CHAPTER VI

SURFACE AND DRINKING WATER MONITORING

INTRODUCTION

Surface water is one of three general categories of environmental media (air, vegetation, and surface water) that were monitored routinely near the Rocky Flats Plant (RFP) throughout the 1950s and 1960s. This fact underscores the importance of surface water monitoring information for the historical public exposures studies. During this study, it has been determined that nearby communities received the greatest exposure to contaminants in the late 1960s through the air, rather than from the drinking water. However, there have been some continual questions about past contamination released into creeks at Rocky Flats that historically flowed offsite into drinking water reservoirs east of the plant.

The two major creeks that drain Rocky Flats are Walnut Creek (which has north and south branches on site) and Woman Creek. The creeks also collected storm runoff from the plant site, which contained numerous waste storage burial and incineration areas near the plant's central industrial area. Walnut Creek, which drains about 51% of the Rocky Flats site, flowed into Great Western Reservoir (GWR) in northeastern Jefferson County about 1.5 mi (2.4 km) from the plant. In 1989, the City of Broomfield built a diversion ditch around the reservoir to prevent surface drainage and runoff from Rocky Flats from entering the reservoir via Walnut Creek. In 1997, the City of Broomfield secured a new drinking water supply; Great Western is no longer used as a drinking water source.

Woman Creek drains about 35% of the Rocky Flats site, particularly the southeastern part. Until recently, Woman Creek flowed from the Rocky Flats site into Standley Lake, a drinking water supply for the Cities of Westminster, Thornton, and Northglenn and some residents of Federal Heights. In 1996, the new Woman Creek Reservoir was completed to prevent Rocky Flats surface water from flowing into Standley Lake. Water in the new reservoir is then pumped to Walnut Creek below the GWR, where it flows downstream into Big Dry Creek and the South Platte River.

Water samples have been collected from the Rocky Flats area and analyzed for radioactivity since 1951, before operations began. Surface water is one of three environmental media (air, vegetation, and surface water) that were monitored routinely throughout the 1950s and 1960s.

The purpose of evaluating the results of surface water monitoring data is to observe general trends in the levels of contaminants over time that may have resulted from RFP operations. To accomplish this goal, it is important to know what radioactive and chemical contaminants were monitored, the frequency of sampling (routine program or special studies), the sampling locations, the analytical techniques, and the quality of the data.

Surface water samples were first collected and analyzed from the RFP area in 1951 for a background survey of radioactivity in water, soil and vegetation (Quimby 1952). When regular operations began at the RFP in 1952 and until the early 1970s, the extent of the monitoring program, the spatial distribution of sampling, and the types of materials

measured were fairly limited. During Phase I of this study, ChemRisk evaluated much of the routine water sampling data that had been taken from 1952 through 1989 because they had been unable to find documentation of continuous effluent monitoring to derive radionuclide and chemical source term estimates for surface water releases. Instead, monitoring data for radioactivity in drinking water supplies from reservoirs downstream of Rocky Flats were evaluated. Their results suggested that contamination of the primary reservoirs (GWR and Standley Lake) from Rocky Flats releases was plausible but inconclusive because similar levels of radioactivity were observed during the same time periods in reservoirs in the area that were assumed to be unaffected by Rocky Flats operations.

Some of the key contributions and findings from Phase I that pertain to environmental sampling of surface water around the RFP (ChemRisk 1992, 1994) are

- A general history of the holding ponds, GWR, Standley Lake, and Mower Reservoir
- Compilation and comparison of RFP data from 1952 through 1970 of the reported gross alpha releases to Walnut Creek to average gross alpha concentrations measured in the receiving reservoir, the GWR
- Compilation and comparison of RFP data for 1952 through 1970 of reported gross alpha concentrations in water from GWR, Standley Lake, and Baseline Reservoir and drinking water from Broomfield, Westminster, Arvada, Boulder, and Golden
- Compilation and comparison of reported concentrations of ^{238}Pu, ^{239,240}Pu, natural uranium, and tritium in drinking water from the cities of Broomfield and Westminster compared to Arvada, Boulder and Golden by the Colorado Department of Health (CDH) from 1970 through 1989. The comparison suggested a possible increase of ^{239,240}Pu from 1972 to 1974 in Broomfield and Westminster drinking water associated with holding pond reconstruction at the RFP. This pond reconstruction resuspended sediments in the North and South Walnut Creek drainage. In addition, an accidental release of tritium in 1973 resulted in increased tritium concentrations in the Broomfield drinking water.

As the Phase II work began, it was determined that more study of the surface water pathways, including the sediments, was necessary to more clearly define their relevance to evaluating historical releases from Rocky Flats. *Radiological Assessments Corporation (RAC)* continued to examine the releases of radionuclides and chemicals in surface water, especially for the early years. In particular, *RAC*'s initial efforts looked more closely at how liquid effluent was processed and handled at the site and evaluated releases from the site, especially in the early years. The results of this evaluation are presented in the report, *Characterization of Releases to Surface Water from the Rocky Flats Plant* (Meyer and Till 1999).

This chapter describes the general features of surface water flow and hydrology of the RFP area and the liquid effluent handling ponds onsite that affect the stream flow to give perspective to the offsite surface water monitoring program. It analyzes routine surface water monitoring data from the site and briefly reviews the Colorado Department of Public Health and Environment (CDPHE) data that ChemRisk evaluated in Phase I. The chapter also assesses some of the special studies involving surface water monitoring. These data may be used in later phases of the study to verify surface water releases from the site.

DOCUMENTATION SOURCES

Both historic and recent records help to understand how liquid effluents were handled at the plant and how and when surface waters were monitored. We have used all the relevant documents that ChemRisk located in Phase I. The most useful historic documents were located in the Environmental Master File at Rocky Flats and at the Federal Records Center in Denver, where some original analytical datasheets for measurements of contaminants in liquid effluents for various years were located (Dow 1952–1953, 1960, 1961, 1969–1972). Current site characterization and remedial investigation activities at the RFP have provided supplementary documentation. In addition, we have had discussions with personnel at the CDPHE and at the site. The following list describes some of the key report series that we have used in this analysis.

Original Handwritten Site Survey and Environmental Logbooks

Logbooks for certain time periods in 1952, 1953, 1959, 1960, 1961, 1969–1970, 1971–1972, 1974, 1975, and 1979 (Dow 1952–1953, 1960, 1961, 1969–1972, 1974–1979) listed the location and type of sample, quantity, counts per minute, activity, lab initials of the analyst, count initials, background (blank counts), and remarks. Written comments on the counting efficiency and the use of spiked samples were usually included. For early years, the efficiency factors and equations for calculating the activity concentration in water samples were based on Hanford procedures. Experiments relating to methods of analysis are documented.

Progress Report—Waste Disposal Unit

A series of monthly waste disposal reports were very valuable in compiling information on liquid wastes. These reports, first written in 1953, provided a summary of the liquid wastes, treated and untreated, that were released from buildings to ponds and from ponds to offsite reservoirs.

These monthly reports were authored by E. S. Ryan. The first monthly report, dated January 1953, introduced the newly organized Waste Disposal Unit, organized under the authority of John G. Epp at the direction of F. H. Langell. The purpose of the unit was “the supervision of the ultimate disposal of processed liquid and solid waste, and the correlation of the allied data.” The reports contained summary descriptions of plant activities until September 1953, when the volume and alpha activity levels in the liquid wastes (treated, untreated, and laundry) released from the main processing areas were given. In July 1954, the name was changed to *Progress Report for the (month, year)—Waste Disposal Co-ordination Group.*

Progress Report—Waste Disposal Co-ordination Group

Mr. E. S. Ryan continued as author of these monthly reports, which were published from July 1954 through December 1954. The reports included a summary of the liquid wastes released, a list of the discharges from Building 71, the drums of contaminated waste in storage at the RFP, and a breakdown of the shipments made during the month to Arco (near Idaho Falls,

Idaho), along with the costs for offsite disposal at Arco. In January 1955, the report name was changed to *History Report—Process Waste Disposal Group*.

History Report—Process Waste Disposal Group

E.S. Ryan continued as author of these monthly reports. They provided a short description of work onsite and summarized the liquid wastes, radioactivity levels in the final holding ponds, the drums of contaminated waste in storage at various buildings onsite, and a breakdown of the trailer shipments to Arco. Some also listed the aqueous liquid wastes received, processed, and released from Building 74 to either the solar evaporation ponds or to Walnut Creek. Information for these monthly reports came from handwritten log sheets at the sanitary treatment plant and Building 74, the process waste treatment plant. The name of the report was changed to *Status Report—Health Physics Waste Disposal* in January 1965.

Status Report—Health Physics Waste Disposal

The author of these reports was still E.S. Ryan. They summarized the quantity and radioactivity levels in liquid wastes, treated and untreated, that were released from buildings to holding ponds and from ponds to Walnut Creek and then to GWR. After May 1971, this report name changed to *Waste Management Status Report—Waste Disposal*.

Waste Management Status Report—Waste Disposal

These reports were similar to the *Status Report—Health Physics Waste Disposal* monthly reports and summarized the same type of information. In addition, they reported the number of trailers and railcars of waste shipped to Idaho. In June of each year, a summary was published of liquid wastes, other than sanitary, released under the supervision of the process waste disposal group during the fiscal year. This summary indicated the type of waste (untreated or treated in Building 74), where the effluent originated, whether it was released to the holding ponds (series A and B) or to the onsite evaporation ponds, the number of discharges, the total volume, and total radioactivity.

Environmental Survey Reports

Beginning in late 1959, quarterly reports were written “in compliance with Presidential Executive Order of August 14, 1959” to tabulate the average daily and the maximum and minimum values for continuous sampling of particulate alpha and beta activity in the air by month (Dow 1960). They usually listed the long-lived radioactivity of particulates in air; radioactivity in raw surface water from GWR, Standley Lake, and Baseline and Ralston Reservoirs; and vegetation sample results from near the RFP and in surrounding communities. ChemRisk analyzed these surface water data in Phase I. The reports usually included map diagrams showing sampling locations.

GENERAL SURFACE WATER FLOW

The general features of surface water flows around the RFP have been well documented. Surface water in the Rocky Flats area flows from west to east, supplying water to reservoirs that were used as municipal water sources and recharging aquifers used for domestic water supplies (Figure VI-1). The water that moves through the waterways results from direct surface runoff following periods of rainfall and snowmelt, flow supplied by seeps and springs, and wastewater from the RFP. Five streams and five ditches drain the general environs of the RFP with many smaller tributaries running into these streams.

Streams

- North Walnut
- South Walnut
- Woman Creek
- Coal Creek
- Rock Creek

Ditches

- Last Chance Ditch
- Church Ditch
- McKay Ditch
- Kinnear Ditch and Reservoir Co. Ditch
- Smart Ditch

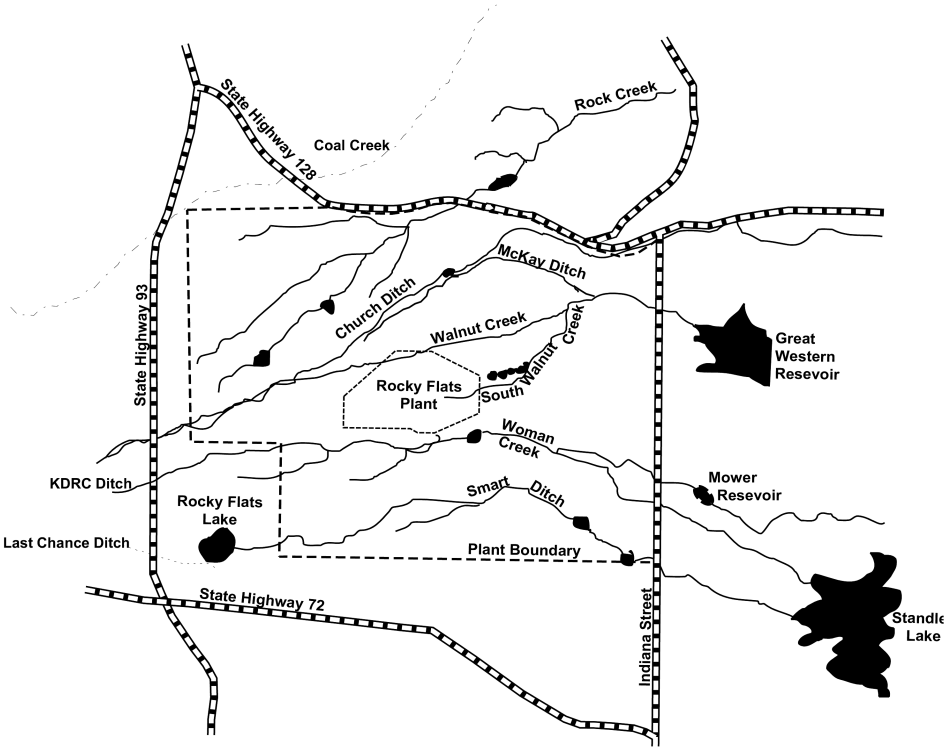

Figure VI-1. Location of key streams and reservoirs in the Rocky Flats area, adapted from EG&G (1991a). North (North Walnut Creek is not marked on the map) and South Walnut Creeks drain the RFP site and discharge into the Great Western Reservoir to the east. Woman Creek flows into Standley Lake. The inner plant perimeter security fence is shown. The "buffer zone," established in the mid-1970s, is outlined with a dashed line marked "Plant Boundary," with Indiana Street as the eastern boundary.

Three of the major water streams (North Walnut, South Walnut, and Woman Creek) are particularly important because they drain the RFP site, which had numerous waste areas within the early site boundary. These waste sites were used for storage, burial, incineration, and spraying liquid effluents (spray fields); thus, they were sources of runoff and leaching to the main streams (Figure VI-2). For example, leachate from the Landfill Pond, located directly north of the site, drained into North Walnut Creek and eventually to GWR (ChemRisk 1992). The frequency and amount of surface runoff depended upon factors such as soil infiltration capacity, surface vegetation, and slope. The clay loam soils have a relatively low infiltration capacity because of clay content, except where fractures may increase permeability.

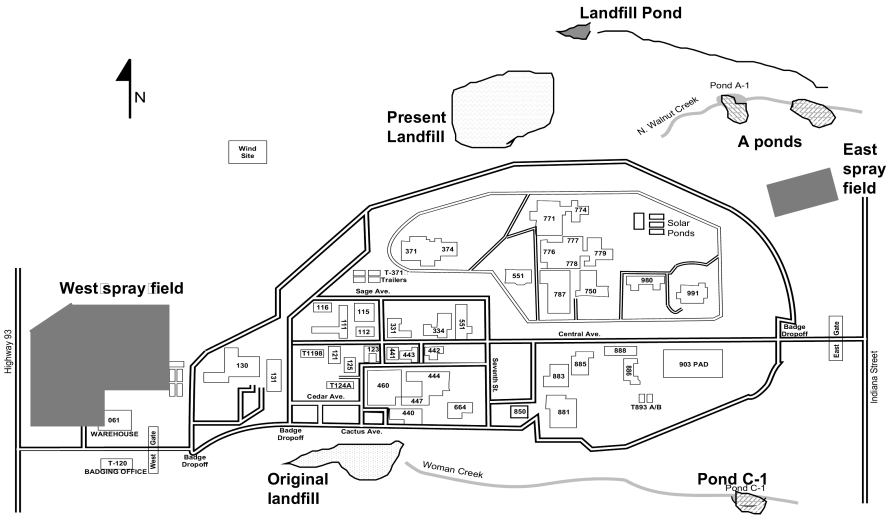

Figure VI-2. A diagram of the Rocky Flats Plant showing some of the early waste storage and disposal facilities. The map is not to scale. The original landfill was used from 1952–1968 for various plant wastes, including some radioactive and chemical wastes. The present landfill operated from 1968 through February 1970, where sanitary sewer sludge was buried. The spray fields were used to spray evaporate water from the solar evaporation or nitrate ponds (west field) and from Pond B-3 (east field). The west field was used from 1982–1985; the east field was used for a short time in 1989.

Spray evaporation, selected as a method to dispose of water from landfill and holding ponds through evaporation, was first used shortly after the present landfill was opened in 1968 (EG&G 1991a). The North and South Spray Fields, located near the present landfill north of the production area, occupied about 172,500 ft^2 (~4 acres) and 40,000 ft^2 (~1 acre), respectively. These spray fields were used to spray water over the ground to enhance evaporation of water from the ponds located near the present landfill and from Buildings 771 and 774 footing drains. During operation of the spray fields, surface water runoff was found to be draining toward North Walnut Creek from the North Spray Field and to an unnamed tributary and subsequently into Walnut Creek. The water sprayed onto the fields contained varying amounts of radioactivity from tritium, strontium, plutonium, and americium (EG&G 1991a). Spray evaporation, or

irrigation, was also used at Holding Pond B3 from 1979 through 1989. Before 1979, treated sanitary waste water from the Sewage Treatment Plant was discharged offsite through the B-series holding ponds. After 1979, the sanitary waste water was routed to Pond B3 where water from the pond was spray irrigated onto the spray fields "as weather permitted" (EG&G 1991b). All spray irrigation was discontinued in 1990.

Rainfall gauges were installed and have been operational on Woman Creek, Walnut Creek, and other Rocky Flats stations since 1972. For a period in the early 1970s, rainfall intensities ranged from less than 0.1 in. (2.5 mm) per hour to about 0.5 in. (13 mm) per hour (Hurr 1976). In the fall and early spring, frontal storms occur with long, low-intensity rainfall. In the late spring and summer months, short, intense cloudbursts produce greater surface runoff than the frontal storms (DOE 1991). Vegetation provides a relatively complete low ground cover in the area of Rocky Flats; the monitoring of that medium is discussed in Chapter V of this report.

Hurr (1976) presented one of the first comprehensive studies of the surface water and groundwater hydrology of the RFP area to determine how contaminants would be distributed spatially and temporally as they moved through the hydrological system. Walnut Creek drains into the GWR, while Woman Creek flows into Standley Lake. Standley Lake is about 3.3 mi. (5.3 km) southeast of the RFP. This lake was formed by an earthen dam on Big Dry Creek and originally was constructed in about 1910 to supply water for irrigation. Beginning in 1965, Standley Lake provided drinking water to the cities of Westminster, Thornton, and Northglenn, which are located 4 mi (6.4 km) southeast, 8 mi (13 km) east. and 7 mi (11 km) northeast of Standley Lake. About two-thirds of the lake water was the municipal water supply, and the other one-third was for irrigation. The full capacity of the lake is abut 43,000 acre-ft with an average depth of about 36 ft (11 m) (Clow and Johncox 1995).

The other major reservoir in the area is GWR, in northeastern Jefferson County, about 1.5 mi (2.4 km) east of the RFP. The GWR has an earthen dam that was built in 1904 and originally was designed to supply water for irrigation. The lake is owned and operated by the City of Broomfield, which is located 2 mi (3.2 km) to the northeast of GWR and supplied drinking water to the city until the mid1990s. The full capacity of the lake is about 3,250 acre-ft. Walnut Creek, which flows from the RFP, previously flowed into the GWR, but in 1992, it was diverted around GWR (DOE 1991; Clow and Johncox 1995).

STREAM FLOW ON CREEKS IN THE ROCKY FLATS AREA

The U.S. Geological Survey (USGS) established stream gauging stations in 1972 on North Walnut, South Walnut, and Woman Creeks to measure outflow from the plant area. The monthly streamflow for each of the three gauging stations is summarized in Tables E-1, E-2, and E-3 in Appendix E. Figures VI-3a, 3b, and 3c show the monthly flow rates for the summer of 1972 through 1974. The flow rate in all three streams showed some seasonal variation, especially in North Walnut Creek. Woman Creek had the highest flow rate of these three drainages, with a median of about 0.4 $ft^3\ s^{-1}$ (10,000 gal hr^{-1}) over this time period. The flow ranged from no flow to a maximum of 60 $ft^3\ s^{-1}$ (1.6 million gal hr^{-1}) in May 1973 during an extensive period of rain. The median flow rate in North Walnut Creek was 0.3 $ft^3\ s^{-1}$ (7500 gal hr^{-1}), while South Walnut Creek had a median flow of 0.2 $ft^3\ s^{-1}$ (~5000 gal hr^{-1}), half of that measured in Woman Creek. These records also show that there were days with no natural stream flow, particularly during late summer and early fall, which is typical for small streams in this region.

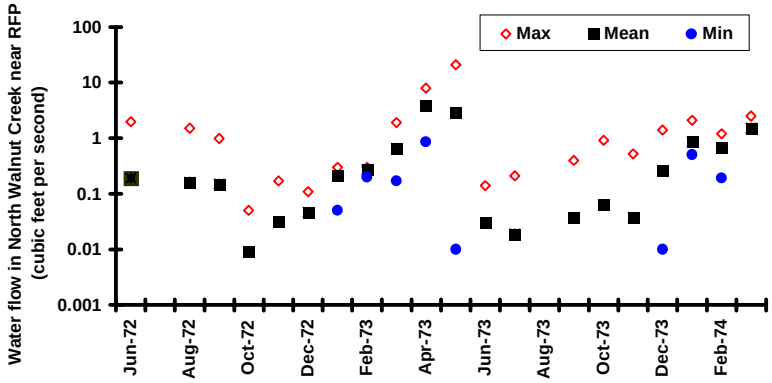

Figure VI-3a. North Walnut Creek

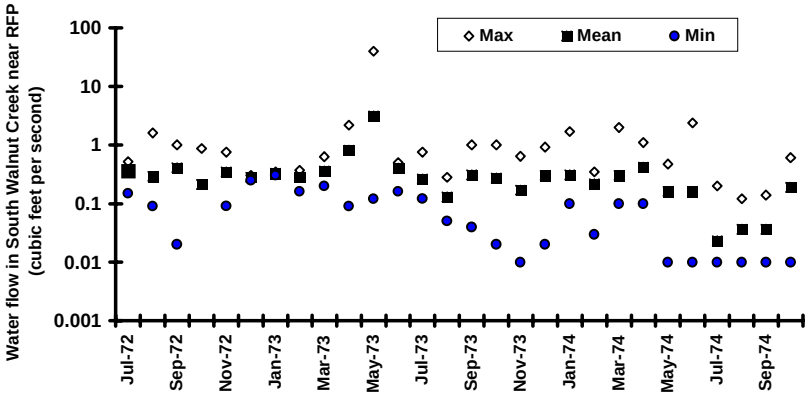

Figure VI-3b. South Walnut Creek

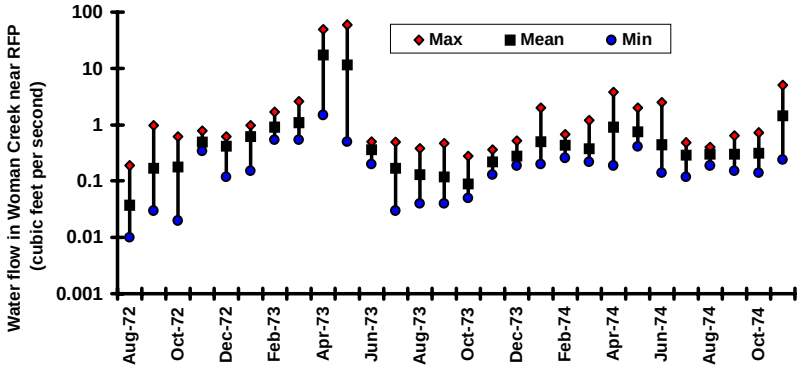

Figure VI-3c. Woman Creek

Figure VI-3. Stream flow measured by the U.S. Geological Survey (Hurr 1976) in North Walnut Creek 0.6 mi (1 km) east of the RFP (VI-3a), South Walnut Creek 0.6 mi (1 km) east of the RFP (VI-3b), and in Woman Creek just southeast of the site (VI-3c).

The USGS measured the stream flow in North and South Walnut and Woman Creeks beginning in 1972. The average flow ranged from 5000 to 10,000 gallons per hour.

Although no routine stream flow data were collected before 1972, it appears that the flow data in Figure VI-3 represent reasonable stream flow characteristics for earlier years of Rocky Flats operations. This assumption is based on observations noted in a number of reports (Hurr 1976); for example, Johnson et al. (1974) noted that the type of plant growth in the area of the A- and C-series ponds indicated no major disturbance in the previous 5 to 10 years. Figure VI-4 shows that the more recent stream flow rates are similar to these earlier measurements (EG&G 1993a). The average flow for both periods was similar, about 0.2 $ft^3\ s^{-1}$ (~5000 gal hr^{-1}), while the maximum flow rate of 30–40 $ft^3\ s^{-1}$ (~1 million gal hr^{-1}) occurred more frequently in 1991 (July and August) and 1992 (March, June, and July) than in the early years. These high flow rates were directly related to intense periods of rainfall in the RFP area, indicated by the arrows in Figure VI-4. The stream flow data were important for determining dilution of liquid effluents released from the RFP. The historic records show that liquid effluents from the RFP increased the natural stream flow of South Walnut Creek.

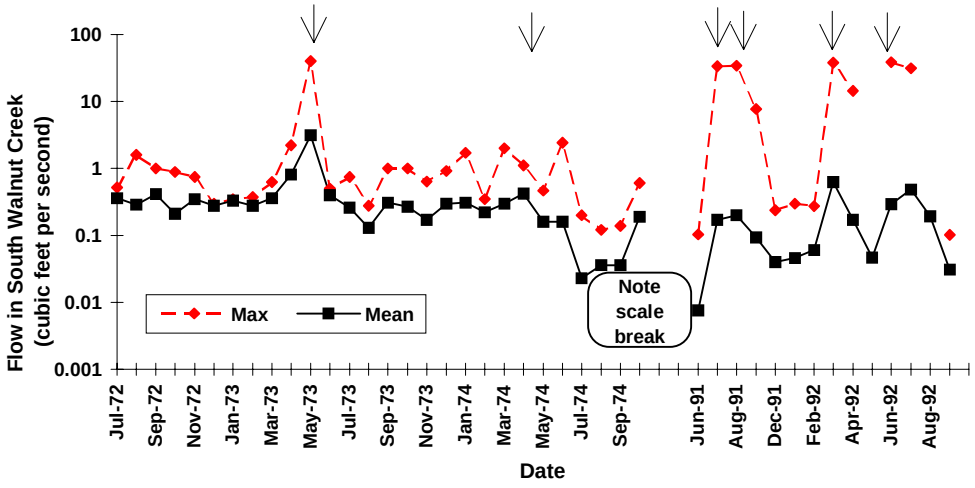

Figure VI-4. Comparison of maximum and average stream flow rates in South Walnut Creek in 1972–1974 and 1991–1992. The arrows at the top represent months when at least 1 in (2.5 cm) of rain fell in a 24-hour period.

The Church Ditch drainage is the primary contributor of water to the GWR (Table VI-1). The USGS determined that the Walnut Creek drainage contributed from 17–37% of the net drinking water supply for the City of Broomfield in the early 1970s (Zillich 1974). Of that volume, RFP sewage treatment plant effluent contributed approximately 12–16% (Dow 1969–1972). As a result, the RFP, by way of the Walnut Creek drainage basin, provided about 2–5% of the annual volume of the GWR water source (Ofte et al. 1973; Hurr 1976).

The south area of the plant is drained by Woman Creek. Woman Creek flows into Standley Lake or it can be diverted into Mower Reservoir, a source of irrigation water. Standley Lake was

the water supply for the city of Westminster and portions of the Thornton-Northglenn area (Werkema 1974; Thompson 1975).

Table VI-1. Water Inputs to the Great Western Reservoir[a]

	RFP contribution	Contribution to GWR from		RFP contribution
Year	to Walnut Creek (%)	Walnut Creek (%)	Church Ditch (%)	to GWR (%)
1970	14.1	17.5	82.5	2.5
1971	16.5	28.4	71.6	71.6
1972	11.7	37.3	62.7	62.7

[a] From Zillich (1974). Because accurate flow measurements were not available for drainage calculations, these figures were based on calculating the amount of water in the reservoir, determining the amount pumped from other sources, and subtracting the amount used by the City of Broomfield. The remainder was assumed to be the contribution of Walnut Creek drainage. Water lost through seepage and evaporation at GWR was not included.

The processing and waste handling activities at the RFP affected these local drainage streams. Before late 1974, the effluent from the sanitary sewage disposal system at the RFP was discharged into South Walnut Creek. From records in the early 1970s, the monthly sanitary sewer effluent volume for the plant averaged 6.8 million gallons (26 million liters) per month during 1971 to 1973 and produced continuous flow in South Walnut Creek (Table VI-2). These values represent only the discharges from the sewage treatment plant; the total effluent volume from all sources, including the sewage treatment plant, was higher (Meyer and Till 1999). Before 1975, backwash from the plant's water supply filter system was also discharged into Woman Creek.

Table VI-2. Monthly Sanitary Sewer Effluent from RFP to South Walnut Creek for 1971–1973 [a]

	Sanitary sewer effluent (millions of gallons)		
Month	1971	1972	1973
Jan	7.47	6.56	5.96
Feb	6.38	6.84	5.41
Mar	6.99	6.62	6.23
Apr	7.43	6.95	7.39
May	7.90	6.82	7.05
Jun	7.35	6.98	5.34
Jul	7.55	6.59	5.33
Aug	7.51	6.91	4.91
Sep	8.44	6.37	4.68
Oct	6.68	6.92	5.50
Nov	6.55	6.47	5.10
Dec	6.80	6.60	5.48
Total	87.1	80.6	68.4

[a] From Hurr (1976); data supplied by the RFP.

After 1974, the RFP maintained the stream flow gauging stations, but no daily flow records could be located for this project. Annual summaries in some of the environmental monitoring reports provide annual flow values. In the spring of 1991, the stream gauging escalated greatly when the Event Related Surface Water Monitoring Program at the RFP was established to support the environmental regulations put forth in the U.S. Department of Energy (DOE) Orders 5400.1 and 5400.5, the Clean Water Act National Pollutant Discharge Elimination System Stormwater Discharge Permitting, and the Agreement in Principle between the DOE and the State of Colorado (EG&G 1993b). A network of 13 new gauging stations provided continuous flow monitoring data on Woman Creek, South Walnut, and Walnut Creek, as well as on Smart Ditch, Rock Creek, and Mower Ditch. The USGS assumed operation of the network in May 1993 (Clow and Johncox 1995).

Holding Ponds

The effluent flow from the RFP has been primarily in an easterly direction with holding ponds or on-channel reservoirs constructed to hold water for a time before release to the offsite creeks. Figures VI-5a, 5b, and 5c show the changes in pond number and location over the years. From the 1950s to the 1970s, there was one pond on North Walnut Creek, four ponds in sequence on South Walnut Creek (B-series ponds), and one pond on Woman Creek (Figure VI-5a). The other figures show the addition of ponds on North Walnut Creek, South Walnut Creek, and Woman Creek in the mid-1970s and 1980s and changes in their flow patterns.

The ponds played an important role in liquid effluent handling and had an impact on decreasing the levels of activity that were released to the creeks and ultimately to the reservoirs (Meyer and Till 1999). Rees et al. (1978) investigated the sediment-water distributions of plutonium in Pond B-1 as a function of pH and contact time and concluded that most of the plutonium in the sediment originated from the waste water effluent discharged to the pond since 1952. They also determined that the average residence time for water in Pond B-1 was approximately 34 hours. Table VI-3 summarizes general features of the ponds. More detailed histories of the holding ponds, the GWR, and Standley Lake are available (ChemRisk 1994; Hurr 1976). Much of this information also has been summarized in the current Environmental Restoration Program documents for Operable Unit 3.

Although the holding ponds did decrease the levels of radioactivity that were released to offsite streams, the effect of the reservoirs on the daily flows was not great. In the early years of operations, the ponds were usually full so that inflow and outflow were nearly equal. Figure VI-6 shows that the volume of effluent discharged from the RFP (final B Pond) to South Walnut Creek varied widely, especially in the early years. The average discharge volume ranged from 2–9 million gallons (7.6–3.4 million liters) per month over this 20-year period. Figure VI-7 demonstrates that the effluent volume discharged from the site was approximately one-tenth of the volume flow normally measured in the creeks.

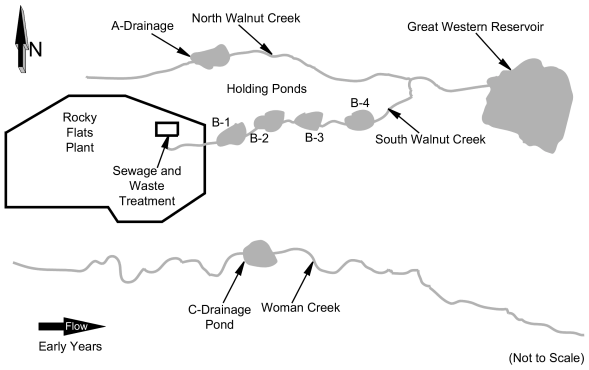

Figure VI-5a. 1950s–1960s.

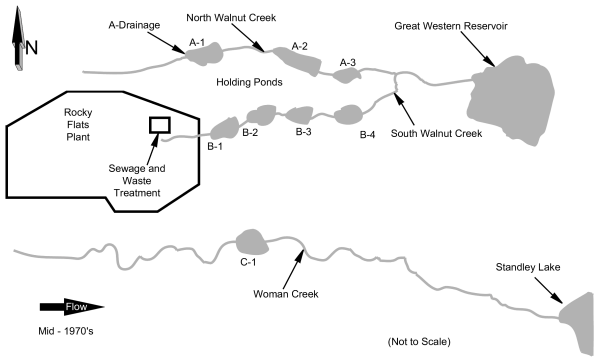

Figure VI-5b. Mid-1970s.

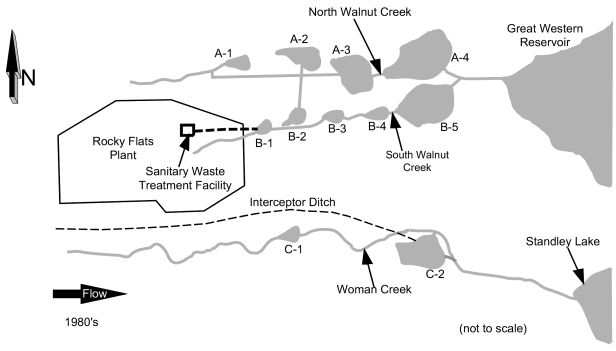

Figure VI-5c. 1980s.

Figure VI-5. Liquid effluent flow direction and holding ponds system at the Rocky Flats Plant in the 1950s and 1960s (VI-5a), in the mid-1970s (VI-5b), and in the 1980s (VI-5c).

Table VI-3 . General Features of the Holding Ponds at the Rocky Flats Plant[a]

Ponds	Date built	RFP effluents received	Area (acres)[b]	Vol (m^3)[b]	Flows into
None from 1952–1953		From 1952–1953, liquid waste containing nitrates, plutonium, and uranium discharged directly from the plant to Walnut Creek			Walnut Creek→GWR
North Walnut Creek					
A-1	1953	Until 1957, untreated low-level waste; in 1957, waste rerouted to process waste treatment facility (Building 774).	1.13	7675	Walnut Creek→GWR
A-3	1971	Runoff from northern portions of plant for hold-up before discharge			To GWR up to 1980; To Pond A-4 → Walnut Creek→GWR after 1980.
A-2	1973	From Pond A-1			Evaporation and sprayed
A-4	1980	From Pond A-3 and B-5			Walnut Creek→GWR
South Walnut Creek					
B-1	1952	Sewage treatment plant effluent and laundry wastewater	0.30	702	Walnut Creek→ GWR
B-2	1950s		0.58	2402	
B-3	1950s		0.53	2341	
B-4	1970		0.42	2193	
B-5	1980				
Woman Creek					
C-1		Before 1975, backwash from the plant's water supply filter system	0.80	2218	Standley Lake
C-2	1980	From South Interceptor Ditch			Broomfield Diversion Ditch to Big Dry Creek

[a] From Hurr (1976); Love et al. (1970), and ChemRisk (1992).
[b] 1 acre = 43,500 ft^2; or 4041 m^2; 1 m^3equals 35 ft^3.

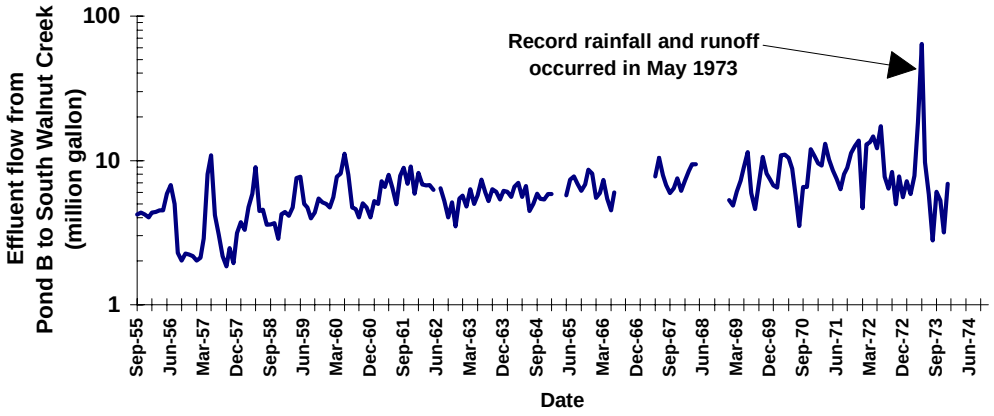

Figure VI-6. The average volume of effluent discharged from the Rocky Flats Plant through Pond B to South Walnut Creek from 1955 through 1974. The median monthly volume in the 1950s was 4.2 million gallons (16 million liters) in the 1960s, 6.2 million gallons (23 million liters), and in the 1970s, 8.2 million gallons (31 million liters). Record-setting rainfall and runoff occurred in May 1973.

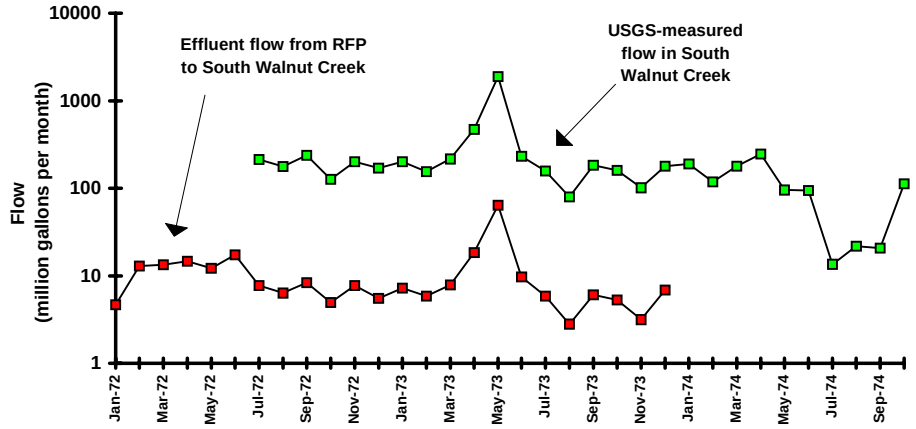

Figure VI-7. A comparison of the average volume of effluent discharged from the Rocky Flats Plant through Pond B to South Walnut Creek from 1972 through 1974 with the average stream flow measured by the U.S. Geological Survey in South Walnut Creek. This illustrates that about 10% of the volume of water in South Walnut Creek originates from Rocky Flats Plant effluents.

Solar Evaporation Ponds

Other onsite ponds for storage of liquid effluents, called the solar evaporation ponds (Table VI-4), served a different purpose than the holding ponds. The solar evaporation ponds were originally intended to store and treat (by evaporation) low-level radioactive process wastes that had high nitrate concentrations. Some of the wastes were acidic wastes that had been with aluminum hydroxide (EG&G 1991a).

Table VI-4. Contrasting Features of Holding and Solar Evaporation Ponds

Holding ponds	Solar evaporation ponds
Unlined, then clay-lined	Clay-lined (1954–1955); Asphalt-lined (August 1956)
Low chemical-low radioactivity	High chemical-low radioactivity
Designed for offsite storage and release	Designed for onsite storage and evaporation
Major renovation and rechanneling in 1972	Series of modifications from 1960 onward

Initially, there appeared to be concern about the release of high levels of nitrates from the site. One of the first activities of the Waste Disposal Unit at the RFP, organized under the authority of John Epp at the direction of F.H. Langell in January, was obtaining "a list of periodicals pertaining to the effects of inorganic nitrates in drinking water on the human body," which was prepared by the Denver Public Library (Ryan 1953). Farrell and Ryan from the RFP visited the Dow Chemical Company Plant in Midland, Michigan in February 1953 to search for information about the physiological effects of nitrates on man and animals. The Midland Waste Disposal Department in Michigan provided them a list of publications on industrial waste treatment and disposal for reference and technical value. Later, the treatment and elimination of high nitrate content liquid wastes was the subject of a meeting held in Building 71 (now called Building 771) in March 1953. In April 1953, E.S. Ryan attended the School for Water and Sewage Plant Operations at the University of Colorado for a week (Ryan 1953).

On December 14, 1953, Dr. C.C. Ruchhoft of the U.S. Environmental Health Center, Cincinnati, Ohio, visited the RFP to discuss various problems arising from the operation of the water treatment plants, especially the toxicity of nitrates "to adults and animals." After reviewing the effectiveness of the retention ponds on South Walnut Creek and the nitrate level of the effluent released from the lower pond, he "felt that there should be no danger to livestock using the effluent." He agreed that literature on the toxicity of nitrate in adult humans was lacking, but that the use of the solar evaporation pond for high-nitrate liquid wastes was the disposal option for this waste at that time (Ryan 1954).

A program of analyzing the waters of the GWR was initiated in April 1953 to "furnish a picture of the chemical content of the GWR before the release of any processed liquid-waste effluent from the plant site."

In June 1954, a test well dug near the northeast corner of the nitrate (unlined evaporation) pond gave no moisture at a depth of 16 ft (4.8 m). However, a spring on the north slope of the mesa toward Walnut Creek showed nitrate content of 540 ppm. "This leads one to believe that a large portion of the nitrate waste has been dispersed through seepage into subsurface waters" (Ryan 1954). William N. Gahr, Director of Division of Sanitation, Colorado State Department of Public Health, visited the site on October 28, 1954, to tour the Water Treatment and Sanitary Sewage Treatment Plants and to view the retention ponds. A monthly report indicates that he "expressed satisfaction with these operations" (Ryan 1954). According to Gahr the maximum permissible alpha activity to be discharged was 0.1 picocuries per milliliter (pCi mL^{-1}) (Ryan 1955).

By the spring of 1955, it was clear the "present earthen pond in use is not water-tight and allows nitrate-contaminated water to seep to underground water courses" (Ryan 1955). This pond was used primarily for high nitrate treated wastes from Building 774. On April 27, 1955, the nitrate content of a spring on the north slope of the mesa where the pond was located showed a nitrate level of 2,800 ppm. As a comparison, water from the holding pond on North Walnut Creek averaged 170 ppm nitrate for the month of April. Walnut Creek passes over private property and feeds the GWR after leaving the RFP. In July 1955, when newly constructed homes in the Broomfield Heights area were to use the domestic water supply coming from the GWR, it was necessary to retain wastes containing high nitrates and any other soluble minerals that violated the U.S. Public Health Service Drinking Water Standards. The RFP directed the replacement of this initial solar pond (designated Pond 2 in monthly waste disposal reports at that time) with a "water-tight pond" (Ryan 1955). Consequently, this first clay-lined pond, which had a maximum of two containment areas measuring 100 × 200 ft (30 × 60 m) and 200 × 200 ft (60 × 60 m), respectively, was operated until 1956 when the new solar evaporation pond was constructed. However, one of the two cells held liquids occasionally after that time.

The asphalt evaporation pond was constructed to prevent seepage or infiltration of liquids with higher contaminant levels. Modifications to the pond linings have been made since the original construction because of cracking and slumping of the existing linings and leakage of pond contents. Table E-4, Appendix E, describes the solar evaporation ponds and details of the modifications that have been made.

The five solar evaporation ponds: 207A (3 acres); 207B series (North, Center, South, 1 acre each); and 207C (1 acre) were used from the late 1950s until 1986. Pond 207C was constructed to provide additional storage capacity and enable the transfer and storage of liquids from the other ponds where repairs were needed. Pond 207C stores low-level radioactive liquid process wastes before evaporation, treatment, and solidification in Building 374. The resulting sludge and sediments from Ponds 207A and B were removed periodically and disposed of at the Nevada Test Site.

The first solar "water-tight evaporation pond" was put into service on August 31, 1956, to store and evaporate low-level radioactive process water containing high concentrations of nitrates and treated acidic wastes. It had a surface area of 3 acres and a working capacity of 15 acre-feet. The solar ponds were initially asphalt-lined, while the holding ponds were unlined.

As technology improved through the 1960s and 1970s, the solar evaporation ponds were relined with various upgraded materials; however, leakage from the ponds into the soil and groundwater was detected. During repairs in the early 1970s, 4-in. diameter underdrains were installed at the 207B ponds. These underdrains were laid so that any waste leaking through the asphalt concrete would be collected and drained toward the northeast corner of the 207B ponds, where a sump and pump system was designed to return the water to 207B North. These interceptor drains were installed in the early 1970s to collect and recycle groundwater contaminated by the ponds and to prevent natural seepage and pond leakage from entering North Walnut Creek. Only the 207B North solar evaporation pond received contaminated water from the interceptor trenches in 1992 (EG&G 1992).

In 1977, the 207B ponds were cleaned of sludge, which was disposed of offsite. Furthermore, the Petro-mat linings of Ponds 207B South and 207B Center were removed, bagged, cemented, and disposed of. Because 207B North had a minimal amount of sludge, the

Petro-mat lining was not removed. After the 1977 cleanout, the 207B solar ponds have not contained process waste. Six interceptor trenches and a French drain system (Rockwell 1988), constructed in the 1970s on the hillside north of the solar ponds, were designed to prevent natural seepage and pond leakage from entering North Walnut Creek. Trenches 1 and 2 were installed in October 1971, Trench 3 in September 1972, Trenches 4 and 5 in April 1974, and Trench 6 in July 1974. Trench 5 drained by gravity to Trench 4. Trench 4 pumped water to Trench 3, and Trench 3 returned the water to Pond 207A. Trenches 1 and 2 pumped water uphill into Sumps 1 and 2, respectively. The six trenches were taken out of service when the current French drain system became operational.

Liquid wastes meeting the drinking water standards for the chemical contaminants, especially nitrates, were stored in the unlined earthen ponds (B Ponds). Wastes meeting the radioactive contaminant standards for onsite storage, but not meeting the drinking water standards for the chemical contaminants, were stored in the asphalt-lined solar evaporation ponds or, after 1982, transferred to Building 374. Subsequently, the Building 374 waste was discharged to the solar evaporation ponds or to the B series holding ponds and finally to the GWR. Although an evaporator was installed and operated in Building 774 from 1965 to 1979 to treat the liquids that had accumulated in the solar evaporation ponds, its limited capacity did not eliminate the need for the ponds.

PERSPECTIVE ON HISTORIC GROUNDWATER MONITORING

The USGS carried out one of the first geochemical studies of the natural radioactivity of both surface water and groundwater in Colorado when they reported on the occurrence and amounts of natural radioactivity (beta/gamma), uranium, and radium, and other physical characteristics of ground and surface waters in Colorado (Scott and Voegeli 1961). Over 200 surface water and 140 groundwater samples were collected and analyzed throughout the state between 1954 and 1961 as part of a nation-wide effort by the USGS to study natural radioactivity of water in the U.S. The depth of the groundwater wells ranged from 30 to almost 2000 ft (9 to 610 m). There was no analysis or interpretation of the data, perhaps because the U.S. Public Health Service had just initiated drinking water standards for radioactivity (PHS 1962).

At the RFP, periodic sampling and sample analysis of water from groundwater monitoring wells began in 1960, when six monitoring wells were drilled to check for movement of contaminants from the solar evaporation ponds.

Table VI-5 provides key pieces of information on these and other early groundwater monitoring wells (Hoffman 1982; Blaha 1987). In 1971, wells were drilled to determine if significant movement of radioactivity from the holding ponds had occurred, and to monitor the 903 Area after the asphalt pad was applied. Before 1982, sampling of the groundwater was done at roughly 5-month intervals. In 1982, quarterly sampling began and additional parameters were analyzed to comply with new requirements from DOE (Hoffman 1984). A major change in the groundwater monitoring program occurred in 1985 with the Resource Conservation and Recovery Act (RCRA), and 56 new monitoring wells were installed. Construction of RCRA quality groundwater monitoring wells began in 1986 with the installation of 69 additional wells. In 1987, 53 more wells were drilled.

Table VI-5. Groundwater Monitoring Wells at Rocky Flats[a]

Wells	Date	Casing material	Study area	Approximate depth (ft)
60 series	1960	Galvanized iron	Solar ponds	30
68 series	1971	Galvanized iron	903 Area	4
71 series	1971	Steel	Holding ponds	22–30
74 series	1974	Plastic	Holding ponds & burial sites	13
85 series	1985	PVC	Waste and drainage areas	3–100
86/87 series	1986	RCRA[b] specifications	Various	Specified by RCRA

[a] From Hoffman 1982, Hoffman 1984, and Blaha (1987).
[b] RCRA = Resource Conservation and Recovery Act.

Historic monitoring results have been summarized previously (Hoffman 1982, Blaha 1987); the results show localized areas of elevated radioactivity at or near past disposal sites, near the solar evaporation ponds, and in the 881 Hillside area. Elevated nitrate concentrations were found in groundwater near the solar ponds and from the 881 Hillside. Volatile organic compounds have been measured in those areas, as well as near the 903 Area and near the former mounds burial area. With the RCRA program, extensive groundwater characterization studies are proceeding. At this point in time, these areas of contamination are within the plant boundary.

The Historical Public Exposure Studies on Rocky Flats focuses on past activities and the releases of contaminants offsite from those historic operations. For this reason, further evaluation of groundwater as a potential exposure pathway for offsite populations during the period of interest for this study (1952–1989) was not appropriate.

BACKGROUND PLUTONIUM IN SURFACE WATER

General Perspective on Plutonium Concentrations in Water

Information about levels of plutonium in water from sources other than Rocky Flats provides perspective for surface water measurements at the RFP. Four major mechanisms that are important to the movement of radionuclides in surface water are deposition from the atmosphere, runoff and soil erosion from land surfaces, movement of the surface water, and transfer between sediments and water (Jirka et al. 1983). As discussed earlier, plutonium occurs in the environment primarily due to fallout from atmospheric nuclear weapons tests. In the early years of operations at the RFP (the 1950s and 1960s, at least), there were significant temporal trends in quantities of plutonium fallout from weapons tests (see Chapter III and Appendix H for perspective on air concentrations and deposition rates). Because of the dynamic processes in the transport and dilution of radionuclides in surface waters, significant temporal trends in the concentrations of plutonium in surface water would also be expected. These temporal trends may be important in our evaluations of the historical surface water monitoring data around the RFP.

A report prepared for the Agency for Toxic Substances and Disease Registry provides general information about plutonium in the environment (Clement 1990). This report compiled

some measured concentrations of plutonium in various sources of water (Table VI-6). These values are intended to provide general perspective on levels of plutonium in various background and contaminated waters. From these locations, plutonium concentrations in water contaminated by local nuclear weapons testing or releases from weapons production sites range widely, from 6.3×10^{-6} to 9.6×10^{-2} Bq L^{-1} (0.17 to 2600 fCi L^{-1}). Concentrations in waters not contaminated by such local sources cover a smaller range, from 3.0×10^{-6} to 3.5×10^{-5} Bq L^{-1} (0.08 to 0.94 fCi L^{-1}). It is noted that these measurements are only a small data set.

Table VI-6. Plutonium Concentrations Measured in Various Waters [a]

Location (Pu Isotopes)	Range of plutonium concentrations		Comments
	Bq L^{-1}	fCi L^{-1}	
North Pacific surface water (^{238}Pu + $^{239,240}Pu$)	8.2×10^{-6}– 3.5×10^{-5}	0.22 – 0.94	
South Pacific surface water (^{238}Pu + $^{239,240}Pu$)	4.8×10^{-6}– 1.3×10^{-5}	0.13 – 0.34	
South Carolina: estuary waters ($^{239,240}Pu$)	6.3×10^{-6}– 9.4×10^{-5}	0.17 – 2.5	Received effluent from Savannah River Plant
South Carolina: river waters ($^{239,240}Pu$)	1.6×10^{-5}– 8.3×10^{-5}	0.43 – 2.3	Received effluent from Savannah River Plant
New York City: drinking water ($^{239,240}Pu$)	3.0×10^{-6}– 2.3×10^{-5}	0.08 – 0.61	
Enewetak, South Pacific: groundwater ($^{239,240}Pu$)	7.4×10^{-6}– 1.0×10^{-2}	0.20 – 280	Some weapons tests were at Enewetak
Idaho National Engineering Laboratory: groundwater (^{238}Pu)	4.1×10^{-4}– 2.9×10^{-3}	11 – 78	Near a disposal well
Nevada Test Site: groundwater (^{239}Pu)	1.6×10^{-3}– 9.6×10^{-2}	42 – 2600	Underground nuclear weapons tests at site

[a] Measurements in this table were compiled by Clement (1990) from other original sources.

Regional Background Plutonium Concentrations in Water

There are few measurement data on concentrations of plutonium in waters in the general region of the RFP before 1970. A small number of measurements were made in 1969 (after the May 1969 fire) by Poet and Martell (1972) in lakes near the RFP that did not receive liquid effluents from the RFP (Table VI-7). These included Boyd Lake near Loveland and Boulder Reservoir and Dodd's Lake, northeast of Boulder (see Figure H–3 for general locations). Results were given in units dpm L^{-1}, but have been converted to Bq L^{-1} and fCi L^{-1} in Table VI-7.

In Phase I of the Historical Public Exposures Studies on Rocky Flats, ChemRisk compiled data on radionuclide concentrations in reservoirs and drinking water in the area of the RFP (ChemRisk 1992). Of the data examined by ChemRisk, the only measurements with plutonium-specific analyses were performed for years 1970 and later. For earlier years, only gross alpha analyses were available. ChemRisk obtained data for 1970–1988, taken by the CDH, for drinking water of three towns that used reservoirs a considerable distance from the RFP that did not

receive runoff or liquid effluents from the RFP. The data were obtained from Monthly Environmental Surveillance Reports of the CDH, and annual averages were calculated by ChemRisk. Table VI-8 shows the calculated annual average concentrations of ^{239,240}Pu. Of the 147 individual measurements used to calculate the annual averages, only 24 were "detected" concentrations. The rest were reported as "less than" values. To calculate the annual average concentrations, ChemRisk replaced the less than values with one-half the detection limit, and then performed the average. This was thought to produce averages that were higher than the actual annual average concentrations (ChemRisk 1992).

Table VI-7. Concentrations of ^{239,240}Pu Measured in 1969 in Lakes Unaffected by Liquid Effluents from the Rocky Flats Plant [a]

Location	Collection date	Bq L^{-1}	fCi L^{-1}
Boulder Reservoir, NE of Boulder	9/11/69	$2.7 \times 10^{-4} \pm 2.7 \times 10^{-4}$	7.2 ± 7.2
Dodd's Lake, NE of Boulder	8/31/69	$3.8 \times 10^{-4} \pm 6.7 \times 10^{-5}$	10 ± 1.8
Dodd's Lake, NE of Boulder	9/11/69	$4.8 \times 10^{-4} \pm 2.3 \times 10^{-4}$	13 ± 6.3
Boyd Lake, Loveland	9/22/69	$5 \times 10^{-5} \pm 3 \times 10^{-5}$	1.4 ± 0.9

[a] The "±" values are one standard deviation analytical errors (Poet and Martell 1972).

Table VI-8. Annual Average Concentrations of ^{239,240}Pu in Drinking Waters not Affected by Liquid Effluents from the Rocky Flats Plant [a]

	pCi L^{-1}			Bq L^{-1}		
Year	Arvada	Boulder	Golden	Arvada	Boulder	Golden
1970	0.015	[b]	0.02	5.6×10^{-4}	[b]	7.4×10^{-4}
1971	0.01	[b]	[b]	3.7×10^{-4}	[b]	[b]
1972	0.01	0.025	0.027	3.7×10^{-4}	9.2×10^{-4}	1.0×10^{-3}
1973	0.013	0.01	0.013	4.8×10^{-4}	3.7×10^{-4}	4.8×10^{-4}
1974	0.01	0.01	0.01	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}
1975	0.43	0.245	0.045	1.6×10^{-2}	9.1×10^{-3}	1.7×10^{-3}
1976	[b]	[b]	[b]	[b]	[b]	[b]
1977	[b]	[b]	[b]	[b]	[b]	[b]
1978	0.03	0.01	0.03	1.1×10^{-3}	3.7×10^{-4}	1.1×10^{-3}
1979	0.01	[b]	0.01	3.7×10^{-4}	[b]	3.7×10^{-4}
1980	0.01	0.01	0.01	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}
1981	0.01	0.01	0.011	3.7×10^{-4}	3.7×10^{-4}	4.1×10^{-4}
1982	0.01	0.0175	0.015	3.7×10^{-4}	6.5×10^{-4}	5.6×10^{-4}
1983	0.0275	0.041	0.01	1.0×10^{-3}	1.5×10^{-3}	3.7×10^{-4}
1984	0.46	0.256	0.0275	1.7×10^{-2}	9.5×10^{-3}	1.0×10^{-3}
1985	0.35	0.03	0.02	1.3×10^{-2}	1.1×10^{-3}	7.4×10^{-4}
1986	0.0075	0.014	0.005	2.8×10^{-4}	5.2×10^{-4}	1.8×10^{-4}
1987	0.004	0.004	0.004	1.5×10^{-4}	1.5×10^{-4}	1.5×10^{-4}
1988	0.002	0.0013	0.003	7.4×10^{-5}	4.8×10^{-5}	1.1×10^{-4}

[a] Averages were calculated by ChemRisk (1992) from CDH data. ChemRisk said the averages were biased high, due to the way the "nondetect" results were handled (see text).
[b] No samples obtained for this year.

Routine monitoring of radioactivity in various environmental media at many locations in the U.S. is currently performed by the National Air and Radiation Environmental Laboratory (NAREL) of the EPA. The present routine monitoring was started by the U.S. Public Health Service (PHS) over 35 years ago. The two agencies issued routine reports with titles that changed with time, as given in Table VI-9. For the period 1981–1990, surface water samples were not analyzed for plutonium or for gross alpha radioactivity. The most relevant data for this period are measurements of gross alpha radioactivity and plutonium in drinking water for Denver and Platteville, Colorado, and plutonium in rainwater, for Denver (see Figure H-3 for general locations of these sites).

Table VI-9. Routine Monitoring Reports by the Public Health Service (PHS) and the U.S. Environmental Protection Agency (EPA)

Years	Agency	Report titles [a]
1960–1970	PHS	Radiological Health Data
1971	EPA	Radiological Health Data and Reports
1972–1975	EPA	Radiation Data and Reports
1975–1994	EPA	Environmental Radiation Data

[a] There were slight variations in titles.

The EPA measurements of gross alpha radioactivity and plutonium in drinking water and plutonium in rainwater are shown in Appendix E in Table E-4 and Table E-5 (EPA 1981, 1982a, 1982b, 1983, 1984a, 1984b, 1985a, 1985b, 1985c, 1985d, 1987a, 1987b, 1988a, 1988b, 1989a, 1989b, 1990, 1993a, 1993b, 1993c, and 1994). These data are results of analyses of annual composite samples, and so represent an annual average value. The EPA reports included analytical uncertainties of the measurements. For the plutonium measurements, in most cases the analytical uncertainties (given as 2 σ errors) were about equal to the results; the uncertainty in the plutonium values are very great. The detection limit was indicated to be 0.015 pCi per sample for plutonium, but the volume of each sample is unclear. From the uncertainties given, it appears that most of the plutonium results are very near the detection limit. Negative results are presumed due to gross analysis results less than the analysis background for the method and instruments used.

The data (Table E-4) indicate that the concentrations of plutonium are generally less than 1% of the gross alpha radioactivity. This is expected, as the background quantities in the environment of naturally occurring uranium, thorium, and radium, which are all alpha-emitters, are significantly higher than background quantities of plutonium in the environment.

For the drinking water and rainwater analyses, there are no significant trends in the data, other than the high results for plutonium in Platteville drinking water obtained in 1985. The reason for the abnormally high value is not known. For years other than 1985, the concentrations of ^{238}Pu in drinking water of Denver and Platteville ranged from negative values to 0.042 pCi L^{-1} (0.0016 Bq L^{-1}), and the concentrations of ^{239,240}Pu ranged from negative values to 0.012 pCi L^{-1} (0.00044 Bq L^{-1}). The concentrations of plutonium in rainwater were generally less than those in drinking water.

These data on concentrations of plutonium in surface water, drinking water, and rainwater are helpful for general perspective on other measurements of plutonium in water made around

the RFP. Of these, however, only a small number are plutonium-specific measurements for background surface water in the general area of the RFP.

WATER MONITORING DATA

The purpose of evaluating the results of surface water monitoring data is to observe general trends of contaminants in time and location that may have resulted from RFP operations. In Phase II of this study, our emphasis in evaluating the water monitoring environmental program at Rocky Flats has been to focus on the effluent handling system onsite and to review and add to the pre-1970 data that had been compiled in Phase I. Much of the offsite environmental monitoring data were compiled and evaluated in Phase I (ChemRisk 1992, 1994), and those data are not included here. Our approach has been to look at the inside of the facility, determine how effluent monitoring was handled, and with this knowledge, interpret the offsite environmental monitoring data. The quality of the measurement data and the regulatory standards in place in the early years of operations at the RFP are explored in this section.

Data Quality

Evaluating data quality means examining the collection, handling, and analysis of samples and checking the calculations of the final reported results against the original raw measurement data. Before standardized quality control procedures were established in the early 1970s, we tried to document how samples were collected and handled and how the laboratory analyses procedures were controlled and checked. (See the section in Chapter III, *Bias and Uncertainty in Air Monitoring Data* and the glossary at the end of this report for definitions). We located site survey laboratory logbooks that listed the results of the collection and laboratory analysis procedures and results of environmental samples for 1952–1953, 1959–1960, 1962, 1969, 1970, 1971, 1972, 1974, 1975, 1979 (Dow 1952–1953, 1960, 1961, 1969–1972, 1974-1979). These logbooks provided information on the laboratory procedures, calculations, routine sampling sites, and data quality checks that were done throughout these time periods. The 1952–1953 logbook noted that water sample collection began on February 27, 1952, and experiments relating to methods of analysis are documented. Water samples were filtered, pretreated with concentrated nitric acid, and digested, resulting in three fractions for analysis: a 10-liter portion, a 1-liter portion, and the residue. The efficiency factors and equations used in the calculation of activity levels were based on Hanford procedures, but were written out in the Dow logbooks (Dow 1952–1953, 1960, 1961, 1969–1972). The handwritten procedure in 1952 specified “a 45% overall efficiency” for water samples with example calculations provided. By 1959, the calculated efficiency was recorded as 43.4%. Appendix E provides a sample of the data listed in these early laboratory logbooks; this example is from 1959 (Table E-7). The data frequently recorded in these books were

At the RFP, laboratory logbooks provided data on quality control measurements in the 1950s. In 1974 a more rigorous quality control program was instituted to provide data on laboratory analysis performance.

- Sample number and location designation
- Collection, lab analysis, and report dates
- Sample size and analyst

- Count time
- Gross counts per minute (cpm)
- Background and blank measurements that were subtracted from the gross activity to give the net count rate
- Net cpm
- Process efficiency
- Disintegration per minute (dpm) per liter
- Remarks.

Split samples were done regularly (usually biweekly), spike samples were done monthly, and all results were tabulated in the laboratory logbooks. We checked these logbook calculations and verified that the monthly averages reported in the routine reports were obtained from these daily logbooks. Samples that had concentrations below the minimum detectable concentration (MDC) values were considered as having the MDC for averaging values, tending to give an overestimate to measurement results (Dow 1974). For the 1950s, the background count rate averaged 0.08 cpm, with a range of 0.03–0.25 cpm, and the count rate for the blanks ranged from 0 to about 0.18. The average gross count rate of offsite water samples ranged from about 0.30 to almost 100 cpm, depending upon the location.

In July 1974, "a rigorous analytical quality control program" was established in the Rocky Flats Environmental Analysis Laboratory. Estimates of variance and bias for standard sample analysis were reported in the annual environmental monitoring reports for the analysis of americium, uranium, plutonium and tritium in surface water. In October 1974, the U.S. Environmental Protection Agency (EPA) issued a water discharge permit to the RFP under the National Pollutant Discharge Elimination System permit program. This program established effluent concentration limits for nitrate, total nitrogen, phosphate, 5-day biochemical oxygen demand, fluoride, dissolved oxygen, residual chlorine, total suspended solids, fecal coliform bacteria, total chromium, oil and grease, and pH in the sewage treatment discharge. Table VI-10 gives a summary of the RFP environmental analysis laboratory performance for plutonium and tritium for the 1970s.

Standards for Radioactivity in Water

The U.S. Public Health Service first adopted drinking water standards in 1914 "to protect the health of the traveling public." There were a series of revisions to those standards over time which were applicable to water supplies in general. With the development of nuclear energy and other technological advances, the standards were revised once again in 1962 to update the 1946 standards (PHS 1962). In the early years of operations at the RFP, the level of nitrates in wastewater was of special interest because of high levels of nitrates in liquid waste waters from the plutonium processing building. In 1962 the drinking water standards for nitrates was 10 mg per liter. For the first time, the 1962 revision of the Drinking Water Standards included limiting concentrations of radioactivity in water. In 1955, according to the Colorado Department of Health, the maximum permissible alpha activity to be discharged was 100 pCi per liter (Ryan 1955). For radioactivity in drinking water, numerical guides were given for ^{226}Ra (3 pCi per liter) and ^{90}Sr (10 pCi per liter) with the assumption that these levels were protective for other alpha and beta emitters, respectively (PHS 1962).

Table VI-10. Reported Performance for the Rocky Flats Plant Environmental Analysis Laboratory, Water Samples, 1974–1980[a]

	Plutonium			Tritium		
Year	Relative error[b] (%)	Bias[c] (%)	Total control analyses	Relative error[b] (%)	Bias[c] (%)	Total control analyses
1974	58.2	8.2	e	3.4	-5.4	e
1975	30.4	-12.4	48	5.7	-4.7	48
1976	22.2	21.5	48	7	-1	60
1977	70.6	25	60	5.3	-4.5	60
1978	54.7	29.7	30 [d]	7	-4	30 [d]
1979	-15.2	-23.2	60	-6.6	-8.7	60
1980	-10.0	[e]	60	-3	[e]	60

[a] Values are from the annual environmental monitoring reports (Dow 1975, Rockwell 1976 through 1981).
[b] The ratio of the standard deviation of the 6-month differences to the average standard value in percent, that is, observed value minus standard value, divided by average standard value, times 100 equals the ratio as expressed in percent. In 1977, the ratio was based on a 12-month average. This term includes all random and systematic error in the standards analytical chemistry and measurement processes for a given radionuclide, media, and procedure.
[c] The six-month average bias in percent. A minus sign indicates a negative bias, that is, the values obtained were low. No sign indicates a positive bias, that is, the values obtained were high. In 1977, the bias was based on a 12-month average.
[d] For March to August 1978.
[e] Not reported in annual report.

In 1968, the Atomic Energy Commission (AEC) reported numerical guides governing the release of radioactive effluents and concentration standards for radioactivity in environmental samples (AEC 1968). For comparison to standards, all radioactivity in plant effluents and environmental samples at Rocky Flats were assumed to be soluble for purposes of comparison with the appropriate concentration standards (Table VI-11). This assumption was reported as an additional safeguard because guidelines for soluble radioisotopes were more restrictive than those for insoluble radioactive materials. These standards were reported in routine monitoring reports along with measurement values (Dow 1970).

Table VI-11. Historic Regulatory Guides for Releases of Constituents to Surface Water

	Standard (pCi per L)		
Date	$^{239,240}Pu$	$^{233,234,238}U$	Natural uranium
1972-1980 (AEC 1968; ERDA 1974)	1600	10,000	40,000
1981 (DOE 1981)	1600	200	

In the mid1970s, the Energy Research and Development Administration (ERDA) took over the regulatory responsibility for setting standards (ERDA 1974). The standards for plutonium

and uranium in waterborne effluents remained the same as those promulgated by the AEC. Then in 1981, the DOE provided guides for radionuclide in ambient air and waterborne effluents (DOE 1981). These guidelines were accepted and implemented by the Colorado Department of Health. The standards for plutonium and americium were again the same as those listed above, but the applicable standard for uranium was lowered to 200 pCi per liter.

For nonradioactive constituents in water, standards for chemicals and water quality standards were reported by the state health department in 1971 (CDH 1971). A water discharge permit was first issued to the Rocky Flats Plant by the EPA under the National Pollutant Discharge Elimination System (NPDES) permit program in October 1974. The NPDES permit established effluent concentration limitations for nonradioactive pollutants; it established limits for nitrate, phosphate, 5-day biochemical oxygen demand, fluoride, dissolved oxygen, residual chlorine, total suspended solids, fecal coliform bacteria, total chromium, oil and grease, and pH in the sewage treatment plant discharge, and for nitrate and pH in the discharge from Holding Pond A3 in Walnut Creek.

In 1976, the EPA provided regulations for radionuclides in drinking water (EPA 1976). These regulations, effective on June 24, 1977, were intended to ensure that each state had primary enforcement for maintaining drinking water quality. To comply with these requirements, the Colorado State Board of Health modified existing state drinking water standard to include radionuclides (CDH 1977). The state standard for gross alpha activity in community water systems was a maximum of 15 pCi per liter. The alpha emitters, americium and plutonium were included in this limit.

Liquid Waste Treatment Options

Table VI-12 summarizes the options that were available for pipeline transfer from different buildings to various onsite destinations (Building 774, Building 995, the 200,000-gallon tank, or to the solar evaporation ponds) or offsite to Walnut Creek. The process liquid wastes released offsite via the B-series ponds were:

- **Treated waste from Building 774** represented roughly 25% of the total process liquid waste released to the B-series ponds. The process waste liquids were pumped from production buildings to Building 774, where they were treated to reduce chemical and radioactive content to appropriate standards (PHS 1962). In the early years of RFP operations, those standards were established by the U.S. Public Health Service (PHS). When the standards were met, the waste was pumped to the final B-series ponds for offsite release to Walnut Creek. There was no constant release rate because releases were dependent on the workload, the amount of untreated liquid waste released, and the amount of treatment required. Releases varied from 25,000 to 300,000 gallon per month.
- **Untreated waste from Building 771** represented only 1-2% of total process liquid waste released to the B-series ponds. The effluents that met the PHS drinking water standards for radioactive and chemicals contaminants were released directly to the pond (Pond 3 before 1975). The remainder was pumped to Building 774 for treatment.

Table VI-12. Liquid Effluent Pipeline Transfers at the Rocky Flats Plant Before 1970[a]

Building source (principal contaminants) [b]	Waste treatment (Bldg. 774)	200,000 gallon tank near Bldg. 774	Sewage treatment (Bldg. 995)	Evap. ponds 207A and B (since 8/56)	Offsite via Walnut Creek
123	X			X	
444/447 (^{238}U, Be)	X		X	X	
881/887 (U, Pu, Be, acids)	X		X [c]	X	
883 (U, Be)	X			X	
889	X			X	
865	X		X [d]	X	
559 (Pu, lab reagents)	X			X	
707 (Pu)	X		X [d]	X	
776 / 777 / 778 (Pu, Be, solvents, acid)	X	X	X [c]	X	X [c]
779 (Pu, Be, chemicals)	X	X		X	X [c]
771 (Pu process: Pu, Am)	X	X			
771 (labs)	X	X		X	X [c]
774 (Pu, Am, U, chemical)		X		X	X [c]
995					X

[a] From Love et al. (1970), Kittinger and Linck (1970).
[b] U = uranium, Be = beryllium, Pu = plutonium, and Am = americium.
[c] Valves must be unlocked by Health Physics personnel for shipment.
[d] Shipment controlled by removable spool piece in pipeline to Building 995, which was normally not in place.

Liquid Effluent Monitoring Before 1970

The Waste Disposal Unit was organized in January 1953 for the "ultimate disposal of processed liquid and solid wastes and the correlations of the allied data" (Ryan 1953). The water laboratory of the general laboratory conducted the analyses, with the major focus on monitoring total solids and nitrates. Table E-9 in Appendix E highlights the effluent monitoring history at the RFP. There was always an effort to remove or reduce nitrate content of liquid wastes because of potential toxic effects on the local environment. Table VI-13 provides the effluent sampling locations in the early years. Table VI-14 makes it clear that the frequency and sampling methods evolved with time (Ryan 1953–1956).

Table VI-13. Liquid Effluent Sampling Locations

Source of liquid effluent	Effluent sampled	Time period
Building 71, now called Building 771, (Pu processing)	To Walnut Creek	1953–1954
	To Pond A-1	After 1954
	To Walnut Creek from Pond A-1	After Feb 1955
Building 774 (Waste processing)	To South Walnut Creek	1953
	To B ponds	After 1954
	To South Walnut Creek from final Pond B	After 1954
Lift station near Building 881	To Woman Creek	After May 1954
	To Pond C-1	After March 1955
	To Woman Creek from Pond C-1	After March 1955

Table VI-14. Liquid Effluent Monitoring Activities

Date	Sampling activity/frequency
July 1953	Retention ponds on North and South Walnut Creeks were sampled for gross alpha; no recording flow meter; volumes estimated. B pond-analysis was done on a weekly composite of twice a day grab samples. A pond analysis was done on grab samples taken twice a day, 3 days per week; samples were taken from the "first water" spilling over the earthen dam.
November 1954	Temporary Parshall flume installed at B pond to measure effluent flow.
August 1955	Crude continuous sampler installed at B pond outlet, collected 50-gallon sample over a 24-hour period.
February 1956	Approval given for the housing structure, metering device, and proportional sampler for Pond B-3; called Facility 207.
August 1956	Facility 207 operational.
1970s	Waste sampled continuously; collected daily from outfalls at B-4 and C-1; daily samples composited weekly for analyses.
	Plutonium and uranium isolated by ion exchange chromatography and detected by alpha spectrometry; total alpha by liquid scintillation.

Water Monitoring Sample Collection and Analysis

Surface water samples have been collected and analyzed from the RFP since 1951, before operations at the site began. However, the extent of the monitoring program, the spatial distribution of sampling, and the types of materials measured were fairly limited until the early 1970s. Figure VI-8 shows the water sampling locations for the background survey that was done before plant startup. These locations formed the basis for the routine water monitoring program

in the 1960s. Tables E-5 and E-6 in Appendix E provide a listing of the historic water and vegetation sampling locations. During this time, the numbering system remained relatively unchanged, with sampling frequency varying with location. Specific monitoring procedures were apparently not documented until the mid-1960s (Bokowski et al. 1981). Although background radiological water monitoring was undertaken before construction of the RFP, only gross alpha and some uranium measurements were made before the early 1970s.

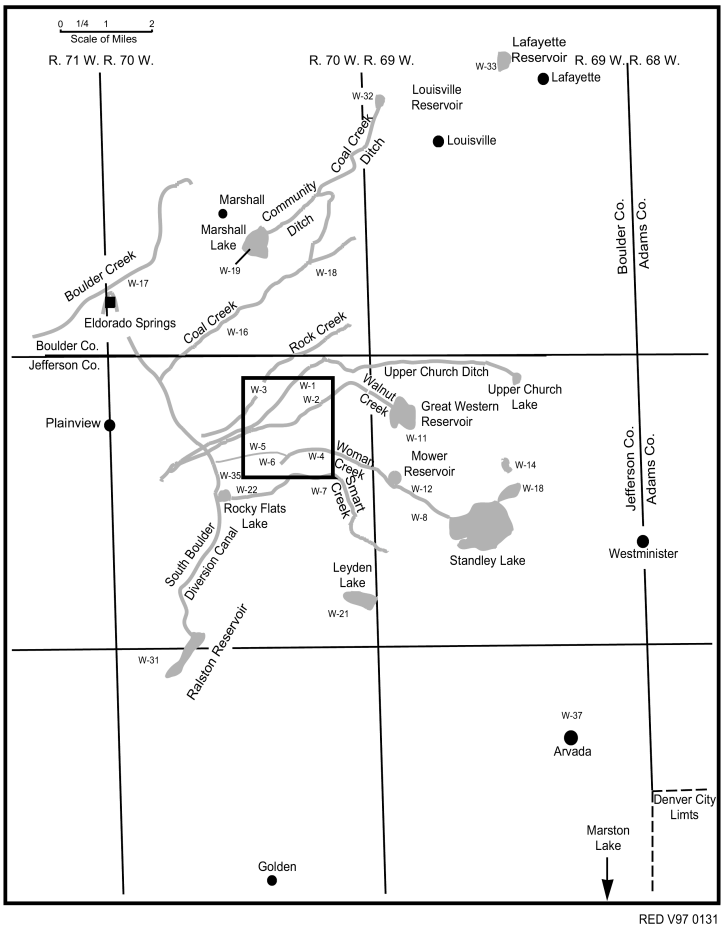

Figure VI-8. Sampling locations of water and some vegetation for Rocky Flats background survey conducted in 1951 by Battelle before startup at the Rocky Flats Plant (Bokowski et al. 1981).

By the early 1970s, all effluent streams leaving the site were sampled (A-, B- and C- series ponds). Water was monitored continuously, and samples (including grab samples) were collected daily from the sewage treatment plant influent and effluent and from Ponds A-3, B-4 and C-1. Continuous sampling was also carried out downstream at Walnut Creek and Indiana Street (Hornbacher and Barker 1975). Offsite water sampling was conducted at the GWR and Standley Lake.

In later years, specific isotopic analyses were done by the site contractor, the CDH and local communities. Referenced laboratory procedures were developed and reported (Williams and Smith 1982). Table VI-15 summarizes the water collection and analysis procedures and major changes that occurred in them at Rocky Flats.

Table VI-15. Water Monitoring Sample Collection and Analysis

Collection/treatment	Laboratory analysis procedures
1952–1972: Grab samples; samples transported to lab, acidified with nitric acid, filtered, evaporated under infrared heater.	**1952–1962**: Diethyl ether extraction removed plutonium, uranium and 40% of naturally occurring thorium isotopes; evaporated, counted in low-background gas-flow proportional counter. Alpha count rate designated gross alpha. Whenever anomalous alpha readings seen, pulse height analysis done with Frisch grid chamber. **1962–1972:** Trioctylphosphine oxide replaces diethyl ether in extraction step.
1972–1978: Untreated sample composites were treated with hydrochloric acid and hydrogen peroxide, concentrated by evaporation. Great Western Reservoir and Standley Lake sampled daily, composited weekly for analysis.	**1972–1978:** Plutonium and uranium extracted together from concentrated samples with triisoctylamine, stripped from triisoctylamine sequentially, and purified by ion exchange; americium separated, purified by cation exchange. The chemical recovery of plutonium was determined by adding ^{236}Pu tracer.
1978–1981: Intact samples concentrated by evaporation, residues wet-ashed with nitric acid.	**1978–1981**: Composite samples of untreated water evaporated, actinides purified by ion exchange-solvent extraction. .

[a] From Bokowski et al. (1981), Boss et al. (1973), Thackeray (1953).

In Phase I of the study, ChemRisk compiled much of the routine water monitoring data that had been collected by the site contractor from 1952 through 1970 and by the CDH and local communities from 1970 through 1989 from various locations around the area. Table VI-16 summarizes the findings of ChemRisk regarding the availability of these gross alpha data for major reservoirs in the area and drinking water monitoring from a variety of communities for the 1950s and 1960s.

Table VI-16. Availability of Gross Alpha Water Monitoring Data from Ponds, Reservoirs, and Community Drinking Water Sources[a]

	Year																		
Water Source	'52	'53	'54	'55	'56	'57	'58	'59	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71
Onsite	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Building 995																				
Effluent	X	X	X	X	X	X	X	X	X	X	X	X			X	X		X		
Pond A-1 [b]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Pond B-3 [c]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Pond C-1	X	X	X	X	X	X	X	X	X			X	X	X		X			X	
Offsite																				
GWR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Standley Lake	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Baseline Reservoir	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Mower Reservoir	X	X																		
Water Supply																				
Arvada	X	X				X			X	X	X	X	X	X	X	X	X	X	X	
Boulder	X	X							X	X	X	X	X	X	X	X	X	X	X	
Broomfield		X	X	X	X	X			X	X	X		X	X	X	X	X	X	X	
Denver		X											X	X	X	X	X	X	X	X
Golden	X	X							X	X	X		X	X	X	X	X	X	X	X
Lafayette	X	X				X			X				X	X	X	X	X	X	X	X
Louisville	X	X							X	X	X		X	X	X	X	X	X	X	X
Thornton													X	X	X	X	X	X	X	X
Westminster	X								X	X	X	X	X	X	X	X	X	X	X	

[a] Information available indicated by X's.
[b] From Piltingsrud (1971); before 1970, this pond was referred to as Pond 1.
[c] From EPA (1972a); before 1970, this pond was referred to as Pond 5.

Gross Alpha Measurements

The period of interest in the Rocky Flats historical public exposures studies is before the early 1970s, the period during which the major releases of plutonium occurred. Before 1970, however, only gross alpha measurements were made for routine surface water effluent and environmental monitoring. There was generally no monitoring of plutonium, beryllium, or organics during this time, even though before 1974 laundry wastes from Building 71 (now called Building 771) and effluents from the sanitary sewer system were being discharged directly into Walnut Creek.

Backwash from the water filtration system, that is water from the washing of the water treatment tanks, was discharged directly to Woman Creek until 1975. In 1971, this amounted to approximately 270,000 gallons of backwash water per month. The backwash passed through the west side of the plant burn pit which received ashes from the plant incinerator before it flowed down to Woman Creek (Ryan 1954).

The holding ponds had a dramatic effect on decreasing the radioactivity discharged to Walnut Creek. When holding pond A was opened in 1955, alpha activity discharged to North Walnut Creek decreased over 10-fold.

The reported monthly average gross alpha concentrations are shown for Pond A-1 for 1953 to 1958 in Figure VI-9. The figure shows the effect that the holding Pond A had on level of alpha activity released offsite to North Walnut Creek. Initially, effluents with alpha concentrations of 50 to 200 pCi L^{-1} were being discharged directly to North Walnut Creek. After Pond A held or stored the waste for a time, the levels of activity discharged to the creek dropped 10-fold to about 10 pCi L^{-1}.

Figure VI-10 is a similar graph for the alpha activity in liquid effluents from the Waste Processing Building 774 to the B ponds and South Walnut from August 1953 through August 1958. The releases to the B pond were somewhat more uniform than those to the A pond. It is clear, however, that the alpha concentrations were much more variable before 1954 and the completion of the B ponds. Again, the alpha activity decreased from over 100 pCi L^{-1} to an average of 10 pCi L^{-1} after the effluents were held up in the ponds before discharge.

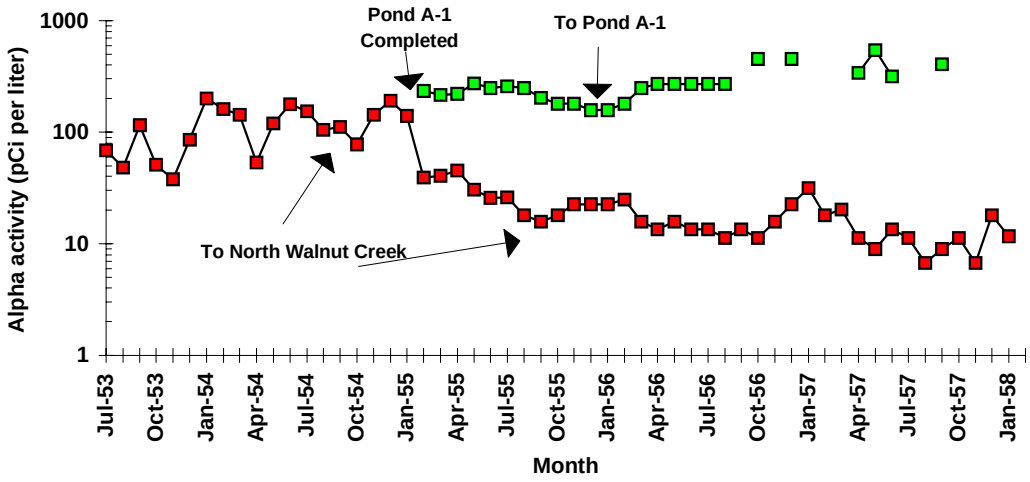

Figure VI-9. Gross alpha activity in liquid effluents from Building 71 to North Walnut Creek. Until early 1955, all Building 71 effluent went directly to North Walnut Creek. After Pond A-1 was operational, the liquid effluents were discharged to the pond. After some settling, liquid effluents from the pond were discharged to North Walnut Creek.

Liquid effluent releases from the RFP were reported monthly from 1954 through 1970. Daily logbooks for some years helped us confirm the values reported in the monthly summaries. The alpha activity released each month tracked the effluent volume fairly well. During the last half of 1969, however, the volume in creeks was much higher than normal, due to the above average rainfall during the spring and summer of that year (Dow 1969). For example, nearly 10 in. (25 cm) of rain fell during May 1969 alone, when the average annual rainfall for the area is only about 8 in. (20 cm).

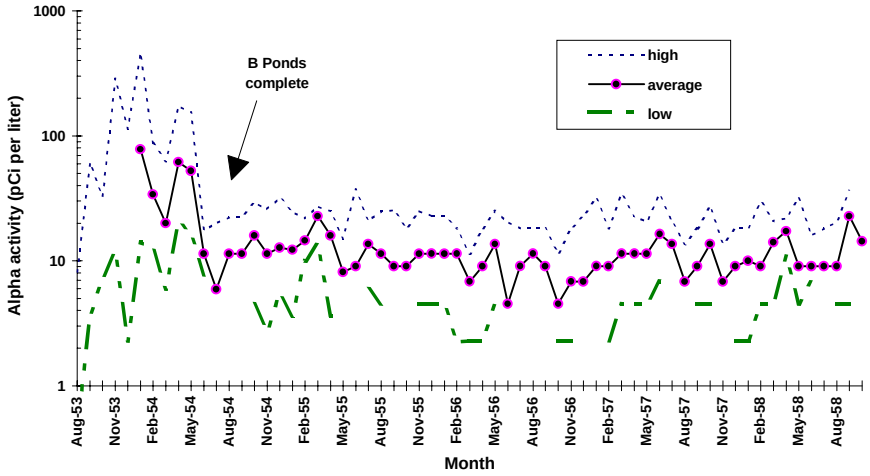

Figure VI-10. Alpha activity in liquid effluent from Building 774, the waste processing building. The heavy middle line represents the average alpha activity. The upper line shows the high value measured that month, and the lower dotted line represents the low value for the month.

Water monitoring at offsite locations was also done during the 1950s and 1960s. Results from the more distant locations can be compared with alpha levels measured in liquid effluents. Figure VI-11 compares the gross alpha concentrations from 1952 through 1971 in the GWR, Standley Lake, Baseline Reservoir (north of the site), and Ralston Reservoir (south of the site). Most concentrations fall between 1 pCi L^{-1} to 3 pCi L^{-1}, with higher concentrations measured periodically in Ralston Reservoir. These data were evaluated previously in Phase I (ChemRisk 1994).

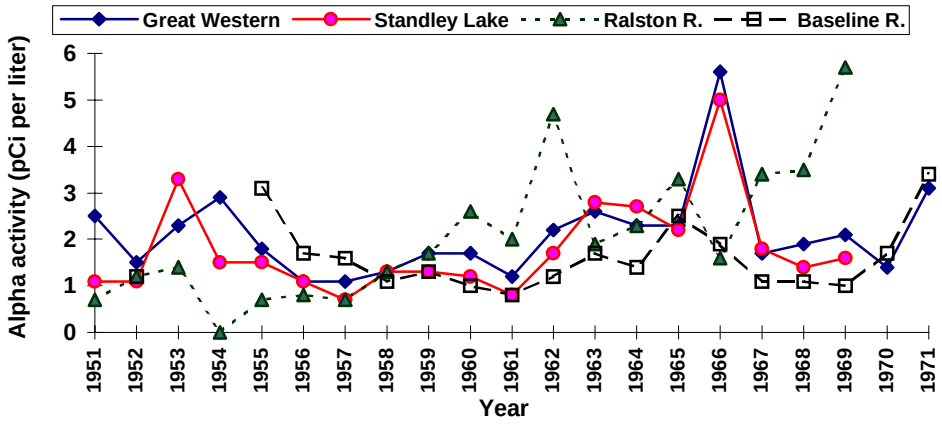

Figure VI-11. Annual average gross alpha (plutonium plus uranium) activity measured from 1951 (background) through 1971 in the Great Western Reservoir and Standley Lake, which receive flow from Walnut and Woman Creeks, respectively. Baseline and Ralston Reservoirs did not receive liquid effluent directly from the Rocky Flats Plant. The results from 1951 were obtained before Rocky Flats operations began.

Before plant startup, survey samples were collected and analyzed by personnel of the Biophysics Section, Radiological Sciences Department, at the Hanford Plant in Richland, Washington. Water samples were obtained from 27 locations within an area of approximately 144 mi^2 (373 km^2). Twenty-two of the samples collected were within a 6-mi (9.7 km) radius of the present plant site (Figure VI-8). Background samples were collected during July, August, September, and November of 1951. A combined plutonium-uranium radiochemical method was used in which total radioactivity was determined with a parallel plate alpha counter. (In 1951, a practical analytical method for specific analysis of plutonium did not exist.) The uranium concentration was determined by fluorometry, and the plutonium concentration was assumed to be the difference (Bokowski et al. 1981). In Figure VI-12, the correlation between the plutonium plus uranium and total uranium concentrations is evident. It was concluded from these types of analyses that no plutonium was present in any samples. Table E-10 in Appendix E lists these data from the 1951 background survey.

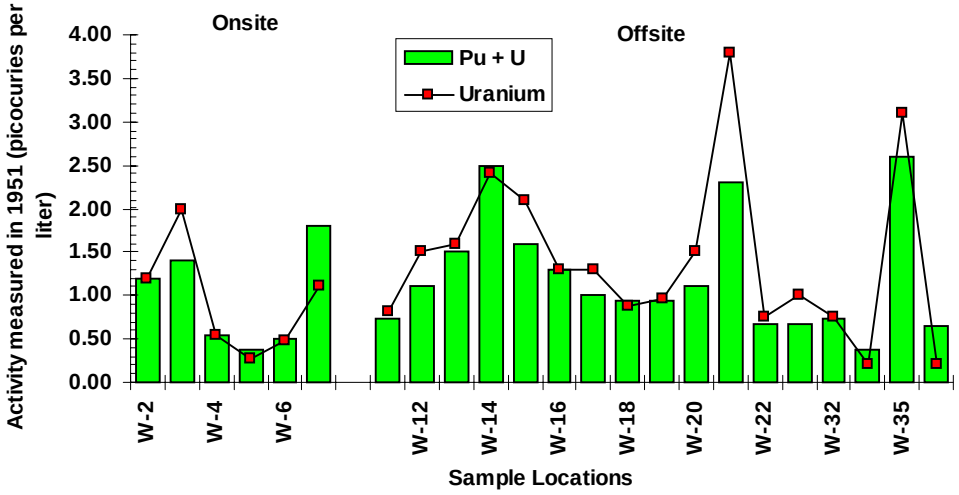

Figure VI-12. Gross alpha (plutonium plus uranium) activity and total uranium levels measured in water samples in July, August, September and November 1951. Preoperational values for gross alpha range from about 0.5 to 2.5 pCi L^{-1} in this area.

Plutonium-Specific Measurements

Routine analyses specific for plutonium (pulse height analysis) began in September 1969. Plutonium concentrations in water from the GWR were greater than 0.60 pCi L^{-1} in April 1971 (0.64 pCi L^{-1}), September 1971 (0.82 pCi L^{-1}), October 1971 (0.68 pCi L^{-1}), and March 1972 (1.18 pCi L^{-1}) (Ellerbrock 1982). To provide perspective to these values, we can compare them with background plutonium measurement data from various types of water—surface water, groundwater, and drinking water—that we have compiled in Appendix H, *Background Concentrations of Plutonium in the Environment*, in this report. Plutonium concentrations in Colorado drinking water from Denver and Platteville for 1981–1992 ranged from 0.001 to 0.01

pCi L^{-1} (EPA 1981, 1982a, 1982b, 1983, 1984a, 1984b, 1985a, 1985b, 1985c, 1985d, 1987a, 1987b, 1988a, 1988b, 1989a, 1989b, 1990, 1993a, 1993b, 1993c, and 1994).

The concentration of plutonium released from the holding ponds to Walnut Creek decreased 100-fold during the 1970s.

For earlier years, some monthly progress site survey reports from 1957 and 1958 reported results of plutonium, ^{238}U, and ^{234}U analyses of water from Walnut Creek, GWR, Standley Lake, Baseline Lake and Ralston Reservoir, in addition to gross alpha measurements. These radionuclide-specific analyses were usually done when the gross alpha activity was higher than usual, in response to concern about offsite contamination (see the special studies section), or occasionally for nonroutine locations such as Coal Creek (west of the plant), South Boulder Creek, Clear Creek at Golden, and McKay Lake (Hammond 1957, 1958).

Figure VI-13 shows the measured plutonium concentrations measured in the final holding ponds on North Walnut Creek (A-3 and A-4), South Walnut Creek (B-4 and B-5) and Woman Creek (C-1). In 1981, Ponds A-4 and B-5 were constructed to receive effluents from Ponds A-3 and B-4, respectively, before discharge to the creeks. The figure reveals that the concentrations of plutonium discharged from the site decreased dramatically in the late 1970s. In the B ponds, the annual average plutonium levels decreased from 15,000 fCi L^{-1} (15 pCi L^{-1}) in 1972 to 5 fCi L^{-1} (0.005 pCi L^{-1}) in 1989.

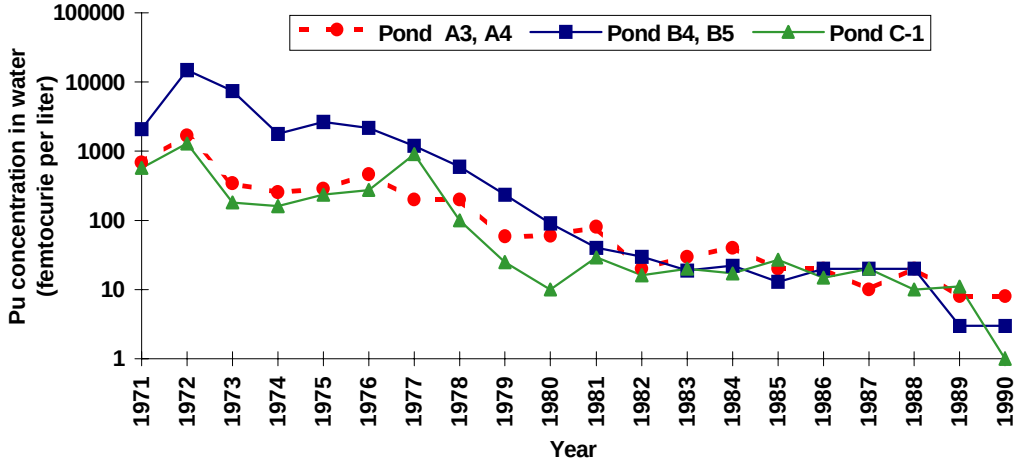

Figure VI-13. Comparison of annual average plutonium concentrations in water from the final holding ponds at the Rocky Flats Plant, from 1972 through 1989. The A- and B-Ponds are located on North and South Walnut Creek, respectively, and discharge to the Great Western Reservoir. The C Ponds are on Woman Creek, which drains into Standley Lake. A femtocurie (fCi) is equal to 1,000 picocuries (pCi).

During Phase II of this study, our focus has been on evaluating the monitoring program before 1970, when plutonium-specific measurements could be used to estimate releases of plutonium in surface water from the RFP. We approached the problem of better characterizing releases of plutonium in liquid effluents in the early years (before 1970) by correlating alpha and plutonium-specific measurements that were done concurrently from 1970 through 1973 on water samples from Pond B-4 to South Walnut Creek (Figure VI-14). The gross alpha measurements

for this time period track the plutonium-specific measurements rather well, with a correlation coefficient of 0.76.

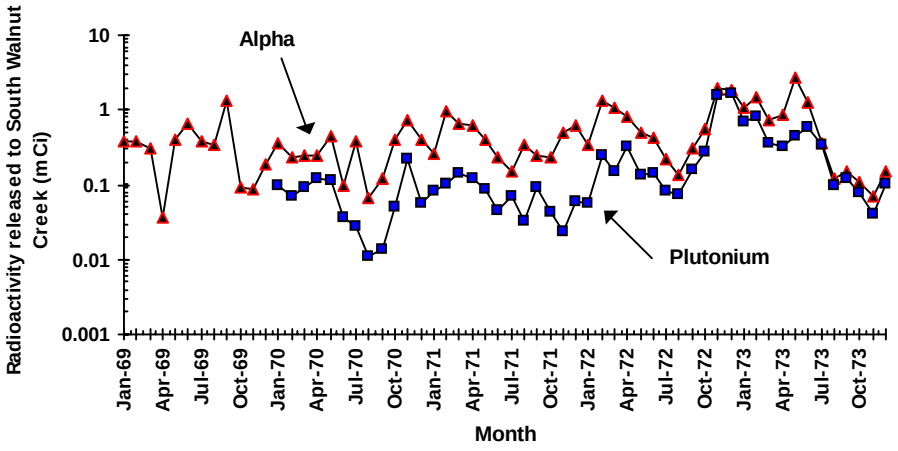

Figure VI-14. Comparison of estimates of release of gross alpha and plutonium from Pond B-3 to South Walnut Creek from January 1970 through December 1973. The estimates are based on monthly average concentrations and effluent volume measurements.

We calculated a ratio of monthly plutonium to alpha activity of 0.37 with a standard deviation of 0.24 (median is 0.33). We applied this ratio to measurements of alpha activity released from the same location from 1952 to 1970 (when plutonium was not measured) (Figure VI-15). This is one method to estimate plutonium releases for earlier years when only gross alpha was measured. We applied our ratio to the alpha release estimates, considering sources of uncertainty using Monte Carlo techniques in the Crystal Ball® program (Decisioneering 1993).

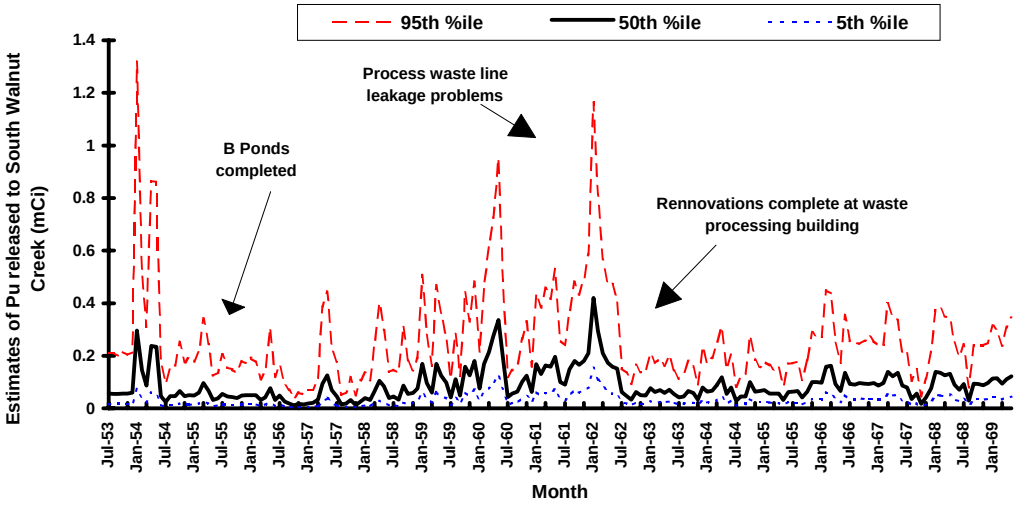

Figure VI-15. Plutonium release estimates from Pond B-4 to South Walnut for 1953 through 1969. The estimates are based on ratios of plutonium to alpha activity measured concurrently from 1970–1973.

The median monthly plutonium releases varied considerably with a range of 0.03–0.1 mCi. There were several months when releases exceeded 0.3 mCi (January 1954, May 1960 and January 1962) (Figure VI-15). In 1961–1962, higher than usual releases through the B ponds can be attributed to problems that arose when the process waste transfer line in the area of the Building 77 was relocated because of new construction south of Building 77. Once, during excavation of the waste line, a flange was broken that allowed liquid waste to be released into an open trench (Ryan 1961). By 1963, the first renovations to the Process Liquid Waste Facility (Building 74) were completed, and plutonium releases decreased. The monthly plutonium release estimates, with 5th and 95th percentile values, are compiled in Appendix E, Table E-11.

It appears that this method may at least allow us to set limits for the amount of plutonium released to South Walnut Creek from the B ponds in the early years. Based on this ratio method, the total plutonium released from the B ponds to South Walnut Creek through 1969 is estimated to be 20 mCi (90% confidence interval of 6 to 55 mCi). There are limitations to this method because it relies on site-measured releases to South Walnut Creek and may not account for all losses to the ponds. However, these studies are important because they may help us to better describe the plutonium inventory in sediment in the GWR. Various sediment studies have shown that the majority of the plutonium inventory in the GWR is from liquid releases from the RFP. Studies by Colorado State University have provided plutonium inventory estimates in the GWR of 50 to 80 mCi (see Chapter VII). The plutonium inventory estimate could be used to bound the estimates of plutonium released to surface water.

Recent studies that quantified the amount of radioactivity in surface waters and sediments at the RFP demonstrated that the largest source of man-made radioactivity was in the sediments in the holding ponds. They calculated that one gram of sediment from a holding pond contains approximately 50 times more plutonium than 1 liter of water from the ponds (Efurd et al. 1993).

Uranium-Specific Measurements

While routine liquid effluent monitoring for alpha activity began in July 1953, measurements of uranium in the holding ponds and streams were not made until 1971. Data from original handwritten logbooks and monthly reports documented releases of alpha activity to North and South Walnut Creeks and Woman Creek (Ryan 1953, 1954, 1955, 1956, 1961, and 1969; Boss et al. 1973). The collection of water samples changed from grab sampling and estimating effluent volumes in 1953 to the use of a crude continuous sampler by August 1955. Until 1972, samples were carried to the laboratory where they were acidified, filtered, and evaporated. The quality of the water monitoring data was affected by factors such as the presence of sediment in collected samples, extraneous radioactivity introduced in the analytical process, and the analytical method itself.

By 1974, water was sampled continuously and collected daily from the outfalls of the final ponds A-4 (on North Walnut Creek), B-5 (on South Walnut Creek), and C-2 (on Woman Creek) before discharge to the site streams. Plutonium and uranium were isolated from other long-loved alpha emitters by ion exchange chromatography and their concentrations determined by alpha pulse-height spectrometry. Uranium recovery was determined by ^{232}U tracers (Dow 1974). Figure VI-16 shows that the highest annual concentrations were measured in the A and B series ponds on Walnut Creek, which drained into the GWR. The C ponds on Woman Creek, which drained into Standley Lake, had the lowest concentrations of uranium during this period.

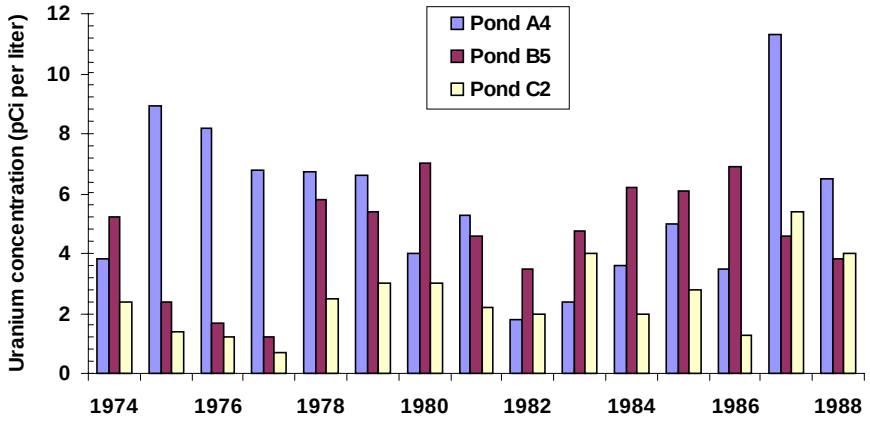

Figure VI-16. Annual average uranium concentrations measured in the final holding ponds (A-4, B-5, and C-2) before discharge to the site streams. Ponds A-4 and B-5 discharged into Walnut Creek and Pond C-2 discharged into Woman Creek. The background uranium levels measured in surrface waters in other parts of Colorado ranged from about 2–8 pCi L^{-1} during this time period.

During this same time, water from Walnut Creek at Indiana Street (the buffer zone boundary) was sampled continuously, samples were composited weekly, and analyzed for plutonium, uranium, and americium. Figure VI-17 shows the annual average uranium concentrations and peak uranium values measured form 1971 through 1988 as Walnut Creek left the Rocky Flats boundary. The annual average uranium values ranged from about 1 pCi L^{-1} in 1977 to about 9 pCi L^{-1} in 1971. The highest maximum uranium values measured during this 18 year period were seen in1974 (19 pCi L^{-1}) and 1978 (18 pCi L^{-1}).

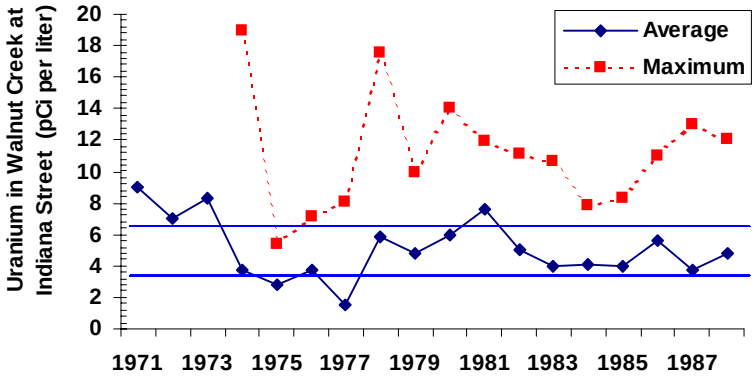

Figure VI-17. Annual average and maximum uranium values measured in Walnut Creek at Indiana Street. The dashed lines shows the approximate background levels of uranium in surface waters in Colorado (3–7 pCi L^{-1}). The regulatory standard for uranium in drinking water from 1971 through 1980 was 10,000 pCi L^{-1}(AEC 1968; ERDA 1974). In 1981 the uranium in drinking water standard was decreased to 200 pCi L^{-1} (DOE 1981).

More recently, researchers at the Los Alamos National laboratory (LANL) used Thermal Ionization Mass Spectrometry (TIMS) measurement techniques to characterize the uranium in the holding ponds at the RFP (Efurd et al. 1994). They concluded that all of the uranium in water samples collected from Pond A-1 and A-2 originated as depleted uranium. All other ponds, except C-1, contained measurable quantities of depleted uranium along with naturally occurring uranium. Furthermore, there was no enriched ^{235}U measured in any water samples collected from the ponds. It was noted that the uranium concentrations in water samples from the final holding ponds (A-4, B-5, and C-2) contained 0.5% or less of the interim standard Derived Concentration Guide for uranium in waters available to the public.

TRITIUM MONITORING

Tritium monitoring has proven to be valuable at the RFP, not because tritium processing and releases were extensive, but because the CDH environmental monitoring program first detected a major release of tritium from the site. At the time of the actual release in 1973, tritium in Walnut Creek was being monitored only by CDH. It is an example of how useful environmental monitoring can be in detecting or verifying site releases.

Tritium has been released accidentally from the RFP on several occasions. These incidents have been described in a number of reports (Dow 1973, Ofte et al. 1973, EPA 1974a, 1974b, 1974c; Donnelly 1973), and evaluated by ChemRisk in Phase I of this project (ChemRisk 1994). At several times throughout Phase II, questions arose regarding the release of tritium to Walnut Creek, which drains into the GWR. The Walnut Creek drainage basins provides approximately 2% of the annual volume of the GWR water source (Ofte et al. 1973; Hurr 1976). This section briefly describes the tritium release event in 1973 and the special monitoring. Four tritium release incidents have been associated with the processing of tritium-contaminated scrap plutonium from Lawrence Livermore Laboratory:

1. April 1969; 57 Ci released
2. March 1971; 40 Ci released
3. November 1971; 29 Ci released
4. April 1973; 350–1600 Ci released to air; 50–100 released to the GWR.

In September 1974, it was estimated that 1.5 Ci was released from exhaust system 205, Building 777 because of a tritium contaminated pressure-cooker (sample container) received from Battelle on July 17, 1974 (Ofte et al. 1973). The incident of most concern to the public was the April 1973 incident that released tritium to Walnut Creek, which feeds into the GWR. This section briefly reviews and summarizes some of the key points of this release event and presents some of the offsite monitoring results collected in the months following the event.

Background Information on Tritium

Tritium reaches surface water directly through precipitation, molecular exchange with water in the atmosphere, or direct releases of tritiated water, for example, from the RFP to Walnut and Woman Creeks (NCRP 1979). Large quantities of tritium that completely overshadowed

naturally produced tritium were released by the atmospheric testing of nuclear weapons before the natural distribution could be completely determined. It is estimated that the natural tritium inventory from cosmic ray interactions within the upper atmosphere is 35 megacuries (MCi) in each hemisphere. This is much lower than the 1,900 MCi added to the Northern hemisphere by nuclear testing through 1963. The tritium inventory due to weapons testing reached a maximum of about 3,100 MCi in 1963, an amount that will decay to the natural level of 70 MCi approximately by the year 2,030 (NCRP 1979).

The kinetics of tritium movement throughout the human body follow those of water. A small fraction of the intake becomes organically bound in two separate compartments. The effective half-life of tritium in free water in 9.7 days compared to 30 days and 450 days from the two compartments into which the fraction is bound (NCRP 1979).

The 1973 Tritium Release Event

Approximately 500-2,000 Ci of tritium were transferred to Rocky Flats from Lawrence Livermore Laboratory in a scrap shipment that reached Rocky Flats on March 19, 1973. The incoming material included some plutonium metal contaminated with tritium. It was packaged in four 30-gallon shipping containers. These were checked for alpha contamination, but not for tritium. The hydriding and oxidizing operations were done on April 9–25, 1973, in Room 154 of Building 779A. These processes converted the plutonium metal to plutonium hydride, and then to plutonium oxide. The completely oxidized plutonium oxide was subsequently transferred to Building 771 for processing to reusable plutonium metal. Much of the tritium was released through the building stacks in airborne effluents. The remaining tritium followed the normal liquid waste processing flow, resulting in movement through Buildings 779, 771, 881, 444, and some other areas that handled the scrap. The treated liquid wastes from these buildings were discharged to the sanitary sewer or to the evaporation ponds over time. It was estimated that about 100–300 Ci accumulated in the solar evaporation ponds and 50–100 Ci accumulated in the GWR (Ofte et al. 1973). In addition, analysis of water samples from the landfill area indicated that tritium was present in the landfill at least as early as May 1973 (Dow 1973).

Tritium Monitoring of Liquid Effluents

The CDH began its own monitoring program for tritium and other radionuclides and nonradioactive constituents following the May 1969 fire. They analyzed water for tritium at Walnut Creek at Indiana Street, Standley Lake and the GWR, and occasionally from Woman Creek at Indiana Street. Figure VI-18 demonstrates that no significant increases in background tritium concentrations were detected in the GWR until April 24, 1973. By 1976, tritium levels in the GWR were near regional background levels of 600 pCi L^{-1} (CDH 1970–1978). Table E-14 in Appendix E contains the weekly measurement values for tritium.

In March 1972, Dow also began analyzing water samples for tritium to provide a cross-check of the CDH analyses at Walnut Creek and Indiana Street. Tritium analysis was done by liquid scintillation counting and data quality was checked (see previous Data Quality section in this chapter). It stopped the program after 5 months. Samples were cross-checked by the Lawrence Livermore Laboratory and EPA during the investigation of the 1973 tritium release incident. Values ranged from about 800 to 10,000 pCi L^{-1}, with most values around 1,000 pCi

L^{-1} in 1972. During and following the tritium release beginning in April 1973, tritium levels rose to a maximum of 3,000,000 pCi L^{-1} on May 23, 1973. The tritium concentration slowly decreased during the next several months.

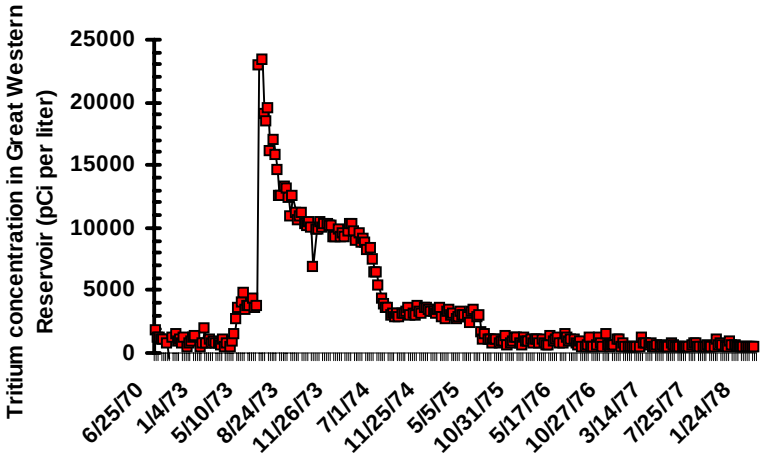

Figure VI-18. Results of the routine weekly monitoring of tritium of treated Great Western Reservoir water, by the Colorado Department of Health from June 1970 through January 1978. They collected weekly samples beginning in June 1970.

Tritium concentrations did increase in water from the GWR but not to the extent seen in water from Walnut Creek at Indiana Street (Figure VI-19). There was no measurable difference in tritium concentrations in Standley Lake water before and after the tritium event because the plutonium processing areas discharged liquid effluent to the Walnut Creek drainage. Standley Lake receives effluents from Woman Creek. The tritium concentration increased over 100 times in Walnut Creek. Smaller increases were seen in treated water from the GWR.

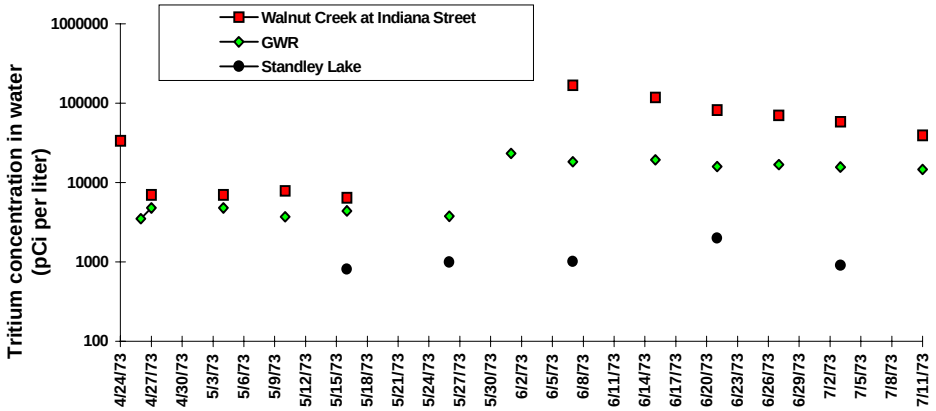

Figure VI-19. A comparison of tritium concentrations measured in water from Walnut Creek at Indiana Street, treated water from the Great Western Reservoir and Standley Lake in April–July 1973, following the accidental releases of tritium. Concentrations peaked at the end of May 1973. The tritium concentration increased over 100 times in water from Walnut Creek. Smaller increases were seen in treated water from the Great Western Reservoir.

Measurement of Tritium in Surface Water From Other Locations

A network for monitoring tritium in surface waters around the U.S. was established in 1964 by the Office of Radiation Programs (later part of the EPA) to measure and monitor tritium concentrations in major river systems in the U.S. and to provide surveillance at surface water stations downstream from selected nuclear facilities (PHS 1969a, 1969b, 1970a, 1970b). The Tritium Surveillance system consisted of 70 quarterly drinking water samples at the Radiation Alert Network (RAN) stations covering the U.S., including Alaska and Hawaii. The specific location for the sampling was determined by examining the water drainage areas to ensure a representative sample was obtained. Figure VI-20 compares the tritium concentrations in water from Walnut Creek at Indiana Street with two locations from the RAN network (the South Platte River and the Colorado River in Nevada). This comparison gives perspective to the magnitude of the increase in tritium concentrations that followed the 1973 release.

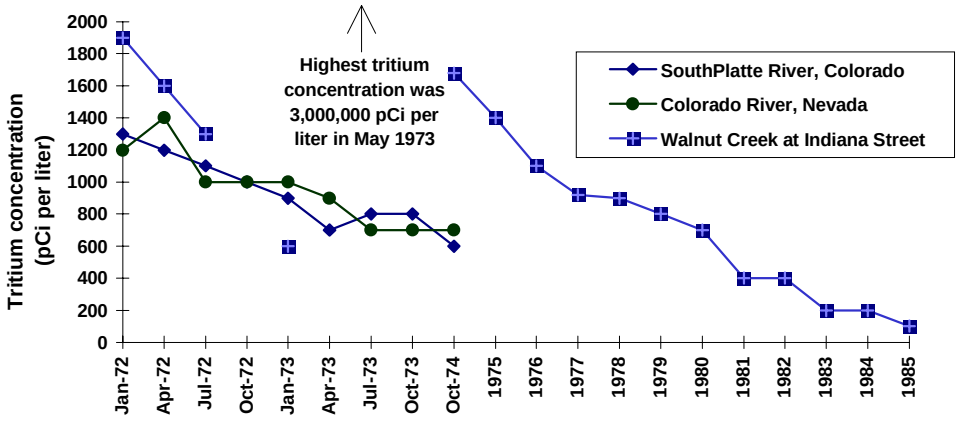

Figure VI-20. Comparison of tritium concentrations in surface water streams in Colorado and Nevada with those measured in Walnut Creek at Indiana Street from January 1972 through 1985. The South Platte River and Colorado River locations were part of the Tritium in Surface Water Network of the U.S. Environmental Protection Agency (EPA 1972a–1972d, 1973a–1973e). Note that the sampling times are not equal time intervals.

Urine Analysis in Broomfield Residents

The CDH collected urine from 36 nonoccupationally exposed Broomfield residents: 17 males (15 over age 20, 2 under age 20) and 19 females (13 over age 20, 6 under age 20) The residents were separated into categories based on their use of the water supply:

1. Lives and works in an area serviced by GWR water supply
2. Works in an area serviced by GWR but lives elsewhere
3. Lives in an area serviced by GWR but works elsewhere.

The overall average tritium concentration for all ages was 4,300 pCi L^{-1} with a standard deviation of 1200, compared to 610 pCi L^{-1} for the 12 control individuals (those not using the Broomfield water system). The geometric mean for all groups was 4,100 pCi L^{-1} with a geometric standard deviation of 1.36, compared to the controls with a geometric mean of 560 pCi

L^{-1} and a geometric standard deviation of 1.59. The tritium concentrations in urine ranged from a high of 8100 pCi L^{-1} to the lowest concentration of 1500 pCi L^{-1}. The minimum detectable activity for the method is 500 pCi L^{-1}. Figure VI-21 shows the results of the sampling program by age and sex. In a study comparing tritium body burdens in children in 1967 and 1968, the tritium concentration in urine of children from nine U.S. locations ranged from about 400 to 1500 pCi L^{-1} (Moghissi and Lieberman 1970).

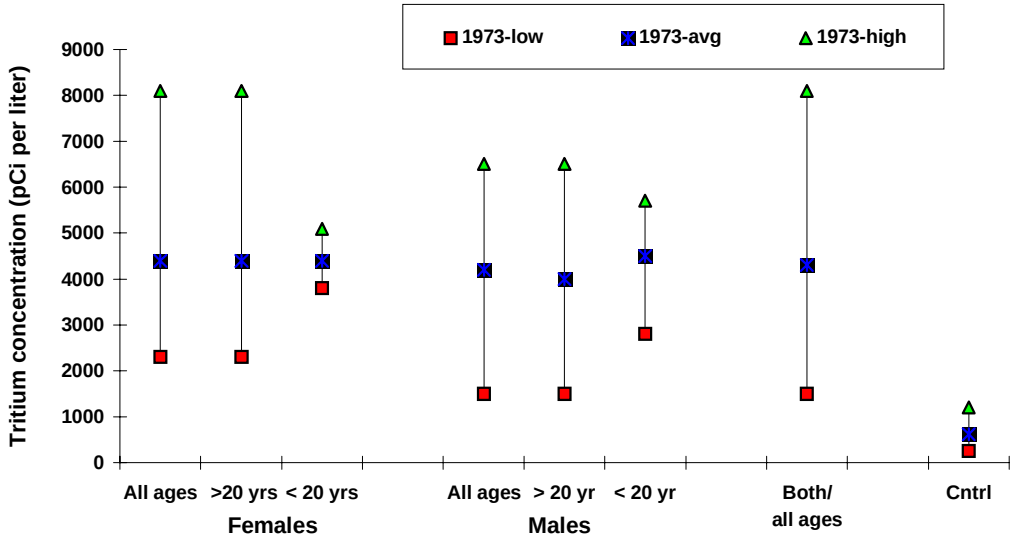

Figure VI-21. Summary of the tritium concentrations measured in the urine of nonoccupationally exposed Broomfield residents in 1973 following an accidental tritium release at the RFP into Walnut Creek. Walnut Creek drains into the GWR, which serves as the water supply of the City of Broomfield. The Walnut Creek drainage basin provided about 2% of the annual volume of the Great Western reservoir water source at that time. "Cntrl" refers to results from a control group of 12 people living in the area but not using the Broomfield water system.

Because tritium levels in the GWR, the water supply for Broomfield, had decreased from the high values measured in 1973 to background levels in 1976, CDH repeated the urine bioassay study of the Broomfield residents at that time. Figure VI-22, which compares the 1973 and 1976 results, indicates a significant decrease in the tritium concentration in urine of the Broomfield residents in 1976.

Radiation Dose Estimate from Tritium Release to Broomfield Drinking Water

This tritium release was previously considered by ChemRisk during Phase I of this project. ChemRisk, supported by the Health Advisory Panel, did not identify tritium as one of the materials of concern for further consideration in Phase II. We have briefly reviewed this incident because of questions raised by a member of the public.

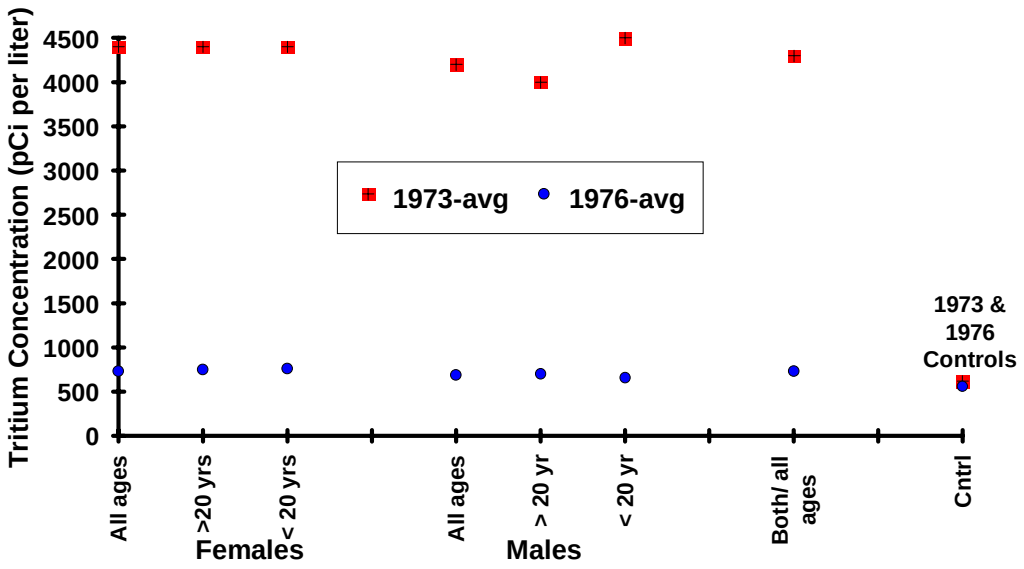

Figure VI-22. Comparison of tritium concentrations in the urine of nonoccupationally exposed Broomfield residents in 1973 and 1976. The samples in 1973 were collected after an accidental tritium releases at the Rocky Flats Plant into Walnut Creek, which drains into the GWR and serves as the water supply of the City of Broomfield.

We used the measured tritium concentrations in the GWR following the tritium release event as the basis for estimating the radiation dose from ingestion of Broomfield water during the period of higher-than-normal tritium concentrations (Figure VI-18). The basic formula for intake from the ingestion of tritium in drinking water is:

$$I\,(wtr) = C_{wtr}(U_{wtr})f_c(T_e) \qquad \text{(VI-1)}$$

where,

I = weekly intake of tritium due to water ingestion (pCi week^{-1})
C_{wtr} = average concentration of tritium in water (pCi L^{-1})
U_{wtr} = average weekly consumption of drinking water (L week^{-1})
f_c = fraction of water consumed that is contaminated (dimensionless, 1.0)
T_e = exposure duration (1 week).

The time integrated water concentration is computed by summing the concentration for each time increment (weekly) over the entire interval of higher-than-normal tritium concentrations. For this calculation, that time interval was from April 1973 through February 1976 (Figure VI-18). By early 1976, the tritium concentration had returned to background levels measured in the GWR before the tritium release.

The committed effective dose equivalent is then determined with the equation:

$$D = I_{wtr}\,(DCF_T) \qquad \text{(VI-2)}$$

where,

D = committed radiation dose equivalent due to ingestion of excess tritium in drinking water from 1973 release (sievert per year)

DCF_T = dose conversion factor for ingestion of tritium, 1.73 x 10^{-11} sievert per becquerel (0.0629 mrem per μCi)

The dose estimate incorporated sources of uncertainty and variability in the above parameters using Monte Carlo techniques in the Crystal Ball® program (Decisioneering 1993). Based on these calculations, the best estimate is 0.32 mrem, with the 5th and 95th percentiles of 0.16 and 0.58, respectively. Table VI-17 provides information on doses from natural and fallout sources of tritium.

Table VI-17. Committed Dose Equivalent From Tritium in the Environment [a]

Source	Dose (mrem y^{-1})
Natural tritium	0.0012
Fallout (1963)	0.2
Fallout (1980)	0.005
1973 tritium release from RFP (ingestion)	0.32[b]

[a] From NCRP (1987).
[b] Fifty-year committed dose.

The estimated tritium concentration in the body water of humans is 400 Bq m^{-3} (12 pCi L^{-1}). The corresponding dose equivalent rate in tissue is 0.012 μSv y^{-1} (0.0012 mrem y^{-1}) (NCRP 1987). A tritium concentration in drinking water of about 20,000 pCi L^{-1} would contribute about 4 mrem to the person's dose for that year assuming that this was the sole water source for the entire year (Zillich 1974).

Total excess total cancer mortality risk estimates for 1980 for low dose rate, low LET radiation are 270/100,000 exposed to 10 rem = (2.7×10^{-4}) for males; 260/100,000 exposed to 10 rem = 2.6×10^{-4} for females (BEIR V). Therefore, for the 0.32 mrem dose from ingestion, excess cancer risk is 8.64×10^{-8} for females and 8.32×10^{-8} for males.

SPECIAL STUDIES INVOLVING SURFACE WATER MONITORING

Special research projects that have involved the monitoring of the Rocky Flats surface water systems were evaluated for their relevance to the goals of this project. Examining data from special sampling initiatives undertaken by the site contractor, the Colorado Department of Health, or other organizations following an accident or nonroutine release can contribute to confirmation of release estimates over time and space if contaminants of interest were measured.

Following 1957 Fire

Following the Building 771 fire on September 11, 1957, "spot sampling of vegetation and soil samples offsite indicated not only possible low-level contamination from this incident but possible low-level contamination by other Rocky Flats materials" (Hammond 1957). As a result, more extensive monitoring of various media was undertaken. Offsite water samples were

collected at seven locations in surrounding communities and in Denver (Table VI-18). Distant locations showed no increase in activity, but onsite locations showed some increased activity that was identified, through pulse height analysis, as uranium. No plutonium was identified in the 10 offsite water samples collected (Hammond 1957).

Table VI-18. Results of Nonroutine Water Sampling Following the 1957 Fire[a]

1957 Date	Sample #	Location	Alpha activity (dpm L^{-1})	Alpha range (dpm L^{-1})	1951 background level (dpm L^{-1}) [b]
10/17	W-17	S Boulder Cr.	2.3		
9/20	W-29	Nissen Res. #2	1.5		
10/17	W-40	S Boulder Cr.	LTD[c]		
9/20	W-41	Eastlake Res.	1.0		
9/20	W-46	City Park L. Denver	1.1		
9/20	W-51	Marsten Res.	2.3		
9/20	W-52	McKay Lake	LTD		
10/29	W-22	Rocky Flats Lake	0.9	0.9-1.6	1.2
11/12	W-23	West Twin Lake	1.8	0.9-1.8	1.2
10/29	W-38	Lookout Mt. Res.	0.9	0.9	1.8
10/29	W-39	Arvada Tap	1.1	0.9-1.5	1.1
11/14	W-45	Berkely Lake	5.5	2.6-24	9.5
10/29	W-50	Clear Creek	5.9	0.9-3.2	2.0
11/7	W-55	Building 95 effluent	17		
11/14	W-56	Wash. Park Lake	5.0	7.5-9.9	8.7

[a] From Hammond (1957)
[b] From Quimby (1952)
[c] Less than detectable.

Following 1969 Fire

Following the fire on Sunday, May 11, 1969, the Radiation Hygiene Section of the State Health Department initiated special air and water sampling procedures in the area around the RFP (Ryan 1969). Beginning on Monday, May 12, 1969, they collected 1-gallon water samples from several lakes and streams adjacent to the RFP, and analyzed them for gross alpha activity. Table VI-19 shows the frequency and results of the special water monitoring program following the fire. Water to fight the 1969 fire, including water trapped in pits under equipment and stairwells, went to the process drains leading to underground storage tanks. It was reported that all water from the fire was transferred to the waste treatment facility (Joshel 1971).

Table VI-19. Gross Alpha in Water Collected by the Colorado Department of Health After the May 1969 Fire at the Rocky Flats Plant[a]

Location	Date Sampled	Days after fire	Gross alpha[b] (pCi L^{-1})
Broomfield Water Supply	4/30	pre-fire	IFB
	5/16	5	IFB
Walnut Creek	5/16	5	9.5±8.6
	5/17	6	7.2±6.9
	5/18	7	IFB
Great Western Reservoir	5/12	1	IFB
	5/15	4	IFB
	5/17	6	IFB
	5/18	7	IFB
Standley Lake	4/30	pre-fire	IFB
	5/12	1	IFB
	5/15	4	IFB
	5/17	6	IFB
	5/18	7	IFB
Boulder Canal	5/12	1	56.8±10.1
			Filtrate[c] 19.3±6.6
			Filter 34
	5/15	4	IFB
Ralston Reservoir	4/30	pre-fire	IFB
			Filtrate IFB
			Filter 5
	5/12	1	13.9±6.0
	5/15	4	22.3±6.7

[a] From Emerson (1969).
[b] IFB = indistinguishable from background; minimum detectable activity reported as 0.4 pCi L^{-1}.
[c] Filtrate refers to the portion of the sample that passes through a filter used to trap suspended particles. The "filter" refers to material remaining on the filter after filtration.

Pond Rebuilding

Extensive water and sediment monitoring was done from 1971 to 1973 in conjunction with a research project directed by Colorado State University to study the movement of plutonium in the aquatic systems of the RFP (Johnson et al. 1974). These data have provided some information for estimating plutonium inventory in sediments in GWR. Hundreds of water samples were taken from the various ponds during this 3-year time period, which included the pond reconstruction activities by the site. Furthermore, plutonium was measured instead of total alpha activity. Rebuilding the ponds resulted in an increase of plutonium concentrations in unfiltered water, probably from an increase of suspended particulate matter in the pond chain.

The CDH began a routine water monitoring program in 1970 in the RFP area. They initially monitored weekly for gross alpha, beta, and tritium, later adding uranium and plutonium-specific measurements. Figure VI-23 illustrates the impact of the holding pond reconstruction activities on levels of activity discharged to the GWR. Levels of alpha activity in water from Walnut Creek at Indiana show a significant increase from about 10 pCi L^{-1} in 1970 and 1971 to a high of almost 800 pCi L^{-1} in March 1973. By June 1973, alpha activity levels had returned to those measured before the pond reconstruction.

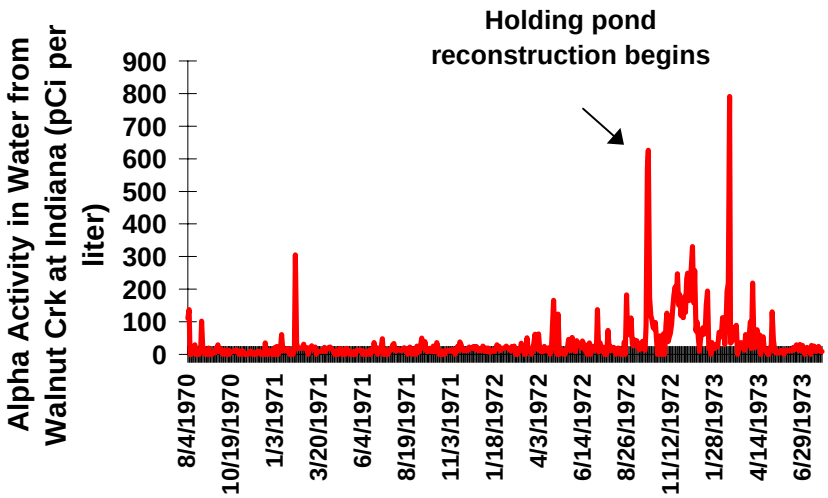

Figure VI-23. Weekly gross alpha activity in water collected by the Colorado Department of Health, from Walnut Creek at Indiana Street from 1970–1973. The reconstruction of the A-ponds resulted in resuspension and release of materials in sediments and increases in weekly alpha activity up to 200 to 800 pCi L^{-1} during the pond reconstruction.

OBSERVATIONS ON HISTORICAL WATER MONITORING AT THE RFP

Through our work to date on compiling and evaluating water monitoring data pertaining to the RFP, we have focused on understanding onsite liquid effluent handling, processing, and control, especially in the early years. There were procedures in place for the routine transfer of liquids to the waste processing areas, but only a limited amount of documentation has been identified to verify how well the procedures were carried out.

Routine liquid effluent monitoring began July 1953. We have located original handwritten logbooks for some years, and monthly reports for most years to document releases to North and South Walnut Creeks and Woman Creek. These values, however, do not include estimates from unmonitored runoff from contaminated ground surfaces. The collection of water samples changed from grab sampling and estimating effluent volumes in 1953 to the use of a crude continuous sampler by August 1955. Until 1972, samples were transported to the laboratory where they were acidified, filtered, and evaporated. The quality of the water monitoring data was affected by factors such as the presence of sediment in collected samples, extraneous activity introduced in the analysis process, and the analytical method itself.

The gross alpha measurements in liquid effluents released from the site before 1970 correspond fairly well to release events onsite, and the data are useful for supporting the relative magnitude of routine releases. By looking at the data on a monthly rather than an annual basis, it is easier to understand the site operations and how effluents were handled on site. We used one method to estimate plutonium releases for earlier years when only gross alpha was measured by calculating a ratio of monthly plutonium to alpha activity and applying it to measurements of alpha activity released from the same location from 1952 to 1970 (when plutonium was not measured). This method provides one approach for bounding the plutonium releases to South Walnut Creek from the B ponds in the early years.

Based on this ratio method, the total plutonium released from the B Ponds to South Walnut Creek through 1969 was estimated to be 20 mCi (90% confidence interval of 6 to 55 mCi). There are limitations to this method, and it is not easily applicable to estimating releases of plutonium to Woman Creek because the historic record of measurements is not as complete. However, these studies are important because they aid in better understanding the plutonium inventory in sediment in the GWR. Various sediment studies have shown that the majority of the plutonium inventory in the GWR is from liquid releases from the RFP. Studies by Colorado State University have provided plutonium inventory estimates in the GWR of 50 to 80 mCi. This method allows us to bound the plutonium releases to South Walnut Creek from the B ponds in the early years and to better understand the source of the plutonium in sediment in the GWR.

More recent studies and projects at the RFP have been designed to improve the effluent handling and waste processing. For example, the RFP Surface Water Control System was completed in 1980. It was designed to improve the water retention capability of the site in the event that surface runoff water from the site proved “unsuitable for discharge” (Henry 1986). The system consisted of three earthfilled dams—[Pond A-4 (95 acre-feet), Pond B-5 (73 acre-feet), and Pond C-2 (69 acre-feet)] —and a concrete and rockfilled diversion dam that intercepts surface runoff from the west side of the plant and delivers it to the McKay Ditch bypass canal [2 mi (2 km) of canal north of the site]. Another concrete and rockfilled diversion dam intercepts surface water from Woman Creek and diverts it around Pond C-2. The south Interceptor Canal [2 mi (3.2 km) of canal south of the site] diverts surface runoff from the southern portion of the plant to Pond C-2.

These modifications resulted in a general decrease in the number and extent of offsite releases to surface water (EG&G 1993b). A statistical analyses of plutonium, americium, uranium, total alpha, and beta levels measured in water from Ponds C-1, C-2, B-5, A-4, Walnut Creek, and the reservoirs from December 1987 to August 1990 supported this observation (Bauer and Weier 1991).

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