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**WATERSHEDS OF THE OAK RIDGE RESERVATION
IN A GEOGRAPHIC INFORMATION SYSTEM**

on the World Wide Web

<http://www.ornl.gov/ceea/pubs/watersheds.html>

John Tauxe

Energy Division

May 1998

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
LOCKHEED MARTIN ENERGY RESEARCH CORP.
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REPORT BRIEF

CATEGORY: ANALYSIS AND ASSESSMENT

OAK RIDGE NATIONAL LABORATORY

ENERGY DIVISION

REPORT NUMBER ORNL/TM-13618

AUTHOR J. D. Tauxe

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Watersheds of the Oak Ridge Reservation in a Geographic Information System

This report presents a new comprehensive catalog of watershed definitions for the Oak Ridge Reservation (ORR) and surrounding areas, digitized in a geographic information system (GIS).

BACKGROUND

The ORR has been the subject of intense environmental analysis and assessment related to both its preservation of the Walker Branch watershed devoted to the purpose, and its legacy of contamination resulting from its missions in nuclear research. Hydrologic contaminant transport is based in part on an understanding of the location and behavior of local watersheds. This comprehensive inventory of watersheds on the ORR is a significant advance in providing data for performing local environmental assessments.

OBJECTIVE

The objective of this work is to produce a complete dataset of georeferenced watershed polygons for use in hydrologic and contaminant transport studies on the ORR. In addition, those areas surrounding the ORR are included in the dataset in order to provide a hydrologic and geomorphologic context.

APPROACH

The delineation of watersheds was done manually using a computer and GIS software, and professional judgement. The selection of basemaps, map scales, and digitizing techniques was based on the guidelines presented by the Natural Resources Conservation Service of the U.S. Department of Agriculture in National Instruction No. 170-304: *Mapping and Digitizing Watershed and Subwatershed Hydrologic Unit Boundaries*. Working from standard 7½-minute 1:24,000-scale quadrangle maps published by the U.S. Geological Survey, as well as the locally standard S-16A map of the Oak Ridge Area, each blue-line stream over 30 m in length was identified. Those with no tributaries were classified as order-1 streams, each with an associated order-1 watershed, or catchment area. Each of these watershed areas was carefully digitized by interpreting the 20-ft contours present on the maps. Following the classical stream-ordering process proposed by Strahler in 1952, an order-2 stream is created where two order-1 streams converge, and an order-2 watershed is identified with the order-2 stream. Similarly, an order-3 stream is created where two order-2 streams join. This process is repeated until the stream reaches the Clinch River, a major waterway which drains the entire area. The highest order reached was 6, for Poplar Creek. Each watershed of each order was digitized and color-coded to aid in interpretation of the complex maps which result when overlaying the watershed polygons.

RESULTS

The results of this work is a collection of electronically-formatted GIS polygons representing every watershed of every order occurring on the ORR and the surrounding area. The total number of digitized watersheds is over 900.

CONCLUSIONS

The completed set of watershed polygons is available in paper form in the document or electronically from either the Oak Ridge National Laboratory Shared Data Initiative or the hypertext version of the TM document, available at the address provided below. This watershed dataset is of sufficient quality to be incorporated into the National Resources Inventory.

This document is available on the World Wide Web at <http://www.ornl.gov/ceea/pubs/watersheds.html>

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This work would not have been accomplished without the aid of Walker Hofmann, who spent many days digitizing watersheds using the techniques described in the document. This work required a basic understanding of topography, stream hydrology, and geographic information systems, as well as a great deal of patience.

EXECUTIVE SUMMARY

This work develops a comprehensive set of watershed definitions for the entire Oak Ridge Reservation and surrounding area. A stream-ordering system is defined based upon the method proposed by Strahler (1952) and using 1:24,000 scale U.S. Geological Survey (USGS) topographic maps and the locally standard S-16A Map (USGS 1987) as sources for topographic contours and locations of streams as recommended by the Natural Resources Conservation Service (NRCS 1995). For each ordered stream, a contributing watershed or catchment area is delineated and digitized into a geographic information system (GIS), generating over 900 watershed polygons of various orders.

This new dataset complements a growing database of georeferenced environmental and cultural data which exist for the Oak Ridge area and are routinely used for socioeconomic and environmental analyses. Because these watersheds are now available in a GIS format, they may be used in a variety of hydrologic analyses, including rainfall/runoff modeling, development of geomorphological parameters, and the modeling of contaminant transport in surface waters. An understanding of the relationships of watersheds to sources of contamination and to administrative and political boundaries is also essential in land use planning and the organization of environmental restoration and waste management activities.

This document is available in color and with data sets in MapInfo® format on the World Wide Web at the following address:

<http://www.ornl.gov/ceea/pubs/watersheds.html>

1. INTRODUCTION

Oak Ridge Reservation (ORR) is an area of federal land in East Tennessee (Fig. 1), currently under the stewardship of the U.S. Department of Energy (DOE). The ORR hosts three major installations: Oak Ridge National Laboratory, the Y-12 Plant, and the East Tennessee Technology Park (ETTP). A large amount of the land is undeveloped and is included in the 90-km² (22,000-acre) Oak Ridge National Environmental Research Park. The total area of the ORR is about 140 km² (34,500 acres), with the valley-and-ridge physiography typical of the Tennessee Valley. The 30-year average annual precipitation of 1.4 m (55 in.) coupled with the intricate topography of the Tennessee Valley (Fig. 2) has produced an intricate network of streams (Fig. 3) and associated watersheds, and the natural environment of the region is understandably driven by water. Although some of these streams and watersheds are undeveloped, many are extensively contaminated by the activities at the ORR facilities. Contaminants include radionuclides, heavy metals, and organic compounds, the environmental transport of which is also dominated by local hydrologic processes.

The ORR lies entirely within the drainage area of the Clinch River, which has a total area of about 9140 km² (3530 mi²). This area is contained in the Tennessee Hydrologic Region (Region 06) as designated by the U.S. Geological Survey (USGS), Subregion 0601 (Upper Tennessee), and Accounting Unit 060102 (Upper Tennessee). The 8-digit hydrologic unit code for the region containing the ORR is Cataloging Unit 06010207 — the Lower Clinch hydrologic unit. Upstream of the Lower Clinch is the Upper Clinch (06010205) and the Powell (06010206) hydrologic units, both of which contribute waters to the Clinch as it flows by the ORR (Seaber *et al.* 1987).

Studies involving watershed dynamics, such as water budget development and contaminant transport analysis, hinge on an understanding of watershed and stream topology, among other things. In general, hydrologic analysis requires a variety of spatially distributed information concerning the occurrence of precipitation, the materials on which it falls, and pathways of water flow. Although the characterization of precipitation is principally a meteorological problem, the behavior of surface waters is a matter of hydrology and geomorphology, including characterization of stream networks and other surface water features, description of land forms, soil types, and land use patterns, as well as the delineation of watersheds.

Recent advances in the use of geographic information systems (GIS) for hydrologic analysis make use of spatially encoded (georeferenced) data and allow for the automation of computational tasks, enabling analysis of large areas using detailed datasets and calculations. The present work contributes to a growing collection of hydrologic information a comprehensive dataset of delineated watershed locations and outlines in the form of GIS polygons, for the ORR and surrounding areas. This work was done using guidelines set forth by the Natural Resources Conservation Service (formerly the Soil Conservation Service) of the U.S. Department of Agriculture in National Instruction No. 170-304 (NI 170-304), *Mapping and Digitizing Watershed and Subwatershed Hydrologic Unit Boundaries* (NRCS 1995). A local standard map of the ORR [known

Fig. 1. Location map for Oak Ridge Reservation (modified from ORNL DWG 93M-9616R3).

as the S-16A Map (USGS 1987)] and the relevant USGS 1:24,000 quadrangles were used as basemaps for topographic and blue line stream data (as shown in Fig. 2 and Fig. 3), and a progression of watersheds corresponding to all Strahler stream orders was constructed, providing information for hydrologic analysis at a variety of scales.

1.1 PURPOSE

The purpose of this document is to present a newly developed dataset of watershed polygons to the hydrologic research community. This dataset complements a growing database of georeferenced environmental and cultural data which exist for the Oak Ridge area and are routinely used for socioeconomic and environmental analyses. Because these watersheds are now available in a GIS format, they may be used in a variety of hydrologic analyses, including rainfall/runoff modeling, development of geomorphological parameters such as stream order/channel length/drainage area relationships, and upstream/downstream tracing of contaminants. An understanding of the relationships of watersheds to sources of contamination and to administrative and political boundaries is also essential in land use planning and the organization of environmental restoration and waste management activities.

1.2 PROGRAMMATIC BACKGROUND

The motivation for this watershed delineation exercise stems from regulatory requirements to perform both localized and reservation-wide assessments of the potential effects and risks from past and current contamination of the environment (DOE 1996a, 1996b, 1996c). Such assessments are largely dependent on an understanding of environmental processes, including surface water contamination and transport. These assessments include remedial investigations, feasibility studies, performance assessments, risk assessments, and composite analyses, in addition to basic environmental science research.

Waste has been intentionally and unintentionally released to the ground across the ORR (Coobs and Gissel 1986), and potential exposures to the public now and in the future are a growing concern. Although current exposure levels at publicly-accessible locations can be assessed via monitoring of environmental media (as in DOE 1997a), the sources of contamination are often not readily identifiable. With the aid of a map of watersheds, however, the surface waters and land areas that contribute to any given water source are more readily recognized. With this information, potential contaminant sources may be identified and monitoring systems may be designed.

Similarly, the fate and transport of contaminants from known or proposed sources (e.g. spill locations, waste disposal areas, and industrial waste outfalls) may be estimated with the aid of stream and watershed information. This transport analysis is fundamental to performance assessment in support of existing or planned waste disposal activities. The inherent linkages of watersheds and surface water networks are apparent only when they are viewed in their natural spatial relationships and are a critical part of understanding how contaminants disperse, overlap, and collect in the local hydrologic system.

Fig. 2. Topography of the Oak Ridge S-16A area.

Fig. 3. Streams and rivers of the Oak Ridge S-16A area.

2. WATERSHEDS

As a naturally-occurring feature of the surface of the earth, watersheds provide a convenient unit of study, both as a basis for hydrologic science and for the assessment of environmental quality. This section defines a watershed and introduces concepts of environmental modeling using the watershed as a fundamental organizational and analytical unit.

2.1 DEFINITION OF A WATERSHED

A watershed—also known as a hydrologic unit, catchment, or drainage basin—is simply that area of land draining into a particular stream or other surface water body. For any location in a stream, there is an associated area of land which contributes water to its flow and to all points upstream of the given location. The watershed divide is that line over the land which divides land contributing water to the stream and land which contributes water to neighboring streams or water bodies. Hence, each watershed is defined by its outlet or pour point (that point in the stream which receives all water in the watershed) and the associated watershed divide derived from that point and the local topography.

The organization and execution of this project revolves around two principles: Watersheds are defined by their outlet, and watersheds are separated by divides, which are based on local topography. Working from maps of streams and topography (as in Fig. 2 and Fig. 3), one can derive watershed areas by identifying that region which contributes to water flowing past any given point. This defining of watershed polygons is the core of this work.

2.2 STREAM AND WATERSHED ORDERING

In general, any point in a stream has a watershed associated with it, but in practical terms this axiom does not in itself lead to well-organized study. An organization of watersheds can be accomplished by borrowing a concept from the topology of streams: stream ordering. This classification scheme, which makes use of the natural branching in a stream network, was first introduced by Strahler (1952).

A presentation of this method of ordering streams requires some basic definitions. For the purposes of this report, a stream is identified by a blue line on the S-16A Map or on the corresponding USGS 7½-minute quadrangle map (1:24,000 scale), as required by NI 170-304 SubPart C, 304.20(a) (NRCS 1995). The smallest streams have no tributaries, and the largest streams of the ORR discharge directly to the Clinch River. Every stream on the map can be ordered as long as its furthest upstream extent is known. This ordering was completed for all streams over 30 m (100 ft) in length on the S-16A Map with the aid of surrounding USGS quadrangle maps, but was not done for the Clinch River itself, because of the large area drained by it.

The method of stream ordering used was adopted from Horton's (1945) quantitative study of stream networks as slightly modified by Strahler (1952). From Chow *et al.* (1988), the basic rules of Strahler stream ordering (Fig. 4) are as follows:

- The smallest recognizable channels are designated order 1; these channels normally flow only during wet weather.
- Where two channels of order 1 join, a channel of order 2 results downstream; in general, where two channels of order i join, a channel of order $i + 1$ results.
- Where a channel of lower order joins a channel of higher order, the channel downstream retains the higher of the two orders.
- The order of the drainage basin is designated as the order of the stream draining its outlet, the highest stream order in the basin, I .

The ordering of watersheds follows the ordering of the streams which drain them. If the outlet of an order i stream is that point where it joins another stream of order i or higher, an order i watershed corresponding to that stream can be derived from the surrounding topography. Although each reach of a stream will have a unique order, each area of land may belong to more than one order of watershed. In general, any order i watershed will contain at least two watersheds of order $i - 1$, and each order i watershed will be contained in some watershed of higher order (see Fig. 5).

2.3 TOPOGRAPHIC DELINEATION

The topographic delineation of watershed boundaries (drainage divides) is based on the principle that water flows downhill. The outlet for the watershed is the lowest point along the boundary and is usually located at the confluence of one stream with another, but it may also coincide with the location of a dam, weir, or stream gauge. All the watersheds presented here are indexed to locations where one stream (or creek) joins another as a tributary, in conformance with NI 170-304 SubPart C, 304.21(b) (NRCS 1995). Starting at the outlet, the boundary follows the line of steepest ascent, working its way up a slope or to a ridgeline, and crossing all topographic contours perpendicularly. When working from a topographic base map, it is useful to imagine that one is walking up the slope, maintaining the steepest ascent so that the ground falls away to both sides of the path. At times, ambiguities such as triple points and peaks will present themselves, but the correct choice of path can always be determined by reviewing the contours of the surrounding region. Often, the delineation will have to proceed up from the outlet in both directions until closure is reached.

Limitations to this method are met in flat ground, where contours are widely spaced and a clear direction of the topographic gradient is not apparent. While this is rarely a problem in the Oak Ridge area, it did present a challenge in the central part of the City of Oak Ridge. The ambiguities imposed by flatness were compounded by the changes in drainage patterns caused by urbanization. Changes in the grading of the ground surface, stream channelization, and the addition of storm sewers and detention ponds causes changes in the shape and behavior of watersheds. Because these

Fig. 4. Strahler stream ordering of White Oak Creek.

First-order watersheds are shaded.

Second-order watersheds (shaded) contain at least two first-order watersheds (outlined).

Third-order watershed (shaded) contains at least two second-order watersheds (outlined).

Fig. 5. An example of the hierarchical nesting of watersheds. A watershed of order i contains at least two watersheds of order $i - 1$.

details are beyond the scope of this study, the watersheds in the vicinity of the City of Oak Ridge are not considered to be accurate on a fine scale.

The principal basemap of stream locations and topographic contours used for this study is the S-16A Map of the Oak Ridge area (USGS 1987). This map has been electronically encoded into a GIS, and was accessed using the MapInfo® GIS software. Other reference maps used include the declassified 1959 version of the S-16A Map (USACE 1959) and the USGS topographic 7½-minute quadrangles for Petros, Windrock, Clinton, Powell, Elverton, Bethel Valley, Lovell, Bearden, Cave Creek, Lenoir City, and Concord Tennessee, all at 1:24,000 scale (see Fig. 6). The electronic basemap used for digitizing watershed boundaries has 20-ft contours and streams and other watercourses for the S-16A area. Detailed correlation of the electronic and printed versions was very good, with only a handful of inconsistencies which were easily remedied. The printed USGS maps were used as the definitive source of data where these minor irregularities existed.

Fig. 6. Location of the S-16A Map (rotated rectangle) with respect to USGS 7½-minute quadrangle maps in east Tennessee.

2.4 THE WATERSHED AS A UNIT FOR ENVIRONMENTAL MODELING

The definition of a watershed is based on natural topologic and hydrologic phenomena and is an appropriate basis for hydrologic modeling. Water originates as precipitation falling on the catchment area and collects as it flows to the outlet of the watershed. In the stream network, the mixing of surface waters and the contaminants they contain can be followed as streams join and increase in order. This conceptual model of the flow of water is intuitive, robust, and appealing.

The classification of streams and watersheds into orders also is convenient for studying hydrologic phenomena at a variety of scales. For example, a study could be made to evaluate the amount of contamination which might be expected to appear in a creek neighboring a waste burial ground within a single small watershed. On a larger scale, an evaluation could be made concerning the contamination resulting from an entire plant, or even the entire ORR. As a further example, by understanding the linkages between watersheds and subwatersheds, one can see that while the Y-12 Plant and the ETTP are in separate subwatersheds, they are in the same major watershed and as a result their respective surface water contamination is commingled. This "watershed approach" for organizing environmental analyses is gaining acceptance at DOE sites as the validity of the concept becomes recognized by decision makers.

Several local studies have made use of the watershed approach, including the *Composite Analysis for Solid Waste Storage Area 6* (ORNL 1997), which considers the fate of radioactive wastes in the White Oak Creek watershed as required in DOE's *Implementation Plan, Defense Nuclear Facilities Safety Board Recommendation 94-2, Conformance with Safety Standards at Department of Energy Low-Level Nuclear Waste and Disposal Sites* (DOE 1996a) using the *Guidance for a Composite Analysis of the Impact of Interacting Source Terms on the Radiological Protection of the Public from Department of Energy Low-Level Waste Disposal Facilities* (DOE 1996b).

Other investigations have used a similar approach but with watersheds defined in a non-traditional way, including the *Remedial Investigation Report on the Melton Valley Watershed at Oak Ridge National Laboratory, Oak Ridge, Tennessee* (DOE 1997b) and the upcoming Remedial Investigation of the Bethel Valley Watershed. Despite its title, the latter work actually spans parts of three watersheds represented in Bethel Valley: White Oak Creek, Raccoon Creek, and Bearden Creek watersheds.

Similar investigations are ongoing in the East Fork Poplar Creek subwatershed, which contains both the Y-12 Plant and the ETTP.

3. GEOGRAPHIC INFORMATION SYSTEMS

Although watershed delineation can often be done simply with a topographic map and a pencil, the product cannot be readily used in quantitative hydrologic analysis. The advent of GIS, however, has made the exercise both easier to accomplish and significantly more useful to hydrologists. Current research in environmental modeling in GIS is making comparatively easy and rapid work of hydrologic analyses which would be far too time consuming and tedious to be attempted by hand.

The term "geographic information system" requires definition. In its broadest sense, it can mean an entire complex of organizations, personnel, databases, hardware, and software used to process geographic information. Burrough (1993) uses the term to indicate a set of hardware and software tools for storing, retrieving, analyzing, and displaying spatial data. More recently, GIS is used to identify the software alone, and it is in this sense used in this work. Obviously, the software cannot be used without the hardware, but it has become rather hardware independent, capable of running on several platforms.

The specific abilities defining a modern GIS are further clarified by Goodchild (1993): A GIS should have the ability to preprocess data from large stores into a form suitable for analysis, including such operations as reformatting, change of projection, resampling, and generalization. It should have direct support for analysis and modeling, such that forms of analysis, calibration of models, forecasting, and prediction are all handled through instructions to the GIS. And finally, a GIS should handle postprocessing of results, including such operations as reformatting, tabulation, report generation, and mapping.

GIS are used in several professional disciplines that require georeferenced data, including cartography, surveying, remote sensing, image processing, geodesy, demography, and more recently hydrology, geoscience and environmental modeling.

For reasons of expense and compatibility with ongoing local GIS projects, MapInfo® was selected as the GIS for producing these watersheds. Translation from MapInfo® tables into common drafting or other GIS formats and coordinate systems is readily done.

3.1 ENVIRONMENTAL MODELING IN GIS

With a growing public perception of adverse changes in the global environment, a great deal of attention has been paid to environmental modeling and information analysis. Global climate studies have drawn together experts from such diverse disciplines as earth and environmental sciences, remote sensing, computer science, civil engineering, and public policy. As each learns more about the others' practice and techniques, new ideas and applications are born. With this interaction, the role of GIS in environmental modeling is that of a bridge between the technically oriented scientists and engineers and the socially oriented policymakers.

In GIS, the unifying concept is one of location, extended to include spatial distribution and the relationships between spatial entities. In environmental modeling, the fundamental entity is one of state, modified by processes of interaction and dynamics. Environmental modeling in a GIS requires an integration of these representations of reality.

As GIS grow beyond its traditional tasks of storing, processing, and presenting static geographic data, researchers in a range of professional fields have become interested in the potential of environmental modeling in GIS to enhance our understanding of the natural world, and to help us manage our activities within it. This need is expressed concisely by Steyaert (1993):

Computer-based, mathematical models that realistically simulate spatially distributed, time-dependent environmental processes in nature are increasingly recognized as fundamental requirements for the reliable, quantitative assessment of complex environmental issues of local, regional, and global concern. These environmental simulation models provide diagnostic and predictive outputs that can be combined with socioeconomic data for assessing local and regional environmental risk or natural resource management issues.

More recently, the importance of scientific models for the assessment of potential global environmental problems, including regional response to global change, has been illustrated by the National Research Council, Earth System Sciences Committee, International Council of Scientific Unions, International Geosphere-Biosphere Programme, and Committee on Earth Sciences.

3.2 GIS DATA TYPES

GIS are designed to operate on two classes of data: vector and raster. A vector GIS recognizes three fundamental data types: points, lines, and polygons. Most geographic features can be described using these data types, and they lend themselves well to storage in a structured query language and database. However, some geographically significant information is better described by a raster dataset or image, such as an aerial photograph or a continuously varying field of data, such as precipitation or soil thickness. By combining raster and vector GIS, we can give geographical significance to our hydrologic models by, for example, overlaying a map of ground surface contamination with land use polygons, streams, and point locations of measurements.

All GIS software share the common functions of a spatial database and analysis system. To different degrees, they are able to handle a variety of data by indexing to an attribute common to all spatial data: location. How these data are stored and analyzed differs between systems, with a primary differentiation being vector *versus* raster data. Goodchild (1993) classifies GIS data into six types, or models: (1) irregular point sampling, such as wells or weather stations; (2) regular point sampling, such as digital elevation models; (3) lines and polylines (series of connected line segments), such as topographic contour lines and streams; (4) polygons, such as soil maps, watersheds, and municipal zoning maps; (5) triangular irregular networks such as elevation models; and (6) cell grids, such as photogrammetric maps and finite difference grids. GIS excels in the ability to convert between these disparate data types. Their integration is a primary function of the GIS.

3.3 STREAMS AS GIS NETWORKS

A useful tool available in many GIS is the network. A geographic network is collection of linked items, usually linear in nature, which have as an attribute connectivity to other geographic entities. This connectivity is usually expressed in the form of FROM and TO nodes along a polyline, implying not only connectivity but direction. Such a representation is ideal for stream networks, which have a true and distinct connectivity and flow direction in the real world, and are modeled well as a GIS network. Tributaries are linked to larger streams which are linked to major channels, and so on to the ocean. Establishing this connectivity, and the stream ordering which follows naturally from it, has not been done for the ORR, and is a target for future work. In addition, stream reaches could be assigned other attributes such as channel width and height, to aid in geomorphological studies.

3.4 THE GIS MODEL OF A WATERSHED

The GIS representation of a watershed is based naturally on the polygon. In this work, watershed polygons are two-dimensional entities, as represented on a flat map. In reality, watersheds are inherently three-dimensional, a property which may be reflected in other GIS entities, such as contour lines with attributed values of elevation. The current standard in GIS is to preserve only two dimensions of data, but there are ways to work around this limitation. As a GIS polygon, the watershed has an area and perimeter length, and can be further assigned attributes for Strahler order and name. In this work, these attributes are incorporated into the name of the coverage (or MapInfo table) which contains the watersheds. Future work could enhance the attributes to include these data for ease of manipulation by query.

4. WATERSHEDS OF OAK RIDGE RESERVATION

This section introduces the new GIS dataset of watersheds of the ORR. This comprehensive collection of georeferenced polygons represents every watershed on the S-16A Map (USGS 1987), from the largest primary watersheds (those discharging directly to the Clinch River) to blue-line streams as small as 30 m in length. The collection is organized into MapInfo tables, indexed by primary watershed name and by order.

The primary area of interest to researchers working on DOE land is the ORR itself, identified in Fig. 2. For the sake of completeness, however, all watersheds on the S-16A Map were delineated. This includes several significant watersheds surrounding and contributing to those found on the ORR, especially those to the north (e.g., Poplar Creek and Brashear Creek). In general, watersheds across the Clinch River from the ORR are of little use in environmental modeling on the ORR itself.

4.1 DELINEATED WATERSHEDS

Over 900 watersheds were delineated for this work. Of these, 693 are of order 1, 173 of order 2, 38 of order 3, 9 of order 4, 3 of order 5, and 1 of order 6. The size of this dataset is sufficient to demonstrate some basic "laws" of geomorphology. For example, Horton (1945) found that the bifurcation ratio R_b of the number N_i of stream channels to the number N_{i+1} of channels $i + 1$ is fairly constant between orders, and that common values for R_b are between 3 and 5. Horton's Law of Stream Numbers is thus expressed as

$$\frac{N_i}{N_{i+1}} = R_b \quad i = 1, 2, 3, \dots, I-1,$$

where I is the highest order in the basin. This law is well illustrated by the ORR streams as well, as shown in Fig. 7. The fractal bifurcation ratio R_b for watersheds in the ORR is 3.36. Horton also proposed an analogous Law of Stream Lengths, and Schumm (1956) a Law of Stream Areas, with similarly derived fractal dimensions. By extrapolating from the orders and areas of the watersheds in this dataset, the Clinch River (with a drainage area of 9140 km²) is estimated to be of order 9.

The naming convention used for the watershed table files is straightforward, based on a concatenation of identifiers. In keeping with the conventions of ORNL's Shared Data Initiative to distinguish coordinate systems, the file names begin with "a", which stands for "administrative grid" — the coordinate system introduced for the S-16A Map, and which is shared for the entire ORR. Other local coordinate systems on the ORR exist for historical reasons, and are identified by other letters ("t" for Tennessee State Plane, or "x" for the X-10 Site, for example).

Following the "a" are the letters "ws" for "watershed." Next are up to four letters used to

Fig. 7. Horton's Law of Stream Numbers applied to Oak Ridge area streams.

identify the stream draining the primary watershed, such as "pop" for Poplar Creek, or "walk" for Walker Branch. Generally, watersheds were given names if they drained directly into the Clinch River. Additional subdivisions were made in the case of two subwatersheds of Poplar Creek: East Fork Poplar Creek and its subwatershed Bear Creek are intensely studied entities unto themselves. Names of surface water features were obtained from the S-16A Map when available. In the few cases where no name appeared on the map, a name was assigned based on a nearby feature, such as a road (example: "Gallaher watershed" named for Gallaher Road). If a minor (order 1 or 2) unnamed stream drained directly into the Clinch, it was added to the "misc" dataset.

Finally, a single numeral indicates the order of the subwatershed within the named watershed. A complete example is, then, "awspop2.tab" which identifies a MapInfo table showing the order 2 watersheds for Poplar Creek, in the ORR administrative grid coordinate system. A complete index of the watershed names is presented in Table 1.

In addition to the file naming conventions, a system of polygon coloring was developed to visually distinguish the watersheds when they are combined on a map. The result is a complex coloring scheme which maintains the relationships of all subwatersheds of the same order in a named watershed (for example, order 1 subwatersheds in the Poplar Creek watershed are in various shades of green) yet distinguishes between orders in that watershed (order 2 subwatersheds are shades of orange, 3 purple, 4 yellow, 5 red, and 6 turquoise) and between adjacent watersheds. This coloring will not be apparent when viewing a printed version of the watershed maps in grayscale, unfortunately.

An index map of the watersheds listed in Table 1 is provided in Fig. 8.

**Table 1. Index of names for the watersheds on or near
Oak Ridge Reservation**

File name (# is the order)	Watershed name	Highest order	Figure index
awsbear#	Bear Creek ^a	4	Fig. 30 – Fig. 53
awsbrdn#	Bearden Creek	3	Fig. 9 – Fig. 11
awsbevr#	Beaver Creek ^b	5 ^c	Fig. 65 – Fig. 68
awsbras#	Brashear Creek ^b	3	Fig. 69 – Fig. 71
awscany#	Caney Creek ^b	3	Fig. 72 – Fig. 74
awsconr#	Conner Creek ^b	4	Fig. 75 – Fig. 78
awsefpc#	East Fork Poplar Creek ^a	5	Fig. 30 – Fig. 53
awsgall#	Gallaher ^{b,d}	3	Fig. 79 – Fig. 81
awsgras#	Grassy Creek	3	Fig. 12 – Fig. 14
awshndx#	Hendrix Creek ^b	3	Fig. 82 – Fig. 84
awshick#	Hickory Creek ^b	3	Fig. 85 – Fig. 87
awsking#	Kings Creek ^b	3	Fig. 88 – Fig. 90
awsmcoy#	McCoy Branch	3	Fig. 15 – Fig. 17
awsmisc#	miscellaneous	2	Fig. 18 – Fig. 29
awspaw#	Pawpaw Creek ^b	4	Fig. 91 – Fig. 94
awspop#	Poplar Creek ^e	6	Fig. 30 – Fig. 53
awspspr#	Poplar Springs Creek ^b	3	Fig. 95 – Fig. 97
awsscar#	Scarboro Creek	4	Fig. 54 – Fig. 57
awswalk#	Walker Branch	3	Fig. 58 – Fig. 60
awswhse#	Warehouse ^{b,d}	3	Fig. 98 – Fig. 100
awswoc#	White Oak Creek	4	Fig. 61 – Fig. 64

^a Subwatershed of Poplar Creek.

^b Watershed is outside the ORR, but is represented on the S-16A Map.

^c No order 4 subwatersheds of Beaver Creek appear on the S-16A Map.

^d Unofficial name assigned, since there is no official mapped name.

^e Maps of Poplar Creek watershed are distributed over four panels because of its large size.

4.2 WATERSHEDS ON OR CONTRIBUTING TO THE ORR

In the following Fig. 9 – Fig. 64 are displayed those watersheds named in Table 1 which are contained wholly within the ORR or contribute to surface waters on the ORR. Except for Poplar Creek watershed, all of these are represented in their entirety in this dataset.

4.3 WATERSHEDS DISTINCT FROM THE ORR

The watersheds shown in Fig. 65 – Fig. 100 are hydrologically distinct from the lands of the ORR. Nevertheless, they are included here for two reasons: (1) they appear on the S-16A Map, and (2) technically, the ORR does include parts of the Clinch River, to which these watersheds contribute. In general, these watersheds are truncated by the boundaries of the S-16A Map.

Index of Major Watersheds of the Oak Ridge Area

Fig. 8. An index of primary watersheds of the Oak Ridge area.

Bearden Creek Watershed

Fig. 9. Order 3 Bearden Creek watershed.

Order 2 Watersheds within Bearden Creek Watershed

Fig. 10. Order 2 Bearden Creek watersheds.

Order 1 Watersheds within Bearden Creek Watershed

Fig. 11. Order 1 Bearden Creek watersheds.

Grassy Creek Watershed

ORR GRID
NORTH

Scale
1:24,000

Fig. 12. Order 3 Grassy Creek watershed.

Order 2 Watersheds within Grassy Creek Watershed

Clinch River

ORR GRID
NORTH

Scale
1:24,000

Fig. 13. Order 2 Grassy Creek watersheds.

Order 1 Watersheds within Grassy Creek Watershed

Fig. 14. Order 1 Grassy Creek watersheds.

McCoy Branch Watershed

Fig. 15. Order 3 McCoy Branch watershed.

Order 2 Watersheds within McCoy Branch Watershed

Fig. 16. Order 2 McCoy Branch watersheds.

Order 1 Watersheds within McCoy Branch Watershed

Fig. 17. Order 1 McCoy Branch watersheds.

Miscellaneous Order 2 Watersheds of the Clinch River

Fig. 18. Order 2 miscellaneous Clinch River watersheds, river miles 9 - 15.

Miscellaneous Order 2 Watersheds of the Clinch River

Fig. 19. Order 2 miscellaneous Clinch River watersheds, river miles 15 - 23.

Miscellaneous Order 2 Watersheds of the Clinch River

Fig. 20. Order 2 miscellaneous Clinch River watersheds, river miles 23 - 34.

Miscellaneous Order 2 Watersheds of the Clinch River

ORR GRID
NORTH

TRUE
NORTH

Scale
1:48,000

River mile 34 - 42

Fig. 21. Order 2 miscellaneous Clinch River watersheds, river miles 34 - 42.

Miscellaneous Order 2 Watersheds of the Clinch River

ORR GRID
NORTH

TRUE
NORTH

Scale
1:48,000

River mile 42 - 49

Fig. 22. Order 2 miscellaneous Clinch River watersheds, river miles 42 - 49.

Miscellaneous Order 2 Watersheds of the Clinch River

Fig. 23. Order 2 miscellaneous Clinch River watersheds, river miles 49 - 53.

Miscellaneous Order 1 Watersheds of the Clinch River

Fig. 24. Order 1 miscellaneous Clinch River watersheds, river miles 9 - 15.

Miscellaneous Order 1 Watersheds of the Clinch River

Fig. 25. Order 1 miscellaneous Clinch River watersheds, river miles 15 - 23.

Miscellaneous Order 1 Watersheds of the Clinch River

Fig. 26. Order 1 miscellaneous Clinch River watersheds, river miles 23 - 34.

Miscellaneous Order 1 Watersheds of the Clinch River

ORR GRID
NORTH

TRUE
NORTH

Scale
1:48,000

River mile 34 - 42

Fig. 27. Order 1 miscellaneous Clinch River watersheds, river miles 34 - 42.

Miscellaneous Order 1 Watersheds of the Clinch River

ORR GRID
NORTH

TRUE
NORTH

Scale
1:48,000

River mile 42 - 49

Fig. 28. Order 1 miscellaneous Clinch River watersheds, river miles 42 - 49.

Miscellaneous Order 1 Watersheds of the Clinch River

Fig. 29. Order 1 miscellaneous Clinch River watersheds, river miles 49 - 53.

Poplar Creek Watershed

Fig. 30. Order 6 Poplar Creek watershed, western section.

Poplar Creek Watershed

Fig. 31. Order 6 Poplar Creek watershed, west central section.

Poplar Creek Watershed

Fig. 32. Order 6 Poplar Creek watershed, east central section.

Poplar Creek Watershed

Fig. 33. Order 6 Poplar Creek watershed, eastern section.

Order 5 Watersheds within Poplar Creek Watershed

Fig. 34. Order 5 Poplar Creek watersheds, western section.

Order 5 Watersheds within Poplar Creek Watershed

Fig. 35. Order 5 Poplar Creek watersheds, west central section.

Order 5 Watersheds within Poplar Creek Watershed

Fig. 36. Order 5 Poplar Creek watersheds, east central section.

Order 5 Watersheds within Poplar Creek Watershed

Fig. 37. Order 5 Poplar Creek watersheds, eastern section.

Order 4 Watersheds within Poplar Creek Watershed

Fig. 38. Order 4 Poplar Creek watersheds, western section.

Order 4 Watersheds within Poplar Creek Watershed

Fig. 39. Order 4 Poplar Creek watersheds, west central section.

Order 4 Watersheds within Poplar Creek Watershed

Fig. 40. Order 4 Poplar Creek watersheds, east central section.

Order 4 Watersheds within Poplar Creek Watershed

Fig. 41. Order 4 Poplar Creek watersheds, eastern section.

Order 3 Watersheds within Poplar Creek Watershed

Fig. 42. Order 3 Poplar Creek watersheds, western section.

Order 3 Watersheds within Poplar Creek Watershed

Fig. 43. Order 3 Poplar Creek watersheds, west central section.

Order 3 Watersheds within Poplar Creek Watershed

Fig. 44. Order 3 Poplar Creek watersheds, east central section.

Order 3 Watersheds within Poplar Creek Watershed

Fig. 45. Order 3 Poplar Creek watersheds, eastern section.

Order 2 Watersheds within Poplar Creek Watershed

Fig. 46. Order 2 Poplar Creek watersheds, western section.

Order 2 Watersheds within Poplar Creek Watershed

Fig. 47. Order 2 Poplar Creek watersheds, west central section.

Order 2 Watersheds within Poplar Creek Watershed

Fig. 48. Order 2 Poplar Creek watersheds, east central section.

Order 2 Watersheds within Poplar Creek Watershed

Fig. 49. Order 2 Poplar Creek watersheds, eastern section.

Order 1 Watersheds within Poplar Creek Watershed

Fig. 50. Order 1 Poplar Creek watersheds, western section.

Order 1 Watersheds within Poplar Creek Watershed

Fig. 51. Order 1 Poplar Creek watersheds, west central section.

Order 1 Watersheds within Poplar Creek Watershed

Fig. 52. Order 1 Poplar Creek watersheds, east central section.

Order 1 Watersheds within Poplar Creek Watershed

Fig. 53. Order 1 Poplar Creek watersheds, eastern section.

Scarboro Creek Watershed

Fig. 54. Order 4 Scarboro Creek watershed.

Order 3 Watersheds within Scarboro Creek Watershed

Fig. 55. Order 3 Scarboro Creek watersheds.

Order 2 Watersheds within Scarboro Creek Watershed

Fig. 56. Order 2 Scarboro Creek watersheds.

Order 1 Watersheds within Scarboro Creek Watershed

Fig. 57. Order 1 Scarboro Creek watersheds.

Walker Branch Watershed

Fig. 58. Order 3 Walker Branch watershed.

Order 2 Watersheds within Walker Branch Watershed

Fig. 59. Order 2 Walker Branch watersheds.

Order 1 Watersheds within Walker Branch Watershed

Fig. 60. Order 1 Walker Branch watersheds.

White Oak Creek Watershed

ORR GRID
NORTH

Scale
1:48,000

Fig. 61. Order 4 White Oak Creek watershed.

Order 3 Watersheds within White Oak Creek Watershed

Fig. 62. Order 3 White Oak Creek watersheds.

Order 2 Watersheds within White Oak Creek Watershed

Fig. 63. Order 2 White Oak Creek watersheds.

Order 1 Watersheds within White Oak Creek Watershed

Beaver Creek Watershed

ORR GRID
NORTH

Scale
1:48,000

Fig. 65. Order 5 Beaver Creek watershed.

Order 3 Watersheds within Beaver Creek Watershed

ORR GRID
NORTH

Scale
1:48,000

Fig. 66. Order 3 Beaver Creek watersheds.

Order 2 Watersheds within Beaver Creek Watershed

ORR GRID
NORTH

Scale
1:48,000

Fig. 67. Order 2 Beaver Creek watersheds.

Order 1 Watersheds within Beaver Creek Watershed

ORR GRID
NORTH

Scale
1:48,000

Fig. 68. Order 1 Beaver Creek watersheds.

Brashear Creek Watershed

83

ORR GRID
NORTH

Scale
1:24,000

Fig. 69. Order 3 Brashear Creek watershed.

Order 2 Watersheds within Brashear Creek Watershed

Fig. 70. Order 2 Brashear Creek watersheds.

Order 1 Watersheds within Brashear Creek Watershed

85

ORR GRID.
NORTH

Scale
1:24,000

Fig. 71. Order 1 Brashear Creek watersheds.

Caney Creek Watershed

Fig. 72. Order 3 Caney Creek watershed.

Order 2 Watersheds within Caney Creek Watershed

87

ORR GRID
NORTH

Scale
1:48,000

Fig. 73. Order 2 Caney Creek watersheds.

Order 1 Watersheds within Caney Creek Watershed

Fig. 74. Order 1 Caney Creek watersheds.

Conner Creek Watershed

ORR GRID
NORTH

Scale
1:48,000

Fig. 75. Order 4 Conner Creek watershed.

Order 3 Watersheds within Conner Creek Watershed

ORR GRID
NORTH

Scale
1:48,000

Fig. 76. Order 3 Conner Creek watersheds.

Order 2 Watersheds within Conner Creek Watershed

ORR GRID
NORTH

TRUE
NORTH

Scale
1:48,000

Fig. 77. Order 2 Conner Creek watersheds.

Order 1 Watersheds within Conner Creek Watershed

Fig. 78. Order 1 Conner Creek watersheds.

Gallaher Watershed

ORR GRID
NORTH

Scale
1:24,000

Fig. 79. Order 3 Gallaher watershed.

Order 2 Watersheds within Gallaher Watershed

Order 1 Watersheds within Gallaher Watershed

ORR GRID
NORTH

Scale
1:24,000

Fig. 81. Order 1 Gallaher watersheds.

Hendrix Creek Watershed

96

ORR GRID
NORTH

Scale
1:24,000

Fig. 82. Order 3 Hendrix Creek watershed.

Order 2 Watersheds within Hendrix Creek Watershed

97

ORR GRID
NORTH

Scale
1:24,000

Fig. 83. Order 2 Hendrix Creek watersheds.

Order 1 Watersheds within Hendrix Creek Watershed

ORR GRID
NORTH

Scale
1:24,000

Fig. 84. Order 1 Hendrix Creek watersheds.

Hickory Creek Watershed

Fig. 85. Order 3 Hickory Creek watershed.

Order 2 Watersheds within Hickory Creek Watershed

100

ORR GRID
NORTH

Scale
1:72,000

Fig. 86. Order 2 Hickory Creek watersheds.

Order 1 Watersheds within Hickory Creek Watershed

Fig. 87. Order 1 Hickory Creek watersheds.

Kings Creek Watershed

ORR GRID
NORTH

Scale
1:24,000

Fig. 88. Order 3 Kings Creek watershed.

Order 2 Watersheds within Kings Creek Watershed

Scale
1:24,000

ORR GRID
NORTH
TRUE
NORTH

Fig. 89. Order 2 Kings Creek watersheds.

Order 1 Watersheds within Kings Creek Watershed

ORR GRID
NORTH

Scale
1:24,000

Fig. 90. Order 1 Kings Creek watersheds.

Pawpaw Creek Watershed

ORR GRID
NORTH

TRUE
NORTH

Scale
1:48,000

Fig. 91. Order 4 Pawpaw Creek watershed.

Order 3 Watersheds within Pawpaw Creek Watershed

Fig. 92. Order 3 Pawpaw Creek watersheds.

Order 2 Watersheds within Pawpaw Creek Watershed

Fig. 93. Order 2 Pawpaw Creek watersheds.

Order 1 Watersheds within Pawpaw Creek Watershed

Fig. 94. Order 1 Pawpaw Creek watersheds.

Poplar Springs Creek Watershed

ORR GRID
NORTH

TRUE
NORTH

Scale
1:24,000

Fig. 95. Order 3 Poplar Springs Creek watershed.

Order 2 Watersheds within Poplar Springs Creek Watershed

Fig. 96. Order 2 Poplar Springs Creek watersheds.

Order 1 Watersheds within Poplar Springs Creek Watershed

III

ORR GRID
NORTH

Scale
1:24,000

Fig. 97. Order 1 Poplar Springs Creek watersheds.

Warehouse Watershed

ORR GRID
NORTH

Scale
1:24,000

Fig. 98. Order 3 Warehouse watershed.

Order 2 Watersheds within Warehouse Watershed

ORR GRID
NORTH

Scale
1:24,000

Fig. 99. Order 2 Warehouse watersheds.

Order 1 Watersheds within Warehouse Watershed

ORR GRID
NORTH

Scale
1:24,000

Fig. 100. Order 1 Warehouse watersheds.

5. FUTURE WORK

The development of the ORR watersheds GIS datasets encourages further development of and improvement in additional companion datasets which would be used in hydrologic analysis. For example, the watershed delineations were based on 20-ft contours from a USGS topographic map, which has a spatial accuracy of perhaps 10 to 15 m. With the aid of global positioning system technology, this topographic definition is undergoing considerable improvement, after which a revision of the watershed delineations would be in order as well.

The database of streams used to define watersheds also needs refinement. The current implementation is simply a table of lines which are not organized into related reaches and are not attributed with elevation or connectivity information. These data would offer more utility to the hydrologist if the following improvements were made:

- While the watershed polygons have areas associated with them, these areas should be built into the attribute tables, along with name of major watershed, order, and hydrologic unit code Cataloging Unit.
- The streams should be broken into order-specific reaches, as was done for the watershed polygons. This can be accomplished using GIS spatial interrogation, by extracting stream reaches which overlap particular orders of watersheds.
- References to the watersheds in which each stream lies should be added as an attribute to aid in identifying which areas of land contribute to a particular reach or point along a stream.
- From-node and to-node connectivity should be built in to the reaches, so that upstream and downstream tracing is made possible. This task would involve a large amount of tedious manual editing.
- Elevation data should be added to points along the streams, in order to provide a dataset for hydrologic analyses which use channel slope as a parameter.
- Although requiring a great deal of fieldwork, the addition of attributes for stream channel width and cross-sectional area coupled with the stream coverages would permit kinematic streamflow analyses.
- Conversion of all of these GIS data to other formats and platforms will occur as the need arises and funding becomes available. A conversion to Arc/Info® would be especially valuable, since it would allow analysis by Arc/Info's powerful modeling functions, producing many derivative coverages and datasets useful in environmental modeling of the Oak Ridge area.

It is anticipated that these watersheds and related GIS data will aid in environmental analysis of the Oak Ridge area, from exposure assessments to basic hydrologic research.

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