SELENIUM AND ASSOCIATED TRACE ELEMENTS IN SOIL, ROCK, WATER AND STREAMBED SEDIMENT OF THE PROPOSED SANDSTONE RESERVOIR, SOUTH-CENTRAL WYOMING

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
acre	4,047	square meter
acre	0.4047	hectare
acre-foot	1,233	cubic meter
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
gallon	3.785	liter
inch	2.54	centimeter
mile	1.609	kilometer
square mile	2.590	square kilometer
ton (short, 2,000 pounds)	0.9072	megagram

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = 5/9\ (°F - 32)$$

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = 9/5\ (°C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviations

kg/d	kilogram per day
mg/kg	milligram per kilogram
mg/L	milligram per liter
mm	millimeter
pCi/L	picocurie per liter
µg/L	microgram per liter
µm	micrometer
µS/cm	microsiemens per centimeter at 25 degrees Celsius

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ABSTRACT

The proposed Sandstone Reservoir is currently (1990) being considered by the Wyoming Water Development Commission to store unused and unappropriated water in the Little Snake River drainage basin in south-central Wyoming. The reservoir, on Savery Creek about 10 miles upstream from the confluence with the Little Snake River, would impound 52,000 acre-feet of water. As part of the environmental assessment for the project, the U.S. Geological Survey investigated the possible effects that filling the reservoir might have on selenium and associated trace-element concentrations in reservoir water and bottom sediment.

The mean concentration of selenium (0.38 milligrams per kilogram) in soil samples collected inside the proposed reservoir boundary was slightly larger than the mean concentration of selenium in soils from selected areas of Montana and Wyoming. Results of sequential extractions on six soil samples indicate the largest concentrations of selenium are associated with the more resistant geochemical phases. These resistant phases will not be readily soluble during initial saturation of the soils by water from the reservoir.

The concentration of selenium in most of the samples of clastic rocks collected in the drainage basin of the proposed Sandstone Reservoir generally was within the normal range of values reported for similar lithofacies in Upper Cretaceous and Tertiary rocks of the Western United States (0.1 to 1.0 milligrams per kilogram). Substantial selenium enrichment (up to 150 milligrams per kilogram) was determined for uranium-bearing rocks collected near the Ketchum Buttes uranium deposits in the reservoir drainage basin.

Concentrations of selenium, arsenic, molybdenum, and uranium in water samples from the study area did not exceed the U.S. Environmental Protection Agency recommended maximum concentration for public-water supplies. The largest concentrations of dissolved plus suspended selenium (3 milligrams per liter) and arsenic (22 milligrams per liter) and gross-alpha activity were determined for water samples from streams that drain the Ketchum Buttes uranium deposits. Concentrations of total arsenic, total uranium, and suspended gross-alpha activity in surface-water samples were related positively to discharge during runoff from lowland snowmelt in the reservoir drainage basin.

Concentrations of selenium and arsenic in streambed-sediment samples from inside the drainage basin of the proposed reservoir decreased (selenium decreased from 1 to less than 0.5 milligrams per kilogram and arsenic decreased from 7 to 5 milligrams per kilogram--both in the less than 53-micrometer size fraction) in a downstream direction toward the proposed

damsite. The largest concentrations of selenium (1.1 milligrams per kilogram) and arsenic (7.0 milligrams per kilogram) were determined in streambed-sediment samples from Little Savery Creek, which receives weathered detrital material from the Ketchum Buttes uranium deposits. Selenium concentration (0.1 to 1.1 milligrams per kilogram) in streambed-sediment samples from streams in the drainage basin of the proposed reservoir usually was less than the selenium concentration (0.9 to 85 milligrams per kilogram) in bottom-sediment samples from areas in Wyoming and Utah that possess potential selenium toxicity to plants and animals.

INTRODUCTION

The Wyoming Water Development Commission is currently (1990) considering the construction of a reservoir to store unused and unappropriated water resources in the Little Snake River basin, south-central Wyoming, for both in-basin and out-of-basin needs. The proposed Sandstone Reservoir would store runoff from most of the Savery Creek drainage basin (fig. 1). Marine rocks of Cretaceous age, the Browns Park Formation of Tertiary age, and alluvial and landslide deposits of Quaternary age derived from these rocks are present in and near the proposed reservoir (pl. 1). On the basis of data in Anderson and others (1961, p. 13-22), sediments deposited by Cretaceous seas in the Western United States are locally seleniferous and are potential parent materials of seleniferous soils. Furthermore, concentrations of selenium greater than 100 mg/kg have been reported in rock samples from the Browns Park Formation upgradient of the proposed reservoir (Dribus and Nanna, 1982, p. 62).

Water from the proposed Sandstone Reservoir will flood soils and rock outcrops containing potentially large concentrations of selenium. Flooding of seleniferous soils could increase the selenium and associated trace-element concentrations in the reservoir water by dissolution, desorption, and oxidation of selenium-bearing materials. The reservoir also has the potential to receive increased amounts of selenium from weathering and washoff of seleniferous materials in the drainage area of the proposed reservoir. By determining the selenium available for dissolution, desorption, and oxidation in the area flooded by the proposed Sandstone Reservoir and in the drainage area of the proposed reservoir, the potential for water-quality degradation can be assessed and possible mitigation implemented. An investigation conducted by the U.S. Geological Survey in cooperation with the Wyoming Water Development Commission was designed to provide information about the potential for selenium and associated trace elements to contaminate water stored in the proposed Sandstone Reservoir.

Purpose and Scope

This report describes the range of selenium and associated trace-element concentrations in soil, rock, water, and streambed-sediment samples in the drainage area of the proposed Sandstone Reservoir. The concentrations of selenium and associated trace elements were determined only for soil samples collected in the area to be flooded by the proposed reservoir. Partial-dissolution techniques were used to determine the potential for the dissolution and mobilization of total selenium in soils to be flooded by reservoir water.

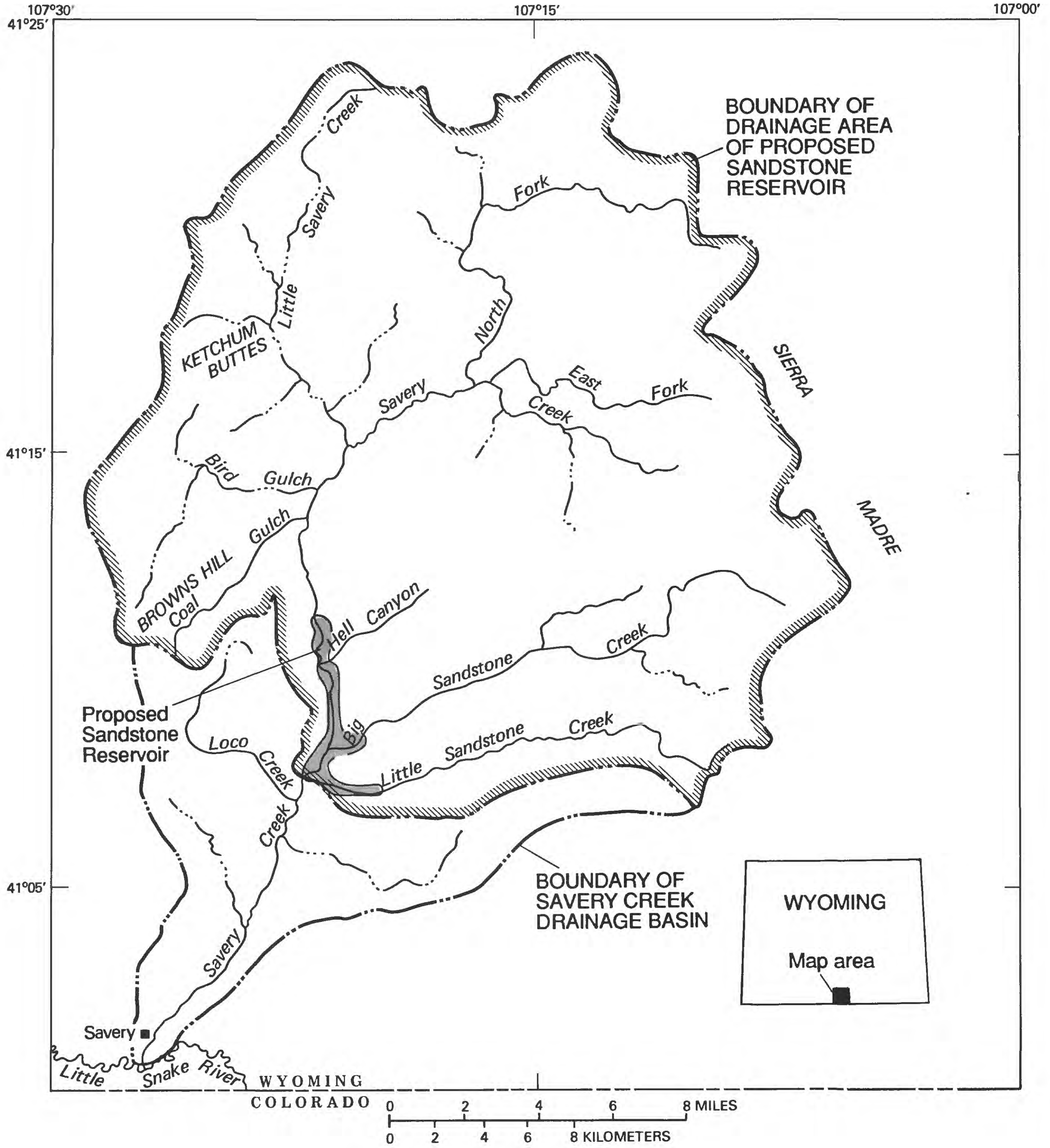

Figure 1.--Location of the study area.

The geology of the area surrounding the proposed reservoir was mapped in detail to define the distribution of rocks that might be potential sources of selenium and associated trace elements. Surface water was sampled during April and part of May 1987 to determine if runoff from lowland snowmelt and associated surface runoff contribute large amounts of selenium and associated trace elements to water and streambed sediments in and adjacent to the proposed reservoir site. Surface-water sampling to determine temporal changes in concentrations of selenium and associated trace elements in streamflow was beyond the scope of this study.

Description of Study Area

The proposed Sandstone Dam and Reservoir are in the Savery Creek drainage basin about 8.5 miles northeast of the town of Savery, Wyo. (fig. 1). The proposed damsite crosses Savery Creek immediately downstream from the confluence of Savery Creek and Little Sandstone Creek (pl. 1). The zoned earthfill dam will be about 200 feet high and 3,100 feet long and will impound an estimated 52,000 acre-feet of water over an area of 960 acres at a normal high water level of 6,932 feet above sea level (U.S. Army Corps of Engineers, 1987). The reservoir will have a drainage area of about 280 square miles and will extend upstream on Savery Creek for about 5 miles, upstream Big Sandstone Creek for about 1 mile, and upstream Little Sandstone Creek for about 2 miles.

Savery Creek flows generally to the southwest from its origin along the western flank of the Sierra Madre (fig. 1). Principal tributaries include North and East Forks of Savery Creek, Little Savery Creek, and Big Sandstone and Little Sandstone Creeks. Streamflow records for Savery Creek and other streams in the Little Snake River drainage basin indicate that the volume of annual flow may vary substantially (Stone and Webster Engineering Corp., 1987). Streamflow in the Savery Creek drainage basin is derived primarily from spring snowmelt. Low flows occur during the summer months and are decreased by irrigation diversion in the basin.

The semiarid climate in the Savery Creek drainage basin is characterized by low precipitation, rapid rates of evaporation, and large daily temperature variations. The average annual precipitation at Dixon, 11 miles southwest of the study area, from 1951 to 1980, was 11.6 inches (U.S. Department of Commerce, 1982). Areas at higher elevations in the Sierra Madre east of Savery Creek may receive as much as 35 inches of precipitation annually. The average annual Class-A pan evaporation rate for May through October 1951 to 1980 was estimated to be about 45 inches (Farnsworth and Peck, 1982).

Summers in the Savery Creek drainage basin are usually mild and dry; winters are generally cold. The frost-free period at Dixon is about 86 days. The mean July temperature at Dixon is reported to be 63.5 °F, and the daily July temperatures ranges from a low of 47.5 °F to a high of 83.0 °F (U.S. Department of Commerce, 1982). January temperatures typically range from 3.9 °F to a high of 32.1 °F, with a monthly mean of 18.0 °F for 1951 to 1980 (U.S. Department of Commerce, 1982).

Geology

The rocks exposed in the study area range in age from Precambrian to Quaternary (fig. 2). Precambrian igneous and metamorphic rocks (Divis, 1976; Houston and Ebbett, 1977) comprise the exposed core of the Sierra Madre. Precambrian rocks crop out in part or all of the areas where North Fork and East Fork of Savery Creek, Savery Creek, and Big Sandstone Creek originate. Exposed sedimentary rocks of Triassic and Jurassic age and some of Cretaceous age (Thermopolis and Mowry Shales, and the Frontier and Niobrara Formations) are present only along the upper part of Big Sandstone Creek; because of their small areal extent, they are not described in this report. Cretaceous rocks are exposed along the western tributaries to Savery Creek, the main stem of Savery Creek, Big Sandstone Creek, and Little Sandstone Creek. The Browns Park Formation of late Oligocene and Miocene age is the most exposed geologic unit in the study area. Quaternary deposits are present along many of the creeks and along some upland areas; only the most extensive deposits are shown in figure 2.

The exposed core of the Sierra Madre uplift is composed of Precambrian igneous and metamorphic rocks (Divis, 1976; Houston and Ebbett, 1977). The sedimentary rocks that flank the Sierra Madre and underlie the eastern part of the Washakie Basin range in age from Cambrian to Miocene (Barlow, 1953; Buffler, 1967; Ritzma, 1949; Vine and Prichard, 1959).

Previous Investigations

Most of the geologic literature for the general area of the proposed Sandstone Reservoir was written to characterize and evaluate coal deposits in the Little Snake River coalfield. The first comprehensive regional report to include most of the Savery Creek drainage basin was prepared by Ball and Stebinger (1910). Barclay (1976) completed a detailed geologic map that includes the area to be inundated by the proposed reservoir with the exception of the valley of Little Sandstone Creek. Geologic data from the shallow subsurface for rocks and sediments in the proposed reservoir area are included in reports prepared during preliminary feasibility studies related to reservoir construction (Rollins, Brown, and Gunnell, Inc., 1982; Stone and Webster Engineering Corp., 1986). Data on rocks exposed in the western part of the drainage basin are in reports on deeper test drilling as part of stratigraphic-framework and coal-resource investigations (Barclay, 1979; Barclay and Shoaff, 1977 and 1978).

A geologic map of the western part of the Savery Creek drainage basin is included in a report by Barclay and others (1978, pl. 2). Graff (1978), Houston and Ebbett (1977), and Houston and others (1978) compiled the geology for the eastern part of the Savery Creek drainage basin as part of an investigation of the uranium mineralization in the Sierra Madre. Vine and Prichard (1959) prepared a geologic map that includes the northern edge of the drainage basin in conjunction with a study of uranium occurrences in rocks of late Tertiary (Neogene) age that crop out along the Continental Divide south of Rawlins, Wyo. Additional regional geologic information of significance to this study is contained in reports by Dribus and Nana (1982), Gill and others (1970), Hale (1961), Weitz and Love (1952), Weimer (1961), and Welder and McGreevy (1966).

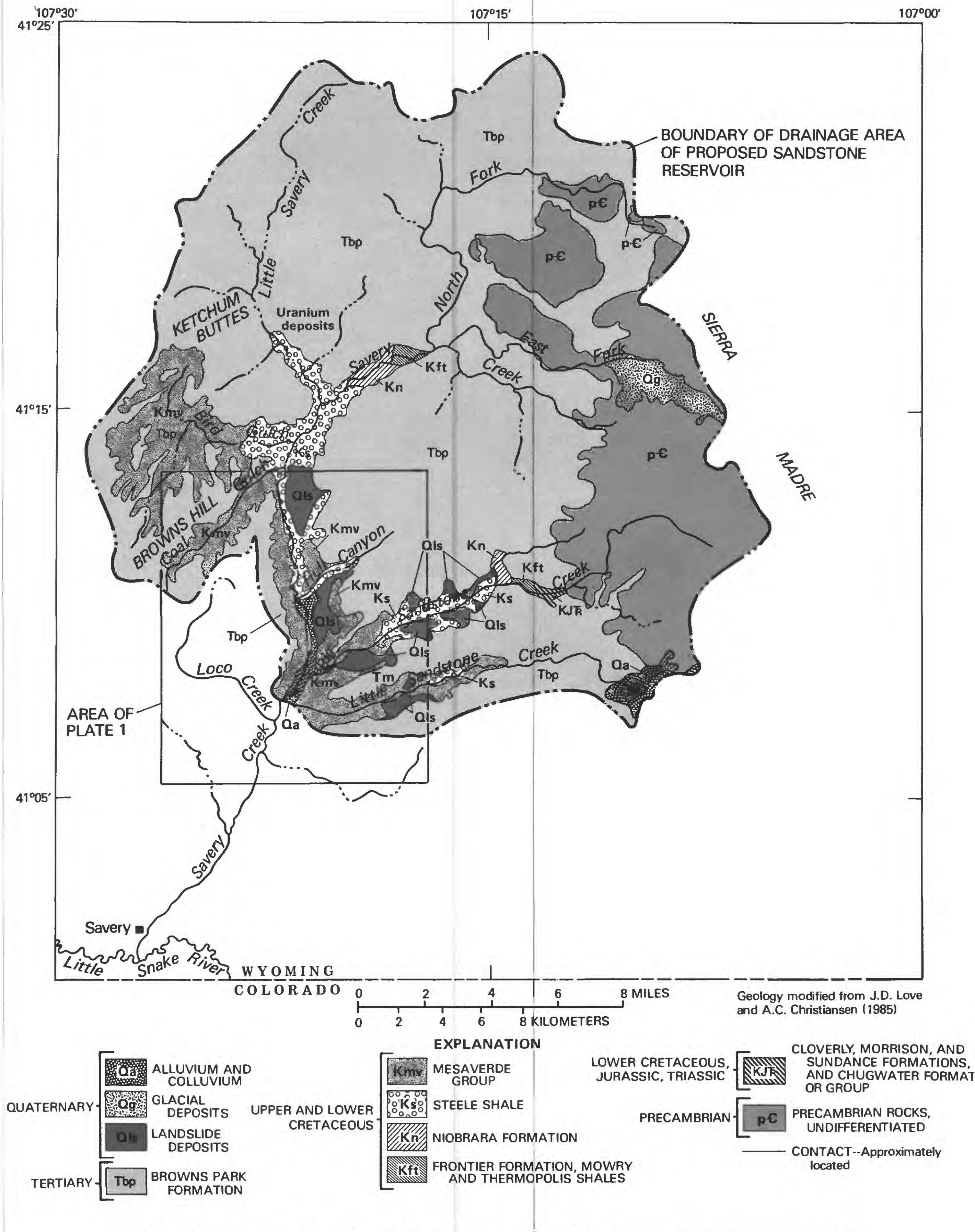

Figure 2.--Generalized geology of the drainage area of the proposed Sandstone Reservoir.

Stratigraphy

The Steele Shale and Mesaverde Group of Late Cretaceous age and the Browns Park Formation of late Tertiary age constitute the principal stratigraphic units that crop out in the vicinity of the proposed Sandstone Reservoir (pl. 1). Quaternary deposits of several types, including landslides, are prevalent locally. Plate 1, which consists of a preliminary geologic map, map explanation, and columnar sections, shows the distribution and stratigraphic relations of the rock formations and sediments at the proposed damsite, along the entire length of the canyon of Savery Creek, and in adjacent areas of the Tullis, Browns Hill, Savery, and Grieve Reservoir 7 1/2-minute quadrangles. It was compiled by the second author of this report from published (Barclay, 1976) and unpublished (including Barclay and others, 1978) maps, from stratigraphic information developed in the late 1970s and early 1980s during the conduct of coal-resource investigations (Barclay, 1979, 1980a, 1980b, 1984; Barclay and Shoaff, 1977, 1978; Bryant, 1984), and from the results of photogeologic mapping in November-December 1986 and January 1987. The following discussion of the stratigraphy pertains primarily to the mapped area on plate 1. In this discussion, that part of the valley of Savery Creek that extends from the confluence of Savery Creek and Little Sandstone Creek, upstream to the confluence of Savery Creek and the creek of Coal Gulch is defined as the canyon of Savery Creek.

The marine Steele Shale of early Campanian age (Gill and others, 1970, p. 6) is the stratigraphically lowest outcropping formation in the immediate area of the proposed reservoir. This formation crops out near the bottom of the canyon of Savery Creek and is the substrate for the alluvium from the northern limit of the proposed reservoir to the northern edge of the map (pl. 1); it also occurs along the upper parts of Hell Canyon and Big Sandstone and Little Sandstone Creeks and near the mouth of Coal Gulch. The Steele Shale is composed mostly of dark-gray, generally noncalcareous, montmorillonitic clay-shale with some thin persistent beds of light yellowish-gray bentonite and layers of sparse, light gray, grayish-orange weathering fossiliferous limestone concretions. The upper part of the Steele Shale contains a few thick sequences of light gray, grayish-orange weathering, very-fine and fine-grained glauconitic, ripple-laminated and crossbedded sandstone. The contact of the Steele Shale and the underlying bluish-gray, calcareous shale of the Niobrara Formation is gradational. At the top, the Steele Shale is thinly interbedded with siltstone and sandstone and grades up into the overlying Deep Creek Sandstone Member of the Haystack Mountains Formation of the Mesaverde Group. Electric logs from Quintana Petroleum Corporation's oil and gas test hole in the SW 1/4, sec. 34, T. 14 N., R. 88 W. indicate that 4 miles east of the proposed reservoir site the Steele Shale is about 3,075 feet thick.

The upper Campanian Mesaverde Group in south-central Wyoming generally is composed of the Haystack Mountains Formation, the Allen Ridge Formation, the Pine Ridge Sandstone, and the Almond Formation, in ascending stratigraphic order (Gill and others, 1970, p. 5-6). In the map area (pl. 1), the Mesaverde Group is composed of the following units: the Haystack Mountains Formation; a unit consisting of the lower, nonmarine part of the Allen Ridge Formation; and a unit consisting of the upper, marine and marginal marine parts of the Allen Ridge Formation, strata possibly equivalent to the Pine Ridge Sandstone, and the Almond Formation.

The Haystack Mountains Formation crops out along the entire length of Savery Creek, and the formation comprises the lower canyon walls in the area of the proposed reservoir. The formation also is exposed along the major tributaries of Savery Creek, including Coal Gulch, Hell Canyon, and Big Sandstone and Little Sandstone Creeks.

The Haystack Mountains Formation was deposited in marine and marginal-marine environments and in the map area is composed principally of two alternating lithofacies--a sandstone lithofacies, which forms prominent, persistent cliffs in the canyon of Savery Creek, and a shale lithofacies, which forms the intervening slopes (see columnar sections on pl. 1). The sandstone lithofacies primarily is composed of thick sequences of light gray, grayish-orange to light-yellowish-gray weathering, reverse graded, very fine to medium-grained, crossbedded sandstone. This sandstone is composed mostly of detrital quartz, chert, and minor feldspar. The sandstone is cemented by quartz overgrowths and clay minerals, and less commonly, by calcite. Some sandstone is glauconitic.

The shale lithofacies consists predominantly of gray, generally noncalcareous clay-shale, mud-shale, and clayey silt-shale, which commonly contain thin layers of sparse, light gray, fossiliferous limestone and limy mudstone concretions and much less commonly, thin sandstone beds. Shale lithofacies generally are in sharp contact with underlying sandstone lithofacies, but at their top, generally grade into overlying sandstone lithofacies within 2- to 20-foot-thick sequences of thinly interbedded and interlaminated shale, siltstone, and very fine-grained sandstone.

In Savery Creek canyon and adjacent areas, the Haystack Mountains Formation is 950 to 990 feet thick (Barclay, 1976; Gill, 1974) and is divided into three parts (Barclay, 1976), each of which contains both sandstone and shale lithofacies. The lower part consists, in ascending order, of (1) the Deep Creek Sandstone Member of Hale (1961), 120 to 140 feet thick, which is in gradational contact with the underlying Steele Shale and which for mapping purposes only (pl. 1) is included in the Steele Shale; (2) an informal shale member, about 315 feet thick, consisting of the Espy Tongue (of the Steele Shale) of Hale (1961) and a few minor sequences of thin-bedded sandstone; and (3) the Hatfield Sandstone Member (Gill and others, 1970), 130 to 150 feet thick. The middle part of the Haystack Mountains Formation consists of a lower shale unit, about 114 feet thick, and (2) an upper sandstone unit, about 172 feet thick, which is informally referred to as the sandstone of Savery Creek. The upper part of the Haystack Mountains Formation consists of (1) a shale unit, about 70 feet thick, and (2) a sandstone unit, about 30 feet thick, which contains root traces at the top and is conformably overlain by coal and carbonaceous shale at the base of the Allen Ridge Formation.

The Haystack Mountains Formation, which in the map area (pl. 1) and in nearby areas contains marine fossils of Middle Campanian age (Bader and others, 1983; Barclay, 1976; Gill, 1974; Gill and others, 1970, p. 14-15, 19-20), was deposited during an overall eastwardly retreat of the Cretaceous Western Interior Sea. The Deep Creek Sandstone and each successive sandstone unit is interpreted to be a progradational marine shoreline deposit. Each intervening shale unit is an offshore deposit marking at least a local pause in shoreline progradation, a reversal in the movement of the shoreline, and a marine transgression.

The Allen Ridge Formation conformably overlies the Haystack Mountains Formation, and in most places north of the mapped area (pl. 1) toward Rawlins, Wyo., consists of a thick (1,000-1,200 feet) nonmarine, lower informal member and a much thinner (140-220 feet) marginal marine, upper informal member (Barclay, 1980a, 1980b). In the mapped area, the lower, nonmarine member crops out along the canyons of Savery Creek, Coal Gulch, and Loco Creek, and is composed principally of four lithologies--sandstone, siltstone, mudrock, and coal. These rocks generally comprise graded, fluviatile, channel-fill and overbank sequences of trough-crossbedded sandstone, ripple-laminated sandstone and siltstone, siltstone, and mudstone, which in some places are capped by thin beds of coal or carbonaceous shale. In addition, near the base of the Allen Ridge Formation, these rocks are found in reverse-graded, crevasse-splay sequences of mudstone, interbedded siltstone and sandstone, and crossbedded sandstone, also locally capped by carbonaceous shale or coal. The sandstone weathers yellowish orange to yellowish gray and is calcareous to noncalcareous, very fine to medium grained, and in lenticular units as thick as 40 feet that form resistant ledges and scarps. The siltstone is yellowish orange, clayey, massive to laminated, and flatbedded. Some outcropping siltstone is hard, calcareous, ferrugenous, concretionary, and has a nodular surface. The mudrocks include claystone, mudstone, and shale, and range in color and organic content from olive-gray rocks with no visible organic matter, to grayish-brown rocks with carbonized plant fragments, to blackish-brown carbonaceous rocks streaked with coal. The coal is banded and bright (vitrinitic), dull with little vitrinite, or impure with a substantial quantity of mineral matter.

Most of the lower member of the Allen Ridge Formation probably formed in an alluvial-plain setting behind an eastwardly prograding shoreline. In the area of the proposed reservoir, coal beds about 1 to 4 feet thick, which directly overlie the highest shoreline sandstone of the Haystack Mountains Formation, and an overlying sequence of weakly bioturbated fine-grained beds are probably paralic, delta-plain deposits. In the map area (pl. 1) and adjacent areas, the lower, nonmarine member of the Allen Ridge is middle and late Campanian in age (Bader and others, 1983; Gill and others, 1970, p. 6, 26).

North and west of the map area (pl. 1), that part of the Mesaverde Group above the lower, nonmarine member of the Allen Ridge Formation is composed of, in ascending order, (1) the upper part of the Allen Ridge, a marginal marine unit; (2) the Pine Ridge Sandstone, a nonmarine, fluvial deposit, 40 to 80 feet thick; and (3) the Almond Formation, a marginal marine and marine unit (Barclay, 1980a, 1980b, 1984; Bryant, 1984). In the map area, the Pine Ridge Sandstone was not recognized (Barclay and Shoaff, 1978; Barclay, 1979), and the upper member of the Allen Ridge could not be differentiated from similar deposits in the Almond Formation. As a consequence, the upper member of the Allen Ridge, the Pine Ridge or its possible equivalents, and the Almond Formation are mapped as a single unit (pl. 1), herein referred to as the upper part of the Mesaverde Group.

Rocks of the upper part of the Mesaverde Group are exposed in upper parts of the Loco Creek drainage basin in the southwestern part of the mapped area and of the Coal Gulch drainage basin in the western part of the mapped area (pl. 1). This part of the Mesaverde is composed of at least two thick shoreline sandstones, each of which is overlain by repetitive, reverse graded, crevasse-splay and bay-fill delta sequences that consist of organic-rich brown mudstone; thinly interbedded, ripple-laminated, and bioturbated mudstone, siltstone, and very fine-grained sandstone; and thinly bedded, ripple-laminated, crossbedded, and bioturbated very fine- to fine-grained sandstone. A few of the shoreline sandstone units and many of the splay sequences are capped by thick coal, and in some places are cut by distributary channels filled with trough-crossbedded, graded sandstone. One of the shoreline sandstones, informally referred to as the sandstone of Loco Creek, is at the base of the upper part of the Mesaverde Group and was mapped separately. In Loco Creek, this sandstone is 50 to 55 feet thick, and is locally split by marine shale that is 20 to 30 feet thick.

In south-central Wyoming, the Mesaverde Group generally is overlain conformably by marine shale of the Upper Cretaceous Lewis Shale (Gill and others, 1970, p. 32, 38). The contact of the Mesaverde and the Lewis Shale is not exposed in the map area (pl. 1) but might be beneath about 125 feet of conglomerate and sandstone of the Browns Park Formation in the NW1/4 of section 5, T. 14 N., R. 89 W.

The upper part of the Mesaverde Group is about 820 feet thick near the southwestern corner of the map area on plate 1 (Barclay, 1979). It thickens southward to about 930 feet near Savery (Barclay and Shoaff, 1978, p. 9) and thins northward beyond the map area to 735 to 795 feet west of the head of Bird Gulch (see fig. 3) (Barclay, 1979).

The upper part of the Mesaverde Group is of late Campanian age (Bader and others, 1983; Gill and others, 1970, p. 6-7, 26, 30-31) and was probably deposited on a delta plain and along the associated shoreline during alternating marine transgressions and regressions in the early stage of the last major westward advance of the Cretaceous epeiric sea.

The Browns Park Formation of late Tertiary age overlies Upper Cretaceous rocks in the map area (pl. 1) with angular unconformity. This formation covers the prominent ridges and extensive mesas bordering the canyons of Savery Creek and its principal tributaries in the map area. The Browns Park Formation is composed of two principal lithofacies, a conglomerate lithofacies, which is in the lower part of the formation, and a sandstone lithofacies.

Along the canyon of Savery Creek, the conglomerate lithofacies generally is composed of conglomerate and minor intercalated sandstone beds. The conglomerate weathers dark yellowish orange to yellowish brown and predominantly consists of rounded cobbles and boulders of igneous and metamorphic rocks in a sandy matrix. In most of the map area (pl. 1), the conglomerate contains clasts of quartzite, amphibolite, and red granite, which was probably derived from outcrops in the Red Mountain and Fletcher Park areas in the southern part of the Sierra Madre (Houston and Ebbert, 1977; Houston and others, 1977; Graff, 1979). In the Coal Gulch area and more northerly parts of the Savery Creek drainage basin, the conglomerate generally is gray, and the clasts are mostly amphibolite and quartzite with a minor amount of Paleozoic sandstone and limestone, all derived from the northwestern part of the Sierra Madre.

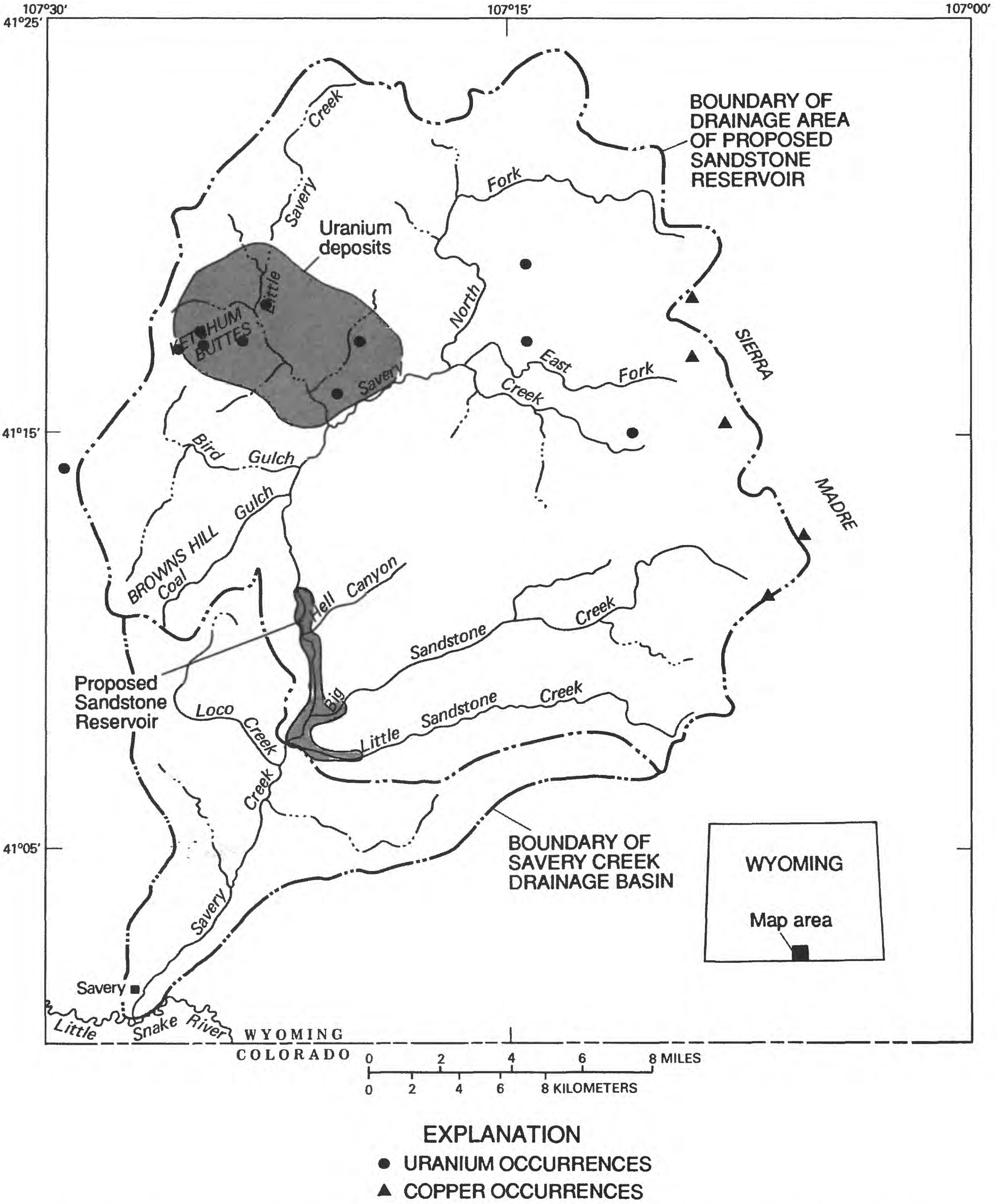

Figure 3.--Uranium and copper occurrences in and adjacent to the drainage area of the proposed Sandstone Reservoir. (Data from Osterwald and others, 1966; area of uranium deposits modified from Dribus and Nanna, 1982.)

In the area of the proposed reservoir, the exposed Browns Park Formation is only 200 to 300 feet thick, and it consists primarily of the conglomerate lithofacies with some thick sequences of the sandstone lithofacies. The conglomerate lithofacies becomes thinner and finer grained, and intertongues with the sandstone lithofacies westward and away from the Sierra Madre. Near Ketchum Buttes, the conglomerate lithofacies is commonly represented by either pebble-conglomerate or a pebbly sandstone, 5 to 10 feet thick, at the base of the formation. To the east in the Sierra Madre, where the Browns Park Formation rests directly on Precambrian rocks, the conglomerate lithofacies generally is absent and sandstone fills topographic lows of the pre-Browns Park erosion surface. The conglomerate lithofacies accumulated probably as coalescing alluvial fans on a surface of little relief at the base of an ancestral Sierra Madre.

The sandstone lithofacies of the Browns Park Formation mostly consists of light gray, light-yellowish-gray weathering, very fine- to coarse-grained sandstone. The sandstone is commonly tuffaceous and clayey, and is locally calcite cemented. In most of the map area (pl. 1), the sandstone is fluvial and trough-crossbedded. South of Loco and Little Sandstone Creeks, the sandstone lithofacies contains both fluvial and large-scale eolian crossbeds. Near Ketchum Buttes and in areas farther north, the sandstone lithofacies of the Browns Park is mostly composed of ripple-laminated and crossbedded sandstone, contains several persistent tuff beds, and in the lower part, intertongues with a lacustrine(?) sequence consisting of grayish-green mudstone, thin white tuffs, and light-gray, tuffaceous, ripple-laminated limestone.

Most of the Browns Park Formation has been eroded from the high tablelands that flank the canyon of Savery Creek. In that area, the thickness of the Browns Park changes westward from about 700 feet on Green Ridge, to 250 to 300 feet near the proposed reservoir, to 100 to 150 feet near the head of Coal Gulch.

The Browns Park Formation in the Savery Creek drainage basin accumulated probably as a sequence of intertonguing bajada and playa-lake deposits that formed on the flanks of an ancestral Sierra Madre and eventually partly filled an ancestral Washakie Basin and partly backfilled valleys in an ancestral Sierra Madre. The Browns Park is considered to be late Oligocene and Miocene in age (Honey and Izett, 1988, p. 10).

Sediments of Quaternary age in the mapped area (pl. 1) consist of floodplain deposits in the valleys of Savery, Big Sandstone, and Little Sandstone Creeks; terrace deposits along Savery Creek; gravels interpreted as pediment deposits; alluvial-fan deposits; landslide deposits; and undifferentiated alluvial and colluvial deposits in the valleys of small streams tributary to Savery, Big Sandstone, and Little Sandstone Creeks. Floodplain sediments in the area of the proposed reservoir are composed primarily of silt, sand, gravel, and some clay. The layers of sand and gravel along Savery Creek are 2 to 26 feet thick, and they are covered by poorly drained organic-rich top soil 4 to 8 feet thick (Rollins, Brown, and Gunnell, Inc., 1982, p. 7).

Many small slumps, mudflows, and debris flows, and some locally extensive composite landslides, some of which contain large coherent blocks of conglomerate from the Browns Park Formation and of sandstone from the Mesaverde Group, are present in the valley of Savery Creek and its tributaries. These features are areally more extensive along the east side of Savery Creek, where springs are numerous near the unconformable contact of the westerly dipping Browns Park Formation and the underlying Cretaceous rocks (Barclay, 1976). Both large, composite landslide deposits and much smaller, discrete slumps and flows are in the vicinity of the proposed reservoir; these features range in size from a few acres to several hundred acres. A minimum of 14 landslides will be at least partially inundated by the reservoir when it is filled to the normal pool elevation (Rollins, Brown, and Gunnell, Inc., 1982, p. 9). Only the large, composite landslide deposits are shown on plate 1.

Occurrence of Coal, Uranium, and Copper

The site of the proposed Sandstone Reservoir is near the eastern margin of the Little Snake River coalfield (Ball and Stebinger, 1910) and the Little Snake River Known Recoverable Coal Resource Area (KRCRA) (Barclay and others, 1978; Dames and Moore, 1979a-e). Coal in the mapped area occurs in the lower part of the Allen Ridge Formation and in the upper part of the Mesaverde Group. A few thin coal beds are exposed near the base of the Allen Ridge Formation on the north side of Big Sandstone Creek in the NW 1/4 sec. 31, T. 14 N., R. 88 W. (pl. 1). Several thick coal seams crop out along Loco Creek above the sandstone of Loco Creek in the upper part of the Mesaverde Group. In the upper part of the Mesaverde Group near Savery, small amounts of coal are currently being mined for local, household use. Coals in the Mesaverde Group vary in rank from volatile bituminous C to subbituminous A (Ball and Stebinger, 1910; Hatch and Barclay, 1979). About 263 million short tons of demonstrated reserve-base coal were identified in the Mesaverde Group in eight recently denied Preference Right Lease Applications south and west of the proposed Sandstone Reservoir site (U.S. Bureau of Land Management, 1988, p. 1).

No occurrences of uranium mineralization have been identified in the area of the proposed Sandstone Reservoir. However, uranium mineralization is regionally ubiquitous (Dribus and Nanna, 1982; Weaver and others, 1978) in the Browns Park Formation, and it has been found in the northern part of the Savery Creek drainage basin (fig. 3). In that area, uranium-bearing minerals are present most commonly as vug and fracture fillings or surface coatings in brecciated and silicified limestone, and to a lesser extent as disseminations in limonitic fluvial sandstone (Vine and Prichard, 1959). Uranophane and meta-autunite are the principal uranium-bearing minerals in the mineralized areas of the Browns Park Formation in, and adjacent to, the drainage basin (Dribus and Nanna, 1982; Finch, 1967). Schroeckingerite, carnotite, weeksite, and sabugalite also have been described as constituents of these uranium-bearing rocks (Dribus and Nanna, 1982; Gruner and others, 1956; Magleby and Mallory, 1954). Small amounts of uranium ore were produced from the Del Oro No. 2 claim near Ketchum Buttes in sec. 8, T. 15 N., R. 89 W., and the Cloudy Group claims in sec. 18, T. 15 N., R. 88 W. (Dribus and Nanna, 1982, p. A-8, A-9; Elevatorski, 1976, p. A-8). Analyses of rock samples collected near Ketchum Buttes indicate a uranium-oxide (U_3O_8) content of 0.02 to 0.8 percent (Magleby and Mallory, 1954, p. 12). Additionally, small amounts of uranium (mostly <0.01 percent U_3O_8) have been detected in both the basal conglomerate and the overlying sandstone unit of the Browns Park Formation south of the map area on plate 1.

Uranium is present in radioactive, Precambrian, quartz-pebble conglomerates that are exposed on the northwestern flanks of the Sierra Madre in the eastern part of the Savery Creek drainage basin (Borgman and others, 1981; Dribus and Nanna, 1982; Graff, 1978; Graff, 1979, p. 149-157; Graff and Houston, 1977; Houston and Ebbett, 1977; Houston and others, 1977; Houston and others, 1978; Karlstrom, Houston, Flurkey and others, 1981; Karlstrom, Houston, Schmidt and others, 1981). The source of the radioactivity is probably the placer concentrations of zircon, a silicate of zirconium with small amounts of uranium; thorium-rich monazite, a phosphate of the cerium (Ce, La, Dy) metals; huttonite(?); a thorium-cerium silicate; and mixtures of monazite and huttonite(?) (Karlstrom, Houston, Flurkey and others, 1981, p. 139-142). Similar Precambrian conglomerates in the Medicine Bow Mountains east of the study area contain the uranium-thorium silicates uranothorite, thorogummite, and coffinite (Houston and others, 1979, p. 38-39). These quartz-pebble conglomerates may be the source for some of the uranium mineralization in the Browns Park Formation in the Ketchum Buttes and adjacent areas of the Savery Creek drainage basin.

Copper and minor amounts of other associated base and precious metals are in the formerly mined deposits in the Encampment Mining District of the Sierra Madre (Spencer, 1904). The copper is primarily in sulfide minerals that are associated with Precambrian mafic igneous rocks (Houston and others, 1975).

Laboratory Methods

The chemical analyses of the soil, rock, and streambed-sediment samples were conducted by the U.S. Geological Survey laboratory in Arvada, Colo., and by the Montana Bureau of Mines and Geology in Butte, Mont. Concentrations of total selenium and arsenic (digestion by nitric, sulfuric, and perchloric acids) were determined by automated continuous-flow hydride generation coupled with atomic absorption spectrometry (Briggs and Crock, 1986). Inductively coupled argon plasma-optical emission spectrometry was used to determine the total concentrations (digestion by aqua regia and hydrofluoric and perchloric acids) of additional and trace elements other than selenium and arsenic (Crock and others, 1983).

Operationally defined geochemical-phase determinations were performed sequentially on selected dried soil samples by the U.S. Geological Survey laboratory in Arvada, Colo., using a procedure developed by Steven Wilson (U.S. Geological Survey, written commun., 1988). The procedure is described in Supplement 1 at back of the report. The selenium concentration of each geochemical phase was determined by hydride generation coupled with atomic absorption spectrometry.

Chemical analyses of the water samples were conducted by the U.S. Geological Survey laboratory in Arvada and by Barringer Laboratories, Inc., Golden, Colo. Dissolved trace-element concentrations were determined by methods described in Skougstad and others (1979). Methods used for the determination of radiochemical concentrations and activities are described in Thatcher and others (1977).

Geochemical data from the NURE (National Uranium Resource Evaluation) program (Dribus and Nanna, 1982) were compiled for areas in the drainage area of the proposed Sandstone Reservoir. Analytical methods that were used for the NURE data are described by Dribus and Nanna (1982, p. 3-6).

OCCURRENCE, MOBILITY, AND TOXICITY OF SELENIUM

Large concentrations of selenium are common in rocks associated with uranium roll-front deposits (Levinson, 1980, p. 880, 885). Roll-front uranium deposits form as oxidizing meteoric solutions moved through the host sandstone and dissolved the readily oxidizable minerals, such as pyrite (Howard, 1977). As a result of the dissolution of pyrite and other minerals, the solution begins to lose its oxidizing potential, resulting in the precipitation of iron, selenium, and uranium minerals. As this process continues over millions of years, selenium becomes increasingly concentrated in the roll-front deposit.

Uranium deposits are present in the Browns Park Formation of Neogene age in south-central Wyoming (Bradley, 1964, p. A57; Dribus and Nanna, 1982, p. 57-65; Osterwald and others, 1966, p. 204-205). Known uranium deposits are in the northwestern part of the drainage area of the proposed Sandstone Reservoir (fig. 3).

The selenium in high-temperature sulfide ores and uranium roll-front deposits is bound in sulfide minerals and is also common as native selenium and selenide minerals (Coleman and Delevaux, 1957; Davidson, 1963; Howard, 1977), such as ferroselite ($FeSe_2$), clausthalite (PbSe), stilleite (ZnSe), cadmoselite (CdSe), berzelianite (Cu_2Se), and eucairite (AgCuSe). Polymetallic sulfide minerals have been noted by Osterwald and others (1966) in the copper mines and prospects in the eastern part of the drainage area of the proposed Sandstone Reservoir area (fig. 3).

Selenium also is associated with fine-grained marine sediments in Upper Cretaceous formations throughout the Western United States (Howard, 1977). Because soils derived from these Cretaceous rocks comprise large areas of farmland in the Western United States, a large volume of selenium data has been collected. Seleniferous soils in Montana, North Dakota, South Dakota, Wyoming, Nebraska, Kansas, and Colorado are derived primarily from sedimentary rocks of Late Cretaceous age (Anderson and others, 1961, p. 24). Rocks of Cretaceous age are present in the drainage area of the proposed Sandstone Reservoir area (fig. 2).

The mobility of selenium in the surficial environment depends on the oxidation state. In oxygenated waters, the Se(IV) oxyanions $HSeO_3^-$ and SeO_3^{2-} are strongly adsorbed by ferric oxides in the pH range of 2 to 8 (Howard, 1977). The selenate Se(VI), oxyanion SeO_4^{2-} is neither strongly adsorbed nor does it form insoluble compounds (Howard, 1977), resulting in its mobility in oxidizing and alkaline waters (Levinson, 1980, p. 880; Rose and others, 1979, p. 23-25). Surface water from the drainage area of the proposed Sandstone Reservoir has a pH greater than 8.0 and total alkalinity (as $CaCO_3$) ranging from 83 to 186 mg/L, creating the potential for the transport of the selenate oxyanion SeO_4^{2-}.

Although selenium is recognized as an essential element in the diets of many species, including humans, it can be toxic in large concentrations (National Academy of Sciences and National Academy of Engineering, 1973, p. 316). The toxic effects of selenium are variable and depend on the chemical species of the selenium, the type and age of the organism affected, the duration of exposure, the type of diet, and the presence and concentrations of other elements, such as arsenic (National Academy of Sciences, 1977). The only documented case of selenium toxicity to humans from a water source (uncomplicated with selenium in the diet) concerned a 3-month exposure to well water with a selenium concentration of 9 mg/L (National Academy of Sciences and National Academy of Engineering, 1973, p. 86). Because of the lack of data on the toxic effects of selenium in humans when ingested with water, it is recommended that public water-supply sources contain no more than 0.01 mg/L selenium (National Academy of Sciences and National Academy of Engineering, 1973, p. 86). It is recommended also that the maximum concentration for selenium in livestock water be 0.05 mg/L (National Academy of Sciences and National Academy of Engineering, 1973, p. 316).

Selenium in water can be toxic in all trophic levels of the aquatic food chain. The ecological effects of selenium on aquatic organisms are summarized by Deverel and others (1984). Selenium may concentrate in primary producers, such as algae, and consequently may be bioconcentrated in more complex organisms, such as invertebrates, fish, and waterfowl. Lemly (1985) determined a bioconcentration factor (the concentration of selenium in the organism divided by the concentration of selenium in the water) of 3,975 for tissue samples from a largemouth bass in a reservoir receiving selenium from fly-ash ponds.

SELENIUM AND ASSOCIATED TRACE ELEMENTS

Soils

The total selenium concentration in soil samples, which were collected inside the boundary of the proposed Sandstone Reservoir during July 1986, ranged from 0.2 to 0.9 mg/kg (table 1). The largest selenium concentrations of 0.9 to 1.3 mg/kg were determined for soil samples from sites SO-28-1, SO-28-2, and SO-40-A (pl. 1). Of the six soil samples with a selenium concentration greater than 0.5 mg/kg, four of the samples were from soils developed from alluvial materials (pl. 1). Large selenium concentration in soils developed from alluvial materials indicates transport of selenium into the area from other areas of the drainage basin. Sources of selenium in the drainage basin include Cretaceous rocks (fig. 2) and uranium and copper occurrences to the north and east of the reservoir (fig. 3).

Leaching of selenium by periodic saturation of and percolation through the alluvial soils could cause selenium to accumulate in deeper soil horizons. According to Ronald Tidball (U.S. Geological Survey, oral commun., 1986), the largest concentration of selenium in soils in the San Joaquin Valley of California was present at 66 to 72 inches below the surface. Four sites, on soils overlying alluvial material inside the proposed reservoir boundary (pl. 1), were sampled to determine the changes in total selenium content with depth. Soil samples were collected at depths to 3.7 feet below the land surface. Although selenium concentration in these samples differed with depth (fig. 4), no distinctive trends were detected, and the selenium concentration did not exceed 0.9 mg/kg.

Table 1.--Total selenium concentration in soil samples from the proposed Sandstone Reservoir area to total selenium concentration in soil samples from selected areas of Wyoming and Montana

[Detection ratio, number of samples with concentrations greater than detection limit to the total number of samples. <, concentration less than indicated detection limit for that analysis]

Sample-collection locality	Detection ratio	Total selenium concentration, in milligrams per kilogram	
		Range	Mean
Proposed Sandstone Reservoir area	40:40	0.2-0.9	0.38
Powder River Basin, Wyoming and Montana[1]	57:64	<0.1-2.2	.30
Big Horn Basin, Wyoming[1]	18:36	<0.1-1.1	.10
Wind River Basin, Wyoming[1]	17:36	0.1-0.4	.10

[1] Data from Ebens and Shacklette (1982)

The mean concentration of total selenium in soil samples from the proposed Sandstone Reservoir area (mean = 0.38 mg/kg, number of samples = 40) was compared to the mean concentration of selenium in soil samples from other areas of Wyoming and Montana (table 1). The mean concentration of selenium in soil samples from inside the proposed reservoir boundary was slightly larger than the mean concentration of selenium in soils from selected areas of Montana and Wyoming.

Soil samples from sites SO-28-1, SO-28-2, and SO-40-A, which have total selenium concentrations of 0.9 to 1.3 mg/kg, were analyzed for an additional 31 trace elements. The results of these additional analyses (table 2) indicate that most concentrations of trace elements were below expected background concentrations in soils. Arsenic and molybdenum concentrations were less than the detection limits of the laboratory analytical method used for the analysis (table 2). Concentrations of barium, chromium, lead, lithium, nickel, vanadium, and zinc were larger than the expected background concentrations in soils.

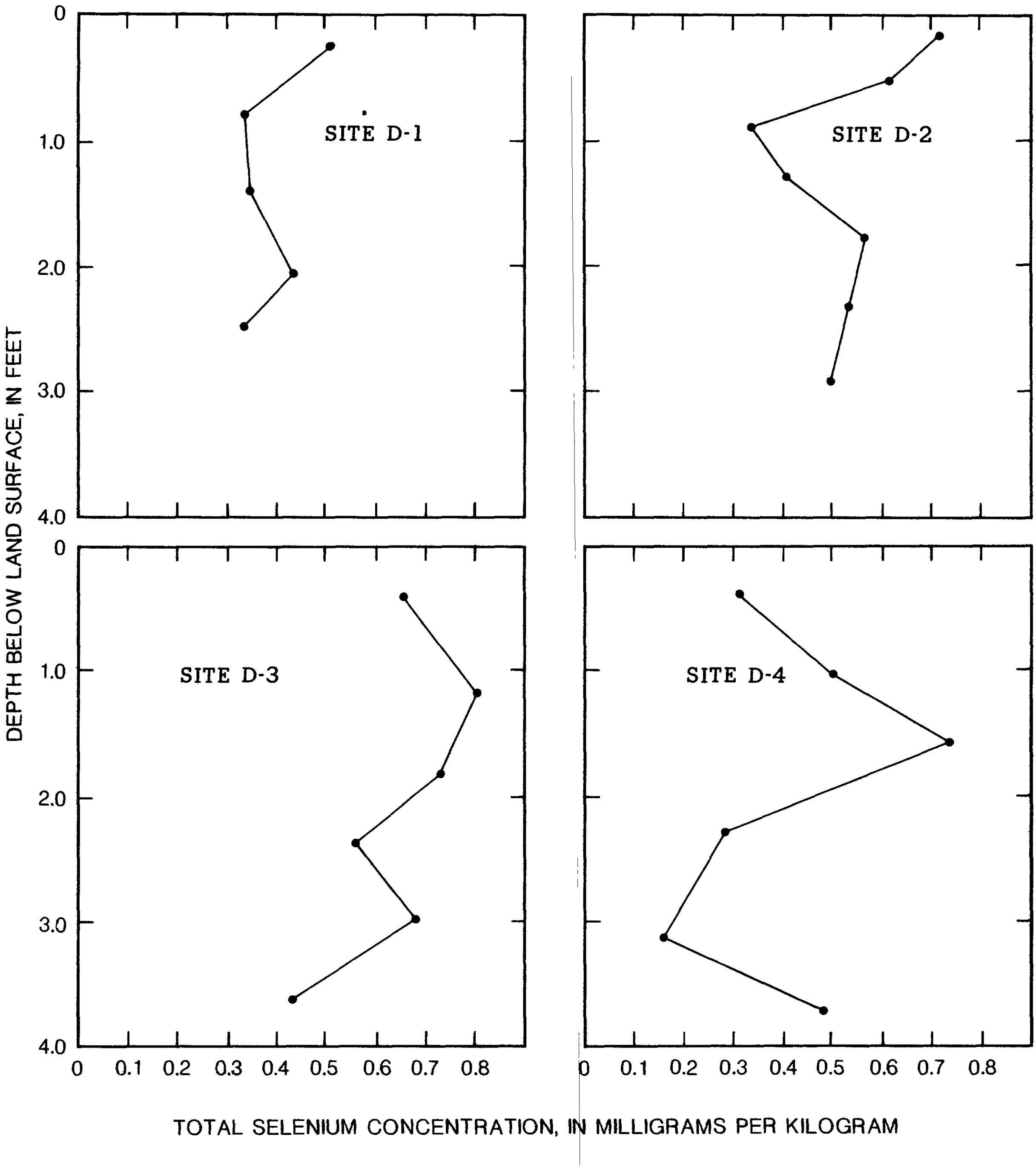

Figure 4.--Total selenium concentration in soil samples collected from different depths at sites inside the boundary of the proposed Sandstone Reservoir.

Table 2.--Concentrations of trace elements in selected soil samples with selenium concentration of 0.9 to 1.3 milligrams per kilogram in soils sampled

[<, concentration less than indicated detection limit for that analysis; --, no data]

	Concentrations of trace elements, in milligrams per kilogram			
Element	Soil sample SO-28-1	Soil sample SO-28-2	Soil sample SO-40-A	Background concentration in soils[1]
Arsenic	<10	<10	<10	5
Barium	600	610	520	500
Beryllium	2	2	1	6
Bismuth	<10	<10	<10	--
Cadmium	<2	<2	<2	1
Cerium	61	64	54	5
Chromium	97	96	94	50
Cobalt	11	10	10	10
Copper	22	21	21	20
Europium	<2	<2	<2	--
Gallium	12	12	12	--
Gold	<8	<8	<8	.001
Holmium	<4	<4	<4	--
Lanthanum	34	36	31	--
Lead	21	18	16	20
Lithium	33	34	30	30
Molybdenum	<2	<2	<2	2
Neodymium	32	33	27	--
Nickel	33	34	35	30
Niobium	7	6	7	15
Scandium	9	9	8	--
Silver	<2	<2	<2	.1
Strontium	120	140	110	--
Tantalum	<40	<40	<40	--
Thorium	10	10	9	13
Tin	<20	<20	<20	10
Uranium	<100	<100	<100	1
Vanadium	94	99	89	80
Yttrium	18	19	18	--
Ytterbium	2	2	2	--
Zinc	91	85	78	50

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[1] Background concentration in soils as reported by Levinson (1980).

Extractable Selenium Concentration

Although the total selenium concentration was determined for all soil samples, additional information was needed to determine the total selenium concentration that might be dissolved and mobilized when soil will be saturated as the reservoir fills with water. Partial-dissolution techniques, commonly called sequential extractions, have been used in environmental (Cutter, 1985 and 1986; Mahan and others, 1987; Tessier and others, 1979) and geochemical exploration (Chao, 1984) work to determine empirically the geochemical phase(s) with which the trace elements of interest could be associated. Conceptually, each of the operationally defined geochemical phases can behave differently under varying environmental conditions. Recent results from Gruebel and others (1988) have indicated that sequential-extraction techniques for selenium and arsenic can produce unreliable results with respect to concentrations of selenium and arsenic associated with both the iron-oxide and organic phases; therefore, results of the sequential-extraction experiments from this study need to be used with caution.

Sequential extractions were conducted on six soil samples collected from sites inside the boundary of the proposed reservoir. Selenium concentration in each of four geochemical phases and total selenium concentration in each sample are listed in table 3. The largest concentration of selenium is associated with the organic-matter and iron- and manganese-oxide phase, with small concentrations of selenium associated with the water-soluble, weak ion-exchange, and moderate ion-exchange phases. Because only small selenium concentrations are associated with these phases, initial saturation of the soil by construction of the reservoir will not release most of the selenium concentration in the soil. The selenium associated with the iron- and manganese-oxide phase will be relatively stable under oxidizing conditions. Under possible reducing conditions on the reservoir bottom, the iron- and manganese-oxide phase could become soluble, and the selenium probably would be transformed to the immobile selenide phase. Horowitz and others (1988) found that arsenic associated with iron and manganese oxides was remobilized under reducing conditions in reservoir sediments and then reprecipitated in the insoluble sulfide phase.

Analysis of Selenium Variance

The number of samples needed to define the concentration of selenium in soil to be saturated by construction of Sandstone Reservoir is related directly to the homogeneity of the soil. If the concentration of selenium is homogeneous in all of the soil inside the reservoir boundary, then one sample anywhere inside the reservoir boundary will accurately represent the selenium concentration in the soil, assuming no sampling and analytical errors. However, many different variables affect the selenium concentration in the soil beneath the proposed Sandstone Reservoir. For example, the concentration of selenium in a soil can be affected by different components of the total variance (for example, geology, geography, time, and analytical method). If these components of variance are not assessed, the adequacy of the soil sampling to determine the baseline selenium concentration in soil cannot be evaluated.

Table 3.--Concentration of selenium in each of four geochemical phases for selected soil samples

[Concentration in milligrams per kilogram; <, concentration less than indicated detection limit for that analysis]

Soil-sample number (pl. 1)	Concentration of selenium for indicated geochemical phase[1]				
	Water-soluble and weak ion-exchange	Moderate ion exchange	Organic matter and iron and manganese oxide	Residue material	Total selenium[2]
SO-28-1	0.05	0.29	0.94	<0.1	1.3
SO-28-2	.02	.22	.84	<.1	1.1
[3]SO-28-2-D	<.02	.53	.75	<.1	1.2
SO-40-A	.08	.14	.87	<.1	.9
SO-40-B	<.02	.22	.72	<.1	.9
SO-47-2	.04	.04	.74	<.1	.8

[1] Determined by sequential-extraction techniques.

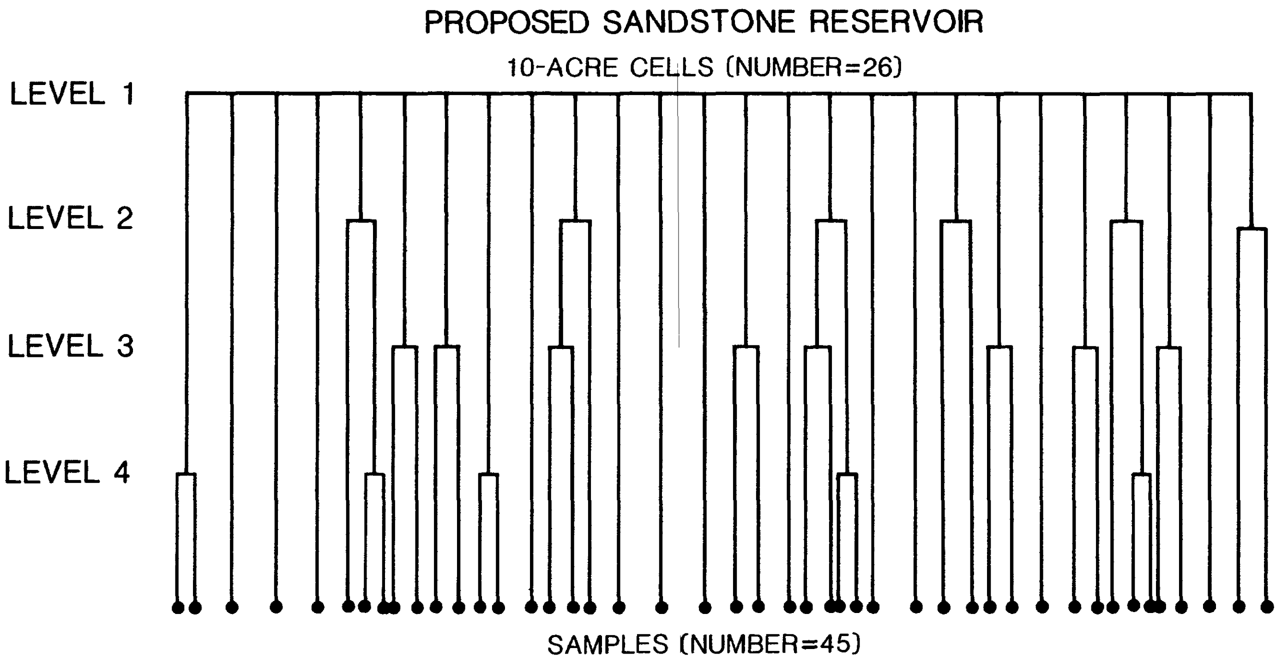
[2] Determined by automated continuous-flow hydride generation coupled with atomic absorption spectrometry.

[3] SO-28-2-D is a duplicate sample.

Because of the many variables possibly controlling the selenium concentration in soil, the soil-sampling program was designed to test the geochemical variability of selenium at different geographic scales as well as the analytical variance. To calculate the significance of the variance components, hierarchical or nested analysis of variance (ANOVA) was applied to the soil samples collected inside the proposed reservoir boundary. For a detailed description of the application and interpretation of nested ANOVA to soil-sampling programs, the reader is referred to Klusman and others (1980).

An unbalanced, inverted nested-sampling design (Garrett and Goss, 1980) was used to guide the sampling of soils inside the proposed Sandstone Reservoir boundary (fig. 5). The four levels of the nested-sampling design consisted of a level between 10-acre cells and three levels in the 10-acre cells. The three levels in the 10-acre cells consisted of samples collected 200 feet apart, at various depths, and replicate samples for quantitative analytical determinations.

Sampling locations were selected by assigning numbers to every 10-acre cell inside the proposed reservoir boundary and then randomly selecting the assigned numbers of 10-acre cells where soil samples would be collected. Soil samples of the B-horizon were collected at 26 10-acre cells inside the proposed reservoir boundary (fig. 6). In six of the 10-acre cells, an additional



EXPLANATION

LEVELS USED FOR ANALYSIS OF VARIANCE OF SELENIUM CONCENTRATION IN SOIL SAMPLES

1 Variance between 10-acre cells (26 samples)

2 Variance in 10-acre cell of samples collected 200 feet apart (6 samples)

3 Variance in 10-acre cell of samples from different depths (8 samples)

4 Variance in 10-acre cell of analytical replicates (5 samples)

Figure 5.--Unbalanced, inverted nested-sampling design showing levels used for the analysis of variance of selenium concentration in soil samples collected inside boundary of the proposed Sandstone Reservoir.

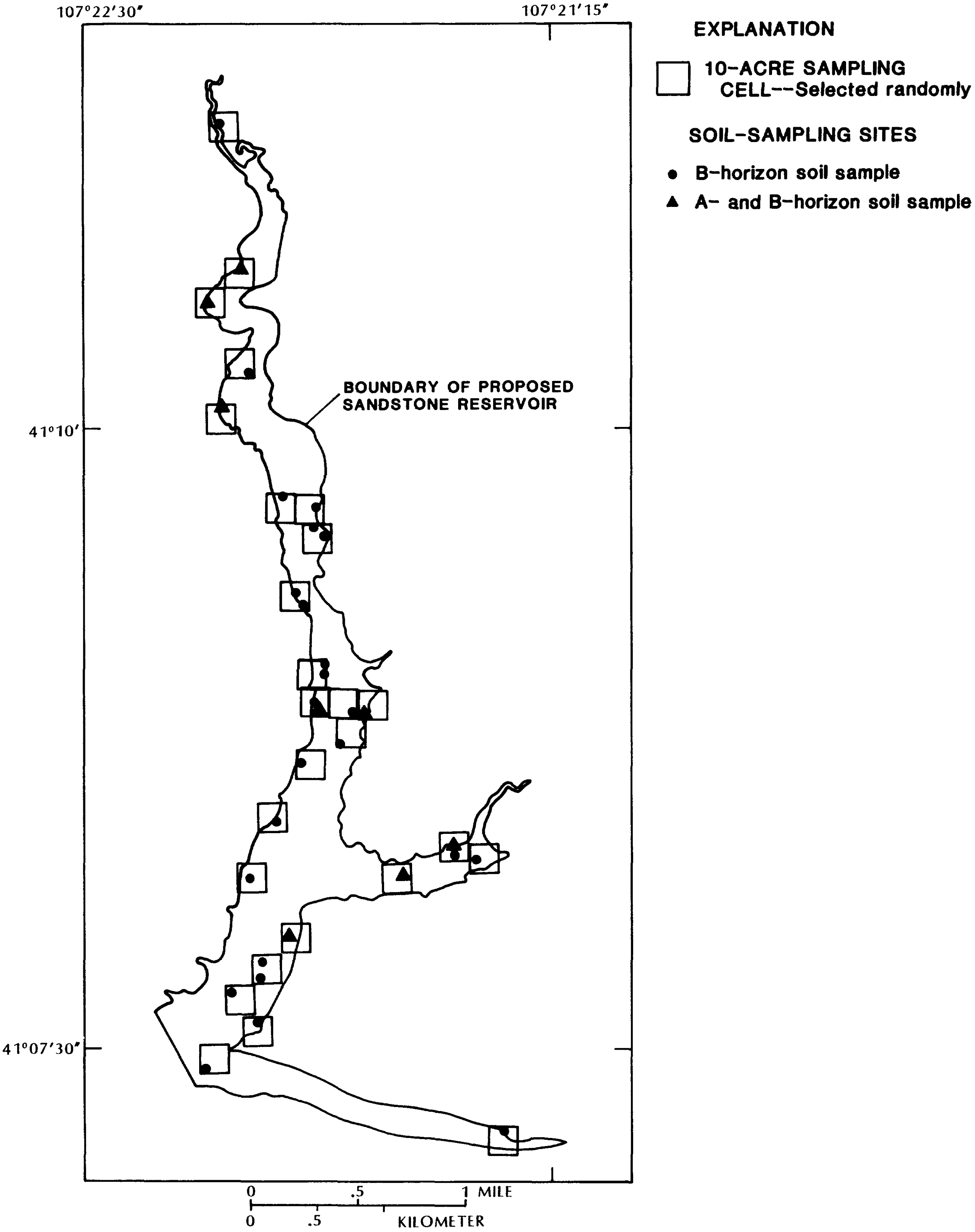


Figure 6.--Location of soil-sampling sites used for the analysis of variance of selenium concentration in soil samples collected inside boundary of the proposed Sandstone Reservoir.

B-horizon soil sample was taken 200 feet in a random direction from the first B-horizon sample (fig. 6). In eight of the 10-acre cells, soil samples of the A- and B-horizons were collected. Five of the 40 samples collected were split and analyzed in duplicate.

The purpose of this sampling design was to measure the geographic variance of the concentration of selenium in the soil to be flooded by the proposed Sandstone Reservoir. The sample variance (s^2) for this soil was partitioned according to the following variance components:

$$s^2_{\text{total}} = s^2_{\text{(between 10-acre cells)}} + s^2_{\text{(200 feet)}} + s^2_{\text{(depth)}} + s^2_{\text{(analytical)}}.$$

The analytical variance included errors because of sample inhomogeneity and sample preparation.

The variance ratio (v) was computed to estimate the importance of any one variance component. The variance component between 10-acre cells was compared to the variance components in the 10-acre cells (200 feet + depth + analytical) by the equation

$$v = \frac{N_v}{D_v} = \frac{s^2_{\text{(between 10-acre cells)}}}{s^2_{\text{(200 feet)}} + s^2_{\text{(depth)}} + s^2_{\text{(analytical)}}},$$

where N_v is the estimated variance component between 10-acre cells, and D_v is the estimated variance component in the 10-acre cells. The larger the variance ratio, the more likely that the variance associated with a regional scale (between 10-acre cells) is significant. For example, a chemical constituent having a large variance ratio has a large variance exhibited between 10-acre cells. This distribution of variance would indicate that the variation in selenium concentration in soil can be described with a small number of samples. In contrast, a small variance ratio would indicate a large part of the total variance is associated with small-scale variance component (in 10-acre cells), which would prohibit meaningful representation of the selenium concentration in soil in areas farther than 200 feet apart.

In addition to using the variance ratio as an indicator of data reliability, the variance ratio also can be used to estimate the minimum number of samples that need to be collected in a specific unit area (Klusman and others, 1980, p. 46). This technique is useful for identifying the number of soil samples needed to accurately depict the mean selenium concentration in soil in a specified unit cell. The variance ratio (v) can be used to determine the number of random soil samples needed per cell (in a 10-acre cell) at the 80- and 95-percent confidence intervals, as shown in figure 7.

An assessment of spatial variation of selenium inside the boundary of the proposed Sandstone Reservoir indicated that one level of the sampling design (between 10-acre cells) accounts for about 80 percent of the measured selenium variation (fig. 8). The measured variation in the other three levels of the sampling design (less than 200 feet, depth, and analytical) indicated a combined variation of about 20 percent. The distribution of variance indicates that trends in selenium concentration in the soil would be most evident between 10-acre cells.

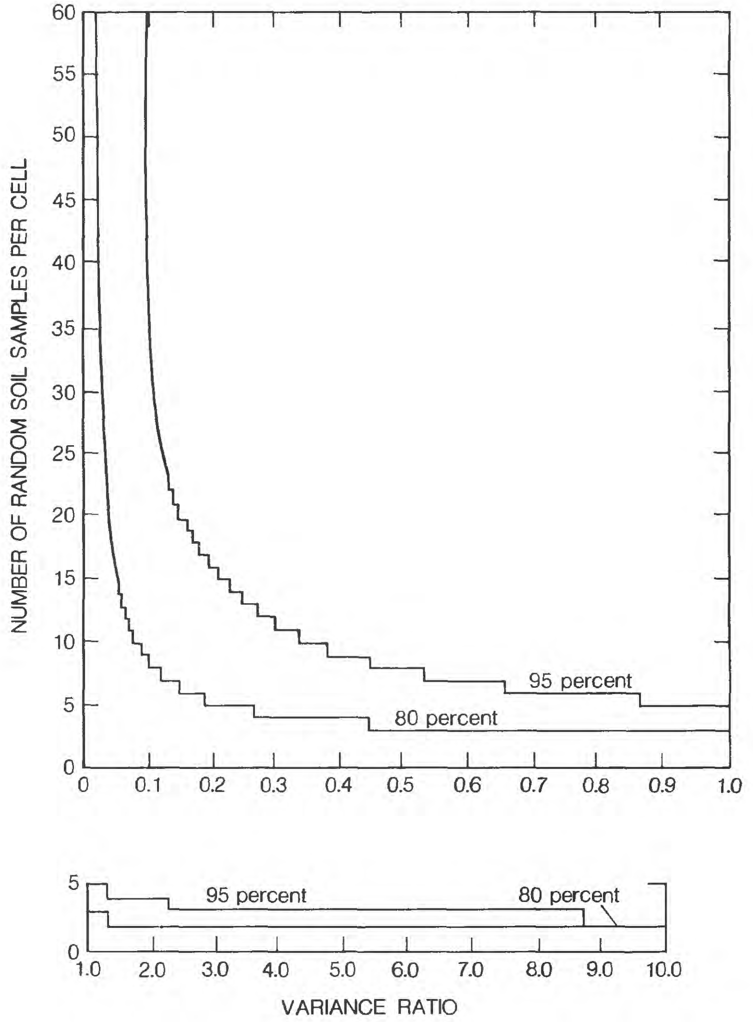


Figure 7.--Variance ratio used to approximate the number of random soil samples needed from each 10-acre cell at 80- and 95-percent confidence intervals (from Dean and others, 1979).

The variance components were used to calculate the variance ratio (v) for the 10-acre cells. Because most of the variance is associated between 10-acre cells, mapping the selenium concentration in soil at this scale would be most useful for determining trends. As only randomly selected 10-acre cells were sampled, the sample density was not adequate to prepare a trend map of selenium concentration in soil. On the basis of the calculated variance ratio for 10-acre cells, the number of samples needed in each 10-acre cell was determined for future soil sampling inside the reservoir boundary.

The calculated variance ratio for selenium was 4:1. On the basis of this ratio for 10-acre cells, three samples are needed from each 10-acre cell inside the reservoir boundary to differentiate between 10-acre cell means at the 95 percent confidence interval, whereas two samples are needed for cell differentiation at the 80-percent confidence interval. If needed, future sampling for selenium concentration in soils inside the reservoir boundary could use the sample densities just described.

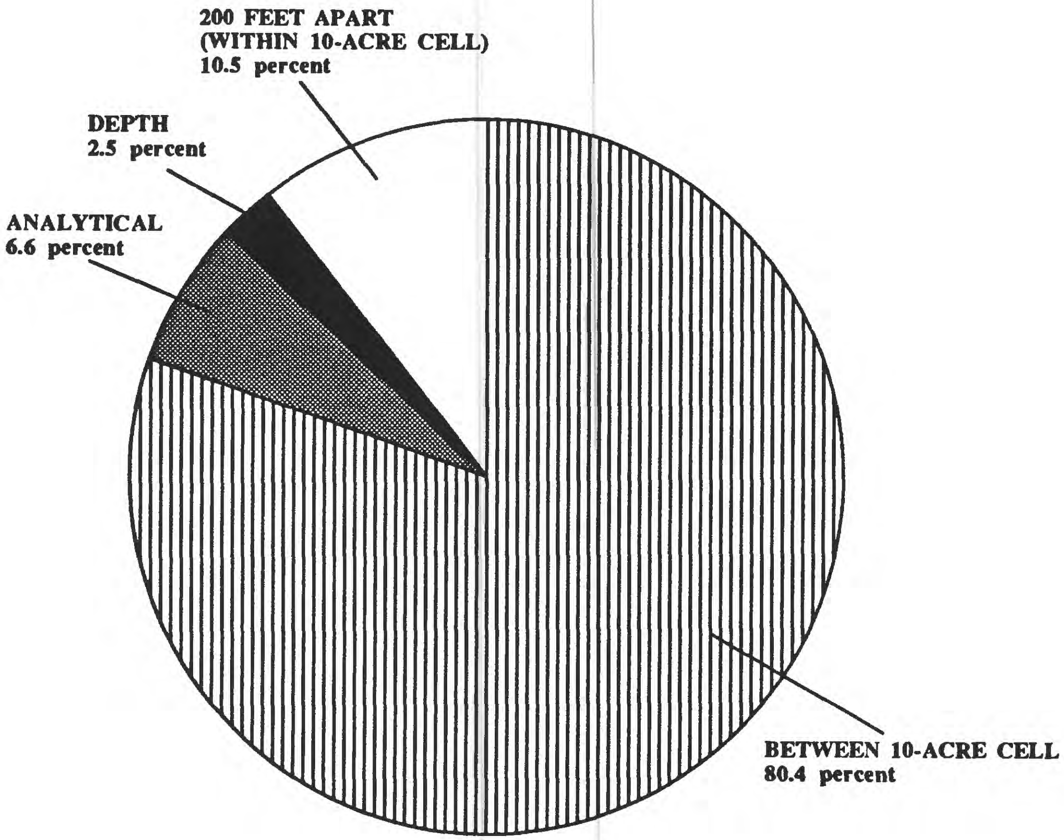
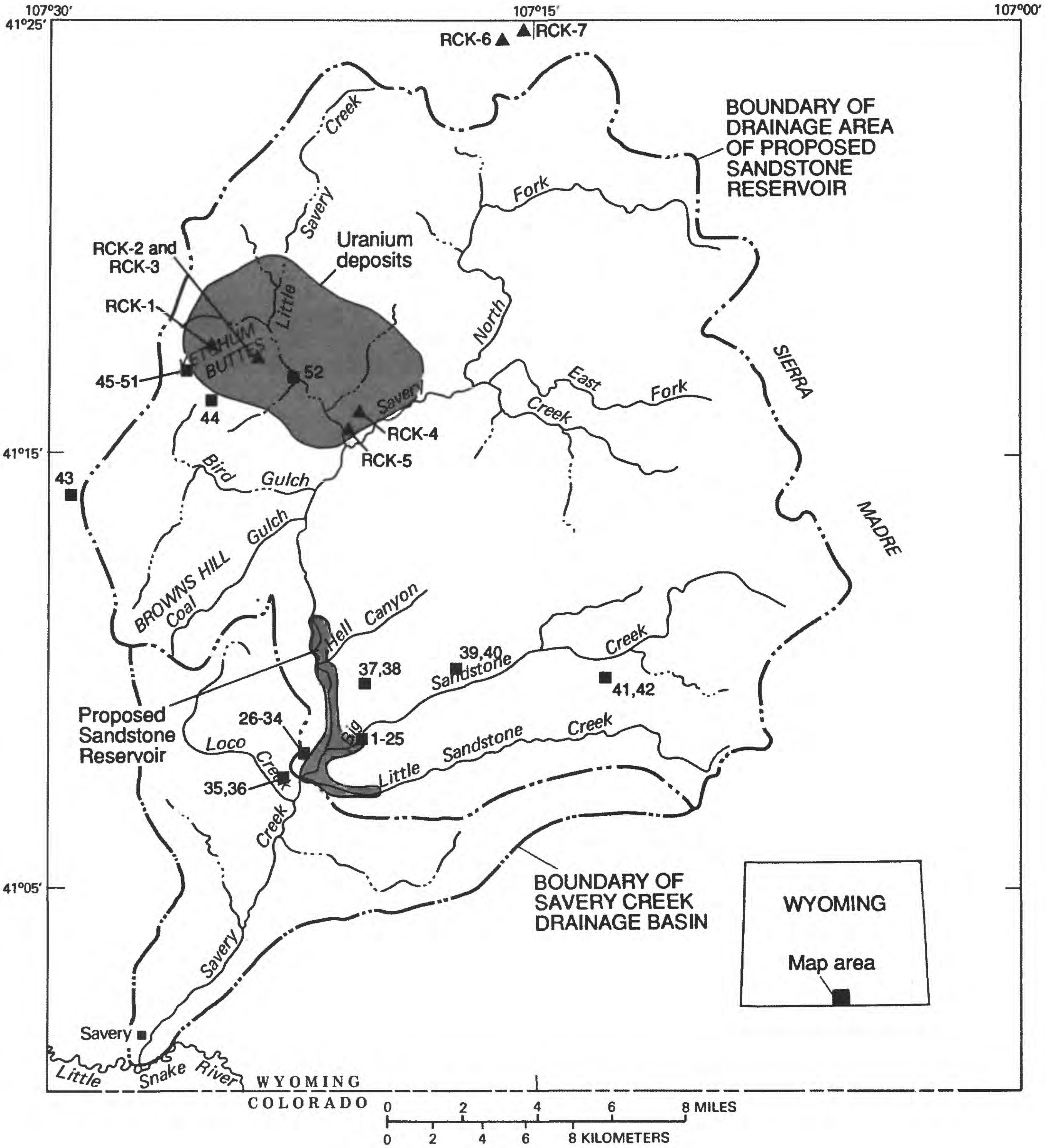


Figure 8.--Variance components expressed as a percentage of the total variance of selenium concentration in the soil samples.

Rocks

Dribus and Nanna (1982) collected seven samples of the Browns Park Formation from in and near the drainage area of the proposed Sandstone Reservoir (fig. 9). Because these samples were used to identify uranium deposits, they are biased toward mineralized rocks. The samples were analyzed for selenium and other trace elements including arsenic, molybdenum, vanadium, and uranium (table 4). The concentration of selenium in these samples ranges from less than 1 to 141 mg/kg. According to Anderson and others (1961, p. 4), the mean selenium concentration of Upper Cretaceous and Tertiary sedimentary rocks of the Western United States ranges from less than 0.1 mg/kg in limestones to 1.0 mg/kg in shales. The selenium concentration of 141 mg/kg in one tuffaceous rock sample (RCK-3) indicates an enrichment of 140 times the mean selenium concentration in shale. The concentrations of arsenic and molybdenum exceed 100 mg/kg only in sample RCK-1, whereas uranium concentration (reported as U_3O_8) ranges from 95 to 2,500 mg/kg in the seven samples. Samples RCK-2 through RCK-4 were collected in the uranium deposits near Ketchum Buttes, which are drained by Little Savery Creek and are about 10 miles upstream from the northern boundary of the proposed Sandstone Reservoir (fig. 9).



EXPLANATION

RCK-5▲ ROCK-SAMPLING SITE AND SAMPLE NUMBER--Sample collected during National Uranium Resources Evaluation Program (Dribus and Nanna, 1982)

44■ ROCK-SAMPLING SITE AND SAMPLE NUMBER--More than one number indicates multiple samples collected at same site

Figure 9.--Location of rock-sampling sites (area of uranium deposits modified from Dribus and Nanna,1982).

Table 4.--Concentrations of selenium and associated trace elements in rocks in and adjacent to the drainage area of the proposed Sandstone Reservoir

[<, concentration less than indicated detection limit for that analysis]

	Concentration, in milligrams per kilogram				
Sample	Selenium	Arsenic	Molybdenum	Vanadium	Uranium (as U_3O_8)
[1]RCK-1	31	140	423	50	95
[1]RCK-2	38	33	11	100	97
[1]RCK-3	141	35	6	255	2,500
[1]RCK-4	<1	32	5	100	232
[1]RCK-5	7	26	5	40	1,400
[1]RCK-6	<1	13	17	15	103
[1]RCK-7	9	21	19	50	1,000

[1] Concentration of trace elements determined by Dribus and Nanna (1982).

Although the extent and geometry of the uranium-bearing, roll-front deposits in the Ketchum Buttes area are not known, the deposits are a potential source of selenium, associated elements, and radionuclides in the proposed Sandstone Reservoir. The pH of stream water in the proposed reservoir area is greater than 8.0, and the total alkalinity (reported as $CaCO_3$) ranges from 83 to 186 mg/L. Selenium, arsenic, molybdenum, vanadium, and uranium are generally quite mobile in oxidizing and alkaline water (Levinson, 1980, p. 864-886).

Fifty-two additional rock samples from the Haystack Mountains Formation, the lower nonmarine member of the Allen Ridge Formation, and the Browns Park Formation in and near the drainage area of the proposed Sandstone Reservoir were analyzed for total selenium concentration to supplement the data from Dribus and Nanna (1982) (table 5). These 52 samples were selected from a much larger set of samples that was collected as part of earlier U.S. Geological Survey coal land-classification and coal-resource assessment programs in the Little Snake River coalfield.

Seventeen of these 52 samples were collected from a stratigraphic section of the Haystack Mountains Formation measured in the NW 1/4, sec. 31, T. 14 N., R. 88 W. (Barclay, 1976). Of the 17 samples, 9 are from the sandstone lithofacies and 8 are from the shale lithofacies of the Haystack Mountains Formation. Nineteen of the 52 samples represent the 4 principal lithologies (sandstone, shale, mudstone, and coal) of the nonmarine member of the Allen Ridge Formation. These samples were collected from stratigraphic sections measured near the top of the ridge on the northwest side of Big Sandstone Creek in the NW 1/4, sec. 31, T. 14 N., R. 88 W., and on the west side of the Savery Creek canyon between Big Sandstone and Little Sandstone Creeks. The samples collected from the Allen Ridge Formation are biased toward coal and

Table 5.--Description and results of selenium analyses for selected rock samples

[Location and stratigraphic distribution of all sampling sites in the Mesaverde Group and of two sampling sites in the Browns Park Formation (samples 37-40) are shown on pl. 1; all rock-sampling sites are shown in fig. 9]

Sample number (fig. 9)	Location	Formation	Member or tongue in/ or part of formation (map unit, pl. 1)	Lithology	Total selenium concentration (milligrams per kilogram)
A.--Samples from outcrops of the the Mesaverde Group in and near the proposed reservoir area					
1	NW side of Big Sandstone Creek in NW1/4 SE1/4 SE1/4 NW1/4 sec. 31, T. 14 N., R. 88 W.	Haystack Mountains	Espy Tongue of Steele Shale in lower part of formation (Khl)	Limestone concretion, muddy	0.5
2	do.	do.	do.	Silt-shale, clayey	.7
3	do.	do.	Hatfield Sandstone Member in lower part of formation (Khl)	Mud-shale interbedded with sandstone	.5
4	SW1/4 NE1/4 SE1/4 NW1/4 sec. 31, T. 14 N., R. 88 W.	do.	do.	Sandstone	.4
5	do.	do.	do.	Sand and white salts from surface of sandstone outcrop	.9
6	do.	do.	do.	White salts from bedding and fracture surfaces of sandstone outcrop	.9
7	do.	do.	do.	Sandstone	.3
8	do.	do.	do.	Sandstone	.4

Table 5.--Description and results of selenium analyses for selected rock samples--Continued

Sample number (fig. 9)	Location	Formation	Member or tongue in/ or part of formation (map unit, pl. 1)	Lithology	Total selenium concentration (milligrams per kilogram)
9	SW1/4 NE1/4 SE1/4 NW1/4 sec. 31, T. 14 N., R. 88 W.	Haystack Mountains	Hatfield Sandstone Member in lower part of formation (Khl)	Silt-shale, clayey	0.6
10	do.	do.	Middle part of formation (Khm)	Clay-shale	.8
11	do.	do.	do.	Silt-shale, clayey	.6
12	do.	do.	do.	Sandstone	2.3
13	do.	do.	do.	Sandstone	.3
14	SE1/4 NW1/4 SE1/4 NW1/4 sec. 31, T. 14 N., R. 88 W.	do.	do	Sandstone, muddy	.9
15	do.	do.	Upper part of formation (Khu)	Silt-shale, clayey	.7
16	do.	do.	do.	Siltstone concretion, calcareous	.5
17	do.	do.	do.	Sandstone	1.5
18	SW1/4 NW1/4 SE1/4 NW1/4 sec. 31, T. 14 N., R. 88 W.	Allen Ridge	Lower, nonmarine member (informal) of formation (Karl)	Coal, bright	.7
19	do.	do.	do.	Sandstone, calcareous, 5 feet thick	.3
20	do.	do.	do.	Carbonaceous shale, with coal	2.9

Table 5.--Description and results of selenium analyses for selected rock samples--Continued

Sample number (fig. 9)	Location	Formation	Member or tongue in/ or part of formation (map unit, pl. 1)	Lithology	Total selenium concentration (milligrams per kilogram)
21	SW1/4 NW1/4 SE1/4 NW1/4 sec. 31, T. 14 N., R. 88 W.	Allen Ridge	Lower, nonmarine member (informal) of formation (Karl)	Coal, bright	1.5
22	do.	do.	do.	Coal, bright	.9
23	do.	do.	do.	Coal, bright	1.3
24	do.	do.	do.	Coal, impure	3.2
25	do.	do.	do.	Claystone, grayish-pink, silty	.8
26	NW1/4 SW1/4 NW1/4 NW1/4 sec. 1, T. 13 N., R. 89 W.	do.	do.	Sandstone, calcareous, 7 feet thick	.4
27	do.	do.	do.	Carbonaceous shale, with coal	2.5
28	do.	do.	do.	Coal, dull	2.1
29	do.	do.	do.	Coal, impure	2.8
30	NE1/4 NE1/4 NE1/4 NE1/4 sec. 2, T. 13 N., R. 89 W.	do.	do.	Clay-shale, silty; contains carbonized plant fragments	.7
31	do.	do.	do.	Siltstone, clayey, sandy; contains carbonized plant fragments	.6

Table 5.--Description and results of selenium analyses for selected rock samples--Continued

Sample number (fig. 9)	Location	Formation	Member or tongue in/ or part of formation (map unit, pl. 1)	Lithology	Total selenium concentration (milligrams per kilogram)
32	NE1/4 NE1/4 NE1/4 NE1/4 sec. 2, T. 13 N., R. 89 W.	Allen Ridge	Lower, nonmarine member (informal) of formation (Karl)	Sandstone, thin-bedded, 3 feet thick	0.7
33	do.	do.	do.	Siltstone, concretion, clayey, calcareous	2.3
34	SW1/4 SW1/4 SE1/4 SE1/4 sec. 35, T. 14 N., R. 89 W.	do.	do.	Sandstone, 34 feet thick	<.1
35	NW1/4 NW1/4 SW1/4 NE1/4 sec. 2, T. 13 N., R. 89 W.	do.	do.	Carbonaceous shale	1.0
36	do.	do.	do.	Clay-shale, silty	.4
B.--Samples from outcrops of the Browns Park Formation in the Savery Creek drainage basin, upstream from the proposed reservoir					
37	SE1/4 SE1/4 SW1/4 sec. 19, T. 14 N., R. 88 W.	Browns Park	Lower part of formation	Sandstone	<.2
38	do.	do.	do.	Sandstone	.4
39	NE1/4 NE1/4 SE1/4 sec. 21, T. 14 N., R. 88 W.	do.	do.	Sandstone, conglomeratic	.7
40	do.	do.	do.	Sandstone, conglomeratic	2.0
41	West side Deep Creek road to Rawlins, in NE1/4 SE1/4 SE1/4 sec. 19, T. 14 N., R. 87 W.	do.	do.	Sandstone, yellowish-brown, conglomeratic	.8

Table 5.--Description and results of selenium analyses for selected rock samples--Continued

Sample number (fig. 9)	Location	Formation	Member or tongue in/ or part of formation (map unit, pl. 1)	Lithology	Total selenium concentration (milligrams per kilogram)
42	West side Deep Creek road to Rawlins, in NE1/4 SE1/4 SE1/4 sec. 19, T. 14 N., R. 87 W.	Browns Park	Lower part of formation	Sandstone, gray, conglomeratic, pyritic	0.6
43	Propsect pit on butte in SW1/4 NW2/4 NE1/4 sec. 35, T. 15 N., R. 90 W.	do.	do.	Sandstone	.6
44	SW1/4 SE1/4 NW1/4 sec. 16, T. 15 N., R. 89 W.	do.	Upper part of formation	Sandstone	.7
45	NE1/4 NW1/4 SE1/4 sec. 8, T. 15 N., R. 89 W.	do.	do.	Sandstone, uraniferous	4.0
46	do.	do.	do.	do.	3.7
47	do.	do.	do.	do.	150.0
48	do.	do.	do.	do.	8.3
49	do.	do.	do.	do.	7.1
50	do.	do.	do.	Sandstone, white	8.0
51	do.	do.	do.	Claystone, hard	75.0
52	On southwest side Little Savery Creek in NE1/4 NE1/4 SE1/4 SW1/4 sec. 11, T. 15 N., R. 89 W.	do.	Lower part of formation	Conglomerate, sandy	1.0

other carbonaceous rocks with the assumption that organic-rich rocks contain more pyrite and selenium than other lithofacies in the Mesaverde Group. The remaining 16 samples were collected from sandstone and conglomerate in the Browns Park Formation in the Savery Creek drainage basin upstream from the proposed reservoir.

The concentration of selenium in sandstone (Beath and others, 1946) and tuff (Everett and Bauerle, 1957) is more variable than that of shale or stone because of the greater permeability of sandstone and the larger variation in mineralogic composition of sandstone and tuff when compared to shale. Compared to sandstone, shale commonly contains more selenium (Anderson and others, 1961, p. 4).

The total selenium concentration in rock samples from the Haystack Mountains Formation (samples 1-17, table 5) ranges from 0.3 to 2.3 mg/kg. The concentration of selenium in these samples is generally less than the mean selenium concentration reported for sandstone (1 mg/kg) (Krauskopf, 1955). Sample 12 contains 2.3 mg/kg selenium, and sample 17 contains 1.5 mg/kg selenium (table 5). These analyses might indicate a slight enrichment of selenium locally near the base of reverse graded, progradational marine sandstone (sandstone of Savery Creek) and just below the top of the Haystack Mountains Formation where it is overlain by coal and carbonaceous shale of the Allen Ridge Formation (see columnar section, pl. 1). The concentration of selenium in silty shale, claystone, and mudstone or sandstone with interbedded shale is generally between 0.5 and 0.9 mg/kg. The concentration of selenium in relatively quartz-rich, coarser-grained sandstone, excluding the two previously described samples, generally is less than 0.5 mg/kg. Two samples possessing a white efflorescence (samples 5 and 6, table 5) and one sample of the host sandstone for the efflorescence (sample 4, table 5) were collected from the base of the Hatfield Sandstone Member of the Haystack Mountains Formation. Analyses of these samples indicated a slight enrichment of selenium in the efflorescent material when compared to the host sandstone and might be a further indication that small quantities of selenium are mobilized locally in oxidizing ground water.

The selenium concentration of the 19 samples collected from the nonmarine member of the Allen Ridge Formation ranges from less than 0.1 to 3.2 mg/kg (samples 18-36, table 5). Samples from sandstone of the Allen Ridge Formation have concentrations of selenium no larger than 0.7 mg/kg. Claystone, carbonaceous and silty shale, and siltstone have concentrations of selenium ranging from 0.6 to 2.9 mg/kg. The concentration of selenium in coal samples ranges from 0.7 to 3.2 mg/kg. The coal samples have some of the largest concentrations of selenium of any of the samples of Upper Cretaceous lithofacies. Analyses of the few coal samples collected from the Allen Ridge Formation (table 5) indicate a selenium enrichment factor of nearly 35. The geometric mean selenium concentration of 29 coal samples from selected fields in the Western United States was noted by Gluskoter and others (1977, p. 73) to be enriched 26 times the Clarke value[1] of 0.05 mg/kg. A similar enrichment of

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[1] Clarke value is a unit of average abundance of an element in the crust of the earth.

selenium in coal from the Rocky Mountain region, with concentrations ranging from 0.1 to 13 mg/kg selenium (Gluskoter and others, 1977; Zubovic and others, 1979), was reported to be 24 times the Clarke value for subbituminous coal and 28 times the Clark value for bituminous coal (Valkovic, 1983, p. 139). Selenium commonly is present in coal as a chelated species, or as organometallic compounds. Most of the demonstrated near-surface coal resources in the Savery Creek drainage basin are present stratigraphically above the proposed normal reservoir pool elevation of 6,932 feet above sea level.

Sixteen samples of the Browns Park Formation were submitted for selenium analysis. These sandstone and conglomerate samples were selected from two separate parts of the drainage area of the proposed Sandstone Reservoir. Samples 37-42 (table 5) were collected from the canyon of Savery Creek and the drainage area of Big Sandstone Creek (fig. 9). The conglomerate lithofacies of the Browns Park Formation in these areas is thick and is characterized by abundant granite clasts derived from the southern part of the Sierra Madre to the east. Five of the six samples collected from this area have a uranium concentration of from less than 10 to 40 mg/kg. The remaining samples of the Browns Park Formation (samples 43-52, table 5) were selected, as follows, from the northwestern part of the drainage area of the proposed Sandstone Reservoir: where the conglomerate lithofacies primarily consists of quartzite and amphibolite pebbles and cobbles derived from the northwestern part of the Sierra Madre; where the sandstone lithofacies includes numerous tuffs; and where both lithofacies are host to uranium mineralization. The concentration of selenium in unmineralized samples of the Browns Park Formation is, with one exception (sample 40, table 5), less than 1 mg/kg. The concentration of selenium in uranium-bearing rocks collected near the Ketchum Buttes uranium deposits ranges from 3.7 to 150 mg/kg (samples 45-51, table 5). Two of the samples collected near or within the Ketchum Buttes uranium deposits contain 1,400 (RCK-5) and 2,500 (RCK-3) mg/kg uranium (table 4).

Surface Water

The concentrations of total selenium and arsenic were determined for 61 surface-water samples from streams collected during 1986 and 1987 at the sites shown in figure 10. The median concentration of total selenium was less than 1 µg/L, and the median concentration of total arsenic was 4 µg/L. Selenium concentrations ranged from less than 1 to 3 µg/L, and arsenic concentrations ranged from less than 1 to 22 µg/L (table 6). The maximum contaminant level[1] of selenium in drinking water is 10 µg/L and of arsenic is 50 µg/L (U.S. Environmental Protection Agency, 1989). The Federal selenium regulation for protection of freshwater aquatic organisms is a 4-day average of 5 µg/L no more than once every 3 years (U.S. Environmental Protection Agency, 1988).

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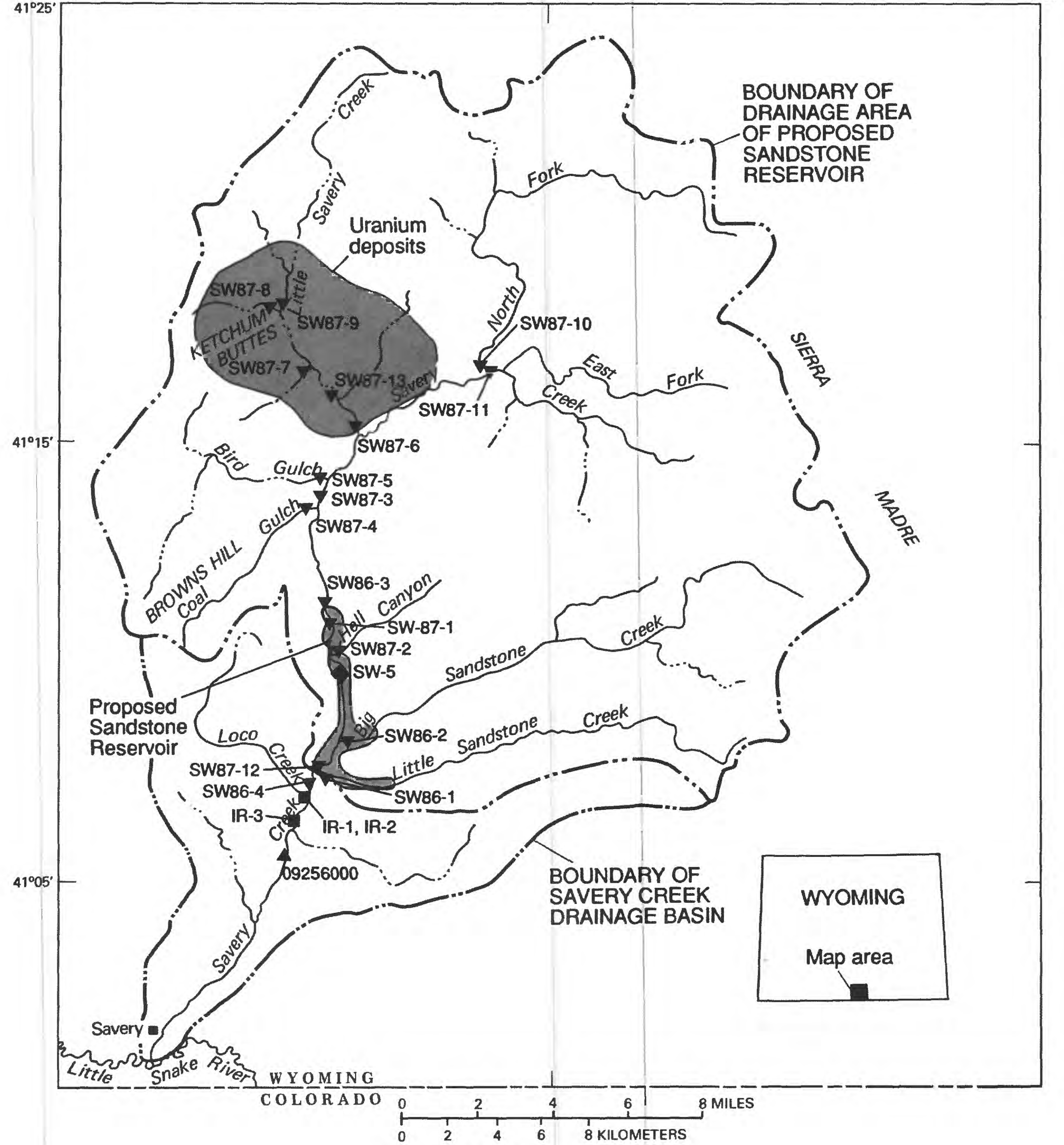
[1] Maximum contaminant level is a level (concentration) of contaminant that may cause adverse human health effects and is enforceable for public-water supplies.



EXPLANATION

09256000▲ STREAMFLOW-GAGING STATION AND NUMBER

SW86-1▼ STREAMFLOW SURFACE-WATER SAMPLING SITES AND NUMBERS

IR-1, IR-2■ Irrigation-return flow

SW-5◆ Pond

Figure 10.--Location of surface-water sampling sites (area of uranium deposits modified from Dribus and Nanna, 1982).

Table 6.--Selenium and arsenic concentrations and specific conductance in surface-water samples collected in and near the drainage area of the proposed Sandstone Reservoir

[--, no data; <, concentration less than indicated detection limit for that analysis; E, estimate]

Sampling site (fig. 10)	Date	Time (24-hour)	Streamflow (cubic feet per second)	Concentrations, in micrograms per liter				Specific conductance (microsiemens per centimeter at 25 degrees Celsius)
				Selenium (total)	Selenium (dissolved)	Arsenic (total)	Arsenic (dissolved)	
SW86-1	07-23-86	0850	495	<1	--	<1	--	495
SW86-2	07-23-86	1000	12	<1	--	2	--	204
SW86-3	07-23-86	1310	34	<1	--	5	--	390
SW86-4	07-23-86	1500	52	<1	--	3	--	350
SW87-1	04-02-87	1600	118	1	--	4	--	--
SW87-2	04-02-87	1730	--	<1	--	<1	--	--
SW87-3	04-03-87	1610	--	2	<1	9	1	--
	04-04-87	1630	--	2	--	14	--	205
	04-05-87	1630	--	<1	--	10	--	195
	04-06-87	1630	--	<1	--	15	--	185
	04-07-87	1630	--	<1	--	22	--	205
	04-08-87	1630	--	<1	--	13	--	205
	04-09-87	1630	--	2	--	5	--	205
	04-10-87	1300	--	2	--	8	--	260
	04-11-87	1250	--	<1	--	5	--	245
	04-12-87	1250	--	<1	--	4	--	245
	04-15-87	1250	--	<1	--	7	--	240
	04-16-87	1250	--	<1	--	10	--	183
	04-17-87	1250	--	<1	--	9	--	200
	04-22-87	1250	--	<1	--	7	--	322
	04-22-87	1830	--	<1	<1	3	2	330
	04-23-87	1830	--	<1	--	6	--	300
	04-24-87	1830	--	<1	--	4	--	272
	04-25-87	1830	--	<1	--	5	--	268
	04-26-87	1830	--	<1	--	6	--	259
	04-27-87	1830	--	<1	--	5	--	266
	04-28-87	1830	--	<1	--	4	--	267
	04-29-87	1830	--	<1	--	4	--	259
	04-30-87	1830	--	<1	--	4	--	268
	05-01-87	1830	--	<1	--	5	--	268
	05-02-87	1830	--	<1	--	4	--	269
	05-03-87	1830	--	<1	--	4	--	291
	05-04-87	1830	--	<1	--	4	--	292
SW87-4	04-04-87	1700	--	1	--	3	--	--
	04-22-87	1900	3.6	1	--	1	--	460
SW87-5	04-04-87	1100	25	1	<1	3	<1	--
	04-22-87	1730	5.5	<1	<1	1	<1	570
SW87-6	04-02-87	1730	--	1	--	1	--	--
	04-04-87	1200	74	3	<1	8	2	--
	04-22-87	1400	16	1	1	4	3	550
	05-07-87	1100	--	1	--	6	--	570

Table 6.--Selenium and arsenic concentrations and specific conductance in surface-water samples collected in and near the drainage area of the proposed Sandstone Reservoir--Continued

Sampling site (fig. 10)	Date	Time (24-hour)	Streamflow (cubic feet per second)	Concentrations, in micrograms per liter				Specific conductance (microsiemens per centimeter at 25 degrees Celsius)
				Selenium (total)	Selenium (dissolved)	Arsenic (total)	Arsenic (dissolved)	
SW87-7	04-04-87	1600	E80	1	<1	3	<1	--
SW87-8	04-04-87	1505	--	1	<1	2	1	--
	04-22-87	1630	9.3	2	1	4	3	440
SW87-9	04-04-87	1500	E20	1	<1	3	<1	--
	04-22-87	1630	1.9	<1	<1	1	1	1,000
SW87-10	04-04-87	1300	31	<1	<1	4	2	--
	04-22-87	1200	42	<1	<1	3	2	278
SW87-11	04-04-87	1310	41	<1	<1	5	1	--
	04-22-87	1230	42	<1	<1	3	2	247
SW87-12	04-05-87	1800	--	1	--	6	--	205
	04-06-87	1800	--	1	--	6	--	205
	04-07-87	1800	--	1	--	5	--	210
	04-08-87	1800	--	1	--	5	--	225
	04-09-87	1800	--	1	--	5	--	225
	04-15-87	1145	--	<1	--	9	--	224
	04-16-87	1145	--	<1	--	17	--	194
	04-17-87	1145	--	<1	--	8	--	175
	04-22-87	1100	--	<1	<1	3	2	295
	05-06-87	1715	--	<1	--	3	--	227
SW87-13	04-22-87	1500	.34	1	1	1	<1	420

Total arsenic discharges were calculated for selected sites (SW86-1 through SW86-4) on streams in and near the proposed reservoir area during July 23, 1986 (fig. 11). The analytical detection limit for selenium of 1 μg/L was not exceeded in any of the samples; therefore, no selenium discharges could be calculated for sites SW86-1 through SW86-4. The largest total arsenic discharge calculated was 0.43 kg/d for site SW86-3 at the inlet to the proposed Sandstone Reservoir (fig. 11). Arsenic discharge calculated for site SW86-4 on Savery Creek downstream of the proposed dam site was nearly the same as the arsenic discharge at the proposed inlet site (SW86-3). Calculated arsenic discharge for sites SW86-1 and SW86-2 (Little Sandstone and Big Sandstone Creeks) was small (fig. 11).

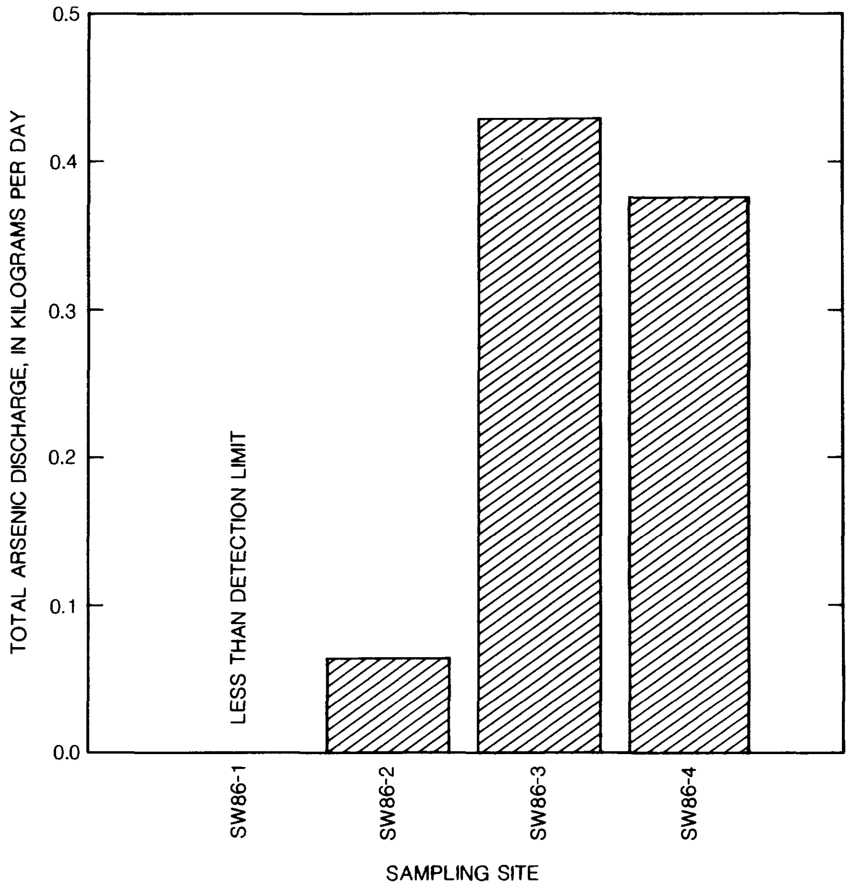


Figure 11.--Total arsenic discharge in streams in and near the proposed Sandstone Reservoir, July 23, 1986.

Discharges of total selenium and arsenic also were calculated for 11 sites in the drainage area of the proposed Sandstone Reservoir during April 1987. The purpose of this sampling was to determine possible source areas of trace-element discharge to the proposed Sandstone Reservoir during runoff from lowland snowmelt. DeLong (1986, p. 8) determined that runoff in ephemeral and intermittent streams is enriched by the "flushing" of salts from normally dry channels and other basin surfaces. Selenium and arsenic associated with salt crusts and fine materials in ephemeral and intermittent channels could be mobilized during runoff associated with snowmelt. The largest estimated total selenium and arsenic discharge in tributaries to Savery Creek was calculated for site SW87-6 on Little Savery Creek (figs. 12 and 13), just upstream of the confluence of Little Savery and Savery Creeks (fig. 10). The estimated total selenium discharge calculated for this site was 0.54 kg/d (fig. 12), and the estimated total arsenic discharge was 1.45 kg/d (fig. 13). Part of Little Savery Creek and some of its tributaries drain the Ketchum Buttes uranium deposits, an area in which large concentrations of selenium and arsenic have been detected in rock samples.

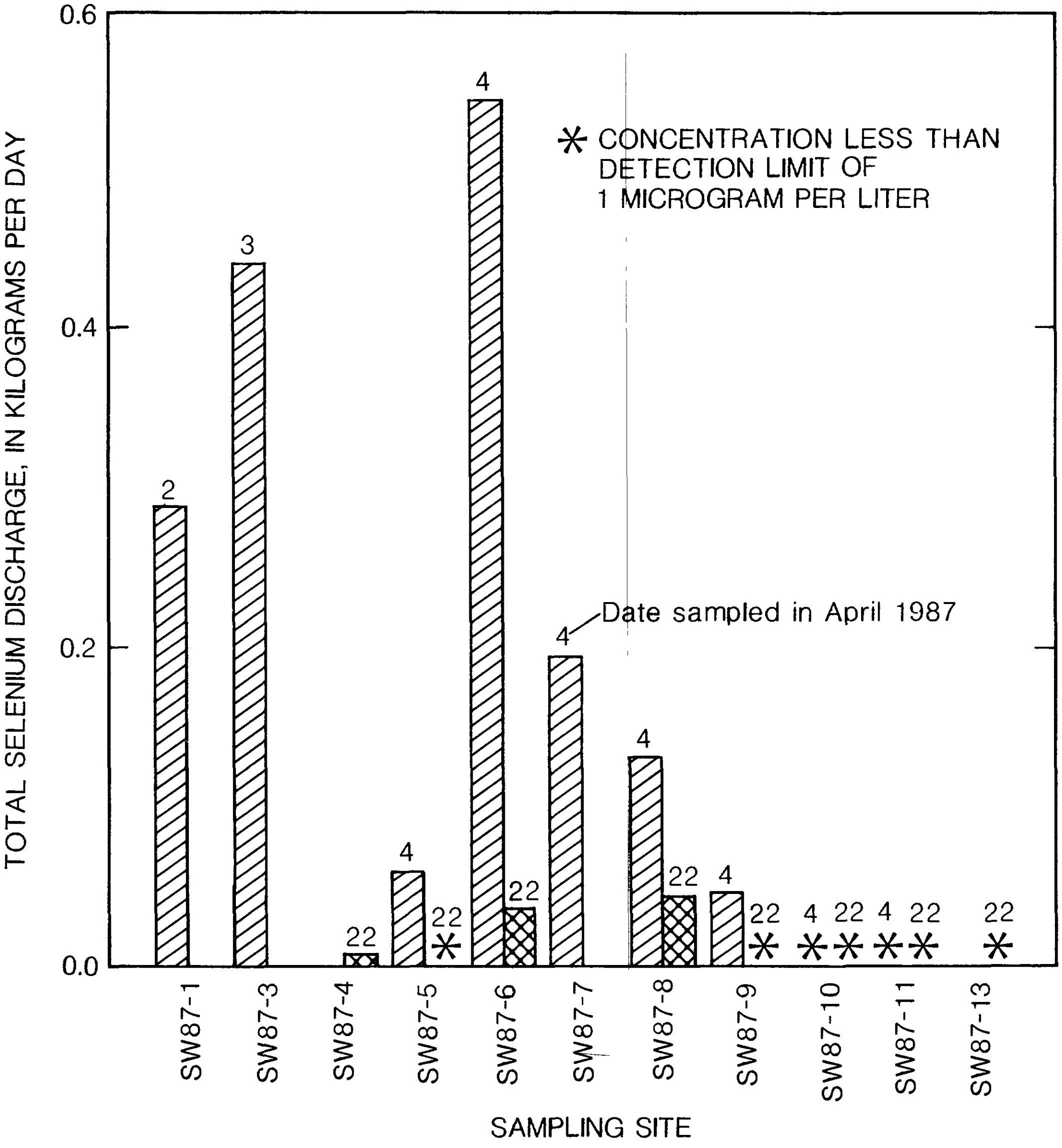


Figure 12.--Estimated total selenium discharge at sampling sites along streams in the drainage area of the proposed Sandstone Reservoir, April 1987.

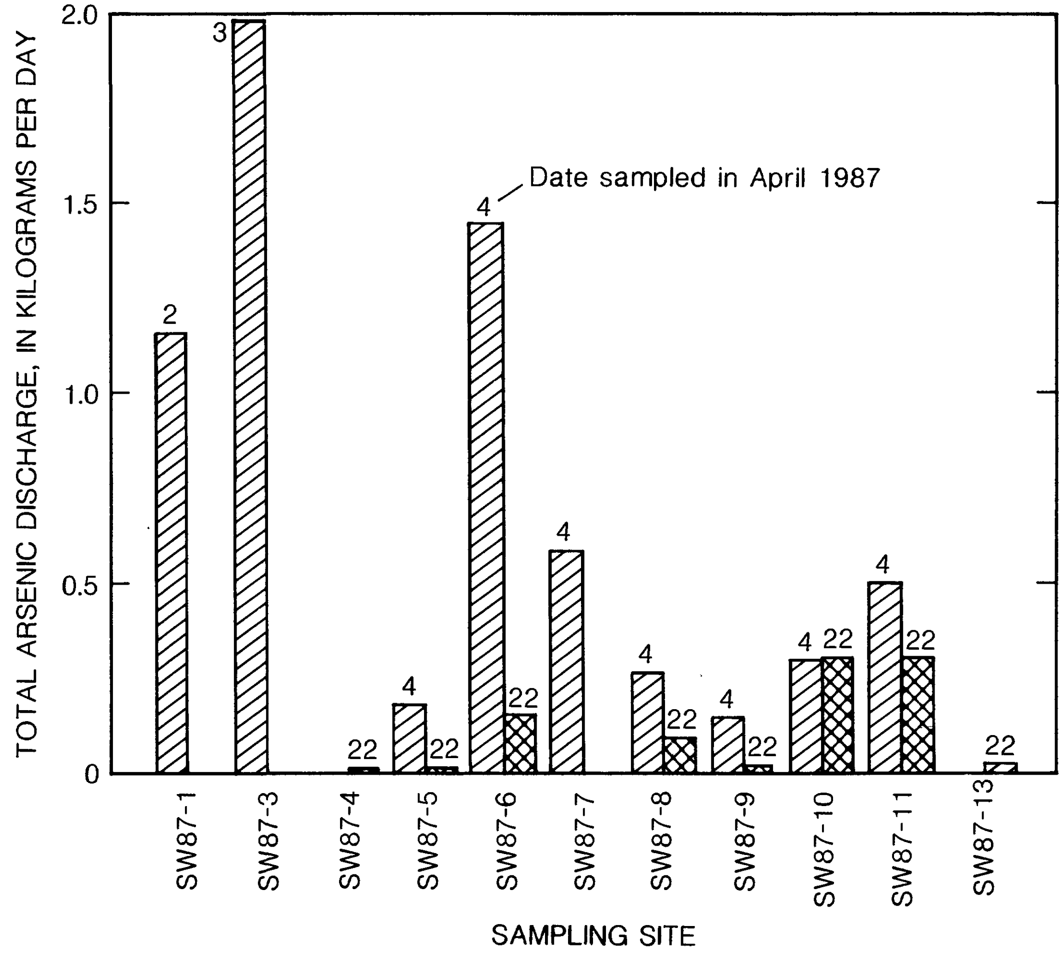


Figure 13.--Estimated total arsenic discharge at sampling sites along streams in the drainage area of the proposed Sandstone Reservoir, April 1987.

Automatic samplers were installed at sites SW87-3 (upstream of the proposed inlet to Sandstone Reservoir) and SW87-12 (at the proposed dam site) (fig. 10) to collect daily water samples during runoff from lowland snowmelt in April and May 1987. Each water sample collected by the automatic samplers was analyzed for total selenium and arsenic concentrations and specific conductance (table 6).

Total selenium concentrations did not exceed 2 µg/L in water collected by the automatic samplers at sites SW87-3 and SW87-12; however, total arsenic concentrations in the drainage area of the proposed Sandstone Reservoir were variable during this sampling period. Peaks in total arsenic concentration at site SW87-3 preceded the daily streamflow peaks at the Savery Creek steamflow-gaging station (fig. 14), about 10 river miles downstream from the sampling site (fig. 10). The positive correlation between discharge and total arsenic concentration may indicate runoff from lowland snowmelt is an important mechanism in supplying concentrations of total arsenic to streams in the central part of the drainage area of the proposed Sandstone Reservoir.

Total arsenic concentrations were usually smaller at site SW87-12, adjacent to the proposed dam site, compared to total arsenic concentrations measured at site SW87-3, in the central part of the drainage area (fig. 14). The larger concentrations of total arsenic measured at site SW87-3 probably were because of dissolved- and suspended-arsenic concentrations from the Ketchum Buttes uranium deposits (fig. 10). One exception to this trend occurred on April 15 and 16, 1987 (fig. 14). During this period, the daily total arsenic concentrations at site SW87-12 (proposed dam site) exceeded the total arsenic concentrations at site SW87-3. This exception probably was due to a resuspension of fine-grained sediments mobilized during previous runoff from lowland snowmelt on April 3-13, 1987 (fig. 14).

A general increase in specific conductance from about 200 to 225 µS/cm to more than 275 µS/cm occurred after the second runoff from lowland snowmelt (fig. 14). The increase in specific conductance probably was because of ground-water recharge from the alluvium. The specific conductance of a ground-water sample from a spring issuing from the alluvium at site GW-1 (pl. 1) was 470 µS/cm.

A water sample from a pond (SW-5) and water samples of irrigation return flow at three sites (IR-1 through IR-3) were analyzed for concentrations of total selenium and total arsenic (fig. 10). Selenium concentrations in these samples did not exceed 1 µg/L, and arsenic concentrations did not exceed 4 µg/L (table 7).

Thirteen surface-water sites were sampled for radiochemical constituents during April and part of May 1987. Dissolved gross-alpha particle activity was used to determine areas of possible radiochemical contamination in the drainage area of the proposed Sandstone Reservoir. If the dissolved gross-alpha particle activity of a water sample was less than 5 pCi/L, no additional radiochemical analysis (for example, radium-226) was needed to compare to drinking-water maximum contaminant levels (Lappenbusch and Cothern, 1985). Nine of the 54 samples analyzed for dissolved gross-alpha activity in the drainage area exceeded 5 pCi/L (table 8). Seven of the nine samples exceeding the 5-pCi/L limit were collected at sites on tributaries to Savery Creek (sites SW87-4, SW87-6, SW87-8, SW87-9, SW87-10, SW87-11, and SW87-13), which

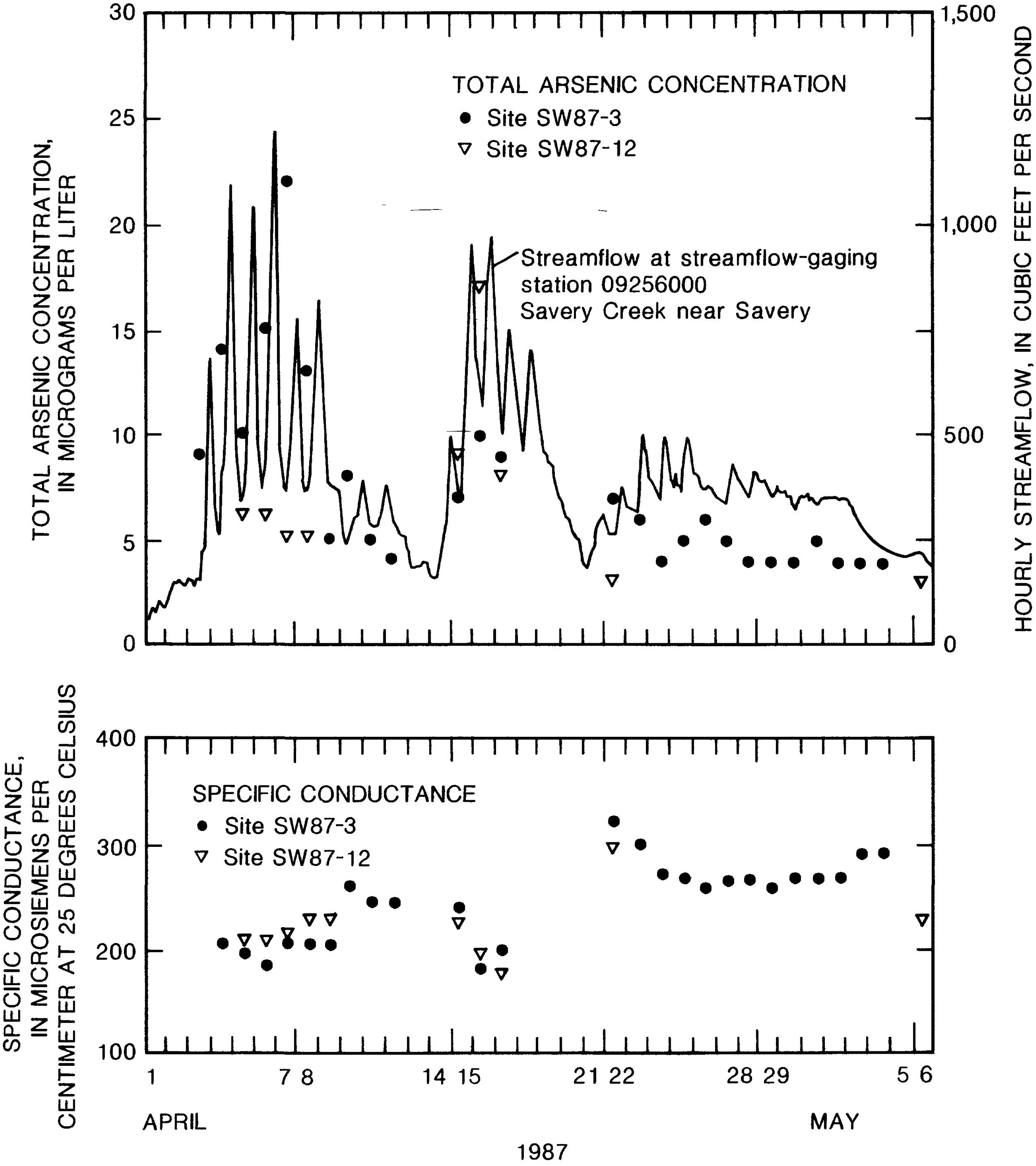


Figure 14.--Total arsenic concentration, streamflow, and specific conductance, as a function of time at two sampling sites on Savery Creek, April and part of May 1987.

Table 7.--Concentrations of total selenium and total arsenic in water samples from a pond and of irrigation return flow in and near the proposed Sandstone Reservoir

[<, concentration less than indicated detection limit for that analysis]

Sampling site (fig. 10)	Date	Concentrations, in micrograms per liter	
		Selenium (total)	Arsenic (total)
	Pond		
SW-5	07-24-86	<1	<1
	Irrigation return flow		
IR-1	07-25-86	<1	<1
IR-2	07-25-86	<1	1
IR-3	07-25-86	<1	4

drain the area in and adjacent to the Ketchum Buttes uranium deposits (fig. 10). The remaining two samples exceeding the 5-pCi/L limit were both collected at site SW87-12, at the proposed dam site for the reservoir (fig. 10). Although only nine samples exceeded the 5-pCi/L limit, future water-quality monitoring after construction of the reservoir that includes determination of gross-alpha activities in water samples from the reservoir would help to monitor radiochemical contamination.

Gross-alpha particle activity of suspended sediments was measured to determine possible sources of radiochemical contamination to aquatic organisms in the drainage area of the proposed Sandstone Reservoir (table 8). Radioisotopes attached to suspended sediments or fixed to streambed sediments are significant exposure pathways of radionuclides to aquatic organisms (National Academy of Science, 1977, p. 272). Gross-alpha activity for 53 suspended-sediment samples ranged from 0 to 160 pCi/L (table 8). The largest gross-alpha activity of suspended sediment (160 pCi/L) was determined for the sample collected at site SW87-3 on Savery Creek downstream of the junction with Little Savery Creek, which drains the Ketchum Buttes uranium deposits (fig. 10).

Total uranium concentrations were measured in 49 water samples from sites in the drainage area of the proposed Sandstone Reservoir during April and part of May 1987. Total uranium concentrations ranged from 1.1 to 14.5 µg/L (table 8). None of the samples exceeded the "guidance level" of 14.7 µg/L proposed for uranium in drinking water (Yang and Edwards, 1984).

Table 8.--Gross-alpha activity and uranium concentrations in surface-water samples collected in the drainage area of the proposed Sandstone Reservoir during April and part of May 1987

[--, no data; <, concentration less than indicated detection limit for that analysis]

Sampling site (fig. 10)	Date	Gross-alpha activity, dissolved (picocuries per liter)	Gross-alpha activity, suspended (picocuries per liter)	Uranium, dissolved (micrograms per liter)	Uranium, total (micrograms per liter)
SW87-1	04-02-87	3.3	4.6	1.3	3.6
SW87-2	04-02-87	0.0	2.6	1.1	2.0
SW87-3	04-03-87	1.7	33	2.0	7.8
	04-04-87	.2	110	--	8.5
	04-05-87	.3	100	--	6.7
	04-06-87	0.0	120	--	9.3
	04-07-87	1.7	160	--	9.8
	04-08-87	.9	42	--	5.9
	04-09-87	1.7	36	--	4.6
	04-11-87	2.5	28	--	2.9
	04-12-87	4.3	26	--	2.9
	04-15-87	2.6	42	--	3.7
	04-16-87	3.4	38	--	5.0
	04-17-87	1.9	39	--	4.3
	04-22-87	3.7	31	--	7.4
	04-22-87	3.4	1	--	4.4
	04-23-87	.3	7	--	3.4
	04-24-87	.5	15	--	4.1
	04-25-87	.7	14	--	2.9
	04-26-87	1.0	2	--	2.8
	04-27-87	1.1	7	--	2.4
	04-28-87	1.1	6	--	3.0
	04-29-87	0	9	--	2.6
	04-30-87	1.6	17	--	3.6
	05-01-87	1.8	12	--	2.3
	05-02-87	0	0	--	2.8
	05-03-87	1.2	37	--	2.5
	05-04-87	.5	11	--	3.5
SW87-4	04-22-87	5.7	23	--	4.7
SW87-5	04-04-87	2.2	--	--	--
	04-22-87	4.4	4	--	6.3
SW87-6	04-04-87	3.0	7	1.1	4.3
	04-22-87	5.6	1.5	--	7.3
	05-07-87	2.0	10	--	7.2
SW87-7	04-04-87	0	10	<.3	--
SW87-8	04-04-87	1.4	15	.5	3.1
	04-22-87	5.7	11	--	7.7
SW87-9	04-04-87	0	19	<.3	--
	04-22-87	8.7	4	--	2.4

Table 8.--Gross-alpha activity and uranium concentrations in surface-water samples collected in the drainage area of the proposed Sandstone Reservoir during April and part of May 1987--Continued

Sampling site (fig. 10)	Date	Gross-alpha activity, dissolved (picocuries per liter)	Gross-alpha activity, suspended (picocuries per liter)	Uranium, dissolved (micrograms per liter)	Uranium, total (micrograms per liter)
SW87-10	04-04-87	2.4	0	1.2	3.4
	04-22-87	5.3	36	--	4.6
SW87-11	04-04-87	0	17	1.5	1.8
	04-22-87	8.0	11	--	1.1
SW87-12	04-05-87	.3	45	2.2	3.9
	04-06-87	0	51	--	--
	04-07-87	.3	32	--	4.3
	04-08-87	1.2	26	.3	--
	04-09-87	0	30	--	3.4
	04-15-87	6.3	13	--	5.8
	04-16-87	3.4	88	--	14.5
	04-17-87	6.4	23	--	5.6
	04-22-87	3.9	8	--	3.5
	05-06-87	1.0	10	--	2.5
SW87-13	04-22-87	9.2	1	--	8.1

Gross-alpha activity of suspended sediments and total uranium concentrations were monitored at sites SW87-3 and SW87-12 (fig. 10) during April and part of May 1987 to evaluate the effect of runoff from lowland snowmelt on radiochemical activity and concentrations. Similar to the total arsenic concentrations at sites SW87-3 and SW87-12 (fig. 14), both suspended gross-alpha activity and uranium concentrations indicated a positive correlation to discharge at the Savery Creek streamflow-gaging station (fig. 15).

Ground Water

Nine ground-water samples were collected from springs and seeps in and near the proposed reservoir (pl. 1) and analyzed for dissolved selenium, arsenic, and molybdenum (table 9). None of the ground-water samples contained dissolved selenium or dissolved arsenic concentrations that exceeded the maximum contaminant level for selenium (10 µg/L) and arsenic (50 µg/L) in public-water supplies as established by the U.S. Environmental Protection Agency (1989). Except for sites GW-3 and GW-5 (in the Haystack Mountains Formation), dissolved selenium concentrations were at or less than the detection limit of 1 µg/L. The largest dissolved arsenic concentration was 3 µg/L (site GW-1), and the largest dissolved molybdenum concentration was 2 µg/L (site GW-8).

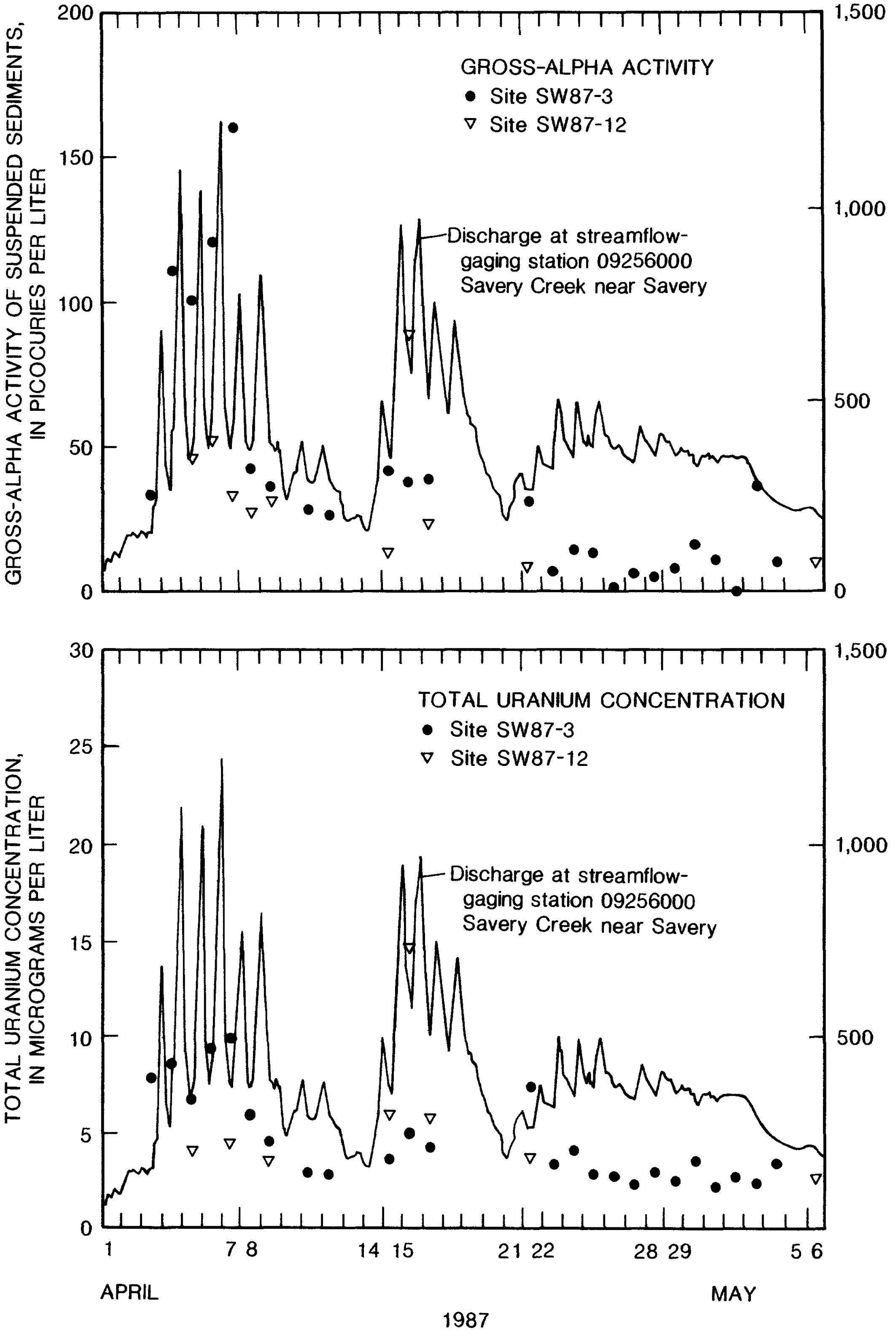


Figure 15.--Gross-alpha activity of suspended sediments, total uranium concentration, and streamflow as a function of time at two sampling sites on Savery Creek, April and part of May 1987.

Table 9.--Concentrations of dissolved selenium, arsenic, and molybdenum and specific conductance in ground-water samples collected in and near the proposed Sandstone Reservoir

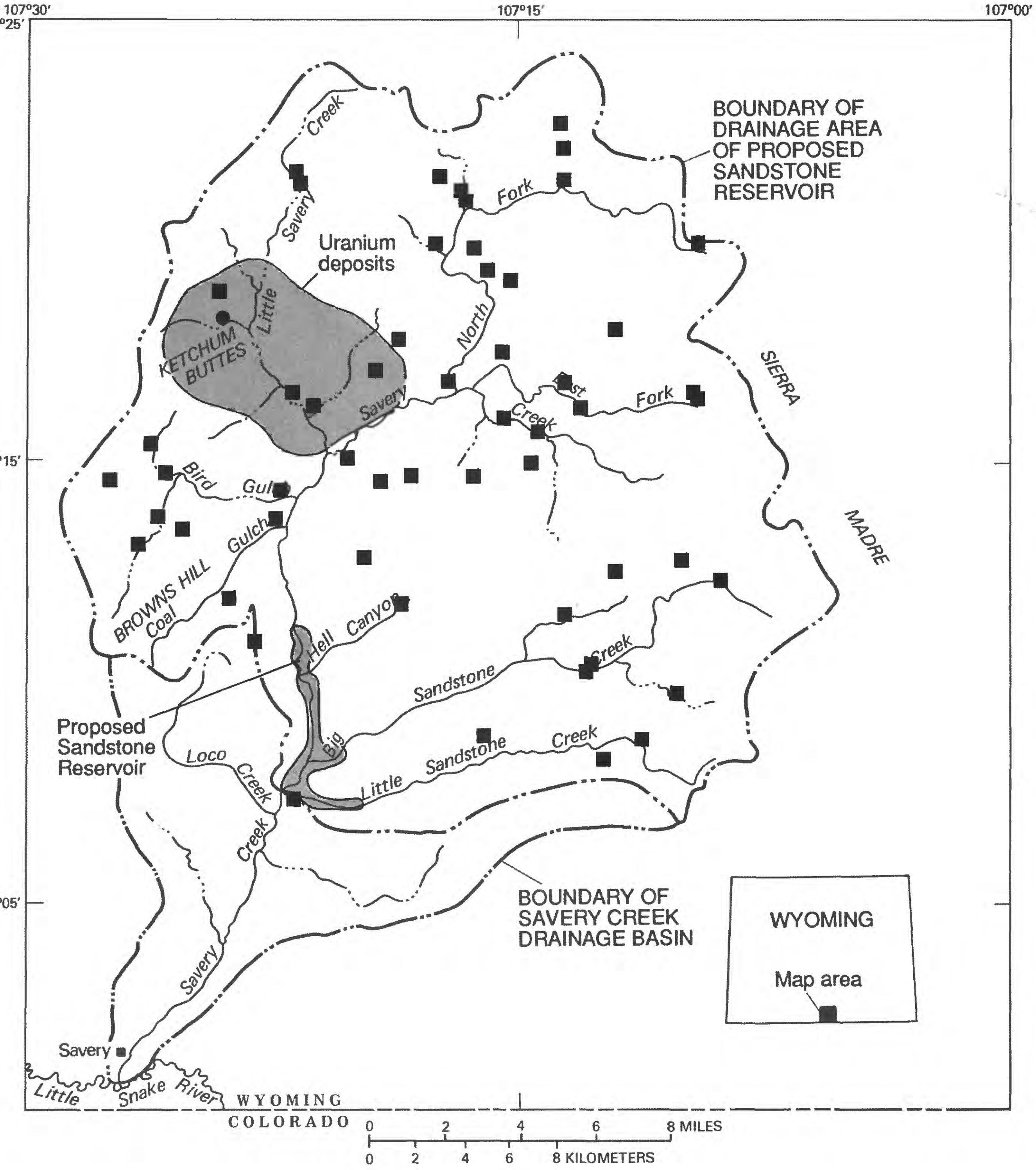
[<, concentration less than indicated detection limit for that analysis; --, no data]

Sampling site (pl. 1)	Date	Geologic unit	Concentrations, in micrograms per liter: Selenium (dissolved)	Arsenic (dissolved)	Molybdenum (dissolved)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)
GW-1	7-10-86	Alluvium	<1	3	<1	470
GW-2	7-10-86	Lower nonmarine part of the Allen Ridge Formation	<1	<1	<1	340
GW-3	7-10-86	Lower nonmarine part of the Allen Ridge Formation	7	<1	<1	1,330
GW-4	7-10-86	Lower nonmarine part of the Allen Ridge Formation	1	<1	<1	520
GW-5	7-24-86	Middle part of the Haystack Mountains Formation	2	<1	1	720
GW-6	7-24-86	Upper part of the Haystack Mountains Formation	<1	<1	<1	520
GW-7	7-24-86	Lower part of the Haystack Mountains Formation	1	<1	1	610
GW-8	7-24-86	Alluvium	<1	<1	2	530
GW-9	7-25-86	Alluvium	<1	<1	--	415

In addition to the ground-water data collected by the U.S. Geological Survey, dissolved molybdenum concentrations in ground water sampled as part of the National Uranium Resource Evaluation (NURE) program (Dribus and Nanna, 1982) were compiled for sites in and near to the drainage area of the proposed Sandstone Reservoir (fig. 16). Dissolved molybdenum concentration in one of the samples from the NURE data in the drainage area exceeded 4 µg/L. The location of this sample was in the northern part of the drainage basin, northeast of Ketchum Buttes.

Streambed Sediment

Streambed-sediment samples were collected at six sites, one on Little Savery Creek and five on Savery Creek, in the drainage area of the proposed Sandstone Reservoir (fig. 17). Each sample was analyzed for concentrations of total selenium and total arsenic in six different size fractions (figs. 18 and 19) to confirm possible source areas of selenium and arsenic to the proposed reservoir. The concentration of selenium in streambed-sediment samples ranged



EXPLANATION

MOLYBDENUM CONCENTRATION, IN MICROGRAMS PER LITER

■ Less than or equal to 4
● Greater than 4 and less than 30

Figure 16.--Molybdenum concentrations in ground-water samples. (Data from Dribus and Nanna, 1982; area of uranium deposits modified from Dribus and Nanna, 1982.)

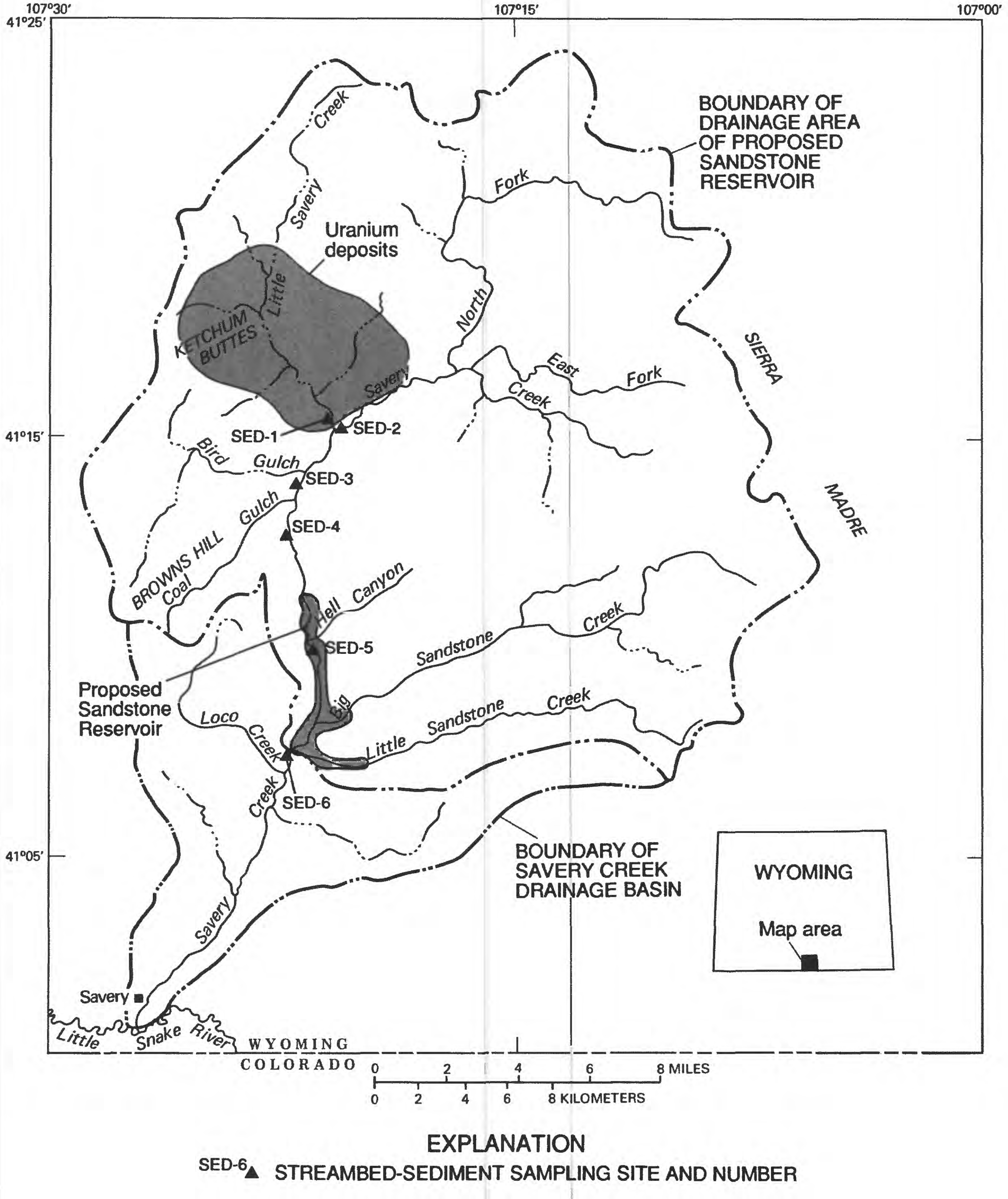


Figure 17.--Location of streambed-sediment sampling sites (area of uranium deposits modified from Dribus and Nanna, 1982).

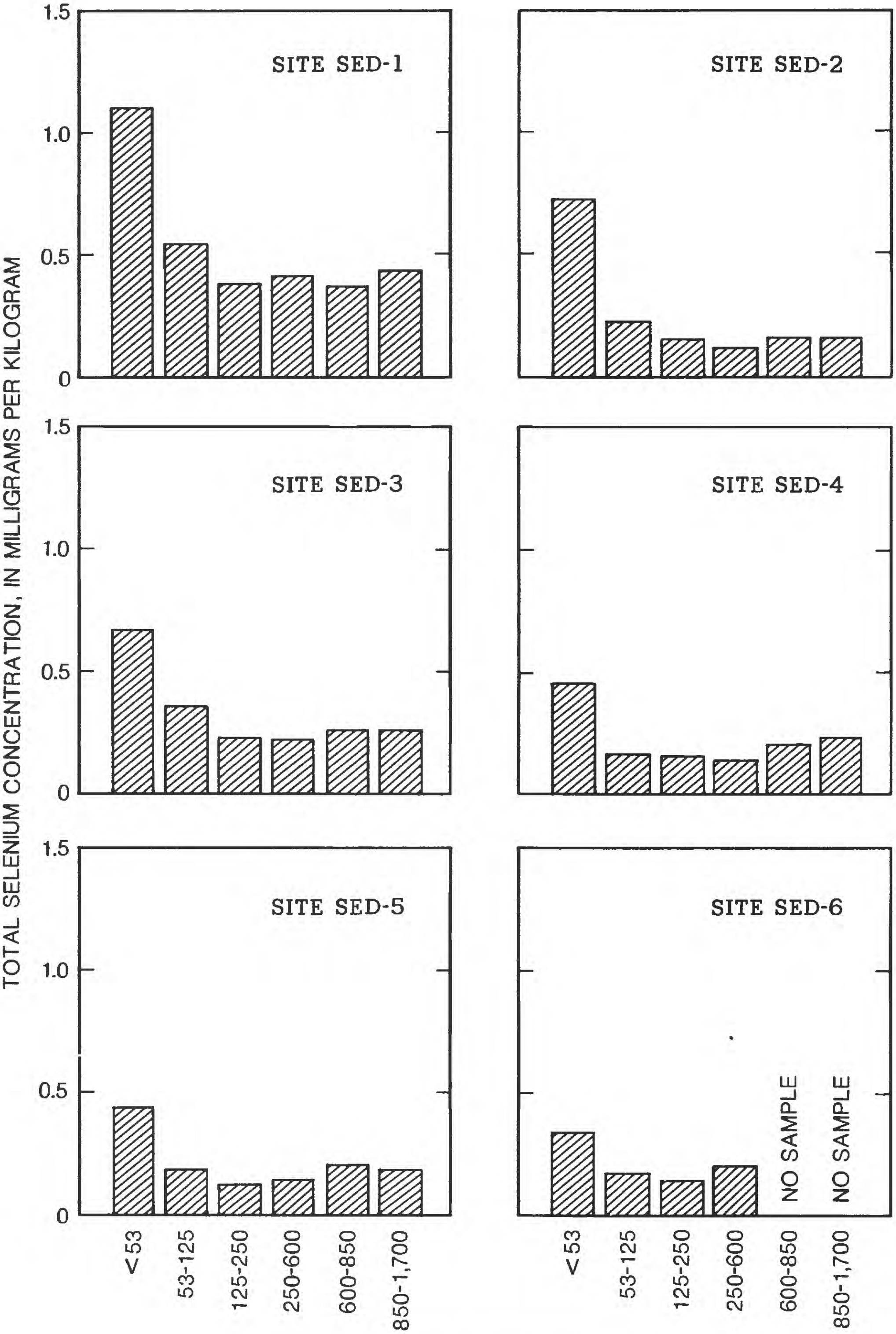


Figure 18.--Distribution of total selenium concentration by grain-size fraction in streambed-sediment samples.

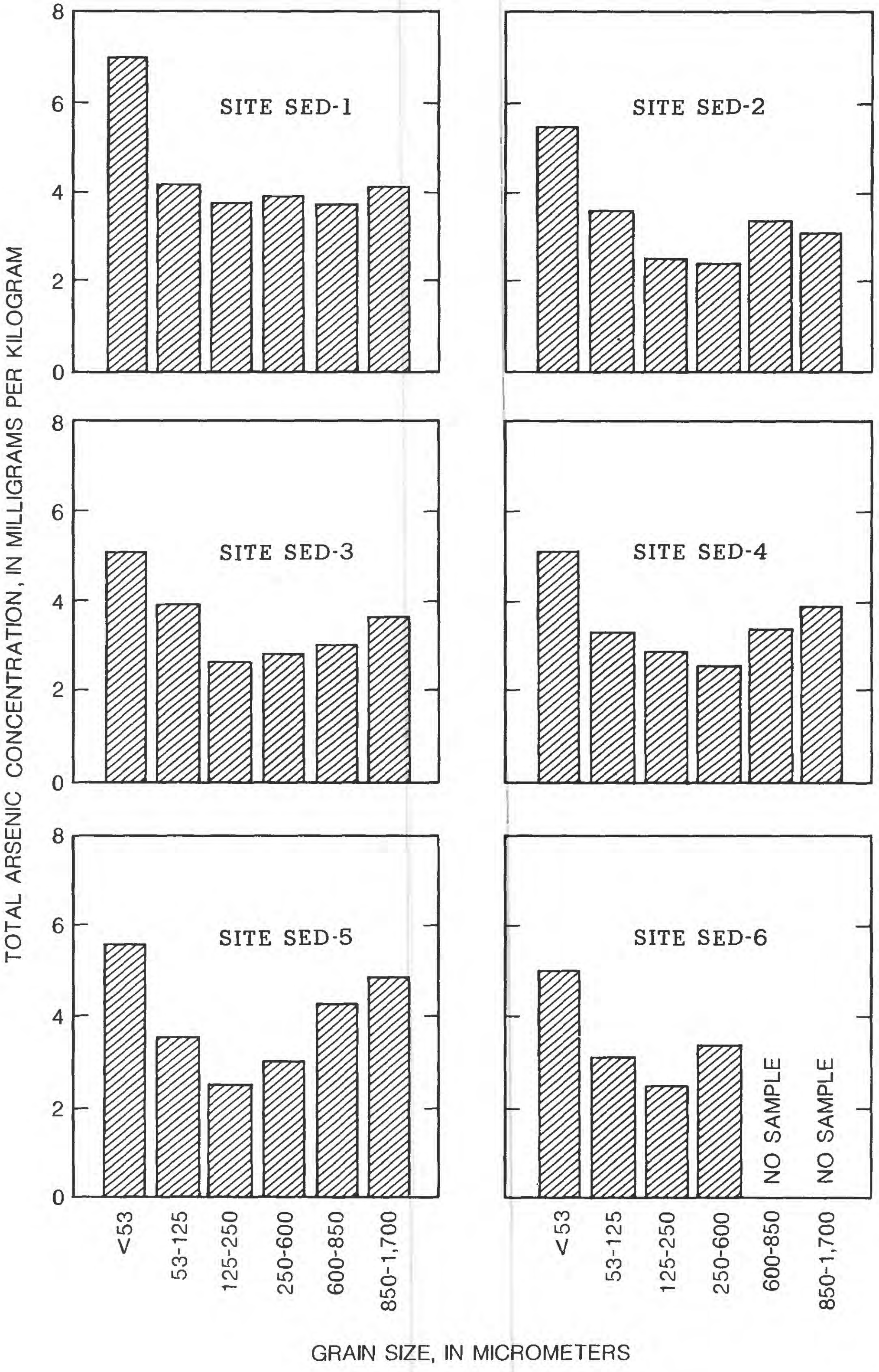


Figure 19.--Distribution of total arsenic concentration by grain-size fraction in streambed-sediment samples.

from 0.1 to 1.1 mg/kg, with the largest concentration of selenium associated with the less than 53-µm size fraction (fig. 18). The concentration of arsenic in streambed-sediment samples ranged from 2.3 to 7.0 mg/kg, with the largest concentration of arsenic also associated with the less than 53-µm size fraction (fig. 19).

Total selenium and arsenic concentrations of the less than 53-µm fraction in streambed-sediment samples generally decreases in the downstream direction toward the proposed dam site (fig. 20). The largest concentrations of selenium and arsenic were measured in a streambed-sediment sample from Little Savery Creek at site SED-1 (figs. 17 and 20), about 5 river miles upstream of the inlet area to the proposed reservoir. Little Savery Creek receives weathered detrital material from the Ketchum Buttes uranium deposits. The contribution of selenium and arsenic in streambed sediment from Little Savery Creek is diluted in samples SED-3, SED-4, SED-5, and SED-6 collected downstream from the confluence of Little Savery Creek and Savery Creek (figs. 17 and 20).

Selenium concentration of the less than 53-µm size fraction in streambed-sediment samples from the drainage area of the proposed Sandstone Reservoir (fig. 18) generally was less than the selenium concentration of bottom-sediment samples from areas in Wyoming and Utah with potential selenium toxicity to plants and animals. For example, concentrations of selenium ranged from 0.9 to 25 mg/kg in bottom-sediment samples (less than 0.062-mm size fraction) from the Kendrick Irrigation Project in Wyoming (Peterson and others, 1988, p. 26) and from 4.2 to 85 mg/kg in bottom-sediment samples (less than 0.062-mm size fraction) collected from the Middle Green River basin in Utah (Stephens and others, 1988, p. 48).

Arsenic concentration of the less than 53-µm size fraction in streambed-sediment samples from the drainage area of the proposed Sandstone Reservoir (fig. 19) was similar to the arsenic concentration of bottom-sediment samples from the Kendrick Reclamation Project in Wyoming and the Middle Green River basin in Utah (Peterson and others, 1988, p. 52; Stephens and others, 1988 p. 48). To date, no arsenic-toxicity problems in plants or animals from these areas have been detected.

Concentrations of total molybdenum in streambed-sediment samples (less than 150-µm size fraction) at springs and in streams were compiled from Dribus and Nanna (1982) for sites in the drainage area of the proposed Sandstone Reservoir (fig. 21). Only 1 out of 54 streambed-sediment samples analyzed had a molybdenum concentration greater than 4 mg/kg (fig. 21). A typical background level for molybdenum in soils is 2 mg/kg (Levinson, 1980). The streambed-sediment sample that had the greatest molybdenum concentration was in the area of the Ketchum Buttes uranium deposits.

EFFECTS OF THE PROPOSED RESERVOIR

On the basis of data analyzed during this study, if the proposed Sandstone Reservoir is constructed, the concentrations of selenium and associated trace elements in the reservoir water probably will not be greater than maximum contaminant levels for public drinking-water supplies and freshwater aquatic organism regulations established by the U.S. Environmental Protection Agency. This conclusion is based on the following reasons:

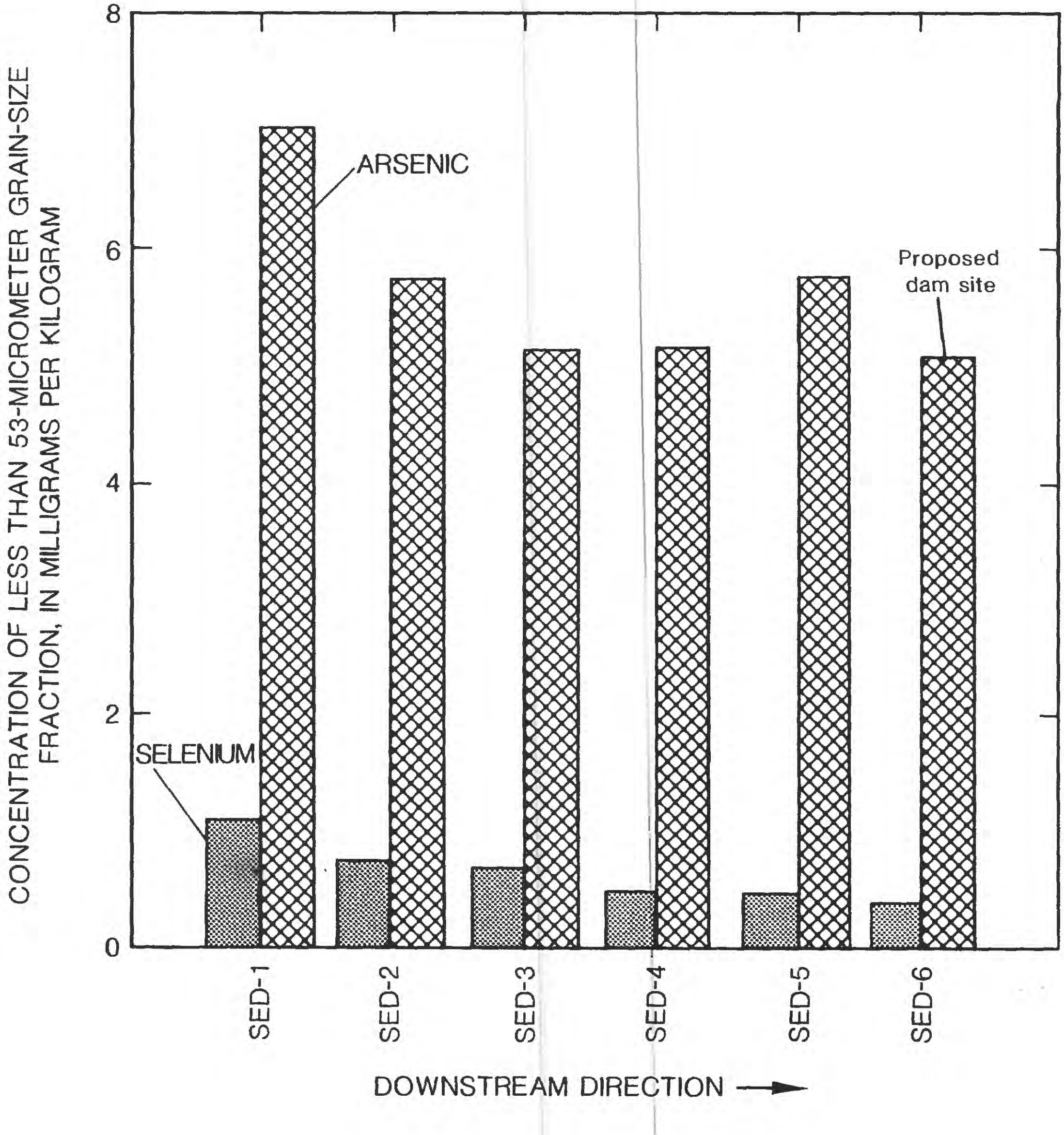
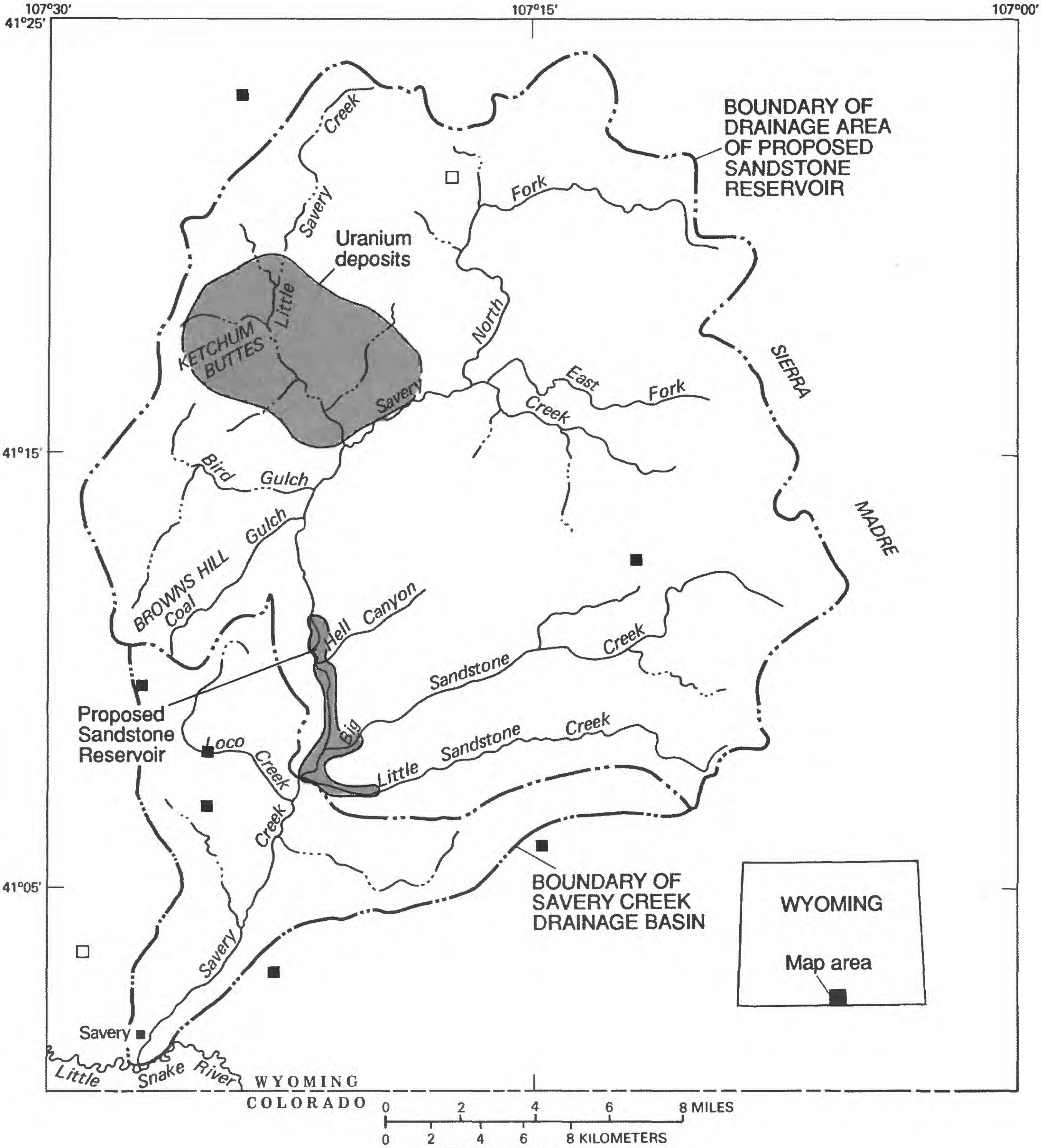


Figure 20.--Distribution of total selenium and arsenic concentrations of the less than 53-micrometer grain-size fraction in streambed-sediment samples.



EXPLANATION

MOLYBDENUM CONCENTRATION,
IN MILLIGRAMS PER KILOGRAMS,
IN WET AND DRY SEDIMENTS

- ■ Less than or equal to 4
- □ Greater than 4 and less than 15

Figure 21.--Molybdenum concentration in streambed-sediment samples at springs and in streams.(Data from Dribus and Nanna, 1982; area of uranium deposits modified from Dribus and Nanna, 1982.)

1. Analyses of the soil-chemistry data indicate that most of the selenium in soils that would be saturated by reservoir water will not be readily soluble during initial saturation. Because of the distribution of geochemical phases of selenium in soil and rocks, substantial leaching of selenium from the soils into the reservoir water is not expected.

2. The selenium concentration of most of the clastic rocks in the drainage area of the proposed reservoir generally is within the baseline range of selenium concentrations reported for similar lithofacies in the Western United States; therefore, substantial source areas of selenium in bedrock probably are not present in the drainage area of the proposed reservoir.

3. Baseline concentrations of selenium and arsenic in surface- and ground-water samples collected in and near the drainage area of the proposed reservoir did not exceed the maximum contaminant level established by the U.S. Environmental Protection Agency for public drinking-water supplies.

4. The concentration of selenium in streambed-sediment samples in Little Savery and Savery Creeks in the drainage area of the proposed reservoir generally was less than the concentration of selenium in bottom-sediment samples from areas in Wyoming and Utah with potential selenium toxicity to plants and animals.

5. Water will have a relatively short residence time in the proposed Sandstone Reservoir (Michael Carnevale, Wyoming Water Development Commission, written commun., 1990). The reservoir will impound 52,000 acre-feet of water and will yield 32,000 acre-feet for agricultural, municipal, and industrial uses. In addition, instream flows downstream from the dam (24 cubic feet per second) and prior downstream water rights must be satisfied. Except for a minimum pool of 12,000 acre-feet, the remaining volume of reservoir water will be released downstream. Therefore, concentration of selenium due to evaporation will not occur.

This study has identified the area of the Ketchum Buttes uranium deposits in the drainage area of the proposed reservoir as the dominant source of trace elements during runoff from lowland snowmelt. Any development in this part of the drainage area of the proposed reservoir could increase trace-element concentrations in the reservoir water.

SUMMARY AND CONCLUSIONS

The mean concentration of selenium (0.38 mg/kg) in soil samples from inside the proposed Sandstone Reservoir boundary was slightly larger than the range in mean concentration (0.1 to 0.3 mg/kg) of selenium in soils from selected areas of Montana and Wyoming. The largest concentration (0.9 mg/kg) of selenium was detected in samples of soil developed from alluvial materials, suggesting transport of selenium into the proposed reservoir site from the northern and eastern parts of the drainage basin. Results of the sequential extraction of six soil samples with the largest concentration of selenium indicate that most of the selenium is associated with the more resistant geochemical phases. These resistant phases will not be readily soluble during initial saturation of the soils by water from the reservoir.

Analysis of the selenium data from rock samples collected near the proposed Sandstone Reservoir damsite indicates the smallest concentration of selenium was present in sandstone lithofacies of the Mesaverde Group. A somewhat larger selenium concentration was measured in relatively fine-grained lithofacies that include olive-gray shale, grayish-brown silty shale, and siltstone. The largest selenium concentration was in samples of carbonaceous shale and coal. Unmineralized samples collected from the Browns Park Formation had concentrations of selenium generally less than 1 mg/kg, whereas substantial selenium enrichment resulting in concentrations as large as 141 mg/kg was determined for uranium-bearing tuffaceous rocks collected in the Ketchum Buttes uranium deposits. The concentration of selenium in most of the clastic rocks collected from the Savery Creek drainage basin generally was within the normal range of values reported for similar lithofacies in Upper Cretaceous and Tertiary rocks of the Western United States (0.1 to 1.0 mg/kg).

Concentrations of selenium, arsenic, and molybdenum in surface- and ground-water samples collected in the study area were small. The concentrations of total selenium and total arsenic in 61 surface-water samples did not exceed the maximum contaminant level established by the U.S. Environmental Protection Agency for public drinking-water supplies. The largest discharges of selenium (0.54 kg/d) and arsenic (1.45 kg/d) were calculated for streams that drain the northwestern part of the drainage basin, which includes areas with large concentrations of selenium and arsenic in rock samples. The positive correlation between discharge and total arsenic concentration during runoff from lowland snowmelt indicates that snowmelt is an important mechanism in supplying total arsenic concentration to the proposed reservoir site. Dissolved selenium and arsenic concentrations in nine ground-water samples from the study area did not exceed the maximum contaminant level established for public drinking-water supplies by the U.S. Environmental Protection Agency (1989).

Dissolved gross-alpha activity and total uranium concentrations in surface-water samples generally were less than proposed guidance and recommended levels for drinking water established by the U.S. Environmental Protection Agency. Samples with the largest gross-alpha activity (greater than 5 pCi/L) were collected from sites on tributaries to Savery Creek, in the area in and adjacent to the Ketchum Buttes uranium deposits. Both suspended gross-alpha activity and total uranium concentration indicated a positive correlation to discharge during runoff from lowland snowmelt in the drainage area of the proposed reservoir.

Concentrations of selenium and associated trace elements in streambed-sediment samples in the drainage area of the proposed reservoir were small. Concentrations of total selenium and arsenic in streambed-sediment samples decreased in the downstream direction toward the proposed damsite. The largest concentrations of total selenium (1.1 mg/kg) and total arsenic (7.0 mg/kg) were measured in a streambed-sediment sample from Little Savery Creek, which receives weathered detrital material from the Ketchum Buttes uranium deposits. The concentration of selenium in streambed-sediment samples from creeks in the drainage area of the proposed reservoir ranged from 0.1 to 1.1 mg/kg and generally was less than the concentration of selenium in bottom-sediment samples from areas in Wyoming and Utah, with potential selenium toxicity to plants and animals. Only 1 out of 54 bottom-sediment analyses compiled from published literature on previous studies in the area had a molybdenum concentration greater than 4 mg/kg.

On the basis of analyses of data collected during this study, construction of the proposed Sandstone Reservoir is not expected to increase the concentrations of selenium and associated trace elements in the reservoir water greater than maximum contaminant levels for public drinking-water supplies and freshwater aquatic organisms established by the U.S. Environmental Protection Agency. The area of the Ketchum Buttes has been identified as a dominant source of trace elements during lowland snowmelt. An increase in trace-element concentrations might occur if the area in and adjacent to Ketchum Buttes is disturbed.

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Supplement 1.--Laboratory procedure for the sequential extraction of selenium from soil samples (Steven Wilson, U.S. Geological Survey, written commun., 1988)

I. Water soluble and mild ion exchange.

Weigh 1 gram of sample into a 65-milliliter culture tube. Add 20 milliliters of 0.25 moles per liter potassium chloride and shake for 30 minutes. Centrifuge, decant, and filter the solution (Whatman #41)[1]. Analyze the supernatant and save the residue for the next step.

II. Moderate ion exchange.

To the residue from step I, add 20 milliliters of potassium orthophosphate dihydrogen (1,000 parts per million phosphate). Shake for 2 hours, centrifuge, decant, and filter (Whatman #41). Save the solid and analyze the solution.

III. Selenium associated with organic material, iron oxide, and magnesium oxide.

To the residue from Step II, add 2 milliliters of sodium pyrophosphate (0.1 molar) solution. Heat the solution at 80 °C for 10 to 15 minutes. Add 3 milliliters of 3:2 hydrogen peroxide/nitric acid in 0.5 milliliter increments, heat this mixture at 100 °C until nearly dry (do not allow dryness). Repeat this last step two more times. Add 20 milliliters of 1 molar ammonium acetate in 6 percent nitric acid and shake for 30 minutes. Centrifuge, decant, and filter the solution (Whatman #41). Analyze the supernatant and save the residue.

IV. Selenium associated with residue material.

Perform a total digestion (for hydride analysis) on the residue using the following procedure: Place 0.3 gram of sample in a 60-milliliter Teflon bomb. Add 400 microliters of Trition-X (1 percent). Add 2 milliliters of concentrated potassium persulfate solution and enough water to create a slurry; swirl the contents and allow to sit for 1 hour. Add 2 milliliter hydrofluoric acid, 2 milliliters nitric acid, 1 milliliter perchloric acid (all concentrated), and put on a hotplate at 110 °C for 1 hour or until solution is 1 centimeter from the bottom. Add a second aliquot of 1 milliliter hydrofluoric acid, 2 milliliters nitric acid and 1 milliliter perchloric acid, and heat at 110 °C for 1 hour. Add 2 milliliters nitric acid, 1 milliliter perchloric acid, and 2.5 milliliters sulfuric acid and put on the hot plate for 3 hours. Remove the Teflon bomb from the hot plate, allow it to cool, and then add 7 milliliters water and 3 milliliters hydrocloric acid. Put a watch

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[1] The use of trade names in this report is for identification purposes only and does not constitute endorsement by either the U.S. Geological Survey or the Wyoming Water Development Commission.

glass on top of the bomb and put back on the hotplate for 1 hour at 80 °C. Remove the watch glass and transfer the solution to a square 60-milliliter polyethylene bottle bringing the solution to a final mass of 34 grams with water.

In this study, because the total mass of residue was analyzed, the analyst would prolong the digestion interval if undigested residue remained in the bomb. All reagents are reagent grade or better unless noted. The acids used in the total digestions are all concentrated unless otherwise noted.

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