Appendix B: Site Geology and Hydrology

ORR is located in the East Tennessee Valley, which is part of the Valley and Ridge Province of the Appalachian Mountains. The East Tennessee Valley is bound to the west by the Cumberland Mountains of the Appalachian Plateau Province and to the east by the Smokey Mountains of the Blue Ridge Province. The defining characteristics of the Valley and Ridge Province are the southwest trending series of ridges and valleys caused by crustal folding and vaulting due to compressive tectonic forces as well as the differential weathering of the various formations underlying the area. There are ten geologic formations underlying parts of the ORR, all are of sedimentary origin. These formations range in age from early Cambrian (530 mya) to early Mississippian (354 mya). From youngest to oldest they are:

1. Fort Payne Chert (Mfp)
2. Chattanooga Shale (MDc)
3. Rockwood Formation (Sr)
4. Sequatchie Formation (Os)
5. Reedsville Shale (Or)
6. Chickamauga Group (Och)
7. Knox Group (O€k)
8. Conasuaga Group (€c)
9. Maynardville Formation (€)
10. Rome Formation (€r)

Each of these formations is described briefly in Table B-1. All of the formations consist mainly of shales, limestones and siltstones. The three major geologic formations are the Chickamauga Group, the Knox Group, and the Conasuaga Group. These formations are considered ‘major’ based on the location of the various plants (ETTP, ORNL, and Y-12), location of the contaminant plumes (see Figure B-1), and proportion of ORR underlain by these three formations.

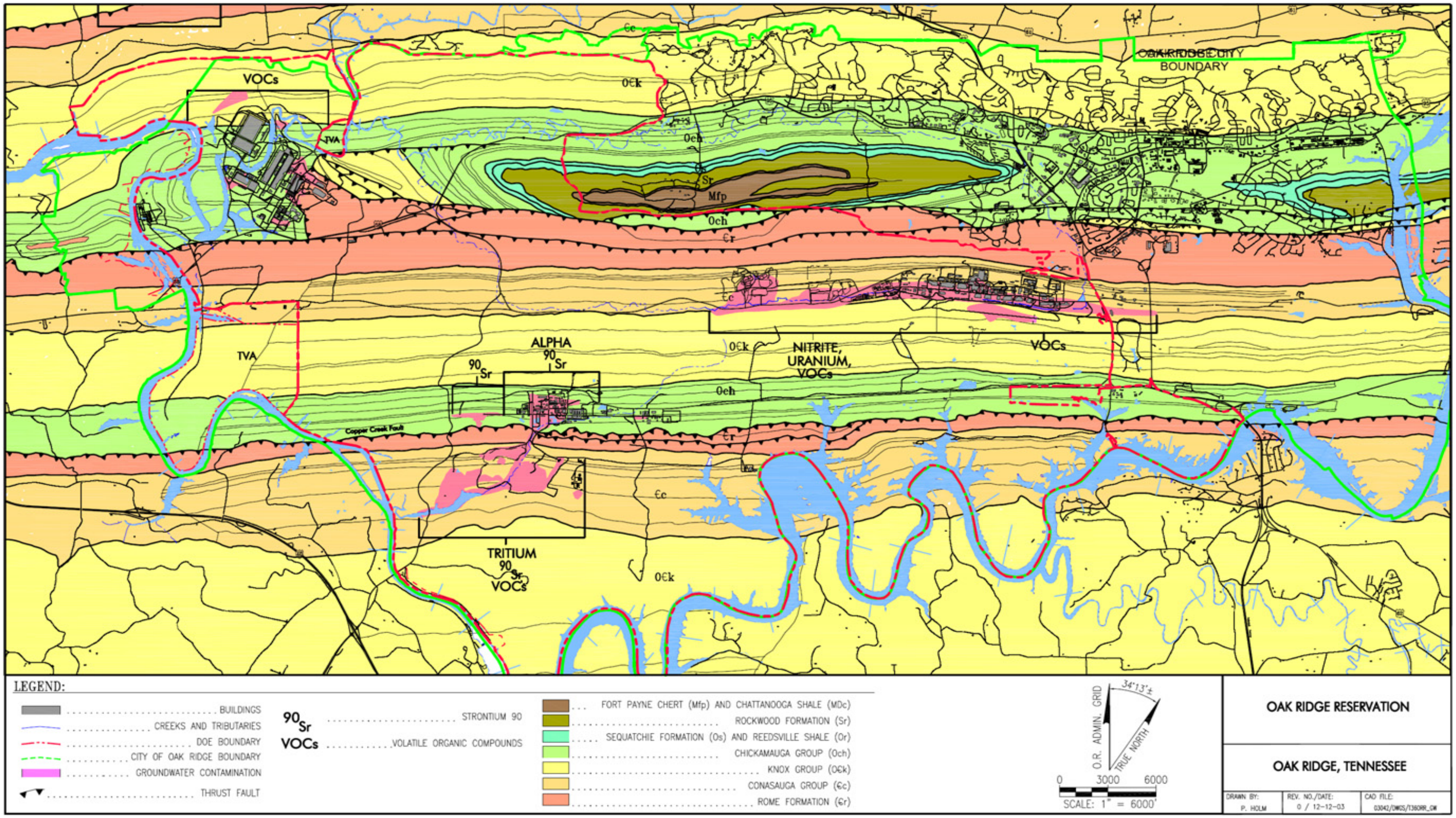

Figure B-1: Geologic Map of the ORR and Groundwater Contaminant Plumes

Table B-1: Hydrogeology of the Formations Underlying the Oak Ridge Reservation

Geologic Feature	*Age*	*Geology*	*Description*	*Conductivity (at ORR)*
Fort Payne Chert (Mfp)	Mississipian (early)	Bluish-gray Limestone	Thin outcrops at western edge of Valley and Ridge Province Average thickness 100' – 250'	Contains water in secondary openings. Yields from 0 to more than 300 gpm.
Chattanooga Shale (MDc)	Mississipian (early), Devonian (late)	Black, fissle shale	About 25 ft thick Very dark to black carbonaceous shale Overlies Rockwood Formation Underlies Fort Payne Chert	Low porosity and permeability. Yields little or no water to wells.
Rockwood Formation (Sr)	Silurian (early – middle)	Greenish to Brownish Shale, Limestone	Ranges in thickness from 150 – 1000 feet Limited outcrop results in limited recharge Some beds associated with iron ore (hematite) deposits Underlies Chattanooga Shale Overlies Sequatchie Formation	Not a good aquifer because of limited recharge. Groundwater occurs in fractures.
Sequatchie Formation (Os)	Ordovician	Shale, Limestone	Near ORR, thickness approx. 100ft. Overlies Chickamauga Group	Poor aquifer Groundwater occurs in fractures.
Reedsville Shale (Or)	Ordovician (late)	Shale	Uppermost layer of the Chickamauga Group Underlies the Sequatchie Formation Near ORR, thickness ranges from 250 – 400 feet	Poor aquifer Groundwater occurs in fractures.
Chickamauga Group (Och)	Ordovician (middle)	Limestone	ORNL (Bethel Valley) and ETTP are built on this group Approximately 2000' thick Overlies the Knox Group Underlies the Sequatchie Formation	AQUITARD - flow limiting strata Groundwater occurs in fractures Variable lithology results in varying conductivities
Knox Group (O€k)	Ordovician (early, middle), Cambrian (late)	Dolomite, Limestone	Overlies Conasauga Group (Shale) Massive calcareous unit that is the prominent formation in the Appalachian Valley ranging from 2000 – 4000 feet thick Contains fossil fuels (oil, gas) in other regions	AQUIFER Most important aquifer in the ORR area Groundwater occurs in joints and fractures Large springs are common Highly variable flow rates: from several gpm to several thousand gpm

Table B-1: Hydrogeology of the Formations Underlying the Oak Ridge Reservation (continued)

Geologic Feature	*Age*	*Geology*	*Description*	*Conductivity (at ORR)*
Maynardville Formation	Cambrian (late)	Limestone, Dolomite	Off-site contamination at Y-12 occurs in this formation. Uppermost unit of the Conasauga Group Historically included in the Knox Group Relatively thin (thickness 60-250ft)	AQUIFER Generally yields several gpm up to 200 gpm
Conasauga Group (€c)	Cambrian	Shale, Limestone, Dolomite	Y-12 complex is built on this group Contains the largest waste management areas at ORR: Bear Creek Valley Melton Valley Very limited migration of contaminant plumes Most groundwater resurfaces to surface water Limestone layers retard downward migration of groundwater In some areas can be up to 2000' thick	AQUITARD – typically flow limiting strata Contains the AQUIFER subunit Maynardville Formation (limestone), which contains the only off-site contaminant plume from Y-12.
Rome Formation (€r)	Cambrian (early)	Shale, Siltstone	Underlies Conasauga Group Approximately 1500 feet thick	Groundwater occurs in fractures Upper zone is more permeable than lower zone Springs are common Wells can yield several gpm.

Source: USGS 2004

Because this health assessment is focused solely on groundwater in and around the ORR, it is necessary to first establish a basic understanding of general groundwater principles, particularly as they relate to the specific geology of the ORR. An important feature of the hydrology of the ORR is the interaction of groundwater with surface water. Depth to bedrock in the ORR is typically very shallow. In this physiographic region, groundwater flow tends to be localized, as opposed to regional, and flow-paths to surface water are short (USGS 1986b). So, a discussion on how groundwater and surface water interact is warranted.

In general, a stream can be described in three ways based upon it's interaction with groundwater. A stream can either be a *gaining stream*, a *losing stream*, or a combination of both (Figure B-2). In order to have a *gaining stream* system, the water table altitude must be higher than that of the stream (USGS 1998). The reverse is true for a *losing stream* system. Because the bedrock is very close to the ground surface in and around the ORR, and in many cases, occurs as outcrops, the streams are gaining. This is a very common situation in East Tennessee because of the topography of the area. The water table and the groundwater flow path typically mirror the undulations of the overlying land. Since surface water occurs at the low areas, groundwater often flows toward surface water. Therefore, the altitude of the water table is higher than that of the surface water. Recharge of groundwater around the ORR is spatially distributed, but discharge areas are at local springs, seeps as well as diffuse discharge into surface waters (MMES 1986; USGS 1986b; SAIC 2004). Indeed, groundwater constitutes much of the baseflow of many streams and tributaries in the area, including East Fork Poplar Creek (EFPC) (USGS 1989; SAIC 2004).

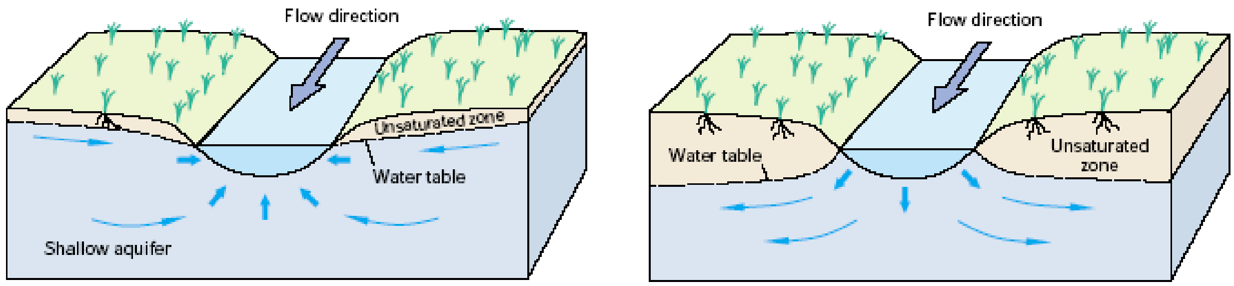

Figure B-2: Gaining (Left) and Losing (Right) Streams and Associated Groundwater Flow Direction

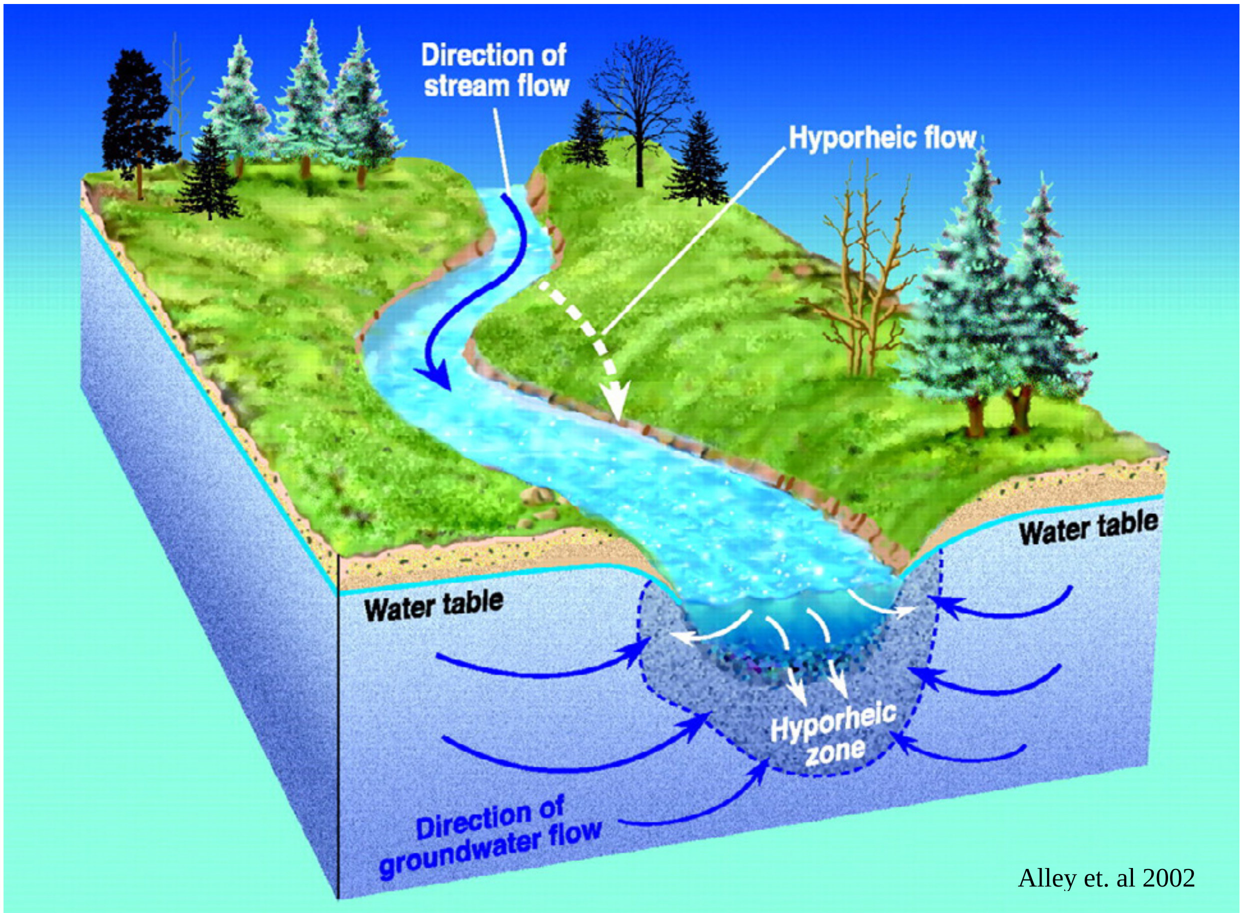

Figure B-3: Groundwater System Involving the Hyporheic Zones

In the Bear Creek Valley watershed there are both gaining and losing reaches of Bear Creek. This illustrates the third groundwater-surface water system where there groundwater enters and exits the surface water at different sections of the stream. In this case the concept of hyporheic flow becomes relevant (Figure B-3). Hyporheic flow, or the hyporheic zone, refers to the areas beneath and adjacent to the stream where surface water and groundwater mix. In systems such as this, surface water contamination can percolate through the sediments and contaminate the groundwater (Alley et al. 2002).

Groundwater flow occurs at many different levels, or depths, in the subsurface. Depending on the geology of the area, flow times from points of recharge to points of discharge can range from days to millennia (Figure B-4). As is the case at the ORR, shallow surface water has short flow paths with relatively quick travel times. However, the limestones and dolomites of the Valley and Ridge Province often contain cracks, fissures, fractures, and solution cavities that can make groundwater flow direction and speed unpredictable (USGS 1997).

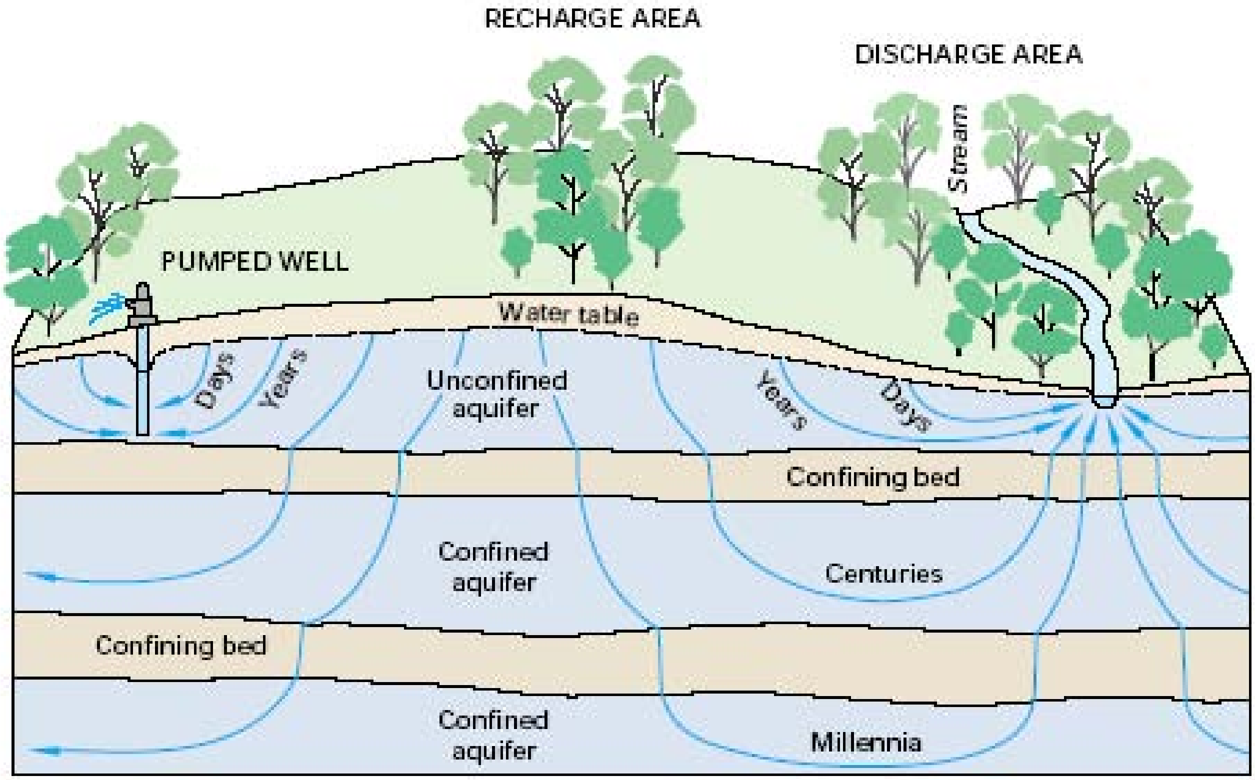

Figure B-4: Groundwater Flow Times

Groundwater flow in this area (ORR) is influenced largely on the extent of fractures in the bedrock which create preferential flow paths. In the regional aquifers of East Tennessee, including those underlying the ORR, fractures in bedrock are typically limited to the upper extents of the bedrock formations and significantly decrease with depth (MMES 1986; USGS 1986b; USGS 1988; USGS 1989; SAIC 2004). The numerous springs and seeps in the area support the notion of a very active shallow groundwater system in the ORR. Also, groundwater will flow along bedding planes and along strike, especially in areas where carbonate units have well-developed conduit systems (ORNL 1982; USGS 1997). This is the case in the UEFPC Watershed where VOC contamination has migrated off-site from the Y-12 Complex and is migrating along strike in the Maynardville Limestone (ORNL 1982; SAIC 2004).

It is unlikely that contaminated groundwater at the ORR will flow beneath, and continue to flow away from, streams and rivers that surround the site. The vast majority of information available concerning the geology and hydrogeology of the site indicates that groundwater occurs as shallow flow with short flow paths to surface water (ORNL 1982; MMES 1986; USGS 1986b; USGS 1988; USGS 1989; SAIC 2004). The fractures and solution cavities present in the bedrock occur in shallow (100’ to 300’ deep) bedrock and significantly decrease at depth. There is also evidence that beneath the alluvium at the bottom of the stream beds there is a silty-clay glei horizon that likely further impedes downward groundwater movement (USGS 1989). The incised meander of the Clinch River in bedrock represents a major topographic feature that prevents groundwater from passing beneath the river (ORNL 1982). The extensive interconnection between groundwater and surface water coupled with the fact that groundwater contamination sources at the ORR are in the shallow subsurface (with the exception of deep-well injection conducted at ORNL, which will be discussed in the Melton Valley Watershed section of this document), leads ATSDR scientist to conclude that on-site contaminated groundwater does not likely migrate beneath and away from streams and rivers either as slug-flow or in fractures, solution channels, or other conduits in the bedrock.

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