DRAFT

# SAFETY ANALYSIS REPORT

# OAK RIDGE GASEOUS DIFFUSION PLANT

# PRE- AND POST-CASCADE

# URANIUM HEXAFLUORIDE HANDLING FACILITIES

August 1977

U. S. ENERGY RESEARCH
AND DEVELOPMENT ADMINISTRATION

#132

# CHAPTER 1
# INTRODUCTION AND GENERAL DESCRIPTION OF THE FACILITIES

This Safety Analysis Report (SAR) covers the procedures, equipment, and facilities required for handling uranium hexafluoride feed material from the time it enters the Oak Ridge Gaseous Diffusion Plant at Oak Ridge, Tennessee, until it is introduced into the enrichment cascade. It also covers the procedures, equipment, and facilities required for handling and storage of the depleted uranium hexafluoride tails and the enriched uranium hexafluoride product from the time these materials are withdrawn from the enrichment process equipment until they are either placed in permanent storage or shipped from the plant.

Background information about the operating Oak Ridge Gaseous Diffusion Plant (ORGDP), a summary description of the plant and its facilities, and a brief description of the processes covered in this SAR are presented in the following portions of this chapter.

## 1.1 Background Information

The primary function of the Oak Ridge Gaseous Diffusion Plant (ORGDP) is the enrichment of uranium hexafluoride in the uranium-235 isotope. This enrichment service is provided to private industry to fuel light water cooled nuclear power reactors. Construction of the ORGDP was begun in 1943, and production by the gaseous diffusion process was started in 1945. The ORGDP is currently one of three government owned plants enriching uranium by the gaseous diffusion process that are operated under the jurisdiction of the Energy Research and Development Administration (ERDA). A second plant is located at Paducah, Kentucky, and the third is near Portsmouth, Ohio.

These three uranium enrichment plants are operated by private corporations under contract with ERDA. The plants in Tennessee and Kentucky are operated by the Nuclear Division of Union Carbide Corporation, and the plant in Ohio is operated by the Goodyear Atomic Division of the Goodyear Tire and Rubber Corporation. The three plants are interrelated to the extent that the slightly enriched uranium hexafluoride product from the Paducah, Kentucky, plant is used as one of the feed materials for the Oak Ridge and Portsmouth plants.

The uranium handled at the ORGDP consists of uranium hexafluoride feed, tails, and product materials. Two types of feed material are generally processed at the ORGDP. They are uranium hexafluoride (yellowcake) manufactured from mined uranium with an assay of 0.711 weight % of U-235, commonly referred to as "normal assay" material, supplied by members of private industry and the slightly enriched uranium hexafluoride product (1.9% U-235) from the Paducah Gaseous Diffusion Plant. In addition, some foreign reactor return material (reprocessed spent fuel from reactors) has been enriched at the ORGDP. Uranium hexafluoride tails (materials depleted in U-235) and the enriched product materials are withdrawn from the process cascade at a rate matching the feed rate.

## 1.2 Facilities Description

The ORGDP is situated on a level 640-acre tract of land in the southwestern portion of the ERDA Oak Ridge Reservation about 13 miles west of the city of Oak Ridge, Tennessee. The ORGDP site is at the southwest and of East Fork Valley near the confluence of Poplar Creek with the Clinch River. Poplar Creek flows from northeast to southwest through approximately the center of the plant area, as indicated in Fig. 1.2-1. The site is bounded on the north by Blair Road, on the west by the Clinch River, and on the south and east by Tennessee Highway 58.

The ORGDP is a complex of production, research, development, and supporting facilities. The principal process facilities are the five gaseous diffusion cascade buildings designated K-25, K-27, K-29, K-31, and K-33. These process buildings are supplemented by about 70 typical diffusion plant administration, service, and maintenance buildings, as indicated in Fig. 1.2-2. Those facilities involved in the uranium hexafluoride handling activities covered by this SAR include the Toll Enrichment Facility in Building K-1423, the Feed Vaporization and Tails Withdrawal Facilities housed in Building K-1131, a small feed area in Building K-33, the Product Withdrawal Facility in Building K-413, the Cylinder Cleaning and Decontamination Facility in Building K-1420, and the cylinder storage areas.

## 1.3 Process Descriptions

Normal assay uranium hexafluoride feed for the diffusion cascade is shipped in cylinders to the Toll Enrichment Facility in Building K-1423, which is the ORGDP receiving and shipping center for private customer owned cylinders. The layout of the Building K-1423 area is shown in Fig. 1.3-1. Functions performed in the Toll Enrichment Facility include weighing of cylinders of uranium hexafluoride feed received from customers, sampling of their contents for analysis, and weighing of empty feed cylinders after their contents have been fed into the diffusion cascade. The uranium hexafluoride product withdrawn from the cascade is also sampled for analysis and transferred to product cylinders at the Toll Enrichment Facility is performed with straddle carriers and forklifts equipped with custom designed lifting fixtures, as shown in Fig. 1.3-2.

The customer owned cylinders of uranium hexafluoride feed that have been weighed, sampled, and certified are transported to the Feed Vaporization Facility in Building K-1131 for vaporization and feeding into the diffusion cascade. Slightly enriched feed from the Paducah Gaseous Diffusion Plant is received in ERDA owned cylinders at Building K-1131. These cylinders are checked, weighed, and sampled at the Feed Vaporization Facility, where their contents are vaporized and fed into the process cascade.

Uranium hexafluoride tails, material depleted in U-235, is withdrawn continuously from the diffusion cascade through heated piping to the Tails Withdrawal Facility in Building K-1131 where it is drainnd as a liquid into cylinders. After cooling and solidification, the tails material is moved to a long term storage yard.

Uranium hexafluoride product is removed from the diffusion cascade through heated piping to the Product Withdrawal Facility in Building K-413 where it is drained as a liquid into ERDA owned product cylinders. After their contents have cooled and solidified, these cylinders are transported to the Toll Enrichment Facility where the product material is sampled and transferred to customer owned cylinders.

Uranium hexafluoride cylinders in service are cleaned routinely in the Cylinder Cleaning and Decontamination Facility in Building K-1420. Each new cylinder to be placed in service is also cleaned thoroughly in this facility.

# CHAPTER 3
# SITE CHARACTERISTICS

The geographical, demographical, meteorological, hydrological, seismological, and geological characteristics of the Oak Ridge Gaseous Diffusion Plant site and surrounding vicinity are described in this chapter. Where appropriate, the site characteristics are discussed with respect to plant safety.

## 3.1 Geography and Demography of Site

The location of the Oak Ridge Gaseous Diffusion Plant is discussed and a description of the site is presented in this section. Information relative to population in the surrounding areas and to the uses of nearby land and water is also presented.

### 3.1.1 Site Location

The Oak Ridge Gaseous Diffusion Plant, known locally as the K-25 Plant, is located in the southwestern portion of the United States Energy Research and Development Administration's Oak Ridge Reservation in Tennessee, as indicated in Fig. 3.1-1. The Energy Research and Development Administration (ERDA) Oak Ridge Reservation currently occupies about 737,000 acres adjacent to the city of Oak Ridge. The eastern and southern boundaries of the reservation are defined by the Melton Hill Reservoir and the Clinch River, and the western boundary is formed by the Clinch River backwaters of the Watts Bar Reservoir on the Tennessee River. Blackoak Ridge and the City of Oak Ridge comprise the northern boundary of the reservation.

About 80% of the ERDA-owned Oak Ridge Reservation lies within Roane County, Tennessee, while the remaining 20% lies to the northeast in Anderson County, Tennessee. As indicated in Fig. 3.1-2, the Oak Ridge Gaseous Diffusion Plant (ORGDP) is located in Roane County, Tennessee. Within a 13-mile radius of the ORGDP, there are five municipalities with a combined population of about 50,000 and portions of five counties (Anderson, Knox, Loudon, Morgan, and Roane) with an overall population of 413,000 (1970 census). As indicated in Fig. 3.1-3, two Tennessee Valley Authority (TVA) lakes, Melton Hill and Watts Bar, adjoin ERDA-owned land near the ORGDP. The dams for both lakes are equipped with a navigation lock and hydroelectric power generating

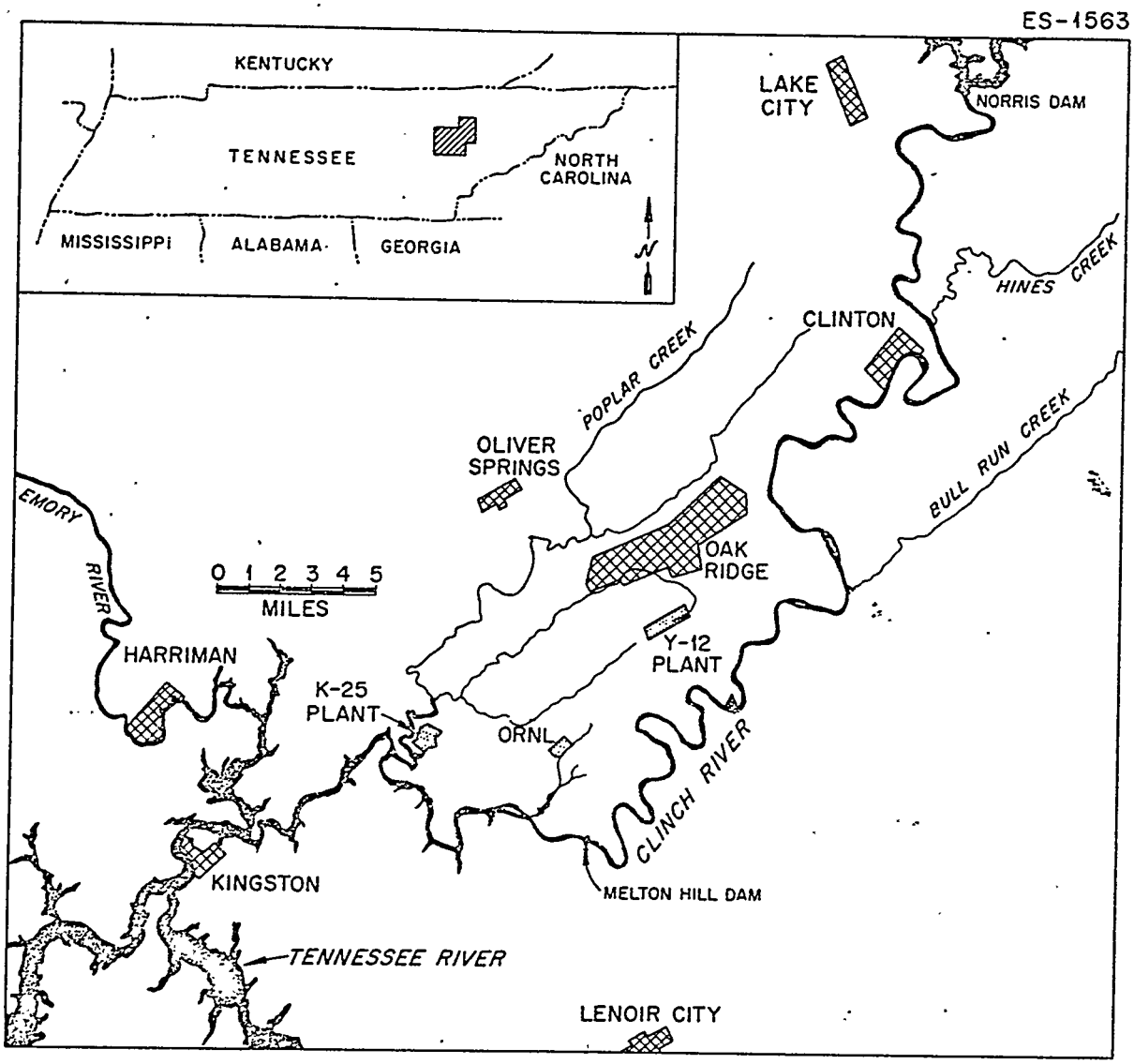


Fig. 3.1-1. United States Energy Research and Development Administration's Oak Ridge Reservation in Tennessee.

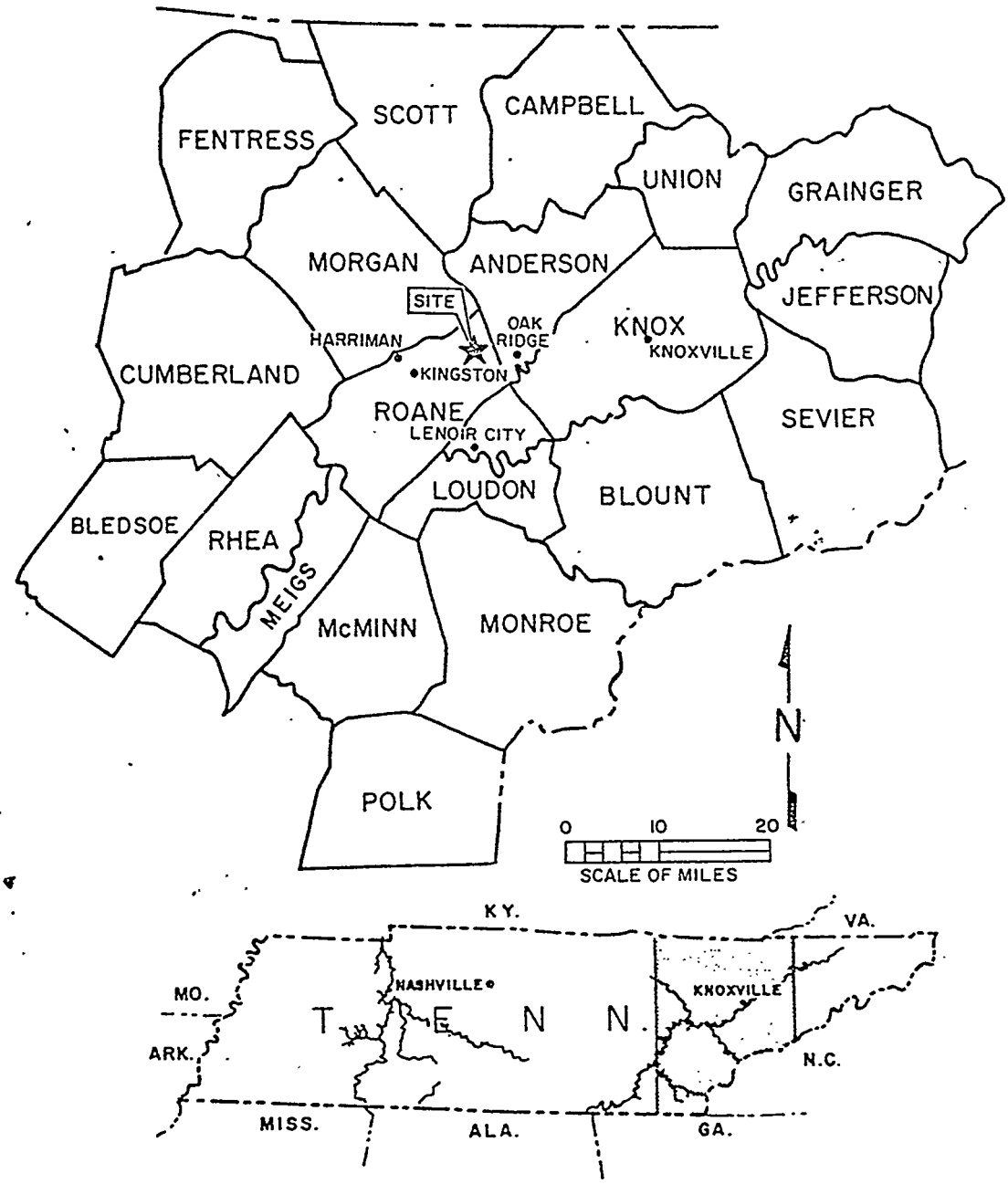


Fig. 3.1-2. Location of the Oak Ridge Gaseous Diffusion Plant With Respect to the State and Adjacent Counties.

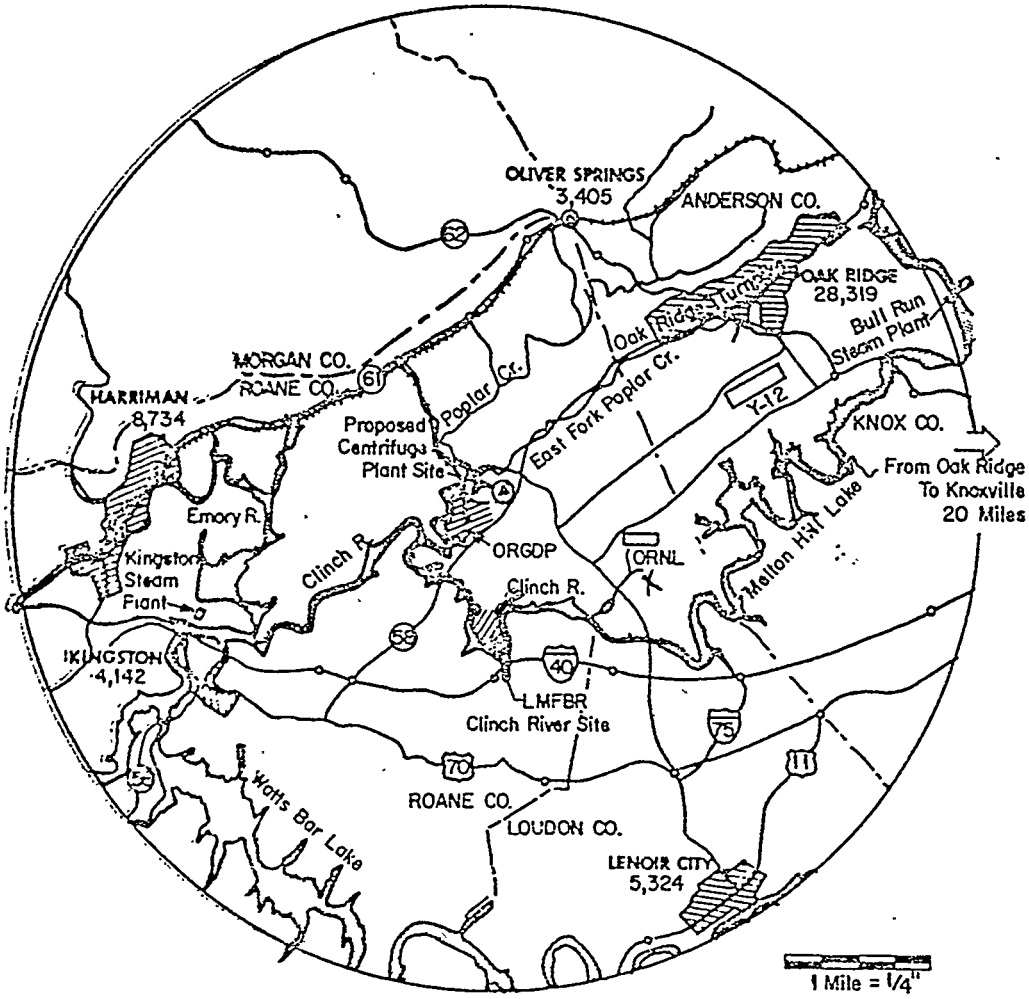


Fig. 3.1-3. Major Features of the Area Within a 13-Mile Radius of the Oak Ridge Gaseous Diffusion Plant.

equipment. The TVA Kingston Steam Plant is within 13 miles of the ORGDP, and the TVA Bull Run Steam Plant is slightly more than 13 miles distant to the northeast. The proposed Clinch River Breeder Reactor site is also within the immediate area.

The ORGDP is about 3 miles from Interstate 40 to the southwest. Access to the plant site is provided by Tennessee Highway 58 from the southwest and northeast and by Blair Road from the north. The Oak Ridge area is served by the Southern and LN Railroads, and the ORGDP site is connected to and served by the Southern Railroad. The ORGDP is also adjacent to the navigable waters of the TVA system that offer commercial shipping and navigation by the Inland Waterway System to the Gulf of Mexico. There are no existing heavy docking and unloading facilities at the present plant site.

The Oak Ridge area is served by the Knoxville Airport which offers regularly scheduled air service to all major cities by five regularly scheduled certified airlines. A well established air freight terminal is also in service. The Knoxville Airport is 44 miles from the Oak Ridge Gaseous Diffusion Plant.

### 3.1.2 Site Description

Physiographically, the Oak Ridge Reservation is considered to be in the western part of the Tennessee section of the Valley and Ridge Subregion of the Appalachian Highlands Physiographic Province. The Appalachian Highlands Province extends from New York to Alabama and varies in width from 20 to 75 miles. Its eastern boundary is the Blue Ridge Front, which contains the highest mountains of Appalachia. The western boundary is formed by the Cumberland Escarpment, which is part of the Appalachian Plateaus Province. The Valley and Ridge Subregion (also referred to as the "newer Appalachians") is confined largely to eastern Tennessee but does include parts of southwestern Virginia and northern Alabama. Thus, it crosses the Tennessee River Bassn.

The Valley and Ridge Subregion is defined by a series of long and narrow ridges intervened by slightly broader valleys with a pronounced northeast-to-southwest trend. The ridges are roughly parallel and fairly evenly topped.[1] The topography of this region reflects the resistance of the underlying geological strata to the forces of weathering. The ridges include relatively resistant sandstones, shales, competent limestones, and cherty dolomites. These rock formations are poor water-bearers and are subjected primarily to mechanical weathering. Conversely, the valleys

consist of weaker shales and more soluble carbonate (limestone) rock that provide the principal water-bearing formations. Therefore, they are acted upon by the combined forces of mechanical and chemical weathering.[2] Hundreds of thousands of years of weathering have produced a topography characterized by the more resistant rocks that maintain the ridges. The less resistant rocks have eroded away to occupy the valley.

The range in altitude within the Oak Ridge Reservation is 741 to 1356 ft above mean sea level, providing a maximum relief of about 600 ft. The highest point of elevation occurs at the peak of Melton Hill, whereas the lowest heights are in the valley regions of the southwestern part of the reservation.[3] The following generalized succession of alternating ridges and valleys occurs in order from the northern end of the reservation to the southern end: Blackoak Ridge, East Fork Valley, East Fork Ridge, Gamble Valley, Pine Ridge, Bear Creek Valley, Chestnut Ridge, Bethel Valley, Haw Ridge, Melton Valley, and Copper Ridge.

The fine topographical features are also indicative of the geology of the area. The ridges underlain by the slightly soluble, cherty dolomite (Copper, Chestnut, and Blackoak) generally have broad, well-rounded or rolling crests. The ridges that rest on bedrock composed of interbedded sandstone and shales (Haw and Pine) tend to have sharper and more pointed crests. Sinkholes are regularly reported wherever limestone and dolomite deposits occur.

The topography of that portion of the Oak Ridge Reservation included within the ORGDP site is illustrated in Fig. 3.1-4. The ORGDP site is encompassed by three ridges: Blackoak Ridge to the north, McKinney Ridge to the west, and Pine Ridge to the south. It lies in the valley of Poplar Creek, which is close to its junction with the Clinch River. The ORGDP is situated on a level, fenced 640-acre tract of land bounded on the north by Blair Road, on the west by the Clinch River, and on the south and east by Tennessee Highway 58. Poplar Creek flows from northeast to southwest through approximately the center of the plant area.

The ORGDP is a complex of production, research, development, and supporting facilities, employing approximately 3000 persons. The primary mission of the plant is the enrichment of uranium hexafluoride in the uranium-235 isotope, and the principal process facilities are the five gaseous diffusion cascade buildings designated K-25, K-27, K-29, K-31, and K-33. These process buildings are supplemented by about 70 typical diffusion plant administration, service, and maintenance buildings that include specialized manufacturing facilities.

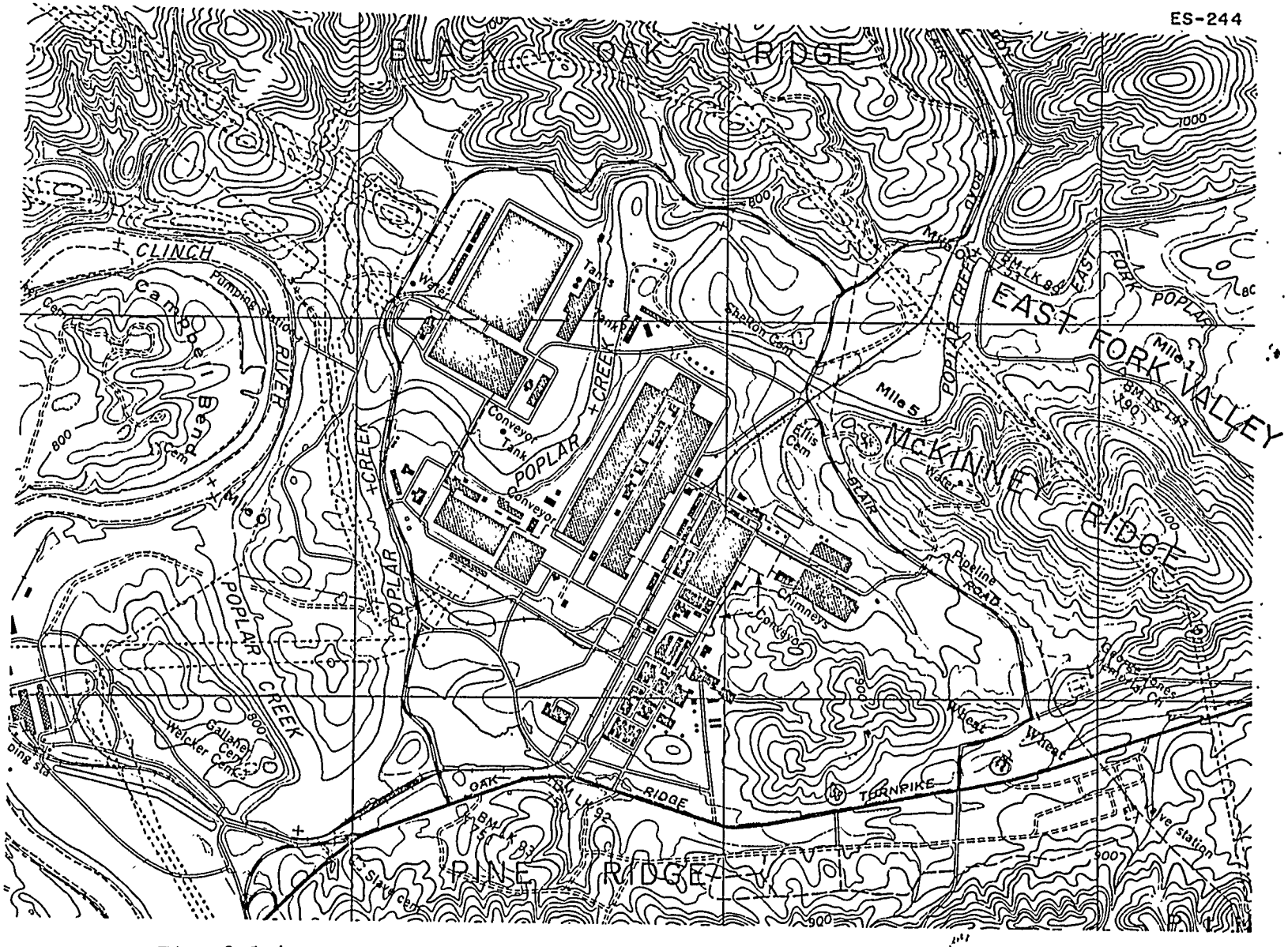


Fig. 3.1-4. Topographical Map of the Oak Ridge Gaseous Diffusion Plant.

The most distinct features of the ORGDP viewed from either Tennessee Highway 58 or Blair Road are the large fluffy plumes of steam that rise above the cooling towers used to cool the plant's process water and the 360-ft-high red and white fire protection water storage tank. A traveler viewing ORGDP from Blair Road (north of the plant) would also see the two 170-ft-high smoke stacks of the plant's steam production facility, while anyone passing by on Highway 58 (south of the plant) would immediately notice the large grassy areas and the lakes that border the front of the plant.

Two areas maintained by, but not located within ORGDP proper, are the old powerhouse area and the sanitary water treatment facility. The powerhouse area was once, as its name implies, the producer of part of the electrical energy requirements of ORGDP. Since these requirements are now met by TVA, the majority of the facilities in this area have been decommissioned. The vacated buildings are now used for salvage storage, training of welders, etc. In addition, the molecular anatomy (MAN) research and development program, which is an Oak Ridge National Laboratory (ORNL) function, is currently located in Building K-702 of the old powerhouse complex. The sanitary water treatment facility (K-1515), located about 1 mile south of the plant proper on Bear Creek Road, consists of typical water treatment equipment, such as settling basins and large concrete storage tanks.

### 3.1.3 Population, Distribution, and Trends

There are no significant concentrations of population within 5 miles of the Oak Ridge Gaseous Diffusion Plant (ORGDP). However, the ORGDP is located about 8 miles west of the westernmost part of the City of Oak Ridge with a population of 28,319 (1970 census).[4] The incorporated limits of the City of Oak Ridge include all of the ERDA controlled land in the immediate vicinity of the ORGDP.

The area surrounding the Oak Ridge Reservation is generally rural to urban in character. For the most part, the rural lands are a mixture of unincorporated communities, suburban home sites, water recreation areas, and small farms devoted to miscellaneous crops and cattle raising. In the northern fringes of this area the pattern changes and includes mountainous and sparsely settled land, some of which is being, or has been devoted to underground or strip mining of coal.

The largest nearby population center is Knoxville, Tennessee, which has a population of about 175,000 persons and is located about 20 miles east of the City of Oak Ridge.

As indicated in Fig. 3.1-3, there are four Tennessee municipalities other than the City of Oak Ridge within a 13-mile radius of the ORGDP. They are Kingston (about 7 miles southwest) with a population of 4142 (1970 census), Lenoir City (about 12 miles southeast) with a population of 5324, Oliver Springs (about 8 miles northeast) with a population of 3405, and Harriman (about 8 miles west) with a population of 8734.

The 1960 and 1970 census data indicate that the rural population within about 10 miles of the ORGDP has remained essentially constant, with the population growth having taken place in and around the existing urban centers. This trend is expected to continue through the year 2000 with a projected[5] increase of about 44.5% in urban population within approximately 10 miles of the ORGDP.

Other than that occasioned by industrial activities, most of the transient population within about 10 miles of the ORGDP is engaged in recreation activities such as camping, fishing, boating, swimming, and attending stock car races.

### 3.1.4 Uses of Nearby Land and Waters

The region within a 5-mile radius of the ORGDP encompasses residential, farm, recreation, and industrial areas as well as the ERDA-owned land in the Oak Ridge Reservation. There are no airports within the 5-mile radius of the site, and the area industries are discussed in Section 3.2. There is no mineral production within the 5-mile radius of the ORGDP. However, mineral production, primarily in the form of strip mining of coal, does play an important role in the adjacent area, particularly in Morgan County.

Schools are the only public facilities located within a 5-mile radius of the ORGDP. They are the Roane County School System schools of Edgewood (grades 1 through 6) with a 1973 enrollment of 110, Cherokee (grades 1 through 6) with a 1973 enrollment of 294, Dyllis (grades 1 through 8) with a 1973 enrollment of 211, and Emory (grades 1 through 8) with a 1973 enrollment of 118 students.[6]

There are approximately 18 recreation sites within a 5-mile radius of the ORGDP.[6] These sites include the visitor's overlook at the ORGDP; the Graphite Reactor at Oak Ridge National Laboratory; two commercial campgrounds with facilities for fishing, boating, and swimming; and a track for stock car racing.[6] The remaining sites are lake public access and incidental use areas. The number of people at these sites with a 5-mile radius of the ORGDP during peak

hour use (assumed to be July 4) was estimated[6] to total 5830 in 1970. The total projjcted[6] for the year 2000 is 8570, an increase of about 47%. Although no quantification of recreational use, such as swimming, fishing, and localized recreational boating, is available, recreational interaction with water is assumed for the sites located along waterways.

### 3.1.4.1 Agriculture

In general, farming in east Tennessee has followed the national trend of a steadily decreasing number of farms with the remaining farms increasing in average size.[6] Because more off-farm employment opportunities exist now than in the past, the trend has been to shift from dairy cows and other forms of farming to raising beef cattle which requires much less labor. There are three dairy farms within a 5-mile radius of the ORGDP. They are in Roane County. One has a livestock population of 45, while each of the other two has a population of 50 animals.[6] Although some grains produced outside of the immediate area are used to supplement their diet, the dairy cows on the farm nearest the site are allowed to graze outside all year.[6]

During a survey conducted in the spring of 1974 by personnel of Project Management Corporation,[6] approximately 475 beef cattle were counted within 5 miles of the proposed Clinch River Breeder Reactor Plant site, which is about 3 miles south of the ORGDP. Interspersed with the beef cattle were 61 milk cows. Agricultural crops were reported[6] as being grown on scattered small plots for single family use.

### 3.1.4.2 Surface water use

Major surface water uses in the Oak Ridge area include withdrawals for industrial and public water supplies, commercial and recreational water traffic, and other recreational activities such as swimming and fishing. The Clinch River, adjacent to the ORGDP, is a component of the Inland Waterway System which permits commercial navigation to the Gulf of Mexico. Commercial traffic locked through Melton Hill Dam amounted to 3600 tons (3268 metric tons) in 1972.[6] In addition, 761 recreational craft passed through Melton Hill Dam in 1972.[6]

No quantitative data are currently available on the number or amount of fish caught in this region by sport fishermen for human consumption. Only two game fish are well represented in the area waters. They are Sauger and the White Bass.[6] Forage and rough fish dominate in both numbers and biomass. Although Watts Bar Reservoir produced a commercial fish harvest of nearly 95,000 lb in 1973, catches within about a 10-mile radius of the site amounted

to only 1% of this total.[6]

Currently, the major surface water withdrawals from the Clinch River within a 5-mile radius of the ORGDP for industrial use are for ERDA Oak Ridge Operations. Approximately 5.5 million gallons a day (Mgd) are withdrawn to supply the ORGDP cooling towers and about 2.5 Mgd are withdrawn to supply potable water to the ORGDP. Water withdrawals for industrial supplies within approximately 20 miles of the ORGDP are given in Table 3.1-1. Industrial expansion in the area will increase water withdrawal, and the Clinch River Breeder Reactor Plant, projected to begin operation in 1987, will require 10.2 Mgd of water to be withdrawn at Clinch River Mile 17.7, of which 6.3 Mgd would be consumed during operation at a 100% load factor.[6]

There are 11 public water supplies withdrawing water from surface sources within about 20 miles of the ORGDP. Public water supplies that could be influenced by Clinch River water flowing past the ORGDP include that of the city of Rockwood, Tennessee, which has an auxiliary public water intake located on the King Creek embayment of Watts Bar Reservoir where the potential for reverse flow exists. Under certain conditions, Clinch River water could flow upstream in the Emory River with the potential of affecting the Cumberland Utilities District surface water intake on the Little Emory River and the Harriman water supply intake in the Emory River. The public water supplies and their sources within about 20 miles of the ORGDP are given in Table 3.1-2.

3.1.4.3 Groundwater use

As indicated in Table 3.1-2, there are 17 public water supplies drawing water from wells and springs within approximately 20 miles of the ORGDP. Two of these groundwater sources are within a 5-mile radius of the ORGDP. They are the Edgewood Elementary School and the Cumberland Utility District of Roane and Morgan Counties. Eight of the industrial supplies within about 20 miles of the ORGDP are also using groundwater sources, as indicated in Table 3.1-1. As well as those industrial and public water supplies given in Tables 3.1-1 and 3.1-2, groundwater use within an approximate 20-mile radius of the ORGDP includes a large number of individual and multi-unit domestic wells, generally of small capacity. Much of the development in the area has been rural residential, and it has not been economicaaly feasible to use public water supplies for every residence.

The Clinch River is the major groundwater sink for the area. Discharge from the aquifer system at the ORGDP site flows directly into the river or its tributaries; that is,

Table 3.1-1. Industrial Water Supplies Within Approximately 20 Miles of the Oak Ridge Gaseous Diffusion Plant[a]

| Supply | Average Daily Use (gallons) | Source |
|---|---|---|
| ERDA[b] [26] | 2,500,000[c] [14] | Surface, Clinch River Mile 14.4[16] [22] |
| ERDA[b] | 5,500,000[d] [14] | Surface, Clinch River Mile 11.5 |
| TVA Kingston Steam Plant[24] | 1,400,000,000[e] | Surface, Emory River Mile 1.5 |
| Lenoir City Car Works | 30,000[e] | Ground, well |
| The Mead Corporation | 2,900,000 | Surface, Emory River Mile 11.4 |
| Charles H. Bacon Company[24] | 255,000[e] | Ground, well |
| Union Carbide Corporation[25] | 2,000,000[e] | Surface, Tennessee River, and ground, spring |
| Charles H. Bacon Company | 300,000[e] | Surface, Tennessee River, and ground, spring[18] [19] |
| ERDA[b] | 22,000,000[f] | Surface, Clinch River Mile 41.5 |
| Ralph Rogers Company, Inc.[26] | 24,000 | Ground, well |
| CNO & TP Railway | 27,000[e] | Surface, Emory River Mile 13.8 |
| A.B. Long Quarries | 1,500,000 | Surface, Emory River |
| John J. Craig Company | 34,600 | Surface, small stream, and ground, well[22] |
| Philadelphia Hosiery Mills[26] | 28,000 | Ground, well |
| TVA Bull Run Steam Plant[24] | 572,000,000[e] | Surface, Clinch River Mile 47.6 |
| Morgan Apparel Company | 3,000 | Ground, well |

[a] Source: Project Management Corporation and Tennessee Valley Authority.

[b] ERDA = Energy Research and Development Administration.

[c] Potable water only.

[d] Daily makeup for ORGDP cooling towers.

[e] Supply also used for potable water within the plant.

20 miles of the Oak Ridge Gaseous Diffusion Plant[a]

| Supply | Population Served | Average Daily Use (gallons) | Source |
|---|---|---|---|
| Edgewood Elementary School[18] | 196 | 4,900 | Ground, well |
| Cumberland Utility District of Roane and Morgan Counties[18,20] | 5,000 | 212,000 | Ground, spring[b] |
| Dixie-Lee Utility District[c] | 4,500 | 395,000 | Ground, spring |
| Kingston | 5,000 | 315,000 | Ground, spring[d] |
| Lenoir City | 6,500 | 995,000 | Surface, Tennessee River Mile 601.3[18] |
| Midtown | 2,090 | 130,000 | Ground, well |
| Harriman[e] | 10,000 | 2,359,000 | Surface, Emory River Mile 12.9 |
| Loudon | 5,000 | 489,000 | Ground, spring |
| Piney Utility District[22] | 2,000 | 75,000 | Ground, spring |
| Paint Rock Elementary School | 250 | 6,200 | Ground, well |
| Midway High School | 515 | 12,900 | Ground, spring |
| Olivin Springs | 3,570 | 188,000 | Ground, spring |
| First Utility District of Knox County | 10,500 | 1,051,000 | Surface, Sinking Creek Embayment |
| West Knox Utility District | 18,000 | 1,000,000 | Surface, Clinch River Mile 46.9, and ground, spring[20] |
| Dutch Valley Elementary School | 140 | 3,500 | Ground, well |
| First Utility District of Anderson County | 3,600 | 270,000 | Ground, spring |
| Hallsdale-Powell Utility District | 22,000 | 1,500,000[f] | Surface, Bull Run Creek Embayment |
| Plateau Utility District | 1,900 | 100,000 | Ground, well |
| Brushy Mountain State Honor Farm | 195 | 69,000 | Ground, well |
| Rockwood | 5,500 | 1,200,000 | Ground, spring and surface, Kuy Creek Embayment |
| Clinton Utility Board | 17,000 | 820,000 | Surface, Clinch River Mile 59 |
| Sweetwater | 5,100 | 700,000 | Ground, spring and surface, Sweetwater Creek |

[a] Source: Project Management Corporation and Tennessee Valley Authority.
[b] Also has auxiliary water intake at Little Emory River Mile 3.9.
[c] Includes Martel Utility District.
[d] Also has auxiliary water intake at Tennessee River Mile 568.2.
[e] Includes Swan Pond Utility District.
[f] Includes water withdrawn from sources outside the 20-mile radius.

Bear Creek and Poplar Creek. Because the incised meander of the Clinch River is a major topographic feature set in bedrock,[7] no significant groundwater flow is likely to pass beneath the river. No groundwater wells are located where they could potentially intercept seepages from the ORGDP site before discharge into the Clinch River system.

## 3.2 Nearby Industrial, Transportation, and Military Activities

Nuclear facilities and activities within a 20-mile radius of the Oak Ridge Gaseous Diffusion Plant (ORGDP) and non-nuclear activities within a 5-mile radius of the ORGDP are discussed in the following subsections.

### 3.2.1 Nuclear

The two major nuclear-oriented facilities within a 20-mile radius of the ORGDP are the Y-12 Plant, about 8 miles northeast, and Oak Ridge National Laboratory, about 4 miles southeast, both of which are within the boundaries of the ERDA Oak Ridge Reservation. The Y-12 Plant employs about 5400 persons for those activities necessary to produce components for nuclear weapons and to provide fabrication support for ERDA weapons design laboratories. Oak Ridge National Laboratory is a research and development installation that employs about 4500 people engaged in reactor and chemical technology, radiation effects, controlled fusion, and many other basic and applied research activities and supportive functions.

One small nuclear-related industry is located on a 33-acre tract in the Clinch River Consolidated Industrial Park about 1.5 miles south of the ORGDP. This industry, U. S. Nuclear, Inc., fabricates neutron absorbers for power reactors and fuel elements for test reactors and employs about 95 people.

In addition, the 1364-acre site of the proposed Clinch River Breeder Reactor Plant is approximately 3 miles south of the ORGDP, and the 100-acre site of the proposed Exxon Nuclear Fuel Recovery and Recycling Center is about 1.5 miles southeast of the ORGDP. The latter site is within the perimeter of the ERDA-operated Oak Ridge Reservation.

### 3.2.2 Non-Nuclear

There are no known non-nuclear industrial organizations operating within a 5-mile radius of the ORGDP. The TVA Kingston Steam Plant is located about 7.5 miles southwest of the ORGDP. The Kingston Steam Plant is a fossil-fired electric power generating plant with an installed capacity of 1700 kW. It employs about 500 persons and is a major supplier of power tc the ORGDP. The TVA Melton Hill Dam is located about 8 miles southeast of the ORGDP. The Melton Hill Dam provides hydroelectric power to the TVA system and extends navigation up the Clinch River. A small crew attends the locks but the power unit operates unattended.

One major highway, Interstate 40, passes about 4.25 miles south of the ORGDP. The closest interchanges on I-40 are with State Route 58, about 5 miles southwest of the ORGDP, and State Route 95, about 6 miles southeast of the ORGDP. Existing data indicate that the average daily traffic at the interchange of I-40 and State Route 58 is 17,530 vehicles, while that at the interchange of I-40 and State Route 95 is 14,680 (Ref. 6).

The closest major main rail line is Harriman Junction, which is approximately 9 miles west of the ORGDP. It is served by the Cincinnati, New Orleans, and Texas Pacific (CNOGTP) Railroad and the Southern Railway System, which also has a spur to the ORGDP. There are no airports within a 5-mile radius of the ORGDP. Oak Ridge Air Park (sport) is located about 9 miles northeast of the ORGDP, Meadowlake Air Park (sport) about 13 miles southwest, and Rockwood Municipal (business and sport) is located about 20 miles west of the ORGDP. McGhee-Tyson is the only airport near the site with scheduled commercial flights. It is located outside Knoxville, Tennessee, about 26 miles southeast of the ORGDP. The nearest flight path is about 13 miles south of the ORGDP, and aircraft approaching McGhee-Tyson would be at a minimum altitude of 5000 ft as they pass south of the site.[6] The nearest holding pattern for McGhee-Tyson is approximately 28 miles northeast of the ORGDP.

There are no military facilities or bases within a 5-mile radius of the ORGDP.

## 3.3 Meteorology

The general climatic characteristics of the region in which the Oak Ridge Reservation is located as well as those local to the area are discussed in the following subsections.

### 3.3.1 Regional Climatology

The climatology of the Oak Ridge area reflects primarily its topography. Because the "Great Valley" (which includes the Valley and Ridge Physiographic Province and the Tennessee River Basin) is nestled between two great mountain ranges, the Appalachians and the Cumberlands, its weather patterns are localized within the lowlands and are generally unlike those that occur in the more mountainous segments of the southeastern United States. Storm tracks and prevailing wind regimes travel predominantly in a northeast to southwest line, both upvalley and downvalley, alignnd with the parallel ridges that were trust-faulted in a similar direction. Intense, highly confined storms of short duration occur frequently within the area, especially at points of topographical discontinuity because of the production of significant barometric gradients.

A climograph (plot of temperature against precipitation) for the Oak Ridge area[8] is given in Fig. 3.3-1. Heavy precipitation occurs in both winter and summer months, whereas spring and autumn are comparatively dry. Only under unusual conditions is snowfall a significant portion of the precipitation. Average temperatures are in the moderate range 40 to 80 degrees Fahrenheit. Extreme temperatures, both hot and cold, are relatively uncommon because of the moderating influences of the adjacent mountain ranges.

A climatic classification scheme based on the water balance of different geographical regions was developed by Thornwaite,[9] who classified the Oak Ridge area as humid subtropical. A graph of water flow as a function of season for such a climatic region is shown in Fig. 3.3-2 in which a soil moisture capacity of 12 in. was assumed. The dotted line slightly skewed to the later summer months represents the precipitation input which, as previously described, generally rises and declines in alternate quarters. The solid bell-shaped curve portrays the hydrological output, which in vegetated areas is largely a function of plant metabolism and accompanying evapotranspiration losses. Obviously, plant photosynthetic activity will be at a maximum in summer months and a minimum in winter months. This diagram indicates that the low frequency of precipitation during May and June may become critical for plant life. However, recharge by the frequent rain storms that commonly occur in July and August is usually sufficient to overcome this drought stress and to produce conditions very adequate for agriculture.

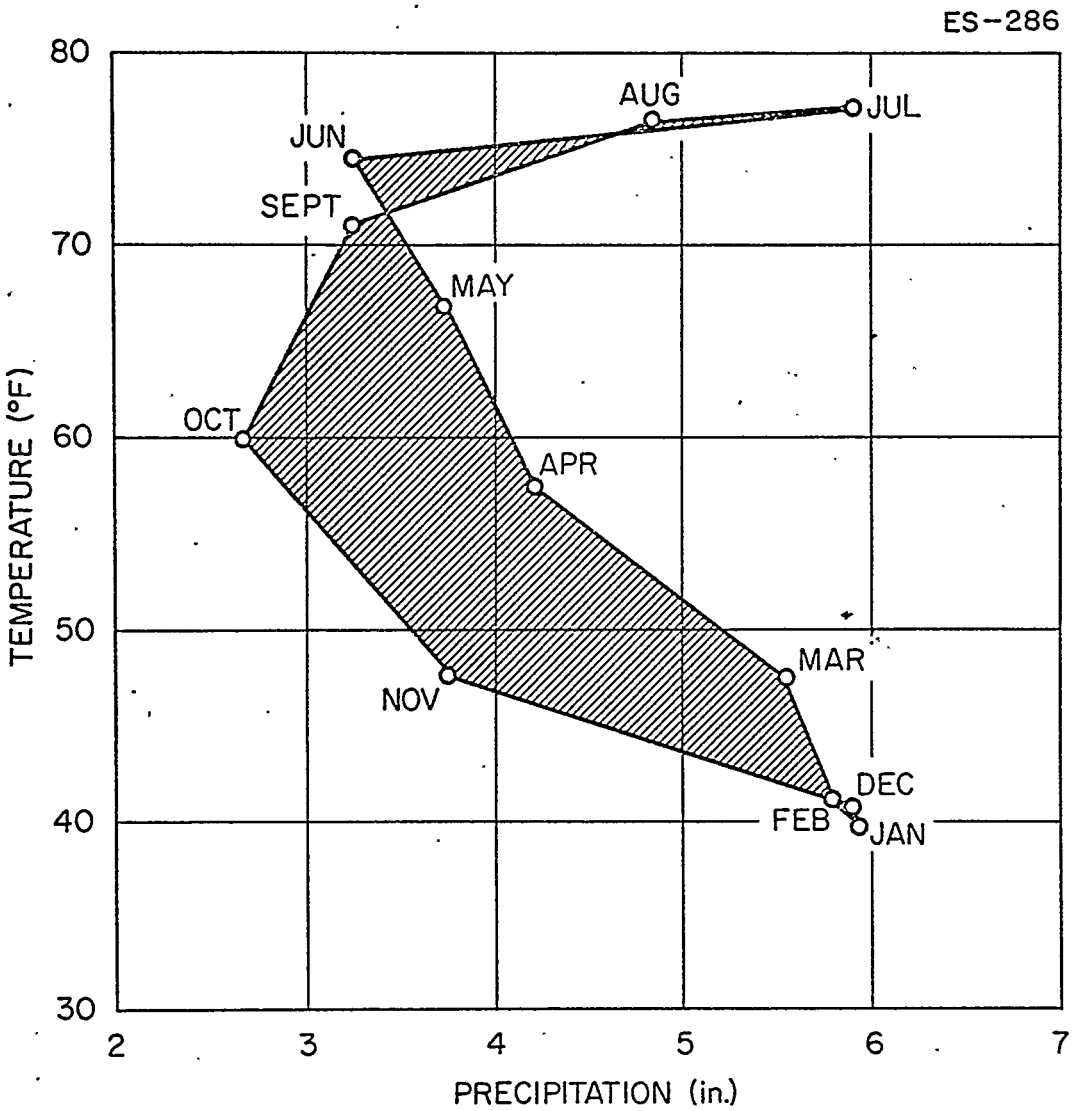


Fig. 3.3-1. Climograph of the Oak Ridge Area.
SOURCE: J. W. Curlin and D. J. Nelson, "Walker Branch Watershed Project: Objectives, Facilities and Ecological Characteristics," USAEC Report ORNL-TM-2271, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September 1968.

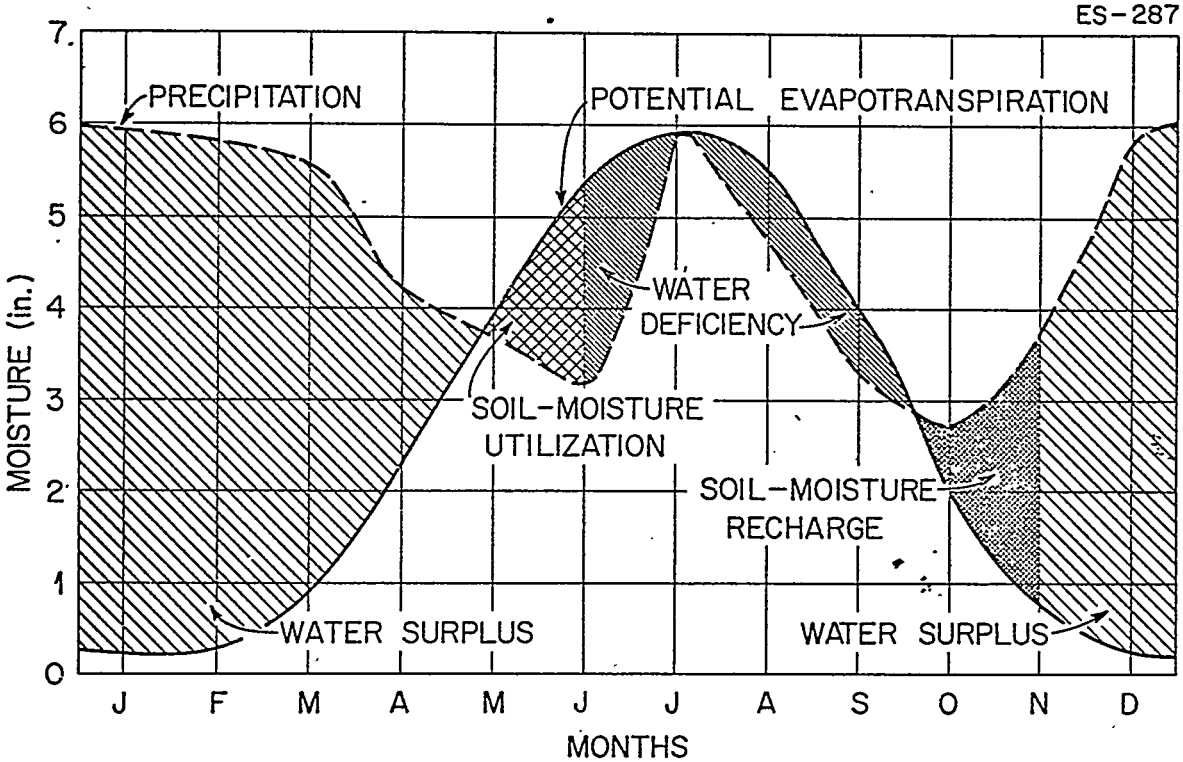


Fig. 3.3-2. Generalized Water Balance Scheme for Humid, Subtropical Climatic Regions Such As the Oak Ridge Area.

SOURCE: J. W. Curlin and D. J. Nelson, "Walker Branch Watershed Project: Objectives, Facilities and Ecological Characteristics," USAEC Report ORNL-TM-2271, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September 1968.

No unique climatic features differentiate weather on the Oak Ridge Reservation from other humid southern Appalachian regions. Humidity varies with wind direction, generally being lowest with northeast winds and highest with southeasterly to southwesterly winds. Relative humidity is lowest in the afternoons and highest at night. Average annual humidity in Tennessee is near 70%.[10] This is about average for most of the United States east of the 95th meridian. Florida, the Gulf Coast, and the Atlantic Seaboard have higher humidities than eastern Tennessee, whereas the mountains and desert regions of the western United States have less humidity.

### 3.3.2 Local Conditions

Prior to the advent of the Manhattan Engineering District's projects, no meteorological records were maintained in the Oak Ridge area. ~~However,~~ climatological data have been recorded in Knoxville since 1871 by the Signal Corps and later by the U.S. Weather Bureau, which was created in 1891. The major Knoxville office is now located at McGhee-Tyson Airport about 20 miles southeast of the reservation. More distant regional meteorological stations include those of Chattanooga, Tennessee; Bristol, Tennessee; Smithville, Tennessee; Asheville, North Carolina; and Rome, Georgia.

Weather recording instruments were installed initially on the Oak Ridge Reservation at the X-10 site (Oak Ridge National Laboratory) in conjunction with the start-up of the "Clinton Pile," now known as the Graphite Reactor, to monitor airborne radioactive wastes. The weather stations at the Y-12 Plant and at the ORGDP (K-25) were created shortly after operations were initiated at these two plants. In 1947, the Oak Ridge stations were designated as official U.S. Weather Bureau Cooperative Offices. Meteorological data from the City of Oak Ridge were incorporated into the program in 1948, and a final recording facility was established in the late 1950s at the Tower Shielding Facility (TSF). Weather records of the Oak Ridge Bureau are now administered by the National Oceanic and Atmospheric Administration's (NOAA) Atmospheric and Turbulence Diffusion Laboratory (ATDL) within the City of Oak Ridge.

The data recorded at the Oak Ridge area weather stations have been analyzed, and the results of those analyses are summarized in three reports. One of these reports contains the results of a detailed analysis by the U.S. Weather Bureau[11] of the parameters that affected the weather in the Oak Ridge area during the period 1948 to 1952. This repoot was updated with the results of a

supplemental analysis reported[12] by Hilsmeier in 1963. Climatological data obtained during the period from 1951 through 1971 are reported but not analyzed in a 1972 publication[13] of the ATDL. These and other data relative to local temperature, precipitation, and wind and stability conditions are discussed in the following paragraphs.

### 3.3.2.1 Temperature

Minimum, maximum, and average monthly temperatures calculated from data collected during the 1951-to-1971 period of record are given in Table 3.3-1. Curves for predicting the probability of the occurrence of a given temperature during a season are shown in Fig. 3.3-3. The daily temperature figures, indicative of the temperatures experienced on the Oak Ridge Reservation, range from a minimum of -9 degrees Fahrenheit in January to a maximum of 105 degrees Fahrenheit in July, with the annual average being 57.9 degrees Fahrenheit. However, temperature distribution curves display a strong central tendency, with temperatures above 100 degrees Fahrenheit or below 0 degrees Fahrenheit being relatively rare events that have occurred in less than half of the 20 years of record. Average temperatures increase steadily from the coldest month (January) to the warmest month (July) and decline uniformly again to winter lows. Significant secondary maxima and minima are not evident during the spring and fall seasons; thus, the yearly temperature distribution is about biomodal. Mean temperatures are very uniform across the entire width of the Valley and Ridge Province terrain; a condition that is very unusual for such a wide range of latitude.

Data on vertical temperature gradients, obtained by simultaneous measurement of the temperatures at ground and tower elevations, were used by Hilsmeier to calculate the percentage frequency of inversion conditions as a function of total hours for the four seasons.[12] These calculated frequencies, given in the following tabulation, indicate that inversion conditions occur about one-third of the time throughout the year.

| Season | Freq (%) |
|---|---|
| Winter | 31.8 |
| Spring | 35.1 |
| Summer | 35.1 |
| Autumn | 42.5 |
| Annual | 35.9 |

Table 3.3-1. Average Monthly Temperatures and Solar Radiation for the Oak Ridge Area From January 1951 Through December 1971

| Month | Temperature (°F) | | | Solar radiation (kcal $cm^{-2}$ $mo^{-1}$) |
|---|---|---|---|---|
| | Maximum | Minimum | Average | |
| January | 47.0 | 28.8 | 37.9 | 5.6 |
| February | 51.2 | 30.6 | 40.9 | 6.7 |
| March | 58.7 | 36.3 | 47.5 | 10.1 |
| April | 71.1 | 46.9 | 59.0 | 12.3 |
| May | 79.1 | 54.5 | 66.8 | 15.3 |
| June | 85.2 | 62.7 | 74.0 | 15.1 |
| July | 87.3 | 66.4 | 76.9 | 13.4 |
| August | 86.7 | 65.2 | 76.0 | 13.5 |
| September | 81.5 | 58.7 | 70.1 | 11.3 |
| October | 71.3 | 47.2 | 59.3 | 9.6 |
| November | 57.8 | 35.9 | 46.9 | 5.8 |
| December | 48.8 | 30.6 | 39.7 | 4.7 |
| Annual | | | 57.9 | 123.4 |

Source: USAEC, *HTGR Fuel Refabrication Plant at the Oak Ridge National Laboratory, Oak Ridge, Tennessee, Draft Environmental Statement,* WASH-1533, January 1974, p. 111.

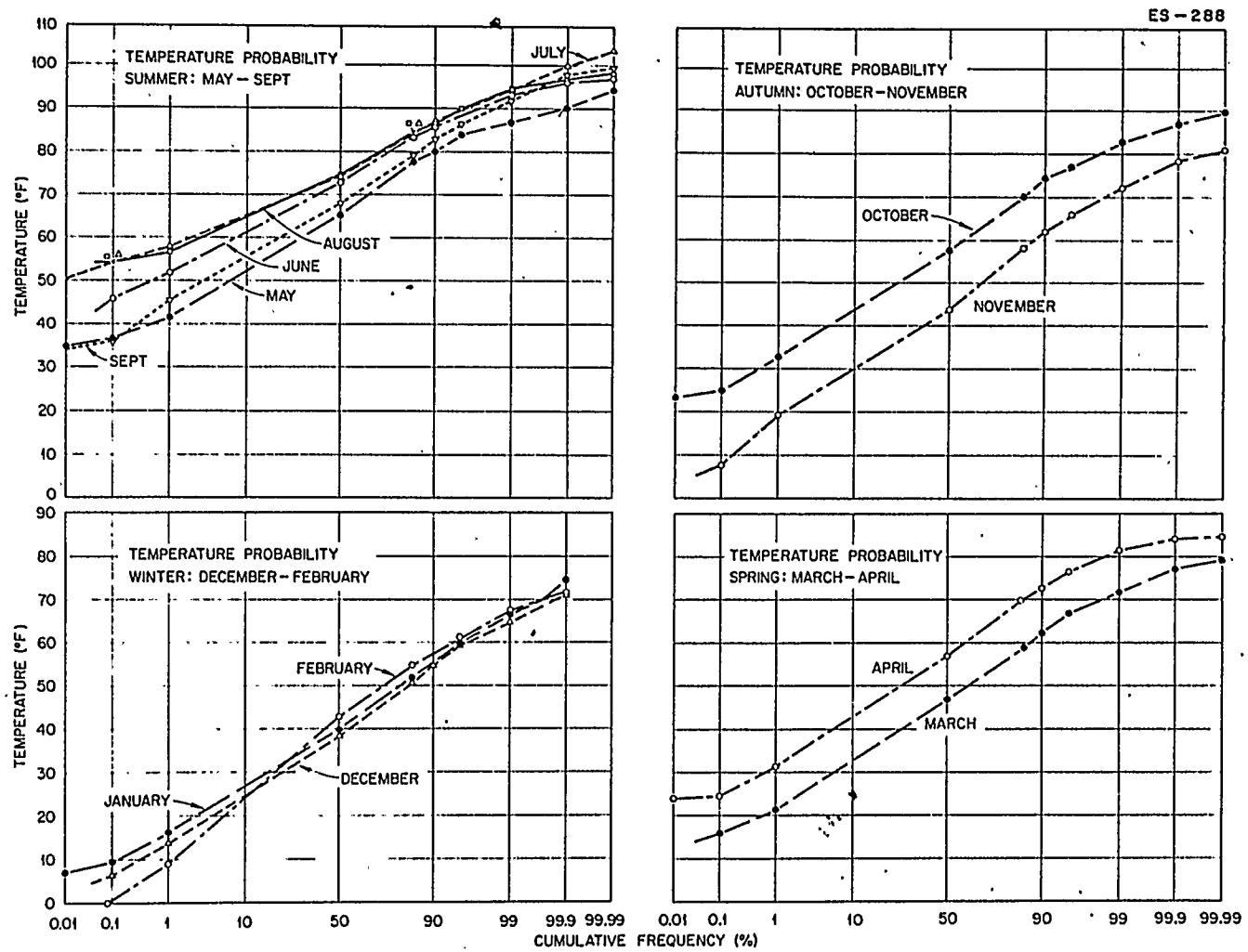


Fig. 3.3-3. Temperature Probability Curves for the Oak Ridge Area By Seasons. SOURCE: J. W. Curlin and D. J. Nelson, "Walker Branch Watershed Project: Objectives, Facilities and Ecological Characteristics," USAEC Report ORNL-TM-2271, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September 1968.

### 3.3.2.2 Precipitation

The monthly precipitation levels at the X-10 weather station given in Table 3.3-2 were averaged from data collected during the period from 1951 through 1971. The monthly frequency of rainstorms of different intensities is illustrated in Fig. 3.3-4.

Significant differences exist among the amounts of rainfall deposited at the various weather stations. For example, the mean annual precipitation during the years from 1951-to-1962 was 54.71 in. in the City of Oak Ridge but only 51.52 in. at Oak Ridge National Laboratory (ORNL). The City experienced events of measurable (greater than 0.01 in.) precipitation about seven more times annually than did the X-10 weather station. Such differences are attributed primarily to the fact that most storm-frontal movement in this region originates in the Cumberland Mountains and then travels along in a northwest-to-southeast track. Consequently, the mean annual precipitation in the Valley and Ridge Region varies from greater than 58 in. in the northwest to less than 46 in. in the southeast, as is indicated in the isohyetal map shown in Fig. 3.3-5. The data illustrated in Fig. 3.3-5 were collected from 11 weather stations in the region by McMaster.[14] The greater quantities of precipitation collected at the City of Oak Ridge collection point than at the X-10 weather station reflect the closer proximity of the town to the point of storm origin and the dissipation of the fronts as they encountered Pine and Chestnut Ridges.

The general pattern of monthly rainfall is similar at all of the weather stations in the Oak Ridge area. Although precipitation is fairly even distributed throughout the year, well-defined seasonal and areal variations do exist. The greatest quantity of precipitation usually falls in January, but December, February, and March also receive heavy water inputs. A second maxima is recorded in July between the low-rainfall periods common to spring and autumn. Such general trends are not absolute and monthly precipitation levels may vary grossly from year to year. For example, January precipitation varied from 1.86 to 10.47 in. during the period from 1948 to 1964.

The average number of consecutive days with and without the incidence of precipitation during the different seasons is indicated on a daily time scale in the histograms shown in Figs. 3.3-6 and 3.3-7. Throughout the year, clear conditions prevail 30% of the time, partly cloudy 25% of the time, and cloudy conditions prevail 45% of the time. An average of 53 thunderstorms and 40 days of heavy natural fog (upper visibility limit, 0.25 mile) occur in a year. Generally, snowfall does not have an appreciable climatological significance in the Oak Ridge area. However,

Table 3.3-2

**Average monthly precipitation levels for the Oak Ridge area, 1951–1971**

| Month | Precipitation (in.) | | |
|---|---|---|---|
| | Rainfall | Snowfall | Total |
| January | 5.3 | 3.4 | 8.7 |
| February | 5.3 | 2.6 | 7.9 |
| March | 5.6 | 1.3 | 6.9 |
| April | 4.4 | 0.01 | 4.4 |
| May | 3.6 | 0 | 3.6 |
| June | 4.0 | 0 | 4.0 |
| July | 5.6 | 0 | 5.6 |
| August | 3.8 | 0 | 3.8 |
| September | 3.3 | 0 | 3.3 |
| October | 2.7 | 0 | 2.7 |
| November | 4.2 | 0.5 | 4.7 |
| December | 5.7 | 2.3 | 8.0 |
| Annual | 53.5 | 10.3 | 63.8 |

Source: USAEC, *HTGR Fuel Refabrication Plant at the Oak Ridge National Laboratory, Oak Ridge, Tennessee, Draft Environmental Statement,* WASH-1533, January 1974, p. 111.

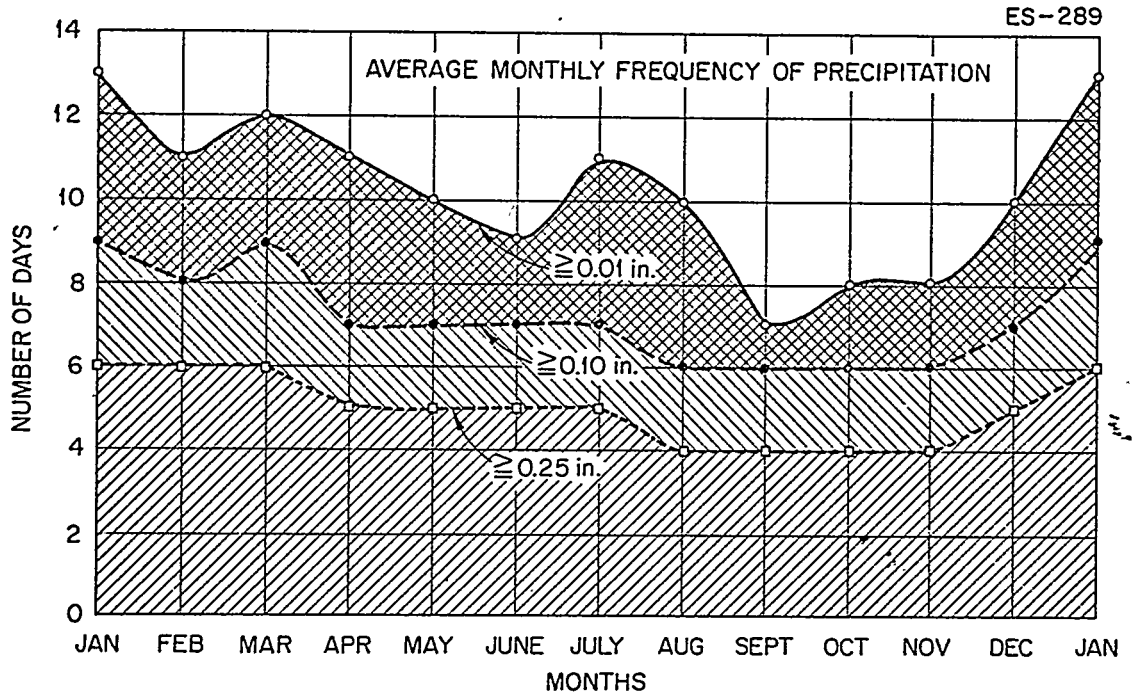


Fig. 3.3-4. Monthly Frequencies and Intensities of Precipitation on the Oak Ridge Area.

SOURCE: J. W. Curlin and D. J. Nelson, "Walker Branch Watershed Project: Objectives, Facilities and Ecological Characteristics," USAEC Report ORNL-TM-2271, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September 1968.

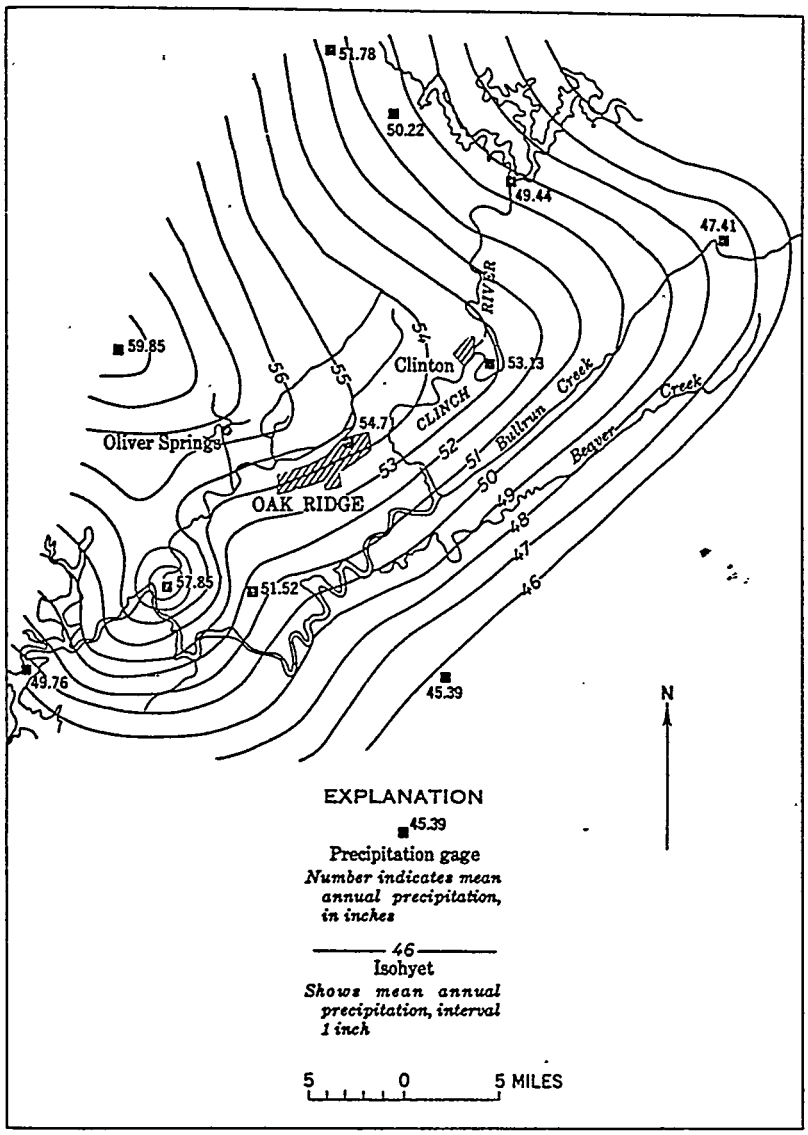


Fig. 3.3-5. Isoheyetal Map of the Oak Ridge Area.
SOURCE: W. M. McMaster, "Hydrologic Data for the Oak Ridge Area, Tennessee," United States Geological Survey Water-Supply Paper 1839-N, 1967.

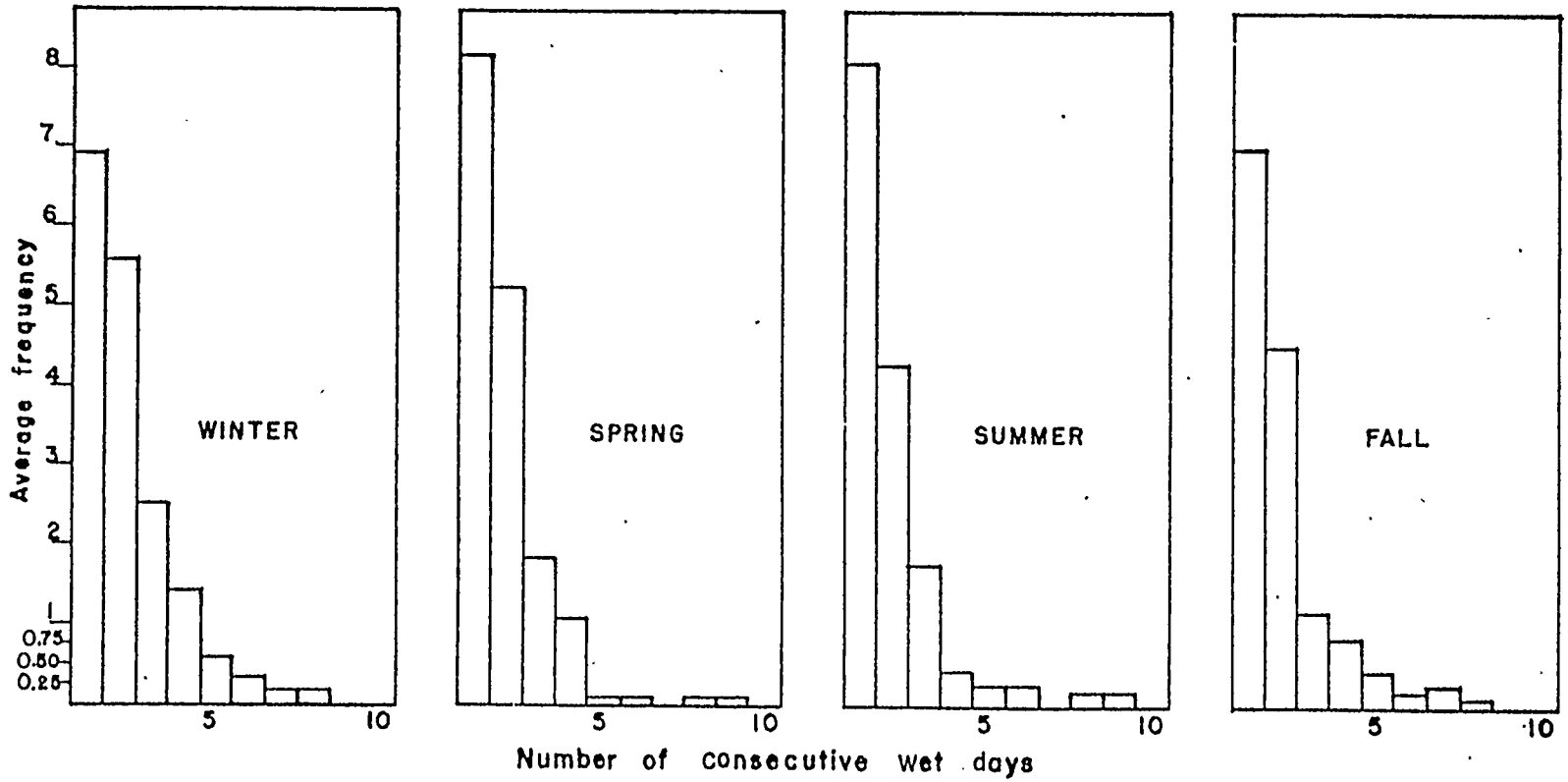


Fig. 3.3-6. Histograms Showing the Seasonal Average Occurrence of Consecutive Wet Days.
SOURCE: W. F. Hilsmeier, "Supplementary Meteorological Data for Oak Ridge," USAEC Report ORO-199, USAEC Oak Ridge Operations, Oak Ridge, Tennessee, March 1963.

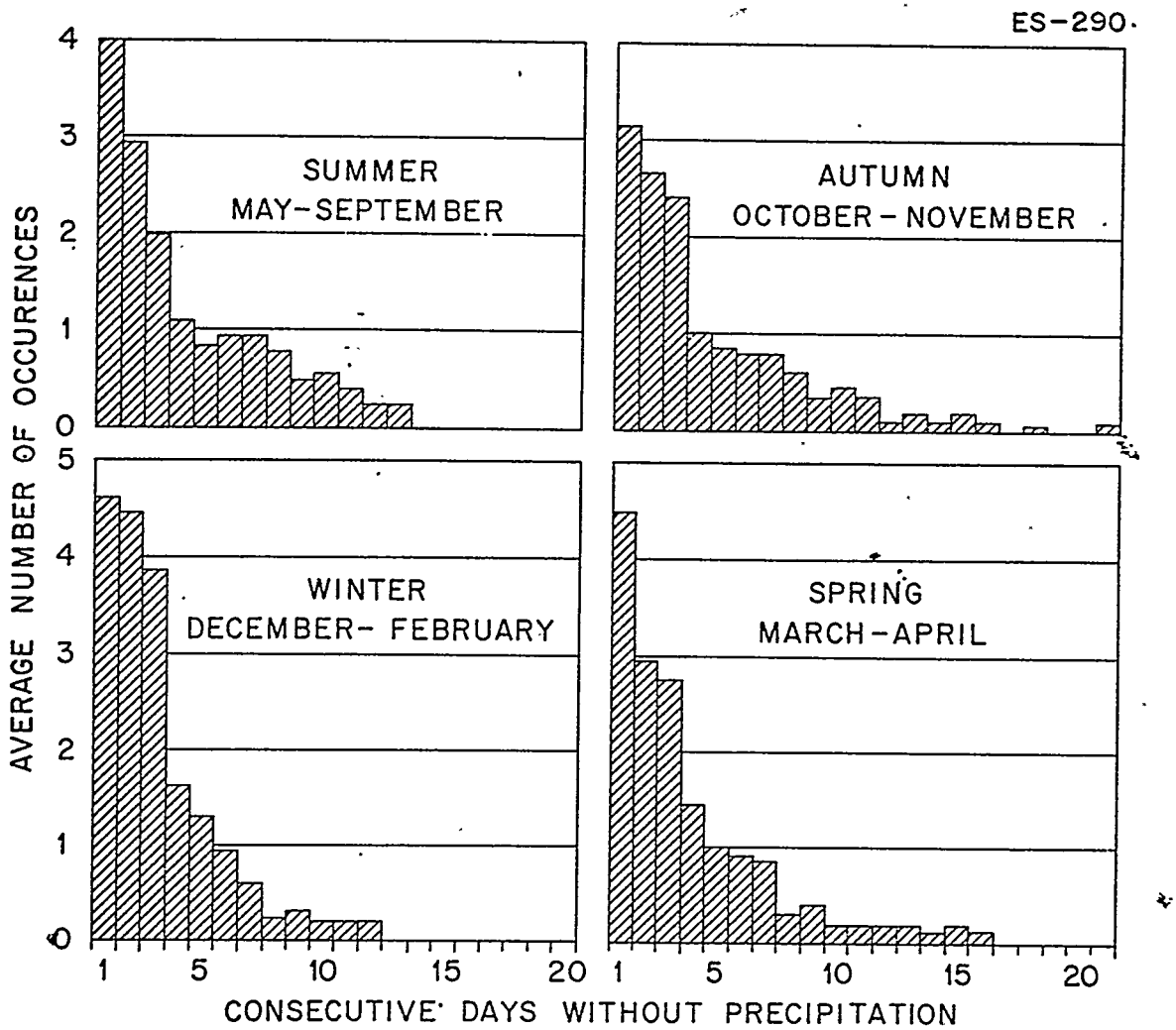


Fig. 3.3-7. Seasonal Histograms Showing the Average Occurrence of Consecutive Dry Days.

SOURCE: J. W. Curlin and D. J. Nelson, "Walker Branch Watershed Project: Objectives, Facilities and Ecological Characteristics," USAEC Report ORNL-TM-2271, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September 1968.

in unusual years it may represent a major portion of the winter precipitation, as during the 1959-60 winter months when 41.4 in. fell.

3.3.2.3 Wind

The prevailing winds reflect the channeling of airflow caused by the orientation of valleys and ridges of the southern Appalachians in that winds are generally northeasterly or southwesterly. The mean annual wind speeds are low when compared with those in other areas of Tennessee and the United States.[10] The mean wind speed at the City of Oak Ridge during the 16-year period of record (1948-1963) was 4.4 mph.[10]

Wind roses generated from measurements made during both lapse and inversion conditions in all seasons are illustrated in Fig. 3.3-8 for the X-10 weather station, Fig. 3.3-9 for the Y-12 Plant weather station, and in Fig. 3.3-10 for the ORGDP weather station. The wind roses at one site are not directly comparable with those at a different site, since the wind vanes and anemometers that generate the data for these figures are located at various locations and elevations. For example, the upper instrument level at the X-10 station is 1026 ft above mean sea level, that at the Y-12 station is 1005 ft, and that at the ORGDP station is 891 ft above mean sea level.[12] In addition, since the anemometers at higher elevations are insensitive to wind velocities of less than 2 mph, uncertainty is introduced into the analyses of lower wind classes with a bias lower than the actual frequency. However, the general patterns of wind flow portrayed are not affected by either of these technical difficulties.

More specific atmospheric dispersion characteristics can be deduced from the joint frequency distribution of wind direction and velocity with respect to Pasquill's seven classes of atmospheric stability. These data for the X-10 weather station during the period from 1963 through 1968 are given in Tables 3.3-3 through 3.3-10. The data in these tables are representative of wind characteristics above the ridge top for the Oak Ridge area. In extrapolating these data to wind flow at lower elevations, consideration must be given to the fact that stable upvalley and downvalley winds would occur more frequently because of wind strengthening as a result of the effects of the immediate terrain.

Data from the wind roses and tables indicate a pronounced biomodal wind direction pattern that consists of prevailing upvalley (southwest and west-southwest) and downvalley (northeast and east-northeast) flow. This type of wind regime reflects the topographic orientation of the Valley and Ridge Province. The stability characteristics of

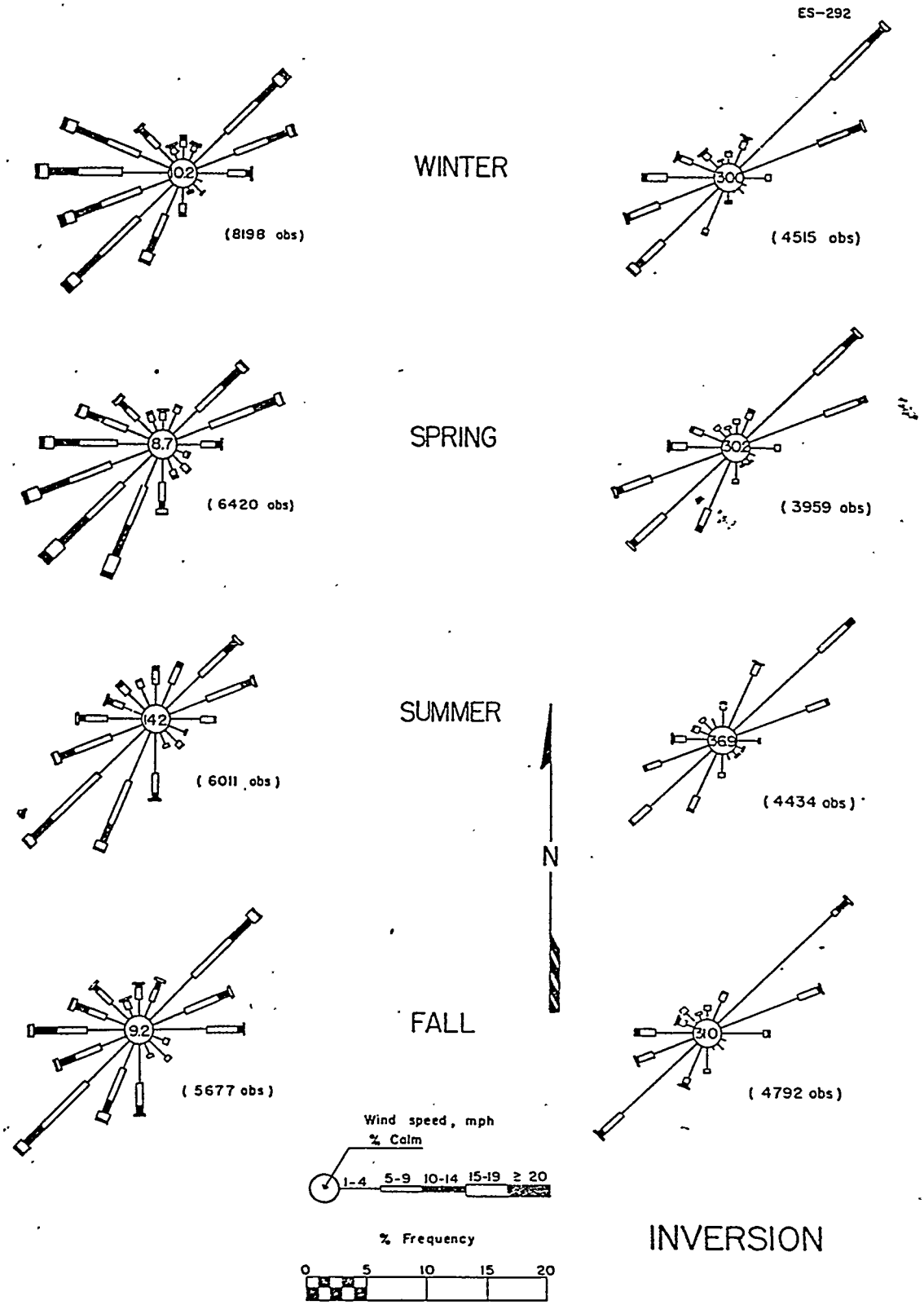


Fig. 3.3-8. Wind Roses for the X-10 Weather Station Under Lapse and Inversion Conditions By Season From 1956 Through 1960.

SOURCE: W. F. Hilsmeier, "Supplementary Meteorological Data for Oak Ridge," USAEC Report ORO-199, USAEC Oak Ridge Operations, Oak Ridge, Tennessee, March 1963.

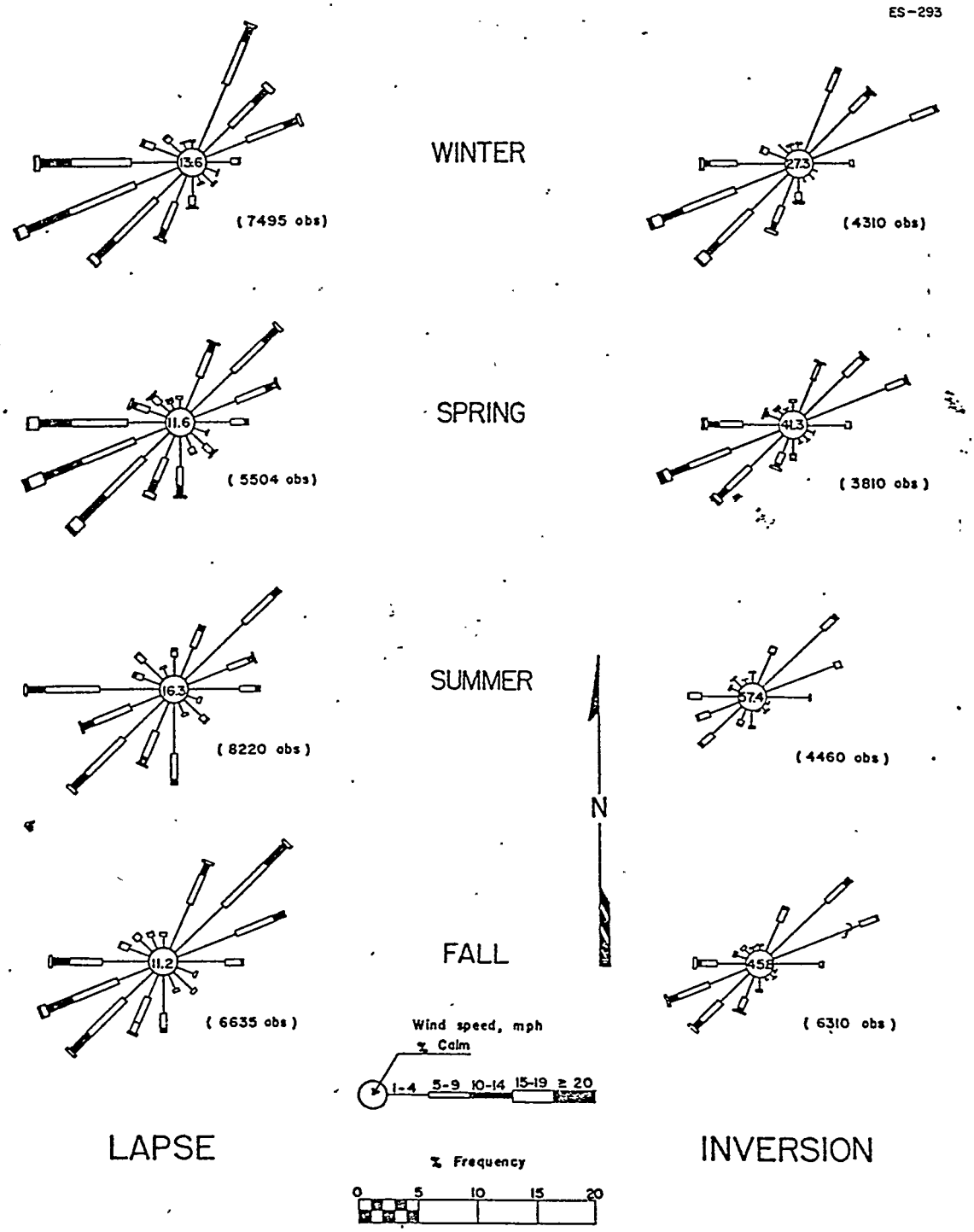


Fig. 3.3-9. Wind Roses for the Y-12 Weather Station Under Lapse and Inversion Conditions By Season From 1956 Through 1960.

SOURCE: W. F. Hilsmeier, "Supplementary Meteorological Data for Oak Ridge," USAEC Report ORO-199, USAEC Oak Ridge Operations, Oak Ridge, Tennessee, March 1963.

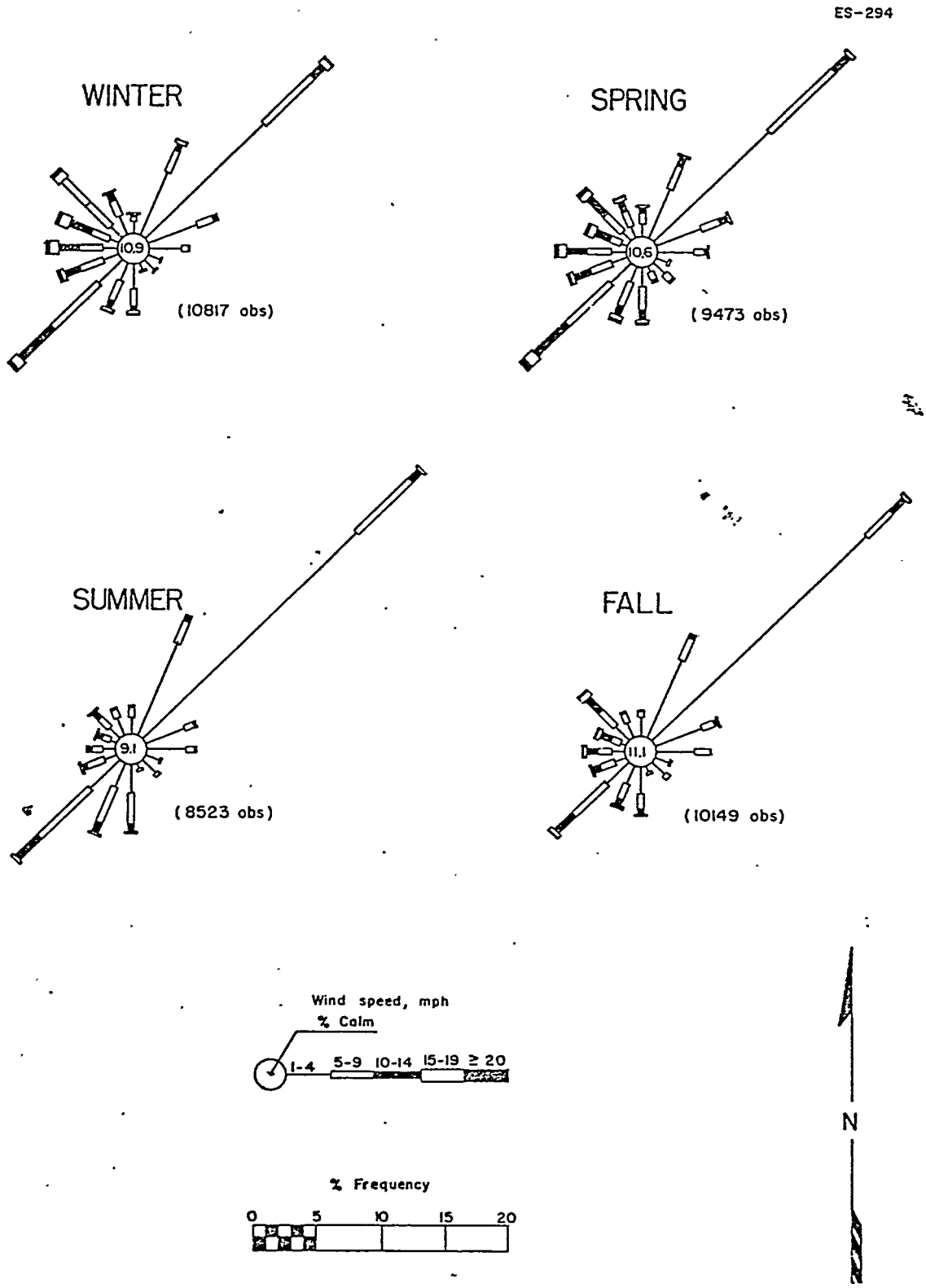


Fig. 3.3-10. Wind Roses for the K-25 Weather Station Under Lapse and Inversion Conditions Combined By Season From 1956 Through 1960.

SOURCE: W. F. Hilsmeier, "Supplementary Meteorological Data for Oak Ridge," USAEC Report ORO-199, USAEC Oak Ridge Operations, Oak Ridge, Tennessee, March 1963.

Table 3.3-3. Joint Percentage Frequencies of Wind Duration and Wind Speed at Oak Ridge Area X-10 Weather Station From 1963 Through 1968

All observations

| Wind direction | Wind speed (mph) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1–3 | 4–7 | 8–12 | 13–18 | 19–24 | ≥25 | Total |
| N | 0.86 | 0.92 | 0.39 | 0.09 | 0.01 | | 2.27 |
| NNE | 0.64 | 0.49 | 0.34 | 0.09 | | 0.01 | 1.57 |
| NE | 3.56 | 3.11 | 2.06 | 0.52 | 0.05 | 0.01 | 9.30 |
| ENE | 3.49 | 3.06 | 1.64 | 0.33 | 0.02 | | 8.54 |
| E | 3.04 | 2.34 | 1.06 | 0.20 | 0.01 | | 6.65 |
| ESE | 1.08 | 0.73 | 0.22 | 0.03 | | | 2.06 |
| SE | 0.92 | 0.55 | 0.13 | 0.03 | | | 1.63 |
| SSE | 0.65 | 0.38 | 0.11 | 0.03 | 0.01 | | 1.18 |
| S | 1.20 | 0.85 | 0.50 | 0.14 | 0.05 | 0.01 | 2.75 |
| SSW | 1.49 | 1.28 | 0.97 | 0.38 | 0.10 | 0.02 | 4.25 |
| SW | 3.79 | 3.93 | 2.95 | 1.29 | 0.30 | 0.05 | 12.31 |
| WSW | 2.35 | 2.95 | 1.80 | 0.73 | 0.19 | 0.04 | 8.06 |
| W | 2.16 | 2.79 | 2.02 | 0.70 | 0.11 | 0.03 | 7.81 |
| WNW | 0.81 | 1.35 | 0.88 | 0.39 | 0.06 | 0.01 | 3.50 |
| NW | 1.01 | 1.23 | 0.77 | 0.24 | 0.03 | | 3.28 |
| NNW | 0.53 | 0.49 | 0.26 | 0.07 | 0.02 | | 1.37 |
| Total | 27.58 | 26.45 | 16.10 | 5.26 | 0.96 | 0.18 | 76.53 |
| Calm | 23.47 | | | | | | |

Table 3.3-4. Joint Percentage Frequencies of Wind Duration and Wind Speed at Oak Ridge Area X-10 Weather Station From 1963 Through 1968

Stability Class A

$\Delta T \leqslant -1.9°C/(100\ m)$

| Wind direction | Wind speed (mph) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1–3 | 4–7 | 8–12 | 13–18 | 19–24 | ≥25 | Total |
| N | 0.16 | 0.24 | 0.14 | 0.03 | | | 0.57 |
| NNE | 0.10 | 0.10 | 0.10 | 0.03 | | | 0.33 |
| NE | 0.48 | 0.64 | 0.55 | 0.21 | 0.02 | | 1.91 |
| ENE | 0.50 | 0.64 | 0.53 | 0.12 | | | 1.79 |
| E | 0.49 | 0.69 | 0.46 | 0.09 | | | 1.74 |
| ESE | 0.20 | 0.27 | 0.14 | 0.02 | | | 0.63 |
| SE | 0.25 | 0.24 | 0.05 | | | | 0.54 |
| SSE | 0.19 | 0.18 | 0.05 | 0.01 | | | 0.43 |
| S | 0.33 | 0.30 | 0.18 | 0.04 | | | 0.85 |
| SSW | 0.27 | 0.35 | 0.30 | 0.10 | 0.03 | | 1.05 |
| SW | 0.61 | 1.06 | 1.10 | 0.52 | 0.10 | 0.01 | 3.40 |
| WSW | 0.31 | 0.74 | 0.57 | 0.30 | 0.07 | 0.01 | 2.00 |
| W | 0.34 | 0.69 | 0.64 | 0.31 | 0.05 | 0.01 | 2.04 |
| WNW | 0.14 | 0.28 | 0.26 | 0.13 | 0.02 | | 0.83 |
| NW | 0.22 | 0.28 | 0.23 | 0.10 | 0.02 | | 0.85 |
| NNW | 0.11 | 0.11 | 0.08 | 0.02 | | | 0.32 |
| Total | 4.70 | 6.82 | 5.36 | 2.04 | 0.31 | 0.05 | 19.28 |
| Calm | 2.20 | | | | | | |

Table 3.3-5. Joint Percentage Frequencies of Wind Duration and Wind Speed at Oak Ridge Area X-10 Weather Station From 1963 Through 1968

Stability Class B

$-1.9 < \Delta T \leqslant -1.7°C/(100\ m)$

| Wind direction | Wind speed (mph) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1–3 | 4–7 | 8–12 | 13–18 | 19–24 | ≥25 | Total |
| N | 0.01 | 0.02 | 0.02 | | | | 0.05 |
| NNE | 0.01 | 0.02 | | | | | 0.03 |
| NE | 0.05 | 0.05 | 0.05 | 0.01 | | | 0.16 |
| ENE | 0.06 | 0.05 | 0.03 | 0.01 | | | 0.15 |
| E | 0.07 | 0.07 | 0.02 | | | | 0.16 |
| ESE | 0.02 | 0.02 | | | | | 0.04 |
| SE | 0.04 | 0.03 | | | | | 0.07 |
| SSE | 0.02 | | | | | | 0.02 |
| S | 0.03 | 0.02 | 0.01 | | | | 0.06 |
| SSW | 0.02 | 0.03 | 0.03 | 0.01 | | | 0.09 |
| SW | 0.07 | 0.10 | 0.07 | 0.04 | 0.01 | | 0.29 |
| WSW | 0.05 | 0.08 | 0.09 | 0.02 | 0.01 | | 0.25 |
| W | 0.05 | 0.09 | 0.09 | 0.03 | 0.01 | | 0.27 |
| WNW | 0.03 | 0.04 | 0.03 | 0.01 | | | 0.11 |
| NW | 0.02 | 0.03 | 0.04 | 0.01 | | | 0.10 |
| NNW | 0.02 | 0.01 | | | | | 0.03 |
| Total | 0.57 | 0.66 | 0.48 | 0.14 | 0.03 | | 1.88 |
| Calm | 0.26 | | | | | | |

Table 3.3-6. Joint Percentage Frequencies of Wind Duration and Wind Speed at Oak Ridge Area X-10 Weather Station From 1963 Through 1968

**Stability Class C**

$-1.7 < \Delta T \leqslant -1.5°C/(100\ m)$

| Wind direction | Wind speed (mph) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1–3 | 4–7 | 8–12 | 13–18 | 19–24 | ⩾25 | Total |
| N | 0.02 | 0.03 | 0.01 | | | | 0.06 |
| NNE | 0.01 | 0.01 | 0.01 | | | | 0.03 |
| NE | 0.04 | 0.07 | 0.06 | 0.01 | | | 0.18 |
| ENE | 0.06 | 0.05 | 0.93 | 0.01 | | | 0.15 |
| E | 0.04 | 0.05 | 0.02 | | | | 0.11 |
| ESE | 0.02 | 0.02 | | | | | 0.04 |
| SE | 0.02 | 0.02 | | | | | 0.04 |
| SSE | 0.01 | 0.02 | | | | | 0.03 |
| S | 0.03 | 0.03 | 0.02 | | | | 0.08 |
| SSW | 0.03 | 0.04 | 0.03 | 0.03 | 0.01 | | 0.14 |
| SW | 0.08 | 0.10 | 0.09 | 0.05 | 0.01 | | 0.33 |
| WSW | 0.04 | 0.07 | 0.08 | 0.01 | 0.02 | | 0.22 |
| W | 0.06 | 0.08 | 0.08 | 0.03 | | | 0.25 |
| WNW | 0.03 | 0.05 | 0.03 | 0.02 | 0.01 | | 0.14 |
| NW | 0.03 | 0.05 | 0.03 | 0.02 | | | 0.13 |
| NNW | 0.01 | 0.01 | 0.01 | 0.01 | | | 0.04 |
| Total | 0.53 | 0.70 | 0.50 | 0.18 | 0.05 | | 1.97 |
| Calm | 0.28 | | | | | | |

Table 3.3-7. Joint Percentage Frequencies of Wind Duration and Wind Speed at Oak Ridge Area X-10 Weather Station From 1963 Through 1968

Stability Class D

$-1.5 < \Delta T \leqslant -0.5°C/(100\ m)$

| Wind direction | Wind speed (mph) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1–3 | 4–7 | 8–12 | 13–18 | 19–24 | ≥25 | Total |
| N | 0.10 | 0.18 | 0.10 | 0.03 | | | 0.41 |
| NNE | 0.07 | 0.09 | 0.07 | 0.03 | | | 0.27 |
| NE | 0.38 | 0.45 | 0.45 | 0.10 | 0.02 | | 1.39 |
| ENE | 0.28 | 0.44 | 0.27 | 0.07 | | | 1.06 |
| E | 0.27 | 0.25 | 0.13 | 0.03 | | | 0.68 |
| ESE | 0.12 | 0.11 | 0.02 | | | | 0.26 |
| SE | 0.10 | 0.09 | 0.03 | 0.01 | | | 0.24 |
| SSE | 0.09 | 0.07 | 0.01 | 0.01 | | | 0.17 |
| S | 0.20 | 0.15 | 0.10 | 0.03 | 0.01 | | 0.49 |
| SSW | 0.22 | 0.25 | 0.20 | 0.09 | 0.02 | 0.01 | 0.79 |
| SW | 0.43 | 0.67 | 0.59 | 0.34 | 0.08 | 0.01 | 2.11 |
| WSW | 0.32 | 0.43 | 0.36 | 0.17 | 0.04 | 0.02 | 1.34 |
| W | 0.33 | 0.51 | 0.46 | 0.17 | 0.03 | 0.02 | 1.50 |
| WNW | 0.13 | 0.29 | 0.25 | 0.13 | 0.02 | | 0.82 |
| NW | 0.16 | 0.33 | 0.18 | 0.05 | 0.01 | | 0.74 |
| NNW | 0.06 | 0.12 | 0.06 | 0.02 | 0.01 | | 0.28 |
| Total | 3.26 | 4.43 | 3.28 | 1.26 | 0.24 | 0.06 | 12.55 |
| Calm | 1.88 | | | | | | |

Table 3.3-8. Joint Percentage Frequencies of Wind Duration and Wind Speed at Oak Ridge Area X-10 Weather Station From 1963 Through 1968

Stability Class E

$-0.5 < \Delta T \leqslant 1.5°C/(100\ m)$

| Wind direction | Wind speed (mph) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1–3 | 4–7 | 8–12 | 13–18 | 19–24 | ≥25 | Total |
| N | 0.31 | 0.29 | 0.08 | 0.02 | | | 0.70 |
| NNE | 0.20 | 0.19 | 0.11 | 0.01 | | | 0.51 |
| NE | 1.02 | 0.98 | 0.69 | 0.17 | 0.01 | | 2.87 |
| ENE | 1.07 | 1.01 | 0.60 | 0.11 | 0.01 | | 2.80 |
| E | 0.97 | 0.76 | 0.33 | 0.06 | | | 2.12 |
| ESE | 0.39 | 0.20 | 0.04 | 0.01 | | | 0.64 |
| SE | 0.31 | 0.15 | 0.04 | 0.01 | | | 0.51 |
| SSE | 0.21 | 0.08 | 0.04 | 0.01 | | | 0.34 |
| S | 0.39 | 0.27 | 0.16 | 0.05 | 0.02 | 0.01 | 0.90 |
| SSW | 0.48 | 0.39 | 0.34 | 0.12 | 0.03 | | 1.36 |
| SW | 1.10 | 1.29 | 0.81 | 0.30 | 0.09 | 0.02 | 3.61 |
| WSW | 0.73 | 0.98 | 0.52 | 0.22 | 0.06 | | 2.51 |
| W | 0.67 | 0.86 | 0.58 | 0.14 | 0.03 | | 2.28 |
| WNW | 0.27 | 0.44 | 0.26 | 0.10 | 0.02 | | 1.09 |
| NW | 0.30 | 0.34 | 0.22 | 0.06 | | | 0.92 |
| NNW | 0.18 | 0.14 | 0.09 | 0.01 | | | 0.42 |
| Total | 8.60 | 8.37 | 4.90 | 1.40 | 0.27 | 0.03 | 23.57 |
| Calm | 6.24 | | | | | | |

Fig. 3.3-9. Joint Percentage Frequencies of Wind Duration and Wind Speed at Oak Ridge Area X-10 Weather Station From 1963 Through 1968

**Stability Class F**

$1.5 < \Delta T \leqslant 4.0°C/(100\ m)$

| Wind direction | Wind speed (mph) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1–3 | 4–7 | 8–12 | 13–18 | 19–24 | ≥25 | Total |
| N | 0.11 | 0.09 | 0.01 | | | | 0.20 |
| NNE | 0.13 | 0.05 | 0.05 | 0.01 | | | 0.23 |
| NE | 0.74 | 0.51 | 0.20 | 0.01 | | | 1.46 |
| ENE | 0.74 | 0.48 | 0.13 | 0.01 | | | 1.36 |
| E | 0.56 | 0.28 | 0.05 | 0.01 | | | 0.90 |
| ESE | 0.20 | 0.05 | | | | | 0.26 |
| SE | 0.09 | 0.02 | 0.01 | | | | 0.12 |
| SSE | 0.08 | 0.02 | 0.01 | 0.01 | | | 0.13 |
| S | 0.11 | 0.04 | 0.03 | 0.01 | | | 0.20 |
| SSW | 0.20 | 0.12 | 0.06 | 0.02 | | 0.01 | 0.41 |
| SW | 0.64 | 0.36 | 0.20 | 0.04 | 0.01 | | 1.25 |
| WSW | 0.36 | 0.29 | 0.13 | 0.01 | | | 0.80 |
| W | 0.28 | 0.32 | 0.11 | 0.01 | | | 0.73 |
| WNW | 0.10 | 0.12 | 0.03 | | | | 0.25 |
| NW | 0.13 | 0.10 | 0.04 | | | | 0.27 |
| NNW | 0.10 | 0.05 | 0.01 | | | | 0.16 |
| Total | 4.59 | 2.90 | 1.07 | 0.15 | 0.01 | 0.01 | 8.73 |
| Calm | 5.35 | | | | | | |

Fig. 3.3-10. Joint Percentage Frequencies of Wind Duration and Wind Speed at Oak Ridge Area X-10 Weather Station From 1963 Through 1968

**Stability Class G**

$\Delta T > 4.0°C/(100\ m)$

| Wind direction | Wind speed (mph) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1–3 | 4–7 | 8–12 | 13–18 | 19–24 | ≥25 | Total |
| N | 0.15 | 0.10 | 0.01 | | | | 0.26 |
| NNE | 0.13 | 0.03 | | | | | 0.16 |
| NE | 0.85 | 0.39 | 0.07 | | | | 1.31 |
| ENE | 0.78 | 0.38 | 0.04 | | | | 1.21 |
| E | 0.65 | 0.29 | 0.05 | | | | 0.99 |
| ESE | 0.12 | 0.05 | | | | | 0.17 |
| SE | 0.11 | 0.01 | | | | | 0.11 |
| SSE | 0.05 | 0.01 | | | | | 0.06 |
| S | 0.12 | 0.03 | | | | | 0.15 |
| SSW | 0.26 | 0.09 | 0.02 | | | | 0.37 |
| SW | 0.86 | 0.34 | 0.10 | 0.01 | | 0.01 | 1.31 |
| WSW | 0.53 | 0.36 | 0.07 | | | | 0.96 |
| W | 0.42 | 0.25 | 0.06 | | | | 0.73 |
| WNW | 0.11 | 0.12 | 0.02 | | | | 0.24 |
| NW | 0.14 | 0.09 | 0.02 | | | | 0.25 |
| NNW | 0.06 | 0.04 | | | | | 0.10 |
| Total | 5.33 | 2.60 | 0.47 | 0.01 | | 0.01 | 8.41 |
| Calm | 7.26 | | | | | | |

these two directional channels are also nearly identical and represent the critical dispersion conditions. However, the similar upvalley and downvalley flows are probably caused by two different meteorological circumstances. The downvalley draft, identified with drainage or gravitational flow down local slopes and the broader Tennessee Valley, prevails during the inversion conditions of late evening through midmorning, whereas regional or synoptic pressure patterns dependent on solar inputs are very weak. However, in the daytime lapses, upvalley flow results when the regional or synoptic flows aloft become sufficiently strong to dominate over the opposing local, downvalley, gravitational winds.

An example of this regional pressure zone is the western extension of the Bermuda-Azores system, which causes weak southwest wind movement over much of the southeastern United States for extended periods during late summer through early fall.[1] Since these higher regional winds do not exert as pronounced an influence on valleys, the local valley wind regime may even maintain its structure and flow in a direction opposite to that of the regional wind tracts.[15] The opposing forces of regional and local winds counteract one another to yield a rather high occurrence of calm periods (23%) and the lowest wind-velocity classes (1 to 3 mph, 28%; and 4 to 7 mph, 26%). In fact, the average wind speed for the Oak Ridge area is only 4.4 mph. Severe wind storms are notably rare. A major factor that causes the stability of air movement to be maintained is the Cumberland plateau which diminishes the force of winter and early spring storms. As was also seen in the case of rainstorms, local irregular ridges further minimize wind impact. The peak gust of record on the reservation is 59 mph, and the probable occurrence rate of gusts of tornado proportion is only once in every 91,000 years.[16] The tornadoes in the southeastern states in the past half century have all been small in scale, short in path length, and low in damage caused.

## 3.4 Surface Hydrology

All waters drained from the ERDA Oak Ridge Reservation eventually reach the Tennessee, Ohio, and Mississippi water system[16] via the Clinch River. As illustrated in Fig. 3.4-1, the headwater tributaries for the Tennessee River arise from points in Virginia, North Carolina, and Georgia. Initially, the river flows generally southwestward and receives inputs from eastern Tennessee and northern Alabama before bending sharply northwest to contiiue a winding path across west Tennessee to the river mouth at Paducah, Kentucky. The total drainage area of 40,910 square miles includes about 80% of the State of Tennessee, a major

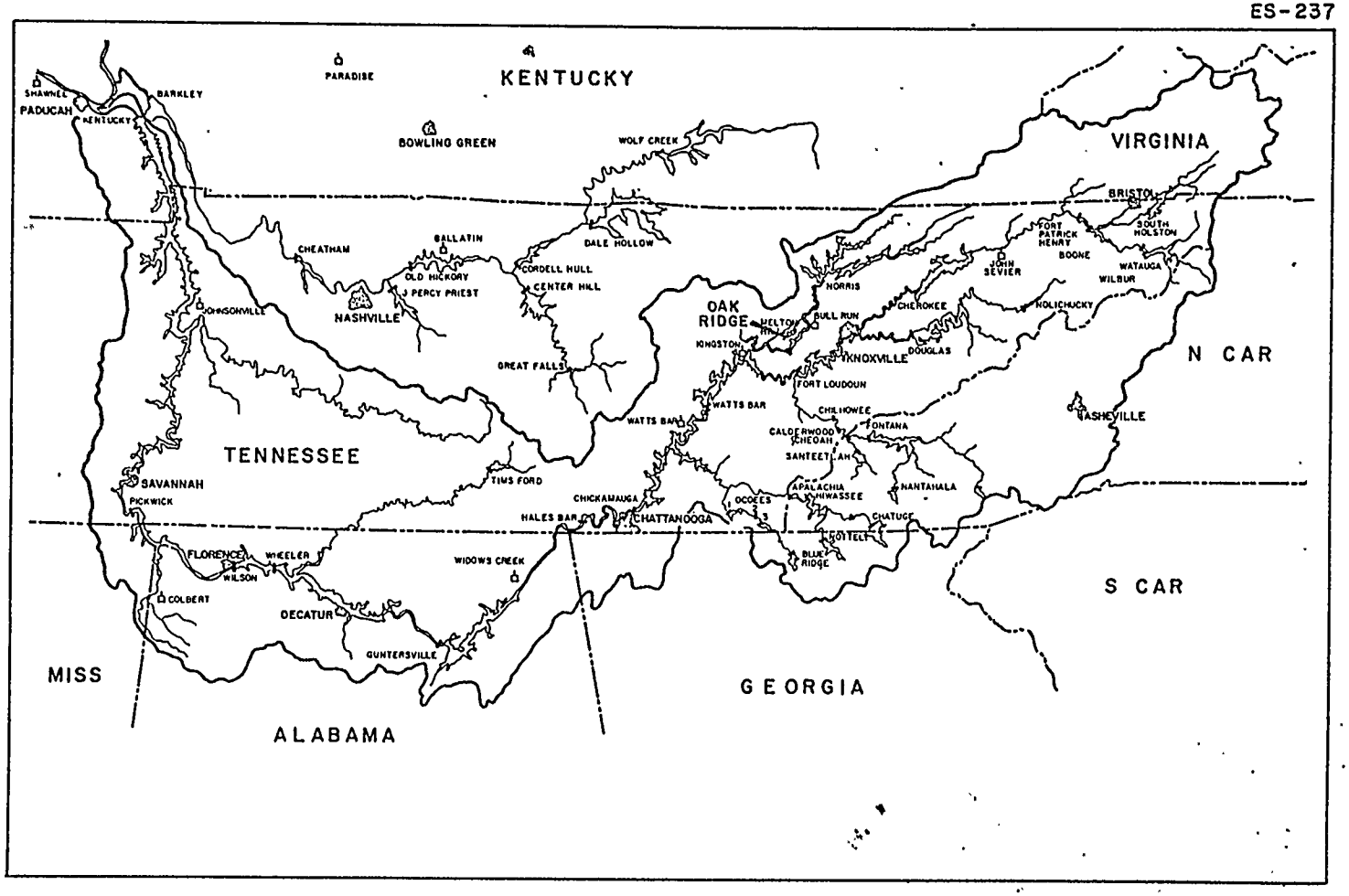


Fig. 3.4-1. Map of the Tennessee River Valley and Vicinity Showing Important Dams and Steam Plants.

SOURCE: E. G. Struxness (Chairman) et al., Clinch River Study Steering Committee, "Comprehensive Report of the Clinch River Study," USAEC Report ORNL-4035, Oak Ridge National Laboratory; Oak Ridge, Tennessee, April 1967.

segment of northern Alabama, and regions of Kentucky, Mississippi, Georgia, Virginia, and North Carolina. Many multipurpose dams regulate flow on this river system, and the Tennessee River alone is dotted with nine mainstream reservoirs from Knoxville to Paducah.

### 3.4.1 Drainage Basin and Watercourse Flow

As discussed in Subsection 3.1.2, the ORGDP site is bounded on the west by the Clinch River, which provides the immediate receptacle for waters discharged from the Oak Ridge Reservation. The Clinch River originates in Tazewell County, Virginia, which is in the southwest corner of Virginia near the Kentucky border 175 air miles northeast of Oak Ridge. The river proceeds in an approximately southwestward direction for more than 350 miles before merging with the Tennessee River near Kingston at Tennessee River Mile (TRM) 567.7 (Ref. 17). The Clinch River drainage basin encompasses an area of 4413 square miles with an average width of 18 miles bounded by the crests of the Cumberland Mountains on the northwest and the Clinch Mountains and Blackoak Ridge on the southeast.

The Clinch River is a highly complex hydraulic system that is influenced predominantly by the operation of three Tennessee Valley Authority (TVA) dams. Elevations of the easterly upper reaches of the Clinch River are controlled by Norris Dam and Melton Hill Dam, while those of the waters downstream from the Melton Hill Dam are controlled by Watts Bar Dam.

Norris Dam is located the farthest upstream at Clinch River Mile (CRM) 79.8. This dam was impounded in March 1936 to provide flood protection and low flow regulation for the downstream areas. The spillway crest elevation for the dam is 1020 ft above mean sea level, and the normal maximum pool elevation is also at this level. The dam is equipped with three 100 by 14-ft gates that can be used to raise the reservoir elevation to 1034 ft if required for flood control operations. The normal minimum pool elevation is 960 ft, and the reservoir provides a storage capacity of approximately 260,000 day-second-feet between elevations of 900 and 960 ft. Of all the annual maximum elevations recorded, the lowest annual maximum elevation of Norris Lake was 993.8 ft in June 1954 (Ref. 18).

The Melton Hill Dam at CRM 23.1 was completed in May 1963. It was constructed for power production, navigation, recreation, and some low flow regulation but it provides little flood protection. The Melton Hill Reservoir forms the eastern and southeastern boundary of the Oak Ridge Reservation. This reservoir extends 44 river miles to Eagle

Bend, which lies about 8 miles above Clinton. A volume of 118,600 acre-ft of water is impounded at the normal maximum pool elevation of 795 ft above mean sea level. The normal minimum pool elevation of the reservoir is 790 ft.[18] Melton Hill Reservoir elevation data for the years 1962 through 1971 are summarized in Table 3.4-1.

Backwaters from the Watts Bar Dam, which was completed in 1942, on the Tennessee River define the southwestern and western boundaries of the ERDA property. The Watts Bar Dam at TRM 529.8 is about 38 miles downstream from the mouth of the Clinch River, and the primary functions of the dam include flood control, navigation, electric power generation, and recreation. Before impoundment of the Melton Hill Reservoir in 1963, Watts Bar regulated flows in the Clinch River adjacent to the Oak Ridge Reservation up to CRM 28. In the vicinity of the reservation, the reservoir ranges in width from 300 to 600 ft and in depth from 22 to 24 ft at full pool elevation.

Minimum elevations based on navigation and flood control requirements have been established for the Watts Bar Reservoir. The TVA generally maintains a pool elevation of between 740 and 741 ft during the spring and summer months (mid-April through September) and a winter pool elevation of 735 to 737 ft during the remainder of the year. Measurements made for the proposed Clinch River Breeder Reactor Plant indicate that the surface elevation of the Watts Bar backwaters at that site is normally 1 to 2 ft higher than the level measured at the dam.[6] Since 1942, the minimum Watts Bar pool elevation recorded was 733.44 ft on March 20, 1945, and the maximum elevation recorded was 745.4 ft on March 17, 1973 (Ref. 6). Watts Bar Reservoir elevation data for the years 1959 through 1973 are summarized in Table 3.4-2.

### 3.4.1.1 Clinch River tributaries

In general, the tributaries of the Clinch River conform to the physiographic layout of the Valley and Ridge Province by paralleling the Clinch for a long distance before crossing a ridge gap to unite with it. The net effect is a trellis drainage pattern; an extended series of troughs drained by many streams as opposed to a simple stream valley.

The largest tributaries of the Clinch River are the Powell River and Emory River. The Powell arises southeast of the headwaters of the Clinch, flows parallel to the Clinch, receives water shed from a 938-square-mile area, and intersects the Clinch just above Norris Dam at CRM 88.8. Northwest of the Oak Ridge Reservation, the Emory River drains a basin of 865 square miles before joining the Clinch

Table 3.4-1. Melton Hill Reservoir Elevations for the Years 1962 Through 1971

| Year | January | | | February | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1962 | — | — | — | — | — | — |
| 1963 | 761.52 | 755.64 | 758.71 | 761.78 | 755.90 | 759.37 |
| 1964 | 793.93 | 791.35 | 792.65 | 793.74 | 790.84 | 792.55 |
| 1965 | 795.34 | 789.81 | 793.26 | 795.29 | 790.54 | 793.31 |
| 1966 | 794.76 | 784.40 | 788.88 | 786.01 | 784.10 | 785.15 |
| 1967 | 795.25 | 793.43 | 794.39 | 795.24 | 793.10 | 794.35 |
| 1968 | 795.02 | 791.33 | 793.48 | 795.08 | 792.44 | 794.04 |
| 1969 | 794.76 | 790.05 | 793.41 | 795.05 | 791.90 | 793.85 |
| 1970 | 795.17 | 789.50 | 793.88 | 795.25 | 790.45 | 793.72 |
| 1971 | 795.10 | 790.83 | 793.65 | 795.10 | 791.80 | 793.82 |

| Year | March | | | April | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1962 | — | — | — | — | — | — |
| 1963 | 770.90 | 755.38 | 765.01 | 761.83 | 754.81 | 757.68 |
| 1964 | 794.53 | 790.52 | 792.34 | 795.33 | 790.22 | 792.91 |
| 1965 | 794.97 | 792.22 | 793.73 | 795.40 | 791.42 | 793.81 |
| 1966 | 795.05 | 785.99 | 791.57 | 794.97 | 792.70 | 793.87 |
| 1967 | 795.94 | 793.36 | 794.46 | 795.24 | 792.44 | 794.22 |
| 1968 | 794.69 | 792.10 | 793.69 | 795.12 | 793.09 | 794.05 |
| 1969 | 795.07 | 793.42 | 794.17 | 795.13 | 792.61 | 793.97 |
| 1970 | 795.05 | 790.24 | 793.22 | 795.20 | 790.32 | 792.83 |
| 1971 | 794.85 | 790.30 | 793.69 | 794.41 | 790.25 | 792.70 |

| Year | May | | | June | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1962 | — | — | — | — | — | — |
| 1963 | 795.23 | 757.09 | 786.01 | 795.41 | 791.55 | 793.52 |
| 1964 | 794.57 | 792.30 | 793.72 | 794.83 | 792.53 | 793.78 |
| 1965 | 794.98 | 789.98 | 793.41 | 795.17 | 791.89 | 794.25 |
| 1966 | 794.69 | 792.41 | 793.77 | 795.05 | 792.32 | 793.79 |
| 1967 | 795.44 | 792.87 | 794.27 | 795.42 | 793.23 | 794.16 |
| 1968 | 794.44 | 792.80 | 793.86 | 794.73 | 791.90 | 793.46 |
| 1969 | 795.00 | 790.50 | 793.19 | 794.79 | 791.00 | 793.26 |
| 1970 | 794.80 | 790.52 | 793.41 | 795.41 | 791.31 | 793.30 |
| 1971 | 795.07 | 791.35 | 793.88 | 794.92 | 790.10 | 793.10 |

Table 3.4-1 (continued)

| Year | July | | | August | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1962 | — | — | — | 760.70 | 740.20 | 755.50 |
| 1963 | 795.04 | 791.90 | 793.32 | 795.00 | 791.70 | 793.51 |
| 1964 | 794.84 | 791.95 | 793.57 | 794.93 | 791.65 | 793.05 |
| 1965 | 795.10 | 793.30 | 794.28 | 795.23 | 793.20 | 794.00 |
| 1966 | 794.84 | 792.81 | 793.89 | 795.12 | 792.94 | 793.27 |
| 1967 | 795.46 | 793.01 | 794.23 | 795.19 | 793.34 | 794.01 |
| 1968 | 795.31 | 792.00 | 793.82 | 795.77 | 791.56 | 793.72 |
| 1969 | 795.07 | 790.59 | 793.04 | 794.93 | 791.39 | 793.61 |
| 1970 | 795.03 | 790.75 | 793.10 | 794.96 | 791.55 | 793.51 |
| 1971 | 795.00 | 790.82 | 793.48 | 794.97 | 792.05 | 793.55 |

| Year | September | | | October | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1962 | 760.40 | 755.60 | 758.51 | 760.55 | 755.68 | 758.17 |
| 1963 | 795.40 | 790.66 | 793.45 | 795.36 | 791.84 | 793.61 |
| 1964 | 794.75 | 790.64 | 793.12 | 794.57 | 791.31 | 793.08 |
| 1965 | 794.92 | 792.60 | 793.85 | 794.55 | 792.95 | 793.96 |
| 1966 | 795.13 | 792.99 | 794.01 | 795.05 | 792.70 | 793.94 |
| 1967 | 795.30 | 792.57 | 793.96 | 795.44 | 793.16 | 793.97 |
| 1968 | 794.49 | 789.68 | 792.44 | 794.90 | 793.00 | 794.13 |
| 1969 | 794.80 | 791.63 | 793.64 | 794.80 | 791.68 | 793.35 |
| 1970 | 794.99 | 792.68 | 793.65 | 795.03 | 790.75 | 793.38 |
| 1971 | 794.86 | 792.19 | 793.54 | 794.89 | 791.30 | 793.07 |

| Year | November | | | December | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1962 | 761.26 | 754.87 | 757.45 | 761.43 | 756.00 | 759.85 |
| 1963 | 795.27 | 790.42 | 793.21 | 794.44 | 791.27 | 792.95 |
| 1964 | 794.31 | 790.95 | 793.28 | 794.64 | 791.13 | 793.23 |
| 1965 | 795.17 | 789.92 | 793.75 | 794.85 | 789.89 | 792.55 |
| 1966 | 795.06 | 792.83 | 794.21 | 795.23 | 793.27 | 794.24 |
| 1967 | 795.13 | 792.40 | 793.66 | 795.20 | 792.50 | 794.10 |
| 1968 | 795.01 | 790.15 | 793.71 | 794.90 | 791.05 | 793.62 |
| 1969 | 794.74 | 791.06 | 793.52 | 795.19 | 790.28 | 793.83 |
| 1970 | 794.74 | 790.15 | 793.67 | 795.24 | 791.40 | 793.95 |
| 1971 | 793.15 | 790.35 | 791.88 | 793.15 | 790.33 | 791.75 |

Source: Tennessee Valley Authority, Division of Water Control Planning, River Control Branch, *Operation of TVA Reservoirs,* Annual Reports, Knoxville, Tenn.

Table 3.4-2. Watts Bar Reservoir Elevations for the Years 1959 Through 1973

| Year | January | | | February | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1959 | 739.79 | 734.82 | 735.95 | 737.26 | 735.16 | 735.88 |
| 1960 | 736.59 | 734.84 | 735.63 | 736.68 | 735.08 | 735.85 |
| 1961 | 736.54 | 734.87 | 735.57 | 739.00 | 735.20 | 735.94 |
| 1962 | 737.84 | 734.80 | 735.89 | 739.31 | 734.79 | 736.12 |
| 1963 | 736.47 | 735.00 | 735.57 | 736.91 | 734.02 | 734.90 |
| 1964 | 736.78 | 734.70 | 735.68 | 737.26 | 734.90 | 735.70 |
| 1965 | 738.28 | 734.93 | 735.67 | 736.21 | 734.96 | 735.52 |
| 1966 | 736.54 | 734.85 | 735.66 | 738.36 | 735.05 | 736.05 |
| 1967 | 737.73 | 734.78 | 735.80 | 737.00 | 734.80 | 735.63 |
| 1968 | 737.09 | 734.69 | 735.67 | 735.74 | 734.88 | 735.24 |
| 1969 | 736.85 | 734.86 | 735.56 | 738.56 | 735.04 | 735.90 |
| 1970 | 742.42 | 734.96 | 735.93 | 736.80 | 734.92 | 735.78 |
| 1971 | 737.35 | 734.92 | 735.84 | 738.05 | 734.90 | 736.02 |
| 1972 | 737.72 | 734.99 | 736.29 | 736.55 | 735.00 | 735.74 |
| 1973 | 736.33 | 734.82 | 735.61 | 736.82 | 734.96 | 735.71 |

| Year | March | | | April | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1959 | 737.36 | 734.97 | 735.91 | 744.57 | 736.89 | 739.90 |
| 1960 | 737.32 | 734.84 | 735.63 | 741.16 | 736.58 | 738.10 |
| 1961 | 737.94 | 735.05 | 735.76 | 742.54 | 735.46 | 740.10 |
| 1962 | 738.71 | 734.61 | 735.64 | 742.44 | 735.10 | 739.24 |
| 1963 | 743.14 | 734.11 | 736.55 | 743.74 | 735.11 | 738.34 |
| 1964 | 738.49 | 734.80 | 735.99 | 743.60 | 735.06 | 740.24 |
| 1965 | 742.61 | 735.01 | 736.87 | 743.23 | 738.08 | 740.62 |
| 1966 | 737.31 | 735.10 | 735.92 | 742.06 | 735.18 | 737.34 |
| 1967 | 739.84 | 734.94 | 735.97 | 740.27 | 735.80 | 738.20 |
| 1968 | 737.57 | 734.95 | 735.64 | 741.88 | 736.62 | 739.69 |
| 1969 | 736.29 | 734.91 | 735.62 | 742.90 | 735.43 | 739.11 |
| 1970 | 737.09 | 734.80 | 735.85 | 744.57 | 736.20 | 739.88 |
| 1971 | 736.74 | 734.80 | 735.79 | 742.39 | 736.26 | 739.34 |
| 1972 | 737.17 | 734.85 | 735.88 | 743.05 | 736.46 | 740.09 |
| 1973 | 745.40 | 734.88 | 737.83 | 743.01 | 736.96 | 739.62 |

Table 3.4-2 (continued)

| Year | May | | | June | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1959 | 741.65 | 740.00 | 741.04 | 741.67 | 739.62 | 740.81 |
| 1960 | 742.54 | 740.63 | 741.21 | 741.66 | 740.02 | 740.92 |
| 1961 | 741.57 | 740.44 | 741.03 | 742.13 | 740.50 | 741.22 |
| 1962 | 741.28 | 740.63 | 741.00 | 741.43 | 739.88 | 740.85 |
| 1963 | 744.43 | 740.33 | 741.15 | 741.26 | 739.82 | 740.69 |
| 1964 | 741.75 | 740.35 | 741.07 | 741.33 | 739.91 | 740.69 |
| 1965 | 742.41 | 741.56 | 742.02 | 742.50 | 740.98 | 741.93 |
| 1966 | 743.88 | 740.48 | 741.43 | 741.20 | 739.54 | 740.71 |
| 1967 | 743.04 | 740.10 | 741.26 | 741.79 | 739.79 | 740.73 |
| 1968 | 742.62 | 740.61 | 741.05 | 741.40 | 739.87 | 740.77 |
| 1969 | 741.87 | 740.20 | 741.14 | 741.69 | 739.99 | 741.97 |
| 1970 | 741.25 | 739.85 | 740.72 | 741.11 | 739.45 | 740.47 |
| 1971 | 743.17 | 740.44 | 741.17 | 741.64 | 739.55 | 740.87 |
| 1972 | 741.55 | 740.35 | 740.89 | 741.24 | 739.65 | 740.70 |
| 1973 | 745.06 | 740.18 | 741.29 | 742.55 | 739.93 | 741.00 |

| Year | July | | | August | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1959 | 741.27 | 739.65 | 740.60 | 741.39 | 739.74 | 740.50 |
| 1960 | 741.15 | 739.88 | 740.53 | 741.53 | 739.77 | 740.62 |
| 1961 | 741.49 | 739.77 | 740.45 | 741.34 | 739.68 | 740.55 |
| 1962 | 741.51 | 739.83 | 740.57 | 741.29 | 739.37 | 740.50 |
| 1963 | 741.40 | 739.91 | 740.65 | 741.17 | 739.60 | 740.55 |
| 1964 | 741.20 | 739.72 | 740.55 | 741.55 | 739.47 | 740.54 |
| 1965 | 742.16 | 740.89 | 741.55 | 742.23 | 740.68 | 741.50 |
| 1966 | 741.35 | 739.55 | 740.54 | 741.43 | 739.38 | 740.88 |
| 1967 | 743.82 | 739.73 | 741.24 | 741.46 | 739.41 | 740.70 |
| 1968 | 741.31 | 739.60 | 740.58 | 741.44 | 739.83 | 740.62 |
| 1969 | 741.24 | 739.86 | 740.64 | 741.42 | 739.42 | 740.61 |
| 1970 | 741.40 | 739.70 | 740.57 | 741.27 | 739.68 | 740.58 |
| 1971 | 741.44 | 739.50 | 740.67 | 741.49 | 739.61 | 740.60 |
| 1972 | 741.41 | 739.61 | 740.54 | 741.12 | 739.69 | 740.51 |
| 1973 | 741.95 | 739.36 | 740.50 | 741.64 | 739.73 | 740.57 |

Table 3.4-2 (continued)

| Year | September | | | October | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1959 | 741.30 | 739.81 | 740.69 | 741.30 | 738.57 | 739.74 |
| 1960 | 741.47 | 739.79 | 740.66 | 741.22 | 738.33 | 739.91 |
| 1961 | 741.28 | 739.69 | 740.50 | 741.10 | 737.92 | 739.57 |
| 1962 | 741.10 | 738.10 | 740.20 | 741.26 | 738.35 | 739.68 |
| 1963 | 741.28 | 739.70 | 740.49 | 740.88 | 738.00 | 739.58 |
| 1964 | 741.11 | 739.47 | 740.46 | 741.01 | 738.32 | 739.69 |
| 1965 | 742.14 | 741.03 | 741.85 | 742.08 | 739.28 | 740.73 |
| 1966 | 741.52 | 740.39 | 740.88 | 741.04 | 738.07 | 739.84 |
| 1967 | 741.16 | 739.82 | 740.71 | 740.90 | 738.37 | 739.94 |
| 1968 | 741.27 | 740.00 | 740.84 | 741.16 | 738.31 | 739.69 |
| 1969 | 741.98 | 739.77 | 740.97 | 740.73 | 736.65 | 739.05 |
| 1970 | 741.30 | 740.33 | 740.82 | 741.14 | 738.50 | 739.88 |
| 1971 | 741.26 | 739.92 | 740.74 | 741.00 | 738.30 | 739.67 |
| 1972 | 741.36 | 740.25 | 740.87 | 741.06 | 738.18 | 738.34 |
| 1973 | 741.28 | 740.36 | 740.87 | 740.89 | 738.35 | 739.65 |

| Year | November | | | December | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1959 | 739.01 | 736.50 | 737.61 | 738.17 | 735.15 | 736.30 |
| 1960 | 738.55 | 736.11 | 737.32 | 736.71 | 734.94 | 735.74 |
| 1961 | 738.22 | 735.45 | 737.09 | 739.28 | 734.95 | 736.00 |
| 1962 | 739.82 | 735.98 | 737.72 | 736.63 | 735.14 | 735.70 |
| 1963 | 738.23 | 735.26 | 736.63 | 736.02 | 734.84 | 735.49 |
| 1964 | 738.35 | 736.05 | 737.35 | 736.40 | 734.74 | 735.71 |
| 1965 | 739.44 | 736.98 | 738.22 | 737.29 | 735.00 | 736.03 |
| 1966 | 739.48 | 736.18 | 737.57 | 738.05 | 734.92 | 735.75 |
| 1967 | 741.50 | 736.07 | 737.76 | 737.79 | 734.77 | 735.59 |
| 1968 | 738.70 | 735.51 | 737.41 | 736.22 | 734.87 | 735.62 |
| 1969 | 737.02 | 734.92 | 735.77 | 743.42 | 734.95 | 736.19 |
| 1970 | 739.38 | 735.81 | 737.27 | 737.42 | 734.80 | 735.77 |
| 1971 | 738.78 | 735.72 | 737.16 | 737.66 | 735.10 | 735.80 |
| 1972 | 739.04 | 736.31 | 737.61 | 741.10 | 735.11 | 736.60 |
| 1973 | 742.70 | 735.73 | 737.77 | 740.05 | 734.89 | 736.28 |

Source: Tennessee Valley Authority, Division of Water Control Planning, River Control Branch, *Operation of TVA Reservoirs,* Annual Reports, Knoxville, Tenn.

River at CRM 4.4 near Kingston. Some of the smaller tributaries, their mouth locations, and drainage areas are given in Table 3.4-3. The Oak Ridge Reservation is composed of a series of limited drainage basins through which small streams feed the Clinch River. These watersheds generally fall about 600 ft from the headwaters to the outlet.[14] The largest of these drainage basins is that of Poplar Creek, which flows from northeast to southwest through approximately the center of the ORGDP area. Poplar Creek receives drainage from an area of 136 square miles that includes the northwestern sector of the Oak Ridge Reservation.

The topographic relief of the Poplar Creek drainage basin exceeds that of all other water systems in the Oak Ridge area.[19] Waters flow from the western half of the watershed lying in the Cumberland Mountain section of the Appalachian Plateau Province at elevations exceeding 3200 ft to valleys in the Valley and Ridge Physiographic Unit at altitudes of 741 ft near the mouth. Most of the basin is underlain by shale and sandstone of relatively low water-bearing capacity, whereas the region's principal aquifer (Knox Dolomite) occurs only in the southeastern segment of the watershed. Three of the major springs that arise from this major waterbearing structure contribute to Brushy Fork, a major tributary of Poplar Creek that flows through the City of Oak Ridge. These springs include Bacon Spring, the largest spring in the Oak Ridge area. Poplar Creek flows through a basin that is about 65% wooded; the remainder is farmland. Extensive surface mining has been undertaken in the Cumberland Mountain district. The creek also receives effluents from several small communities including Oliver Springs.

The East Fork of Poplar Creek drains a roughly rectangular watershed with an area of 29.8 square miles that is about 9 miles long and 3.5 miles wide[19] before it intersects Poplar Creek at Poplar Creek Mile (PCM) 5.5. East Fork originates from Chestnut Ridge, and altitudes in this basin range from 1280 ft on Pine Ridge to 741 ft at the mouth.

### 3.4.1.2 Water flow

Stream gages that measure flow have been maintained by the U.S. Geological Survey at three sites on the Clinch River in the vicinity of the Oak Ridge Reservation during various periods.[20-23] Those locations and the record periods are given in Table 3.4-4. Before construction of the Melton Hill Reservoir and by agreement with the TVA, a flow of not less than 150 cfs was sustained on the Clinch River near Oak Ridge after August 28, 1943. During that period, the maximum Clinch River flow noted was 42,900 cfs

Table 3.4-3. Location and Drainage Areas of Clinch River Tributaries

| Stream | Mouth location | Drainage area (sq miles) |
|---|---|---|
| Emory River | CRM[a] 4.4 | 865 |
| Poplar Creek | CRM 12.0 | 136 |
| East Fork of Poplar Creek | PCM[b] 5.5 | 29.8 |
| Bear Creek | EFPCM[c] 1.47 | 7.15 |
| Whiteoak Creek | CRM 20.8 | 6.37 |
| Melton Branch | WOCM[d] 1.55 | 1.48 |
| Hickory Creek | CRM 28.2 | 6.92 |
| Walker Branch | CRM 33 | 1.5 |
| Conner Creek | CRM 35.5 | 6.40 |
| Beaver Creek | CRM 39.6 | 90.5 |
| Bull Run Creek | CRM 46.7 | 104 |
| Hinds Creek | CRM 65.8 | 63.5 |
| Coal Creek | CRM 75.0 | 36.6 |
| Clear Creek | CRM 78.1 | 3.57 |
| Big Creek | CRM 83.0 | 67.3 |
| Powell River | CRM 88.8 | 938 |

[a]CRM = Clinch River Mile.
[b]PCM = Poplar Creek Mile.
[c]EFPCM = East Fork of Poplar Creek Mile.
[d]WOCM = Whiteoak Creek Mile.

Source: TVA Division of Water Control Planning, Hydraulic Data Branch, *Drainage Areas for Streams in the Tennessee River Basin*, Report 0-5829, Chattanooga, Tenn., May 1958.

Table 3.4-4. U.S. Geological Survey Stream Gages on the Clinch River in the Vicinity of Oak Ridge

| Station location | River mile | Period of record | Drainage area (sq miles) |
|---|---|---|---|
| Near Wheat | 14.4 | 1939–1941 | 3385 |
| | 14.4 | 1967–1968 | 3385 |
| Below Melton Hill Dam | 23.1 | 1962–1964 | 3343 |
| Near Scarboro | 39.0 | 1941–1962 | 3300 |

on February 9, 1937 (Ref. 22). The average flow at the station near Scarboro between the years 1936 and 1960 was 4564 cfs.[24] Before 1963, this river flow was influenced primarily by power releases from Norris Reservoir and by the runoff of about 40% of the average rainfall down the slope of the Clinch River Basin, which averages 1.5 ft/mile.[19] The typical variation in the flow of water near Melton Hill Dam as affected by power generating releases from the Norris Reservoir is illustrated in Fig. 3.4-2.

Construction of the Melton Hill Dam changed the regimen of the flow on the lower portion of the Clinch River. The average annual flow on this portion of the river since closing of the Melton Hill Dam has been about 4600 cfs.[6] The maximum hourly average release from the dam was 43,400 cfs and the maximum daily average release was 26,900 cfs; both of which accurred on March 16, 1973 (Ref. 6).

Data on monthly discharges from Melton Hill Dam from the time of its construction through 1973 are summarized in Table 3.4-5. The intermittent water discharges from Melton Hill Dam resulting from electric power generation during a standard summer week are depicted in the bar graph illustrated in Fig. 3.4-3. These data indicate that no releases from Melton Hill Dam occur on about 50 days throughout the year, usually on weekends when industrial power requirements are diminished. The longest continuous period of no flow on the Clinch was 29 days during February and March of 1966.[18] To sustain peak power demands, intermittent releases of 18,000 cfs frequently result on week days. Pulsations in river flow are particularly noteworthy in winter months when reservoir levels are raised following the cessation of heavy precipitation and by magnified runoff and hydroelectric requirements.

Values for maximum, minimum, and average flows of the major tributaries that drain the three laboratory sites are given in Table 3.4-6. Operation of the Whiteoak Dam has affected flow on Whiteoak Creek, whereas additions of waste water from the Y-12 Plant (10 to 20 cfs) and from the Oak Ridge Sewage Plant (3 to 10 cfs) have significantly augmented discharge at the headwaters of East Fork. However, the flow data are generally similar to tributary releases from catchments throughout the Tennessee section of the Valley and Ridge Province, and thus, the operation of the Oak Ridge laboratories has not affected significantly the flow regimen in the area.

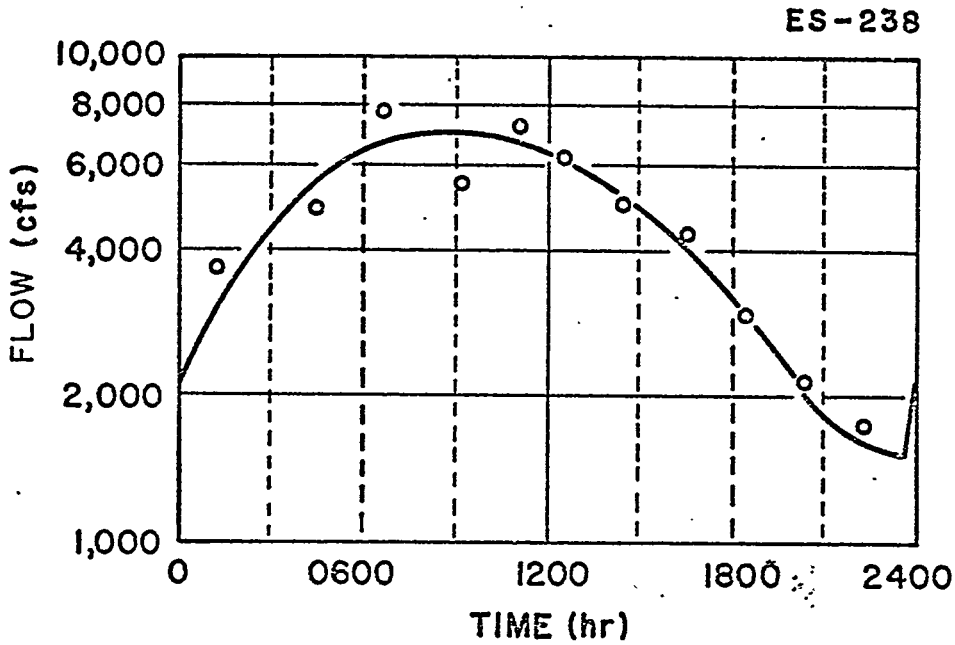


Fig. 3.4-2. Typical Daily Flow on Clinch River Near Melton Hill Dam Resulting From Variations in Power Releases From Norris Dam.

SOURCE: E. G. Struxness (Chairman) et al., Clinch River Study Steering Committee, "Comprehensive Report of the Clinch River Study," USAEC Report ORNL-4035, Oak Ridge National Laboratory, Oak Ridge, Tenn., April 1967.

Table 3.4-5. Melton Hill Dam Discharges (in cfs) for the Years 1963 Through 1973

| Year | January | | | February | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1963 | — | — | — | — | — | — |
| 1964 | 6,690 | 0 | 2,783 | 6,720 | 0 | 2,398 |
| 1965 | 19,780 | 2,620 | 10,126 | 11,451 | 102 | 5,123 |
| 1966 | 6,421 | 0 | 2,491 | 6,550 | 0 | 1,369 |
| 1967 | 10,682 | 0 | 7,098 | 9,095 | 0 | 4,505 |
| 1968 | 22,769 | 6,415 | 12,146 | 9,698 | 1,888 | 4,856 |
| 1969 | 14,964 | 0 | 2,850 | 8,445 | 769 | 4,930 |
| 1970 | 15,475 | 0 | 6,101 | 13,084 | 0 | 6,705 |
| 1971 | 10,646 | 0 | 3,522 | 10,758 | 0 | 5,855 |
| 1972 | 18,819 | 2,859 | 11,750 | 21,574 | 1,356 | 9,002 |
| 1973 | 21,320 | 1,173 | 8,463 | 11,788 | 949 | 4,914 |

| Year | March | | | April | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1963 | — | — | — | — | — | — |
| 1964 | 10,280 | 0 | 1,854 | 10,230 | 0 | 2,442 |
| 1965 | 14,323 | 0 | 3,568 | 13,240 | 560 | 5,891 |
| 1966 | 4,264 | 0 | 179 | 6,175 | 0 | 2,110 |
| 1967 | 20,518 | 2,942 | 10,184 | 6,808 | 0 | 3,399 |
| 1968 | 6,151 | 0 | 1,530 | 2,456 | 0 | 849 |
| 1969 | 5,155 | 0 | 2,444 | 4,800 | 0 | 1,607 |
| 1970 | 13,096 | 0 | 4,533 | 7,628 | 0 | 2,826 |
| 1971 | 11,901 | 0 | 2,490 | 9,473 | 0 | 2,508 |
| 1972 | 22,115 | 0 | 6,468 | 9,496 | 0 | 4,902 |
| 1973 | 22,291 | 0 | 9,577 | 10,270 | 0 | 4,058 |

| Year | May | | | June | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1963 | 4,300 | 0 | 1,115 | 10,900 | 0 | 4,302 |
| 1964 | 4,840 | 0 | 2,323 | 4,872 | 1,130 | 3,019 |
| 1965 | 6,493 | 0 | 3,997 | 7,540 | 0 | 2,505 |
| 1966 | 4,184 | 0 | 1,066 | 6,930 | 0 | 2,414 |
| 1967 | 5,070 | 0 | 1,011 | 7,865 | 1,193 | 4,683 |
| 1968 | 2,039 | 0 | 393 | 6,834 | 0 | 2,789 |
| 1969 | 10,543 | 0 | 2,276 | 9,458 | 0 | 3,002 |
| 1970 | 9,815 | 0 | 4,491 | 10,320 | 0 | 4,708 |
| 1971 | 12,709 | 0 | 5,719 | 11,624 | 1,068 | 6,342 |
| 1972 | 10,187 | 2,354 | 6,875 | 8,890 | 0 | 5,712 |
| 1973 | 20,980 | 1,326 | 8,905 | 18,380 | 1,893 | 9,258 |

Table 3.4-5 (continued)

| Year | July | | | August | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1963 | 8,020 | 0 | 2,728 | 4,810 | 0 | 2,806 |
| 1964 | 4,381 | 0 | 2,898 | 4,986 | 0 | 2,529 |
| 1965 | 5,633 | 0 | 2,390 | 8,880 | 1,768 | 5,099 |
| 1966 | 5,267 | 0 | 3,471 | 9,110 | 2,109 | 6,226 |
| 1967 | 11,706 | 0 | 5,009 | 9,776 | 0 | 6,132 |
| 1968 | 10,254 | 357 | 6,325 | 11,871 | 0 | 7,060 |
| 1969 | 9,799 | 0 | 4,506 | 8,284 | 0 | 3,310 |
| 1970 | 10,631 | 0 | 5,243 | 11,250 | 0 | 5,098 |
| 1971 | 7,232 | 0 | 3,332 | 8,600 | 1,307 | 5,564 |
| 1972 | 8,803 | 0 | 4,489 | 10,348 | 1,234 | 6,229 |
| 1973 | 10,597 | 1,326 | 4,929 | 10,085 | 672 | 7,451 |

| Year | September | | | October | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1963 | 10,900 | 986 | 5,391 | 8,190 | 994 | 5,450 |
| 1964 | 6,235 | 0 | 3,404 | 7,701 | 0 | 4,124 |
| 1965 | 7,751 | 2,520 | 5,626 | 4,891 | 2,541 | 3,524 |
| 1966 | 8,474 | 306 | 5,094 | 7,351 | 0 | 2,498 |
| 1967 | 10,206 | 532 | 7,121 | 8,525 | 5,362 | 7,296 |
| 1968 | 7,920 | 0 | 1,699 | 5,699 | 0 | 3,376 |
| 1969 | 8,402 | 0 | 2,557 | 7,123 | 0 | 1,734 |
| 1970 | 8,213 | 0 | 5,357 | 8,709 | 0 | 3,622 |
| 1971 | 9,193 | 0 | 5,483 | 9,467 | 4,146 | 6,073 |
| 1972 | 10,002 | 765 | 4,127 | 6,949 | 0 | 3,617 |
| 1973 | 9,340 | 0 | 5,456 | 7,016 | 0 | 1,838 |

| Year | November | | | December | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | Maximum | Minimum | Average |
| 1963 | 6,220 | 0 | 3,106 | 8,000 | 0 | 3,655 |
| 1964 | 10,665 | 3,722 | 7,500 | 10,295 | 3,628 | 7,441 |
| 1965 | 6,768 | 1,599 | 4,269 | 7,715 | 0 | 3,181 |
| 1966 | 5,708 | 0 | 1,781 | 11,219 | 3,234 | 7,224 |
| 1967 | 7,798 | 0 | 3,920 | 22,340 | 642 | 10,608 |
| 1968 | 11,996 | 0 | 3,897 | 10,150 | 0 | 3,153 |
| 1969 | 12,643 | 0 | 3,296 | 17,576 | 0 | 3,434 |
| 1970 | 11,194 | 0 | 2,844 | 9,116 | 799 | 3,653 |
| 1971 | 10,780 | 5,086 | 7,580 | 9,766 | 5,140 | 7,187 |
| 1972 | 13,046 | 0 | 6,970 | 23,102 | 8,062 | 17,020 |
| 1973 | 20,748 | 604 | 4,993 | 22,299 | 2,147 | 10,288 |

Source: Tennessee Valley Authority, Division of Water Control Planning, River Control Branch, *Operation of TVA Reservoirs,* Annual Reports, Knoxville, Tenn.

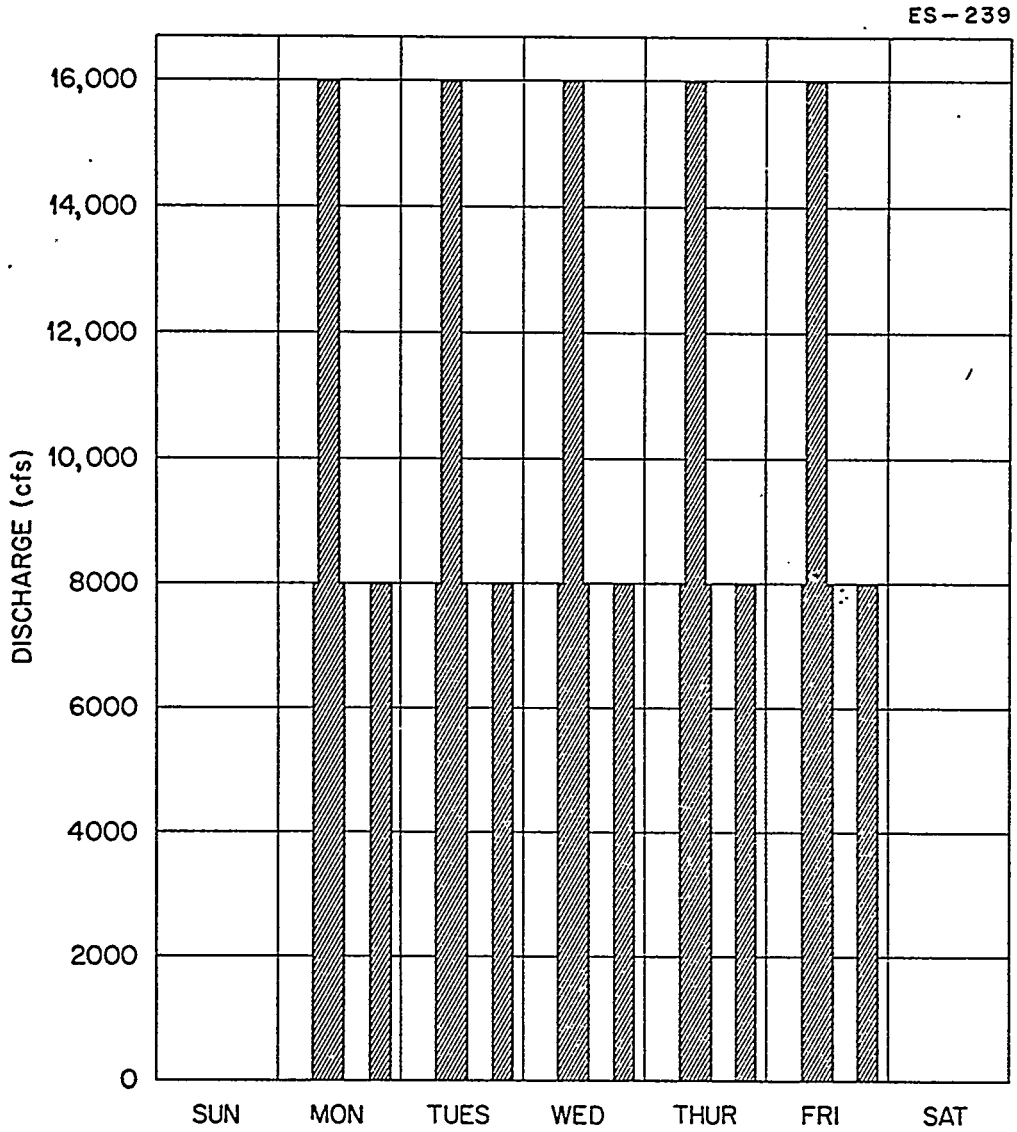


Fig. 3.4-3. Typical Summer Week Discharge Pattern for Power Releases From Melton Hill Dam.

SOURCE: E. G. Struxness (Chairman) et al., Clinch River Study Steering Committee, "Comprehensive Report of the Clinch River Study," USAEC Report ORNL-4035, Oak Ridge National Laboratory, Oak Ridge, Tenn., April 1967.

Table 3.4-6. Flow Characteristics of Some of the Major Tributaries on the Oak Ridge Reservation

| Stream | Gage location | Discharge | | | | | Period of record |
|---|---|---|---|---|---|---|---|
| | | Maximum | | Minimum | | Average (cfs) | |
| | | (cfs) | Date | (cfs) | Date | | |
| Melton Branch | MBM 0.1 | 242 | 03/11/62 | 0 | 09/02/62 | 2.50 | 1955–1963 |
| Whiteoak Creek | WOCM 1.65 | 642 | 08/30/50 | 0 | 09/16/61 | 9.62 | 1950–1953<br>1955–1963 |
| Whiteoak Creek | WOCM 0.6 | 669 | 12/29/54 | 0 | (During power releases from Melton Hill Dam) | 13.5 | 1950–1952<br>1955–1963 |
| East Fork of Poplar Creek | EFPCM 3.3 | 2610 | 07/06/67 | 13 | 08/16/69 | 48.3 | 1960–1970 |
| Bear Creek | BCM 0.8 | 594 | 03/12/63 | 0.50 | 08/12–14/62 | | |
| Poplar Creek | Mouth | 6350 | 03/12/63 | 5.0 | 10/27/63 | 165 | 1961–1965 |

Source: Various U.S. Geological Survey Water-Supply Papers.

### 3.4.2 Floods

Stage and discharge gages have been operated at different locations on the Clinch River by the U. S. Geological Survey over various periods. Clinch River stage records are available for Scarboro (CRM 39.0) for the years 1941 to 1962, for Melton Hill Dam (CRM 23.1) from 1962 to 1964, and near Oak Ridge (CRM 14.5) from 1937 to 1963 and during the water year 1967-68 (Refs. 6 and 25). Stage records are also available downstream near the mouth of the Clinch River at Kingston since 1874 except for the period from 1877 to 1882.

From the available records and from newspaper and other historical accounts, the greatest known flood on the Clinch River occurred in March 1826 (Ref. 19). However, no gages were in operation at the time, and the crest stages were taken from high water marks. The greatest gaged flood stage occurred on March 31, 1886, and the flood crest reached an elevation of 817.8 ft above mean sea level at Clinton, Tennessee.[19] The natural flood crest reached an elevation of approximately 755.5 ft at CRM 14, 754.5 at CRM 13, and 753.0 ft at CRM 12 (mouth of Poplar Creek).[19]

A record breaking flood occurred in March 1929 on the Emory River, which enters the Clinch River at Mile 4.4. This flood did not exceed the 1886 flood levels upstream on the Clinch River. However, under present-day conditions, a repetition of this 1929 flood would cause the maximum known regulated Clinch River level of about 751 ft from CRM 4.4 upstream to Melton Hill Dam at CRM 23.1 (Ref. 19). Under present-day conditions, the maximum Clinch River flood of 1886 would be reduced to an elevation of about 748 ft by the Norris Reservoir.[6]

The largest flood since completion of the present TVA system occurred in March 1973 when elevations of 749.6 and 748.6 ft were reached at CRM 17.8 and CRM 14.5, respectively.[6] This flood resulted from unusually intense rainfall below Norris Dam and below other TVA tributary reservoirs, resulting in high flows in the Emory River and in smaller local streams as well as a record high elevation in Watts Bar Reservoir. The maximum elevation recorded at Watts Bar Dam is 745.4 ft, and this occurred March 17, 1973 (Ref. 6).

### 3.4.3 Probable Maximum Flood on Streams and Rivers

A detailed analysis of the probable maximum flood (PMF) on the Clinch River was performed for the Clinch River Breeder Reactor preliminary safety analysis[6] to determine

probable maximum water levels. The evaluation of seasonal and areal variations of probable maximum storms showed that the PMF level at the Clinch River Breeder Reactor Plant site would be caused by a sequence of two storms occuring in March and centered in the watershed above Watts Bar Dam. The flood crest at the plant site would be augmented by the failure of the earth embankment at Fort Loudoun Dam, upstream on the Tennessee River, and the nonoverflow section at Melton Hill Dam, upstream on the Clinch River. Failure of the earth embankment at Watts Bar Dam, downstream on the Tennessee River, would lower the flood level at the plant site 3.5 ft. The estimated maximum discharge at the plant site would be 242,000 cfs. The PMF elevation at the plant site would be 777.5 at CRM 18 and 776.0 at CRM 16, including the three dam failures but excluding any wind wave effects.[6]

It is stated in Ref. 6 that occurrence of the PMF as determined and applied in that study is extremely unlikely. The postulated combination of events results in a probability of occurrence which approaches zero. The events combined include a main storm with rainfall volumes which are the physical upper limit that the present climate can produce, an assumed antecedent storm amounting to 40% of the main storm volume, which exceeds the maximum recorded on the watershed to date, and assumption of an exact centering of the storm to cause that combination of Clinch and Tennessee River flows which produce maximum flood levels at the plant.

The surface elevation cf Poplar Creek, which runs in close proximity to the process buildings at the ORGDP, varies generally between 740 and 745 ft, depending upon the level of Watts Bar Lake. Its level during flood conditions determines the maximum flood level in the plant area. The maximum probable flood level for Poplar Creek adjacent to the ORGDP area has been predicted at elevation 773.5 at Poplar Creek Mile 1.5.

Recent elevations from a study being conducted in the ORGDP area by the TVA indicate that at Clinch River Mile 12 (mouth of Poplar Creek), the 100-year flood would crest at 748.1 ft above mean sea level, the 500-year flood at 750.5 ft, and the probable maximum flood would crest at 758.4 ft. In an earlier determination of the probable maximum flood on the Clinch River,[19] regulated flood crest elevations of 758.5 ft at CRM 12, 760.5 ft at CRM 14, 763.0 ft at CRM 16, and 765.5 ft at CRM 18 were postulated.

### 3.4.4 Potential Dam Failures (Seismically Induced)

The ORGDP site and upstream reservoirs are located in the Southern Appalachian Tectonic Province and are therefore subject to moderate earthquake forces. An investigation of

all upstream dams whose failure in a seismic event might cause problems was conducted for the Clinch River Breeder Reactor Plant.[6] An operational basis earthquake imposed concurrently with the one-half probable maximum flood resulting in postulated failure of Norris Dam would result in a maximum water surface elevation of 804.3 ft at CRM 18 and 798.2 ft at CRM 16, excluding any wind wave effects.[6] The peak flow would be 921,000 cfs.

It is stated in Ref. 6 that by furnishing this information, the TVA does not imply or concede that its dams are inadequate to withstand great floods and/or earthquakes that might be reasonably expected to occur in the region under consideration. The TVA has a program of inspection and maintenance carried out on a regular schedule to keep its dams safe. Instrumentation was installed in many of the dams during their construction to help keep check on their behavior, and other instrumentation has been added since and is still being added as the need appears or as new techniques become available. The TVA is confident that its dams are safe against catastrophic destruction by any natural forces that could be expected to occur.[6]

### 3.4.5 Probable Maximum Surge and Seiche Flooding

Because of the inland geographic location of the ORGDP and the physical characteristics of the Clinch River system, the effects of surge and seiche flooding were not considered.

### 3.4.6 Probable Maximum Tsunami Flooding

Because of the inland geographic location of the ORGDP, the adverse effects of tsunami flooding were not considered.

### 3.4.7 Ice Flooding

Because of the location in a temperate climate, significant amounts of ice do not form on the lakes and rivers in the Oak Ridge area. There are no records of frazil or anchor ice on the Clinch River in the vicinity of the ORGDP.[6] The potential for ice formation at the site is less today than in the past because daily fluctuations in the water level from the Watts Bar and Melton Hill Reservoirs would break up surface ice before significant thicknesses could be formed. Increased water depths in the backwaters of Watts Bar Reservoir result in the need to cool a greater mass by radiation for freezing than was the case

before the dam was constructed.

### 3.4.8 Low Water Considerations

As discussed in Subsection 3.4.1, the surface elevation of the Clinch River adjacent to the ORGDP site is controlled by operation of Watts Bar Dam as well as the reservoirs upstream from Watts Bar Dam. Requirements for power generation, navigation, and flood control have determined the minimum water levels that have occurred in the Clinch River at the site. Regulation of low flows and water elevations at the site is accomplished by controlled releases from Norris, Melton Hill, and Watts Bar Reservoirs. These reservoirs store very large volumes of water, and the controlled releases greatly alter the natural flow patterns in the river system. In fact, historical low flows at the site have resulted from regulated rather than from natural flows. Therefore, low water and flows at the site are explained in terms of the operating policies of the reservoirs which control the water level at the site.

Since the closure of Melton Hill Dam in 1963, there has been an average of about 46 days per year on which no water was released. The longest period of no release was 29 consecutive days. This occurred during February and March of 1966 (Ref. 6). The second longest period of zero release from the dam was 11 consecutive days which occurred in the April to May period of 1967 (Ref. 6). Both zero release periods resulted from special reservoir operations conducted to aid in controlling the growth of Eurasian water milford in the Melton Hill Reservoir. The days of zero flow from Melton Hill Dam resulted in essentially zero velocities in the Clinch River at CRM 16 and a minimum surface elevation of 735.32 ft at Watts Bar Dam.[6]

The TVA generally maintains Watts Bar Reservoir at a pool elevation of between 740 and 741 ft during the spring and summer months (mid-April through September) and at a normal winter pool elevation of between 735 and 737 ft during the remainder of the year. Drawdown from summer-pool level (741) is allowed to begin as early as July 1 during dry weather to provide downstream flow augmentation or power generation.

During the 32 years of record since the initial filling of Watts Bar Reservoir, the TVA has been able to follow closely the above plan of normal operation. Sufficient inflow has been available each year to raise the reservoir from winter level to summer level on schedule, and no extended period of drought has forced a significant lowering of lake level below either the normal summer or winter operating levels. The normal minimum operating elevation of

Watts Bar Reservoir for navigation purposes is 735 ft above mean sea level. However, the reservoir can be drawn down temporarily to an elevation of 733 ft at Watts Bar Dam if a minimum tailwater elevation of 735 can be maintained upstream at Melton Hill and Fort Loudon Dams. It is possible to lower Watts Bar Reservoir to about 713 ft by opening the gated spillway at the dam, and computations indicate that more than 12 hours would be required to lower the reservoir from elevation 735 ft to elevation 725 ft.[6] It is emphasized that TVA policy requires that Watts Bar Reservoir be maintained at a minimum level of 735 ft. There appears to be no reason to lower Watts Bar Reservoir below elevation 735 ft.

### 3.4.9 Chemical and Biological Composition of Adjacent Watercourses

In general, the waters of the Clinch River are of the calcium, magnesium, and bicarbonate type. These ions impart the alkalinity and hardness characteristic of streams in this region. These properties result from the fact that surface flows in the Valley and Ridge Province are sustained by base flows derived primarily from limestone and dolomite aquifers. The major geological strata, expressed as a percentage of the surface area, for some representative watershed basins in the Oak Ridge area are given in Table 3.4-7. The waters of Poplar Creek, the lower Clinch River, and the Tennessee River are of lower pH (more acid); a characteristic which is probably related directly to a significant decrease in the calcium, magnesium, and bicarbonate buffering capacity. This change in chemical parameters is created by the introduction of flows from silicate drainage basins in the Cumberland Mountains. Poplar Creek and other streams that originate in the mountains are also burdened with substantial amounts of sulfate released by the oxidation of pyrite (iron sulfide) exposed during surface mining. Higher concentrations of metallic cations, such as those of iron, aluminum, and manganese, are also released by the leaching action of sulfuric acid created during this oxidation reaction.

Most of the other stable chemical constituents of drainage basins in the Oak Ridge area do not differ significantly from those of other Valley and Ridge Province streams. Unusually low levels of suspended solids are reported frequently. This condition can probably be ascribed to sedimentation in reservoirs. Most of the cations, in particular those of iron, occur in oxidized form because the rapidly flowing tributaries of the Clinch system are well supplied with dissolved oxygen.

Table 3.4-7. Stratigraphic Composition of Some Drainage Basins in the Oak Ridge Area

| Watershed | Composition (% of watershed surface area) | | | | |
|---|---|---|---|---|---|
| | Rome Formation and Conasauga Group | Knox Dolomite | Chickamauga Limestone | Late Ordivician to Mississipian Age | Pottsville Age |
| Clinch River at CRM 51.1 | | 50 | 50 | | |
| Scarboro Creek | 38 | 62 | | | |
| Whiteoak Creek | 44 | 30 | 26 | | |
| Melton Branch | 95 | 5 | | | |
| Poplar Creek | 35 | 5 | 5 | | 55 |
| East Fork of Poplar Creek | | 78 | 22 | | |
| Mill Branch | 41 | | 9 | 50 | |
| Gum Hollow Branch | 44 | | 20 | 36 | |
| Bear Creek | 74 | 26 | | | |

Source: R. J. Pickering, "Quality of Surface Water and Geochemical Relationships," in W. M. McMaster, *Hydrologic Data for the Oak Ridge Area, Tennessee,* U.S.G.S Water-Supply Paper 1839-N, 1967, p. 49.

Samples of water from 29 streams in the vicinity of Oak Ridge have been analyzed chemically to determine the base flow water quality of the region. The resulting data for three collection points on the Clinch River are summarized in Table 3.4-8. The results of stable chemical and trace element analyses are given in Table 3.4-9 for some tributaries of the Clinch River within the Oak Ridge Reservation.

Since virtually all base flow within the Oak Ridge Reservation originates as groundwater, the concentrations of chemical constituents in the surface water given in Tables 3.4-8 and 3.4-9 reflect primarily the mineral composition of the soils and bedrock underlying the watershed. This correspondence is particularly striking during periods of low flow when groundwater passage is retarded enough to permit equilibration of ions between the solid state adsorbed on mineral surfaces and the dissolved state in the groundwater. Saturation of water supply usually represents the limiting condition to geochemical dissolution.

Chemical loads display seasonal variations that are related largely to how much flow is being diverted to groundwater. Maximum concentrations are recorded in fall when the groundwater contribution to total flow also is highest. Lowest chemical concentrations occur in spring when surface water flow predominates. However, even in autumn, the chemical quality of watersheds in the Oak Ridge area is generally very good.

## 3.5 Subsurface Hydrology

Subsurface hydrological features characteristic of the Oak Ridge area and the ORGDP site are discussed in the following subsections.

### 3.5.1 Regional and Area Characteristics

As indicated in the discussion of surface water in Subsection 3.4.9, the base flow of the water systems that drain the Oak Ridge Reservation is maintained primarily by groundwater discharge. The nature and extent of an aquifer, or waterbearing formation, is determined by the character, distribution and structure of the bedrock and by the size, shape, and continuity of the interstices; these are interrelated factors.

Table 3.4-8. Results of Stable Chemical Analyses of Water Samples Taken At Three Sampling Sites on the Clinch River Near the Oak Ridge Reservation

| Component of property | Concentration (ppm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | At CRM 41.5[a] | | | At CRM 14.4[b] | | | At CRM 5.5[c] | | |
| | Maximum | Minimum | Average | Maximum | Minimum | Average | Maximum | Minimum | Average |
| Ca | 36 | 18 | 27 | 27 | 17 | 21 | 43 | 17 | 27 |
| $HCO_3$ | 130 | 105 | 117 | 141 | 87 | 110 | 135 | 57 | 112 |
| Cr | 0.19 | 0.00 | 0.02 | NA[d] | NA | NA | 0.18 | 0.00 | 0.01 |
| Cl | 11 | 1 | 5 | 4.5 | 1.0 | 1.6 | 8 | 1 | 3 |
| Fe | 9.2 | 0.3 | 3.4 | 0.37 | 0.01 | 0.06 | 7.1 | 0.1 | 1.7 |
| Mg | 18.0 | 5.1 | 9.4 | 10.0 | 4.5 | 7.7 | 22.6 | 4.1 | 9.4 |
| Mn | 1.1 | 0.0 | 0.4 | NA | NA | NA | 0.6 | 0.0 | 0.1 |
| $NO_3^-$ | 2.4 | 0.2 | 1.0 | 19 | 0.3 | 2.7 | 12.7 | 0.0 | 1.5 |
| $PO_4^{3-}$ | 0.4 | 0.1 | 6.2 | 0.75 | 0.05 | 0.22 | 0.6 | 0.0 | 0.1 |
| K | 3.1 | 0.8 | 1.7 | 2.3 | 1.1 | 1.3 | 3.5 | 0.6 | 1.6 |
| Si | 4.0 | 1.5 | 2.9 | 2.4 | 0.1 | 1.5 | 4.4 | 0.9 | 2.7 |
| Na | 5.2 | 1.0 | 2.3 | 4.7 | 1.8 | 2.4 | 9.5 | 0.0 | 2.4 |
| Sr | 0.086 | 0.058 | 0.073 | 0.80 | 0.040 | 0.07 | 0.080 | 0.43 | 0.069 |
| $SO_4^{2-}$ | 23 | 2 | 12 | 29 | 1 | 10 | 29 | 0 | 12 |
| Suspended solids | 557 | 18 | 185 | 104 | 1.0 | 25.3 | 275 | 2 | 55 |
| Dissolved solids | 201 | 67 | 125 | 218 | 90 | 129 | 549 | 25 | 133 |
| Total solids | 677 | 140 | 310 | 231 | 127 | 154 | 601 | 112 | 188 |
| Turbidity | 68 | 6 | 28 | NA | NA | NA | 86 | 1 | 17 |
| Hardness, as $CaCO_3$ | 148 | 78 | 107 | NA | NA | NA | 169 | 69 | 106 |
| Specific conductance[e] | (263) | (119) | (195) | (282) | (190) | (216) | (312) | (105) | (196) |
| Acidity, as $CaCO_3$ | 10 | 0 | 3 | NA | NA | NA | 14 | 0 | 4 |
| pH | (8.2) | (7.1) | NA | (8.1) | (7.0) | NA | (8.5) | (7.2) | NA |

[a] Based on 104 weeks of samples between December, 1960, and November, 1962.
[b] Based on 58 weeks of samples from November, 1960, through January, 1962.
[c] Based on 104 weeks of samples from November, 1960, through December, 1962.
[d] NA denotes "data not available."
[e] In micromhos at 25°C.

Source: R. J. Pickering, *Composition of Water in Clinch River, Tennessee River and Whiteoak Creek as Related to Disposal of Low-level Radioactive Liquid Wastes, in Transport of Radionuclides by Streams,* U.S.G.S. Professional Paper 433-J, 1970.

Table 3.4-9. Results of Stable Chemical Analyses and Spectrographic Trace Element Analyses of Water Samples From Some Tributaries of the Clinch River That Flow Through the Oak Ridge Reservation

| Component or property | Scarboro Creek | East Fork near its mouth | Mill Branch | Gum Hollow | East Fork near Oak Ridge | Bear Creek near Oak Ridge | Poplar Creek near Oak Ridge | Whiteoak Creek above ORNL | Melton Branch | Whiteoak Creek near Whiteoak Dam |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Concentration (ppm) | | | | | |
| Al | 0.05 | 0.2 | 0.06 | 0.1 | 0.06 | 0.06 | 0.1 | 0.06 | 0.03 | 0.07 |
| Ca | 36 | 33 | 40 | 34 | 39 | 40 | 29 | 24 | 39 | 36 |
| $HCO_3$ | 184 | 111 | 149 | 120 | 136 | 154 | 102 | 132 | 143 | 144 |
| $CO_3^{2-}$ | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cl | 1.6 | 32 | 4.4 | 0.9 | 26.2 | 1.9 | 1.9 | 0.9 | 4.2 | 7.6 |
| F | 0.04 | 1.3 | 0.1 | 0.1 | 0.9 | 0.2 | 0.1 | 0.1 | 0.4 | 0.7 |
| Fe | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.01 | 0.05 | 0.01 | 0.01 | 0.04 |
| Li | 0.05 | 0.4 | 0.06 | 0.06 | 0.3 | 0.05 | 0.01 | 0.02 | 0.1 | 0.2 |
| Mg | 17 | 8.0 | 9.0 | 6.1 | 10.0 | 16.2 | 8.8 | 12.6 | 8.1 | 8.4 |
| Mn | 0.01 | 0.01 | 0.01 | 0 | 0.01 | 0 | 0.01 | 0.01 | 0.01 | 0.01 |
| $NO_3^-$ | 0.6 | 35 | 0.8 | 0.2 | 20.6 | 14.0 | 0.5 | 0.3 | 1.2 | 7.6 |
| $PO_4^{3-}$ | 0 | 0.6 | 0 | 0 | 2.3 | 0 | 0 | 0.02 | 0.06 | 0.35 |
| K | 0.8 | 2.4 | 2.6 | 1.3 | 2.7 | 1.4 | 1.3 | 0.6 | 1.4 | 1.7 |
| $SiO_2$ | 7.6 | 4.7 | 11.2 | 9.2 | 6.5 | 8.5 | 7.2 | 6.9 | 5.2 | 5.4 |
| Na | 0.8 | 48 | 4.2 | 1.8 | 26.0 | 2.5 | 3.3 | 0.6 | 5.1 | 20 |
| $SO_4^{2-}$ | 3.5 | 29 | 16.3 | 12.5 | 27 | 29 | 26 | 2.7 | 15.9 | 29 |
| Dissolved solids | 155 | 273 | 162 | 126 | 232 | 162 | 129 | 112 | 152 | 189 |
| Detergent | 0.03 | 0.5 | 0.05 | 0.06 | 0.7 | 0.1 | 0.06 | 0.05 | 0.08 | 0.1 |
| Ca-Mg hardness total | 158 | 116 | 136 | 110 | 139 | 166 | 108 | 112 | 130 | 124 |
| Ca-Mg hardness noncarbonate | 7 | 12 | 14 | 11 | 27 | 40 | 24 | 4 | 13 | 7 |
| Specific conductance[a] | 285 | 452 | 273 | 215 | 393 | 322 | 224 | 209 | 267 | 325 |
| pH | (7.8) | (8.3) | (7.7) | (7.7) | (7.1) | (7.8) | (7.4) | (7.9) | (7.8) | (7.4) |
| | | | | | Concentration (ppb) | | | | | |
| B | 26 | 34 | 49 | 22 | 110 | 34 | 31 | 8.0 | 27 | 32 |
| Ba | 63 | 68 | 59 | 48 | 140 | 120 | 68 | 120 | 100 | 100 |
| Cr | 0.44 | 3.0 | <0.31 | 0.30 | 2.4 | <0.34 | <0.21 | <0.24 | 1.0 | 120 |
| Co | <3.1 | ND[b] | ND | ND | ND | ND | <2.1 | ND | ND | ND |
| Cu | 4.1 | 5.4 | 7.1 | 9.3 | 51 | 2.8 | 3.7 | 2.4 | 8.0 | 17 |
| Pb | 9.1 | <5.7 | 3.4 | 6.7 | 12 | 4.0 | 2.7 | 3.4 | 3.9 | 6.8 |
| Li | 6.47 | 130 | 2.4 | 1.3 | 130 | 10 | 0.58 | 0.24 | 1.3 | 2.7 |
| Mo | ND | <1.7 | ND | ND | 4.3 | ND | ND | ND | ND | 24 |
| Ni | 3.5 | <5.7 | 4.3 | 8.0 | 71 | 6.1 | 6.4 | <2.4 | 6.0 | 22 |
| Rb | ND | 5.7 | 3.1 | ND | <5.1 | ND | <2.1 | 2.4 | ND | <3.0 |
| Ag | <0.31 | 1.8 | 0.31 | ND | <0.51 | ND | <0.21 | ND | 0.23 | <0.30 |
| Sr | 31 | 97 | 100 | 61 | 130 | 130 | 37 | 21 | 4 | 130 |
| Ti | 5.3 | <5.7 | <3.1 | 2.6 | 5.1 | 3.4 | 3.5 | <2.4 | 3.7 | 5.0 |
| V | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Yb | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Y | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Zn | <310 | ND | <310 | ND | ND | ND | ND | ND | <230 | ND |
| Zr | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |

[a] In micromhos at 25°C.

[b] ND denotes "not detectable."

Source: R. J. Pickering, "Quality of Surface Water and Geochemical Relationships," in W. M. McMaster, *Hydrologic Data For the Oak Ridge Area, Tennessee,* U.S.G.S. Water-Supply Paper 1839-N, pp. 50-60.

Two regions of subsurface water are commonly distinguished. The unweathered soil horizon usually constitutes the zone of subsaturation, or zone of aeration, which contains water only temporarily while it is in transit to recharge the deeper groundwater storage reservoir. These recharge accretions eventually enter the zone of saturation where all the rock interstices are filled with water under hydrostatic pressure. The water table is defined as the upper surface of this zone of saturation. If a well is drilled deep enough to penetrate the saturated zone, water will flow into the well until it reaches the same elevation as the adjacent water table.[26] To estimate and to understand the hydrologic characteristics of a given area, the overlying soil mantle in the zone of aeration and the geology of the underlying strata in the zone of saturation are equally important and should be considered simultaneously.[27]

Because of the threat of contamination of areas adjacent to the reservation, it is important to determine whether artesian or water-table conditions prevail for groundwater flow.[27] If artesian conditions exist, it is theoretically possible for waters polluted with radionuclides to transverse the bedrock in independent channels, to travel for miles deep underground (even conceivably beneath the Clinch River), and to emerge in distant springs used for drinking purposes. Alternatively, if groundwater movement follows water-table conditions, the bedrock is found to be fractured and jointed sufficiently that subsurface water movement closely parallels the contours of the surface topography, and the water emerges to contribute to local streamflow.

Although local, semiconfined, artesian conditions probably exist, groundwater flow on the Oak Ridge Reservation is determined primarily by water-table conditions, and discharge contributes to the base flow of surface streams that utlimately augment the Clinch River water supply. The Clinch River is a hydraulic sink for this region. The river bed lies at the base level of the zone of saturation; hence, all groundwater from both sides of the channel must enter it. There is no force to drive water from one side of the Clinch to the opposite side except for the rare instance when a large well is drilled on one side that generates sufficient force to pump water against the gradient of this hydraulic barrier.

As discussed in Subsection 3.1.4, almost all of the industrial and drinking water for the Oak Ridge area is taken from surface water supplies. However, wells are common in adjacent rural lands such as Hardin Valley. One of the major reasons this area does not depend on groundwater resources is that the average well in Oak Ridge

is estimated to yield less than 10 gal/min. Even on the Knox Dolomite, the principal aquifer of the reservation, a well would probably sustain a flow of only 50 gal/min.[14] The pertinent characteristics of some of the wells in the Oak Ridge area are summarized in Table 3.5-1.

The lack of wells on the Oak Ridge area has made difficult the creation of a depth-to-water map for the reservation. Certain sites have been mapped with respect to groundwater levels by use of core drillings undertaken in conjunction with plant or burial-ground construction. However, the extensive unstudied regions prohibit the generalization of those data to the entire Oak Ridge Reservation. Moreover, data for the available maps were collected during different seasons. Water-table levels are affected significantly by climatic conditions. Subsurface elevations follow a pattern according to which levels begin to rise in November, peak in March, and then decrease as discharge exceeds recharge.[14] Hence, groundwater contours reported at different periods of the year cannot be equated. However, all of the maps do indicate that water-table conditions are prevalent in all regions plotted since water contours closely parallel physiographic contours.

If it can be assumed that all major groundwater reservoirs in the Oak Ridge area adhere to water-table conditions, then base flows of surface streams are defined largely by the physical and chemical composition of the geological materials. The existence of fault zones on the reservation would not affect this assumption since these tectonic discontinuities have been sealed by mineralization processes that have occurred over the last 200,000 years. Percolation through these fault blocks is therefore highly improbable. The hydrological properties of the four major stratigraphic units and their overlying residual materials are discussed in the following paragraphs to provide a general description of the hydrological features of the region.

#### 3.5.1.1 Major stratigraphic units

Information on the Rome Formation groundwater capacity is sparse, since very few wells have been drilled in it. The limited number of road cuts and water gaps do indicate that this stratigraphic unit has very little capacity for receiving, storing, and transmitting water. In unweathered bedrock, the occurrence of groundwater is restricted to small openings along joints and bedding planes. Moreover, vertical drainage of recharge precipitation is further depleted by the steep terrain typically underlain by the Rome which favors increased surface runoff. The thin mantle of residual clay and weathered bedrock contains more extensive openings which probably account for the greater

Table 3.5-1. Description of Some Wells in the Vicinity of the City of Oak Ridge[a]

| Location relative to Jackson Square | Owner | Driller | Topographic position | Altitude (ft) | Depth (ft) | Character of geological material | Yield (gal/min) |
|---|---|---|---|---|---|---|---|
| 3 mi N | Braden | | Valley | 850 | | Shale | 10 |
| 1.5 mi NW | Henderson | | Valley | 845 | 100 | Shale | |
| 2 mi NE | Coplin | Beets | Slope | 1010 | 300 | Dolomite | |
| 1.5 mi E | Preston | | Slope | 820 | 202 | Limestone | |
| 3.5 mi NE | Miller | | Slope | 880 | 200 | Limestone | |
| 4 mi E | Fraker | Davis | Slope | 850 | 52 | Shale | |
| 1.5 mi W | Owens | | Valley | 815 | 18 | Shale | |

[a]Water used for drinking.

Source: G. D. DeBuchananne and R. M. Richardson, *Ground-water Resources of East Tennessee,* Tennessee Department of Conservation, Division of Geology, Bulletin 58, Part I, 1956, pp. 32–46, 56–66, and 335–344.

part of subterranean water movement in the Rome.[27] McMaster concludes that this geologic unit is the poorest aquifer in the region.[14] No industrial supplies throughout east Tennessee are developed from it.[28]

The hydrological properties of the Conasauga Shale are somewhat variable because of its heterogeneous composition. Generally, the ability of this group to transmit water increases with the thickness of the limestone strata. The lower two members of this geologic unit, located under Melton Valley with poor Maynardsville Limestone development, are practically devoid of permeability below a depth of 100 ft. In these instances, groundwater is confined principally to the weathered zone where joints and bedding members are slightly enlarged by circulating waters.[27] The bedrock does not weather easily; therefore, these openings are confined to shallow depths, and the capacity for groundwater storage is relatively limited.[28] When recharge is limited in summer by evaporation and transpiration losses, discharges from this groundwater reservoir are severely depleted.[27] The more calcareous members of this formation which provide bedrock for Bear Creek Valley often contain cavities that are several feet wide and extend for at least 100 ft below the surface.[1] The capacity to transmit water is facilitated by these numerous large solution openings, and springs are particularly common at the Knox and Conasauga interface.[14]

The Knox Dolomite is the principal aquifer of the Oak Ridge area[14] and of east Tennessee.[28] The extensive water storage capacity of this geologic unit is due to fractures of bedrock enlarged by dissolution of the soluble dolomite compounds.[28] Some of these openings even attain cavernous proportions. Sinkholes occur frequently in the outcrop belts, and many sizeable springs arise from the base of the ridges. Depths of the water table reach 125 ft at the ridge tops.[27] The position of the water table commonly coincides with the interface between bedrock and the residual clay overburden.[6] The residual material, which is the thickest soil mantle in the area and varies in depth from 30 to 125 ft, actually provides the major basin for this unit's groundwater storage.[14] This huge expanse of overburden has a high infiltration capacity, which also tends to minimize overland runoff while maximizing recharge.[6] In most instances, ridges underlain by Knox also define the watershed divides of the area.

The Chicamauga Limestone is not a good aquifer because it is composed of so much shale and siltstone. This formation is practically devoid of any significant solution cavities, and the only water derived from it probably permeates along thin bedding plans and joint partings.[1] Although numerous small openings may occur within but rarely beyond 100 ft of the surface, rates and quantity of water transport are very small. Recharge is further restricted by

the high clay content of the overburden.[27] The residual material is typically less than 10 ft thick; therefore, most water input is diverted to surface runoff.

In summary, it is evident that groundwater conditions on the Oak Ridge Reservation basically follow water-table conditions. Hence, water movement parallels topographic contours and generally flows in a northeast-to-southwest direction. Most of the groundwater in the area travels through unconsolidated soil. Groundwater in bedrock is largely confined to fractures of limestone strata enlarged by dissolution. No major groundwater resources have been developed in the area because the geologic formations are, to a first approximation, too impenetrable to retain a significant reservoir of stored groundwater.

### 3.5.1.2 Area soils

Since groundwater flow on the Oak Ridge Reservation is described primarily by water-table conditions rather than by artesian conditions, the soils of the area play a major role in regulating water flow to the various spheres of the hydrological environment. Despite these important hydrological considerations, a thorough investigation of the soils of the Oak Ridge Reservation has not yet been completed. However, certain sections of the area have been mapped. Swann and associates[29] completed a soil survey of Roane County, Tennessee, for the U. S. Department of Agriculture in 1942, but the survey has not been revised to conform with recent nomenclature changes. Moneymaker[30] of the U. S. Soil Conservation Service is currently attempting to record the soils of Anderson County, Tennessee, and Carroll[31] made a very general analysis of the soils of the Oak Ridge vicinity for the U. S. Geological Survey. The soils of the Walker Branch Watershed have been analyzed extensively; the soils of the Whiteoak Creek Basin have been described, and segments of the UT-ERDA Agriculture Experiment Farm have been studied. Although the information from these studies is insufficient to permit the construction of a detailed soil map, the data of Swann and Associates, Monemaker, and Carroll have been combined and correlated to produce the general soil association map shown in Fig. 3.5-1. The numbered areas in Fig. 3.5-1 are defined in Table 3.5-2. The broad soil associations suggested in Fig. 3.5-1 can be subdivided further into three major soil classes. All the major soils in a given association fall within the category of upland residual soils. Residual soils are defined as those soils formed by the in-situ weathering of the rocks and minerals of the underlying geology.[32] Thus, corresponding with each of the four major stratigraphic units that occur extensively in this part of the Valley and Ridge Province is an associaton of residual soils. Minor soils include residual soils that have arisen

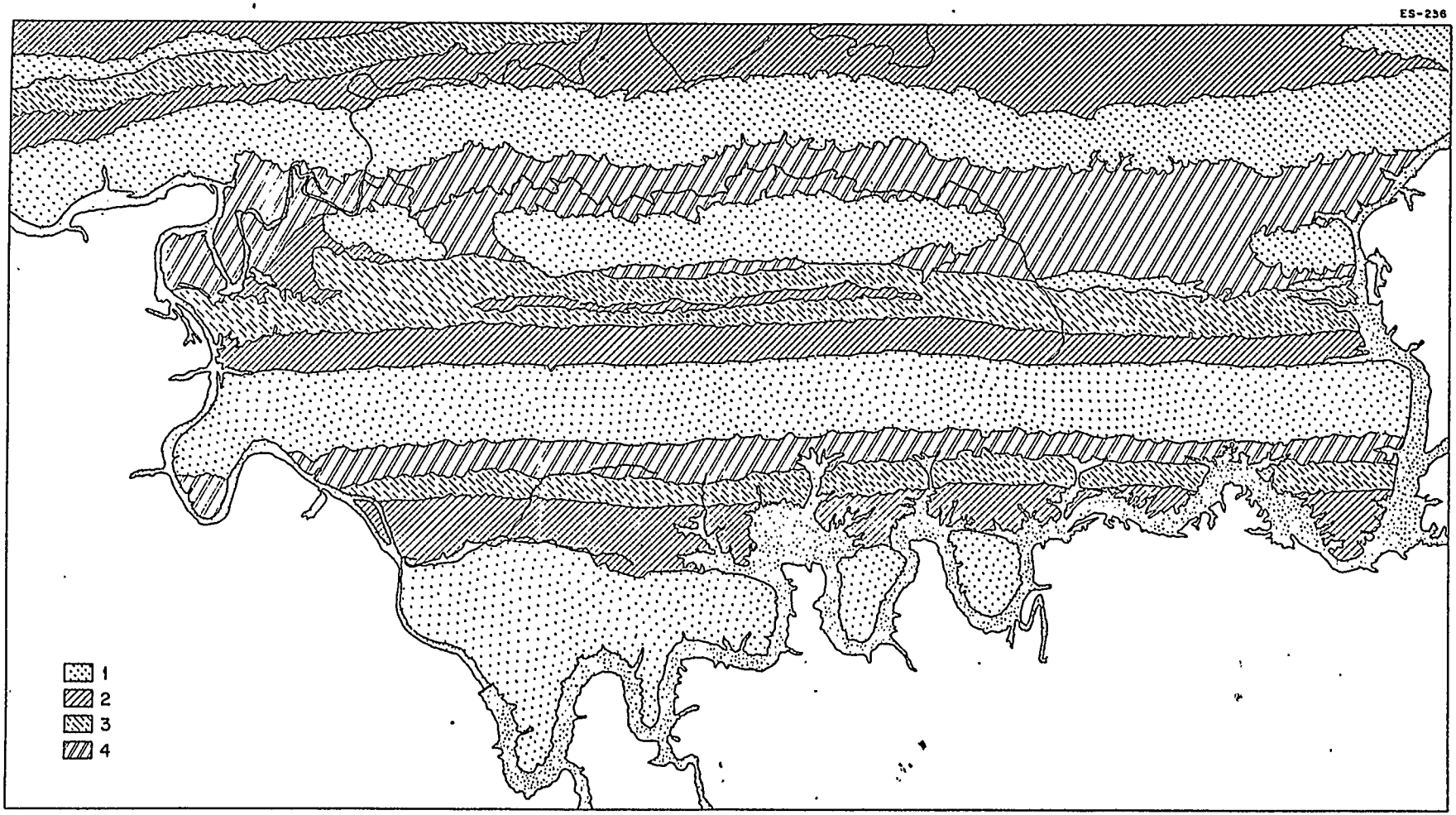


Fig. 3.5-1. General Soil Association Map of the Oak Ridge Reservation.

Table 3.5-2. Soil Origin and Types in Numbered Areas of Fig. 3.5-1

| Area | Soil Origin | Soil Types | |
|---|---|---|---|
| | | Major | Minor |
| 1 | Knox Dolomite | Fullerton<br>Bodine<br>Claiborne | Dewey<br>Dunning<br>Emory<br>Greendale |
| 2 | Conosauga Shale | Litz<br>Sequoia<br>Hamblen | Leadvale<br>Newark |
| 3 | Rome Formation | Lehew<br>Sensabaugh | Hamblen<br>Jefferson<br>Litz |
| 4 | Chickamauga Limestone | Talbott<br>Colbert<br>Rock outcrop | Gladeville<br>Bradyville<br>Emory<br>Sullivan |

from minor geological strata and also two other soil classes: colluvial and local alluvial. Colluvium is a heterogeneous deposit of rock fragments and soil material accumulated, primarily through gravitational forces, at the bases of comparatively steep slopes. An azonal group of soils developed from recently deposited materials, transported mainly by water, and characterized by a weak modification of the original material by soil-forming processes is known as alluvium.[32] This group settles primarily along narrow drainageways and stream depressions.

The characteristics of the various soil series reported to be on the Oak Ridge Reservation are summarized in Table 3.5-3. Such soils have developed under forests and contain an A-horizon that is typically light-colored and covers a tougher, clayey subsoil of red, yellow, or mottled color.[31] The major soils are generally silty (grain size 0.06 to 0.002 mm) rather than sandy or clayey. However, considerable clay may be present in the B-horizon.[31] The Knox soils contain koalinite as their principal clay, whereas illite and vermiculite constitute the bulk of Conasauga clay. Most of the Chicamauga clay occurs as kaolinite and illite, although patches with significant amounts of montmorillonite have been noted.[27]

Given a constant rate of precipitation and vegetation, the initial rate and direction of verticle movement of water and ions is largely determined by the relative pore space and clay content. The surface layers of Oak Ridge soils are typically very permeable and well drained. However, the dominant clay content of the subsoils outweighs this porosity, and the drainage of this region is characterized by low permeabilty and fast runoff.[27] The extensive clay subsoils channel most of the hydrological input into surface flow.

Chemically, the soils of the Oak Ridge area are acid (pH, 4.5 to 5.7) and are strongly leached of exchangeable cations.[31] Such materials have exchange capacities less than 0.1 milliequivalents per gram of soil. In particular, the clays are undersaturated with respect to bases; therefore, hydrogen ions occupy the exchange positions of the clay. The extent to which this hydrogen-ion replacement may occur is quite variable; the recorded base saturation values are in the range of 10 to 60%.[31] Usually, the soils are also low in organic matter and in plant nutrients.

### 3.5.2 Site Characteristics

Groundwater elevations in the area of the ORGDP vary for specific locations within the site, but for general purposes, they may be considered as being between 740 and

Table 3.5-3. Characteristics of the Soil Series on the Oak Ridge Reservation

| Soil series | Brief profile description | Physiographic position | Soil drainage | Slope range (%) | Parent material |
|---|---|---|---|---|---|
| Bland | Reddish-brown silt loam surface, underlain by weak-red silty clay at 8 in. Weathered bedrock is at 20 to 40 in. Class 1 rockiness is common over most areas. Very erodable; surface soil has been removed over much of the area by sheet erosion. | Upland | Well drained | 5 to 60 | Calcareous siltstone (muddy limestone)<br>Chickamauga Unit Ochb |
| Bodine | Pale-brown very cherty silt loam surface underlain at 12 in. by strong-brown very cherty silty clay loam. Variegated yellow, brown, red, and gray very-cherty silt loam substratum occurs at 30 in. Depth to weathered cherty dolomitic limestone bedrock ranges from 6 to 20 ft, but chert beds are common below a depth of 26 in. Occurs on the more cherty hill crests along Copper Ridge and Chestnut Ridge. | Upland | Excessively drained | 5 to 60 | Cherty dolomite or limestone<br>Knox Dolomite<br>Chickamauga Unit Ocha<br>Chickamauga Unit Ochc |
| Claiborne | Dark-brown silt loam surface about 8 in. thick over a brown silty clay loam transistion layer, which grades into a yellowish-red silt or clay at 16 in. Small dark-stained chert fragments are generally present throughout the profile. Bedrock occurs at a depth of 10 to 40 ft. | Upland | Well drained | 5 to 30 | Dolomitic Limestone |
| Colbert | Dark yellowish-brown silt loam surface over a very firm yellowish-brown clay. Weathered argillaceous limestone bedrock is at 24 to 48 in. Rock outcrops are common. Top soil usually removed from nonforested areas by sheet erosion. | Upland | Moderately drained | 2 to 7 | Argillaceous limestone<br>Chickamauga Limestone |
| Dewey | Brown silt loam surface over red silty clay or clay subsoil. Profile is relatively chert-free. Weathered bedrock is at 15 to 40 ft. Occurs intermittently along the broader, smoother, more chert-free ridge crests. | Upland | Well drained | 3 to 30 | Dolomite<br>Knox Dolomite |
| Dunning | Dark grayish-brown silty clay loam surface which grades to a silty clay at 6 in. A very dark grayish-brown firm clay subsoil is at 12 in., which becomes mottled with depth. Extensive surface cracking occurs during dry summer months. Thickness of alluvium over limestone rock ranges from 3 to 6 ft. Most extensive area is located along the northern base of Copper Ridge. | Depressions and narrow bottoms | Poorly drained | 3 | Local alluvium<br>Argillaceous limestone |
| Emory | Dark reddish-brown loam surface underlain at 14 in. by a weakly developed reddish-brown silty clay loam subsoil. Alluvial deposit is 4 to 10 ft thick. | Narrow bottom, toe slopes, and depressions | Well drained | 2 to 5 | Local alluvium chiefly from limestone<br>Knox Dolomite<br>Chickamauga Limestone |
| Fullerton | Grayish-brown cherty silt loam over yellowish-red cherty silty clay or cherty clay underlain at 36 in. by red cherty silty clay variegated with yellowish-brown and strong brown. Depth to bedrock usually ranges from 8 to 25 ft. | Upland | Well drained to excessively drained | 4 to 50 | Cherty dolomite or limestone<br>Knox Dolomite<br>Chickamauga Unit Ocha<br>Chickamauga Unit Ochc |

Table 3.5-3 (continued)

| Soil series | Brief profile description | Physiographic position | Soil drainage | Slope range (%) | Parent material |
|---|---|---|---|---|---|
| Greendale | Brown silt loam surface over yellowish-brown silt loam subsoil that becomes somewhat finer textured with depth, grading to a silty clay loam. Free of mottling to a depth of 30 in. or more. | Toe slopes, alluvial fans, and narrow drainageways | Well drained | 2 to 5 | Local alluvium from cherty dolomitic limestone<br>Knox Dolomite |
| Hamblen | Brown silt loam that becomes slightly mottled at 15 in. and becoming progressively more mottled with depth. A mottled dark grayish-brown layer occurs at 24 in. Depth to bedrock varies from 4 to 20 ft. Sometimes called Hamblen in areas where the alluvium originates primarily from sandstone and shale areas. | Bottoms and local alluvial | Imperfectly to moderately well drained | 0 to 3 | General alluvium<br>Local alluvium from mixture of sandstone, shale, and limestone |
| Hartsells | Yellowish-brown loam surface over yellowish-brown loam subsoil. Depth to weathered bedrock is generally 24 to 30 in. Occurs intermittently on the broader ridge crests on Haw Ridge. | Upland | Well drained | 5 to 12 | Medium-grained sandstone<br>Rome Formation |
| Jefferson | Yellowish-brown loam surface over yellowish-brown or brownish-yellow moderately friable clay loam subsoil that becomes slightly mottled with yellow and gray at 36 in. Depth of the colluvial deposit ranges from 3½ to 8 ft; deposit is underlain by shale or sandstone residuum. | Foot slopes and colluvial benches | Well drained | 4 to 30 | Colluvium from sandstone<br>Rome Formation |
| Landisburg | Light yellowish-brown silt loam over yellowish-brown silty clay loam subsoil. Fragipan layer at 28 in. Depth of the colluvial deposit varies from 3 to 10 ft and is underlain by cherty dolomitic limestone residuum. Developed in soil deposits transported from cherty Fullerton and Clarksville soils. | Foot slopes and colluvial benches | Moderately well drained | 2 to 12 | Colluvium from cherty dolomite and limestone |
| Leadvale | Grayish-brown silt loam surface over yellowish-brown silty clay loam subsoil. Fragipan at 24 in. Colluvial deposit is generally 2½ to 5 ft thick and is underlain by shale residuum. Developed in soil deposits transported from Litz and Sequoia soils. | Foot slopes and colluvial benches | Moderately well drained | 3 to 12 | Colluvium and local alluvium from acid shale<br>Conasauga Shale<br>Chickamauga Unit Ochh |
| Lehew | Weak-red loam surface underlain at 8 in. by weak-red shaly loam substratum. Weathered bedrock is 20 to 40 in. deep. The weak-red color is not uniform, many brownish-yellow bands are interwoven. | Upland | Excessively drained | 5 to 60 | Interbedded sandy shale and siltstone |
| Litz | Yellowish-brown silt loam surface over yellowish-red shaly silt clay loam or shaly silt clay loam subsoil. Weathered bedrock is at depths of about 12 to 24 in. Gully-erosion common in areas that had been cultivated prior to AEC purchase. | Upland | Well drained to excessively drained | 5 to 30 | Acid shale<br>Conasauga Shale Units Ꞓcb and Ꞓce<br>Chickamauga Unit Ochh |
| Minvale | Brown to dark yellowish-brown silt loam surface over yellowish-red silty clay subsoil. Depth of colluvial deposit varies from 3 to 8 ft; generally underlain by dolomitic limestone residuum. Develops in colluvial material generally transported from Fullerton Upland soils. | Foot slopes and colluvial benches | Well drained | 4 to 20 | Colluvium from cherty dolomite and limestone<br>Chickamauga Unit Ocha |

Table 3.5-3 (continued)

| Soil series | Brief profile description | Physiographic position | Soil drainage | Slope range (%) | Parent material |
|---|---|---|---|---|---|
| Montevallo | Dark grayish-brown silt loam surface underlain at 6 in. by brown silt loam soil material mixed with grayish colored shale fragments. Soil depth is 10 to 20 in. | Upland | Well drained | 5 to 30 | Fissle shale Conasauga Unit-Єca |
| Muse | Yellowish-brown silt loam surface over strong brown silty clay loam or silty clay subsoil. Depth to colluvial deposit varies from 2½ to 6 ft and is underlain by acid shale residuum. | Foot slopes | Well drained | 3 to 20 | Colluvium from acid shale |
| Muskingum | Yellowish-brown or brown silt loam surface underlain at 9 in. by brownish-yellow silt loam subsoil. Depth to shale bedrock is 20 to 40 in. Class-2 and Class-3 rockiness are common. | Upland | Excessively drained | 8 to 75 | Shale or siltstone Rome Formation |
| Newark | Dark grayish-brown silt loam surface over gleyed subsurface layers that become finer textured with depth. The grayish-brown subsurface layers are mottled with yellow and brown. Water table generally is within 2 ft of the surface. Depth to bedrock is generally greater than 5 ft. Occurs primarily in Whiteoak Creek flood plain. Sometimes called Prader in areas where alluvium originates primarily from sandstone and shale soils. | Bottom | Poorly drained | 0 to 2 | General alluvium from mixture of sandstone, shale, and limestone |
| Sensabaugh | Brown friable fine sandy loam surface that grades into a yellowish-brown very friable loam at 12 in. Free of mottling to a depth of 30 in. or more. Alluvial deposit varies from 2½ to 6 ft. Depth to bedrock is seldom less than 5 ft. | Local alluvium along narrow drainageways | Well drained | 2 to 5 | Local alluvium from sandstone |
| Sequoia | Brown silt loam or silty clay loam surface over yellowish-red silty clay subsoil that grades into yellowish-red shaly silty clay at 20 to 22 in. Weathered shale bedrock generally occurs at 20 to 40 in.; usually occurs on the broader smoother hill tops. | Upland | Well drained | 3 to 12 | Yellowish-red acid shale Conasauga Unit-Єcb Chickamauga Unit Ochh |
| Talbott | Brown silty clay loam over yellowish-red very firm clay subsoil that grades into a yellowish-red clay, mottled with yellow and brown at 25 in. Depth to weathered bedrock ranges from 3 to 5 ft. Occurs on relatively chert-free units in areas where rock outcrops are less common. | Upland | Well drained | 3 to 20 | Argillaceous limestone Chickamauga Limestone |

Sources:

1. W. M. McMaster and H. D. Waller, *Geology and Soils of Whiteoak Creek Basin, Tennessee*, ORNL-TM-1108, Oak Ridge National Laboratory, Oak Ridge, Tenn., May 1965.
2. R. P. Sims, State Soil Scientist, Soil Conservation Service, U.S. Department of Agriculture, letter to W. C. Abbott, Oak Ridge National Laboratory, Aug. 1, 1974, regarding data of R. H. Moneymaker, U.S. Soil Conservation Officer, Anderson County, Tenn.

750 feet above mean sea level. These elevations correspond generally to pool elevations of 741 to 745 feet for Watts Bar Reservoir on the Clinch River. Solution cavities in limestone rock and the fractured and jointed nature of the rock structures tend to link the grcundwater elevation and the reservoir level closely in many locations. The ORGDP site is underlain primarily by Chickamauga Limestone and a small area of Conosauga shale.

The results of chemical analyses performed to determine the water quality in the area as well as those of trace element analyse performed on the waters of Poplar Creek and the East Fork of Poplar Creek are discussed in Subsection 3.4.9. Since virtually all base flow within the area originates as groundwater, the concentrations of chemical constituents in the surface water reflect primarily the mineral composition of the soils and bedrock underlying the watershed. It should be noted that the mineral composition of the soils and bedrock underlying the ORGDP site is not the same as that underlying the major portion of the watershed area of Poplar Creek and the East Fork of Poplar Creek.

### 3.5.3 Contaminant Transport Analysis

In general, movement of grcundwater occurs in a direction normal to the groundwater contours. At the ORGDP site, movement is from topographically high areas to topographically low areas and generally in a northeast to southwest direction. The Clinch River acts as a sink to which all groundwater at the site as well as that on the opposite side of the river migrates.

Water samples for radioactivity analyses are collected continuously in the Clinch River at the ORGDP sanitary water intake upstream from the mouth of Pcplar Creek and at the ORGDP recirculating water intake downstream from the Poplar Creek outfall. Water samples are also collected at those locations for the analysis of nonradioactive substances. All samples are composited and analyzed monthly for a variety of anions and cations related to process release potential and background information needs.

## 3.6 Geology and Seismology

The geolcgic and seismic characteristics of the region and the ORGDP site area are presented in the following subsections.

### 3.6.1 Basic Geologic and Seismic Information

The ORGDP site is located in the Valley and Ridge Physiographic Province in the eastern United States. Early in the Paleozoic Era, the region of the present Appalachian Mountain system is thought to have been an elongated subsiding trough occupied by marine waters in which up to 40,000 feet of sediments had accumulated. This concept of a long belt of crustal subsidence was originally advanced in 1859 by James Hall who believed that subsidence was caused by an increasing load of sediment. The theory was modified in 1873 by James Dana who suggested the name geosyncline and proposed that crustal movements pricr to sedimentation initiated the subsidence and made room for incoming sediment.

A geosyncline typically is subdivided into two portions, which Kay in 1951 named miogeosyncline and eugeosyncline. The northwestern portion of the Appalachian geosyncline, represented by the present Valley and Ridge Provinne, consisted of a slowly subsiding, shallow area (the miogeosyncline) in which well-sorted sandstones, shales, and limestones accumulated. The region of the Blue Ridge and Piedmont Provinces represent the eugeosyncline, a more rapidly subsiding deeper portion in which poorly sorted sandstones (including graywackes), shales, and a few limestones were deposited. Alternating with these sediments are basaltic lava flows derived from a volcanic island arc chain within the eugeosyncline.[25]

During the early part of the Palezoic Era (Cambrian Period), the sediments of the miogeosyncline were derived from the interior of the continent, but in the remainder of the Paleozoic Era, diastrophism and volcanic activity in the eugeosynclinal area (beginning at least 350 to 400 million years ago) resulted in sedimentation predominantly from an eastern source.

Major crustal movements in the area of the Appalachian geosyncline during the Paleozoic Era were chiefly confined to the eugeosynclinal area. Two significant unconformities (surfaces that represent missing intervals in the rock record) are recognized in the Palezcic rocks of the Valley and Ridge area of east Tennessee. One of these separates the Lower Ordovician (upper Knox Group) from the Middle Ordovician Chicamauga Group. The second separates the Lower Silurian Rockwood Formation from the Devonian-Missippian Chattanooga shale. Generally these unconformities are of the disconformity type wherein layers below and above the erosion surface are parallel. Only locally does one see a slight angular unconformity at this contact. Thus, it appears that no significant folding (or faulting) was associated with formation of these unconformities. Any

deformations that occurred in the Valley and Ridge Province during the Paleozoic Era were simply the results of rising of the land due to broad upwarps or to a lowering of sea level.

During early and middle Paleozoic time, several episodes of diastrophism occurred in the eugeosyncline area. The sediments of the present Blue Ridge and Piedmont Provinces were severely deformed and injected with magmas, and as a result, underwent a high degree of metamorphism. Although the sediments of the Valley and Ridge were not strongly deformed during these early and middle Paleozoic episodes, they do reflect the influence of the deformation in their sedimentary character. Middle Ordovician to Early Silurian formations thicken and coarsen eastward attesting to the existence of mountainous areas in the Blue Ridge and Piedmont Provinces caused by deformations in the eugeosyncline during early Paleozoic time. The Devonian Period is poorly represented in east Tennessee, but an eastward thickening and coarsening wedge of Devonian clastic formations in the northern Appalachians (New York and Pennsylvania) resulted from a Devonian age deformation east of there. Mississipian age formations also coarsen eastward indicating a high scurce area in the region of the Blue Ridge and Piedmont Provinnes.

By late Paleozoic time (Pennsylvanian) the mountainous areas had encroached westward and a thick accumulation of alternating marine and nonmarine sediments, in the form of delta, alluviating river and swamp deposits prevailed. These sediments are present chiefly in the Cumberland Plateau but at least one occurrence of Pennsylvanian sediments (near Chattanooga) in the Valley and Ridge Province suggests that they were originally more extensive. No Permian strata are present in east Tennessee.

Deformation of sediments of the present Valley and Ridge Province and the area northwestward was restricted to holding and major thrust faulting near the end of the Paleozoic with no extensive metamorphism occurring. At this time, the entire region was uplifted and has not since been submerged except in localized basins where continental sediments accumulated (traditionally assigned Triassic age) and in the eastern and southern margins underlying the present Coastal Plain.

During the Mesozoic and Cenozoic Eras, erosion of the present Appalachian Mountains supplied the sediments that comprise the Coastal Plain formations that cover remnants of the earlier eroded Paleozoic mountains.[25]

### 3.6.1.1 Regional tectonics

The ORGDP site is within the folded and faulted structural province of the Appalachians (Valley and Ridge Physiographic Province). The Alleghenian Orogeny that produced the Valley and Ridge geologic structure, as well as some of the structures in the Blue Ridge and Piedmont Provinces, occurred near the end of the Paleozoic Era. Pennsylvanian strata are involved in folds and faults on the northwest side of the Valley and Ridge. This is evidence that the latest Valley and Ridge deformation is post-Carboniferous. Coastal Plain strata of Cretaceous age extend unfaulted across the Valley and Ridge Province in Alabama,[33] and Triassic igneous dikes transect the Valley and Ridge Province in Virginia[34-35] providing the age of Valley and Ridge deformation is pre-Mesozoic. The PSAR for the Clinch River Breeder Reactor Plant[6] presents two potassium/argon radiometric ages for mylonite along one of the major thrust faults (the Copper Creek fault). They are 280 and 290 million years, plus or minus 10 million years, further confirming a late Paleozoic (Late Pennsylvanian/Early Permian) age for the latest regional thrust faulting.

During the Alleghenian Orogeny, tectonic forces directed toward the west deformed the rocks of the Appalachian geosyncline. Deformation was greatest in the eastern mobile thermal core (Piedmont and Blue Ridge) where the rocks were again metomorphosed and injected by magmas. This eastern portion was thrust to the west along boundary faults such as the Great Smoky Fault. Rocks for several miles to the west of this boundary were shingled into a series of thrust blocks. These tilted blocks have been eroded to form the folded and faulted Valley and Ridge Province. The thrusting abruptly diminished toward the west where a broad syncline was developed (Appalachian Plateaus), and large lateral movements occurred along bedding plane faults.

The Valley and Ridge Province is dominated by the Paleozoic thrust faults that extend parallel to the northeast to southwest regional strike for many miles.[36] Elongate folds, usually the synclincal limbs of broken anticline-syncline couplets, parallel the regional strike within the major thrust blocks. The region is further characterized by shear in the vertical plane normal to regional strike (cross-faulting) and overturning of folds to the northwest.

The attitude of southern Appalachian thrust faults at depth has been of major concern to geologists during the past few decades, as fault attitudes are related to deformational forces. However, no indication exists of continued structural mobility since the end of the Paleozoic

tectonics. The present Valley and Ridge Province is believed to be a "fossilized" remnant of Paleozoic activity. The geosynclinal theory used to explain the Appalachian Orogeny rests on the assumption of continental drift. If this condition is true, every continent must have a leading and a trailing edge. Geologists believe that the Pacific coast in the United States has been the leading edge since the end of Paleozoic times. The trailing margin, the Appalachian Region, is believed to be tectonically stable.[37] Indeed, throughout the Mesozoic and Cenozoic Eras, only erosion has accentuated the geological structure of the Valley and Ridge region.

3.6.1.2 Area geology

The first detailed geological survey of the Oak Ridge Reservation was made by Stockdale,[38] and his findings are summarized in Table 3.6-1. He identified nine Paleozoic sedimentary formations but considered only the oldest four to be of major significance. The nine strata range in age from early Cambrian to Pennsylvanian, but the four primary units were deposited in Cambrian and Ordovician times. This first study was extended by McMaster,[3] who prepared a geological map of the Oak Ridge Reservation. The geological characteristics of the four major formations are summarized in Table 3.6-2. Tectonically, the Tennessee Division of the Valley and Ridge Physiographic Province is characterized by a series of linear fault blocks with a pronounced northeast to southwest strike and a southeast dip. In this southeastern dip, the Cambrian and Precambrian stratigraphic units have slipped northwest along the Great Smoky fault. When this tectonic event occurred, the less competent formations that remained in the northwest shingled into a series of imbricate thrust plates. In the Oak Ridge vicinity, these plates typically involved incompetent shales of the Rome Formation. The existence of as many as ten fault sheets has been proposed, but only three master faults are currently recognized: the Pulaski, Saltville, and Pineville. All other faults are subsidiary. Geologists also believe that these faults do not extend completely through the crust but rather are a series of decollements (small hills) developed in the relatively incompetent horizon of the Rome lying above the more massive crystalline floor of the basement. These features probably existed prior to the final Appalachian Orogenic events of the late Paleozoic.[6-39]

With particular reference to the Oak Ridge Reservation, the strata dip southeast at an angle that varies from 20 to 45 degrees and strike northwest at an angle of about 35 degrees. There are three regional thrust faults in the area.[25] They are the Kingston, Whiteoak Mountain, and Copper Creek Faults. All three strike to the northeast and

Table 3.6-1. Generalized Geologic Section of the Bedrock Formations in the Oak Ridge Area

| System | Group | Formation | "Member" or Unit | Thickness (feet) | Characteristics of Rocks |
|---|---|---|---|---|---|
| Mississippian | | Ft. Payne "chart" | | | Impure limestone and calcareous siltstone, with much chert |
| | ? | Chattanooga shale | | | Shale, black, fissile |
| Devonian | | | | | |
| Silurian | | | | | |
| | Rockwood group | Brassfield | | 1000+ | Shale, sandy shale, sandstone; calcareous; red, drab, brown |
| | | Sequatchie | | | |
| Ordovician | Chickamauga group | | ? H | 300+ | Limestone, shaly limestone, calcareous siltstone, and shale; mostly gray, partly maroon; with cherty zones in basal portions |
| | | | G | 300 | |
| | | | F | 25 | |
| | | | E | 380 | |
| | | | D | 160 | |
| | | | C | 115 | |
| | | | B | 215 | |
| | | | A | 240 | |
| | Knox group | | | 2600 | Dolomitic limestone; light to dark gray; with prominent chert zones |
| Cambrian | Conasauga group | Maynardsville limestone | | 1500 | Shale; gray, olive, drab, brown; with beds of limestone in upper part |
| | | Conasauga shale | Pumpkin valley | | |
| | | Rome formation | | 1000+ | Sandstone and shale; variegated with brilliant yellow, brown, red, maroon, olive-green; with dolomitic limestone lenses |

Source: P. B. Stockdale, *Geologic Conditions at the Oak Ridge National Laboratory (X-10) Area Relevant to the Disposal of Radioactive Waste*, ORO-58, Oak Ridge Operations, Oak Ridge, Tenn., Aug. 1, 1951, Plate 11.

Table 3.6-2. Geologic Characteristics of Four Major Formations Underlying the Oak Ridge Reservation Area

| AGE | FORMATION NAME AND THICKNESS | UNIT | GEOLOGIC CHARACTERISTICS | RESIDUAL MATERIAL |
|---|---|---|---|---|
| Early Cambrian | Rome Formation (Ꞓr) ~800 ft | | Siltstone, shale, and sandstone. Variegated color, including brown, tan, red-brown, maroon, and green. Mica common, mostly on bedding surfaces.. Thinly bedded; sandstone beds generally less than one ft thick. Siltstone and shale dominant in lower half. Upper half contains interbedded sandstone. Small faults and folds common. Lower beds generally dip very steeply; dip decreases towards upper beds. Rome is thrust-faulted over Chickamauga. Underlies Haw Ridge. | Silty, sandy, coarse-textured material containing small amounts of light-colored primarily micaceous clay; contains fragments of siltstone and sandstone remnants up to boulder size. Probably everywhere less than 20 ft to unweathered bedrock. |
| Middle Cambrian | Conasauga Group (Ꞓc) 1,500-2,000 ft (?) | Ꞓca | Shale and siltstone, mostly brown, red-brown, maroon, and green-brown. Fine mica abundant on bedding surfaces. Deformation by folding and faulting appears to be much less than that of overlying unit. Contains little limestone or calcareous shale. Underlies narrow valley at southeastern base of Haw Ridge. | Silty brown, tan, greenish and maroon primarily micaceous clay retaining bedding of parent rock in most places; elsewhere, contains many thin flakes of shale. Depth to bedrock less than 20 ft. |

Table 3.6-2 (continued)

| AGE | FORMATION NAME AND THICKNESS | UNIT | GEOLOGIC CHARACTERISTICS | RESIDUAL MATERIAL |
|---|---|---|---|---|
| Middle Cambrian | Conasauga Group (continued) | Ꞓcb | Variable lithology, ranging from shale and siltstone to limestone. Limestone is characteristically pebble conglomerate or edgewise conglomerate having irregular bedding surfaces coated with thin film of dark gray clay and marked by abundant ropy "worm trails". Limestone occurs in zones of shale and siltstone. Siltstone in this unit is commonly calcareous and white or light gray when fresh. Shale is thinly bedded, colored brown, olive, and tan, and locally, maroon. In many places unit is deformed by very small, sharp folds and faults of small displacement. Underlies line of low knobs on northwestern side of Melton Valley. | Unit weathers to bedded shale appearance, leaving little or no indication of original calcareous nature. Limestone weathers to porous brown siltstone or to light orange-yellow illitic clay. Residuum is generally light tan to yellow-brown but local variations include maroon and green bands. Black manganese oxide stains common on joint surfaces. Residuum is locally more than 20 feet thick on crests of knobs, but is less than 20 ft thick on flanks of knobs. |

Table 3.6-2 (continued)

| AGE | FORMATION NAME AND THICKNESS | UNIT | GEOLOGIC CHARACTERISTICS | RESIDUAL MATERIAL |
|---|---|---|---|---|
| Middle Cambrian | Conasauga Group (continued) | Ꞓcc | Exposures of this unit are very limited; appears to be similar to unit Ꞓcb but contains less limestone. Minor folding common. Underlies central, lowest part of Melton Valley. | Appears to be more thoroughly weathered than unit Ꞓcb. Residuum consists of yellow-tan clay containing abundant flakes and chips of shale. Thickness not known. |
| Late Cambrian | | Ꞓcd | Alternating zones of limestone and shale, limestone increasing in proportion towards upper part of unit. Limestone is very similar to that of unit Ꞓcb but is commonly siliceous, more thickly bedded, and more resistant to weathering; also, pebble conglomerates are less common than edgewise conglomerates. Oolitic limestone present in upper part of unit. Shale is very thinly bedded, brown, tan, and gray. Underlies belt along base of Copper Ridge, where basal layers form low, rounded knobs. | Yellow-tan to brown clay containing abundant shale chips and locally containing dense caramel-brown to jasper chert up to boulder size. Ground surface commonly strewn with boulders and blocks of limestone. Residuum is very thin and projecting ledges of limestone are very common. |

Table 3.6-2 (continued)

| AGE | FORMATION NAME AND THICKNESS | UNIT | GEOLOGIC CHARACTERISTICS | RESIDUAL MATERIAL |
|---|---|---|---|---|
| Late Cambrian | Conasauga Group (Ꞓc) (continued) | Ꞓce | Fairly pure limestone and dolomitic limestone, light to medium gray, finely to coarsely crystalline, in beds from less than 1 ft to 5 ft thick. Thin beds of interbedded shale in lower part. Contains very little chert. Crops out along northwestern face of Copper Ridge. | In most places overburden is very thin, but where present is a light orange-red granular clay containing little or no chert. |
| Late Cambrian-Early Ordovician | Knox Dolomite (OꞒk) 2,600 ft | | Mostly siliceous dolomite, medium to light gray, dense to coarsely crystalline, in beds up to four ft thick. Upper 400 ft is largely light-gray to medium-gray dense to finely crystalline dolomite and dolomitic limestone containing jasper chert. Underlies Chestnut Ridge and the upper part of Copper Ridge. | Generally light yellow-tan to red to red-brown largely kaolinitic clay containing abundant chert fragments and blocks ranging up to boulder size. Thickness of overburden is in most places greater than 30 ft; known maximum thickness on Chestnut Ridge is 125 ft and on Copper Ridge, 65 ft. |

Table 3.6-2 (continued)

| AGE | FORMATION NAME AND THICKNESS | UNIT | GEOLOGIC CHARACTERISTICS | RESIDUAL MATERIALS |
|---|---|---|---|---|
| Middle Ordovician | Chickamauga Limestone (Och) 1,800 ft | Ocha | Mixture of calcareous siltstone, limestone, and bedded chert; siltstone is olive, gray, and maroon; limestone is dark to light-gray; chert is dark gray. About 250 ft thick. | Residuum on Chickamauga typically heavy yellow or yellow-brown montmorillonite-like clay generally containing small chips of white or yellow chert, fragments of porous brown siltstone, and small blocks of limestone. Unit Ocha, however, has thick overburden of extremely cherty red clay, the chert occurring as loose rectangular blocks or in beds inter-layered with residual clay. Also, unit Ochb has only a very thin veneer of overburden in most places and in relatively large areas none is present. A series of 50 core holes drilled into units Oche, Ochf, Ochg, and Ochh by Stockdale showed depths to bedrock ranging from 1 ft to 25 ft. This range of thickness |
| | | Ochb | Laminated calcareous shaly siltstone, mostly maroon but locally contains blotches of green and yellow. About 200 ft thick. | |
| | | Ochc | Limestone, light to medium gray, finely to coarsely crystalline, partly shaly. Contains some thin beds of light maroon calcareous siltstone. Nodular gray chert present in more pure limestone. About 120 ft thick. | |
| | | Ochd | Shaly, cherty limestone, gray to olive, thinly bedded. Contains abundant chert in lower beds, resulting in resistance to erosion. Underlies chain of low hills on northwestern side of Bethel Valley. About 220 ft thick. | |

Table 3.6-2 (continued)

| AGE | FORMATION NAME AND THICKNESS | UNIT | GEOLOGIC CHARACTERISTICS | RESIDUAL MATERIAL |
|---|---|---|---|---|
| Middle Ordovician | Chickamauga Limestone (Och) (continued) | Oche | Shaly limestone and calcareous shale, gray to gray tan, containing some maroon-gray limestone in lower part of unit. Shale partings along bedding planes common. Upper part of unit weathers to produce small rounded masses of yellow, silt-encrusted limestone mixed with clay residuum. About 380 ft thick. | is probably typical of all units except units Ocha and Ochb. |
| | | Ochf | Calcareous shaly siltstone, mostly maroon. Very similar to unit Ochb. 25-30 ft thick. | |
| | | Ochg | Mixture of various types of limestone, mostly medium to light gray and brown gray; generally shaly and thin bedded. About 300 ft thick. | |
| | | Ochh | Maroon calcareous siltstone at base, overlain by gray or maroon-gray shaly limestone, about 300 ft thick. | |

SOURCE: W. M. McMaster and H. D. Waller, "Geology and Soils of Whiteoak Creek Basin, Tennessee," USAEC Report ORNL-TM-1108, Oak Ridge National Laboratory, Oak Ridge, Tennessee, May 1965.

dip to the southeast. These faults were formed during the Alleghenian Orogeny. As discussed in the Preliminary Safety Analysis Report for the Clinch River Breeder Reactor Plant,[6] mylonite from the Copper Creek fault yielded whole rock potassium/argon radiometric dates of 280 and 290 million years, plus or minus 10 million years, confirming latest movements on them to be Late Pennsylvanian and Early Permian in age. Therefore, these faults are not capable.[6]

The Kingston Fault originates about 25 miles northeast of the ORGDP site, near Norris, Tennessee.[25] It extends to the southwest across Tennessee and into Georgia. Mainly Cambrian Rome or Conasauga strata are thrust onto younger rocks. Southeast of the site area, this fault truncates the southeastern limb of a syncline. The maximum stratigraphic displacement of about 8200 feet is attained along this faulted syncline. In the site area, the Rome Formation is thrust onto Conasauga and Knox Groups for stratigraphic displacements of about 1500 to 3000 feet.

The Whiteoak Mountain Fault originates northeast of the ORGDP site near Clinton, Tennessee, by the mergence of the Hunter Valley and Wallen Valley Faults.[25] It extends about 80 miles to the southwest and merges with the Copper Creek Fault near Cleveland, Tennessee (about 60 miles southwest of the ORGDP site). This fault is the lower boundary of the Rome Formation. The Early Cambrian Rome Formation has been thrust onto younger rocks that range in age from Cambrian to Mississippian, resulting in stratigraphic displacements up to about 8200 feet.[40] The fault projects to depths of 1500 feet or more in the vicinity of the ORGDP site.[25]

The Copper Creek Fault extends southeast from Virginia and merges with the Whiteoak Mountain Fault near Cleveland, Tennessee, about 60 miles southwest of the ORGDP site. It is, with few exceptions, a single fault along which the Rome Formation is thrust onto Chickamauga rocks for a stratigraphic displacement of about 7200 feet.[3] The average strike of the fault in the Oak Ridge area is north 55 degrees east.[3] The fault is reported[6] to dip to the southeast at 25 to 30 degrees at the ground surface. The Joy Test Well encountered the Copper Creek Fault at a depth of about 1370 feet,[6] indicating a decreasing fault dip southeast of its outcrop.

### 3.6.2 Analysis of Geologic Stability

The seismic history of the region surrounding the ORGDP is described, and the correlation between the geologic structures in the area and the historic epicenters is discussed. On the basis of the historic and physical data available, the seismic risk in the site area is assessed.

3.6.2.1 Seismic history of region

There have been 20 recorded earthquake epicenters with Modified Mercalli (MM) intensities of IV to V or greater within a radius of about 50 miles from the ORGDP site, 33 within a 100-mile radius, and 79 within a 200-mile radius.[25] The Modified Mercalli intensity scale is defined in Table 3.6-3. The epicenters of all of the reported earthquakes within approximately 200 miles of the ORGDP site that had intensities of IV to V MM or greater and were likely to have been felt at the site are located in Fig. 3.6-1 and are listed in Table 3.6-4 with the estimated intensities felt at the ORGDP site.

The largest earthquakes ever recorded in the southeastern United States are the New Madrid earthquake series of 1811-1812 (December 16, 1811, and January 23 and February 7, 1812) and the Charleston, South Carolina, earthquake of August 31, 1886. New Madrid, Missouri, and Charleston, South Carolina, are located about 290 and 320 miles from the site, respectively.

The epicentral intensity during the New Madrid events is estimated to have been XII MM, representing total destruction at the epicenter. These earthquakes shook an area of at least 2,000,000 square miles and caused topographic changes over an area of 30,000 to 50,000 square miles. Only a very small amount of damage was reported, probably due to the sparse population at that time. The duration of motion at distances of 100 miles and greater (which includes the ORGDP site) may have been as much as 1 to 2 minutes.[41] The New Madrid earthquakes produced ground motions in the site vicinity greater than any other earthquake in historic time. These motions produced an estimated VI to VII MM intensity in the vicinity of the ORGDP site.[42]

The epicentral intensity of the Charleston earthquakes are reported to have been IX to X MM. These earthquakes are also reported to have been felt over an area of 2,000,000 square miles.[43] The Charleston earthquakes are estimated to have been felt in the vicinity of the ORGDP site at intensities of VI MM.

On May 31, 1897, a moderately large earthquake occurred in Giles County, Virginia, about 220 miles from the site. This earthquake has a reported epicentral intensity of VII to VIII MM.[44] The Giles County earthquake is estimated to have been felt at the site at an intensity of about V MM.[45]

Table 3.6-3

## MODIFIED MERCALLI INTENSITY SCALE OF 1931

(ABRIDGED)

I. Not felt except by a very few under specially favorable circumstances. (I Rossi-Forel scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale.)

III. Felt quite noticeably indoors, especially on upper floors of building, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel scale.)

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale.)

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale.)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (VIII Rossi-Forel scale.)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX− Rossi-Forel scale.)

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel scale.)

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into air.

Source: R. A. Eppley, *Earthquake History of the United States, Part I, Stronger Earthquakes of the United States (Exclusive of California and Western Nevada)*, U.S. Government Printing Office, Washington, D.C., 1965, p. 4.

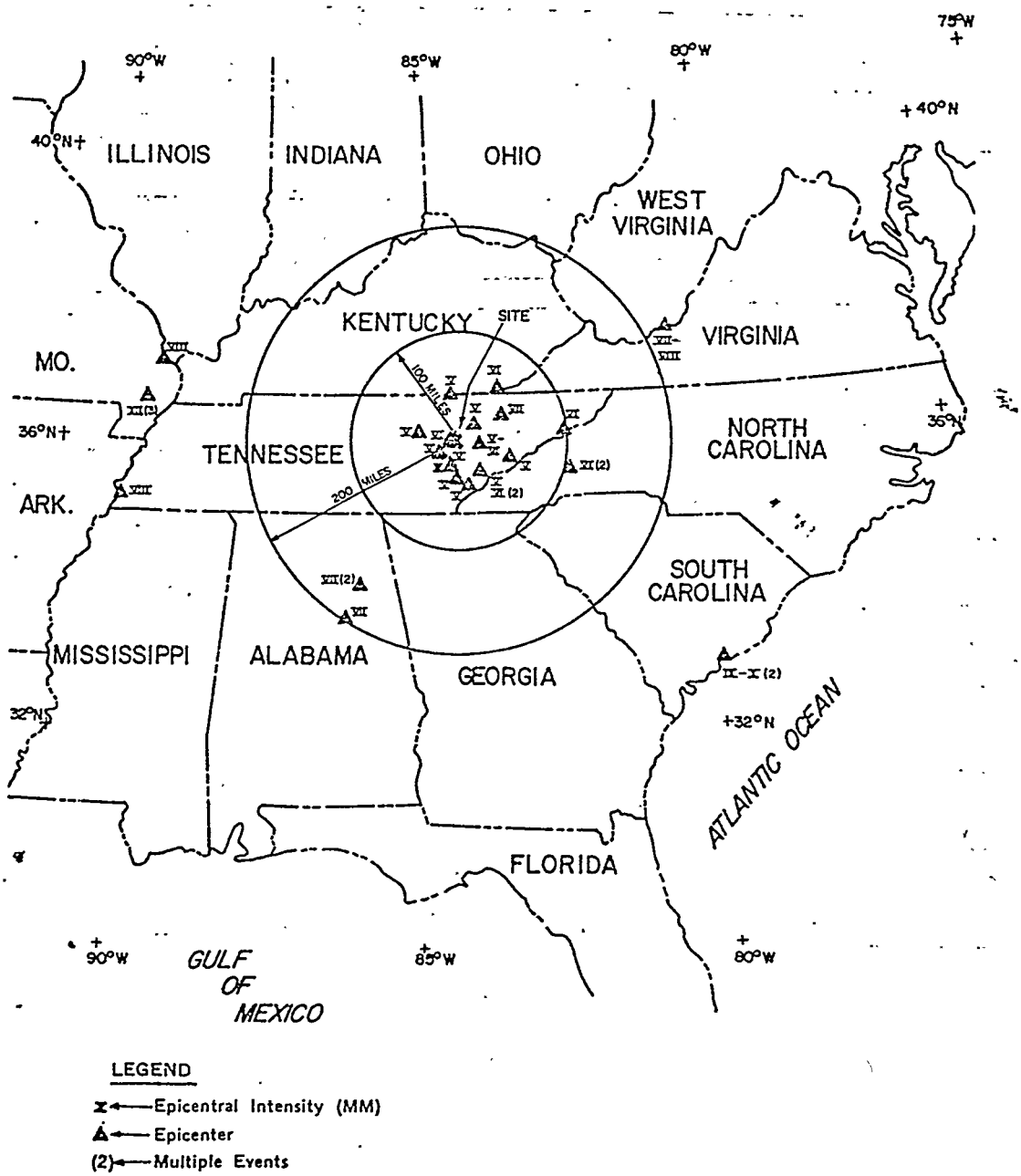


Fig. 3.6-1. Location of Epicenters of Historical Earthquakes With Modified Mercalli Intensities of V or Greater Within Approximately 200 Miles of the Oak Ridge Gaseous Diffusion Plant.

SOURCE: Exxon Nuclear Company, Inc., "Nuclear Fuel Recovery and Recycling Center, Preliminary Safety Analysis Report," Report XN-FR-32, Docket No. 50-564, Vol. 1.

Table 3.6-4 Historic Earthquakes That Were Probably Felt at the Oak Ridge Gaseous Diffusion Plant Site

| Earthquake Epicenter or Name | Date | Earthquake Epicenter Coordinates Latitude N | Longitude W | Approximate Epicenter Distance From Site (miles) | Intensity Reported at Epicenter (MM) | Intensity Estimated at Site (MM) |
|---|---|---|---|---|---|---|
| New Madrid Missouri | Dec, Jan, Feb. 1811 - 1812 | 36.6 | 89.6 | 290 | XII | VI-VII |
| Western Tennessee | Jan. 4, 1843 | 35.2 | 90.0 | 320 | VIII | IV-V |
| Western N. C. and Eastern Tennessee | Nov. 16, 1877 | 35.5 | 84.0 | 30 | V | < IV |
| Charleston S. C. | August 31, 1886 (Two Events) | 32.9 | 80.0 | 320 | IX-X | VI |
| Missouri | October 31, 1895 | 37.0 | 89.4 | 285 | VIII | < V |
| Giles County Virginia | May 31, 1897 | 37.3 | 80.7 | 220 | VII-VIII | V |
| Eastern Tennessee | March 4, 1904 | 35.7 | 83.5 | 25 | V | < III |
| Alabama | Jan. 27, 1905 | 34.0 | 86.0 | 165 | VII | IV |
| Alabama | Jan. 28, 1905 | 34.0 | 86.0 | 165 | VII | IV |
| Eastern Tennessee | March 28, 1913 | 36.2 | 83.7 | 45 | VII | V |
| Eastern Tennessee | April 17, 1913 | 35.3 | 84.2 | 40 | V | < IV |
| Eastern Tennessee | Jan. 23, 1914 | 35.6 | 84.5 | 35 | V | < IV |
| Western N. C. | Feb. 21, 1916 | 35.5 | 82.5 | 105 | VI | III-IV |
| Alabama | October 18, 1916 | 33.5 | 86.2 | 200 | VII | III |
| Tennessee | June 21, 1918 | 36.1 | 84.1 | 20 | V | < IV |
| Eastern Tennessee | Dec. 24, 1920 | 36.0 | 85.0 | 40 | V | < IV |

Table 3.6-4 (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| Kingston Tennessee | Dec. 15, 1921 | 35.8 | 84.6 | 15 | V | III-IV |
| Western N. C. | Nov. 2, 1928 | 36.0 | 82.6 | 100 | VI | III |
| Eastern Tennessee | Aug. 30, 1930 | 35.9 | 84.4 | 3 | V | V |
| LaFollette, Tennessee | Feb. 9, 1948 | 36.0 | 84.5 | 9 | VI | V-VI |
| Middlesboro, Kentucky | Jan. 1, 1954 | 36.6 | 83.7 | 60 | VI | IV-V |
| Athens and Etowah, Tennessee | Jan. 22, 1954 | 35.3 | 84.4 | 40 | V | < IV |
| Eastern Tennessee | Sept. 7, 1956 (Two Events) | 35.5 | 84.0 | 30 | VI | IV |
| E. Central Tennessee | June 23, 1957 | 36.5 | 84.5 | 45 | V | < IV |
| Western N. C. | July 2, 1957 | 35.5 | 82.5 | 105 | VI | < V |
| Eastern Tennessee | April 15, 1960 | 35.8 | 84.0 | 20 | V | < III |
| Maryville-Alcoa, Tennessee | Nov. 30, 1973 | 35.8 | 84.0 | 20 | VI | V-VI |

SOURCE: Exxon Nuclear Company, Inc., "Nuclear Fuel Recovery and Recycling Center, Preliminary Safety Analysis Report," Report XN-FR-32, Docket No. 50-564, Vol. 1.

The Maryville-Alcoa, Tennessee, earthquake occurred November 30, 1973, with its epicenter located approximately 20 miles southeast of the ORGDP site. Intensity reports from surrounding communities determined that the area in which the earthquake was felt was about 25,000 square miles and that the epicentral intensity was VI MM. Its intensity at the site is estimated to have been V to VI MM.[46]

### 3.6.2.2 Vibratory ground motion

As discussed in Subsection 3.6.2.1, the most severe earthquake associated with the province surrounding the ORGDP site was the Giles County, Virginia, earthquake with a maximum reported epicentral intensity of VII to VIII MM. The Richter relationship between earthquake intensity and acceleration, illustrated in Fig. 3.6-2, was used to determine a peak horizontal ground acceleration of 0.18 g for the safe shutdown earthquake (SSE) with an intensity of VIII MM selected for the proposed Exxon Nuclear Fuel Recovery and Recycling Center (NFRRC) site.[25] The return period for this maximum earthquake with a postulated total duration of 20 seconds and strong motion interval of 5 seconds was calculated as one event within a time interval of $10^5$ to $10^6$ years.[25]

A study was also made to determine the earthquake intensity with a return period of 100 years for the proposed Exxon NFRRC site, and the result was an intensity of VI MM. The maximum horizontal ground acceleration selected for the operating basis earthquake (OBE) associated with an intensity of VI MM was 0.05 g.[25] The design response spectra for horizontal and vertical motions for both the SSE and the OBE were scaled linearly from Figures 1 and 2 of the Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," and the multiplication factors and control points in Tables I and II of Regulatory Guide 1.60 were used.[25]

### 3.6.2.3 Surface faulting

There are many Paleozoic thrust faults in the Tennessee Valley and Ridge Province, and three of these faults occur in the site area.[25] Many geologists believe these faults flatten with depth and merge into a regional decollement within the Rome Formation. The significance of this concept is that faults which crop out at the surface are not related to geologic structures in the crystalline basement. Watkins estimates the basement surface to be at a depth of 13,000 feet in the site area.[47] Thus, the infrequent earthquakes in the Valley and Ridge with normal hypocenters at depths between 50,000 and 65,000 feet occur in the basement and are

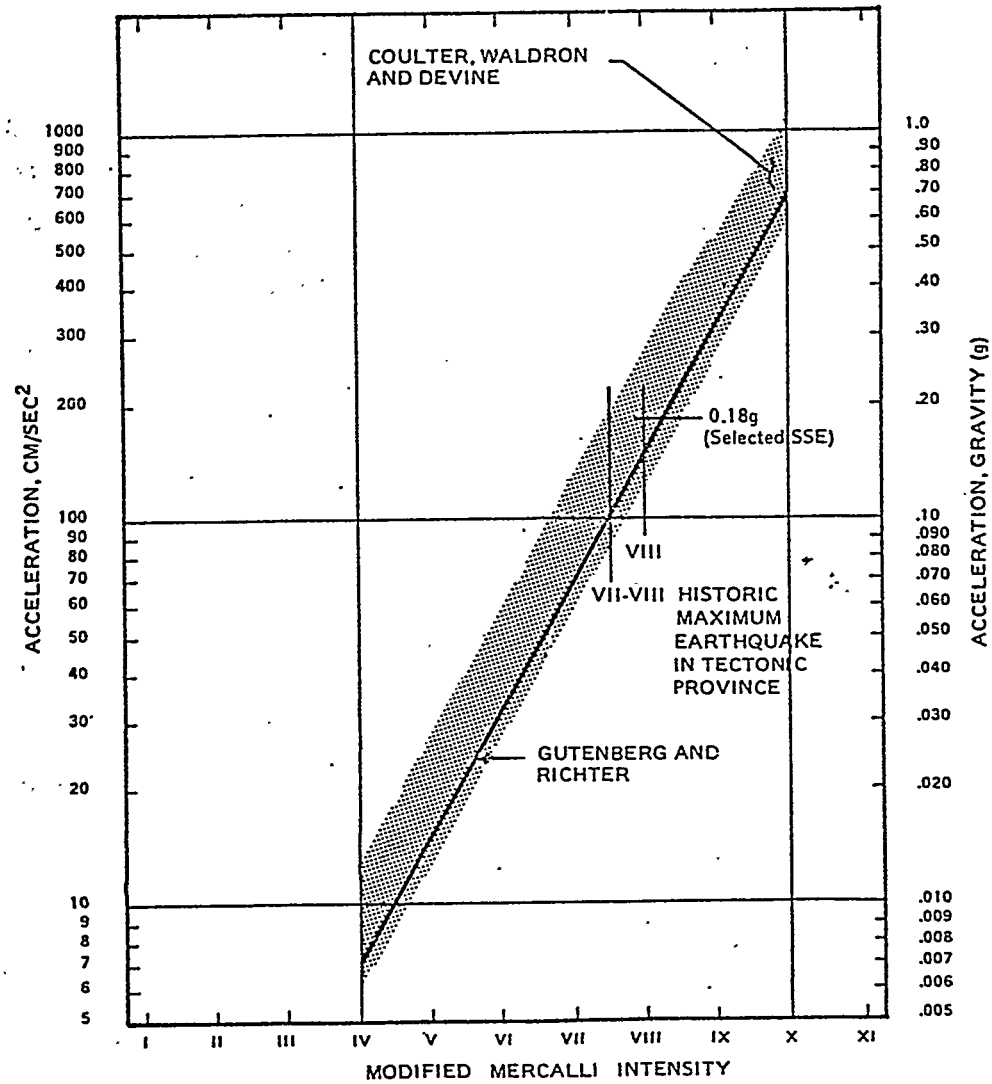


Fig. 3.6-2. Richter Relationship Between Earthquake Acceleration and Modified Mercalli Intensity.

SOURCE: Exxon Nuclear Company, Inc., "Nuclear Fuel Recovery and Recycling Center, Preliminary Safety Analysis Report," Report XN-FR-32, Docket No. 50-564, Vol. 2.

not associated in any way with the ancient (noncapable) faults that crop out at the surface.

The Maryville-Alcoa earthquake, with its epicenter near Knoxville, has been studied in considerable detail and no correlation with the northeasterly trending thrust faults was found. The Cumberland Plateau Observatory was the nearest operating seismic recording station to the epicenter. This station is 90 miles west of the epicenter.[46]

The geology of the Valley and Ridge has been studied by numerous geologists for over 100 years. During this period, no data have been revealed that suggest surface faulting is occurring. Even in the Epicentral area of historic earthquakes, there is no evidence of associated surface faults. No evidence of surface faulting exists in the area of the Maryville-Alcoa earthquake fault plane projections. The fault associated with the Maryville Alcoa earthquake is unrelated to any observable region fault because (1) fault plane solutions yield attitudes contrary to the regional trend, and (2) surface faulting does not occur.[25]

There is no geologic evidence of surface faulting within the Valley and Ridge Province related to earthquakes that have occurred in historic time. It has been concluded that there are no identifiable capable faults that could be expected to produce surface displacement anywhere within the Southern Appalachian Tectonic Province nor within 200 miles of the site.

### 3.6.2.4 Subsurface stability

The ORGDP is in the Tennessee Valley and Ridge portion of the Appalachian Highlands physiographic province which is characterized by a series of long narrow ridges and slightly broader intervening valleys with a pronounced northeast to southwest trend. The ridges are underlain by relatively resistant sandstones and competent limestones or dolomites, whereas the valleys are underlain by weaker shales and the more soluble carbonate rock.

The soil conditions at the ORGDP site consist of a pinnacled rock surface nearly outcropping in places with an overburden of predominantly clayey residual soils varying in depth from a few feet to about 60 feet. These soils are underlain by Paleozoic sedimentary rocks. The Chickamauga limestone of Middle Ordovician age underlies most of the site. It consists of gray fossiliferous shaly limestone with inclusions of chert. In the plant vicinity, the limestone beds trend from north-northwesterly to northeasterly with easterly dips ranging between about 10 to 35 degrees.

Minor portions of the plant site are underlain by rocks of the Knox group and the Conasauga group. The Knox group of Cambro-Ordovician age is a cherty, dense to crystalline dolomite typically light to medium gray in color. In the site vicinity, the Cambrian Conasauga group consists of shale and siltstone with massive limestone interbeds. The Chickamauga, Knox, and Conasauga rocks are separated from the Cambrian Rome formation (shale) by the White Oak Mountain Fault, a regional thrust fault that trends northeasterly between East Fork Ridge and Pine Ridge. A discontinuous branch of this fault separates the Knox and Conasauga rocks from the Chicamauga limestone under the eastern portion of the plant site.[48]

The ORGDP site is occupied by a building complex that covers an area in excess of a square mile. The foundation soils in this area are compressible and of a low bearing capacity. Generally, the soil materials have a dry density range of 72 to 100 pcf. The moisture content of the upper 8 feet of soil is about 21%, while that of the soil at depths below 8 ft is about 48%. The shear strength of the upper 8 feet of soil is about 0.51 ton per square foot.[49]

### 3.6.2.5 Slope stability

The ORGDP is situated on a level 640-acre tract of land located at the southwest end of East Fork Valley at the confluence of Poplar Creek with the Clinch River. The valley is flanked on the northwest by Black Oak Ridge and on the southeast by Pine Ridge. These slopes are not expected to affect operations conducted at the ORGDP.

### 3.6.2.6 Seismic risk

A review of earthquake incidence in the southeastern United States permits identification of the areas of continuing seismic activity.[50] Four major sites of current tectonic mobility are indicated. They are the Mississippi Valley; the Lower Wabash Valley; Charleston, South Carolina; and the Appalachian Mountains.

The Mississippi Valley encompasses the New Madrid Region of Arkansas, Kentucky, Missouri, and Tennessee. This seismic province includes the epicenter of the great series of New Madrid earthquakes, which repeatedly attained an MM intensity of XII. This area lies more than 250 miles northwest of the Oak Ridge Reservation. The New Madrid Quakes retained an intensity of V to VI at the Oak Ridge area.

The Lower Wabash Valley is located in the southern regions of Illinois and Indiana. A southern Illinois earthquake of MM intensity VII in 1968 was felt over a 400,000 square mile area, including a mild shock of intensity II to III in the Oak Ridge vicinity. The Oak Ridge Reservation lies more than 230 miles southeast of this region of active seismicity.

Charleston, South Carolina, was the site of one of the greatest historic earthquakes experienced in the eastern United States. The August 31, 1886, shock of MM intensity IX to X was felt over the entire eastern coast and registered an intensity of V to VI in the Oak Ridge region. Recurrent seismic activity continues in this area, which is 325 miles southeast of the Oak Ridge Reservation.

The Appalachian Mountains of eastern Tennessee and western North Carolina are centers that exhibit moderate seismic activity at the frequency of one to two shocks per year. Portions of this seismic area are only 50 miles east of the Oak Ridge Reservation and account for most of the seismicity native to the east Tennessee region.

As discussed previously, no correlation has been observed between recorded earthquakes on the Oak Ridge Reservation and superficial tectonic structures of the Valley and Ridge Physiographic Unit. During historic times, the zone of relatively high seismicity in the adjacent Blue Ridge Front Physiographic Unit has involved only movements of low intensity that probably represent minor adjustments of highly disturbed rock informations.[50] Other regions of the southeastern United States, such as Charleston, South Carolina, and the New Madrid area, have seismic activity that is much more intense and extensive, but even these more active areas are far less earthquake prone than are such regions as California and Nevada.[50]

The seismic risk map of the United States shown in Fig. 3.6-3 was prepared by Algermissen[51] to assist in the establishment of design requirements for buildings in various segments of the country. Seismicity ratings were based on either an historical earthquake of considerable intensity or on frequency of seismic incidences irrespective of intensity. The Oak Ridge Reservation lies in what Algermissen designated as Seismic Zone 2, which is an area of moderate activity.

Taking the seismic history of the region and using probabilistic techniques generally similar to those published by Cornell and Vanmarcke, Dames and Moore[48] estimated return periods for different earthquake acceleration levels at the ORGDP site. They estimated that the return period for an earthquake with a maximum ground

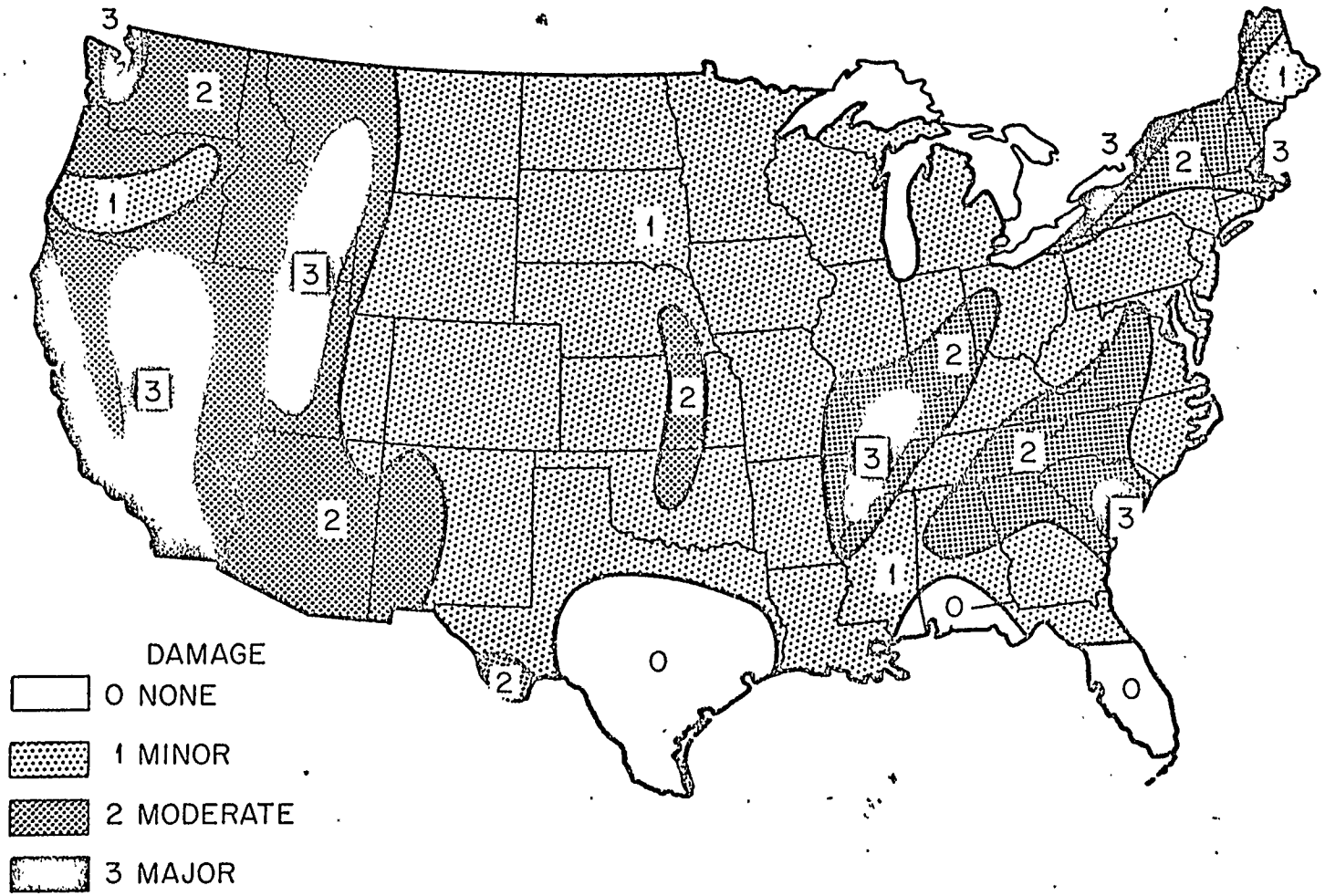


Fig. 3.6-3. Seismic Risk Map of the United States.
SOURCE: S. T. Algermissen, "Seismic Risk Studies in the United States," pp. 14-27 in Proceedings of the 4th World Conference on Earthquake Engineering, Santiago, Chile, January 13-18, 1969, Vol. I, 1969.

acceleration of 0.05 g is 60 years, that for an acceleration of 0.10 g is 550 years, that for 0.15 g is 2500 years, and that for 0.2 g is 8000 years.[48]

The probabilities of seismic events at the existing gaseous diffusion plants were also investigated by John A. Blume and Associates.[49] They calculated that there is a 50% probability of an earthquake with peak ground acceleration exceeding 0.03 to 0.09 g at the ORGDP site in 100 years. They also calculated that in 50 years, there is a 50% probability of exceeding 0.02 to 0.06 g and a 16% probability of exceeding 0.04 to 0.14 g.[49]

## 3.7 Site Suitability Summary

What is known today as the Oak Ridge Reservation is the result of a plan which was conceived and implemented hastily to perform a vital wartime mission. Ninety square miles of rolling wooded land were purchased by the United States Government in 1942 for the purpose of building the facilities necessary to produce the uranium-235 needed to end World War II. The selection of this site was based on several factors, which included the topography, driving distance to Knoxville of about 20 miles, immediate availabilty of two major railroad lines, and a regulated source of water. The topography of the Oak Ridge Reservation permitted the location of a number of operations on reasonably flat areas separated by protective hills with enough land around each research and production facility to provide security, space for expansion, and isolation to protect the general public from exposure to radiation and releases of hazardous material.

Construction of an enormous plant for the separation of isotopes of uranium by the gaseous diffusion process was begun in 1943, and production by this process was started in 1945. This process is still used in the production of uranium-235 at the ORGDP, which is situated on a level 640-acre tract of land located at the southwest end of East Fork Valley at the confluence of Poplar Creek with the Clinch River. This site afforded the plentiful supply of water needed for operation of the gaseous diffusion process. A total of 14 million gallons of water is withdrawn from the Clinch River each day for ORGDP operations, and about 9 Mgd of this is required for recirculating cooling water system makeup to replace evaporative, drift, and blowdown losses. At the time the ORGDP site was selected, the Clinch River was regulated by the Tennessee Valley Authority's Norris Dam, and the water was relatively free of silt. The Tennessee Valley Authority (TVA) is also the source of the large quantities of electrical power (1600 MW) necessary for

operation of the ORGDP at full capacity. At full uprated capacity, the plant demand will be about 2180 MW of continuous power. Electric power is supplied to all of the Oak Ridge operations form the TVA 161-kV power grid.

The ORGDP is located in a moderate temperature zone. For the 26-year period from 1948 through 1974, the annual mean maximum and minimum temperatures at Oak Ridge were 68.7 and 46.9 degrees F, respectively. Temperature extremes of above 100 and below zero degrees F are rare. The extreme high temperature recorded at Oak Ridge was 105 degrees F in July 1952, and the extreme low was -9 degrees F in January 1966. Winter and early spring are the seasons of heaviest precipitation with monthly maximum rainfalls normally occurring from January through March. The mean annual precipitation is about 54 inches. Light snow usually occurs in the months from November to March, and the total snowfall for some winters is less than one inch. The prevailing wind is from the southwest and near the surface, it tends to follow the trend of the valley and ridge topography. The Cumberland Mountains have a moderating influence on the local climate in the winter by retarding the flow of cold air from the north and west.

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statistical basis that uranium-233-bearing fuel elements can be transported and irradiated successfully in high-temperature gas-cooled reactors.

In addition, the proposed HTGR Fuel Refabrication Pilot Plant will be of sufficient capacity tc permit testing of the economics of remote fuel refabrication processes. Data will be obtained to establish plant operating factors, equipment reliability, product characteristics, utility requirements, operating labor requirements, maintenance costs, and other pertinent cost factors.

## D. Existing Environment

The proposed HTGR Fuel Refabrication Pilot Plant will be installed in the existing TURF, Building 7930, which is located on the USAEC Oak Ridge Reservation at Oak Ridge National Laboratory, as shown in Fig. 1. Nearby facilities include the HFIR and the TRU, as shown in Fig. 2.

Located in the west central portion of eastern Tennessee, as shown in Fig. 14, the Oak Ridge Reservation is bounded on the northeast, southeast, and southwest by the Clinch River and on the northwest by Black Oak Ridge. The Reservation, established in 1942 by the U.S. Army Corps of Engineers (Manhattan Engineering District) and Stone and Webster Engineering Corporation, presently covers approximately 37,000 acres.

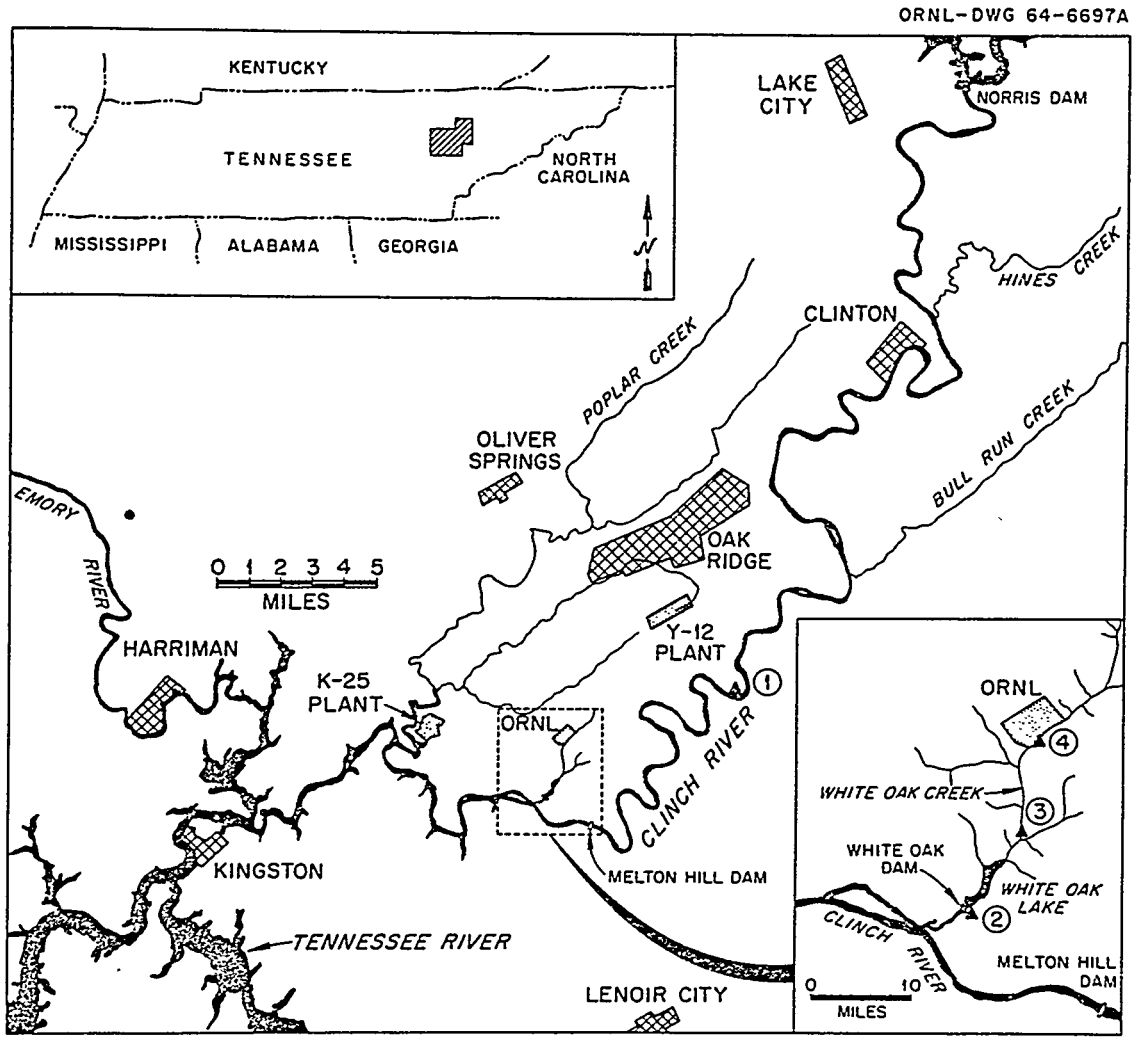


Fig. 14. Location Map of USAEC Reservation at Oak Ridge, Tennessee (numbers in circles indicate stream gaging stations).

Four separate production and research facilities are operated within the Reservation. Three of these, Oak Ridge National Laboratory (X-10), the Y-12 Plant, and the Oak Ridge Gaseous Diffusion Plant (K-25), are operated for the USAEC by Union Carbide Corporation, Nuclear Division. The Comparative Animal Research Laboratory (CARL) is located along the Clinch River between X-10 and Y-12, and it is operated by The University of Tennessee. Buffer zones are designated around each of the four facilities for health, safety, and future

expansion. Access to the Reservation is limited primarily to public roads and visitor centers for reasons of health, safety, and national security.

The area surrounding the Reservation is generally rural to urban in character, with the largest population center (Knoxville, population 175,000) located 15 miles to the east. Other population centers, all with populations of less than 35,000 persons, are Oak Ridge (located on the northeast boundary), Clinton (10 miles northeast), Kingston (10 miles southwest), Harriman (10 miles west), and several smaller communities within Anderson and Roane Counties. The climatology, geology, seismology, ecolcgy of the site, and land use within the Reservation are discussed briefly in the following subsections and in more detail in Appendix B.

## 1. Topography and Climatology

The Oak Ridge site is in the western part of the Tennessee section of the Ridge and Valley province, consisting of parallel ridges and valleys trending northeast. The range in altitude is from 220 to 407 m (720 to 1335 ft) above mean sea level.

The climate of Oak Ridge is typical of the humid southern Appalachian region.[9] The mean annual rainfall is approximately 53.5 in. (136 cm), and the mean temperature is 57.9 degrees F (14.4 degrees C). Precipitation is predominately in the form of rainfall although under unusual

conditions snowfall can represent a significant portion of the total winter precipitation, as happened in the winter of 1959-1960 when 41.4 in. (105.2 cm) of snow fell.

Storm tracks appear to travel from northwest to southeast. The precipitation pattern during the year is characterized by wet winters and comparatively dry springs followed by relatively wet summers and dry autumns. July rainfall (5.6 in.) normally approaches that of the wet winter months, while June (4.0 in.) is almost as dry as the autumn months, as is shown in Fig. 15. July is generally the hottest month (76.9 degrees F), while January is the coldest (37.9 degrees F).

The striking feature of the Oak Ridge climate with respect to plant growth is the develcpment of comparatively early moisture deficits in the spring. However, rainfall in July and August is normally adequate to prevent the development of severe summer deficits, which often occur in other areas of the southern United States. Additional climatological data are included in Appendix B.

## 2. Geology and Soils

The Oak Ridge Reservation lies in the Tennessee Valley and Ridge portion of the Appalachian Highland physiographic province. This province is characterized by a series of long narrow ridges and slightly broader intervening valleys with a pronounced northeast-southwest trend. The ridges in general

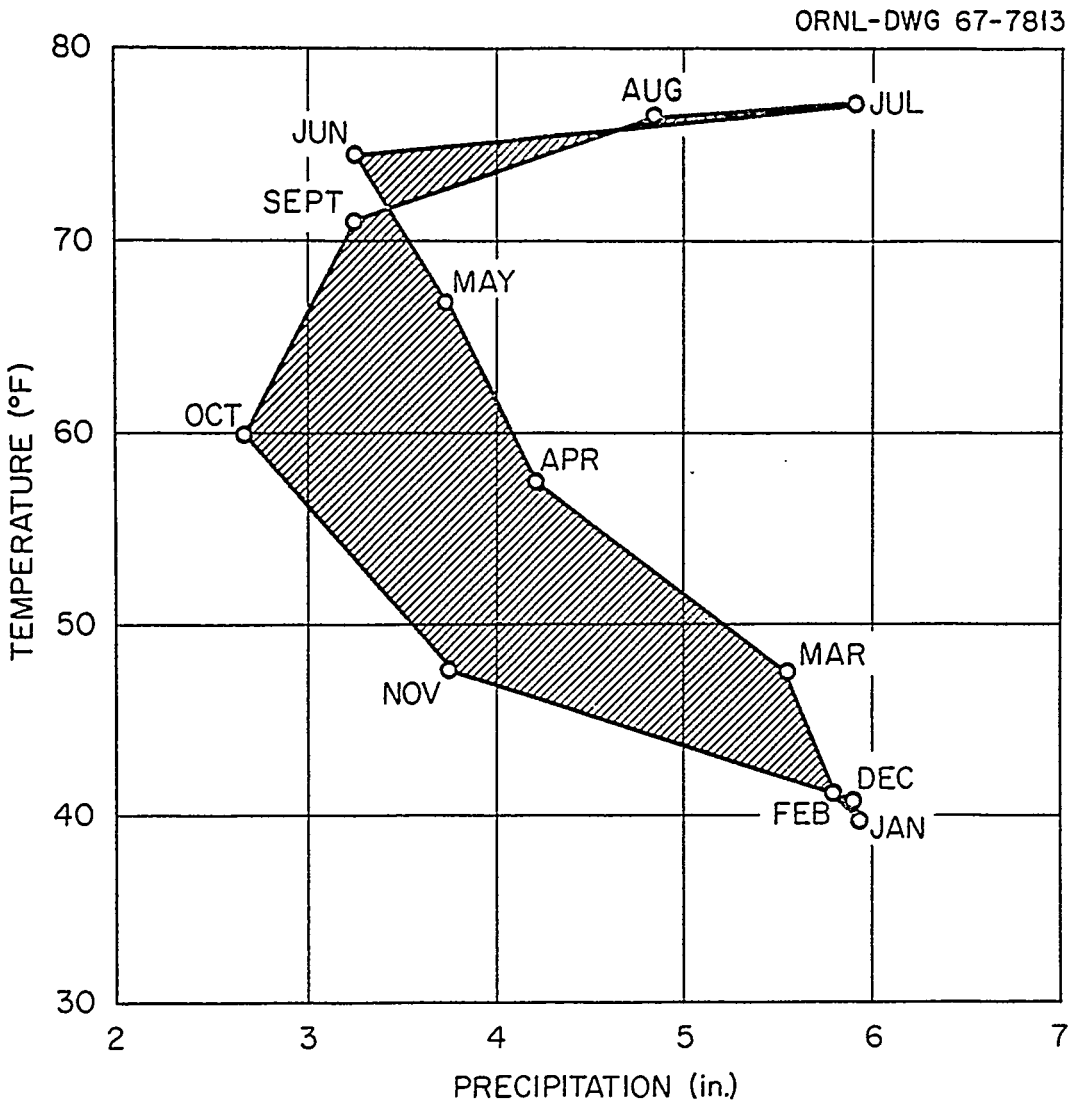


Fig. 15. Climograph of the Oak Ridge Area.

are underlain by relatively resistant sandstones and competent limestones or dolomites, whereas the valleys are underlain by weaker shales and more soluble carbonate rock.

The White Oak Creek basin, upon which the TURF is situated, is underlain by four major geologic formations. The two oldest, the Rome Formation and the Conasauga Group, are made up of shale, siltstone, sandstone, and limestone and are poor water-bearing formations.[10] The two younger formations,

the Knox Dolomite and the Chickamauga Limestone, are the principal water-bearing formations.

The soils of the basin belong to the red-yellow podsolic, the reddish-brown laterite and lithosol groups. These are strongly leached, low in organic matter, acidic, and generally have exchange capacities less than 10 milliequivalents per 100 g of soil. Soil profiles range in depth from 6 in. in some shale areas to approximately 15 ft in the dolomite and alluvial areas. Clay fractions present include illite, kaolinite, and montmorillinite, with base saturation ranging from 10 to more than 60 %.

## 3. Hydrology

Drainage of the ORNL area is to the Clinch River by way of various smaller streams. Among these streams is White Oak Creek (Fig. 14), which courses through Oak Ridge National Laboratory and forms the principal drainage system for the site. Groundwater levels in the immediate vicinity of the TURF range from 25 to more than 100 ft below surface contour. These levels undergo marked seasonal fluctuations, reaching peak levels in March and gradually declining as discharge rates exceed recharge rates.[10] Belts of residual materials overlying bedrock are relatively thin, reducing the volume available for grcundwater storage. Consequently, it is estimated that the average well in the Oak Ridge area would yield less than 10 gpm. The Clinch River, which has a

drainage area of 4413 square miles, is the source of most of the water used in the area.

Flow in the Clinch River is regulated at Norris Dam and at Melton Hill Dam. Stages below Melton Hill Dam are further affected by operation of Watts Bar Lake. Power generation began at Melton Hill Dam in the summer of 1964, and it exerts a significant influence on the flow patterns of the Clinch River. Operation of the turbine generators ususally coincides with peak power demands (except on weekends), resulting in intermittent flow releases as high as 18,000 cfs.[11]

These high flow releases from Melton Hill Dam cause water levels to rise rapidly, blocking the outflow of water from White Oak Creek for about 6 hours each day. White Oak Creek is impounded by White Oak Dam, which is a small highway-fill structure located 0.6 miles above the stream mouth where White Wing Road (Tennessee State Highway 95) crosses the creek. The impoundment, White Oak Lake, covers approximately 20 acres and provides the final on-site monitoring area for liquid effluents from ORNL. Upon cessation of power generation at Melton Hill Dam, the waters of White Oak Creek begin to flow into the main stream and are flushed downstream with the next power generation flow release. Monitoring stations are located on White Oak Creek, on Melton Branch, and on the Clinch River.

## 4. Seismology

A seismic risk map of the United States is illustrated in

Fig. 16. This map was prepared for use in establishing design requirements for structures to be located in various portions of the country.[12] Within the southeastern region of the United States, the only zones of highest risk (zone 3) are those around centers of seismic activity in the Mississippi Valley and at Charleston, South Carolina, both of which are about 400 miles from the site of the proposed project. The TURF site is in an area of lesser activity assigned a zone-2 risk, indicating a potential for moderate damage.

## 5. Ecology of Site and Environs

The Oak Ridge Reservation is typical of the landscape and ecological systems which occur in the Appalachian Region of the eastern United States. As such, the area is comprised of a number of representative terrestrial and aquatic ecosystems, ranging from smaller, established southern coniferous forests to northern hardwood types and from smaller stream tributaries to man-made reservoir streams.

A preliminary inventory of the flora of the general Oak Ridge area was completed in 1966.[13] However, this inventory has since been supplemented with observations of spring flowering for 171 species of herbaceous and woody plants representing 55 plant families.[14]

Five Appalachian forest types are found naturally on the Reservation.[15] The oak-hickory type shares equal prominence

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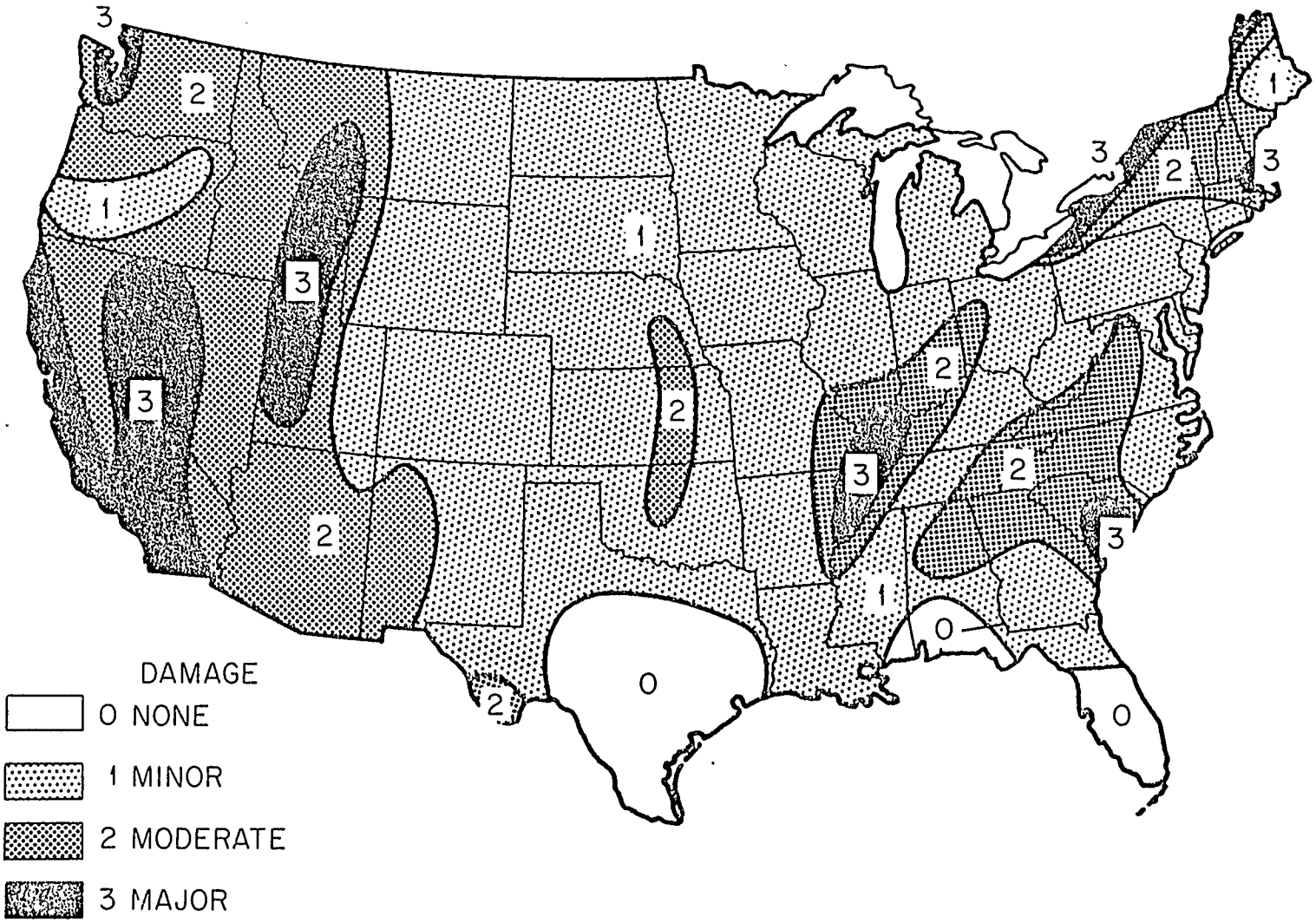


Fig. 16. Seismic Risk Map of the United States (from Ref. 12).

with the yellow pine-hardwood type. Cove hardwoods are found interspersed between the dissected ridge systems, and northern hardwoods occur in sheltered areas on northern exposures. A minor type, white pine-hardwood, is found along the northern boundary of the property. Large areas of open land were planted to pine between 1947 and 1956, thereby creating a sixth type.

There are several available studies describing the fauna of the area, with special reference to Melton Valley wherein lies the TURF. The fauna are typical for forested and semi-forested regions of the United States, and they are described in detail in Appendix B. Over 65 separate species of birds were observed in a 1957 summer survey. The southern bald eagle (*Haliaeetus* l. *leucocephalus* L.) is listed as an endangered species whose range encompasses the local area.[16] However, no recent sitings of the bird have been reported. Typical species of mammals include mice, shrews, opossums, racoons, woodchucks, rabbits, foxes, and the white-tail deer.

Various facets of the aquatic system, represented by the White Oak Creek, White Oak Lake, Clinch River, and Tennessee River continuum, have been studied over the past two decades, particularly with respect to the behavior and transport of radioactive materials in the aquatic environment.[11] The biotic composition of White Oak Lake is typical of the present aquatic system downstream from Melton Hill Reservoir and immediately adjacent to the proposed project. White Oak Lake

has been characterized as having high phytoplankton productivity and well developed benthic fauna, with the most common forms being comprised of varicus insect larvae.[17] Fishes present in the shallow embayment (maximum depth of 7.3 ft) include bluegill and redear sunfish, largemouth bass, warmouth, gizzard shad, golden shiners, goldfish, and the mosquitofish, Gambusia affinis affinis. The aquatic system is discussed further in Appendix B.

## 6. Land Use

The 92-square-mile Oak Ridge Reservation was originally acquired as a site for production facilities and nuclear research, and a security buffer and safety zone were established around each USEAC plant within the Reservation. The original 59,000 acres acquired in 1942 have since been reduced to approximately 37,000 acres through land transfers to the municipal government of Oak Ridge and to state and federal agencies.[15]

The allocation of land among the USAEC users is given in Table 3. Buffer areas around each of the facilities allow for increased security and protection against accidental releases of chemical or radioactive materials and also provide room for future expansion. Little forested acreage is included in the buffer areas around the Y-12 and K-25 Plants, but extensive forested areas lie within the ORNL (X-10) and UT-AEC (CARL) sections. The remainder of the Reservation (15,000 acres) is

Table 3. Allocation of Land Use Among Installations in the AEC Oak Ridge Reservation[a]

| Administrative Unit | Acres |
|---|---|
| Research and Management | 15,108 |
| ORNL | 8,843 |
| Y-12 | 3,632 |
| K-25 | 5,645 |
| UT-AEC[b] | 3,786 |
| Total | 37,014 |

[a]Data taken from Task Force Report FY-1972 "Surveys of Real Property Holdings," AEC-ORO, June 1972.

[b]Does not include 720 acres of UT-AEC farm located within the Y-12 Plant buffer zone.

approximately 95% forested with pine (36%), upland hardwoods (32%), mixed pine-hardwoods (21%), and cedar and miscellaneous species (11%).

It has recently been proposed that the Oak Ridge Reservation be designated an Environmental Study Park.[18] Within this context, a total of 41 study areas were delineated as being unique and important in terms of present day environmental problems. Additional discussion of historic and present land use is presented in Appendix B.

## E. Monitoring of Existing Environment

The Oak Ridge National Laboratory conducts a continuous monitoring program on the USEAC-controlled reservation and the surrounding environs. A monitoring network, extending 75 miles from ORNL, provides information on quantities and

concentrations of airborne radioactive pollutants. Similarly, a water and biota monitoring program is conducted on the Clinch River, which is the eventual receiving body of water for all potentially contaminated liquid effluents leaving the controlled reservation. A comprehensive, multi-agency investigation of the potential radiation exposures received by the public use of the Clinch River waters was the subject of the 5-year Clinch River Study which was completed in 1964. In the final report of this study on the doses to populations from ORNL operations, it was concluded that average exposures were well below the applicable dose limits and that the maximum individual dose was a small fraction of the dose limits.[19] External gamma radiation levels or background levels in the ORNL area and in the Oak Ridge area are measured routinely. The background level for the Oak Ridge area off the ORNL site averages approximately 0.012 mR per hour, which is about the same as that measured prior to the start of ORNL operations.

Sanitary, chemical, and miscellaneous industrial waste effluents are monitored through an established environmental surveillance program which is conducted by the ORNL Industrial Hygiene Department and the Operations Division. A more detailed description of the environmental monitoring programs for radioactive and chemical effluents is presented in Appendix C.

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level by strict administrative control and by other safety measures, such as mass limitation of hazardous material.

The maximum credible criticality accident[7] in the pilot plant could disperse gaseous fission products and an aerosol of nonvolatile fission products to the cell containing the accident, and a small portion of these materials could be released through the filtered cell ventilation system. The high-efficiency particulate air filters are located a great enough distance (about 60 ft) from the processing cells that they are not expected to be affected by a criticality incident. The quantities of aerosols of the fuel and nonvolatile fission products released through the filtered ventialtion system would not be significant. Hence, no adverse environmental effects are expected to result from such an accident.

4. Natural Disturbances

Consideration was given to the release of radioactivity from the proposed HTGR Fuel Refabrication Pilot Plant as a result of possible damage to the TURF from natural disturbances. The disturbances considered included (a) earthquakes, (b) flooding, (c) high winds, and (d) tornados.

(a) Earthquakes. The TURF site is located within a zone of low earthquake activity, as illustrated in Fig. 16 (subsection II.D.4), and the probability for significant

earthquake damage to the TURF has been estimated to be low (Appendix B). The epicenters of damaging earthquakes of intensity VII or larger have never been recorded in the area surrounding the TURF site. From the seismic risk map (Fig. 16), which is based on known distributions of damaging earthquakes and corresponding intensities, no shockwaves from distant earthquakes that might reach the TURF site are expected to be of sufficient frequency or amplitude to impart physical damage to the structure.

The site is located in seismic risk zone 2, which has a corresponding potential for a maximum ground acceleration of from 0.03 to 0.09 g. The areas in the TURF that will contain large amounts of special nuclear material will be surrounded by thick concrete walls (subsection II.A.1). In addition, the relatively short operating life of the pilot plant will decrease the probability of damaging earthquake activity in the site area. No structural or equipment damage which would result in appreciable release of radioactive materials as a result of an earthquake is expected.

(b) Flooding. The possibility of extensive flooding of the proposed project site is considered to be extremely remote since the TURF is located on a knoll well above the valley floor and therefore above any possible flood plain. The natural grade of the surrounding area should provide adequate drainage to accomodate any maximum postulated rainfall intensity. Flooding is, therefore, not anticipated to result

in damage to the proposed facility that would allow the release of radioactivity to the environment.

(c) High Winds. The specifications to which the TURF was built included the requirement that it withstand wind speeds of at least 90 miles per hour. As the maximum wind speed recorded in the area during the last 20 years was 59 miles per hour, the possibility of high winds having an adverse effect on building integrity is considered to be remote.

(d) Tornados. The project site seems protected by the Appalachian and Cumberland Mountain Ridges. Two small tornados have been identified in the vicinity of Oak Ridge within the past 20 years. The probability of damage to the TURF from tornado activity is therefore considered to be very small. In addition, the areas in the TURF that will contain large amounts of special nuclear material will be surrounded by thick concrete walls (Subsection II.A.1). The cell structures of the TURF were designed to withstand an internal shock wave of 970 psf without failure, and this would make such areas withstand damage from tornadc activity.

5. Handling Accidents

A handling accident could occur during transfer of uranyl nitrate solution from tank storage in Building 3019 to tank storage in the TURF. However, the transfer process described

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Appendix B

CHARACTERIZATION OF EXISTING ENVIRONMENT

The United States Atomic Energy Commission's Oak Ridge Reservation presently consists of approximately 37,000 acres of land adjacent to the City of Oak Ridge in Anderson and Roane Counties, Tennessee. The land is part of an original 92-square mile tract purchased in 1942 to serve as an atomic development and production center for the U.S. Army Corps of Engineers Manhattan Project. The Reservation, which may be visualized as an irregular land mass encompassing the USAEC installations illustrated in Fig. 14 (Subsection II.D), is located 15 miles west of Knoxville, Tennessee, the major population center in the area. The Tennessee Valley Authority's Melton Hill and Watts Bar Reservoirs on the Clinch and Tennessee Rivers, respectively, form eastern, southern, and western boundaries of the property and the City of Oak Ridge lies along the northern perimeter.

The Reservation is located in the Ridge and Valley physiographic province, which is characterized by parallel ridges of sandstone, shale, and cherty dolomite separated by valleys of less weather resistant limestone and shale. The ridges are oriented southwest-northeast, and elevations range from 750 to 800 ft at the valley floor to 1000 to 1200 ft at the ridge crests.

The ecological systems of the Reservation are

characteristic of those found in the intermountain regions of Appalachia from the Allegheny Mountains in southern Pennsylvania to the southern extension of the Cumberlands in northern Alabama. The area has been under governmental control for the past 30 years and has not been unduly disturbed except for experimental use and regulated forest management.

## Climatology

The National Oceanographic and Atmospheric Administration (NOAA) has operated a meteorological observation program at Oak Ridge for over 20 years. In addition to recording day-to-day weather data for the plant sites (X-10, Y-12, and K-25) and Oak Ridge townsite, the NOAA staff has maintained a research and development program to improve the reliability of prediction and measurement of meteorological parameters which influence safe conduct of operations on the Oak Ridge Reservation. A monthly climatic summary for the Oak Ridge area, based on 20 years of records, is given in Table B.1. Seasonal wind speeds and directions in the Oak Ridge area during periods of lapse and inversion conditions are presented in Fig. B.1.

During the 20-year period of record (1951-1971), the extremes of daily temperature have varied from a low of -9 degrees F in January to a high of 105 degrees F in July.

Table B.1. Monthly Climatic Summary for the Oak Ridge Area Based on a 20-Year Record[a]

| Month | Temperature (°F) | | | Precipitation (in.) | | Solar Radiation ($kcal\ cm^{-2}\ month^{-1}$) |
|---|---|---|---|---|---|---|
| | Mean | Maximum | Minimum | Rain | Snow | |
| Jan | 37.9 | 47.0 | 28.8 | 5.3 | 3.4 | 5.6 |
| Feb | 40.9 | 51.2 | 30.6 | 5.3 | 2.6 | 6.7 |
| March | 47.5 | 58.7 | 36.3 | 5.6 | 1.3 | 10.1 |
| April | 59.0 | 71.1 | 46.9 | 4.4 | 0.01 | 12.3 |
| May | 66.8 | 79.1 | 54.5 | 3.6 | 0 | 15.3 |
| June | 74.0 | 85.2 | 62.7 | 4.0 | 0 | 15.1 |
| July | 76.9 | 87.3 | 66.4 | 5.6 | 0 | 13.4 |
| Aug | 76.0 | 86.7 | 65.2 | 3.8 | 0 | 13.5 |
| Sept | 70.1 | 81.5 | 58.7 | 3.3 | 0 | 11.3 |
| Oct | 59.3 | 71.3 | 47.2 | 2.7 | 0 | 9.6 |
| Nov | 46.9 | 57.8 | 35.9 | 4.2 | 0.5 | 5.8 |
| Dec | 39.7 | 48.8 | 30.6 | 5.7 | 2.5 | 4.7 |
| Annual | 57.9 | | | 53.5 | 10.3 | 123.4 |

[a]"Daily, Monthly, and Annual Climatological Data for Oak Ridge, Tennessee, January 1951 through December 1971," Air Resources Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, Tennessee, July 1972.

The average wind speed in the Oak Ridge area is 4.4 miles per hour (mph). The peak gust of record was 59 mph. Calm conditions prevail 10% of the time. Storm tracks travel northwest to southeast.

The average annual rainfall in the Oak Ridge area is 53.5 in. Annual snowfall averages 10.3 in., and 95% of this precipitation occurs between December and March. The average number of thunderstorms per year is 53, and there are 24 days of heavy fog. Clear conditions prevail 30% of the time; partly cloudy, 25%; and cloudy, 45%.

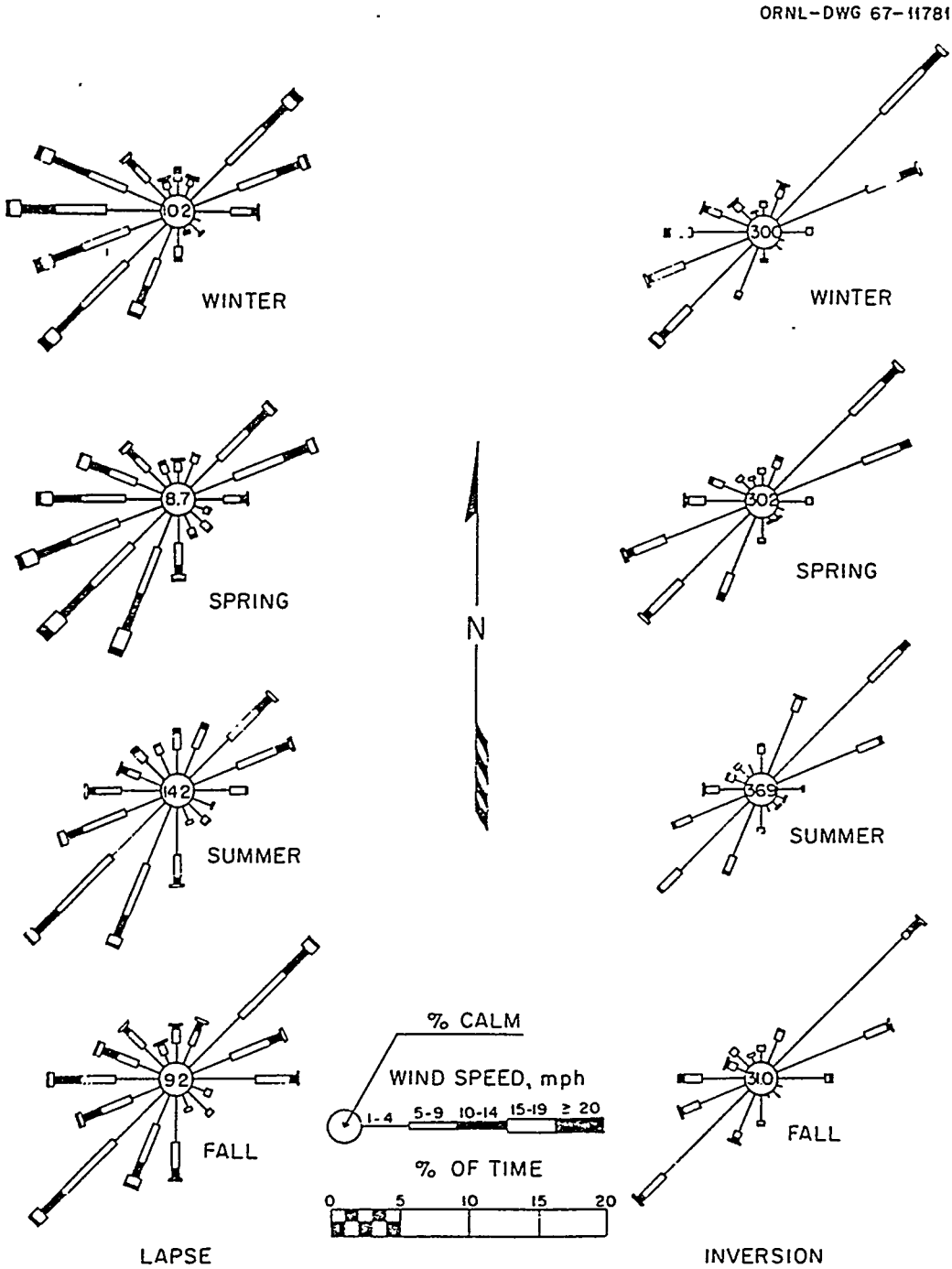



Fig. B.1. Wind Speed and Direction During Lapse and Inversion.

## Geology and Soils

The geology and soils of the Oak Ridge area have been reported on by several investigators. A generalized soils map which includes summarizations of mineralogical soil and rock types is given in Ref. B.1. A geolcgic map of the area is presented in Ref. B.2.

Of particular importance to the present project is a discussion of the geologic features of White Oak Creek Basin, which is located in Roane County, Tennessee, in the southern part of the Oak Ridge Reservation. The Basin has an area of 6.01 square miles, and it drains to the Clinch River by way of White Oak Creek.

Four major rock units or formations occur in the Basin. In descending order of age, these are the Rome formation, underlying Haw Ridge; the Conasauga Group, underlying Chestnut Ridge and Melton Hill; and the Chickamauga Limestone, underlying Bethel Valley. These rocks originated early in the Paleogoic era as masine sediments and became uplifted toward the end of the era. A mantle of residual material is nearly everywhere present, extending to depths of 100 ft in some areas, particularly over the Knox Dolomite.

Soils of the area are described in detail in Ref. B.1. These belong primarily to the broad groups of red-yellow podsolic, reddish brown lateric, and lithosols and are, in general, strongly leached, acidic, low in organic matter, and

with exchange capacities of less than 10 milliequivalent per 100 grams of soil. Depths of soil profiles within the basin vary from 6 in. in some of the shale and sandstone areas to more than 15 ft in areas overlying dolomitic limestone and within alluvial deposits along drainageways.

Soils derived from Knox Dolomite contain kaolinite as the principal clay fraction, those from the Conasauga Shale contain illite and vermiculite, and those derived from Chickamauga Limestone contain a mixture of kaolinitic and illitic materials, with some units having significant montmorillonitic contents. The base saturation ranges from 10 to 60% within the various groups. The radionuclide specificity of the respective clay minerals has been determined, particularly with respect to the behavior of radioactive cesium, strontium, and cobalt, in sediments of White Oak Lake and the Clinch River (Ref. B.3).

## Hydrology

Drainage of the area is to the Clinch River by way of various small streams. Included among these streams is White Oak Creek, which courses through Oak Ridge National Laboratory and forms the principal drainage system for the site. The average annual discharge measured at White Oak Dam for the period 1968-1972 is 11 cfs.

Within the area, major aquifers are associated with the

Knox Dolomite formation. Water occurs to a lesser extent in small openings along points and bedding planes in the shale and sandstone rocks of Pottsville age and of the Rome Formation. Belts of residual materials overlying bedrock are relatively thin, reducing the volume available for groundwater storage. Consequently, it is estimated that the average well in the Oak Ridge area would yield less than 10 gpm (Ref. B.4).

The Clinch River, including its Melton Hill Lake impoundment, has a drainage area of 4413 square miles, and it is the source of most of the water in the area. Water pumped by the Oak Ridge pumping station is delivered to ORNL, the Y-12 Plant, and to the city of Oak Ridge. Waste water from ORNL is returned to the Clinch River via White Oak Creek, from the Y-12 Plant via East Fork Poplar Creek, and from the city of Oak Ridge via East Fork Poplar Creek and via a tributary at river mile 51.1. The Gaseous Diffusion Plant (K-25) is served by a separate pumping station, with waste water from the plant being returned directly to the river.

Operation of the TVA multipurpose dams for flood control, navigation, and power generation results in regulated flow in the Clinch and Tennessee Rivers. Navigation locks are incorporated in all dams on the Tennessee River and in Melton Hill Dam on the Clinch. During the winter months, following cessation of heavy precipitation and runoff, reservoir levels are raised to provide increased hydroelectric capability. Subsequent power releases cause pulsations in river flows.

Within the Clinch River, these discharges may reach 18,000 cfs, and they are not attenuated significantly between Melton Hill Dam and the mouth of White Oak Creek.

These high flow releases cause water levels to rise rapidly, blocking the outflow of water from White Oak Creek for about 6 hours each day. Upon cessation of power generation, the waters of White Oak Creek begin to flow into the main stream and are flushed downstream with the next power release, becoming thoroughly mixed in about 7 miles (Ref. B.4).

Morton (Ref. B.5) observed that the dispersion process due to intermittent releases by Melton Hill Dam was not greatly different than that for steady flow conditions, and that downstream dye concentrations could be predicted on the basis of a uni-dimensional transport equation incorporating eddy diffusion coefficients computed from steady-flow tracer tests.

In general, the waters of small streams in the Oak Ridge area are of the calcium-magnesium-bicarbonate type. Uncontaminated major sources range in hardness from moderate to very hard, with low contents of sodium, potassium, and chloride (Ref. B.4). No significant irrigation usage is apparent.

## Seismology

The Oak Ridge Reservation lies in the Southern

Appalachian seismotectonic province, which is characterized by a series of northeast to southwest trending folds and thrust faults in Paleozoic rocks. The region has been the source of continuing minor seismic activity. A chronological listing of the complete seismic history of the southeast region (including earthquakes with epicenters outside the region which produced detectable tremors within the specified area) is presented in Ref. B.6.

The epicenters of 270 earthquakes which occurred during the 40-year period, 1930-1969, are plotted in Fig. B.2 according to their equivalent Richter magnitude. An approximate relationship is given by M=2/3 of Intensity + 1. This plot does not include the two largest seismic events in the history of the southeast. These were the 1811-1812 shocks at New Madrid, Missouri, Intensity XII, and the 1886 shock of Charleston, South Carolina, Intensity X. The intensity at the project site from these shocks was probably about VI or less. Two major centers of seismic activity are apparent from Fig. B.2. These centers are within the Mississippi Valley area and on the coast of South Carolina in the Charleston area. A third zone of relatively high seismicity coincides with the southern portion of the Appalachian Mountain geologic province.

A more detailed analysis of the seismicity of the southeastern United States can be obtained from an analysis of

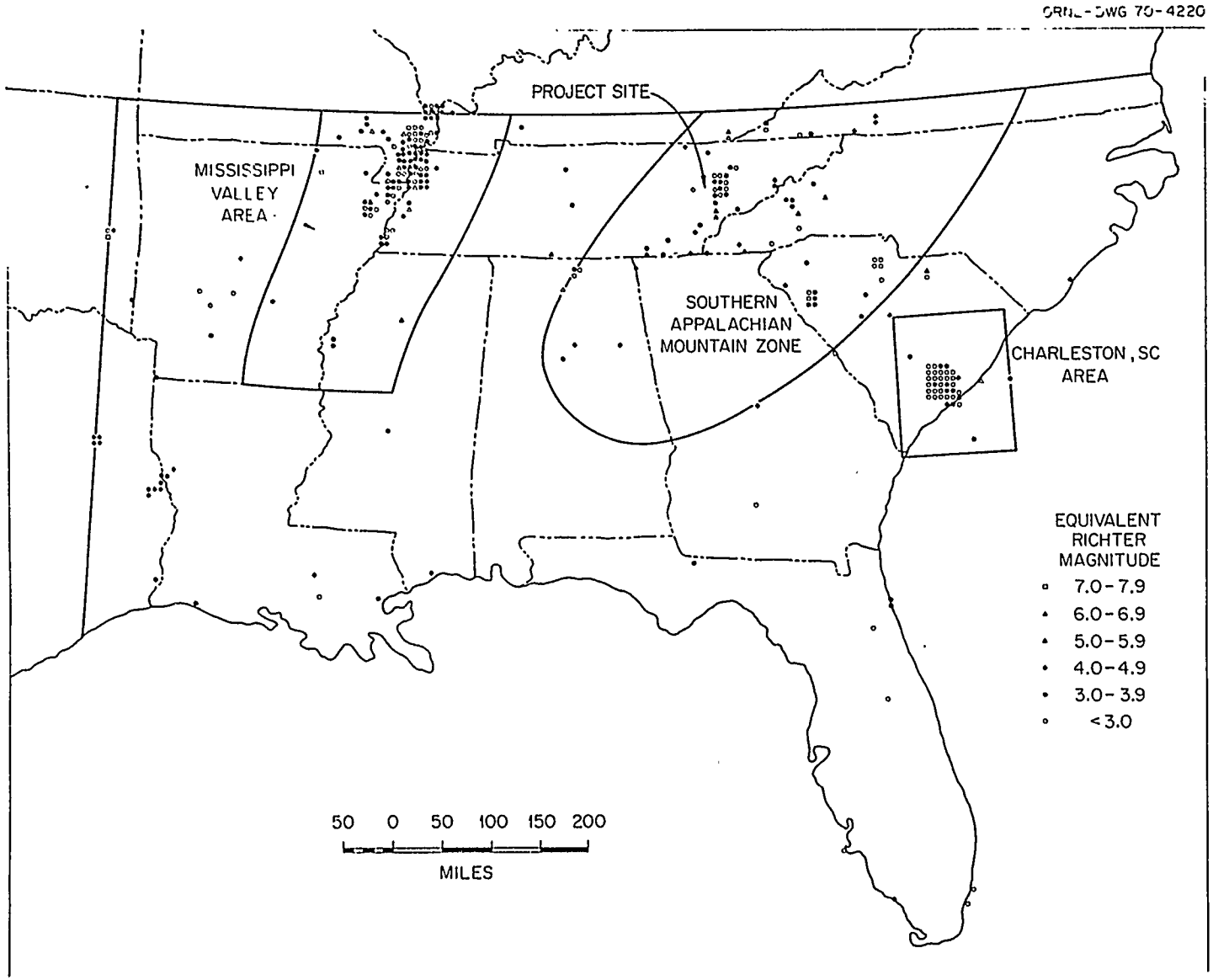



Fig. B.2. Epicenter Locations for Southeast Region Earthquakes in the Period 1930 Through 1969.

recurrence curves of the type shown in Fig. B.3. While the "fit" of the data are not good, extrapolation of the curve for the Southern Appalachian Region suggests a once-per-40-year quake of intensity VIII (modified Mercalli), a once-per-100-year shock of intensity IX, and a recurrence interval between destructive shocks of 106 years, as determined from statistical treatment of past records (Ref. B.6). Seismic evaluations of the Oak Ridge area suggest that within a 100-year period there exists a 50% probability for ground motion acceleration to exceed 0.03 to 0.09g.

## Area Access

Access for other than employees to the USAEC Oak Ridge Reservation is limited to public roads. However, the public road network within the area is well developed. State highway 62 bisects the Reservation east and west, providing a direct route to Knoxville. State highways 95 and 61 run north and south through Oak Ridge, while U. S. Highway 25W, which connects Knoxville, Tennessee, and Lexington, Kentucky, passes 4 miles northeast of the eastern boundary of the Reservation. Interstate Highway 40 connecting Knoxville and Nashville, Tennessee, is 2 miles southeast of the western boundary of the Reservation. The primary and secondary road system of the Reservation is excellent.

The area is adequately served by rail transportation,

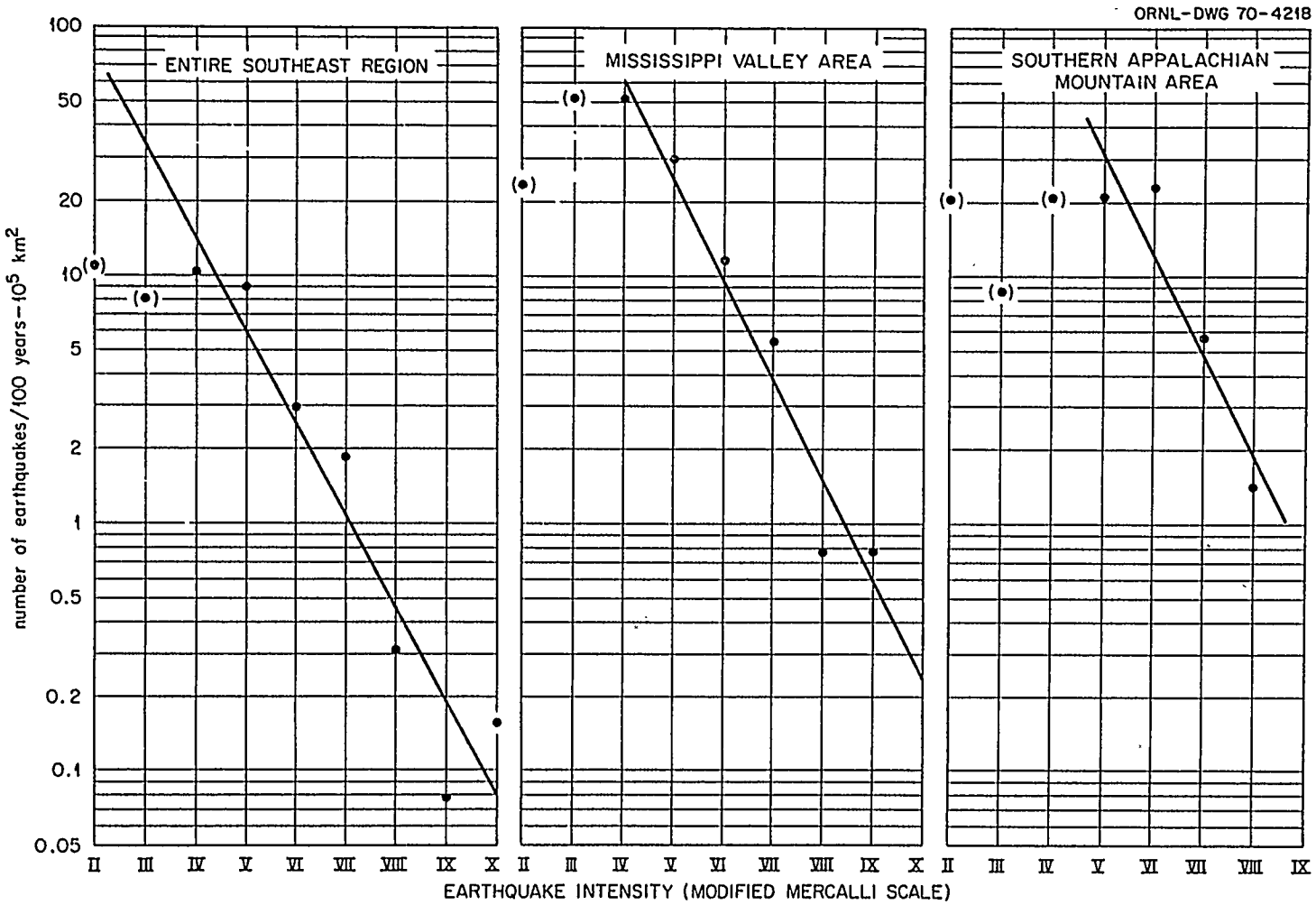



Fig. B.3. Recurrence Curves for (a) Total Southeast Region, (b) Mississippi Valley Area, and (c) Southern Appalachian Mountain Zone. (Curves represent least-squares fits of the relationship log N = a + bI, where N is the number of earthquakes per 100 years and per 100,000 $km^2$ of intensity, I.)

with connecting points located at Harriman, Tennessee. The Clinch River waterway forms the southern boundary of the Reservation and joins the Tennessee River system 10 miles downstream. A 9-ft navigation channel extends above Clinton, Tennessee, to Clinch River Mile 61.

## Ecology of Site and Environs

The Oak Ridge Reservation is typical of the landscape and ecological systems which occur in the Appalachian Region of the eastern United States. As such, the area is comprised of a number of representative terrestrial and aquatic ecosystems that range from smaller, established southern coniferous forests to northern hardwood types and from small stream tributaries to man-made reservoir systems.

A preliminary inventory of the flora of the general Oak Ridge area was completed in 1966 (Ref. B.7). This inventory has since been supplemented with observations of spring flowering for 171 species of herbaceous and woody plants representing 55 plant families (Ref. B.8).

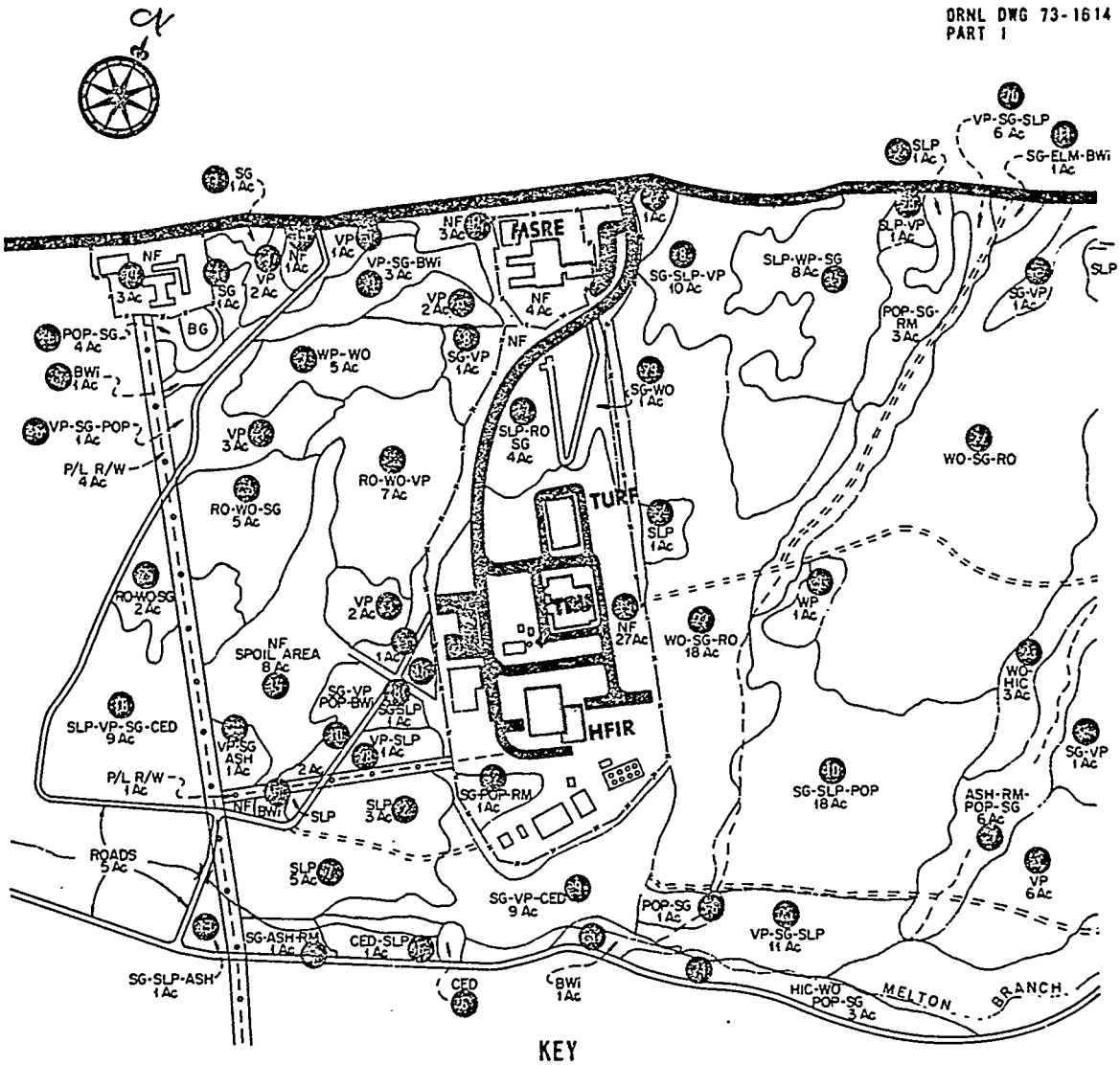
Five Appalachian forest types occur naturally on the Reservation (Ref. B.9). The oak-hickory type shares equal prominence with the yellow pine-hardwood type. Cove hardwoods are found interspersed between dissected ridge systems, and northern hardwoods occurr in sheltered areas with northern exposures. A minor type, white pine-hardwood, is found along the northern boundaries of the property. Between 1947 and

1950, large areas of open land were planted to loblolly pine, creating a sixth forest type.

A detailed map of the dominant vegetation within the immediate area of the proposed facility is illustrated in Fig. B.4. The area is relatively heavily wooded with a large proportion of the total cover being comprised of sweet gum and white and red oaks. Yellow poplar, ash, and red maple are present on more mesic sites, and short-leaf and virginia pine are scattered along roads and in open areas generally as a result of managed plantings.

There are several available studies describing the fauna of the area, with special reference tc Melton Valley wherein lies the site of the proposed fuel refabrication pilot plant. A 1958 survey of summer bird populations at 157 stations resulted in the reccrding of 1870 individuals representing 65 separate species (Ref. B.10). Density of individuals was highly correlated with vegetation cover, with the greater number of birds being observe in habitats characterized by low growing herbaceous material interspersed with younger trees. A greater diversity of species, with lesser numbers of individuals was found to be typical fcr forested habitats. Summer birds typical of habitats represented in Fig. B.4 include the red-eyed vireo, Carolina wren, tufted titmouse, Carolina chickadee, and numerous other pure forest as well as edge species.

In contrast to area bird populaticns, which were shown to




KEY

| STRA # | VEGETATION TYPE | ACRES |
|---|---|---|
| 1 | WP | 1 |
| 2 | SLP | 10 |
| 3 | VP | 19 |
| 4 | SG | 2 |
| 5 | BWi | 3 |
| 6 | CED, CED-SLP | 1 |
| 7 | WP-WO | 5 |
| 8 | SG-VP, SG-SLP, SG-SLP-VP | 15 |
| 9 | SG-VP-CED | 9 |
| 10 | SG-SLP-POP, SG-VP-POP-BWi | 20 |
| 11 | SG-ELM-BWi | 1 |
| 12 | SG-POP-RM | 1 |
| 13 | SG-SLP-ASH | 1 |
| 14 | SG-ASH-RM | 1 |
| 15 | SLP-WP-SG | 8 |
| 16 | VP-SG-POP | 1 |
| 17 | SLP-RO-SG | 4 |
| 18 | SLP-VP-SG-CED | 9 |
| 19 | NF BUILDING SITES | 46 |
| 20 | VP-SG-SLP | 18 |
| 21 | VP-SG-ASH, VP-SG-BWi-VP-SG-POP | 5 |
| 22 | WO-SG-RO | 52 |
| 23 | WO-HIC | 3 |
| 24 | HIC-WO-POP-SG | 3 |
| 25 | RO-WO-SG | 7 |
| 26 | POP-SG, POP-SG-RM | 4 |
| 27 | ASH-RM-POP-SG | 6 |
| 28 | SLP-VP, VP-SLP | 2 |
| 29 | SG-WO | 1 |
| 30 | RO-WO-VP | 7 |
| 31 | POWER LINE R/W | 5 |
| 32 | ROADS | 5 |
| | TOTAL ACREAGE | 275 |

Fig. B.4. Vegetation Type Map for the Area Surrounding the TURF.

ORNL DWG 73-1614
PART 2

| COMMON NAME | CODE | SCIENTIFIC NAME |
|---|---|---|
| ASH | ASH | FRAXINUS SP. |
| BLACK GUM | BG | NYSSA SYLVATICA |
| CEDAR | CED | JUNIPERUS VIRGINIANA |
| ELM | ELM | ULMUS AMERICANA |
| HICKORY | HIC | CARYA SP. |
| RED MAPLE | RM | ACER RUBRUM |
| YELLOW POPLAR | POP | LIRIODENDRON TULIPIFERA |
| NORTHERN RED OAK | RO | QUERCUS RUBRA |
| SWEETGUM | SG | LIQUIDAMBAR STYRACIFLUA |
| SHORTLEAF PINE | SLP | PINUS STROBUS |
| BLACK WALNUT | BWi | JUGLANS NIGRA |
| WHITE OAK | WO | QUERCUS ALBA |
| WHITE PINE | WP | PINUS MONTICOLA |
| VIRGINIA PINE | VP | PINUS VIRGINIANA |

Legend for Fig. B.4.

be dependent upon vegetation cover, mammalian faunal makeup is more directly linked with soil fertility and depth of humus and litter layers (Ref. B.11). Typical species include mice, shrews, opossums, racoons, woodchucks, cottontail rabbits, and the gray fox. White-tail deer have been observed in the area, and appear to be increasing in numbers, as evidenced by an increasing frequency of road kills on the Reservation.

The herpetofauna of the area have been described, including a categorization of habitat types (Ref. B.12). Various species of salamanders, turtles, frogs and toads, lizards, and snakes, including the northern copperhead, make up this particular component of the area's biota. Various facets of the aquatic system, represented by the White Oak Creek-White Oak Lake-Clinch River-Tennessee River continuum,

have been studied over the past several decades, particularly with regard to the behavior and transport cf radioactive materials in the aquatic environment (Ref. B.13). For the most part these investigations were conducted prior to the establishment of Melton Hill Reservoir, and they were primarily concerned with selected organisms (e.g., tubificid worms, crayfish, Chironomid larvae, clams, and several species of fish, including white crappies, carp, and smallmouth buffalo) as they related to the transport of radioactive materials.

A characterization of fishes commcn to the Clinch River system prior to the establishment of Melton Hill Reservoir (Ref. B.13) showed major groups to include the Centrarchidai (sunfishes, basses and crappies), Catostomidae (suckers), and Ictaluridae (catfishes). Except for carp, the Cyprinidae (minnows) were pocrly represented, primarily due to a lack of suitable habitat. Forage for piscivorcus fish is provided by large populations cf Clupeidae (threadfin shad, gizzard shad). In addition to the above groups, sauger and white bass, both carnivorous species, are regularly caught.

The fisheries resources of the Tennessee River system are exploited by both commercial and sports fishermen. Some commercially harvested nongame species (e.g., carp, buffalo) are marketed for human consumption. Records of commercial takes from the Tennessee River, 1946-1963, show harvests ranging from a low of 1,073,000 lb in 1947 to 8,532,000 lb in

1963, comprised mainly of catfish and buffalo (Ref. B.13).

Typical of the present aquatic system downstream from Melton Hill Reservoir and immediately adjacent to the proposed facility is the biotic composition of White Oak Lake at ORNL. The lake has been characterized as having high phytoplankton productivity and a well-developed benthic fauna, with the most common forms being comprised of various insect larvae (Ref. B.14). Fishes present in the shallow embayment (maximum depth 7.3 ft) include bluegill and redear sunfish, largemouth bass, warmouth, gizzard shad, golden shiners, goldfish, and the mosquitofish, *Gambusia affinis affinis*.

## Land Use

The 92-square-mile Oak Ridge Reservation was originally acquired as a site for production facilities and nuclear research, and a security buffer and safety zone were established around each AEC plant. The original 59,000 acres acquired in 1942 have since been reduced to approximately 37,000 acres through land transfers to the municipal government and to state and federal agencies (Ref. B.9). A study of aerial photographs made in 1942 indicates that about 43% of the area was at that time comprised of pastures and fields. The remaining areas were forested.

The amount of timber harvested for construction of the Oak Ridge facilities is unknown. In 1947, Management Services

Incorporated, an AEC contractor, began a reforestation program which ended in 1960. During that period, approximately 9 million pine seedlings were planted in old field and open areas to the extent that as of 1965, approximately 4300 acres of shortleaf, loblolly, and eastern white pine plantations existed in the Reservation (Ref. B.9).

A 1961 survey of forest lands by the TVA summarized then extant timber resources of the Reservation, leading to the establishment of a forest management program at CRNL in 1964.

The present allocation of land use among plant installations is given in Table 3 (subsection II.D.6). Buffer areas around each of the facilities provide increased security and protection against accidental release of chemical or radioactive materials and also provide room for future expansion. Little forested acreage is included in the buffer areas around the Y-12 and K-25 Plants, but extensive forested areas lie within the ORNL and UT-AEC sections. Excluding buffer areas around USAEC facilities, the remainder of the Reservation is subdivided into 24 management compartments that range in size from 400 to 1200 net manageable acres (Ref. B.9). Approximately 93% of the total manageable land (15,000 acres) is forested in pine (36%), upland hardwoods (32%), mixed pine-hardwoods (21%), and cedar and miscellaneous species (11%).

Objectives of the present forest management plan are a maximization of yield and quality of timber resources to

assure a substantial yield of high-quality stumpage within the constraints of primary research and production objectives of the AEC facilities. Twenty-five research areas, totalling 2300 acres, are reserved for ecological studies. These areas provide a variety of landscape units for research and permit the use of a holistic approach to ecosystem analysis. It was recently proposed that the Oak Ridge Reservation be designated an Environmental Study Park (Ref. B.15). Within this context, a total of 41 study areas were delineated as being unique and important in terms of present-day environmental problems.

One historic landmark, the Oak Ridge Graphite Reactor, is located on the USAEC Oak Ridge Reservation at Oak Ridge National Laboratory.

## Regional Demography

As previously discussed, the proposed HTGR Fuel Refabrication Pilot Plant is to be installed in the existing TURF, which is located in the Melton Valley area of Oak Ridge National Laboratory. Incremental population data, based on the 1970 United States Census, out to a distance of 70 miles in all directions from the TURF site are given in Table B.2. The total population in this area is 1,025,864. The two largest cities near the plant site are Knoxville, Tennessee, and Oak Ridge, Tennessee. The city limit of Knoxville, which has a population of 175,000, is approximately 13 miles toward

Table B.2. Incremental Population Data for TURF Site

| Direction | Distance (miles) 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-10 | 10-20 | 20-30 | 30-40 | 40-50 | 50-60 | 60-70 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 0 | 0 | 0 | 0 | 1,490 | 5,578 | 2,177 | 1,441 | 2,223 | 4,509 | 13,686 | 7,314 |
| NNE | 0 | 0 | 0 | 0 | 1,461 | 13,783 | 4,362 | 11,189 | 12,674 | 6,119 | 7,978 | 17,980 |
| NE | 0 | 0 | 0 | 0 | 0 | 9,713 | 12,479 | 7,167 | 4,392 | 7,476 | 21,097 | 8,781 |
| ENE | 0 | 0 | 0 | 0 | 0 | 0 | 27,462 | 74,686 | 18,723 | 13,872 | 23,240 | 31,800 |
| E | 0 | 0 | 0 | 0 | 0 | 3,059 | 44,883 | 100,488 | 11,793 | 12,900 | 8,965 | 21,468 |
| ESE | 0 | 0 | 0 | 0 | 0 | 6,096 | 5,363 | 36,015 | 4,132 | 6,840 | 346 | 0 |
| SE | 0 | 0 | 0 | 0 | 0 | 1,167 | 4,304 | 15,010 | 46 | 0 | 0 | 0 |
| SSE | 0 | 0 | 0 | 0 | 1,374 | 7,277 | 1,200 | 4,091 | 469 | 0 | 0 | 0 |
| S | 0 | 0 | 0 | 0 | 0 | 943 | 8,742 | 7,309 | 6,560 | 1,222 | 4,101 | 2,055 |
| SSW | 0 | 0 | 0 | 0 | 0 | 721 | 2,055 | 7,897 | 21,582 | 10,527 | 17,018 | 34,253 |
| SW | 0 | 0 | 0 | 0 | 0 | 733 | 1,840 | 1,909 | 3,962 | 8,578 | 10,312 | 21,909 |
| WSW | 0 | 0 | 0 | 0 | 0 | 622 | 9,862 | 3,495 | 4,562 | 4,204 | 5,894 | 2,799 |
| W | 0 | 0 | 0 | 0 | 0 | 666 | 13,099 | 4,595 | 9,038 | 7,318 | 4,129 | 14,856 |
| WNW | 0 | 0 | 0 | 0 | 0 | 587 | 2,971 | 1,543 | 0 | 4,151 | 5,055 | 29,862 |
| NW | 0 | 0 | 0 | 0 | 0 | 1,073 | 4,804 | 1,538 | 1,896 | 7,552 | 2,396 | 9,358 |
| NNW | 0 | 0 | 0 | 0 | 0 | 1,495 | 0 | 1,152 | 4,559 | 4,676 | 2,097 | 8,030 |
| Total | 0 | 0 | 0 | 0 | 4,325 | 53,518 | 145,673 | 279,525 | 106,611 | 99,433 | 126,314 | 210,465 |

the east of the plant site. The populated area of Oak Ridge (population, 28,000) begins at approximately 5 miles north of the plant site.

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# Appendix C

## ENVIRONMENTAL MONITORING OF EXISTING ENVIRONMENT

The Oak Ridge National Laboratory conducts a continuous program of surveillance over the Oak Ridge reservation and its surrounding environs to monitor all types of environmental pollution. This program has been in effect for approximately 30 years to assure the continuing safety and protection of installation personnel and the general public. Similar programs of surveillance are conducted at the Oak Ridge Y-12 Plant and the Oak Ridge Gaseous Diffusion Plant (K-25) which are close by and share the same environment. All programs are coordinated by the inter-plant office of Safety and Environmental Protection.

### Radioactive Effluents

Information derived from the ORNL radioactivity monitoring program is contained in the "Annual Environmental Monitoring Report, USAEC Oak Ridge Facilities" issued by the Union Carbide Office of Safety and Environmental Protection. In addition, the ORNL Inspection Engineering Department issues reports on testing of pollution control devices, chiefly filters.

Atmospheric Releases

Atmospheric releases are monitored with in-plant and in-stack monitors, a local air monitoring network, perimeter air monitoring network, and remote air monitoring network, and a milk sampling network.

(a) In-Plant and In-Stack Monitors. It has been a long-standing policy to monitor all effluents at the points of release to the environment to obtain accurate estimates of total releases. Monitoring data indicate that yearly releases have decreased steadily although operations involving radioactivity are still widespread and the sensitivity and accuracy of monitoring equipment have improved.

(b) Local Air Monitoring (LAM) Network. Atmospheric contamination and fallout on the ORNL site are monitored with continuous airflow filters, fallout trays, and rain collectors. There are 22 monitoring stations which comprise the LAM network at ORNL. Three of these stations are located in the Melton Valley area, and one of these (station 20) is adjacent to the TURF. The real-time readings for instruments at all LAM sites are telemetered to a central readout panel.

(c) Perimeter Air Monitoring (PAM) Network. The PAM network consists of nine stations located on the perimeter of the AEC-controlled area, as illustrated in Fig. C.1, and it provides data for evaluation of the impact of all Oak Ridge

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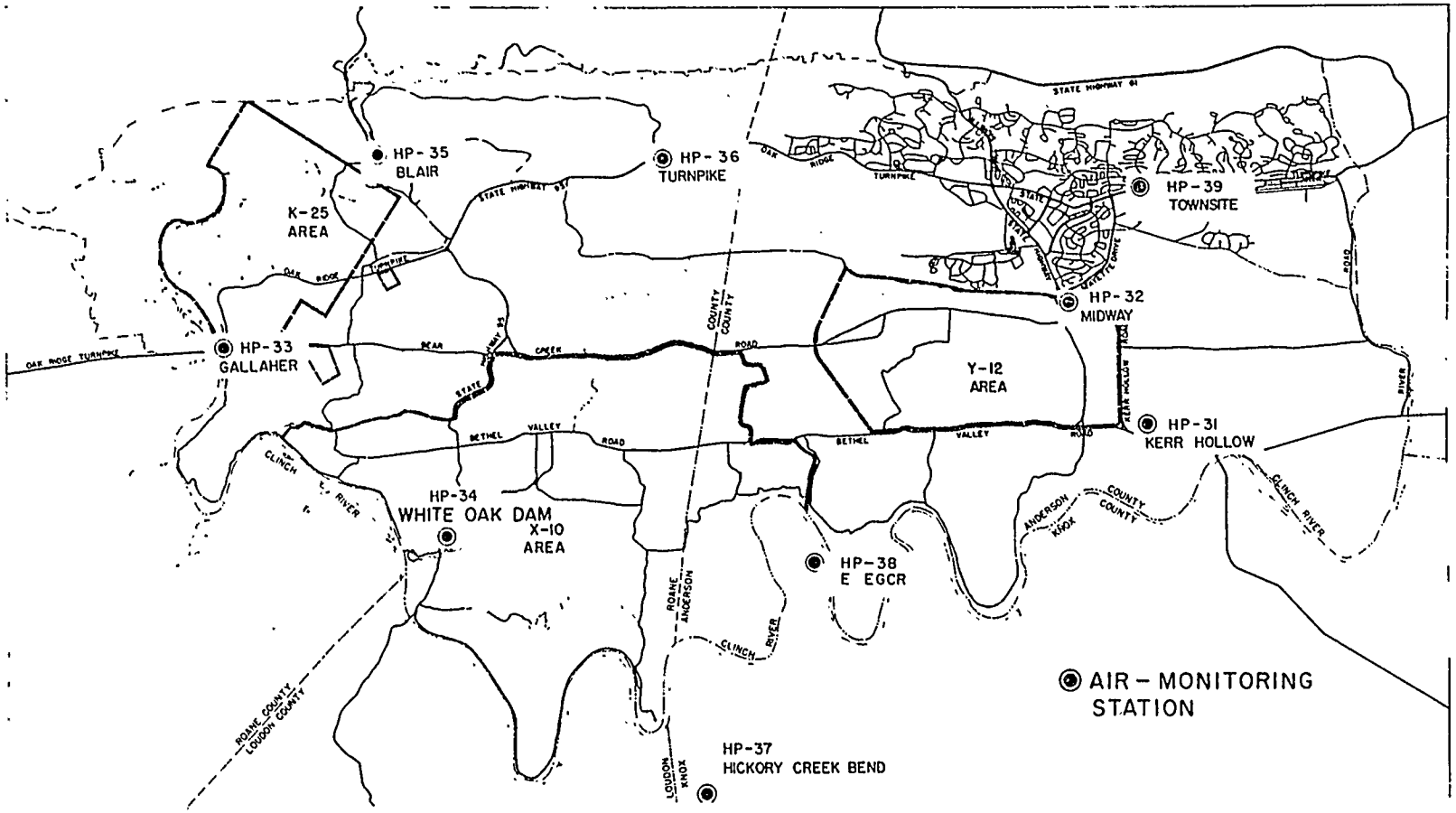


Fig. C.1. Perimeter Air Monitoring (PAM) Network.

operations on the immediate environment. These stations are similar to the ones in the LAM network, and the readings are also continuously telemetered to a central readout panel.

(d) Remote Air Monitoring (RAM) Network. The Ram-network consists of eight stations located outside the AEC-controlled area at distances of from 12 to 75 miles from ORNL, as is shown in Fig. C.2. This system provides data to aid in the evaluation of local conditions and to assist in determining the spread or dispersal of contamination if a major incident should occur.

(e) Milk Sampling Network. Samples of raw milk are collected at 12 sampling stations located within a radius of 50 miles of ORNL. Samples are taken on a weekly basis from the eight stations shown in Fig. C.3. These stations are located outside the AEC-controlled area within a 12-mile radius of ORNL. Samples are collected every 5 weeks from the four remaining stations, all of which are located outside the 12-mile radius up to distances of about 50 miles. The samples are prepared in a radioanalytical laboratory for counting iodine-131 and strontium-90.

## Liquid Releases

Low-level radioactive liquid wastes originating from ORNL operations are discharged, after preliminary treatment, to

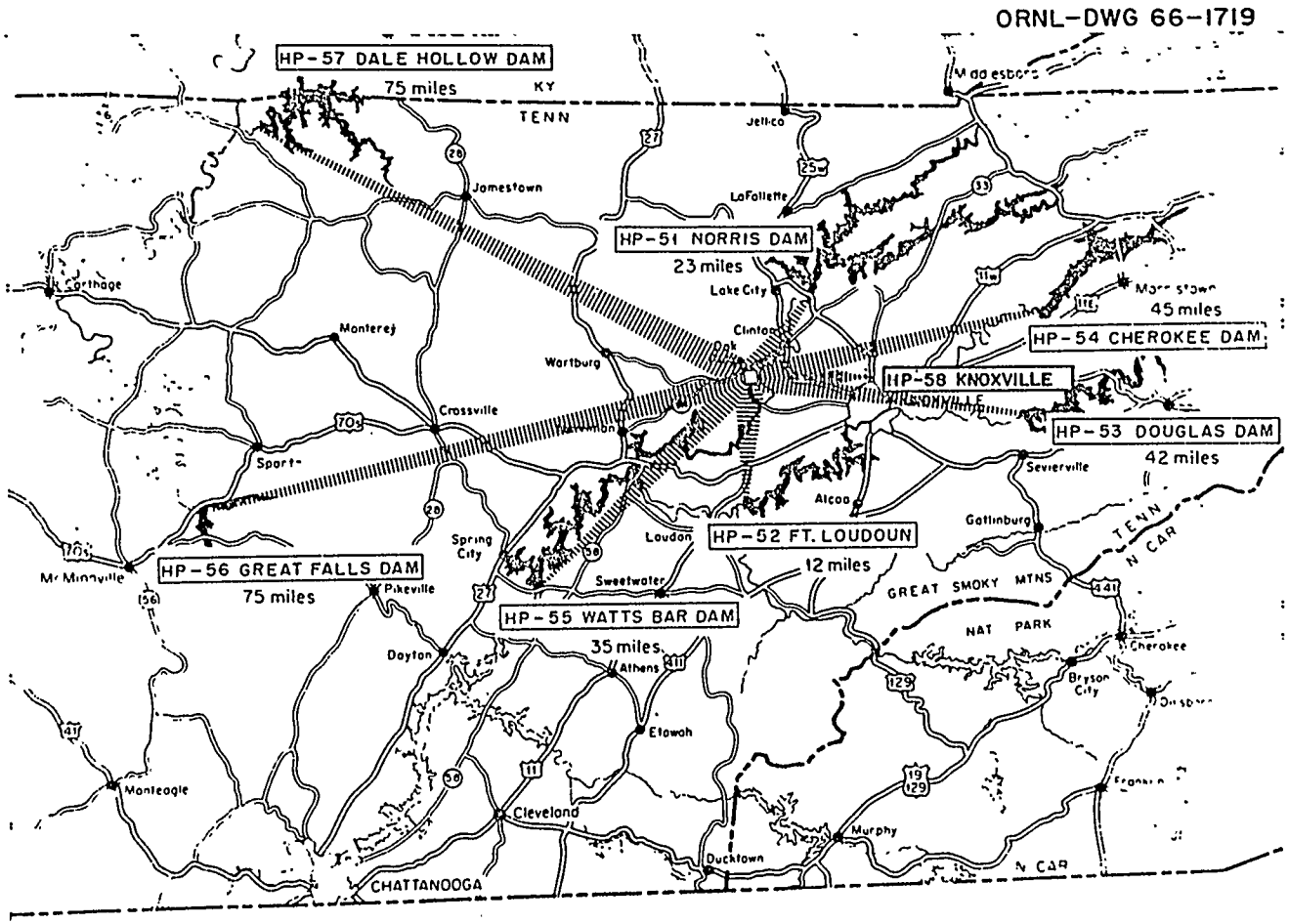


Fig. C.2. Remote Air Monitoring (RAM) Network.

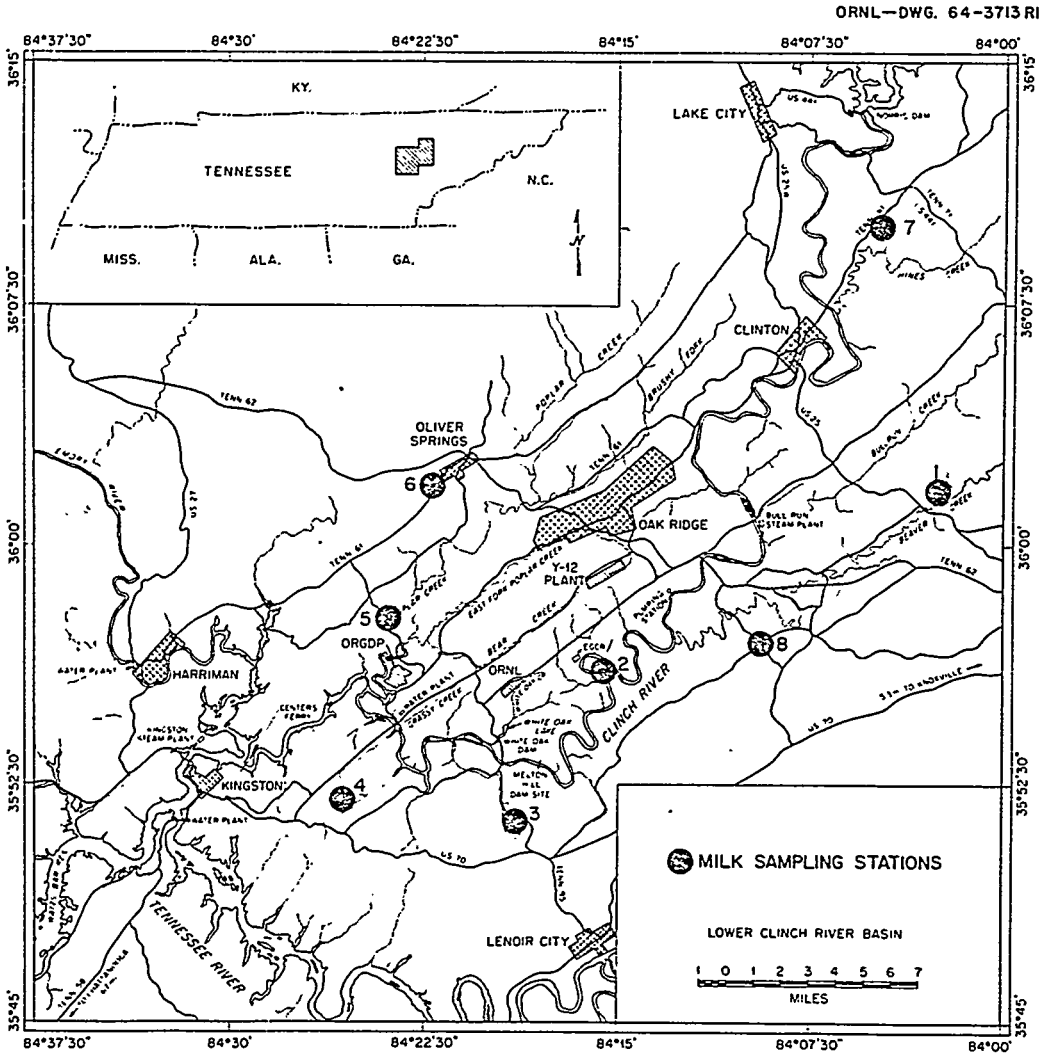


Fig. C.3. Location of Milk Sampling Stations.

White Oak Creek, which is a small tributary of the Clinch River. The radioactive content of the White Oak Creek discharge is determined at White Oak Dam, which is the last control point along the stream prior to the entry of White Oak Creek into the Clinch River.

(a) In-Plant Monitors. All facilities at ORNL are equipped with continuously operating radiation monitors. Radiation and contamination detection and alarm systems are

installed in the TURF to continuously and automatically monitor the air contamination level and gamma and neutron radiation levels.

(b) White Oak Dam Monitoring Station. Samples of White Oak Creek effluent are collected at White Oak Dam by a continuous stream flow proportional sampler. The samples are analyzed weekly for transuranic alpha emitters, total strontium, and iodine-131. Composite samples are analyzed for all individual radionuclides present in detectable quantities. The monitoring station at White Oak Dam provides information to determine the percentage distribution and concentrations of the various radionuclides in the effluent stream and to calculate the quantity of each radionuclide released to the Clinch River.

(c) Clinch River Monitoring Stations. As a follow-up to monitoring at White Oak Dam, two sampling stations are maintained in the Clinch River below the point of entry of the wastes. One is located at the water intake to the Oak Ridge Gaseous Diffusion Plant, and the other is located at Centers Ferry, near Kingston, Tennessee. Background or comparison data are provided by a sampling station at Melton Hill Dam, located upstream from the confluence of White Oak Creek and the Clinch River.

## Nonradioactive Effluents

A surveillance program for assessing effluent waste waters from ORNL and the subsequent levels of chemical pollutants in the Clinch River has been in operation since 1962. The locations of six sampling points are shown on Fig. C.4.

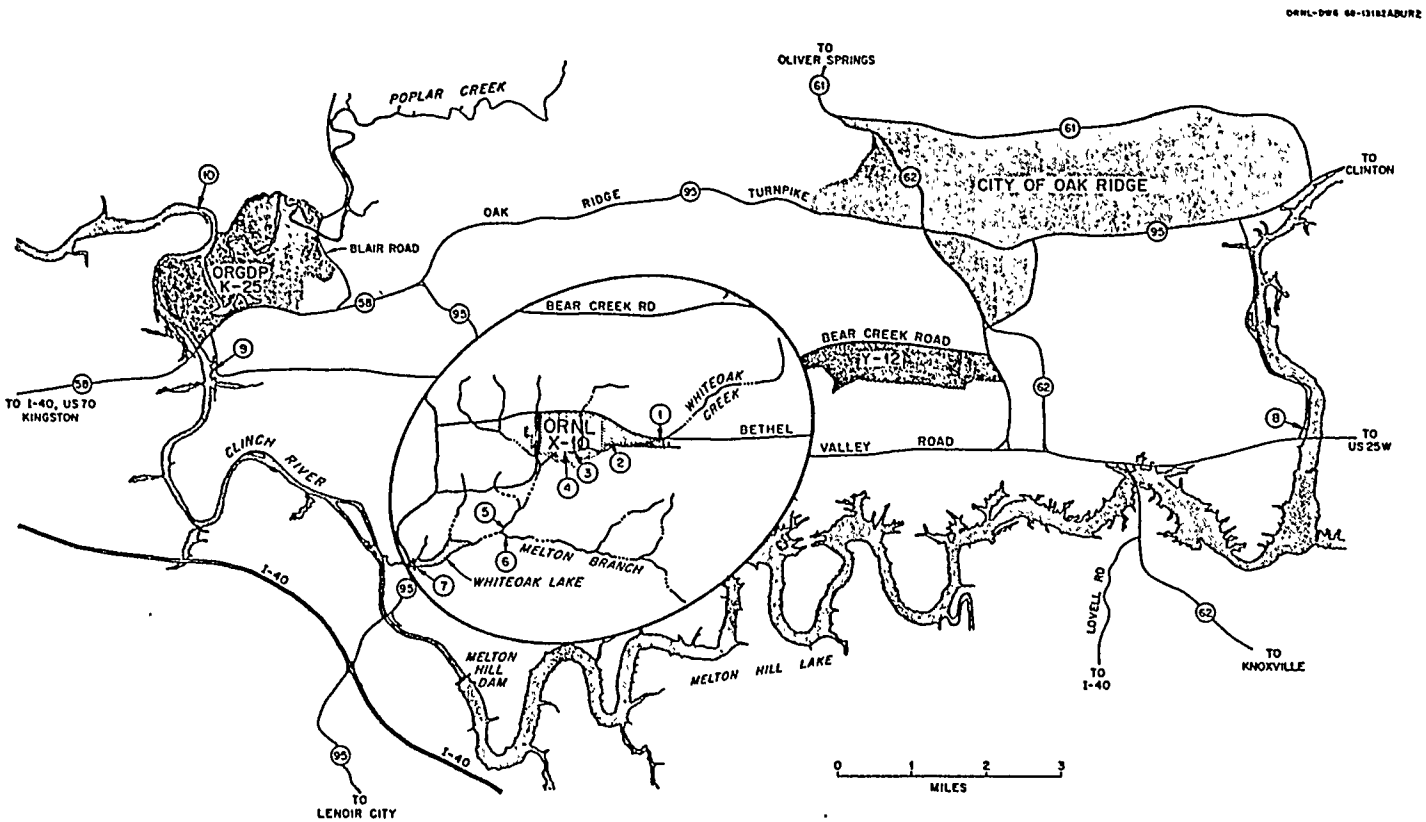


Fig. C.4. Location of Sampling Stations for Nonradioactive Effluents.

# Appendix D

## ATMOSPHERIC DISPERSION OF STACK RELEASES

The equation used to estimate the radionuclide air concentrations at ground level is the Gaussian plume equation of Pasquill[1] as modified by Gifford.[2]

$$\chi = \frac{Q}{\pi\sigma_y \sigma_z \mu} \exp\left(-\frac{y^2}{2\sigma_y^2} - \frac{h^2}{2\sigma_z^2}\right),$$

where

$\chi$ = radionuclide concentration in air at ground level at a point x meters downwind from the plant and y meters in the crosswind direction, $Ci/m^3$,

Q = uniform rate of release of the radionuclide from the plant, Ci/sec,

y = distance crosswind from the center line of plume, m,

h = effective stack height, m,

$\mu$ = wind speed, m/sec,

$\sigma_y$ = horizontal dispersion coefficient, m, and

$\sigma_z$ = vertical dispersion coefficient, m.

The downwind distance (x) comes into the Pasquill equation through the parameters $\sigma_y$ and $\sigma_z$, which are functions of both x and the degree of atmospheric stability. Pasquill devised a classification scheme for atmospheric stability that consists of six categories ranging from A, the most turbulent category, to F, the most stable category. The plume disperses rapidly in both the horizontal and vertical directions in category A, and it disperses slowly in category F. Plots of $\sigma_y$ and $\sigma_z$ as a function of x for each of the six atmospheric stability categories derived from Pasquill's classification scheme can be found in the USAEC report Meteorology and Atomic Energy 1968.[3]

The meteorological information required to compute average ground-level air concentrations of a radionuclide as a function of distance and direction from a plant uniformly releasing a radionuclide from its stack is

1. the annual frequency of each of the six Pasquill atmospheric stability categories,
2. the annual frequency with which the wind blows toward each of 16 directions away from the plant, and
3. wind speeds as a function of wind direction and atmospheric stability category.

Meteorological data for the plant site, based on U. S. Weather Bureau observations, are given in Tables D.1 and D.2 for C and E stabilities, the two generalized stabilities applicable to the area.[4]

The effective stack height, h, in the Pasquill equation is the sum of the physical stack height, $h_o$, and the plume rise, which is $k/\mu$ for a plume rise resulting from momentum. The physical stack height is 80.8 meters and the stack constant, k, is 29 meters$^2$/sec.

An effective perimeter was established for the AEC-controlled reservation with respect to the plant site.[4] Dilution factors at ground level were obtained in a computer run using the input data of Tables D.1 and D.2. The dilution factors for each direction from the stack at the distance in meters at the edge of the effective area perimeter are given in Table D.3. The log polar isopleths of expected annual average stack dilution factors for the plant site are shown in Fig. D.1. A low inversion lid was assumed for category E, and this maximizes the ground-level air concentrations for this category because it imposes a restriction on vertical dispersion. No correction was made for ground deposition of particulates. The dilution factors in Table D.3 are thus maximized because a plume is depleted by particle deposition.

The least dilution occurs in the northeast sector and results in a $\chi/Q$ of $2 \times 10^{-7}$ sec/m$^3$ (see Table D.3). This conservative $\chi/Q$ is used to dilute the expected annual average atmospheric releases listed in the text.

Table D.1. Frequency of Wind Speed and Wind Direction Under C-Stability Conditions at Oak Ridge National Laboratory (Based on Observations Made by the United States Weather Bureau)

| Wind Direction | Wind Speed (Miles per Hour) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.5 | 2.5 | 7.0 | 12.0 | 17.0 | 22.0 | 27.0 | 29 |
| SSW | 0.001065 | 0.002813 | 0.004800 | 0.004610 | 0.003561 | 0.002337 | 0.000238 | 0.000016 |
| SW | 0.001828 | 0.005818 | 0.009219 | 0.008774 | 0.005102 | 0.002766 | 0.000366 | 0.000016 |
| WSW | 0.001319 | 0.003513 | 0.005977 | 0.003942 | 0.001701 | 0.000397 | 0.000016 | 0.0 |
| W | 0.001780 | 0.004753 | 0.004514 | 0.001749 | 0.000397 | 0.000207 | 0.000016 | 0.000016 |
| WNW | 0.001001 | 0.001812 | 0.001399 | 0.000477 | 0.000032 | 0.000048 | 0.000016 | 0.0 |
| NW | 0.001272 | 0.002225 | 0.001510 | 0.000525 | 0.000111 | 0.000064 | 0.0 | 0.000032 |
| NNW | 0.001303 | 0.002051 | 0.002003 | 0.000954 | 0.000334 | 0.000191 | 0.000079 | 0.000032 |
| N | 0.002051 | 0.005341 | 0.008854 | 0.005945 | 0.003227 | 0.002066 | 0.000477 | 0.000318 |
| NNE | 0.001685 | 0.005293 | 0.010221 | 0.006469 | 0.003449 | 0.001764 | 0.000620 | 0.000207 |
| NE | 0.002607 | 0.008758 | 0.013543 | 0.008536 | 0.003227 | 0.001446 | 0.000350 | 0.000302 |
| ENE | 0.001240 | 0.004546 | 0.008266 | 0.007566 | 0.003052 | 0.001828 | 0.000604 | 0.000493 |
| E | 0.001224 | 0.004006 | 0.008138 | 0.008917 | 0.005786 | 0.003481 | 0.001256 | 0.000445 |
| ESE | 0.000381 | 0.002273 | 0.003815 | 0.005818 | 0.003672 | 0.001987 | 0.000477 | 0.000127 |
| SE | 0.000381 | 0.001780 | 0.003799 | 0.003910 | 0.002130 | 0.001160 | 0.000159 | 0.000048 |
| SSE | 0.000302 | 0.001160 | 0.001907 | 0.001319 | 0.000890 | 0.000318 | 0.000048 | 0.0 |
| S | 0.000556 | 0.002130 | 0.002655 | 0.001764 | 0.000922 | 0.000556 | 0.000048 | 0.0 |

Table D.2. Frequency of Wind Speed and Wind Direction Under E-Stability Conditions at Oak Ridge National Laboratory (Based on Observations Made by the United States Weather Bureau)

| Wind Direction | Wind Speed (Miles per Hour) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.5 | 2.5 | 7.0 | 12.0 | 17.0 | 22.0 | 27.0 | 29 |
| SSW | 0.002035 | 0.006533 | 0.012573 | 0.013861 | 0.011620 | 0.005850 | 0.000286 | 0.000079 |
| SW | 0.004324 | 0.013050 | 0.026275 | 0.026371 | 0.016817 | 0.007312 | 0.000429 | 0.000064 |
| WSW | 0.002480 | 0.006915 | 0.012033 | 0.008965 | 0.002416 | 0.000572 | 0.0 | 0.0 |
| W | 0.004419 | 0.010380 | 0.012478 | 0.005198 | 0.000970 | 0.000223 | 0.0 | 0.0 |
| WNW | 0.002464 | 0.005198 | 0.004085 | 0.001415 | 0.000302 | 0.000079 | 0.0 | 0.0 |
| NW | 0.003799 | 0.007662 | 0.006215 | 0.002225 | 0.000668 | 0.000254 | 0.000016 | 0.000016 |
| NNW | 0.002394 | 0.006994 | 0.007741 | 0.004292 | 0.001224 | 0.000684 | 0.000127 | 0.000095 |
| N | 0.004657 | 0.013336 | 0.023494 | 0.017262 | 0.008393 | 0.004165 | 0.000509 | 0.000350 |
| NNE | 0.004832 | 0.013018 | 0.023859 | 0.017676 | 0.007487 | 0.002813 | 0.000318 | 0.000143 |
| NE | 0.007662 | 0.022715 | 0.037211 | 0.019663 | 0.006104 | 0.001749 | 0.000254 | 0.000175 |
| ENE | 0.002066 | 0.007646 | 0.014576 | 0.013527 | 0.005214 | 0.001860 | 0.000302 | 0.000207 |
| E | 0.002432 | 0.007010 | 0.015673 | 0.015291 | 0.007423 | 0.002893 | 0.000493 | 0.000064 |
| ESE | 0.001446 | 0.003576 | 0.008250 | 0.007487 | 0.003259 | 0.001319 | 0.000318 | 0.000095 |
| SE | 0.001701 | 0.004260 | 0.008250 | 0.007328 | 0.002686 | 0.000699 | 0.000048 | 0.000048 |
| SSE | 0.000827 | 0.002925 | 0.004769 | 0.003116 | 0.001256 | 0.000334 | 0.000016 | 0.0 |
| S | 0.001780 | 0.004276 | 0.007884 | 0.006152 | 0.002861 | 0.000779 | 0.000079 | 0.0 |

Table D.3. Annual Average Stack Dilution Factors of Effective Area Perimeter

| Direction from Stack | Distance (meters) | Dilution Factor ($\mu Ci/m^3$ per $\mu Ci/sec$) |
|---|---|---|
| N | 3465 | $1.08 \times 10^{-7}$ |
| NNE | 3925 | $9.30 \times 10^{-8}$ |
| NE | 3315 | $1.72 \times 10^{-7}$ |
| ENE | 3315 | $7.20 \times 10^{-8}$ |
| E | 3355 | $7.52 \times 10^{-8}$ |
| ESE | 3160 | $4.21 \times 10^{-8}$ |
| SE | 2780 | $4.76 \times 10^{-8}$ |
| SSE | 2935 | $2.47 \times 10^{-8}$ |
| S | 3505 | $3.62 \times 10^{-8}$ |
| SSW | 3580 | $5.62 \times 10^{-8}$ |
| SW | 3660 | $1.06 \times 10^{-7}$ |
| WSW | 3885 | $5.30 \times 10^{-8}$ |
| W | 4380 | $6.20 \times 10^{-8}$ |
| WNW | 3350 | $4.03 \times 10^{-8}$ |
| NW | 3085 | $6.26 \times 10^{-8}$ |
| NNW | 3050 | $5.38 \times 10^{-8}$ |

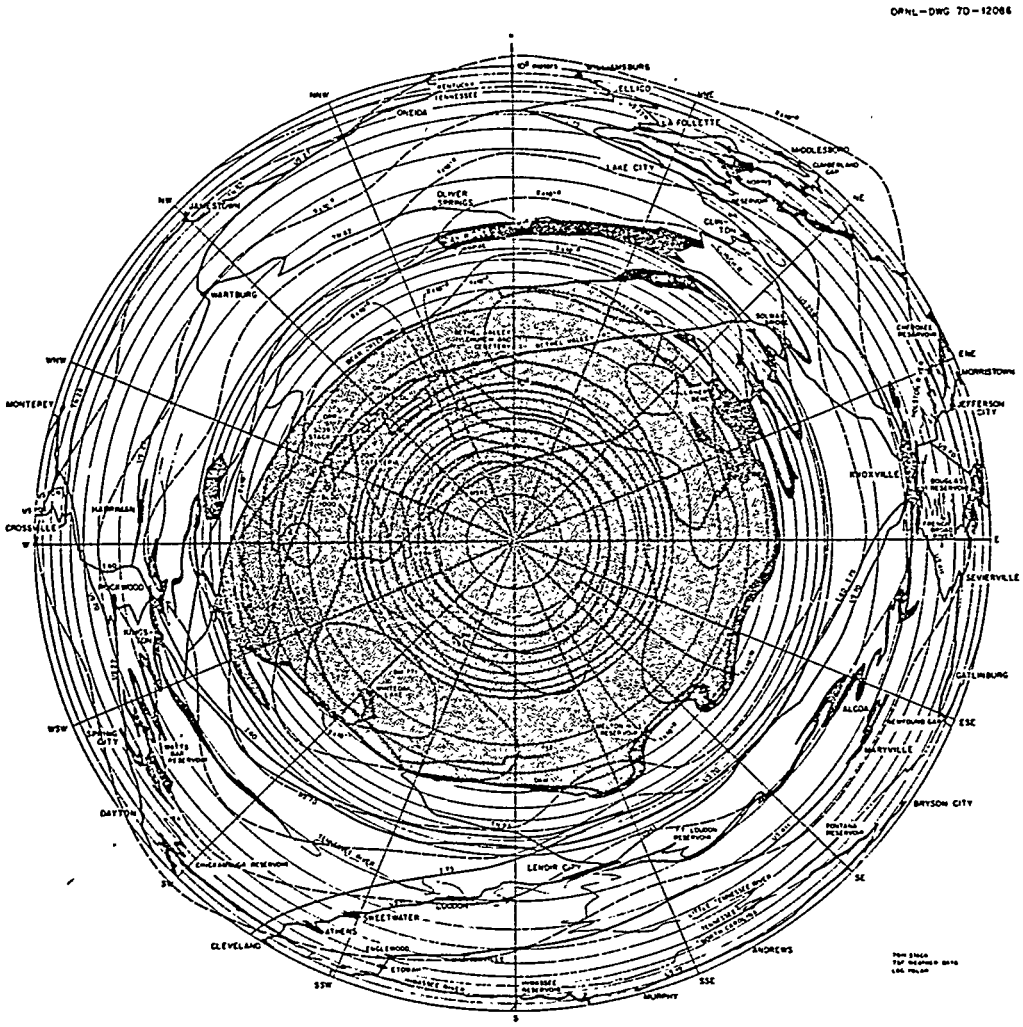


Fig. D.1. Log Polar Isopleths of Expected Annual Average Stack Dilution Factors for the Plant Site.

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