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Chehalis River Watershed Surficial Aquifer Characterization

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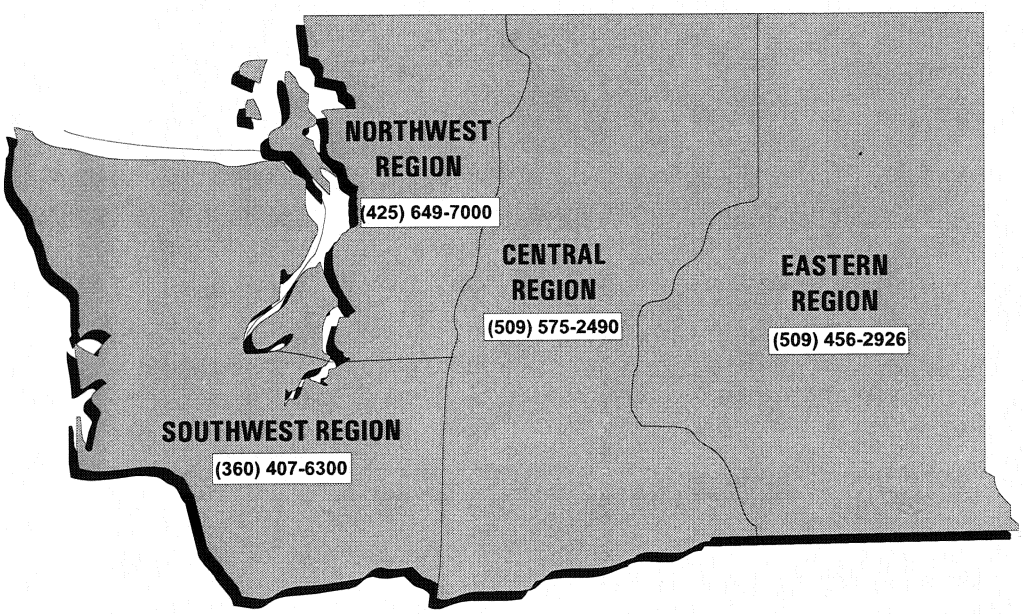

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ECOLOGY

Chehalis River Watershed Surficial Aquifer Characterization

by

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Abstract

This report characterizes and documents the distribution of the surficial aquifers within the Chehalis River Watershed. Theoretically, if the location and character of surficial aquifers is known, local governments can use such information to help plan development to protect ground-water supplies.

The Chehalis River Watershed is the second largest watershed in Washington State, encompassing an area of approximately 2,711 square miles. It is surpassed in size only by the Columbia River system. As human populations increase in western Washington, development increases within the watershed. Development has occurred mostly along the major river valleys where the depth to ground water is shallowest, the soil permeability is highest, and where risks of ground-water contamination are greatest. This development pattern is expected to continue.

Surficial aquifers are defined here as the uppermost saturated zone, typically an unconfined aquifer, of mappable extent. We further restrict the definition to include important water-supply aquifers that are the most likely to be degraded by human activities.

Surficial aquifers were delineated and mapped based on comparisons of physical properties such as depth to ground water, surficial geology, soil properties, and the presence or absence of near-surface aquitards.

The diverse geology of the Chehalis River Watershed controls the occurrence and movement of groundwater. The watershed's principle surficial aquifers are contained within the thick, unconsolidated glacial and alluvial deposits that underlie the major river valleys and upland prairies. Surficial aquifers in the watershed typically lie only a few feet below land surface and extend to a depth of no more than 100 feet. A notable exception is near Aberdeen where the alluvial aquifer is about 200 feet thick. Depth to the water table varies by location, but ranges from less than ten feet to a maximum of about 50 feet. The principle alluvial and glacial aquifers are capable of sustained well yields of 200 to more than 3,000 gallons per minute.

Bedrock units produce ground water locally, but well yields are generally low. Bedrock aquifers are not classified as surficial aquifers in this study.

Comparisons of ground-water levels (measured at time of drilling) in wells across the watershed show that water-level altitude and hydraulic heads are higher in the upper tributary stream valleys and along the upland aquifer perimeters and lower along the principal river valleys. Ground water generally moves from upland recharge areas near the aquifer perimeter, toward natural points of discharge along the rivers and tributary streams. Water also moves vertically downward to recharge underlying regional aquifers.

Introduction

This report is part of an ongoing effort, by the Washington State Department of Ecology (Ecology), to delineate the distribution and areal extent of Washington's surficial aquifers. A surficial aquifer is defined as the uppermost saturated zone, typically an unconfined aquifer, of mappable extent (Tooley and Erickson, 1996). We further restrict the definition to include important water-supply sources that are the most likely to be degraded by human activities. Knowledge about the nature and extent of Washington's surficial aquifers is a critical component of Ecology's assessment of ground water vulnerability, its allocation of water resources, and review of land-use management decisions.

This report documents the distribution of surficial aquifers within the Chehalis River Watershed, which encompasses portions of Grays Harbor, Mason, Thurston, Lewis, Pacific, and Cowlitz counties (Figure 1). To characterize the surficial aquifers, we compiled maps showing depth to ground water and water levels at the time wells were drilled, high permeability soils in the watershed, and a map that compares soil permeability to the location of dairies and nitrate concentrations in ground water.

Since an understanding of the surficial geology is essential to understanding the surficial aquifer system, we describe the principle geologic units that affect ground-water movement and availability in the watershed.

We also describe the methods used to delineate the surficial aquifers and provide descriptions of the digital data used in this analysis. The digital data sets are available from Ecology and the Washington Department of Natural Resources (DNR) as described in Appendix A.

In conducting this assessment, we relied solely on available reports and data. We used ARC/INFO® and ArcView®, advanced GIS software programs by ESRI, to evaluate, store, and analyze information about the watershed soils, geology, and water quality.

Watershed Description

The Chehalis River Watershed encompasses an area of approximately 2,711 square miles and is the second largest watershed in Washington State, surpassed only by the Columbia River system (Lewis County Conservation District, 1992). The Chehalis River Watershed is located at the extreme southern end of the Puget Sound lowland and includes portions of Thurston, Mason, Lewis, Grays Harbor, Pacific, and Cowlitz counties (Figure 1). Land surface elevations within the watershed range from sea level at the Pacific Ocean coast to about 1,540 meters (5,050 ft.) at Capitol Peak in the southern Olympic Mountains.

The upper Chehalis Watershed, upstream of the town of Porter, covers an area of roughly 1,293 square miles (Figure 1). The broad drift plain of the southernmost Puget Sound lowland extends southward joining with the lowlands along the mainstem of the Chehalis River (Washington Department of Ecology et al, 1972). The watershed is bounded on the north and west by the southern and eastern slopes of the Black Hills, on the southwest by the eastern slopes of the Willapa Hills, and on the east by the western part of the Bald Hills. Major tributaries to the upper Chehalis River include the South Fork Chehalis River, the Skookumchuck and Newaukum Rivers, the Black River, Scatter Creek, and Lincoln Creek.

Forest lands cover approximately 996 square miles or 77% of the upper watershed. The remaining area consists largely of agricultural land with interspersed urban development. The watershed population is approximately 77,000 people with Centralia (population 12,000) and Chehalis (population 6,000) being the largest urban centers (Wildrick and others, 1995). Mean annual precipitation for the upper watershed varies from roughly 40 inches per year near Centralia and Chehalis, to more than 120 inches per year near the headwaters of the Chehalis River.

The lower Chehalis Watershed, lying downstream of the town of Porter (Figure 1), covers an area of approximately 1,418 square miles, of which roughly 1,290 square miles are forest lands (Washington Department of Ecology, et al, 1972). The remainder of the watershed is used largely for agricultural purposes. The major urban centers which include Ocean Shores, Westport, Hoquiam, Aberdeen, Elma, Montesano and McCleary, are situated along the Pacific coast or in the broad alluvial valley of the Chehalis River (Figure 1).

The lower watershed is drained by numerous rivers and streams that emanate from the Olympic Mountains and foothills. Among the larger rivers are the Humptulips, the Wynoochee, the Satsop, and the Mox Chehalis. Mean annual precipitation for the lower watershed varies from approximately 55 inches near the town of Porter to more than 220 inches in the headwaters of the Wynoochee and Humptulips Rivers.

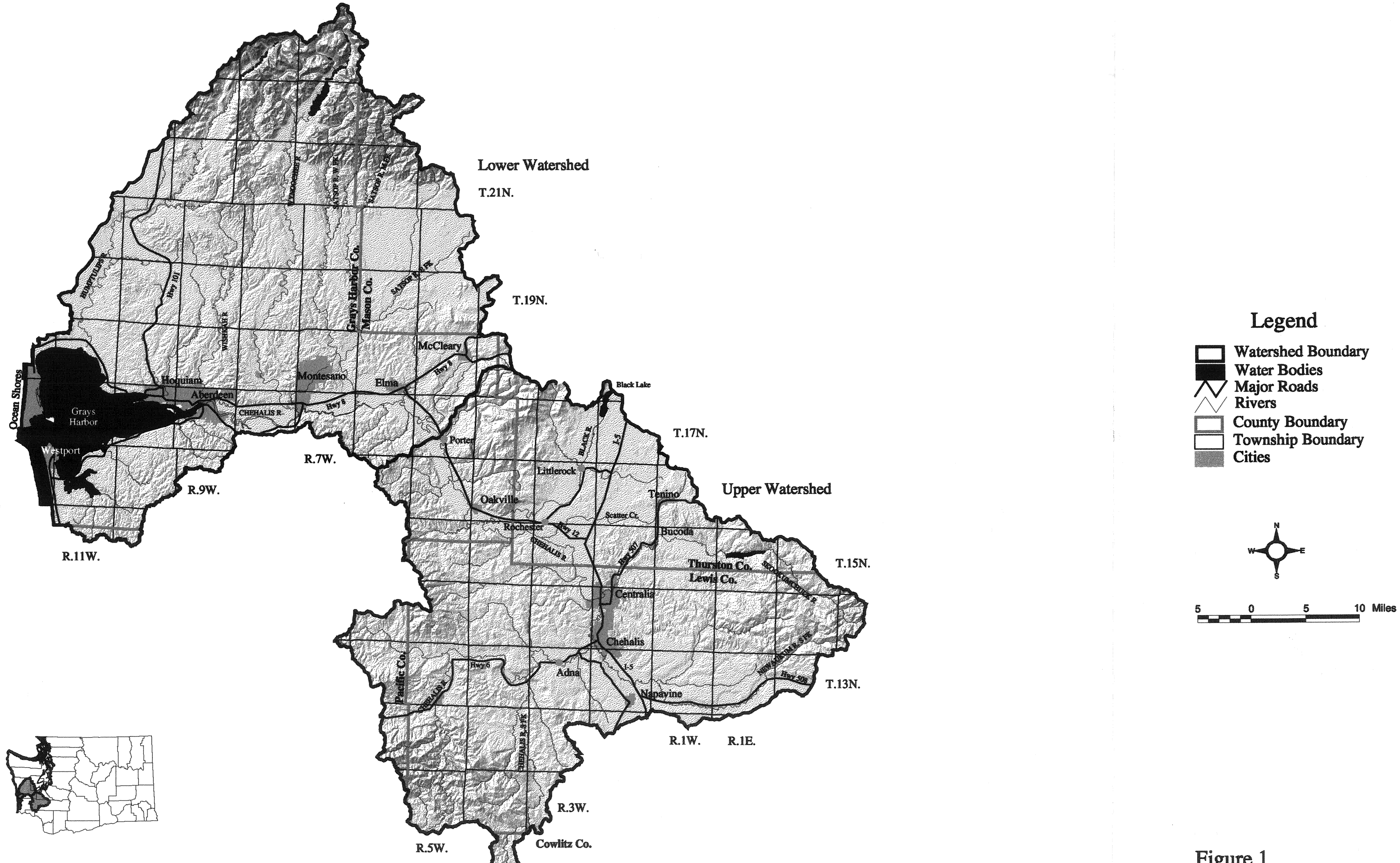

Figure 1
Chehalis River Watershed

Methods

In undertaking this project, we relied on three primary information sources. These included digital geologic and soils maps, published geologic and hydrogeologic reports, and well construction/ground-water-level information from the U.S. Geological Survey. The data and methods we used to produce this report are described below.

Delineation of Surficial Aquifers

In accord with the methods of Tooley and Erickson (1996), we used an iterative process to define the distribution and areal extent of surficial aquifers within the watershed.

We first identified those geologic units that would probably contain surficial aquifers. These picks were based on published geologic descriptions provided by Walsh et al (1987), Sinclair and Hirschey (1992), Eddy (1966), Eddy and Carson (1973), Lea (1984), Noble and Wallace (1966), Rau (1967), and Weigle and Foxworthy (1962). We compared geologic parameters such as unconsolidated deposits, depositional environments, age, compaction, cementing, and depth of the deposit to pick those units we felt would comprise surficial aquifers. We selected and plotted these units, including alluvium, undifferentiated glacial drift, glacial outwash, and beach and terrace deposits, using ArcView GIS software to define a rough outline of the surficial aquifers.

Second, we superposed the digital soil coverage (Appendix A) from the Washington Dept. of Natural Resources, Division of Geology and Earth Resources, (DNR), and compared the soil parent-material descriptions with our previously selected geologic units. Soil polygons in which the soil parent material matched the underlying geology (ie: soils derived from glacial outwash overlying glacial outwash) were classified as primary candidates for inclusion as surficial aquifer polygons. Soil polygons in which soil parent materials did not match the underlying geology (ie: soil derived from till overlying glacial outwash) were grouped in a "conflicting data" category for further analysis. Likewise, soil polygons with parent-material descriptions indicating "surficial-aquifer-likely" geologic units, such as outwash, overlying non-aquifer geologic units, such as till, were placed in the conflicting data category for further analysis. Soil polygons, in which soils were formed from geologic units such as bedrock, colluvium derived from bedrock, or glacial till which overlaid matching geologic units, were classified as "non-surficial aquifer".

The third and final step in defining the aquifer perimeter consisted of evaluating digital well reports to determine whether the reported lithology and water levels were consistent with the mapped geology and soils, to confirm or refute surficial aquifer classifications, and to resolve surficial aquifer picks in "conflicting data" polygons. For instance, if we had preliminarily included a set of polygons within the surficial aquifer perimeter, but water levels in the area were too deep to make conceptual sense, the area was excluded. The well data we used to make these decisions included lithology (where available), well depth, screened intervals (production zones), and water levels at the time of drilling. Those areas where near-surface till or confined aquifer conditions were indicated in the drilling reports were excluded from surficial aquifer classification.

We did not attempt to define the thickness of the surficial aquifers since digital lithology data are available only for the Thurston County portion of the watershed.

Analysis of Water Levels

After establishing the surficial aquifer perimeter, we further characterized the aquifers by analyzing the ground-water levels within the surficial aquifers.

We prepared depth-to-ground-water and water-level-altitude maps (Figures 3, 4, 6, and 7) using ground-water-level information from the USGS ground water site inventory (GWSI) database. We only included wells that had been field located by USGS personnel or whose location was otherwise considered reliable. We further narrowed our selection to wells 100 feet or less in depth that fell within our surficial aquifer perimeter. We determined depth to ground water using water levels measured by drillers at the time of well construction. Ground-water altitudes for each well were calculated by subtracting the depth to water, measured at the time of drilling, from the land surface elevation at the well.

To check the relative accuracy of the water level altitudes we obtained using the USGS data, we superimposed water-level contours previously prepared by Sinclair and Hirschey (1992) for the Scatter Creek/Black River Aquifer system (Figure 9). Sinclair and Hirschey developed their contours based on a December 1989 synoptic measurement of approximately 120 surveyed wells. As shown on Figure 9, the USGS data yielded results similar to those obtained by Sinclair and Hirschey (1992).

Delineation of High Permeability Soils

Soil permeability, defined by Evans and Fibich (1987) as "the ability of a soil to transmit water or air" is an important aspect of aquifer vulnerability where ground-water levels are shallow. Evans and Fibich (1987) classify soil permeability as a function of soil infiltration rate -- an estimate of the rate of downward movement of water when the soil is saturated. They categorize soil infiltration rates in ranges as follows:

Table 1 - Soil Permeability/Infiltration Rate Categories (Evans & Fibich, 1987)

Infiltration Rate in Inches/Hour	Range Category
Less than 0.06	Very Slow
0.06 to 0.2	Slow
0.2 to 0.6	Moderately Slow
0.6 to 2	Moderate
2 to 6	Moderately Rapid
6 to 20	Rapid
Greater than 20	Very Rapid

In accord with Tooley and Erickson (1996) and based on the above referenced scale, we classified soils with infiltration rates of greater than two inches/hour as high permeability soils. The distributions of high permeability soils are shown as an overlay to the surficial aquifer on Figures 5, 8, and 10.

Study Limitations

This study relied largely on digital data and information. Limitations in the availability or nature of the source data, and the results based on that data are described below.

Surficial Aquifers

We did not attempt to rigorously classify or subdivide the surficial aquifers we identified during this project, owing largely to the lack of available information upon which to base such decisions. Two exceptions are the Scatter Creek/Black River Aquifer and the Upper Black River drainage aquifer, for which there is considerable detailed information as described in Results and Conclusions.

Surficial Aquifer Thickness

We were not able to define surficial-aquifer thickness because digital lithology data is not available for most of the watershed. See the Recommendations section for further discussion.

Nitrate Concentrations

The nitrate concentrations shown on Figure 10 are included to illustrate how ground-water-quality data can be compared to land-use information using Geographic Information System (GIS) techniques. However, the concentrations shown may not accurately represent nitrate concentrations in the surficial aquifer. We have not defined the surficial-aquifer thickness and, therefore, cannot be sure that all nitrate concentrations shown are from the surficial aquifer only.

Soils Data

Digital soils data from DNR are currently available for all counties within the Chehalis River Watershed, except Mason County (Appendix A). Accordingly, we were not able to delineate or characterize the surficial aquifers within Mason County.

Geology Data

DNR digital geology, based on the geologic map of Walsh et al (1987), is available for all of the upper watershed and the southern portion of the lower watershed south of Township 19 N (Appendix A). The surficial aquifer north of Township 18 N was characterized using digital soils data, in combination with visual inspection of paper geologic maps, where available (Figures 3, 4, and 5).

Water Levels

The water levels we used to prepare depth to ground water and water level head maps are those recorded by the driller at the time of well construction. The accuracy of individual measurements varied depending on the driller's measurement method. The wells depicted on Figures 3, 4, 6, 7, and 9 were constructed over a period of several decades. Thus, the associated water levels represent different climatic conditions and seasons. While these water levels are not strictly comparable, much can be discerned from them. For instance, regional differences in depth to ground water, head distribution, and ground-water flow direction are apparent in the above referenced figures. These gross patterns may not accurately depict current conditions within a localized portion of the watershed. Likewise, apparent abnormalities depicted at the regional scale may not actually exist upon closer inspection of current site-specific data, were it available.

Hydrogeology

The geology of the Chehalis River Watershed is diverse and controls the occurrence and movement of groundwater within the watershed. An understanding of the surficial geologic units is essential to understanding the character of the surficial aquifers. The following geologic discussion is provided to increase understanding of the geology that controls ground-water occurrence in the Chehalis River Watershed.

Bedrock

Area bedrock consists of Miocene-to-Eocene age marine and continental sedimentary rocks, basalt flows, and igneous intrusive rocks (Walsh and others, 1987). Bedrock outcrops, covered by thin sporadic deposits of Pleistocene glacial drift and Holocene alluvium, predominate in the upland areas of the watershed. In the lowland river valleys and broad prairies, bedrock is generally overlain by a thick veneer of glacial drift and/or alluvium.

Although the bedrock units produce ground water locally, well yields are generally low. Bedrock forms an effective no-flow boundary at the base of the unconsolidated sediments throughout the watershed.

Principal Surficial Hydrogeologic Units

The watershed's principle aquifers are contained within the thick glacial and alluvial deposits that underlie the major river valleys and upland prairies. For simplicity, we have divided the Pleistocene deposits into two groups on the basis of age: 1) Proglacial deposits of the Vashon glacier, deposited between 13,500 and 15,000 years before present (B.P.); and 2) older glacial drift deposited prior to the Fraser Glaciation, termed "pre-Fraser Drift" by Walsh et al, (1987) and "Penultimate Drift" by Lea (1984). These older drift units were probably deposited from 125,000 to 400,000 years B.P.

Deposits of the Vashon Stade of the Upper Pleistocene Fraser Glaciation

Vashon age proglacial sediments constitute a large portion of the watershed's glacial deposits. Vashon deposits underlie much of the northern area of the upper Chehalis Watershed including the Black River and Scatter Creek drainages and isolated segments of the Chehalis River valley downstream of the Black River confluence. The three principal Vashon units: recessional outwash, advance outwash, and till are described below. The geologic units of the Vashon Stade are shown on Figures 2A and 2B as glacial outwash gravel (Qgog), glacial outwash sand (Qgos), undifferentiated glacial outwash (Qgo), and glacial till (Qgt). The geologic map of Walsh et al (1987), upon which the digital geologic coverage is based, does not distinguish between advance and recessional outwash. Never the less, the distinction is an important one since the depositional environment can strongly influence aquifer characteristics.

Vashon Advance Outwash

As the Vashon glacier advanced toward its southern terminus, meltwater streams deposited gravel, sand, silt and clay in front of the glacier. The advancing glacier subsequently overran, compacted, and reworked the new fluvial deposits. The deposits left by this dynamic depositional environment are similar in character to Vashon recessional outwash, but are generally more compact and less continuous, having been over-ridden and reworked by the glacier.

Vashon Recessional Outwash

As the Vashon glacier retreated from its southernmost terminus near the base of the Black Hills, meltwater emanating from the glacier laid down extensive deposits of poorly sorted, stratified-to-massive course sand, pebbles, gravel, cobbles, and boulders with local accumulations of silt or clay (Walsh and others, 1987; Sinclair and Hirschey, 1992). Vashon recessional deposits have not been reworked or compacted by subsequent glaciation. Consequently, they are largely undisturbed, very porous, and where saturated, contain some of the most prolific aquifers in the watershed.

Vashon Till (Qgt)

Vashon Till is composed of compact, very poorly sorted, gravel and sand in a silt and clay matrix ("Qgt" on Figures 2A and 2B). Vashon till is a poor aquifer, due to its compact nature and silt/clay-rich matrix, and usually impedes ground-water movement. As such, it is usually an aquitard (confining layer) within the glacial deposit sequence. In many areas, till overlies advance outwash, which usually contains the regional water-supply aquifer (Figures 2A and 2B). In these areas, the outwash aquifer may be confined and relatively protected from surface contamination. However, even in areas where the till is thickest and most extensive, it can be discontinuous thereby providing pathways through which water can pass quickly from the surface to underlying aquifers.

Beach Deposits (Qb)

The beach deposits, shown on Figure 2A as "Qb", consist of fine to course sand forming beaches and associated active and stabilized back-beach dune fields, and minor estuarine deposits (Walsh et al, 1987).

Terraced Sediments (Qt)

The terraced sediments ("Qt" on Figure 2A) occur mostly south and east of Grays Harbor and consist of silt, sand, and gravel. The deposits are of diverse compositions and origins, such as proglacial outwash, glacial outburst deposits, older alluvium, lahars, and uplifted coastal marine and estuarine deposits (Walsh et al, 1987).

Pre-Fraser Glaciation Drift Deposits

The glacial drift of the pre-Fraser glaciation ("Qgp" and "Qapo" on Figures 2A and 2B) also contains aquifers with good water production potential. These deposits tend to be more compact and discontinuous than the Vashon deposits because they were overrun and reworked by the Vashon glaciers. Numerous, relatively small deposits of pre-Fraser drift form local, discontinuous aquifers throughout the watershed. The Penultimate Drift (Lea, 1984; Sinclair and Hirschey, 1992), the older Undifferentiated Drift, and the Logan Hill Formation occur in significantly large deposits and are described below.

Penultimate Drift (Qgp)

Penultimate Drift ("Qgp" on Figures 2A & 2B) was deposited by the last glacial advance into the area prior to the Vashon glaciation. Sinclair and Hirschey (1992) consider the Penultimate Drift of Lea (1984) and the Salmon Springs Drift (?) of Noble and Walace (1966) to be the same drift sequence, with and Early Wisconsin age of > 125,000 years B.P. Penultimate Drift is composed of interbedded thin discontinuous till, and poorly sorted, non-stratified, outwash silt, sand and gravel which is commonly oxidized (Lea, 1984; Sinclair and Hirschey, 1992; Walsh et al, 1987). Penultimate Drift is mostly overlain by younger Vashon deposits, but there are significant outcrops north and east of Tenino.

Logan Hill Formation (Qapo)

The Logan Hill Formation underlies an extensive area south of Centralia along the Newaukum River (Figure 2B) and is the surficial geologic unit beneath Napavine Prairie, Jackson Prairie, Alpha Prairie, and Logan Hill -- the type location (Weigle and Foxworthy, 1962). The Logan Hill Formation was deposited in a glaciofluvial environment from 800,000 to 1,900,000 years B.P. during the early Pleistocene to late Pliocene Epochs (Easterbrook, 1985). The unit can exceed 150 feet in thickness and is composed principally of poorly sorted gravel and sand with minor amounts of silt and clay. Although the Logan Hill Formation is an important aquifer in the area, we did not classify it as a surficial aquifer. The upper 20 to 50 feet is often highly weathered and is described by well drillers as yellow or red clay intermixed with soft gravel (Weigle and Foxworthy, 1962). The weathered zone produces small amounts of water while the deeper, less weathered sand and gravel produces moderate to large volumes of water to wells (Weigle and Foxworthy, 1962). We believe that the upper, thick, weathered layer confines and protects the aquifer from surficial contaminants over most of the area.

Older Undifferentiated Drift (Qapo)

The "Qapo" unit, as mapped on Figures 2A and 2B, also includes the undifferentiated drift referred to by Walsh et al (1987) as "Qap". These drift deposits include isolated outcrops of the Hayden Creek and the Wingate Hill Drifts, mostly located along the main Chehalis River drainage. The drift is composed of till and outwash sand and gravel. Some of the outcrops were classified as surficial aquifers based on the source-rock descriptions in the soil classifications.

Results and Conclusions

In the discussion of the results, conclusions and implications of this study, we draw liberally from the work of prior authors to summarize and present some of the important information that is available for these aquifers.

Scatter Creek/Black River Aquifer

Sinclair and Hirschey (1992) described the highly productive surficial aquifer that underlies the broad prairies of the Scatter Creek and southern Black River drainages. The Scatter Creek/Black River aquifer is contained within glacial drift laid down during the Penultimate and Vashon glacial periods. These drift deposits are comprised of poorly sorted, non-to-poorly stratified sand, gravel, and cobbles with interbedded lenses of clay and silt. Within the Scatter Creek valley, Vashon and Penultimate drift directly overlies bedrock and attains an average thickness of approximately 100 feet. Wells completed within the Scatter Creek/Black River Aquifer are capable of sustained withdrawals of 500 to 2,000+ gallons per minute (gpm), with little drawdown. The aquifer has a median hydraulic conductivity of 864 ft/day (with values ranging from 69 to 3,325 ft/day), a mean storage coefficient of 0.002, and a mean specific yield of 0.025 (Sinclair and Hirschey, 1992).

Ground water within the Scatter Creek aquifer moves generally east to west, from the upland recharge area near Tenino toward natural points of discharge along the Chehalis and Black Rivers (Figure 9). The horizontal hydraulic gradient for ground water within the Scatter Creek valley varies from approximately 0.001 to 0.003 feet per feet, or 5.3 to 15.8 feet per mile. Ground-water-seepage velocities vary from 1.3 to 60 feet per day with a mean value of 16 feet per day. Seasonal water table fluctuations are greatest in the central and eastern Scatter Creek valley, where ground-water levels vary as much as 20 to 25 feet annually. In the western portion of the valley, where ground water discharges to the Chehalis and Black Rivers, the water table fluctuates seasonally by about 3-8 feet (Sinclair and Hirschey, 1992).

Ground water from the Scatter Creek/Black River aquifer provides significant baseflow to the Black and Chehalis Rivers. Where these rivers traverse the aquifer, roughly between the towns of Grand Mound and Oakville, the aquifer discharges approximately 3.1 and 1.8 cubic feet per second per river mile to the Chehalis and Black Rivers respectively (Sinclair and Hirschey, 1992).

Upper Black River Drainage

Noble and Wallace (1966) subdivided the upper Black River drainage into two major geohydrologic areas - the western prairie and the north-central prairie. The western prairie includes that portion of the Black River watershed lying south of Black Lake, north of Rochester, and west of the Black River. The north-central prairie includes that portion of the Black River drainage lying north of the town of Littlerock, east of the Black River, and west of the Deschutes River drainage divide (Figure 1).

The western prairie surficial aquifer is contained within Vashon age recessional deposits and Holocene alluvium. These deposits consist of poorly to moderately well sorted sand and gravel extending to depths of 25 to 50+ feet below ground surface. Where underlain by till, the recessional deposits are commonly saturated and can be a productive local aquifer. The water table lies within 25 to 50 feet of land surface throughout most of the Western Prairie (Figure 9). South of Littlerock, the surficial aquifer is used extensively to supply water for domestic needs, stock watering, and irrigation.

Ground water within the western prairie surficial aquifer moves generally from upland recharge areas near the western and eastern perimeter of the subarea toward natural points of discharge along the Black River (Figure 9). Water also moves vertically downward to recharge underlying regional aquifers.

The north central prairie is underlain largely by Vashon age recessional sand with interspersed gravel. The water table lies within 20 feet of land surface throughout much of the area (Figure 6). Ground water within the north central prairie moves generally from upland recharge areas within the prairie interior toward natural points of discharge along the Black and Deschutes Rivers. The regional water-supply aquifer for the north central prairie is contained within Vashon advance outwash and Penultimate drift which are separated, in large part, from the surficial aquifer by an intervening till layer.

Alluvial Surficial Aquifers of the Chehalis River

The Quaternary alluvium ("Qa" on Figure 2) deposited by the Chehalis River and its tributaries, contain important surficial aquifers. Larson (1994) identified two principle alluvial aquifers underlying the Chehalis River valley proper. These aquifers, informally named the East and West Chehalis aquifers, consist of laterally extensive deposits of interbedded clay, silt, sand, and gravel laid down in flood plains, alluvial fans, and low river terraces. The hydraulic characteristics of these sediments vary widely due to the dynamic fluvial environment in which they were deposited.

East Chehalis Surficial Aquifer

The East Chehalis Aquifer underlies the Chehalis River valley upstream of the Scatter Creek confluence with the Chehalis River, and extends up valley into the main stem and South Fork Chehalis River drainages (Figures 6,7, and 8). The aquifer is from four to ten feet thick in the upper Chehalis River valley west of Adna and increases toward the north to about 90 feet thick near Fords Prairie, northwest of Centralia (Larson, 1994).

Depth to ground water varies by location and ranges from less than 10 to 20 feet below ground surface west of Adna. East of Adna, ground water typically lies between 10 and 30 feet below land surface (Figure 6). Ground water moves generally toward the Chehalis River from the aquifer perimeter. Ground water discharge to the river ranges from 0.5 to 4.5 cfs/river mile and is lowest West of Adna, where the aquifer is relatively thin, and highest near Centralia (Erickson, 1993).

West Chehalis Surficial Aquifer

The West Chehalis Aquifer extends from the mouth of the Chehalis River at Grays Harbor upstream to the confluence of the Chehalis River with Scatter Creek (Larson, 1994). From Aberdeen upstream to Elma, the aquifer consists of an upper zone that extends to about 100 feet below land surface and a lower more permeable zone that typically lies from 100 to 200 feet below land surface (Eddy, 1966). While there is no specific geologic layer that differentiates these zones, the lower zone is the principle aquifer in the area owing to it's better water quality and yield to wells. Wells completed in the lower zone can produce 200 to 3000 gallons per minute (Eddy, 1966). The water table is generally less that 20 feet below land surface throughout most of this reach (Figure 3).

From Elma upstream to Oakville, the Chehalis River valley is underlain by a single aquifer composed of course-grained-highly-permeable alluvium and reworked drift. Percolation of water to the water table is rapid and horizontal hydraulic conductivity is high. The water table is typically less than 20 feet below land surface and ground-water levels closely follow the level of the Chehalis River. The alluvial deposits in this area are highly productive and well yields average about 300 gpm, with specific capacities of up to 37 gpm/foot of drawdown (Eddy and Carson, 1973).

The terrace deposits bordering the Chehalis River between Elma and Oakville are not as thick or continuous as the adjacent alluvium. However, some wells completed in this unit can yield significant amounts of ground water. Three wells, ranging from 71 to 85 feet deep, completed in terrace deposits on the west side of the valley yielded 80 to 300 gpm with specific capacities ranging from 20 to 150 gpm/foot of drawdown (Eddy, 1966).

Throughout the West Chehalis Surficial Aquifer, ground water is directly coupled with the Chehalis River, which serves as the natural point for ground water discharge from the aquifer.

Surficial Aquifers in Tributary Stream Valleys

Alluvial deposits in the tributary stream valleys of the Chehalis River are thinner, narrower, and more discontinuous than those underlying the Chehalis River Valley proper. Alluvium within the Wynoochee and Satsop River valleys, for example, ranges from a few feet to as much as 30 feet thick (Rau, 1967). The water table in the tributary valleys is usually less than 20 feet below land surface (Figures 3 and 6). The tributary alluvial aquifers are important local water sources for farms, domestic residences, and small public water systems. These aquifers are often highly susceptible to contamination due to their shallow ground water depth and hydraulic connection with surface waters.

Beach Deposit Surficial Aquifer

The Ocean Shores and Westport peninsula surficial aquifers are contained within fine-to-course grained beach sand with minor interspersed estuarine deposits (Figure 2A). These sediments can be hundreds of feet thick.

Recharge to the Ocean Shores and Westport peninsula aquifers originates from direct infiltration of precipitation. The water table generally lies less than 20 feet below ground surface in most areas (Figure 3). The peninsula surficial aquifers discharge directly to the Pacific Ocean and Grays Harbor. Accordingly, sea-water intrusion can be a limiting factor to development of near-shore ground water.

Ground Water Quality and Susceptibility to Contamination

Ground water's susceptibility to contamination from surface activities is a function of several hydrogeologic variables including: depth to ground water, soil properties, the presence or absence of near-surface clay layers, and the nature and rate of contaminant loading. Based on these broad criteria, the surficial aquifers within the Chehalis River watershed are highly susceptible to contamination. In most areas the water table is generally within 20 feet of land surface (Figures 3 and 6), laterally extensive, near-surface clay layers are scarce, and soil permeabilities are often high (Figures 5, 8, and 10).

Specific examples of probable surficial-aquifer contamination, due to land use practices, can be seen in the Scatter Creek Black River aquifer system. There, as shown on Figures 8 and 10, dairy farms tend to be located on or near surficial aquifers with high permeability soils. Agricultural practices such as land application of dairy wastes in these areas could result in elevated nitrate concentrations in drinking water supply aquifers. Indeed, Figure 10 shows that nitrate concentrations in ground water tend to be relatively high down gradient of large dairies. Figures 5, 8, and 10 illustrate that soil-property data, of the sort compiled for this report, can be a valuable tool for assessing an aquifer's vulnerability to contamination, when combined with surficial geology information.

Similar comparisons of potential contaminate sources and ground-water quality may be possible using other data sets available through Ecology's Geographic Information Systems (GIS) Technical Services Dept (see Appendix A for contact information) and from Ecology Web pages (http://www.wa.gov/ecology/). These sources contain numerous land-use and potential-contaminate-source data sets which include coverages such as: critical aquifer recharge areas; sole source aquifers; ground-water management areas; wellhead-protection zones; National Pollutant Discharge Elimination System (NPDES) outfalls in Washington; Resource Conservation Recovery Act (RCRA) facilities; Superfund sites; Toxic Release Inventory facilities; Water Quality Permit Life Cycle System (WPLCS) facilities, plus UST's and LUST's (Underground Storage Tanks and Leaking Underground Storage Tanks, respectively).

Extensive information is available for U.S. Geological Survey monitoring wells and for Washington Department of Health drinking-water wells through Ecology's GIS Technical Services. Monitoring-site wells and related data established by the Department of Ecology are being entered into Ecology's Environmental Information Management (EIM) database. Ground-water data are sparse at present, but will become more readily available as other Ecology databases are moved to the EIM platform. All new data collected by Ecology are placed in the EIM database as a matter of course and historic data will be added as time allows.

Evaluation of the Surficial Aquifer Characterization Process

The Chehalis River Watershed Surficial Aquifer Characterization is the second such study conducted by the Environmental Assessment Program. As we conducted this characterization, we also assessed the effectiveness and efficiency of the iterative process described in the methods section and the overall value of the products we were able to generate using available digital data.

Iterative Method to Define the Surficial-Aquifer Perimeter

We found that the surficial aquifer can be roughly defined using either digital geology or digital soils data alone, but a comparison of the two data sets through an iterative process yields a more detailed, accurate surficial-aquifer perimeter. Queries of digital geology data yield a good first-cut surficial-aquifer perimeter if the queries are based on a firm knowledge of the character and water-bearing properties of the geologic units within the watershed. On the other hand, queries based on digital soil data alone tend to include too much area within the surficial-aquifer perimeter. The best, most realistic surficial-aquifer perimeter was obtained by an iterative comparison of geology data, soils data, and well data as described in the Methods Section, above.

It is easy, however, to overdo the iterative evaluation process and pass a point of diminishing returns. As mentioned above, digital geology can yield a good first-cut surficial-aquifer perimeter. This perimeter, based on geology alone, could even serve as an adequate "quick and dirty" surficial aquifer delineation, depending upon the intended application. Iterative comparisons of the geology coverages with soils data definitely improved the accuracy of the perimeter. Further comparisons to well data refined and raised confidence in the final boundaries. However, in the early stages of our work, we dedicated a lot of time to detailed visual inspections of individual polygons to evaluate and check the results of the geology/soils electronic-query comparisons. This effort yielded little improvement in accuracy or detail and the time could have been used to better advantage in assessment of aquifer and soil characteristics.

Value of the End Products

If the only product were delineation of the surficial aquifer perimeter, a surficial aquifer report such as this would be of limited value. Descriptions and illustrations of aquifer characteristics such as ground-water levels, water-level altitude, hydraulic head maps, ground-water flow directions, water transmitting properties, soil properties, soil infiltration rates, juxtaposition of surficial aquifers and land uses, and ground-water quality characteristics greatly enhance the value and usefulness of the report. Of course, availability of digital data is the principle limiting factor governing what products are possible for any given watershed. (See the Recommendations section for further discussion.)

Recommendations

Conducting Surficial Aquifer Characterization Studies

During this study, we used available digital data almost exclusively. In the interest of time and efficiency, we recommend that future surficial aquifer characterization studies do the same. We believe it would be more beneficial to concentrate future work on watersheds where adequate digital data are available, rather than try to produce similar products using conventional non-digital data and methods.

We recommend that the primary method for delineation of the surficial aquifer be an iterative comparison of digital geology coverage and soil parent-material descriptions. This method should yield a surficial aquifer perimeter that needs only to be refined and confirmed by comparison to well data. Designating the geologic units that make up the surficial aquifers must be based on a solid understanding of the depositional environments and the water bearing characteristics of the geologic units in the watershed.

A map showing the areal extent of the surficial aquifers is of limited use by itself. The usefulness of the information is greatly enhanced if information about aquifer characteristics is also provided. Therefore, it is important to describe and illustrate what is known and can be surmised about the water-bearing characteristics of the surficial aquifer. The following are aquifer characteristics that are important in understanding a surficial aquifer system and should be evaluated and illustrated as well as available digital data will allow.

- Depth to ground water
- Surficial aquifer thickness
- Water-level elevation contour maps (hydraulic head maps)
- Ground-water-flow directions
- Soil infiltration rates
- Well locations, depths, screened intervals (production zones), and production rates
- Ground-water quality data

Future Studies in the Chehalis River Watershed and Other Watersheds Where Watershed Planning is a Priority

Figures 9 and 10 illustrate the level of detail that can be accomplished with the relative abundance of data that is available for the Scatter Creek/Black River Aquifer. With better information about the occurrence and movement of ground water, maps such as these can be fashioned for important developing areas of the watershed. These tools can be used to make informed decisions about urban development, agricultural practices, and protection of ground-water supplies. The following would serve well to enhance the understanding of ground water in the watershed.

- Establish ground-water-quality and ground-water-level monitoring networks for the surficial aquifers in the watershed -- particularly in areas where agricultural and development activities correspond with high permeability soils (Figures 5, 8 and 10).

- Establish a program to systematically enter all new ground-water-quality data, water-level data, and lithologic information into an electronic database format that is compatible with GIS technology.

What the Chehalis Surficial Aquifer Characterization Project Shows Us

- GIS-compatible data are becoming widely available in Washington, but in some areas digital data coverages are inadequate to support a surficial aquifer characterization. In these watersheds, we recommend establishing programs to systematically convert data to a digital format and to make sure that all new data is compiled in a digital format as a matter of course.

- Data is highly useful when it is compatible with GIS technology. Advantages to using GIS-compatible data for these surficial aquifer characterizations include:

    - Regional and area-specific ground-water analyses and maps can be generated in a short time, relative to working with non-digital data.

    - Data comparisons through queries and overlay maps are easy and quick. Therefore, it is easy to run "what if" scenarios that would be difficult and time consuming using conventional methods and non-digital data.

    - Maps and analyses developed through the GIS methods such as those described in this report should be useful, effective development-planning tools.

- Digitized soils and geologic data are essential for GIS-based surficial aquifer characterization studies. For example, since no digitized soils or geology data are available for Mason County, that area had to be excluded from this study.

- Digitized lithology for the watershed would be a valuable asset for GIS evaluations. The current lack of digitized lithologic information is a major gap in the data set. Until digitized lithology is available it will be difficult and time consuming to: 1) define surficial-aquifer thickness, 2) confidently assign ground-water-quality data to the appropriate aquifer, 3) define the tops and bottoms of aquifers; and 4) to do GIS assisted ground-water resource assessments.

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Appendix A

Data Set Descriptions and How to Obtain Data from Ecology and Other Sources

The data coverages used to do the evaluations and generate the maps associated with this report are listed and described in Table A1, below. To obtain these data sets and coverages, contact the people or departments listed.

Table A1 - Summary of Spatial and Tabular Data Sets

Data Type	Data Layer Name/Type	Description	Data Location	Contact Person
Surficial Aquifer	Chesurfaq (Shapefile)	Surficial aquifer layer for the Chehalis River Watershed based on soil attributes and surficial geology, as well as assigned aquifer attributes.	Ecology WRIA Library - WRIA Directory 22 & 23	Joy Denkers, Manager GIS Technical Services P.O. Box 47600 Olympia, WA 98504-7600 (360) 407-7128 Fax: (360) 407-6493 jden461@ecy.wa.gov
Ground-Water Level Altitude (State wide)	GWSI (Related DBASE Table)	Calculated field based on GWSI coverage. Contains ground-water altitude for GWSI wells as measured by the driller.		
Soil Permeablility	High Permeability Soils (Shapefile & DBASE Table)	Coverage for WRIA's 22 & 23 showing areas where soil permeability is greater than two inches per hour		
Dairy Farms (State wide)	Dairy 96 (Coverage)	Locations of permitted dairy farms in Washington State as of 1/1/96 – including associated production figures and herd size.	Internet (www.wa.gov/ecology/)	
Well Information (State wide)	GWSI (Coverage)	U.S. Geological Survey (USGS) wells from Ground Water Site Information Database, April 1996. Includes depth to water, total depth of well, open intervals, well-head elevation, well location, and other pertinent information.	Ecology WRIA Library	
Geology (State Wide)	GUNIT (Coverage)	This coverage contains the geologic spatial data used to define the surficial aquifer in this report. It also contains polygon information describing age-lithology units and linear information describing the interface between those units.	Ecology Quad 100 Library	
Soils	Soils (Coverage)	This coverage contains the spatial and tabular soils data used to define the surficial aquifer in this report.	WDNR	Sandra Bahr WA Dept. of Natural Resources P.O. Box 47020 Olympia, WA 98504-7020 (360) 902-1544 or 902-1790 sandra.bahr@wadnr.gov