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DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

INDUSTRIAL SAFETY AND APPLIED HEALTH PHYSICS DIVISION

TECHNICAL BACKGROUND INFORMATION FOR THE ENVIRONMENTAL AND SAFETY REPORT, VOL. 4: WHITE OAK LAKE AND DAM

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CONTENTS

Page

ACKNOWLEDGMENTS iii

LIST OF TABLES vii

LIST OF FIGURES xiii

HIGHLIGHTS 1

EXECUTIVE SUMMARY 1
- The Problem 1
- Background 2
- Environmental Assessment 3
- Recommendations 4

1. INTRODUCTION 5

2. HISTORY OF WHITE OAK LAKE AND DAM 7
   - 2.1 WHITE WING ROADBED RAISED, 1941 7
   - 2.2 COFFERDAM BUILT, 1943 7
   - 2.3 LAKE LEVEL LOWERED TO 227.2 m (745.3 ft), 1948 9
   - 2.4 WHITE OAK LAKE DRAINED, 1955 9
   - 2.5 WHITE OAK DAM INSPECTION REPORT, 1979 12
   - 2.6 FOLLOW-UP ON RECOMMENDATIONS, DECEMBER 1979 19
   - 2.7 SEEPAGE THROUGH THE DAM 31

3. DESCRIPTION OF WHITE OAK CREEK WATERSHED 40

4. HYDROLOGICAL CONDITIONS OF WHITE OAK CREEK WATERSHED 46

5. REVIEW OF SEDIMENT DATA 69
   - 5.1 REVIEW OF HISTORICAL WHITE OAK CREEK DATA 69
     - 5.1.1 Sediment data, 1945-58 69
     - 5.1.2 Radiation measurements, 1958 89
     - 5.1.3 Summary of historical data for White Oak Lake 101
   - 5.2 RADIOACTIVITY IN THE CLINCH RIVER SEDIMENTS 103
   - 5.3 REVIEW OF WHITE OAK CREEK SEDIMENT DATA, 1978-79 106
     - 5.3.1 White Oak Lake samples, 1979 106
     - 5.3.2 White Oak Creek below WOD sediment samples, 1978-79 116
   - 5.4 ESTIMATE OF ACTIVITY STORED IN THE SEDIMENTS OF WHITE OAK LAKE 116

6. REVIEW OF WATER DATA 126
   - 6.1 WATER DATA, 1949-78 126
   - 6.2 WATER DATA, NOVEMBER-DECEMBER 1979 127

Page

7. INVESTIGATION OF ^{137}Cs, ^{60}Co, and ^{90}Sr CONCENTRATIONS IN WATER AND SEDIMENT AS A FUNCTION OF FLOW IN WHITE OAK CREEK 134
   - 7.1 HIGH-FLUX STUDIES, 1962 134
   - 7.2 HIGH-FLOW STUDY, MARCH 4, 1979 134
   - 7.3 HIGH-FLOW STUDY, JUNE 3-4, 1979 140
   - 7.4 REVIEW OF SEDIMENT TRANSPORT AS A FUNCTION OF FLOW 146

8. PATHWAYS ANALYSIS 148
   - 8.1 CONCENTRATION FACTORS (CF) FOR UPTAKE OF RADIOACTIVITY BY PLANTS AND FISH FROM WATER 148
   - 8.2 UPTAKE OF RADIOACTIVITY OF PLANTS 148
     - 8.2.1 Soil mechanics 148
     - 8.2.2 White Oak Lake plant studies 153
   - 8.3 UPTAKE OF RADIONUCLIDES BY ALGAE 162
   - 8.4 UPTAKE OF RADIOACTIVITY BY FISH IN WHITE OAK LAKE AND CLINCH RIVER 167
     - 8.4.1 General observations 167
     - 8.4.2 Environmental fish-sampling program 172
   - 8.5 UPTAKE OF RADIONUCLIDES BY INSECTS ON WHITE OAK LAKE BED 192
   - 8.6 UPTAKE OF RADIOACTIVITY BY OTHER ANIMALS 197
   - 8.7 RADIONUCLIDE UPTAKE IN WATERFOWL AT WHITE OAK LAKE BED AND OTHER NUCLEAR FACILITIES 208
   - 8.8 SUMMARY OF PATHWAYS ANALYSIS 215

9. RADIOLOGICAL DOSE COMMITMENTS 219

10. NEED FOR A MONITORING SYSTEM AND SPILLWAY IMPROVEMENTS AT WHITE OAK DAM 221

REFERENCES 227

LIST OF TABLES

Table Page

2.1 Temperature data from White Oak Dam observation program 38

4.1 Lake area vs elevation 47

4.2 Lake elevation vs volume 48

4.3 Estimated maximum depth of White Oak Lake at elevation 227 m (745 ft) vs year, 1953-1979 49

4.4 Daily flow duration values for White Oak Creek at WOD (1953-55, 1960-63) 50

4.5 Number of days flow exceeded 4.25 m/s (150 cfs) at WOD during calendar years 1972 through 1979 51

4.6 Estimated flood discharge [m^3/s (cfs)] of specified recurrence intervals computed by the method proposed by Speer and Gamble (1964) 51

4.7 Precipitation data for Oak Ridge Townsite station from 1951 through 1973 53

4.8 Estimates of flood discharge (cfs) of various recurrence intervals computed by the method proposed by Sheppard (1974), White Oak Creek at WOD 54

4.9 Estimates of flood discharge [m^3/s (cfs)] at WOD of various recurrence intervals computed from the equations obtained by Randolph and Gamble (1976) 55

4.10 Data at White Oak Dam for four floods 57

5.1 Total activity of White Oak drainage system, 1945-46 71

5.2 Total activity in White Oak Lake, 1948-52 72

5.3 Comparison of upper and lower White Oak Lake soils in 1959 73

5.4 Changes in ^{90}Sr in White Oak Lake bed 75

5.5 Concentrations of radionuclides and chemical properties of soil plots in White Oak Lake bed, 1958 77

Table Page

5.6 Distribution of gross gamma activity in the bed of White Oak Lake, 1961 . . . 79

5.7 Quantity and distribution of radionuclides in White Oak Lake bed, 1962 . . . 86

5.8 Distribution of ^{90}Sr and ^{137}Cs from sediments collected in White Oak Lake bed and the mouth of White Oak Creek, 1970 . . . 90

5.9 Summary of radionuclide concentrations of bottom sediments for White Oak Lake, 1972 . . . 91

5.10 Radionuclide content of cores obtained from Clinch River . . . 105

5.11 Sediment data (nCi/g wet), White Oak Lake, 1979 . . . 112

5.12 Cesium-137 concentration in White Oak Lake cores, 1979 . . . 113

5.13 Cobalt-60 concentration in White Oak Lake cores, 1979 . . . 114

5.14 Strontium-90 concentration in White Oak Lake cores, 1979 . . . 115

5.15 Quantity and distribution of radionuclides in sediment cores from White Oak Creek downstream from dam, 1979 . . . 118

6.1 Annual discharges of radionuclides to the Clinch River, 1949 to 1978 . . . 128

6.2 Total amount of radionuclides discharged into Clinch River, 1949-80 . . . 131

6.3 Water data, White Oak Dam, November-December 1979 . . . 133

8.1 Reported concentration factors (CF) for various classes of freshwater edible organisms . . . 152

8.2 Comparisons of radionuclide content in native plant species 1957 and 1958 . . . 155

8.3 Accumulation of radionuclides in 1 m^2 of vegetation percent of total soil burden of radionuclides . . . 157

8.4 Uptake of radionuclides by plants growing in pens on upper White Oak Lake bed, June 1962 . . . 158

8.5 Concentrations of elements in corn (*Zea mays*) . . . 160

Table Page

8.6 Summary of concentrations of radionuclides in three species of forage plants in White Oak Lake bed 161

8.7 Summary of radionuclide concentrations in White Oak Lake bed vegetation studies 163

8.8 Summary of recommended bioaccumulation factors for algae 166

8.9 Radioactivity in algae on surface of White Oak Lake, 1979 168

8.10 Radioactivity in fish taken in White Oak Lake and the Clinch River, 1948 171

8.11 Concentration of radionuclides in Clinch River fish, 1960 through 1965 173

8.12 Radionuclide content of Clinch River fish 175

8.13 Estimated percentage of MPI that man may attain by eating Clinch River fish 176

8.14 Radionuclide content of Clinch River fish, 1971 176

8.15 Radionuclide content of Clinch River fish, 1972 177

8.16 Radionuclide content of Clinch River fish, 1973 177

8.17 Radionuclide content of Clinch River fish, 1974 177

8.18 Radionuclide content of Clinch River fish, 1975 178

8.19 Radionuclide content of Clinch River and Melton Hill Lake fish, 1976 179

8.20 Radionuclide content of Clinch River fish, 1977 180

8.21 Radionuclide content in Clinch River fish, 1978 181

8.22 Radionuclide content in Clinch River fish, 1979 182

8.23 Radionuclide content in Clinch River fish, 1980 183

8.24 Strontium and strontium-90 in white crappie bone 185

8.25 Concentration and concentration factors of three radionuclides in five species of fish from White Oak Lake 187

Table | Page

8.26 Concentration of ^{137}Cs in bluegill of different sizes in White Oak Lake 187

8.27 Concentration of ^{137}Cs in White Oak Lake fish 188

8.28 Cobalt-60 in black bullhead tissues after 32 d of excretion and cobalt-60 in tissues of White Oak Lake bullheads 189

8.29 Concentration of ^{137}Cs and ^{60}Co in bluegills, goldfish, and gizzard shad from White Oak Lake, April 1969 through May 1970 191

8.30 Concentrations of ^{90}Sr and ^{137}Cs in insects feeding on vegetation of White Oak Lake bed, 1959 193

8.31 Comparison of 1958 and 1961 estimates of ^{137}Cs and ^{90}Sr concentrations in the plant-to-insect food chain on White Oak Lake bed, 1962 195

8.32 Distribution of radioisotopes along arthropod food chains on White Oak Lake bed's west seep area 196

8.33 Results of radioanalyses of lake-bed mammals 200

8.34 Concentrations of radionuclides in cotton rats of White Oak Lake bed, area 3 202

8.35 Comparison of specific activity of radiostrontium in bone and radiocesium in muscle of birds from different zones and seasons 203

8.36 Estimated amounts of ^{90}Sr and ^{137}Cs present at different trophic levels 203

8.37 Calculated and radioassay body burdens of radionuclides for two cotton rats from lower White Oak Lake bed 205

8.38 Concentrations and whole-body burdens (exclusive of GI-tract contents) of radionuclides in four cotton rats from lower White Oak Lake bed 206

8.39 Concentrations of radionuclides in one cotton rat, two white-footed mice, and one pine mouse from shoreline of lower White Oak Lake bed 207

8.40 Estimated input of ^{137}Cs and stable cesium by migratory waterfowl during 1970 210

Table Page

8.41 Deposition rate and accumulation of ^{137}Cs from precipitation 211

8.42 Bioaccumulation factors for ^{137}Cs in waterfowl 212

8.43 Radionuclide concentrations of duck tissues 212

8.44 Mean concentration of radionuclides in tissue samples from experimental mallards analyzed at capture and after 52 days of biological and physical elimination 213

8.45 Calculated potential maximum whole body dose to man consuming waterfowl from the Test Reactor Area Radioactive Leaching Pond 214

LIST OF FIGURES

Figure		Page
2.1	Cross section of Highway 95 at White Oak Lake (1941)	8
2.2	White Oak Dam, looking downstream from lake, 1950	10
2.3	White Oak Dam, looking from roadway, 1950	11
2.4	Aerial photograph of White Oak Lake bed soon after draining, 1955	13
2.5	Revegetated White Oak Lake bed, 1956	14
2.6	Revegetated White Oak Lake bed, 1956	15
2.7	Aerial view of White Oak Lake bed after a period of flooding, 1956	16
2.8	Aerial view of White Oak Lake indicating higher lake level after period of flooding in October 1956, looking west to east	17
2.9	Aerial view of White Oak Lake indicating higher lake level after period of flooding in October 1956, looking east to west	18
2.10	White Oak Lake before draining began, 1979	20
2.11	White Oak Lake after draining, 1979	21
2.12	White Oak Lake after draining, 1979	22
2.13	Upper portion of White Oak Lake after draining, 1979	23
2.14	Upper portion of White Oak Lake after draining, 1979	24
2.15	Downstream bed of White Oak Dam (looking north) just before vegetation removal, December 1979	25
2.16	Downstream bed of White Oak Dam (looking north) just after vegetation removal, December 1979	26
2.17	Downstream bed of White Oak Dam (looking south) just after vegetation removal, December 1979	27
2.18	Upstream bed of White Oak Dam (looking south) just after vegetation removal, December 1979)	28

Figure		Page
2.19	Upstream bed of White Oak Dam (looking north) just after vegetation removal, December 1979	29
2.20	Schematic cross section of the berm at White Oak Dam	30
2.21	White Oak Dam berm, March 20, 1980	32
2.22	Design plan of the new discharge structure	33
2.23	Downstream side of White Oak Dam, looking north toward the seeps	34
2.24	Seep No. 1 in White Oak Dam (appearing in the right center of the photograph)	35
2.25	Seep No. 2 in White Oak Dam (appearing in the center of the photograph)	36
2.26	View from White Oak Dam toward the Clinch River, showing combined seep flow entering White Oak Creek	37
3.1	Map showing White Oak Creek watershed	41
3.2	White Oak Creek drainage basin	43
4.1	Frequency of maximum after precipitation at Oak Ridge for 1-, 3-, 24-, and 48-h storms	52
4.2	Flood frequency curves for monitoring stations 3, 4, and 5	56
4.3	Monitoring station at White Oak Dam	58
4.4	White Oak Lake at elevation 227.1 m (745 ft)	59
4.5	White Oak Creek downstream of the dam [Watts Bar Lake elevation, 225.6 m (740 ft)]	60
4.6	Normal flow over White Oak Dam weirs at elevation 227.1 m (745 ft)	61
4.7	High flow over White Oak Dam on Apr. 3, 1977, scene 1	62
4.8	High flow over White Oak Dam on Apr. 3, 1977, scene 2	63
4.9	High flow over White Oak Dam on Apr. 3, 1977, scene 3	64
4.10	High flow over White Oak Dam on Apr. 3, 1977, scene 4	65
4.11	High flow over White Oak Dam on Apr. 3, 1977, scene 5	66

Figure Page

4.12 White Oak Creek downstream of the dam on Apr. 7, 1977 . . . 67

4.13 White Oak Creek downstream of the dam after the lake began to recede, April 1977 68

5.1 Sediment sampling locations during 1945 and 1946 70

5.2 Changes in ^{90}Sr in upper and lower White Oak Lake bed . . . 74

5.3 Map of White Oak Creek drainage basin 76

5.4 Location of 61-cm (2-ft) core samples in bed of former White Oak Lake, 1962 80

5.5 Map of former White Oak Lake bed (1962) showing thickness of contaminated sediment 81

5.6 Map of White Oak Lake bed showing ^{137}Cs concentrations in 10^{-3} µCi per gram of dry weight for 0 to 15 cm (0 to 6 in.) of soil layer, 1962 83

5.7 Map of White Oak Lake bed showing ^{137}Cs concentrations in 10^{-3} µCi per gram of dry weight for 15 to 30 cm (6 to 12 in.) of soil layer, 1962 84

5.8 Map of White Oak Lake bed showing ^{90}Sr concentrations in pCi per gram of dry weight for 0 to 15 cm (0 to 6 in.) of soil layer, 1963 85

5.9 Distribution of radioactivity in White Oak Creek, 1964 . . . 87

5.10 Concentration of ^{137}Cs in White Oak Lake core samples . . . 88

5.11 Average concentration of radionuclides present in the top 4 in. of White Oak Lake bed soil (grid area, 1958) . . . 93

5.12 View of ecology grid area (White Oak Lake bed) 94

5.13 Aerial view of agricultural plot 95

5.14 Air dose rates 1 m above the ecology grid area (10-m grid of lower White Oak Lake bed), 1958 96

5.15 Air dose rates 1 m above the ungridded ecology study area (upper lake bed), 1958 97

5.16 Air dose rates 1 m above White Oak Lake bed in 15-mR/h increments, 1958 98

Figure Page

5.17 Sediment deposit and associated radiation field (White Oak Lake bed), 1958 99

5.18 Sediment deposit and associated radiation field (White Oak Lake bed), 1958 100

5.19 Aerial view showing relative location of ORNL waste disposal pits (in foreground) to White Oak Lake bed 102

5.20 Cesium distribution in the sediment of Clinch River, 1977 107

5.21 Cobalt distribution in the sediment of Clinch River, 1977 108

5.22 Strontium distribution in the sediment of Clinch River, 1977 109

5.23 Radionuclides discharged in water and sediment concentration in Clinch River, 1954-1963 110

5.24 Map of White Oak Lake showing sampling locations, 1979 . . . 111

5.25 Sediment sampling locations in White Oak Creek, December 1979 117

5.26 Cesium-137 content (Bq/g) in White Oak Creek sediment, 1978 sampling program 122

5.27 Cobalt-60 content (Bq/g) in White Oak Creek sediment, 1978 sampling program 123

5.28 Cesium-137 content in core 23, 1978 sampling program 124

5.29 Cobalt-60 content in core 23, 1978 sampling program 125

6.1 Percent of MPC_w total over White Oak Dam 129

6.2 Percentage concentration guide levels in the Clinch River 130

6.3 Curies discharged over White Oak Dam 132

7.1 Stream flow, concentration of suspended solids, and ^{90}Sr and ^{137}Cs transport in White Oak Creek resulting from light rainfall 135

7.2 Water flow profile over White Oak Dam, 0330 Mar. 4 to 2400 Mar. 5, 1979 137

Figure | Page

7.3 Sediment transfer over White Oak Dam, 0330 Mar. 4 to 2400 Mar. 5, 1979 138

7.4 Temporal variation of radionuclide transport in sediments over White Oak Dam, 0330 Mar. 4 to 2400 Mar. 5, 1979 139

7.5 Temporal variation of radionuclide transport in solution over White Oak Dam, 0330 Mar. 4 to 2400 Mar. 5, 1979 141

7.6 Water flow over White Oak Dam gate 1600 June 3 to 1500 June 4, 1979 142

7.7 Solid transport over White Oak Dam 1600 June 3 to 1500 June 4, 1979 143

7.8 Radionuclide transport over White Oak Dam (solution) 1600 June 3 to 1500 June 4, 1979 144

7.9 Radionuclide transport over White Oak Dam (solids) 1600 June 3 to 1500 June 4, 1979 145

7.10 White Oak Dam June 3 to June 4, 1979, Ca and Mg in H_2O 147

8.1 Exposure pathways to man 149

8.2 Pathways between radioactive materials released to ground and surface water and man 150

8.3 Exposure pathways to organisms other than man 151

8.4 White Oak Lake bed, ecology study area, distribution of vegetation, July 1957 154

8.5 View of agricultural crops planted on the lake bed in 1957 159

8.6 Vertical distribution of activity density in the periphyton biomass, 1954 164

8.7 Accumulation of algae behind boom at White Oak Dam 169

8.8 Numbers of small mammals caught per 100 trap-nights in lake bed and old field areas 198

8.9 Distribution of radionuclide concentrations in small mammals of the upper White Oak Lake bed 201

Figure **Page**

8.10 Waterfowl in the vicinity of White Oak Lake, December 1979 216

8.11 Waterfowl in the vicinity of White Oak Lake. December 1979 217

8.12 Waterfowl in the vicinity of White Oak Lake, December 1979 218

10.1 Concentration of ^{90}Sr in the sediment of White Oak Creek and its tributaries 223

10.2 Concentration of ^{137}Cs in the sediment of White Oak Creek and its tributaries 224

10.3 Concentration of ^{60}Co in the sediment of White Oak Creek and its tributaries 225

TECHNICAL BACKGROUND INFORMATION FOR THE ENVIRONMENTAL AND SAFETY REPORT, VOL. 4: WHITE OAK LAKE AND DAM

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HIGHLIGHTS

This report has been prepared to provide background information on White Oak Lake for the Oak Ridge National Laboratory Environmental and Safety Report. The paper presents the history of White Oak Dam and Lake and describes the hydrological conditions of the White Oak Creek watershed. Past and present sediment and water data are included; pathway analyses are described in detail.

EXECUTIVE SUMMARY

The Problem

In 1979, geological studies of White Oak Dam (WOD) indicated that it had suffered internal erosion that could lead to subsidence of the dam. Five alternatives were proposed for the solution to this problem:

A. Leave the current dam with the lake at its old elevation of 227 m (745 ft). This alternative may entail both short-term (such as a berm below the dam) and long-term (such as grout curtains above and below the dam) efforts to stabilize the current structure.

B. Leave the current dam with the lake at a lower elevation. This alternative will entail short-term efforts (such as a berm); long-term efforts may not be necessary.

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C. Build a new dam to replace the current one.

D. Remove the dam and let White Oak Creek return to its natural state.

E. Build a new weir and bypass structure.

Before deciding on which course to pursue, the environmental impacts of each alternative was evaluated. The following sections present an evaluation of each alternative.

Background

WOD was constructed in 1943 to create a holdup basin for ORNL wastes. The dam stayed in operation until 1955, when White Oak Lake was drained. It remained in this state because of ecological studies until 1962, when White Oak Lake was again formed for waste holdup.

Before lowering the lake in 1979, the dam impounded approximately 6.4×10^4 m^3 (2.3×10^6 ft^3) of water at an elevation of 227.1 m (745 ft). This lake collects drainage from a 15.5-km^2 (6-sq mile) area and discharges to the Clinch River (CR) at CR km 33.5 (mile 20.8). Over the years, ~1.3×10^5 m^3 (4.6×10^6 ft^3) of sediment has collected behind the dam, containing an estimated 23.8 TBq (644 Ci) of radioactivity, mostly ^{60}Co, ^{90}Sr, ^{137}Cs and trace amounts of ^{152}Eu and ^{154}Eu. For the top 15 cm of sediment, the transuranic nuclide content (^{238}Pu, ^{239}Pu, ^{241}Am, and ^{244}Cm) is estimated to be 0.03 TBq (0.87 Ci), mostly ^{244}Cm.

In addition to this sediment radioactivity, the lake water itself contains quantities of ^{3}H and ^{90}Sr and trace amounts of other nuclides (i.e., ^{60}Co, ^{106}Ru, ^{131}I, ^{137}Cs, ^{239}Pu, ^{241}Am, and ^{244}Cm). These nuclides are released over WOD to the Clinch River. A monitoring station is located at the dam in order to monitor the Laboratory's discharges.

During periods of heavy rainfall, both waterborne activity and contaminated sediment are released from the lake. Cesium-137 releases increase rapidly with flow due to increased sediment transport. Cobalt-60 and strontium-90, carried mainly in solution, increase to a lesser extent.

The impact on the environment from these discharges results from accumulation of the released activity by plants and animals. Pathways to man are created when these plants and animals are consumed, with the activity moving along the food chain. Of special concern are those plants and animals which can easily migrate from White Oak Lake to the public domain. Algae, insects, fish, and waterfowl fall into this category.

Environmental Assessment

The environmental assessment of the four alternatives is discussed as follows:

A. Raise the level in White Oak Lake to its old elevation [227 m (745 ft)]

The direct effects of refilling the lake would be the stirring up of sediments now exposed. Pathways to humans include release of fish and aquatic life to the Clinch River and uptake of activity by waterfowl. The most serious impact, however, would be a postulated failure of the dam and the subsequent release of contaminated sediment. While this release would not lead to a significant drinking water problem, the uptake by fish of the activity in the sediments could be a more significant long-term problem. It is estimated that between 20-50% of the contaminated sediment might be released into the Clinch River if the dam failed.

B. Lower White Oak Lake to elevation 226.2 m (742 ft)

This is the course of action currently being taken. Direct effects of this alternative would include erosion of exposed sediments and the possibility of dry sediment creating a dust problem. Discharge of sediment over the dam is a lesser problem as long as the lake level stays above elevation 226.2 m (742 ft). High flows will increase sediment discharges. The same pathways to humans exist here as with alternative A.

C. Remove White Oak Dam

The greatest danger of this option is the uncontrolled release of the contaminated sediments to the Clinch River. Reseeding would slow but not stop this release. Removal of the sediment will eliminate this danger as long as the exhumed sediment is disposed of safely. The cost of the removal and disposal of this large volume of sediment 1.3×10^5 m^3 (4.6×10^6 ft^3) could be as high as \$30/ft^3.

D. Replace White Oak Dam with a new structure

This alternative would have the same impact as alternative A; however, failure of the dam would no longer be a consideration.

E. Build new weir and bypass sturcture

This alternative would have the saw impact as alternativer A. A small amount of sediment would be released during construction.

Recommendations

Recommendations for the short term and long term are as follows:

A. Short term

1. The current WOD structure should be stabilized.
2. White Oak Lake should be maintained at or above 226.2 m (742 ft) until the White Oak Dam structure is stabilized.
3. All areas where White Oak Lake sediments have been exposed should be seeded to minimize erosion.
4. Methods to place screens over the existing weir to prevent the escape of fish and algae from White Oak Lake should be investigated.
5. Methods to prevent ducks and other waterfowl from feeding around White Oak Lake should be investigated.

B. Long term

1. A new weir and bypass structure should be constructed.
2. A permanent structure should be maintained at WOD to perform three functions:
    a. to contain the contaminated sediment which has accumulated above the dam,
    b. to monitor Laboratory effluents (some sources can not be monitored by any other on-site monitors), and
    c. to provide an emergency holdup capability in the event of a major spill.
3. Once the new weir is installed and the WOD is stabilized, the lake level should be raised back to 227 m (745 ft).

1. INTRODUCTION

The White Oak Dam is an earthfill and rock structure located on Department of Energy (DOE) controlled property in Oak Ridge, Tennessee. The dam, which is crossed by Tennessee Highway 95, is approximately 91.4 m (300 ft) long, 4.6 m (15 ft) high, and 10.7 m (35 ft) wide at its crest. The location is 3.2 km (2 miles) north of the Tennessee 95 (Melton Hill) exit on Interstate 40, about 40.2 km (25 miles) west of Knoxville.

A coffer dam was placed in front of the existing box culvert in 1943 to impound White Oak Lake, which serves as a dilution basin for low levels of radioactivity discharged from Oak Ridge National Laboratory (ORNL). It is approximately 3.7 km (2.3 miles) downstream from ORNL and 1 km (0.6 mile) upstream from the point where White Oak Creek enters the Clinch River (Watts Bar Lake).

The dam is described as a low-head structure, since at its normal level elevation 227.1 m (745 ft) White Oak Lake stands only 0.9 m (3 ft) above full pool in the Clinch River 226.2 m (742 ft). The lake covers an area of 10.1 hectares (25 acres) extending due east of the dam and has a maximum depth of 1.5 to 1.8 m (5 to 6 ft). The lake and White Oak Creek which feeds it drain an area of 15.5 km^2 (6 square miles), which includes the 1173.6-hectare (2900-acre) ORNL site.

Water passing over the gate that controls the lake level enters a concrete-box culvert running through the dam and then flows the short distance into the Clinch River. Radioactivity levels are monitored continuously at the dam and at several downstream locations.

Following geological studies (1979) which indicated the possibility of some internal erosion that could lead to subsidence of the dam, causing road damage, DOE determined on November 20, 1979, that White Oak Lake should be lowered 0.9 m (3 ft) to the present elevation of 226.2 m (742 ft). This was done to relieve pressure on the dam and permit a better assessment of repairs believed to be necessary. The State Highway Department also took action to limit vehicle loads to a maximum of 4.5 tonnes (5 tons) over that section of Highway 95, pending further assessment of the dam's condition.

Construction of a berm to stabilize the dam was completed on March 20, 1980. Vehicle loads on Highway 95 have been returned to normal and the future plans are for the elevation of White Oak Lake to be returned to 227.1 m (745 ft). Construction on the new weir and bypass structure began in August 1981. A description of the new structure is contained in *Conceptual Design Report for Streamflow Monitoring and Control System Improvement*, Project No. 80-ORNL, ORNL-X-OE-61, Oak Ridge, Tennessee, August 1978.

The purpose of this report is threefold:

a. To summarize the history of White Oak Lake and White Oak Dam, including construction of the dam, modifications made over the years, and the events which have led to the dam's current condition;

b. To describe the physical systems which affect the dam and the lake it impounds and the interaction between the lake and surrounding plant and animal life; and

c. To assess the environmental consequences of White Oak Lake.

2. HISTORY OF WHITE OAK LAKE AND DAM

2.1 WHITE WING ROADBED RAISED, 1941

In July 1941, the Tennessee Valley Authority (TVA) prepared a set of plans for a fill to be placed over the old roadway on White Wing Road (State Highway 95) across White Oak Creek. This work was proposed in order to raise the height of the fill and to widen it. Construction was completed in the fall of 1941 and involved extending the existing 4.9 x 3.7 m (16 x 12 ft) culvert and placing fill over this part of the road (Smith, 1945).

The fill was composed of 1.3- to 2.5-cm (0.5- to 1-in.) particles of shale (Fig. 2.1), which was available on site and constituted an easily compacted and desirable roadway fill. In order to provide a dilution basin for Laboratory waste, it was deemed necessary in the spring of 1943 to employ this roadway section as a dam for White Oak Creek. A cofferdam was to be placed at the inlet side of the existing culvert. This cofferdam was designed to hold water in the pond at elevation 228.6 m (750.0 ft) (Smith, 1945).

2.2 COFFERDAM BUILT, 1943

In the fall of 1943, an interlocking steel cofferdam was built and equipped with two control gates. The upper one was 1.2 x 1.8 m (4 x 6 ft) with the top elevation at 228.6 m (750.0 ft), and the lower one was 1.2 x 1.2 m (4 x 4 ft) with the bottom elevation at 226.2 m (742.0 ft). Part of the roadway section was removed during construction in order to provide a bypass for White Oak Creek. This portion was backfilled with shale, and traffic was allowed to continue. No stone was placed on this backfilled section as had been done on the rest of the roadway. WOD is approximately 7.6 m (25 ft) in maximum height with a length slightly under 91.4 m (300 ft). Water passing over the gate that controls the lake level enters a concrete-box culvert running through the dam. On September 29, 1944, floodwaters raised the lake elevation to 229.7 m (753.6 ft), which was 0.3 m (1 ft) over the top of the roadway. [Note: The top of the road is now at 230.0 m (754.6 ft)]. This flood washed out the upper dike on White Oak Creek. The concern over whether or not the dam was safe under flood conditions resulted in an investigation of the structural strength of the dam in 1944 (Smith, 1945). Some of the recommendations from this study were:

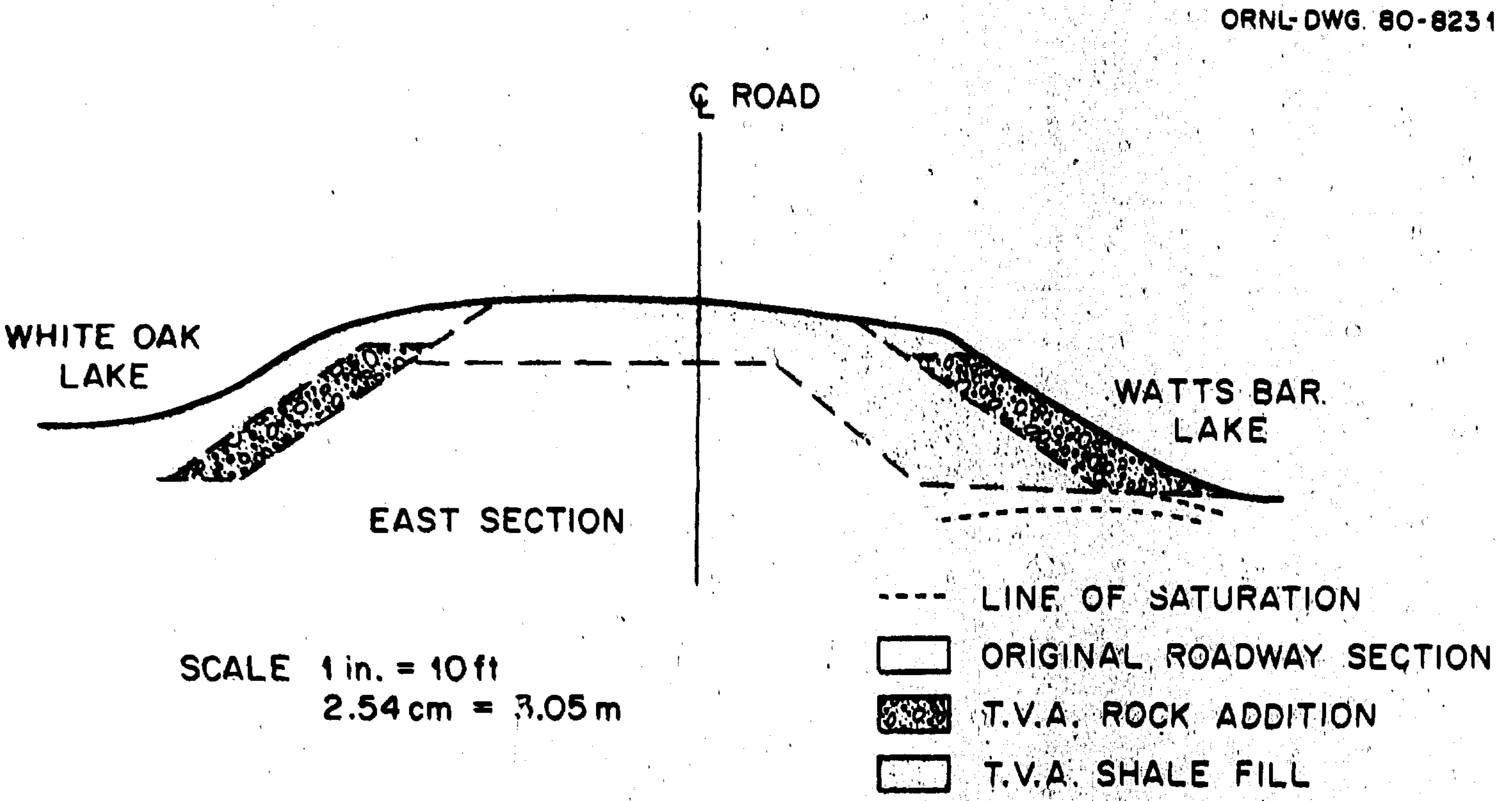

Fig. 2.1. Cross section of Highway 95 at White Oak Lake (1941).

(1) Maintain the lake elevation at 227.5 m (746.5 ft), since very little could be gained by maintaining the lake level below 227.5 m due to storm events.
(2) Open both gates during storm events.
(3) Stabilize the rock of the downstream face and place riprapping on the downstream face around the culvert.

The lake level remained at 227.5 m (746.5 ft) until June of 1948.

2.3 LAKE LEVEL LOWERED TO 227.2 m (745.3 ft), 1948

At this time the lake level was lowered to elevation 227.2 m (745.3 ft) in order to facilitate mud sampling. During flood stages the level was over 228.9 m (751 ft). Normal operation from 1948 to 1955 was between elevations 227.7 m (747 ft) and 228.3 m (749 ft) (Setter and Kochtitzky, 1950). Photographs of the earth dam, cofferdam, screen, and discharge gate in 1950 are shown in Figs. 2.2 and 2.3.

Below WOD, the creek constitutes an embayment of Watts Bar Reservoir. At full pool level [elevation 225.9 m (741 ft)], backwater from Watts Bar extends up the Clinch River and up White Oak Creek to WOD. However, at 225.9 m about half the White Oak embayment is less than 1.8 m (6 ft) deep, and at the lower end is less than 0.3 m (1 ft). With drawdown of Watts Bar [224 m (735 ft) elevation], these depths are reduced (Setter and Kochtitzky, 1950).

2.4 WHITE OAK LAKE DRAINED, 1955

By 1954, White Oak Lake was in equilibrium with White Oak Creek in terms of its ability to dilute and otherwise hold up radioactive materials (Lee and Auerbach, 1959). In order to provide the Laboratory with more volume for holdup in case of a large release and to reduce the probability of ducks residing on the contaminated water, the fish populations were poisoned and removed, and the lake was drained in October 1955 (Burnett, 1979; Abee, 1980).

The alluvial material which comprised the lake bottom contained various amounts and kinds of transported soil and subsoil. This material came in contact with solutions containing radioactive materials. Draining was done

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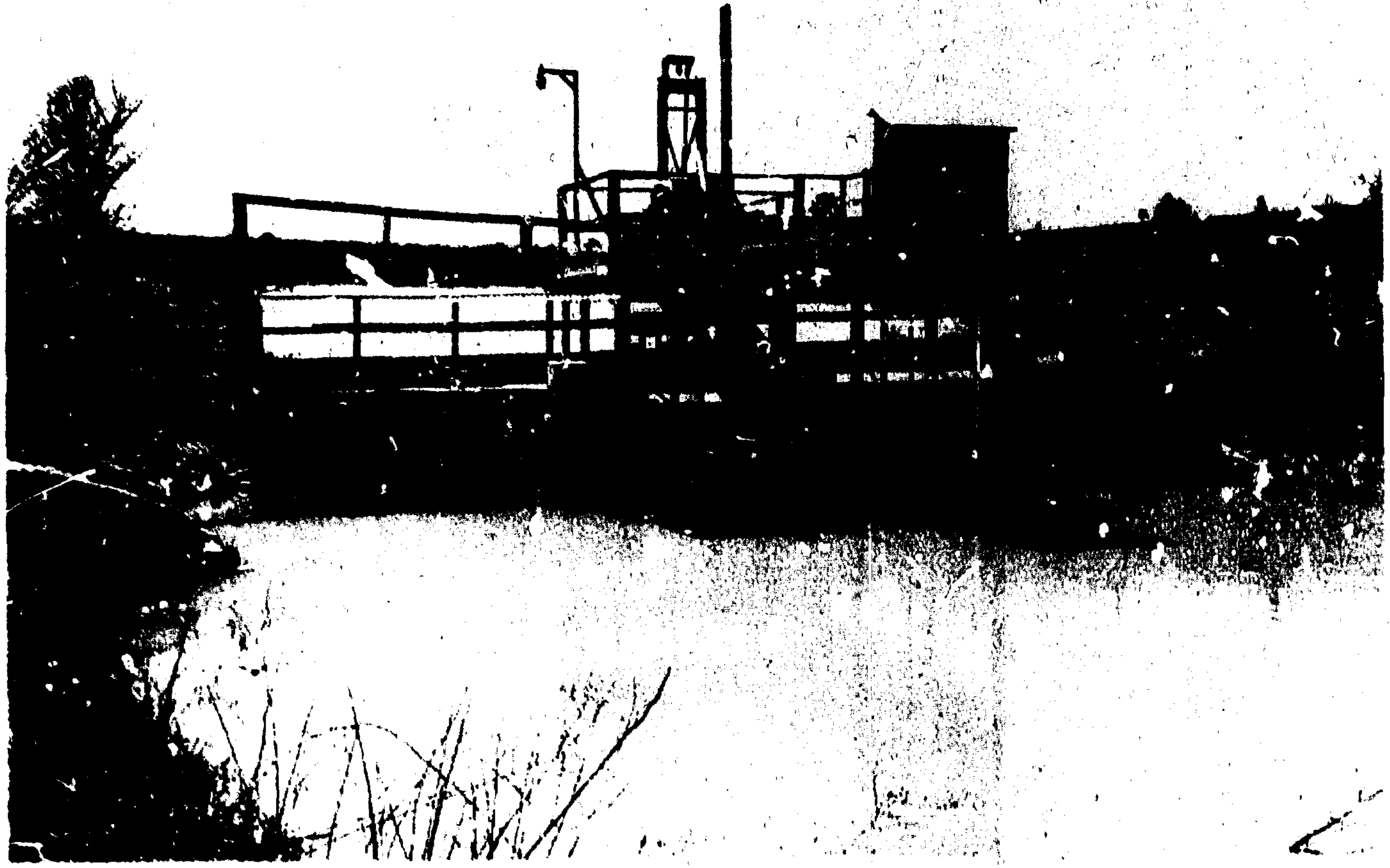

Fig. 2.2. White Oak Dam, looking downstream from lake, 1950.

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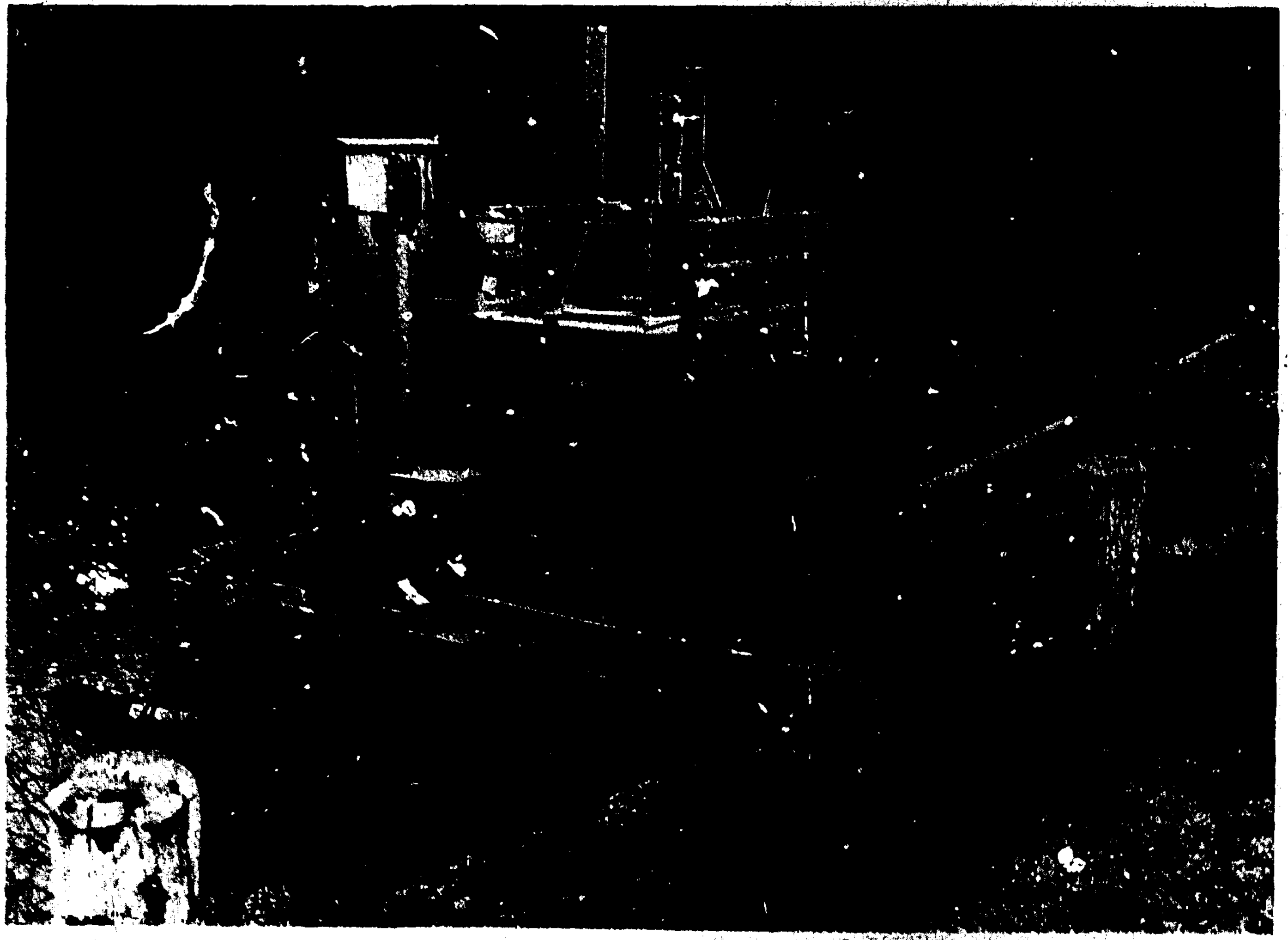

Fig. 2.3. White Oak Dam, looking from roadway, 1950.

slowly so that nearly all the alluvial material remained, leaving a base, silty area, which is shown in Fig. 2.4. Revegetation of the bed occurred rapidly (see Figs. 2.5 and 2.6). Among the invading species were sedge and smartweed. By June 1956, most of the bed was covered. Figure 2.7, a photograph taken in October 1956 after a period of flooding, shows the creek to be flowing through the upper lake bed in two channels in addition to the normal one. Aerial photographs of White Oak Lake, after the 1956 flood, looking west to east and east to west are shown in Figs. 2.8 and 2.9 respectively. In order to allow the lake to be lowered to elevation 225.6 m (740 ft), modification to the WOD gates was made in 1959 (Abee, 1980).

In 1961, an investigation was made to determine the extent of sediment deposition and/or losses in the lake bed since the draining in 1955. A previous investigation by TVA indicated that as of June 1953 the lake bed contained 29,170 m^3 (1,030,000 ft^3) of sediment with an average annual buildup of 2830 m^3 (100,000 ft^3). Measurements of the depth of sediment in 1961 were compared with those made by TVA in 1953. The results indicated:

(1) The channel of White Oak Creek, which was filled with sediments before the lake was drained, for the most part eroded to its pre-impoundment depth.

(2) The depth of sediments over the lower one-third of the bed, with the exception of the stream channel, was approximately the same as reported in 1953.

(3) The middle and upper two-thirds of the lake had slightly less sediment than that reported in 1953.

Therefore, approximately 4250 m^3 (150,000 ft^3) of silt left the lake bed due to channel erosion.

2.5 WHITE OAK DAM INSPECTION REPORT, 1979

In October 1979, a safety evaluation of WOD was conducted. This study consisted of several field inspections, ten borings taken into the dam along its crest (adjacent to Tennessee Highway 95), and laboratory testing of the resulting cores. Four boring holes were converted for monitoring purposes: two were converted into observation wells; piezometers were installed in the other two holes.

ORNL PHOTO 15903

Fig. 2.4. Aerial photograph of White Oak Lake bed soon after draining, 1955.

ORNL PHOTO 41339

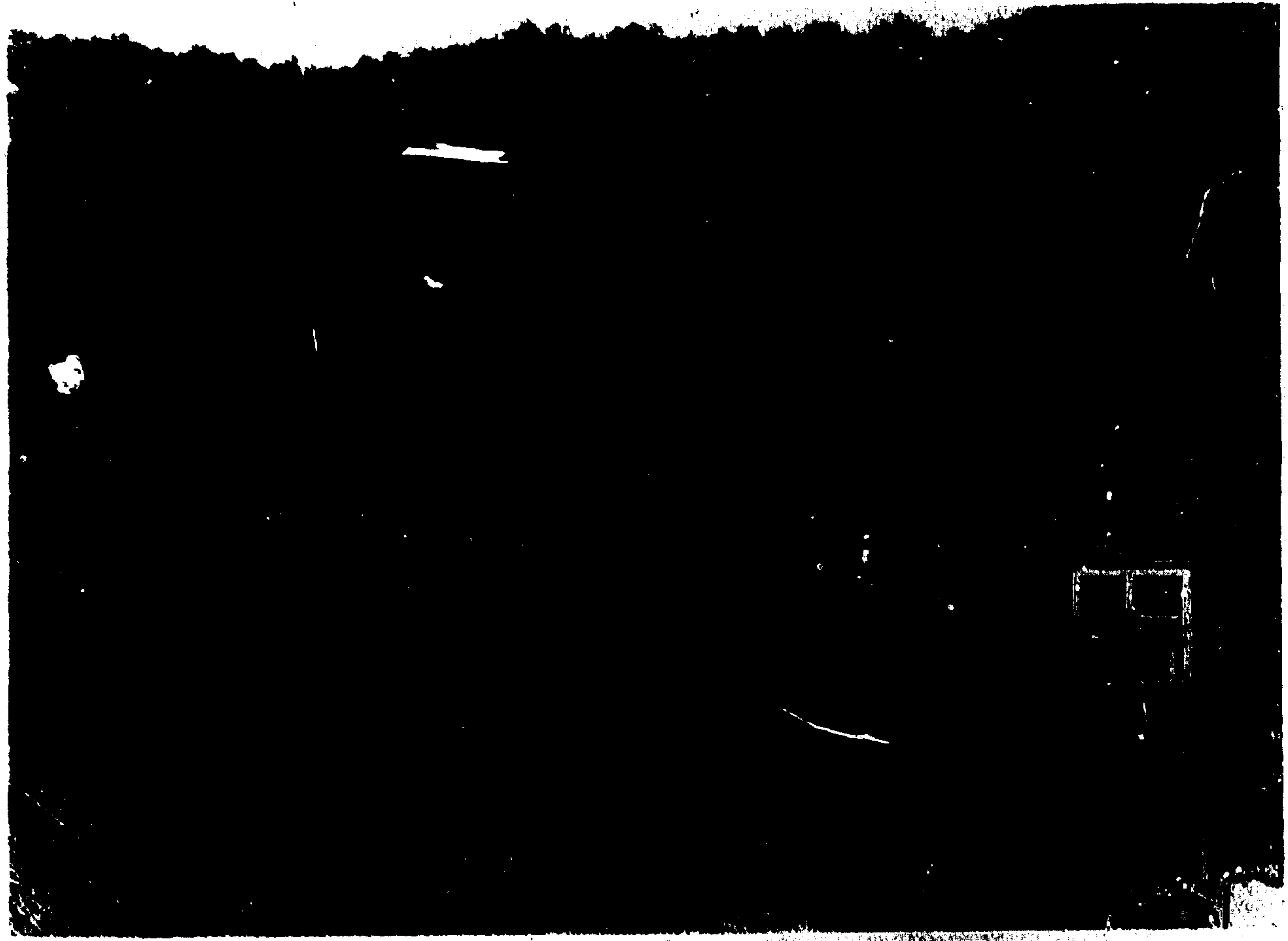

Fig. 2.5. Revegetated White Oak Lake bed, 1956.

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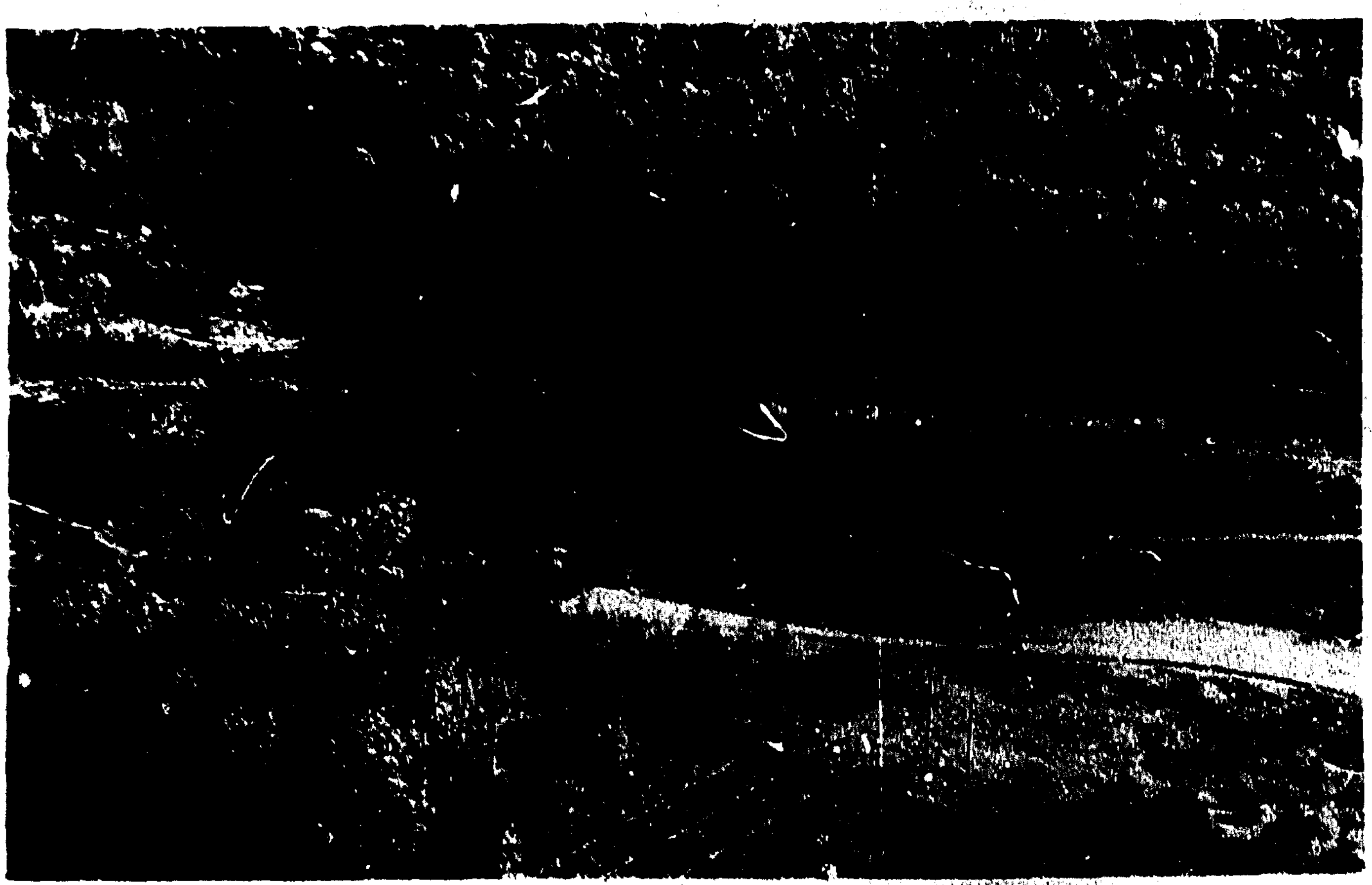

Fig. 2.6. Revegetated White Oak Lake bed, 1956.

ORNL PHOTO 19238

Fig. 2.7. Aerial view of White Oak Lake bed after a period of flooding, 1956.

ORNL PHOTO 19247

Fig. 2.8. Aerial view of White Oak Lake indicating higher lake level after period of flooding in October 1956, looking west to east.

ORNL PHOTO 19246

Fig. 2.9. Aerial view of White Oak Lake indicating higher lake level after period of flooding in October 1956, looking east to west.

2.6 FOLLOW-UP ON RECOMMENDATIONS, DECEMBER 1979

The results of this evaluation indicated the possibility of some internal erosion that could lead to subsidence of the dam. Internal erosion was indicated by the existence of several fluid zones within the dam that were uncovered by the borings. Recommended remedial measures included a clearing operation to remove vegetation along the dam slopes and a weekly inspection program.

In response to these recommendations, staff members of Oak Ridge National Laboratory took the following actions:

(1) A gradual reduction in lake level behind the dam to reduce the hydrostatic pressure on the structure. This program, which commenced on November 20, 1979, brought the lake level from 227.3 m (746 ft) above Mean Sea Level (MSL) to 226.2 m (742.2 ft) above MSL (see Figs. 2.10 through 2.14).

(2) In accordance with other recommendations, both slopes of the dam were cleared of all vegetation (see Figs. 2.15 through 2.19).

(3) A series of monitoring programs began around the dam. Horizontal and vertical alignment of the dam structure was monitored, elevation and temperature data were collected from the lake and the observation wells, and seep temperature and suspended solids data were also collected.

Methods to stabilize the dam were then evalutated. The options considered were:

(1) The placement of a sand berm on the downstream side of the dam, stabilized by riprap. This berm (schematically shown in Fig. 2.20) would function as a filter to stop any further soil erosion while still allowing water to drain.

(2) The placement of a grout curtain along the dam to stop the soil migration from the dam. This placement would be accomplished by a drilling and grouting program to seal off the flow channels in the bedrock below the dam. The downstream side of the dam would be grouted first to prevent excessive grout migration from the upstream side; the upstream side would then follow. If necessary, a third grout curtain would be placed in the center of the dam to fill any remaining flow paths.

(3) Construction of a slurry trench wall on the upstream face of the dam. A trench would be dug along this face and then filled with a bentonite slurry to create a water-impermeable boundary.

ORNL PHOTO 0054-80

Fig. 2.10. White Oak Lake before draining began, 1979.

ORNL PHOTO 0049-80

Fig. 2.11. White Oak Lake after draining, 1979.

ORNL PHOTO 0042-80

Fig. 2.12. White Oak Lake after draining, 1979.

ORNL PHOTO 0046-80

Fig. 2.13. Upper portion of White Oak Lake after draining, 1979.

ORNL PHOTO 0039-80

Fig. 2.14. Upper portion of White Oak Lake after draining, 1979.

ORNL PHOTO 5344-79

Fig. 2.15. Downstream bed of White Oak Dam (looking north) just before vegetation removal, December 1979.

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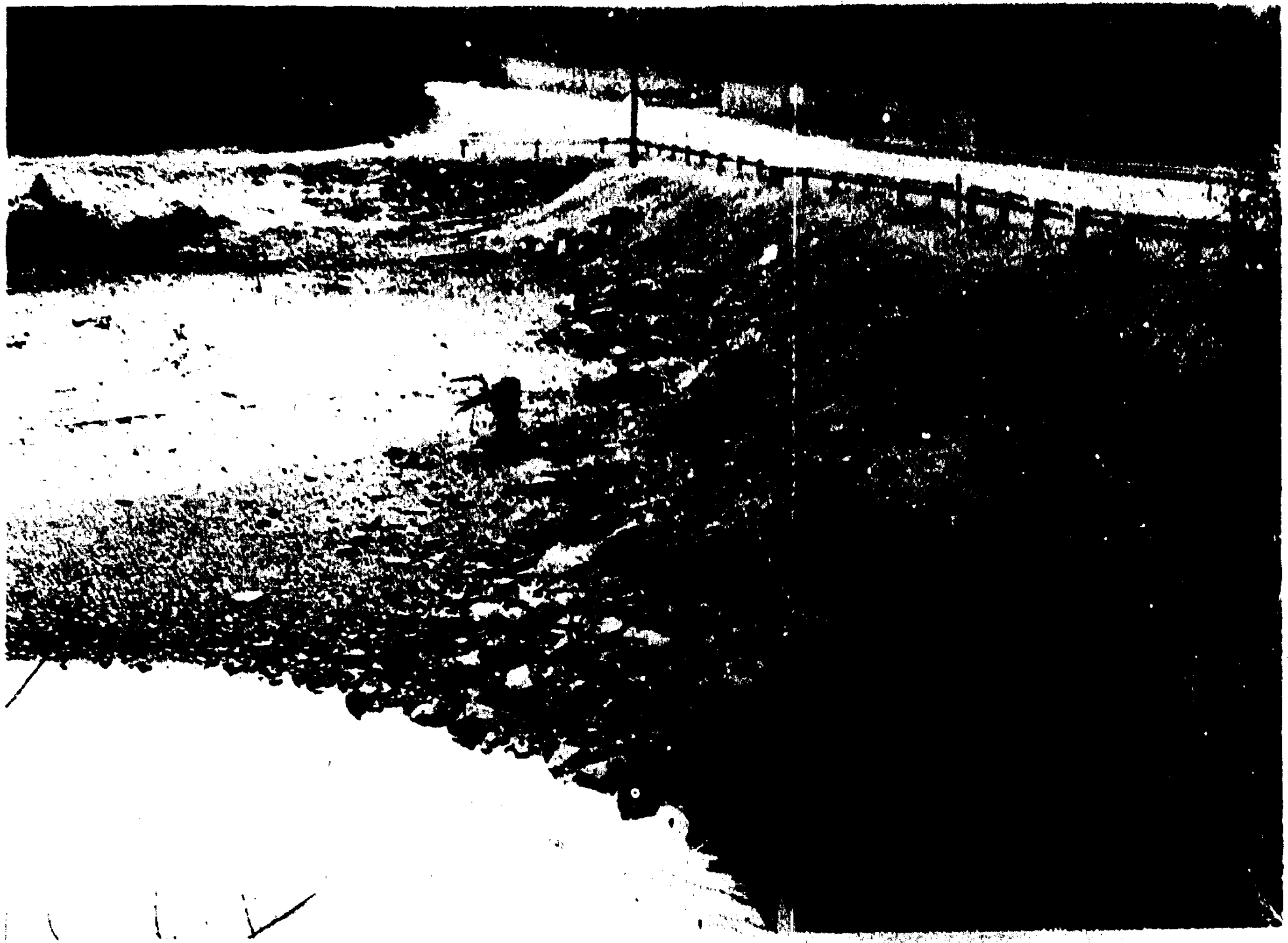

Fig. 2.16. Downstream bed of White Oak Dam (looking north) just after vegetation removal, December 1979.

ORNL PHOTO 0060-80

Fig. 2.17. Downstream bed of White Oak Dam (looking south) just after vegetation removal, December 1979.

ORNL PHOTO 0061-80

Fig. 2.18. Upstream bed of White Oak Dam (looking south) just after vegetation removal, December 1979.

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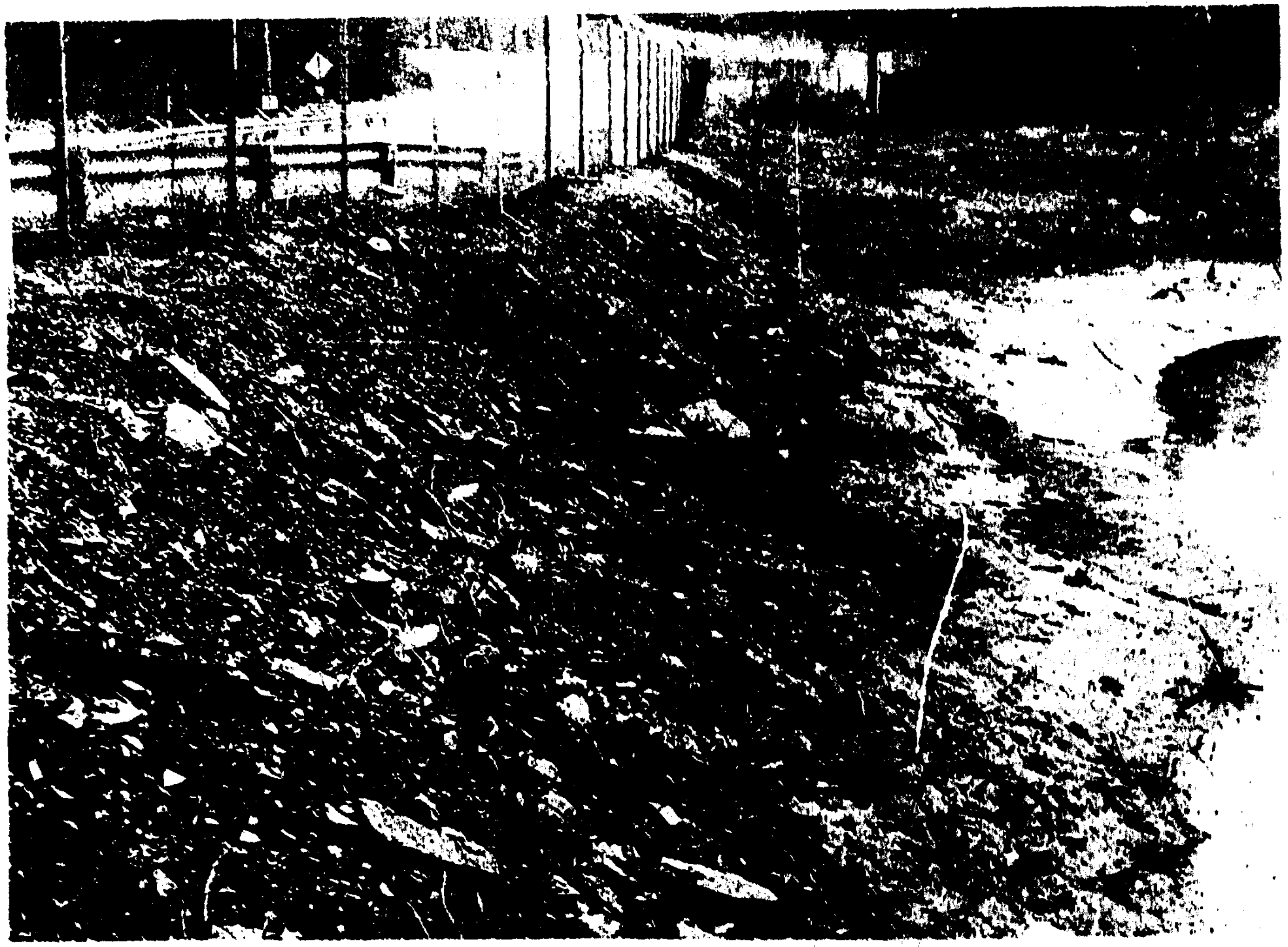

Fig. 2.19. Upstream bed of White Oak Dam (looking north) just after vegetation removal, December 1979.

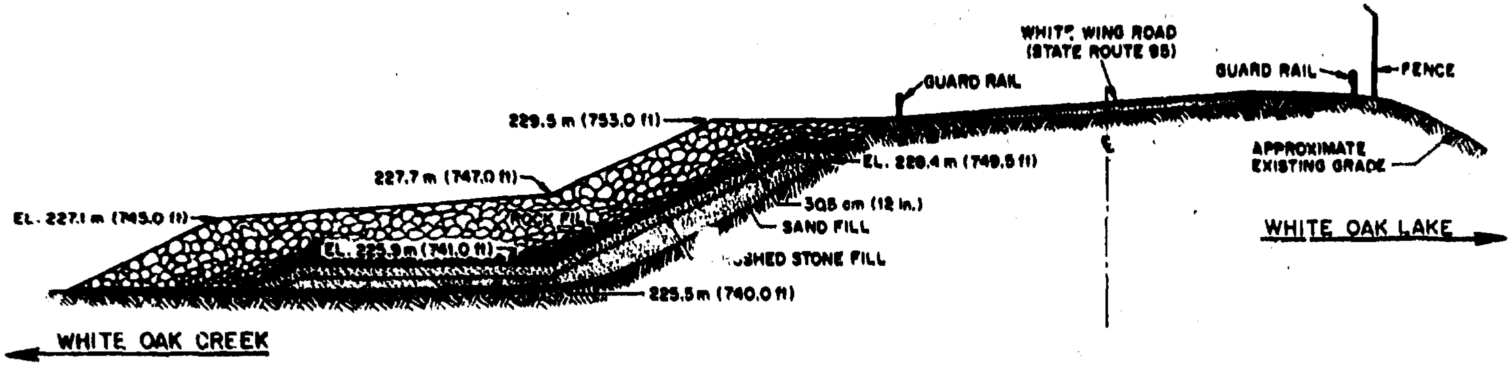

Fig. 2.20. Schematic cross section of the berm at White Oak Dam.

After discussions with two private consultants, the Tennessee Valley Authority, the Army Corps of Engineers and the State of Tennessee, option 1 was selected. The basis for the selection was threefold: (1) the berm adds structural integrity to the dam; (2) it acts as a filter to stop internal erosion of the dam; (3) and in the event the dam is overtopped during a storm event, the berm will protect the downstream face from erosion.

Construction of the berm commenced on February 13, 1980 and was completed on March 20, 1980. The completed berm can be seen in Fig. 2.21.

The only remaining problem with the dam is the size of its discharge structure. By Corps of Engineers' standards, earthen dams should be designed to accommodate a storm with a 100-year return period. WOD's current discharge structure does not meet this standard. To remedy this problem, a 1981 line item project ("Improvements to Radioactive Waste Facilities") is underway to, in part, construct a new discharge structure on the north side of the dam. This new structure, which is shown in Fig. 2.22, is being designed to handle 56.6 m^3/s (2000 cfs), the flow estimated in the White Oak Lake watershed for a 100-year storm, based on empirical studies.

2.7 SEEPAGE THROUGH THE DAM

Observations of the downstream side of WOD identified the presence of two possible seeps at its north end (see Fig. 2.23). The two areas are shown in detail in Figs. 2.24 and 2.25. The seep's flow path as it enters White Oak Creek is shown in Fig. 2.26.

To confirm that these seeps are indeed coming from the interior of the dam, a monitoring program was started to measure the water temperatures in White Oak Lake, in observation wells going into the dam, and in the seeps. These data (see Table 2.1) were then examined for correlations between the seep water temperature and either the lake or the well temperatures. Suspended solids concentrations were also measured at each of the seep wells and at the lake. Finally, flow measurements and concentrations of radioactivity in water were taken at each seep.

ORNL PHOTO 1832-80

Fig. 2.21. White Oak Dam berm, March 20, 1980.

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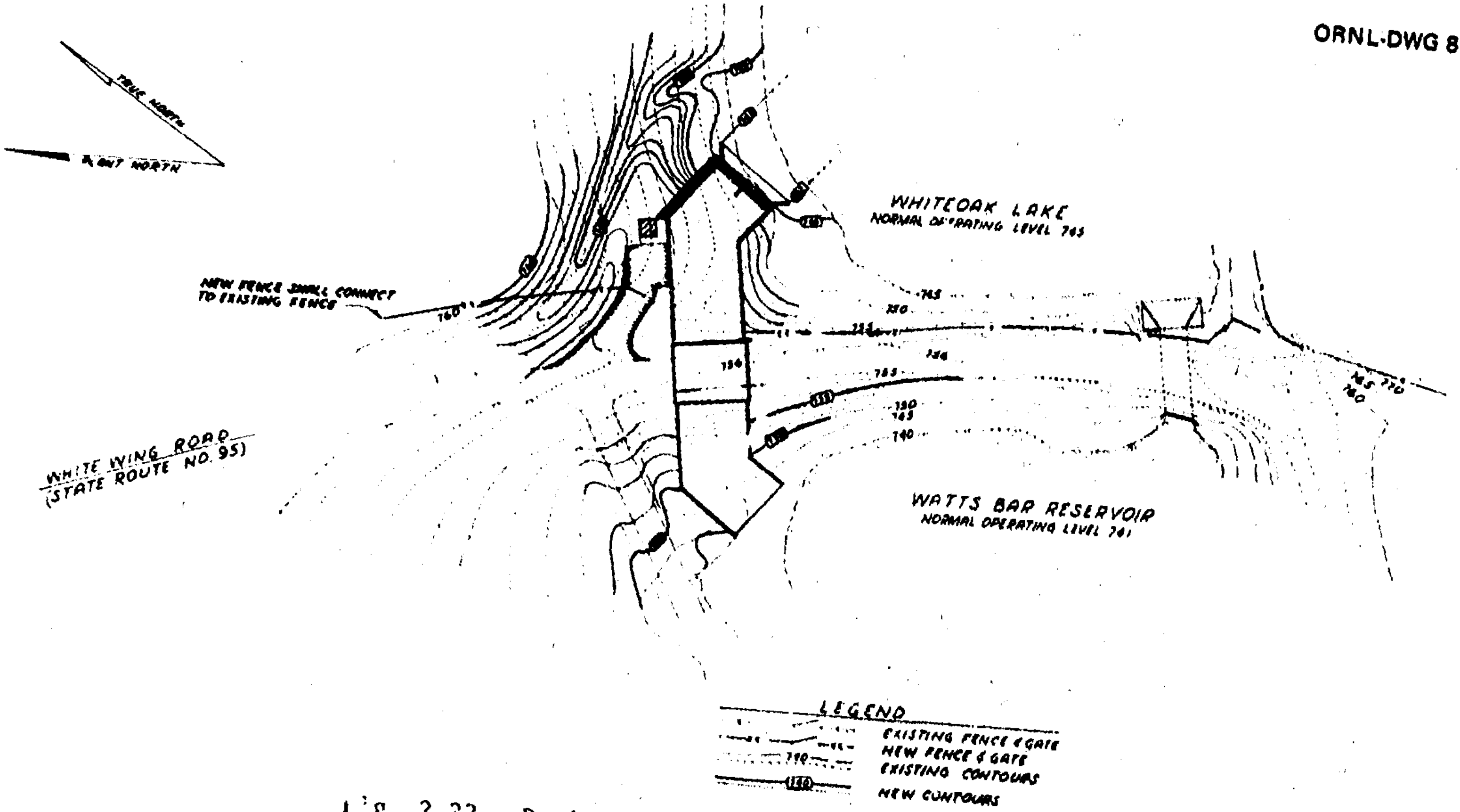

Fig. 2.22. Design plan of the new discharge structure.

ORNL PHOTO 5344-79

Fig. 2.23. Downstream side of White Oak Dam, looking north toward the seeps.

ORNL PHOTO 5343-79

Fig. 2.24. Seep No. 1 in White Oak Dam (appearing in the right center of the photograph).

ORNL PHOTO 0035-80

Fig. 2.25. Seep No. 2 in White Oak Dam (appearing in the center of the photograph).

ORNL PHOTO 0044-80

Fig. 2.26. View from White Oak Dam toward the Clinch River, showing combined seep flow entering White Oak Creek.

Table 2.1. Temperature data from White Oak Dam observation program

Date	White Oak Lake temp (°C)	Well 4 (upstream) temp (°C)	Well 7B (Downstream) temp (°C)	Seep 1 temp (°C)	Seep 2 temp (°C)
12/10/79	10	16	16	14	10
12/12/79	14	18	18	12	13
12/14/79	12	16	18	10	10
12/17/79	9	14	16	10	10
12/19/79	10	16	16	10	10
12/21/79	8	16	13	8	10
12/26/79	10	18	16	10	10
12/28/79	11	15	16	12	12
12/31/79	12	15	15	12	12
01/02/80	10	15	14	16	15
01/07/80	9	12	14	7	8
01/09/80	10	16	17	10	10
01/11/80	13	14	13	9	8
01/14/80	10	16	16	10	10
01/16/80	10	17	18	14	14

The results of this program seemed to indicate a correlation between the lake and seep temperatures and no obvious correlation between the well and seep temperatures. These data were taken as evidence of seepage through bedrock that allowed water to pass under the dam. Flow data (to gauge the severity of seepage) and suspended solids data (to gauge the rate of erosion) produced no significant results.

During construction of the berm, it was discovered that Seep 1 was actually a spring. Seep 2 is still believed to be coming through the dam. The installed berm will filter any solids from the water before it is discharged.

3. DESCRIPTION OF WHITE OAK CREEK WATERSHED

White Oak Creek watershed (Fig. 3.1) has a drainage area of 16.8 km^2 (6.5 sq miles) at its mouth, where it flows into the Clinch River. The White Oak Creek basin is located within the Tennessee section of the ridge and valley physiographic province (Edgar, 1978). The headwaters of White Oak Creek originate on the forested slopes of Chestnut Ridge, north of Oak Ridge National Laboratory. The topography consists of parallel, northeast-southwest trending valleys and ridges formed by differential erosion of alternating weak and resistant rock strata (Edgar, 1978). A mantle of residual material covers bedrock to a depth ranging from one meter to more than 30.5 m (100 ft) (McMaster and Waller, 1965).

Numerous springs intersecting with the upper reaches of White Oak Creek provide a relatively stenothermic aquatic environment. Before the creek comes into contact with Laboratory discharges, the stream width varies from 0.6 to 1.2 m (2.0 to 4.0 ft), and the depth varies from 10 to 25 cm (3.9 to 9.8 in.). Stream bed substrate is predominately rocks of 5 to 8 cm (2 to 3.2 in.) in diameter with some exposed bedrock. The northern drainage divide of the basin is formed by Chestnut Ridge, and the crest of Copper Ridge forms the southern divide. Haw Ridge bisects the basin and separates Melton Valley on the south and Bethel Valley on the north.

The topography of the White Oak Creek basin is similar to that in the western part of the Tennessee section of the valley and ridge province. This consists of parallel ridges and valleys trending northeast. Altitude ranges from 224 m (735 ft) above mean sea level at the mouth of White Oak Creek during low pool of Watts Bar Lake to 413.3 m (1356 ft) at the crest of Melton Hill (McMaster and Waller, 1965).

Four major rock formations occur in White Oak Creek basin (McMaster and Waller, 1965):

(1) Rome formation underlies Haw Ridge and is made up of shale, siltstone, and sandstone;

(2) Conasauga group underlies Melton Valley and is made up of shale, siltstone, and limestone;

(3) Knox dolomite underlies Chestnut Ridge and Melton Hill; and

(4) Chickamauga limestone underlies Bethel Valley.

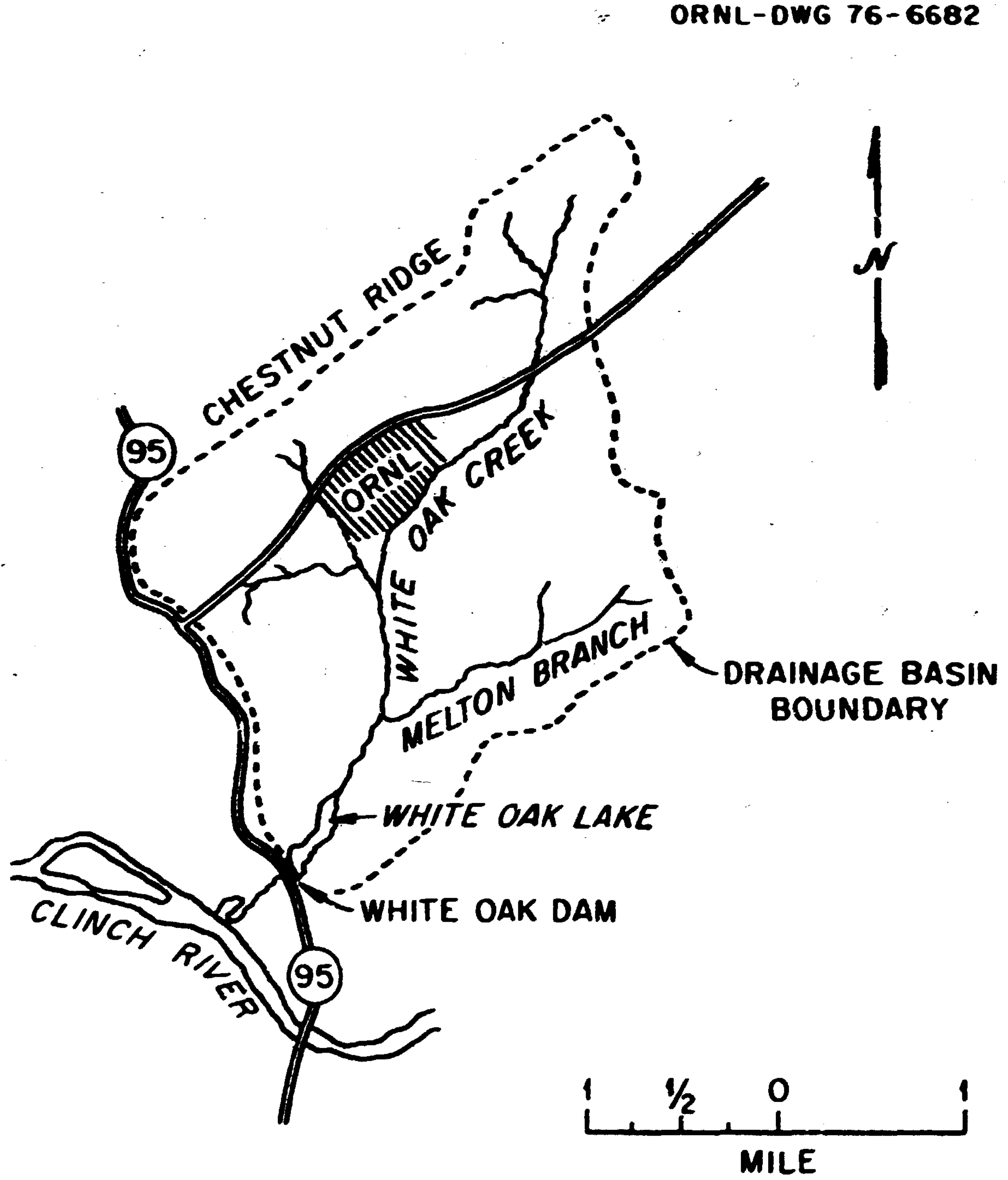

Fig. 3.1. Map showing White Oak Creek watershed. Note: This figure was generated before metrification and has not been changed. However, multiplying miles by 1.6 will convert miles to kilometers.

The Rome formation and Conasauga group are poor water-bearing formations. The Knox dolomite and the Chickamauga limestone are the principal water-bearing formations of the basin and discharge from the Knox is the main source of base flow in the creek (McMaster and Waller, 1965).

The soils of the basin are of the red-yellow podsolic, the reddish-brown laterite, and the lithosol groups. These soils are strongly leached, low in organic matter, acidic, and generally have exchange capacities of less than 10 meq/100 g of soil. Textures vary from silty loam to plastic clay with infiltration capacities ranging from 25 cm/h (10 in./h) to less than 0.5 cm/h (0.2 in./h) (McMaster and Waller, 1965).

Because most of the White Oak Creek basin is underlain by the Rome formation and Conasauga group, the base-flow discharge of White Oak Creek is low, and during intervals of low rainfall, no natural flow occurs. The belt of Knox dolomite underlying Chestnut Ridge, which forms the northwestern drainage divide of the basin, is the principal water-bearing formation. Several springs along the base and in the Chestnut Ridge valleys are tributaries to White Oak Creek. Ninety percent of the White Oak Creek dry-weather discharge originates as groundwater discharge from the Knox dolomite of Chestnut Ridge, the Chickamauga limestone of Bethel Valley, and ORNL plant effluent.

Approximately 2.5 km (1.55 miles) from the source, White Oak Creek enters the confines of ORNL in Bethel Valley. A substantial part of the flow in White Oak Creek is wastewater from ORNL. Gravel substrate predominates the bottom. The Melton Branch tributary of White Oak Creek drains 3.83 km^2 (1.48 sq miles) in Melton Valley and enters White Oak Creek 2.5 km (1.55 miles) above the Clinch River (Fig. 3.2). The substrate in Melton Branch is mainly gravel and small rubble. Both streams receive liquid effluents from ORNL operations and leachates from radioactive waste disposal areas in the drainage basin. Species composition of biota in the lower portions of both streams has been altered significantly as a result of these effluents (Dahlman et al., 1976). Levels of radioactive constituents in the discharge are monitored, and the results are reviewed in Sect. 6. of this report.

White Oak Creek begins on Chestnut Ridge northeast of ORNL and flows through the southern portion of the Laboratory area. Just south of the Laboratory, the Creek passes through a water gap in Haw Ridge and flows

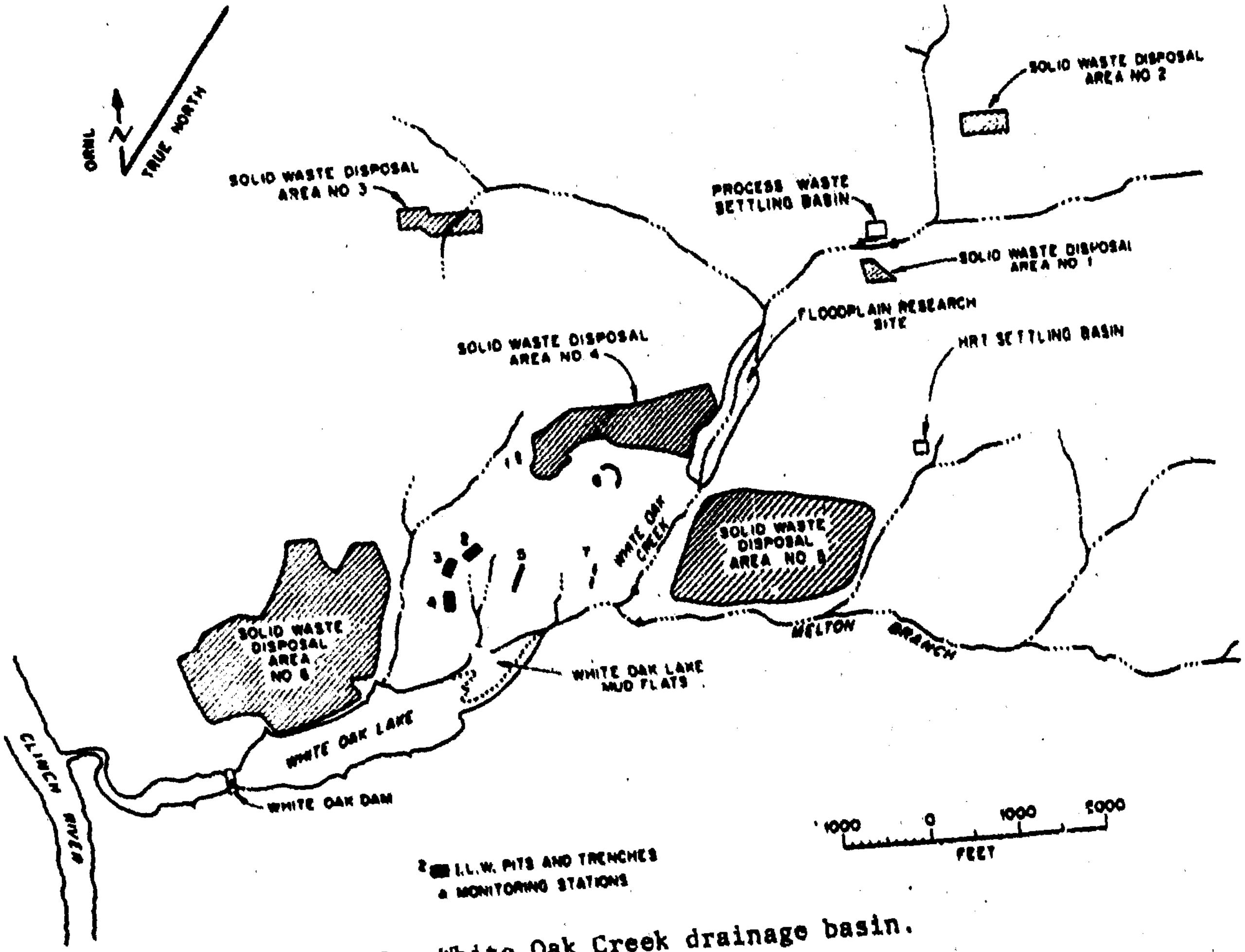

Fig. 3.2. White Oak Creek drainage basin.

south-southwestward in Melton Valley, where it is joined by Melton Branch. White Oak Lake is formed by an earth-filled embankment. The lake is a shallow reservoir of approximately 10.1 hectares (25 acres) areal extent. White Oak Lake serves as the final settling basin and can be characterized as an eutrophic lake (see Sect. 2). Bottom sediments are primarily silt and clay. Water from White Oak Lake discharges through a weir at WOD at a flow rate of 425 ℓ/s (15 cfs) or less during 80% of the time at lake elevation 227.1 m (745.0 ft). The creek meanders for approximately 1 km (0.6 mile) and empties directly into the Clinch River. Gravel and clay-mud substrates are the predominant bottom material in White Oak Creek below the dam. The channel area below WOD resembles a large mud flat and is a site of active erosion-sedimentation processes, depending upon water level fluctuation in the Clinch River and to a lesser extent upon the levels in White Oak Lake. Water level in the Clinch River is determined primarily by the relative release rates at Watts Bar and Melton Hill dams. During high stage on the Clinch River, backwater extends up the channel to WOD and forms an embayment. Due to this regulated condition, the watershed is generally considered to be the 15.5 km^2 (6.0 sq miles) of drainage area above WOD.

White Oak Lake is located in an open area and is bordered by typical wetland vegetation. Dominant overstory species in this type are sycamore, sweet gum, some Virginia and shortleaf pine, and assorted oak species. The understory is composed mostly of pines, ash, elm, poplar, and sweet gum. Many species of birds (30–40 species) inhabit this type of woodland throughout the reservation. Mammals expected to reside in the wetland or floodplain forests would include muskrats, gray squirrels, weasels, and rice rats. A casual passerby such as the skunk, gray fox, whitetail deer, or mink might be seen on occasion. No unique floral or faunal features have been noted in the area.

The small streams draining forest catchments on the reservation such as White Oak Creek and Melton Branch are heterotrophically based. Periphytic communities in these streams are dominated by diatoms with relatively low cell densities. Primary production rates in the forested streams average less than 1 g of organic matter m^{-2} d^{-1}. Macrophytes in the small streams include watercress (*Nasturtium officinale*), false loosestrife (*Ludwigia* spp.), and moss (*Fontinalis* sp.). Benthic invertebrate communities in the streams on the reservation are dominated by aquatic insects, followed in order by mollusca, oligochaeta, and crustacea.

Diversity of benthic invertebrates in White Oak Creek, which receives industrial effluents, generally is lower than in the uncontaminated, forested streams (e.g., White Oak Creek above ORNL) (Loar et al., 1981). Possible reasons for the lower benthic diversity include lower diversity of substrate types and discharges of industrial and sanitary effluents from ORNL facilities.

4. HYDROLOGICAL CONDITIONS OF WHITE OAK CREEK WATERSHED

The lake area vs elevation is given in Table 4.1. Lake elevation vs lake volume is given in Table 4.2 for 1944 and 1950 and for 1979 estimated. The estimated depth of White Oak Lake at elevation 227 m vs years 1953-79 is given in Table 4.3 [calculated by ORNL, Department of Environmental Management (DEM) personnel, 1980].

Discharge data at WOD are obtained by means of a rating curve developed by the U.S. Geological Survey for the sluice gate of the dam. This rating indicates a flow of 5.69 m^3/s (198 cfs) at maximum head. However, it has been noted that measurements in excess of 4.2 m^3/s (150 cfs) are above accurate monitoring capability. McMaster (1967) summarized hydrologic data for the Oak Ridge area and presented duration curves for the mean daily flow of White Oak Creek at WOD.

Representative discharge values, the corresponding flow duration, and the period of record from which these data were derived are given in Table 4.4 (McMaster, 1967). These data and the curves presented indicated that the maximum measurable discharge at WOD is 4.2 m^3/s (150 cfs) with a flow duration value of 0.15%. This indicates that the mean daily discharge at WOD for the five years of record was equal to or greater than 4.25 m^3/s (150 cfs) only 0.15% of the time (approximately 0.5 d/year) (Edgar, 1978). More recent data collected at WOD (Table 4.5) indicate that 4.25 m^3/s (150 cfs) was exceeded much more than 0.5 d/year. The average number of days when the flow exceeded 4.25 m^3/s between 1972 and 1979 was 5.25 d/year. Table 4.6 contains estimates calculated by equation from Speer and Gamble (1964) for flood discharge of various recurrence intervals at WOD (Edgar, 1978).

The results of a frequency analysis conducted by Shepperd (1974) of annual maximum precipitation for varying durations (1, 3, 24, and 48 h) recorded at the Oak Ridge Townsite station are given in Fig. 4.1 and Table 4.7. Edgar (1978) estimated the flood discharge at WOD, shown in Table 4.8, using $Q = 4.7\ A^{0.8}p^2$ and precipitation data from Table 4.7. In the formula, Q is peak discharge (cfs), A is drainage area (sq miles), and p is precipitation (in.) from Table 4.7.

Randolph and Gamble (1976) presented a set of equations to estimate flood magnitude of selected frequency in Tennessee (Edgar, 1978). Flood

Table 4.1. Lake area vs elevation

Elevation [m (ft)]	Area [ha[a] (acres)]
228.6 (750)	17.7 (44.19)
228.3 (749)	16.0 (39.90)
228.0 (748)	14.3 (35.67)
227.7 (747)	12.9 (32.29)
227.4 (746)	11.4 (28.57)
227.1 (745)	9.8 (24.48)
226.7 (744)	7.6 (19.11)
226.5 (743)	5.8 (14.43)
226.2 (742)	4.6 (11.45)
225.9 (741)	2.8 (7.07)
225.6 (740)	1.6 (3.88)
225.2 (739)	0.67 (1.67)
224.9 (738)	0.24 (0.60)
224.6 (737)	0.08 (0.21)
224.3 (736)	0.04 (0.09)
224.0 (735)	0.02 (0.04)
223.8 (734.1)	0.00 (0.00)

[a] 1 ha (hectare) = 10,000 m^2.

Table 4.2. Lake elevation vs volume

Elevation [m (ft)]	Original volume [m^3 (ft^3)]	1950 volume [m^3 (ft^3)]	1979 volume[a] [m^3 (ft^3)]
228.6 (750)	297,942 (10,521,730)	278,861 (9,847,879)	297,248 (10,497,211)
228.3 (749)	246,085 (8,690,410)	227,014 (8,016,915)	235,580 (8,319,437)
228.0 (748)	199,363 (7,040,428)	180,495 (6,374,124)	182,289 (6,437,488)
227.7 (747)	157,345 (5,556,580)	158,921 (4,905,944)	137,543 (4,857,294)
227.4 (746)	119,827 (4,231,650)	102,089 (3,605,267)	98,204 (3,468,032)
227.1 (745)	87,116 (3,076,455)	70,274 (2,481,691)	64,015 (2,260,659)
226.8 (744)	61,262 (2,163,438)	46,043 (1,625,980)	34,258 (1,209,801)
226.5 (743)	40,592 (1,433,480)	27,713 (978,666)	14,002 (494,476)
226.2 (742)	24,653 (870,628)	13,329 (470,712)	1,695 (59,851)
225.9 (741)	12,761 (450,660)	4,156 (146,763)	0
225.6 (740)	5,526 (195,138)	497 (17,544)	0
225.2 (739)	2,115 (74,700)	0.6 (20)	0
224.9 (738)	756 (26,698)	0	0
224.6 (737)	267 (9,413)	0	0
224.3 (736)	96 (3,373)	0	0
224.0 (735)	20 (698)	0	0
223.8 (734.1)	0	0	0

[a] Volumes were calculated using the acres listed in ORNL-562; depths were calculated by ORNL DEM personnel using a 2830-m^3/year (100,000-ft^3/year) sediment input to the lake and the assumption of an ellipsoidal basin.

Table 4.3. Estimated maximum depth of White Oak Lake at elevation 227 m (745 ft) vs year, 1953-1979

Year	Lake depth [m (ft)]	Year	Lake depth [m (ft)]
1953	3.05 (10)	1967	2.75 (9.02)
1954	3.03 (9.93)	1968	2.73 (8.95)
1955	3.01 (9.86)	1969	2.71 (8.88)
1956	2.98 (9.79)	1970	2.69 (8.81)
1957	2.96 (9.72)	1971	2.66 (8.74)
1958	2.94 (9.65)	1972	2.64 (8.67)
1959	2.92 (9.58)	1973	2.62 (8.6)
1960	2.90 (9.51)	1974	2.60 (8.53)
1961	2.88 (9.44)	1975	2.58 (8.46)
1962	2.86 (9.37)	1976	2.56 (8.39)
1963	2.83 (9.44)	1977	2.54 (8.32)
1964	2.31 (9.23)	1978	2.51 (8.25)
1965	2.79 (9.16)	1979	2.49 (8.18)
1966	2.77 (9.09)		

Table 4.4. Daily flow duration values for White Oak Creek at WOD (1953-55, 1960-63)

Flow [m³/s (cfs)]		Percentage of time indicated discharge was equaled or exceeded
0.048	(1.7)	99.9
0.054	(1.9)	99
0.093	(3.3)	90
0.125	(4.4)	80
0.150	(5.3)	70
0.178	(6.3)	60
0.207	(7.3)	50
0.246	(8.7)	40
0.311	(11.0)	30
0.425	(15.0)	20
0.651	(23.0)	10
2.83	(100.0)	1
7.08	(250.0)	0.1

Source: McMaster, 1967.

Table 4.5. Number of days flow exceeded 4.25 m /s (150 cfs) at WOD during calendar years 1972 through 1979

Year	No. of days
1972	5
1973	9
1974	4
1975	4
1976	2
1977	5
1978	5
1979	8

Table 4.6. Estimated flood discharge [m^3/s (cfs)] of specified recurrence intervals computed by the method proposed by Speer and Gamble (1964)

Flow [m^3/s (cfs)]	Recurrence intervals (years)
9.91 (350)	1.1
23.4 (825)	2
35.4 (1250)	5
44.6 (1575)	10
60.2 (2125)	25
72.2 (2550)	50
89.2 (3150)	100

Source: Edgar, 1978.

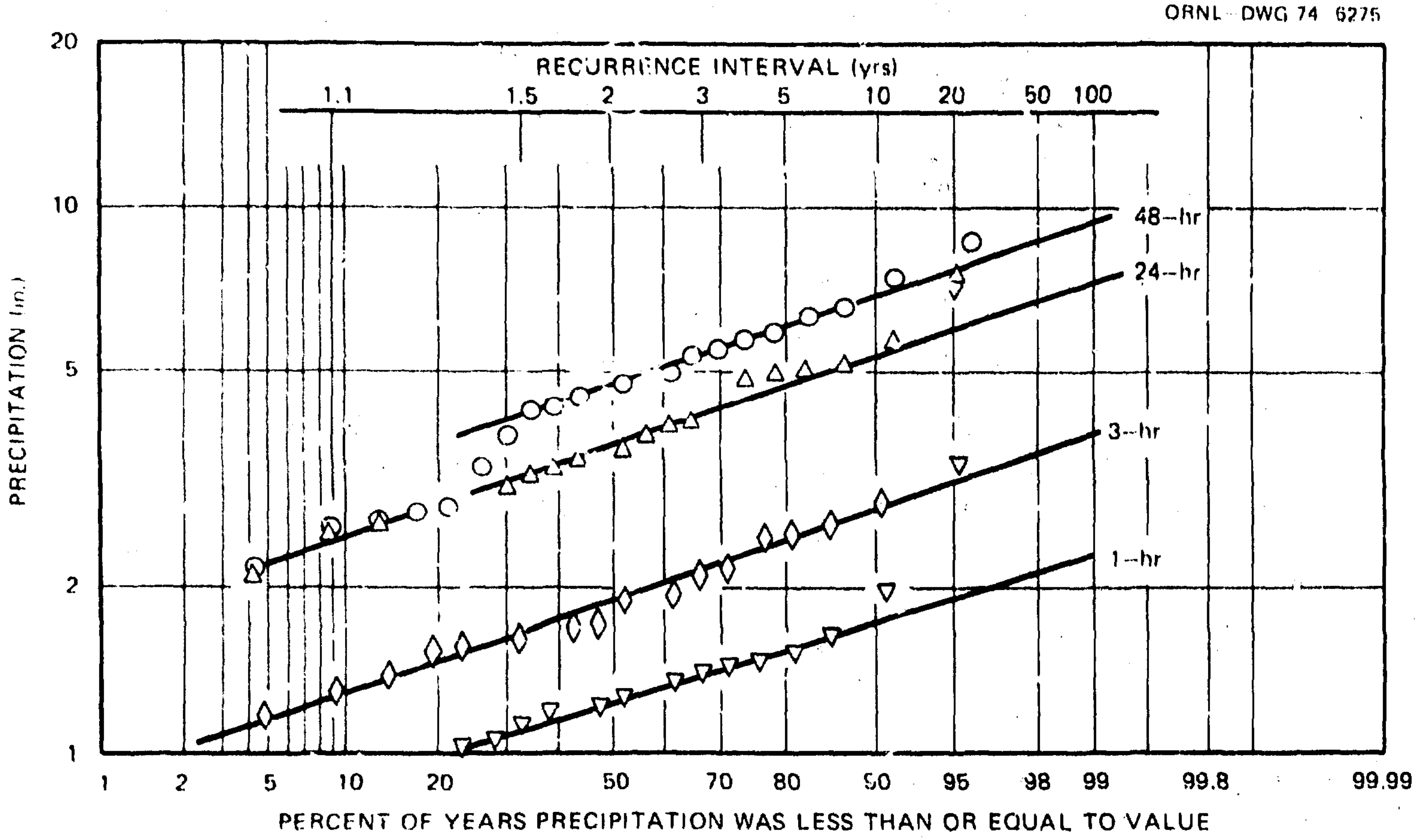

Fig. 1.1. Frequency of maximum after precipitation at Oak Ridge for 1-, 3-, 24-, and 48-h storms. Note: Since this figure was generated before metrification, it has not been changed. However, multiplication of the figures by 2.54 will give the precipitation in centimeters.

Table 4.7. Precipitation data for Oak Ridge Townsite station from 1951 through 1973

Precipitation duration (h)	Recurrence interval (year)	Average intensity [cm/h (in./h)]	Total precipitation [cm (in.)]
1	1.1	<2.54 (<1.0)	<2.54 (<1.0)
	2	3.05 (1.2)	3.05 (1.2)
	5	3.81 (1.5)	3.81 (1.5)
	10	4.32 (1.7)	4.32 (1.7)
	25	5.08 (2.0)	5.08 (2.0)
	50	5.59 (2.2)	5.59 (2.2)
	100	5.84 (2.3)	5.84 (2.3)
3	1.1	1.09 (0.43)	3.30 (1.3)
	2	1.60 (0.63)	4.83 (1.9)
	5	1.78 (0.70)	5.33 (2.1)
	10	2.36 (0.93)	7.11 (2.8)
	25	2.72 (1.07)	8.13 (3.2)
	50	2.97 (1.17)	8.89 (3.5)
	100	3.23 (1.27)	9.65 (3.8)
24	1.1	0.25 (0.10)	6.35 (2.5)
	2	0.38 (0.15)	9.14 (3.6)
	5	0.51 (0.20)	11.9 (4.7)
	10	0.58 (0.23)	13.7 (5.4)
	25	0.64 (0.25)	15.5 (6.1)
	50	0.71 (0.28)	17.0 (6.7)
	100	0.76 (0.30)	18.3 (7.2)
48	1	0.18 (0.07)	8.13 (3.2)
	2	0.25 (0.10	11.9 (4.7)
	5	0.33 (0.13)	15.2 (6.0)
	10	0.36 (0.14)	17.3 (6.8)
	25	0.41 (0.16)	19.8 (7.8)
	50	0.46 (0.18)	21.8 (8.6)
	100	0.48 (0.19)	23.6 (9.3)

Source: Sheppard, 1974.

Table 4.8. Estimates of flood discharge (cfs) of various recurrence intervals computed by the method proposed by Sheppard (1974)[a], White Oak Creek at WOD

Recurrence interval (year)	Precipitation duration (h) 1	3	24	48
1.1		33	123	202
2	28	71	255	435
5	44	87	435	709
10	57	155	575	911
25	79	202	733	1200
50	95	241	885	1458
100	104	285	1022	1704

[a] Note: This table was generated before metrification and has not been changed.

Source: Edgar, 1978.

discharge estimates derived from these equations for White Oak Creek at WOD are given in Table 4.9. Flood-frequency data for monitoring stations 3 (White Oak Creek), 4 (Melton Branch), and 5 (WOD) from Table 4.9 are shown in Fig. 4.2. Data for WOD from four storms are given in Table 4.10.

On April 2-4, 1977, approximately 14.7 cm (5.8 in.) of precipitation was recorded at ORNL (Edgar, 1978). This rainfall resulted in stream discharges on April 4 that exceeded measurement capacity at WOD for a total of 96 h (April 3-6). Figure 4.3 is a photograph of the monitoring station at WOD. White Oak Lake at elevation 227.1 m (745 ft) is shown in Fig. 4.4. The downstream side of White Oak Creek at the dam [Watts Bar elevation, 225.6 m (740 ft)] is shown in Fig. 4.5. Flow over the WOD weir under normal conditions is shown in Fig. 4.6. White Oak Dam shortly after peak flow on April 3, 1977, is shown in Figs. 4.7 through 4.10. The downstream side of White Oak Creek on April 3, 1977, is shown in Figs. 4.11 and 4.12. Figure 4.13 shows the area of the White Oak Creek after the lake began to recede following the April 1977 flood.

Table 4.9. Estimates of flood discharge [m^3/s (cfs)] at WOD of various recurrence intervals computed from the equations obtained by Randolph and Gamble (1976)

Recurrence interval (year)	Flow [m^3/s (cfs)]
2	13.9 (490)
5	22.4 (790)
10	28.7 (1015)
25	37.7 (1330)
50	45.0 (1590)
100	53.0 (1870)

Source: Edgar, 1978.

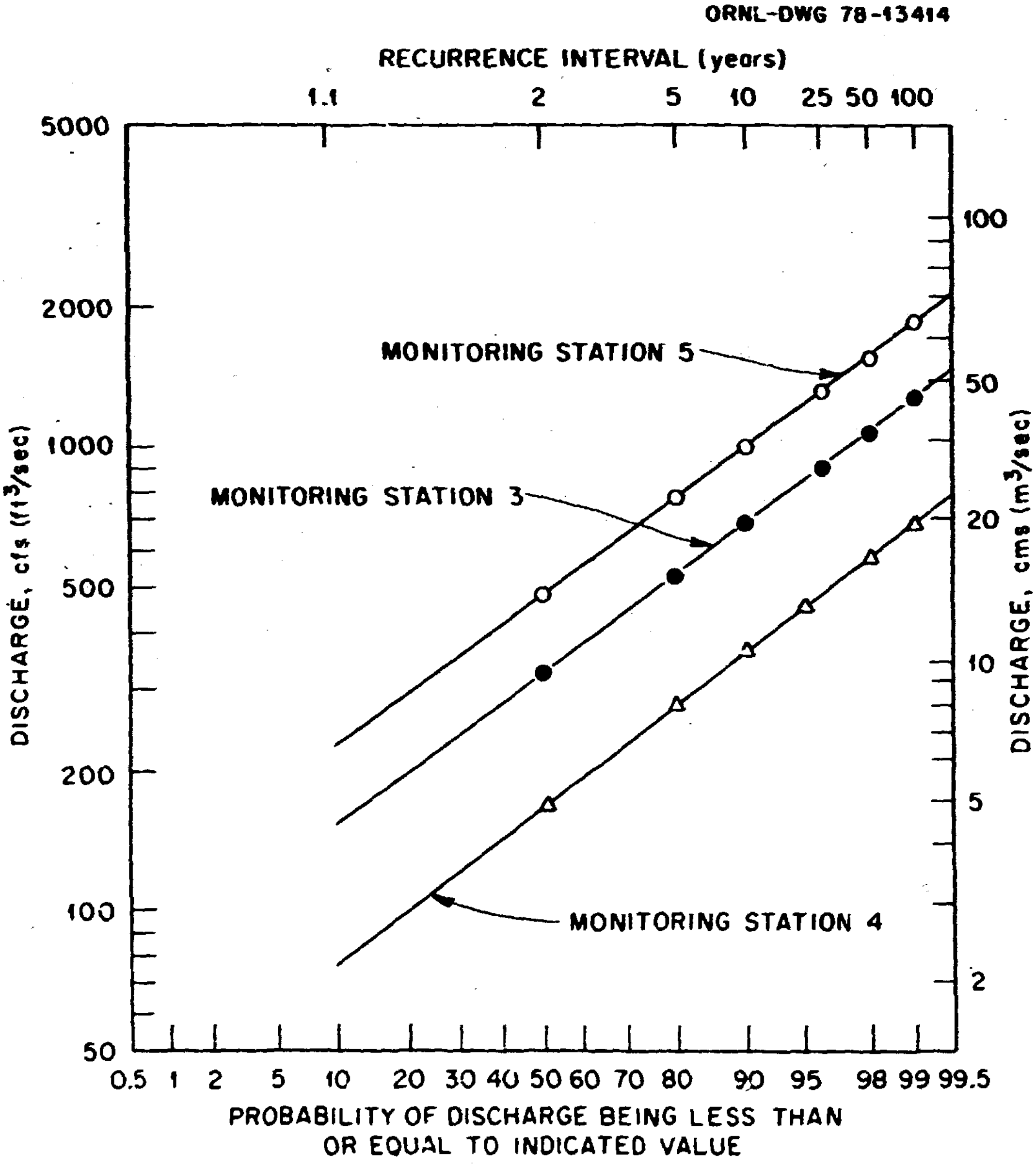

Fig. 4.2. Flood frequency curves for monitoring stations 3, 4, and 5.

Table 4.10. Data at White Oak Dam for four floods

Date	Precipation		Estimated peak discharge [m^3/s (cfs)]	Estimated recurrence interval (year)
	Total cm (in.)	Duration (h)		
Mar. 15-16, 1973	17.3 (6.8)	48	25.8 (910)	5.7
Nov. 27-28, 1973	22.1 (8.7)	48	42.2 (1492)	25
Apr. 2-4, 1977	14.7 (5.8)	41	18.7 (660)	2.3
June 7-8, 1978	9.6 (3.8)	48	8.07 (285)	1-1.5

Sources: Sheppard, 1974; Edgar, 1978.

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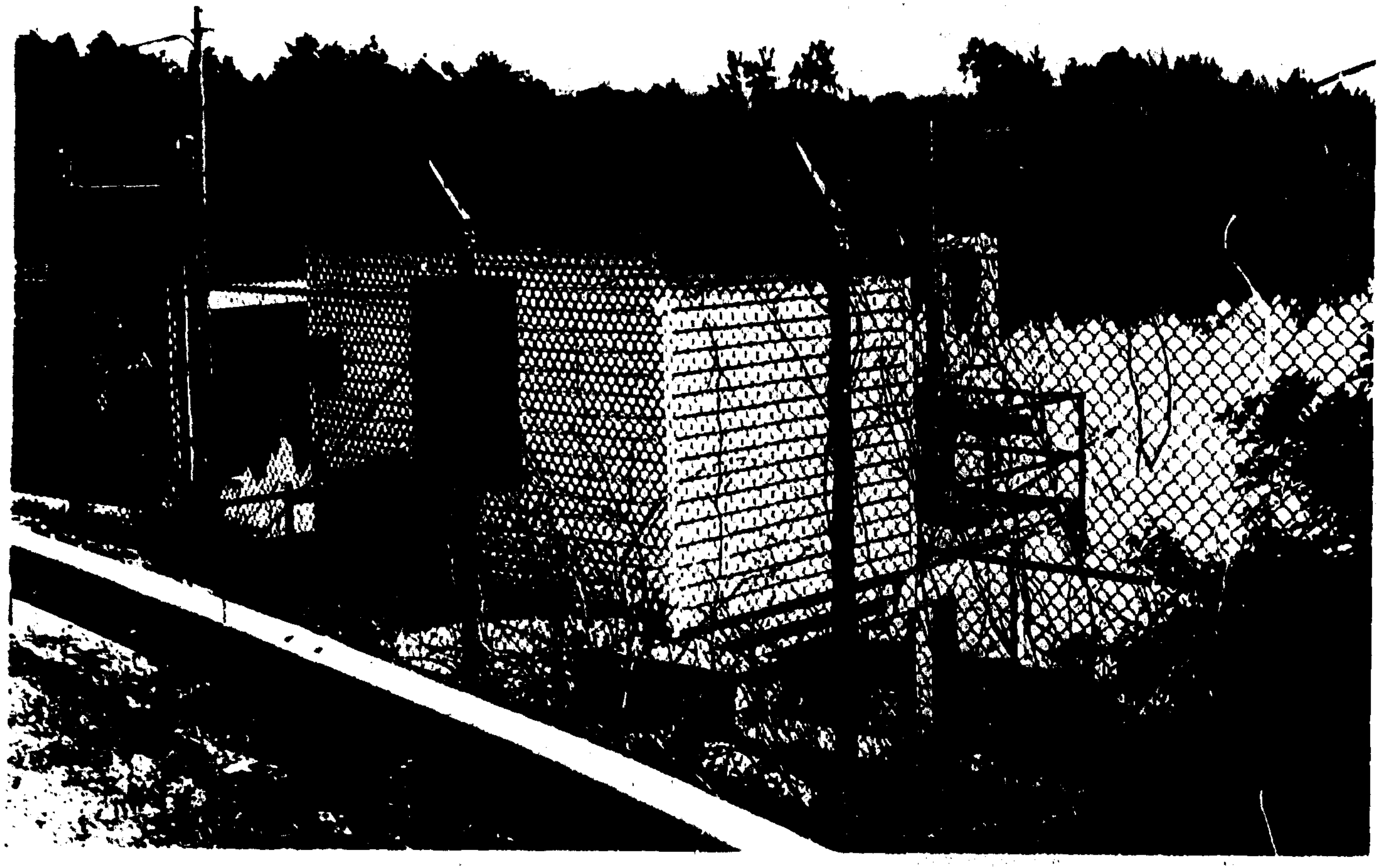

Fig. 4.3. Monitoring station at White Oak Dam.

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Fig. 4.4. White Oak Lake at elevation 227.1 m (745 ft).

ORNL PHOTO 2735-76

Fig. 4.5. White Oak Creek downstream of the dam [Watts Bar Lake elevation, 225.6 m (740 ft)].

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Fig. 4.6. Normal flow over White Oak Dam weirs at elevation 227.1 m (745 ft).

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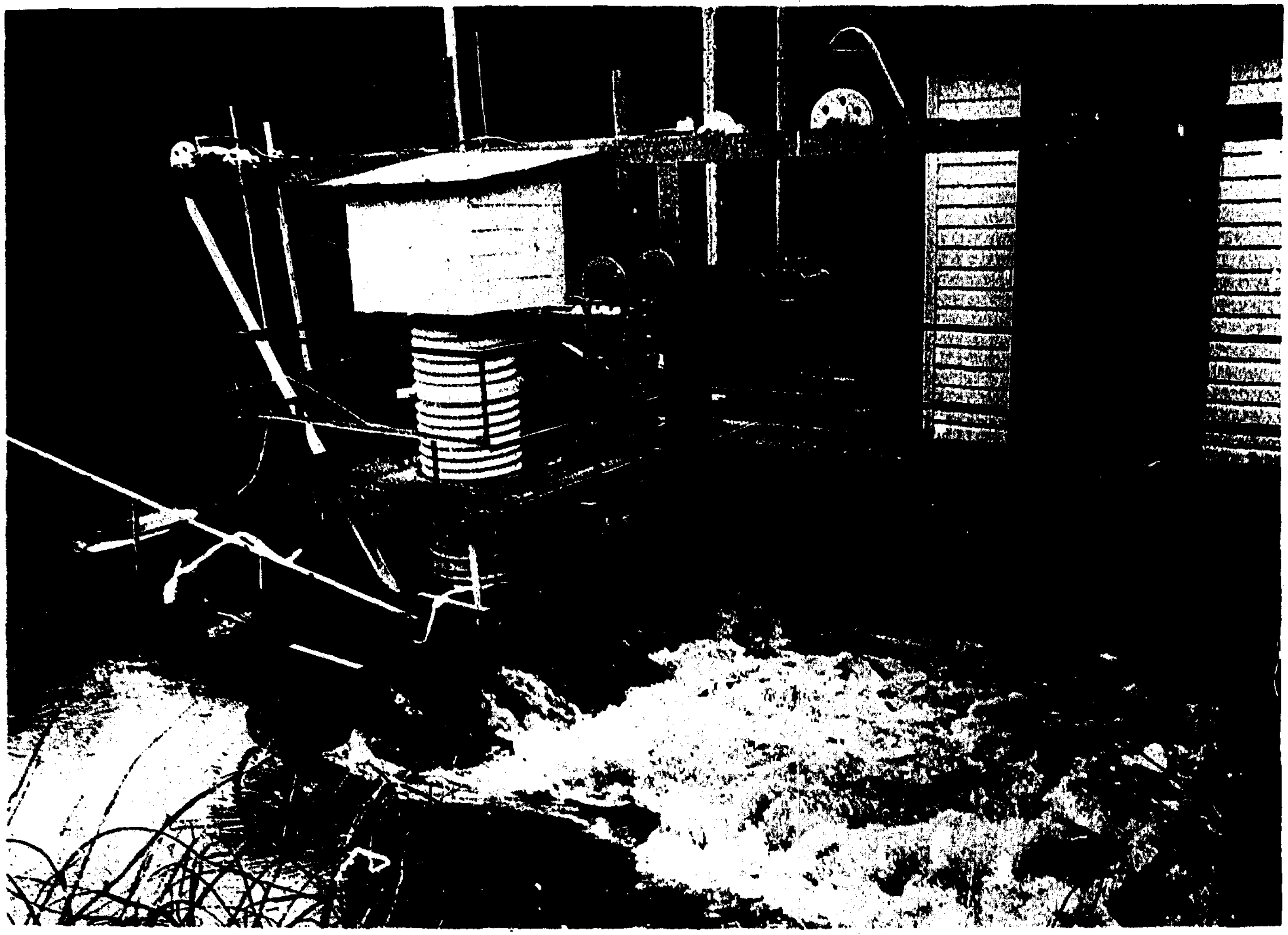

Fig. 4.7. High flow over White Oak Dam on Apr. 3, 1977, scene 1.

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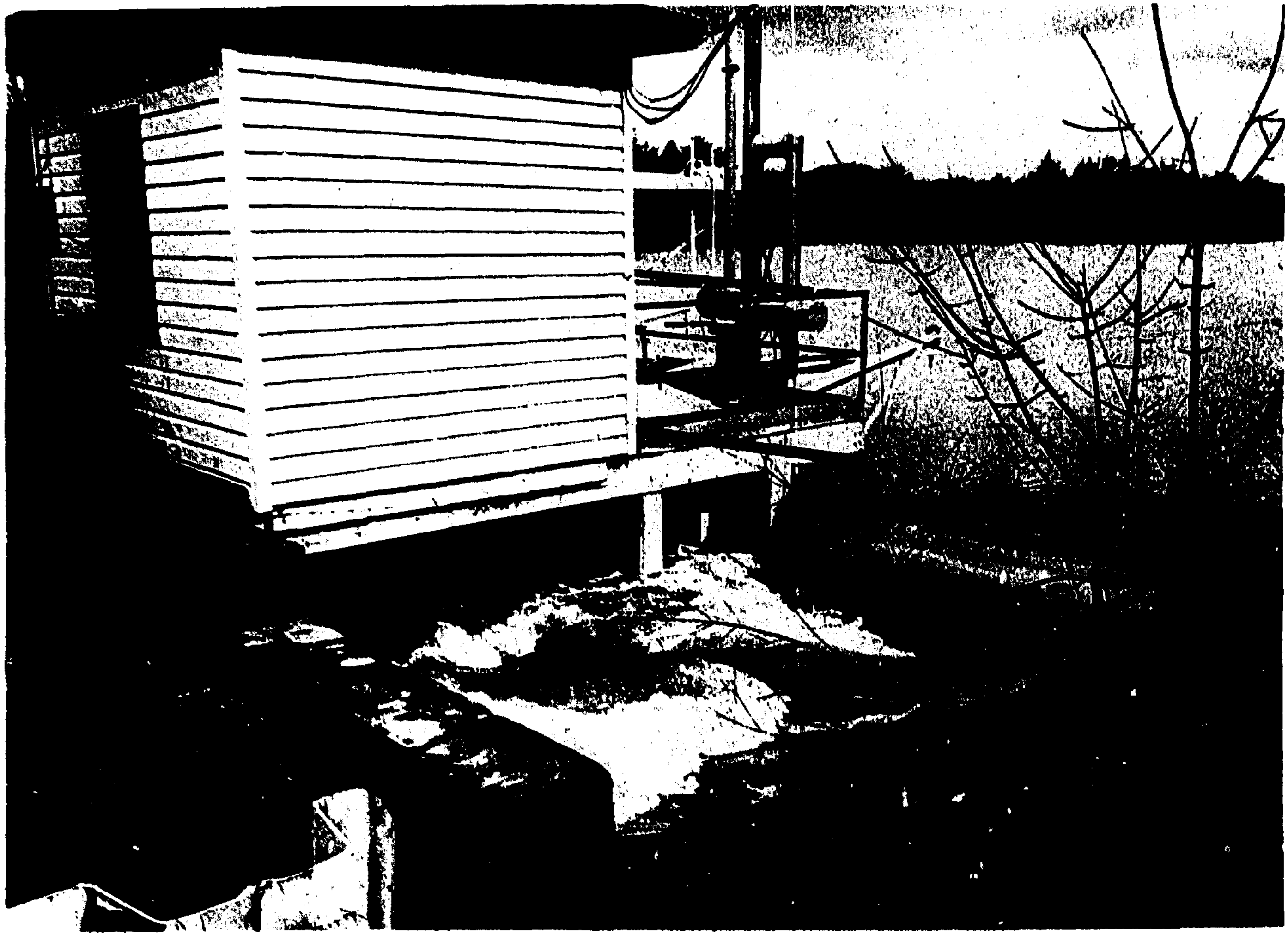

Fig. 4.8. High flow over White Oak Dam on Apr. 3, 1977, scene 2.

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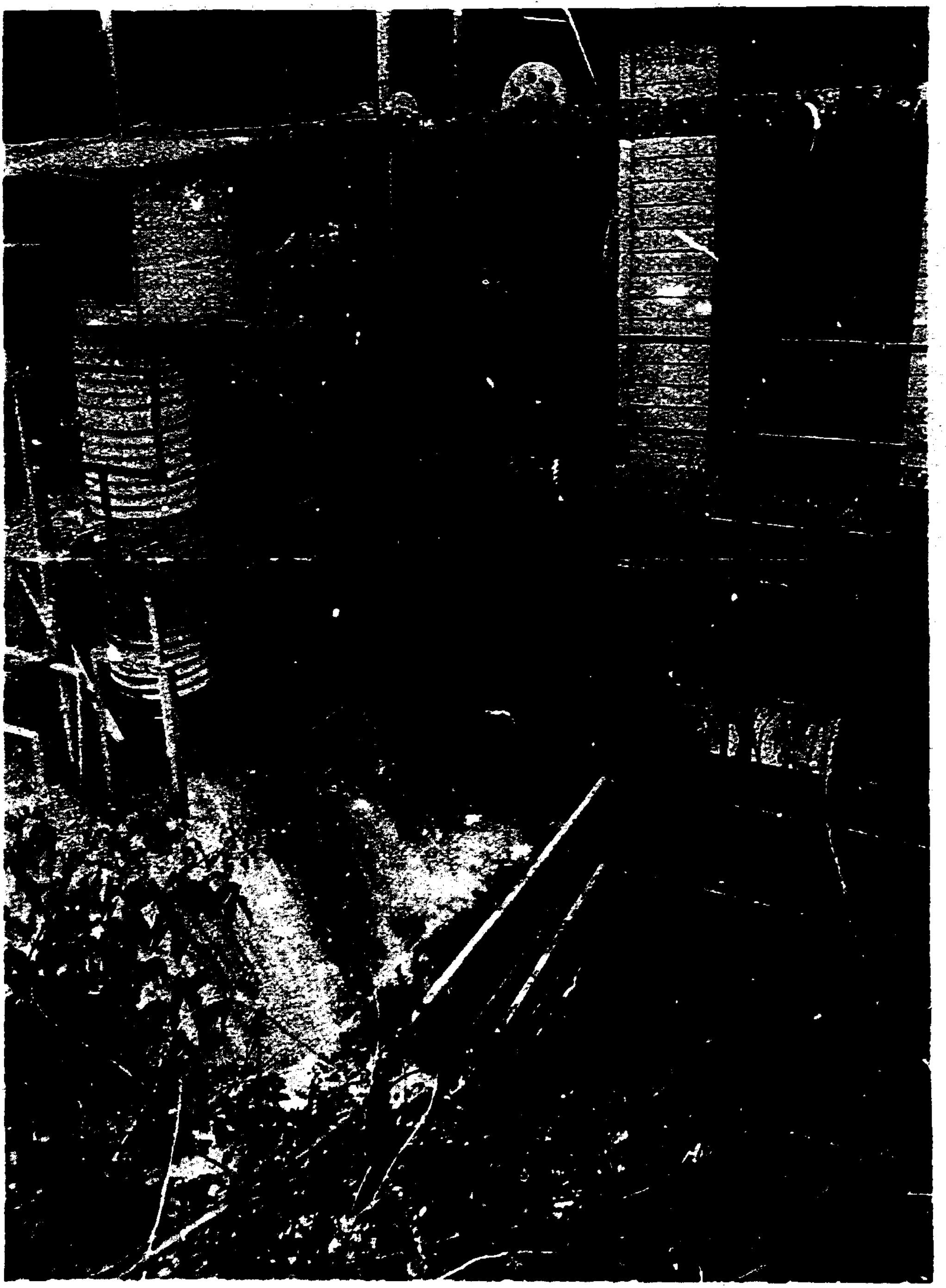

Fig. 4.9. High flow over White Oak Dam on Apr. 3, 1977, scene 3.

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Fig. 4.10. High flow over White Oak Dam on Apr. 3, 1977, scene 4.

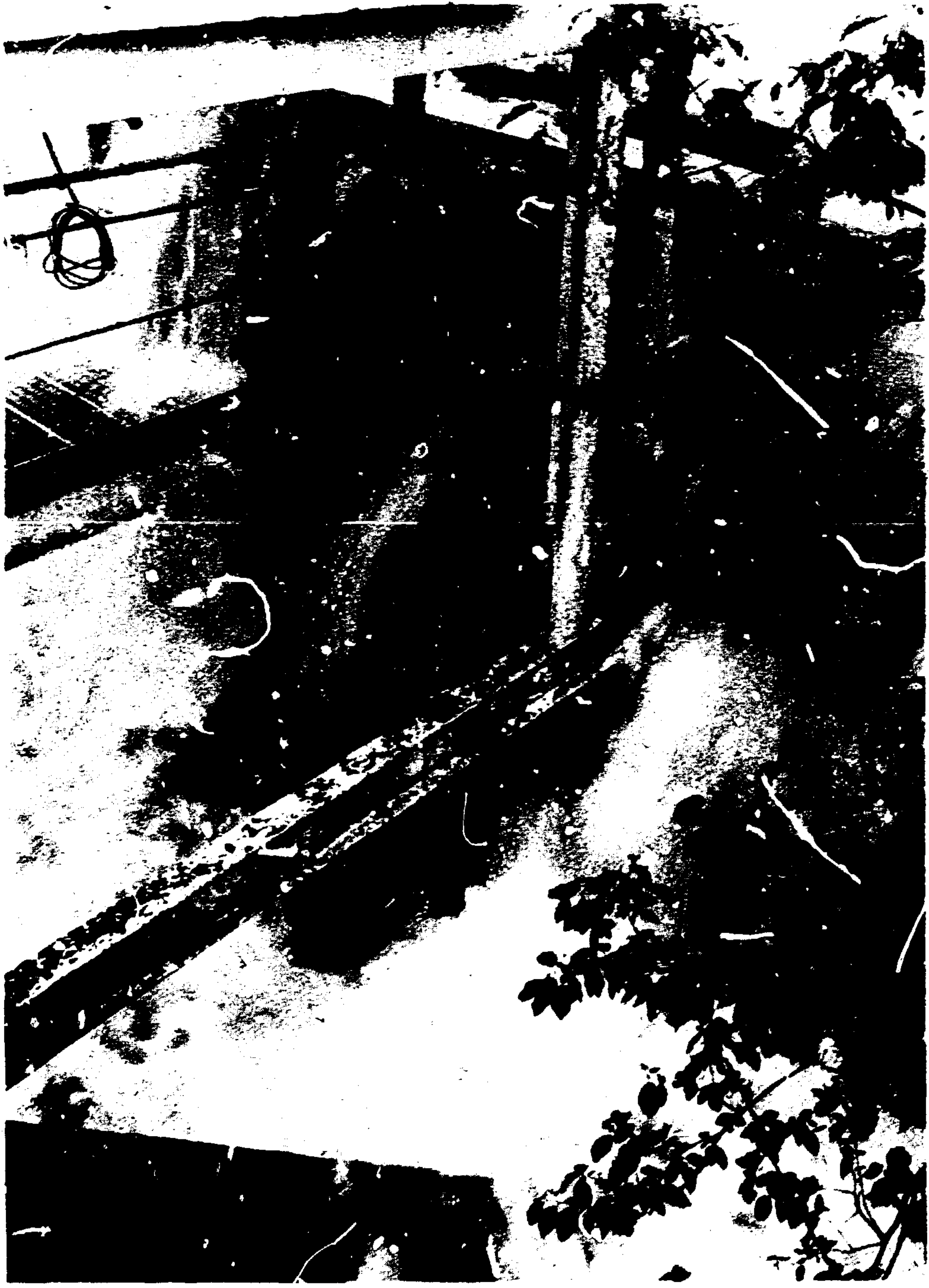

Fig. 4.11. High flow over White Oak Dam on Apr. 7, 1977, scene 5.

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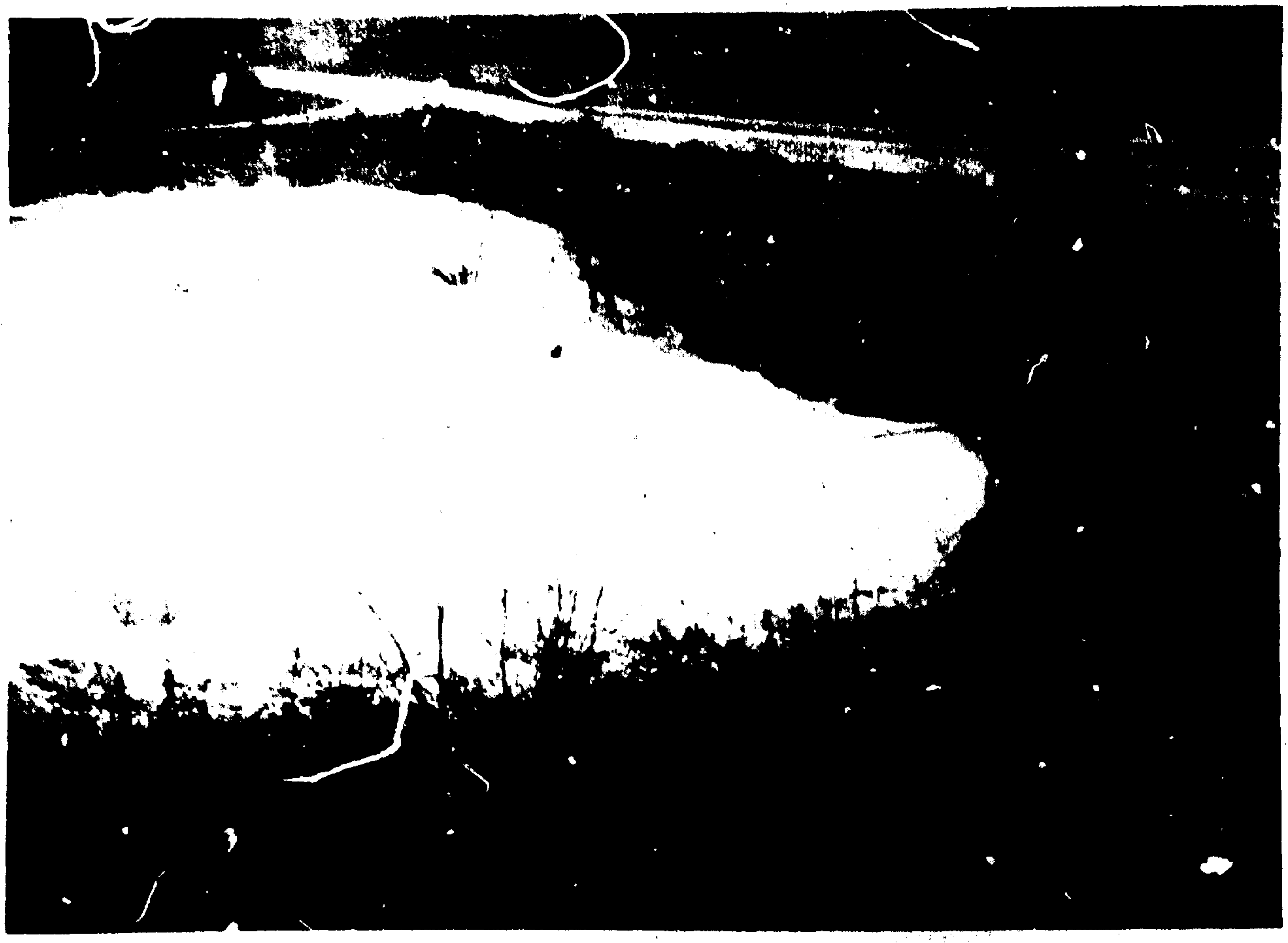

Fig. 4.12. White Oak Creek downstream of the dam on Apr. 3, 1977.

ORNL PHOTO 2783-77

Fig. 4.13. White Oak Creek downstream of the dam after the lake began to recede, April 1977.

5. REVIEW OF SEDIMENT DATA

5.1 REVIEW OF HISTORICAL WHITE OAK CREEK DATA

5.1.1 Sediment data, 1945-78

Sediment sampling in White Oak Creek was conducted during 1945 and 1946. The White Oak drainage system was divided into five sections; these are shown in Fig. 5.1. The sections were the marsh, intermediate pond, White Oak Lake mud flats, White Oak Lake, and the area below the spillway (Morgan and Cheka, 1947). The results of this sampling program are given in Table 5.1. During 1950, 1951, and 1952, sediment samples were collected at 30 m (100 ft) intervals on White Oak Lake bed (Abee, 1953). The total activity found and the average Bq/m^2 (μCi/ft^2) are given in Table 5.2. Results from the 1948 and 1949 sampling program are also given in Table 5.2.

General chemical characteristics of the White Oak Lake bed soils indicated little change up through 1958 (Auerbach et al., 1959). The results of analyses of soils from the upper and lower lake bed are given in Table 5.3. A detailed analysis and mapping of the radiation fields above the two parts of the bed demonstrated a profound difference in the air-dose rates in the two areas, resulting primarily from differences in concentrations of ^{137}Cs and ^{60}Co in the soils (Lee and Auerbach, 1959). Details of these radiation measurements are given in Sect. 5.1.2. Sixty-eight soil samples [0-15 cm (0-6 in.)] taken during 1956, 1957 and 1958 were analyzed for total ^{90}Sr. The results are summarized in Fig. 5.2 and Table 5. (Auerbach et al., 1959). The soil mass in the lake bed was determined to be 1.6 to 1.8 x 10^2 kg/m^2 (1.4 to 1.6 x 10^6 lb/acre) to a depth of 15 cm (6 in.). Table 5.4 is a list of the ^{90}Sr results for 1956-58. Three experimental agricultural plots were established on White Oak Lake bed in 1958 (Fig. 5.3) (Auerbach et al., 1959).

Results of analyses of the soil from these plots are given in Table 5.5. Plot III had the largest concentration of radionuclides and the greatest amount of exchangeable calcium and phosphorus.

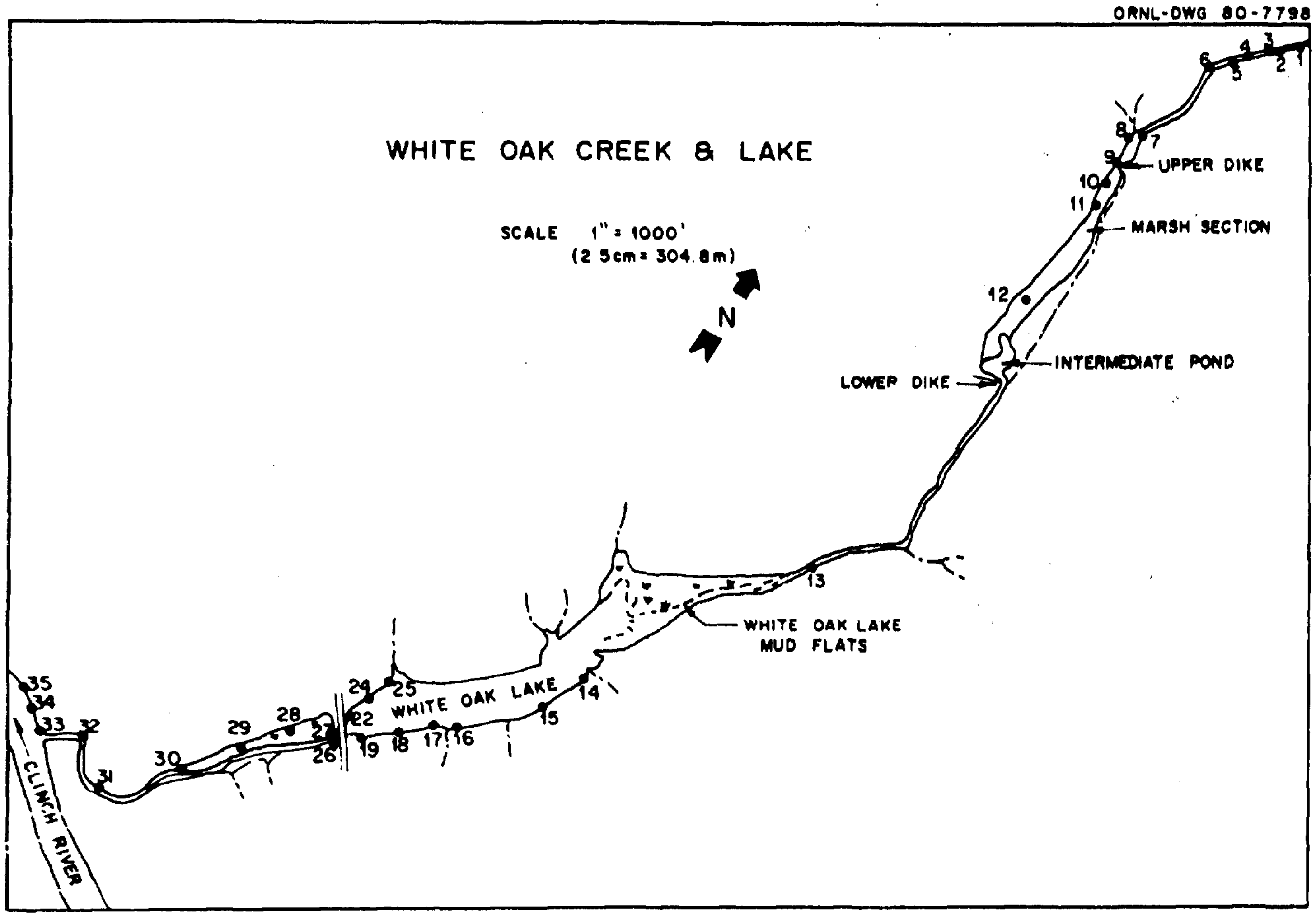

Fig. 5.1. Sediment sampling locations during 1945 and 1946.

Table 5.1. Total activity of White Oak drainage system, 1945-46

Location	Distance below settling pond [m (ft)]	1945			1946		
		Average		Total	Average		Total
		[MBq/m^2	(μCi/ft^2)]	[TBq (Ci)]	[MBq/m^2	(μCi/ft^2)]	[TBq (Ci)]
Marsh	646 (2,120)	36.4	(91.5)	1.58 (42.7)	58.0	(145.5)	2.51 (67.8)
Intermediate pond	991 (3,250)	34.9	(87.6)	0.17 (4.6)			
W.O. Lake mud flats	2103 (6,900)	8.8	(22.0)	0.55 (14.9)	3.8	(9.6)	0.24 (6.5)
W. O. Lake	2621 (8,600)	3.4	(8.5)	0.25 (6.8)	6.8	(17.1)	0.5 (13.6)
Area below spillway	3155 (10,350)	0.41	(1.04)	0.01 (0.3)	1.1	(2.7)	0.03 (0.9)
Total				2.56 (69.3)			3.28 (88.8)

Source: Cheka and Morgan, 1947.

Table 5.2. Total activity in White Oak Lake, 1948-52

Year	Total activity [TBq (Ci)]	Average [MBq/m^2 (µCi/ft^2)]
1948	0.78 (21)	8.8 (22.0)
1949	0.74 (20)	3.4 (8.5)
1950	14.5 (392)	109.8 (275.8)
1951	13.3 (359)	96.9 (243.4)
1952	11.2 (303)	

Source: Abee, 1953.

Table 5.3. Comparison of upper and lower White Oak Lake soils in 1959

Constituent	Upper lake bed		Lower lake bed	
^{90}Sr [kBq/100 g (μCi/100 g)]	2.01	(0.0544)	1.33	(0.036)
^{137}Cs [Bq/100 g (μCi/100 g)]	151.3	(4.089)	27.2	(0.734)
^{60}Co [Bq/100 g (μCi/100 g)]	39.2	(1.059)	29.9	(0.8068)
Ca (meq/100 g)		(36.0)		(20.1)
K (meq/100 g)		(0.195)		(0.221)
Na (meq/100 g)		(0.653)		(0.0366)
P (ppm)		(3.50)		(2.04)
pH		(7.53)		(6.67)

Source: Morgan et al., 1959.

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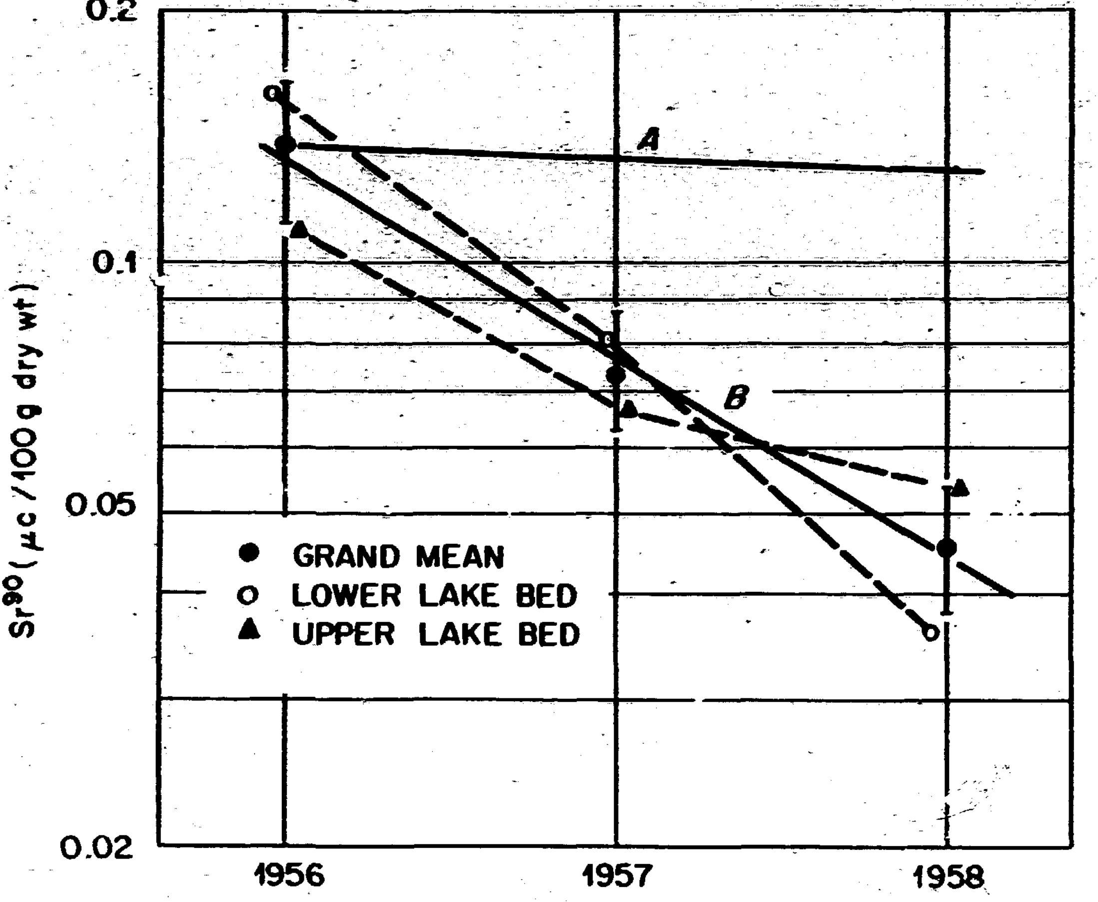

Fig. 5.2. Changes in ^{90}Sr in upper and lower White Oak Lake bed. Curve A is loss due to radioactive decay only. Curve B was fitted visually and applies to both parts of the lake bed. Source: Auerbach et al., 1959.

Table 5.4. Changes in ^{90}Sr in White Oak Lake bed

Year	Concentration				Total lake bed	
	[kBq/100 g	(µCi/100 g)]	[MBq/m^2	(Ci/acre)]	[TBq	(Ci)]
1956	5.07	(0.137)	8.14	0.888)	1.31	(35.5)
1957	2.78	(0.075)	4.43	(0.483)	0.71	(19.3)
1958	1.67	(0.045)	2.69	(0.293)	0.43	(11.7)

Source: Auerbach et al., 1959.

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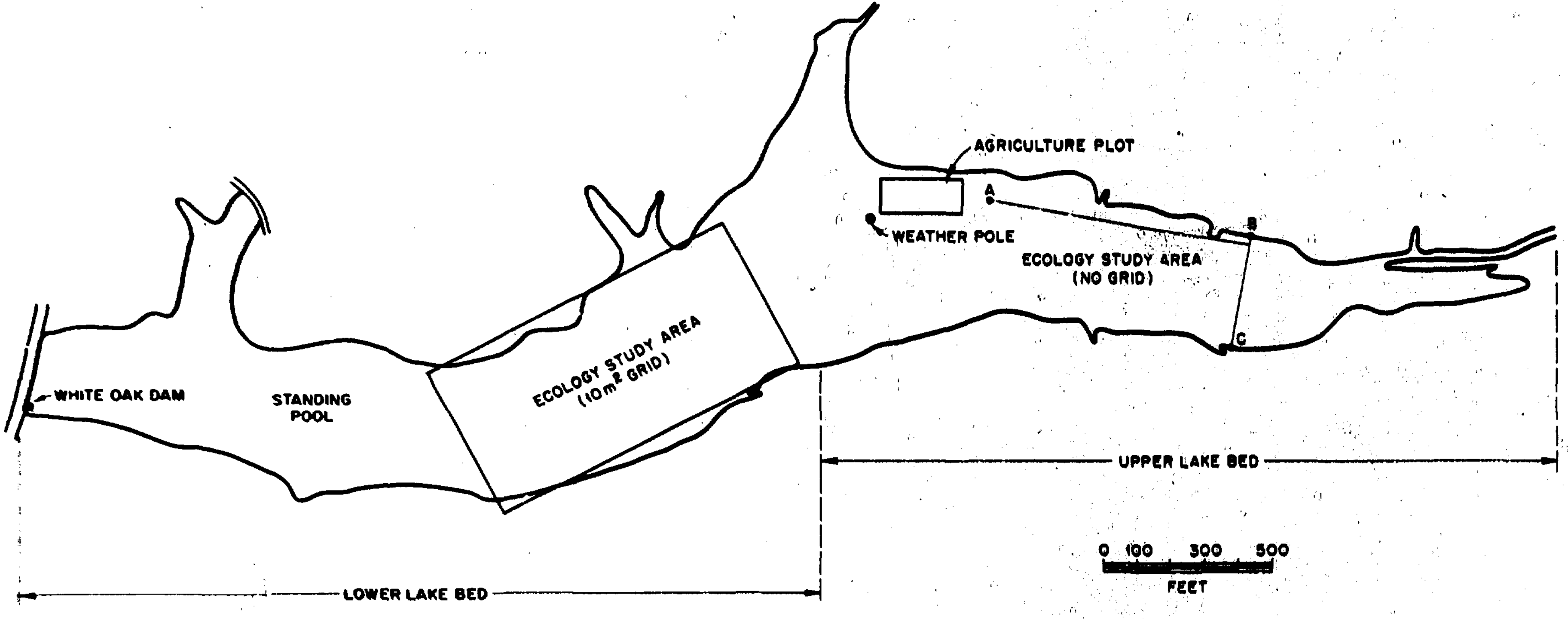

Fig. 5.3. Map of White Oak Creek drainage basin.

Table 5.5. Concentrations of radionuclides and chemical properties of soil plots in White Oak Lake bed, 1958

Plots	^{90}Sr [kBq/100 g	(µCi/100 g)]	^{137}Cs [kBq/100 g	(µCi/100 g)]	^{60}Co [kBq/100 g	(µCi/100 g)]	Ca (meq/100 g)	K (meq/100 g)	Na (meq/100 g)	P (ppm)	pH
I	0.936	(0.0253)	10.3	(0.279)	4.63	(0.125)	17.7	0.34	0.33	2.1	6.95
II	0.762	(0.0206)	9.47	(0.256)	3.44	(0.093)	16.9	0.31	0.33	2.4	7.05
III	1.13	(0.0305)	35.1	(0.948)	5.59	(0.151)	21.2	0.28	0.27	3.2	7.39

Source: Auerbach et al., 1959.

During 1961, an area sampling program was initiated to determine the vertical and lateral distribution of radionuclides in the lake bed (Lomenick et al., 1961). A summary of the gross gamma activity in the cores is given in Table 5.6. From these data, it was generally noted that (Lomenick et al, 1961):

(1) more gamma activity/gram of soil was detected at the upper lake bed [White Oak Lake km 2.1 (mile 1.3)] than at the lower one [White Oak Lake km 1.4 (mile 0.9)],

(2) most of the gamma activity was contained in the first 30 cm depth of soil, and

(3) activity in the upper few centimeters of each core was rather uniformly distributed.

A study of ^{106}Ru distribution in White Oak Creek was conducted in 1962. It was concluded that most of the activity enters the upper few centimeters of the lake bed soil during the dry months when the water table is low but that it is transported laterally and vertically through the soil during the winter months when the water table lies relatively near the surface (Lomenick et al., 1962; Cowser et al., 1961).

A series of soil samples were taken within the lake bed during February 1962 and radiochemically analyzed to determine the distribution and total amount of ^{106}Ru in the soil. The cores, ranging in depth from 61 cm (24 in.) to 152 cm (60 in.), were taken approximately 15.2 m (50 ft) apart along lines at right angles to the surface flow of waste over the lake bed (Lomenick et al., 1962). As of February 1962, the lake bed contained approximately 44 TBq (1200 Ci) of ^{106}Ru.

Also in 1962, a series of 250 core samples were taken within the White Oak Lake area and analyzed for ^{106}Ru, ^{137}Cs, ^{60}Co, TRE, and ^{90}Sr (Lomenick et al., 1963). A map of White Oak bed showing the sample locations is given in Fig. 5.4; the thickness of the sediment is shown in Fig. 5.5. In general, most of the ^{137}Cs was associated with the relatively thin layer of the recent lacustrine sediment that covered the lake bed. In areas near the shoreline, where the sediment is thinnest, the activity was lowest. For the first 15 cm of soil, the ^{137}Cs concentrations varied from <3.7 x 10^{-5} to 2.85 x 10^{-5} mBq/g (<1 x 10^{-3} to 77 x 10^{-3} μCi/g). The areas of maximum

Table 5.6. Distribution of gross gamma activity in the bed of White Oak Lake, 1961 (counts $min^{-1} g^{-1}$ wet weight)

Depth (cm)	Distance from left bank (m) Upper transect (White Oak Creek km 2.1) 15	24	43	58	73	Lower transect (White Oak Creek km 1.4) 27	58	76	104	125
0-2.5	21,300	36,500	16,700	32,500	18,540	3,000		15,700	8,000	8,700
2.5-5	19,800	30,600	29,400	28,000	13,700	6,000	14,000[a]	14,400	8,600	13,400
5-7.5	19,600	20,500	29,200	27,000	21,400	2,100		13,400	18,100	13,700
7.5-10	190	18,400	31,700	28,000	21,000	450	13,800[b]	18,700	24,500	14,400
10-12.5	110	23,800	27,800	25,000	20,500	15			26,100	16,500
12.5-15	10	63,000	21,400	43,100	11,000	15	17,300[c]	1,300[c]	24,400	13,000
15-23	10	57,900	23,500	21,000	4,900	230	2,100	65	3,300	2,900
23-30	6	8,700	28,600	5,500	3,200	5	450	10	100	700
30-46	35	1,400	6,800	2,000	1,500	15	300		80	95
46-61	30	800	1,800	500	1,400	5	7	450	7	30
61-91	2	600	300	400	1,400	5	100	6	10	5
91-122	2	180	100	270	750	5	3	10	7	5
122-152	750	50	75	170	630	2	3	2	8	6
152-183	90	25	85	200	700	3	5	3	3	15

[a] Total for depth of 0 to 2.5 cm.

[b] Total for depth of 0 to 10 cm.

[c] Total depth of 0 of 15 cm.

Source: Lomenick et al., 1961.

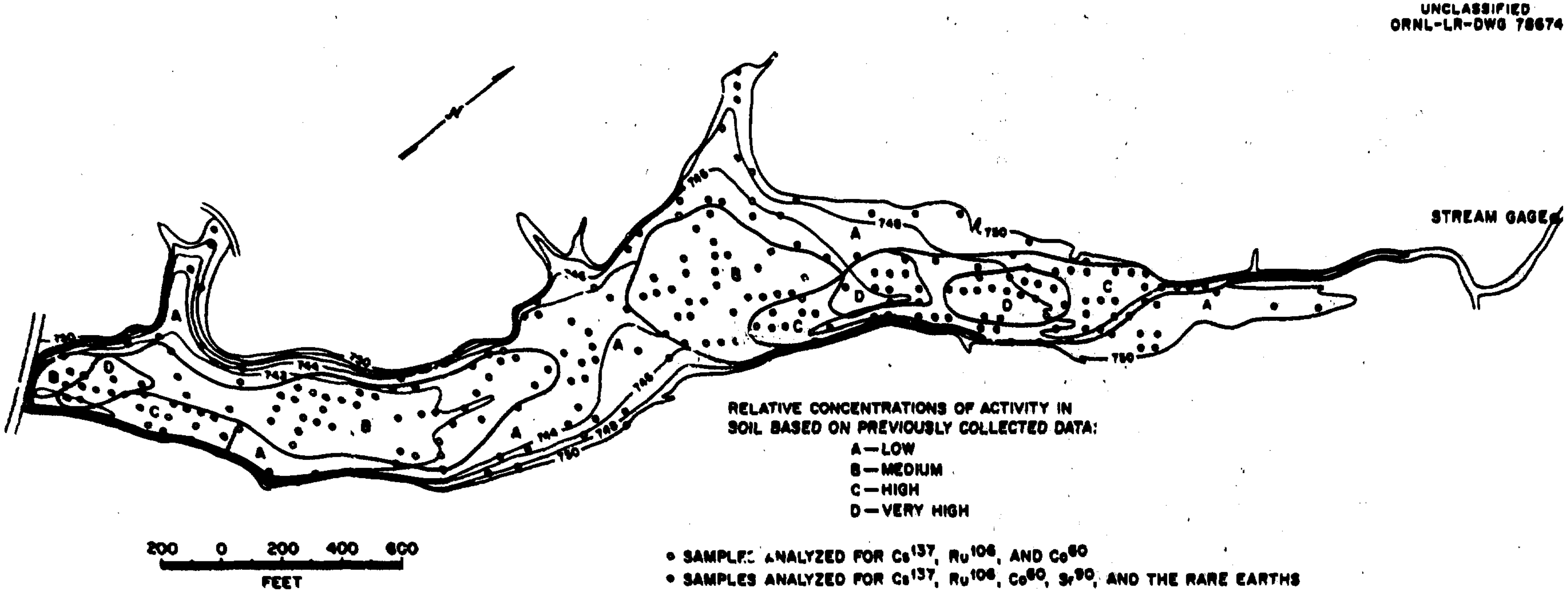

Fig. 5.4. Location of 61-m (2-ft) core samples in bed of former White Oak Lake, 1962.

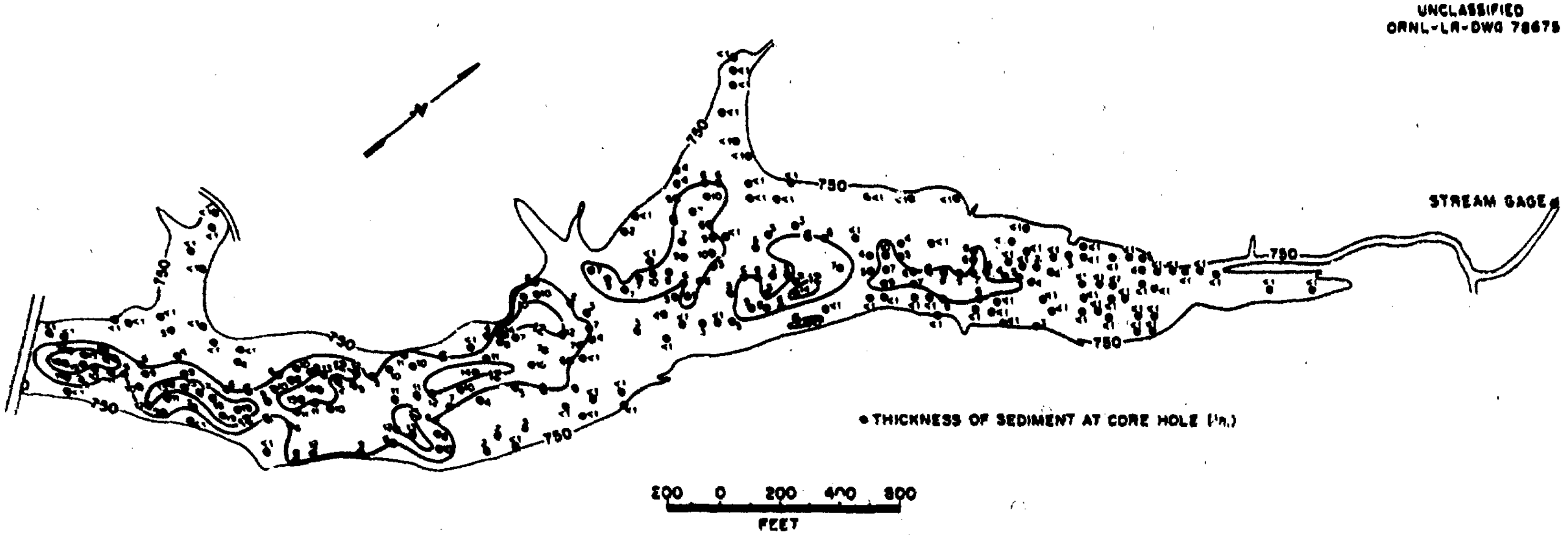

Fig. 5.5. Map of former White Oak Lake bed (1962) showing thickness of contaminated sediment. Note: Since this figure was generated before metrification, it has not been changed. However, multiplication of the figures by 2.54 will give the thicknesses in centimeters.

concentrations lie roughly adjacent to the course of White Oak Creek through the bed and in the present impoundment area behind the dam. Distribution of ^{137}Cs in the lake is shown in Fig. 5.6 [0-15 cm (0-6 in.)] and in Fig. 5.7, [15-30 cm (6-12 in.)].

The highest concentrations of ^{90}Sr were found within the inundated area behind the dam, with the exception of a few narrow zones parallel to the creek in the upper part of the bed (Lomenick et al., 1963). Distribution of ^{90}Sr [0-15 cm (0-6 in.)] in the lake is shown in Fig. 5.8. The quantity and distribution of radionuclides in White Oak Lake bed in 1962 are given in Table 5.7.

During 1964, a series of ten sediment ranges were established in White Oak Creek. Samples were collected from the upper 0.06 m (0.2 ft) of bottom sediment. The distribution of radionuclides in the less than 63 μm particle size fraction of the sediment is shown in Fig. 5.9 (McMaster and Richardson, 1964).

In 1964, it was determined that the sediment of White Oak Lake had accumulated 25.9 TBq (700 Ci) of ^{137}Cs (Lomenick et al., 1964). Nearly all the cesium in the lake bed is associated with lacustrine sediment. Figure 5.10 shows the concentrations of cesium in several cores taken throughout the lake bed. There is little difference in the concentration of cesium in the cores where the sediment is only a few centimeters thick and in some of the cores where the sediment is up to 30 cm thick. There did not seem to be a relationship between sediment thickness and cesium concentration.

Most of the activity was not in the upper 15 cm (6 in.) of sediment as it was in the 1965 sampling (Lomenick and Gardiner, 1965) but was at a deeper location, between 16 to 34 cm. This was expected, since the annual discharges of radionuclides to White Oak Lake had decreased between 1965 and 1972, and additional sedimentation had covered most of the older contaminated sediments (Blaylock et al., 1972).

The concentration of ruthenium decreased considerably between 1965 and 1972. Radioactive decay and reduction in released ruthenium are the major factors contributing to this decrease. The largest concentrations of ^{137}Cs, ^{90}Sr, and ^{65}Zn were found in the upper shallow portion of the lake.

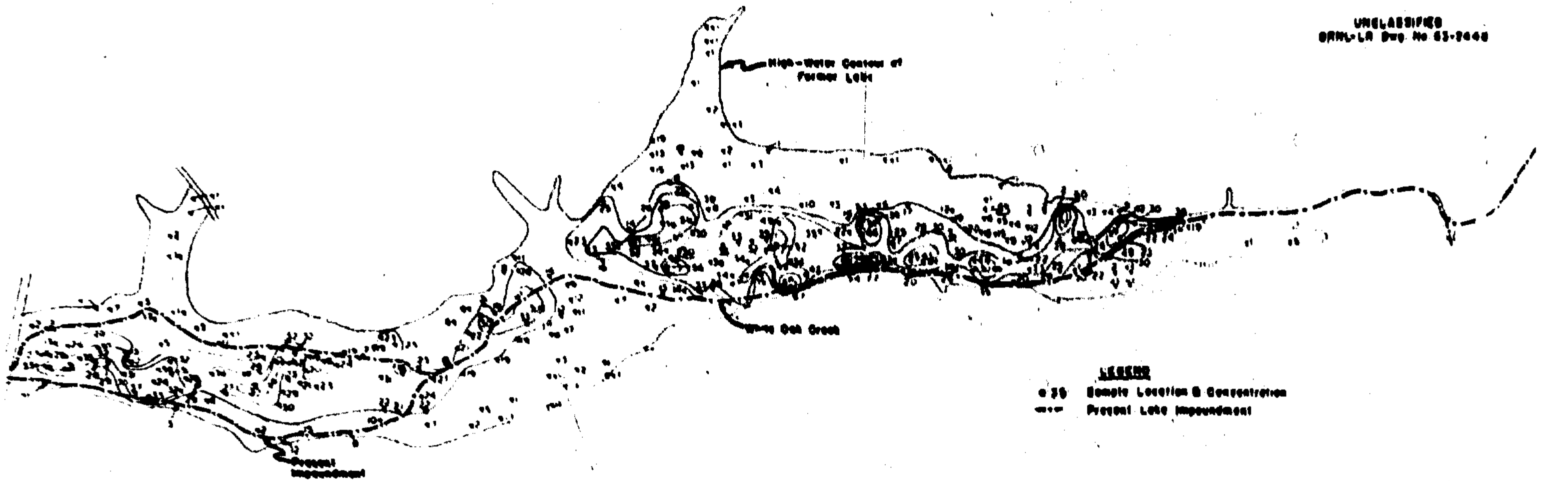

Fig. 5.6. Map of White Oak Lake bed showing ^{137}Cs concentrations in 10^{-3} µCi per gram of dry weight for 0 to 15 cm (0 to 6 in.) of soil layer, 1962. Note: Since this figure was generated before metrification, it has not been changed. However, multiplication of the figures by 37.0 will give the concentration in Bq/g.

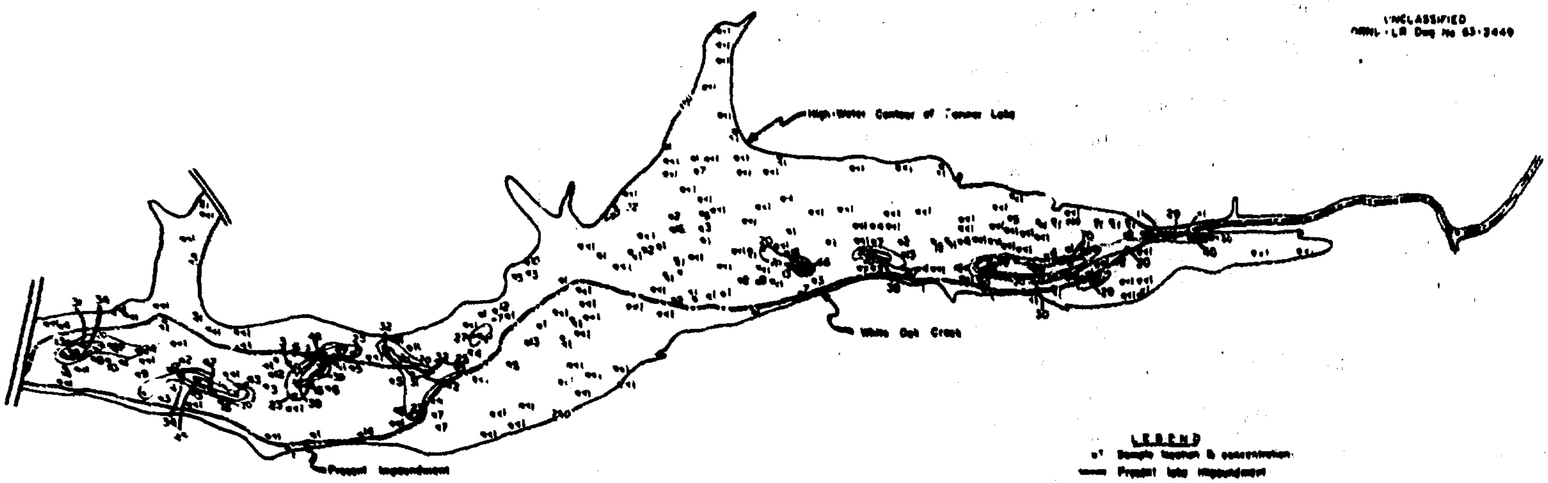

Fig. 5.7. Map of White Oak Lake bed showing ^{137}Cs concentrations in 10^{-3} µCi per gram of dry weight for 15 to 30 cm (6 to 12 in.) of soil layer, 1962. Note: Since this figure was generated before metrification, it has not been changed. However, multiplication of the figures by 37.0 will give the concentrations in Bq/g.

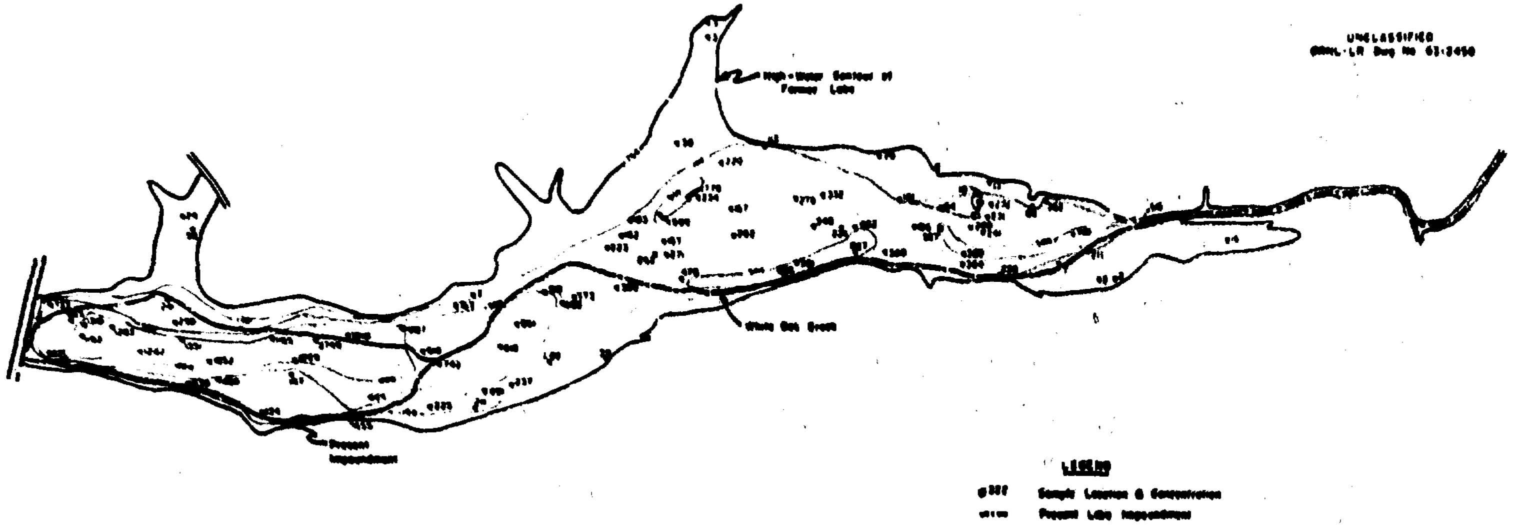

Fig. 5.8. Map of White Oak Lake bed showing ^{90}Sr concentrations in pCi per gram of dry weight for 0 to 15 cm (0 to 6 in.) of soil layer, 1962. Note: Since this figure was generated before metrification, it has not been changed. However, multiplication of the figures by 0.037 will give the concentrations in Bq/g.

Table 5.7. Quantity and distribution of radionuclides in White Oak Lake bed, 1962
[TBq (Ci)]

Radionuclides	Depth from surface [cm (in.)]				
	0-15 (0-6)	15-30 (6-12)	30-45 (12-18)	45-60 (18-24)	Total
^{106}Ru	22 (594)	10.2 (276)	4.1 (112)	2.1 (56)	38.4 (1038)
^{137}Cs	17.3 (468)	7.6 (204)	1.1 (29)	0.1 (3)	26.1 (704)
^{60}Co	4.4 (119)	0.8 (22)	0.3 (8)	0.1 (3)	5.6 (152)
TRE[a]	0.5 (13)	0.1 (2.5)	0.004 (1.0)	0.004 (0.1)	0.64 (17.2)
^{90}Sr	0.4 (10)	0.1 (3.5)	0.004 (1.0)	0.004 (0.1)	0.54 (14.6)

[a] Trivalent rare earths less ^{90}Y.

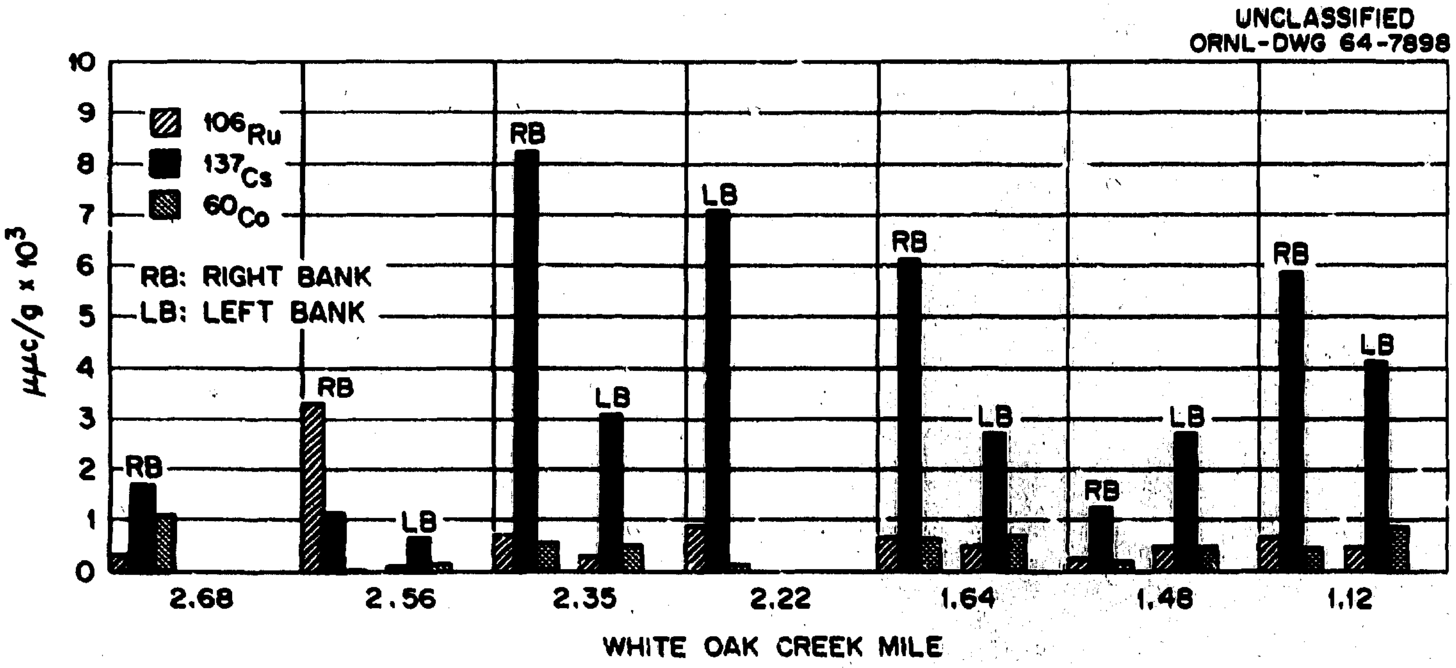

Fig. 5.9. Distribution of radioactivity in White Oak Creek, 1964. Note: Since this figure was generated before metrification, it has not been changed. However, multiplication of the locations by 1.61 will convert miles to kilometers; multiplying the concentrations by 0.037 will convert pCi/g to Bq/g.

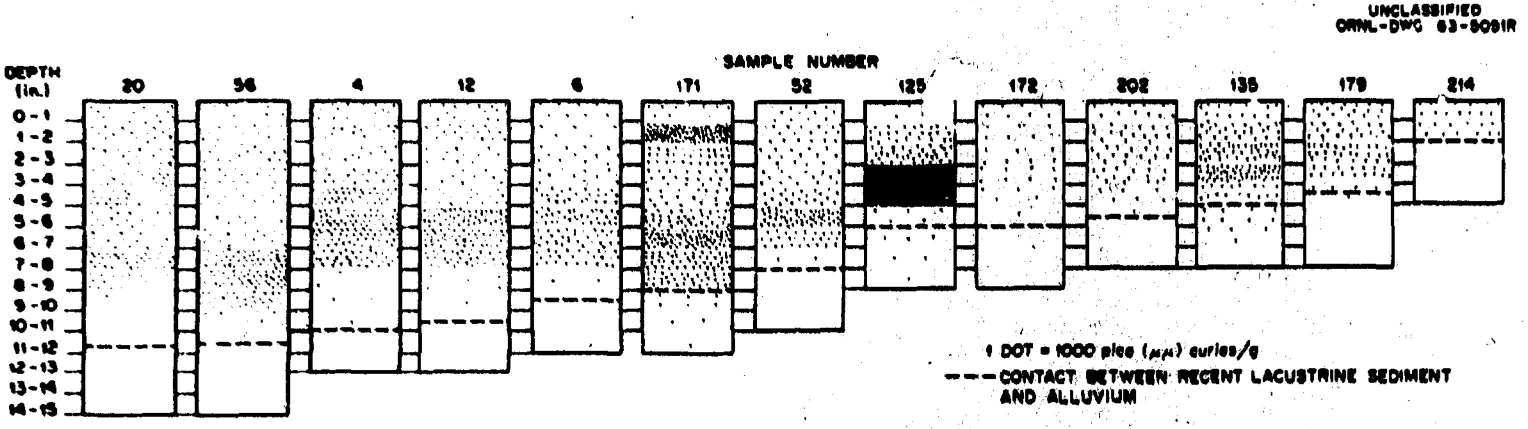

Fig. 5.10. Concentration of ^{137}Cs in White Oak Lake core samples. Note: Since this figure was generated before metrification, it has not been changed. However, multiplication of the depths by 2.54 will convert inches to centimeters; multiplying the concentrations by 0.037 will convert pCi/g to Bq/g.

In 1970, sediment samples were obtained from the mouth of White Oak Creek entering the Clinch River and from White Oak Lake (Tamura et al., 1970). Results of the radionuclide distribution are given in Table 5.8. The ^{137}Cs concentration in the creek 0.21 kBq/g (5.8×10^{-3} μCi/g) was higher than in the lake bed sample 0.07 kBq/g (1.9×10^{-3} μCi/g). The total ^{90}Sr content was similar in the creek and lake samples (Tamura et al., 1970).

During 1972, a study was conducted to update an assessment of the concentration of radionuclides in the bottom sediment of White Oak Lake (Blaylock et al., 1972). Earlier investigations indicated that the upper 15 cm (6 in.) of the sediments contained more than 65% of the ^{137}Cs and ^{90}Sr, 80% of the ^{60}Co, and 55% of the ^{106}Ru (Lomenick and Gardiner, 1965). The mean concentration and the percentage of the total site activity are given in Table 5.9. Cesium-137 was the most abundant radionuclide in the sediment and accounted for 62 to 86% of the total gamma emitters with only two sampling sites being the exception (Blaylock et al., 1972).

During 1977, tritium concentrations in White Oak Lake sediments were investigated (Blaylock and Frank, 1979). The bound ^{3}H was determined using freeze-drying techniques. The concentration of ^{3}H in the overlying water was 648 pCi/ml compared to 450 pCi/ml in the water removed from the sediment. The dried sediment contained 17 pCi/g of ^{3}H. Approximately 11% of the dried White Oak Lake sediment was organic material. It was assumed that the ^{3}H in the sediment was organically bound, resulting in concentrations within the range of tritium found in the tissue bound tritium of plants and animals in the lake.

5.1.2 Radiation measurements, 1958

Direct radiation measurements were also made on the White Oak Lake bed (Lee and Auerbach, 1959). These readings were made during 1958 when the lake was drained. A portable ionization type instrument (cutie-pie) with two separate chambers (gamma + beta sensitive, gamma sensitive only) was used. Film was also used, primarily DuPont 502 type. The quality of the radiation was approximately 90% gamma. Weekly fluctuations in the radiation field in the portion of the lake where radioactive material (^{106}Ru) was being deposited were up to 50 mR/h, primarily due to seepage from waste disposal pits. K. Z. Morgan (Lee and Auerbach, 1959) derived the equation:

$$D = \Sigma \frac{2\pi}{\mu_i} Nn_i G_i \; [1 - E_2(\mu_i h_i)] \;.$$

Table 5.8. Distribution of ^{90}Sr and ^{137}Cs from sediments collected in White Oak Lake bed and the mouth of White Oak Creek, 1970

Band	Density (g/cc)	Weight (g)	Percent by weight	^{90}Sr (counts/min)	Percent in band	^{137}Cs (counts/min)	Percent in band	Band characteristics
				White Oak Creek				
1	1.86	0.0025	1.8	15	11.7	15	1.2	Amorphous material
2	1.86-2.30	0.0072	5.6	16	12.5	118	9.7	Amorphous material
3	2.30-2.41	0.0230	17.7	35	25.8	456	37.4	Clay minerals
4	2.41-2.47	0.0220	17.0	10	7.8	212	17.4	Clay minerals with feldspar
5	2.47-2.56	0.0562	43.3	25	19.5	281	23.1	Primarily quartz; some clay minerals
6	2.56-2.78	0.0143	11.0	10	7.8	77	6.3	Mica and chlorite (?)
7	2.78	0.0045	3.5	19	14.8	59	4.8	Heavy minerals, including dolomite
Total		0.1287		128		1218		
unbanded		0.1500		132		1326		
				White Oak Lake bed				
1	1.86	0.0013	1.0	5	3.8	8	2.2	Amorphous material
2	1.86-2.30	0.0012	0.9	7	5.3	23	6.3	Amorphous material
3	2.30-2.47	0.0486	35.8	37	28.0	148	40.5	Clay minerals includes band 4
4								Clay minerals includes band 4
5	2.47-2.59	0.0552	40.6	30	22.7	101	27.7	Primarily quartz; some calcite and clay materials
6	2.59-2.78	0.0267	19.17	44	33.3	65	17.8	Primarily calcite
7	2.78	0.0029	2.1	9	6.8	20	5.5	Heavy minerals including dolomite
Total		0.1359		132		365		
unbanded		0.1500		105		406		

Table 5.9. Summary of radionuclide concentrations of bottom sediments for White Oak Lake, 1972

Site No.	^{106}Ru		^{137}Cs		^{125}Sb		^{65}Zn		^{60}Co	
	Bq/g (pCi/g)	%	Bq/g (pCi/g)	%	Bq/g (pCi/g)	%	Bq/g (pCi/g)	%	Bq/g (pCi/g)	%
1	3.5 (94.5)	5.4	50.5 (1364.3)	78.1	2.0 (55.4)	3.2	0 (0)	-	8.6 (232.1)	13.3
2	9.0 (243.1)	5.3	132.3 (3575.1)	77.9	5.4 (145.6)	3.2	1.6 (43.6)	1.0	21.4 (579.3)	12.7
3	14.7 (396.4)	7.0	129.9 (3510.7)	62.4	5.3 (143.1)	2.6	2.0 (54.6)	1.0	56.4(1524.4)	27.1
4	20.2 (546.6)	7.9	163.7 (4424.6)	63.9	10.4 (280.0)	4.1	5.1(137.8)	2.0	56.7(1533.7)	22.2
5	10.0 (270.9)	5.6	130.6 (3528.7)	72.8	4.8 (128.4)	2.6	3.1 (84.7)	1.7	30.9 (835.5)	17.2
6	2.7 (73.4)	4.2	52.6 (1420.7)	80.2	0.7 (18.9)	1.1	0 (0)	-	9.8 (265.5)	14.6
7	2.8 (75.7)	4.3	51.3 (1385.5)	80.5	0.9 (25.4)	1.4	0 (0)	-	9.1 (246.3)	13.7
8	0.15(4.0)	5.4	2.5 (67.4)	85.0	0.1 (2.7)	3.5	0.02(0.5)	0.9	0.1 (4.0)	5.1
9	1.2 (33.0)	5.5	20.3 (548.2)	85.8	0.9 (23.6)	4.0	0.03(0.7)	0.1	1.1 (29.5)	4.2
10	3.5 (95.8)	5.2	57.1 (1543.0)	85.4	2.2 (58.9)	3.3	0.1 (3.3)	0.2	4.0 (107.4)	6.0

Source: Blaylock et al., 1972.

where

D = expected dose rate above a large slab,

h_i = thickness of slab,

i = number of radionuclides,

m_i = concentration of given radionuclide,

μ_i = absorption coefficients,

G_i = point Kernel for 1 μCi source in lake bed,

E^2 = exponential integrals of the second order.

After scattering is considered, solution of this equation gave 18 mR/h, as opposed to a measured mean of 16 mR/h.

Results of analyses indicate that most of the radionuclides are heterogeneously distributed in the top 10 cm (4 in.) of soil (Fig. 5.11). The concentrations of these radionuclides may be up to 50%-100% higher near the inlet of White Oak Lake, as opposed to the lower lake bed.

More emphasis was placed on defining the radiation field above the gridded areas used for ecology studies because of a permanent reference system in the grid area, and because of lack of access to some heavily grown over areas of White Oak Lake. Figure 5.12 is a photograph of this area, showing the metal co-ordinate markers of the grid. Figure 5.13 shows an aerial view of the Agricultural Plot.

The average readings of the surveys taken at 100-cm height with the thin-walled (7 mg/cm^2) ionization chamber were used to define the configuration of the radiation field above the lake bed. Dose rates varied from a low of nondetectable along the Southern shore to a high of 30 mR/h at reference points along the creek bank (Fig. 5.14). The average dose rate at 100-cm height over the grid areas is 16 mR/h . Fluctuations above the grid area were about 1 mR/h, but because of difficulty in reading the scale and the energy response of the instrument (small, but none the less present), the field was considered to be constant during the study. The wide fluctuations near the inlet were due to influx of ^{106}Ru from radwaste pits upstream (Fig. 5.15). Figure 5.16 shows the nonuniformity of the radiation field above the ecology areas. Regions of lowest dose are along the shore lines, and maximum above the body of the lake bed. Transects of the dose rate above the two ecology areas (Figs. 5.17 and 5.18) also show this pattern. Figures 5.17 and 5.18 are plotted with the equivalent cross

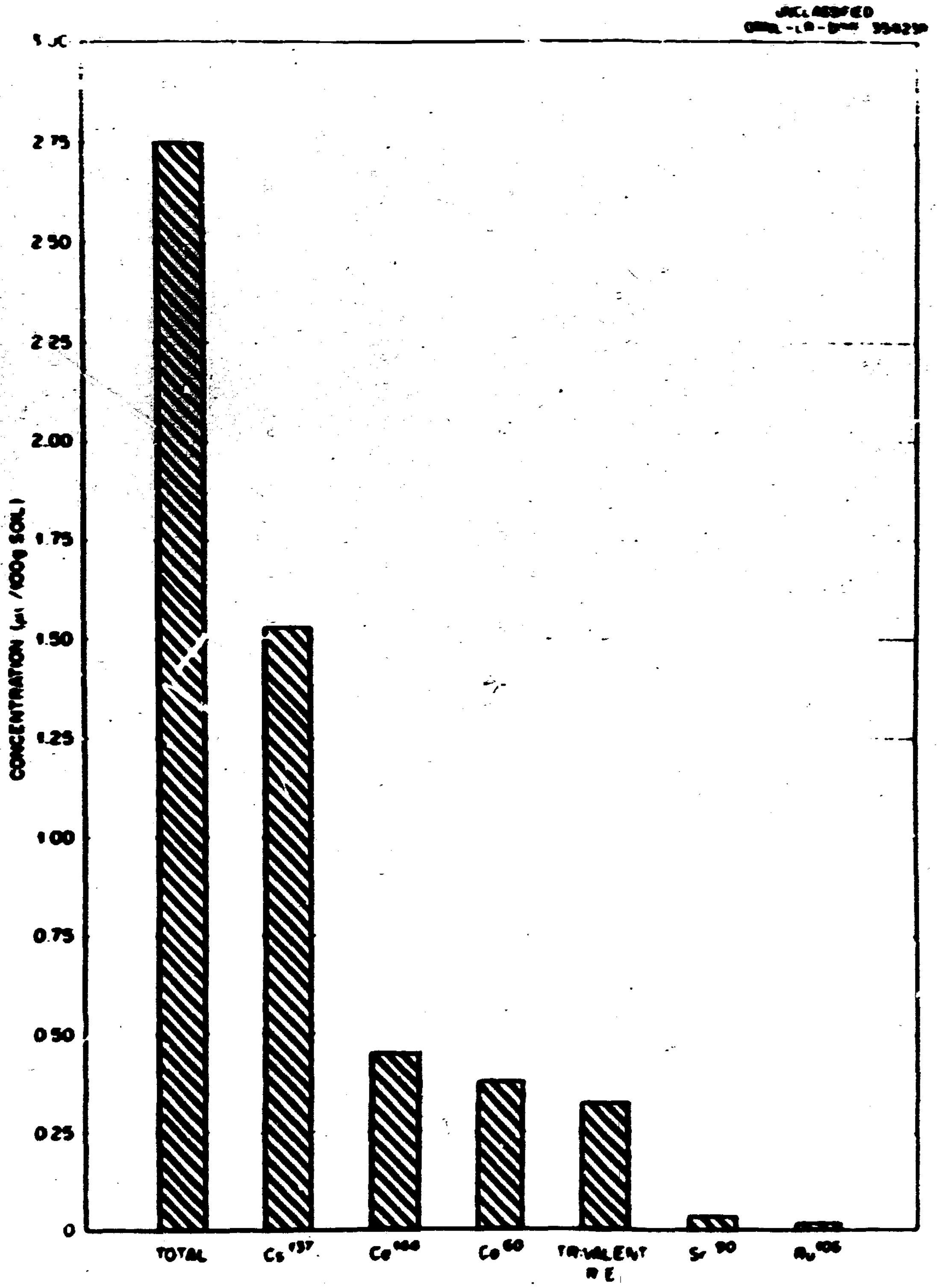

Fig. 5.11. Average concentration of radionuclides present in the top 4 in. of White Oak Lake bed soil (grid area, 1958). Note: Since this figure was generated before metrification, it has not been changed. However, multiplying the concentrations by 0.037 will convert μCi/100 g to MBq/100 g. Inches may be converted to centimeters by multiplying by 2.54.

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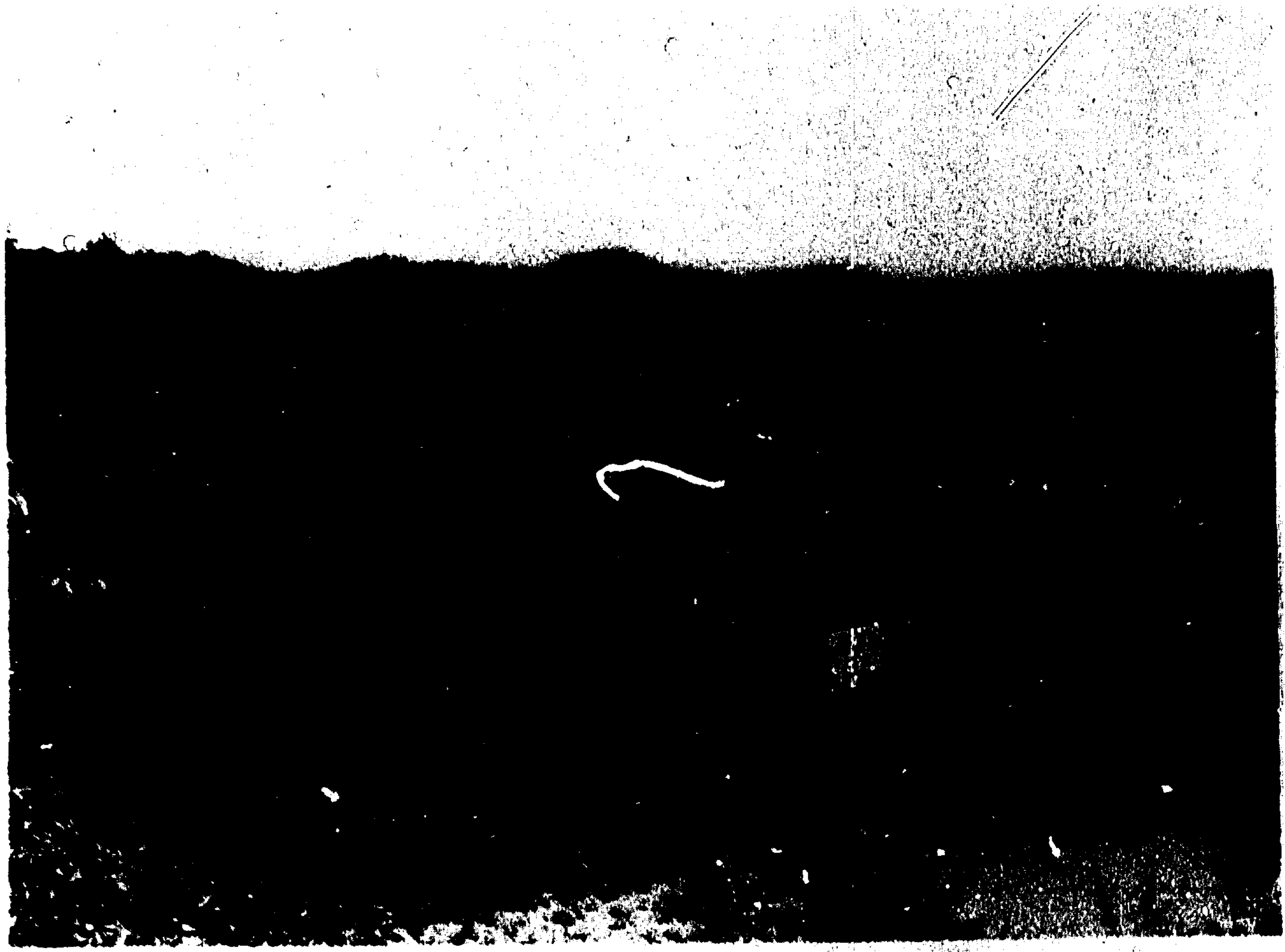

Fig. 5.12. View of ecology grid area (White Oak Lake bed).

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Fig. 5.13. Aerial view of agricultural plot.

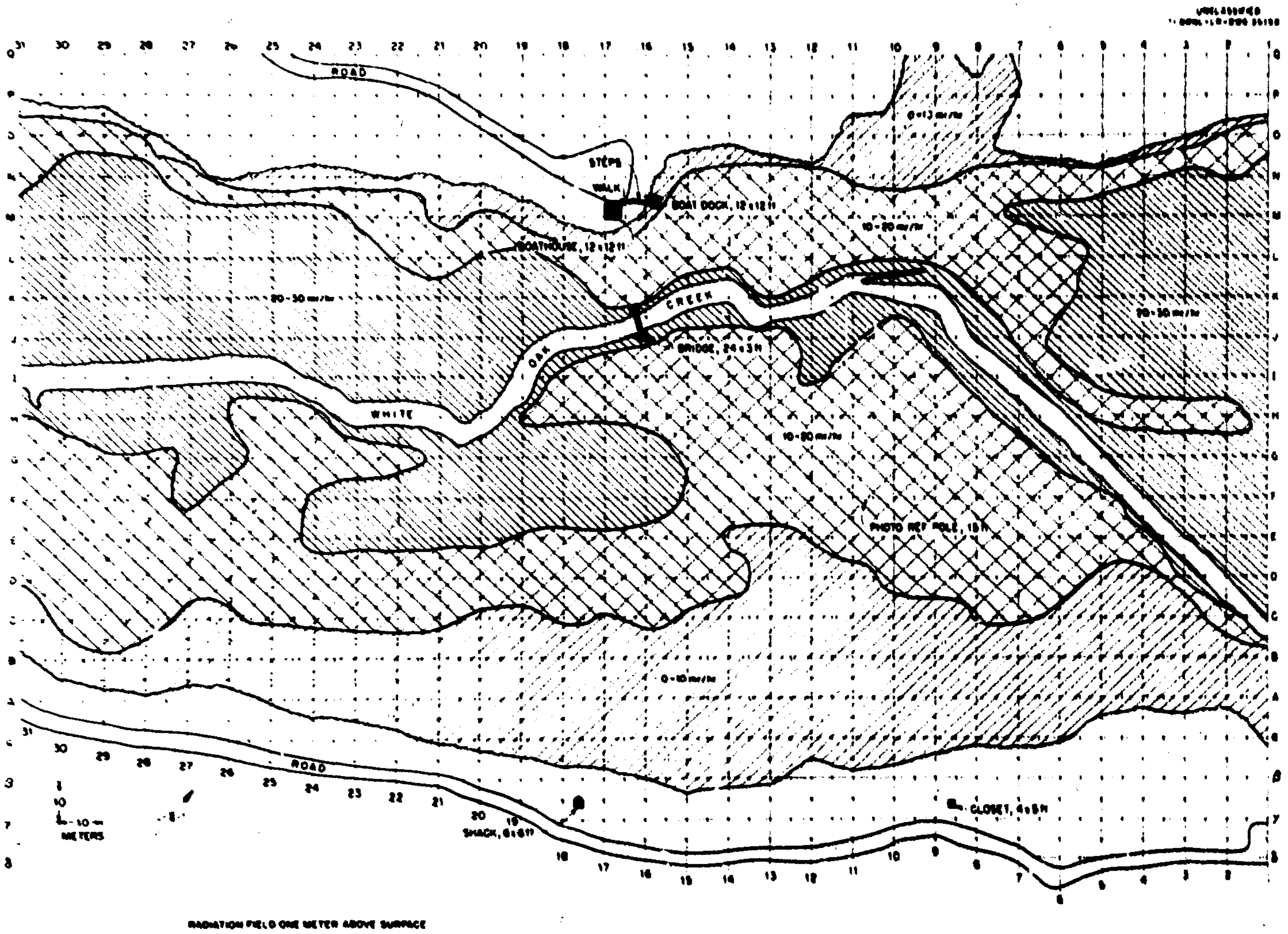

Fig. 5.14. Air dose rates 1 m above the ecology grid area (10-m grid of lower White Oak Lake bed), 1958.

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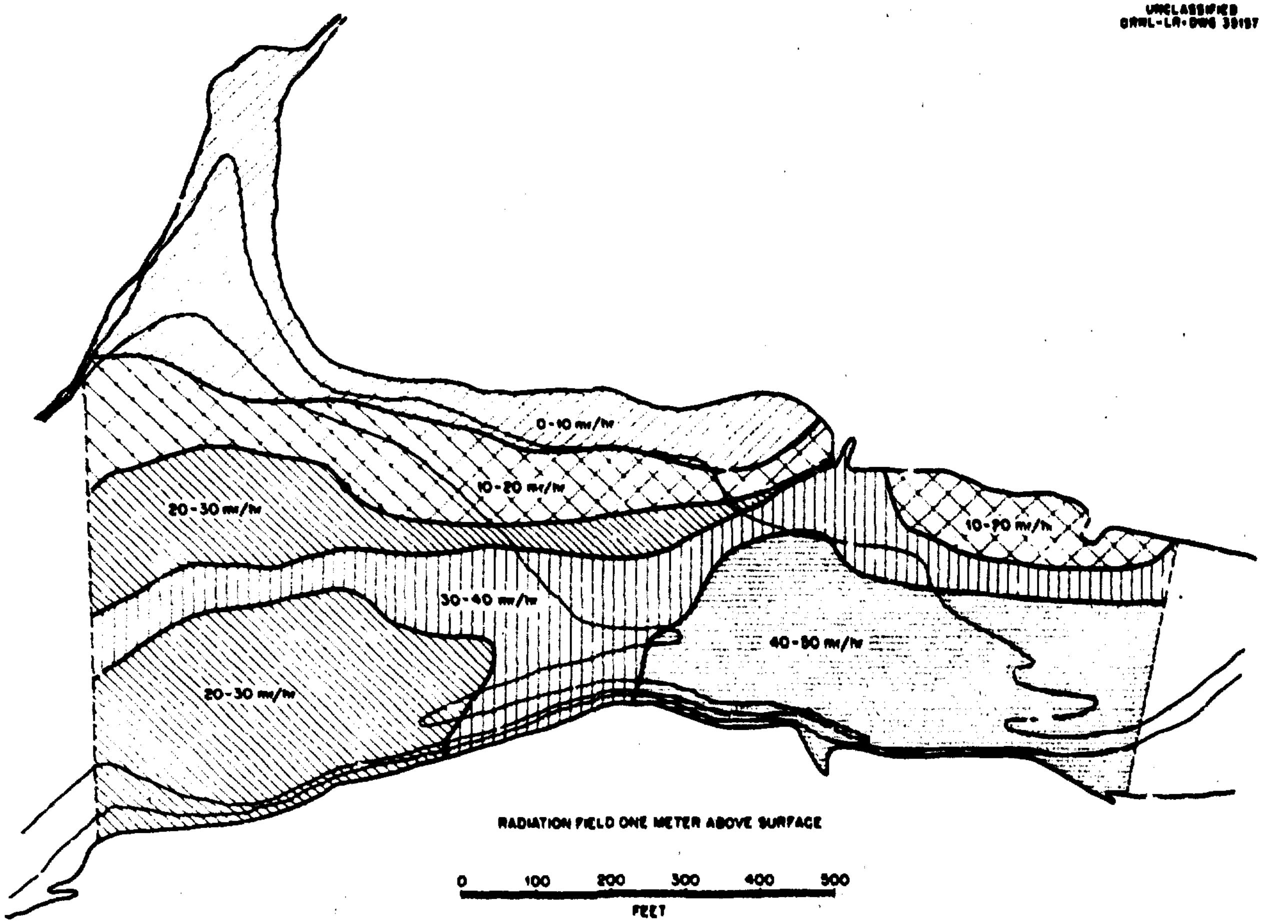

Fig. 5.15. Air dose rates 1 m above the ungridded ecology study area (upper lake bed), 1958.

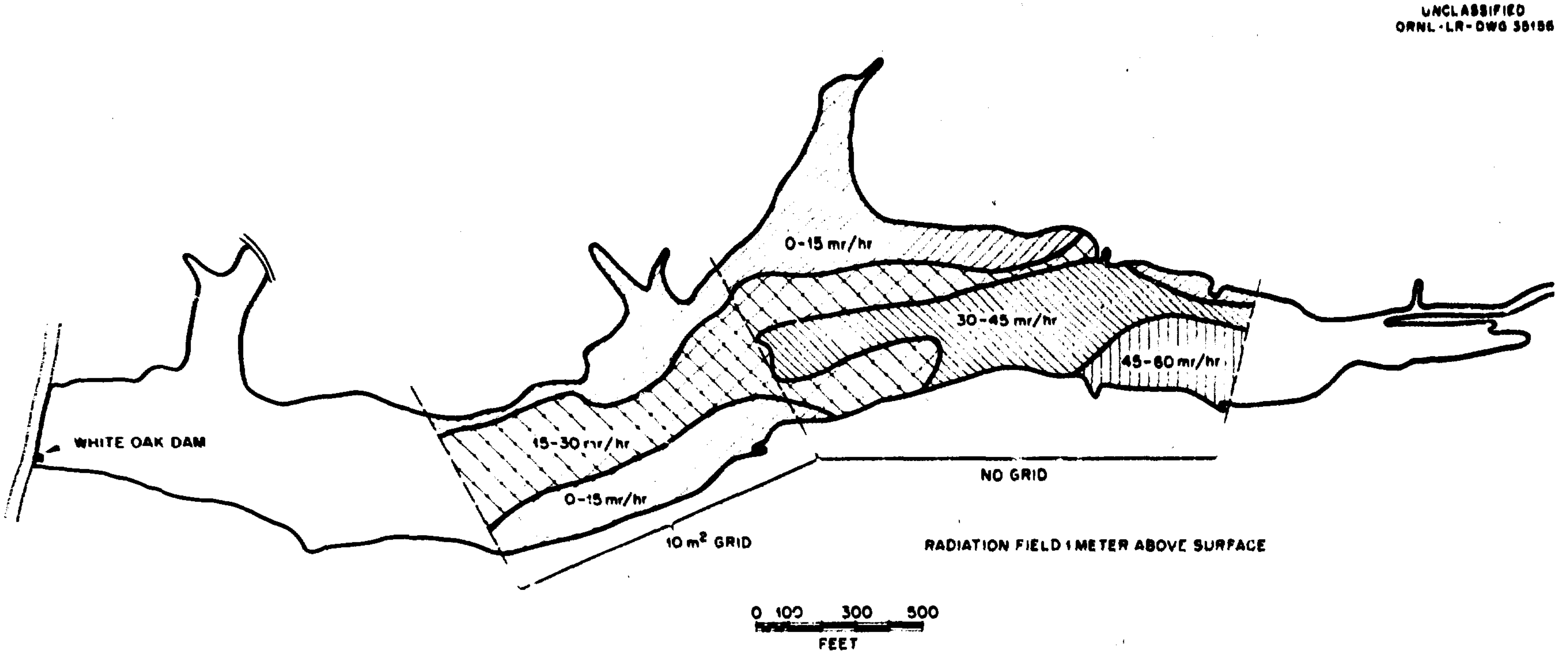

Fig. 5.16. Air dose rates 1 m above White Oak Lake bed in 15-mR/h increments, 1958.

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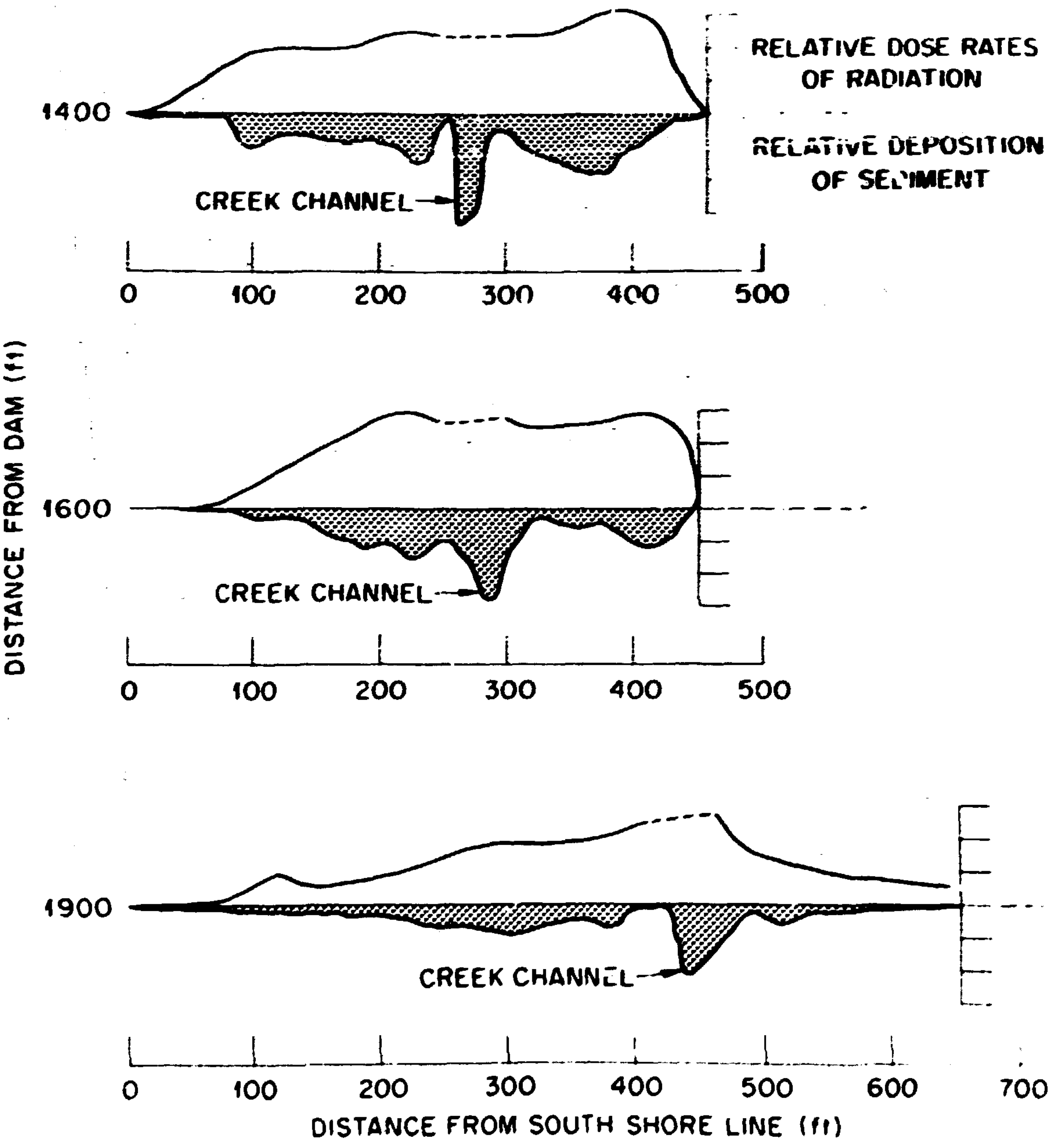

Fig. 5.17. Sediment deposit and associated radiation field (White Oak Lake bed), 1958.

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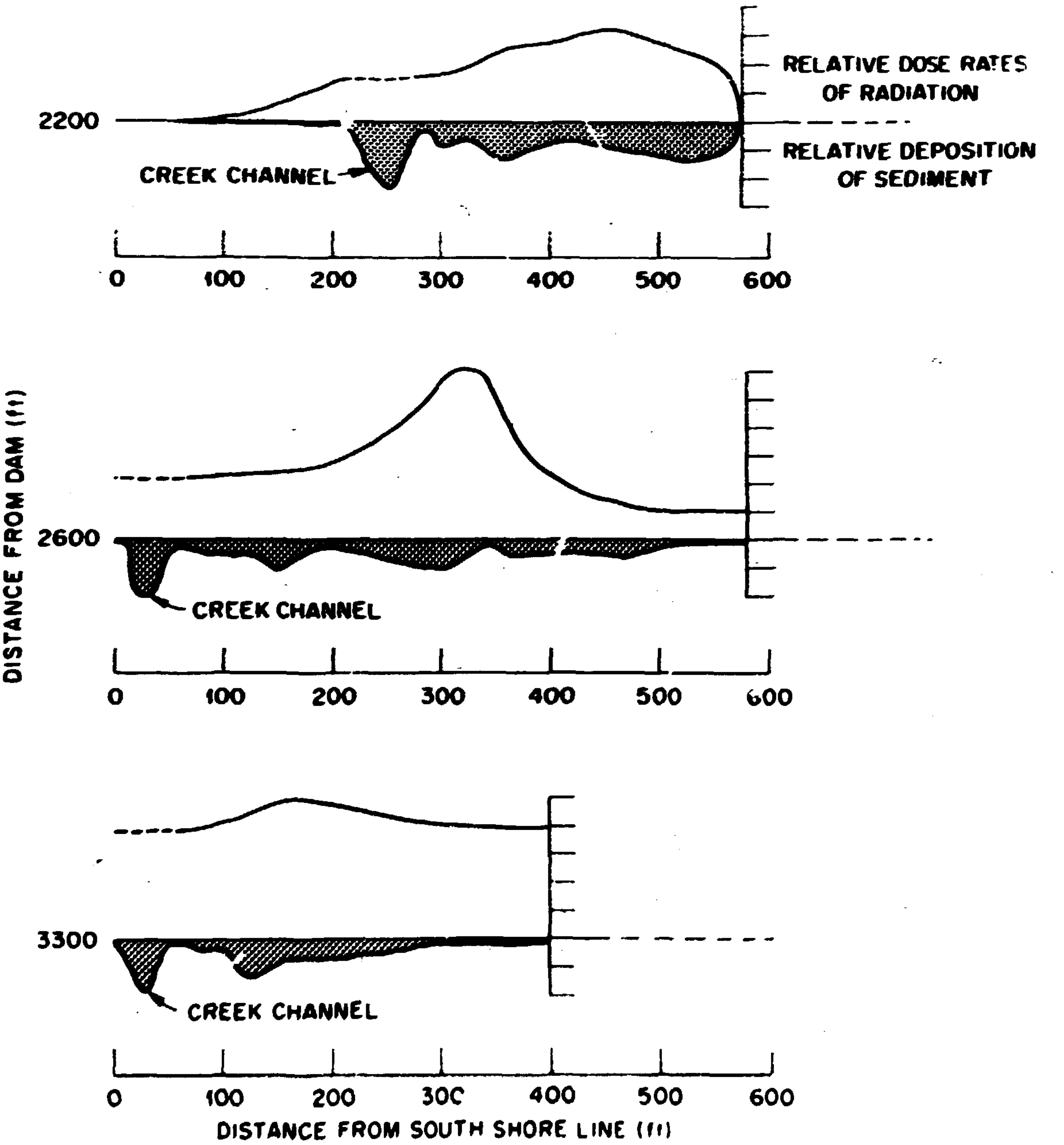

Fig. 5.18. Sediment deposit and associated radiation field (White Oak Lake bed), 1958.

sections of sediment depositions. There is a positive correlation with the depth of associated silt and the radiation levels. The other is a negative correlation between the dose rates and the depth of silt deposited at various distances from WOD. At 1006 m (3300 ft) from the dam, only small depths of sediment are present, but higher dose rates. At 427 m (1,400 ft) there are relatively large amounts of silt, but lower dose rates. This effect is of course due to a decrease in specific activity of the silt as it travels through the length of the lake. The location of the waste pits in relation to White Oak Lake bed is shown in Fig. 19.

It should also be noted that plowing the agricultural plot decreased the radiation level above it by about 25% over neighboring undisturbed ground.

5.1.3 Summary of historical data for White Oak Lake

(1) Sediment sampling began as early as 1945. For the period 1945-49, the average MBq/m^2 on the lake bed was 6.8 (17 μCi/ft^2) and the total terabecquerels averaged 0.48 (13 Ci). For the period 1950-1951, the averages were 140 MBq/m^2 (351 μCi/ft^2) and 9.44 TBq (255 total curies) respectively.

(2) The average ^{90}Sr in the lake bed over 1956-59 was 28.9 Bq/g (780 pCi/g).

(3) In 1961, a gamma-ray survey program was conducted on the lake. This study indicated that (a) most of the gamma activity was contained in the first 30 cm, and (b) the radioactivity in the upper few centimeters of each core was rather uniform.

(4) In 1962, an extensive coring survey arrived at the following average values for the first 15 cm: ^{90}Sr - 0.4 Bq/g (10 pCi/g), ^{106}Ru - 22 Bq/g (594 pCi/g), ^{137}Cs - 17.3 Bq/g (468 pCi/g), and ^{60}Co - 4.4 Bq/g (119 pCi/g). The high values for ^{106}Ru are noted (^{106}Ru has a physical half-life of approximately one year).

(5) In 1964, ten cores were taken. The major note was the even distribution of ^{137}Cs through the cores.

(6) Additional sampling was carried out in 1972. At this time, most of the activity was located between 16 to 34 cm. The concentration of ruthenium also decreased considerably, as expected.

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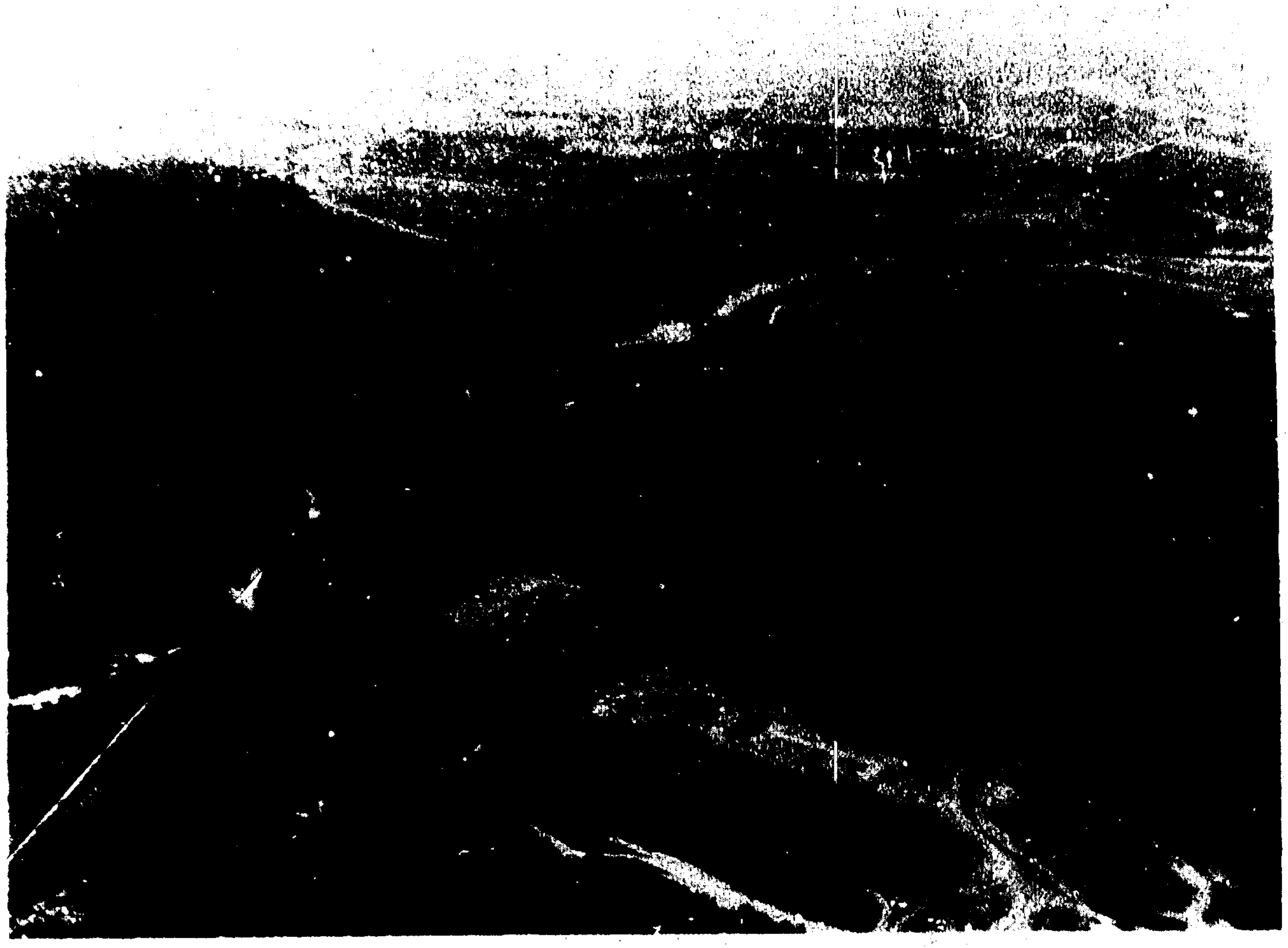

Fig. 5.19. Aerial view showing relative location of ORNL waste disposal pits (in foreground) to White Oak Lake bed.

5.2 RADIOACTIVITY IN THE CLINCH RIVER SEDIMENTS

A Clinch River study was drawn up in 1959 and conducted over a period of five years, 1960 to 1964 (Struxness et al., 1967). It involved several federal agencies — the U.S. Atomic Energy Commission (USAEC), the U.S. Geological Survey, the U.S. Public Health Service, and the Tennessee Valley Authority; three state agencies — the Tennessee Department of Public Health, the Tennessee Stream Pollution Control Board, and the Tennessee Game and Fish Commission; and Oak Ridge National Laboratory. The work program was provided by the Health Physics Division.

Radionuclides of primary importance in the study [based on quantities released, radioactive half-lives, and recommended MPC_w values (maximum permissible concentrations in water)] were ^{60}Co, ^{90}Sr, ^{106}Ru, and ^{137}Cs. The distribution, redistribution, and concentration of these radionuclides were determined by systematic collection and analysis of samples of water, bottom sediment, fish, and other aquatic organisms. Most environmental samples were analyzed for stable-chemical constituents as well. Additional knowledge of the dynamics of the river system was gained from hydrologic measurements, dispersion tests, laboratory experiments, and various computer programs.

Results of the water sampling and analysis program indicated that ^{90}Sr, ^{60}Co, and ^{106}Ru in the waters of White Oak Creek, Clinch River, and Tennessee River were associated principally with "dissolved" solids. This means that the radionuclides were either in solution or retained by very fine suspended particles. In marked contrast, most of the ^{137}Cs (69 to 92%) was associated with the larger size of suspended solids in White Oak Creek and Clinch River waters. In the Tennessee River, however, 70 to 80% of the ^{137}Cs was in solution or associated with very fine solids, that is, solids not removed by a high-speed centrifuge.

From information obtained by the analysis of cores taken from bottom sediments of the Clinch River, the variation of gross gamma radioactivity with depth essentially reflected the variations of ^{137}Cs concentration in sediments. There were notable similarities in the annual releases of ^{137}Cs with depth in the sediment of many cores. This suggests that the ^{137}Cs was deposited in the bottom sediments by the settling of suspended solids entering the river from White Oak Creek.

To make a total mass balance of radionuclides within the study reach, it was necessary to know the flux of nuclides into and out of the study reach and the buildup or decline of the radionuclide reservoir within the study reach. Consequently, representative cores of the contaminated sediments in the Clinch River bottom were recovered and analyzed. In 1960, a set of 0.6 m (2 ft) cores was taken with a Phleger sampler. Though it was known that the total depth of contaminated sediment had not been sampled, it was estimated that in the top 36 cm (14 in.) of sediment between Clinch River km 7.6 and km 33.5 (CRM 4.7 and 20.8), 2.8 TBq (76.5 Ci) of radioactivity were present: ^{137}Cs, 1.6 TBq (43.2 Ci); TRE, 0.5 TBq (14.7 Ci); ^{106}Ru, 0.5 TBq (13.2 Ci); ^{60}Co, 0.154 TBq (4.17 Ci); and ^{90}Sr, 0.03 TBq (0.7 Ci). At the same time another estimate was made, assuming that the total depth of sediment from Clinch River km 0.0 to 33.5 (CRM 0.0 to 20.8) was uniformly contaminated and that the concentrations were the same as those in the 0.6 m (2 ft) cores. Under these assumptions the estimated total was 61.8 TBq (1,670 Ci): ^{144}Ce-^{144}Pr, 0.1 TBq (3.3 Ci); ^{106}Ru-^{106}Rh, 35.4 TBq (957.7 Ci); ^{137}Cs-^{137}Ba, 22.6 TBq (609.8 Ci); ^{95}Zr-^{95}Nb, 0.24 TBq (6.5 Ci); ^{60}Co, 2.5 TBq (66.8 Ci); ^{90}Sr, 0.9 TBq (25.6 Ci).

Due to the wide difference in these estimates and the admittedly inadequate coring, a more comprehensive coring program was undertaken in 1962 with the Swedish foil sampler. From the results of the analyses of these cores, a total inventory of 7.4 TBq (200.7 Ci) was computed to be in the Clinch River from Clinch River km 0 to 33.5 (CRM 0.0 to 20.8), including the tributaries. The radionuclide content of these cores was as shown in Table 5.10.

The total volume of sediments in the study reach was calculated to be 2.58×10^6 m^3 (91×10^6 ft^3). Of this total, 2.40×10^6 m^3 (84.8×10^6 ft^3) was estimated to be contaminated. Most of the contaminated sediment was concentrated in the lower reaches of the river, where most of the uncontaminated sediments are also found. Over 81% of the uncontaminated sediment is below Clinch River km 27.2 (CRM 16.9).

The releases from 1963 through 1979 were added to Table 5.10. Appropriate radioactive decay constants were used along with the percentage of nuclides released that end up in the sediment. This resulted in a maximum total present inventory of approximately 4.4 TBq (120 Ci). Cesium-137 has

Table 5.10. Radionuclide content of cores obtained from Clinch River

Nuclide	Curies	Percent of total	Percent of nuclide released over White Oak Creek dam in sediment[a]
^{137}Cs	154.6	77.0	21
^{60}Co	17.5	8.7	9
^{106}Ru	15.5	7.7	0.4
Total rare earths	10.2	5.1	b
^{90}Sr	2.9	1.5	0.2

[a] These values have taken radioactive decay into account.

[b] Not obtained due to the different half-lives and the unknown relative abundance of the various rare earths.

Source: Struxness et al., April 1967.

a maximum total of 4.0 TBq (108 Ci); ^{60}Co, 0.2 TBq (5 Ci); ^{90}Sr, 0.1 TBq (2 Ci); and transuranics, 0.2 TBq (5 Ci). (It was assumed that the total release of transuranics from 1949 to 1979 ended up in the sediment between Clinch River km 0.0 and 33.5 (CRM 0.0 and 20.8). It should also be noted that since 1964, 4884 TBq (132,000 Ci) of ^{3}H has been released from WOD.

When considering the total amount of radioactivity and the volume of sediment in the Clinch River and White Oak Lake, the sediment concentration in the lake is calculated to be approximately 100 times higher than that for the river (Table 5.8 and Figs. 5.20-5.22). Radionuclides discharged in water and found in Clinch River sediment (1954-1963) are shown in Fig. 5.23.

5.3 REVIEW OF WHITE OAK CREEK SEDIMENT DATA 1978-79

5.3.1 White Oak Lake samples, 1979

To arrive at an accurate assessment of the radioactivity present in White Oak Lake, sediment samples were taken in December 1979. The locations chosen are shown in Fig. 5.24; samples were taken near the dam since it was postulated that this location posed the greatest potential for release to the public. The cores were divided into 2.5 cm (1 in.) segments in order that a depth profile could be performed. To expedite the analyses, only the top 15 cm (6 in.) was initially analyzed. The average values for the cores are presented in Table 5.11. Transuranic analyses will be performed at a later date. The data for these cores are given in Tables 5.12, 5.13, and 5.14.

When assessing the data, it was noted that ^{60}Co decreased with depth, ^{137}Cs increased with depth (up to 15 cm), ^{90}Sr remained relatively constant with depth; ^{152}Eu and ^{154}Eu decreased with depth with "less than" values occurring after the first 10 cm (4 in.).

These values can be compared to soil samples taken during 1978 at perimeter air-monitoring stations; however, care must be exercised in comparing these numbers as the perimeter values are for only the top 2.5 cm (1 in.) and are reported as dry weight. Average perimeter values were ^{90}Sr, 0.02 Bq/g (0.6 pCi/g) and ^{137}Cs, 0.01 Bq/g (0.4 pCi/g); ^{60}Co and europium values were not detectable.

ORNL-DWG 78-21143

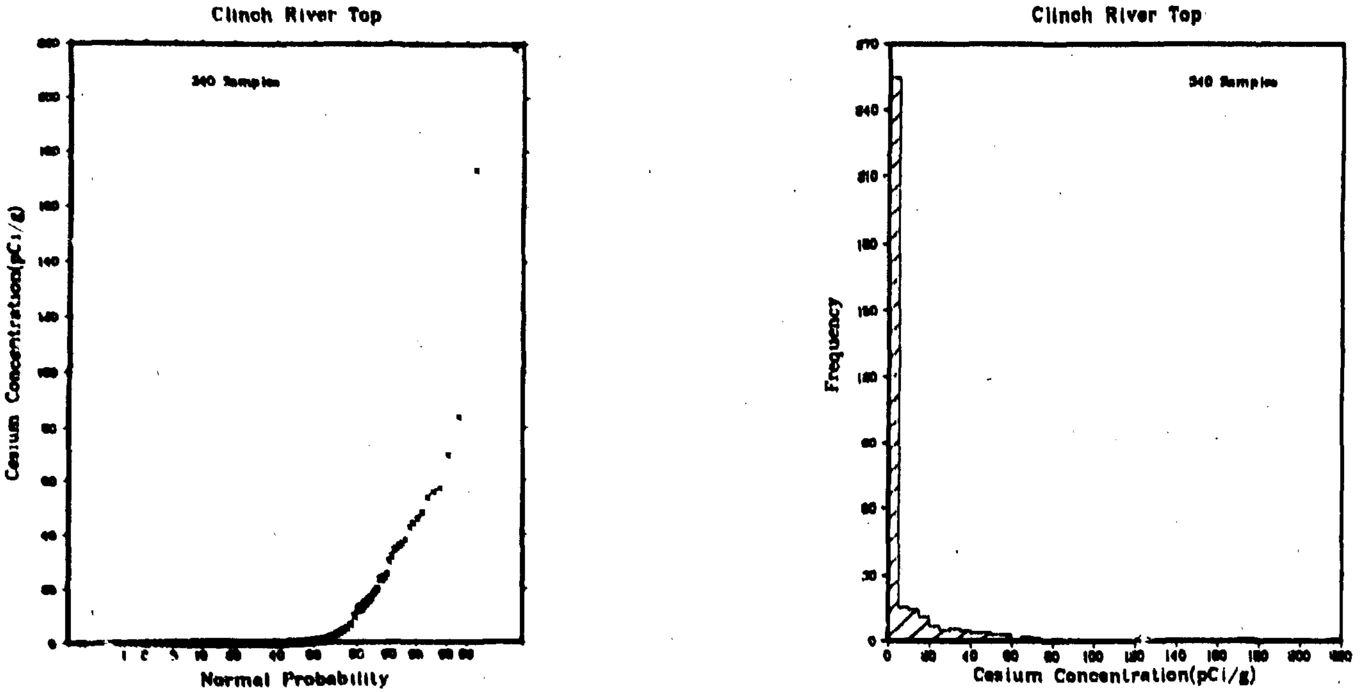

Fig. S.20. Cesium distribution in the sediment of Clinch River, 1977. Note: Since these figures were generated before metrification, they have not been changed. However, multiplying the concentrations by 0.037 will convert pCi/g to Bq/g.

ORNL-DWG 78-21165

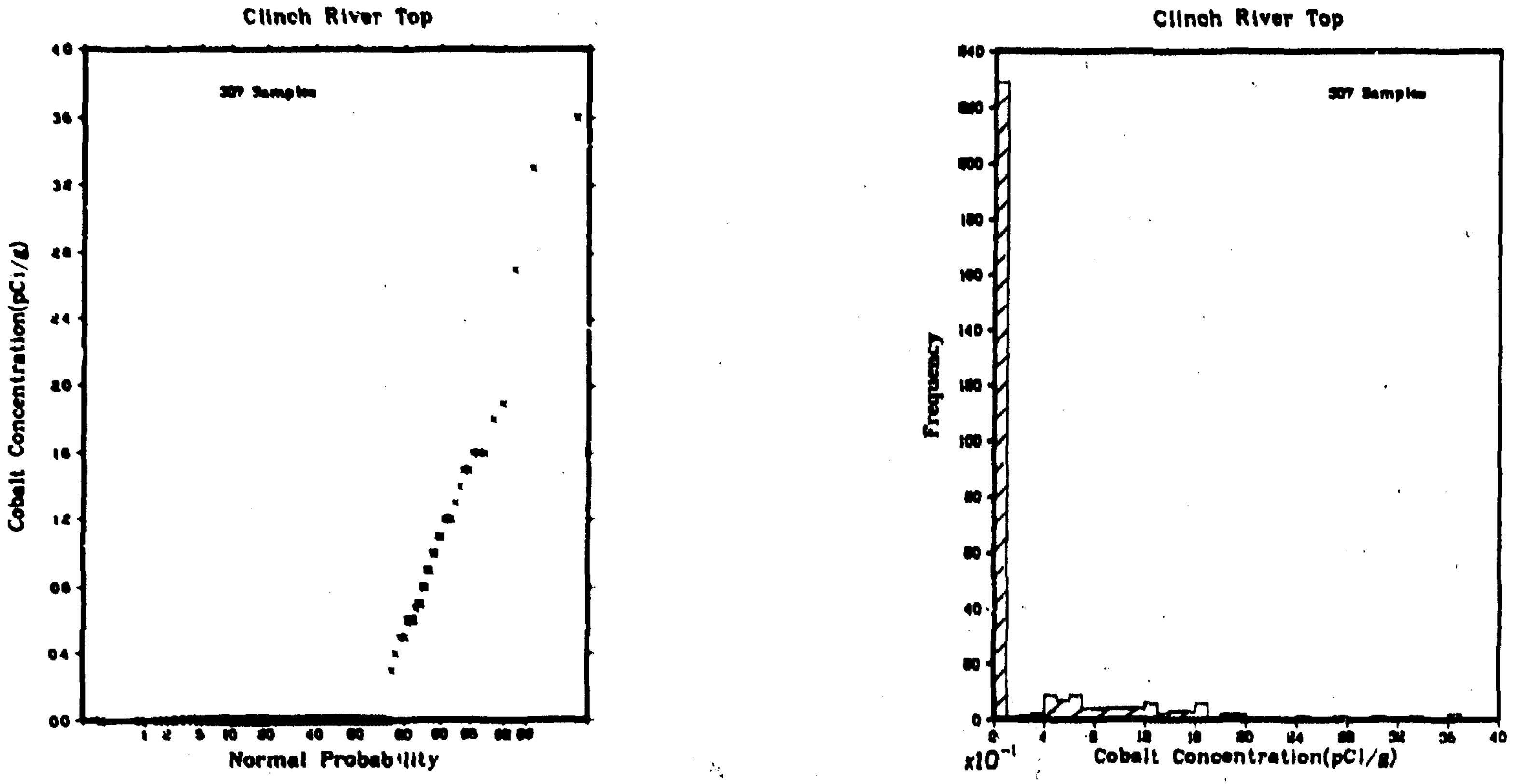

Fig. 5.21. Cobalt distribution in the sediment of Clinch River, 1977. Note: Since these figures were generated before metrification, they have not been changed. However, multiplying the concentrations by 0.037 will convert pCi/g to Bq/g.

ORNL-DWG 78-21141

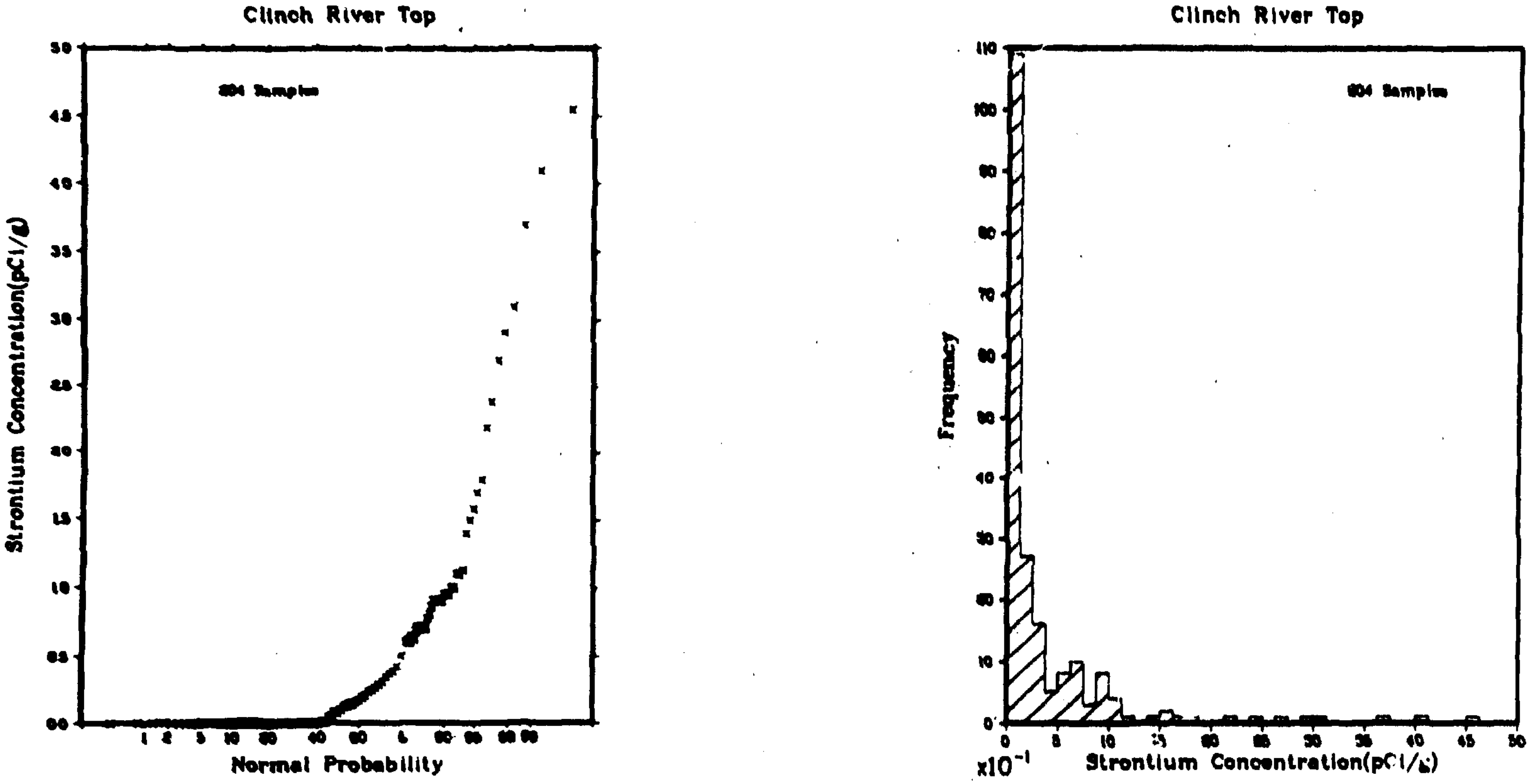

Fig. 5.22. Strontium distribution in the sediment of Clinch River, 1977. Note: Since these figures were generated before metrification, they have not been changed. However, multiplying the concentrations by 0.037 will convert pCi/g to Bq/g.

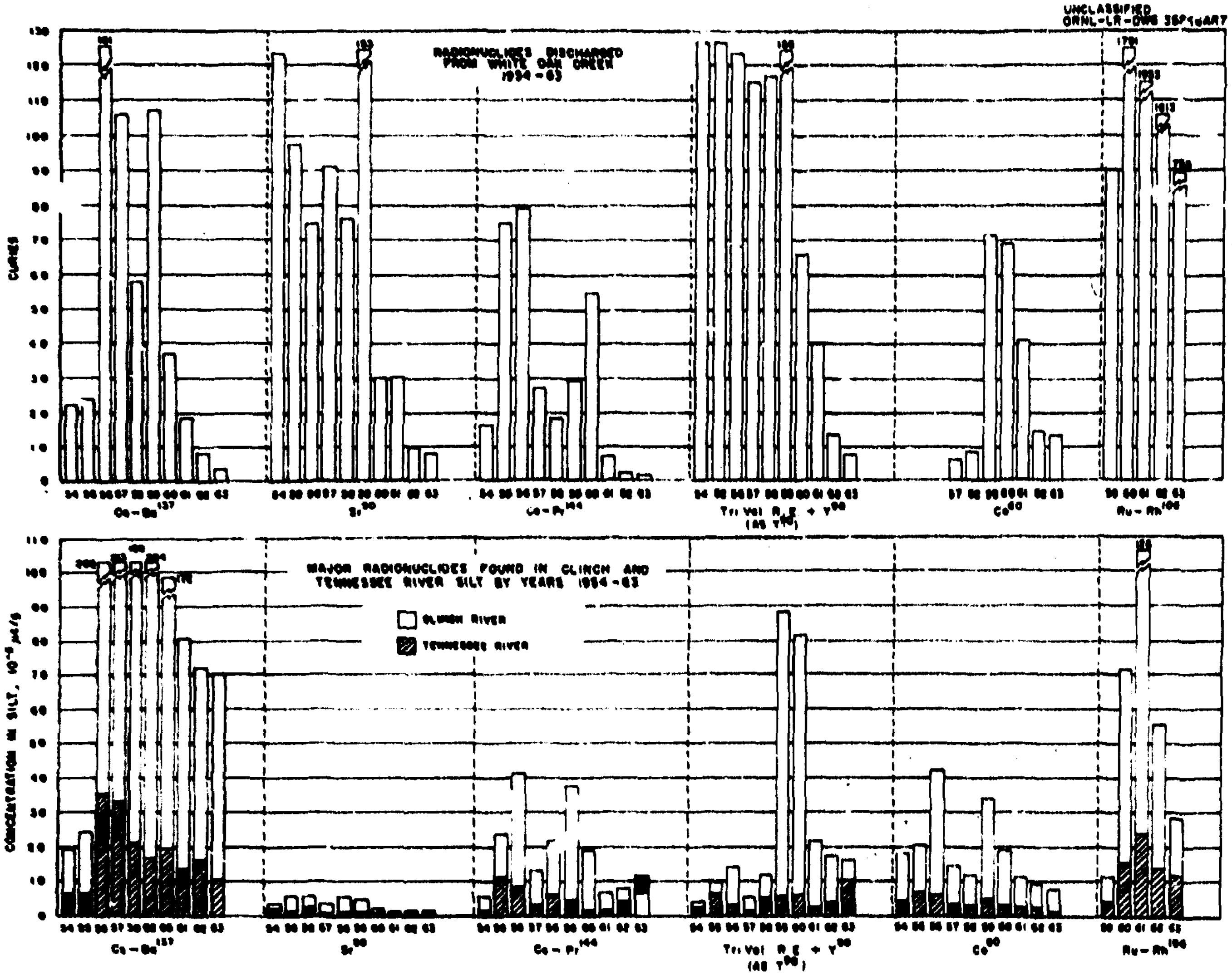

Fig. 5.23. Radionuclides discharged in water and sediment concentration in Clinch River, 1954-1963.

ORNL-DWG 80-7797

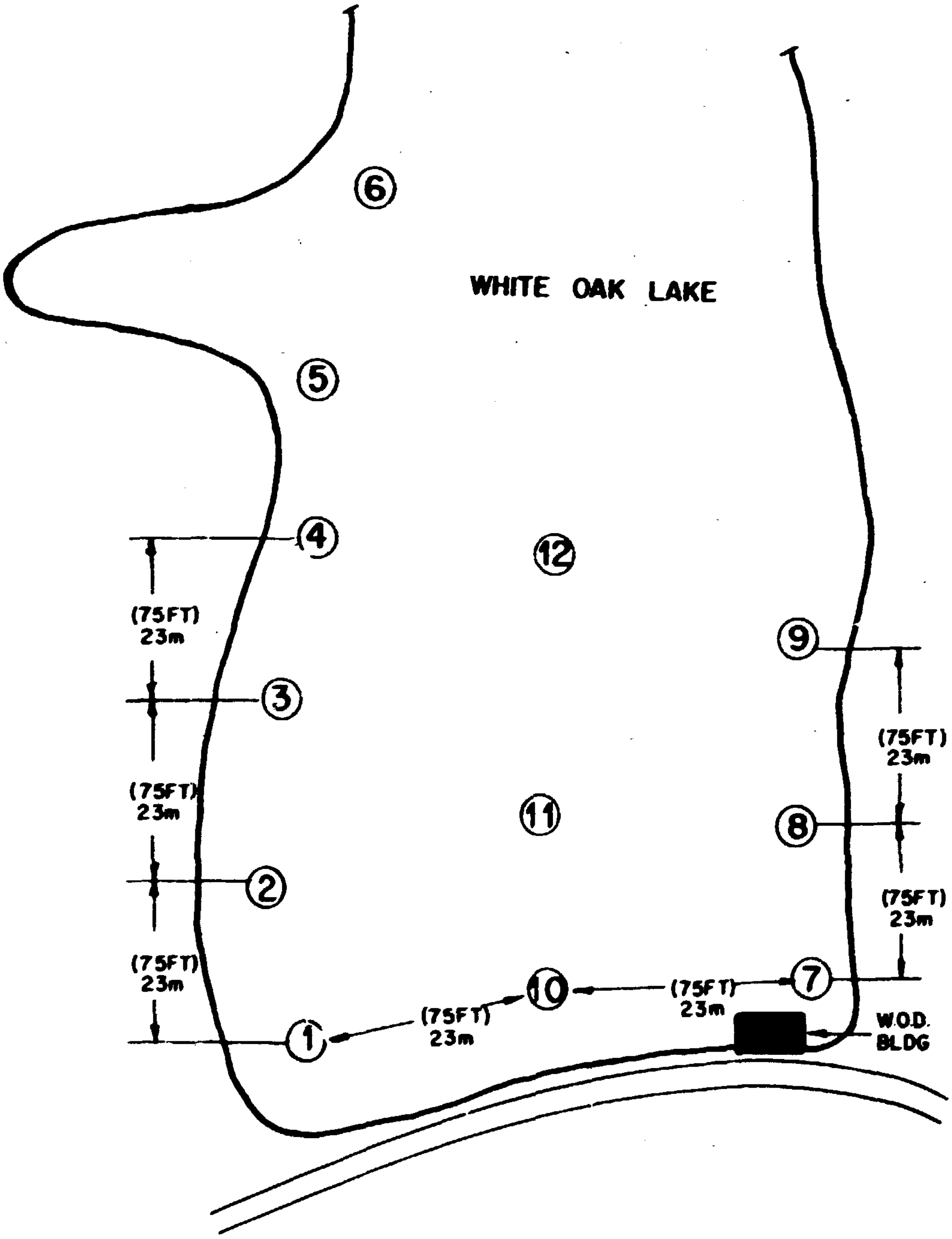

Fig. 5.24. Map of White Oak Lake showing sampling locations, 1979.

Table 5.11. Sediment data (pCi/g wet), White Oak Lake, 1979

Core sample	^{60}Co[a]	^{137}Cs[a]	^{152,154}Eu[a,b]	^{90}Sr[c]
1	123	617	16	37
2	131	447	11	39
3	87	420	6	32
4	76	348	10	29
5	108	545	10	85
6	66	377	12	32
7	94	328	16	28
8	58	133	10	29
9	104	339	12	55
10	110	725	18	38
11	93	722	18	33
12	96	701	20	55
Average	96	475	13	41

[a] Average of six 2.5 cm (1 in.) segments.

[b] Eu-154 is approximately 1.4 times the Eu-152 concentration.

[c] Average of top 2.5 cm (1 in.) segment and bottom 2.5 cm (1 in.) segment.

Table 5.12. Cesium-137 concentration in White Oak Lake cores, 1979 [Bq/g (pCi/g)]

Core number	Depth (cm)					
	0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-12.5	12.5-15.0
1	16.2 (439)	18.1 (489)	21.5 (580)	22.8 (617)	28.2 (763)	30.1 (814)
2	13.4 (363)	15.1 (409)	17.5 (474)	17.8 (482)	18.3 (495)	16.9 (458)
3	10.8 (292)	11.8 (319)	11.4 (308)	12.2 (330)	18.5 (499)	28.5 (769)
4	13.5 (365)	17.5 (472)	16.4 (442)	18.5 (501)	10.1 (274)	2.1 (57.7)
5	15.5 (420)	16.3 (440)	16.4 (443)	19.3 (521)	25.6 (692)	27.9 (754)
6	13.8 (372)	13.3 (360)	13.5 (364)	14.2 (383)	13.7 (371)	15.2 (410)
7	18.7 (506)	17.2 (465)	16.8 (454)	14.2 (384)	4.8 (129)	1.2 (31.3)
8	10.4 (280)	7.8 (211)	6.1 (165)	2.8 (77)	1.6 (44)	0.8 (22)
9	9.5 (256)	11.4 (309)	10.2 (275)	13.9 (377)	14.9 (402)	15.4 (415)
10	18.2 (492)	22.0 (595)	25.9 (700)	29.8 (805)	31.9 (862)	33.1 (895)
11	18.4 (497)	23.2 (627)	27.9 (754)	30.2 (816)	30.2 (816)	30.5 (824)
12	17.8 (481)	23.1 (624)	27.2 (735)	28.6 (773)	27.9 (754)	31.0 (838)

Table 5.13. Cobalt-60 concentration in White Oak Lake cores, 1979
[Bq/g (pCi/g)]

Core number	Depth (cm)					
	0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-12.5	12.5-15.0
1	5.8 (157)	5.1 (138)	5.0 (134)	4.1 (111)	3.9 (105)	3.5 (95.4)
2	5.8 (156)	5.1 (137)	5.2 (141)	4.8 (130)	4.3 (117)	3.8 (102)
3	3.9 (104)	2.9 (77)	2.9 (79)	2.9 (79)	3.1 (83)	3.8 (102)
4	4.6 (124)	4.4 (119)	3.2 (87)	3.1 (84)	1.2 (32.4)	0.3 (9.1)
5	4.1 (111)	3.9 (106)	3.4 (92.8)	3.9 (106)	4.2 (114)	4.3 (117)
6	2.8 (74.5)	2.8 (74.7)	2.7 (72.0)	2.2 (60.4)	2.1 (55.8)	2.1 (57.5)
7	4.4 (118)	3.9 (104)	4.6 (124)	5.0 (134)	2.4 (63.4)	0.9 (23.0)
8	5.7 (153)	3.2 (85.3)	2.0 (53.9)	1.0 (26.7)	0.7 (18.6)	0.3 (8.9)
9	7.3 (197)	5.3 (144)	3.0 (79.8)	2.4 (65.6)	2.6 (69.3)	2.6 (68.9)
10	5.8 (157)	4.4 (119)	3.7 (100)	3.8 (103)	3.7 (100)	3.0 (81.1)
11	4.5 (122)	3.2 (86.5)	3.1 (83.8)	3.3 (89.2)	3.2 (86.5)	3.3 (89.2)
12	4.5 (122)	3.9 (105)	3.0 (81.1)	3.5 (94.6)	3.2 (86.5)	3.3 (89.2)

Table 5.14. Strontium-90 concentration in White Oak Lake cores, 1979 [Bq/g (pCi/g)]

Core number	Depth (cm)	
	0-2.5	12.5-15.0
1	1.4 (37)	1.3 (36)
2	1.7 (47)	1.1 (31)
3	1.3 (34)	1.1 (30)
4	1.1 (29)	1.0 (28)
5	2.5 (69)	3.7 (100)
6	1.0 (28)	1.3 (36)
7	1.3 (35)	0.7 (20)
8	0.8 (22)	1.3 (35)
9	1.1 (31)	2.9 (78)
10	0.9 (23)	1.9 (52)
11	1.3 (34)	1.2 (32)
12	1.9 (51)	2.2 (59)
	Gross alpha via PrF_3	
1	0.01 (0.4)	0.05 (1.4)
2	0.17 (4.7)	0.15 (4.0)
3	0.19 (5.1)	0.14 (3.7)
4	0.31 (8.5)	0.05 (1.4)
5	0.44 (12)	0.36 (9.6)
6	0.33 (8.9)	0.28 (7.7)
7	0.11 (3)	0.08 (2.2)
8	0.28 (7.7)	0.04 (1.1)
9	0.08 (2.1)	0.12 (3.2)
10	0.33 (8.8)	0.40 (10.9)
11	0.39 (10.5)	0.31 (8.5)
12	0.28 (7.7)	0.23 (6.1)

5.3.2 White Oak Creek below WOD sediment samples, 1978-79

The sediment immediately downstream of WOD (White Oak Creek km 0.0-0.1) (White Oak Creek mile 0.0-0.6) was sampled during 1978-1979, and the samples were analyzed by high-resolution gamma-ray spectroscopy. The sampling locations are indicated on Fig. 5.25. Cores were prepared by extracting the moist soil in 2.5 cm increments directly into a plastic dish, 7.1 cm diameter by 2.8 cm height. Total results are presented in units of Bq/g wet weight in Table 5.15. The data for the first 43 cm (15 in.) of all cores are presented in Figs. 5.26 and 5.27 for ^{137}Cs and ^{60}Co. Core 23 was singled out for a separate presentation in Figs. 5.28 and 5.29. This core was taken at the first sharp bend in the creek below WOD (see Fig. 5.25). The sediment buildup is interesting in that the highest concentrations were 66 cm (26 in.) below the surface; a concentration of 2250 Bq/g (60,700 pCi/g) for ^{137}Cs was observed.

5.4 ESTIMATE OF ACTIVITY STORED IN THE SEDIMENTS OF WHITE OAK LAKE

In order to obtain an estimate of the activity stored in the sediments, it was first necessary to ascertain the spatial relationship of the available core data. To do this, the sediment input of 2832 m^3/year (100,000 ft^3/year) was used to calculate how the sediment thickness changed with time. The results of this calculation showed that the 15 cm (6 in.) core taken in 1979 (Tables 5.12, 5.13, and 5.14) began where the 15 cm core taken in 1972 (Table 5.8) ended. However, the 1972 core began 6.4 cm (2.5 in.) above where the 1962 core (Table 5.9) ended. Since no data were available on this intervening space (between 1962 and 1972), the 1972 core data were used to represent the activity in this region.

Thus, activity data on a 98 cm (38.4 in.) cross section of the sediment became available. The volume of the sediments was calculated to be 1.3×10^5 m^3 (4.6×10^6 ft^3). Using a sediment density of 1.1 g/cm^3, the total activity in the sediments could be estimated. The total activity in White Oak Lake sediments is estimated to be 23.8 TBq (644 Ci) which is made up of the following nuclides: ^{137}Cs, 21.9 TBq (591 Ci); ^{60}Co, 1.2 TBq (33 Ci); ^{90}Sr, 0.74 TBq (20 Ci).

TRU data are only available for the top 15 cm (6 in.) and indicate 0.03 TBq (0.87 Ci) of TRU nuclides: ^{238}Pu, 0.004 (0.096); ^{239}Pu, 0.01 (0.250); ^{241}Am, 0.001 (0.024); ^{244}Cm, 0.02 (0.498).

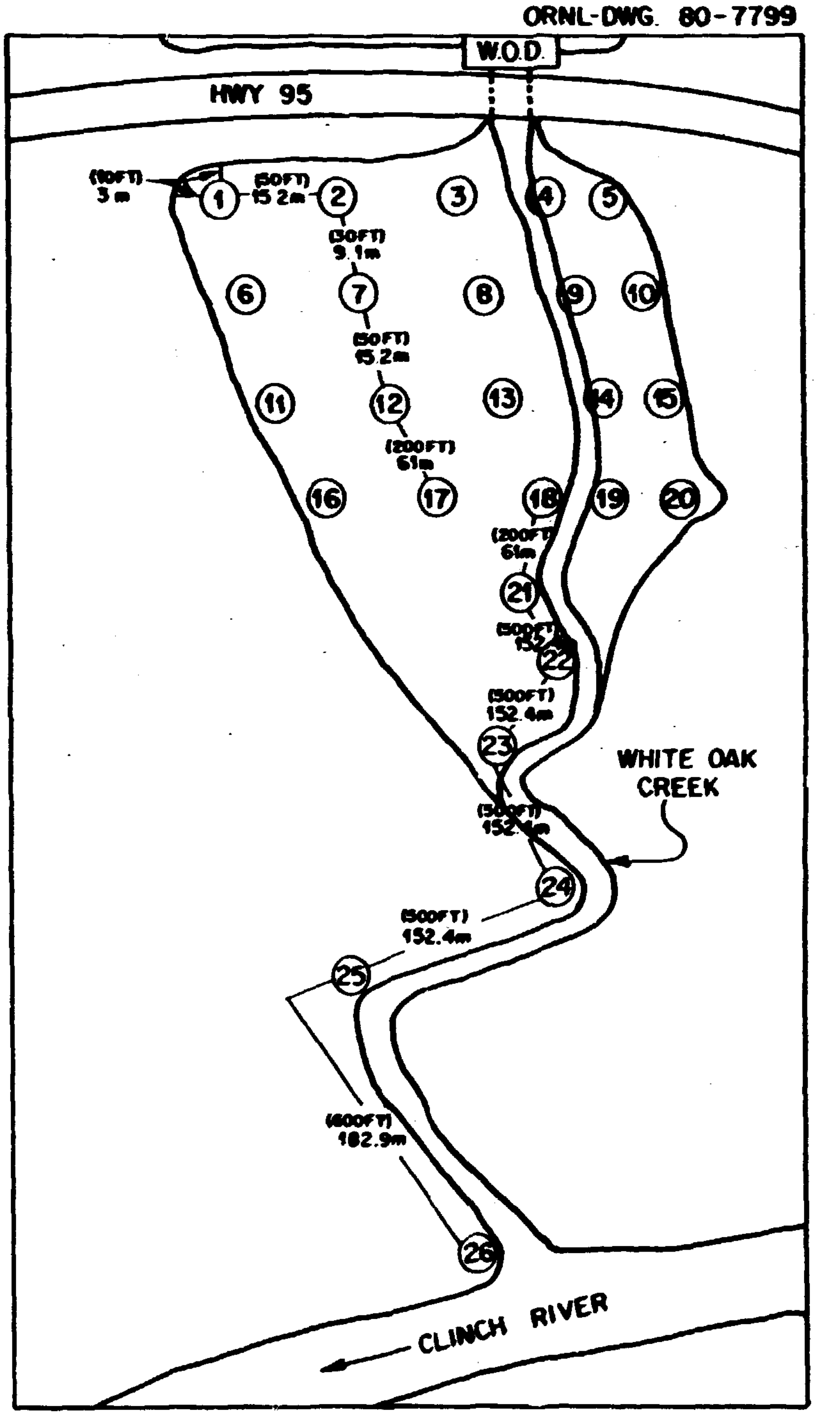

Fig. 5.25. Sediment sampling locations in White Oak Creek, December 1979.

Table 5.15. Quantity and distribution of radionuclides in sediment cores[a] from White Oak Creek downstream from dam, 1979

[Bq/g (pCi/g)]

Core 1	^{137}Cs	^{60}Co
1-1[b]	15.0 (406)	1.9 (50)
1-2[b]	14.8 (400)	1.7 (47)
1-3[b]	10.2 (275)	1.4 (37)
1-4[b]	10.4 (281)	1.3 (36)
1-5	9.0 (243)	0.67 (18)
1-6	8.3 (224)	0.52 (14)
1-7	2.9 (78)	0.2 (6)
1-8	0.44 (12)	0.03 (0.8)
1-9	0.07 (2.0)	
1-10	0.04 (1.0)	
1-11	0.04 (1.0)	
1-12	0.04 (1.0)	
1-13	0.05 (1.3)	0.03 (0.7)
1-14	0.02 (0.6)	0.03 (0.9)
1-15		
1-16	0.01 (0.2)	0.01 (0.2)
1-17		<0.01 (0.1)
1-18	<0.01 (0.1)	
1-19	0.01 (0.3)	
1-20	0.07 (2.0)	

[Bq/g (pCi/g)]

Core 3	^{137}Cs	^{60}Co
3-1[b]	11.4 (309)	1.6 (42)
3-2[b]	11.8 (318)	1.5 (41)
3-3	6.3 (170)	0.85 (23)
3-4	2.4 (64)	0.3 (8)
3-5	0.85 (23)	0.1 (3)
3-6	0.3 (8)	0.04 (1)
3-7	0.2 (5)	0.02 (0.6)
3-8	0.2 (5)	0.01 (0.4)
3-9	0.04 (1)	
3-10	0.03 (0.8)	0.01 (0.2)
3-11	0.03 (0.7)	0.01 (0.2)
3-12	0.02 (0.6)	<0.01 (0.1)
3-13	0.20 (5)	0.01 (0.4)
3-14	0.07 (2)	0.02 (0.5)
3-15	0.81 (22)	0.1 (3)

Core 2	^{137}Cs	^{60}Co
2-1[b]	18.2 (491)	1.8 (49)
2-2	1.8 (49)	0.2 (6)
2-3	1.7 (45)	0.2 (6)
2-4	0.85 (23)	0.2 (4)
2-5	0.41 (11)	0.07 (2)
2-6[b]	0.1 (3)	0.03 (0.8)
2-7	0.1 (3)	0.02 (0.5)
2-8	0.04 (1)	
2-9	0.04 (1)	
2-10	0.03 (0.9)	
2-11	0.03 (0.9)	
2-12	0.03 (0.7)	
2-13	0.03 (0.7)	0.01 (0.2)
2-14	0.04 (1)	
2-15	0.04 (1)	
2-16	0.02 (0.6)	
2-17		
2-18	0.03 (0.7)	
2-19		
2-20	0.01 (0.4)	
2-21	0.04 (1)	
2-22	0.3 (9)	0.03 (0.8)
2-23	0.07 (2)	
2-24	0.04 (1)	
2-25	0.07 (2)	

Core 6	^{137}Cs	^{60}Co
6-1[b]	23.1 (625)	2.6 (71)
6-2	19.0 (513)	2.3 (63)
6-3	15.2 (410)	1.8 (49)
6-4[b]	14.6 (395)	1.7 (47)
6-5	9.6 (260)	1.2 (32)
6-6	1.2 (31)	0.1 (3)
6-7	0.48 (13)	0.07 (2)
6-8	0.2 (4)	0.02 (0.5)
6-9	0.1 (3)	0.02 (0.5)
6-10	0.03 (0.7)	
6-11	0.02 (0.5)	
6-12	0.02 (0.5)	0.01 (0.4)
6-13	0.01 (0.3)	
6-14		
6-15	0.02 (0.6)	
6-16		
6-17		
6-18	0.81 (22)	0.1 (3)

Table 5.15. Quantity and distribution of radionuclides in sediment cores[a] from White Oak Creek downstream from dam, 1979 (continued)

	[Bq/g (pCi/g)]			[Bq/g (pCi/g)]	
Core 7	^{137}Cs	^{60}Co	Core 11	^{137}Cs	^{60}Co
7-1[b]	58.5 (1580)	4.7 (128)	11-1[b]	24.9 (672)	1.8 (49)
7-2	57.7 (1560)	4.3 (117)	11-2[b]	23.6 (637)	1.8 (48)
7-3	14.3 (387)	1.2 (32)	11-3	21.4 (579)	1.5 (40)
7-4	13.7 (369)	1.1 (30)	11-4	16.1 (434)	0.78 (21)
7-5	12.8 (345)	0.89 (24)	11-5[b]	15.8 (426)	0.56 (15)
7-6	23.3 (630)	1.4 (39)	11-6	10.8 (292)	0.48 (13)
7-7	14.7 (397)	0.85 (23)	11-7	5.1 (137)	0.2 (5)
7-8	3.6 (97)	0.2 (6)	11-8	Data Lost	
7-9	0.5 (13)	0.05 (1.3)	11-9	6.1 (165)	0.04 (1.1)
7-10	0.3 (7)	0.02 (0.5)	11-10	14.8 (400)	0.07 (2.0)
7-11	0.2 (5)	0.01 (0.4)	11-11	37.4 (1010)	0.10 (2.6)
7-12	0.3 (7)	0.01 (0.4)	11-12	46.0 (1242)	0.05 (1.3)
7-13	0.07 (2)	0.01 (0.2)	11-13	34.3 (927)	0.03 (0.9)
7-14	0.07 (2)	0.01 (0.3)	11-14	15.3 (413)	0.01 (0.4)
7-15	0.07 (2)		11-15	0.85 (23)	
7-16	0.07 (2)		11-16	1.3 (34)	
7-17	0.04 (1)	0.01 (0.3)	11-17	1.1 (30)	
7-18			11-18	1.9 (50)	0.02 (0.6)
7-19	0.04 (1)				
7-20	0.44 (12)	0.04 (1.0)			

Core 8	^{137}Cs	^{60}Co	Core 12	^{137}Cs	^{60}Co
8-1[b]	35.9 (969)	2.2 (58)	12-1	82.2 (2222)	4.5 (122)
8-2[b]	11.7 (316)	0.67 (18)	12-2	88.3 (2385)	4.7 (127)
8-3[b]	9.2 (249)	0.59 (16)	12-3	89.9 (2430)	4.6 (124)
8-4	1.4 (39)	0.07 (2)	12-4	100.0 (2704)	3.3 (90)
8-5	0.37 (10)	0.03 (0.8)	12-5	25.1 (678)	0.96 (26)
8-6	0.2 (5)	0.01 (0.3)	12-6	10.3 (279)	0.44 (12)
8-7	0.07 (2)	0.01 (0.2)	12-7	10.4 (281)	0.44 (12)
8-8	0.07 (2)	0.01 (0.4)	12-8	3.7 (100)	0.20 (5.3)
8-9	0.11 (3)	0.01 (0.3)	12-9	1.5 (41)	0.10 (2.6)
8-10	0.15 (4)	0.01 (0.3)	12-10	0.89 (24)	0.07 (1.9)
8-11	0.03 (0.7)		12-11	0.89 (24)	0.10 (2.7)
8-12	0.03 (0.9)		12-12	0.78 (21)	0.07 (2.0)
8-13	0.04 (1)	0.01 (0.2)	12-13	0.56 (21)	0.06 (1.7)
8-14	0.04 (1)		12-14	0.32 (8.7)	0.05 (1.4)
8-15	0.04 (1)		12-15	0.13 (3.6)	0.02 (0.5)
8-16	0.04 (1)	<0.01 (0.1)	12-16	0.04 (1.0)	0.01 (0.2)
8-17	0.04 (1)		12-17	0.02 (0.6)	
8-18	0.02 (0.5)		12-18		
8-19	0.01 (0.3)		12-19	0.04 (1.1)	
8-20	0.22 (6)	0.02 (0.5)	12-20	0.03 (0.8)	
			12-21	0.04 (1.1)	
			12-22	0.06 (1.7)	
			12-23	1.2 (32)	0.04 (1.1)

Table 5.15. Quantity and distribution of radionuclides in sediment cores[a] from White Oak Creek downstream from dam, 1979 (continued)

[Bq/g (pCi/g)]

Core 13	^{137}Cs	^{60}Co
13-1[b]	80.8 (2185)	5.85 (158)
13-2[b]	79.5 (2149)	5.44 (147)
13-3	34.6 (937)	2.4 (64)
13-4	2.6 (71)	0.3 (8)
13-5	0.52 (14)	0.1 (3)
13-6	0.81 (22)	0.07 (2)
13-7	0.56 (15)	0.07 (2)
13-8	0.3 (7)	0.03 (0.8)
13-9	1.2 (32)	0.1 (3)

Core 16	^{137}Cs	^{60}Co
16-1	10.8 (293)	0.96 (26)
16-2	4.66 (126)	0.44 (12)
16-3	2.7 (72)	0.3 (7.9)
16-4	1.7 (47)	0.2 (5.6)
16-5	1.1 (30)	0.1 (3.3)
16-6	0.77 (21)	0.07 (1.9)
16-7	0.48 (13)	0.3 (0.7)
16-8	0.09 (2.5)	
16-9	0.1 (3.9)	0.01 (0.3)
16-10	0.1 (2.8)	0.01 (0.3)
16-11	0.04 (1.0)	
16-12	0.04 (1.2)	
16-13	0.1 (3.0)	0.003 (0.1)
16-14	0.2 (6.5)	
16-15	0.1 (3.4)	
16-16	0.07 (1.8)	
16-17	0.06 (1.5)	
16-18	0.06 (1.6)	

Core 17	^{137}Cs	^{60}Co
17-1	183.1 (4949)	5.3 (143)
17-2	136.0 (3677)	4.4 (120)
17-3	162.8 (4400)	5.1 (138)
17-4	220.8 (5968)	5.7 (154)
17-5	263.7 (7127)	6.4 (174)
17-6	195.0 (5271)	5.4 (147)
17-7	132.0 (3567)	4.7 (128)
17-8	85.0 (2297)	3.7 (99)
17-9	53.1 (1435)	2.4 (66)
17-10	31.6 (854)	1.5 (40)
17-11	22.6 (610)	1.04 (28)
17-12	8.5 (229)	0.37 (10)
17-13	4.8 (130)	0.32 (8.7)
17-14	3.6 (96)	0.25 (6.8)
17-15	1.1 (31)	0.10 (2.6)
17-16	0.4 (10)	0.04 (1.1)
17-17	0.16 (4.4)	
17-18	0.15 (4.0)	0.02 (0.5)
17-19	0.06 (1.6)	
17-20	0.05 (1.5)	
17-21	0.30 (8.2)	
17-22	6.3 (170)	0.12 (3.3)

[Bq/g (pCi/g)]

Core 18	^{137}Cs	^{60}Co
18-1	110.5 (2986)	3.8 (104)
18-2	141.9 (3837)	4.3 (117)
18-3	150.7 (4073)	4.3 (117)
18-4	150.2 (4059)	4.4 (118)
18-5	150.0 (4054)	4.1 (111)
18-6	146.2 (3950)	4.0 (108)
18-7	126.8 (3428)	3.3 (89)
18-8	65.4 (1768)	1.7 (46)
18-9	45.6 (1232)	1.2 (32)
18-10	18.0 (487)	0.5 (13)
18-11	15.1 (408)	0.4 (12)
18-12	0.93 (25)	0.03 (0.8)
18-13	2.8 (75)	0.07 (1.9)
18-14	10.5 (3.8)	
18-15	0.81 (22)	0.02 (0.6)
18-16	0.52 (14)	0.01 (0.3)
18-17	0.13 (3.5)	
18-18	0.19 (5.0)	
18-19	0.05 (1.3)	
18-20	0.01 (0.3)	
18-21	3.03 (82)	0.08 (2.1)

Core 19	^{137}Cs	^{60}Co
19-1	45.2 (1222)	3.2 (86)
19-2	34.4 (929)	2.3 (61)
19-3	11.1 (301)	0.6 (16)
19-4	5.0 (135)	0.3 (7.3)
19-5	4.3 (116)	0.2 (6.3)
19-6	0.8 (22)	0.04 (1.2)
19-7	0.7 (19)	0.04 (1.0)
19-8	0.15 (4.1)	0.01 (0.3)
19-9	0.04 (1.2)	
19-10	0.06 (1.5)	
19-11	0.07 (1.9)	
19-12	0.14 (3.8)	
19-13	0.21 (5.8)	
19-14	0.28 (7.7)	
19-15	0.13 (3.6)	
19-16	0.10 (2.8)	
19-17	0.16 (4.3)	
19-18	0.13 (3.6)	
19-19	0.17 (4.6)	
19-20	0.12 (3.2)	
19-21	0.13 (3.5)	
19-22	0.09 (2.4)	
19-23	0.04 (1.2)	
19-24	0.02 (0.5)	
19-25	0.63 (17)	0.04 (1.0)

Table 5.15. Quantity and distribution of radionuclides in sediment cores[a] from White Oak Creek downstream from dam, 1979 (continued)

[Bq/g (pCi/g)]

Core 20	^{137}Cs	^{60}Co
20-1	16.2 (439 ,	1.3 (36)
20-2	9.9 (268)	1.0 (28)
20-3	8.4 (227)	0.93 (25)
20-4	3.4 (91)	0.41 (11)
20-5	1.6 (43)	0.16 (4.4)
20-6	1.1 (29)	0.07 (2.0)
20-7	1.4 (38)	0.07 (2.0)
20-8	1.3 (34)	0.08 (2.2)
20-9	0.33 (8.8)	0.05 (1.3)
20-10	0.18 (4.8)	0.03 (0.8)
20-11	0.27 (7.3)	0.04 (1.0)
20-12	0.08 (2.1)	0.02 (0.6)
20-13	0.21 (5.6)	0.03 (0.8)
20-14	0.16 (4.3)	
20-15	0.21 (5.7)	0.02 (0.5)
20-16	0.20 (5.5)	0.02 (0.5)
20-17	1.9 (50)	0.14 (3.9)

Core 24	^{137}Cs	^{60}Co
24-1	19.5 (526)	0.44 (12)
24-2	17.5 (473)	0.41 (11)
24-3	20.0 (540)	0.48 (13)
24-4	21.6 (584)	0.52 (14)
24-5	17.4 (470)	0.37 (10)
24-6	16.2 (439)	0.41 (11)
24-7	9.6 (258)	0.27 (7.2)
24-8	6.1 (164)	0.18 (4.9)
24-9	35.7 (966)	0.59 (16)
24-10	87.7 (2369)	1.3 (34)
24-11	151.3 (4089)	1.3 (34)
24-12	160.3 (4331)	1.0 (27)
24-13	115.1 (3110)	0.81 (22)
24-14	159.3 (4304)	1.2 (32)
24-15	131.4 (3551)	0.70 (19)
24-16	39.6 (1071)	0.24 (6.6)
24-17	12.7 (34[illegible])	0.10 ([illegible].8)
24-18	11.0 (297)	0.11 (2.9)
24-19	11.1 (299)	0.13 (3.4)
24-20	21.9 (593)	0.30 (8.0)
24-21	70.0 (1893)	1.1 (30)
24-22	52.8 (1427)	0.01 (0.3)

[Bq/g (pCi/g)]

Core 23	^{137}Cs	^{60}Co
23-1	37.7 (1,020)	1.4 (37)
23-2	36.5 (986)	1.3 (35)
23-3	37.4 (1,011)	1.4 (37)
23-4	42.7 (1,155)	1.6 (43)
23-5	48.9 (1,322)	2.0 (53)
23-6	41.8 (1,401)	2.0 (53)
23-7	57.6 (1,556)	1.9 (51)
23-8	64.3 (1,738)	1.9 (50)
23-9	60.9 (1,647)	1.7 (47)
23-10	61.3 (1,657)	1.8 (48)
23-11	58.9 (1,591)	1.9 (50)
23-12	59.4 (1,604)	1.6 (43)
23-13	63.5 (1,716)	1.4 (39)
23-14	67.9 (1,836)	1.6 (42)
23-15	66.6 (1,801)	1.6 (42)
23-16	68.2 (1,843)	1.6 (42)
23-17	68.0 (1,837)	1.5 (41)
23-18[b]	75.9 (2,050)	1.6 (44)
23-19[b]	78.1 (2,110)	1.4 (38)
23-20	116.8 (3,157)	2.2 (59)
23-21	282 (7,610)	4.6 (124)
23-22	477 (12,900)	8.7 (234)
23-23	658 (17,800)	10.4 (282)
23-24	784 (21,200)	8.4 (227)
23-25	1080 (29,300)	14.2 (383)
23-26	2250 (60,700)	21.5 (581)
23-27	821 (22,200)	18.4 (498)
23-28	588 (15,900)	16.5 (446)
23-29	459 (12,400)	12.3 (332)
23-30A	217 (5,875)	5.3 (144)
23-30B	58.8 (1,590)	2.4 (64)
23-31	33.9 (917)	1.5 (40)
23-32	57.2 (1,547)	2.2 ([illegible])
23-33	21.8 (590)	1.7 (47)
23-34	20.1 (542)	1.8 (48)
23-35	108.3 ([illegible],927)	2.8 (76)

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[a] Number after dash in core identification indicates depth within the core (inches).

[b] Samples may contain ^{241}Am.

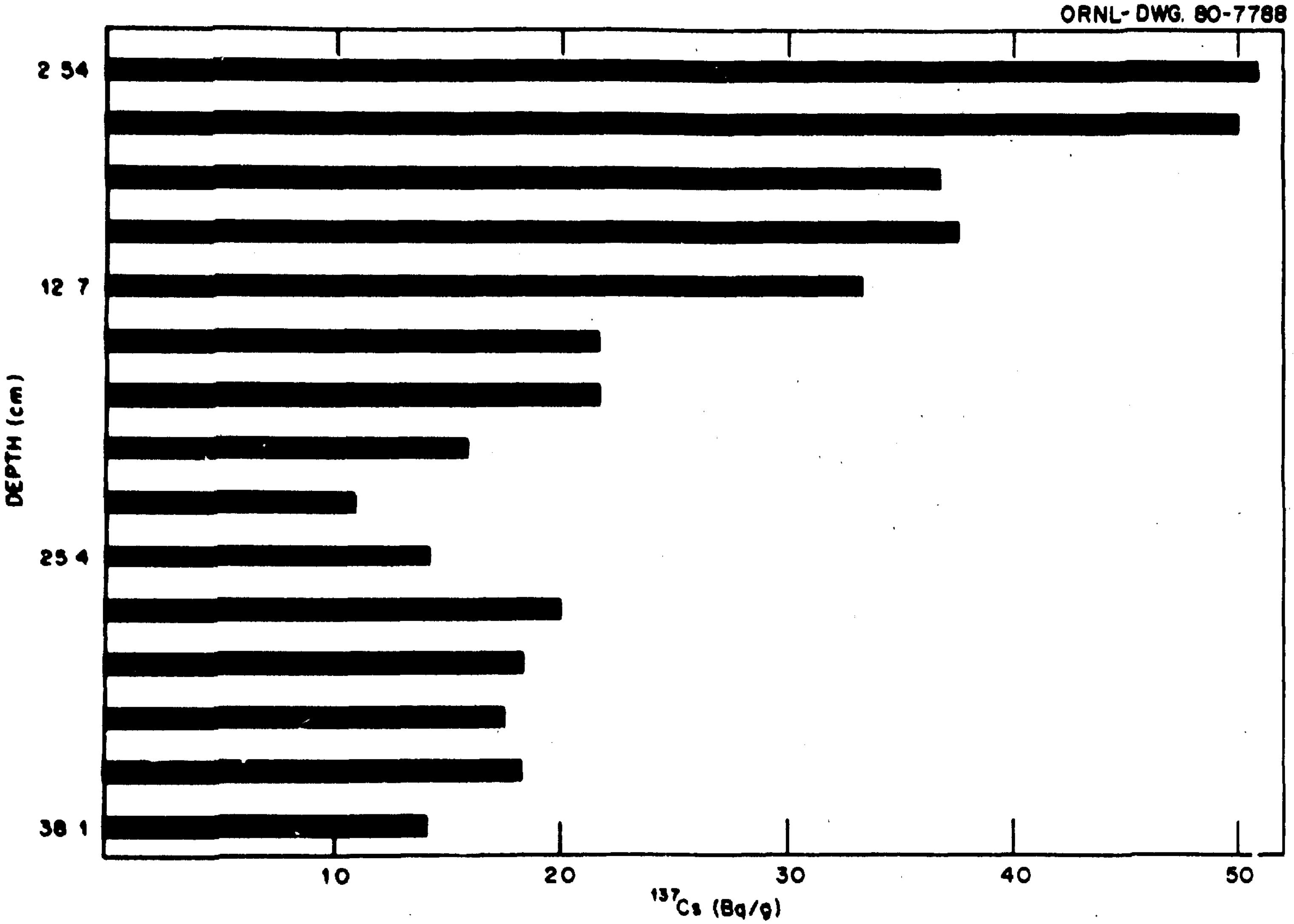

Fig. 5.26. Cesium-137 content (Bq/g) in White Oak Creek sediment, 1978 sampling program.

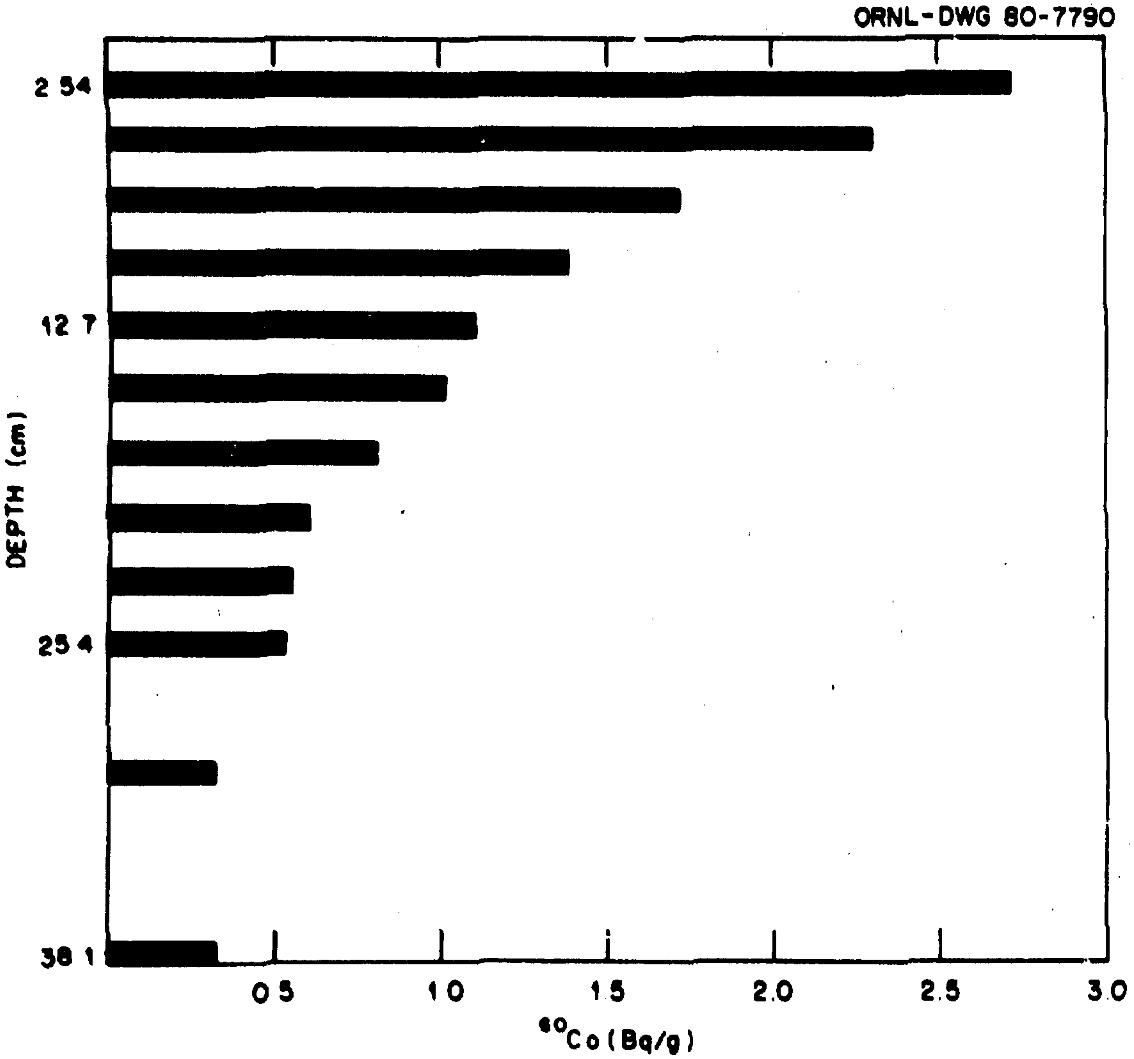

Fig. 5.27. Cobalt-60 content (Bq/g) in White Oak Creek sediment, 1978 sampling program.

ORNL-DWG 80-7789

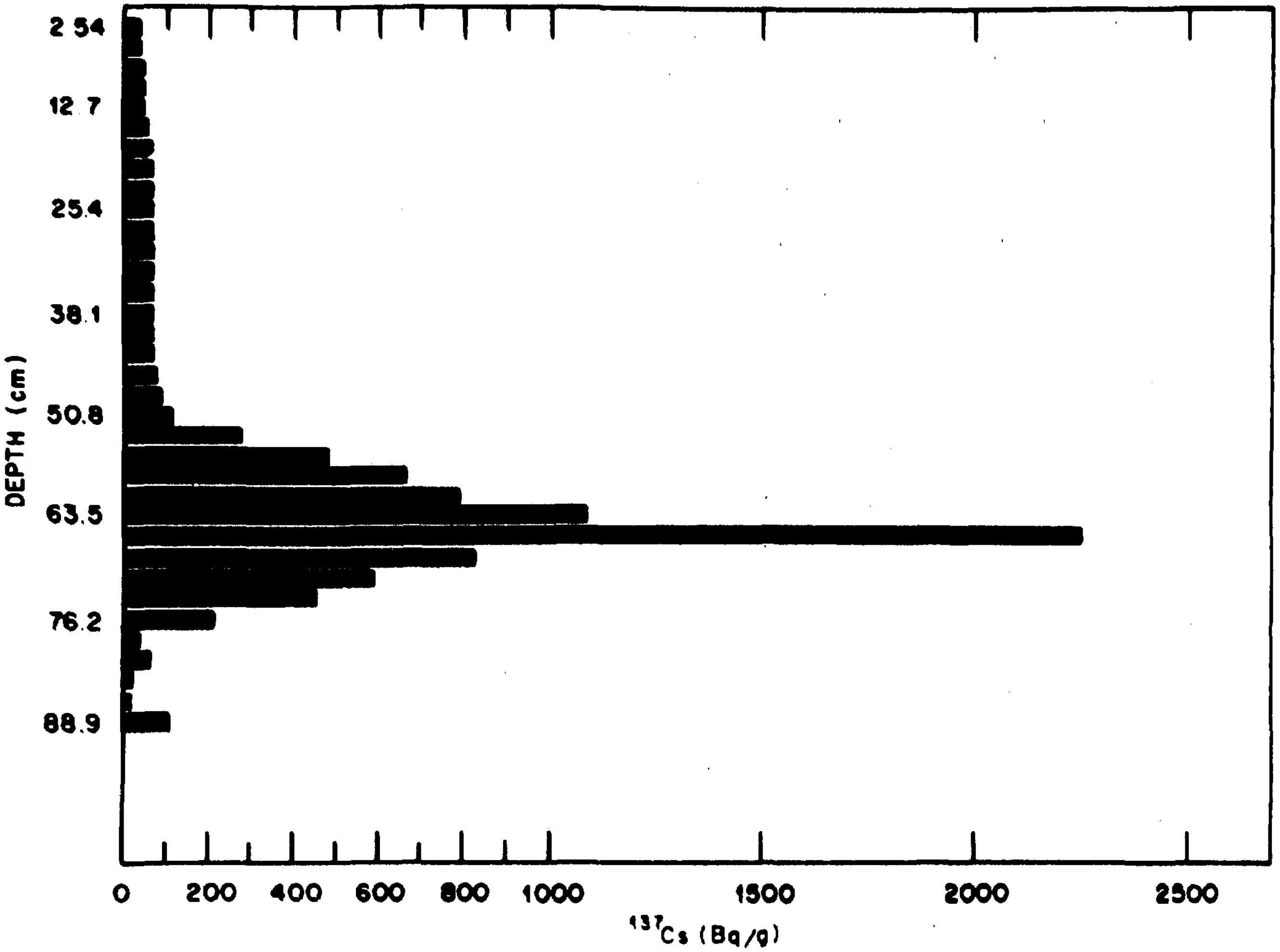

Fig. 5.28. Cesium-137 content in core 23, 1978 sampling program.

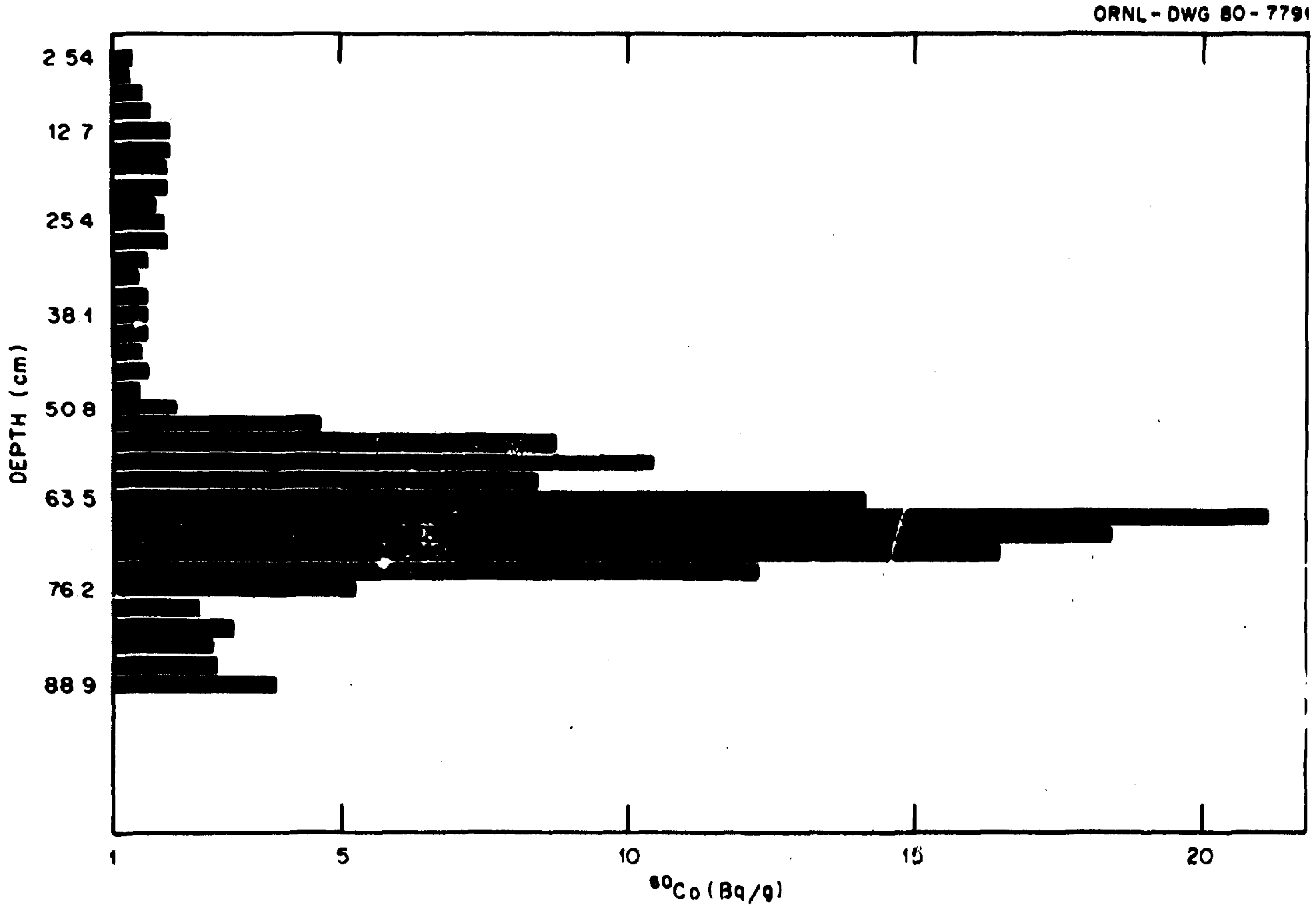

Fig. 5.29. Cobalt-60 content in core 23, 1978 sampling program.

6. REVIEW OF WATER DATA

6.1 WATER DATA, 1949-78

Water is continuously monitored as it discharges through White Oak Dam (WOD). In the past, samples were taken at WOD by a continuous proportional sampler designed and constructed at ORNL. Proportional sampling is necessary to obtain a truly representative sample, since stream flow and concentration of radioactive materials in the stream may vary independently over a relatively wide range in a relatively short period of time, depending upon weather and operating conditions. Stream flow at WOD was measured by means of a Stevens water-level recorder and stilling well in the lake pool in conjunction with the WOD gate, which serves as a rectangular weir through which the water flows.

Until November 1979 samples were collected weekly from WOD and analyzed for gross beta activity as a control measure and as a means of evaluating the gross concentration of radioactivity entering the Clinch River. Portions of the weekly samples were composited, proportional to the flow, into monthly composite samples that were subjected to more detailed analyses by wet chemical and gamma spectrometric techniques. The weekly samples were analyzed for the transuranic alpha emitters, total strontium, and ^{131}I, which represent the elements in the waste stream with the highest hazard indices.

The monthly composites were concentrated and analyzed by radiochemical and gamma spectrometric techniques, normally for the following radionuclides: ^{90}Sr, ^{137}Cs, ^{131}I, ^{106}Ru, ^{60}Co, ^{3}H, transuranics, and gross beta. Analyses for other nuclides were performed as the need arose. These analyses were performed to determine the percentage distribution and concentrations of the various nuclides in the effluent stream and to calculate the quantity of each radionuclide released to the Clinch River. More frequent analyses were made if concentration levels in White Oak Creek varied significantly from the experienced norm.

Calculations are made of the concentrations of radioactivity in the Clinch River, using the concentrations measured at WOD and the dilution provided by the river. These calculations are based on uniform mixing of the two streams within a short distance downstream from the point of entry of the wastes. The calculated concentration of each radionuclide in the river was compared with its representative MPC_w value as specified by Chapter 0524 of the DOE Manual, and the resulting fractions are summed to arrive at the % MPC_w in the Clinch River.

The annual discharges of radionuclides to the Clinch River as measured at WOD from 1949-80 are given in Table 6.1. The measured MPC_w at WOD and the calculated MPC_w in the Clinch River from 1974-80 are given in Figs. 6.1 and 6.2, respectively. Of the MPC_w values, approximately 70% are due to ^{90}Sr, 20% to ^{3}H, and the remaining to transuranics and other isotopes. The total amount of radionuclides discharged into the Clinch River is given in Table 6.2. The amount of curies released to the Clinch River from 1976-80 is given in Fig. 6.3.

As a follow-up to this calculated concentration, two sampling stations are maintained in the Clinch River below the point of entry of the wastes: one at the ORGDP water intake, Clinch River km 23.3 (CRM 14.5), and the other at Center's Ferry near Kingston, Tennessee, Clinch River km 7.2 (CRM 4.5). In addition, a sampling station is maintained in the Clinch River above the point of entry of the waste at Melton Hill Dam, Clinch River km 37.2 (CRM 23.1), to provide background data.

6.2 WATER DATA, NOVEMBER-DECEMBER 1979

The flow sampling device at WOD was changed on November 20, 1979, and the method of water monitoring was changed from the method described in the previous section. As the water level was falling, time-proportional samples were taken. For several days, hourly collections were made; however, this procedure changed to a collection once every 8 h toward the end of November; the values are shown in Table 6.3.

The tritium values have remained essentially constant over the two-month period. The entire weekly collection ending December 28 yielded an average concentration of 2.7×10^4 Bq/ℓ (7.2×10^5 pCi/ℓ) with a standard deviation of 25%.

Table 6.1 Annual discharges of radionuclides to the Clinch River, 1949 to 1978

(curies)

Year	^{137}Cs	^{106}Ru	^{89}Sr	^{90}Sr	TRE (-Ce)[a]	^{144}Ce	^{95}Zr	^{95}Nb	^{131}I	^{60}Co	^{3}H	TRU
1949	77	110		150	77	18	180	22	77		NA[b]	0.009 (from 8/12/49)
1950	19	23		38	30	NA	15	42	19			0.04
1951	20	18		29	11	NA	5	2	18			0.08
1952	10	15		72	26	23	19	18	20			0.03
1953	6	26		130	110	7	8	4	2			0.08
1954	22	11		140	160	24	14	9	4	NA		0.07
1955	63	31		93	150	85	5	6	7	7		0.25
1956	170	29		100	140	59	12	15	4	46		0.28
1957	89	60		83	110	13	23	7	1	5		0.15
1958	55	42	NA	150	240	30	6	6	8	9		0.08
1959	76	520	0.3	60	94	48	27	30	1	77		0.68
1960	31	1900	1.9	28	48	27	38	45	5	72		0.19
1961	15	2000	2.0	22	24	4	20	70	4	31		0.07
1962	6	1400	1.7	9	11	1	2	8	0.4	14		0.06
1963	4	430	1.0	8	9	2	0.3	0.7	0.4	14		0.17
1964	6	191	0.8	7	13	0.3	0.2	0.1	0.3	15	1,939	0.08
1965	2	69	0.6	3	6	0.1	0.3	0.3	0.2	12	1,161	0.50
1966	2	29	0.9	3	5	0.1	0.7	0.7	0.2	7	1,090	0.16
1967	3	17	0.7	5	9	0.2	0.5	0.5	0.9	3	13,271	1.03
1968	1	5	0.6	3	4	0.03	0.3	0.3	0.3	1	9,686	0.04
1969	1	2	0.3	3	5	0.02	0.2	0.2	0.5	1	12,247	0.20
1970	2	1	0.3	4	5	0.06	0.02	0.02	0.3	1	9,473	0.40
1971	1	0.5	0.2	3	3	0.05	0.01	0.01	0.2	1	8,945	0.05
1972	2	0.5	NA	6	5	0.03	0.01	0.01	0.3	1	10,600	0.07
1973	2	0.7		7	NA	0.02	0.05	0.05	0.5	1	15,000	0.08
1974	1	0.2		6		0.02	0.02	0.02	0.2	0.6	8,611	0.02
1975	0.6	0.3		7		NA	NA	NA	0.3	0.5	11,001	0.02
1976	0.2	0.2		5					0.03	0.9	7,422	0.01
1977	0.2	0.2		3					0.03	0.4	6,249	0.03
1978	0.3	0.2		2					0.04	0.4	6,292	0.03
1979	0.2	0.1							0.04	0.4	7,700	0.03
1980	0.6	0							0.04	0.4	4,554	0.04

[a] Total rare earths minus cerium.

[b] No analysis performed.

NOTE: Since this table was prepared prior to metrication, it has not been changed. However, multiplying the activity by 0.037 will convert curies to terabecquerels.

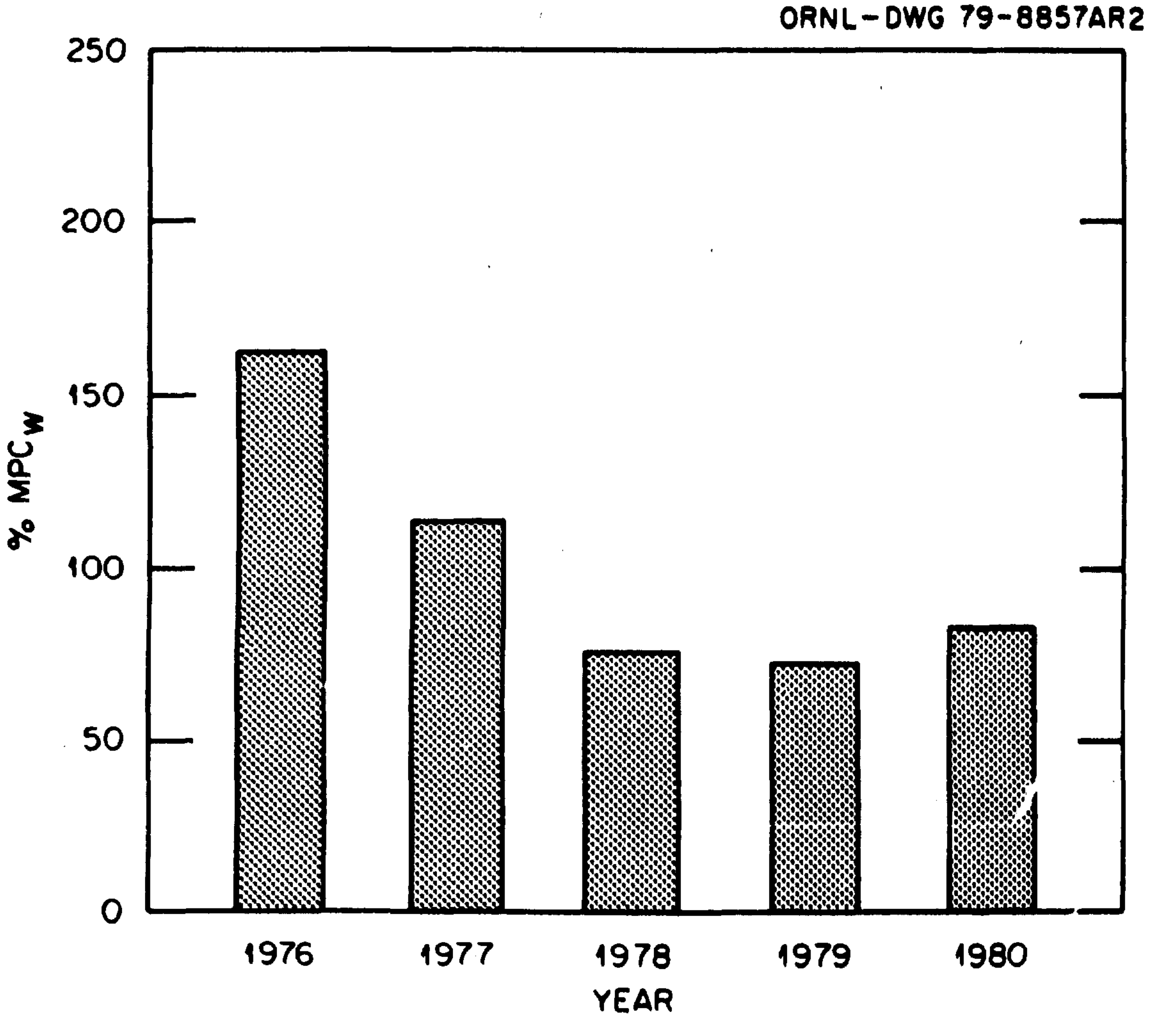

Fig. 6.1. Percent of MPC_w total over White Oak Dam.

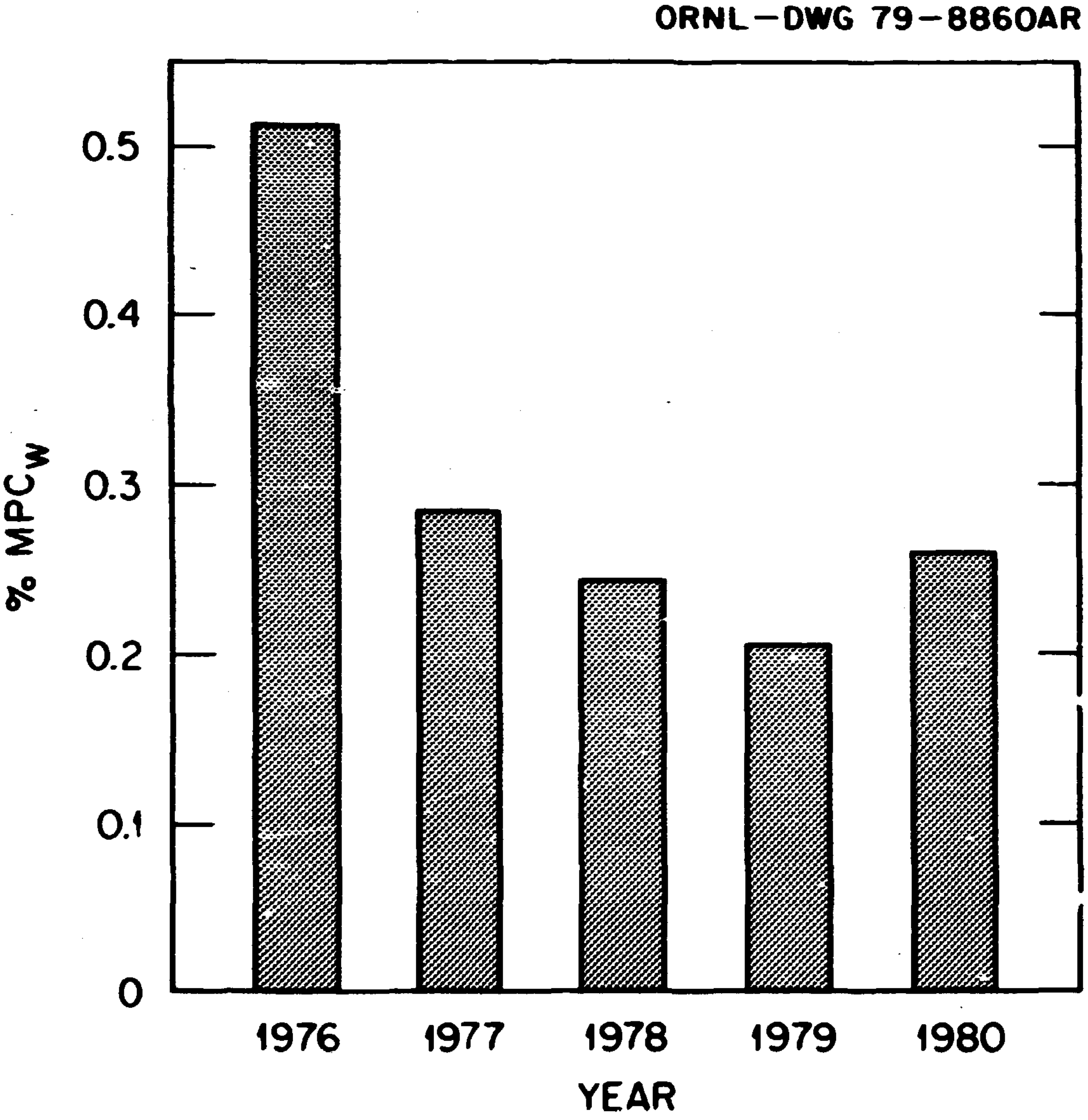

Fig. 6.2. Percentage concentration guide levels in the Clinch River. Note: Values given are calculated values based on those concentrations measured at White Oak Dam and dilution afforded by the Clinch River.

Table 6.2. Total amount of radionuclides discharged into Clinch River, 1949-80

Time interval	Radionuclide	TBq	(Ci)
1949-80	^{90}Sr	43.6	(1,183)
1949-80[a]	^{95}Sb	10.6	(286)
1949-80[a]	^{95}Zr	13.9	(375)
1949-80	^{106}Ru	265.5	(6,932)
1949-80	^{131}I	6.5	(175)
1949-80	^{137}Cs	25.5	(688)
1964-80	^{3}H	5,081	(137,199)
1955-80	^{60}Co	11.9	(322)
1949-80[a]	^{144}Ce	12.6	(342)
1949-80[a]	TRE(-Ce)[b]	47.7	(1,289)

[a] Analyses not performed after 1971.

[b] Trivalent rare earths minus cerium.

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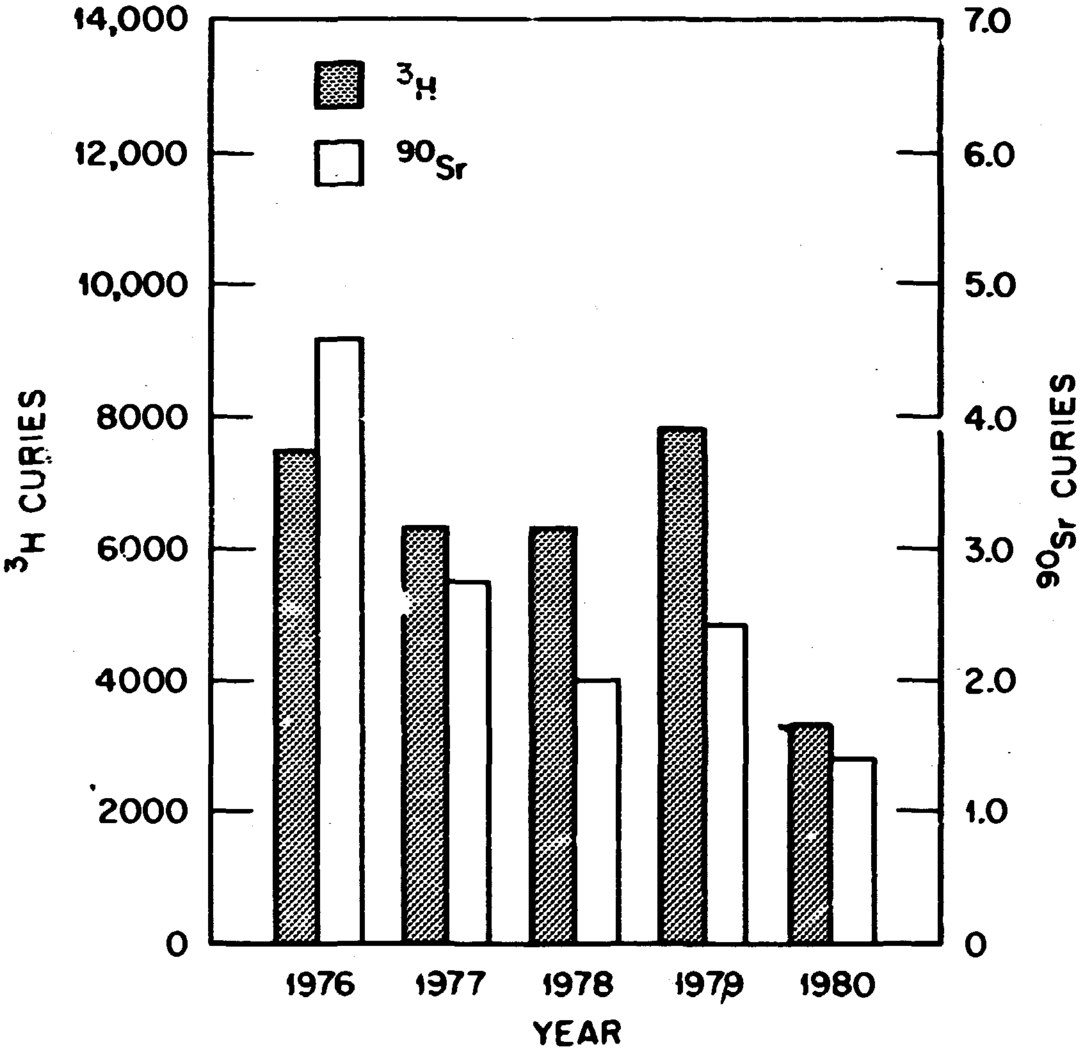

Fig. 6.3. Curies discharged over White Oak Dam.

Table 6.3. Water data, White Oak Dam, November-December 1979
[Bq/ℓ (pCi/ℓ)]

Radionuclide	Minimum	Maximum	MPC_w
^{137}Cs	0.6 (15)	8.0 (215)	740 (20,000)
^{60}Co	1.8 (49)	12.6 (340)	1,850 (50,000)
^{90}Sr	15 (405)	22.2 (600)	11.1 (300)
Gross α	1.0 (27)	11.5 (310)	
Gross β	81.4 (2,200)	215 (5,800)	
^{3}H	17,390 (470,000)	26,640 (720,000)	111,000 (3,000,000)

7. INVESTIGATION OF ^{137}Cs, ^{60}Co, and ^{90}Sr CONCENTRATIONS IN WATER AND SEDIMENT AS A FUNCTION OF FLOW IN WHITE OAK CREEK

7.1 HIGH-FLUX STUDIES, 1962

Lomenick et al. (1963) made studies of the movement of radionuclides in White Oak Creek by hydrocloning creek water in a sampling train with four separators. The four units removed suspended solids with median diameters of 29, 19, 12, and 9 µm, respectively. Their studies encompassed flow rates of 140 ℓ/s (5 cfs) to 1600 ℓ/s (57 cfs), with suspended solid variations from 0.004 to 3.26 g/ℓ. The studies made in the stream-sampling system showed features similar to those of the present study: (1) During quiescent periods (low flow rate and low suspended solids), the ^{137}Cs was found mainly in the liquid phase, with smaller quantities in the solid phase of the sediment with particle size less than 9 µm. Two experiments with suspended solids ranging from 0.7 to 3.3 g/ℓ showed a reversal of this trend in that >90% of the ^{137}Cs was found in the suspended solids. (2) Most of the ^{90}Sr (>95%) occurred in the liquid phase (see Fig. 7.1).

The 1962 studies (Lomenick et al., 1963) included one "light rainfall" flow study similar to the present work. That study had a maximum discharge rate of 311 ℓ/s (11 cfs) and 0.1 g/ℓ suspended solids. Those authors found little variation in the quantity of ^{137}Cs transported in solution, but the amount associated with suspended solids increased with stream flow and/or suspended-solids concentration. The ^{90}Sr behavior showed little variation in the quantity sorbed on sediments. The authors speculated that the additional cesium and strontium accompanying a rise in stream flow and/or suspended-solids concentration was due to scouring of the stream bed.

The maximum transport of ^{137}Cs was 13.7 kBq/s (0.37 µCi/s) in solids at a flow rate of 300 ℓ/s, while the ^{90}Sr maximum was 10.4 kBq/s (0.28 µCi/s) in the liquid phase. This contrasts with the present study where the ^{137}Cs crested at 27.8 kBq/s (0.75 µCi/s) in solids at a flow rate of 8000 ℓ/s; the corresponding ^{90}Sr transport in solution was 40.7 kBq/s (1.1 µCi/s).

7.2 HIGH-FLOW STUDY, MARCH 4, 1979

White Oak Creek tributary surface streams flow through the Oak Ridge National Laboratory Reservation and receive treated low-level radioactive

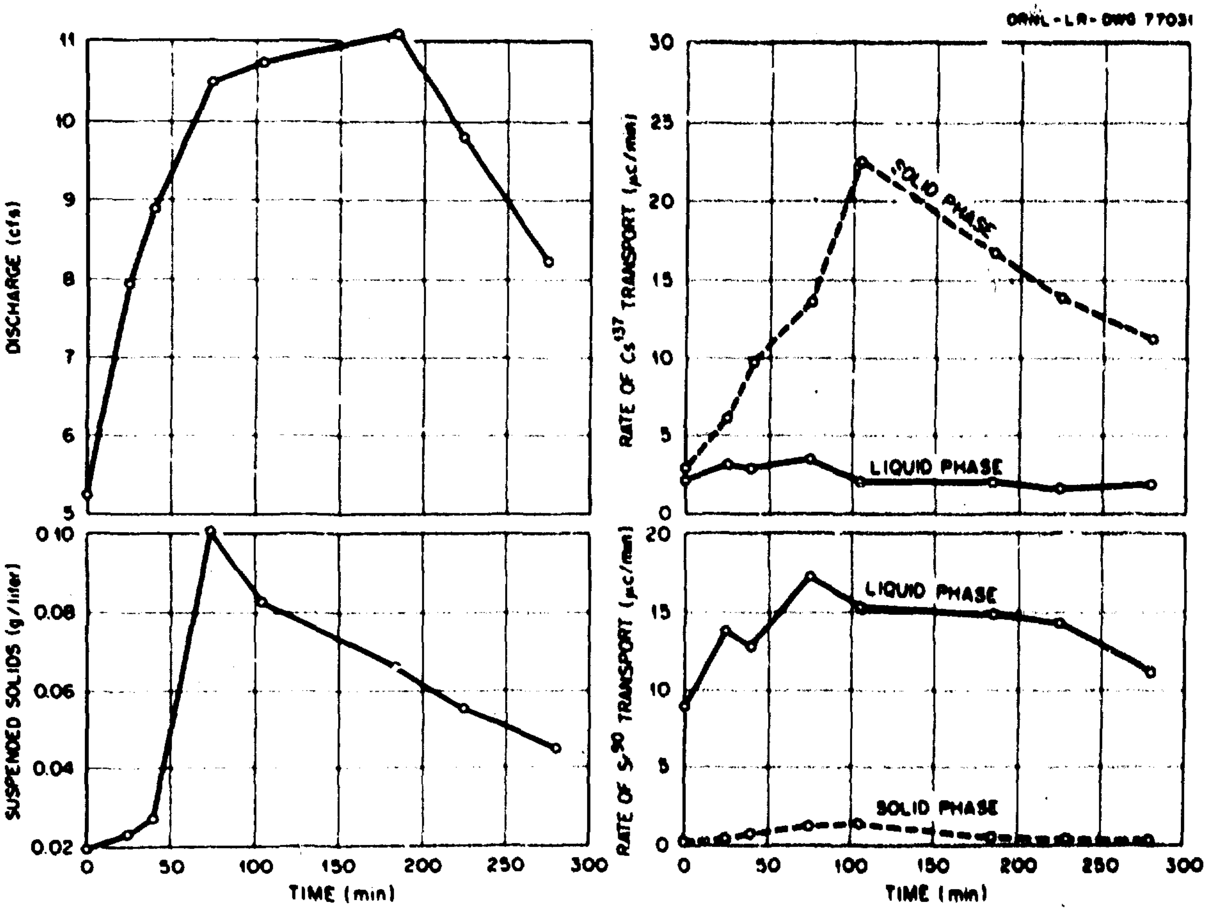

Fig. 7.1. Stream flow, concentration of suspended solids, and ^{90}Sr and ^{137}Cs transport in White Oak Creek resulting from light rainfall.

liquid waste which originates from various Laboratory operations. The streams receive additional low-level liquid waste by seepage of radioactive materials from solid-waste burial grounds, hydrofracture sites, and intermediate-level liquid waste burial sites.

An important consideration in the measurement of radionuclide discharges is the amount transported in the water and sediment. Because ^{137}Cs, ^{60}Co, and ^{90}Sr may become adsorbed by stream sediments as well as remaining in solution, the percentage of these nuclides associated with the water and sediment as a function of flow is being investigated at periods of high flow conditions.

Sample collection is initiated at times of heavy rains, when the flow reaches 800 to 1000 ℓ/s. Samples are collected at half-hour intervals, changing to hourly collections as the study progresses. The water samples are filtered through 1-μm Millipore filters as soon as possible after collection. The filtrate is acidified with 10 mℓ of concentrated hydrochloric acid, and the filters containing the sediment are dried and weighed to determine the total sediment transport. High-resolution gamma-ray spectroscopy is used to determine the radionuclide content of the solution and sediment fractions. Radiochemical separations are performed to determine the ^{90}Sr content of each solution and sediment sample.

In a two-day study, sufficient samples were taken to characterize the system thoroughly while high flow persisted. Figure 7.2 shows the water flow pattern during the March 3 study starting with a flow of 1400 ℓ/s, reaching a crest of 8000 ℓ/s after 5 or 6 h, and then tapering off to a flow of 1400 ℓ/s on the second day. Figure 7.3 shows the profile of the solid transfer for the same period. Note the dramatic rise in solid transfer (100 to 700 g/s) occurring during the 1-h span between samples 8 and 10. It is also seen that solids are moving across the dam at 0.8 to 0.9 kg/s at the peak flow period. Figure 7.4 illustrates the temporal variation of radionuclide transport in sediment. The sediment radioactivity consists predominately of ^{137}Cs, with lesser quantities of ^{60}Co and ^{90}Sr. The ^{137}Cs transport in solids crested at approximately 300 kBq/s (8 μCi/s), near the flow maximum. However, the ^{137}Cs content per gram of sediment was greatest near the beginning of the experiment when the sediment levels were of the order of 10 to 12 mg/ℓ.

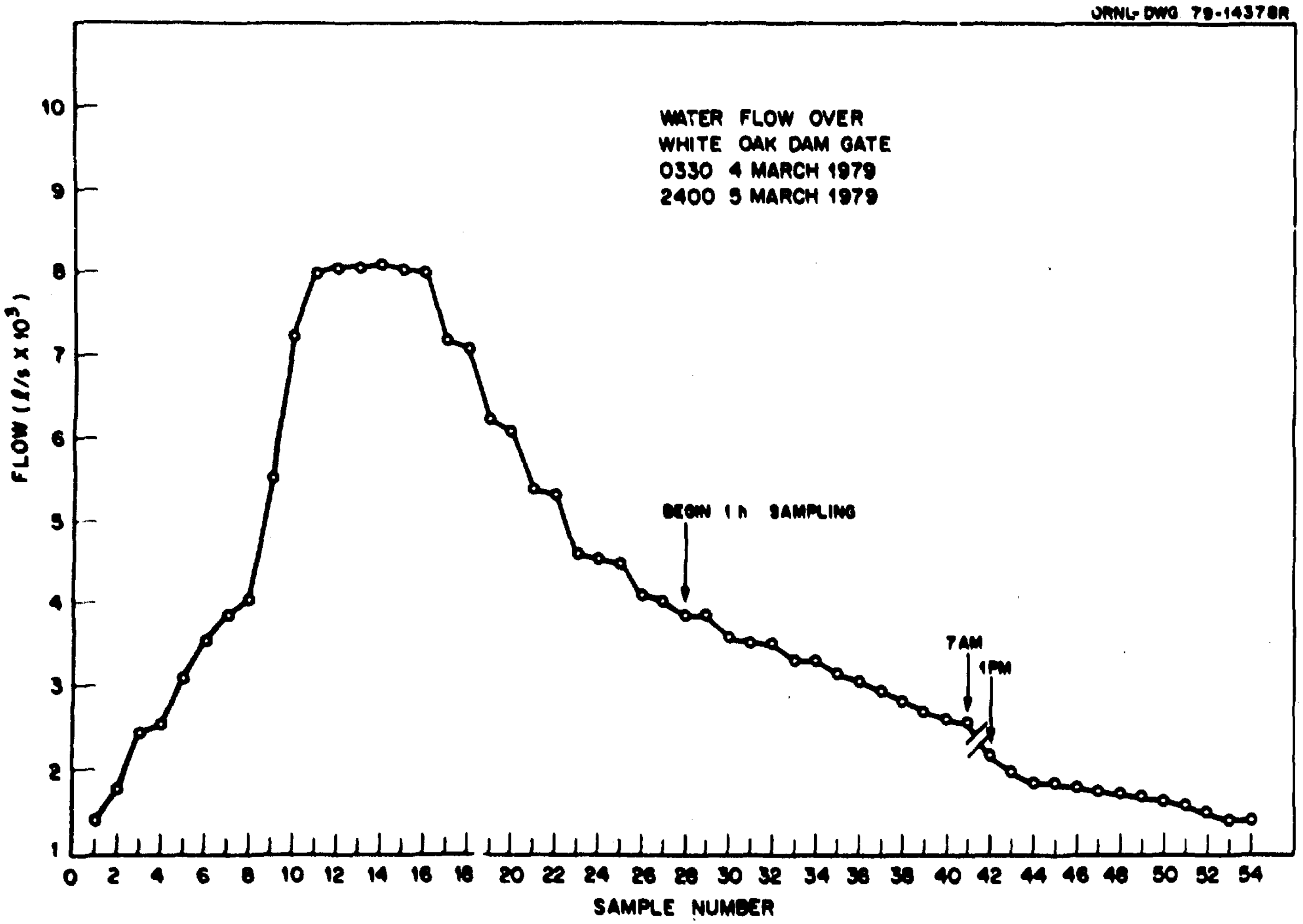

Fig. 7.2. Water flow profile over White Oak Dam, 0330 Mar. 4 to 2400 Mar. 5, 1979.

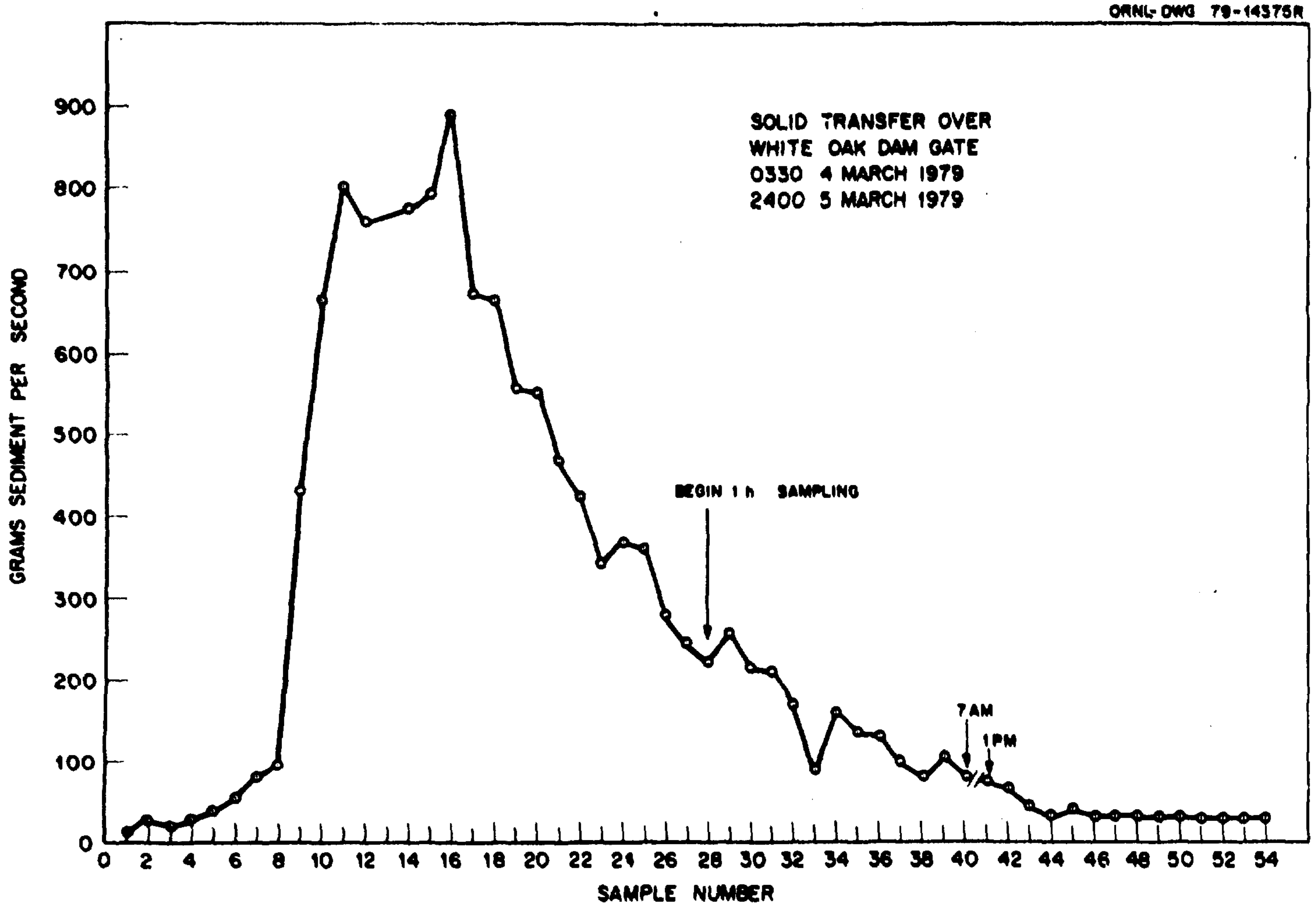

Fig. 7.3. Sediment transfer over White Oak Dam, 0330 Mar. 4 to 2400 Mar. 5, 1979.

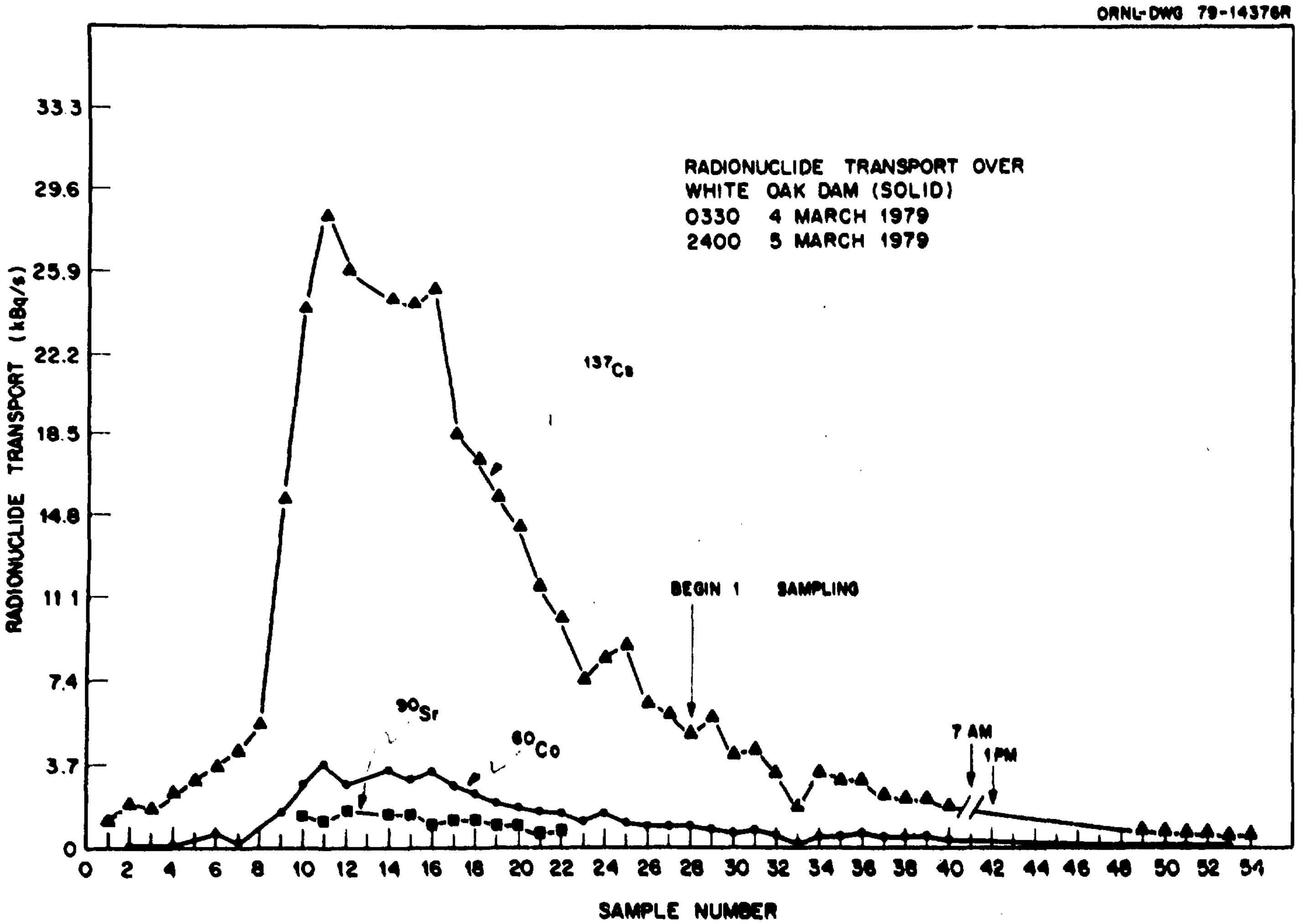

Fig. 7.4. Temporal variation of radionuclide transport in sediments over White Oak Dam, 0330 Mar. 4 to 2400 Mar. 5, 1979.

As shown in Fig. 7.5, ^{90}Sr and ^{60}Co are the two major nuclides moving in solution across the dam. Note that ^{137}Cs was not detected in solution after the first 4 h and that values plotted for ^{90}Sr are scaled down by 10; that is, the maximum point shown for ^{90}Sr at sample 11 is 41 kBq/s (1.1 μCi/s).

On the basis of results from the studies of March 3 and 4, it can be shown that ^{137}Cs movement out of the White Oak Creek-Lake system is almost exclusively as a component of sediment, whereas ^{90}Sr moves mainly in solution. Movement of ^{60}Co is seen to be intermediate between the other nuclides; that is, it moves in both solution and sediment phases. This agrees with past data that showed 2% of ^{90}Sr moved with the sediment, 6% for ^{106}Ru, 19% for ^{60}Co, and 69% for ^{137}Cs (Struxness et al., 1967).

7.3 HIGH-FLOW STUDY, JUNE 3-4, 1979

A second high-flow study was performed during heavy rains and high-flow-rate conditions during a one-day storm on June 3-4, 1979. Figure 7.6 presents the flow profile over the dam gate as a function of sample number. It can be seen that there was a 2-h period in which the water flow exceeded 10,000 ℓ/s . Figure 7.7 shows the solids transport profile for the same period. The crest in the solids curve occurred at levels of 0.6 to 0.7 kg/s. [The point for sample 9 (approximately 400g/s) is probably in error due to a mistake in weighing.] Note the time lag in the solids transport curve compared with the water flow curve. The rate for the water flow exceeded 10,000 ℓ/s at sample 5, whereas the solids did not peak until sample 8.

Figure 7.8 presents the curves for radionuclide transport in solution for the study. Note that ^{137}Cs was only detected in sample 27 in the entire study. Stontium-90 contributes most to the solution radioactivity, reaching a crest of 44 kBq/s (1.2 μCi/s). The ^{60}Co crested at 8.5 kBq/s (0.23 μCi/s), but the flow pattern exhibited a secondary rise at sample 27. There is a relationship between the water flow profile and the radionuclide solution transport. Sediment radioactivity transport profiles are shown in Fig. 7.9, where it can be seen that ^{137}Cs contributes most to sediment radioactivity transported over the dam gate. Note that there is a direct correlation between the radionuclide transport in solids and the total solids transport curve.

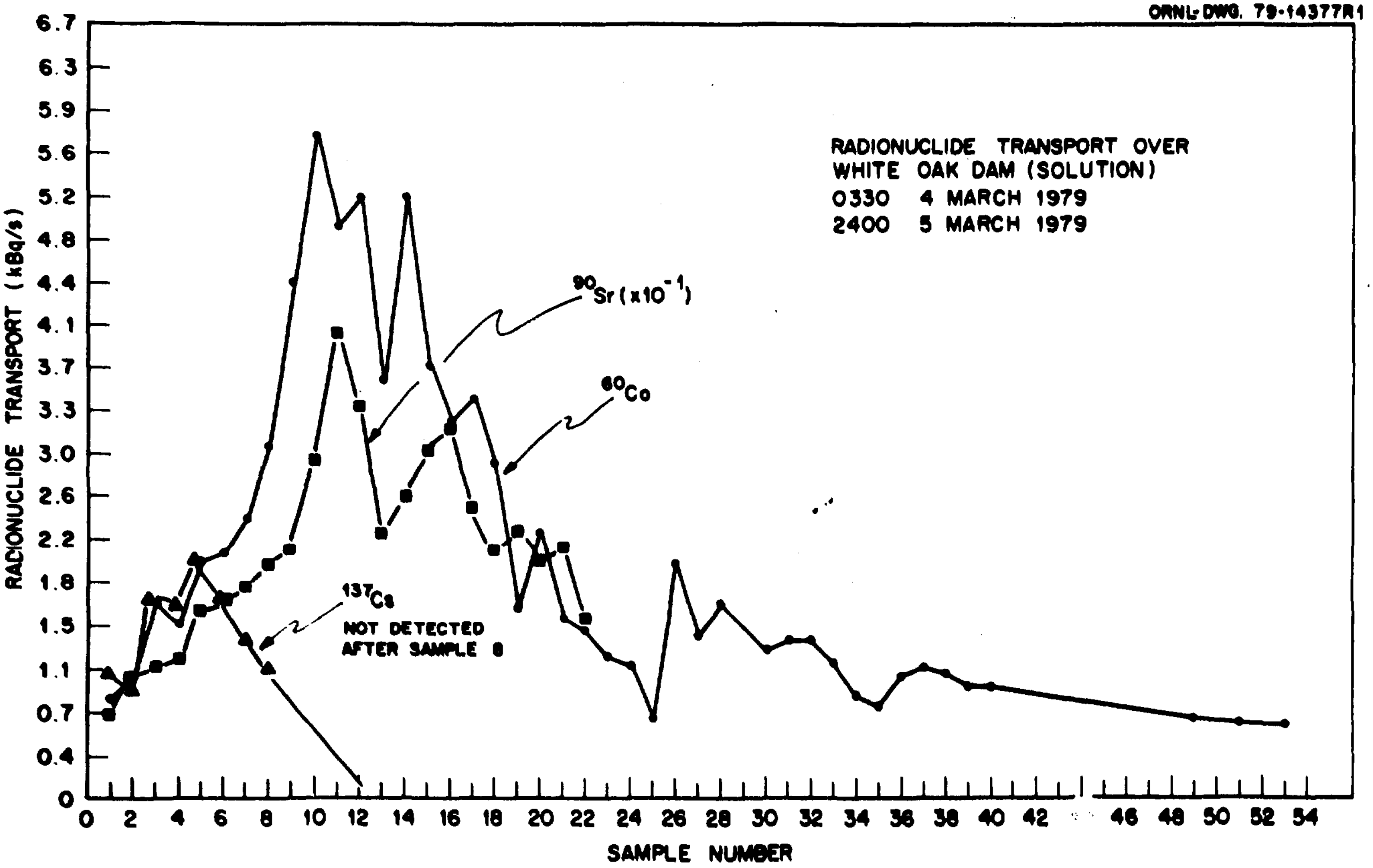

Fig. 7.5. Temporal variation of radionuclide transport in solution over White Oak Dam, 0330 Mar. 4 to 2400 Mar. 5, 1979.

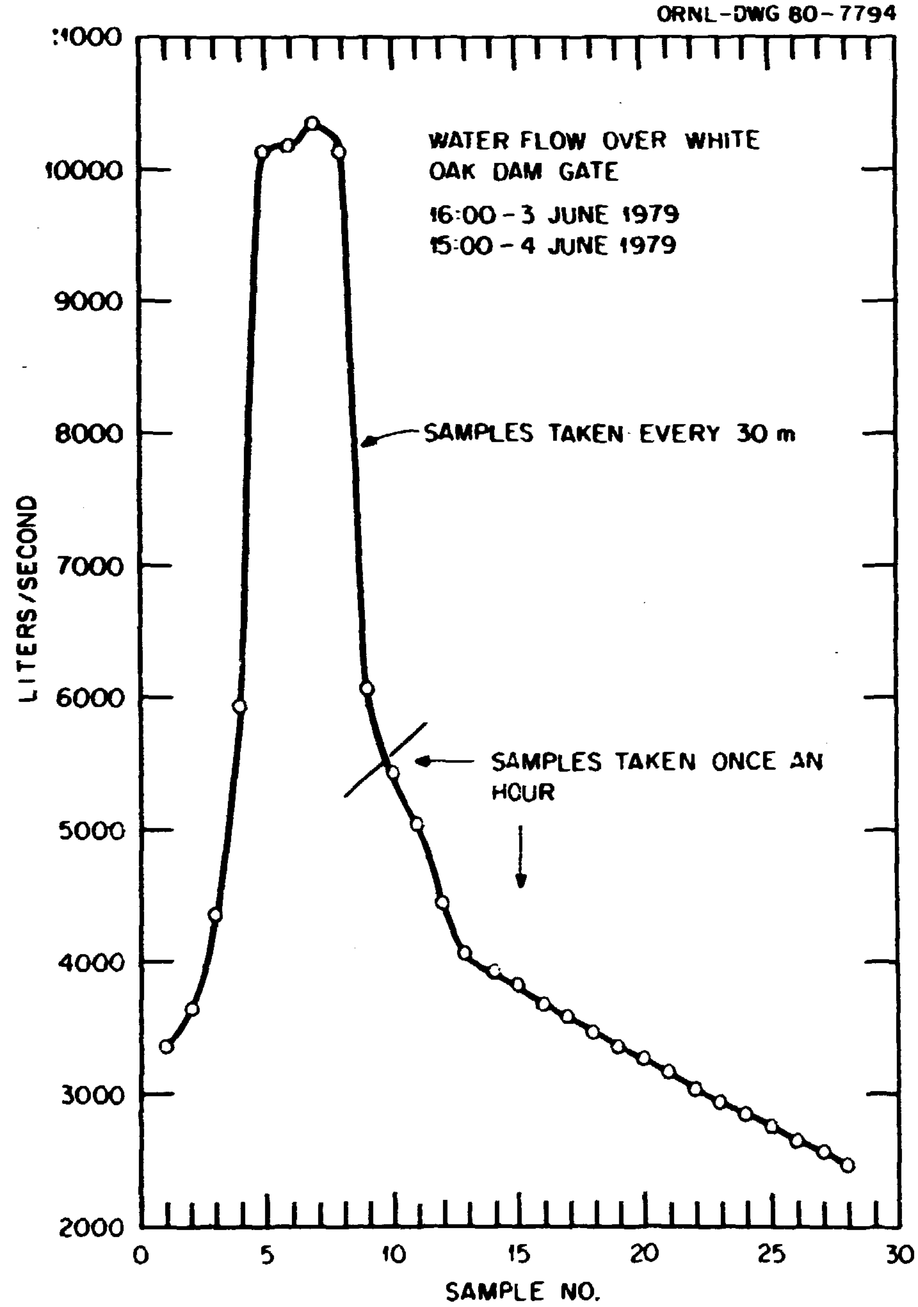

Fig. 7.6. Water flow over White Oak Dam gate 1600 June 3 to 1500 June 4, 1979.

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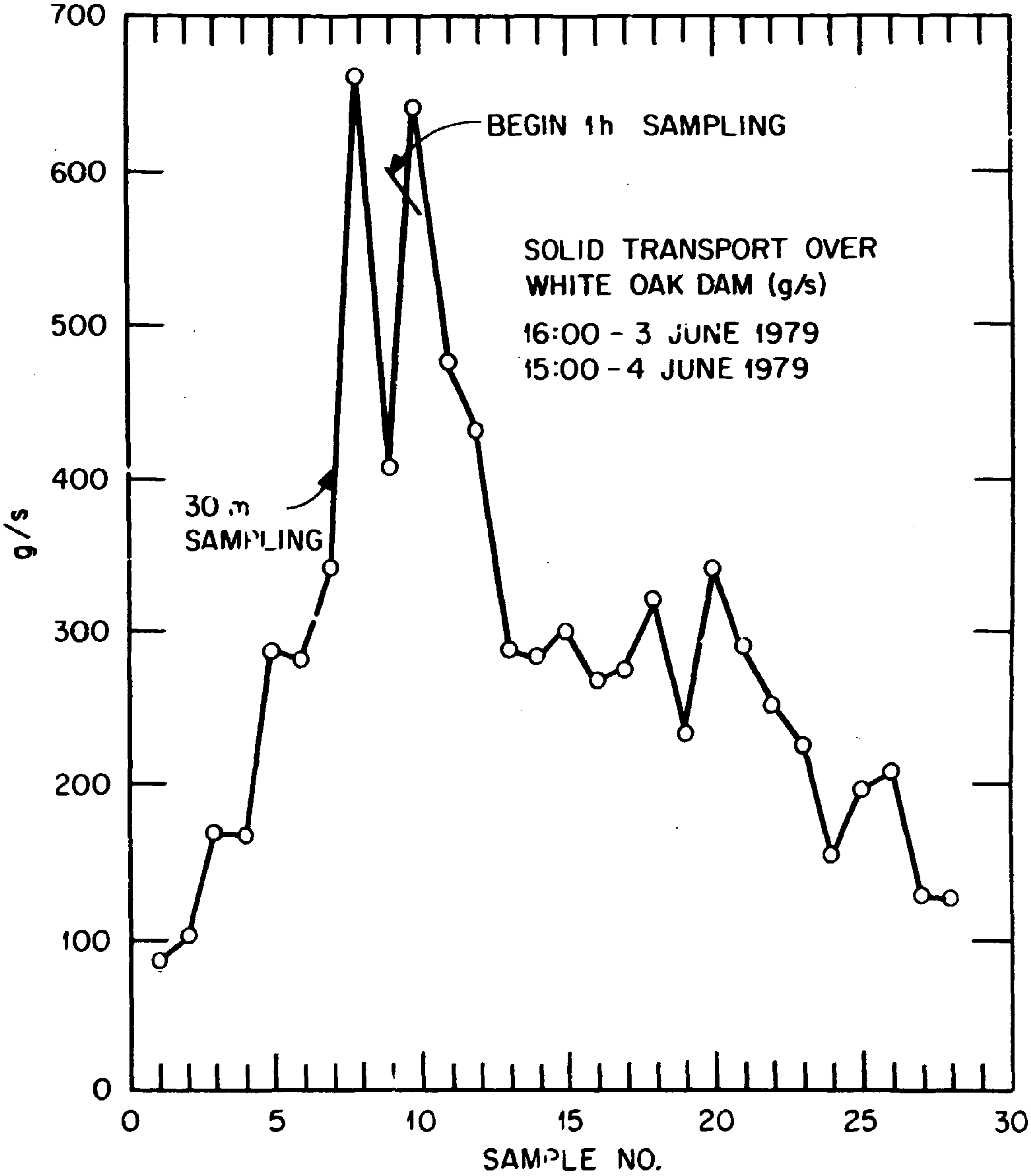

Fig. 7.7. Solid transport over White Oak Dam 1600 June 3 to 1500 June 4, 1979.

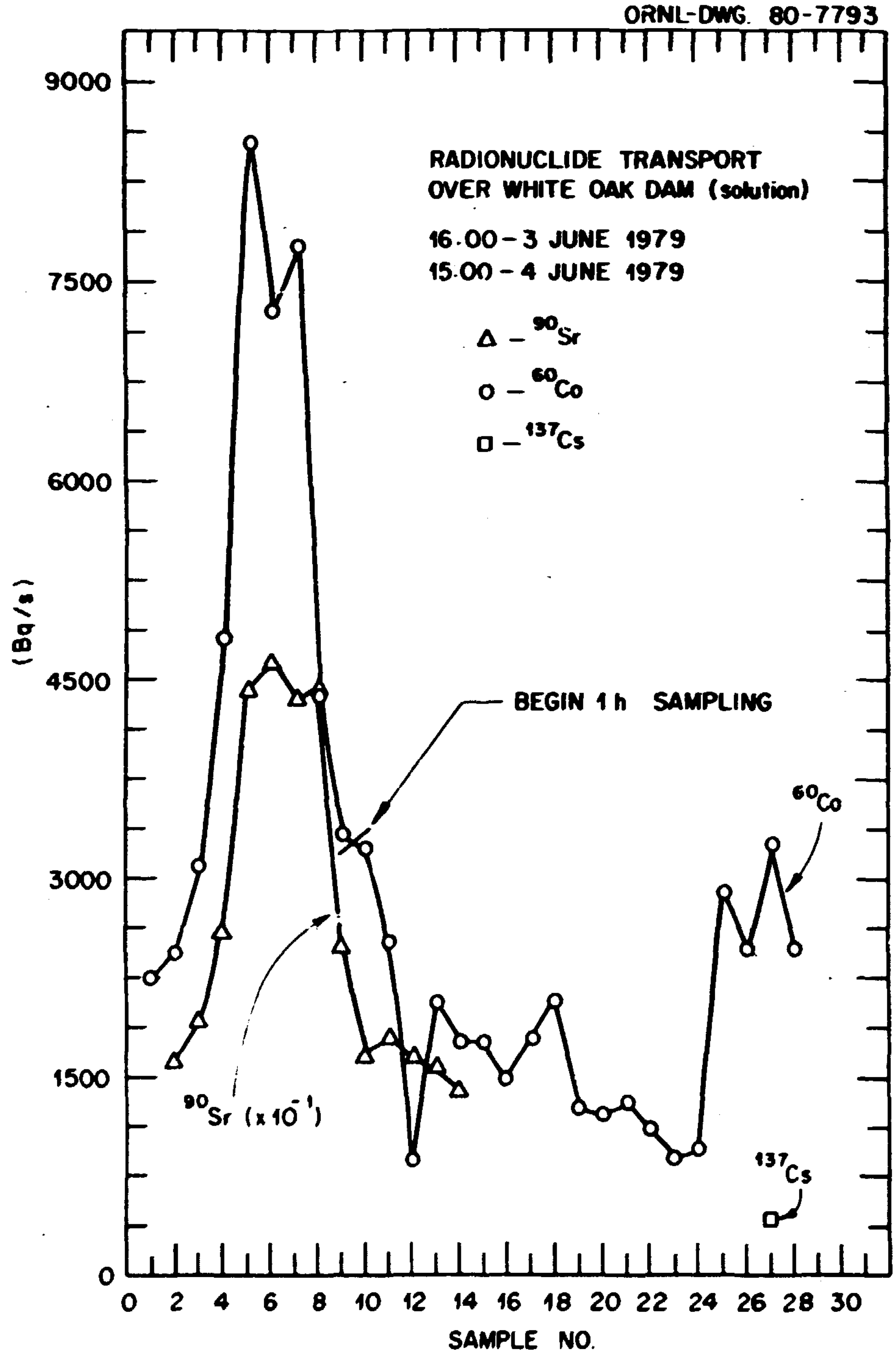

Fig. 7.8. Radionuclide transport over White Oak Dam (solution) 1600 June 3 to 1500 June 4, 1979.

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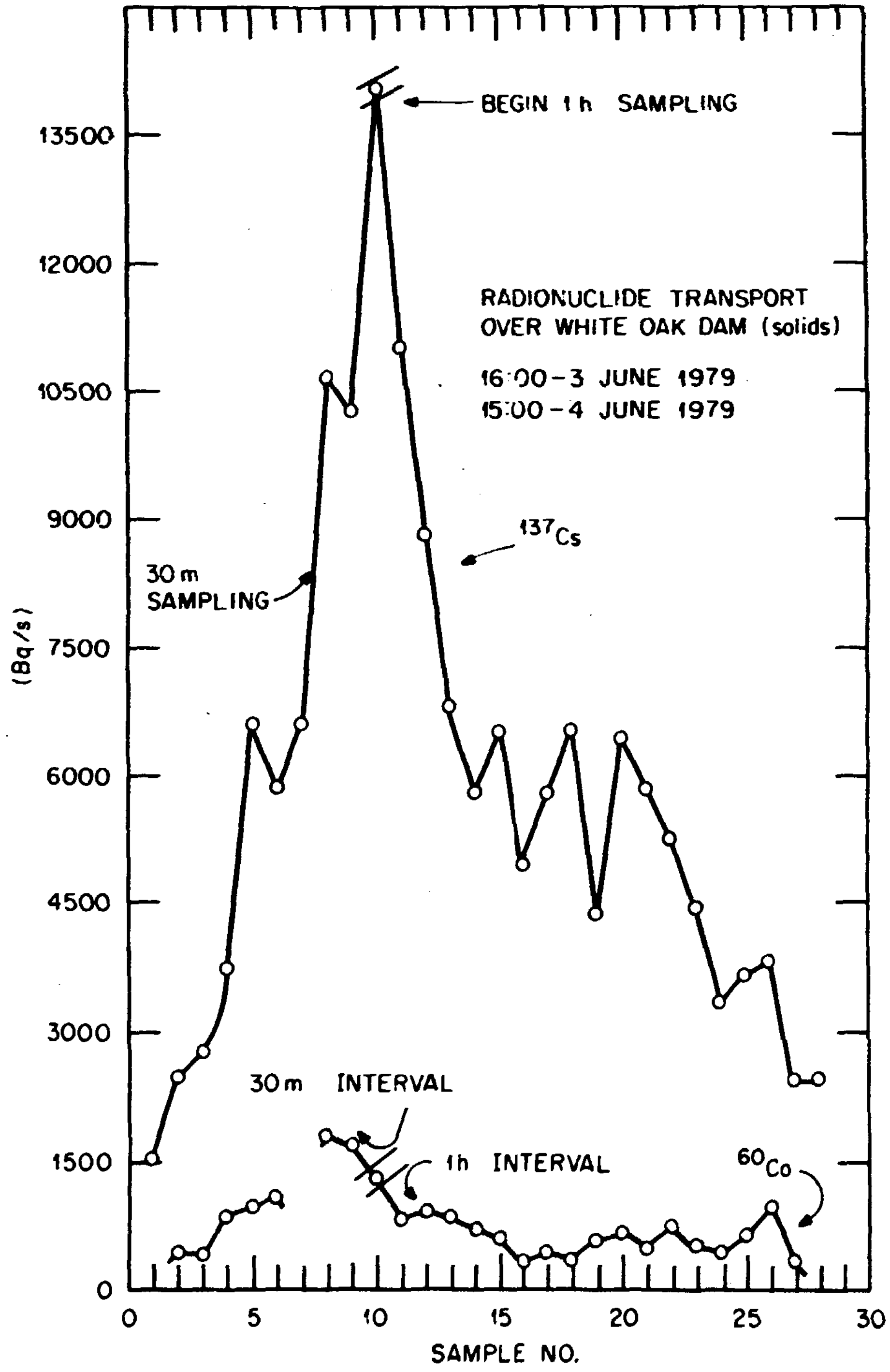

Fig. 7.9. Radionuclide transport over White Oak Dam (solids) 1600 June 3 to 1500 June 4, 1979.

Figure 7.10 presents the temporal variation of calcium and magnesium concentrations as a function of sample number. Although magnesium remained relatively constant, calcium exhibited a general decrease after a slight initial rise at the maximum flow period.

The conclusions drawn from the second high-flow study are the same as those from the first study: The major transport mechanism for ^{137}Cs out of the White Oak Lake system is as a component of sediment during high-flow conditions. Strontium-90 moves mainly in solution, while ^{60}Co behaves intermediately.

7.4 REVIEW OF SEDIMENT TRANSPORT AS A FUNCTION OF FLOW

Lomenick et al. (1963) presented the suspended particulate concentration as a function of flow. They noted a variation of 4 mg/ℓ at 0.14 m^3/s (4.99 cfs) to 44 mg/ℓ at 1.6 m^3/s (57 cfs). Normal concentrations are approximately 10 to 12 mg/ℓ. For 10 mg/ℓ and using a discharge of 1.1×10^6 m^3/mo (average flow over WOD for 1978), a total amount of 120 m^3/year is calculated to have been discharged. The average concentration during December 1979, when the lake was draining, was 60 mg/ℓ; this results in a yearly amount of 720 m^3/year. Measurements made on sediment discharge when the lake was completely drained in the late 1950s resulted in an average of 4200 m^3/year (Lomenick et al., 1961). During the flood events of March 1979, at the peak water flow, the sediment concentration was 113 mg/ℓ.

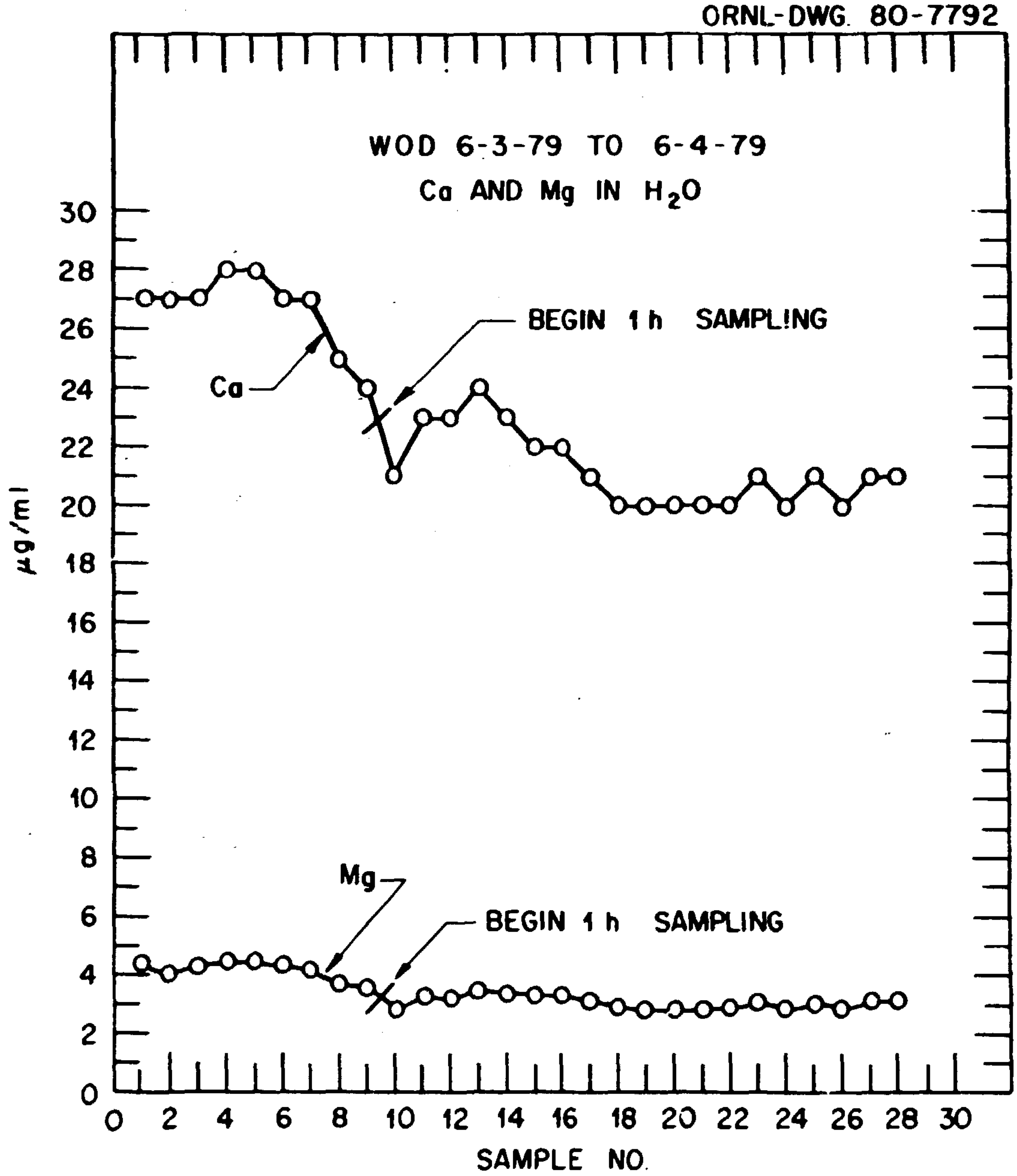

Fig. 7.10. White Oak Dam June 3 to June 4, 1979, Ca and Mg in H_2O.

8. PATHWAYS ANALYSIS

Generalized pathways are shown in Figs. 8.1, 8.2, and 8.3. Specific technical considerations for discharges from White Oak Lake to the Clinch River are discussed in more detail in the remainder of this chapter.

8.1 CONCENTRATION FACTORS (CF) FOR UPTAKE OF RADIOACTIVITY BY PLANTS AND FISH FROM WATER

Plants and fish concentrate radioactivity from water. The concentration factors (CF) for relevant radioisotopes are presented in Table 8.1.

8.2 UPTAKE OF RADIOACTIVITY BY PLANTS

8.2.1 Soil mechanics

The ability of plants to take up a radioactive substance depends partly on its accessibility, both chemical and spatial to the plant roots. Strontium-90 and cesium-137 are probably the most important fission products which can be readily taken up by plants.

In general, the extent of penetration of an ion depends on its valence. A divalent cation will ordinarily be bound more tightly by soil than the monovalent cations, but other factors may be overriding. Thus, ^{90}Sr, which in ionic form is divalent, will penetrate more readily than monovalent ^{137}Cs because strontium ions are relatively abundant in soil compared to cesium ions. The latter ions are relatively rare in soil, and monovalent ^{137}Cs is actually bound in soil more readily than divalent strontium. In situations where there is abundant moisture and a deficiency of soil potassium, ^{137}Cs is more readily available than otherwise for uptake by forage plants.

Field studies in the USSR indicated that ^{90}Sr migrated at a rate of 1.1 to 1.3 cm/d through soils that had modestly high exchange capacity and that were permeated with ground water (Spitsyn et al., 1959). Since the average life of a ^{90}Sr atom is about 40 years, the mean distance that would be traversed by the isotope before its decay would be less than 200 m under the given conditions. The total amount of ^{90}Sr would diminish to 0.1% of

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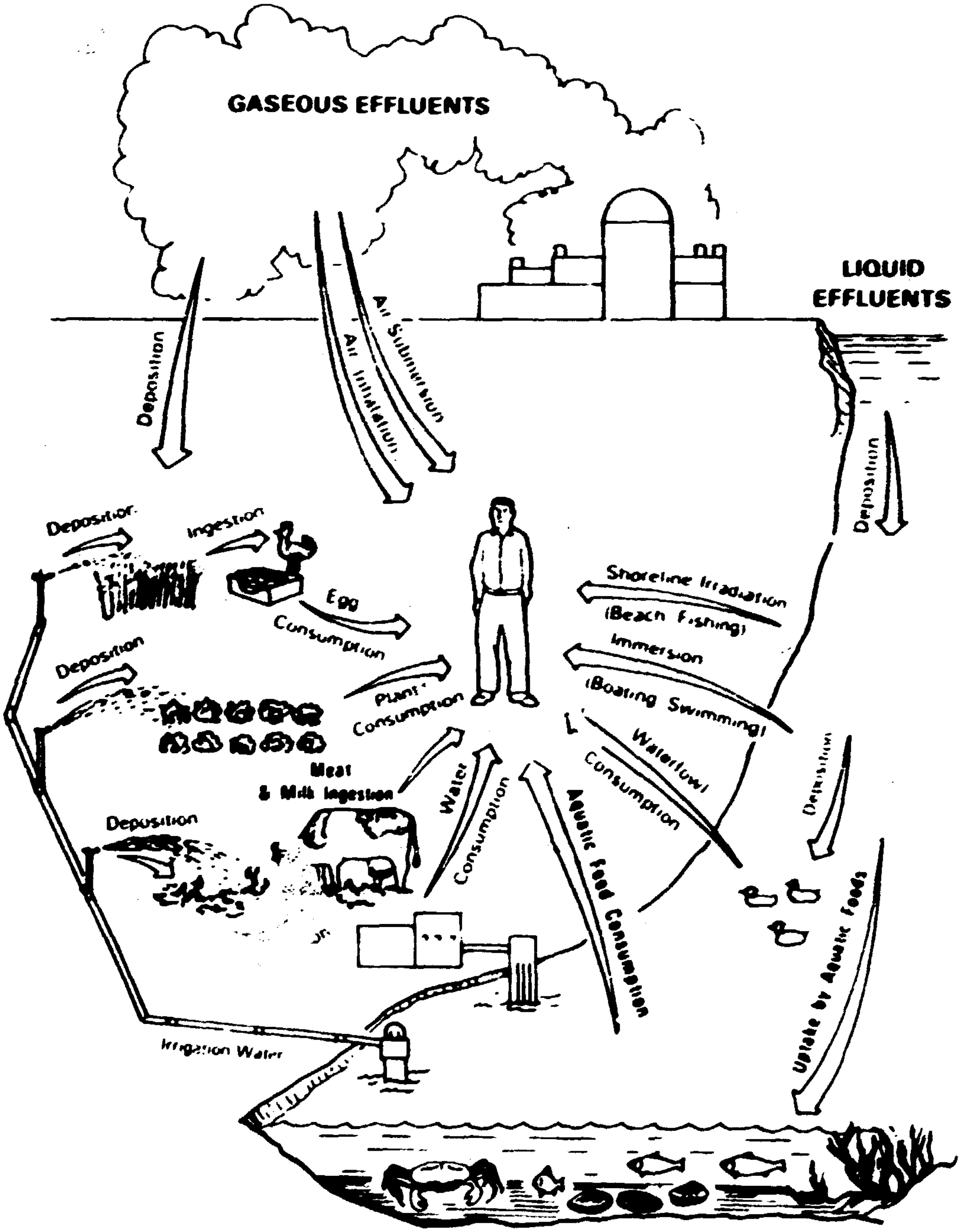

Fig. 8.1. Exposure pathways to man.

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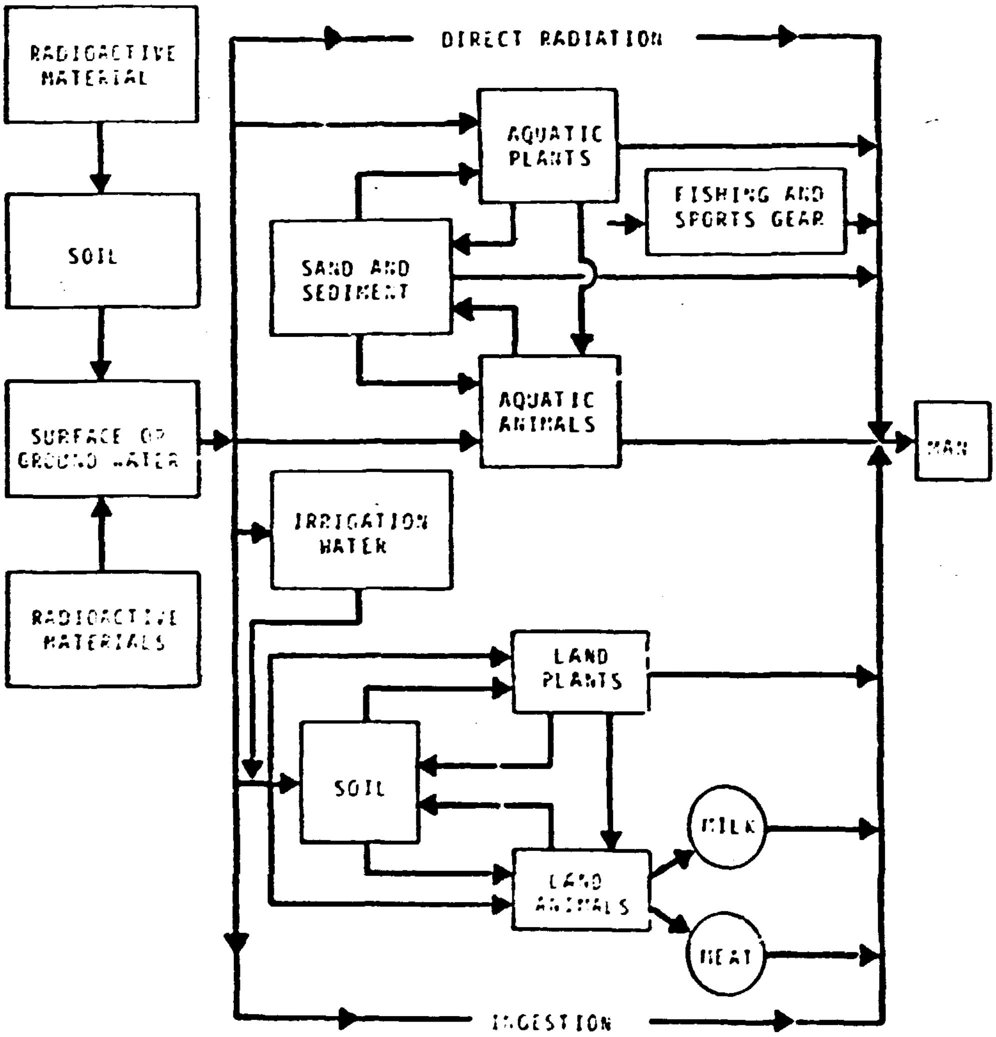

Fig. 8.2. Pathways between radioactive materials released to ground and surface water and man.

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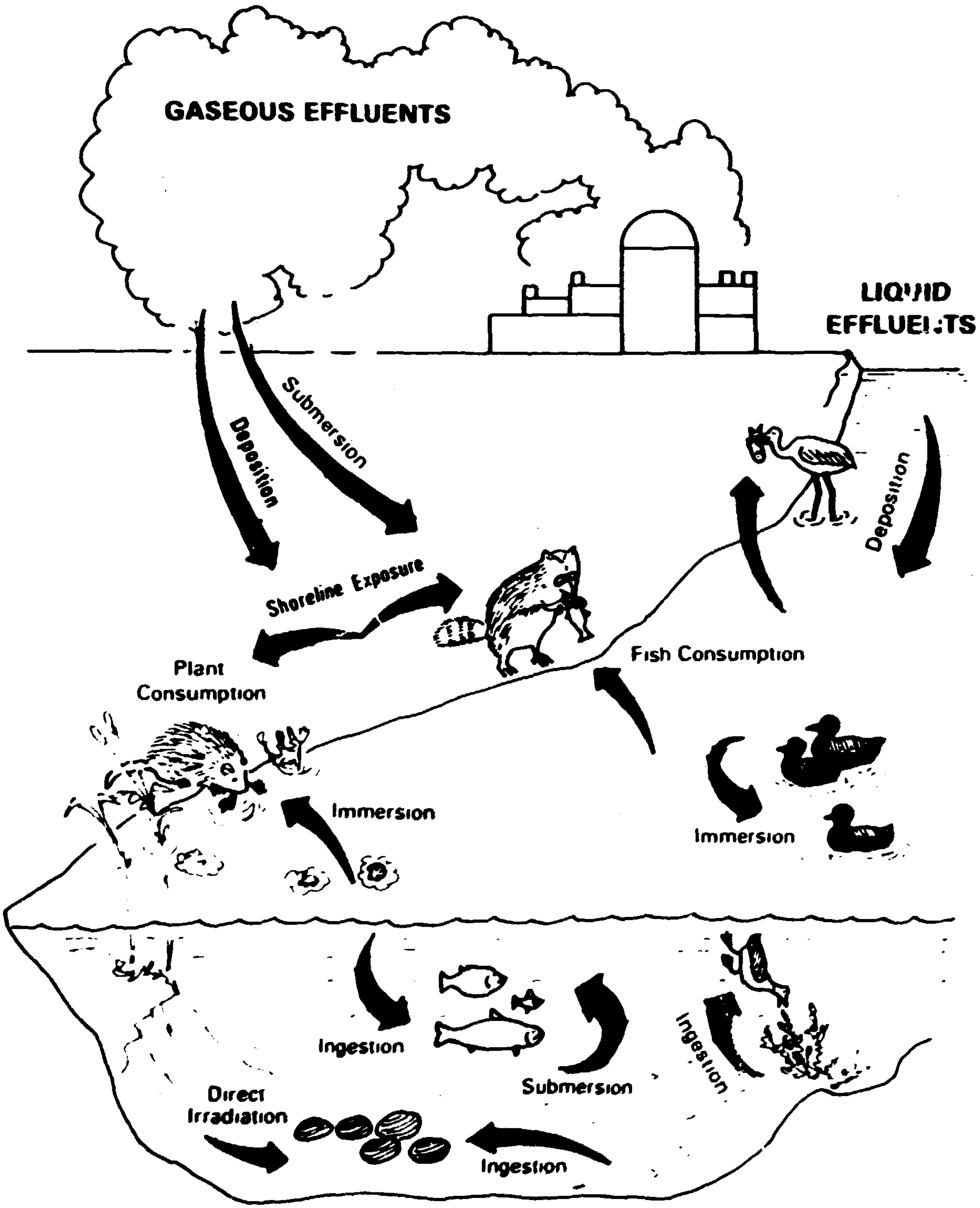

Fig. 8.3. Exposure pathways to organisms other than man.

Table 8.1. Reported concentration factors (CF) for various classes of freshwater edible organisms

		CF range	Mean CF
Strontium	Plants	80-410	200
	Fish	0.85-90	14
Cesium	Plants	80-4,000	907
	Fish	120-22,000	3680
Cobalt	Plants	300-30,000	6760
	Fish	60-3,450	1615
Pu[a]	Plants		350
	Fish		3.5

[a] Thompson et al., 1972.

Source: Eisenbud, 1973.

the original in 10 half-lives, by which time the distance traveled would be 1400 m. The capacity of soils to store fission products in ionic form thus seems to be substantial.

As a general rule, radioisotopes present in soil will pass into the root system in the same manner as nonradioactive isotopes of the cations. It may be assumed that if a cation is present in the soil, it will probably be present in the tissue of plants grown in the soil.

The extent to which a radionuclide is absorbed from the soil by plants depends on the chemical form of the nuclide, the metabolic requirement of the plant, and physiochemical factors in the soil. The relative concentration factor (CF) varies for the different radioisotopes. Strontium is slightly concentrated in plants from soils and has a CF from 1 to 100. Cobalt does not concentrate and has a CF of approximately unity. Cesium is slightly discriminated against and has a CF from 0.01 to 1. The transuranics, including plutonium, are strongly discriminated against in the soil to plant pathway, and they have a CF of approximately 10^{-4}.

8.2.2 White Oak Lake plant studies

The revegetation of White Oak Lake bed following the draining of White Oak Lake in 1955 provided the opportunity to study successional trends and floristic changes as well as the accumulation of radionuclides by plants. During the period that the lake bed was exposed, a number of research activities were carried out concerning the uptake of radionuclides by plants on the contaminated lake bed sediments. In conjunction with some of the plant studies, insects associated with the plants were examined for radionuclide levels in order to assess the transfer of radionuclides from plants to animals. White Oak Lake bed plant studies were carried out on both natural vegetation and also agricultural crops planted in controlled plots.

A major portion of these plant studies involved analyses of radionuclide content of White Oak Lake bed vegetation. Figure 8.4 illustrates the distribution of White Oak Lake bed vegetation, soil and plant concentrations in July 1957. Results of analyses of ^{90}Sr and ^{137}Cs content in native plant species during 1957 and 1958 are given in Table 8.2 (Auerbach et al., 1959). Additional analyses of plants in 1961 indicated that ^{90}Sr

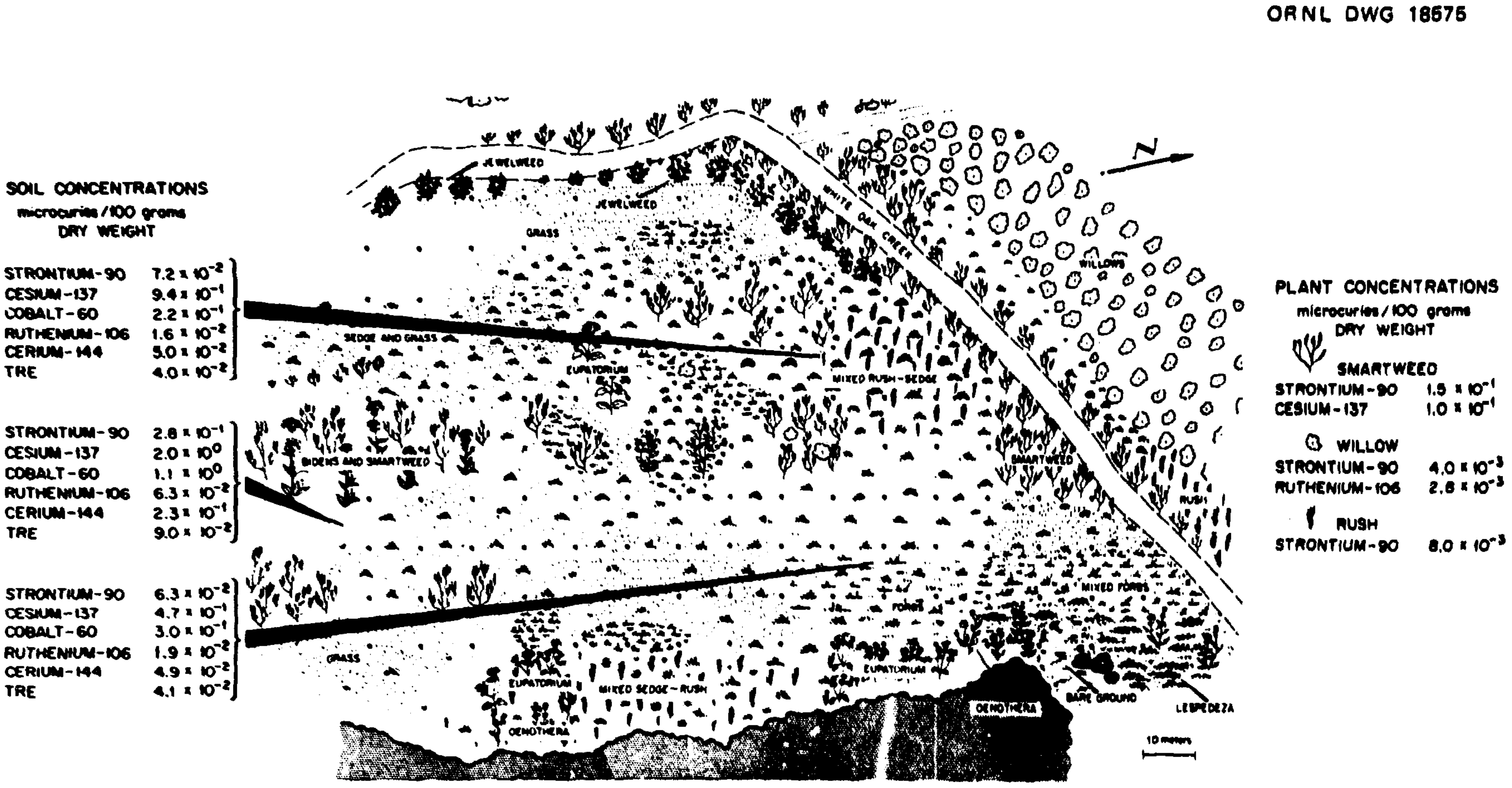

Fig. 8.4. White Oak Lake bed, ecology study area, distribution of vegetation, July 1957.

Table 8.2. Comparisons of radionuclide content in native plant species 1957 and 1958
[Bq/100 g (pCi/100 g)][a]

Species	Plant Part	^{90}Sr				^{137}Cs			
		1957		1958		1957		1958	
Polygonum	Leaves	5,587	(0.151)	3,959	(0.107)				
	Stems	2,109	(0.057)	1,887	(0.051)				
Eupatorium									
Upper lake bed	Leaves	5,661	(0.153)	2,757	(0.0745)	442	(0.012)	1554	(0.042)
	Stems	1,147	(0.031)	777	(0.021)	222	(0.006)	962	(0.026)
	Flowers	1,850	(0.050)	1,258	(0.034)	851	(0.023)	1480	(0.040)
Lower lake bed	Leaves	2,294	(0.062)	4,477[b]	(0.121)	185	(0.005)	1443	(0.039)
	Stems	770	(0.021)	1,110	(0.030)	148	(0.004)	444	(0.012)
	Flowers	962	(0.026)	1,665	(0.045)	296	(0.008)	925	(0.025)
Rhus									
Upper lake bed	Leaves	4,514	(0.122)	5,069	(0.137)	1036	(0.028)	814	(0.022)
	Stems	3,515	(0.095)	5,143	(0.139)	333	(0.009)	740[b]	(0.020)
	Petioles	7,400	(0.200)	7,363	(0.199)	1036	(0.028)	1295	(0.035)
Lower lake bed	Leaves	4,107	(0.111)	5,587	(0.151)	185	(0.005)	111[b]	(0.003)
	Stems	3,478	(0.094)	8,584	(0.232)	111	(0.003)	148	(0.004)
	Petioles	5,883	(0.159)	15,170	(0.410)				
Solidago	Leaves	3,626	(0.098)	2,738	(0.074)	1036	(0.028)	2405[c]	(0.065)
	Stems	1,628	(0.044)	1,332	(0.036)	666	(0.018)	518	(0.014)
	Flowers	1,036	(0.028)	1,184	(0.0318)	1480	(0.040)	1924	(0.052)
Bidens	Leaves	1,554	(0.042)	3,663	(0.099)				
	Stems	1,221	(0.033)	1,036	(0.028)				
	Flowers	1,147	(0.031)	888	(0.024)				
Impatiens	Leaves	8,917	(0.241)	6,549	(0.177)				
	Stems	14,245	(0.385)	5,846[c]	(0.158)				
Fraxinus	Leaves					851	(0.023)	666	(0.018)
	Stems					259	(0.007)	481	(0.013)
	Petioles					851	(0.023)	999	(0.027)

[a] Differences are not significant unless indcated.

[b] Significant at $P = 0.05$.

[c] Significant at $P = 0.01$.

Source: Auerbach et al., 1959.

and ^{137}Cs concentrations in natural vegetation were essentially unchanged from the 1957-58 concentrations (Crossley et al., 1962). Considering the amount of radionuclides in White Oak Lake bed soil available for plant uptake, this was a significant finding. A study of plant uptake of the soil burden revealed that most plants removed less than 1% of the total soil burden of radionuclides (Auerbach et al., 1959). Table 8.3 lists the total amount of ^{90}Sr, ^{137}Cs, and ^{60}Co per square meter of vegetation expressed as percent of the total soil burden.

In conjunction with a penned-mammal study on White Oak Lake bed in 1962, analyses of the radionuclide contents of plants growing in the pens were made and are summarized in Table 8.4 (Dunaway et al., 1963). This data for ^{137}Cs and ^{90}Sr agreed well with previous findings for plants on White Oak Lake bed. The presence of sizeable amounts of ^{106}Ru was attributed to the intermediate waste seeps at that time. A comparison of radionuclide contents in cotton rats indicated a positive correlation with the corresponding concentrations in the plants, which were the only source of food (Dunaway et al., 1963).

In addition to this research on the natural vegetation in White Oak Lake bed, studies using agricultural crops planted on the lake bed plots were ma . (Fig. 8.5). Soil-to-plant studies were investigated on several crops. corn crop was planted in May 1957 on a White Oak Lake bed plot, and, upon harvesting, radioanalyses were performed on various plant parts (Auerbach et al., 1958). Table 8.5 presents the results of analyses for ^{90}Sr, ^{137}Cs, and various nonradioactive elements. Both ^{137}Cs and ^{90}Sr were found in higher concentrations in leaves and flowers than in the other plant parts sampled.

Three species of forage crops, German Millet, Sweet Sudan Grass, and Orange Fodder Cane, were also planted in the White Oak Lake bed agricultural plot (Auerbach et al., 1959). Each species was harvested at maturity, and samples were processed for radiochemical analyses. The results are presented in Table 8.6. Significant differences between crop species were observed.

In summary, turnover of fission products by vegetation in the White Oak Lake bed has indicated that the following factors are important:

Table 8.3. Accumulation of radionuclides in 1 m^2 of vegetation percent of total soil burden of radionuclides

Quadrat No.	Plant type	^{90}Sr	^{137}Cs	^{60}Co
1	Barnyard grass (Echinochloa)	0.12	0.017	0.003
2		0.004	0.0004	0.041
3		0.09	0.007	0.018
4		0.007	0.001	0.006
5		0.06	0.002	0.001
6		0.05	0.001	0.001
7	Smartweed (Polygonum)	0.069	0.006	0.019
8		0.93	0.015	0.048
9	Sericea (Lespedeza)	2.3	0.011	0.007
10		1.3	0.009	0.004
11	Begger-tick (Bidens)	0.62	0.006	0.006
12		0.54	0.041	0.006

Source: Auerbach et al., 1959.

Table 8.4. Uptake of radionuclides by plants growing in pens on upper White Oak Lake bed, June 1962

[Bq/g (pCi/g)] - Oven-dry weight

Pen Number	Plant Genus	^{106}Ru		^{137}Cs		^{60}Co		^{90}Sr	
		x 10^2		x 10^2		x 10^2		x 10^2	
11	*Festuca*	1.21	(32.8)	0.06	(1.61)	0.05	(1.42)	0.01	(0.38)
	Festuca (stems)	0.66	(17.9)	0.05	(1.36)	0.04	(1.08)	0.01	(0.34)
	Polygonum	3.03	(81.9)	0.11	(2.85)	0.23	(6.20)	0.05	(1.33)
	Eupatorium	1.51	(40.8)	0.05	(1.50)	0.07	(1.99)	0.01	(0.38)
	Rumex	2.01	(54.4)	0.07	(1.83)	0.13	(3.42)	0.08	(2.05)
12	*Festuca*	1.10	(29.7)	0.13	(3.55)	0.05	(1.27)	0.03	(0.92)
	Festuca (stems)	0.67	(18.0)	0.07	(1.97)	0.04	(1.05)	0.01	(0.37)
	Polygonum	4.18	(113)	0.17	(4.52)	0.32	(8.64)	0.08	(2.20)
	Eupatorium	1.17	(31.6)	0.10	(2.70)	0.07	(1.88)	0.05	(1.31)
	Aster	1.65	(44.7)	0.33	(9.04)	0.05	(1.42)	0.03	(0.91)
13	*Festuca*	0.91	(24.7)	0.09	(2.46)	0.04	(1.2)	0.04	(1.04)
	Festuca (stems)	1.99	(53.9)	0.09	(2.35)	0.08	(2.25)	0.02	(0.48)
	Polygonum	3.63	(98.1)	0.18	(4.92)	0.28	(7.64)	0.08	(2.18)
	Impatiens	1.28	(34.7)	0.08	(2.05)	0.08	(2.06)	0.22	(5.99)
	Aster	1.20	(32.5)	0.65	(17.6)	0.05	(1.40)	0.04	(1.10)
14	*Festuca*	2.40	(64.8)	0.11	(2.99)	0.09	(2.57)	0.04	(0.99)
	Festuca (stems)	1.24	(33.6)	0.07	(1.98)	0.07	(1.88)	0.02	(0.52)
	Polygonum	6.99	(189)	0.14	(3.79)	0.06	(1.58)	0.05	(1.28)
	Aster	2.88	(77.8)	0.35	(9.56)	0.12	(3.26)	0.03	(0.76)
15	*Festuca*	1.17	(31.5)	0.11	(2.86)	0.08	(2.05)	0.01	(0.38)
	Festuca (stems)	1.59	(43.1)	0.06	(1.63)	0.10	(2.64)	0.005	(0.14)
	Polygonum	8.51	(230)	0.17	(4.67)	0.56	(15.2)	0.06	(1.55)
	Aster	2.89	(78.2)	0.44	(11.9)	0.09	(2.42)	0.02	(0.64)
16	*Festuca*	3.16	(855)	0.11	(3.00)	0.11	(3.05)	0.02	(0.52)
	Festuca (stems)	4.85	(13[illegible])	0.15	(3.99)	0.19	(5.07)	0.01	(0.30)
	Polygonum	8.66	(234)	0.21	(5.88)	0.06	(1.68)	0.04	(1.18)
	Aster	3.51	(94.9)	0.29	(7.88)	0.11	(3.09)	0.02	(0.59)
17	*Festuca*	2.10	(56.8)	0.05	(1.36)	0.08	(2.19)	0.04	(1.20)
	Festuca (stems)	0.55	(15.0)	0.02	(0.67)	0.08	(2.22)	0.03	(0.75)
	Solidago	1.03	(27.8)	0.54	(14.7)	0.51	(13.7)	0.15	(4.18)
	Juncus	0.64	(17.3)	0.07	(2.02)	0.19	(5.11)	0.03	(0.93)
	Aster	5.4[illegible]	(148)	0.50	(13.4)	0.21	(5.76)	0.05	(1.35)

Source: Dunaway et al., 1963.

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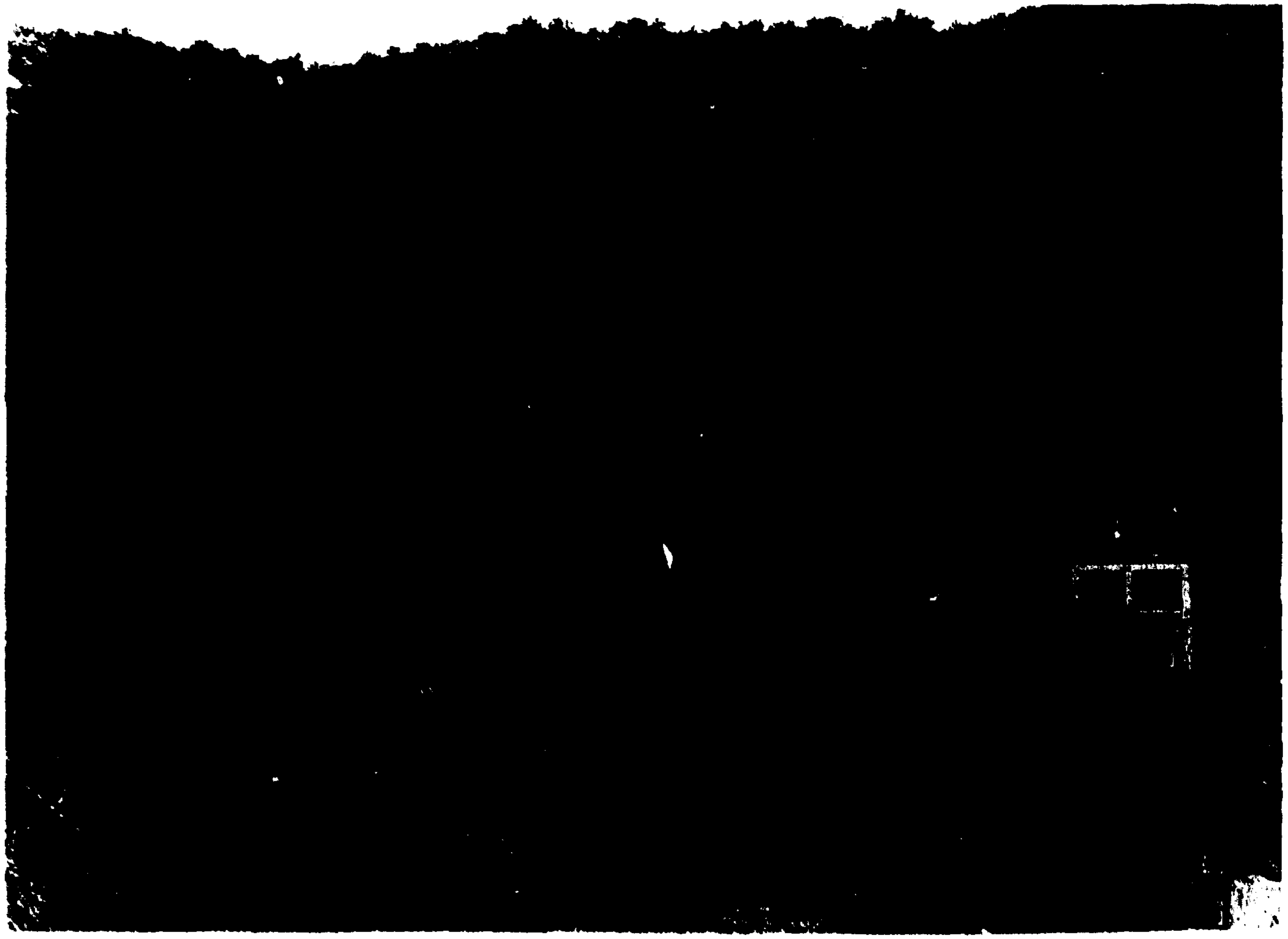

Fig. 8.5. View of agricultural crops planted on the lake bed in 1957.

Table 8.5. Concentrations of elements in corn (*Zea maya*)
(Numbers represent mean values)

Constituent	Part of plant						Least significant difference
	Leaf	Husk	Grain	Cob	Stem	Flower	
$^{90}Sr^a$	1,47 (39,7)	0,23 (6,3)	0,09 (2,5)	0,16 (4,4)	0,45 (12,1)	1,05 (28,4)	11,00
$^{137}Cs^a$	1,82 (49,1)	0,81 (21,9)	0,47 (12,7)	0,72 (19.5)	0,63 (17,1)	2,56 (69,1)	6,38
K^b	1,54	0,98	0,12	0,94	0,67	0,64	0,25
Ca^b	0,568	0,111	0,107	0,0568	0,165	0,228	0,047
Na^b	0,0133	0,0049	0,0041	0,0034	0,0028	0,0054	0,0041
P^b	0,163	0,153	0,174	0,154	0,186j	0,071	0,056
Mg^b	0,166	0,0656	0,0707	0,0437	0,0895	0,111	0,041

[a] Bq x 10^3 per 100 g, dry wt. (μCi x 10^{-3} per 100 g, dry wt.)

[b] Gram per 100 grams, dry wt.

Source: Auerbach, et al., 1958.

Table 8.6. Summary of concentrations of radionuclides in three species of forage plants in White Oak Lake bed

[Bq/100 g (μCi/100 g)]

Element	Block	Millet	Sudan Grass	Orange Fodder Cane
		(Values given are means of four replicates)[a]		
^{90}Sr	I	2350 (6.35)	2664 (7.20)	481 (1.30)
	II	2246 (6.07)	1332 (3.60)	611 (1.65)
	III	2017 (5.45)	1265 (3.42)	618 (1.67)
^{137}Cs	I	803 (2.17)	562 (1.52)	266 (0.72)
	II	988 (2.67)	655 (1.77)	370 (1.00)
	III	1073 (2.90)	1129 (3.05)	692 (1.87)
^{60}Co	I	396 (1.07)	111 (0.30)	30 (0.08)
	II	544 (1.47)	174 (0.47)	30 (0.08)
	III	407 (1.10)	63 (0.17)	33 (0.09)

[a] Multiply all μCi values by 0.01.

Source: Auerbach et al., 1959.

(1) the concentration of fission product in the soil,
(2) the physiological control of nutrient uptake by the various species population, and
(3) the productivity (yield) of the different species populations.

Table 8.7 summarizes the radionuclide concentrations in White Oak Lake bed vegetation studies during the period in which the lake was drained.

8.3 UPTAKE OF RADIONUCLIDES BY ALGAE

Both unicellular and multicellular algae, which form the base of the White Oak Lake aquatic food web, accumulate radionuclides from the soluble phase (Vanderploeg et al., 1975). The movement of ^{137}Cs through the aqueous phase → algae → fish → man/mammal food chain is based on the uptake of the radionuclides by algae. An early ecological survey of White Oak Creek detected 253 species of invertebrate animals and 93 genera of algae, and this list was known to be incomplete (Krumholz, 1954).

The effluent from the wastewater treatment plant at the Laboratory could be expected to enhance the productivity of White Oak Lake, especially that of algae.

Krumholz (1954) reported that radioactivity in White Oak Lake water usually increased from surface to bottom. Mostly this is due to resuspension and re-solution of materials associated with sediments. This pattern was reflected in vertical distributions (Fig. 8.6) of activity density in the periphyton biomass (Neal et al., 1967). The results from a study (Cushing, 1967) of a contaminated portion of the Columbia River indicated that radioisotope concentrations in phytoplankton more closely relate to the activity of the water than to other environmental factors. (Neal et al., 1967) concluded that in White Oak Lake quantitative and qualitative differences between surface and bottom populations contributed significantly to the radioisotope patterns in Fig. 8.6. Quantitatively, the uptake of materials may be linear over a certain range of biomass, but as the mass increases, proportional accumulation diminishes. The results shown in Fig. 8.6 indicate that the activity densities of all nuclides tend to be lowest in the zone of maximum biomass and conversely (Neal et al., 1967). The ^{60}Co accumulation may be due to microorganisms which synthesize cobalamin or to blue-green algae for which cobalt is an essential element (Holm-Hansen et al., 1954).

Table 8.7. Summary of radionuclide concentrations in White Oak Lake bed vegetation studies

(Bq/g)

Study vegetation	^{137}Cs	^{60}Co	^{90}Sr	^{106}Ru
Native plants 1957-58	1.1-19.2		7.7-151.7	
Upper lake bed, 1962 native plants	2.0-65.0	4.0-56.0	1.0- 22.0	68.0-866.0
Corn	4.7-25.6		0.9- 14.7	
Forage plants	0.02-0.11	0.003-0.050	0.05-0.27	

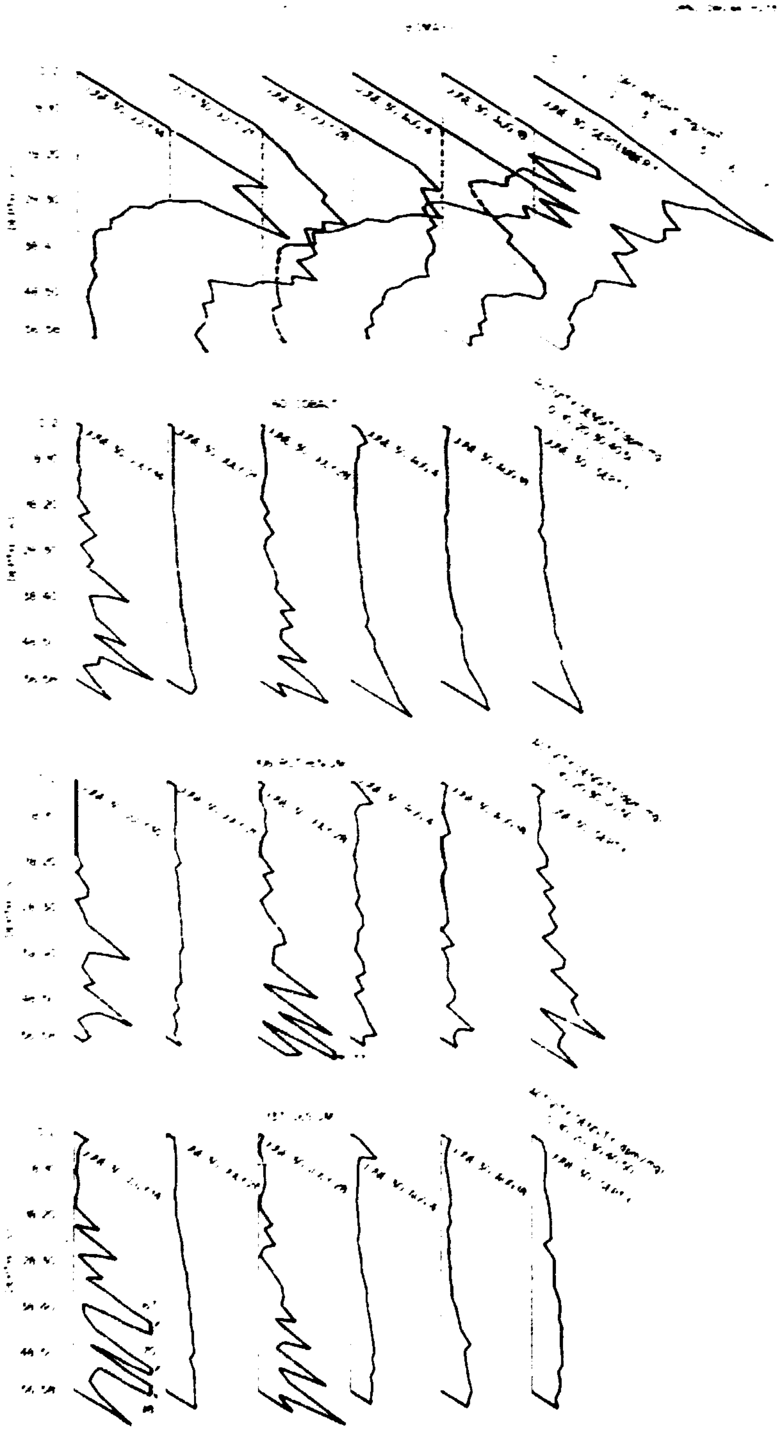

Fig. 8.6. Vertical distribution of activity density in the periphyton biomass, 1954.

Cesium-137, a predominant radionuclide in White Oak Lake, is known to be strongly adsorbed by suspended particulate materials, especially clays. Because of this, the proportion of ^{137}Cs in the soluble phase decreases with increasing suspended solids concentrations. Since algae accumulate ^{137}Cs from the soluble phase, the availability to the food chain of ^{137}Cs decreases with increasing suspended solids concentrations. Both the nutrient concentration and general health of the algae influence the ^{137}Cs bioaccumulation factor for algae (Gertz, 1973; Williams, 1970; Williams, 1960). Moreover the ^{137}Cs bioaccumulation factor for multicellular algae is higher in flowing water than in still water (Watts and Harvey, 1963). It has been recommended that for algae, in general, a bioaccumulation factor of 10^3 be used (Vanderploeg et al., 1975). Unlike the pattern for animals and fish, the potassium concentration of water has only a slight effect on the ^{137}Cs bioaccumulation factor in algae.

Strontium-90 is not as strongly adsorbed by suspended particulate material as ^{137}Cs, and so a greater proportion would be expected in the soluble phase, where it would be available for algae uptake. The calcium concentration of the water has only a small effect on the ^{90}Sr bioaccumulation factor in algae.

Cobalt bioaccumulation factors are relatively high for algae, estimated to be 10^4 (Vanderploeg et al., 1975). Cobalt is essential for some bacteria, some fungi, and several species of algae (Bowen, 1966). Cobalamin (Vitamin B-12) is required by some green algae and diatoms, many dinoflagellates and yellow-green algae, as well as by higher plants, insects, fish, birds, and mammals. The availability of ^{60}Co to algae is dependent on the nature of the water (Vanderploeg, 1975). The proportion of cobalt in solution and on suspended solids influences the availability. The soluble form of ^{60}Co is generally more available to algae.

The uptake of tritium by algae and movement through the food chain occurs through two major pools: tissue-water tritium and tissue-bound tritium (Vanderploeg, 1975). Tritium has been shown to move rapidly from ambient water into tissue water, with bioaccumulation factors approximating unity (Blaylock and Frank, 1979). A summary of recommended bioaccumulation factors for algae are given in Table 8.8. Results of radioactive analyses of algae in the White Oak Lake during 1979 and the resulting BF are given

Table 8.8. Summary of recommended bioaccumulation factors for algae

Element	Bioaccumulation factor
Cesium	10^3
Strontium	2×10^3
Iodine	260
Tritium	1
Manganese	10^4
Cobalt	10^4

Source: Vanderploeg et al., 1975.

in Table 8.9. In 1979, tritium concentrations in algae were found to be 610 pCi/mℓ tissue water and 79 pCi/mℓ tissue bound with CFs of 1 and 0.38, respectively (Blaylock and Frank, 1979).

Algae appear to be a major link in the food-chain movement of radionuclides out of White Oak Lake. Figure 8.7 illustrates an accumulation of algae behind an oil boom at White Oak Dam during the fall of 1979. In addition to being the base of the aquatic food web, the suspension of algae in water provides a medium besides the aqueous phase for radionuclides to move out of White Oak Lake and into an uncontained environment.

8.4 UPTAKE OF RADIOACTIVITY BY FISH IN WHITE OAK LAKE AND CLINCH RIVER

8.4.1 General observations

Numerous studies on fish in White Oak Lake have been made at the Laboratory. The contamination of the lake has provided a "living laboratory" for research involving the uptake and effects of ionizing radiation on various species of fish. Fish accumulate radionuclides either by ingestion of radioactive materials or by direct contact with radioactive materials.

It was found that the bioaccumulation of ^{137}Cs in fish is highly variable from one environment to another and much of this variation derives from differing proportions of ^{137}Cs relative to the potassium in the soluble phase and possibly sediment type (Vanderploeg et al., 1975). The primary mode of accumulation of ^{137}Cs in fish is generally thought to be via absorption from food (Kolehmainen, 1972). However absorption of ^{137}Cs from ingested sediments may be significant in some systems (Gallegos et al., 1970).

The bioaccumulation of ^{90}Sr in fish is strongly dependent on the calcium concentration, and the primary uptake of calcium and strontium in fish occurs directly from the water (Vanderploeg et al., 1975). Only about one-tenth of the strontium taken up by fish is through the food chain (Agnedal, 1966). Unlike cesium, strontium is not strongly sorbed by suspended particulates in water.

Tritium is rapidly taken up by fish either from the tissue water hydrogen pool or the tissue-bound hydrogen pool (Vanderploeg et al., 1975). The bioaccumulation factor for tritium in fish is approximately unity.

Table 8.9. Radioactivity in algae on surface of White Oak Lake, 1979

Sample No.	Bq/mℓ (pCi/mℓ)			Bioaccumulation factor		
	^{137}Cs	^{60}Co	^{90}Sr	^{137}Cs	^{60}Co	^{90}Sr
1	2.0 (54)	1.0 (27)				
2	3.3 (89)	1.2 (32)				
3	1.7 (45)	1.0 (26)	4.1 (110)	10,000	1,000	1,000
4	0.06 (1.7)	0.8 (21)				

ORNL PHOTO 5420-79

Fig. 8.7. Accumulation of algae behind boom at White Oak Dam.

The bioaccumulation of ^{60}Co by fish depends on the available form (Vanderploeg et al., 1975). The soluble form is more available to algae, and thus subsequent trophic levels, than the particulate form of ^{60}Co. However, chelated ^{60}Co is less available to food webs than free ion ^{60}Co. The tendency of ^{60}Co to chelate or form other associations with dissolved organic matter explains the less than expected availability of soluble ^{60}Co in aqueous environments. Cobalamin (Vitamin B-12) is synthesized by bacteria and actinomycetes but is required by fish. Absorption efficiencies for cobalt from food has been estimated at about 5% in fish (Vanderploeg et al., 1975).

An early study, starting in 1948, at ORNL was made to survey the radioactivity in fish in the White Oak Lake area (Knobf, 1951). Heavy contamination of various species of fish in White Oak Lake was indicated. Table 8.10 indicates the average gross beta activity detected in the fish sampled. Radiochemical analyses were made on samples of flesh, bone, and scales for several radionuclides. Almost all of the activity in the edible fish parts was found to be due to ^{137}Cs.

An ecological survey of White Oak Creek (1950-53) found 23 species of fish (Krumholz, 1954). An in-depth study of bluegill, black crappie, white crappie, large-mouth black bass, carp, goldfish, bullheads, redhorse, and gizzard shad revealed abnormalities in these White Oak Lake populations, data concerning eating habits, and radionuclide contents of these fish. Rotenone was added to the lake, and dead fish were analyzed for stomach contents and radioactivity.

Stomach analyses revealed food habits of the different fish. The black crappie fed primarily on free-swimming macroplanktons and bottom fauna of the pelagic zone of the lake. The bluegills were more omnivorous and generally foraged food along the littoral zone, indicating that they would eat practically anything. In the crappies. the amount of radioactivity ranged from about 100 to 1800 counts per minute per gram of food, whereas those from the bluegill ranged from 250 to 14,350; the average for the crappies' stomachs was about 1000 counts per minute, and that for the bluegill was about 1250. The greater amounts of radioactivity in the contents of the bluegill were traceable primarily to the large quantities of

Table 8.10. Radioactivity in fish taken in White Oak Lake and the Clinch River, 1948 (gross beta)

Site of collection	Number processed	Average counts per minute per gram of sample		
		Flesh	Bone	Scale
Clinch River mile 14.4	31	2	13	39
Clinch River mile 18-19	62	5	51	92
White Oak Creek	54	27	525	1204
Lower White Oak Lake	38	134	1264	1971
Upper White Oak Lake	13	423	2290	2901

Source: Knobf, 1951.

filamentous algae. Radiochemical analyses of the organisms which were most frequently found in the stomachs of both species indicated that most of the radioactivity was due to ^{32}P and smaller amounts of ^{90}Sr and ^{137}Cs.

Another part of this study involved a year-round study of the accumulation of radioactive substances by fish in White Oak Lake. Three black crappies and three bluegills were dissected each week from September 1951 until February 1953. Conclusions resulting from the study were:

(1) Every fish had selectively accumulated radionuclides in their tissues far in excess of the concentrations in White Oak Lake water.
(2) The primary radionuclide in the soft tissues was ^{137}Cs.
(3) The primary radionuclides in the hard tissues were ^{90}Sr and ^{32}P.
(4) Black crappies generally accumulated considerably greater amounts of radioactivity in the hard tissues than bluegills.
(5) Bluegills generally accumulated more radioactivity in the soft tissues than black crappie.
(6) In both species, the amounts of radionuclides accumulated in the skeleton were as much as 50 times as great as those accumulated in the muscle tissue.
(7) There were definite seasonal fluctuations in the amounts of radionuclides accumulated in both species.

8.4.2 Environmental fish-sampling program

The Industrial Safety and Applied Health Physics Division has routinely sampled Clinch River fish for radionuclide content. Annually, fish of each species are composited, and the samples analyzed by gamma spectrometry and radiochemical techniques for the critical radionuclides contributing significantly to the potential radiation dose to man. Locations of sampled fish include areas above Melton Hill Dam (CRM 24.0), below Melton Hill Dam and above the mouth of White Oak Creek (CRM 22.0), the mouth of White Oak Creek (CRM 20.8), below the mouth of Poplar Creek (CRM 12.0), and at Kingston, Tennessee (CRM 4.0). An estimated percentage of the maximum permissible intake (MPI) is calculated assuming a maximum permissible intake of fish comparable to a daily intake of 2.2 ℓ of water containing the MPC_w of these radionuclides for a period of one year. Table 8.11 presents data for concentrations of radionuclides in Clinch River fish for

Table 8.11. Concentration of radionuclides in Clinch River fish [collected between Clinch River mile (CRM) 4.5 and CRM 19.1], 1960 through 1963

[Bq/kg (pCi/kg) fresh weight]

Fish Species	Sample Period	^{90}Sr		^{137}Cs		^{106}Ru		^{60}Co	
		Flesh	Total[a]	Flesh	Total[a]	Flesh	Total[a]	Flesh	Total[a]
Carp	1960-1962	18.5 (500)	188.7 (5100)	18.9 (510)	20.7 (560)	6.3 (170)	10.7 (290)	2.4 (66)	1.8 (49)
	1963	3.4 (91)		11.8 (320)					
Carpsucker	1960-1962	20.0 (540)	34.8 (940) 177.6 (4800)	44.4 (1200)	23.7 (640)	4.4 (120)	2.1 (56)	4.4 (120)	1.2 (32)
	1963	0.8 (22)		17.0 (460)					
Buffalo	1960-1962	8.9 (240)	30.7 (830)	17.8 (480)	21.8 (590)	4.1 (110)	5.5 (150)	2.9 (78)	1.2 (32)
	1963	1.6 (43)		20.7 (560)					
Sight feeders[b]	1960-1962	6.7 (180)		25.2 (680)		4.4 (120)		0.8 (22)	

[a] Total fish consists of flesh and bone.

[b] Sight feeders include white crappie, bluegill, white bass, largemouth bass, sauger, and drum; catfish also included.

Source: Morton et al., 1965.

the sampling period 1960-63. Table 8.12 presents data for radionuclide analyses of fish sampled in 1965-1968. Table 8.13 presents estimates of percentage of MPI's for the years 1965-1968. Tables 8.14 through 8.23 present the results of radionuclide analyses and estimations of MPI's of Clinch River fish for the years 1971-80. Estimates of man's intake of radionuclides from eating the fish were made assuming an annual rate of fish consumption of 16.8 kg (37 lbs) except for the years 1971-73, in which an assumption of 6.4 kg (14 lbs) was used.

The data for radionuclide content of Clinch River fish indicate fluctuations over time and among species. No general trends are apparent in a comparison of years or species. The two predominant radionuclides found were ^{137}Cs and ^{90}Sr, with generally lesser amounts of ^{60}Co and ^{106}Ru.

Based on the fish sampled, the MPIs indicate that usually the intakes of radionuclides from eating Clinch River fish would be less than one percent of the MPI, although there were some exceptions. Occasionally, estimated MPIs were higher: up to 8.1% for white crappie, up to 5.8% for bluegill, and up to 3.5% for bass.

Given the mobility of fish in the Clinch River, it is difficult to determine to what extent the radionuclide content of a fish reflects the radionuclide levels in the water from where it was taken. Prior to being caught, a fish could have lived almost entirely in White Oak Lake, where radionuclide levels were relatively high. At the other extreme, a fish could have lived miles upstream from the point of being caught in water containing background levels of radionuclides. Where locations are noted, it is evident that fish caught at the mouth of White Oak Creek (CRM 20.8) had higher contents of ^{90}Sr, ^{137}Cs, and ^{60}Co compared to points upstream or downstream, while levels of other radionuclides were not appreciably higher. Radionuclide contents of fish caught upstream and downstream of the mouth of White Oak Creek do not reflect the levels of radionuclides of the waters upstream and downstream.

The commercial fishing on the Clinch River has not changed dramatically over the last ten years [Smith (TVA), 1980]. Fish are being sold commercially to distributors in Memphis, Chattanooga, and Knoxville, Tennessee, and in Cantersville and Rogersville, Alabama. The fish that are being sold commercially include channel catfish, smallmouth buffalo, largemouth buffalo,

Table 8.12. Radionuclide content of Clinch River fish [Bq/kg (pCi/kg)] - Fresh weight

Species	Year	^{90}Sr		^{106}Ru		^{137}Cs	
White crappie	1965	0.52	(14)	10.50	(284)	7.36	(199)
	1966	0.35	(9.4)	14.10	(381)	3.22	(87)
	1967	1.00	(27)	*a*		14.32	(387)
	1968	0.27	(7.3)	*a*		12.25	(331)
Smallmouth buffalo	1965	1.18	(32)	239.18	(6467)	7.18	(194)
	1966	3.48	(94)	6.85	(185)	48.21	(1303)
	1967	1.00	(27)	4.51	(122)	14.87	(402)
	1968	0.59	(16)	*a*		4.88	(132)
Gizzard shad	1966	75.03	(2028)	18.98	(513)	53.76	(1453)
	1967	4.37	(118)	*a*		14.76	(399)
	1968	17.50	(473)	*a*		20.68	(559)

[a] None detected.

Source: Morgan et al., 1968.

Table 8.13. Estimated percentage of MPI that man may attain by eating Clinch River fish

Year	^{90}Sr	^{106}Ru	^{137}Cs	Total (%)
		Smallmouth buffalo		
1965	0.24	1.4	0.020	1.66
1966	0.66	0.039	0.137	0.836
1967	0.19	0.026	0.044	0.260
1968	0.11	*a*	0.014	0.126
		White crappie		
1965	0.099	0.060	0.021	0.180
1966	0.066	0.082	0.009	0.157
1967	0.19	*a*	0.041	0.231
1968	0.051	*a*	0.035	0.086

[a] None detected.

Source: Morgan et al., 1969.

Table 8.14. Radionuclide content of Clinch River fish, 1971 [Bq/kg (pCi/kg) – wet weight]

Species	^{90}Sr	^{106}Ru	^{137}Cs	Estimated %MPI
White crappie	5.00 (135)	6.66 (30)	12.69 (343)	<0.38
Smallmouth buffalo	4.00 (108)	11.66 (315)	12.43 (336)	<0.32

Source: Morgan et al., 1972.

Table 8.15. Radionuclide content of Clinch River fish, 1972
[Bq/kg (pCi/kg) wet weight]

Species	^{90}Sr	^{137}Cs	Estimated %MPI
White crappie	2.29 (62)	6.85 (185)	0.18
Carp	1.29 (35)	1.59 (43)	0.10

Source: Auxier et al., 1973.

Table 8.16. Radionuclide content of Clinch River fish, 1973
[Bq/kg (pCi/kg) wet weight]

Species	^{90}Sr	^{137}Cs	Estimated %MPI
White crappie	2.22 (60)	55.50 (1500)	0.28
Carp	5.18 (140)	19.98 (540)	0.45

Source: Auxier et al., 1974.

Table 8.17. Radionuclide content of Clinch River fish, 1974
[Bq/kg (pCi/kg) wet weight]

Species	^{90}Sr	^{137}Cs	Estimated %MPI
White crappie	1.59 (43)	6.92 (187)	0.32
Carp	1.92 (52)	1.00 (27)	0.36

Source: Auxier et al., 1975.

Table 8.18. Radionuclide content of Clinch River fish, 1975

Species	Samples[a]	Bq/kg (pCi/kg) Wet Weight						Estimated % MPI[b]
		^{90}Sr	^{60}Co	^{106}Ru	^{137}Cs	^{110m}Ag	^{125}Sb	
Clinch River mile 21.0 (above ORNL waste outfall)								
White Crappie	1	5.18 (140)	1.52 (41)	4.81 (130)	18.13 (490)	2.66 (72)	1.04 (28)	1.0
Carp	1	1.70 (46)	0.22 (5.9)	0.93 (25)	1.07 (29)	0.74 (20)	0.37 (10)	0.33
Clinch River mile 14.5 (below ORNL waste outfall)								
White Crappie	1	8.14 (220)	1.67 (45)	8.51 (230)	1.11 (30)	3.33 (90)	1.44 (39)	1.6
Carp	1	0.48 (13)	0.52 (14)	0.96 (26)	0.63 (17)			0.10

[a] Composite of ten fish in each species.

[b] Maximum Permissible Intake – intake of radionuclides from eating fish is calculated to be equal to a daily intake of 2.2 liters of water, over a period of one year, containing the concentration guide of the radionuclides in question. Consumption of fish is assumed to be 37 lb/year of the species in question.

Source: Auxier et al., 1979.

Table 8.15. Radionuclide content of Clinch River and Melton Hill Lake fish, 1976
Bq/kg (pCi/kg) wet weight - flesh

Species	Location	Samples[b]	Isotopes[a]					Estimated % MPI[c]
			^{90}Sr	^{60}Co	^{137}Cs	^{226}Ra	^{239}Pu	
Shad	CRM 12.0 Below mouth of Poplar Creek	1	0.30 (8)	0.78 (21)	6.81 (184)	0.70 (19)	0.01 (0.29)	0.083
White Crappie	CRM 20	1	40.7 (1100)	2.49 (67.4)	126.42 (3417)	3.89 (105)	0.01 (0.23)	8.1
Shad	Below mouth of	1	0.96 (26)	0.93 (25)	16.21 (438)	1.18 (32)	0.01 (0.27)	0.26
Bass	White Oak Creek	1	15.57 (420.9)	2.92 (79)	290.73 (5155)	3.55 (96)	0.001 (0.02)	3.5
Buffalo Carp	CRM 22.0	1[d]	0.26 (7)	0.22 (6)	4.92 (133)	0.44 (12)	0.001 (0.03)	0.067
Shad	Below Melton Hill Dam and above mouth of White Oak Creek	1	0.93 (25)	1.88 (51)	31.71 (857)	0.96 (26)	0.01 (0.40)	0.28
Crappie	CRM 32	1	0.09 (2.3)	0.29 (7.8)	1.04 (28)	0.48 (13)	0.002 (0.05)	0.023
Bluegill	above Melton	1	0.30 (8.2)	0.44 (12)	0.78 (21)	0.48 (13)	ND	0.065
Carp	Hill Dam	1	0.24 (6.4)	0.12 (3.2)	0.10 (2.7)	0.17 (4.6)	0.05 (1.5)	0.047
Bass		1	0.96 (26)	0.28 (7.7)	2.96 (80)	0.24 (6.4)	0.007 (0.18)	0.19
Bluegill	CRM 41	1	0.96 (26)	0.23 (6.2)	1.22 (33)	0.23 (6.4)	0.01 (0.3)	0.19
Shad	Bay close to CARL	1	0.19 (5.1)	0.17 (4.7)	0.15 (4.1)	2.89 (78)	0.007 (0.2)	0.039

[a] Values for other isotopes are available from Department of Environment Management of Industrial Safety and Applied Health Physics Division.

[b] Composite of ten fish in each species, unless otherwise noted.

[c] Maximum Permissible Intake – intake of radionuclide from eating fish calculated to be equal to a daily intake of 2.2 liters of water, over a period of one year, containing the concentration guide of radionuclides in question. Consumption of fish is assumed to be 37 lb/y of the species in question. Only man-made radionuclides were used in the calculation.

[d] Sample is one individual, 22 lbs total wet weight.

Source: Auxier, 1977.

Table 8.20. Radionuclide content of Clinch River fish, 1977
Bq/kg (pCi/kg) wet weight - flesh

Location	Species[b]	^{40}K	^{60}Co	^{90}Sr	^{134}Cs	^{137}Cs	^{239}Pu	Estimated % MPI[b]
CRM 22 above White Oak Creek and below Melton Hill Dam	Crappie	73.26 (1980)	1.74 (47)	4.48 (121)	6.66 (180)	95.41 (2038)	0.0009 (0.024)	1.1
	Bluegill	139.12 (3760)	1.44 (39)	1.00 (27)	3.74 (101)	24.79 (670)	0.004 (0.112)	0.28
	Carp	88.8 (2400)	0.70 (19)	4.92 (133)	0.20 (19)	5.70 (154)	0.0004 (0.012)	0.95
	Bass	86.03 (2325)	0.48 (13)	0.48 (13)	0.70 (20)	13.32 (360)	0.0005 (0.013)	0.13
	Shad	210.57 (5691)	0.59 (16)	1.63 (44)	2.33 (63)	1.81 (49)	0.002 (0.063)	0.33
CRM 20.8 mouth of White Oak Creek	Crappie	79.22 (2141)	1.44 (39)	5.55 (150)	≤1.92 (≤ 52)	54.06 (1461)	0.0003 (0.007)	1.2
	Bluegill	76.29 (2062)	2.66 (72)	30.15 (815)	≤2.81 (≤ 76)	51.69 (1397)	0.003 (0.086)	5.8
	Carp	85.25 (2309)	0.74 (20)	2.55 (69)	≤1.07 (≤ 29)	11.32 (306)	0.0006 (0.016)	0.52
	Bass	79.33 (2144)	2.03 (55)	12.21 (330)	≤3.89 (≤105)	199.70 (5397)	0.003 (0.093)	0.29
	Shad	74.07 (2002)	8.03 (217)	1.59 (43)	≤4.70 (≤127)	117.92 (3187)	0.001 (0.027)	0.66
CRM 12 below mouth of Poplar Creek	Bass	32.49 (878)	0.37 (10)	1.63 (44)	0.74 (20)	0.37 (10)	0.0007 (0.02)	0.31
	Shad	59.50 (1608)	1.74 (47)	5.66 (145)	2.74 (74)	27.16 (734)	0.003 (0.082)	1.1

[a] Composite of ten fish in each species for CRM 22 and CRM 12; twenty fish in each species for CRM 20.8.

[b] Maximum Permissible Intake — intake of radionuclide from eating fish is calculated to be equal to a daily intake of 2.2 liters of water, over a period of one year, containing the concentration guide of radionuclides in question. Consumption of fish is assumed to be 37 l[illegible]year of the species in question. Only man-made radionuclides were used in the calculation.

Source: Auxier, 1978.

Table 8.21. Radionuclide content in Clinch River fish, 1978

pCi/kg Wet Weight

Location	Species[a]	^{90}Sr	^{239}Pu	^{238}Pu	^{238}U	^{235}U	^{234}U	^{137}Cs	^{60}Co	^{40}K	% MPI[b]	Hg(ng/g)	% of A.L.[c]
CRM 4.0	Bass	1.8	0.01	0.10	0.08	0.01	0.10	121	5.1	4117	0.03	3.5	0.7
	Blue Gill	7.8	0.07	0.08	0.16	0.16	0.34	608	10.7	4489	0.20	17.0	3.4
	Carp	4.5	0.01	0.01	0.27	0.08	0.59	76	0.1	3280	0.03	2.8	0.6
	Shad	3.7	0.04	0.02	1.90	0.26	2.23	106	13.6	3101	0.05	1.6	0.3
CRM 5.0	Bass	1.7	0.01	0.01	0.12	0.06	29.26	136	0.4	3830	0.15	7.2	1.4
	Blue Gill	3.2	0.02	0.01	0.39	0.16	0.39	122	12.0	4254	0.04	9.0	1.8
	Carp	4.6	0.01	0.01	0.23	0.17	0.41	348	0.4	2258	0.07	5.9	1.2
	Shad	5.9	0.01	0.01	0.29	0.15	0.21	181	0.5	4743	0.06	1.2	0.2
CRM 12.0	Bass	0.6	0.02	0.03	0.03	0.13	0.38	166	3.8	3891	0.18	1.9	0.4
	Blue Gill	4.9	0.03	0.02	2.63	0.42	2.77	94	6.3	3727	0.04	2.7	0.5
	Carp	2.9	0.01	0.01	1.20	0.24	1.20	71	2.9	3644	0.03	6.0	1.2
	Shad	5.5	0.16	0.22	4.20	0.47	3.89	23	11.6	5052	0.04	4.5	0.9
	Crappie	11.9	0.12	0.12	0 59	0.48	0.59	12	20.2	3590	0.09	7.6	1.5
CRM 20.8[d]	Bass	42.2	0.03	0.01	0.16	0.07	0.34	10287	28.2	3925	0.51	3.1	0.6
	Blue Gill	428.0	0.18	0.75	0.39	0.14	0.53	3369	79.2	3912	1.25	3.2	0.6
	Carp	33.5	0.02	0.01	0.48	0.06	0.67	440	12.6	2044	0.28	3.1	0.6
	Shad	59.8	0.05	0.11	3.33	0.23	5.06	1208	30.7	2852	0.54	0.7	0.1
	Crappie	41.0	0.12	0.54	0.44	0.18	2.77	3293	16.6	4903	0.56	3.7	0.7
CRM 22.0	Bass	9.5	0.02	0.02	0.56	0.01	0.22	61	15.0	3890	0.07	4.3	0.8
	Blue Gill	19.3	0.03	0.02	0.23	0.30	0.68	175	23.2	3617	0.15	5.0	1.0
	Carp	2.6	0.01	0.01	0.06	0.06	0.23	164	3.8	3840	0.03	1.4	0.3
	Shad	4.8	0.01	0.01	1.86	0.04	2.70	300	14.5	3350	0.07	0.6	0.1
	Crappie	4.8	0.05	0.01	0.13	0.12	0.45	48	7.9	3168	0.01	0.8	0.2
CRM 24.0	Bass	1.3	0.01	0.01	0.21	0.04	0.28	96	4.7	3428	0.02	0.8	0.2
	Blue Gill	3.1	0.06	0.03	0.14	0.13	0.32	12	7.8	3744	0.02	3.4	0.7
	Carp	1.5	0.17	0.03	0.08	0.03	0.14	25	3.6	3648	0.01	1.5	0.3
	Shad	2.4	0.01	0.01	0.92	0.14	1.15	27	5.5	3208	0.02	0.1	0.03

[a] Composite of 10 fish in each species.

[b] Maximum Permissible Intake – Intake of radionuclide from eating fish is calculated to be equal to a daily intake of 2.2 liters of water, over a period of one year, containing the concentration guide of radionuclides in question. Consumption of fish is assumed to be 37 lb/yr of the species in question. Only man-made radionuclides were used in the calculation.

[c] Percent of proposed FDA action level of 500 ng/g.

[d] Average of quarterly samples.

Source: Auxier et al., 1979.

Table 8.22. Radionuclide content in Clinch River fish, 1979

pCi/kg wet weight

Location	Species[a]	^{90}Sr	^{239}Pu	^{238}Pu	^{238}U	^{235}U	^{234}U	^{137}Cs	^{60}Co	^{40}K	% MPI[b]	Hg(ng/g)	% A.L.[c]
CRM 5.0	Bass	2.1	0.03	0.02	0.35	0.03	0.49	151	6.1	327	0.03	2.6	0.5
	Blue Gill	6.3	0.05	0.02	0.72	0.16	1.15	77	3.9	4137	0.05	3.1	0.6
	Carp	4.9	0.01	0.02	0.63	0.08	0.84	59	3.1	3525	0.04	5.6	1.1
	Shad	8.8	0.05	0.02	6.20	0.34	9.24	66	4.8	2508	0.07	0.7	0.1
	Crappie	4.9	0.02	0.02	0.42	0.01	0.80	56	3.8	2819	0.11	2.0	0.4
CRM 12.0	Bass	8.9	0.06	0.03	1.20	0.23	2.32	1649	12.7	16177	0.21	5.2	1.0
	Blue Gill	21.1	0.88	0.88	9.40	2.31	11.7	120	14.6	12870	0.16	5.9	1.2
	Carp	17.6	0.23	0.17	8.10	0.68	13.0	406	15.9	1896	0.17	20.0	4.0
	Shad	46.9	0.26	0.03	10.4	0.79	13.5	416	19.5	7288	0.38	1.7	0.3
	Crappie	13.7	0.03	0.10	1.3	8.50	3.10	683	13.6	1808	0.17	4.2	6.8
CRM 20.8[d]	Bass	10.6	0.01	0.01	0.21	0.06	0.44	1352	9.4	3275	0.51	3.1	0.3
	Blue Gill	255.4	0.03	0.08	0.70	0.08	1.25	3955	91.9	3159	2.20	3.7	0.7
	Carp	56.7	0.02	0.03	0.29	0.08	0.56	502	16.6	3314	0.45	2.6	0.5
	Shad	23.4	0.06	0.09	2.04	0.27	3.28	513	82.0	7668	0.23	0.5	0.1
	Crappie	14.0	0.01	0.15	0.71	0.09	1.85	393	10.8	4021	0.14	3.2	0.6
CRM 25.0	Bass	6.9	0.04	0.08	1.20	0.23	1.69	219	11.5	23870	0.07	1.2	0.2
	Blue Gill	6.9	0.07	0.70	1.90	1.40	5.21	153	20.8	20126	0.07	0.7	0.1
	Carp	3.8	0.08	0.08	1.10	0.56	1.8	29	18.0	13875	0.03	1.4	0.3
	Shad	6.6	0.07	0.07	3.40	0.33	3.29	32	16.6	10528	0.07	0.2	0.1

[a] Composite of 10 fish in each species.

[b] Maximum Permissible Intake — Intake of radionuclide from eating fish is calculated to be equal to a daily intake of 2.2 L of water, over a period of one year, containing the concentration guide of radionuclides in question. Consumption of fish is assumed to be 37 lb/year of the species in question. Only man-made radionuclides were used in the calculation.

[c] Percent of proposed FDA action level of 500 ng/g.

[d] Average of quarterly samples.

Table 8.13. Radionuclide content in Clinch River fish, 1980

[Bq/kg (pCi/kg)] wet weight

Location	Species[a]	^{90}Sr	^{238}Pu	^{239}Pu	^{234}U	^{235}U	^{238}U	^{137}Cs	^{60}Co	^{40}K	%MPI[b]	Hg(ng/g)	%A.L.[c]
CRM 5.0	Bass	0.081 (2.2)	0.0004 (0.01)	0.0004 (0.01)	0.0037 (0.1)	0.0007 (0.02	0.011 (0.3)	4.50 (122)	0.056 (1.5)	130.0 (3573)	0.03	157	31%
	Blue Gill	0.190 (5.2)	0.0004 (0.01)	0.0019 (0.05)	0.0096 (0.26)	0.0022 (0.06)	0.016 (0.42)	2.40 (66)	0.052 (1.4)	140.0 (3900)	0.04	220	44
	Carp	0.710 (19.2)	0.0048 (0.13)	0.0022 (0.06)	0.027 (0.72)	0.0067 (0.18)	0.052 (1.4)	2.50 (67)	0.089 (2.4)	160.0(4277)	0.14	199	40
	Shad	0.65 (17.6)	0.0011 (0.03)	0.0011 (0.03)	0.18 (4.8)	0.0180 (0.48)	0.24 (6.6)	3.60 (97)	0.15 (4)	140.0 (3917)	0.08	25	5
	Crappie	0.51 (13.9)	0.0004 (0.01)	0.0004 (0.01)	0.23 (6.3)	0.0078 (0.21)	0.035 (0.94)	2.80 (77)	0.21 (5.6)	140.0 (3831)	0.11	65	13
CRM 12.0	Bass	0.33 (9)	0.0048 (0.13)	0.0004 (0.01)	0.027 (0.72)	0.0041 (0.11)	0.041 (1.1)	12.0 (334)	0.29 (7.9)	130.0 (3475)	0.10	430	86
	Blue Gill	0.53 (14.4)	0.0033 (0.09)	0.0044 (0.12)	0.052 (1.4)	0.0041 (0.11)	0.089 (2.4)	1.30 (34.6	0.20 (5.3)	180.0 (4771)	0.10	470	94
	Carp	0.15 (4.2)	0.0004 (0.01)	0.0004 (0.01)	0.014 (0.38)	0.0019 (0.05)	0.019 (0.52)	1.0 (27.5)	0.10 (2.7)	130.0 (3480)	0.03	102	20
	Shad	2.0 (53)	0.0063 (0.17)	0.0015 (0.04)	0.44 (11.9)	0.028 (0.75)	0.60 (16.3	2.40 (66)	0.16 (4.4)	110.0 (2948)	0.38	18.2	4
	Crappie	0.40 (10.8)	0.0011 (0.03)	0.0030 (0.08)	0.012 (0.32)	0.0022 (0.06)	0.018 (0.50)	2.9 (79)	0.12 (3.2)	120.0 (3338	0.09	122	24
CRM 20.8[d]	Bass	0.53 (14.4)	0.0026 (0.07)	0.0015 (0.04)	0.0059 (0.16)	0.0015 (0.04)	0.011 (0.3)	5.0 (136)	0.25 (6.8)	120.0 (3278)	0.11	99	20
	Blue Gill	14.0 (381)	0.010 (0.28)	0.0096 (0.26)	0.052 (1.4)	0.016 (0.44)	0.052 (1.4	48.0 (1289)	2.2 (59)	160.0 (4406)	2.46	219	44
	Carp	1.80 (49)	0.0019 (0.05)	0.0004 (0.01)	0.012 (0.32)	0.0022 (0.06)	0.018 (0.49)	8.60 (233)	0.57 (15.3)	130.0 (3584)	0.37	193	39
	Shad	0.69 (18.7)	1.90 (0.53)	0.0026 (0.07)	0.089 (2.4)	0.010 (0.28)	0.14 (3.7)	13.0 (345)	1.3 (34)	120.0 (3163)	0.17	24	5
	Crappie	0.48 (12.9)	0.0093 (0.25)	0.0004 (0.01)	0.041 (1.1)	0.0059 (0.16)	0.048 (1.3)	1.7 (47)	0.19 (5.1)	130.0 (3625)	0.10	45	9
CRM 25.0	Bass	0.20 (5.4)	0.0011 (0.03)	0.0011 (0.03)	0.025 (0.68)	0.021 (0.57)		0.17 (4.7)	0.092 (2.5)	150.0 (4057)	0.04	11	2
	Blue Gill	0.28 (7.7)	0.0037 (0.1)	0.0059 (0.16)	0.063 (1.7)	0.019 (0.52)		0.52 (14)	0.18 (4.8)	170.0 (4608)	0.06	59	12
	Carp	0.12 (3.2	0.0007 (0.02)	0.0011 (0.03)	0.018 (0.5)	0.0030 (0.08)		0.31 (8.4)	0.063 (1.7)	110.0 (2854)	0.02	21	4
	Shad	0.24 (6.6)	0.0016 (0.43)	0.0030 (0.08)	0.018 (0.48)	0.0026 (0.07)		0.33 (9)	0.081 (2.2)	150.0 (4136)	0.05	7.4	1
	Crappie	0.027 (0.72)	0.0011 (0.03)	0.0059 (0.16)	0.048 (1.3)	0.028 (0.75)		0.12 (3.4)	0.11 (2.9)	150.0 (3949)	0.01	109	22

[a] Composite of 10 fish in each species.

[b] Maximum Permissible Intake   Intake of radionuclide from eating fish is calculated to be equal to a daily intake of 2.2 liters of water over a period of one year, containing the concentration guide of radionuclides in question. Consumption of fish is assumed to be 16.8 kg y^{-1} of the species in question. Only man-made radionuclides were used in the calculation.

[c] *Percent of proposed FDA Mercury in fish action level of 500 ng/g; Mercury data included in this table as a matter of convenience.*

[d] Average of quarterly samples.

carp, drum, and paddlefish roe (fish eggs). The channel catfish are being sold fresh in local markets, as well as some buffalo. There is a tremendous demand for buffalo whole friers and broilers from major northern urban areas, especially Chicago, Detroit, and New York. The Jewish populations of these cities are the predominant consumers.

Fish sticks and paddies are being made from buffalo. Almost all portions of the fish are being used. Fillets are also being sold, consisting of only the flesh. The paddlefish roe are a big commercial item, bringing $27/lb in December 1979. The most productive season for commercial fishing is during the spring, the second during winter.

Fish-tagging studies were initiated in 1961 (Nelson et al., 1961) on the Clinch River in the vicinity of White Oak Lake to determine the movement of fish in this portion of the Clinch-Tennessee River system. Of 5,245 fish, at the time of the report, 15[illegible] were recovered. The majority were white bass and white crappies. The white bass moved an average distance of 45 km (28 miles) downstream, while the white crappie moved an average distance of 19.0 km (11.8 miles). The results indicated that fish in the Clinch River in the vicinity of White Oak Lake will move considerable distances in the Tennessee River system. One sauger was recovered almost 160 km (100 miles) downstream from the location of tagging.

During 1962, flesh and bone analyses of white crappies from the Clinch River in the vicinity of White Oak Lake were made for ^{90}Sr content (Nelson and Griffith, 1962). Table 8.24 indicates strontium levels detected. It was suggested that the variability of ^{90}Sr values may be associated with the movement of fish into and out of White Oak Creek where the ^{90}Sr concentration is higher.

In 1965, studies were made on feeding rates and radiation effects on carp from White Oak Lake (Kevern and Griffith, 1965). An estimation of the feeding rate was made based on the uptake of ^{137}Cs in White Oak Lake which offered a unique opportunity to study this problem in a natural population. Radioactive contamination offered an opportunity to study the long range effects of chronic low-level radiation on the reproductive capacity of the carp population in White Oak Lake (Blaylock et al., 1967). A comparison with carp reproductive capabilities in Fort Loudoun Reservoir was made. Indications were that the percent of egg hatchability was reduced by exposure to chronic radiation received by the carp living in White Oak Lake.

Table 8.24. Strontium and strontium-90 in white crappie bone

	Strontium (µg/g of bone)	Strontium-90 Bq/g (pCi/g)	
	217	1.4	(36.7)
	250	0.9	(24.5)
	218	0.4	(10.0)
	204	10.3	(277.0)
	189	0.5	(12.6)
	234	10.9	(295.0)
	251	0.15	(3.0)
	230	0.40	(9.4)
	244	11.0	(299.0)
	233	8.00	(232.0)
Av.	227	4.4	(120.0)

Source: Nelson and Griffith, 1962.

In 1966, an investigation of fish in White Oak Lake was initiated to determine if trophic position of the fish was correlated with its concentration of radionuclide (Kevern and Griffith, 1966). Five species of fish were collected and analyzed for ^{137}Cs, ^{60}Co, and ^{90}Sr. The results are presented in Table 8.25. No correlation was found between trophic level and radionuclide concentration. The radiological dose commitment that results in the consumption of 16.8 kg (37 lbs) of bluegill is 0.25 millirems per year to the whole body and 13.0 millirems per year to the bone (critical organ).

An extensive study involving ^{137}Cs during the period June 1967 to January 1969 was used to calculate the feeding rates of bluegills at different times of the year (Kolehmainen and Nelson, 1969). Results indicated that the concentration of ^{137}Cs in bluegill increased linearly with the size of bluegill up to 70 g. Table 8.26 presents the ^{137}Cs levels in bluegill in White Oak Lake. A seasonal variation in ^{137}Cs levels in the fish was observed, with a maximum in February and a minimum in August. The concentrations of ^{137}Cs in other White Oak Lake fish were determined, and are given in Table 8.27. Concentrations in all species followed a seasonal cycling similar to the bluegill. The highest concentration of ^{137}Cs was found in largemouth bass. The consumption of 16.8 kg of this fish results in a radiological dose committment of 38 millirems per year to the whole body and 98 millirems per year to the liver (critical organ).

The uptake of ^{60}Co by black bullheads was examined in a combination laboratory/White Oak Lake study (Reed, 1971). Uptake and elimination, both whole body and tissue, of ^{60}Co were examined. The body organ pathway of ^{60}Co uptake was investigated. Results indicated that black bullheads accumulated ^{60}Co rapidly from water. Comparisons of lab fish and White Oak Lake fish showed that the blood and blood-rich organs, particularly the kidney, were principal sites of ^{60}Co accumulation. Table 8.28 presents ^{60}Co levels in laboratory and White Oak Lake black bullheads.

Research on the accumulation of radionuclides by bluegill, gizzard shad, and goldfish continued with an investigation of their food habits (Nelson et al., 1970). Fish were collected monthly from White Oak Lake during the period from April 1969 to May 1970. Cesium-137 and ^{60}Co were found in the fish consistently, while ^{106}Ru, ^{125}Sb, and ^{65}Zr occurred in

Table 8.25. Concentration and concentration factors of three radionuclides in five species of fish from White Oak Lake [Bg/g (pCi/g)]

Species	Sample size	^{90}Sr		^{137}Cs		^{60}Cs	
			C.F.		C.F.		C.F.
Carp	5	No data		0.71 (20)	60	0.3 (8.8)	6.4
Shad	5	0.7 (18)	46	1.2 (32)	140	0.5 (15)	13.0
Bullhead	5	3.2 (85)	220	0.95 (23)	100	3.0 (83)	70.0
Bluegill	5	3.4 (93)	240	1.4 (38)	170	0.2 (6)	5.0
Bass	5	1.3 (36)	93	1.3 (35)	150	0.2 (6.2)	5.5

Source: Kevern and Griffith, 1966.

Table 8.26. Concentration of ^{137}Cs in bluegill of different sizes in White Oak Lake

Weight of Fish (g) Mean	No. of Fish	Concentration of ^{137}Cs Bq/g (pCi/g) Mean
2.1	31	0.4 (10.4)
10.5	13	0.5 (13.3)
32.0	19	0.8 (21.2)
55.1	13	1 (30.9)
78.0	20	1.5 (39.8)
109.6	186	1.5 (40.1)

Source: Kolehmainen and Nelson, 1969.

Table 8.27. Concentration of ^{137}Cs in White Oak Lake fish

Species	Number of fish	^{137}Cs Bq/g (pCi/g) - fresh weight
Gizzard shad	15	1.7 (47.0)
Golden shiner	15	2.3 (62.6)
Goldfish	10	1.3 (34.5)
Redear sunfish	40	1.0 (26.9)
Bluegill	186	1.5 (40.1)
Warmouth	37	1.4 (36.7)
Largemouth bass	6	2.0 (52.8)

Source: Reed, 1971.

Table 8.28. Cobalt-60 in black bullhead tissues after 32 d of excretion and cobalt-60 in tissues of White Oak Lake bullheads

	Mean $\frac{\text{Tissue (Bq)}}{\text{Whole-body (Bq)}}$ (%)	
Tissue	32 d N = 2	WOL N = 5
Blood	10.54	12.83
Skin	12.95	7.49
Flesh	24.58	18.53
Liver	2.94	6.93
Stomach	2.66	0.81
Gut	3.41	7.06
Kidney	17.45	28.99
Heart	0.18	0.00
Bone	19.93	7.19
Gills	5.28	10.10

Source: Kolehmainen and Nelson, 1969.

small quantities in all three species of fish. The contribution of these latter three radionuclides to the body burden of the White Oak Lake fish analyzed was insignificant. Levels of ^{137}Cs and ^{60}Co in these White Oak Lake species are given in Table 8.29.

The behavior of tritium in fish in White Oak Lake was examined by placing uncontaminated bluegills in White Oak Lake and assaying for tritium for 36 d (Blaylock et al., 1972). Concentration ratios for tissue-bound tritium and tissue-water tritium ranged from 0.4 to 0.7 and 0.8 to 1.0, respectively. Turnover of tissue-bound and body-water tritium was measured in goldfish from White Oak Lake after placing them in uncontaminated water in the laboratory. The results indicated that under long-term chronic exposure to tritium in food and water, fish do not appear to concentrate tritium in either their body water or tissue-bound component. A study of tritium content of the mosquito fish in White Oak Lake indicated that the tritium level in tissue water closely paralled that of the lake water (Blaylock and Frank, 1979).

An investigation was made as to whether abnormalities of fish in White Oak Lake could be linked with chronic low-level exposure to ionizing radiation (Blaylock et al., 1972). Since White Oak Lake contains contaminants other than radioactivity due to sanitary and chemical wastes, it was concluded that the data could not single out radiation as the sole cause of abnormalities. It was suggested that future studies concentrate on possible synergistic combinations of chemical, environmental variables, and ionizing radiation, rather than ionizing radiation alone.

The availability of ^{137}Cs to fishes via sediment ingestion was investigated in a laboratory study (Eyman and Kitchings, 1975). Three different clays (kaolinite, montmorillonite, and illite) were tagged with ^{137}Cs and fed to channel catfish and bluegills at two temperatures. Elimination rates for each fish were calculated. Uptake of ^{137}Cs from kaolinite and montmorillonite (65-85%) was approximately eight times greater than that from illite (8-12%) in both species at both temperatures. It was noted that previous studies had indicated a high illite content of White Oak Lake sediments. Conclusions will depend on sediment composition, particularly of the clay and organoclay complexes and also whether the association of ^{137}Cs with White Oak Lake sediment is to the strong affinity of the illite mineral for cesium sorption.

Table 8.29. Concentration of ^{137}Cs and ^{60}Co in bluegills, goldfish, and gizzard shad from White Oak Lake, April 1969 through May 1970

Species	No. of fish	Concentration Bq/g (pCi/g)		Concentration Factor	
		^{137}Cs	^{60}Co	^{137}Cs	^{60}Co
Bluegill	115	0.7 (19.3)	0.1 (2.5)	120	25.8
Goldfish	73	0.9 (23.4)	0.2 (4.7)	147	48.9
Gizzard shad	84	1.8 (49.2)	0.1 (2.9)	307	31.8
White Oak Lake water	Bq/mℓ (pCi/mℓ)	0.006 (0.2)	0.003 (0.01)		

Source: Nelson, 1970.

In summary, it appears that White Oak Lake fish accumulate ^{137}Cs primarily from ingestion of food and sediments, ^{90}Sr primarily from direct contact with water, and ^{60}Co and ^{3}H from both ingestion of food and direct contact with water. The major link in the food-fish chain is algae, which has been found to contain appreciable amounts of ^{137}Cs, ^{90}Sr, ^{60}Co, and ^{3}H in White Oak Lake. The radioactive contamination of White Oak Lake has provided the opportunity for numerous research projects involving radiation effects on fish. Results have indicated appreciable contamination of fish in White Oak Lake particularly, ^{137}Cs, ^{90}Sr, ^{60}Co, and tritium. Due to the presence of other pollutants from chemical and sanitary wastes, the effects of radiation separate from other contaminants in White Oak Lake is difficult to assess. The potential for White Oak Lake fish to travel miles in the Clinch-Tennessee River system presents a potential exposure path to humans.

8.5 UPTAKE OF RADIONUCLIDES BY INSECTS ON WHITE OAK LAKE BED

The invasion of White Oak Lake bed by insects after the draining of White Oak Lake in October 1955 provided an opportunity to investigate the transfer of radionuclides from plants to insects in a terrestrial system. Concurrent with the invasion of White Oak Lake bed by plant species in 1956, insect associates of these plants appeared and large populations of insects soon developed.

Intensive studies of these insect populations were conducted during the summers of 1956-1958, with the following objectives:

(1) to determine the extent to which insects would accumulate ^{90}Sr and ^{137}Cs from their host plants and

(2) to evaluate the influence of insects in the herbivore trophic level upon the redistribution of radionuclides in the lake bed system (Anderson et al., 1957; Auerbach et al., 1958; Auerbach et al., 1959; Crossley and Howden, 1961; and Crossley, 1961).

Table 8.30 presents concentrations of ^{90}Sr and ^{137}Cs in insects feeding on vegetation of White Oak Lake bed in 1959. Comparisons between concentrations of radionuclides in host plants and individual insect species indicated a direct function.

Table 8.30. Concentrations of ^{90}Sr and ^{137}Cs in insects feeding on vegetation of White Oak Lake bed, 1959

Insect species	Concentrations [Bq/g (µCi/g × 10^{-4}) - dry wt]	
	^{137}Cs	^{90}Sr
Conocephalus	5.55 (1.50)	5.18 (1.40)
Systena	5.18 (1.40)	6.59 (1.78)
Bees	2.41 (0.65)	2.63 (0.71)
Chauligognatbus	2.29 (0.62)	5.18 (1.40)
Melanoplus		
Hemiptera-Homoptera	1.59 (0.43)	0.06 (0.22)

Source: Auerbach et al., 1959.

Additional laboratory and field work during the summers of 1960 and 1961 substantiated the earlier work on White Oak Lake bed insects (Auerbach, 1960; Crossley, 1962; Howden and Crossley, 1961). Table 8.31 gives a comparison of 1958 and 1961 radionuclide concentrations in the plant-to-insect food chain on White Oak Lake bed.

A comparison of the movement of ^{106}Ru, ^{60}Co and ^{137}Cs in the arthropod food chains on White Oak Lake bed was made in the summer of 1964 (Crossley and Shanks, 1967). High ^{106}Ru contents of soils in the vicinity of waste seepage pits provided the opportunity to examine this radionuclide also. Compared to ^{137}Cs, more efficient food chain movement was suggested by the data for ^{106}Ru and ^{60}Co. Uptake from the soil was greater for these latter radionuclides than for ^{137}Cs. Table 8.32 indicates the comparative distribution of these radionuclides based on data from this study.

With the enlarging of White Oak Lake in 1959, a study was made of chromosomal aberrations in irradiated larvae of two natural populations of the species Chironomus. The conclusions were that the ionizing radiation at White Oak Lake increased the frequency of new chromosomal aberrations (Blaylock, 1966).

Data from past studies on accumulation of radionuclides by individual insect species have showed that the transfer of ^{137}Cs from plant to insect tissue was more efficient than transfer of ^{90}Sr (80% vs 10%). Apparently these differences could be attributed to the more rapid elimination of ^{90}Sr by insects, resulting in lower equilibrium values. Evidently, the insects had very little effect on the distribution of radionuclides on the lake bed or removal of nuclides from the system. It was estimated that, in the extreme case, if all of the insects on the lake bed at any one time were to leave, the loss of radionuclides would be about 3 μC each of ^{90}Sr and ^{137}Cs. While not insignificant, this loss would be relatively small compared to the total activity in the lake bed.

In summary, substantial research has been performed on insects which inhabited White Oak Lake bed. The invasion of the lake bed by insects after draining provided a unique opportunity to observe ecosystem successions and population dynamics. The contamination of the lake bed provided a unique opportunity to study radionuclide uptake and effects in relation to insects. These studies on White Oak Lake have indicated that the insect pathway is not significant in comparison to others.

Table 8.31. Comparison of 1958 and 1961 estimates of ^{137}Cs and ^{90}Sr concentrations in the plant-to-insect food chain on White Oak Lake bed, 1962

[Bq/g (pCi/g)] -- Dry weight

	^{137}Cs		^{90}Sr	
	1958	1961	1958	1961
Soil	270.1 (7300)	*b*	16.7 (450)[a]	*b*
Plants	4 (100)	5.9 (160)	25.9 (700)	25.5 (690)
Herbivorous insects	3.2 (87)	2.9 (78)	3.4 (91)	4.3 (117)
Predaceous insects	3.6 (97)	2.7 (73)	3.0 (91)	2.0 (55)

[a] Soil values based on grand means from core samples.

[b] No samples taken.

Source: Morgan et al., 1962.

Table 8.32. Distribution of radioisotopes along arthropod food chains on White Oak Lake bed's west seep area (Samples are from two line transects during an eight-week period, Summer 1964.)

Trophic level	^{106}Ru		^{90}Co		^{137}Cs	
	Bq/mg	CF[a]	Bq/mg	CF[a]	Bq/mg	CF[a]
Soil	1.05		0.17		0.52	
Vegetation	0.06	0.062	0.01	0.058	0.01	0.027
Herbivore	0.03	0.41	0.005	0.43	0.004	0.29
Predator	0.03	2.86	0.005	1.07	0.004	0.92

[a] Concentration factor = $\frac{\text{grand mean for trophic level}}{\text{grand mean for preceding level}}$.

Source: Crossley et al., 1967.

8.6 UPTAKE OF RADIOACTIVITY BY OTHER ANIMALS

From 1943 to 1955, low-level and intermediate-level radioactive wastes generated by Clinton Laboratories and later Oak Ridge National Laboratory (ORNL) were discharged into the White Oak Creek drainage basin. Since 1955, numerous investigations were initiated to determine:

(1) the bioaccumulation of radionuclides in the populations of native mammals at White Oak Creek, and

(2) the effects of environmental radiation on the mammal populations.

The fate of fission products discharged from ORNL translocated to small animals from an aquatic environment provide important pieces of information that can help determine the pathway of these radionuclides to man.

In 1957 a small-mammal program was started at ORNL (Auerbach et al., 1958). The purpose was to examine native mammal populations inhabiting White Oak Creek bed and to determine the effects of low-level chronic exposure, both internal and external, over a long period of time. Most of the field work was done on two areas, one on the former impoundment known as White Oak Lake and the other area located approximately 0.24 mile below the confluence of the Clinch River and White Oak Creek. The animals examined were subjected to external radiation (∿ 20 mR/h) and were continually ingesting various radionuclides from the impoundment.

Mammal data for 1956 and 1957 were not extensive due to the exploratory nature of the studies. Mammal succession in the White Oak Lake area is indicated in Fig. 8.8 (Dunaway and Kaye, 1961). House mice were the first to inhabit the area followed by cotton rats in the summer of 1957. Rice rats were detected in the area in 1958 while white-footed mice, short-tailed shrew, least shrew, and the Norway rats only occurred as occasional visitors.

In 1958, the White Oak Lake trapping was enlarged to 7.5 acres to obtain more meaningful data (Auerbach et al., 1959). The study of small mammal succession information and number of native mammal populations was continued. However, in 1960, the small mammal program initiated investigations concerning radionuclide accumulation by native mammal populations and the effects of chronic, low-level external radiation from contaminated environments as well as the effects of internally deposited emitters.

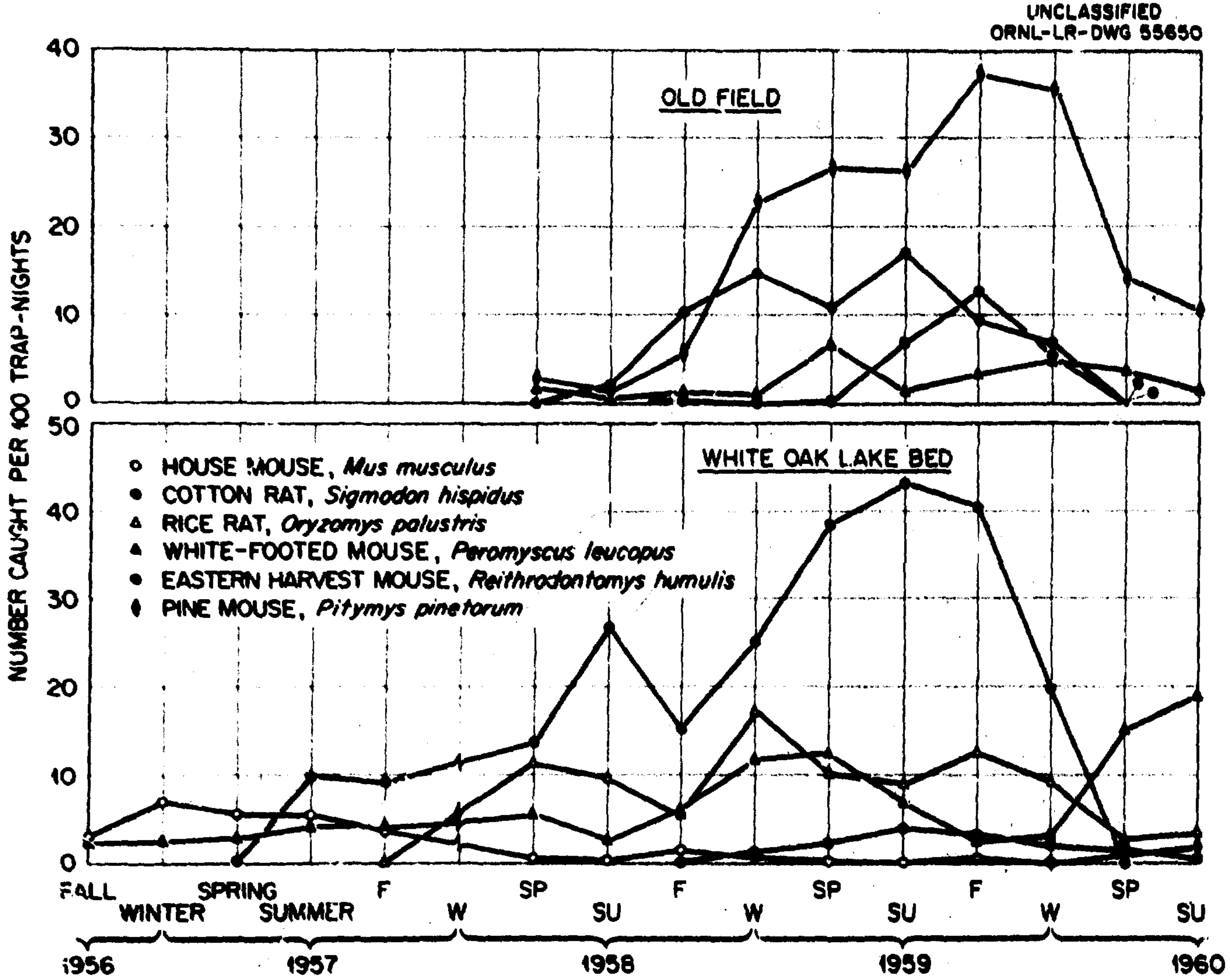

Fig. 8.8. Numbers of small mammals caught per 100 trap-nights in lake-bed and old field areas.

During the late winter and spring of 1960, twenty-nine small mammals of eight different species were analyzed by alpha and beta radiochemical and gamma spectrometric techniques (Auerbach et al., 1961). Organ and tissues were analyzed after vacuum-oven drying. In Table 8.33, concentrations of various radionuclides in stomach contents for three species from the lake bed area is shown. A bioaccumulation of ^{106}Ru and ^{90}Sr can be seen in the critical organs of the muskrat, while only ^{90}Sr is accumulated by the rabbit and cotton rat. Figure 8.9 indicates radionuclide concentrations in five different rodents. The cotton rats had the highest average concentration of ^{60}Co, while the muskrat contained the highest levels of ^{106}Ru, ^{137}Cs, and ^{90}Sr. The reader should note that the concentrations of ^{90}Sr are higher in the critical organ (femur) than in the stomach content as expected, however the stomach contents have higher concentrations of gamma emitters than does the critical organ for the particular isotope. One possible reason for the higher concentrations in the muskrat can be attributed to its feeding in White Oak Creek which receives low-level effluents.

Concentrations of various radionuclides per acre and square-meter are given in Table 8.34 these estimates were obtained by assuming the concentration in four cotton rats are representive of the terrestrial native mammal population. Strontium-90 in mammals was three times higher than in insects but no distinction can be made between these species for ^{137}Cs levels. It was shown that mammals had 35 times more ^{90}Sr and a third higher value for ^{137}Cs than did birds of the lake bed area. These differences were probably due to the different feeding habitats. In 1958, Willard compared specific activities of ^{90}Sr and ^{137}Cs in birds from different habitats on White Oak Lake bed as shown in Table 8.35. The higher levels of inner-zone birds compared with the outer-zone birds as well as the relatively large concentrations of ^{137}Cs in winter are seen. Willard (1960) suggested that the seasonal change in the ^{90}Sr/^{137}Cs ratio in tissues that uptake by the bird population in summer was attributed to the food chain (mainly insects), while winter uptake was probably due to ingestion of contaminated soil. Table 8.36 compares amounts of ^{90}Sr and ^{137}Cs present at different trophic levels.

Table 8.33. Results of radioanalyses of lake-bed mammals
Dry weight - bq/g (μCi x 10^{-4}/g)

Species	No. in sample	Sample	Concentration of radionuclides			
			^{106}Ru	^{137}Cs	^{60}Co	^{90}Sr
Muskrat	1	Stomach contents	72.9 (19.7)	49.2 (13.3)	4.8 (1.3)	26.3 (7.1)
		Critical organ[a]	148.7 (40.2)	14.8 (4.0)	3.7 (1.0)	348.9 (94.3)
Rabbit	4	Stomach contents	42.9 (11.6)	13.7 (3.7)	2.2 (0.6)	10.7 (2.9)
		Critical organ[a]	7.0 (1.9)	1.9 (0.5)	1.5 (0.4)	28.5 (7.7)
Cotton rat	4	Stomach contents	16.7 (4.5)	25.9 (7.0)	11.8 (3.2)	4.8 (1.3)
		Critical organ[a]	0 (0)	3.7 (1.0)	8.5 (2.3)	62.2 (16.8)

[a] Isotope and critical organ: ^{106}Ru, kidneys; ^{137}Cs, muscle; ^{60}Co, liver; and ^{90}Sr, femur.

Source: Auerbach et al., 1960.

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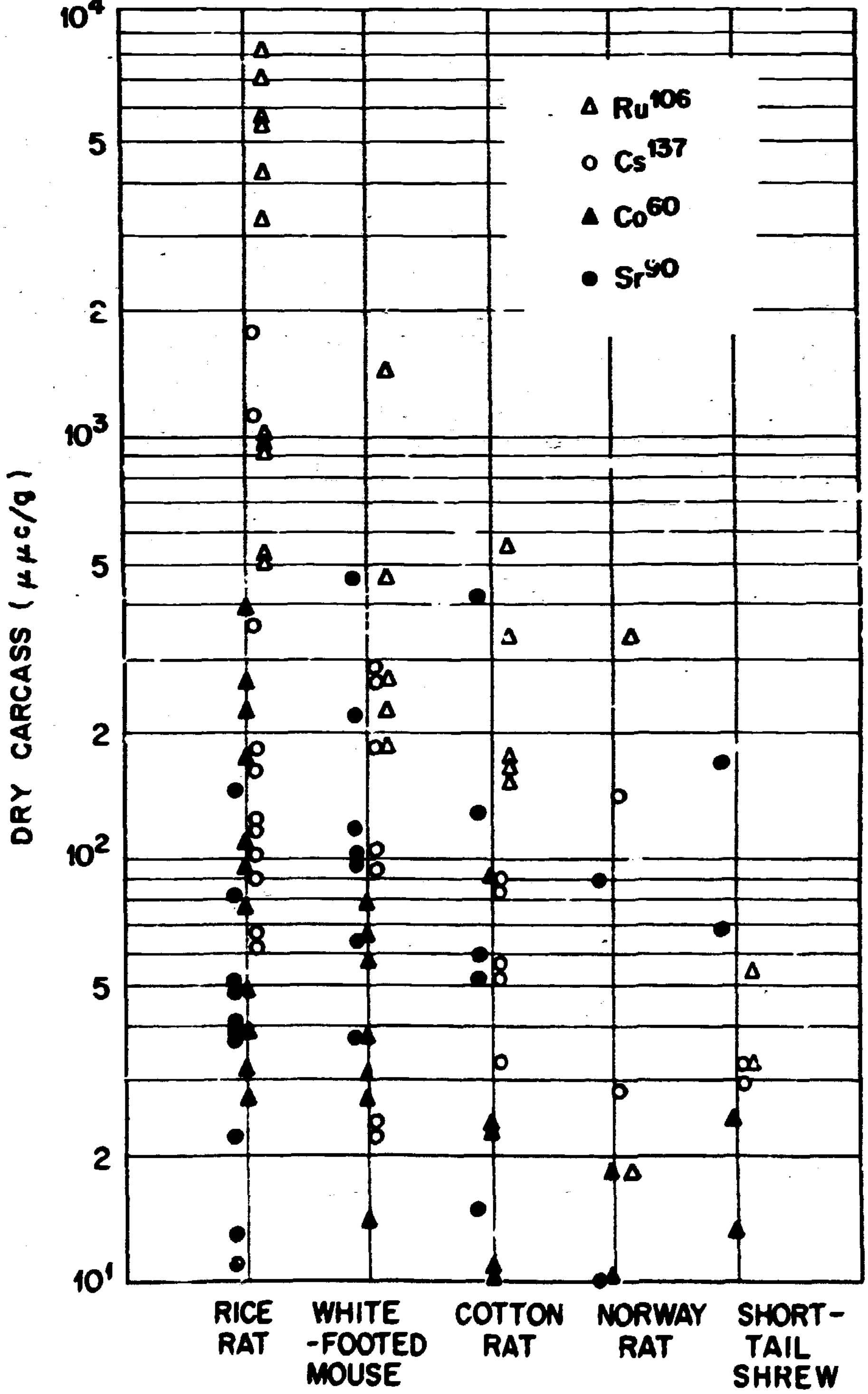

Fig. 8.9. Distribution of radionuclide concentrations in small mammals of the upper White Oak Lake bed.

Table 8.34. Concentrations of radionuclides in cotton rats of White Oak Lake bed, area 3

Radionuclide	Whole-body concentrations [Dry wt. - Bq/g (nCi/g)				Average	Concentration per unit area	
	Rat 1	Rat 2	Rat 3	Rat 4		Bq/acre (nCi/acre)	Bq/m^2 (nCi/m^2)
^{106}Ru	6.03 (0.16)	8.14 (0.22)	3.96 (0.11)	6.47 (0.18)	6.14 (0.17)	2554.1 (69.3)	0.63 (0.02)
^{137}Cs	5.44 (0.15)	4.11 (0.11)	4.11 (0.11)	5.03 (0.34)	4.66 (0.13)	1820.4 (49.2)	0.48 (0.01)
^{60}Co	3.96 (0.11)	3.63 (0.10)	2.00 (0.05)	4.03 (0.11)	3.40 (0.92)	1417.1 (39.3)	0.35 (0.01)
^{90}Sr	22.1 (0.60)	19.91 (0.54)	23.87 (0.65)	23.25 (0.6[illegible])	22.31 (0.60)	9298.1 (251.3)	2.33 (0.06)

Source: Auerbach, et al., 1960.

Table 8.35. Comparison of specific activity of radiostrontium in bone and radiocesium in muscle of birds from different zones and seasons

Wet weight - Bq/g (pCi/g)

	^{90}Sr - ^{90}Y		^{137}Cs	
	Average	Range	Average	Range
Summer, inner habitat zone	11.17 (302)	0.48-22 (13-595)	1.85 (50)	0.41-3.8 (11-102)
Summer, outer habitat zone	2.52 (63)	0.63-5.9 (17-160)	0.81 (22)	0.11-2.3 (3-62)
Winter, inner habitat zone	8.47 (229)	0.55 (0-1487)	103.64 (2801)	1.6-688 (43-18,600)

Source: Willard, 1960.

Table 8.36. Estimated amounts of ^{90}Sr and ^{137}Cs present at different trophic levels (Data pertain to White Oak Lake bed, Oak Ridge, Tennessee)

kBq/acre (mCi/acre)

Trophic Level	^{90}Sr		^{137}Cs	
Birds[a]	0.26	(0.7×10^{-5})	0.70	(1.9×10^{-5})
Plants[b]	5.2×10^4	(1.4)	7.4×10^3	(0.2)
Soil[b]	1.1×10^5	(290)	5.6×10^8	(15,000)

[a] Estimate for bird population based on data from Table 8.33 and a density of 20 birds per acre.

[b] Plant and soil data from Auerbach.

Source: Willard, 1960.

In 1961, population-dynamics studies of small-mammal succession on White Oak Creek bed (Kaye et al., 1962) continued. Whole-body dose rates for muskrats ranged from 15.1 mrems/w (contents of the GI-tract not included) to 112 millirems per week (including the GI-tract contents). Studies from cotton rats indicated 84% of the dose in tissues was caused by ^{90}Sr while ^{137}Cs, ^{106}Ru, and ^{60}Co deposited in the lake bed soil accounted for almost all the external radiation dose. In Table 8.37 body burdens for two cotton rats were calculated from radionuclide analysis of their various organ. These rats were 170 d old. They were first captured, marked and released when 1 d old. Assuming that the animals lived the entire period on the lake bed, a theoretical body burden at the time of capture was calculated. Whole-body dose rates for cotton rats was estimated at 2.6 rems per week where 86% of this dose rate was due to the lake bed radiation field, 10% was due to the deposition of radionuclides in tissues and the remaining 4% of the whole-body dose rate was due to the GI-tract contents. Examination of tissues from radioactive and nonradioactive areas revealed an unpredictably small amount of various pathologies, none of which was conclusively attributed to radiation exposure.

Bioaccumulation studies of various radionuclides in native mammals of the White Oak Creek bed were made in 1962 by the Health Physics Division. Body burdens from the more abundant radionuclides, ^{90}Sr, ^{106}Ru, ^{137}Cs and ^{60}Co were determined to be greater than the theoretical body burdens calculated from world-wide weapons fallout. Kaye and Dunaway (1963) estimated a whole-body dose rate from internal and external sources of cotton rats trapped on the White Oak Lake impoundment was 2.9 rads per week. Table 8.38 shows the whole body burden and concentrations of radionuclides for four cotton rats. Carcass and GI-tract radioassay of several rodent species from White Oak Lake bed can be examined in Table 8.39.

A continuation of the small animal program by the Health Physics Division in 1963 revealed that concentrations of radionuclides in cotton rat tissues correlated with the concentrations in the GI-tract contents and plants (Dunaway et al., 1964). Tissue concentrations of radionuclides were not correlated with the concentrations found in the soil. Although ^{90}Sr was the only radionuclide shown to accumulate in the femurs, placental and mammary barriers effectively reduced the ^{90}Sr concentrations in fetuses and

Table 8.37. Calculated and radioassay body burdens of radionuclides for two cotton rats from lower White Oak Lake bed

Bq (pCi)

Isotope	Body burdens			
	Calculated		Radioassay	
	Q_e	Q_{170}	156SVK	158SVK
^{90}Sr	2123.8 (57,400)	606.8 (16,400)	473.7 (12,800)	348.5 (9,420)
^{106}Ru	421.8 (11,400)	315.2 (8,520)	48.1 (1,300)	44.8 (1,210)
^{60}Co	352.6 (9,530)	352.6 (9,530)	22.8 (616)	22.1 (598)
^{137}Cs	1058.2 (28,600)	1058.2 (28,600)	40.3 (1,090)	36.9 (998)

Source: S. V. Kaye and P. B. Dunaway, 1962.

Table 8.38. Concentrations and whole-body burdens (exclusive of GI-tract contents) of radionuclides in four cotton rats from lower White Oak Lake bed

Dry weight - Bq/g (pCi/g)

Specimen No.	^{90}Sr	^{106}Ru	^{137}Cs	^{60}Co
	Concentration of radionuclide			
155SVK	24.0 (648)	2.7 (74.1)	2.5 (67.9)	1.1 (30.9)
156SVK	23.7 (640)	2.4 (65.2)	2.0 (54.7)	1.1 (30.9)
157SVK	23.6 (638)	1.3 (36.7)	1.7 (47.2)	0.7 (18.1)
158SVK	21.2 (573)	2.7 (73.6)	2.2 (60.7)	1.3 (36.4)
	Whole-body burden			
155SVK	349 (9,440)	40 (1,080)	36.6 (989)	16.7 (451)
156SVK	474 (12,800)	48 (1,300)	40.3 (1,090)	22.8 (616)
157SVK	599 (16,200)	34 (932)	44.4 (1,200)	17.0 (460)
158SVK	349 (9,420)	44.8 (1,240)	36.9 (998)	22.1 (598)

Source: Kaye and Dunaway, 1962.

Table 8.39. Concentrations of radionuclides in one cotton rat, two white-footed mice, and one pine mouse from shoreline of lower White Oak Lake bed

Dry weight - Bq/g (pCi/g)

Species	Specimen no.		Concentration of radionuclide		
			^{137}Cs	^{60}Co	^{90}Sr
Cotton rat	192SVK	Pelt	1.18 (32)	1.00 (27)	a
White-footed mouse	193SVK		b	b	a
White-footed mouse	194SVK		b	b	a
Pine mouse	195SVK		b	b	a
Cotton rat	192SVK	Gi-tract and contents	5.00 (135)	2.37 (64)	0.85 (23)
White-footed mouse	193SVK		b	b	0.26 (7)
White-footed mouse	194SVK		b	b	0.11 (3)
Pine mouse	195SVK		b	b	0.44 (12)
Cotton rat	192SVK	Residual carcass	1.18 (32)	2.77 (60)	7.29 (197)
White-footed mouse	193SVK		0.30 (8)	0.04 (1)	3.51 (95)
White-footed mouse	194SVK		0.22 (6)	b	0.78 (21)
Pine mouse	195SVK		0.33 (9)	b	3.96 (107)

[a] Sample not radioanalyzed for this nuclide.

[b] None detected.

Source: Kaye and Dunaway 1963.

nursing siblings. Hemotological analysis of cotton rats entailed total erythrocyte counts, leukocyte counts, leukocyte differential counts, hematocrits, mean corpuscular volumes, cell-volume distributions and total serum solids. These measurements revealed that effects of ionizing radiation were not detected in the blood of cotton rats that lived on the White Oak Lake bed. However, significant hemotological findings for comparable doses to laboratory rats have been reported. The radio resistance of the native cotton rats could be attributed to the species of rats tested.

White Oak dry impoundment was covered with water again, forming White Oak Lake in the early sixties. Since that time up to the present, radionuclide uptake studies of the native small mammals inhabiting the lake bed had been more research oriented. The lake bed monitoring program was no longer possible due to the reformation of White Oak Lake. In late December 1979, the lake was drained again, exposing the lake bed to the wildlife and again presenting a possible radionuclide pathway to man and his environment. Currently, the Laboratory is actively seeking state licensure for small animal and bird trapping in order to continue the small mammal monitoring program.

8.7 RADIONUCLIDE UPTAKE IN WATERFOWL AT WHITE OAK LAKE BED AND OTHER NUCLEAR FACILITIES

In the early 1950s, an ecological study of migratory waterfowl from the White Oak Lake bed was initiated (Krumholz, 1954). This investigation obtained information concerning migratory movements of 649 birds that were banded and released which included: 390 mallards, 137 wood ducks, 96 black ducks, 17 coot, 6 pintails, 1 gadwall, 1 baldpate, and 1 green-winged teal. Krumholz indicated that more than 6500 migratory waterfowl visited the lake in 1952. Some of the banded ducks traveled to parts of Tennessee, Kentucky, Alabama, Louisiana, Texas and as far north as Ontario, Canada, and were then killed by hunters.

An estimate of the average total body burden of the migratory waterfowl which fed at the White Oak Lake bed was set at 5 μCi. Almost all of the activity that was concentrated in the muscle, skin, and giblets was due to ^{32}P accumulation.

Ducks have been reported to carry ^{137}Cs in a bound state as excreta which is deposited to the sediments of northern lakes (Eyman and Kevern, 1975). Wintergreen Lake in Kalamazoo County, Southwestern Michigan, contained a detectable amount of ^{137}Cs as seen in Table 8.40. For 1970, it was calculated that for Wintergreen Lake 0.01% of the total deposition was due to waterfowl, with the remaining 99.99% due to precipitation as seen in Table 8.41. Therefore, the input of ^{137}Cs by waterfowl to the pool of cesium at Wintergreen Lake was considered insignificant. In 1958, Pendleton and Hanson collected bioaccumulation factors for ^{137}Cs in waterfowl (Table 8.42) indicating a high degree of accumulation in the liver.

In 1978, studies of radionuclide concentrations were determined in wild waterfowl using a radioactive leaching pond as a resting area at the Idaho National Engineering Laboratory site (INEL) (Halford et al., 1978). Eight ducks, one coot, and seven waterfowl background samples were disected and the tissues analyzed for gamma-emitting radionuclides. Of the 25 radionuclides identified, the highest radionuclide concentrations were located in the gut, feathers, liver and muscle (Table 8.43).

Ducks had lower concentrations of radionuclides in edible tissues than in non-edible tissues. The thyroid dose and whole body dose to man consuming contaminated ducks were calculated using duck muscle concentrations of ^{137}Cs, ^{134}Cs and ^{131}I. These calculations showed that even the highest dose committments were below the limits set by the International Commission on Radiological Protection (ICRP) for individuals of the general population. This average dose to man assuming a total consumption of 198 g, was estimated to be 20 mrem.

Retention studies of fission radionuclides from the INEL pond site showed 17 gamma-emitters detected (Halford et al., 1978). Twenty semi-wild mallard ducks were banded and fitted with ventral and dorsal thermoluminescent dosimeter packets and released on the leaching pond at INEL for 75 to 145 days. Upon capture, some ducks were sacrificed and analyzed for various radionuclides. The remaining ducks were whole-body counted.

The results of studies of radionuclides in the tissue of mallards and dose from consuming other waterfowl on the INEL site are given in Tables 8.44 and 8.45. Biological and physical elimination of various nuclides

Table 8.40. Estimated input of ^{137}Cs and stable cesium by migratory waterfowl during 1970

Characteristic	Geese	Ducks
Birds use (day/year)	1.43×10^5	1.00×10^5
Excreta/bird/day (g day wt)	142[a]	32[a]
Excreta/year (metric tons)	20.3	3.2
^{137}Cs [mBq/g (pCi/g)]	4.18 (0.113)	4.92 (0.133)[b]
Stable cesium (ng/g)	15.2	15.2[b]
^{137}Cs added to lake in 1970 [kBq (μCi)]	84.7 (2.29)	13.32 (0.36)
Stable cesium added to lake in 1970 (mg)	309	49

[a] Kear, 1962.

[b] Estimated values.

Table 8.41. Deposition rate and accumulation of ^{137}Cs from precipitation

Year	Deposition rate		Total deposition[a]	
	[MBq/$km^{-2}y^{-1}$	(mCi/$km^{-2}y^{-1}$)]	[MBq/km^2	(mCi/km^2)]
1954	56.6	(1.53)	38.5	(1.04)
1955	213.9	(5.78)	186.9	(5.05)
1956	226.4	(6.12)	347.8	(9.40)
1957	201.3	(5.44)	495.8	(13.40)
1958	314.5	(8.50)	728.9	(19.70)
1959	44.3	(11.90)	1065.6	(28.80)
1960	106.9	(2.89)	1147.0	(31.00)
1961	207.6	(5.61)	1313.5	(35.50)
1962	1276.5	(34.50)	2356.9	(63.70)
1963	1924.0	(52.00)	3959.0	(107.00)
1964	980.5	(26.50)	4810.0	(130.00)
1965	314.5	(8.50)	5069.0	(137.00)
1966	125.8	(3.40)	5180.0	(140.00)
1967	75.5	(2.04)	5254.0	(142.00)
1968	62.9	(1.70)	5328.0	(144.00)
1969	75.5	(2.04)	5402.0	(146.00)

[a] Corrected to 1970 for decay.

Source: Eyman and Kevern, 1975.

Table 8.42. Bioaccumulation factors for ^{137}Cs in waterfowl

Species/Tissue	BF
American coot *(fulica a. americana)*:	
muscle	1,800
liver	2,200
bone	800
Common mallard *(Anas platyrhynchos)*:	
muscle	2,000
liver	2,500
bone	700
Ruddy duck *(Oxyura jamaicensis rubida)*:	
muscle	2,200
liver	2,800
bone	900

Source: Pendleton and Hanson, 1958.

Table 8.43. Radionuclide concentrations of duck tissues

Radionuclide	Location	Concentration Bq/g (pCi/g)
^{51}Co	gut	4800 (130,000)
	feathers	1390 (37,500)
^{147}Ne	feathers	3850 (104,000)
^{137}Cs	muscle	150 (4,070)

Source: Halford et al., 1978.

Table 8.44. Mean concentration of radionuclides in tissue samples from experimental mallards analyzed at capture and after 52 days of biological and physical elimination

Nuclide	Half-life	Mean Radionuclide concentrations [MBq (pCi/g)][a]							
		Muscle		Gut		Feathers		Liver	
		Before (3)	After (6)	Before (3)	After (6)	Before (3)	After (6)	Before (3)	After (6)
^{137}Cs	30.0 y	25.60 (692)	1.55 (42)	10.40 (281)	0.30 (8)	8.55 (231)	3.55 (96)	6.70 (181)	0.30 (8)
^{134}Cs	2.05 y	4.95 (134)	0.30 (8)	1.92 (52)	0.04 (1)	1.96 (53)	0.81 (22)	1.26 (34)	ND
^{75}Se	120.4 d	1.26 (34)	0.48 (13)	2.33 (63)	0.30 (8)	ND	ND	6.36 (172)	0.89 (24)
^{203}Hg	46.6 d	0.19 (5)	0.04 (1)	0.15 (4)	0.04 (1)	ND	ND	0.70 (19)	0.19 (5)
^{58}Co	71.3 d	0.07 (2)	<0.04 (<1)	1.48 (40)	0.04 (1)	10.10 (273)	2.7 (73)	1.85 (50)	0.48 (13)
^{60}Co	5.27 y	2.04 (55)	1.63 (44)	18.94 (512)	2.76 (75)	54.02 (1460)	25.20 (681)	48.47 (1310)	20.17 (545)
^{65}Zn	245.0 d	1.67 (45)	1.04 (28)	5.55 (150)	1.55 (42)	8.14 (220)	3.81 (103)	11.91 (322)	3.11 (84)
^{140}Ba	12.8 d	ND[b]	ND	1.78 (48)	ND	28.71 (776)	ND	ND	ND
^{140}La	40.22 h	ND	ND	0.33 (9)	ND	5.14 (139)	0.22 (6)	ND	ND
^{51}Cr	27.8 d	ND	ND	80.92 (2187)	ND	137.38 (3713)	19.83 (536)	8.33 (225)	ND
^{54}Mn	303.0 d	ND	ND	0.15 (5)	ND	0.85 (23)	0.22 (6)	0.41 (11)	ND
^{95}Zr	65.0 d	ND	ND	0.11 (3)	ND	ND	ND	ND	ND
^{95}Nb	35.0 d	ND	ND	0.07 (2)	ND	0.41 (11)	0.11 (3)	ND	ND
^{141}Ce	33.0 d	ND	ND	ND	ND	4.48 (121)	0.41 (11)	ND	ND
^{144}Ce	284.0 d	ND	ND	ND	ND	12.28 (332)	5.07 (137)	ND	ND
^{57}Co	270.0 d	ND	ND	ND	ND	0.07 (2)	ND	ND	ND
^{110m}Ag	253.0 d	ND	ND	ND	ND	ND	ND	0.22 (6)	ND

[a] ( ) = Sample size.

[b] ND = Not detected.

Source: Halford et al., 1978.

Table 8.45. Calculated potential maximum whole body dose to man consuming waterfowl from the Test Reactor Area Radioactive Leaching Pond

Species	Date collected	Total wet weight (g)	Whole body dose (millirem)
American coot[a] *(Fulica americana)*	12-14-76	590	84[b] (100)[c]
Common goldeneye *(Bucephala clangula)*	12-28-76	736	36 (53)
Mallard *(Anas platyrhynchos)*	01-06-77	1090	40 (89)
Lesser scaup *(Aythya affinis)*	11-25-77	740	11 (17)
Lesser scaup *(A. affinis)*	11-25-77	754	12 (18)
Common goldeneye *(B. clangula)*	11-25-77	948	16 (30)
Pintail *(Anas acuta)*	11-28-77	553	17 (19)
Bufflehead *(Bucephala albeola)*	11-28-77	501	30 (30)
Mallard *(A. platyrhynchos)*	12-08-77	723	13 (19)

[a] On TRA pond 20 days.

[b] Doses if estimated serving weight of muscle (248 g) were consumed.

[c] Doses if entire muscle mass were consumed (muscle mass assumed to be 50% of total body weight).

Source: Halford et al., 1978.

from mallards is indicated in Table 8.44. Whole-body doses to man from consuming waterfowl from the INEL leaching pond ranged from 17-100 millirems. Bioaccumulation factors for ^{137}Cs for waterfowl are given in Table 3.42.

Many hundreds of ducks have been found on White Oak Lake during 1979. In December 1979, the lake area was drained, exposing the lake bed to these waterfowl. This exposed lake bed seems to attract ducks, increasing the numbers on the lake significantly. Figures 8.10 through 8.12 show flocks of waterfowl inhabiting the lake and mud flats of the lake bed.

8.8 SUMMARY OF PATHWAYS ANALYSIS

In the context of pathways to man, fish and ducks appear to be the most significant carriers of radioactivity from White Oak Lake. Although insects, plants, algae, and small mammals have been shown to contribute radionuclides via the food chain, the direct transfer of radionuclides from these organisms to man does not appear likely.

Sports and commercial fishing activities in Watts Bar Reservoir are susceptible to contaminated White Oak Lake fish. The migratory behavior of ducks that have been observed in and around White Oak Lake provide the possibility of human consumption in areas far removed.

The scenario of human consumption of fish and ducks contaminated by radionuclides from White Oak Lake must be considered as a real possibility, and monitoring should be continued to assure that any significant changes in exposure potential are detected.

ORNL PHOTO 0050-80

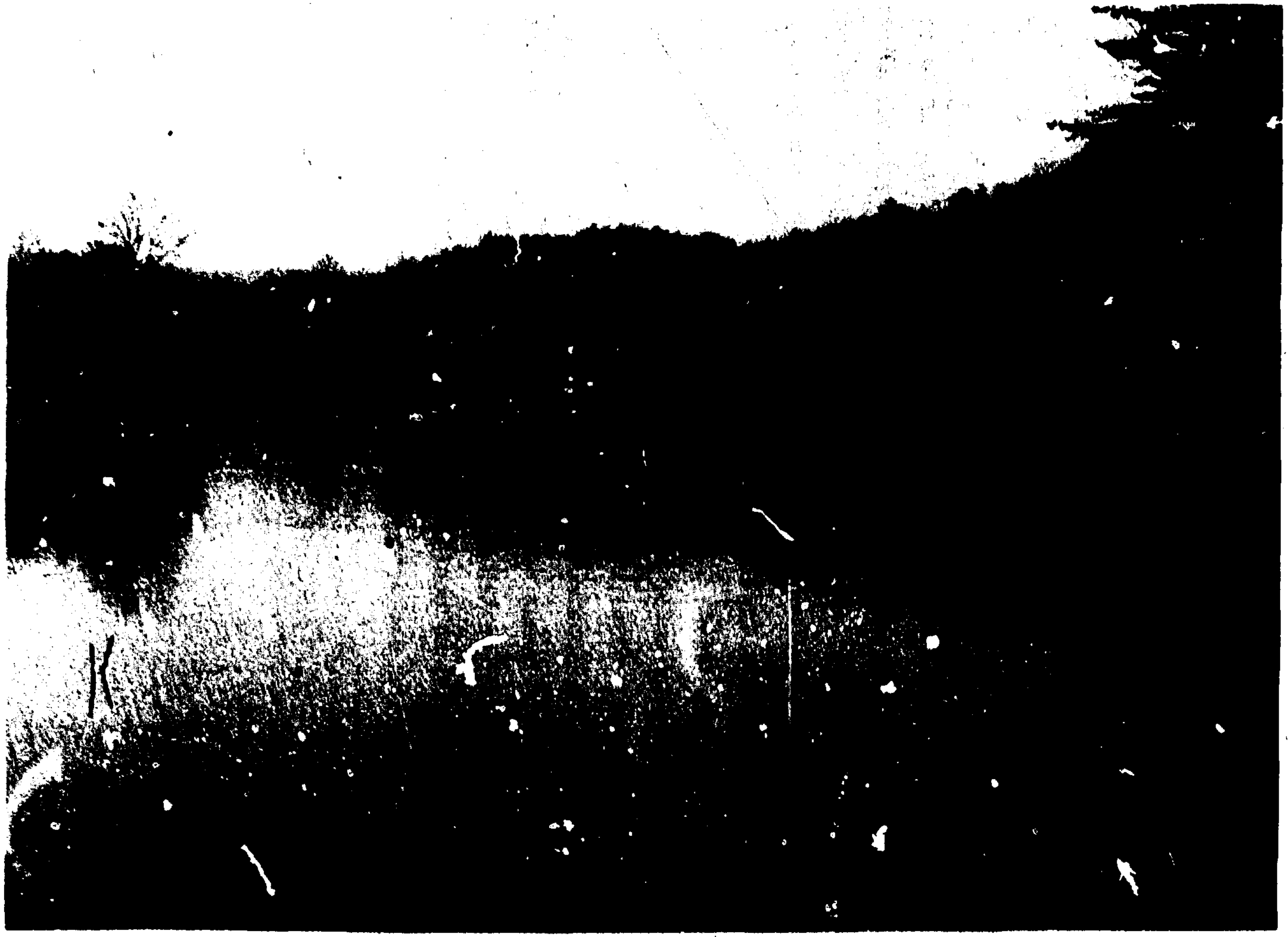

Fig. 8.10. Waterfowl in the vicinity of White Oak Lake, December 1979.

ORNL PHOTO 0034-80

Fig. 8.11. Waterfowl in the vicinity of White Oak Lake, December 1979.

ORNL PHOTO 0036-80

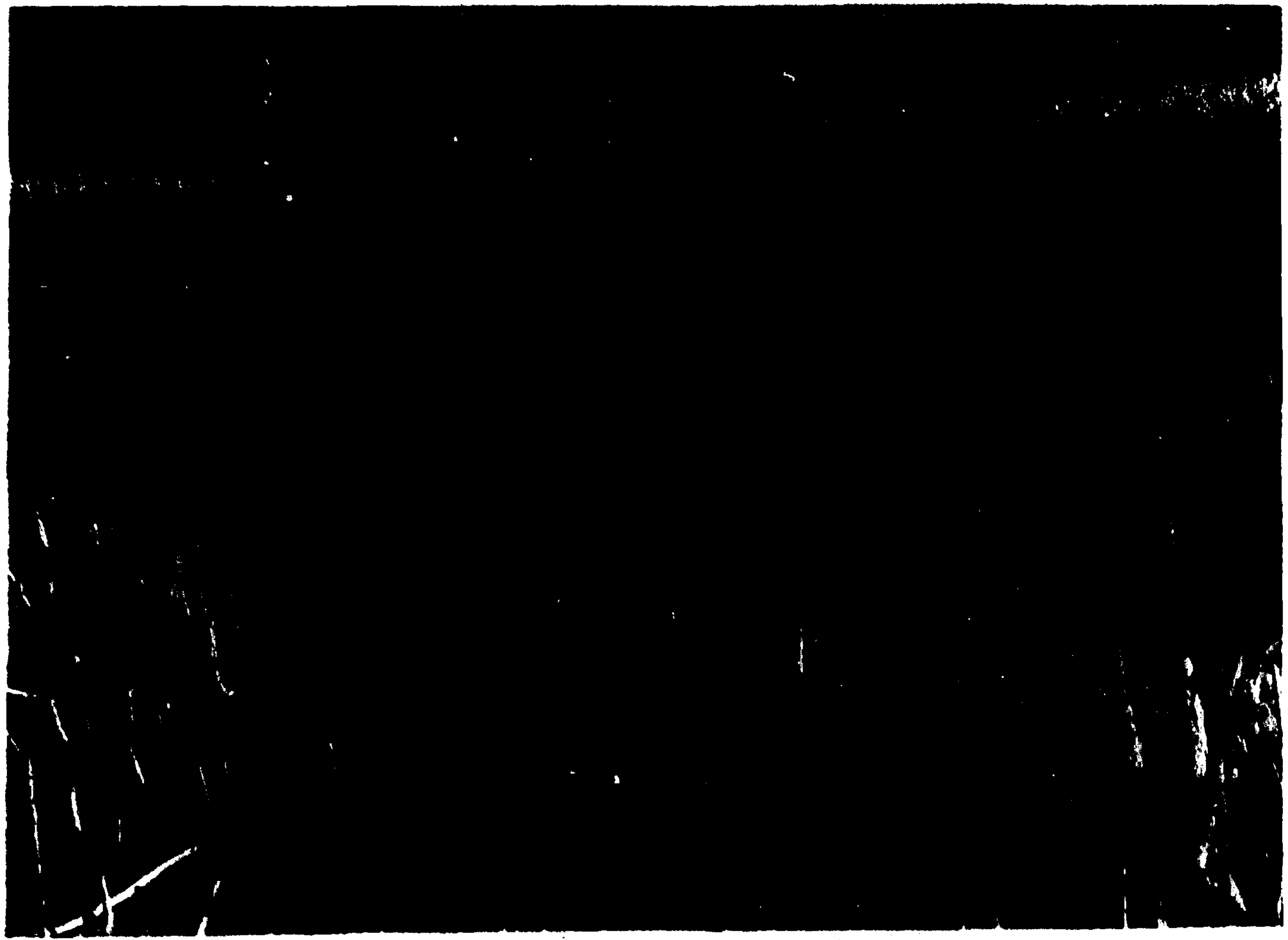

Fig. 8.12. Waterfowl in the vicinity of White Oak Lake, December 1979.

9. RADIOLOGICAL DOSE COMMITMENTS

Fish from White Oak Lake and from the Clinch River near the discharge of White Oak Lake are potentially the food chain's most significant source of radionuclides originating from ORNL liquid discharges. Radionuclides in the water are selectively concentrated by the fish and by the organisms that they feed upon.

The dose commitment to a person depends on many factors. Obviously the quantity of fish eaten and the condition of the waters inhabited by the fish are major factors. For instance, the radionuclide uptake by fish taken from the Clinch River is lessened by the river's dilution of the discharges from White Oak Dam. An exact calculation of dose commitment from eating fish is impossible because of the uncertainty of many of the factors, but the following example will demonstrate how these factors control dose commitment:

$$\text{Dose commitment} = \text{concentration} \times \begin{matrix}\text{sediment}\\ \text{factor}\end{matrix} \times \begin{matrix}\text{Clinch}\\ \text{dilution}^{*}\end{matrix} \times$$

$$\begin{matrix}\text{suspension}\\ \text{factor}\end{matrix} \times \begin{matrix}\text{bioaccumulation}\\ \text{factor}\end{matrix} \times \begin{matrix}\text{fish}\\ \text{consumption}\end{matrix} \times \begin{matrix}\text{dose}\\ \text{conversion}\end{matrix} ,$$

where

$$\text{Concentration} = \frac{\begin{matrix}\text{total activity of nuclide in sediment}\\ \text{and water of White Oak Lake}\end{matrix}}{\text{volume of lake sediment and water}} ,$$

$$\text{sediment factor} = \begin{matrix}\text{fraction of total sediment removed from}\\ \text{lake bed,}\end{matrix}$$

$$\text{clinch dilution}^{*} = \frac{\text{flow of White Oak Creek}}{\begin{matrix}\text{flow of White Oak Creek + flow}\\ \text{of Clinch River}\end{matrix}} ,$$

$$\text{suspension factor} = \begin{matrix}\text{fraction of sediment released which remains}\\ \text{in suspension,}\end{matrix}$$

$$\text{bioaccumulation factor} = \frac{\text{concentration of activity found in fish}}{\begin{matrix}\text{concentration of activity in water and}\\ \text{suspended sediment}\end{matrix}} ,$$

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[*] The least dilution that has been observed has been approximately 1/100. The values are usually between 1/200 and 1/400.

fish consumption = mass of fish eaten during one year,*

dose conversion factor = dose commitment per unit activity consumed.

As an example of how to apply the above formula, assume the following:

Concentration = 1.3×10^{-3} µCi/ml ^{137}Cs.

Sediment fraction = 0.1 (10% of sediment stays in solution).

Bioaccumulation factor = 100 (concentration in fish is 100 times that in the solution).

Fish consumption = 1×10^4 g (100 kg).

Dose conversion factor = 4.32×10^{-2} rem/µCi (the dose commitment to the whole body due to ingesting ^{137}Cs).

Using the above formula for dose commitment and substituting the assumed values,

$$\text{dose commitment} = 1.3 \times 10^{-3}\ \mu\text{Ci/ml} \times 0.1 \times 1/250 \times 0.1$$

$$\times\ 100 \times 10^4\ \text{g} \times 4.32 \times 10^{-2}\ \text{rem}/\mu\text{Ci}$$

$$\times\ 1\ \text{ml} = 2.2 \times 10^{-3}\ \text{rem}\ .$$

The maximum dose commitment that could be postulated for any individual after a total failure of White Oak Dam would result from the consumption of fish released from the lake.

Bluegill taken from White Oak Lake during the year 1979 were analyzed for radioactivity by gamma ray spectrometry and radiochemical analyses. Results indicate that the consumption of 17 kg of fish contaminated at the measured levels would result in a dose commitment to the total body of 5 millirems due to ^{137}Cs and a dose commitment to bone of 170 millirems due to ^{90}Sr. It should be noted that the samples included only muscle and skin of the fish. Had the fish bone been included, the ^{90}Sr analysis results would probably have been 3 to 10 times higher (see Table 8.11 of this report). Bone must be included in the evaluation because commercial fish markets prepare and sell fish patties that include ground bone.

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*The maximum estimated annual consumption is taken as 16.8 kg, which is 2.5 times the national average.

10. NEED FOR A MONITORING SYSTEM AND SPILLWAY IMPROVEMENTS AT WHITE OAK DAM

Present DOE policy (DOEM Chapters 0511, 0513 and 0524) regarding environmental quality calls for the reduction of offsite effluents to "as low as is reasonably achievable." In order to ensure adherence to this stated policy, accurate measurements are needed to determine the quantity and sources of radioactive materials being released to the environment by ORNL.

The functions of the monitoring program at White Oak Dam are numerous. First, the program measures radioactive releases due to facility operation. Second, radioactive seepage trends from the waste disposal areas are monitored. Information provided by these measurements indicates the effectiveness of control systems to limit radioactive release and provides an indication of changes in seepage trends. Other functions of the program include the deduction of environmental pathways and the encouragement of public acceptance. Finally, one of the primary functions of the program is to quantify the releases of radioactive liquid materials to the offsite environment, thereby ensuring that regulating criteria for acceptable population dose are being met.

No environmental monitoring program can be effective without direct knowledge of the effluent constituents and frequency of routine and non-routine effluent discharges. Natural stream flow and discharges from plant operations must be known in order to compute the quantity and rate of radioactivity release to and from the watershed, dilution capacity, rate of transport and retention of contaminants, and protective actions in the event of a large accidental release. This type of information could be used in the operation of ORNL facilities to ensure compliance with legal and environmental constraints.

Accurate data are particularly necessary at White Oak Dam because this site is the final monitoring point before materials leave White Oak Creek watershed and enter the Clinch River, a public access area, a short distance downstream. The sampler at White Oak Dam also measures radioactivity that other onsite sampling stations will not. These additional sources are from burial ground 6 and intermediate liquid waste trenches. Data showing concentrations of ^{90}Sr, ^{137}Cs, and ^{60}Co in the sediments of White Oak Creek and its tributaries are shown in Figs. 10.1, 10.2, and 10.3, respectively (Spalding and Cerling, 1979).

For these reasons, a new weir at White Oak Dam is being constructed to measure accurately the flow over the dam and to permit accurate sampling even during anticipated flood events. In addition, the new weir will provide a useful capability to hold up discharges in the event of a major radionuclide release. This capability could mitigate the consequences of such a release by increasing dilution in the lake and allowing for more response time for emergency personnel to assess recovery operations.

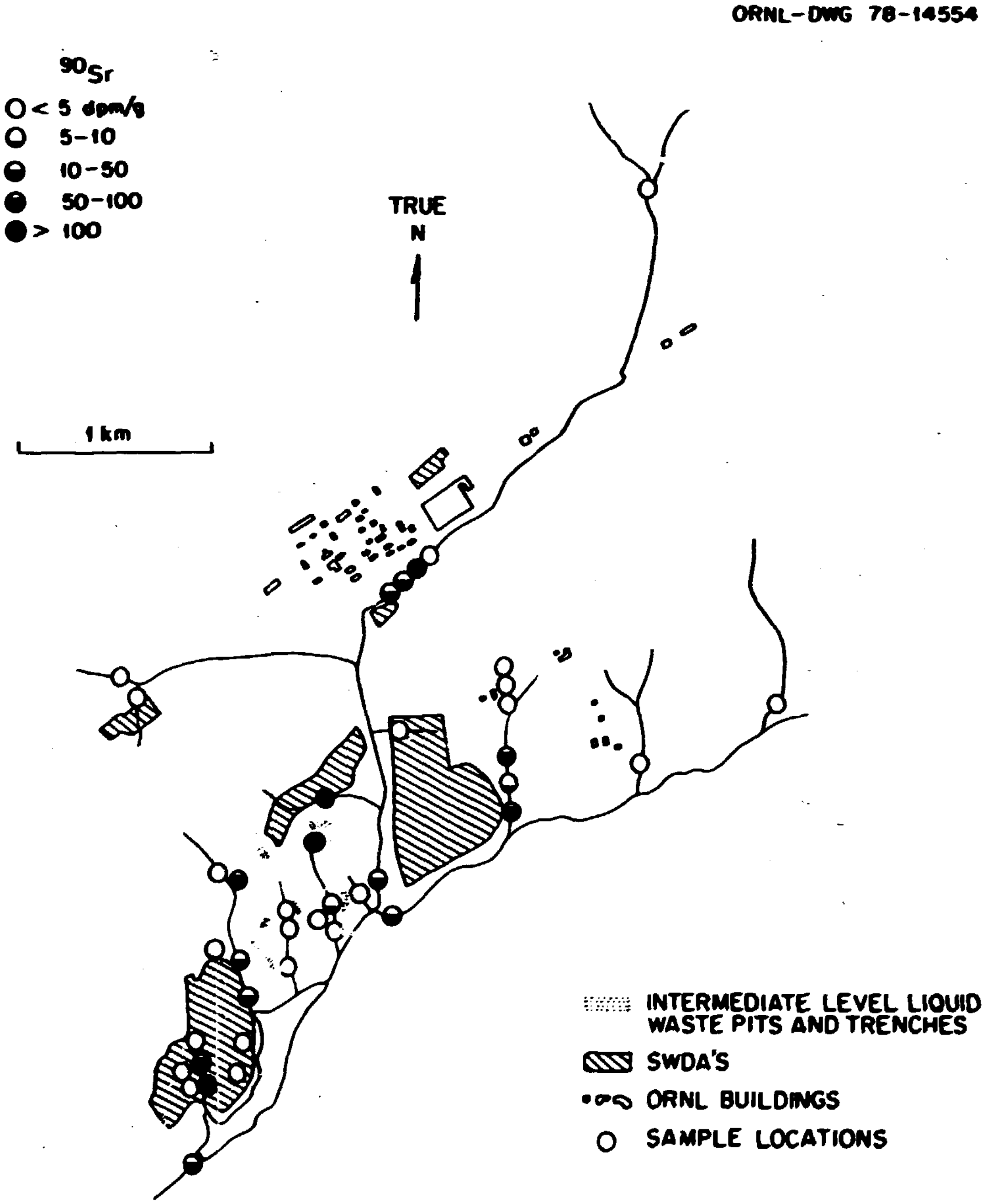

Fig. 10.1 Concentration of ^{90}Sr in the sediment of White Oak Creek and its tributaries.

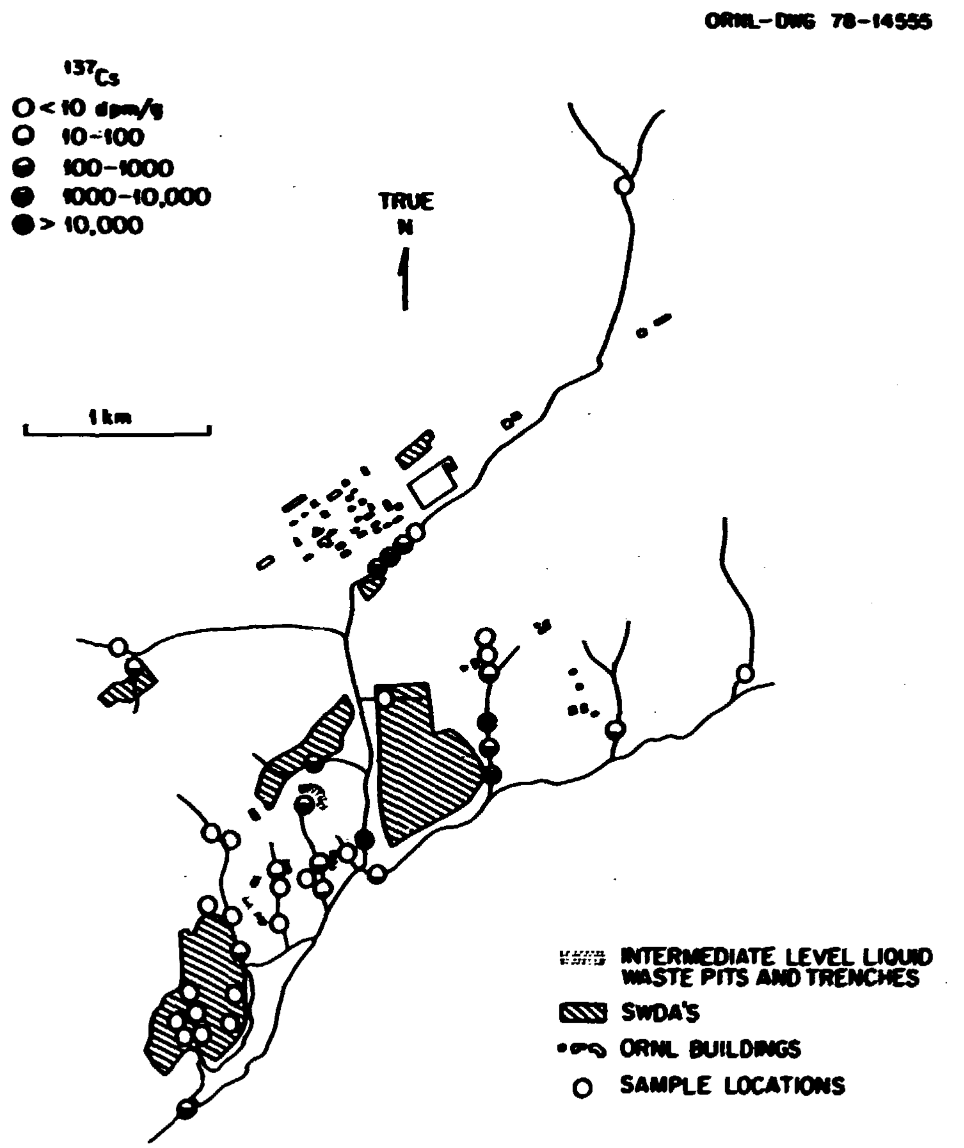

Fig. 10.2. Concentration of ^{137}Cs in the sediment of White Oak Creek and its tributaries.

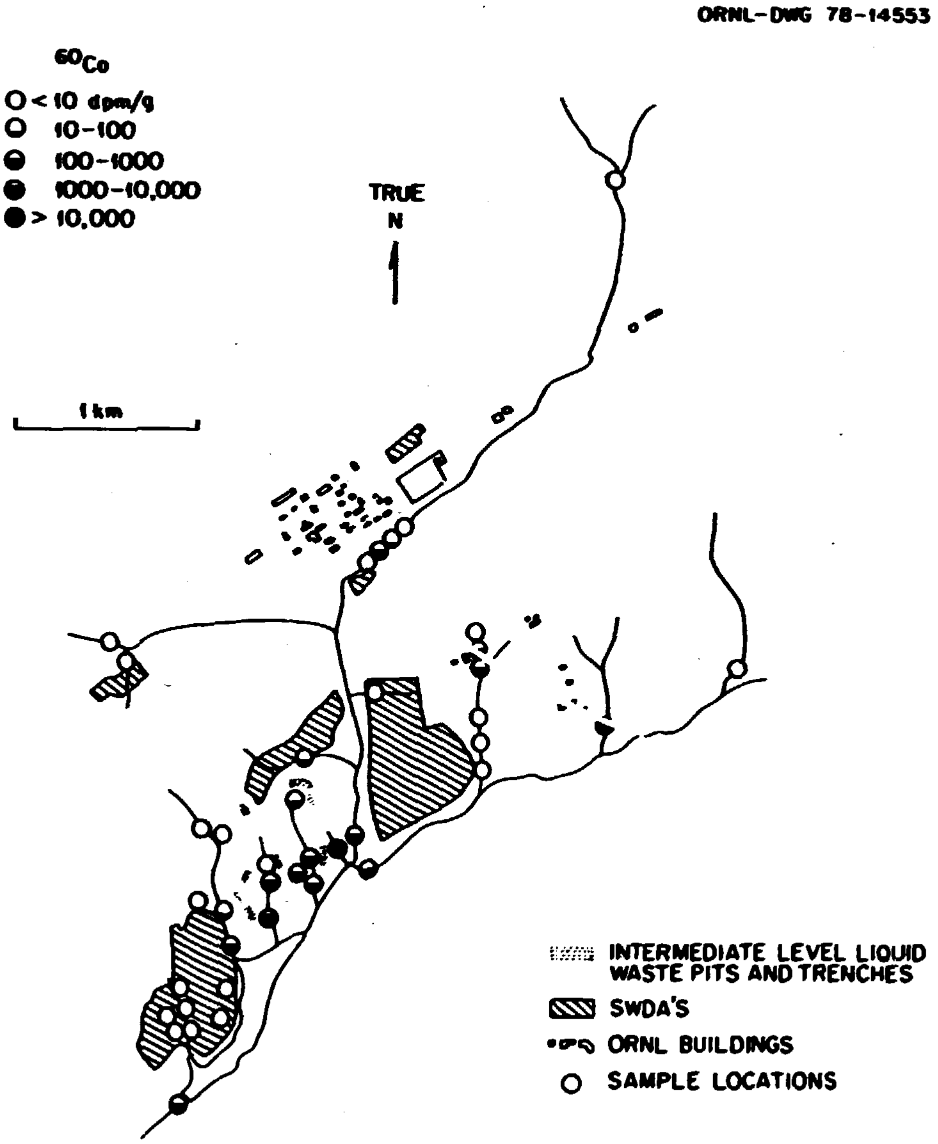

Fig. 10.3. Concentration of ^{60}Co in the sediment of White Oak Creek and its tributaries.

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