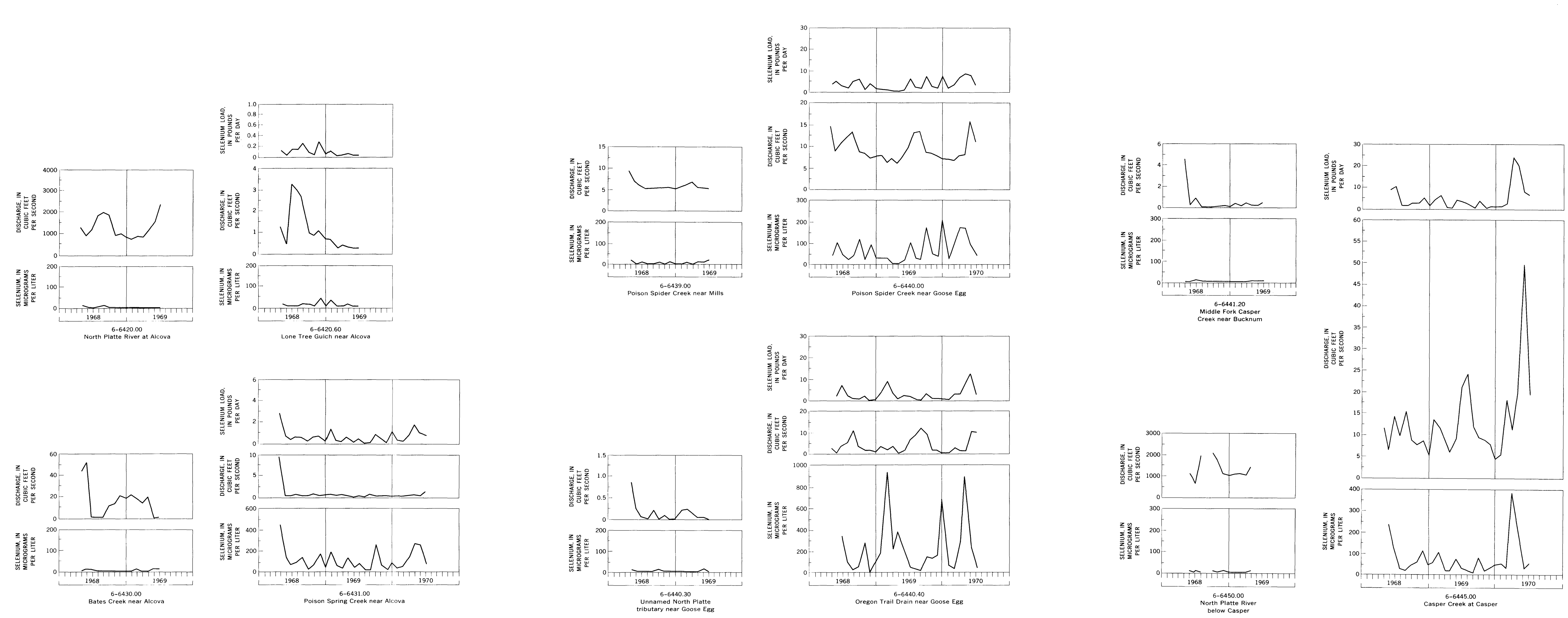
WYOMING GAME AND FISH COMMISSION
WYOMING DEPARTMENT OF HEALTH



A. OBSERVATION WELLS



B. SURFACE-WATER SAMPLING SITES

GRAPHS SHOWING SELENIUM CONCENTRATION AND RELATED HYDROLOGIC DATA FOR SELECTED OBSERVATION WELLS AND SURFACE-WATER SAMPLING SITES IN THE AREA OF SELENIUM INVESTIGATION IN NATRONA COUNTY, WYOMING

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