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Environmental Radiological Studies Conducted During 1986 in the Vicinity of the Rancho Seco Nuclear Power Generating Station

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DISCLAIMER

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ABSTRACT

This report summarizes the information compiled in 1986 for our assessment of the environmental impact of radionuclides discharged with aqueous releases from the Rancho Seco Nuclear Power Generating Plant. In October 1984, a liquid-effluent control program was initiated that significantly reduced the quantities of radionuclides discharged with liquid waste from the plant. However, results from our sampling program in 1986 indicate that previously discharged radionuclides persist in the downstream environment and are found in many aquatic dietary components although at concentrations much lower than those measured in 1984 and 1985. The greatly reduced activities in the dietary components from the aquatic environment attest to the effectiveness of the liquid-effluent control program. Concentrations in the flesh of fish from the creeks have decreased over time and with distance from the plant outfall. These changes in concentrations can be described by exponential equations, the coefficients of which are obtained from a least-squares analysis of the data. The mean concentration of ^{137}Cs in fish collected from Laguna Creek at locations more than 7.5 km from Rancho Seco is now comparable to the concentration determined in fresh-water fish randomly selected from Chicago, Illinois, markets. By August 1986, the mean concentration of ^{137}Cs in the flesh of bluegill had fallen to 7% of the concentration measured in fish from comparable locations in 1984 and was 30% of the mean concentration measured in these fish during August 1985. Stable potassium in the water plays a major role in the accumulation of ^{137}Cs by fish. Concentrations of ^{137}Cs in the surface sections of creek sediments also declined between the end of 1984 and 1986 with an effective half-life of approximately 2 y. Surface soils collected around a perimeter 11 km from Rancho Seco and from ranchlands closer to the plant showed only concentrations of ^{137}Cs originating from global fallout. Soils previously irrigated with Clay Creek water retain levels of both ^{134}Cs and ^{137}Cs.

INTRODUCTION

The Rancho Seco Nuclear Power Generating Station, operated by the Sacramento Municipal Utility District (SMUD), is located in Sacramento County near the town of Clay, California.

Steam-generator leaks, which occurred at the plant in May 1981, November 1982, September 1983, and July 1984, contributed low-level quantities of some fission and activation products to plant wastewaters. These wastewaters were collected in holding tanks located on the site. The type and quantity of radionuclides in the liquid waste contained in each holdup tank were determined by SMUD prior to release of the material to on-site retention basins.

Periodically the contents of the basins, or fractions of the contents, were diluted and discharged to Clay Creek. The water in this creek flows to the site boundary fence, 0.5 km fron the point of discharge, and continues until it intersects Hadselville Creek, 3.0 km downstream from the plant. Water from Hadselville Creek intersects Laguna Creek 6.5 km downstream from the plant. Laguna Creek water drains into the Cosumnes River at a point near Twin Cities Road between Interstate Highway 5 and State Highway 99.

In October 1984, a liquid-effluent control program was initiated by the District; it has significantly reduced the quantities of radionuclides discharged with liquid wastes from the plant. Releases of ^{137}Cs and ^{134}Cs (the two radionuclides contributing the major fraction of the estimated dose to individuals) decreased from 1984 measured values of 300 mCi and 150 mCi, respectively, to 4 mCi and 2.5 mCi in 1985, and to less than 1 mCi total ^{137}Cs and ^{134}Cs during the first half of 1986 (1).

In the spring of 1984, we initiated a scientific program to obtain site-specific analytical information about the concentrations and fate of the gamma-emitting radionuclides discharged with liquid wastes from Rancho Seco. A major priority for off-site dose assessments was to determine the levels of radionuclides, in particular ^{134}Cs and ^{137}Cs, associated with the edible parts of organisms in the aquatic food pathway to man.

As the study progressed, we were requested to expand the program to provide a variety of other radiological information that could be used by SMUD to estimate doses from other pathways to provide reasonable assurance to the

local population, governmental agencies, and other interested parties that no individual will receive an annual dose to the whole body from previously discharged radioactivity that exceeds the EPA guideline of 25 mrem.

The results from the scientific studies conducted during 1984 and 1985 are summarized in previously published reports (2,3,4,5,6,7).

No previous studies adequately address the contamination of food products or the biological availability of radiocesium when components in stream-bed sediments, rather than stream water, are the source of radionuclides. Because radionuclides associate with sediments, there is a sedimentary source term in the aquatic environment downstream from Rancho Seco. Consequently, one major objective in 1986 was to determine the rate at which the ^{137}Cs and ^{134}Cs concentrations change in fish and other organisms; this determination will permit reasonable estimates of radiological dose from the consumption of any aquatic food product to continue to be made.

Additional downstream sampling stations were added in 1985 and 1986 to better define relationships between differences in concentrations in fish (and other environmental samples) with time and downstream distance. The analytical results generated from the environmental samples collected during 1986 are presented in this report. Some of the studies are continuations of efforts initiated in 1984, while others developed from recommendations (5,6) made after an assessment of our results from the first two years of effort.

SAMPLE COLLECTION, PROCESSING, AND ANALYSIS

General Comments

Table 1 shows a comparison of the types and number of samples collected for analysis during 1984, 1985 and 1986. The total number of samples collected in 1986 for processing and analysis represents a 77% increase over the number collected in 1985 and a 170% increase over the number of samples collected in 1984. This increased effort in 1986 was necessary for several reasons. Four additional fish collection sites were added to the program to provide additional data that would fill the information gaps noted in our 1985 data base. We also made an increased effort to collect and analyze frogs, crayfish, and water hyacinth from downstream locations. A further reason we

Table 1. Types of environmental samples collected and analyzed for gamma-emitting radionuclides in 1986 compared to those collected in 1985 and 1984.

Sample type	No. of samples collected 1986	No. of samples collected 1985	No. of samples collected 1984
Fish			
Bluegill	638	375	190
Bass	206	144	114
Catfish	155	182	23
Other	6	0	8
Other aquatic samples			
Frog	169	88	0
Crayfish	159	48	2
Water hyacinth	39	10	0
Stream sediment	90	53	224
Stream water for radionuclides	42	46	18
Stream water for stable K	35	4	0
Duck	0	0	4
Terrestrial samples			
Cattle	1	5	1
Pasture grass	8	2	5
Silage	3	1	2
Soil	38	12	10
Well water	2	20	0
Honey	2	1	1
Blackberries	3	0	2
Milk	0	0	2
Corn	0	0	2
TOTAL	1634	987	608

increased the number of samples was a direct result of the lower concentrations now found in fish and other organisms; lower concentrations require a larger sample size for reliable analysis.

Locations of the sampling stations referred to in this and past reports are shown in Fig. 1. In August, we were asked to sample soil and grass from the ranch of Mr. R. Gudgel. The location of the ranch is shown in Fig. 1. Figure 2 is an enlarged plot of the sections of the ranchland showing the locations sampled. Data for the soil and grass from the different ranch sections are provided in Appendix VIII. Detailed discussions of the collection methods, sample processing, and analysis can be found in previously published reports (3,4,5,6). Abbreviated versions of these discussions follow.

Aquatic Organism Sampling and Processing

Fish collections were made using fishing gear with either bait or artificial lures. This method was adopted over other authorized fishing methods, or methods such as chemical immobilization or electric shock, because it best mimicked the method used by local fishermen. Thus, the fish sampled would be more representative of the species normally caught from the creeks for consumption. A total of 1005 fish were collected for analyses from 12 downstream locations in 1986. Of this total, there were 638 bluegill, 206 bass, and 155 catfish. The land- and aquatic-use survey (2) indicated that bluegill, bass, and catfish were the species normally caught for consumption by the local residents. This fact justified the choice of the fish sampled for analysis.

Crayfish were captured in commercial traps using cat food for bait. Frogs were speared at night from downstream locations on the creeks. We are indebted to Mr. Roy Marciel of the staff at Rancho Seco for assisting with the frog collections.

Samples were kept on ice and returned to Lawrence Livermore National Laboratory (LLNL), where the organisms were frozen until processed. The standard length, sex, and fresh whole-body weight of each fish were recorded, and the fish were dissected to separate the edible flesh for analysis. The flesh from fish of the same species that were collected from the same sampling site were sometimes pooled for analysis. The judgment to analyze single or pooled samples of fish was based on anticipated concentrations at the sampling

Figure 1. Location of sampling stations.

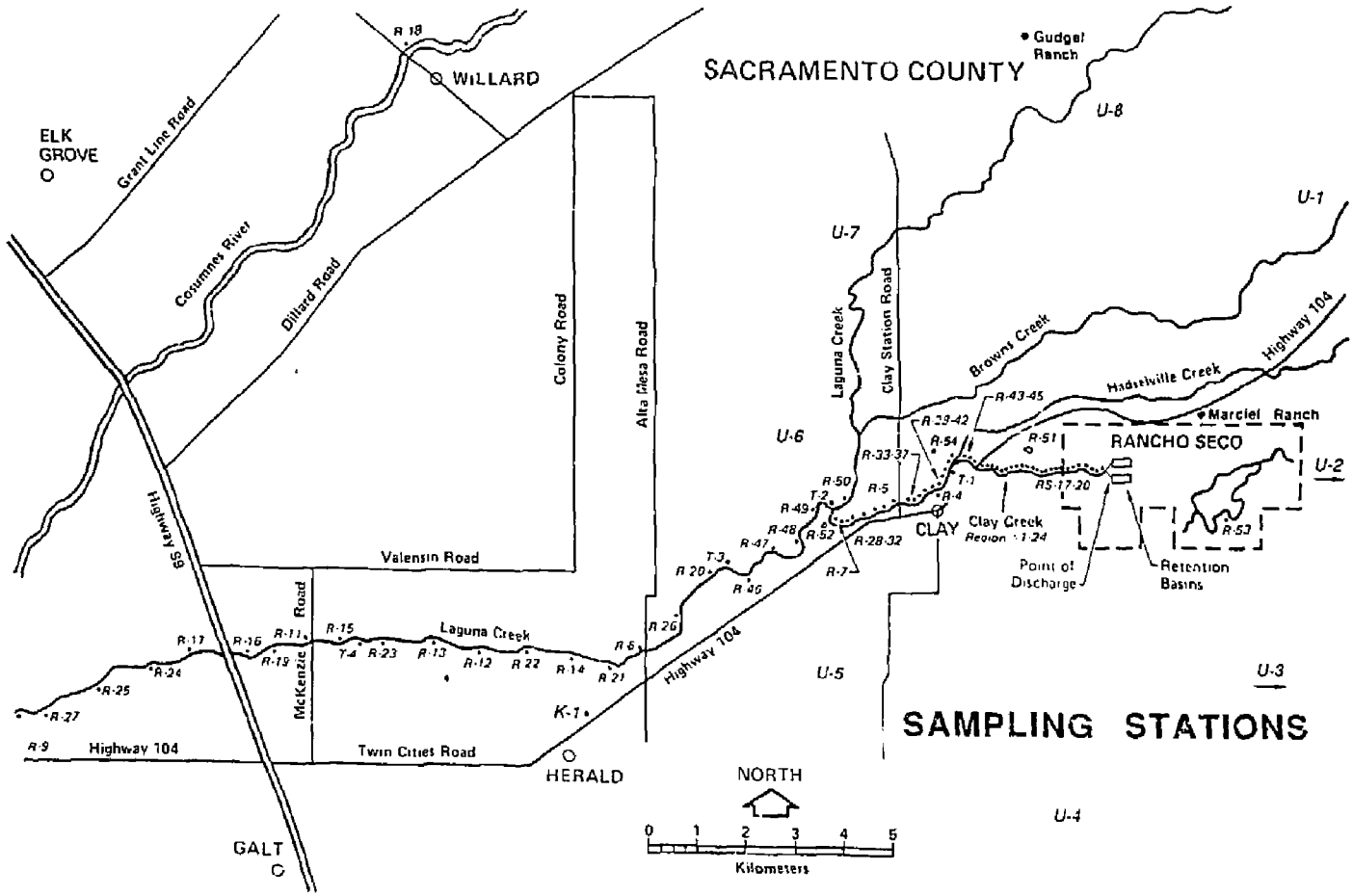
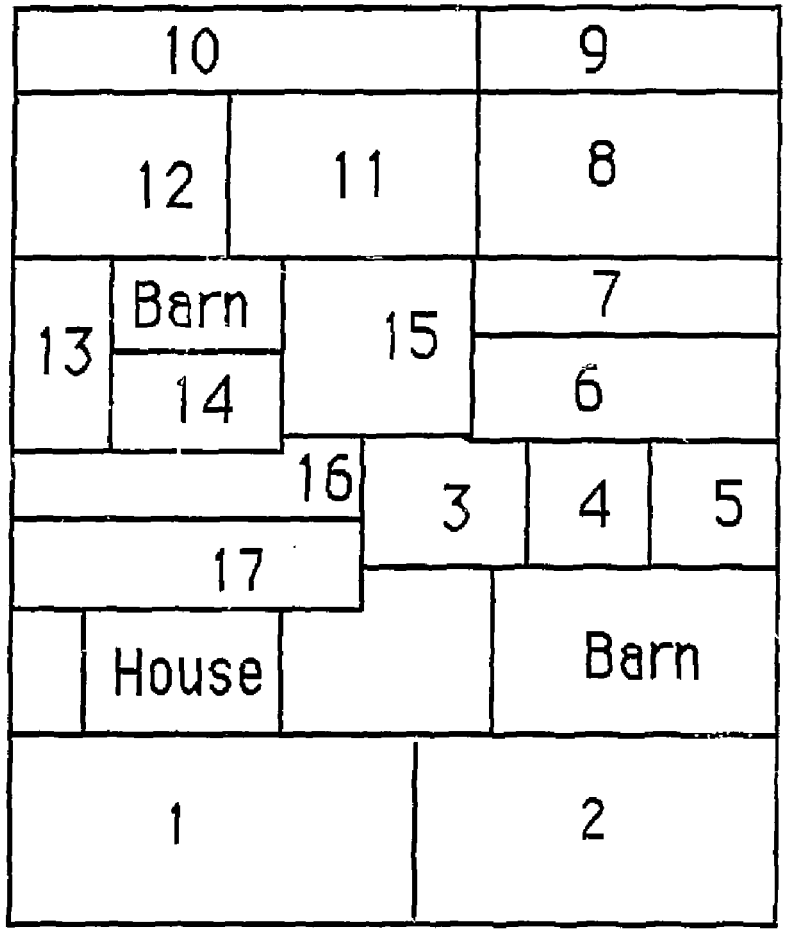

SACRAMENTO COUNTY
ELK GROVE
WILLARD
GALT
HERALD
CLAY
RANCHO SECO
Gudgel Ranch
Marciel Ranch
Grant Line Road
Cosumnes River
Dillard Road
Colony Road
Alta Mesa Road
Clay Station Road
Laguna Creek
Browns Creek
Hadselville Creek
Highway 104
Highway 99
Valensin Road
McKenzie Road
Twin Cities Road
Clay Creek
Point of Discharge
Retention Basins
U-1
U-2
U-3
U-4
U-5
U-6
U-7
U-8
K-1
R 18
R 20
R 26
R-1
R-2
R-3
R-4
R-5
R-6
R-7
R-9
R-11
R-12
R-13
R-14
R-15
R-16
R-17
R-19
R-21
R-22
R-23
R-24
R-25
R-27
R-28-32
R-33-37
R-39-42
R-43-45
R-46
R-47
R-48
R-49
R-50
R-51
R-52
R-53
R-54
T-1
T-2
T-3
T-4
RS-17-20
SAMPLING STATIONS
NORTH
0 1 2 3 4 5
Kilometers

Figure 2. Location of plots sampled at the Gudgel Ranch.


10
9
12
11
8
13
Barn
14
15
7
6
16
3
4
5
17
House
Barn
1
2

sites. Frog legs were separated from the body, skinned, and deboned to provide samples of edible flesh; the flesh from small frogs was often pooled for analysis. The edible portion of the crayfish was separated from several individuals and pooled for analysis. Each sample was dried in an oven at 90°C to constant weight, homogenized, and transferred to aluminum or plastic containers for analysis by gamma spectrometry. Material with low levels of activity was often ashed to produce a more condensed sample having a better geometry for counting by gamma spectrometry.

Sampling and processing the terrestrial animal and vegetation samples have been previously described (5).

Sediment and Soil Sampling

The same devices used to collect sediment and soil samples in 1984 and 1985 were used to obtain samples in 1986. Sediment to a depth of 12 cm was collected from the creeks using a stainless steel hand corer; the entire 12-cm section was dried, sieved (to remove large rocks), ball-milled, and analyzed as a single sample.

Water Sampling and Processing

Fifty-liter water samples were usually obtained at stations in conjunction with the fish collections. The water was pumped through 1-μm (pore size) cartridge filters into 15-gal polyethylene containers, acidified and returned to LLNL for processing. Cesium isotopes were first concentrated on ammonium molybdophosphate (AMP); the AMP was separated from the water by filtration; and the cesium was then separated from the AMP and prepared as solid samples for analysis on Ge(Li) detectors. The 1-μm filters containing the particulate material were ashed at 450°C, and concentrations of radionuclides in the particulate material were determined by gamma spectrometry.

Unfiltered ground water was sampled for analysis from domestic fresh-water wells located in the vicinity of Rancho Seco. Fifty-liter samples were obtained at each of the locations. The samples were processed as described above for ^{134}Cs and ^{137}Cs. Tritium measurements were made on aliquots from the same samples.

Gamma-Spectrometry Analysis and Data Reduction

Gamma-spectrometry measurements were made on all samples at LLNL using a variety of Ge(Li)-diode detector systems. Counting times were usually 1000 min or longer for each sample. A general purpose computer program, called GAMANAL (8), was used for the data reduction of all gamma-ray spectra. In GAMANAL, the observed photopeak in the measured spectra is compared to that in a library of photopeaks of gamma-ray fission and activation products and naturally occurring radionuclides to identify the radionuclides in the sample. All radionuclides routinely released to the waterway from the plant are included in the library. The program then applies correction factors for sample size, density, counting time, counting geometry, and decay to convert the measured counting rate to pCi/g of sample on the reference date sampled. The program also generates an upper-limit amount of specific radionuclides based on those spectral regions where signals would be seen if the radionuclide were present in detectable quantities. Our mean minimal detectable concentrations (based on a counting time of 1000 min) for each of the principal longer-lived gamma-emitting radionuclides previously discharged to Clay Creek are shown in Table 2. These value. are the averages for the different sample configurations (geometries) and are independent of sample weight. Samples prepared for analysis ranged in weight from a fraction of a gram for dry stomach contents of fish to over 300 g for dry soil. Detection limits on a per gram basis are, therefore, different for samples of different weights.

Data quality has always been an important aspect of our analytical measurements. As a standard practice, 5 to 10% of our time is devoted to quality-assurance work in all projects involving analytical measurements. This quality-assurance work includes:

- Analysis of background samples and blanks.
- Instrument calibration.
- Duplicate sampling and analysis.
- National and international interlaboratory standardization.
- Replicate measurements.
- Analysis and calibration traceable to National Bureau of Standards (NBS) samples.
- Appropriate statistical analysis of the results.

Table 2. Mean detection limits of selected gamma-emitting radionuclides released in liquid effluents from Rancho Seco (pCi/sample).[a]

	Radionuclide							
	^{58}Co	^{60}Co	^{54}Mn	^{110m}Ag	^{137}Cs	^{134}Cs	^{125}Sb	^{131}I
Detection limit (pCi/sample)	1	1	1	1	1	1	3	2

[a] Based on a counting time of 1000 min; prior to decay correction.

RESULTS AND DISCUSSION

All of the individual sample results for 1986 appear in a separate volume of this report, UCID-20963 Part II (Appendices).

Aquatic Organisms

The concentrations of the radionuclides measured in the muscle tissue of the fish from the different stations are given in Appendix I. All results have been decay corrected to the date of collection. The data in the Appendix are arranged to show concentrations in the samples of fish according to the time sampled and according to increasing distance downstream from Rancho Seco. The concentrations are listed relative to fresh wet weight, but the dry/wet weight ratios provided may be applied to convert concentrations to a dry-weight basis. Other than ^{134}Cs and ^{137}Cs, no gamma-emitting radionuclides from plant discharges were above detection limits in the flesh of the fish. Concentrations of natural ^{40}K in the flesh of fish are also provided in the tables.

The weighted mean concentration for both ^{134}Cs and ^{137}Cs in the flesh of fish during the month collected is computed using Equation (1). First, the sum of the products of the concentration (C_i), the number of fish in the sample (n_i), and the whole-body fresh weight (w_i) is determined. This sum is divided by the sum of the products of the whole-body fresh weight and the number of fish in the respective sample.

$$C\ (pCi/g\ wet) = \Sigma C_i w_i n_i \ /\ \Sigma w_i n_i \qquad (1)$$

Our sampling locations were selected to enable us to examine the difference in the ^{137}Cs (and ^{134}Cs) concentrations in flesh as a function of the distance downstream and as a function of time. Mean concentrations of ^{137}Cs and ^{134}Cs in the flesh of bluegill, bass, and catfish collected at downstream stations during 1984, 1985, and 1986 are shown in Tables 3 to 5. Reading across these tables from left to right shows the change in the concentration of ^{137}Cs and ^{134}Cs in the flesh of fish with distance downstream

from Rancho Seco. Reading the tables from top to bottom shows the trend for the change in concentration at each sampling station with time.

Data from the preceding tables were used to construct Figs. 3 to 7, which show the change in concentration with time for ^{137}Cs in the flesh of the bluegill, bass, and catfish caught at 5 downstream stations. The stations are located on the creeks between 0.5 and 12.6 km downstream from Rancho Seco. In general, the mean concentration in the fish from all downstream stations began to decrease in early 1985 a few months after the effluent control program was initiated at Rancho Seco.

Figure 8 shows the change over time since 1985 in the natural log of the $^{134}Cs/^{137}Cs$ activity ratio measured in fish from stations RS-17 and T-1 (shown plotted on days since January 1, 1984). The ^{134}Cs has been decreasing and now has an effective half life of 2.0 y; this is essentially the radiological half-life of ^{134}Cs (2.06 y). No new ^{134}Cs has been generated at the plant since the reactor was shut down for maintenance. In 1986, the mean activity ratio in aquatic samples was 0.25.

Figures 9 and 10 show the change in concentration of ^{137}Cs in the flesh of bluegill collected downstream for 1985 and 1986. The regression lines in the figures result from a least-squares analysis of the concentrations measured at the downstream stations during the first and final sampling period of each year. By October 1986, the mean concentration in bluegill flesh decreased by half every 2.3 km downstream from the plant. Between March 1985 and October 1986, the concentration decreased at each station, with a mean effective half-life of approximately 170 d.

Changes in the mean concentration of ^{137}Cs in the flesh of bass and catfish during 1985 and 1986 were not as uniform as the changes noted in bluegill (Tables 3 to 5). For example, the mean concentrations of ^{137}Cs and ^{134}Cs in bass caught at stations T-1, R-5, and T-2 during certain months in 1986 were higher than those in fish caught during preceding months (see Table 4). Figure 11 shows the concentrations measured in the flesh of bass caught at downstream stations during July 1985 and September 1986. Reasonably good correlations were found for the regression lines developed from the data. The concentrations in fish caught nearest the plant changed only slightly between the sampling dates, while more significant differences are noted between the average concentrations in fish from greater downstream distance.

Table 3. Mean concentration of ^{137}Cs and ^{134}Cs in flesh of bluegill caught at different downstream stations from 1984 to 1986. ("<dl" means less than detection limits.)

	Station ID and downstream distance (km)										
Date sampled	RS-17 0.5	RS-30 0.5	RS-15 1.5	T-1 3.0	R-5 4.6	T-2 7.5	T-3 10.2	R-8 12.6	R-22 15.4	T-4 17.2	R-11 19.5
					^{137}Cs (pCi/g wet wt)						
4/26/84	11.10										
5/18/84	10.40	5.60									
7/18/84	8.90				5.80			0.57			0.15
8/14/84	13.10				4.50			0.54			0.10
10/18/84	15.20				3.10			0.43			
2/7/85											
3/19/85	9.30	5.41		4.60	2.60	0.97	0.36	0.18		0.14	0.08
4/26/85	4.10			5.20	4.70	0.84	0.33	0.18		0.10	0.05
5/23/85	6.10			2.70	2.50	0.58	0.18	0.18		0.08	0.06
7/11/85	5.20			2.40	2.20	0.32	0.22	0.11		0.07	<dl
8/30/85	2.70			2.40	1.04	0.27	0.20	0.10		0.05	<dl
10/16/85	2.20			1.40	1.70	0.33	0.15	0.09		0.05	<dl
4/8/86		1.03		1.05	0.61	0.05		0.05			
6/3/86	1.03			1.38	0.21	0.06	0.05	0.03		0.03	0.02
7/9/86	0.65			0.89	0.21	0.02	0.03	0.03			0.02
8/14/86	0.58	0.88		0.67	0.31	0.08	0.05	0.03	0.02	0.01	<dl
9/17/86	0.34			0.61	0.24	0.07		0.02	0.02	0.02	<dl
10/28/86	0.46	0.63	0.42	0.34	0.27	0.06	0.02	0.02			
					^{134}Cs (pCi/g wet wt)						
4/26/84	5.70										
5/18/84	5.10	2.50									
7/18/84	4.10				2.80			0.28			0.07
8/14/84	5.70				2.10			0.26			0.05
10/18/84	6.40				1.30			0.27			
2/7/85											
3/19/85	3.50	2.00		1.70	1.00	0.36	0.16	0.08		<dl	<dl
4/26/85	1.50			1.80	1.80	0.33	0.13	0.07		0.04	<dl
5/23/85	2.10			1.00	0.92	0.20	0.07	0.06		<dl	<dl
7/11/85	1.80			0.87	0.73	0.16	0.07	0.05		0.03	<dl
8/30/85	0.86			0.75	0.33	0.08	0.08	0.03		<dl	<dl
10/16/85	0.76			0.44	0.56	0.09	<dl	<dl		<dl	<dl
4/8/86		0.27		0.28	0.17	<dl		<dl			
6/3/86	0.28			0.35	0.05	<dl	0.02	<dl		<dl	<dl
7/9/86	0.15			0.24	0.04	0.01	<dl	<dl			<dl
8/14/86	0.15	0.19		0.16	0.07	0.03	<dl	<dl	<dl	<dl	<dl
9/17/86	0.08			0.13	0.05	0.02		<dl	<dl	<dl	<dl
10/28/86	0.08	0.11	<dl	0.07	0.05	<dl	0.01	<dl			

Table 4. Mean concentration of ^{137}Cs and ^{134}Cs in flesh of bass caught at different downstream stations from 1984 to 1986. ("<dl" means less than detection limits.)

	Station ID and downstream distance (km)										
Date sampled	RS-17 0.5	RS-30 0.5	T-1 3.0	R-5 4.6	R-7 6.3	T-2 7.5	T-3 10.2	R-8 12.6	R-22 15.4	T-4 17.2	R-11 19.5
					^{137}Cs (pCi/g wet wt)						
4/26/84	7.00	3.50									
5/18/84		5.70									
7/18/84	2.80							0.57			0.06
8/14/84	4.40			2.80				0.57			0.14
10/18/84	11.80							0.46			
2/7/85											
3/19/85	8.00	13.00		7.60		0.88	1.30	5.10		0.26	0.15
4/26/85	10.40			7.70				1.00		0.29	<dl
5/23/85	1.80					4.50	1.30	0.83		0.16	0.10
7/11/85	2.40		1.10	1.20		0.62	<dl	0.17		0.15	<dl
8/30/85	0.90		1.20	0.90			0.24	0.17		0.11	0.10
10/16/85	1.40						0.37	0.27		0.04	<dl
4/8/86	0.31	3.08		0.21		0.35					
6/3/86	1.01		1.05	0.64		0.13		0.06		0.08	0.05
7/9/86	0.87		0.52	0.30		0.50	0.12	0.05			0.01
8/14/86	1.17	1.96	0.65	0.35		0.13	0.04	0.03	0.06	0.02	
9/17/86	1.28	1.83	0.73	2.21	0.22		0.03	0.05	0.04	0.01	0.01
10/28/86	0.38	1.75	0.52	0.38		0.10	0.07	0.05			
					^{134}Cs (pCi/g wet wt)						
4/26/84	3.30	1.60									
5/18/84		2.60									
7/18/84	1.30							0.25			<dl
8/14/84	1.90			1.20				0.26			0.07
10/18/84	5.00							0.20			
2/7/85											
3/19/85	3.00	4.82		2.80		0.34	0.51	1.80		0.10	0.07
4/26/85	3.70			2.80				0.37		0.12	<dl
5/23/85	0.70					1.50	0.49	0.30		0.07	0.03
7/11/85	0.80		0.36	0.36		0.23	<dl	<dl		0.06	<dl
8/30/85	0.30		0.39	0.30			<dl	0.06		0.04	0.04
10/16/85	0.45						0.13	0.08		<dl	<dl
4/8/86	0.11	0.81		<dl		0.10					
6/3/86	0.27		<dl	0.17		<dl		0.01		0.02	<dl
7/9/86	0.22		0.14	<dl		0.13	<dl	0.02			<dl
8/14/86	0.29	0.43	0.15	0.10		0.03	<dl	<dl	<dl	<dl	
9/17/86	0.31	0.43	0.16	0.52	<dl		<dl	0.02	<dl	<dl	<dl
10/28/86	0.07	0.40	0.11	0.02		<dl	0.02	<dl			

Table 5. Mean concentration of ^{137}Cs and ^{134}Cs in flesh of catfish caught at different downstream stations from 1984-1986. ("<dl" means less than detection limits.)

	Station ID and downstream distance (km)										
Date sampled	RS-17 0.5	RS-30 0.5	T-1 3.0	R-5 4.6	RS-52 6.0	T-2 7.5	T-3 10.2	R-8 12.6	R-22 15.4	T-4 17.2	R-11 19.5
					^{137}Cs (pCi/g wet wt)						
4/26/84		2.05									
5/18/84											
7/18/84											0.08
8/14/84											
10/18/84					5.10						
2/7/85				11.40							
3/19/85	6.30		4.50	4.90	1.63	2.00					
4/26/85	6.70		5.10	4.50		2.00					
5/23/85	2.60		3.80	2.60		2.00	0.38	0.37			0.04
7/11/85	2.40		1.20	2.20		0.97		0.35			0.10
8/30/85	2.10		1.50			0.44		0.20			<dl
10/16/85			0.86			1.04		0.10			
4/8/86				1.00				<dl			
6/3/86	0.97		0.46	1.61				0.04			0.02
7/9/86			0.27				0.23	0.09			<dl
8/14/86			0.28		0.18	0.19	0.07		0.03		0.01
9/17/86			0.27			0.29	0.03	0.04			
10/28/86				0.54		0.10		0.05			
					^{134}Cs (pCi/g wet wt)						
4/26/84		0.93									
5/18/84											
7/18/84											0.03
8/14/84											
10/18/84					2.22						
2/7/85				4.50							
3/19/85	2.30		1.70	1.90	0.62	0.75					
4/26/85	2.40		1.90	1.60		0.71					
5/23/85	0.93		1.40	0.91		0.72	0.14	0.19			<dl
7/11/85	0.83		0.41	0.77		0.34		0.11			
8/30/85	0.69		0.49			0.14		0.07			
10/16/85			0.34			0.33		<dl			
4/8/85				0.28				<dl			
6/3/86	0.29		0.20	0.40				0.02			<dl
7/9/86			0.07				<dl	<dl			<dl
8/14/86			<dl		0.05	<dl	0.07		<dl		<dl
9/17/86			<dl			0.06	<dl	<dl			
10/28/86				0.11		<dl		<dl			

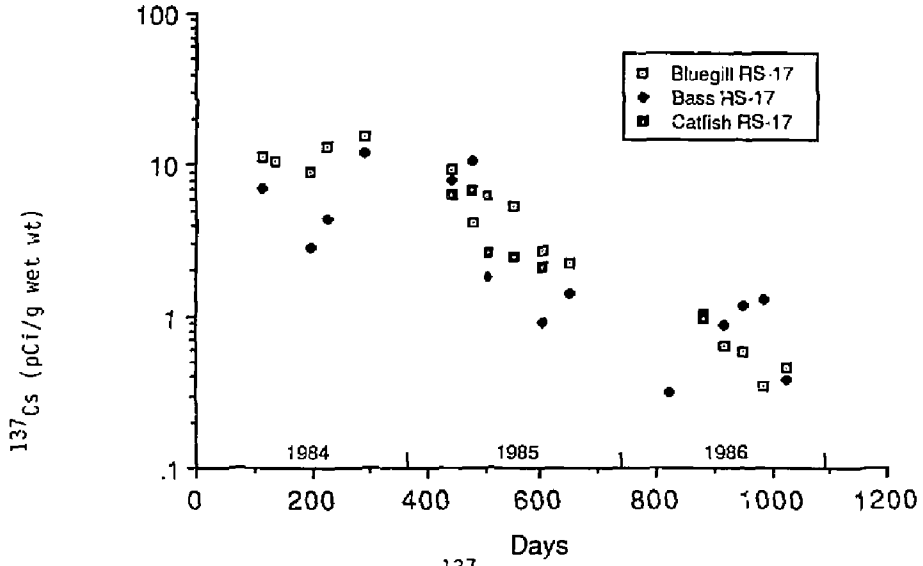


Figure 3. Mean concentration of ^{137}Cs measured in flesh of bluegill, bass and catfish caught at Station RS-17 (0.5 km downstream from Rancho Seco) on days since January 1, 1984.

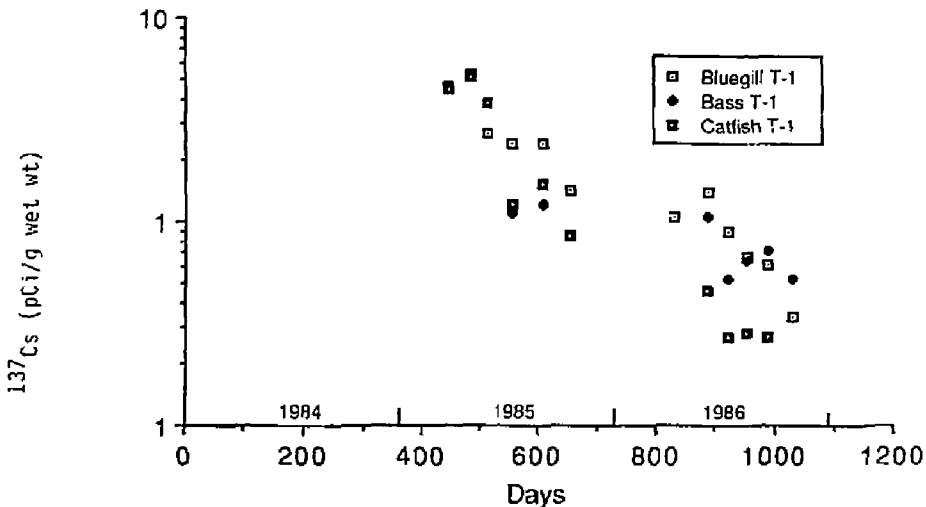


Figure 4. Mean concentration of ^{137}Cs measured in flesh of bluegill, bass and catfish caught at Station T-1 (3.0 km downstream from Rancho Seco) on days since January 1, 1984.

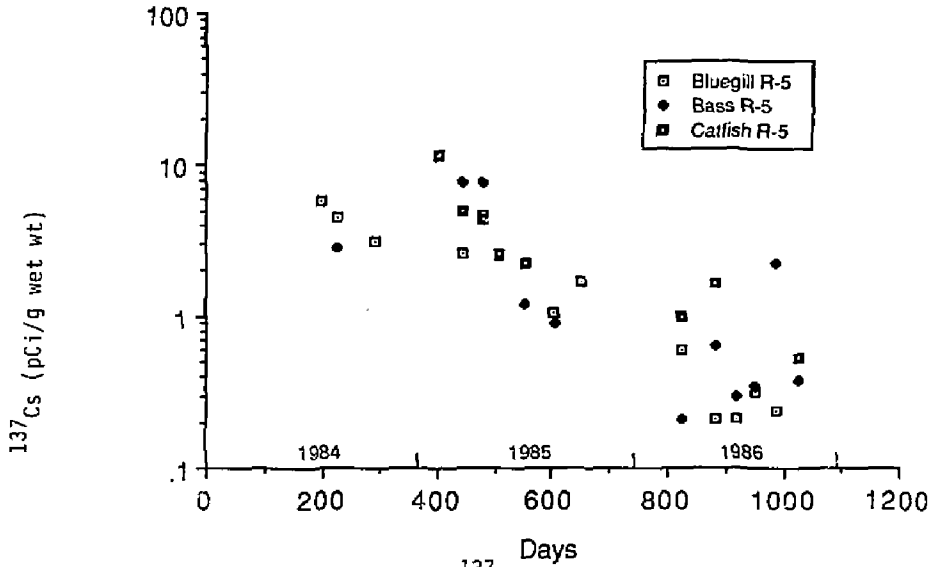


Figure 5. Mean concentration of ^{137}Cs measured in flesh of bluegill, bass, and catfish caught at Station R-5 (4.6 km downstream from Rancho Seco) on days since January 1, 1984.

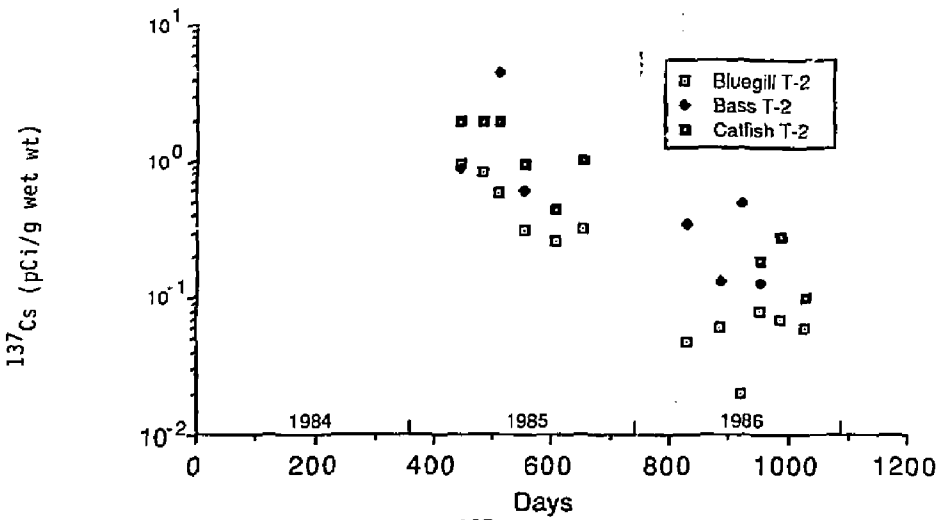


Figure 6. Mean concentration of ^{137}Cs measured in flesh of bluegill, bass, and catfish caught at Station T-2 (7.5 km downstream from Rancho Seco) on days since January 1, 1984.

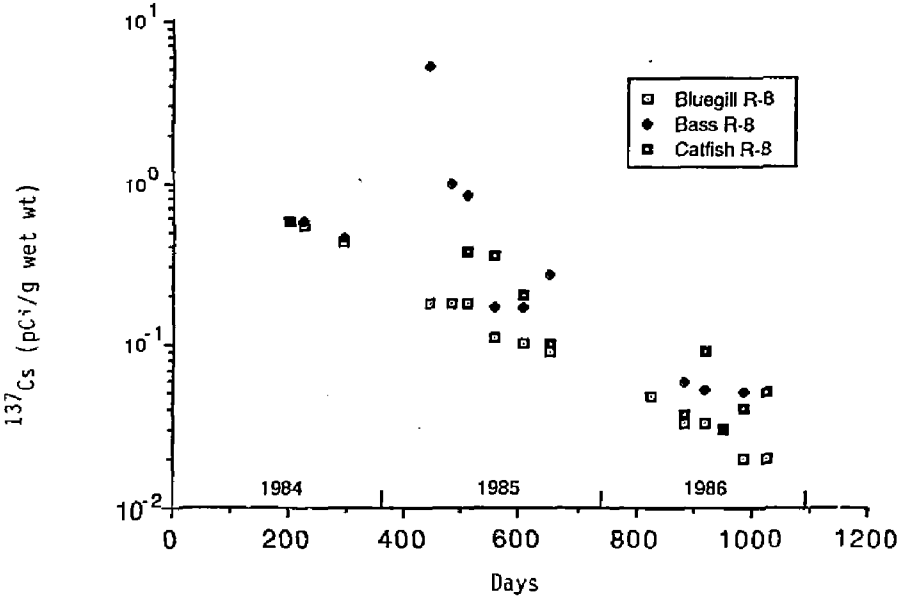


Figure 7. Mean concentration of ^{137}Cs measured in flesh of bluegill, bass, and catfish caught at station R-8 (12.6 km downstream from Rancho Seco) on days since January 1, 1984.

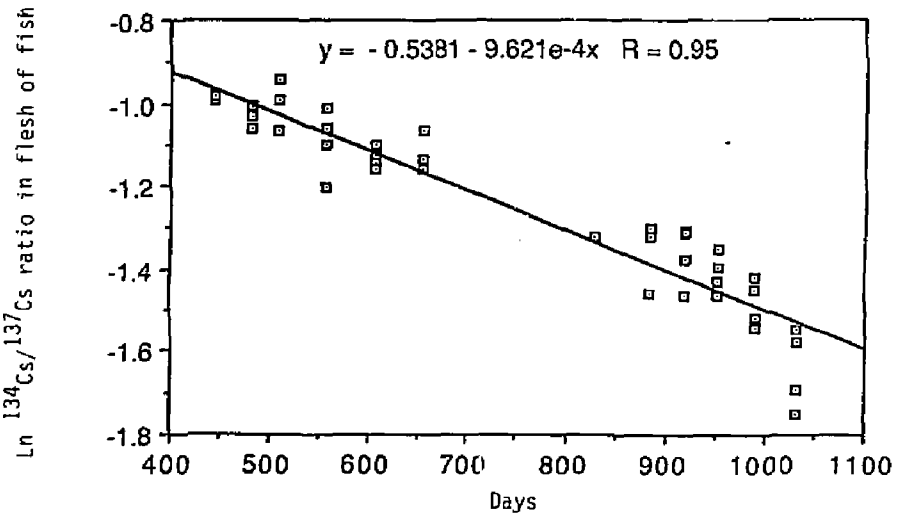


Figure 8. ^{134}Cs/^{137}Cs activity ratio in fish from stations RS-17 and T-1 measured on days since January 1, 1984. Regression line has been fitted to the data by the method of least squares.

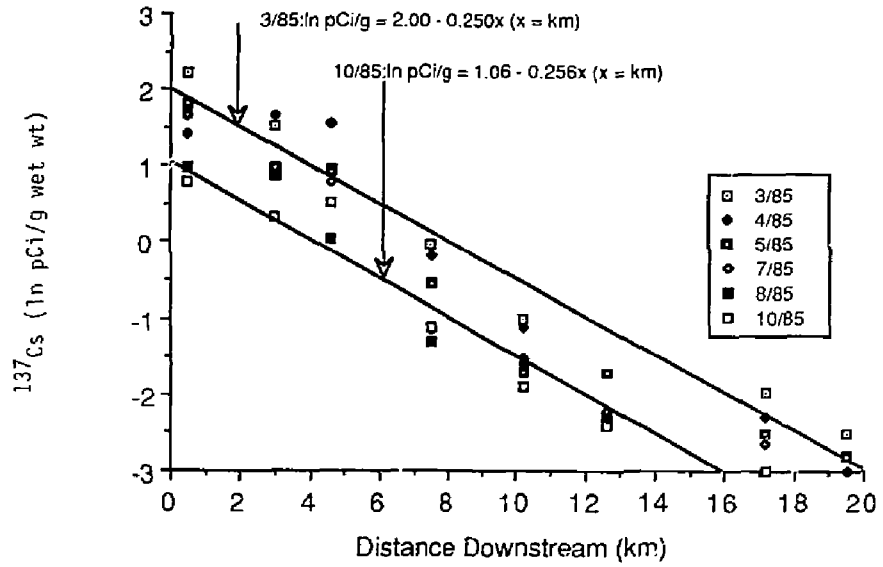


Figure 9. Concentration of ^{137}Cs in flesh of bluegill caught in 1985 at different stations downstream from Rancho Seco. Computed best fit to the March and October data is shown.

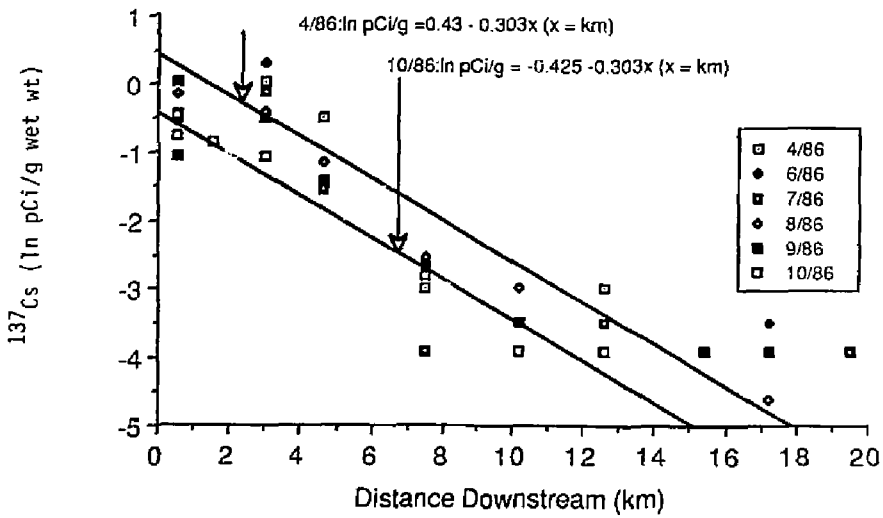


Figure 10. Concentration of ^{137}Cs in flesh of bluegill caught in 1986 at different stations downstream from Rancho Seco. Computed best fit to the April and October data is shown.

Table 6 shows the average concentration measured in the flesh of all of the species of fish caught at each downstream station in 1986. Highest average concentrations were measured in fish at station RS-30, an irrigation pond connected to Clay Creek at station RS-17. The mean concentration of ^{137}Cs in the flesh of all fish collected downstream of station T-2 (7.5 km from Rancho Seco) is 0.07±0.08 pCi/g wet wt. In most fish from locations below this station, the level of ^{134}Cs was very low or below our detection limit. The mean value of 0.07 pCi/g is approximately 64% of the 0.11 pCi/g measured in fresh-water fish randomly sampled from market counters of Chicago, Illinois food stores in 1982 (9). The ^{137}Cs in fresh-water fish in Chicago markets orignates from world-wide global fallout. It is obvious that a computed, annual body dose-equivalent rate to individuals from ^{137}Cs in fresh-water fish caught for consumotion in Laguna Creek, downstream from station T-2, would be comparable to or less than the computed dose from consumption of an equivalent quantity of fresh-water fish purchased in 1982 over the counter in Chicago, IL.

Measured concentrations of ^{137}Cs and ^{134}Cs in edible frog legs and flesh of crayfish collected from downstream locations during 1986 are presented in Appendixes II and III. Concentrations of naturally occurring ^{40}K in the muscle of frog legs are also shown in Appendix II. No other gamma-emitting radionuclide associated with the releases from Rancho Seco was detected in the edible flesh of these organisms. Figure 12 shows the concentration of ^{137}Cs in the flesh of frogs compared to that in bluegill flesh from all stations sampled during 1986. It is apparent from Fig. 12 that at each station the concentration of ^{137}Cs in bluegill flesh was either equivalent to or greater than the concentration in flesh of frogs. In the absence of downstream site-specific data for concentrations of ^{137}Cs in frogs, the levels in the flesh of bluegill and Equation (2) may be used with some certainty to estimate conservative values for mean concentrations during 1986 in these organisms from any downstream location.

$$^{137}Cs\ (pCi/g\ wet\ wt\ frog) = 0.055 + 0.40 \times (^{137}Cs\ pCi/g\ wet\ wt\ bluegill) \qquad (2)$$

Too few crayfish were analyzed to develop any meaningful concentration ratios from the data with fish.

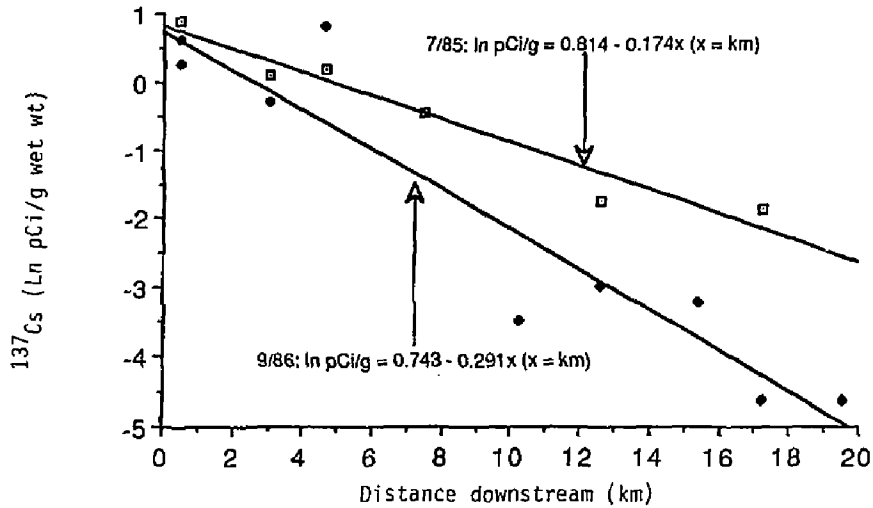


Figure 11. Concentrations of ^{137}Cs in flesh of bass caught during July 1985 and September 1986 at different stations downstream from Rancho Seco. Computed best fit to the data is shown.

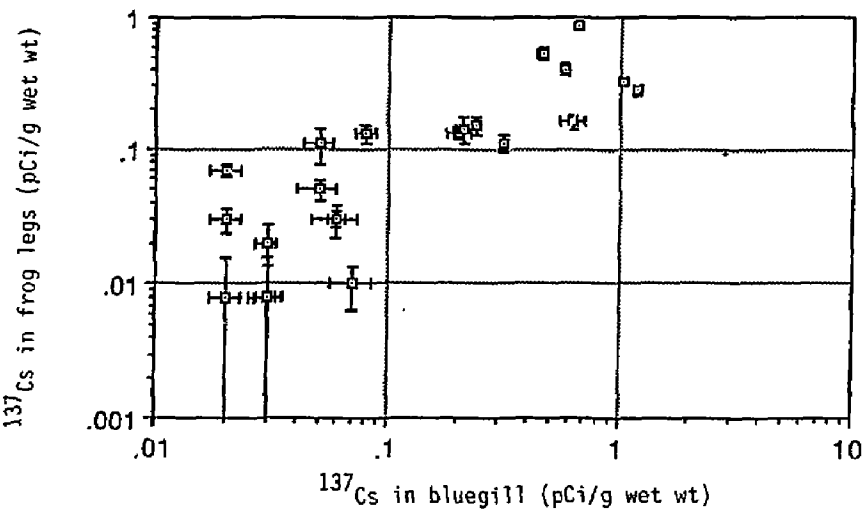


Figure 12. Concentrations of ^{137}Cs in flesh of bluegill and in frog legs collected during 1986 at stations downstream from Rancho Seco.

Table 6. Mean concentration of ^{137}Cs and ^{134}Cs in the flesh of all fish collected at each downstream station in 1986.

Station	Downstream distance (km)	pCi/g wet wt[a] ^{137}Cs	^{134}Cs
RS-17	0.5	0.78 ± 0.33 (14)	0.20 ± 0.09
RS-30	0.5	1.7 ± 0.8 (8)	0.4 ± 0.2
T-1	3.0	0.7 ± 0.6 (16)	0.2 ± 0.2
R-5	4.6	0.6 ± 0.6 (19)	0.2 ± 0.2
T-2	7.5	0.15 ± 0.14 (18)	0.05 ± 0.04
T-3	10.2	0.07 ± 0.06 (12)	0.01 ± 0.01[b]
R-8	12.6	0.05 ± 0.02 (17)	0.02 ± 0.01[b]
R-22	15.4	0.03 ± 0.02 (5)	b
T-4	17.2	0.03 ± 0.03 (6)	b
R-11	19.5	0.02 ± 0.01 (12)	b

[a] Value in parenthesis is the number of samples averaged over the year.
[b] ^{134}Cs is below detection limits in the majority or in all samples.

Concentrations of Radionuclides in Sediment Samples

The concentrations of radionuclides determined in the creek sediments sampled during 1986 are given in Appendix VII. Figures 13 to 15 show the concentrations of ^{137}Cs in the 0- to 12-cm surface sediment sections collected in 1984, 1985, and 1986 from different downstream regions of Clay, Hadselville, and Laguna Creeks. During each year, the concentrations associated with the sediments decrease more or less uniformly with increasing distance downstream from Rancho Seco. The equations stated in the figures best describe the relationship between concentration and downstream distance. The coefficient for x, relating the change in concentration to downstream distance, is unchanged over the 3-y period and is identical to the coefficient describing the changes in concentration in bluegill (see Figs. 9 and 10) with downstream distance.

Between 1985 and 1986, the mean concentration of ^{137}Cs in the surface sediment at all downstream locations decreased, with an effective half-life of approximately 2 y.

During October 1986, the highest concentration of ^{137}Cs in surface sediment was measured in samples collected between stations RS-16 and RS-6, 0.6 to 1.6 km downstream from Rancho Seco. This is the region identified as a relative "hot" spot on the creek during the aerial radiological survey conducted by EG&G in December 1984 (10).

Concentrations for ^{40}K (a naturally occurring radionuclide) measured in surface sediments collected in 1986 are shown in Fig. 16. The differences encountered in the concentration of ^{40}K were quite unexpected. The mean concentration of ^{40}K in the surface sediment of Clay Creek (to a distance of 3.0 km from the plant), Hadselville creek (between 3.0 and 6.5 km downstream from the plant), and Laguna creek (between 6.5 and 20.5 km downstream from the plant) are 4.7±1.4, 14.4±2,3, and 9.7±1.3 pCi/g, respectively. It is not clear why concentrations in Clay Creek are low or why Hadselville Creek sediments contain higher levels of ^{40}K than Laguna Creek sediments. Clearly, the chemical composition of the sediments from each creek must differ. This difference must affect the binding capacity of the alkali metals, potassium (^{40}K) and cesium (^{137}Cs and ^{134}Cs). It appears warranted to evaluate the K_d

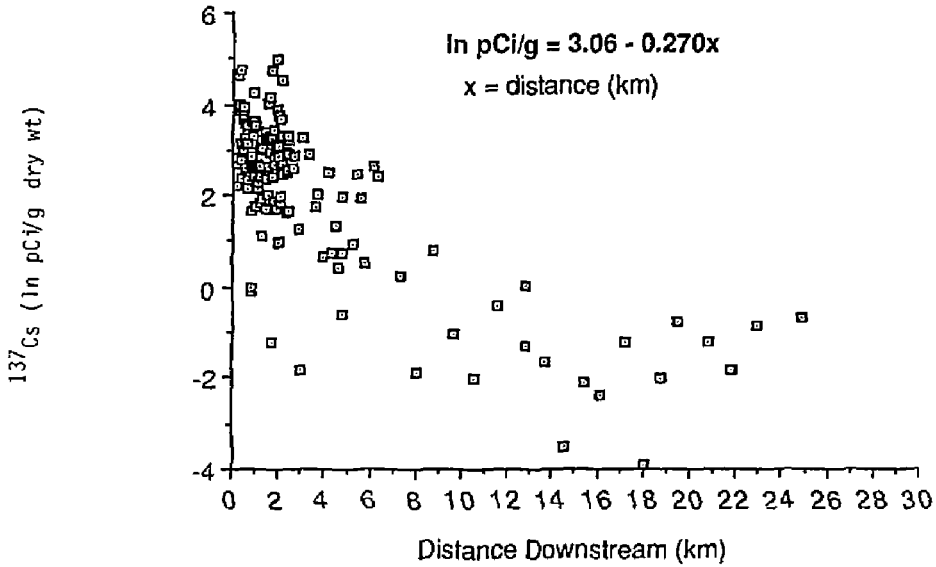


Figure 13. Concentration of ^{137}Cs in surface (0-12 cm) sediment collected downstream from Ranch Seco during 1984. The equation results from a least-squares analysis of the measured concentration with downstream distance.

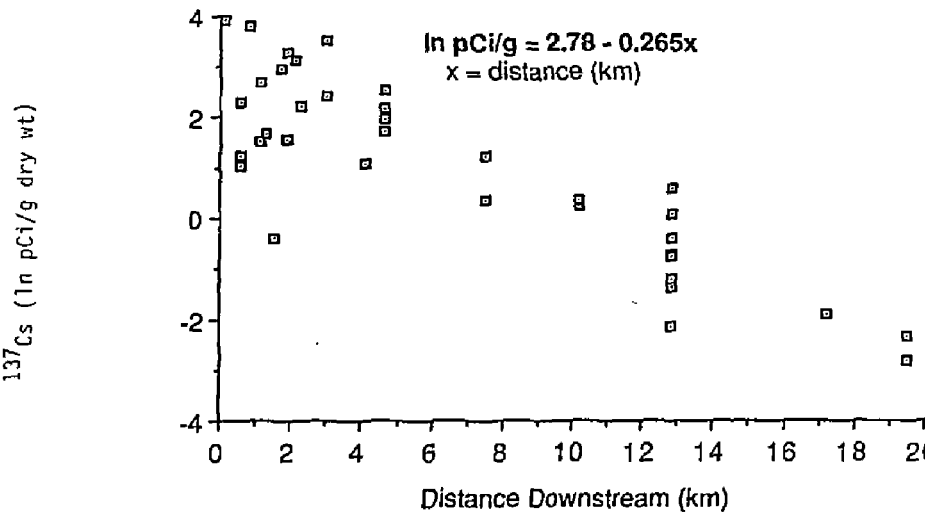


Figure 14. Concentration of ^{137}Cs in surface (0-12 cm) sediment collected downstream from Rancho Seco during 1985. The equation results from a least-squares analysis of the measured concentration with downstream distance.

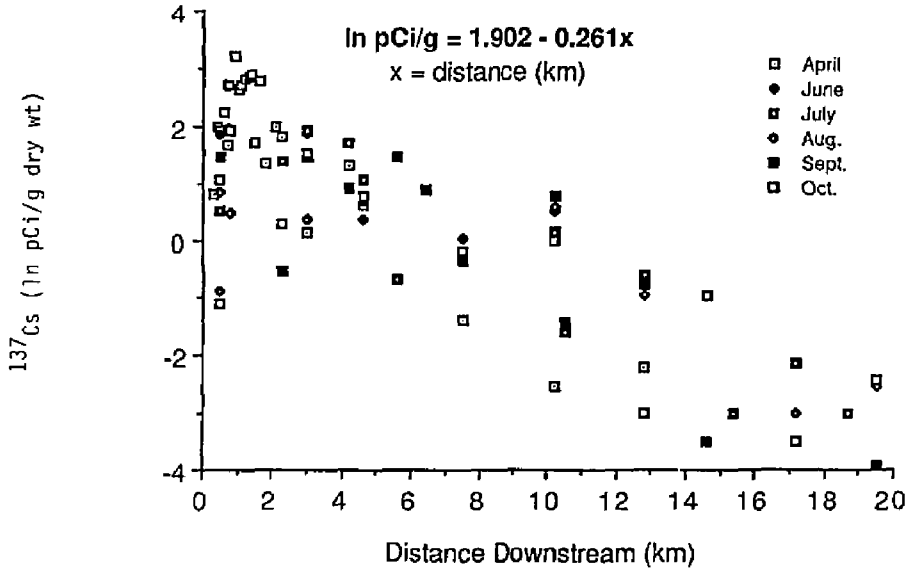


Figure 15. Concentration of ^{137}Cs in surface (0-12 cm) sediment collected downstream from Rancho Seco during 1986. The equation results from a least-squares analysis of the measured concentration with downstream distance.

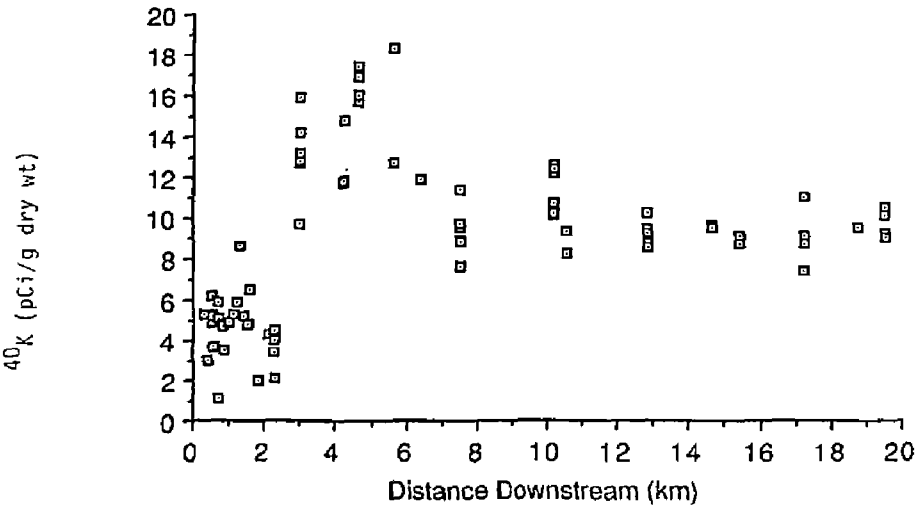


Figure 16. Concentration of ^{40}K in surface (0-12 cm) sediment collected downstream from Rancho Seco during 1986.

values for cesium with sediment from the different creeks to better understand the partitioning of ^{137}Cs between water and the different sediments from the region.

A sediment core was collected to a depth of 24 cm from Station R-5 (4.6 km downstream from Rancho Seco) in April. The core was sectioned into 5-cm increments to determine the vertical distribution of the activity in the sediment column. Concentrations in the vertical sections are shown in the Appendix (Table VII-2). Similar concentrations of ^{137}Cs are found in all depth increments of the core. This represents a change from 1984 when most sediment profiles showed a decrease in activity between the surface and depths. This recent sediment has been physically well mixed. The changes noted in surface concentrations with time may, in part, result from vertical mixing processes in which the higher surface concentrations measured in 1984 (see Fig. 15) have mixed with low concentrations from the lower depths. A core from this location in 1984 contained 7.1 pCi/g of ^{137}Cs in the surface layer (4). In the 1986 core, the surface concentration is 1.53 pCi/g. This represents a 79% reduction in the surface concentration over 2 y. However, the integrated amounts of ^{137}Cs in the 1984 and 1986 sediment column were 82 (4) and 71 pCi/cm^2, respectively, to the maximum depth sampled. The integrated inventory of ^{137}Cs decreased only 13% over this time period, suggesting that the majority of ^{137}Cs previously accumulated by the sediment deposits has been mixed to deeper depths within the sediment column. We can hardly make a serious case for this burial mechanism on the basis of results from a single comparison, and we recommend that additional studies be undertaken on sediment core samples to better assess the fate of ^{137}Cs in this environment.

Concentrations of Radionuclides in Creek Water Samples

Concentrations of ^{134}Cs and ^{137}Cs in filtered creek water samples and in the separated particulate material from downstream locations are shown in Appendix IV. The small quantities now present in solution originate from plant releases, from creek sediments by remobilization, and from agricultural run-off in areas where creek water was previously used for irrigation.

An NRC (Nuclear Regulatory Commission) inspection at Rancho Seco in April 1986 caused the district to reevaluate the 1985 radioactive liquid-effluent discharges. The district now reports discharges to Clay Creek of 4 mCi of ^{137}Cs for 1985 and 0.7 mCi of ^{137}Cs for the first half of 1986 (1).

Station RS-17 is 0.5 km below the plant outfall on Clay Creek at the western boundary of the site. We have made collections and analysis of water from this site since the spring of 1984. The different concentrations of total ^{137}Cs (dissolved and particulate fraction) measured in water samples collected from this station on days since January 1, 1984, are shown in Fig. 17. Figure 18 shows the percentage of the total ^{137}Cs measured in solution on the respective sampling days. The mean concentration measured in solution at this station during 1984 was 2.8±2.1 pCi/l (5). During 1985 and 1986, the mean concentrations in solution were 0.47±0.43 and 0.05±0.04 pCi/l, respectively. Because releases from the plant possibly occurred during periods when we were not sampling, these values do not necessarily represent a true mean concentration for the entire year; they are useful only to show the general trend in the change occurring in the concentration over time. The results are, however, an independent illustration of the effectiveness of the district initiated liquid-effluent control program. It is of interest, to note that the 4 mCi of ^{137}Cs, which was reported released in 1985 (1), was discharged with 10.1×10^9 L of dilution water to Clay Creek. Therefore, the average concentration in water discharged from the plant over the year was 0.41 pCi/L; a value in good agreement with our mean value of 0.47 pCi/L at station RS-17 on Clay Creek.

Since 1984, we have consistently found that the concentration of ^{137}Cs in water sampled as far as 10 km downstream was equivalent to or greater than the concentration measured at station RS-17 at the site boundary. This clearly would not be the case during the initial stages of a release from the plant. Figures 19 and 20 show the concentrations measured at downstream locations normalized to the concentration measured in solution at RS-17 for 1984 and 1985 (Fig. 19) and 1986 (Fig. 20). The pattern is repeated monthly during each year, regardless of the absolute concentration in the water. During 1984, 1985, and January to September 1986, higher concentrations were found in water sampled at stations T-1 (3.0 km downstream) and R-5 (4.6 km downstream) than at station RS-17. The higher concentrations in water persist to at least 10 km downstream.

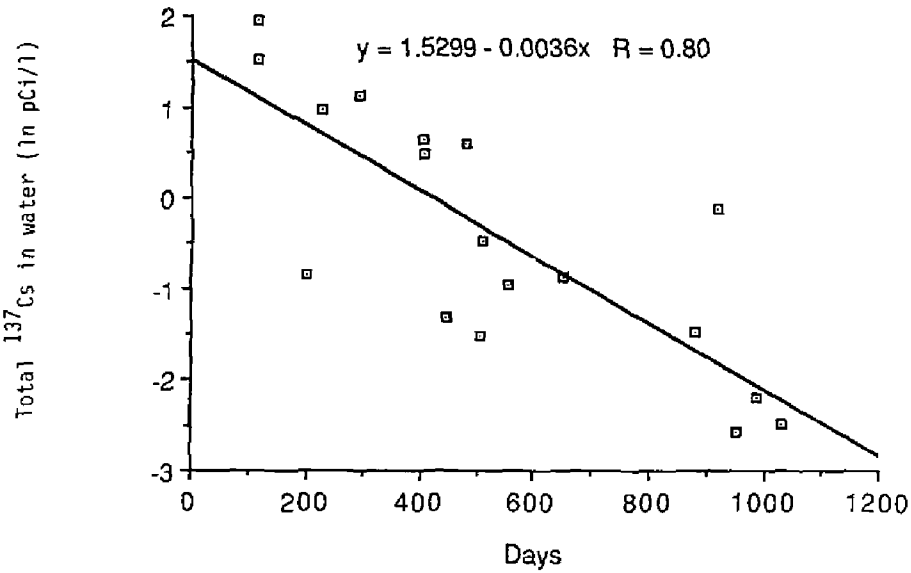


Figure 17. Concentration of total ^{137}Cs in water samples collected at Station RS-17 (0.5 km downstream of Rancho Seco) on days since January 1, 1984.

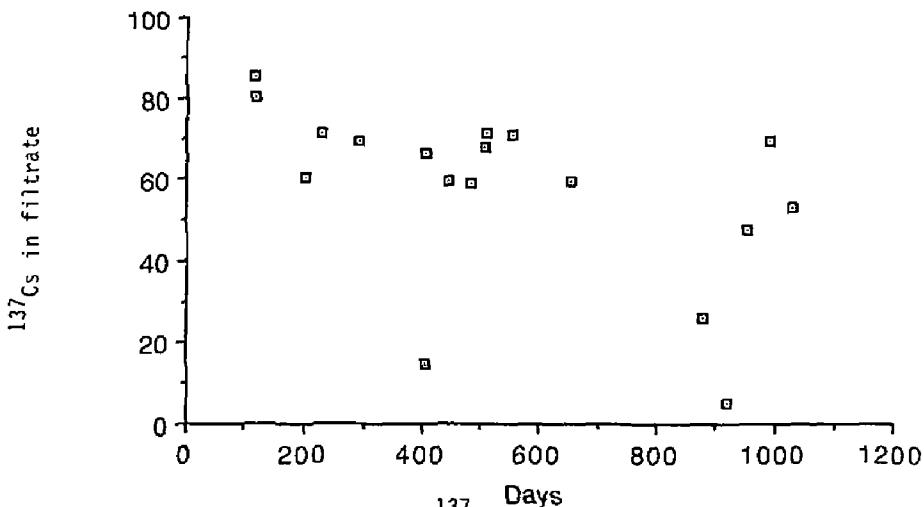


Figure 18. Percentage of total ^{137}Cs in filtrate at Station RS-17 on days since January 1, 1984.

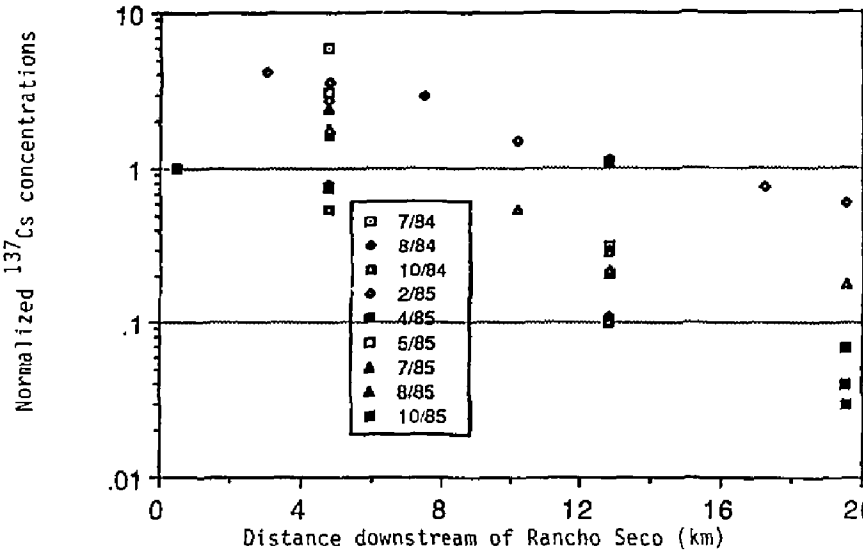


Figure 19. Concentration of ^{137}Cs in filtered water collected at downstream stations in 1984 and 1985 normalized to the concentration at Station RS-17 (0.5 km from Rancho Seco).

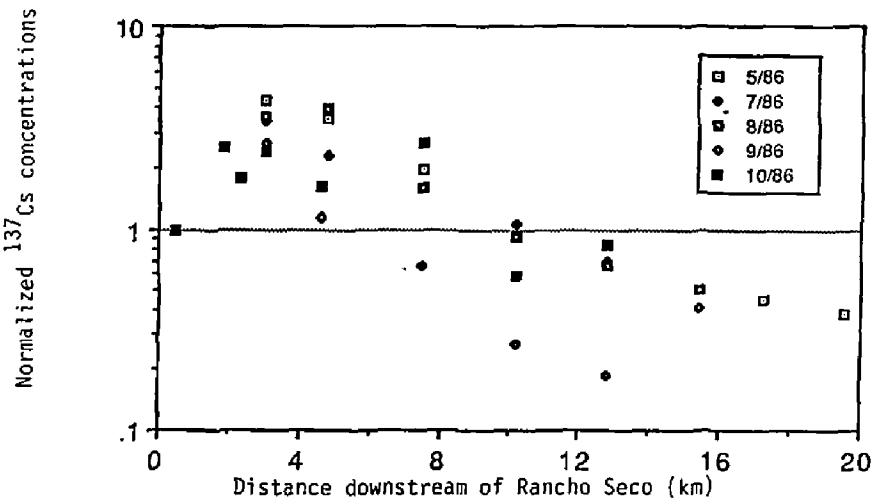


Figure 20. Concentration of ^{137}Cs in filtered water collected at downstream stations in 1986 normalized to the concentration at Station RS-17 (0.5 km from Ranch Seco).

In October 1986, we looked for another possible source of ^{137}Cs between stations RS-17 and T-1. Station RS-5 (1.8 km downstream from the plant) is the region of Clay Creek that had previously been identified as a relative hot spot on the creek during the EG&G aerial survey in 1984 (10). In October, we measured higher concentrations at this location and identified an irrigation pipe that drained excess irrigation water to the creek from the adjacent field. Since 1981 (when ^{137}Cs was first reported in liquid effluents from Rancho Seco), this field had been irrigated with water pumped from station RS-17. The excess water was discharged to the creek at station RS-5, 1.3 km downstream from the irrigation pump. Some of the ^{137}Cs previously applied to the field with irrigation water is mobilized by the application of irrigation water in later years. The irrigation water also erodes some soil that is subsequently transported to the creek at station RS-5. The eroded solids may contribute to the higher sediment concentrations that we now find in this region of the creek and to the elevated activity seen in this region during the EG&G flyover (10). This source also contributes to the inventory of ^{137}Cs immediately downstream of RS-5. However, because the concentration of ^{137}Cs in the water is lowered further downstream by dilution (from field drains and other sources), this source cannot be entirely responsible for the higher levels in water to a distance of 10 km downstream.

Concentration Factors

Another reason for the continued collection of water samples is to strengthen our data base on concentration factors for ^{137}Cs for the species of fish in the creek. Over the last 3 years, we have consistently found that the concentration factor for ^{137}Cs in the flesh of fish caught nearest the plant was larger than the concentration factor for fish caught further downstream.

The concentration factor is the ratio of radionuclide concentration in the organism or tissue to that in the water. Concentration factors were computed from the mean concentrations of ^{137}Cs in fish muscle and the appropriate filtered-water concentration measured in 1984, 1985, and 1986 at the different stations. Median and mean (and the standard deviation of the arithmetic mean) values for the concentration factors were computed for ^{137}Cs in fish from Clay, Hadselville, and Laguna Creeks. The results are shown in Table 7. These values are not necessarily equilibrium concentration factors.

Table 7. Median and mean values for concentration factors (CF) for ^{137}Cs in bluegill, bass, and catfish.

	Clay Creek			Hadselville Creek			Laguna Creek		
	No.[a]	Median CFx10^{-3}	Mean CFx10^{-3}	No.[a]	Median CFx10^{-3}	Mean CFx10^{-3}	No.[a]	Median CFx10^{-3}	Mean CFx10^{-3}
Bluegill	15	14	16±8	21	3.2	3.6±0.5	31	1.4	1.5±0.1
Bass	15	8.9	13±3	16	3.4	5.3±1.5	29	2.1	3.5±1.0
Catfish	6	11.4	15±5	13	3.3	5.2±1.2	18	2.9	2.9±0.4

[a] The number of samples averaged.

The standard deviations show that differences were encountered among the individual values; an explanation for these differences is that the concentration in water is measured in samples taken on a specific date, while the fish may have encountered different concentrations in the water or food for an extended period prior to sampling. However, by repeating the measurements a number of times over the years, as we have done, the mean values shown are probably quite close to being true equilibrium concentration factors.

It is appropriate to find differences in concentration factors for ^{137}Cs among the different species of fish (bluegill, bass, and catfish). The differences among species are caused by a number of factors. It was unexpected, however, to find different concentration factors for ^{137}Cs in the same species of fish from different locations (in Table 7, compare values for bluegill from Clay and Laguna Creeks). Figures 9 and 10 show that concentrations in the flesh of bluegill decrease with distance downstream. However, Figs. 19 and 20 show that the concentration in water as far as 10 km downstream was equivalent to or greater than the concentration in water at the site boundary (Station RS-17). If concentrations of ^{137}Cs in fish were only related to the levels in water, the measured concentration factors should be identical (or greater) for fish collected between the site boundary and 10 km downstream. This is not the case for the bluegill, bass, and catfish from Clay, Hadselville, and Laguna Creeks.

Concentrations of Stable Potassium

Vanderploeg et al. (11) had previously reported that the concentration factor for ^{137}Cs is influenced by the stable potassium in fresh water. They recommended an upper-bound bioaccumulation factor to predict cesium concentration in non-piscivorous fish (in this case bluegill) of $5 \times 10^3/K_{ppm}$, if the stable potassium level is known.

In October 1985, we collected a series of water samples for stable potassium analysis. The potassium was determined by measurements with atomic absorption. Our results are shown in Fig. 21 along with the concentrations measured in water in samples subsequently collected in 1986. In October 1985, the levels of potassium in the water sampled from Clay and Hadselville Creeks were much less than the concentrations measured in Laguna Creek. These

results were unexpected but showed that there could be another factor influencing the amount of ^{137}Cs accumulated by the fish. Potassium was measured in water collected from the creeks during April, May, and July 1986. Figure 21 shows that the concentrations measured during these periods generally increased with distance downstream from Rancho Seco.

The source of this additional potassium was not obvious. In July 1986, we sampled a series of irrigation drains that were located along the creek. During July, the amount of water draining from the irrigated fields through these drains to the creek was significant. The water originates from wells or reservoirs and is used to irrigate crops during the growing season. Flow rates over the year from the fields are irregular; they depend on the time of year and the amount of water applied for irrigation. The concentration of potassium in the water sampled at downstream locations of the creek and at the field drains during July are shown in Fig. 22. Water from several drains at approximately 4 and 13 km downstream contained elevated levels of potassium. Mixing of the drainage water with the creek water resulted in graduated increases in the concentration of potassium in the water. The different potassium levels in the water probably originate from high potassium fertilizers that were applied to the fields during the planting season.

Between April and July 1986, the mean potassium level in creek water at the plant boundary (Station RS-17) was 0.77 ppm. At 5 and 16 km downstream, the mean potassium concentration was 1.35 and 2.6 ppm, respectively. The predicted concentration factors (using the Vanderploeg *et al.* (11) relationship) for cesium in bluegill from the measured potassium concentrations are 7000, 3700, and 1100 at 0.5, 5, and 16 km, downstream from Rancho Seco. The median values, shown in Table 7, for the ^{137}Cs concentration factors for bluegill of 14000 for Clay Creek (0.5 km), 3200 for Hadselville Creek (5 km), and 1400 for Laguna Creek (16 km) are in reasonable agreement with these values. Although there are somewhat higher ^{137}Cs levels in the water below the site boundary, the higher potassium levels in the water plays a major role in regulating the amount of the cesium radionuclides accumulated by fishes at downstream locations.

Figure 22 shows that in July, water with a relatively high potassium concentration entered the creek (through field drains) between 4.0 and 4.6 km downstream from Rancho Seco. This location is between the plant boundary (RS-17) and Station R-5. There are other field drains between these stations

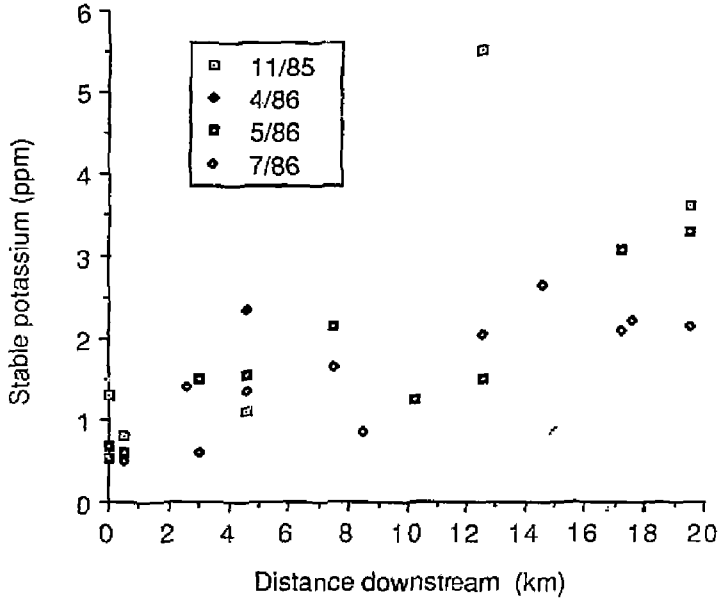


Figure 21. Concentrations of stable potassium in creek water sampled at different times and different locations downstream from Rancho Seco.

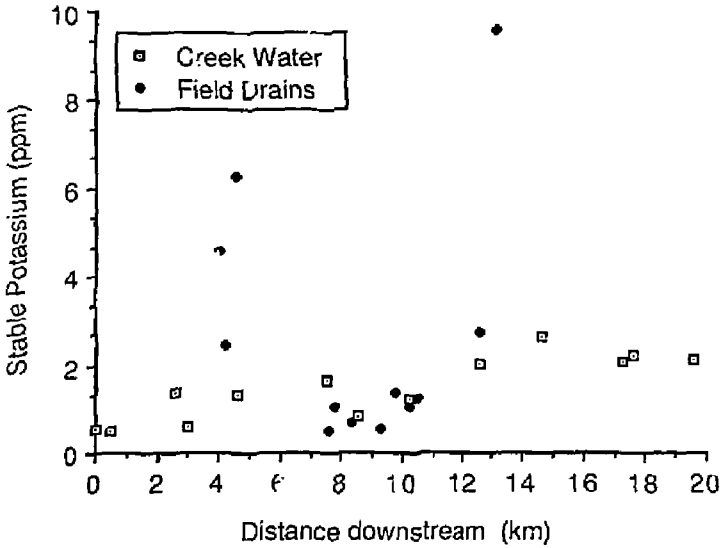


Figure 22. Concentrations of stable potassium in creek and field-drain water sampled in July 1986 at locations downstream from Rancho Seco.

where flowing water (possibly containing increased levels of potassium) was encountered but not sampled. These higher potassium concentrations must displace a fraction of ^{137}Cs sorbed to the sediments, causing the ^{137}Cs concentrations in water to increase. This labeled water flows downstream; consequently, higher concentrations would be found in solution at Stations T-1, R-5, and other downstream locations. This ^{137}Cs remobilization mechanism (caused by increased potassium levels in water) persists during years of high- and low-level releases from the plant. Release of ^{137}Cs from sediments will occur at all downstream locations; the quantities mobilized will be regulated by potassium concentrations in water. The literature indicates that cesium can be displaced from some soils by potassium, but the rates and quantities are probably site specific and should be determined locally. Because potassium will compete for binding sites with the sediment-bound cesium, increased potassium concentrations may offer a solution to "cleaning-up" some residual cesium from the creek surface sediments.

Concentrations of Radionuclides in Leaves of Water Hyacinth

Water hyacinth (Eichhornia crassipies) collection was initiated in 1985 to evaluate the usefulness of the plant as an indicator species for future monitoring of the waterway. The concentrations of the radionuclides detected by gamma spectrometry in the stem-leaf sections of the plants collected from different downstream stations are shown in Appendix VI. In addition to accumulating ^{134}Cs and ^{137}Cs, the plant accumulates ^{54}Mn and ^{60}Co, making it a useful indicator species during the spring to fall months for a variety of different radionuclides released from Rancho Seco.

No radionuclides originating from Rancho Seco releases were found in plants (or in water nor fish) sampled from Skunk Creek, flowing to the south of and parallel to Laguna creek. (There has been speculation that exchange of water occurs between the two creeks, especially during the rainy season. On the basis of our measurements of radionuclide tracers, we do not believe that such an exchange occurs.)

The data indicate that the leaves of the plant may obtain a significant fraction of the measured radionuclides by direct uptake from water. ^{60}Co, for example, was found in the majority of surface sediments sampled as far as 4.5 km downstream from Rancho Seco. This radionuclide is continuously

available to the roots of plants growing in this region. Yet only during May and July was ^{60}Co above detection limits in the leaves of plants between 3 and 4.5 km downstream from Rancho Seco. Small quantities of ^{60}Co must have been released to the water in the creek during early summer and accumulated by the hyacinth. Between July 8th and August 13th, the quantities of ^{60}Co originally accumulated by the plants sampled between 3 and 4.5 km downstream, were absent, implying a rapid turnover rate in this plant for this radionuclide.

Concentrations of ^{137}Cs in the plant varied more over the seasons than concentrations in fish or water. The plant seems to act as an indicator of specific releases from Rancho Seco rather than as a long-term integrator. The computed, mean concentration factors for ^{137}Cs accumulated by the plants from Station RS-17 (0.5 km from Rancho Seco), Station T-1 (3.0 km), Station R-5 (4.6 km), and Station R-8 (12.6 km) are 6100, 600, 700, and 700, respectively. As with fish, we find the highest concentration factor is associated with plants sampled from Clay Creek. Potassium in the water must also play a role in regulating the uptake of ^{137}Cs (and ^{134}Cs) by the water hyacinth.

Concentration of Radionuclides in Soil Samples

Soil samples were collected for analysis from different locations during the year. Concentrations of the different radionuclides measured in the samples are shown in 4 tables of Appendix VIII.

In late 1984, the NRC sponsored an environmental radiological survey of the region around Rancho Seco (12). As part of this survey, a number of surface (0 to 5 cm) soil samples were collected from locations selected to have typical background levels of radioactivity for the general area. Fallout background concentrations of ^{137}Cs determined in 12 samples ranged from <0.04 to 1.3 pCi/g. "Concentrations of radionuclides in soil at background locations averaged 0.41 pCi/g of ^{137}Cs, effectively zero pCi/g ^{134}Cs,...." (12). Tables 1, 2, and 3 of Appendix VIII show the levels of ^{137}Cs measured in surface soil from the ranchland of Mr. R. Gudgel, in surface soil collected at ranchlands located approximately 5 miles (11 km) from Rancho Seco on different compass headings from the plant, and in surface soil from the Marciel ranch located 1 km from the plant. Concentrations in the surface 4-cm-deep layer ranged from 0.06 to 1.65 pCi/g. No ^{134}Cs was detected in

these soil samples. The concentrations are within the range of global-fallout background levels that have been reported previously (12) in soils from the region. No ^{137}Cs or ^{134}Cs originating from Rancho Seco, either as atmospheric particles or in solution from the aqueous releases, has contaminated the soil collection sites described in Tables 1, 2, and 3 of Appendix VIII.

Concentrations of radionuclides in soil-profile samples collected in August 1986 from stations RSP-1 and RSP-5 are shown in Appendix VIII (Table VIII-4). Soil from these locations had been sampled in November 1984 and analyzed (5). Station RSP-1 is on land 50 m south of the irrigation pond (Station RS-17), at the western boundary line of the Rancho Seco property. RSP-5 is located 200 m west, or downstream, of RSP-1, 50 m from the south bank of the creek. This region of pastureland has not been cultivated for several years and is regularly irrigated with Clay Creek water. At RSP-5 and RSP-1, a pit was excavated next to the location sampled in 1984. Soil was sampled in increments from the side wall of the pit to a depth of 51 cm. Table 8 is a comparison of the concentration and inventory of ^{137}Cs determined in soil samples collected in 1984 and 1986. At Station RSP-1, both the concentration and inventory in the surface 0- to 15-cm section of soil increased between 1984 and 1986. At Station RSP-5, the concentration at depth and the total soil column inventory of ^{137}Cs also increased, but not as much as the increase in inventory noted at station RSP-1.

While concentrations of ^{137}Cs associated with environmental samples (e.g., fish, water, sediment, and hyacinth) from the creek at RS-17 and from other downstream locations significantly decreased between 1984 and 1986, concentrations in soil sampled from irrigated ranchland have increased over the 2-y period probably as a result of continued irrigation.

Concentrations of Radionuclide in Miscellaneous Samples

No radioactivity was found in samples of honey from hives 0.5 km from the plant and the level of ^{137}Cs in the flesh sample from one cow, collected in January 1986, was less than level measured in beef samples collected in 1984 and comparable to concentrations of global fallout in store purchased beef.

Table 8. Concentrations and inventory of ^{137}Cs in soil samples collected in November 1984 and August 1986 ("<dl" means less than detection limits).

Depth intervals (cm)	November 1984		August 1986	
	^{137}Cs concentration (pCi/g)	^{137}Cs inventory (pCi/cm^2)	^{137}Cs concentration (pCi/g)	^{137}Cs inventory (pCi/cm^2)
	Station RSP-1			
0 - 15	1.87	9.2[a]	2.40	19.3[a]
	Station RSP-5			
0 - 5.1	1.13		1.50	
5.1 - 10.2	0.51		0.87	
10.2 - 15.2	0.60		0.95	
15.2 - 20.3	0.92		1.19	
20.3 - 25.4	0.73		0.82	
25.4 - 30.5	0.22		0.08	
30.5 - 40.6	<dl		<dl	
40.6 - 50.8			<dl	
0 - 40.6		12.5[b]		14.2[b]

[a] Inventory to 15 cm depth.

[b] Inventory to 40.6 cm depth.

CONCLUSIONS

Since mid-October 1984, the levels of ^{134}Cs and ^{137}Cs, the two radionuclides contributing the major fraction of the estimated dose to individuals (1), and other gamma-emitting radionuclides discharged to Clay Creek from Rancho Seco have been significantly reduced as a result of a liquid-effluent control program initiated by the Sacramento Municipal Utility District. However, the results from our sampling program in 1986 indicate that the radionuclides previously released persist in the downstream environment and are still present in many of the aquatic dietary components, although at concentrations much lower than those measured in 1984 and 1985. The greatly reduced activities in the aquatic environment attest to the effectiveness of the liquid-effluent control program. As in the results generated in 1984 and 1985 (3,6), ^{134}Cs and ^{137}Cs were the primary gamma-emitting radionuclides detected in the edible flesh of different fish, crayfish, and frog legs sampled from the creek for analysis in 1986. The ^{134}Cs in aquatic samples is now approximately 25% of the ^{137}Cs concentration.

Concentrations in the flesh of fish decreased over time and with distance from the plant outfall. These changes in concentrations can be described by exponential equations, the coefficients of which are obtained from a least squares analysis of the data. The mean concentration of ^{137}Cs in fish collected from Laguna Creek below a distance of 7.5 km from Rancho Seco is now comparable to the average concentration determined in fresh-water fish randomly selected from Chicago, Illinois markets. By August 1986, the mean concentration of ^{137}Cs in the flesh of bluegill had fallen to 7% of the concentration measured in fish from comparable locations in 1984 and was 30% of the mean concentration found in these fish during August 1985. Between March 1985 and October 1986, the concentration of ^{137}Cs in bluegill decreased at all stations sampled; the ^{137}Cs had a mean effective half-life of 170 d. The changes in the concentration of ^{137}Cs in frogs closely follow the changes in concentration measured in the flesh of bluegill.

Concentrations in the surface (0 to 12 cm) sections of creek sediments also declined between 1984 and 1986. Between 1985 and 1986, the mean concentration of ^{137}Cs in the surface sediments at all downstream locations decreased resulting in an effective half-life of approximately 2 y.

The values computed for the ^{137}Cs concentration factors are highest for fish from Clay Creek and lowest for fish from Laguna Creek. This trend is evident in the data from samples collected in 1984, 1985, and 1986. We find that stable potassium levels in the water play a role in regulating the magnitude of the ^{137}Cs concentration factor. Potassium levels in the creek water increase in a downstream direction; the higher concentrations are associated with runoff water from nearby fields.

Surface soils collected around a perimeter 11 km from Rancho Seco and from ranchlands closer to the plant, soils not affected by the aqueous releases, showed only concentrations of ^{137}Cs originating from global fallout and no ^{134}Cs. The locations sampled showed no evidence of ^{137}Cs contamination that could be perceived to originate with atmospheric particles from Rancho Seco.

Soil previously irrigated with Clay Creek water retains both ^{134}Cs and ^{137}Cs. Samples of soil collected near station RS-17 in 1986 contained higher inventories of ^{137}Cs than was found in adjacent soil sites sampled in 1984.

We recommend that support for the scientific activities conducted in the vicinity of Rancho Seco be extended through 1987. The studies will provide an uninterrupted record of environmental data to validate the continued effectiveness of the liquid-effluent control program. Recommendations for specific, continuing and new studies will be provided in a proposal for research currently in preparation.

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