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Annual Reduction of ^{90}Sr Migration from Solid Waste Storage Area 4 to White Oak Creek by Flow Diversion

L. A. Melroy
D. D. Huff

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 2504

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ENVIRONMENTAL SCIENCES DIVISION

ANNUAL REDUCTION OF ^{90}Sr MIGRATION FROM SOLID WASTE STORAGE AREA 4 TO WHITE OAK CREEK BY FLOW DIVERSION

L. A. Melroy and D. D. Huff

Environmental Sciences Division
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ABSTRACT

MELROY, L.A., and D.D. HUFF. 1985. Annual reduction of ^{90}Sr migration from Solid Waste Storage Area 4 to White Oak Creek by flow diversion. ORNL/TM-9620. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 55 pp.

The discharge from Solid Waste Storage Area 4 (SWSA 4) at Oak Ridge National Laboratory was studied to determine the effect of a new flow diversion system on the annual flux of ^{90}Sr into White Oak Creek. The diversion structure was built in late 1983 to route runoff from the SWSA 4 catchment headwaters area (56% of the basin) around the burial ground, because an earlier study showed that this would be an effective remedial measure for reducing ^{90}Sr migration. A preliminary evaluation of the diversion was conducted during the winter of 1984, and an average flow reduction of 56% and a ^{90}Sr flux reduction of 44% were observed during the initial study period. The results presented here indicate that an overall annual flow reduction of 66% and an annual ^{90}Sr flux reduction of 47% were achieved during the 1984 calendar year.

An additional goal of the study was to rank SWSA 4 and the surrounding areas as sources of ^{90}Sr input into White Oak Creek. Runoff from SWSA 4 was found to contribute 58% of the ^{90}Sr flux to the adjacent reach of White Oak Creek and therefore is the major source of contamination in that area. Statistical analysis suggests that the remaining 42% of the influx is attributable to groundwater inflows from adjacent contaminated areas rather than to the considerable uncertainty associated with flow and ^{90}Sr measurements.

INTRODUCTION

Groundwater movement is often considered to be the dominant mechanism of solute transport from waste disposal sites. However, at shallow land disposal sites located in topographically lower regions of a watershed, surface runoff may be of particular importance, since it may infiltrate into the buried waste, leach out radionuclides, and transport the solutes from the disposal area. As the surface runoff moves over the burial ground, some of it may infiltrate into the waste disposal trenches; since the trenches generally have a greater porosity than an undisturbed area, significant quantities of runoff may infiltrate into the trenches. This subsurface water has a strong potential for becoming contaminated through direct contact with the buried wastes. With continued infiltration from the surface, the trenches may begin to fill with water, which may overflow, if the subsurface percolation out of the trenches occurs more slowly than the inflow. Such an overflow condition is known as the "bathtub effect." This may result in contamination of surface and subsurface waters and groundwater in adjacent areas.

An example of this situation, which occurred at Solid Waste Storage Area 4 (SWSA 4) at the Oak Ridge National Laboratory (ORNL), Tennessee, was described by Huff et al. (1982). They found that surface water runoff was the major factor responsible for transport of ^{90}Sr from this low-level radioactive waste disposal area. Since much of this runoff originated upgradient of the disposal site, they estimated that a reduction of up to 80% in the ^{90}Sr flux from the burial ground could be obtained by diverting this upslope runoff around the burial areas.

In response to the recommendation given in that study, a surface water diversion system was designed and constructed at SWSA 4 in late 1983. During the first part of 1984, a preliminary evaluation of the effectiveness of the diversion system was conducted, and the results were reported by Melroy and Huff (1985). They reported that an average flow reduction of 56% and a flux reduction of 44% were obtained during the study period (February through May 1984). However, since the greatest precipitation and streamflow occur in the winter, the diversion was expected to be most effective during these months. Therefore, further evaluation was conducted to determine the effect of the surface water diversion through an entire 12-month cycle (January to December, 1984). This report documents the findings of that second study. Because the runoff from SWSA 4 enters White Oak Creek, another goal of the study was to evaluate the relative current importance of SWSA 4 as a source of ^{90}Sr to White Oak Creek.

SITE HISTORY

SWSA 4 is located to the west of White Oak Creek and covers an area of approximately 10.0 ha (24.7 acres). Most of the burial ground is situated within the watershed shown in Fig. 1. This watershed occupies 24.6 ha (60.7 acres) and drains, via a small tributary along the southern edge of the burial ground, into White Oak Creek.

In the spring of 1944, a small earth-fill dam was constructed across White Oak Creek. The impoundment, shown in Fig. 1, acted as a settling basin, collecting radionuclide-contaminated sediments, including ^{90}Sr, ^{137}Cs, and $^{239-240}Pu$. The dam failed in early winter,

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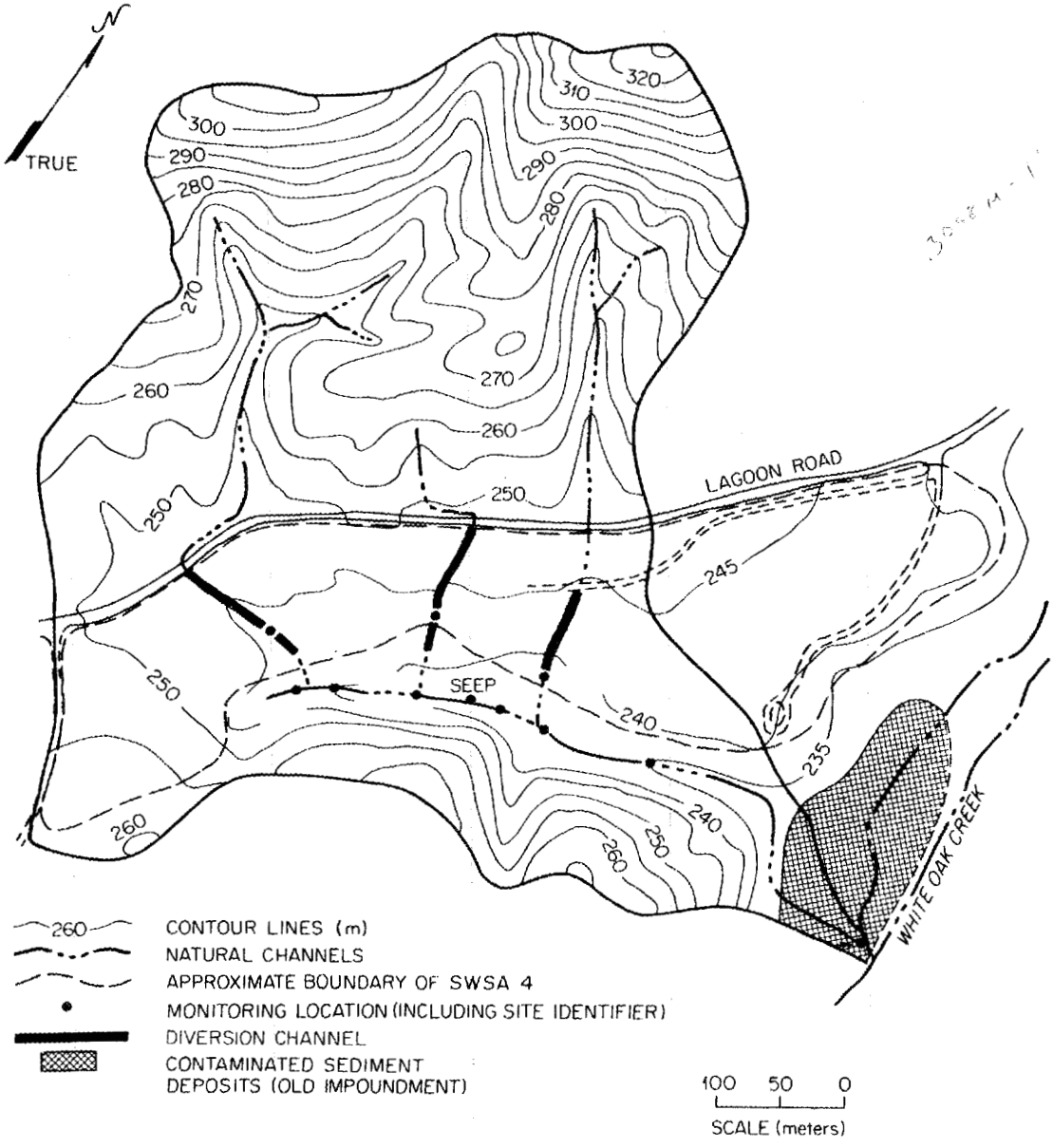

Fig. 1. Map of SWSA 4, showing drainage features before construction of the flow diversion system.

but an "intermediate pond" remained until sometime after 1951 (TVA 1951). Runoff from SWSA 4 and flooding of the contaminated sediments may cause present-day migration of ^{90}Sr to the adjacent reach of White Oak Creek by leaching or erosion.

Between 1951 and 1959, SWSA 4 was used as a low-level radioactive waste disposal site. Wastes were buried in trenches and auger holes to depths up to 5-6 m. After the burial ground was closed in 1959, up to 6 m of uncontaminated fill and construction debris was placed on the disposal site, raising the elevation of the site. A detailed review of the history of SWSA 4 is presented in a report by Melroy and Huff (1985).

Huff et al. (1982) investigated SWSA 4 to determine the hydrologic factors and transport mechanisms affecting the migration of ^{90}Sr from the burial ground. They found that surface runoff was a major transport mechanism. During storm events, the total amount of ^{90}Sr transported was found to be an average of 2.8 times greater than that transported during periods without storms. They recommended that a surface flow diversion system be constructed to divert the storm flow around the contaminated areas.

In 1983, a diversion system was designed and constructed for SWSA 4. The diversion system (Fig. 2) consists of a paved interceptor channel, which collects runoff from the area north of Lagoon Road; four catch basins (Sites B, C, D, and E), which collect the runoff from the interceptor channel and upslope areas; and the storm drain system, which diverts the runoff around the burial ground.

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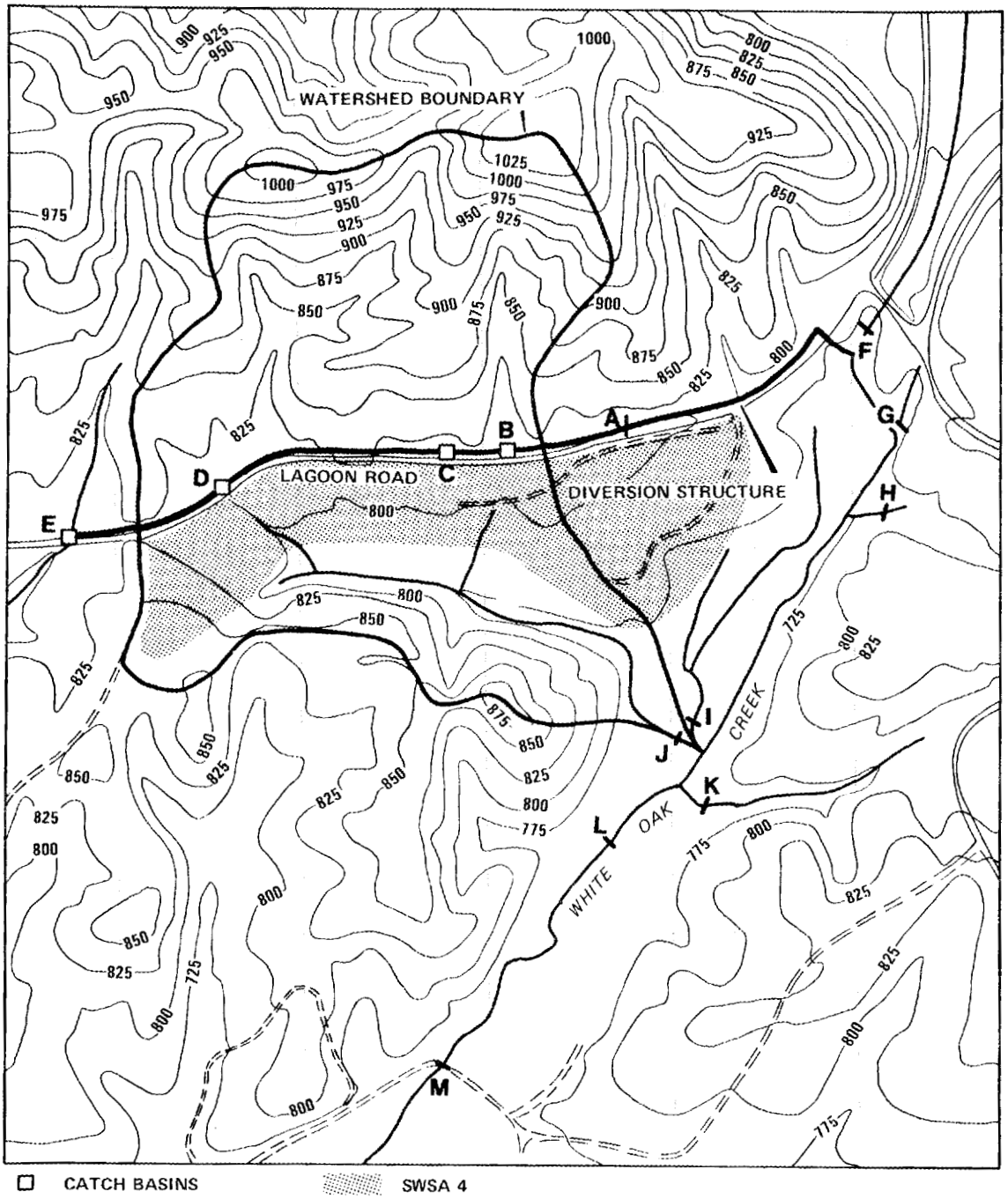

CATCH BASINS SWSA 4

MONITORING SITES

Fig. 2. Map of SWSA 4 site, showing features of flow diversion system and sampling and flow measurement sites.

The area affected by the diversion covers 56% of the total drainage basin and is located to the north of Lagoon Road. Surface runoff from this area is collected by the paved interceptor ditch, which runs parallel to Lagoon Road. At three locations along the interceptor ditch (Sites B, C, and D), catch basins are placed to allow the collected runoff to enter the storm drains. Two storm drains are used to divert the runoff around the contaminated areas. The eastern storm drain consists of a 45.72-cm (18-in.) plastic pipe connecting Site C to Site B, with a 76.2-cm (30-in.) plastic pipe running from Site B to its discharge point at Site A. From Site A, the runoff enters a paved channel, where it then flows east and is discharged to White Oak Creek. The western storm drain consists of a 91.44-cm (36-in.) plastic pipe which connects the catch basin at Site D to Site E. At Site E, runoff from an adjacent watershed is also collected by the catch basin, and the combined flow is discharged through a culvert under Lagoon Road to a natural tributary to White Oak Lake.

In addition to the surface runoff collection structures between Sites B and A and between Sites D and E, the excavations for the storm drains also contain perforated piping and were backfilled with gravel to allow interception and diversion of shallow groundwater (Fig. 3). Further details of the diversion system are given in the historical review by Melroy and Huff (1985).

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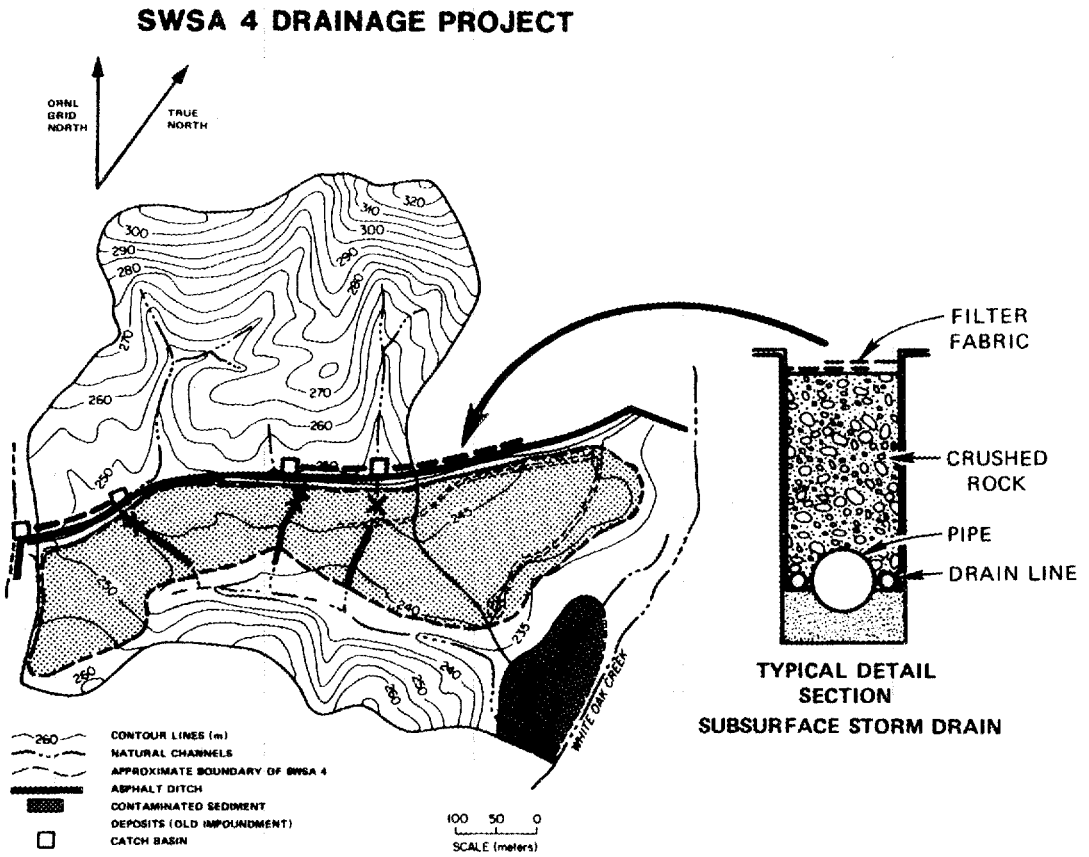

Fig. 3. Map of the SWSA 4 diversion system, showing subsurface drainage features.

EVALUATION OF THE SURFACE WATER DIVERSION SYSTEM

METHODS

Evaluation Model

A simple model was used to evaluate the effectiveness of the surface diversion system (Melroy and Huff 1985). Before construction of the surface diversion system, Site J received the runoff from the entire watershed, as shown in Fig. 4a:

$$\text{Before diversion:} \quad Q'(\text{total}) = f(\text{total area}) \quad , \qquad (1)$$

where Q' = discharge in L/s.

After the surface diversion system was constructed, Site J received the runoff only from the area south of Lagoon Road (Fig. 4b), and the remaining runoff was diverted around the burial ground:

$$\text{After diversion:} \quad Q(\text{Site J}) = f(\text{area south of Lagoon Road}) \quad , \qquad (2)$$

$$Q(\text{diverted}) = f(\text{area north of Lagoon Road}) \quad , \qquad (3)$$

where Q = discharge in L/s.

The total flow without the diversion system was assumed to be the sum of the discharges from the areas north and south of Lagoon Road:

$$\text{Model:} \quad Q(\text{total}) = Q(\text{Site J}) + Q(\text{diverted}) \quad . \qquad (4)$$

The modeled total discharge, Q'(total) represents an estimate of what the actual total discharge, Q(total), would have been without the flow

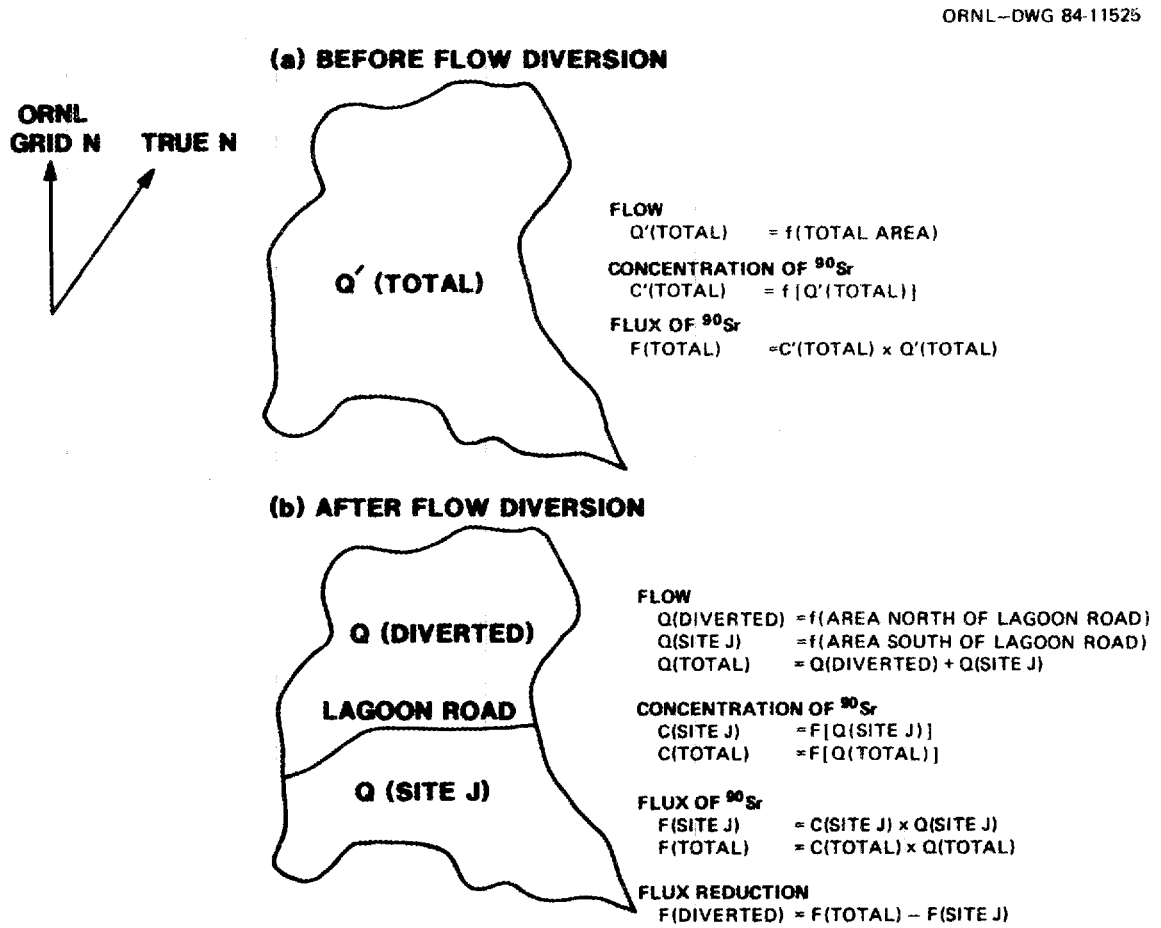

Fig. 4. Model used to evaluate the effects of flow diversion on the ^{90}Sr flux input to White Oak Creek from SWSA 4.

diversion. The flow diverted can be expressed as a percentage of the total flow:

$$\text{Flow reduction (\%)} = [Q(\text{diverted})/Q(\text{total})]100 \quad . \qquad (5)$$

Since the purpose of the diversion system was to reduce migration of ^{90}Sr, the next step in the model involves estimating the reduction in ^{90}Sr flux due to the anticipated changes in flow. A correlation derived by Huff et al. (1982) relates the concentration of ^{90}Sr to the discharge at Site J (presented in the next section). By using the flow measurements and this correlation, comparisons of the ^{90}Sr concentrations without and with construction of the diversion system can be made:

$$\text{Without diversion:} \quad C(\text{total}) = f[Q(\text{total})] \quad , \qquad (6)$$

$$= f[Q(\text{Site J}) + Q(\text{diverted})] \quad , \qquad (7)$$

$$\text{With diversion:} \quad C(\text{Site J}) = f[Q(\text{Site J})] \quad , \qquad (8)$$

where C = concentration of ^{90}Sr in pCi/mL.

The final step in evaluating the surface diversion system involves analyzing the changes in the ^{90}Sr flux into White Oak Creek. The flux can be computed from the ^{90}Sr concentration and flow, as shown in Eqs. (9) and (10):

$$\text{Without diversion:} \quad F(\text{total}) = [Q(\text{total}) \bullet C(\text{total})]1000 \quad , \qquad (9)$$

$$\text{With diversion:} \quad F(\text{Site J}) = [Q(\text{Site J}) \bullet C(\text{Site J})]1000 \quad , \qquad (10)$$

where F = flux of ^{90}Sr in pCi/s.

The reduction in flux is equal to the difference between the ^{90}Sr flux without diversion, F(total), and the flux with diversion, F(Site J):

$$\text{Flux reduction:} \quad F(\text{diverted}) = F(\text{total}) - F(\text{Site J}) \quad . \tag{11}$$

$$\text{Flux reduction (\%):} \quad F(\text{diverted}) = [F(\text{diverted})/F(\text{total})]100 \quad . \tag{12}$$

Correlation Between ^{90} Sr Concentration and Flow

A mathematical correlation, shown in Eq. (13), relating the discharge rate to the ^{90}Sr concentration at Site J was determined by Huff et al. (1982), using 250 data points:

$$Cp = \{C1 - (C2 \bullet Q) + C3[\exp(-C4 \bullet Q)]\}/2.22, \tag{13}$$

where

Q = flow at Site J in L/s,

Cp = predicted ^{90}Sr concentration at Site J in pCi/mL,

C1 = 6.3722,

C2 = 0.02132,

C3 = 13.3955,

C4 = 0.06592.

The correlation coefficient for this relationship was 0.82. A plot of this relationship for flows up to 160 L/s is shown in Fig. 5, but the data from the original study by Huff et al. (1982) are not shown in the figure.

This relationship was developed in 1980 prior to the construction of the diversion system. To check its applicability, the measured ^{90}Sr concentrations from the present study were plotted with the

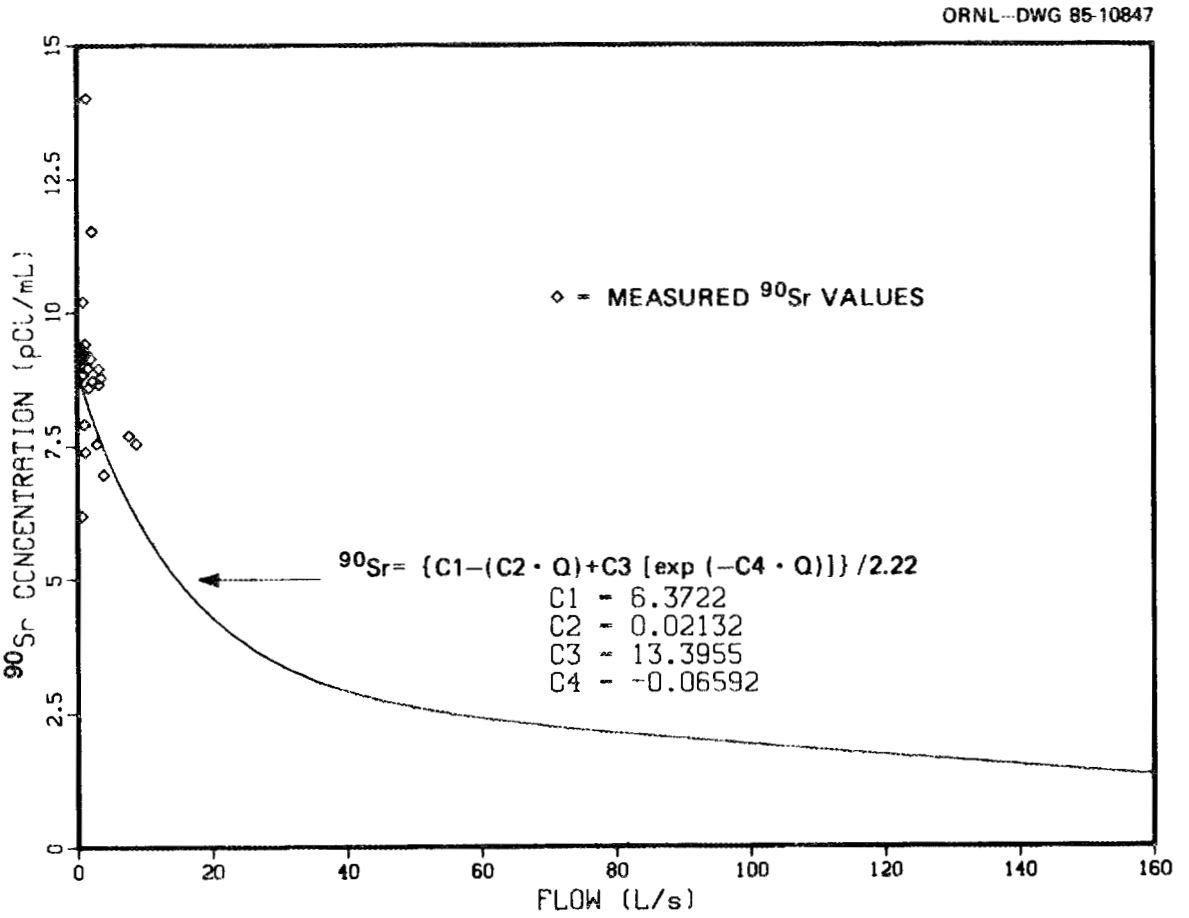

Fig. 5. Relationship between discharge rate and ^{90}Sr concentration at Site J, SWSA 4.

correlation equation in Fig. 5, and a comparison was made between the measured and predicted ^{90}Sr concentrations (Table 1). A relative error term was computed, as shown in Eq. (14):

$$\text{Relative error (\%)} = [(Cp - Cm)/Cm]100 \quad , \tag{14}$$

where Cm = measured ^{90}Sr concentration at Site J in pCi/mL.

The relative error ranged between -40.4 and 38.7%, with an average error of (-7 ± 14)%. Although the data taken during the study to recheck the correlation equation encompass relatively low flow conditions, no evidence was found to indicate that the relationship had changed since the earlier study.

For additional verification of the ^{90}Sr correlation equation, monthly estimates of the flux from the SWSA 4 tributary were made, using Eq. (13) and continuous flow records from Site J (discussed further in the following sections). These estimates were compared with data for the reach of White Oak Creek adjacent to SWSA 4, gathered by ORNL Operations Division (L. C. Lasher, personal communication, March 1985), as shown in Fig. 6. The data reported by Lasher were determined by comparing the difference between the continuous flow monitoring and sampling results at Sites F and M (Fig. 2). The flux estimates made using Eq. (13) showed good correlation with the data by Lasher, except during December 1983 and July 1984, where the difference between the flux values is believed to be related to uncertainty in the continuous flow measurement and sampling results for White Oak Creek during the extremely high and low flow periods. Therefore, because direct

Table 1. Comparison between measured and predicted concentrations of ^{90}Sr at Site J, SWSA 4

Date	Q(Site J), discharge (L/s)	Cm, measured ^{90}Sr concentration (pCi/mL)	Cp, predicted ^{90}Sr concentration (pCi/mL)	Relative error (%)
01/31/84	1.22	7.40	8.43	13.9
02/15/84	3.94	6.97	7.49	7.4
02/21/84	1.13	7.91	8.46	7.0
03/01/84	2.39	8.717	8.00	-8.2
03/06/84	2.30	11.514	8.03	-30.2
03/12/84	0.96	8.846	8.53	-3.6
03/20/84	1.43	14.02	8.35	-40.4
03/27/84	1.46	9.226	8.34	-9.6
04/03/84	3.27	8.941	7.70	-13.8
04/18/84	0.86	8.83	8.56	-3.0
04/23/84	2.06	9.13	8.12	-11.1
05/01/84	2.94	7.55	7.81	3.5
05/04/84	7.64	7.70	6.44	-16.3
05/09/84	8.78	7.55	6.17	-18.3
05/24/84	0.76	6.20	8.60	38.7
05/31/84	0.92	10.2	8.54	-16.3
10/24/84	3.60	8.78	7.60	-13.5
11/15/84	0.79	9.21	8.59	-6.7
11/21/84	1.61	8.96	8.28	-7.6
11/30/84	1.72	8.59	8.24	-4.1
12/07/84	0.99	9.30	8.51	-8.5
12/13/84	0.79	9.30	8.59	-7.6
01/03/85	3.27	8.66	7.70	-11.0
01/10/85	1.21	9.41	8.43	-10.4
01/16/85	0.52	9.27	8.70	-6.2
01/25/85	0.70	9.03	8.62	-4.5
01/30/85	0.58	9.12	8.67	-4.9

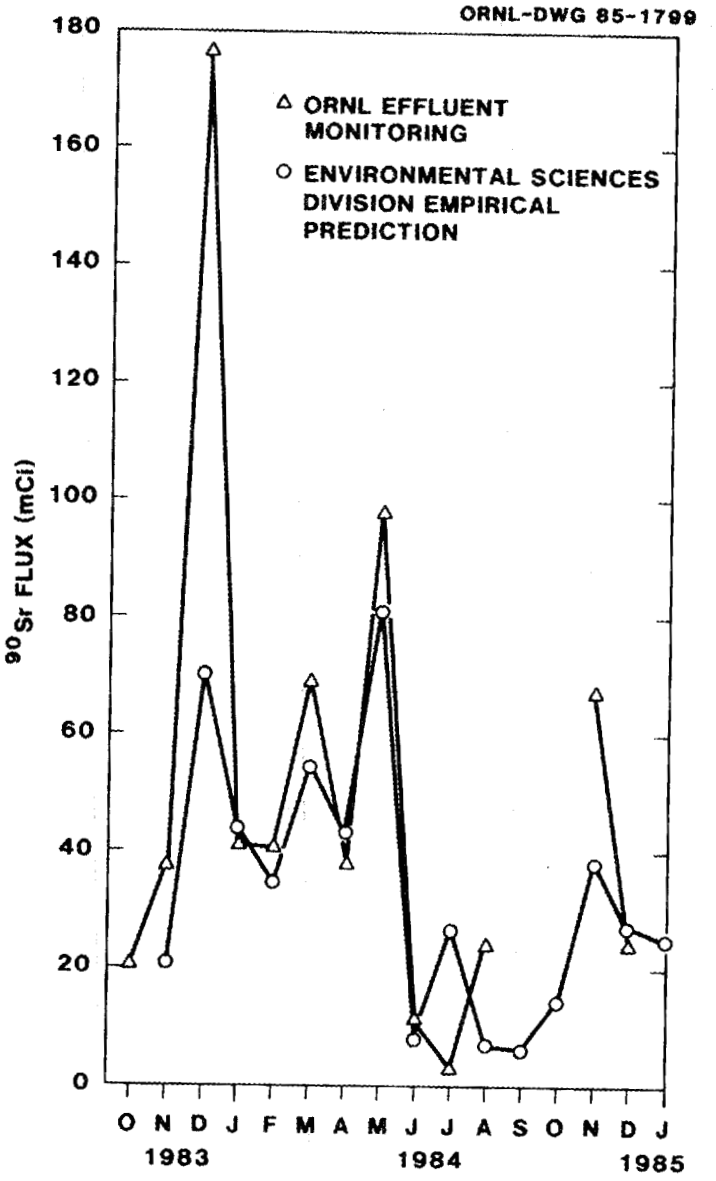

Fig. 6. Monthly ^{90}Sr flux estimates from SWSA 4.

measurement is generally more accurate than a value derived by difference between measured values, Eq. (13) and continuous flow data from Site J were used in this study to predict the concentration of ^{90}Sr in the SWSA 4 tributary.

Flow Measurement

Weekly streamflow measurements were made at Sites A, D, and J (Fig. 2), volumetric measurements were made at Sites A and J, and floating chip measurements were made at Site D, as discussed in the historical review by Melroy and Huff (1985).

At Site J, continuous streamflow monitoring was also conducted, using a trapezoidal flume and a portable water-level recorder. Several ratings were computed for this flume, using a complex flume rating program (Replogle 1975) and various friction factors (Melroy and Huff 1985). A final rating was derived that fit the observed flow measurements at low flows (<15 L/s) and conformed to the manufacturer's rating at high flows. This rating, with a friction factor of 0.0009, is shown in Table 2. A plot of the manufacturer's rating and the computed rating for flows between 0 and 50 L/s is shown in Fig. 7. The measured stage and discharge values are also shown.

RESULTS AND DISCUSSION

Flow measurements were made periodically between February 1984 and January 1985 to evaluate the effects of the surface flow diversion system on the migration of ^{90}Sr from SWSA 4. The flow measurements, the modeled total discharge [Q(total)], and the diverted discharge

Table 2. Computed stage-discharge rating for the trapezoidal flume at Site J, SWSA 4, using a friction factor of 0.0009[a]

(Discharge is in L/s; maximum stage is 40.45 cm; stage is expressed as a percentage of the maximum stage)

Stage	0	1	2	3	4	5	6	7	8	9
0	0.00	0.55	1.22	1.98	2.78	3.64	4.52	5.46	6.44	7.46
10	8.49	9.59	10.70	11.88	13.00	14.29	15.59	16.87	18.21	19.52
20	20.88	22.29	23.76	25.28	26.75	28.26	29.82	31.43	32.99	34.69
30	36.33	38.03	39.76	41.55	43.32	45.19	46.95	48.76	50.74	52.64
40	54.56	56.52	58.53	60.60	62.49	64.65	66.63	68.84	70.90	73.03
50	75.35	77.53	79.77	82.03	84.33	86.45	88.83	91.23	93.44	95.93
60	98.45	100.78	103.16	105.79	108.22	110.69	113.43	115.98	118.56	121.16
70	123.80	126.46	129.18	131.64	134.42	137.22	140.08	142.68	145.57	148.55
80	151.24	154.24	156.98	160.07	162.90	165.73	168.93	171.82	174.77	177.74
90	181.05	184.08	187.17	190.26	193.37	196.51	199.71	202.94	206.17	209.45
100	212.77									

[a]For example, for a stage of 84% (34 cm), find the intersection of the 80% row with the 4% column to determine the discharge of 162.90 L/s.

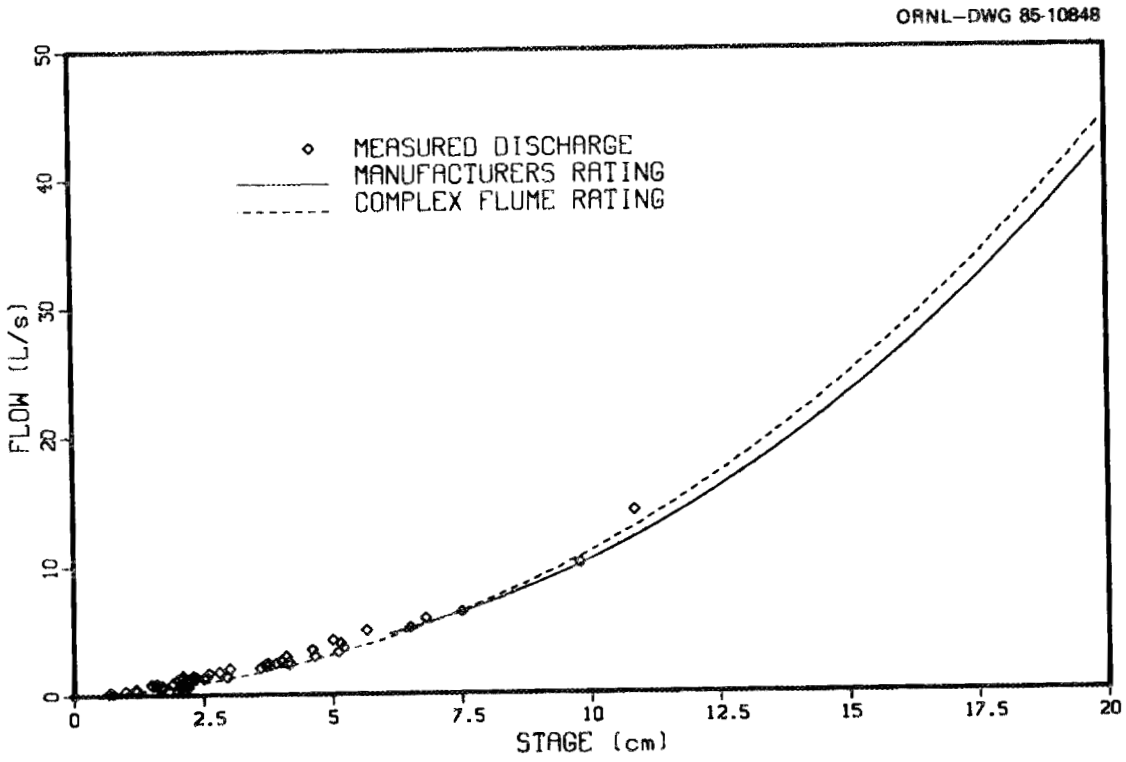

Fig. 7. Discharge rating curves for the trapezoidal flume at Site J, SWSA 4.

[Q(diverted)] are shown in Table 3. The diverted flows ranged from 0 to 118 L/s, and the total flows varied from 0 to 153 L/s.

During the study period, flow reductions of 20 to 88% were observed, resulting in an average reduction of 50%. A plot comparing the flow reduction, in percent, versus the flow at Site J is provided in Fig. 8. Although limited data were taken during the study period and substantial variability was observed in the data, a relationship was developed between the flow reduction and the discharge, using a nonlinear least-squares procedure:

$$\text{Flow reduction } (\%) = K\{Q(\text{Site J})^M/[1 + Q(\text{Site J})^M]\} \quad , \qquad (15)$$

where

$K = 79.42$,

$M = 0.6686$.

From Fig. 8, it can be seen that the flow reduction is not a constant value. Variations in such factors as the precipitation intensity, antecedent moisture conditions, and the infiltration rate will all affect the response of the watershed; thus, the flow reduction was not a constant fraction of the total flow rate.

Calculated ^{90}Sr flux reduction attributable to the diversion system were made for specific observations of flow and estimated ^{90}Sr concentration, using the previously described model [Eqs. (1-13)], and the results are summarized in Table 4.

Without flow diversion, concentrations of ^{90}Sr at Site J were estimated to range between 1.4 and 8.5 pCi/mL. With the diversion

Table 3. Percent flow reduction in the SWSA 4 tributary resulting from the surface water diversion system at SWSA 4

Date	Flow (L/s)					Percent flow reduction
	Q(Site A)[a]	Q(Site D)[b]	Q(Site J)[c]	Q(total)[d]	Q(diverted)[e]	
02/27/84	6.74	11.35	14.17	32.26	18.09	56.1
03/01/84	1.25	3.05	2.39	6.69	4.30	64.3
03/06/84	0.63	1.06	2.30	3.99	1.69	42.4
03/12/84	0.33	0.41	0.95	1.69	0.73	43.4
03/20/84	2.10	4.74	1.43	8.27	6.84	82.8
03/21/84	8.15	13.99	10.13	32.27	22.14	68.6
03/27/84	0.52	0.39	1.46	2.37	0.91	38.4
03/28/84	20.49	16.11	16.21	52.81	36.60	69.3
04/03/84	0.82	1.03	3.27	5.12	1.85	36.2
04/18/84	0.25	0.29	0.86	1.40	0.54	38.8
04/23/84	1.74	1.13	2.06	4.93	2.87	58.2
04/27/84	2.39	1.48	6.36	10.24	3.88	37.9
04/30/84	4.02	5.26	5.13	14.40	9.27	64.4
05/01/84	2.11	3.26	2.94	8.31	5.37	64.6
05/02/84	70.16	47.47	35.85	153.48	117.63	76.6
05/04/84	4.99	9.75	7.64	22.39	14.75	65.9
05/07/84	40.00	47.35	11.81	99.16	87.35	88.1
05/09/84	4.91	8.27	8.78	21.96	13.18	60.0
05/24/84	0.14	0.095	0.76	0.995	0.235	23.7
05/31/84	0.18	0.37	0.92	1.47	0.55	37.6
06/15/84[f]	0.00	0.00	0.00	0.00	0.00	--
09/18/84[f]	0.00	0.00	0.00	0.00	0.00	--
09/25/84[f]	0.00	0.00	0.00	0.00	0.00	--
10/02/84[f]	0.00	0.00	0.00	0.00	0.00	--
10/10/84[f]	0.00	0.00	0.00	0.00	0.00	--
10/17/84[f]	0.00	0.00	0.00	0.00	0.00	--
10/24/84	0.62	1.66	3.60	5.88	2.28	38.8
11/15/84	0.13	0.13	0.79	1.05	0.27	25.2
11/21/84	0.49	0.60	1.61	2.70	1.09	40.4
11/30/84	0.61	0.86	1.72	3.19	1.47	46.1
12/07/84	0.36	0.47	0.99	1.83	0.83	45.6
12/13/84	0.17	0.30	0.79	1.26	0.47	37.2
01/03/85	1.61	3.63	3.27	8.51	5.24	61.6
01/10/85	0.34	0.50	1.21	2.05	0.84	40.9
01/16/85	0.15	0.23	0.52	0.90	0.38	42.4
01/25/85	0.07	0.11	0.70	0.88	0.18	20.3
01/30/85	0.09	0.15	0.58	0.82	0.24	29.5

[a]Q(Site A) = discharge from the eastern end of the SWSA 4 surface water diversion.

[b]Q(Site D) = discharge from the western end of the SWSA 4 surface water diversion.

[c]Q(Site J) = discharge from the tributary on SWSA 4.

[d]Q(total) = Q(Site A) + Q(Site D) + Q(Site J).

[e]Q(diverted) = Q(Site A) + Q(Site D).

[f]No flow occurred on these dates, so flow reduction was not possible.

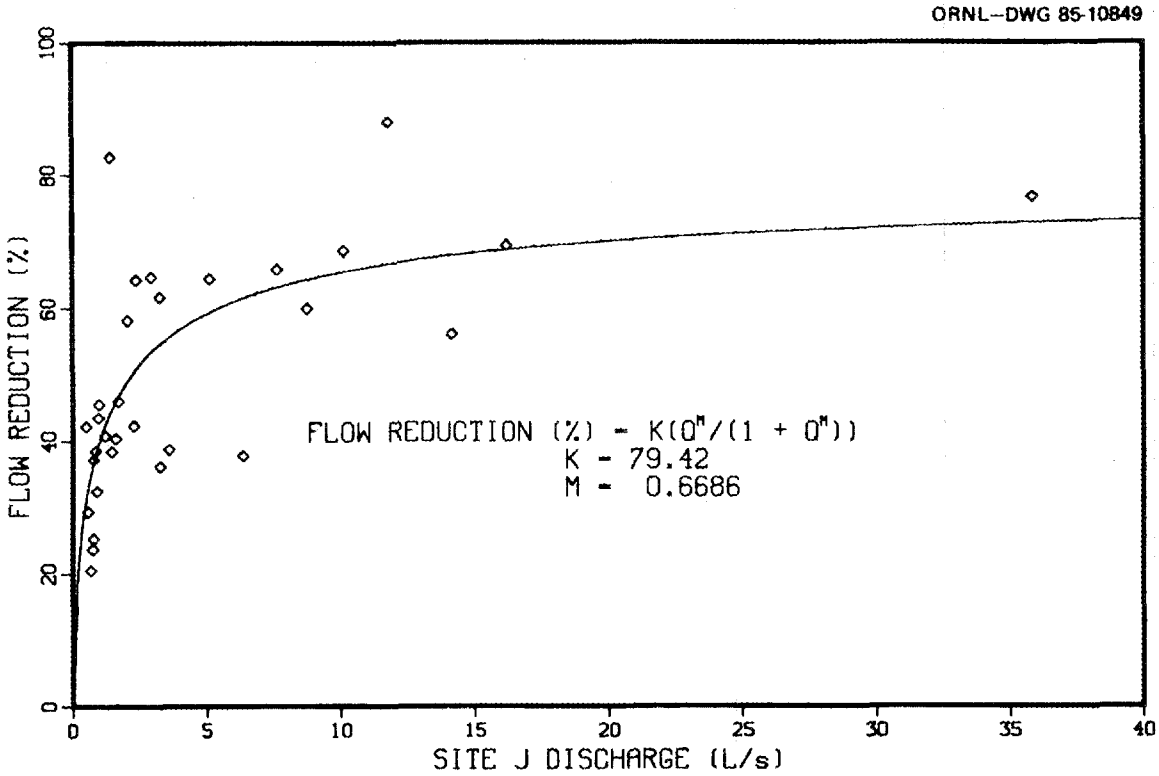

Fig. 8. Comparison between the observed flow reduction and the measured flow at Site J, SWSA 4.

Table 4. Evaluation of the ^{90}Sr flux reduction in the SWSA 4 tributary due to the surface water diversion system at SWSA 4

Date	Concentration (pCi/mL)		Flux (pCi/s)			Percent flux reduction
	C(total)	C(Site J)	F(total)	F(Site J)	F(diverted)	
02/27/84	3.28	5.11	106,000	72,300	33,500	31.6
03/01/84	6.69	8.00	44,700	19,100	25,600	57.3
03/06/84	7.47	8.03	29,800	18,500	11,400	38.1
03/12/84	8.25	8.53	14,000	8,160	5,800	41.5
03/20/84	6.29	8.35	52,000	11,900	40,100	77.1
03/21/84	3.28	5.87	106,000	59,400	46,400	43.8
03/27/84	8.01	8.34	19,000	12,200	6,810	35.8
03/28/84	2.55	4.79	135,000	77,600	57,000	42.3
04/03/84	7.13	7.70	36,500	25,200	11,300	31.0
04/18/84	8.36	8.56	11,700	7,360	4,370	37.3
04/23/84	7.18	8.12	35,400	16,700	18,700	52.8
04/27/84	5.84	6.78	59,800	43,100	16,700	28.0
04/30/84	5.07	7.12	73,000	36,600	36,400	49.9
05/01/84	6.28	7.81	52,200	23,000	29,200	56.0
05/02/84	1.40	3.09	214,000	111,000	103,000	48.3
05/04/84	4.03	6.44	90,300	49,200	41,100	45.5
05/07/84	1.93	5.53	191,000	65,300	126,000	65.8
05/09/84	4.08	6.17	89,600	54,200	35,400	39.5
05/24/84	8.51	8.60	8,490	6,540	1,940	22.9
05/31/84	8.33	8.54	12,300	7,860	4,430	36.1
06/15/84[a]	0.00	0.00	0	0	0	--
09/18/84[a]	0.00	0.00	0	0	0	--
09/25/84[a]	0.00	0.00	0	0	0	--
10/02/84[a]	0.00	0.00	0	0	0	--
10/10/84[a]	0.00	0.00	0	0	0	--
10/17/84[a]	0.00	0.00	0	0	0	--
10/24/84	6.91	7.56	40,600	27,300	13,300	32.7
11/15/84	8.49	8.59	8,940	6,770	2,180	24.3
11/21/84	7.90	8.28	21,300	13,300	7,980	37.5
11/30/84	7.73	8.24	24,700	14,200	10,500	42.5
12/07/84	8.20	8.51	15,000	8,460	6,520	43.5
12/13/84	8.41	8.59	10,600	6,810	3,800	35.8
01/03/85	6.23	7.70	53,000	25,200	27,900	52.5
01/10/85	8.12	8.43	16,600	10,200	6,430	38.6
01/16/85	8.55	8.70	7,720	4,520	3,190	41.4
01/25/85	8.55	8.62	7,570	6,080	1,490	19.7
01/30/85	8.58	8.67	7,070	5,040	2,030	28.7

[a]No flow occurred on these dates, so flux reduction was not possible.

system, concentration values between 3.1 and 8.6 pCi/mL were predicted. Due to the lower average flow rates after construction of the diversion system, higher average concentrations were predicted in the SWSA 4 tributary relative to those prior to the construction of the flow diversion system. The flux of ^{90}Sr at Site J, without diversion, was estimated to be between 0.61 and 18.5 mCi/d. The total flux, with the diversion in place, ranged from 0.39 to 9.6 mCi/d. Thus, the resulting reduction in the ^{90}Sr flux into White Oak Creek ranged from 0.13 to 10.8 mCi/d. The estimated percent of flux reduction ranged from 20 to 77%, with an average reduction of 41%, or 2.1 mCi/d for the specific dates shown. A plot comparing the observed ^{90}Sr flux reduction to the flow at Site J is shown in Fig. 9. Since the data in Fig. 9 show a wide range of variation, no relationship between the flux reduction and the discharge was sought.

Continuous flow monitoring records were kept at Site J starting in October 1983, after completion of the surface water diversion system. To evaluate the long-term effects of the flow diversion system, estimates were made, from the continuous flow records, of what the flow and ^{90}Sr flux would have been without the diversion system. Based on Eqs. (4), (5), (13), and (15), monthly estimates of the flow and ^{90}Sr flux without diversion were made (Table 5). Hourly flow records from Site J were used to determine the flow reduction using Eq. (15). The total flow, without diversion, was estimated using Eq. (16):

$$Q(\text{total}) = Q(\text{Site J})/(1 - \text{flow reduction}) \quad . \qquad (16)$$

Daily flows and monthly totals were then computed from the hourly data. Flux estimates without the effects of the diversion system were made,

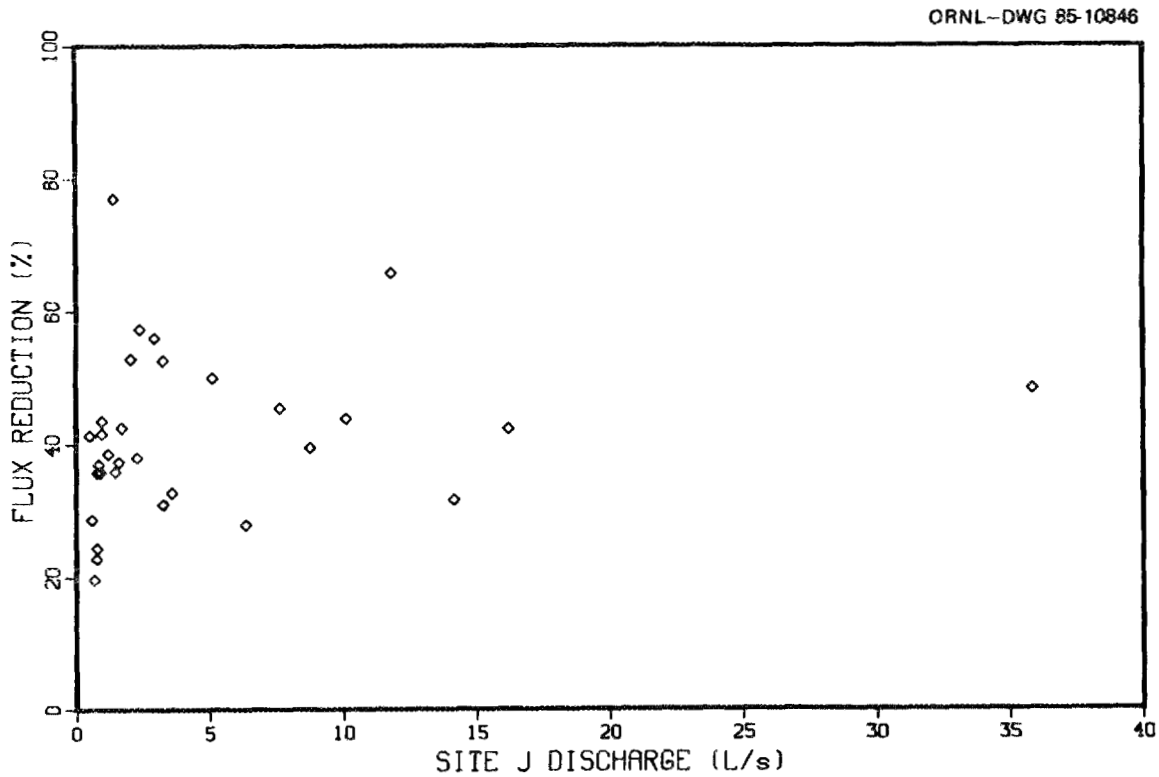

Fig. 9. Relationship between the computed flux reduction and the measured flow at Site J, SWSA 4.

Table 5. Estimates of the monthly ^{90}Sr flux from SWSA 4 before and after construction of the surface water diversion system

		Before diversion		After diversion	
Month	Year	Flow volume (m^3)	^{90}Sr flux (mCi)	Flow volume (m^3)	^{90}Sr flux (mCi)
Nov.	1983	8,230	36.76	3,240	21.15
Dec.	1983	30,100	124.89	11,200	70.03
Jan.	1984	12,600	77.62	5,790	44.00
Feb.	1984	12,400	59.77	5,080	34.70
Mar.	1984	23,000	96.02	8,710	54.30
Apr.	1984	14,100	76.40	6,070	43.22
May	1984	105,000	201.91	28,000	81.84
June	1984	1,960	13.07	1,010	8.08
July	1984	10,300	45.31	4,040	26.36
Aug.	1984	4,800	13.36	1,550	7.31
Sep.	1984	1,510	11.56	806	6.63
Oct.	1984	9,520	26.41	3,030	14.34
Nov.	1984	13,200	66.85	5,560	38.36
Dec.	1984	5,590	44.79	3,200	26.83
Jan.	1985	6,000	42.31	3,150	25.39
Total	(1984)	214,000	733.07	72,800	385.97

using the total flows computed from Eq. (16) and the ^{90}Sr correlation, Eq. (13). A plot showing the total monthly flow without and with surface water diversion is shown in Fig. 10, and a similar plot for ^{90}Sr flux is shown in Fig. 11.

It was estimated that a total flow of 141,000 m^3 was diverted around the burial ground during calendar year 1984, resulting in a flux reduction of 347 mCi. This represents a net flow reduction over the year of 66% and a flux reduction of 47%. The computed flow reduction of 66% derived from the yearly flow records differs significantly from the average reduction of 50% derived from individual observations and from the partial year reduction of 56% as reported by Melroy and Huff (1985). Although the annual values are the best estimate available to date, it is clear that variability will be present from year to year, and a wider range of hydrologic conditions would be desirable.

The total precipitation measured at the Oak Ridge National Weather Service station in 1984 was 169 cm (66.42 in.), whereas the long-term average is 139 cm (54.61 in.) (National Oceanic and Atmospheric Administration 1984). The precipitation in 1984 was somewhat higher than the long-term average, but does not represent an extreme variation. However, although the yearly precipitation was similar to average conditions, unusual events occurred during several periods of the year. Precipitation in May was the maximum recorded since establishment of the station in 1947, and this was offset by near drought conditions in June and September (B. J. Frederick, University of Tennessee; and L. A. Melroy, unpublished data, 1985). Nonetheless, over the annual cycle, the hydrologic conditions studied were representative of the typical range of conditions.

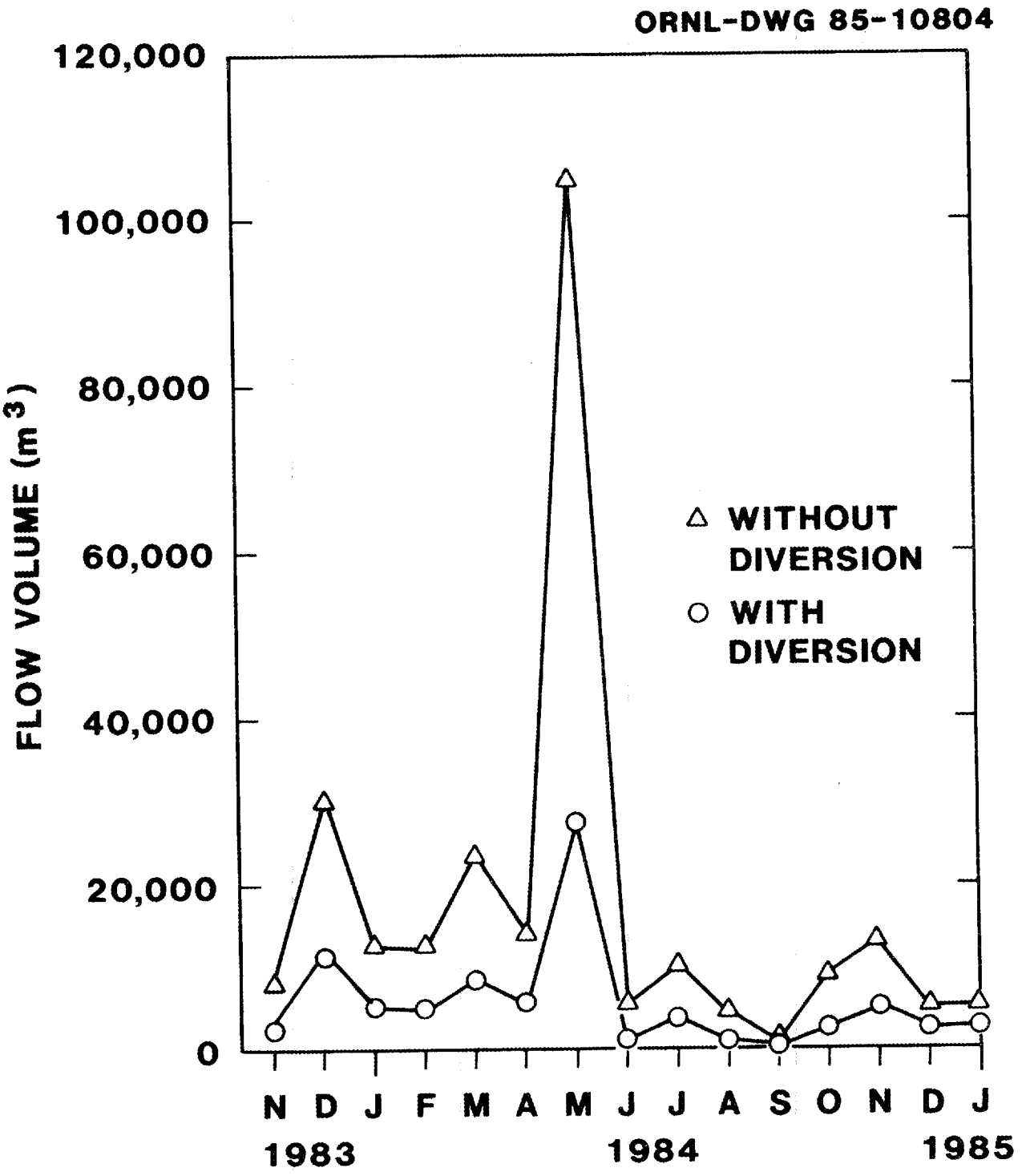

Fig. 10. Comparison of the monthly flow in the SWSA 4 tributary before and after surface water diversion.

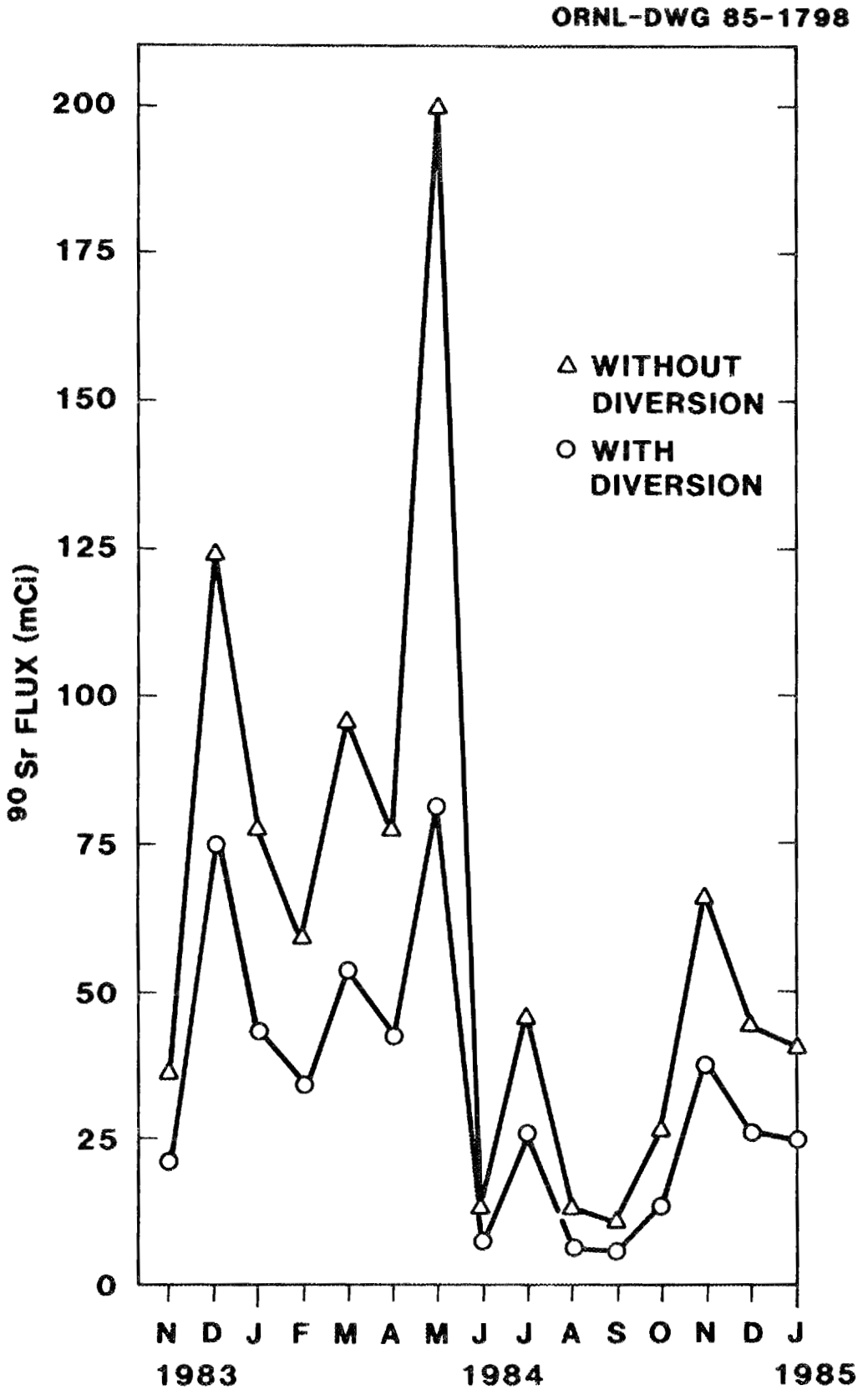

Fig. 11. Comparison of the monthly flux of ^{90}Sr from the SWSA 4 tributary before and after surface water diversion.

A similar length of study period effect is seen with the flux reduction data: an average reduction of 41% was computed from individual field measurements, Melroy and Huff (1985) reported 44% for a partial year, and 47% was computed from the annual continuous flow records. Although these three values are not significantly different, the reduction of 47% computed over a yearly cycle represents the best available estimate of the total effect of the surface diversion system.

The results of the diversion evaluation have shown that a 66% reduction in flow and a 47% reduction in ^{90}Sr flux were attributable to the surface water diversion system constructed at SWSA 4. The diversion system was therefore responsible for a significant decrease in the ^{90}Sr flux migration from SWSA 4 via the SWSA 4 tributary.

In an earlier study by Huff et al. (1982), it was estimated that a reduction of up to 80% in the ^{90}Sr flux from SWSA 4 could be obtained by the diversion of all off-site runoff. Although the results presented here show the earlier prediction was an over estimate, the nearly 50% reduction that was actually achieved clearly demonstrates the value of the surface water diversion project for SWSA 4.

EFFECTS OF SOLID WASTE STORAGE AREA 4 ON WHITE OAK CREEK

BACKGROUND

White Oak Creek and the surrounding watershed are subject to contamination from several other burial grounds and contaminated areas that exist within the watershed. SWSA 4 was reported to be the major nonpoint source of contamination to White Oak Creek by Stueber et al.

(1981), but after the remedial action taken in 1983, a reevaluation of the impact from SWSA 4 and the nearby area was necessary to assess the need for any further remedial actions.

METHODS

^{90}Sr Mass Balance

To evaluate the sources of ^{90}Sr influx to the section of White Oak Creek adjacent to SWSA 4, a mass balance was conducted between Site F and Site M (Fig. 2). The net ^{90}Sr influx to the study reach was determined by subtracting the upstream flux from the downstream flux:

$$F(\text{net input}) = F(\text{Site M}) - F(\text{Site F}) \quad . \tag{17}$$

The ^{90}Sr influx to the study reach of White Oak Creek was monitored at four surface runoff point sources (Sites H, I, J, and K), and the measured surface water influx was determined as follows:

$$F(\text{surface input}) = F(\text{Site H}) + F(\text{Site I}) + F(\text{Site J}) + F(\text{Site K}) \quad . \tag{18}$$

Any difference between the net input of ^{90}Sr and the measured surface influx represents additional nonpoint inputs to White Oak Creek:

$$F(\text{additional inputs}) = F(\text{net input}) - F(\text{surface input}) \quad . \tag{19}$$

The mass balance approach allows the various sources of ^{90}Sr influx to White Oak Creek to be ranked according to their impact on the creek, and any additional significant sources of contamination to be detected.

^{90}Sr Measurement

Water samples (500 mL) were taken at approximately weekly intervals at Sites F, H, I, J, K, and L for ^{90}Sr analysis. Flow measurements were taken concurrent with the water samples to allow calculation of the ^{90}Sr flux from those sites. Note that on White Oak Creek, the water sample was taken at Site L, but for convenience the flow measurement was made downstream at Site M.

The samples were treated with stable strontium carrier, then filtered and acidified. Because of the low concentrations at Sites F, H, K, and L, these samples were concentrated by evaporating the 500-mL volume to a 20-mL volume. The ^{90}Sr analysis was performed using Cerenkov counting, as discussed by Larsen (1981). The results from the ^{90}Sr analyses are shown in Table 6.

Flow Measurement

Flow measurements were taken concurrent with the water samples. At Sites F and M, rated weirs were used to determine the flow rate. The weir at Site F is a trapezoidal weir, and the one at Site M is a dual V-notch weir. The head on the weir was determined from a portable point gage, and the discharge was computed according to the weir ratings:

$$\text{Site F:} \quad Q = 1131.7(R - 0.0245)^{1.5} \quad , \tag{20}$$

$$\text{Site M:} \quad Q = 202.7(R - 0.484)^{2.4} \quad , \tag{21}$$

where

Q = discharge in L/s,

R = point gage reading in feet.

Table 6. Measured ^{90}Sr concentration at six sites on SWSA 4 and White Oak Creek

Date	^{90}Sr concentration (pCi/mL)					
	Site F[a]	Site H[b]	Site I[c]	Site J[d]	Site K[e]	Site L[f]
01/31/84	0.068	0.02	1.92	7.40	0.06	0.12
02/15/84	0.081	0.003	1.86	6.97	0.056	0.15
02/21/84	0.071	0.006	2.03	7.91	0.05	0.12
03/01/84	0.075	0.0004	1.961	8.717	0.063	0.126
03/06/84	0.131	0.003	2.127	11.514	0.061	0.222
03/12/84	0.119	0.003	2.070	8.846	0.059	0.160
03/20/84	0.089	0.003	2.980	14.02	0.053	0.155
03/27/84	0.096	0.004	2.118	9.226	0.068	0.139
04/03/84	0.085	0.0008	2.32	8.941	0.055	0.192
04/18/84	0.103	0.003	2.08	8.83	0.0618	0.139
04/23/84	0.078	0.001	1.92	9.13	0.068	0.134
05/01/84	0.166	0	1.90	7.55	0.047	0.255
05/04/84	0.191	0[g]	1.74	7.70	0.044	0.296
05/09/84	0.263	0	1.67	7.55	0.058	0.322
05/24/84	0.074	0.003	1.48	6.20	0.055	0.176
05/31/84	0.097	0.003	2.05	10.2	0.048	0.150
06/15/84	0.092	0.002	--	--	--	0.099
09/18/84	0.099	0	--	--	--	0.117
09/25/84	0.139	0	--	--	--	0.133
10/02/84	0.140	0	--	--	--	0.136
10/10/84	0.111	0	--	--	--	0.115
10/17/84	0.114	0	--	--	--	0.115
10/24/84	0.473	0	1.88	8.78	0.071	0.599
11/15/84	0.100	0	1.95	9.21	0.065	0.158
11/21/84	0.105	0	1.88	8.96	0.075	0.184
11/30/84	0.110	0	1.79	8.59	0.03	0.16
12/07/84	0.105	0	1.90	9.30	0.065	0.163
12/13/84	0.109	0	1.92	9.30	0.063	0.165
01/03/85	0.088	0.06	1.87	8.66	0.063	0.161
01/10/85	0.153	0.001	1.93	9.41	0.059	0.199
01/16/85	0.101	0.002	1.87	9.27	0.065	0.148
01/25/85	0.596	0.002	1.77	9.03	0.060	0.668
01/30/85	0.550	0.016	1.66	9.12	0.103	0.597

[a]Site F: upstream location on White Oak Creek.
[b]Site H: tributary to White Oak Creek.
[c]Site I: small tributary draining eastern section of SWSA 4.
[d]Site J: SWSA 4 tributary, which drains the greater part of SWSA 4.
[e]Site K: tributary to White Oak Creek.
[f]Site L: downstream location on White Oak Creek.
[g]Value estimated because laboratory sample was lost.
[h]No flow.

The flow at the other sites was determined by bucket gaging, except for an occasional high-flow period when floating chip (area-velocity) measurements were made. The flow measurements are presented in Table 7.

RESULTS AND DISCUSSION

The ^{90}Sr flux was computed for Sites F, H, I, J, K, and L from the measured ^{90}Sr concentrations (Table 6) and the streamflow measurements (Table 7). The results are shown in Table 8. The net input, the surface input, and the additional input of ^{90}Sr flux were also determined (Table 9).

The surface input accounted for 58% of the net input, with the additional input accounting for 42%. In an earlier study by Melroy and Huff (1985), it was reported that surface input accounted for 67% of the net input of ^{90}Sr to White Oak Creek between Sites F and M. However, the data in that study were limited to the period January through June 1984, before the dry summer months when the SWSA 4 tributary goes dry. The results from this report are more representative of the overall annual cycle contribution of the surface water sites.

Of the four surface water sites, Site J was the major contributor of ^{90}Sr flux to the White Oak Creek reach studied, accounting for approximately 85% of the flux from surface water sources. Site I was the second largest source, contributing approximately 14%. The input from the remaining sites was approximately 1% of the total surface water input, and they are therefore not significant sources of

Table 7. Measured streamflow at six sites on SWSA 4 and White Oak Creek

Date	Flow (L/s)					
	Site F[a]	Site H[b]	Site I[c]	Site J[d]	Site K[e]	Site M[f]
01/31/84	234.84	1.57	1.07	1.22	0.26	271.80
02/15/84	467.29	5.37	2.56	3.94	2.68	541.54
02/21/84	216.00	1.49	1.03	1.13	0.26	245.45
03/01/84	338.78	3.30	1.73	2.39	1.30	400.43
03/06/84	284.69	2.73	1.95	2.30	1.04	329.90
03/12/84	208.23	1.31	0.89	0.96	0.28	240.58
03/20/84	241.91	2.39	1.36	1.43	0.75	298.50
03/27/84	264.58	1.75	1.23	1.46	0.44	307.11
04/03/84	335.38	3.35	1.84	3.27	2.32	482.28
04/18/84	216.00	1.26	0.80	0.86	0.31	257.03
04/23/84	339.92	3.84	2.02	2.06	1.43	400.43
05/01/84	307.49	5.07	2.01	2.94	2.14	371.40
05/04/84	999.46	11.73	6.18	7.64	5.44	1180.89
05/09/84	1152.99	9.25	4.51	8.78	3.19	1308.45
05/24/84	205.34	0.89	0.50	0.76	0.11	249.82
05/31/84	203.42	1.24	0.74	0.92	0.24	232.07
06/15/84	200.55	0.38	0.00	0.00	0.00	222.19
09/18/84	179.03	0.53	0.00	0.00	0.00	197.39
09/25/84	133.48	0.31	0.00	0.00	0.00	147.12
10/02/84	142.74	0.37	0.00	0.00	0.00	159.94
10/10/84	146.16	0.69	0.00	0.00	0.00	162.50
10/17/84	203.42	1.14	0.00	0.00	0.00	241.66
10/24/84	355.96	4.41	3.43	3.60	1.07	441.39
11/15/84	199.60	1.47	0.87	0.79	0.09	227.88
11/21/84	240.89	2.84	1.33	1.61	0.26	282.89
11/30/84	247.00	2.77	1.33	1.72	1.16	293.04
12/07/84	214.05	2.43	1.15	0.99	0.79	247.08
12/13/84	171.73	1.48	0.72	0.79	0.47	202.70
01/03/85	394.73	5.45	1.71	3.27	2.97	460.79
01/10/85	217.96	1.80	0.69	1.21	0.64	252.58
01/16/85	165.43	1.20	0.35	0.52	0.24	192.63
01/25/85	151.33	2.64	0.32	0.70	0.28	174.73
01/30/85	160.98	1.21	0.19	0.58	0.22	186.55

[a]Site F: upstream location on White Oak Creek.
[b]Site H: tributary to White Oak Creek.
[c]Site I: small tributary draining eastern section of SWSA 4.
[d]Site J: SWSA 4 tributary, which drains the greater part of SWSA 4.
[e]Site K: tributary to White Oak Creek.
[f]Site M: downstream location on White Oak Creek.

Table 8. Comparison of the ^{90}Sr flux measured at SWSA 4 and White Oak Creek

Date	^{90}Sr flux (pCi/s)					
	Site F[a]	Site H[b]	Site I[c]	Site J[d]	Site K[e]	Site L[f]
01/31/84	16,000	31.3	2,060	9,030	15.5	32,600
02/15/84	37,900	16.1	4,760	27,400	150	81,200
02/21/84	15,300	8.97	2,090	8,940	13.0	29,500
03/01/84	25,400	1.32	3,380	20,800	81.7	50,500
03/06/84	37,300	8.19	4,140	26,500	63.2	73,200
03/12/84	24,800	3.94	1,840	8,460	16.5	38,500
03/20/84	21,500	7.16	4,060	20,000	39.6	46,300
03/27/84	25,400	7.01	2,610	13,500	29.9	42,700
04/03/84	28,500	2.68	4,280	29,200	128	92,600
04/18/84	22,200	3.77	1,670	7,590	19.4	35,700
04/23/84	26,500	3.84	3,890	18,800	97.3	53,700
05/01/84	51,000	0	3,820	22,200	101	94,700
05/04/84	191,000	0	10,800	58,800	239	350,000
05/09/84	303,000	0	7,520	66,300	185	421,000
05/24/84	15,200	2.68	746	4,720	6.01	44,000
05/31/84	19,700	3.72	1,520	9,380	11.5	34,800
06/15/84	18,500	0.75	0	0	0	22,000
09/18/84	17,700	0	0	0	0	23,100
09/25/84	18,600	0	0	0	0	19,600
10/02/84	20,000	0	0	0	0	21,800
10/10/84	16,200	0	0	0	0	18,700
10/17/84	23,200	0	0	0	0	27,800
10/24/84	168,000	0	6,450	31,600	75.6	264,000
11/15/84	20,000	0	1,700	7,250	6.1	36,000
11/21/84	25,300	0	2,510	14,400	19.8	52,100
11/30/84	27,200	0	2,390	14,800	34.9	46,900
12/07/84	22,500	0	2,180	9,240	51.6	40,300
12/13/84	18,700	0	1,380	7,380	29.4	33,400
01/03/85	34,700	327	3,190	28,300	187	74,200
01/10/85	33,300	1.80	1,330	11,400	37.7	50,300
01/16/85	16,700	2.40	654	4,820	15.8	28,500
01/25/85	90,200	5.28	574	6,360	16.7	117,000
01/30/85	88,500	19.3	312	5,300	22.6	111,000

[a]Site F: upstream location on White Oak Creek.
[b]Site H: tributary to White Oak Creek.
[c]Site I: small tributary draining eastern section of SWSA 4.
[d]Site J: SWSA 4 tributary, which drains the greater part of SWSA 4.
[e]Site K: tributary to White Oak Creek.
[f]Site L: downstream location on White Oak Creek.

Table 9. Evaluation of the source of ^{90}Sr influx to White Oak Creek

Date	Flux (pCi/s)			Surface input as a percent of the net input
	Net input[a]	Surface input[b]	Additional input[c]	
01/31/84	16,700	11,100	5,550	66.7
02/15/84	43,400	32,400	11,000	74.6
02/21/84	14,100	11,100	3,070	78.2
03/01/84	25,000	24,300	764	96.9
03/06/84	35,900	30,700	5,260	85.4
03/12/84	13,700	10,300	3,380	75.3
03/20/84	24,700	24,100	650	97.4
03/27/84	17,300	16,100	1,150	93.5
04/03/84	64,100	33,600	30,500	52.5
04/18/84	13,500	9,280	4,200	68.9
04/23/84	27,100	22,800	4,350	84.0
05/01/84	43,700	26,100	17,500	59.8
05/04/84	159,000	69,800	88,800	44.0
05/09/84	118,000	74,000	44,100	62.7
05/24/84	28,800	5,470	23,300	19.0
05/31/84	15,100	10,900	4,160	72.4
06/15/84	3,550	0.76	3,550	0.0
09/18/84	5,370	0	5,370	0.0
09/25/84	1,010	0	1,010	0.0
10/02/84	1,770	0	1,770	0.0
10/10/84	2,460	0	2,460	0.0
10/17/84	4,600	0	4,600	0.0
10/24/84	96,000	38,100	5,790	39.7
11/15/84	16,000	8,960	7,080	55.9
11/21/84	26,800	16,900	9,830	63.3
11/30/84	19,700	17,200	2,520	87.2
12/07/84	17,800	11,500	6,330	64.5
12/13/84	14,700	8,790	5,940	59.7
01/03/85	39,500	32,000	7,440	81.1
01/10/85	16,900	12,800	4,150	75.4
01/16/85	11,800	5,500	6,310	46.6
01/25/85	26,500	6,961	19,600	26.2
01/30/85	22,800	5,650	17,200	24.8

[a]Net input = difference between the upstream and downstream ^{90}Sr flux on White Oak Creek.

[b]Surface input = combined influx of ^{90}Sr from four surface runoff point sources.

[c]Additional input = net input minus surface input.

contamination to White Oak Creek. Figure 12 presents a bar chart showing the net input of ^{90}Sr to the White Oak Creek reach studied and the major known influxes.

The surface inputs accounted for 58% of the net input. Several possible sources may account for the remaining 42% of ^{90}Sr influx, such as groundwater input or contamination from the floodplain areas, but it may also arise from measurement insensitivity in determining the ^{90}Sr flux. In order to determine whether this 42% was due to additional ^{90}Sr sources, statistical analysis was used to determine if the net input to White Oak Creek was statistically different from the measured surface input. If the results of the analysis indicated a significant difference between the net input and the surface input, this would strongly suggest that additional ^{90}Sr sources exist.

A Student's t-test (Table 10) was conducted on the flux data. The t-test compared the net input of ^{90}Sr and the surface input and found that they were significantly different. This difference provides strong evidence that another source of ^{90}Sr exists, but it is not conclusive. Several possible sources of additional contamination exist, including groundwater input from SWSA 4 and the adjacent contaminated floodplain.

CONCLUSIONS AND SUMMARY

The surface water diversion system has caused a significant reduction in the ^{90}Sr flux from the SWSA 4 tributary and represents a major advance toward site stabilization, even though SWSA 4 is still an important source of contamination to White Oak Creek. During the study

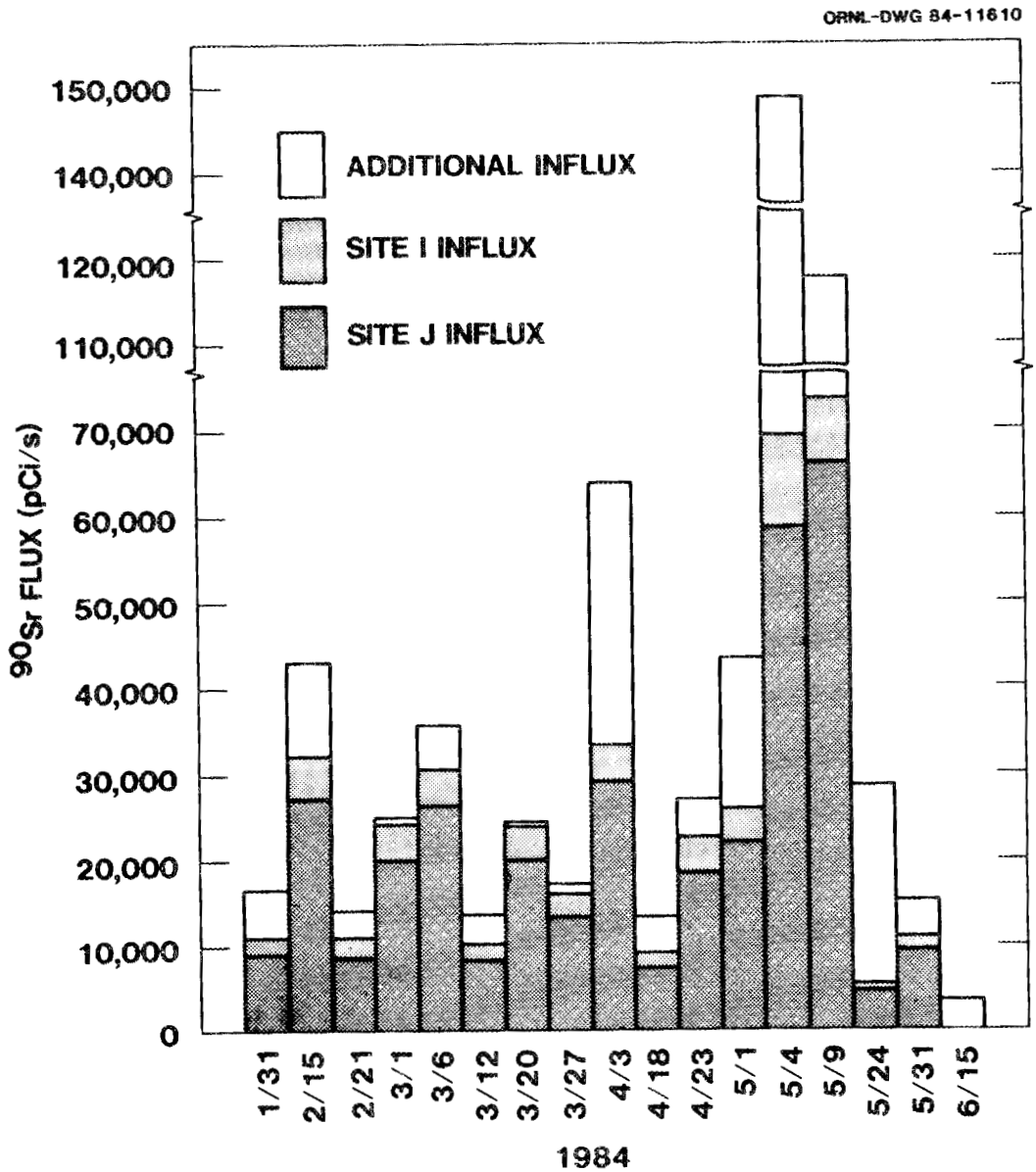

Fig. 12. Measured ^{90}Sr influxes to White Oak Creek from SWSA 4 and the nearby area.

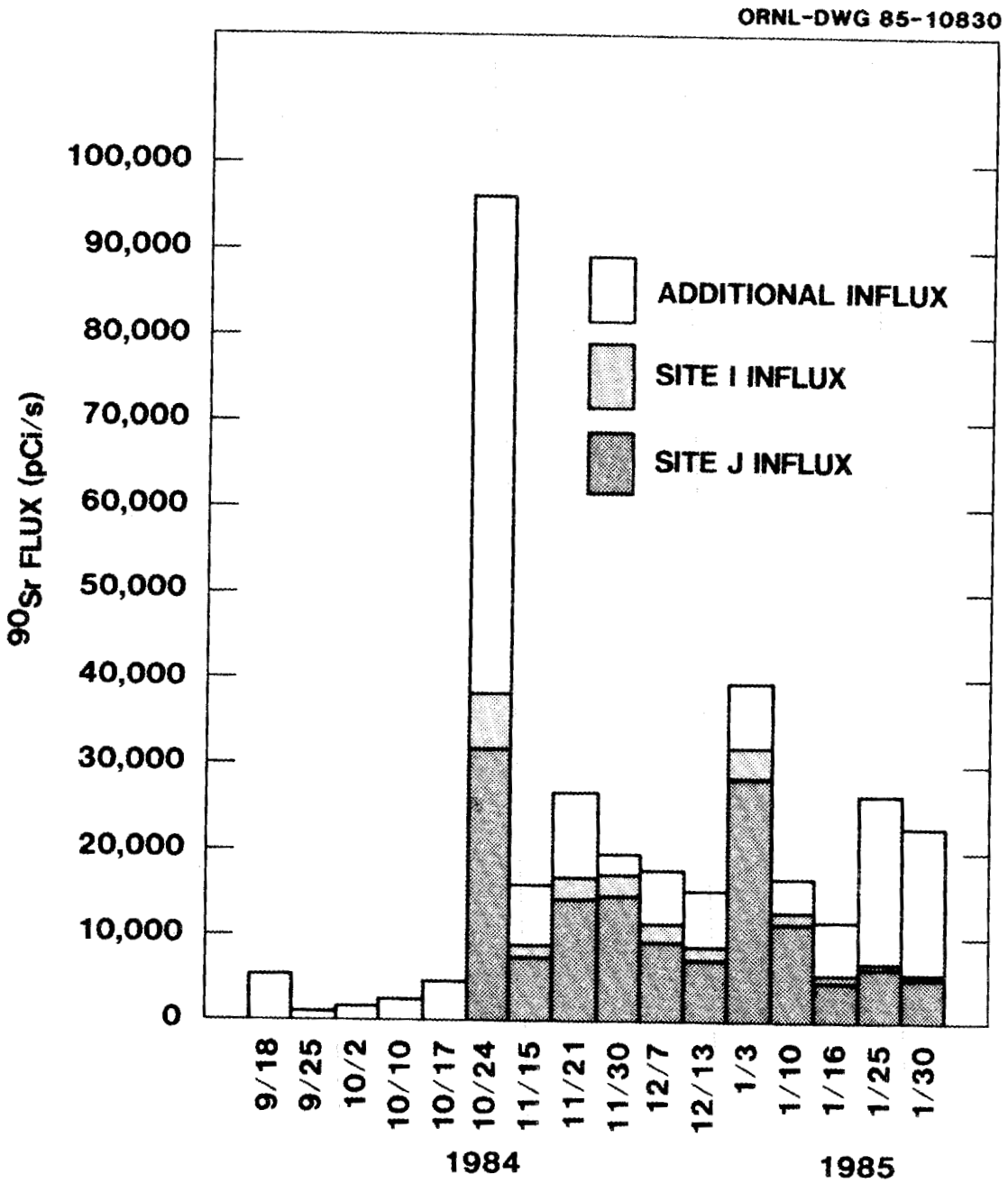

Fig. 12. Continued.

Table 10. Statistical analysis of ^{90}Sr flux data using a Student's t-test

Variable	Symbol	Value
Mean	m	12,447
Standard deviation	s	18,707
Number of data	n	33
Level of significance	-	95%
Degrees of freedom	-	32
Student's t-test value	t	3.764
Student's t-statistic (single-tailed test)		1.710

[a]Student's t-test value is computed as follows: $t = m/(s^2/n)^{0.5}$.

period, the major source of ^{90}Sr contamination to the adjacent reach of White Oak Creek came from SWSA 4, with Sites I and J contributing 50% and 8% of the flux, respectively. The statistical analysis of the data suggests that the remaining 42% may be attributable to additional ^{90}Sr sources, but the evidence is not conclusive.

Since some ^{90}Sr migration from SWSA 4 is still occurring, further work toward site stabilization is needed. Quantification of groundwater movement and ^{90}Sr migration in and around the burial ground is needed before more corrective action can be taken. Several seeps have already been identified at SWSA 4 (Huff et al. 1982), and groundwater movement near these seeps should be characterized so appropriate control measures can be designed.

Evaluation of the SWSA 4 surface water diversion system over an annual cycle has shown that control of surface runoff is an important factor in managing ^{90}Sr migration from SWSA 4. The runoff from 56% of the watershed has been diverted around the contaminated areas. During 1984, approximately 141,100 m^3, or 66%, of the runoff was diverted around the burial ground, resulting in a 47% reduction in the flux from the SWSA 4 tributary to White Oak Creek. Therefore, although groundwater is often considered the major solute transport mechanism, the surface water diversion system at SWSA 4 has shown that surface runoff can also contribute significantly to solute migration from shallow land disposal sites.

REFERENCES

Huff, D. D., N. D. Farrow, and J. R. Jones. 1982. Hydrologic factors and ^{90}Sr transport: A case study. Environmental Geology 4: 53-63.

Larsen, I. L. 1981. Strontium-90 determinations by Cerenkov radiation counting for well monitoring at Oak Ridge National laboratory. ORNL/TM-7760. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Melroy, L. A. and D. D. Huff. 1985. Evaluation of a flow diversion system for reducing ^{90}Sr migration from SWSA 4 to White Oak Creek. ORNL/TM-9374. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

National Oceanic and Atmospheric Administration. 1984. Local climatological data monthly summary, January-December 1984. National Climatic Data Center, Asheville, North Carolina.

Replogle, J. A. 1975. Critical-flow flumes with complex cross section. pp. 366-388. IN Proceedings, A.S.C.E. Irrigation and Drainage Division Specialty Conference, August 13-15. American Society of Civil Engineers, New York.

Steuber, A. M., D. D. Huff, N. D. Farrow, J. R. Jones and I. L. Munro. 1981. An evaluation of some ^{90}Sr sources in the White Oak Creek drainage basin. ORNL/TM-7290. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Tennessee Valley Authority (TVA). 1951. Sediment investigation, White Oak Creek and Lake, Roane County, Tennessee. pp. 1-4. IN Hydraulic Data Branch Report. Tennessee Valley Authority, Knoxville, Tennessee.

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