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Resource Management Plan for the Oak Ridge Reservation

Volume 20: Soil Conservation Plan for the Oak Ridge Reservation

D. A. Lietzke
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T. Tamura

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FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A04 Microfiche A01

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Oak Ridge Reservation

Volume 20: Soil Conservation Plan for the Oak Ridge Reservation

Date Published: July 1986

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Prepared by

MARTIN MARIETTA ENERGY SYSTEMS, INC.
P.O. Box X
Oak Ridge, Tennessee 37831
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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RESOURCE MANAGEMENT PLAN FOR THE U.S. DEPARTMENT OF ENERGY OAK RIDGE RESERVATION

ORNL-6026/V1	Management Plan Overview and Summary
ORNL-6026/V2	Aquatic Habitats
ORNL-6026/V3	Archeological Considerations
ORNL-6026/V4	Endangered and Threatened Plant Species
ORNL-6026/V5	Environmental Monitoring
ORNL-6026/V6	Forest Management
ORNL-6026/V7	Geography, Demography, Topography, and Soil
ORNL-6026/V8	Geology
ORNL-6026/V9	Health, Safety, and Environmental Affairs
ORNL-6026/V10	Hydrology
ORNL-6026/V11	Site Development
ORNL-6026/V12	Laws/Regulations/Guidelines
ORNL-6026/V13	Oak Ridge National Environmental Research Park
ORNL-6026/V14	Utilities
ORNL-6026/V15	Waste Management
ORNL-6026/V16	Wildlife Management
ORNL-6026/V17	Maps
ORNL-6026/V18	Forest Management Cost/Benefit Review
ORNL/ESH-1/V19	Inventory of Groundwater Wells
ORNL/ESH-1/V20	Soil Conservation Plan

CONTENTS

Page

LIST OF ACRONYMS v

LIST OF FIGURES vii

LIST OF TABLES vii

ABSTRACT ix

1. INTRODUCTION 1
   - 1.1 OBJECTIVES 1
   - 1.2 SOIL CONCEPTS 2

2. SOIL AND LAND USE OVERVIEW 5
   - 2.1 PRE-ATOMIC ENERGY COMMISSION LAND USE ON THE ORR 5
   - 2.2 MANAGEMENT FROM 1941 to 1985 5

3. SOIL OVERVIEW 11
   - 3.1 SOIL GROUPS FROM RESIDUUM 11
     - 3.1.1 Rome Soils 11
     - 3.1.2 Conasauga Soils 12
     - 3.1.3 Knox Soils 14
     - 3.1.4 Chickamauga Soils 17
     - 3.1.5 Reedsville-Rockwood Soils 18
   - 3.2 SOIL GROUPS FROM COLLUVIUM AND ALLUVIUM 18

4. SOIL GROUP INTERPRETATIONS 21
   - 4.1 SOIL CHEMICAL PROPERTIES 21
   - 4.2 SOIL PHYSICAL AND ENGINEERING PROPERTIES 22
   - 4.3 SOILS INPUT FOR WOODLAND MANAGEMENT 25

Page

4.4 SOILS INPUT FOR WILDLIFE MANAGEMENT 27

4.5 SOIL CONSIDERATIONS FOR SITE DEVELOPMENT 29

5. MANAGEMENT AND PLANNING FOR SOIL CONSERVATION 31

5.1 PRESENT CONDITIONS 31
5.1.1 Soil Groups for Planning 31
5.1.2 Fragile Soils 32
5.1.3 Fragile Lands 32
5.1.4 Prime Land 32

5.2 FUTURE MANAGEMENT AND PLANNING FOR SOIL CONSERVATION 35

6. SUMMARY AND RECOMMENDATIONS 39

7. COORDINATING WITH OTHER PLANS 43

REFERENCES 45

LIST OF ACRONYMS

AEC	anion exchange capacity
CEC	cation exchange capacity
EPA	Environmental Protection Agency
GIS	Geographical Information System
LE	linear extensibility
NERP	National Environmental Research Park
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PI	plastic index
SWSA	Solid Waste Storage Area
TVA	Tennessee Valley Authority
USLE	universal soil loss equation

LIST OF FIGURES

Figure		Page
1	Definitions of soil nomenclature used to describe a soil	3
2	Land use as either openland or forestland in 1942	6
3	Aerial photograph showing current land use around the ORNL area	7
4	Residuum soil groups	9
5	Soil groups of alluvium and colluvium	10
6	Fragile land and prime land on the ORR	34

LIST OF TABLES

Table		Page
1	Acreage of different land uses on the ORR	8
2	Soil chemical properties	22
3	Woodland Management	23
4	Soil physical and engineering properties	26
5	Wildlife habitat potential	28
6	Ratings for site development	30
7	Soil series placed into soil groups	33
8	Soils shallow to hard rock	33
9	Prime land mapping units on the ORR	35

ABSTRACT

Soil conservation does not imply preserving soils in a pristine state but rather using both soils and land within their capabilities and potentials without degrading them. There can be no cookbook of soil management techniques: each site requires unique management and conservation techniques designed specifically for that site's characteristics and intended use.

Soils are variable in their properties, and specific information cannot be obtained from available Oak Ridge Reservation (ORR) soil survey maps. However, the available information is valuable and useful for screening programs. Planning and management of ORR soils involves not only conserving soil but also conserving the quality of surface water and groundwater. Because of the biotic activity concentrated in the surface and subsoil horizons, soil has a high capacity to filter and purify water as it infiltrates the soil surface and percolates downward. Polluted water or wastes placed below the soil zone of biotic activity have a much higher probability of not being filtered and purified. Also, there are pollutants and wastes that natural soils have no capacity to filter, render harmless, or even contain. Thus, it is crucial that soil properties be known; how soil properties can be modified before land is used should also be known.

The great volume of the no man's land between the horizons of the surface soil and hard rock below (where most low-level radioactive, domestic, and construction wastes are placed) is scarcely understood regarding its chemical, physical, and mineralogical properties or even its capacities for retention, filtration, and purification. Expanding the database of this soil zone is a high priority. Relating soils and weathered rock beneath to the geology is also a high-priority item. Geologists, pedologists, and hydrologists must work together if such an undertaking is to be successful.

To best use this report, please refer to Sect. 6 and to the material under headings marked **Important considerations for planning and management.**

1. INTRODUCTION

This document is organized by soil groups with common properties and geologic parentage. Soil management for conservation and continued land use is accomplished at several levels depending on site specificity. Soil conservation and management planning at the ORR level starts with a broad overview of the entire area. At this level, more detailed soil survey information can be generalized into fewer groupings that can be more readily grasped by planners and managers (usually at a map scale of 1:48,000).

However, when a specific tract of land is to be more intensively used, soil maps made at a scale of 1:24,000 to 1:12,000 should be consulted. Soils information currently available on maps made at these scales is organized at the level of individual soil series and phases of soil series and with mostly agricultural uses in mind. The Anderson County soil survey was made during the 1970s at a map scale of 1:15,840.[1] The Anderson County soil survey report contains more specific (although mostly estimated) physical and chemical properties of each soil series, and only to a depth of 1 to 1.5 m (3.3 to 5 ft). The Roane County soil survey was made during the 1930s and published at a scale of 1:48,000 on a planimetric base.[2] Any management interpretations in the Roane County soil survey report are therefore either obsolete or nonexistent.

The soils base map for this document was developed from the correlated field sheets of the Anderson County soil survey and the enlarged Roane County soil survey planimetric map[3] that were overlain on an enlarged topographic base map (drawing scale 1:15,840). The differences in detail between the two soil surveys reveal different mapping scales, changes in concepts of soil series, and increased knowledge of basic soil properties. All interpretations in this report are based on the Anderson County soil survey and additional data from the National Cooperative Soil Survey Program.[4] The Roane County soil map does have limited usefulness for this soil conservation plan but should not be relied upon for detailed or intensive planning.

For intensive and detailed site planning, additional soil mapping with more detail is required, and eventually a site-specific database is needed to plan for actual site development or intensive land use. Several intensive soil surveys of the ORR have been recently made at scales of 1:1,200 to 1:2,400.[5-7] When precise location of different soils was required for site-specific research projects, maps have been made at a scale of 1:240.

1.1 OBJECTIVES

The objectives of this soil conservation and management plan are:

(1) To provide basic information about each different group of soils (residuum, colluvium, and alluvium), including their origin, formation, distribution, and extent.

(2) To provide data for engineering interpretations and planning.
(3) To provide interpretations for planning and managing soil resources on the ORR for multiple uses.
(4) To integrate important aspects of the soil conservation plan into detailed plans for forestry, geology, wildlife, waste management, and site utilization and other plans where soils input should be considered in planning activities.
(5) To provide soils input into ORR database organization so that it will have maximum use, and to propose supplemental soil and land use databases based on the Geographical Information System (GIS) methodology or other suitable methods using different layers of information at different scales and intensities.

1.2 SOIL CONCEPTS

Because scientists, engineers, and specialists from other disciplines will be relying on this plan, soil must be defined so that soil scientists, geologists, and engineers can share a common understanding of what a soil is.

Soil is defined in the *Dictionary of Geological Terms*[8] as "That earth material that has been so modified and acted upon by physical, chemical, and biological agents that it will support rooted plants."

Soil scientists within the discipline of pedology study the weathering of rocks and the genesis, formation, and classification of soils. They describe soil horizons (the visual product of soil formation) by using master horizon symbols. The A horizon has received the greatest amount of organic matter. The B horizon, or subsoil, is chemically altered and usually has a higher clay content than the horizons above and below. The C horizon becomes less chemically altered with depth. It loses soil structure, and remnants of geologic rock structure can still be observed. The Cr (paralithic) horizon inhibits most biological activity (especially plant roots), and it gradually merges with the unleached and unoxidized rock (R lithic) below (Fig. 1). The finer subdivisions by pedologists are understandable because the A, B, and C horizons greatly influence plant production. Geologists tend to equate soil with regolith in their definition.

Regolith is defined as "The layer or mantle of loose incoherent rock material, of whatever origin, that nearly everywhere forms the surface of the land in the absence of true soil and rests on bedrock."[8] The words "true soil" evidently refer to the A and B master horizons (as described by pedologists). The engineer usually considers soil to be that earthy material that can be moved and transported by heavy bulldozers and pans, as opposed to rock that must be drilled and blasted before it can be moved. Thus, the engineer's definition of soil can include what both pedologist and geologist consider to be hard and coherent but rippable rock.

Saprolite (also used by geologists and pedologists) is isovolumetrically weathered rock that includes the C and Cr horizons. Saprolite still retains the original rock structure but is much more porous and has a lower bulk density; also, many of the primary silicate minerals have been chemically altered. Saprolite forms only where there is a strong framework of resistant minerals left after most soluble components have been removed to support the soil above. However, rocks do

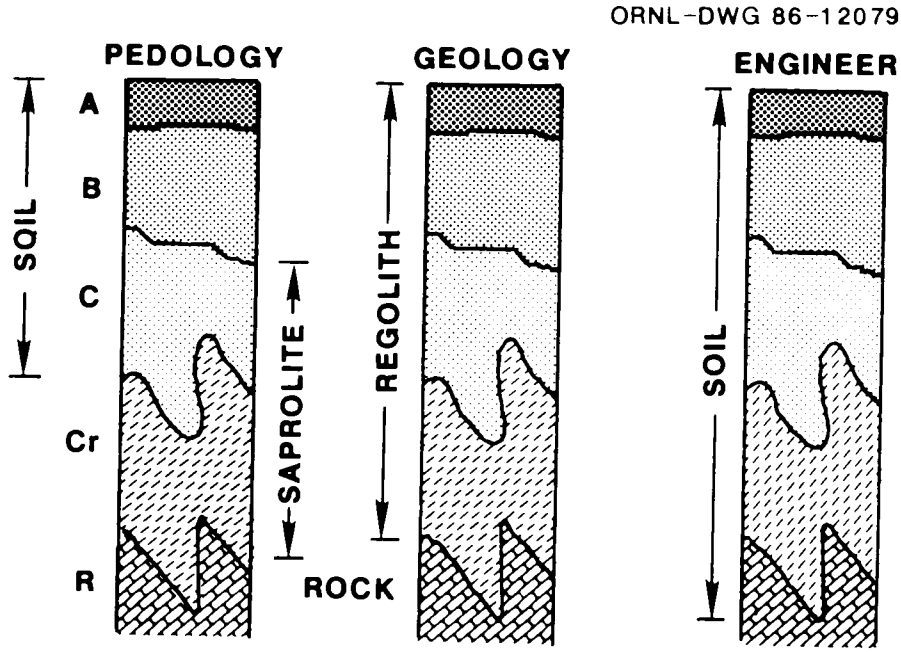

Fig. 1. Definitions of soil and nomenclature used to describe a soil.

not form saprolite if there is an insufficient quantity of framework to support the soil above. Saprolite becomes the parent material for the formation of soil horizons close to the surface. Soil horizons form at and below the soil surface to a depth of usually not more than 1 to 2 m (3.3 to 6.5 ft). Figure 1 compares the three major definitions of soil and the rough correlation of the various master horizons or layers that compose a soil.

In the broad planning aspects of the ORR, soils with mostly common properties can be grouped together. Most of the soils shown on the present ORR soil survey are confined to certain geologic groups, each of which contains several formations. Each formation weathers chemically to form the distinctive parent materials of each kind of soil. Soil parent materials (regolith) are grouped into two major catagories—residuum (the chemical weathering of in-place rock) and transported soil materials. The latter is further subdivided into colluvium (mostly preweathered soil materials identified from the source geologic group that have been transported downslope under the influence of gravity and water) and alluvium (soil materials transported and deposited by running water in floodplains and low stream terraces and which are even further separated into two classes based on their geologic age). These soil groups are discussed in greater detail in Sect. 3.

2. SOIL AND LAND USE OVERVIEW

2.1 PRE-ATOMIC ENERGY COMMISSION LAND USE ON THE ORR

Land use in the area now within the ORR was dominated by the activities of small subsistence farmers and landholders. Land use in 1941 (as shown on U.S. Geologic Survey [USGS] topographic or planimetric sheets) is outlined on topographic overlays contained in Fig. 2. The Bethel Valley Quad illustrates the distribution of open land areas (pasture, hayland, and cropland) within larger areas of woodland. Most of the boundaries between open land and woodland tend to be curvilinear, the result of trial and error over many years by farmers trying to determine the best lands for agricultural use. Straight lines between open land and woodland generally corresponded to ownership boundaries rather than to soils or topographic features. Many of the upland landforms in the area were named from the forest vegetation, such as Chestnut Ridge, Pine Ridge, Haw Ridge, and Black Oak Ridge. It is doubtful that any old growth woodland exists on the ORR, since almost all areas were accessible to land users. Much land that was cleared for agriculture reverted to woodland when the soils were found to be unfarmable because of low residual fertility, physical and chemical problems, or severe erosion and the resultant gullying and appearance of rocks. Gullies and severely eroded soils now in forest provide evidence for changes in land use before 1941. The Tennessee Valley Authority (TVA) stabilized gullied land and planted trees on abandoned land in the mid-1930s.

2.2 MANAGEMENT FROM 1941 TO 1985

With the creation of the ORR in 1941 and the removal of landowners, most of the agricultural lands reverted to sage grass (broomsedge), weeds, briars, and scattered trees or to woodland. This process occurred either by old field succession or by large-scale tree planting between 1947 and 1961.[9] The tree species that appeared or were planted and thrived were partly dependent both on the physical and chemical properties of the soil and the extent to which chemical properties had been altered by past additions of lime and fertilizers. The amount of erosion also affected the rate of old field succession, as well as affecting the trees, brush, and weeds that could survive under starvation conditions. Areas of soils with good natural fertility and other soils that had been made fertile by lime and fertilizer often reverted to tulip poplar, or, if planted to tulip poplar, the trees grew rapidly. Eroded soils and other areas of open soils that had not been limed or fertilized reverted to Virginia pine or to impoverished stands of mixed hardwoods dominated by sourwood, chestnut oak, red maple, and pines. Some

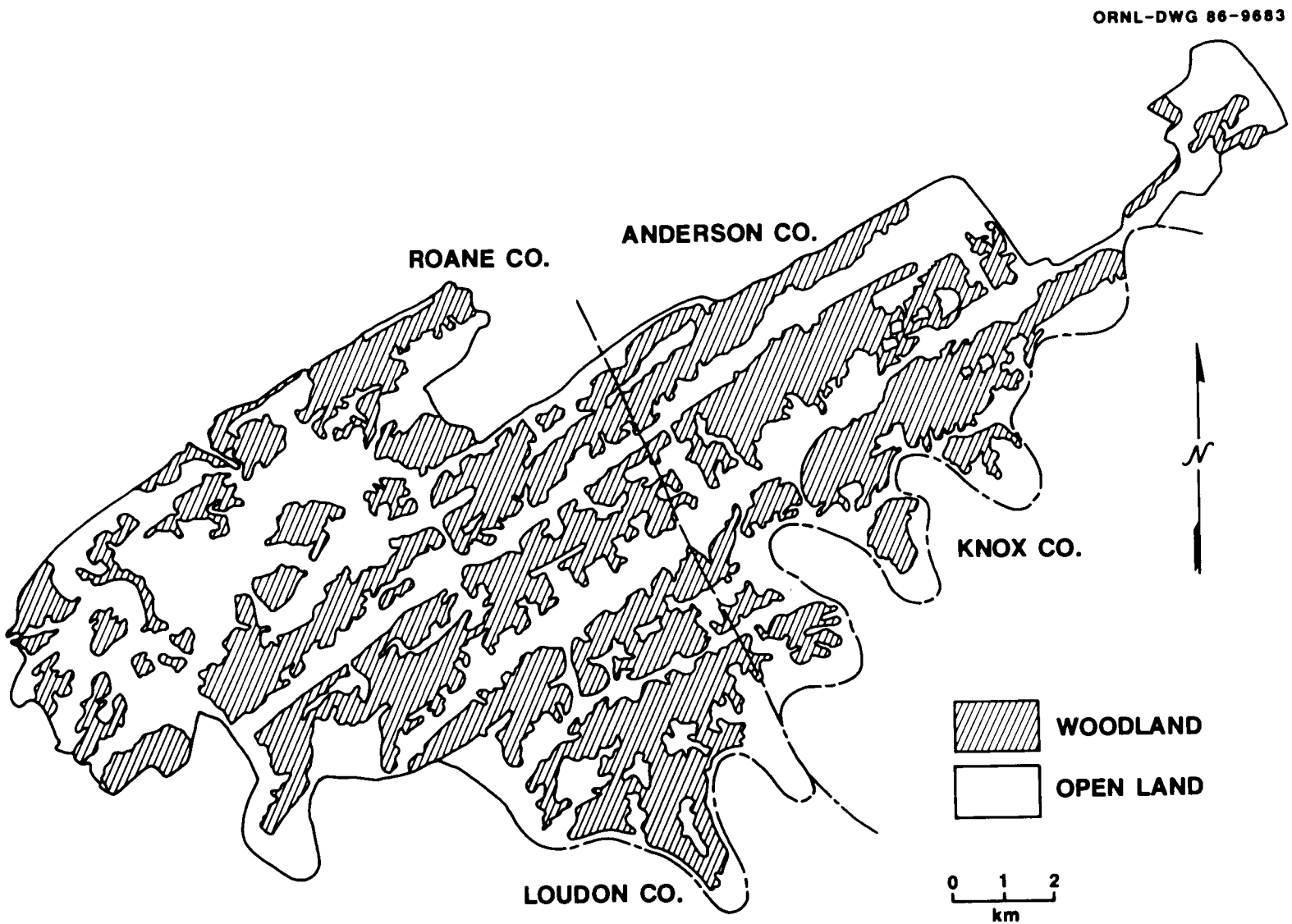

Fig. 2. Land use as either openland or forestland in 1942.

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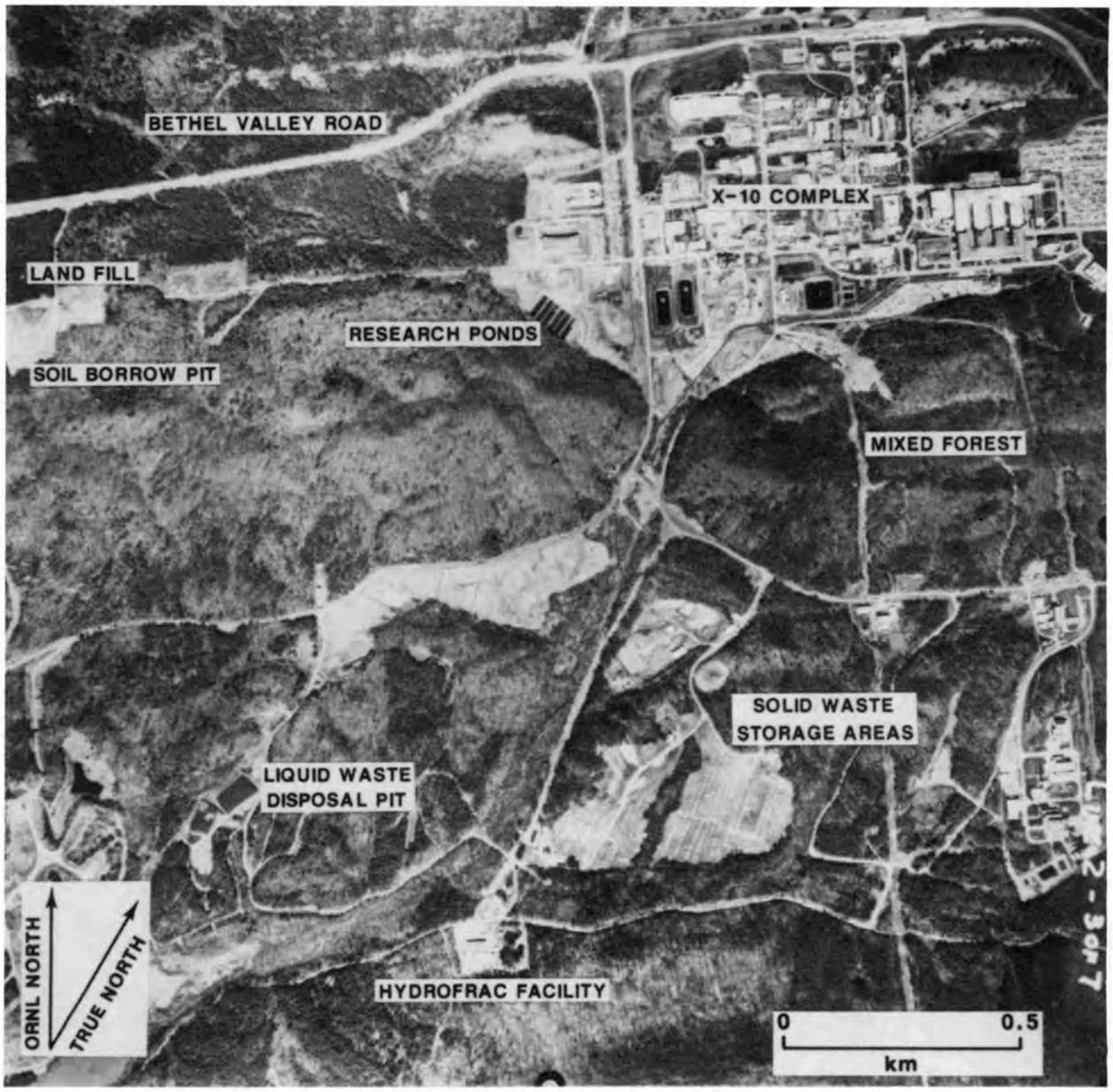

Fig. 3. Aerial photograph showing current land use around the ORNL area.

severely eroded areas (mostly on shale and siltstone with very low natural fertility) reverted to sage grass, briars, and scattered trees, mostly red cedar and elm. Many acres reverted to red cedar because of very shallow soil depth to limestone bedrock.

Considerable acreage had also been planted to shortleaf pine. However, pine beetle damage has almost wiped out these stands, necessitating a large-scale replanting effort (mostly of loblolly pine). Large wooded areas on the ORR that had been previously pastured and burned one or more times a year were allowed to regenerate a forest floor and adjust to the ravages of past mismanagement.

Bradburn and Rosenbalm[9] list the dominant tree species on the ORR and discuss the relationship of site quality and stand management to site and soil characteristics.

Figure 3 illustrates current land use around the Oak Ridge National Laboratory (ORNL), and Table 1 shows present land use groups on the ORR. To plan for conservation, management, and various land uses, knowledge of soils and their properties and characteristics is needed. In this report, soils are grouped according to geologic and geomorphic parentage, as shown in Figs. 4 and 5 and are discussed in the following section.

Table 1. Acreage of different land uses on the ORR

Classification	Area[a] (hectares)		Percent
Administration/technical services	48.6	(120)	0.3
Research and development	149.8	(370)	1.0
Production	180.2	(445)	1.2
Support	1,720.6	(4,250)	11.6
Waste	303.6	(750)	2.1
Public	319.8	(790)	2.2
Natural	11,609.3	(28,675)	78.3
Buffer	493.9	(1,220)	3.3
Total	14,825.9	(36,620)	100.0

[a]Area in acres is given in parentheses.

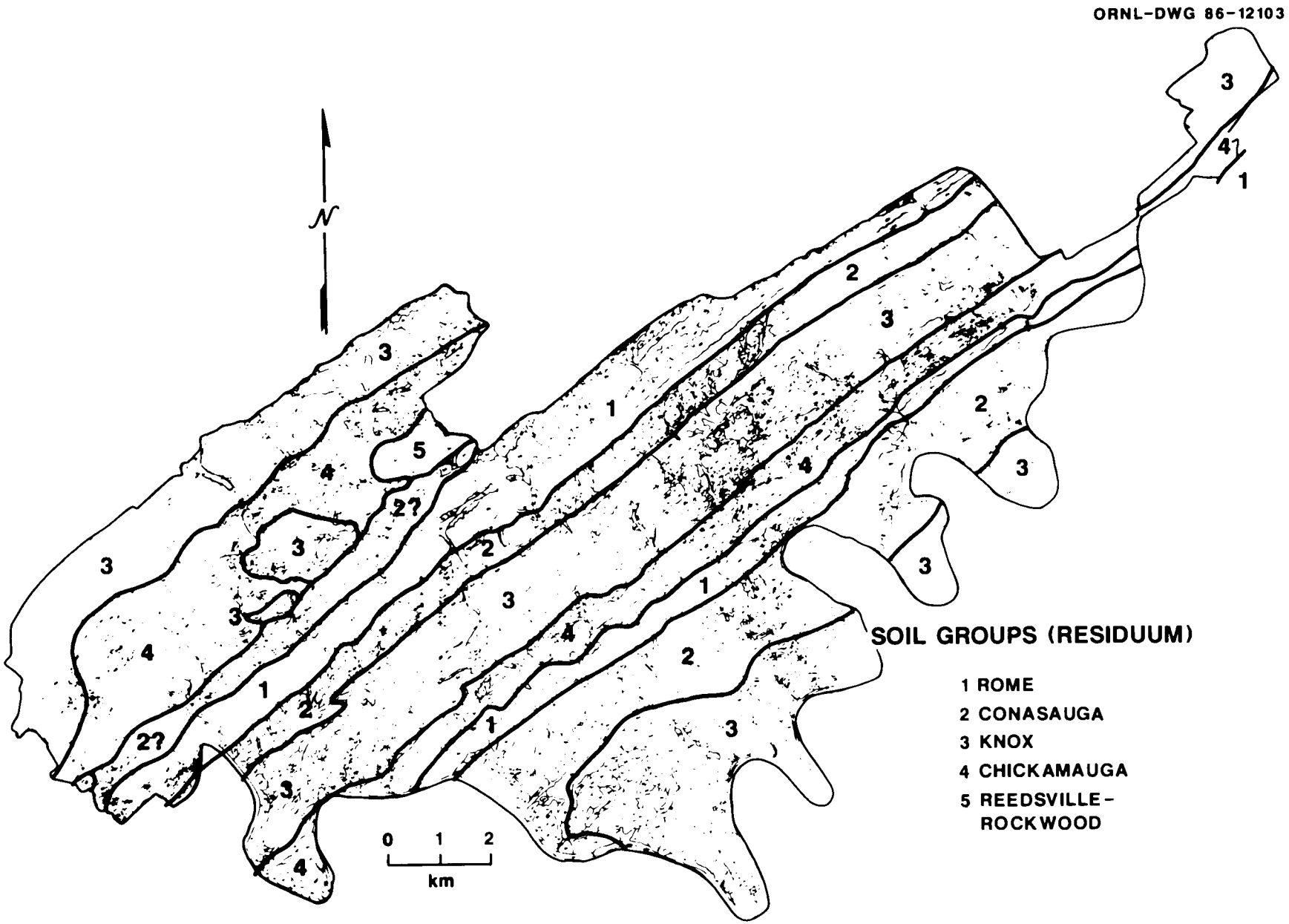

Fig. 4. Residuum soil groups.

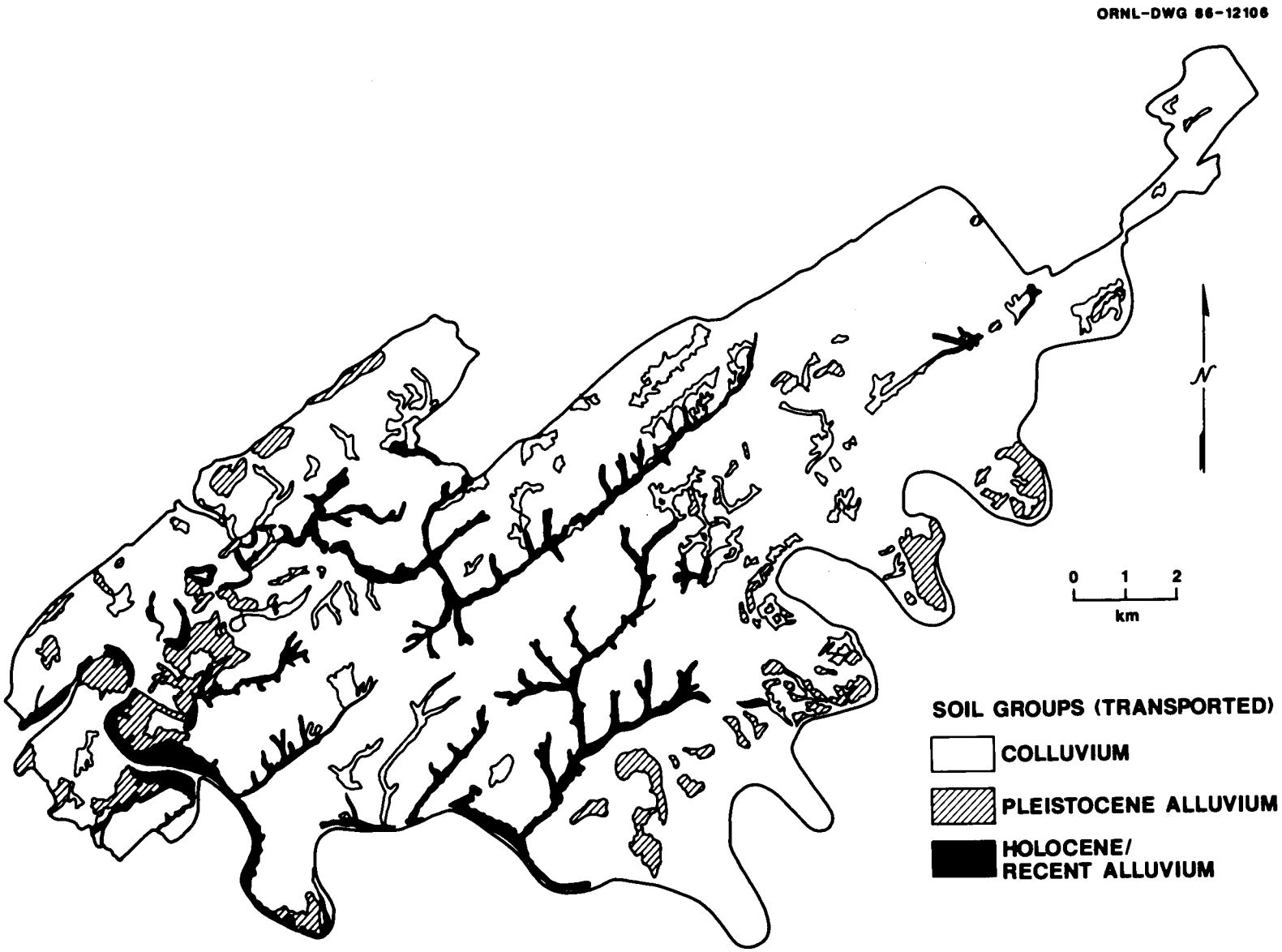

Fig. 5. Soil groups of alluvium and colluvium.

3. SOIL OVERVIEW

3.1 SOIL GROUPS FROM RESIDUUM

3.1.1. Rome Soils

The Rome Formation of different shales, siltstones, sandstones, and thin limestone strata is described by McMaster.[10] This geologic group is often described as highly heterogeneous. The base of the Rome Formation is a red shale, but at its upper boundary (where it merges with the Conasauga Group) the formation consists of red-brown-green calcareous glauconitic interbedded sandstone, siltstone, and shale. Colors within the Rome Formation are highly variegated, with different strata showing colors ranging from maroon to olive and gray. Siltstone and sandstone strata contain abundant mica, and some strata also contain abundant glauconite, an iron-rich mica.

Weathering. The rate of weathering and depth to unoxidized, unleached rock depends on four important factors: (1) closeness of joints and fractures, (2) dip of individual strata, (3) thickness of individual strata, and (4) configuration of the land surface. Weathering depends on how much water enters the regolith and hard rock beneath and where it flows within the soil and the underlying rock. Factors 1-3 relate to the permeability and porosity of the rock, whereas the landform configuration relates to whether water flows off the landform or infiltrates and then percolates downward. The depth of weathering is strongly related to the geomorphic stability of the landform. If most rainfall runs off, it carries soil particles (physical erosion), and the products of weathering are stripped away as fast as they form. Deep percolation dissolves soluble components and carries them downward (a process called chemical erosion).

Geomorphic processes. Rome soils are an important source of the widespread colluvium that mantles lower footslope and toeslope landforms. Because the rocks that compose the Rome Formation are mostly particulate (clastic) sediments rather than chemical, chemical erosion does not greatly alter the volume of weathered rock. Rome soils also exist on steeper landforms than other kinds of soils on the ORR. As a consequence, overland runoff of rainfall detaches soil particles and transports them downslope. The net result over hundreds of thousands of years is that the soils are maintained in a youthful or immature state because the rate of soil removal from the surface occurs almost as rapidly as the weathering of rock to form soil. The sandstone strata of the Rome Formation, in contrast to the limestone strata, are more resistant to weathering. Thus, some sandstone derived Rome soils tend to be quite shallow and occupy ridgetop landforms, whereas shale, siltstone, and interbedded limestone strata weather more deeply and occur below sandstone-capped ridges.

Soil forming processes. Three major soil forming processes in the Rome soils group are (1) leaching of soluble components, (2) transformation of primary silicate minerals to secondary silicate clay minerals, and (3) translocation of clay minerals (and other fine soil particles including iron) and aluminum compounds from the upper part of the soil downward or laterally depending on water flow pathways. Over time and with geomorphic stability, a clay-enriched subsoil B horizon forms. The B horizon becomes thicker, redder, and higher in clay content with time. On similar parent materials, B horizon thickness, clay content, and reddening are keys in evaluating relative soil age and geomorphic stability.

Important considerations for planning and management.

- Most Rome soils are on steep slopes and have a very high erosion hazard if forest vegetation is removed and the surface left bare. Disturbed areas should be replanted with a grass for temporary cover or trees for long-lasting cover.
- Little is known of chemical and mineralogical properties of Rome soils and saprolites that have weathered from the Rome Formation.
- The geologic dip of the strata is very steep on south-facing slopes of the Rome Formation and more or less parallel to the slope gradient. As a consequence, whenever the lower slope is cut, the landform above becomes unstable. Mass earthflows or mudflows are common on these steep dip slopes. Water also flows readily downward and laterally along dip planes and may come to the surface as seeps during wet periods. On north-facing slopes the dip is into the slope and, thus, north-facing slopes tend to be more stable if a cut is made into them.

3.1.2 Conasauga Soils

The Rome Formation gradually changes upward and stratigraphically into the Conasauga Group. Thus, the lowermost Conasauga rocks (Pumpkin Valley Formation) have some characteristics of the Rome geology, namely the reddish colors and some sandstone strata. Glauconite is abundant in some soils and appears as pellets.[11] Glauconite contains considerable iron and magnesium, which are released when this mineral weathers to a secondary clay mineral-vermiculite. The iron gives rise to the red subsoil color of both Valley and residual soils and the associated colluvial soils. Saprolites containing Conasauga glauconite should possess considerable cation exchange capacity (CEC), and adsorption potential should also be high. However, little is known of chemical and mineralogical properties of saprolites that contain glauconite or of the degree of glauconite weathering and transformation with depth. The rest of the Conasauga rocks contain very little sand strata but have higher silt and clay content and more calcium carbonate. Reports are available that describe the major components of the individual formations of this group.[10,12] Most areas of the Conasauga Group are located in Bear Creek Valley and Melton Creek Valley although not all formations of the Conasauga Group occur within the ORR. Melton Creek Valley contains a thicker sequence than does Bear Creek Valley, and the relationship of Conasauga Group rocks in each valley to each other is not clear.[13] Special soil surveys of Solid Waste Disposal Area (SWSA) 6 and SWSA 7 in

Melton Creek Valley[5,7] revealed that within a few miles along the strike different soils occurred that were associated with different parts of the Maryville Formation.

The extreme folding and fracturing of much of the Conasauga Group rocks adds to the complexity of relating soils to each formation within the geologic group. Most exposures of Conasauga Group rocks or saprolites reveal the extremely folded and fractured nature of the strata, which makes visual tracing of waterflow pathways difficult. For this reason predictions based on observations in one area have a low probability of repetition elsewhere.

Weathering processes. Because of the reported presence of pyrite in some unoxidized shale strata of the Maryville Formation,[12] the possibility of acid sulfate weathering at depth along with the close fracture pattern appears to be responsible for the relatively great depth of oxidation. This hypothesis for deep oxidation and weathering needs to be explored in more detail for the ORR soils, including the soils at SWSA 6. The other major weathering process is the slow leaching of calcium carbonate. Leaching and deep oxidation are enhanced by the highly fractured nature of the rocks, which have greater porosity than less-fractured zones or areas of higher calcium carbonate content. Although the Conasauga rocks that contain high silt and clay content are deeply oxidized and leached, they are only partially delithified. There are a few locations where both Rutledge and Maynardville formations of the Conasauga Group occur on the ORR. These particular formations chemically weather without forming saprolite, leaving a red clayey residue through which there are numerous rock outcrops, or else they are buried by alluvium and colluvium.

Geomorphic processes. The high silt and clay content of the Conasauga soils makes them sensitive to geomorphic processes. Overland runoff and surface erosion have been dominant factors in maintaining the soils in a youthful state and shallow to harder rock. The high silt and clay members of Conasauga soils generate large amounts of colluvium and alluvium, with the exception of the Rutledge and Maynardville formations, where there is little overland runoff and surface erosion. The primary geomorphic process on the Rutledge and Maynardville formations is chemical erosion that produces typical karst features of sinkholes and numerous solution cavities.

Soil forming processes. Soil acidification is the general process in humid climates where downward-moving water carries soluble minerals below the lowermost tree roots, preventing recycling. Thus, most of the present soils are acidic, even though the rocks they formed from were at one time calcareous.

A large pH gradient exists between the soil surface and calcareous hard rock. The rate of silicate mineral weathering and formation of secondary clay minerals depends on soil pH. Consequently, most mineral alterations occur at the surface, where soils are most acidic. This weathering sequence is aptly illustrated in Ref. 12.

In addition to leaching and mineral weathering, clay-sized particles are also translocated downward. Clay minerals accumulate in the subsoil B horizons, while lower in the C and Cr horizons red iron compounds coat weathered rock fragments—and still lower in the profile black manganese compounds coat frag-

ments. In limestone strata, soil horizons form in the highly weathered and leached red or yellow-red clayey residue remaining after all calcium carbonate has been removed by leaching. Translocated clay also increases the subsoil clay content in these soils.

Important considerations in planning and management.

- Much of the radioactive waste from ORNL and the Y-12 Plant have been buried in the Maryville Formation of the Conasauga Group. One could argue that the unfavorable properties of the soil and saprolite are more significant than the favorable properties of high-cation-exchange capacity and adsorptive properties. Because the soil horizons end at a shallow depth, most waste is placed in saprolite, which does not have many desirable chemical properties in its undisturbed state. Desirable saprolite properties decrease with increasing depth. Also, the depth of water tables is not always possible to determine or predict.

  As more of a disposal area is used, watershed hydrologic properties change as trees are removed and more surface water infiltrates porous trench fill. Using the fragmental materials dug from trenches for cover material only hides the waste materials. This cover material is porous and possesses little adsorptive capacity: it takes from five to seven years for fragmental materials to weather sufficiently to reduce permeability. Raw shale fragments also make a poor seedbed for vegetative cover. It is important to establish a vegetative cover for erosion control and to enhance evapotranspiration and thereby lessen deep water flow into the waste. Cover material (or at least the final cover material) should be obtained from the colluvial soils present on waste burial grounds. Colluvial soil has effective cover properties, including lower porosity.

- Burial ground soil should be tested once a year and recommended applications of lime and fertilizer carefully applied until soil pH is adjusted to a suitable level and adequate soil levels of phosphorous and potassium are obtained.

- A shallow-rooted legume should be planted along with a suitable grass species, which will allow for the grass to maintain itself. Grass cover will not maintain itself without periodic additions of nitrogen, a nutrient totally lacking in raw shale cover materials.

3.1.3. Knox Soils

The Conasauga Group grades upward into the Knox Group. The uppermost Conasauga Group limestone, the Maynardville Formation, changes to the basal Knox Group dolomitic limestone-dolomite, the Copper Ridge Formation.[10] Chert content increases in the Knox Group and probably reaches a maximum in the weathered residuum of the Longview Dolomite Formation. In addition to dolomite and calcium carbonate, the Knox Group contains substantial quantities of chert fragments, iron oxide, and silt and clay particles. The residual saprolite and soils are of most interest to the soil scientist and engineer.

Weathering. The dominant weathering process is chemical leaching from soil and rock into groundwater, making the water hard. The rock does not weather uniformly because of the differing joint spacings, fracture zones, and differential folding. More massive zones weather more

slowly, leaving unattached ledges, attached ledges, and pinnacles.

In most Knox soils, depth to hard and unleached rock is highly variable. Water flowing down joints has enlarged them from small solution channels to large caverns. Roof fall above a cavern results in the formation of sinkholes, some having an open swallow hole, or cave opening, through which surface water flows directly into the groundwater without being filtered and purified by the soil.

Chemical weathering and subsurface erosion in carbonate rock produce distinctive landforms, a process termed *karstification.* Because the Knox Group contains substantial matrix impurities, removal of carbonates does not result in collapse of the less-soluble remaining components. This saprolite is low in bulk and is quite porous. Eventually, pores in the saprolite become filled with clay and iron oxide particles. Porosity decreases, and water becomes perched as soil formation processes continue.

Geomorphic processes. In their natural and undisturbed state the residual soils formed in Knox Group saprolites do not generate much overland runoff, so most rainfall infiltrates and percolates downward. Most hills and valleys in this area are the result of differential solution and subsurface erosion, but there is some surface flow and particle transport during intense storm events or when the ground is saturated. Fine particles are gradually washed away, which concentrates surface chert fragments.

Landform surfaces of the Knox soils are the most stable on the ORR. On nearly level upland summits and in old and stable shallow depressions, wind-blown dust and loess (silt sized particles) accumulations have buried the cherty soil surface. Ancient alluvium, pre-Pleistocene in age (more than two million years old), is also preserved on the most stable upland landforms.

However, intense geomorphic processes during Pleistocene climatic fluctuations destabilized some soil surfaces, producing downslope mud flows of cherty material (periglacial or frost-induced and frost-accelerated processes). These events occurred in cold periods during which the soil was frozen to some depth. Thawing from the surface downward during snow melt or rainstorms produced saturated soil on top of a frozen zone. Soil flowed downhill carrying many chert fragments.

Colluvium blankets old sinkholes, saddles, and lower footslope landform segments on Chestnut Ridge. At least one drill core at the West Chestnut Ridge site encountered more than 30.48 m (100 ft) of colluvium.[6] During Pleistocene periglacial periods Rome, Conasauga, and Chickamauga soils were mostly stripped down to hard rock, but there was much less stripping of Knox soils. Also during the Pleistocene, there were several episodes of mass wastage and stripping. The most recent episode of land stripping occurred about 25,000 years ago.

Soil formation. Soil formation involves a long and continuing process of leaching, weathering, and transforming of silicate minerals into secondary clay minerals. Under long-term acidic conditions clay minerals in the soil surface are destroyed, a process of desilication with release of silica and alumina compounds. Silica moves downward, while alumina tends to accumulate near the surface as gibbsite or to enter the interlayer position of vermiculite (where it is retained). Clay particles are constantly translocated downward, forming a thick, clay enriched subsoil. Some clay minerals also form in the subsoil and saprolite from solution. The

thickness of the clay-enriched subsoil indicates the time of geomorphic stability and soil formation. Clay particles also move deeper into the saprolite, gradually plugging the pores and transforming saprolite into subsoil by the process of saprolite destruction; soil structure is then formed by shrink-swell activity.

When the West Chestnut Ridge soil survey mapping was started, an effort was made to identify each kind of soil that formed in the saprolite of each Knox Group.[6] The Anderson and Roane County soil surveys identified most of the Knox soil group as belonging to the Fullerton series, but with a few exceptions. The Dunmore soil series was mapped on low chert content soils, whereas Bodine and Clarkesville soil series were mapped on the highest chert content soils. None of the soils was evidently mapped with regard to the underlying Knox Group formations.

Important considerations for planning and management.

- Knox soils occupy the largest area of the ORR and are among the oldest and most stable landforms on the Reservation, but these soils are among the least utilized. Most Knox soils are deep. Because of karstic geomorphic processes, however, it is common to find pinnacles and ledges when a large trench is excavated. There is no easy way to predict the presence of pinnacles, even with closely spaced drilling. They can often be located by geophysical methods.

- Knox soils, even though they have a subsoil clay content of up to 80%, are relatively permeable and do not have a high erosion potential under forest vegetation.

- Preserved on Knox soils are the remnants of much older landscapes from previous weathering and erosion cycles. Ancient alluvium is located on some of the most stable parts of Chestnut Ridge, Melton Hill, Black Oak Ridge, and McKinney Ridge.

- Knox soils on less sloping hillsides have good potential for a variety of uses including building sites and waste disposal areas. Knox soils can be used for waste disposal, but the design of burial trenches or other fill methods of waste burial must be different from current practices in Conasauga soils.

- Trenches in Knox soils must be made impermeable, and the trench bottoms must be sloped to channel leachate toward the trench end for treatment, otherwise the leachate percolates downward. Trench bottoms can also be suitably doped with chemicals, special clays, or zeolites to filter and contain contaminants. This same type of design could also be used in SWSA 7 on the steeper slopes and in the northwest sector of SWSA 6.

- One substantial advantage to using Knox soils for waste burial is the suitable soil properties of cover materials. Clayey cover can be compacted and made relatively impermeable, thus slowing the infiltration of water. Layers of gravel can also be placed near the surface and a final clayey cover added to reduce the downward movement of water. Tile drains placed in the gravel will remove ponded water and prevent it from breaking through to the waste filled clayey soil beneath. Waste must still be precompacted and carefully placed in trenches so that large voids do not occur.

- Differential settlement is a major problem in current burial sites at ORNL and Y-12 and will ruin attempts to keep water from infiltrating and percolating downward through trench cover. Differential settlement also presents a long-term maintenance problem because water ponds and infiltrates wherever settlement has occurred.
- Knox soils, if properly managed, have fair to good potential for forestry production and wildlife habitat.

3.1.4. Chickamauga Soils

Knox Group formations abruptly change upward into Chickamauga Group formations. Between the two geologic groups lies a red calcareous shale that lies on cherty Knox dolomite. Most Chickamauga rocks are limestone, but the group also includes claystone and siltstone beds.[10] Chickamauga rocks are diverse, and each rock type has distinct weathering patterns that are well expressed in the soils of Bethel Valley. An important difference between Knox and Chickamauga carbonate rocks is the higher purity of the Chickamauga limestones. Another important difference between the two geologic groups is the bentonite contained in some formations in the Chickamauga Group.

Weathering. Little residue remains when these high-purity limestone rocks chemically weather. As a consequence, the soils are shallow to hard rock and typically have a very high clay content. Shale and siltstone members weather similarly, like their equivalents in the Conasauga soil group. The residual clays also contain inherited bentonite, which is lacking in Knox or Conasauga soil clays (and which changes the clays' mineralogy). Because of the high clay content and bentonite (which imparts high shrink-swell properties), soils are less permeable and have a higher erosion potential. Soil erosion, even on gentle slopes, was a problem for farmers in the past.

Geomorphic processes. Karstic geomorphic processes have played an important role in shaping landforms of soils derived from Chickamauga limestones. The solution of the underlying rock has produced a honeycomb of channels, caves, pinnacles, and other features produced by chemical weathering of high-purity limestones. Because high calcium carbonate purity keeps saprolite from forming, an abrupt transformation from reddish or yellow-brown clay to hard rock occurs. Because of these types of erosion—physical particle transport from the less permeable soil surface and chemical erosion from beneath—most Chickamauga soils are in Bethel Valley topographic landforms. Generally, the Knox soils (which form thick saprolites from "dirty" dolomite) appear on one side of the Valley. The Rome soils on the other side of the Valley have low carbonate content and slower rates of weathering. Many valleys are cut by running water, but this is not totally the case in Bethel Valley or in the other large expanse of Chickamauga soils located near the Oak Ridge Gaseous Diffusion Plant (ORGDP).

Soil formation. Most Chickamauga soils are shallow to rock because of high-purity limestone and high rates of physical erosion. Some of these soils, however, are quite deep to rock. Soil depth depends on the dirtiness of the limestone, fracture patterns, and the geologic rate of erosion. Many Chickamauga soils on gently sloping landforms typically contain numerous outcrops of rock or rock ledges on hillsides.

Base saturation remains high in most soils except the deeper ones. Chickamauga soils contain less-weathered clay minerals of higher cation exchange capacity and also have higher shrink-swell characteristics than other soils on the ORR. The possible exceptions are certain Conasauga Group soils that form from Rutledge and Maynardville limestones.

Important considerations for planning and management.

- Most shallow-to-rock Chickamauga soils cannot support intensive land use.
- Soils deeper to rock have fair to good potential for forest production and sustaining natural wildlife. The best use for most Chickamauga soils is sustained intensive forest production because of the gentle slopes, relatively low erosion potential under forest, and natural high fertility. Rock outcrops do present management problems for intensive forestry where site preparation is a soil management practice.
- Most Chickamauga soils are unsuited for waste disposal because of shallow depth or numerous solution channels in the rock beneath.
- Some endemic and endangered plants occur only on some Chickamauga soils that are shallow to rock and are locally known as *glades.*

3.1.5. Reedsville-Rockwood Soils

The Reedsville Formation is the uppermost member of the Chickamauga Group. It is a calcareous shale that grades upward to the Sequatchie Formation of interbedded shale, siltstone, and limestone. Above the Sequatchie Formation lies the Rockwood Formation of interbedded shale, siltstone, and sandstone. The Rockwood Formation is still calcareous, but less so than the formations beneath. The soils that form from these mostly clastic sediments are somewhat similar in weathering, geomorphology, and soil formation to the shale and siltstone members of the Conasauga soil group. The Reedsville-Rockwood soil group occupies a small portion of the ORR on the west end of the East Fork Ridge syncline. This particular group is not discussed in detail because of its limited extent and the general lack of information.

3.2. SOIL GROUPS FROM COLLUVIUM AND ALLUVIUM

Colluvial and alluvial soils are scattered throughout the ORR (Fig. 5). Pleistocene alluvium is located on the higher Clinch River terraces, and older Pleistocene or pre-Pleistocene alluvium is mostly located on stable uplands of Knox soils. Colluvial soils are also scattered throughout the ORR. The source of most colluvium is soil materials derived from Rome and Knox soils, although some are derived from Conasauga soils. Chickamauga soils do not appear to generate much colluvium. Colluvium derived from each residual soil group has its own distinctive physical, chemical, and morphologic properties. Colluvial soils also have distinctive concave landform characteristics and can be readily identified and separated from the associated residual soils on higher, mostly convex, parts of upland landforms. Holocene/Modern alluvium soils are located on low terraces and floodplains of flowing streams throughout the ORR.

Weathering. After deposition, most weathering occurs as leaching. Most soils favor lateral movement of near-surface water, which can cause hardpans (restric-

tive layers of soil) to develop in some colluvial soils, but not in residual soils, at a depth of 80 to 125 cm (31.5 to 49.2 in.). Once a hardpan has formed, lateral movement of water flowing across the hardpan is accentuated.

Geomorphic processes. Colluvial and alluvial soils that have been transported and deposited are metastable in a geomorphic sense and will remain so unless they become water saturated (which destabilizes them). Colluvial soils can also become destabilized if the toe of the landform is cut out, which can result in the entire mass moving downslope. The definite stratification of Holocene/Modern alluvial soils changes water flow patterns from downward to a more lateral direction. Most of the stratification in Pleistocene alluvial soils has been destroyed by soil-structure-forming processes so that there is a greater tendency for water to flow downward until deeper strata or residuum beneath is encountered.

Soil formation. Soil horizons tend to form rapidly in these soil groups because most of the sediments are preweathered. Some colluvial soils appear older than the upland residuum soils that were the sediment source but tend to be more fertile and productive than any of the upland residuum soil groups on the ORR because of lateral recharge of nutrients and water from residual soils. Most of the soils are deep, and some have benefited from plant nutrients either by lateral flow or fertilizer additions. Most of these soils were intensively formed in the past and received additions of lime, manure, and fertilizers. Water supplies are usually adequate for plant growth during periods of drought.

Important considerations for planning and management.

- Soils in these groups have high potential for forestry and wildlife development.
- They are important in maintaining surface water quality because they provide final filtering to surface and lateral flow of water before it enters the stream channel.
- Vegetation should be maintained in a natural state near stream channels along with a buffer strip during forest clearcutting and site preparation activities to prevent sediment from entering the stream.
- Stream floodplains and low terraces should not be filled with landclearing debris in waste burial grounds, nor should all the trees be cut in the bottom or in a strip adjacent to the bottom.
- Colluvial soil groups are a good source of trench cover material in the currently active ORR burial grounds located on Conasauga Group soils.
- Pleistocene and pre-Pleistocene soils have potential for revealing long-term rates of geologic erosion, especially the higher periods of erosion during glacial epochs. A dating technique using ^{10}Be for determining the age of these old soils[14] and their landforms would be extremely useful in predicting long-term erosion rates of all residuum soils, and the age and stability of all ORR landforms.

4. SOIL GROUP INTERPRETATIONS

4.1. SOIL CHEMICAL PROPERTIES

Chemical properties of soils are important in engineering applications, in understanding processes of soil formation, in soil-plant relationships, and in waste disposal. Soil pH conveys information about associated soil characteristics such as percent base saturation, phosphorous availability, and micronutrient availability or toxicity. The soil pH range in Table 2 is estimated for the upper 1.5 m (5 ft) of soil and is based on laboratory values for similar soils in East Tennessee. Soil pH values for deeper soil horizons and saprolite will need to be determined from bore holes or from soil material removed from deep excavations. Soil pH is one of the properties used to predict whether corrosion of uncoated iron pipes, concrete tile, or the steel reinforcing mesh of concrete pipe will be of concern. It does not relate directly to the risk of corrosion, but whenever soil pH is 4.0 or less, a high corrosion potential for uncoated steel exists. Of more importance in acid soils is the extractable acidity, the quantity related to pH and the clay mineralogy.

Other properties that influence corrosion are soil drainage, clay content, specific ion contents, and conductivity of the soil solution. The corrosion hazard increases when soil boundaries are crossed, where the soil drainage changes, where pipe goes from one soil horizon to another, or where pipe goes through a disturbed zone in the soil. Deterioration of concrete pipes is related to soil texture and pH, the presence of sodium or magnesium sulfates, or the presence of sodium chloride. Recognizing potential problems and incorporating preventive measures at the time of pipe installation is less expensive than taking corrective measures later. Some potential problem areas along the route of a pipeline can be seen from a soils map, but on-site investigations are also necessary, both before and while the trench is open. A pH of 5.5 or less is the basis of a high concrete corrosion potential for any soil texture. Acid soils are widespread throughout the ORR.

Cation exchange capacity (CEC) is a significant chemical property of soils. CEC is usually expressed as centimoles (+) kg^{-1} soil (milliequivalents per 100 g of soil) and measures the soil's capacity to hold and retain positively charged particles. There are two types of CEC. The first is the result of electrical charges of clay minerals (i.e., clay minerals having a net negative electrical charge that is balanced by positive charges of cations attracted to clay particles). The second type of CEC is contributed by organic matter and oxyhydroxide coatings on soil particles. This type of CEC can be altered by changing the soil pH and is commonly called pH-dependent CEC.

Soil CEC values higher than 15 are good, 5 to 15 are fair, and less than 5 are poor for the application of municipal sludge to the upper 25 to 50 cm (10 to 20

Table 2. Soil chemical properties[a]

Soil group	Corrosivity		pH range	Estimated CEC[b]		
	Steel	Concrete		Surface	Subsoil	Saprolite
			Residuum			
Rome	low	mod-high	4.5-6.0	5-15	10-20	NA[c]
Conasauga	mod	mod	4.5-6.0	10-15	15-20	NA
Knox	high	mod-high	4.5-5.5	5-10	8-20	NA
Chickamauga						
Gladeville	high	low	6.6-8.2	20-40	40-80	NA
Colledgedale	high	mod-high	4.5-5.5	10-15	20-40	NA
			Colluvium			
Rome/Conasauga	low-mod	mod-high	4.5-6.0	5-10	5-10	NA
Knox	mod	mod	4.5-5.5	5-10	5-10	NA
			Alluvium			
Holocene/ Modern	mod-high	low-mod	4.5-7.8	5-10	5-10	NA
Pleistocene	mod	mod	4.5-5.5	5-10	5-10	NA

[a]Data from Ref. 4.
[b]Millequivalents per 100 g of soil (centimoles (+) kg^{-1} soil).
[c]NA = data not available.

in.) of soil. Similar CEC values are also important in rating deeper soil materials for the emplacement of radioactive waste and the absorption of cations released whenever water invades and leaches contaminants into the soil cover or adjacent trench matrix. Cation exchange values below a depth of about 1.5 m (5 ft) are not known on the ORR except in a few cases where actual determinations have been made.

Anion exchange capacity (AEC) and anion retention are derived from positive charges, most of which are from organic matter and oxyhydroxides. AEC is highest near the surface, where soil horizons contain organic matter. AEC measurements are very low in saprolite and weathered rock.

4.2. SOIL PHYSICAL AND ENGINEERING PROPERTIES

Several physical properties of soils are important in planning and managing soil conservation (see Table 3). Shrink-swell potential relates to the ability of soils to shrink and swell with changes in moisture content. The amount of volume change depends on clay content and the type of clay minerals present. Shrink-swell classes are based on the change in

Table 3. Woodland management[a]

Soil group	Erosion hazard	Seedling mortality	Windthrow hazard	Trees to plant	Rating[b]	Trees to manage
			Residuum			
Rome	slight-mod	slight-mod	slight-severe	wh. pine	50-60	oaks hickories
Conasauga	mod	mod	slight	lob. pine	50-65	y. poplar oaks hickories V. pine
Knox	slight-mod	slight	slight	lob. pine wh. pine y. poplar	70-80	oaks hickories y. poplar
Chickamauga						
Gladeville	mod	severe	severe	red cedar	10-30	red cedar
Colledgedale	mod	slight	slight	y. poplar lob. pine	75-85	y. poplar oaks hickories
			Colluvium			
Rome/Conasauga	mod	slight	slight	lob. pine	85-95	all species
Knox	slight	slight	slight	y. poplar b. walnut lob. pine	75-85	all species
			Alluvium			
Holocene/Modern	slight	slight	mod-slight	sw. gum lob. pine scyamore wh. pine y. poplar	100	all species
Pleistocene	slight-mod	slight	slight	y. poplar b. walnut lob. pine	95-100	all species

[a]Ratings of productivity are derived from SCS-5 interpretations for the major soils in each group (Ref. 15).

[b]Rating based on 0 to 100, with 100 being highest rating.

length of a remolded clod as moisture content is lowered from a moist to an air-dry state. The value obtained (expressed as a percent) is defined as linear extensibility (LE). The low shrink-swell class has an LE of less than 3%, the medium class 3 to 6%, the high class 6 to 9%, and the very high class more than 9%. Shrink-swell potential is an important measurement not only in the evaluation of soil stability for both roads and shallow foundations but also in the evaluation of on-site soil materials for trench or lagoon liners or for remolded and compacted cover material.

The following properties of remolded soil are important in planning soils for engineering practices. The liquid limit is the boundary that separates plastic and semiliquid states of soil. It is expressed as percent moisture content based on dry weight. At a much lower moisture content the remolded soil ceases to behave like a plastic and behaves like a solid. This moisture content is defined as the plastic limit. When the moisture content is below the plastic limit, the soil has high weight-bearing capacity.

The difference in percent moisture content between liquid limit and plastic limit, expressed as a percent, is the plastic index (PI). Soils that have a moisture content between the liquid limit and the plastic limit behave as plastics because they will deform under a load. As a consequence, soil weight-bearing capacity is reduced. A high PI leads to potential problems with the stability of structures, roads, or other engineering uses of soils where weight-bearing capacity is involved.

The Unified Soil Classification System considers important engineering properties of soils: (1) percentage of soil that passes through or is retained on a #200 sieve, (2) particle size distribution, (3) whether the soil is well or poorly graded, (4) organic matter content, (5) liquid limit, and (6) plastic index. The system's ML class consists of soils with a high content of fines (particles that pass through a standard screen) smaller than #200 mesh, with a liquid limit less than 50% and a PI less than 4. These soils are called *silts*. They have low plasticity, high compaction, and low cohesion. The CL class has properties similar to ML soils but with a PI higher than 7. Soils in this class are often described as *lean clays*. The CH class consists of soils with more than 50% passing through a #200 sieve and having a liquid limit higher than 50%. The PI plots above the "A" line on the classification chart. Soils in this class are often described as *fat clays*. Unified classes of GC, GM, SM, or SC describe those soils that retain more than 50% on a #200 sieve. The coarser fragments are either gravels (G) or sands (S). Soils in the GC class are commonly described as *clayey gravels*, while soils in the GM class are described as *silty gravels*. Soils in the SM class are labeled *silty sands*, and soils in the SC class are termed *clayey sands*.

Soil erosion (including the susceptibility of soils to erosion) is an important criterion in any soil conservation and management plan. The soil erodibility factor (K) is a quantitative measure of a soil's susceptibility to having particles detached and transported by rainfall. Values of K are dimensionless and are experimentally determined. However, because of the high cost of experimentally determining values of K, most values are estimated based on a nomograph.[15] Low values of K signify that the soil has less potential to erode than soils with high K values.

The universal soil loss equation (USLE) predicts the long-term average soil loss by sheet and rill erosion, processes that

are usually difficult to detect visually. The USLE is used on the ORR to determine soil loss from wildlife food plots, from cutover tracts of land being prepared for tree replanting, and from grass-covered tracts of land. It cannot be used to predict soil loss in burial grounds once gullying has started. The USLE is useful in a disturbed site (after the site has been revegetated) for predicting future soil loss from sheet and rill erosion. Active building and waste burial sites, where there is no vegetation, will generate high soil loss, but with suitable containment practices the sediment should and can be retained on-site.

4.3. SOILS INPUT FOR WOODLAND MANAGEMENT

Woodland management should meet several objectives, one of which should be sustained income production from forests, provided the soils can sustain productivity without additions of lime and fertilizer. Meeting this objective requires short rotations of pine trees and conversion of hardwood stands to pines. However, forest monoculture has its drawbacks. Disease and less-suited soils result in uneven maturation and understocked stands. Monoculture stands of pines also provide poor wildlife habitat for many species.

Another possible objective of forest management on the ORR is multiple use of forest stands to provide for a more scenic view, better wildlife habitat, and periodic renewal of stands and habitat (either by timber stand improvement techniques or by clear cutting and natural regeneration or intensive site preparation). Much of the ORR's soil is acidic, has low natural fertility and limited ability to replenish required nutrients by deep root cycling, or is on steep slopes highly susceptible to erosion.

It would seem that the best approach to forest soil planning and management in most areas of the ORR would be to provide for the natural diverse patterns of trees and tree species most suited to each kind of soil with minimal expense involved in liming, fertilizing, and other management practices. Most soils from both the colluvial and alluvial soil groups can be intensively managed without soil deterioration and with minimal loss of productivity.

Table 4 lists important site and soil properties along with a rating for hazards or soil problems associated with intensive site preparation and tree planting. Pines will grow on most ORR soils except the shallow Gladeville soils. However, some soils are better adapted to broad-leaf tree species such as yellow poplar, walnut, and oak. The rotation period between planting and harvesting for these species is much longer than for pines. Oaks are not listed in the trees-to-plant column because they are difficult to transplant. Oak forests must be managed so that seed trees and squirrels disperse acorns. Like pines, oaks will grow on all ORR soils with the exception of the Gladeville soils. Silvicultural aspects of forest management are covered in detail in the *Forest Management Plan* (volume 6) of this series.

Because of the acidic nature and low fertility of soils, it is recommended that the larger acreage of forest on the ORR be managed as mixed mesophytic forest (requiring moderate moisture for growth). A large number of species will provide for diverse wildlife habitats. Intensive forestry is best restricted to areas of the ORR where steep slopes and erosion hazard are not problems. This recommendation precludes a high yearly income

Table 4. Soil physical and engineering properties[a]

Group	Surface					Subsoil				
	Shrink-swell	LL[b] %	PI[c] %	Unified class	K factor	Shrink-swell	LL %	PI %	Unified class	K factor
					Residuum					
Rome	low	20-30	NP[d]-8	ML, CL	0.24	low	15-40	NP-13	GM, SM	0.28
Conasauga	low	20-40	5-15	ML, CL	0.32	mod	45-75	17-40	MH, ML, CL, CH	0.37
Knox	low	15-30	3-15	ML, CL	0.28	mod	40-70	20-40	MH, ML,	0.24
Chickamauga		30-60	20-35	GC, CL, CH	0.17	high	35-70	35-70	CH, MH, CL	0.17
Gladeville	mod									
Colledgedale	low	20-40	5-16	ML, CL	0.37	mod	40-80	20-50	MH, CH	0.24
					Colluvium					
Rome/ Conasauga	low	20-35	2-10	SM, SC	0.28	low	20-35	2-10	GM, SM, ML	0.28
Knox	low	20-30	NP-10	ML, CL	0.34	low	20-30	5-15	CL, GC	0.28
					Alluvium					
Holocene/Modern	low	<30	NP-10	ML, CL	0.32	low	20-40	4-20	ML, CL	0.43
Pleistocene	low	20-30	3-10	ML, CL	0.37	low	40-70	10-25	CL, ML	0.32

[a]Adapted from Refs. 1, 4, 15.
[b]LL = liquid limit.
[c]PI = plastic index.
[d]Nonplastic.

from lumber but will improve existing quality and encourage reproduction of higher quality trees on a large acreage. Crooked, diseased trees with poor genetic traits must be removed. Such work is labor intensive and produces only firewood, but it is needed to return the existing broad-leaved forests to a productive state.

Erosion hazard ratings are related to site preparation practices where the existing forest floor and soil are disturbed to control broad-leaf tree competition when maintaining a tract of land in pine monoculture. Erosion hazard is not only related to the general landform slope gradient but also to the soil thickness in which trees can extend roots. Some soil groups can tolerate more erosion than others. However, it is more difficult to successfully establish succeeding generations of trees as soils become more eroded with each tree harvest and subsequent site preparation for the next crop of pines.

Seedling mortality is affected by competition for water during the first one or two seasons after planting; it is also affected by frost heaving before roots are firmly established. The windthrow hazard rating (shown in Table 4) is related to depth of rooting, which is restricted by (1) depth to hard rock or to a Cr horizon (paralithic contact) and (2) depth to a constant water table. The trees-to-plant column lists those that are easy to plant and transplant; these trees are preferred for short rotation. The rating column lists each soil group's productivity on a scale of 0 to 100. Although the Gladeville soils are rated poorly, limited trials with loblolly pines have shown promise in seedling survival and growth rate (See volume 6 of the *Resource Management Plan*).

4.4. SOILS INPUT FOR WILDLIFE MANAGEMENT

This section discusses the soil related aspects of wildlife management (see Table 5). For a more detailed discussion of wildlife management the reader is referred to volume 16 of the *Resource Management Plan.*

Grain crops such as agricultural grains and natural plants produce large quantities of seeds. Soil properties considered in grain crop ratings are soil depth, water retention, slope, and native fertility. Many grain crops are initially established by inputs of lime and fertilizer, with the expectation that the crop will reseed and grow for successive generations on the residual fertility.

Herbs, grasses, and forbs are either native to the ORR, or they are introduced species that can thrive with little care. These plants often provide food and shelter when domesticated grains cannot. Ratings for herbs and grasses are based on natural soil fertility, with minimal if any additional care needed.

Ratings of openland habitat potential are based on a combination of intermingled cropland, pastureland, wasteland, and woodland. The ratings also indicate the land's ability to support such diversity. Openland habitats usually support the largest numbers and diversity of wildlife. Woodland habitat potential is rated for the variety of trees, shrubs, and ground plants that will support woodland wildlife (such as grouse, raccoons, wildcats, deer, birds, squirrels, and foxes). Wetland habitat potential is based on the ability to support wet and swampy areas along with water-tolerant species of trees, shrubs, reeds, sedges, and other forbs that

Table 5. Wildlife habitat potential[a]

Soil group	Habitat elements for				Potential for		
	grain crops	herbs and grasses	hardwoods	conifers	openland	woodland	wetland
			Residuum				
Rome	v. poor	good	fair	fair	poor	fair	NA[b]
Conasauga	v. poor-fair	poor-good	fair	fair	poor	fair	NA
Knox	poor-fair	poor-good	fair-good	fair-good	fair-good	fair	NA
Chickamauga Gladeville[c]	v. poor	poor	v. poor	v. poor	v. poor	v. poor	NA
			Colluvium				
Rome/Conasauga	fair	good	good	good	good	good	NA
Knox	fair-good	good	good	good	good	good	NA
			Alluvium				
Holocene/Modern							
Well drained	good	good	good	good	good	good	poor
Poorly drained	good	good	good	good	fair	good	fair
Pleistocene	good	good	good	good	good	good	good

[a]Habitat ratings derived from National Soils Handbook (Ref. 15).
[b]NA = not applicable.
[c]Other soils of the Chickamauga group compare with the Conasauga Group.

will attract ducks, shore birds, muskrats, and other species.

Soils in the colluvial and alluvial groups generally provide the best overall site conditions for natural wildlife habitats because of their natural fertility or better soil moisture conditions during the growing season. These soils are scattered throughout the ORR.

The merging of soils information and soil management conditions and restraints into wildlife and forest management goals and policies (as stated in volume 16 of the *Resource Management Plan*) is crucial to the activities of both programs. Another step must be taken beyond combining the two programs: to establish goals and policies for forestry and wildlife programs, the properties and potentials of each soil group must be understood.

4.5. SOIL CONSIDERATIONS FOR SITE DEVELOPMENT

Soil ratings for site development are related to physical properties of soil, namely the content of silt plus clay, the slope gradient at the site and the potential erosion hazard, the properties of the underlying geologic materials, and the depth to hard rock or to rippable rock (Table 6). Most soils on the ORR are of poor quality for roads and streets; their high silt and clay content makes them subject to plastic flow and compaction under heavy loads. The Knox Group soils with high gravel content have slightly better properties for roads and streets and for road fill. Colluvial soils also have slightly better properties for road fill because they have lower clay content than the residuum soils. Soil properties related to fill or roadfill are based mostly on the properties of disturbed and remolded soil materials. These properties are shrink-swell, the American Association of State Highway Transportation Organization group index number, and the amount and size of coarse fragments. Site wetness and slope relate to the stability of compacted fill. Soil properties that directly affect excavations and cut and fill operations are depth to rock, high clay content, and slope.

Several important soil and site properties affect the suitability of soils for trenches or landfills: slope, texture, depth to bedrock, permeability, depth to water table, presence or evidence of perched water, lateral movement of water, and stability of trench sidewalls or side slopes of area fills.

The use of soils for waste management is currently important on the ORR and will become even more so with time. There are two basic options for waste disposal in soils: (1) a maximum amount of waste is concentrated in a minimum area, and (2) a minimal amount of waste is applied to a large area. The first option is used for its short-term economics and the ability to recover the waste in the future. The second option (known also as the dilution option) requires larger land area and a higher level of soil management and conservation. Radioactive and other hazardous wastes are usually concentrated in specially designed and monitored burial grounds, while sewage sludge and wastewater are often diluted by applying small amounts to a large area of land and allowing the natural vegetation or crops to capture nutrients. This will allow for soil biochemical filtration and purification to proceed without overloading the ability of the soil to filter and purify.

Several important soil and site properties are evaluated for the disposal of

Table 6. Ratings for site development[a]

Soil group	Roads and streets	Cut and fill	Landfill	Sewage and sludge	Roadfill
		Residuum			
Rome	poor	poor	v. poor	v. poor	poor
Conasauga	poor	poor-fair	poor	poor-fair	poor
Knox	fair	fair	fair	fair-good	poor-fair
Chickamauga	v. poor-poor	v. poor-poor	v. poor	unsuited	v. poor
		Colluvium			
Rome/Conasauga	fair	fair	poor-fair	good	fair
Knox	fair	fair	fair	good	fair
		Alluvium			
Holocene/ Modern	poor	poor-fair	v. poor	poor	poor
Pleistocene	fair-good	good	good	good	good

[a]Ratings based on National Soils Handbook (Ref. 15).

municipal sewage sludges: soil permeability, depth to a high water table, slope, depth to bedrock, CEC, and ability of surface vegetation to maintain itself. Another important consideration is the ability of the soil to denitrify nitrogen compounds or the ability of plants to use soluble nitrogen compounds and prevent deep leaching. Environmental Protection Agency (EPA) and Tennessee Department of Health and Environment guidelines must be adhered to when determining loading rates on soil and evaluating sites for sludge and wastewater disposal.

The most crucial concern on the ORR regarding soil conservation and land management is the dearth of knowledge of soil properties between the master A and B horizons of the pedologist and the hard rock of the geologist. Wastes have been and continue to be buried in this soil zone.

The soil is the final repository for the near-surface burial of waste materials, whether they be domestic, municipal, hazardous, or radioactive types. The interdisciplinary commitment of geologists, pedologists, geochemists, geophysicists, hydrologists, and scientists from other related disciplines will be required to establish a suitable soil database from which reasonable modeling can be performed.

5. MANAGEMENT AND PLANNING FOR SOIL CONSERVATION

5.1. PRESENT CONDITIONS

The reforestation of most open areas, with the exception of the Scarboro Facility area (which remained in agricultural land use), was an early soil management concern. After the large-scale loss of shortleaf pine in 1972 and 1973, tree replanting efforts were begun. Test plots of many broadleaf and needleleaf species were set up to determine which species would perform best with which soils or landforms. In considering the many ways forest land can support wildlife, the number of tree species considered for planting and replanting was expanded. Important forest management concerns were the improvement of existing mixed forest areas in terms of both timber quality and wildlife quality. These concerns must be balanced against the ability of the soil to supply water and nutrients.

Concern about soil erosion also entered forest management plans in the 1970s, especially regarding haul road construction and site preparation for replanting. Another long-standing concern has been the maintenance of vegetation around power lines and the soil erosion problems associated with power line rights-of-way. Still another soil management concern has been the spreading of sewage effluent and sludge from Oak Ridge in both openland and forested areas and the long-term effects on soil productivity. Suitable areas for domestic waste disposal are being sought by Oak Ridge and surrounding communities. Landfills on the ORR are desired because they are isolated and involve fewer political problems with the not-in-my-backyard syndrome.

Most land use planning and management concerns about the ORR's open areas have focused on the location of buildings, parking lots, roads, and disposal areas for both hazardous and radioactive wastes, as well as domestic wastes. Soil and vegetation management considerations have high priority at ORR burial grounds because of the need to control intense, short-term erosion while the site is active. These considerations also apply to long-term vegetation maintenance and future geologic erosion. Immediate concerns exist at both ORNL and Y-12 Plant burial grounds about increased infiltration of water into burial trenches and gully erosion control (in addition to sheet and rill erosion controls). Inadequate establishment and maintenance of vegetation and retaining sediments on site are present and future concerns at ORNL and Y-12 Plant burial grounds.

5.1.1. Soil Groups for Planning

For intensive planning, soil maps that have more detail than those in this document must be used. All currently available detailed soil maps and descriptive legends that identify all mapping units on

ORR soil maps can be found in Ref. 3. On these larger-scale maps, each soil that is delineated is identified by a certain symbol. Table 7 includes all ORR soil series that were organized into the soil groups of this document.

5.1.2. Fragile Soils

The concepts of fragile soils and prime farmland have to be considered in both present and future land use. *Fragile soils* are those that are easily damaged or degraded through management practices and use or by natural catastrophic events. These events result in a significant loss of productivity that cannot be recovered easily.

Fragile soils are highly erosive soils, soils shallow to hard rock, and soils with undesirable subsoil or substratum chemical or physical properties that cannot be altered economically. Some soil series on the ORR are defined as fragile because of shallow depth to hard rock (Table 8).

5.1.3. Fragile Lands

Fragile land refers to those properties of the landscape and soils that allow them to become easily disturbed and degraded through conventional management practices. If these practices are continued, permanent loss of productivity will result. Land uses, both past and present, are considered in defining degrees of fragility by using the ecosystem approach, whereby all components of the ecosystem are examined (e.g., soil resources plus social, economic, and political decisions) in evaluating current or future aspects of land use.

Ecological consideration is the use of natural resources without causing permanent or long-term degradation. It includes the use of land to provide economic gains to the user and, at the same time, to maintain the ecosystem in a dynamic steady state so that the system can adjust to natural and man-induced changes. Social and political considerations encompass policies that consider and promote a harmonious relationship among society, the resources used by society, and the disposal of wastes without long-term land and water degradation.

The general criteria for determining fragile lands are (1) the ease with which land can be degraded, (2) the rate of productivity loss for a specific land use, and (3) the difficulty of returning abused land to its presumed potential productivity, considering the soil properties, climate, landforms, and types of natural geomorphic processes that can further degrade or improve the state of the ecosystem. Fragile lands on the ORR include all map units of fragile soil series, map units of soils that have slopes greater than 25%, and all severely eroded phases of soils (Fig. 6).

Most fragile lands should be allowed to revert to natural vegetation that is in balance with the existing climate and that experiences minimal disturbance and management. Fragile lands should be considered the scenic, natural parts of the ORR. Some soils and lands that are labeled as fragile should still be considered for some intensive purpose. The fragile label should serve as an alert that there are one or more important problems associated with using that soil.

5.1.4. Prime Land

Prime land is that with the best combination of physical and chemical characteristics for producing food, feed, forage,

Table 7. Soil series placed into soil groups

Residuum	
Geologic formation	*Soil series*
Rome Group	Lehew, Armuchee-Muskingum, Calvin
Conasauga Group	Sequoia, Armuchee, Apison, Montevallo, Colledgedale
Knox Group	Fullerton, Bodine, Clarkesville, Dunmore
Chickamauga Group	Gladeville, Talbott, Colledgedale, Colbert, Upshur-Variant
Colluvium	
Source of colluvium	*Soil series*
Rome and Conasauga groups	Jefferson, Shouns, Leadvale, Shelocta
Knox Group	Minvale, Tasso, Roane, Emory, Greendale, Tarklin
Alluvium	
Age of soil material	*Soil series*
Holocene/Modern	Hamblen, Pope-Philo, Newark, Melvin
Pleistocene	Allen, Dewey, Claiborne Holston, Waynesboro, Etowah, Nolichucky

Table 8. Soils shallow to hard rock

Geologic name	Soil series
Rome	Calvin, Lehew, Muskingum
Conasauga	Montevallo
Chickamauga	Gladeville

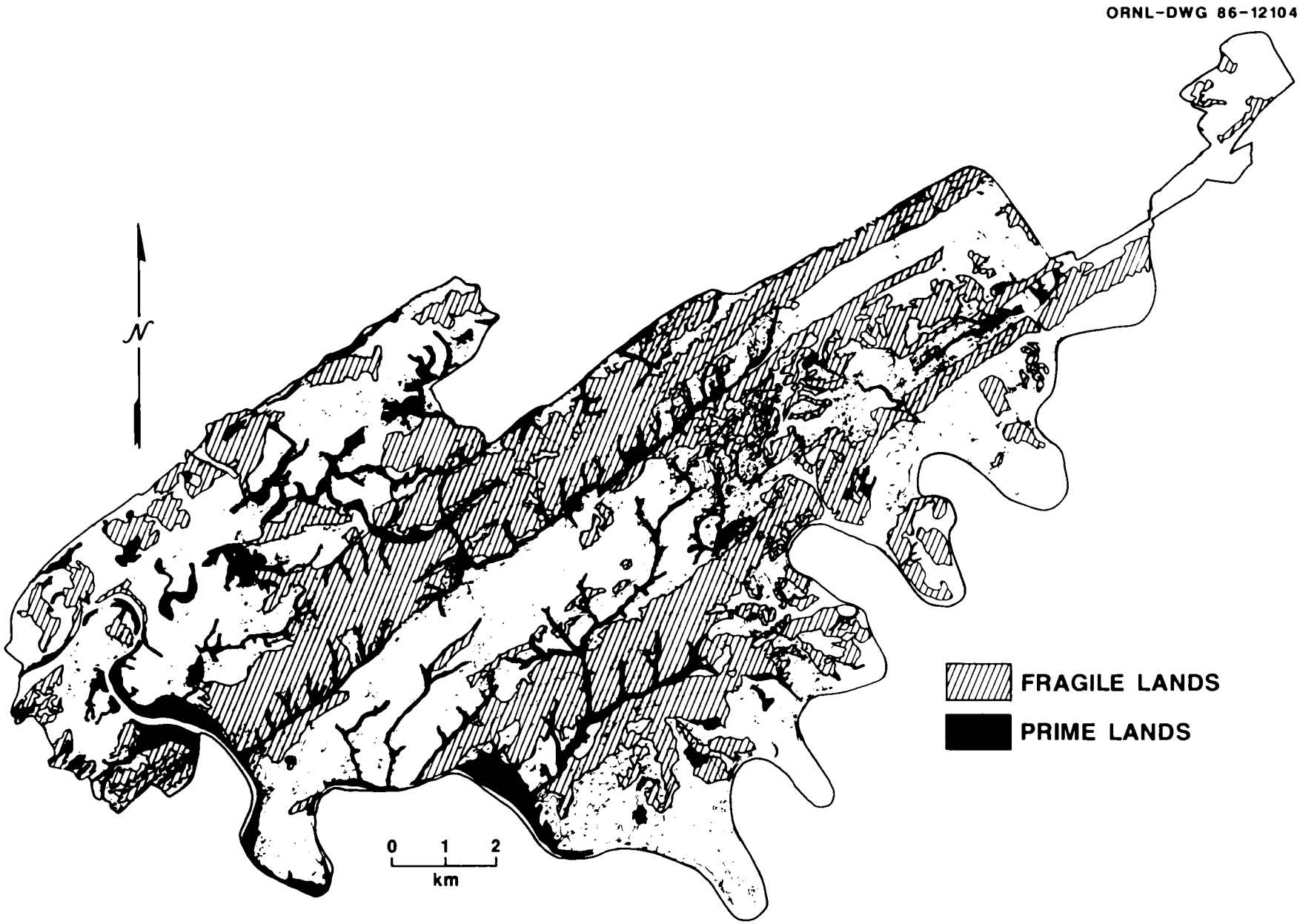

Fig. 6. Fragile land and prime land on the ORR.

fiber, and oilseed crops.[15] This includes crop, pasture, forest, and other available land. Excluded are urban lands and other lands dedicated to long-term, incompatible uses. Many urban and industrial structures are placed on prime land because of the mostly favorable soil properties for these uses. Most prime land areas on the ORR are widely scattered (Fig. 6). Many areas are on stream floodplains, terraces, or drainageways. The only areas of any extent are on terraces adjacent to the Clinch River; the largest is located close to ORGDP. Soil mapping units that currently qualify as prime land are listed in Table 9.

5.2. FUTURE MANAGEMENT AND PLANNING FOR SOIL CONSERVATION

Soils are the basis of many activities on the ORR. Planning for conservation involves the recognition of important soil properties so that each major kind of soil can be used to its highest potential without degrading either the soil or the environment. Soil management involves the recognition of potential problems and also knowing what corrective or preventive measures must be taken to alleviate a problem.

Properties of undisturbed soils and chemically weathered saprolite beneath are virtually unknown but must be characterized if successful modeling of soil systems is to be fruitful. Before engineers design projects, they should understand both the remolded soil properties and properties of undisturbed soils deeper in the earth.

The soil scientists who made the Roane County and Anderson County soil surveys examined the upper 0.9 to 1.5 m (3 to 5 ft) of soil and used mostly agricultural concepts of soils in mapping. This is not to imply that these soil surveys have no use, for they do locate the major surface changes in geologic formations. Geologists looked for rock outcrops or observed drill

Table 9. Prime land mapping units on the ORR[a]

Allen (0 to 6% slopes)	Apison (0 to 5% slopes)
Claiborne (0 to 6% slopes)	Colledgedale (0 to 5% slopes)[b]
Dewey (0 to 6% slopes)	Dunmore (0 to 6% slopes)
Emory (0 to 6% slopes)	Etowah (0 to 5% slopes)
Fullerton (0 to 5% slopes)[b]	Greendale (0 to 6% slopes)
Hamblen[c]	Holston (0 to 6% slopes)
Jefferson (0 to 6% slopes)[d]	Leadvale (0 to 5% slopes)
Minvale (0 to 6% slopes)	Newark[c]
Nolichucky (0 to 8% slopes)	Pope[c]
Roane (0 to 8% slopes)[c]	Shelocta (0 to 6% slopes)
Shouns (0 to 8% slopes)	Tarklin (0 to 6% slopes)
Tasso (0 to 5% slopes)	Waynesboro (0 to 8% slopes)

[a]Source: Ref. 3.
[b]Except severely eroded units.
[c]Except occasionally and frequently flooded phases.
[d]Except cobbly and stony phases.

cores of hard rock to identify geologic formations at depth. In the last few years researchers have worked to determine the properties of weathered rock and saprolite in the zone where low-level radioactive waste has been emplaced. Special soil surveys of current or proposed waste burial grounds have emphasized the relationship of geology to the soil horizons near the surface, including the amount of saprolite weathering and soil formation that is related to geomorphic processes of slope stability and water flow pathways over the surface, downward, and laterally.

Three-dimensional water flow pathways in soil and rock also need to be known if successful modeling is to be completed. A large-scale effort is currently under way in this area of research. Removal of water from waste trenches creates an ongoing expense in several burial grounds because of a lack of knowledge about water flow pathways (or morphological indicators of groundwater or fluctuating groundwater zones). For example, trenches were dug in colluvial soils or partly in colluvium and the residual soil beneath, and water now pours in from the upslope side during each wet period. Trenches were dug too deep during dry periods. Water tables also rose after trees were removed from a potential burial ground and no longer transpired water from deeper soil zones.

Special planning must be considered for the Holocene/Modern alluvial soil group, which serves an important function in surface water quality. Water flows over or through these soils or upwells through them before entering the stream channel. Research is needed into filtration and purification of water as it passes through these soils. Can the soil's chemistry be modified by surface application of chemicals to increase their filtration and purification capacities? A buffer of trees and natural vegetation is needed on and around floodplain soils and low-terrace alluvial soils if they are to be most effective in filtering and purifying water. For surface waters leaving the ORR to meet EPA drinking water standards, special attention should be paid to these soils.

A plan for erosion control and sediment containment, if there is not one already, should be established immediately for all burial grounds and construction areas. Sediment control structures (either temporary or permanent) have not been used until recently. Some sediment containment structures and temporary seeding practices have been observed around the active burial grounds and the security clearing areas around the Y-12 Plant complex.

It is important to keep sediment on site and out of drainageways or stream channels because the sediments of active erosion provide poorer filtration than the natural drainageway soils.

Vegetative cover greatly reduces erosion. However, subsoil removed from trenches makes a poor seedbed for temporary or permanent grass cover. Nitrogen is an important nutrient for sustained vegetative growth, and shallow-rooted legumes would supply nitrogen for longer-term grass maintenance. A strong and thick grass sod will also slow down the invasion of trees.

An expanded database of soils information is needed for overall ORR planning—for example, planning the intensity of land use and mapping the location and extent of infertile or drought-stricken soils. All current soils information should be placed in a database, and all additional soils investigations (e.g., high-intensity mapping, chemi-

cal analysis, and water flow analysis) should be part of the soil and geologic databases.

The minimum geographic size of a database should be at the watershed level. A watershed model is probably the best way to model and manage geologic, soil, and water data. Planning is under way to develop such models of Bear Creek watershed and White Oak Lake (Melton Creek) watershed. Modeling the fenced area of SWSA 6 will be incomplete because the effect of the watershed area above the burial ground to the burial ground is not known.

Methods of burying and containing radioactive wastes and controlling the use of these sites in the future are probably the most critical concerns for future soil planning and management on the ORR. Good estimates of long-term rates of geologic erosion would be useful for predicting whether wastes should be exhumed before radioactivity decays to acceptable levels. Techniques are being developed to determine the age of surficial soils and landforms. A method of determining soil age using ^{10}Be is being developed and tested.[14] It shows promise for determining the age of ORR soils and the rate of geologic erosion. Information is needed on what can be done to prevent the long-term use of burial grounds. Information is also needed on long-term maintenance of burial ground vegetative cover.

6. SUMMARY AND RECOMMENDATIONS

Soils on the ORR are diverse and represent a typical cross section of the Great Appalachian Valley of Tennessee between the Cumberland and Unaka Mountains. Every soil identified on the ORR survey maps differs from every other soil in one or more important properties, such as depth to rock, slope gradient, erosion hazard, clay content, kinds of clay minerals, acidity, suitabilities, limitations, and problems for any present or proposed use.

Soil conservation involves the use of land to its highest potential but without its degradation. If each major kind of soil on the ORR is to be used in accordance with this principle, the relevant properties of that soil (from the surface down to hard rock) must be quantified. These data, along with the spatial distribution of soils, then become the ORR soil database and part of its natural resources database.

The following recommendations should be considered in planning and managing ORR lands for soil conservation purposes:

(1) The soil survey of the Roane County part of the ORR is obsolete. It had limited use in preparing this conservation document but is not usable for more detailed planning. A new soil survey conducted with specifically defined objectives to relate soils, geology, and geomorphology would greatly assist planning and management.

(2) The area from 1.5 m (5 ft) down to hard rock is where most low-level radioactive and domestic construction wastes are being buried. Virtually nothing is known of this part of the soil. Studies have been started at the Central Waste Disposal Facility on West Chestnut Ridge and at SWSA 6 and SWSA 7. It is crucial that this soil zone be explored and that important soil properties be defined and quantified to successfully predict the effects of land use on a tract of land and to learn if the soil has the capacity and capability to retain certain hazardous materials.

(3) Soil erosion is an important concern in burial ground management, especially because it is desirable to contain contaminated burial ground sediments on-site. Certain sediment management practices will contain sediments generated at active burial sites and not allow them to move into stream channels and floodplains. Temporary and permanent vegetation must be established and maintained on burial grounds for the maximum reduction of erosion rates. Floodplain and low-terrace soils of the ORR play a vital role in filtering and purifying water. These soils must be maintained in their natural state and cleared of debris and other objects.

(4) In areas where radioactive and hazardous materials are buried, surface infiltration properties of cover materials and adjacent natural soils should be studied. Efforts to reduce infiltration should then be studied

and evaluated on the basis of soil properties.

(5) Long-term rates of geologic erosion need to be estimated. The ^{10}Be method of finding the age of a landform surface shows promise. This method is about the only one currently available to determine rates of geological erosion of different soils with a reasonable degree of certainty.

(6) More soils input into the forestry plan is needed. Some soils can support a high rate of pine production, but soils that are infertile or acidic have a limited capability for high production. Other forest areas are on steep slopes, and disturbing them could generate large amounts of sediment.

(7) Some areas of the ORR may be underused. For example, the soils underlain by the Knox Group have a higher priority for intensive uses (construction, landfills and waste disposal) than for forestry and wildlife. Other areas of the ORR may be over used. Too much waste may be concentrated in an area too small for soil filtration and purification to be of maximum benefit. Some wastes, if they are to be retained in the soil, must be diluted greatly by a large volume of soil.

(8) Present methods of placing waste in soil trenches are inefficient. Too many voids and too much differential settlement exist, which leads to expensive, long-term maintenance. Filled trenches also pond water if a mounded, relatively impervious soil cap has not been placed over them.

(9) Attention should be given to controlling the use of burial grounds. Questions to be addressed include: (a) Can the surface be covered with large quarry rocks to prevent future land disturbance? (b) What should be done about long-term vegetation and its maintenance (for without periodic renewals of lime, potassium, phosphorous, and nitrogen grass will not maintain itself and eventually trees will invade)? (c) Can the land surface be altered to prevent deep rooted trees from invading and cycling radioactive ions back to the surface?

(10) Sewage sludge disposal by injection causes several problems. Sludge is rendered inert and harmless by the indigenous soil microorganisms. Consequently, a vital soil biochemical environment must be maintained if soil microbes are to destroy harmful bacteria and viruses in sewage sludge. A vigorous stand of grass must be maintained for two reasons: (a) to maintain and improve the soil microbial environment and (b) to prevent soil erosion. The current sludge disposal site is almost devoid of vegetation. If the sludge is contaminated with radionuclides and if no vegetative cover or erosion containment practices exist, then soil erosion will transport contaminants into stream floodplains.

(11) Keeping power lines cleared of brush and trees is a continuing problem because removing or killing woody vegetation with chemicals exposes the soil to erosion. Rights-of-way maintained in a thick grass sod will keep soil erosion under control and reduce maintenance costs. However, a grass sod must be fertilized periodically with nitrogen. Sludge disposal under power lines (where slopes are suitable) supplies grass with the proper nutrients. Also, a thick sod slows or

retards the invasion of woody vegetation. Where slopes are too steep, a combination grass and legume mix performs well. Native forbs are also low growing and require little maintenance. Recommendations for planting vegetation and minimizing maintenance on steep slopes are available from the Soil Conservation Service, the University of Tennessee, and the Tennessee Department of Highways.

7. COORDINATING WITH OTHER PLANS

Managing soils and planning for conservation will lead to interaction with all surface land uses on the ORR. Soil properties should be considered for some plans even if those properties are to be modified by engineering practices. For other plans in which natural and unmodified soil properties are important, this soil conservation plan must be considered in planning and management. Natural areas (about 78% of the ORR) also include zones designated by the National Environmental Research Park (NERP). These parks have been established to provide natural land for research and education in the environmental sciences.[16] A recent proposal seeks to associate the Oak Ridge Reservation's NERP with the Biome of the Great Smokies National Park and Coweeta to coordinate research across several types of geologic formations, soils, forests, and ecosystems. A detailed soils database is crucial to the transfer of research results.

The ORR also supports several rare and endangered plant species.[17] Most of these plant species live in soils of limited extent on the ORR. Additional knowledge of soils, their extent, and distribution should make possible the propagation of these plants in similar soils elsewhere on or off the ORR. Emphasizing both natural properties of soils for the NERP areas of the ORR and engineering properties of modified soils for waste burial and construction are essential objectives for current and future soils research.

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