TRITIUM, STABLE ISOTOPES, AND NITROGEN IN FLOW FROM SELECTED SPRINGS THAT DISCHARGE TO THE SNAKE RIVER, TWIN FALLS-HAGERMAN AREA, IDAHO, 1990-93

By Larry J. Mann and Walton H. Low

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CONVERSION FACTORS AND ABBREVIATED UNITS

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second	0.02832	cubic meter per second
curie (Ci)	$3.7x10^{10}$	becquerel
picocurie per liter (pCi/L)	0.037	becquerel per liter

For temperature, degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) by using the equation:
°F = (1.8)(°C) + 32.

Abbreviated units used in report: mL (milliliter); mg/L (milligram per liter).

Tritium, Stable Isotopes, and Nitrogen in Flow from Selected Springs that Discharge to the Snake River, Twin Falls-Hagerman Area, Idaho, 1990-93

By Larry J. Mann *and* Walton H. Low

Abstract

In 1990-93, tritium concentrations in water from 19 springs along the north side of the Snake River near Twin Falls and Hagerman ranged from 9.2±0.6 to 78.4±5.1 picocuries per liter (pCi/L). The springs were placed into three categories on the basis of their locations and tritium concentrations: Category I springs are the farthest upstream and contained from 52.8±3.2 to 78.4±5.1 pCi/L of tritium; Category II springs are downstream from those in Category I and contained from 9.2±0.6 to 18.5±1.2 pCi/L; and Category III springs are the farthest downstream and contained from 28.3±1.9 to 47.7±3.2 pCi/L.

Differences in tritium concentrations in Category I, II, and III springs are a function of the ground-water flow regimes and land uses in and hydraulically upgradient from each category of springs. A comparatively large part of the water from the Category I springs is from excess applied-irrigation water which has been diverted from the Snake River. A large part of the recharge for Category II springs originates as many as 140 miles upgradient from the springs. Tritium concentrations in Category III springs indicate that the proportion of recharge from excess applied-irrigation water is intermediate to proportions for Category I and II springs.

Tritium concentrations in precipitation and in the Snake River were relatively large in the 1950's and 1960's owing to atmospheric testing of nuclear weapons. Conversely, tritium concentrations in ground water with a residence time of several tens to a few hundred years, as occurs in the Snake River Plain aquifer hydraulically upgradient from the Category II springs, are comparatively small because of the 12.4-year half-life of tritium.

The conclusion that recharge from excess applied-irrigation water from the Snake River has affected tritium in the Snake River Plain aquifer is supported by differences in the deuterium (^{2}H) and oxygen-18 (^{18}O) ratios of water. These ratios indicate that water discharged by the springs is recharged by waters of different origins. Irrigation recharge is more enriched in ^{2}H and ^{18}O than the regional ground water. Water from Category I springs is more enriched in ^{2}H and ^{18}O than is water from Category II or III springs because a large proportion of irrigation recharge mixes with the regional ground water in Category I springs. Nitrite plus nitrate as nitrogen concentrations also are greater in water from Category I springs than in water from Category II springs.

INTRODUCTION

Concern has been expressed that some of the approximately 31,000 Ci of tritium discharged to the Snake River Plain aquifer from 1952 to 1990 at the Idaho National Engineering Laboratory (INEL) has migrated or will migrate to the Snake River in the Twin Falls-Hagerman area (fig. 1). Analyses of water samples collected in 1989 from 19 springs on the north side of the Snake River in the Twin Falls-Hagerman area indicated

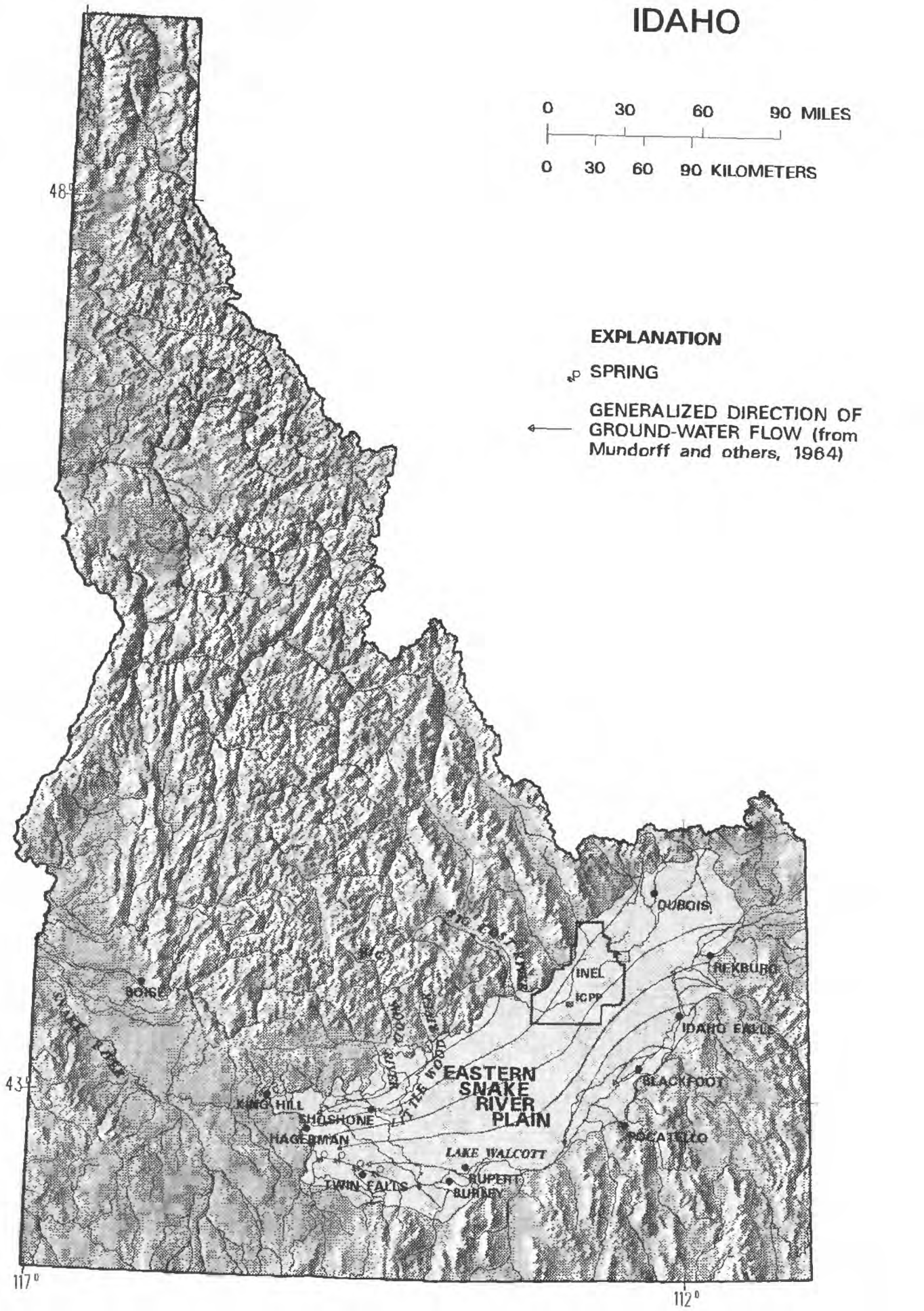

Figure 1. Locations of the eastern Snake River Plain, Twin Falls-Hagerman area, and Idaho National Engineering Laboratory, and generalized direction of ground-water flow in the Snake River Plain aquifer

that the tritium concentrations were less than or equal to 200±200 pCi/L (Mann, 1989, p. 13). Additionally, analyses of samples by the U.S. Environmental Protection Agency indicated a slight decrease in tritium concentrations in the Snake River near Buhl since the 1970's owing to the radioactive decay of tritium produced by atmospheric testing of nuclear weapons in the 1950's and 1960's (Mann, 1989, p. 14). After analyses of the 1989 samples, a long-term program to monitor tritium concentrations in the spring flow was established by the U.S. Geological Survey (USGS) in cooperation with the U.S. Department of Energy.

Because the 1989 samples had tritium concentrations that were less than or equal to 200±200 pCi/L, samples collected from the 19 springs in 1990-93 were analyzed using an electrolytic-enrichment, gas-counting method. This method primarily is limited to the analyses of samples that contain concentrations of tritium between 0.2 and 100 pCi/L (Pritt and Jones, 1989, p. 5-19). In contrast, the method and counting time used to analyze the 1989 samples could not detect concentrations less than 200 pCi/L.

This report documents tritium concentrations in spring-flow samples collected in 1990-93 in the Twin Falls-Hagerman area and discusses why the concentrations differ in different areas. It also presents stable-isotope ratios and concentrations of nitrate plus nitrite as nitrogen in water from selected springs and discusses relations between these and concentrations of tritium. The electrolytic-enrichment, gas-counting method of analysis was selected to document concentrations resulting from natural tritium production and from atmospheric testing of nuclear weapons. Analyses of samples collected in 1990-93 will serve as a baseline to quantitatively document whether tritiated water discharged to the aquifer at the INEL has a measurable, long-term effect on tritium concentrations in spring flow.

Geohydrologic Setting and Wastewater Disposal at the Idaho National Engineering Laboratory

The eastern Snake River Plain is a northeast-trending structural basin about 200 mi long and 50 to 70 mi wide. The plain is underlain by a layered sequence of basaltic lava flows and cinder beds intercalated with alluvium and lakebed sedimentary deposits. Individual lava flows generally range from 10 to 50 ft in thickness, although the average thickness may be from 20 to 25 ft (Mundorff and others, 1964, p. 143). The sedimentary deposits consist mainly of lenticular beds of sand, silt, and clay with lesser amounts of gravel. Locally, rhyolitic lava flows and tuffs are exposed at the land surface or occur at depth. The basaltic lava flows and intercalated sedimentary deposits combine to form the Snake River Plain aquifer, which is the main source of ground water on the plain.

The Snake River Plain aquifer is recharged by the infiltration of precipitation and irrigation water, and by underflow from tributary valleys on the perimeter of the plain. Water recharged to the aquifer generally moves southwestward along the axis of the plain and is discharged to springs along the Snake River (fig. 1).

In 1980, about 1.33 million acres of land were irrigated on the eastern Snake River Plain (Garabedian, 1986, p. 7). About 8.6 million acre-ft/year of water were diverted for irrigation from the Snake River and its tributaries (Garabedian, 1989, fig. 8). From the 1902 to the 1980 water years, discharge to springs along the north side of the Snake River increased from about 3.1 million to about 4.3 million acre-ft/year as a result of increased recharge to the Snake River Plain aquifer from the infiltration of irrigation water (Kjelstrom, 1992, fig. 27); a water year

begins in October and ends in September the following year and is designated by the year in which it ends.

The INEL includes about 890 mi^2 of the northeastern part of the eastern Snake River Plain and is about 100 mi northeast of Twin Falls and about 110 mi northeast of Hagerman. The general direction of ground-water movement in the Snake River Plain aquifer is southwestward. Ground water from the INEL moves in this southwestward direction and is discharged to springs in the Twin Falls-Hagerman area (fig. 1). Tritiated water and other aqueous wastes were discharged to wells and ponds in the south-central part of the INEL from 1952 to February 1984; much of these aqueous wastes was injected directly into the aquifer through a deep disposal well. The disposal of tritium in wastewater at the INEL for 1952-88 is described by Mann and Cecil (1990). From February 1984 to 1993, most of the aqueous wastes were discharged to unlined infiltration ponds. Wastewater discharged to ponds recharges the aquifer after percolating through about 450 ft of basalt and sediment that overlie the aquifer.

Tritium has migrated at least 9 mi southwest of the disposal areas at the INEL (Orr and Cecil, 1991). Tritium, which is one of the most mobile constituents in wastewater discharged to the aquifer, was detected periodically in 1983-86 at concentrations of 3,400±200 pCi/L or less in water from two wells along the southern boundary of the INEL. Since April 1986, tritium concentrations in water from wells along the southern boundary have been less than the method detection limit of 500 pCi/L.

Acknowledgments

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METHODS AND QUALITY ASSURANCE

Methods used to collect water samples for tritium analyses generally followed guidelines established by the USGS (Wood, 1976; Thatcher and others, 1977; and Skougstad and others, 1979). Sampling methods used in the field and the method used to report tritium concentrations are outlined in the following sections. Sample collection for stable isotopes are part of the USGS's routine data-collection activities and follow guidelines cited above.

Sample Collection

Water samples for tritium analyses were collected in 500-mL polyethylene bottles and were not treated prior or subsequent to being bottled in the field. Water from the springs was collected as close as reasonably possible to the spring orifices. Some springs had multiple orifices or the flow was diverted for use by fish hatcheries. Where possible, the samples were collected upstream from diversions. The 500-mL polyethylene bottle was lowered by hand in the area of the orifice or in the channel downstream from the orifice(s); where flow was channeled, care was taken to sample moving water instead of water in eddies and ponded areas. The bottle was rinsed at least three times with spring water prior to sample collection. After collection, the bottle immediately was capped, and the exterior was dried; laboratory film was placed around the cap, and a label, that included identification information for the sample, was attached to the bottle. A second sample was collected at each site in

the event that the first sample was destroyed inadvertently during transport or storage. The samples were placed in a secured vehicle or in the USGS Project Office at the INEL until they were shipped to the USGS National Water Quality Laboratory, Arvada, Colorado.

Physical conditions at the springs during sample collection were recorded in a field logbook and a chain-of-custody record was used to track samples from the time of collection until delivery to the analyzing laboratory. These records are available for inspection at the USGS Project Office at the INEL.

Reporting of Data

For each tritium concentration, an associated analytical uncertainty, 2**s**, is calculated such that there is a 95-percent probability that the true tritium concentration in a sample is in the range of the reported concentration plus or minus the analytical uncertainty. For example, given an analytical result of 18.1±1.5 pCi/L, there is a 95-percent probability that the true concentration is in the range of 16.6 to 19.6 pCi/L.

TRITIUM IN FLOW FROM SELECTED SPRINGS

Tritium is a naturally occurring isotope of hydrogen with a 12.4-year half-life and is produced by reaction of cosmic rays with nitrogen in the upper atmosphere. It also is a radioactive waste product from nuclear powerplant operations, fuel processing, and weapons production and testing. Prior to atmospheric testing of nuclear weapons in the 1950's and 1960's, the average background tritium concentration in environmental waters from cosmic-ray production was less than 16 pCi/L (National Council on Radiation Protection and Measurements, 1979). Atmospheric weapons tests markedly increased tritium concentrations in precipitation and surface waters. Tritium concentrations in precipitation at Dubois, INEL, and Shoshone that resulted from the atmospheric testing of nuclear weapons and natural production are shown on figure 2; the concentrations were calculated using data from Michel (1989). Mean annual tritium concentrations in precipitation at these locations were less than 75 pCi/L in 1953, about 4,000 pCi/L in 1963, and less than 37 pCi/L in 1983. Concentrations differed at the three locations because of differences in precipitation; the 1953-83 mean annual precipitation at Dubois, the INEL, and Shoshone was about 313, 226, and 260 mm, respectively. In 1963, the mean concentration of tritium in surface water of the United States was about 3,500 pCi/L. By 1990, however, the mean concentration in surface water was about 65 pCi/L (R.L. Michel, USGS, oral commun., 1992). For the purpose of comparison, the maximum contaminant level for tritium in public drinking-water supplies is 20,000 pCi/L (U.S. Environmental Protection Agency, 1983, p. 236).

During 1990-93, 19 springs each were sampled from three to five times; locations of the springs are shown on figure 3 and they are listed in downstream order on table 1. For ease of discussion, the springs were placed into three categories on the basis of their locations and tritium concentrations. Category I springs include Devils Washbowl, Devils Corral (upper), an unnamed spring upstream from Blue Lakes Spring, Blue Lakes, Warm Creek, and Crystal Springs (fig. 3 and table 1). Tritium concentrations in the flow from these springs are markedly greater than concentrations in flow from downstream springs. Category II springs include Clear Lakes, Briggs Creek, Banbury, an unnamed spring upstream from Blind Canyon Spring, Blind Canyon, Box Canyon, Blue Heart, Sand, Thousand, Bickel, Riley Creek, and

Table 1.—***Springs at which water samples were collected for tritium analyses, Twin Falls-Hagerman area, Idaho***

[Springs are numbered in downstream order; see figure 3 for locations]

	Category I Springs	
1 Devils Washbowl	3 Spring (unnamed)	5 Warm Creek
2 Devils Corral (upper)	4 Blue Lakes	6 Crystal
	Category II Springs	
7 Clear Lakes	11 Blind Canyon	15 Thousand
8 Briggs Creek	12 Box Canyon	16 Bickel
9 Banbury	13 Blue Heart	17 Riley Creek
10 Spring (unnamed)	14 Sand	18 Billingsley Creek
	Category III Springs	
19 Birch Creek		

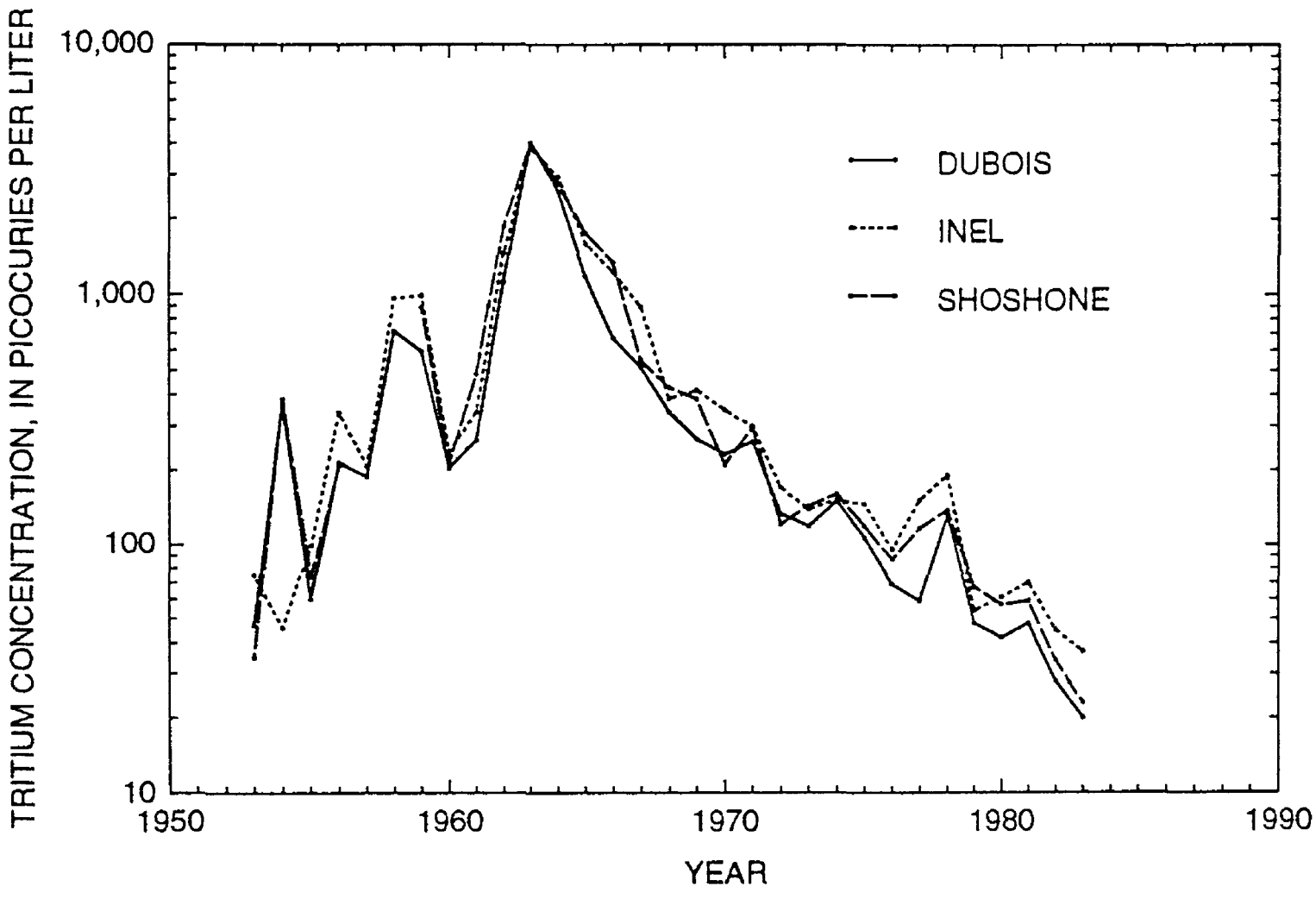

Figure 2. Calculated concentrations of tritium in precipitation at Dubois, Idaho National Engineering Laboratory (INEL), and Shoshone as a result of the atmospheric testing of nuclear weapons and natural production.

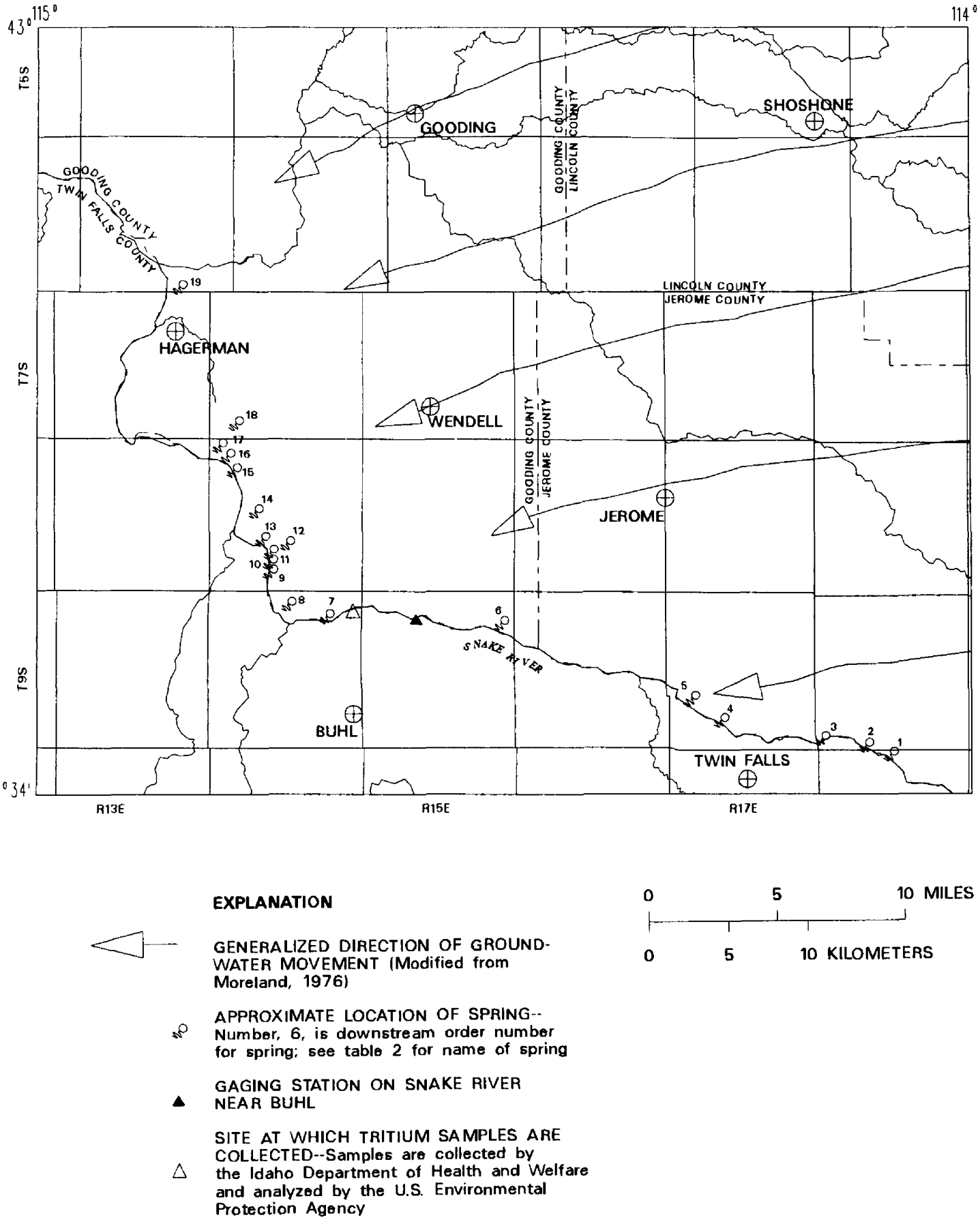

Figure 3. Locations of springs at which water samples were collected for tritium analyses, Twin Falls-Hagerman area, Idaho.

*Table 2.—**Physical and chemical characteristics of and tritium concentrations in water from selected springs in the Twin Falls-Hagerman area, Idaho***

[See figure 3 for locations of springs and table 1 for their downstream order. Tritium concentrations and analytical uncertainties determined by U.S. Geological Survey's National Water Quality Laboratory, Arvada, Colorado; analytical uncertainties reported as 2s. Remarks: Replicate indicates a second sample was submitted for analysis with a different identifier. Abbreviation: NM, discharge was not measured]

Name of spring(s)	Date sampled	Discharge (cubic feet per second)	Temper-ature (°C)	pH (units)	Specific conductance (micro-siemens per centimeter at 25°C)	Tritium concentration and analytical uncertainty (picocuries per liter)	Remarks
Banbury	11/6/90	NM	13.4	8.7	424	14.7±1.0	
	3/19/91	105	13.2	8.3	421	12.1±0.8	
	3/2/92	113	14.5	8.7	419	12.0±0.8	
	3/8/93	112	14.0	8.7	410	11.9±0.8	
Bickel	11/6/90	23.9	15.4	8.2	334	15.6±1.0	
	3/19/91	17.8	14.9	8.3	313	12.2±0.9	
	3/3/92	18.9	15.5	8.2	317	12.0±0.8	
						12.1±0.8	Replicate
	3/10/93	15.2	14.9	8.3	334	10.3±0.7	
Billingsley Creek	11/6/90	46.4	12.6	7.9	359	18.1±1.5	
	3/18/91	29.6	13.5	8.2	350	16.5±1.1	
	3/3/92	26.6	13.0	7.8	349	16±1	
	3/10/93	19.2	10.8	8.1	388	14±1	
Birch Creek	11/6/90	10.3	13.2	8.2	505	47.7±3.2	
	3/18/91	11.4	13.4	8.3	407	35.8±2.6	
	3/3/92	9.25	14.0	8.1	435	34.0±1.9	
	3/10/93	12.1	13.0	8.1	450	28.3±1.9	
Blind Canyon	11/6/90	11.2	13.8	8.5	434	12.7±0.8	
	3/19/91	10.8	14.0	8.4	425	12.7±0.8	
	3/2/92	9.77	14.0	8.4	435	10.1±0.8	
	3/8/93	9.01	14.5	8.6	438	12.9±0.8	

*Table 2.—**Physical and chemical characteristics of and tritium concentrations in water from selected springs in the Twin Falls-Hagerman area***—Continued

Name of spring(s)	Date sampled	Discharge (cubic feet per second)	Temperature (°C)	pH (units)	Specific conductance (microsiemens per centimeter at 25°C)	Tritium concentration and analytical uncertainty (picocuries per liter)	Remarks
Blue Heart	11/6/90	NM	14.8	7.9	398	15.8±1.0	
	3/19/91	NM	15.2	7.9	385	11.2±0.8	
						12.2±0.8	Replicate
	3/2/92	NM	15.0	8.0	395	11.5±0.8	
	3/8/93	NM	15.0	8.1	385	9.2±0.6	
Blue Lakes	11/5/90	205	15.8	7.8	630	65.3±4.5	
	3/21/91	182	15.8	7.9	627	53.1±3.2	
	3/2/92	172	15.2	7.6	644	61.1±3.8	
	3/9/93	163	15.6	7.7	650	55.4±3.8	
Box Canyon	11/2/90	383	14.1	8.2	406	12.8±0.8	
	3/22/91	351	14.0	8.2	410	14.1±1.0	
	3/2/92	334	14.2	7.9	408	12.8±0.8	
	3/8/93	321	14.3	8.0	418	13.1±0.9	
Briggs Creek	11/2/90	117	14.2	7.7	490	18.5±1.2	
	3/19/91	105	14.0	8.0	449	16.1±1.0	
	8/15/91	104	15.0	8.0	498	15.4±0.8	
	3/2/92	100	14.0	7.9	451	15.0±1.3	
	3/8/93	105	14.0	7.8	481	13.4±0.9	
Clear Lakes	11/5/90	528	14.2	8.1	420	16.2±1.1	
	3/20/91	449	14.0	8.0	448	13.5±0.9	
	3/2/92	456	14.0	8.1	455	13.0±0.9	
	3/8/93	450	14.5	7.9	435	11.2±0.8	
						12.2±0.8	Replicate

Table 2.—***Physical and chemical characteristics of and tritium concentrations in water from selected springs in the Twin Falls-Hagerman area***—Continued

Name of spring(s)	Date sampled	Discharge (cubic feet per second)	Temper-ature (°C)	pH (units)	Specific conductance (micro-siemens per centimeter at 25°C)	Tritium concentration and analytical uncertainty (picocuries per liter)	Remarks
Crystal	8/16/90	NM	14.5	8.0	690	64.3±3.8	
	11/7/90	452	14.7	8.1	692	63.7±4.5	
	3/21/91	400	14.3	8.1	665	60.5±3.8	
	3/3/92	398	14.5	8.0	660	59.0±3.8	
	3/9/93	429	14.3	7.7	698	55.7±3.8	
						52.8±3.2	Replicate
Devils Corral (upper)	3/22/91	39.8	14.2	8.2	615	71.7±4.5	
	3/4/92	37.4	15.0	8.0	630	61.0±3.8	
	3/10/93	41.1	15.0	8.1	654	61.1±3.8	
Devils Washbowl	11/1/90	15.4	15.0	8.0	669	72.8±5.1	
	3/20/91	12.2	15.1	8.6	629	78.4±5.1	
	3/4/92	14.4	14.0	8.3	638	73.0±5.1	
	3/10/93	10.2	13.0	8.4	670	67.2±4.5	
Riley Creek	11/6/90	69.7	15.0	8.3	335	17.2±1.2	
	3/19/91	72.9	14.8	8.0	314	14.0±0.9	
	3/3/92	75.3	15.0	8.1	298	13.0±0.9	
	3/10/93	85.7	14.6	8.1	329	10.2±0.7	
Sand	11/7/90	99.2	14.4	7.9	386	16.2±1.3	
	3/19/91	76.3	14.2	7.9	385	12.3±0.8	
	8/13/91	NM	14.0	7.9	410	13.6±0.9	
	3/2/92	74.4	14.0	7.8	380	11.0±0.8	
	3/10/93	64.4	14.8	7.9	379	9.3±0.8	

*Table 2.—**Physical and chemical characteristics of and tritium concentrations in water from selected springs in the Twin Falls-Hagerman area***—Continued

Name of spring(s)	Date sampled	Discharge (cubic feet per second)	Temperature (°C)	pH (units)	Specific conductance (microsiemens per centimeter at 25°C)	Tritium concentration and analytical uncertainty (picocuries per liter)	Remarks
Thousand	11/6/90	NM	14.8	8.2	366	17.9±1.2	
	3/18/91	1320	16.8	8.3	355	15.1±1.0	
						15.6±1.0	Replicate
	3/3/92	1240	14.0	8.0	365	14.9±1.0	
	3/9/93	1290	14.4	8.3	373	12.3±0.9	
Unnamed springs above Blind Canyon springs	11/6/90	4.87	13.5	8.5	458	17.2±1.2	
	3/19/91	2.42	14.1	8.5	401	13.0±0.8	
	3/2/92	3.40	14.0	8.5	425	12.0±0.8	
	3/8/93	2.19	13.5	8.6	420	10.8±0.7	
Unnamed spring above Blue Lakes Spring	11/8/90	5.37	12.5	8.1	526	65.0±4.5	
	3/22/91	1.64	11.9	8.5	618	62.7±3.8	
	3/4/92	0.25	14.0	8.1	610	57.9±3.8	
						58.9±3.2	Replicate
	3/10/93	3.34	9.0	8.3	665	58.2±3.8	
Warm Creek	11/5/90	25.0	13.0	8.3	656	66.8±4.5	
	3/21/91	25.7	15.9	7.9	602	55.7±3.8	
	3/4/92	18.6	14.6	7.7	618	56.3±3.8	
	3/9/93	27.8	14.1	7.7	662	55.0±3.8	

Billingsley Creek Springs. Category III consists of Birch Creek Spring, at which the tritium concentration is less than that from Category I springs, but greater than that from Category II springs.

Tritium concentrations in spring flow ranged from 9.2±0.6 to 78.4±5.1 pCi/L (table 2) and averaged 29.6 pCi/L; the standard error of estimate for the mean concentration was 2.5 pCi/L. Flow from Category I springs contained larger concentrations of tritium than flow from downstream springs. Tritium concentrations in flow from Category I springs ranged from 52.8±3.2 to 78.4±5.1 pCi/L and averaged 62.0 pCi/L with a standard error of estimate for the mean concentration of 1.3 pCi/L. In contrast, concentrations in flow from Category II springs ranged from 9.2±0.6 to 18.5±1.2 pCi/L and averaged 13.5 pCi/L; the standard error of estimate for the mean concentration was 0.3 pCi/L. Flow from the Category III spring contained smaller concentrations of tritium than Category I springs, and greater concentrations than Category II springs. Tritium concentrations in four water samples from the Category III spring were 28.3±1.9, 34.0±1.9, 35.8±2.6 and 47.7±3.2 pCi/L, respectively (table 2); the average concentration was 36.4 pCi/L and the standard error for the mean was 4.1 pCi/L.

Between November 1990 and March 1993, when most of the samples were collected, tritium concentrations generally remained relatively constant or decreased. Concentrations in flow from Blind Canyon and Box Canyon Springs remained relatively constant and the concentrations in flow from the 17 other springs decreased from a minimum of about 8 percent to slightly more than 40 percent.

The differences in tritium concentrations in Category I, II and III springs are a function of the ground-water flow regimes, land uses, and irrigation practices in and hydraulically upgradient from each category of springs. In 1959, Mundorff and others (1964, pl. 4) concluded that part of the ground water discharged to Category I springs originates in areas a few tens of miles east of Twin Falls, near Burley and Lake Walcott; their conclusion was based on a water-table map and a flow-net analysis of the Snake River Plain aquifer. The configuration of the water table in the spring of 1980, as described by Lindholm and others (1988), also supports this conclusion. In contrast, part of the ground water discharged to Category II springs originates in areas near Dubois and Rexburg, about 140 mi northeast of Twin Falls, and part of the water discharged from Category III springs originates in the Big and Little Wood River basins.

Land use along the north side of the Snake River from Lake Walcott to near Crystal Spring largely is irrigated agriculture. Most of the area is irrigated with surface water diverted from the Snake River, although several large acreages are irrigated with ground water (Lindholm and Goodell, 1986). Tritium concentrations in surface-water runoff from rainfall and snowmelt are greater than concentrations in deep ground-water flow systems in which the residence time of water is tens or hundreds of years or more. Rain and snow contain residual concentrations of tritium from atmospheric weapons testing and from natural production, whereas radioactive decay reduces tritium concentrations proportionately with the residence time of water in deep aquifers such as the Snake River Plain aquifer; because of its 12.4-year half-life, about 5.5 percent of tritium radioactively decays annually. For example, the August 1989 water sample collected by the Idaho Department of Health and Welfare from the Snake River contained 300±200 pCi/L (U.S. Environmental Protection Agency, 1990, p. 19; see figure 3 for sample-

collection site). A concentration of 300±200 pCi/L in water from the Snake River is not unique; from 1974 to 1988, tritium concentrations ranged from 100±200 to 900±200 pCi/L (Mann, 1989, p. 19). A sample collected at the gaging station on the Snake River near Buhl (fig. 3) contained 56±4 pCi/L in 1993. In contrast, tritium concentrations in spring flow in 1990-93 ranged from 9.2±0.6 to 78.4±5.1 pCi/L.

A large part of the ground-water recharge in irrigated areas along the north side of the Snake River hydraulically upgradient from Category I springs consists of excess applied-irrigation water diverted from the Snake River. Garabedian (1989, pl. 8) estimated that for 1976-80, from 4 to more than 20 in./year of water were recharged to the aquifer in areas where diverted surface water was used for irrigation; in nonirrigated areas, less than 2 in./year of precipitation recharges the aquifer.

Although flow from Category II springs contained detectable concentrations of tritium, the concentrations were less than or equal to 18.5±1.2 pCi/L as compared to a minimum of 52.8±3.2 pCi/L from Category I springs. Because a large part of the ground water discharged to Category II springs originates 140 mi or more east and northeast of the springs, pre-1950's tritium concentrations may have been a small percentage of the 16 pCi/L from cosmic-ray production owing to the long residence times of ground water in the aquifer. Tritium in recharge to the aquifer from precipitation and locally, from excess-applied irrigation water diverted from the Snake River would, in turn, increase the concentration of tritium in the flow from Category II springs.

Tritium concentrations in flow from Category III springs are less than those in flow from Category I springs but greater than those in flow from Category II springs. Part of the water discharged to Category III springs originates in the Big and Little Wood River basins (Mundorff and others, 1964, plate 4; and Lindholm and others, 1988); water from the Snake River also is diverted into canals to irrigate crops in areas near Gooding and Shoshone. Flow from Category III springs represents a mix of water, part from recharge in the Big and Little Wood River basins and part from the recharge of water diverted from the Snake River. The fact that tritium concentrations in Category III springs are intermediate to concentrations in Category I and II springs, suggests proportionately different amounts of recharge from excess applied-irrigation water diverted from the Snake River and different ground-water residence times in the aquifer.

Data provided by Wegner and Campbell (1991, table 4) indicate that tritium concentrations in water from wells are relatively consistent with concentrations in spring flow. In 1989, water samples were collected from 50 wells and 5 springs that obtain water from the Snake River Plain aquifer between the southern boundary of the INEL and Hagerman. The water samples were collected as part of a cooperative long-term monitoring program between the USGS, U.S. Department of Energy, and Idaho Department of Water Resources. Tritium concentrations in the 55 water samples ranged from -12.8±25.6 to 134.4±25.6 pCi/L (Wegner and Campbell, 1991, table 4); the samples were analyzed using a liquid-scintillation counting method, which has a larger detection limit than the electrolytic-enrichment, gas-counting method. Water samples from wells in areas adjacent to the Snake River from near Rupert to the Category I springs contained more than 30.0±25.6 pCi/L of tritium; water from 11 of these wells contained more than 75.0±25.6 pCi/L. Water samples from most wells in the area from the Category II springs eastward and northeastward to the southern boundary

of the INEL, contained less than 30.0±25.6 pCi/L. Water from wells east of the Category III springs contained tritium concentrations comparable to concentrations in water from Category I springs.

Data provided by Wegner and Campbell (1991, table 4) also suggest that the tritium concentrations are not uniform with depth in the aquifer. For example, tritium concentrations differed in water from each well in two pairs of wells identified as MV01 and MV02, and MV10 and MV53 (Wegner and Campbell, 1991, fig. 2, and tables 2 and 4); wells in each pair are less than 0.3 mi apart. Wells MV02 and MV53 are comparatively shallow domestic wells, and wells MV01 and MV10 are comparatively deep irrigation wells. The uses of water, depths of wells, and tritium concentrations in the water are shown on the following table:

Well identifier	Use of water	Depth (feet)	Tritium concentration (picocuries per liter)
MV01	Irrigation	217.5	86.4±25.6
MV02	Domestic	150	48.0±25.6
MV10	Irrigation	516	35.2±25.6
MV53	Domestic	350	83.2±25.6

A comparison of concentrations in water from wells MV01 and MV02 shows that tritium concentrations locally increase with depth in the aquifer. General directions of ground-water flow described by Lindholm and others (1988) show that part of the ground water in the vicinity of these wells originates at or near Lake Walcott about 5 mi to the southeast. Land-use data presented by Lindholm and Goodell (1986) show that ground water is the primary source of irrigation water near wells MV01 and MV02 and between the wells and Lake Walcott.

A comparison of concentrations in water from wells MV10 and MV53 shows that in places tritium concentrations also decrease with depth in the aquifer. General directions of ground-water flow described by Lindholm and others (1988) indicate that part of the water in the vicinity of these wells originates in the area between Burley and Lake Walcott where surface water is the primary source of irrigation water. Irrigation water in the vicinity of this pair of wells, however, is derived from both ground water and surface water, although ground water is the main source. Although data are insufficient to adequately describe the processes that cause increases and decreases of tritium with depth in the aquifer, the data clearly show that recharge from surface water has increased the concentrations of tritium.

SELECTED STABLE ISOTOPES AND NITROGEN

The conclusion that recharge from excess applied-irrigation water diverted from the Snake River has affected tritium concentrations in the Snake River Plain aquifer is supported by data for selected stable isotopes and concentrations of nitrogenous compounds in spring flow. Wood and Low (1988) showed that recharge from irrigation affected the ratios of two stable isotopes—deuterium (^{2}H) and oxygen-18 (^{18}O). Data from Brockway and Robison (1992) show that concentrations of nitrite plus nitrate as nitrogen (NO_2+NO_3 as N) in water from some springs have been impacted by agricultural practices.

Deuterium and Oxygen-18

Deuterium and ^{18}O are stable isotopes of hydrogen and oxygen. Differences in ^{2}H and ^{18}O ratios for water from springs can be used to identify the source of water discharging from springs. Irrigation recharge is more enriched in ^{2}H and ^{18}O than the regional ground water because of evaporation; therefore, differences in ratios of ^{2}H and ^{18}O indicate whether water from a spring contains a greater portion of irrigation recharge.

Absolute measurement of isotopic ratios is a difficult analytical task; as a result, relative isotopic ratios are measured as a matter of convention (Toran, 1982). For example,
$^{18}O/^{16}O$ for a sample is compared with $^{18}O/^{16}O$ for a standard:

$$\delta^{18}O = (R_{sample}/R_{standard}-1) \times 1{,}000$$

where:

R_{sample} = $^{18}O/^{16}O$ in the sample,

$R_{standard}$ = $^{18}O/^{16}O$ in the standards, and

$\delta^{18}O$ = relative difference in concentration in permil (parts per thousand).

The delta notation (δ) for example, $\delta^{18}O$ is the value reported by laboratories for stable-isotope analysis. The $\delta^{2}H$ can be derived by analogy to $\delta^{18}O$ where the ratio $^{2}H/H$ replaces $^{18}O/^{16}O$ in R_{sample} and $R_{standard.}$ The standard used for determining $\delta^{18}O$ and $\delta^{2}H$ in water is Vienna Standard Mean Ocean Water (VSMOW) as defined by Craig (1961). The respective precisions of measurement for $\delta^{18}O$ and $\delta^{2}H$ at the NWQL are 0.15 permil and 1.5 permil (Ann Mullin, USGS, oral commun., 1991). The ^{2}H and ^{18}O for natural water are commonly reported as negative values when compared to the standard.

Global ^{2}H and ^{18}O ratios for precipitation and freshwater generally lie along a straight line defined as:

$$\delta^{2}H = 8^{18}O + 10,$$

generally referred to as the world meteoric water line (fig. 4). Ratios for precipitation and freshwater near coastal areas also generally lie along this line. Because inland-continental freshwater generally undergoes greater evaporation, the slope of the meteoric water line is less than 8 (Gat and Gonfiantini, 1981, p. 132). The local surface-water meteoric line for the Snake River Plain is defined as:

$$\delta^{2}H = 6.4\delta^{18}O - 21$$ Wood and Low, 1988, p. 15).

Deuterium and ^{18}O ratios for water from selected springs lie near the local meteoric water line, indicating that prior to recharge, the spring water is derived from local surface water (fig. 4). Stable-isotopic ratios for water from selected springs are shown on table 3.

Stearns and others (1938, p. 62) and Mundorff and others (1964, p. 172) concluded that recharge to springs (Category I) between Twin Falls and Buhl mostly is derived from local irrigation. Water from Blue Lakes and Crystal Springs (Category I) contains a greater portion of irrigation recharge than water from Briggs, Box Canyon, Blue Heart, and Sand Springs (Category II), which are farther downstream. Wood and Low (1988, p. 31) contrasted ^{2}H and ^{18}O ratios for water from Blue Lakes Spring and the regional ground water and argued that the isotopically-enriched water from Blue Lakes Spring is the result of irrigation recharge mixing with the regional ground water. The average of 15 ^{2}H and ^{18}O samples from Box Canyon Springs (Category II) was -137.2 permil and -17.9 permil, respectively; the average from Blue Lakes Spring was -131.7 permil and -16.9 permil, respectively. The Box Canyon Springs ratios compare closely with the regional ground water average of -136.4 permil for ^{2}H and -17.7 permil for ^{18}O, whereas, water from Blue Lakes Spring are enriched (Wood and Low, 1988, p. 31). Water from Category I

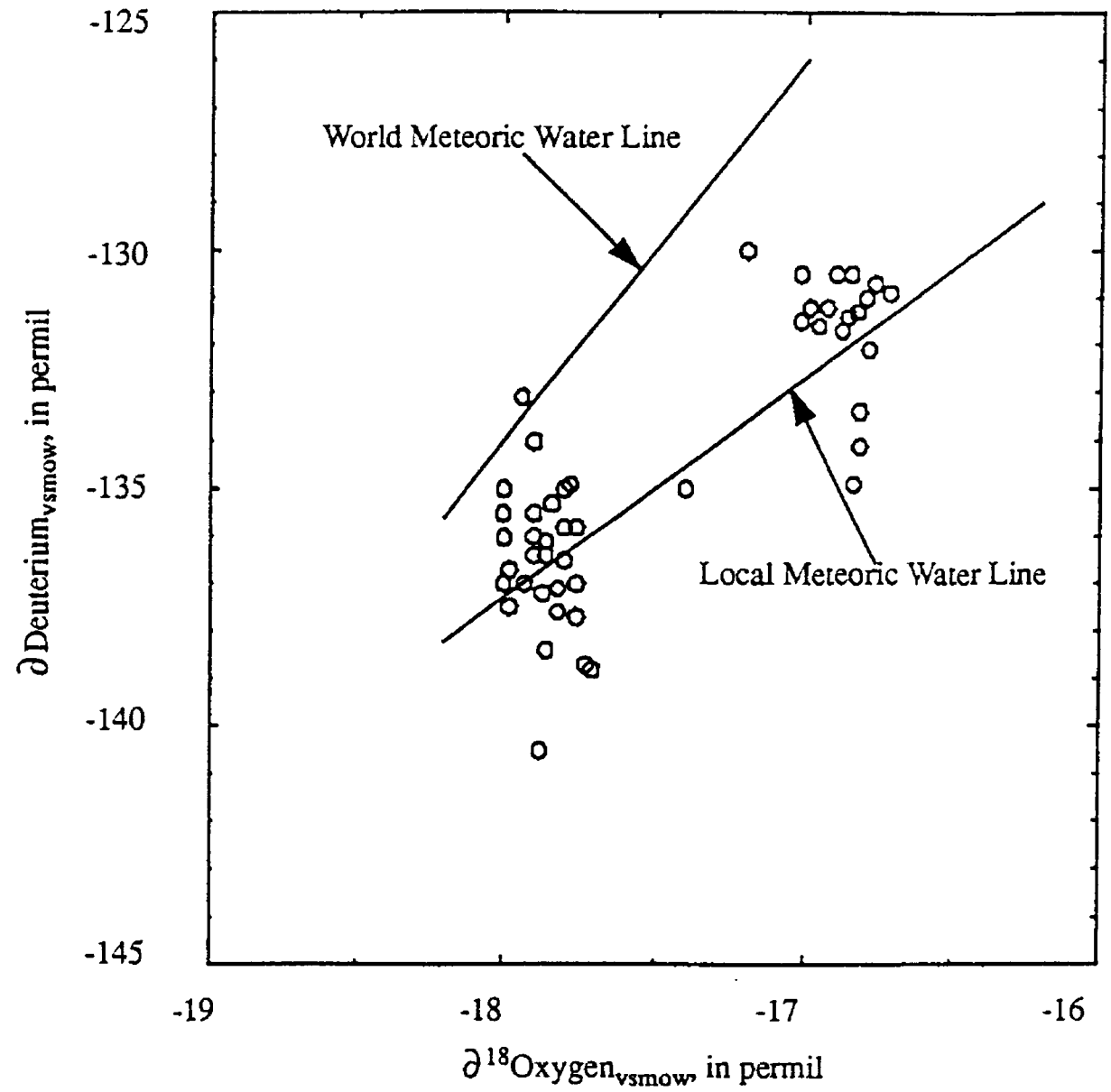

Figure 4. Deuterium and oxygen-18 isotopic ratios in water from selected springs, Twin Falls-Hagerman area, Idaho.

Table 3.—***Stable-isotope ratios in water from selected springs, Twin Falls-Hagerman area, Idaho***

[See figure 3 for location of springs and table 1 for their downstream order. Deuterium, permil VSMOW; oxygen-18, permil VSMOW]

Name of spring(s)	Date sampled	δ deuterium	δ oxygen-18
Blue Heart	12/6/84	-135.8	-17.8
	8/22/86	-134.0	-17.9
	3/17/87	-135.0	-18.0
Blue Lakes	11/5/80	-131.0	-17.2
	3/20/85	-130.7	-16.8
	3/19/87	-129.5	-17.0
	3/12/84	-131.7	-16.9
	7/2/84	-131.6	-17.0
	8/20/84	-134.1	-16.8
	10/2/84	-134.9	-16.8
	12/5/84	-130.5	-16.9
	1/17/85	-131.4	-16.9
	5/9/85	-131.2	-16.9
	7/1/85	-131.2	-17.0
	8/6/85	-133.4	-16.8
	9/16/85	-131.3	-16.8
	10/21/85	-131.5	-17.0
	11/25/85	-132.1	-16.8
Box Canyon	11/7/80	-137.0	-18.0
	3/13/84	-137.6	-17.8
	7/17/84	-137.5	-18.0
	8/28/84	-138.7	-17.7
	10/3/84	-138.4	-17.9
	12/7/84	-140.5	-17.9
	1/18/85	-137.1	-17.8
	3/21/85	-137.0	-17.8
	5/9/85	-137.2	-17.9
	7/1/85	-136.4	-17.9
	8/6/85	-136.4	-17.9
	9/12/85	-137.0	-17.9
	10/21/85	-136.4	-17.9
	11/25/85	-134.9	-17.8
	3/17/87	-135.5	-18.0

Table 3.—***Stable-isotope ratios in water from selected springs, Twin Falls-Hagerman area, Idaho***—continued

Name of spring(s)	Date sampled	δ deuterium	δ oxygen-18
Briggs Creek	11/5/80	-136.0	-17.9
	3/13/84	-135.3	-17.8
	12/3/84	-137.7	-17.8
	3/21/85	-136.1	-17.9
	11/13/85	-135.8	-17.8
	3/17/87	-135.5	-18.0
Crystal	3/20/85	-130.5	-17.0
	11/13/85	-130.9	-16.8
	3/18/87	-130.0	-17.2
Sand	11/3/80	-137.0	-18.0
	3/12/84	-138.8	-17.7
	3/18/85	-136.7	-18.0
	11/12/85	-133.1	-17.9
	3/17/87	-136.0	-18.0

springs are more enriched in ^{2}H and ^{18}O and ratios of ^{2}H and ^{18}O plot higher along the local meteoric line that ratios for Category II springs. These differences in ratios show that springs in Category I have a greater proportion of irrigation recharge than springs in Category II.

Nitrite Plus Nitrate as Nitrogen

Concentrations of NO_2+NO_3 as N commonly indicate water pollution caused by activities such as irrigated agriculture, sewage treatment, and livestock feedlots. Brockway and Robison (1992) presented concentrations of NO_2+NO_3 as N in water from some of the springs for which tritium concentrations have been determined. Concentrations of NO_2+NO_3 as N in water from two Category I springs—Devils Corral and Warm Creek—were greater than those in water from four Category II springs—Banbury, Blind Canyon, Clear Lakes, and Riley Creek. Concentrations of NO_2+NO_3 as N in three samples from Category I springs ranged from 2.050 to 3.100 mg/L (table 4). In contrast, concentrations of NO_2+NO_3 as N in 55 samples from Category II springs ranged from 0.060 to 2.060 mg/L and averaged 1.09 mg/L.

Brockway and Robison (1992, p. 66-67) concluded that the "average seasonal concentration of nutrients in the main [Snake] river reflect the locations of nutrient inflows as well as the inflow of spring water from the Snake [River] Plain aquifer. Average NO_2+NO_3 as N concentrations increase from approximately 1 mg/L at Milner to over 1.6 mg/L from Twin Falls Pool to Clear Lakes Bridge. The NO_2+NO_3 as N level

decreases and remains relatively constant at about 1.4 mg/L from Clear Lakes to King Hill***Tributary stream nutrient load levels reflect integrated effects of surface irrigation return flow, ground-water returns, and aquacultural activities but show significant increases in suspended solids during the irrigation season." Tributary streams as defined by Brockway and Robison (1992) include those springs listed on table 4.

SUMMARY

Concern has been expressed that some of the approximately 31,000 Ci of tritium in wastewater discharged to the Snake River Plain aquifer from 1952 to 1990 at the INEL has migrated or will migrate to the Snake River in the Twin Falls-Hagerman area. Analyses of samples collected in 1990-93 from 19 springs on the north side of the Snake River will serve as a baseline to quantitatively document whether tritiated water disposed to the aquifer at the INEL has a measurable long-term effect on tritium concentrations in spring flow.

Tritium, a naturally occurring isotope of hydrogen with a 12.4-year half-life, also is a radioactive waste product from nuclear powerplant operations, fuel processing, and weapons production and testing. Tritium concentrations in surface water in the United States increased from less than 16 pCi/L in the 1950's to about 3,500 pCi/L in 1963 owing to atmospheric testing of nuclear weapons.

In 1990-93, tritium concentrations in the flow of the 19 springs ranged from 9.2±0.6 to 78.4±5.1 pCi/L. On the basis of their locations and tritium concentrations, the springs were placed into three categories: Category I springs are the farthest upstream and contained from 52.8±3.2 to 78.4±5.1 pCi/L of tritium; Category II springs are downstream from those in Category I and contained from 9.2±0.6 to 18.5±1.2 pCi/L of tritium; and Category III springs are the farthest downstream and contained from 28.3±1.9 to 47.7±3.2 pCi/L.

Differences in the tritium concentrations in the Category I, II, and III springs are a

*Table 4.—**Concentrations of nitrite plus nitrate as nitrogen in water from selected springs, Twin Falls-Hagerman area, Idaho***

[From Brockway and Robison, 1992, appendices C and D]

Name of spring(s)	Number of samples	Concentration (milligrams per liter) Minimum	Maximum	Mean
Banbury	1	.992	.992	--
Blind Canyon	26	.060	1.300	.588
Clear Lakes	27	.667	2.060	1.583
Devils Corral	1	2.050	2.050	--
Riley Creek	1	.716	.716	--
Warm Creek	2	2.390	3.100	2.745

function of the ground-water flow regimes, land uses, and irrigation practices in and hydraulically upgradient from each category of springs. Part of the ground water discharged to Category I springs originates a few tens of miles east of Twin Falls. In contrast, part of the ground water discharged to Category II springs originates about 140 mi northeast of Twin Falls and part of the ground water that discharged to Category III springs originates in the Big and Little Wood River basins. A large part of the ground-water recharge in irrigated areas hydraulically upgradient from Category I springs consists of excess applied-irrigation water diverted from the Snake River. It is estimated that in areas where diverted surface water was used for irrigation for 1976-80, from 4 to more than 20 in./year of irrigation water recharged the aquifer; in nonirrigated areas, less than 2 in./year of precipitation recharged the aquifer.

Because a large part of the ground water discharged to Category II springs originates up to 140 mi or more to the east and northeast, and because of the long residence time in the aquifer, concentrations of tritium in Category II springs are smaller than concentrations in Category I springs. The fact that tritium concentrations in Category III springs are intermediate to concentrations in Category I and II springs suggests proportionately different amounts of recharge from excess applied-irrigation water diverted from the Snake River and different residence times of ground water in the aquifer.

The conclusion that recharge from excess applied-irrigation water diverted from the Snake River has affected tritium concentrations in the Snake River Plain aquifer is supported by differences in the $\delta^{18}O$ and $\delta^{2}H$ ratios of water from springs. These differences indicate that the springs are recharged by water from different origins. Irrigation recharge is more enriched in ^{2}H and ^{18}O than the regional ground water. Water from Category I springs is more enriched in ^{2}H and ^{18}O than water from Category II and III springs because a large proportion of irrigation recharge mixes with the regional ground water in Category I springs. Concentrations of NO_2+NO_3 as N are greater in water from Category I springs than in water from Category II springs because of the integrated effects of irrigation and aquacultural activities.

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