

APPENDIX A: *SURFACE AND GROUND WATER QUANTITY*

INTRODUCTION

Appendix A presents the technical reports for the surface water and ground water quantity portion of the Chehalis Basin Level 1 Watershed Assessment. Information found in the technical summary report is gleaned from the technical depth presented herein.

GROUND WATER HYDROLOGY

The geology and associated hydrogeologic conditions of the Chehalis Basin vary widely and reflect the complex geologic history of the area. The basic geology of the basin can be summarized as older bedrock of both sedimentary and volcanic origin exposed on hillslopes and ridges, with more recent depositions of glacial and alluvial sediments overlying these rock units in the valley bottoms and lowland prairies. Groundwater in substantial quantities is present in the glacial deposits, as well as alluvial sediments in the major river valleys.

GEOLOGY

Bedrock

The bedrock sequence from oldest to youngest in the Chehalis Basin starts with Eocene epoch basalt flows which covered the region. A fluctuating sea level also allowed deposition of sediments over the volcanic material, forming sedimentary rocks belonging to the McIntosh formation. Over time, younger sedimentary rocks known as the Lincoln Creek, Astoria, and Montesano formations were deposited over earlier sediments as well as the volcanic material. These units vary in composition and extent, often existing in interbedded layers and discontinuous beds. These bedrock units underlie the entire basin and define the surficial lithology of most of the upland areas of the basin.

The largest block of volcanics, which have not been covered by sedimentary deposits or inundated by glacial or alluvial material, comprises the Black Hills west of the Black River (Walsh et al., 1987). Two other blocks of old volcanic rocks (Eocene epoch) are located in the Doty Hills, as well as the headwaters of the rivers draining the south slope of the Olympic Mountains (Humptulips, Wynoochee, and Satsop Rivers north of township 20N) (Hunting et al., 1961). These rocks are fine to coarse grain basalt flows and breccia (Crescent formation).

Other volcanic rocks in the basin include andesite flows and associated breccia from this same epoch. These comprise the headwaters of the Skookumchuck and Newaukum Rivers. Subsequent weathering of this bedrock produced unconsolidated material, which filled the valley bottoms and was reworked by streams in the basins.

The other significant bedrock units which have not been inundated by glacial and/or alluvial material are of sedimentary origin. These sedimentary rocks can be roughly divided into two groups based on their age. The older group of sedimentary rocks (McIntosh formation and later the Lincoln Creek formation) are from the Oligocene/Eocene epoch. The older McIntosh formation can be found in the Lincoln Creek and South Fork Chehalis subbasins, while the Lincoln Creek formation occupies the terraces on either side of the Chehalis River west and southwest of the Black Hills. The Lincoln Creek deposits are often basaltic sand and siltstones, approximately 2,000 to 4,000 feet in thickness (Beikman et al., 1967).

The younger sedimentary rocks are from the Miocene epoch (Astoria and Montesano formations) and occupy a north/south running band roughly 12 miles in width between the Wynoochee and Satsop Rivers in the north and the central Willapa Hills in the south. These marine sedimentary units consist of moderately consolidated sand and siltstone (Hunting et al., 1961). Given their distribution, this unit likely underlies the alluvial material in the mainstem Chehalis valley downstream from the confluence of Cloquallum Creek. Sedimentary rocks, which are non-marine in origin, are also present in the Hoquiam River drainage and scattered throughout the Chehalis Basin.

Glacial/Alluvial Sediments

Although the Chehalis Basin is underlain by these bedrock units and associated sediments, the surface features of much of the basin, as well as the prominent aquifer characteristics, are the result of more recent glacial and alluvial processes. The results of these processes are evident in the valley bottoms and prairies, where a number of glacial advances and retreats, as well as redistribution of sediments by meltwater and modern river channels has left a thick layer of sediment. The thickness, composition, and density of these deposits varies greatly, as does the hydrogeologic characteristics of the deposits.

Depending on location, the Chehalis Basin has been glaciated three or four times during the Pleistocene epoch (Crandell, 1964, Moore, 1965). These events include alpine glaciers, which flowed south from the Olympic Mountains, as well as the Vashon Stage of the Fraser glaciation, which filled Puget Sound and the northeast portion of the Chehalis Basin. Sediment deposited from the earlier glaciations has been reworked and often compacted by subsequent glaciations.

The first major glaciation occurred early in the Pleistocene epoch (800,000 to 1,600,000 years ago) and left deposits known as the Logan Hill formation (Garrigues et al., 1998). This formation is likely an outwash plane from alpine glaciers (Weigle and Foxworthy, 1962). This unit is composed of poorly sorted gravels and sand that can exceed 150 feet in thickness. In most areas, it is covered by a thicker layer of more recent sediments. It is, however, mapped as the primary lithology in much of the middle and lower Newaukum River basin (Walsh et al., 1987).

More recent pre-Fraser glacial deposits have been identified as Salmon Springs or Penultimate drift (Sinclair and Hirschey, 1992). The drift is composed of discontinuous till and poorly sorted silt, sand, and gravel. Again, these deposits are mostly inundated by more recent glacial material, but significant surface or near surface deposits occur north of Tenino. Scattered pockets of this material can also be found in terraces along the lower Chehalis River, occupying

narrow bands between the bedrock uplands and the alluvial sediments of the mainstem valley floor. Thickness of the deposits likely ranges from 15 to about 60 feet (Drost et al., 1998).

More recent glaciations occurred between 13,000 and 15,000 years ago and consist of the Vashon Stade of the Fraser glaciation and alpine glaciers flowing south from the Olympic Mountains. The Vashon Stade was part of a larger glacial system, which filled Puget Sound and moved south from British Columbia. The glaciers reached their southern extent near Scatter Creek in Thurston County, likely halted by bedrock at the land surface (Drost et al., 1999). To the west, the ice sheet was halted by the volcanic rocks of the Black Hills, but extended around the hills to the East Fork of the Satsop River.

Glacial material, including till, outwash, and undifferentiated materials, was deposited by the Vashon Stade in the lowland areas of Thurston County and Lewis County north of Centralia. Till is composed of a poorly sorted, very compact mix of gravel, sand, and silt which often impedes vertical movement of water. It often overlies more permeable outwash material, and can be discontinuous, thereby allowing surface water to move through to aquifers below. Outwash also consists of a mix of gravel, sand, silt, and clay, but tends to be much more permeable. Outwash can be further differentiated as advance or recessional deposits. Advance deposits are those which have been reworked by the glacier, while recessional deposits have not been reworked and are considerably more porous.

These glacial deposits are discontinuous, often occurring in alternating beds of varying thickness. Local variation in the till/outwash layering sequence is considerable, but some general patterns emerge. For example, the deposits in the Scatter Creek area tend to be permeable outwash gravels. To the north, in the Beaver Creek area, glacial till tends to dominate, while outwash sands are common north of Beaver Creek. Thickness of the deposits in this area range from about 10 to 60 feet (Drost et al., 1998). In the lower Black River, glacial and recent alluvial sediments average about 100 feet in thickness.

As the glacier advanced south, it dammed the Chehalis and Newaukum Rivers near Centralia, forming a large lake (Bretz, 1913). The resultant lacustrine deposits are not exposed at the surface, and consist primarily of sand, silt, clay and some organic matter. Eventually the lake was breached, sending water southwest and west through the valley of the Chehalis. Large volumes of unconsolidated material were moved and deposited in the broad valley of the mainstem and low lying tributary valleys downstream.

Alpine glaciers descended south from the southern Olympic Mountains at least four times during the Pleistocene epoch (Crandell, 1964). These glaciers moved down the major river valleys, depositing a mix of till and outwash material. Glaciers reached their southern extent in the Humptulips Valley near the confluence of the East and West Forks (Crandell, 1964), but outwash from the older of these glaciations is evident south into Township 19 (Walsh et al., 1987). Alpine glaciers also descended into the Wynoochee and Satsop basins, depositing drift as far south as the northern portion of Township 19. Alluvial forces have reworked glacial deposits in the valley floor of all of these basins.

The most recent geologic unit mapped in the Chehalis Basin is alluvial material. This unit consists primarily of unconsolidated sand and gravel along major river and stream courses. The valley floor of the Chehalis, Black, and Newaukum Rivers contain significant deposits. The alluvium is often mixed with glacial outwash material, producing a permeable matrix roughly 100 feet in thickness near the confluence of the Black and the Chehalis Rivers. Downstream in the Chehalis valley, these sediments reach up to 200 feet in depth. Depending on location, this material rests on older glacial deposits or tertiary sedimentary or volcanic bedrock. Alluvial deposits also comprise the valley floor material in the rivers draining the southern Olympics. The depth and composition of these deposits is not well studied, but it can be assumed that they are largely unconsolidated and poorly sorted.

HYDROGEOLOGY

Hydrogeologic conditions within the Chehalis Basin are quite diverse, due in large part to the complex geologic history of the area. Groundwater conditions in the Newaukum, Black, middle Chehalis Rivers, as well as the Scatter Creek area have received considerable study (Drost et al., 1998, Drost et al., 1999, Erickson, 1993, Garrigues et al., 1998, Weigle and Foxworthy, 1962). These areas provide significant quantities of groundwater from a series of aquifers present in the relatively shallow glacial and alluvial deposits. Much less is known about deeper aquifers and groundwater conditions in the older deposits and bedrock elsewhere in the basin. The following discussion parallels the geologic text presented above, starting with information on hydrogeologic conditions in the bedrock units.

Bedrock

As stated above, detailed information on hydrogeologic conditions in the bedrock underlying the basin is not available. In general, however, bedrock units do not contain significant quantities of water, and are largely impermeable (Garrigues et al., 1998). Water of some quantity exists primarily in fractures and contact zones, often near the top of the bedrock unit. In the upper portions of the Chehalis valley, wells drilled into the tertiary marine sedimentary bedrock have yielded only small quantities of water, while wells tapping the younger, non-marine sedimentary rocks generally produce moderate quantities of water (Van Denburgh and Santos, 1965, Weigle and Foxworthy, 1962). Considerable local variation exists in the quantity of water available from bedrock. In Thurston County, only about 5 percent of 1,100 wells studied are located in this unit (Drost et al., 1999). Wells tapping water in fractures in bedrock zones tend to be over 250 feet in depth.

Glacial/Alluvial Sediments

These sediments contain the principle aquifers within the Chehalis Basin. As expected, these deposits contain a complex mix of compacted glacial material, which confines aquifers, as well as unconsolidated material through which water moves relatively freely. The following discussion follows the geologic discussion presented above, with the older, deeper deposits discussed first.

In many areas of Thurston and Lewis County, pre-Fraser sediments of glacial and non-glacial origin exist between the bedrock and more recent glacial deposits. These older sediments, such as the Logan Hill Formation, possess lenses of unconsolidated deposits which can hold moderate

amounts of groundwater. These lenses are often bound by denser layers which form effective aquitards. Groundwater conditions in these deposits have not received as much study as conditions in the overlying, younger deposits which often possess more well developed aquifer systems. Approximately 15 percent of the 1,100 wells studied extensively in Thurston County tap aquifers in these older, deeper deposits (Drost et al., 1998).

Other pre-Fraser glacial deposits which contain groundwater are labeled as the Salmon Springs or Penultimate drift. Depending on location, these deposits can possess large aquifer systems, and contain approximately 35% of the wells studied in the Thurston County area (Drost et al., 1998). In most areas, the aquifer is confined, but where an overlying confining unit is absent, this aquifer merges with aquifers in the more recent deposits, forming a thick productive aquifer. The aquifer is generally about 30 feet in thickness.

Of the most recent series of glaciations in the basin, deposits of the Vashon Stade which cover part of the middle Chehalis Basin (including the Black River and Scatter Creek areas), likely contain the most extensive groundwater bodies. These deposits have been tapped by the greatest number of wells and have received the most study.

The greatest quantity of groundwater exists in the recessional and advance outwash in this area, with lesser amounts present in the till, which acts as a discontinuous confining layer. The aquifer varies in thickness between 10 and about 150 feet, although it may reach 200 feet in places (Weigle and Foxworthy, 1962). Of the 1,100 wells studied in Thurston County, the median well depth is about 105 feet (Drost et al., 1998).

Other aquifers in the Chehalis Basin have received less study and are associated primarily with alluvial deposits in the major river valleys. In the Chehalis river valley upstream of Adna, the surface aquifer is between 4 to 10 feet in thickness. Aquifer thickness increases to about 90 feet downstream in the area northwest of Centralia (Larson, 1994). Depth to groundwater in the valley floor varies considerably, but commonly ranges from 10 to 30 feet (Garrigues et al., 1998).

Downstream from Oakville to Elma, the Chehalis valley is underlain by an aquifer composed of coarse alluvium and reworked glacial material. The aquifer is typically less than 20 feet from the ground surface and highly productive. Further downstream to Grays Harbor, the valley aquifer tends to be thicker due to the increased depth of deposits. Groundwater can typically be found at about 20 feet below the ground surface, with the aquifer extending down approximately 200 feet. The lower 100 feet of the aquifer typically produces water in greater quantity when tapped by wells.

Surficial aquifers can also be found in the tributary stream and river valleys. Depending on the basin, these aquifers are held in glacial and/or alluvial deposits that are thinner and more discontinuous than those associated with the Chehalis River. As these aquifers are not used to the extent of those in the Chehalis and Black River/Scatter Creek valleys, less is known about their characteristics. Typically, groundwater in the Wynoochee and Satsop valleys is within 20 feet of the ground surface, and may extend through the alluvial deposits, which can range up to 30 feet in thickness (Rau, 1967).

Table A-1 contains information concerning the dominant geologic and groundwater conditions for each of the 30 Chehalis subbasins.

Table A-1. Chehalis subbasin geology and groundwater summary

Subbasin no.	Subbasin name	Dominant geology	Groundwater summary
1	Chehalis River Headwaters	The upper three quarters of the basin is Eocene epoch basalt rocks (Crescent formation) and tuff. There is a small area of Eocene marine sedimentary rocks (McIntosh formation) in the southwest corner of the subbasin. The lower quarter of the basin is younger Eocene marine sedimentary rocks (Lincoln Creek formation) with alluvium in valley bottoms.	The upper three quarters of the basin likely contains minimal amounts of groundwater in fractures of dense bedrock. There is likely a limited shallow aquifer in alluvium at the north end of basin.
2	Elk Creek	The north half of the basin is Eocene epoch marine sedimentary rocks (Astoria formation) with alluvium in the valley bottom. The foothills in the south portion of the basin are Miocene Grande Ronde Columbia River basalt. The foothills in the extreme north corner of the subbasin are Eocene basalt (Crescent formation).	Sedimentary rocks in most of the basin are generally thought to provide limited, discontinuous groundwater at considerable depth. A shallow aquifer in alluvium in the valley bottom likely interacts with Elk Creek.
3	South Fork Chehalis River	The majority of the basin is Eocene epoch marine sedimentary rocks (McIntosh formation) with alluvium in the valley bottoms. The hill slopes west of the river are Eocene basalt intrusives.	The bedrock units on hillslopes provide limited quantities of groundwater; there is likely more water present in sedimentary rocks in the east half of basin than in the west half. There are likely increasing quantities of groundwater in the shallow alluvial aquifer as you progress north (downstream). A significant valley bottom aquifer is present in the northern 3 miles of the subbasin.

Table A-1 (Continued). Chehalis subbasin geology and groundwater summary cont.

Subbasin no.	Subbasin name	Dominant geology	Groundwater summary
4	Upper Chehalis River	Numerous units are present; the hillslopes are generally older marine sedimentary rocks (Lincoln Creek formation) with volcanic material along the footslopes. Stillman Creek is underlain by volcanics.	The largest aquifer in the upper basin is likely associated with the mainstem Chehalis valley alluvium. Varied conditions exist elsewhere in the basin.
5	South Fork Newaukum	The lower quarter of the basin is glacial outwash from pre-Fraser glaciations (Logan Hill formation). The upper portion of the basin is Eocene epoch andesite flows with pockets of non-marine sedimentary rocks from the same epoch.	Groundwater in any quantity is likely only in the lower part of the basin as either a surface alluvial or deeper confined aquifer associated with the Logan Hill formation.
6	North Fork Newaukum	The upper two thirds of the basin is Eocene epoch andesite flows. The lower third is a mix of Eocene epoch marine and continental sedimentary rocks, with valley floor alluvium.	Groundwater in any quantity is likely only in the lower part of the basin as a surface alluvial aquifer.
7	Newaukum	The majority of the basin is glacial outwash from pre-Fraser glaciations (Logan Hill formation). Significant deposits of alluvium exist in the river valley (South Fork only) which decrease as you progress upstream.	The Logan Hill formation can produce significant quantities usually under confined conditions; not considered a surface aquifer. Well data indicate the valley surface alluvial aquifer is generally 10-20 feet below the ground surface.

Table A-1 (Continued). Chehalis subbasin geology and groundwater summary cont.

Subbasin no.	Subbasin name	Dominant geology	Groundwater summary
8	Salzer Creek	Eocene epoch marine sedimentary rocks (Lincoln Creek formation) underlie the majority of the basin. Alluvial deposits exist in the lower basin.	Groundwater in any quantity is likely only in the lower part of the basin as a surface alluvial aquifer.
9	Skookumchuck	The upper half of the basin is Eocene epoch andesite flows. The lower half is Eocene epoch continental marine sedimentary rock (Skookumchuck formation) with alluvial deposits in the valley bottoms.	Significant quantities of groundwater are unlikely in the upper basin. Thin aquifers are possible in the sedimentary rocks at depth. In the lower basin, well data indicate water in the alluvial aquifer is at depths of 20-30 feet.
10	Chehalis River	The upper half of the basin (Lincoln Cr.) is underlain primarily by continental sedimentary rocks from the Eocene epoch (Skookumchuck formation). The valley floor is mapped as alluvium. The Chehalis valley is a mix of alluvium and Vashon outwash gravel.	A shallow alluvial aquifer is likely in Lincoln Creek. In the Chehalis valley, alluvial and glacial material is up to 50 thick, with wells tapping a surface aquifer in the 10 to 40 foot depth range.
11	Black River	The majority of the basin is glacial deposits (approximately 100 feet in depth) from the Vashon Stade of the Fraser glaciation. Alluvial material exists along the river channel. The upper portion of Waddell Creek and other west side tributaries are mapped as Eocene epoch basalt (Crescent formation).	A significant, unconfined aquifer is associated with the Vashon glacial outwash. Aquifer located in the 40 to 120 feet of unconsolidated material. Exchange rates between groundwater and the River are available.

Table A-1 (Continued). Chehalis subbasin geology and groundwater summary cont.

Subbasin no.	Subbasin name	Dominant geology	Groundwater summary
12	Cedar Creek	The majority of the basin is Eocene epoch basalt (Crescent formation). Thin bands of marine sedimentary rocks Eocene (Lincoln Creek formation) are mapped near the mouth of the creek. Alluvium is found at the creek mouth.	Minimal aquifer development is likely except that associated with the Chehalis valley system, where water levels are generally 10 to 20 feet below the ground level.
13	Chehalis River	Most of the Scatter Creek basin is underlain by about 100 feet of Vashon outwash gravels. Some sedimentary rock (Skookumchuck formation) is mapped in the hillslopes to the south.	An extensive aquifer is associated with the glacial material. The aquifer is a well studied and productive system.
14	Cloquallum Creek	The upper two thirds of the basin is underlain by Vashon till in the headwaters, with Lincoln Creek formation and younger marine sedimentary rocks at the lower elevations. The bottom third is a mix of glacial and alluvial material.	A surface aquifer associated with the Chehalis valley is likely within 10 to 20 feet of the ground surface.
15	East Fork Satsop	The upper two thirds of the basin is mapped as Vashon till. Hillslopes in the lower basin are mapped as marine sedimentary rocks (Lincoln Creek formation).	Flow data indicate that a very high percentage of total flow is from groundwater input. There is likely a very shallow aquifer associated with the glacial till. There is limited aquifer development in the sedimentary rocks.
16	Decker Creek	The upper two thirds of the basin is mapped as Vashon till. Hillslopes in the lower basin are marine sedimentary rocks (Lincoln Creek formation) and older glacial deposits.	There is likely a very shallow aquifer associated with the glacial till. There is limited aquifer development in the sedimentary rocks. An alluvial aquifer exists in the lower basin.

Table A-1 (Continued). Chehalis subbasin geology and groundwater summary cont.

Subbasin no.	Subbasin name	Dominant geology	Groundwater summary
17	Middle Fork Satsop	Marine sedimentary rocks underlie the hillslopes west of the river, while the east side is pre-Vashon glacial drift.	There is likely a shallow alluvial aquifer with diffuse groundwater patterns in the bedrock.
18	Satsop River	The lower third of the basin is marine sedimentary rocks (Montesano formation). The upper basin is a mix of sedimentary rocks and older glacial material with volcanics (Crescent formation) in the headwaters.	There is likely a shallow alluvial aquifer with diffuse groundwater patterns in the bedrock.
19	Chehalis River	The valley floor is alluvium with some glacial material. Hillslopes south of the valley are mapped as sedimentary rocks. The Sand Creek basin is underlain by a mix of sedimentary rocks (Astoria and Lincoln Creek formations) and old volcanics.	The valley aquifer is well developed in thick alluvium. Water is usually within 10 to 20 feet of the ground surface. There is likely a small alluvial aquifer in Sand Creek.
20	Wynoochee River	The lower third of the basin is mapped as marine sedimentary (Astoria/Montesano formations) rocks and alluvial material. The upper basin is underlain by volcanic rocks of the Crescent formation.	A significant shallow aquifer is likely in the wide valley bottom in the lower basin. Highly variable groundwater conditions exist in the upper basin.

Table A-1 (Continued). Chehalis subbasin geology and groundwater summary cont.

Sub basin no.	Subbasin name	Dominant geology	Groundwater summary
21	Wishkah River	The lower third of the basin is bound by hills underlain by marine sedimentary rocks. The middle third is underlain by older alluvial sediments. The headwaters are a mix of glacial material and sedimentary rock.	A Significant shallow aquifer is likely in the wide valley bottom in the lower basin. Highly variable groundwater conditions exist in the upper basin.
22	Hoquiam River	The majority of the basin is underlain by non-marine sedimentary rocks with alluvium in the valley bottom.	Little information is available for the Hoquiam. There is likely a well developed alluvial aquifer in the lower basin.
23	Middle Fork Hoquiam	The majority of the basin is underlain by non-marine sedimentary rocks with alluvium in the valley bottom.	Little information is available for the Hoquiam. There is likely a well developed alluvial aquifer in the lower basin.
24	East Fork Hoquiam	The majority of the basin is underlain by non-marine sedimentary rocks with alluvium in the valley bottom. Older alluvium is mapped in the headwaters.	Little information is available for the Hoquiam. There is likely a well developed alluvial aquifer in the lower basin.
25	Humtulpis River	Alluvium and glacial drift is mapped in the lower portion of basin. Crescent formation volcanics are mapped in the headwaters.	Little information is available for the Humtulpis. There is likely a well developed alluvial aquifer in the lower basin.
26	Elks River	The majority of the basin is mapped as unconsolidated to partly consolidated marine terrace deposits. Recent alluvium is mapped in the major river valley bottoms.	The aquifer characteristics of terrace sediments are not well studied; well developed aquifer systems are unlikely. A small alluvial aquifer is likely.
27	Johns River	The majority of the basin is mapped as unconsolidated to partly consolidated marine terrace deposits. Recent alluvium is mapped in the major river valley bottoms.	The aquifer characteristics of terrace sediments are not well studied. Large aquifer systems are unlikely. A small alluvial aquifer is likely.

Table A-1 (Continued). Chehalis subbasin geology and groundwater summary cont.

Sub basin no.	Subbasin name	Dominant geology	Groundwater summary
28	Newskah Creek	The hillslopes in the lower half of the basin are Pliocene epoch unconsolidated to partly consolidated marine terrace deposits. Recent alluvium is mapped in the creek valley bottom and mouth. The hillslopes in the upper half of the basin are Miocene sedimentary rocks (Astoria formation).	Hillslopes likely do not have significant quantities of groundwater present. A small alluvial aquifer is likely.
29	Charley Creek	The hillslopes in the lower half of the basin are Pliocene epoch unconsolidated to partly consolidated marine terrace deposits (Astoria formation). Recent alluvium is mapped in the creek valley bottom and mouth. The hillslopes in the upper half of the basin are Miocene sedimentary rocks.	Hillslopes likely do not have significant quantities of groundwater present. A small alluvial aquifer is likely.
30	Chehalis River	The valley floor is alluvium approximately 100 to 200 feet thick. The footslopes are mapped as glacial outwash and sedimentary rocks (Astoria and Montesano formations).	A well developed unconfined alluvial aquifer exists in the valley floor. Ground/surface water exchange is assumed but unquantified.

WELL WATER LEVEL DATA

There are a number of sources of water level data for wells in the Chehalis Basin. Although numerous, the initial water level reported on the drillers log is a one time measurement with limited value. Although not presented at this level, these data could be accessed and evaluated in a Level 2 analysis.

The two other well level data sets available are from the Washington Department of Ecology (WDOE) and the US Geological Survey (USGS). There is some overlap between these data sets, but the degree of the overlap is not known. The WDOE data evaluated is a download of data for the WRIA and contains water levels for 208 wells, mostly taken within the past 25 years. Number of observations per well varies considerably, and the vast majority (88%) of wells were

located in the Scatter Creek and Black River drainages. Table A-13 below presents the WDOE data by subbasin.

Table A-13. Summary of WDOE well water level data for the Chehalis Basin.

Subbasin number	Number of wells with data	Number of observations	Mean water level below ground surface	Median water level below ground surface	Water level range
5	1	82	21.9	22.5	22.1-43.4
7	5	462	31.0	28.9	0.4-98.0
8	1	158	10.4	10.2	5.3-15.7
9	2	21	29.8	31.0	22.1-43.4
10	2	189	6.8	6.7	0.7-11.5
11	46	953	32.5	35.3	0.1-114.0
13	136	4,935	23.7	23.6	0.2-68.7
19	4	71	21.2	20.9	5.3-33.8
26	11	469	15.4	10.7	5.0-36.0

All data in feet

As expected, most wells were drilled in the glacial outwash near the end of the Vashon ice sheet. These wells commonly reported water at depths of between 20 and 50 feet.

The majority of the USGS data set contains one-time water level measurements for wells within the basin. There was no way to request only data from those wells with multiple measurements. Well data for the five selected subbasins covers 411 wells, only 3 of which have more than one observation. These three are covered in the WDOE database. It is likely that the one time measurements are those reported in the drillers log (Fuste, pers. comm.). As stated above, these one time observations are not evaluated in the Level 1 analysis.

HYDRAULIC CONTINUITY-SURFACE/GROUNDWATER INTERACTIONS

The bulk of the groundwater within the Chehalis Basin is from direct infiltration of precipitation. In some cases, recharge from streams, lakes, and wetlands may add to aquifer volumes. The underlying geology of the basin suggests that for all but the deeper, regional aquifers, groundwater basin divides and movement roughly parallels that of surface water.

Commonly, groundwater associated with bedrock units either moves from the hillslopes to the valley floor, or infiltrates into fractures associated with rock folding and deformation. In most cases, groundwater held in bedrock units is too deep to interact directly with surface waters.

Water which moves to the valley floor enters alluvium and glacial drift where unconfined surface aquifers likely interact with the stream or river. The type and degree of this interaction can be complex. Variation with respect to discharge/recharge capabilities varies along the stream network as well as fluctuates seasonally in most basins. This variation is due in part to the stratification of confining and nonconfining layers resulting from glacial and alluvial processes.

While all subbasins in the Chehalis possess surface aquifers which interact with the stream or river, variation exists as to the degree of this interaction. Table A-3 presents the results of a study which attempts to define the contribution of baseflow to the total streamflow. Subbasins have been arranged in order of baseflow as a percentage of mean streamflow.

Table A-3. Chehalis Basin Baseflow Data

Subbasin number	Subbasin name	Median of annual means-baseflow as % of total flow
15	E.F. Satsop	77
11	Black River	75
10	Lincoln Creek	69
13	Porter Creek	68
22	SF Newaukum near Onalaska	67
6	NF Newaukum near Forest	67
13	Rock Creek	66
20	Wynoochee near Montesano	66
2	Elk Creek	65
20	Wynoochee at Oxbow	65
20	Wynoochee below Black Creek	65
14	Cloquallum Creek	64
29	Charley Creek	63
20	Big Creek near Gridale	63
7	Newaukum near Chehalis	62
9	Skookumchuck near Vail	62
18	Satsop near Satsop	61
20	Anderson Creek near Montesano	61
28	Newshkah Creek	60
9	Skookumchuck below Centralia	60
19	Chehalis at South Elma	60
25	Humptulips near Humptulips	60
8	Salzer Creek	59
1	Chehalis near Doty	57
10	Chehalis near Grand Mound	56
3	SF Chehalis near Boisfort	55
13	Chehalis at Porter	55
3	SF Chehalis at Boisfort	54
	Mean	63
	Median	63

Data source: Sinclair and Pitz, 1999

Subbasin boundaries in Sinclair and Pitz (1999) may not correspond exactly with those mapped for the Chehalis Basin Partnership watershed assessment

Data in the table confirms that subbasins within the Chehalis rely heavily on baseflow contribution to streamflow. It is obvious that subbasins, which possess extensive glacial or alluvial deposits near the surface, support aquifers that interact with surface flows. The Black River, mainstem Chehalis, and lower reaches of the larger rivers all likely possess significant shallow aquifer systems which interact directly with the river. Basins such as the upper South Fork Chehalis and Salzer Creek, which lack significant unconsolidated deposits, likely rely less on groundwater inflow to maintain stream flow.

While the above information links groundwater and surface water flow, only limited study into direct measurement of this connection has occurred. Not surprisingly, surface/ground water interactions of the aquifers associated with the Black River/Scatter Creek and the Middle Chehalis River have received the most study. Surficial aquifers in these basins provide a significant portion of the stream flow during low flow periods. The greatest exchange of ground and surface water occurs in the glacial and alluvial deposits in the Black River/Scatter Creek/Chehalis River area. Lewis and Thurston Counties have recognized the direct link between surface and groundwater, as both counties have mapped the valley floors of the Chehalis and Black Rivers as moderate to severe Critical Aquifer Recharge Areas in terms of aquifer sensitivity. This sensitivity is due to the permeability of glacial and alluvial deposits which extend from the ground surface to the base of the surficial aquifers.

The surficial aquifer of the Chehalis River valley is connected directly to the river, with the river acting as a discharge point for the aquifer. Discharge from the aquifer to the river varies with location and season, but Erickson (1993) has calculated rates between 0.1 and 10.3 cubic feet per second per mile of river (cfs/mi) in the 26 miles of river downstream of the Thurston/Lewis County border. Sinclair and Hirschey (1992) measured inflow rates of 3.1 cfs/mi in this same area. In general, inflows increased as you move downstream due to increased aquifer thickness and greater hydraulic conductivity.

Both the Black River and Scatter Creek are also seasonal discharge points for the valley aquifers. While the Black and Chehalis Rivers receive the bulk of the groundwater discharge, Scatter Creek and a number of smaller creeks also receive inflow (Sinclair and Hirschey, 1992). Data collected over an eight month period indicated that inflows to a 16 mile reach of Scatter Creek varied from near zero to a high of 8.0 cfs/mi. Recharge from the creek to the aquifer during this same period ranged up to 5.6 cfs/mi (Sinclair and Hirschey, 1992). In general, the upper and lower portions of the creek are groundwater discharge points, while the central portion of the creek acts as a groundwater recharge zone. The Black River also receives considerable inflows from groundwater. Inflows measured during a period of low stream flow indicate that over a 5 mile reach, the Black gained an average of 1.8cfs/mi.

These types of interactions likely occur in every subbasin in the Chehalis. As stated earlier, the degree of this interaction elsewhere in the basin is unquantified, but unlikely to be of the magnitude of that observed in the Black River and central Chehalis. Depth and condition of the valley floor sediments dictate to a large degree the interaction between surface and groundwater.

SURFACE WATER HYDROLOGY

The Level 1 assessment of surface water quantity in the Chehalis Basin included several independent analyses which can be summarized under the following four headings:

- ◆ the compilation of available data (e.g. streamflow records, climate data, subbasin characteristics, and structural features);
- ◆ the analysis of gaged flows;
- ◆ the analysis of natural climate variability; and
- ◆ undepleted gage flows.

The products presented in this report will serve as building blocks for the Level 2 efforts.

The majority of these analyses were conducted at the basinwide scale, while others produced information by WRIA or are specific to certain subbasins. In many cases, this information will have to be refined at a subbasin level. A notable local example is the Black River Subbasin where the hydrology of the upper basin has been greatly modified. Although Black Lake historically flowed into the Black River, at the present, at least during the dry season, there is no surface water connection from the lake to the river, and the lake flows out of the Chehalis Basin toward Percival Creek (Berg, 1993). Some of the factors believed to be contributing to this change in hydrology include: a ditch built in the 1920s from Black Lake to Percival Creek to prevent flooding; a pipeline installed in the 1960s through wetlands at the southern end of the lake, which has formed a topographical high point; and several dozen beaver dams.

COMPILATION OF AVAILABLE DATA

The Chehalis Basin was fortunate to have a substantial amount of hydrologic and climatic data available for use in assessing watershed processes. Of particular notice, were the several streamflow stations which have been continuously monitored dating back to the early part of the 20th Century. Characteristics of current and historic streamflow and climate data stations located in or near the Chehalis Basin were identified and are presented below.

Streamflow Data

Systematic streamflow records were available at fifty-four locations in the Chehalis Basin with 30 in WRIA 23 and 24 in WRIA 22 (Tables A-1 and A-2). Map 4 displays the spatial location of each of these streamflow gaging stations. Few of these streamflow stations recorded flows unhampered by human uses. The actual flow at some of the stations may be near "natural" or undepleted by withdrawals, while many of the stations recorded flows that were substantially depleted from natural flows due to regulation or withdrawals of water for municipal, irrigation, or other uses.

The final column in Tables A-1 and A-2 provides remarks on the degree of regulation and diversion upstream of each streamflow station. The information portrayed in the final column was obtained primarily from the USGS gaging station remarks; the WDOE Water Supply Bulletin #60 (Sinclair and Pitz, 1999), and the WDOE GIS coverage of the dams in Washington provided some additional information. The diversion information from the USGS and WDOE

addressed surface water diversions only; these data sources did not explicitly account for the degree of ground water withdrawals in a basin. Groundwater withdrawals in continuity with surface water sources could be depleting the surface water streamflow.

In addition to systematic streamflow data collection, numerous miscellaneous discharge measurements have been taken in the Chehalis Basin since the turn of the century. Miscellaneous measurements, taken by the USGS, the WDOE, and other local interests, will be useful during level 2 analyses. These data points could provide an excellent source of information for use in extending the period of record at streamflow gaging stations and estimating frequency information at a location without the benefit of continuous streamflow records.

Climate Data

Several climate stations within or near the Chehalis Basin (Table A-3) were reviewed for their usefulness in analyzing local climate trends and the resulting affect on streamflow in the Chehalis Basin. Map 4 displays the spatial location of each of these climate stations. Annual precipitation values were found to be available for the some of the stations (Aberdeen and Centralia stations) for the years where daily records were missing.

Subbasin Characteristics

Drainage area, elevation features, and mean annual precipitation characteristics were compiled for the 30 subbasins defined in the Chehalis Basin (Table A-4).

Structural Features

The investigation of structural features in the Chehalis Basin was limited to the identification of dams. The WDOE has available on its web site a GIS layer portraying attributes and location of the dams in Washington. According to this data source, seventy dams were located within the Chehalis Basin. Map 3 displays the location of these dams by subbasin and Table A-5 provides information on the dams by the map number listed on Map 3. The majority of the dams were concentrated around the City of Aberdeen, and in the Black and Skookumchuck River subbasins.

Table A-1. Streamflow Gaging Stations -- Lower Chehalis WRIA 22

Station Number	Station Name	Period of Record	Drainage Area (mi ²) Elevation (ft)	Remarks on Regulation and Diversions *= USGS Water Supply Bulletin #15 , 1962 Data source for all other Earthinfo 1994 CDRom
12016500	Little North R Cosmopolis	1946-49, 1953	18.6 mi ²	No remarks
12017500	Johns R nr Markham	1942-43	18.9 mi ²	No remarks
12018500	Charley Crk nr Aberdeen	1945-49	5.93 mi ² 20 ft	No remarks
12018000	Newskah Crk nr Aberdeen	1945-49	7.44 mi ² 40 ft	No remarks
12039000	Humtulpis R nr Hump	1933-35 1942-79	130 mi ² 120 ft	No diversion above station Slight low flow regulation by fish hatchery on west fork*
12037500	Wynoochee R Blw Black Crk nr Montesano	1942-50	40 ft	No remarks
12037400	Wynoochee R Abv Black Crk nr Montesano	1956 – current	155 mi ² 179 mi ² * 40 ft	1957-69 unregulated; 1969-72 some regulation from dam construction 1972-current regulated by Wynoochee Dam (45.7 mi upstream) Municipal water supply (City of Aberdeen) Small diversions for domestic and irrigation use
12036650	Anderson Crk nr Montesano	1972-85	2.72 mi ² 150 ft	No remarks
12036500	Wynoochee R nr Montesano	1923-30	112 mi ²	No remarks
12036400	Schafer Crk nr Grisdale	1987-96	12.1 mi ² 280 ft	No regulation or diversions upstream
12036000	Wynoochee R Abv Save Crk nr Aberdeen	1925-52; 1952- current	74.1 mi ² 401 ft	1925-52 unregulated (published as at Oxbow 12035500) 1952-69 unregulated 1969-72 some regulation from dam construction 1972-current regulated by Wynoochee Dam USGS adjusts some of the summary statistics for the change in contents of Wynoochee Lake No diversions upstream of station
12035500	Wynoochee R at Oxbow nr Aberdeen	1925-52	70.7 mi ²	No remarks
12035450	Big Crk nr Grisdale	1972-96	9.57 mi ² 600 ft	No regulation or diversions upstream
12035400	Wynoochee R nr Grisdale	1965- current	41.3 mi ² 630 ft	1965-69 unregulated 1969-72 some regulation from dam construction 1972-current regulated by Wynoochee Dam USGS adjusts some of the summary statistics for the change in contents of Wynoochee Lake No diversions upstream of station
12035380	Wynoochee Lake nr Grisdale	1972- current	41.0 mi ²	Lake created by dam; Useable Capacity 67,288 ac-ft between 690 ft (sluice gate invert) and 800 ft (full pool level)
12035002	Chehalis R nr Satsop	1977-83	1,761 mi ² 2.66 ft	No remarks

Table A-1 (Continued). Streamflow Gaging Stations -- Lower Chehalis WRIA 22

Station Number	Station Name	Period of Record	Drainage Area (mi ²) Elevation (ft)	Remarks on Regulation and Diversions *= USGS Water Supply Bulletin #15 , 1962 Data source for all other Earthinfo 1994 CDRom
12035000	Satsop R nr Satsop	1929-current	299 mi ² sea level	No regulation or diversion upstream of station
12034200	E Fk Satsop R nr Elma	1957-71	65.8 mi ² 205 ft	No regulation or diversion upstream of station *
12034000	Bingham Cr nr Matlock	1946-49	30 mi ²	No remarks
12033500	E Fk Satsop R nr Matlock	1946-48	23.7 mi ²	No remarks
12033000	Chehalis R at South Elma	1942-45 1947-52	1,417 mi ² 15 ft	No remarks
12032500	Cloquallum R at Elma	1942-73	64.9 mi ² 20 ft	Small diversions on minor tributaries Some regulation by log pond -Wildcat Crk*
12032000	Wildcat Crk nr Elma	1944	19.8 mi ²	No Remarks
12030900	Porter Crk at Porter	1942-49	35.3 mi ² 60 ft	No remarks

Table A-2. Streamflow Gaging Stations -- Upper Chehalis WRIA 23

Station Number	Station Name	Period of Record	Drainage Area (mi ²) Elevation gage (ft)	Remarks on Regulation and Diversions *= USGS Water Supply Bulletin #15 , 1962 Data source for all other Earthinfo 1994 CDRom
12031000	Chehalis R at Porter	1952-72 1975-current	1,294 mi ² 23.64 ft	1952-1971 Unregulated 1971-current Minor regulation Skookumchuck Dam Consumptive Use – 54.5 peak, 30 cfs avg by Centralia Steam Plant Municipal water supply 4cfs (Centralia, Chehalis)
12030500	Cedar R nr Cedarville	1944	38.2 mi ²	No Remarks
12030000	Rock Crk nr Cedarville	1942-71	24.8 mi ² 70 ft	No regulation upstream Some diversion for irrigation*
12029500	Garrard Crk nr Oakville	1944	27.7 mi ²	No remarks
12029000	Black R at Little Rock	1942-50	63.7 mi ² 125 ft	No remarks
12028500	Wadell Crk nr Little Rock	1944	15.9 mi ²	No remarks
12028000	Scatter Crk n Ground Mnd	1944	21.0 mi ²	No remarks
12027500	Chehalis R nr Grand Mound	1928-current	895 mi ² 123.65 ft	1928-1971 Unregulated 1971-current Minor regulation Skookumchuck R Dam Consumptive Use by Centralia Steam Plant Municipal water supply 4cfs (Centralia, Chehalis) Small diversions for domestic and irrigation use

Table A-2 (Continued). Streamflow Gaging Stations -- Upper Chehalis WRIA 23

Station Number	Station Name	Period of Record	Drainage Area (mi ²) Elevation gage (ft)	Remarks on Regulation and Diversions *= USGS Water Supply Bulletin #15 , 1962 Data source for all other Earthinfo 1994 CDRom
12027000	Lincoln Crk nr Rochester	1942-50	19.3 mi ² 190 ft	No remarks
12026500	Hanaford Crk nr Centralia	1944	13.3 mi ²	No remarks
12026400	Skookumchuck R nr Bucoda	1967-current	112 mi ² 198.19 ft	1967-71 Unregulated; 1971-current regulated by Skookumchuck Dam Consumptive Use – by Centralia Steam Plant Minor diversions for domestic and irrigation use
12026150	Skookumchuck R Blw Bldy Rn Cr N Centralia	1929-33 1939-current	65.9 mi ² 301.04 ft	Published as “near Centralia” prior to 1969 1967-71 Unregulated; 1971-current regulated by Skookumchuck Dam No diversions upstream
12026000	Skookumchuck R nr Centralia	1929-34 1939-69	61.7 mi ² 317.34 ft	No regulation No diversions upstream
12025700	Skookumchuck R nr Vail	1967-current	40.0 mi ² 710 ft	No regulation No diversion upstream
12025500	Chehalis R at Centralia	1910-11	653 mi ²	No remarks
12025300	Salzer Crk nr Centralia	1968-72	12.6 mi ² 185 ft	No remarks
12025000	Newaukum R nr Chehalis	1929-31 1942-81 82-current	155 mi ² (revised) * 190 ft	Municipal diversion of 5 cfs (Chehalis and Centralia) No regulation upstream
12024500	NF Newaukum R nr Forest	1944, 1957-66	31.5 mi ² 380 ft	No regulation upstream Municipal diversion 15 cfs (Chehalis and Centralia) *
12024000	SF Newaukum R nr Onalaska	1944-49 1957-72	42.4 mi ² 540 ft	No regulation or diversion above station *
12023500	Chehalis R nr Chehalis	1929-31	434 mi ²	No remarks
12023000	Stearns Crk nr Adna	1944	27.1 mi ²	No remarks
12022500	Stearns Crk nr Napaville	1945	14.1 mi ²	No remarks
12022000	Bunker Crk nr Adna	1944	20.1 mi ²	No remarks
12021500	Halfway Crk nr Boistfort	1944	13.4 mi ²	No remarks
12021000	SF Chehalis R at Boistfort	1942-50 1961-66	48 mi ² 255 ft	No remarks
12020900	SF Chehalis R nr Boistfort	1961-81	44.9 mi ² 280 ft	No remarks
12020500	Elk Crk nr Doty	1942-50 1968-70	46.7 mi ² 360 ft	No remarks
12020000	Chehalis R nr Doty	1939-current	113 mi ² 302.1 ft	No regulation or diversions upstream 23A160 DOE Ambient Monitoring
12019000	Chehalis R nr Pe Ell	1944	54.7 mi ²	No remarks
12019500	Rock Crk nr Pe Ell	1944	13.4 mi ²	No remarks

Table A-3. Climate Stations in or near the Chehalis Basin

Station Name	Type of Station *	Elevation (ft)	Period of Record	Mean Annual Precipitation (in) ⁺
Aberdeen	Climate Data	10	1931-53,55-63,65-86,88-current	83
Aberdeen 20 NNE	Climate Data Hourly Precip since 1948	435	1931-32,34,36-63,66-current	130
Hoquiam FCWOS AP	Climate Data	12	1954-86,88-current	70
Hoquiam	Climate Data	15	1949-50	82
Humptulips Salmon Hatchery	Climate Data	140	1988-current	109
Montesano 1 S	Hourly Precipitation	25	1949-50	91
Matlock 8 S	Climate Data	110	1986-current	78
Elma	Climate Data	69	1949,51-60,62-92,94-current	67
Oakville	Climate Data	80	1948-94	56
Doty 3 E	Climate Data	260	1979-85,87,90-91	52
Olympia WSO AP	Climate and Hourly Precip	195	1949-current	50
Centralia 1W	Hourly Precipitation	185	1967-current	41
Centralia	Climate Data	185	1931-77,79-81,84-current	46
Chehalis	Climate Data Hourly Precip	180	1951 1948-68	41
Dryad	Climate Data	312	1964-77	58
Toledo	Climate Data	325	1951-54,62-63,66-71,73-81,83	46
Mayfield Power Plant	Climate Data	280	1981-current	54
Cinebar	Hourly Precipitation	1,040	1948-53,62-94	72
Glenoma 1 W	Climate Data	781 840	1933-64 1968-84,86-88,91-92	62 66

* Climate Data station records daily values for temperature precipitation
Hourly Precipitation records hourly and daily precipitation values
+ summary statistics from Earthinfo (1994) CDRom

Table A-4. Chehalis Sub-basin Characteristics for Upper Chehalis Basin (WRIA 23) and Lower Chehalis Basin (WRIA 22)

Sub-basin No.	Sub-basin Name [Reach Description]	Drainage Area (mi ²)	Mean Basin Elevation (ft)	Range in Basin Elevation (ft)		Mean Annual Precipitation (in)
				Min	Max	
1	Chehalis River Headwaters [Upper Chehalis above Doty]	116	1,280	293	3134	89
2	Elk Creek [Elk Creek mouth to headwaters]	60	871	276	2404	73
3	South Fork Chehalis River	50	860	240	2621	74
4	Upper Chehalis River [Chehalis above Chehalis below Elk and Doty]	211	642	160	2992	56
5	South Fork Newaukum	42	1,486	559	3804	63
6	North Fork Newaukum	32	1,323	379	2827	57
7	Newaukum	82	548	160	2096	45
8	Salzer Creek	19	430	161	893	42
9	Skookumchuck River	177	945	140	3812	53
10	Chehalis River - Middle Reach 1 [Chehalis above Grand Mound below Chehalis]	102	419	120	2475	45
11	Black River	137	358	48	2572	48
12	Cedar Creek	39	973	39	2656	54
13	Chehalis River – Middle Reach 2 [Chehalis above Porter below Grand Mound] WRIA 23	226	509	25	2660	51
14	WRIA 22 Cloquallum Creek	70	422	16	1580	68
15	East Fork Satsop River	57	483	223	2851	98
16	Decker Creek	48	576	115	3013	106
17	Middle Fork Satsop River	57	983	98	3325	114
18	Satsop River	137	769	11	3876	102
19	Chehalis River – Lower Reach 1 [Chehalis above Satsop below Porter]	94	309	10	1814	59
20	Wynoochee River	198	916	5	4981	123
21	Wishkah River	104	412	sea level –	1637	106

Table A-4 (Continued). Chehalis Sub-basin Characteristics for Upper Chehalis Basin (WRIA 23) and Lower Chehalis Basin (WRIA 22)

Sub-basin No.	Sub-basin Name [Reach Description]	Drainage Area (mi ²)	Mean Basin Elevation (ft)	Range in Basin Elevation (ft) Min Max	Mean Annual Precipitation (in)
<i>Basins Draining to Grays Harbor</i>					
22	Hoquiam River	52	195	sea level - 502	82
23	Middle Fork Hoquiam	10	259	13 - 442	94
24	East Fork Hoquiam	26	288	26 - 868	104
25	Humtulpis R.	244	722	sea level - 4,397	127
26	Elks River	18	235	sea level - 575	71
27	Johns River	30	272	sea level - 667	75
28	Newskah Creek	12	314	sea level - 834	88
29	Charley Creek	8	237	5 - 647	87
30	Chehalis River – Lower Reach 2 [from mouth to Satsop R confluence]	60	149	sea level - 823	75

Table A-5: Location of Dams in the Chehalis Basin (Source: WDOE GIS Layer Dams in Washington)

Map Number	Name of Dam	Legal Description Section Township Range	County Name	Name of Stream	Name of Dam Owner	Year Dam Completed
1	Sea Horse Ranch Dike	S15 T18 R11W	GRAYS HARBOR	Tr-Gillis Slough		1961
2	Failor Lake Dam	S30 T19 R10W	GRAYS HARBOR	Deep Creek	Washington Dept. of Wildlife	1956
3	Aberdeen Lake Dam	S12 T17 R9W	GRAYS HARBOR	Van Winkle Creek	City of Aberdeen	1928
4	Sylvia Lake Dam	S31 T18 R7W	GRAYS HARBOR	Sylvia Creek	Washington Parks & Recreation	1918
5	Wishkah Reservoir No. 2 Dam	S33 T21 R8W	GRAYS HARBOR	Wishkah River	City of Aberdeen	1928
6	Surge Pond Dam	S30 T15 R1W	LEWIS	Hanaford Creek	PacifiCorp	1971
7	Skookumchuck Dam	S14 T15 R1E	THURSTON	Skookumchuck River	PacifiCorp	1970
8	Berger Dam	S15 T16 R1W	THURSTON	Tr-Scatter Creek		1970
9	Carlisle Lake Dam	S30 T13 R1E	LEWIS	Tr-South Fork Newaukum River	Washington Dept. of Wildlife	1920
10	PEO Dam No. 1A	S29 T15 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1972
11	PEO Dam No. 5C	S32 T15 R1W	LEWIS	Tr-Packwood Creek	PacifiCorp	1970
12	PEO Dam No. 3A	S32 T15 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1970
13	PEO Dam No. 6B	S32 T15 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1970
14	PEO Dam No. 5	S29 T15 R1W	LEWIS	Tr-Packwood Creek	PacifiCorp	1971
15	PEO Dam No. 8A	S16 T14 R1W	LEWIS	Tr-South Hanaford Creek	PacifiCorp	1972
16	PEO Dam No. 8	S9 T14 R1W	LEWIS	Tr-South Hanaford Creek	PacifiCorp	1972
17	Wynoochee Dam	S20 T22 R7W	GRAYS HARBOR	Wynoochee River	City of Aberdeen	1973
18	Malinowski Dam	S33 T21 R8W	GRAYS HARBOR	Wishkah River	City of Aberdeen	1963
19	French Canyon Dam	S11 T14 R16E	YAKIMA	North Fork Cowiche Creek	Dept. of Interior, Bureau Rec.	1985
20	PEO Dam No. 3B	S32 T15 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1980
21	PEO Dam No. 22	S25 T15 R2W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1973
22	PEO Dam No. 3C - North	S32 T15 R1W	LEWIS	South Hanaford Creek-Offstre	PacifiCorp	1987
23	PEO Dam No. 3C - South	S32 T15 R1W	LEWIS	Tr-Packwood Creek-Offstream	PacifiCorp	1987
24	PEO Dam No. 3C - East	S32 T15 R1W	LEWIS	Tr-Packwood Creek-Offstream	PacifiCorp	1987
25	PEO Dam No. 20B	S24 T15 R2W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1981
26	PEO Dam No. 20C	S19 T15 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1981

Table A-5 (Continued): Location of Dams in the Chehalis Basin (Source: WDOE GIS Layer Dams in Washington)

Map Number	Name of Dam	Legal Description Section Township Range	County Name	Name of Stream	Name of Dam Owner	Year Dam Completed
27	Swano Lake Dam	S16 T17 R9W	GRAYS HARBOR	Tr-Charley Creek	Grays Harbor College	1949
28	Fairview Reservoir No. 1	S5 T17 R9W	GRAYS HARBOR	Wishkah River-Offstream	City of Aberdeen	1917
29	Spoils Pond Dam	S17 T17 R9W	GRAYS HARBOR	Grays Harbor-Offstream	Weyerhaeuser Company	1970
30	Maytown Ski Pond Dam	S16 T16 R2W	THURSTON	Tr-Scatter Creek		1987
31	PEO Dam No. 36	S29 T15 R1W	LEWIS	Hanaford Creek-Offstream	PacifiCorp	1989
32	PEO Dam No. 36A	S29 T15 R1W	LEWIS	Hanaford Creek-Offstream	PacifiCorp	1989
33	PEO Dam No. 3D	S5 T14 R1W	LEWIS	Tr-Packwood Creek	PacifiCorp	1988
34	PEO Dam No. 44	S33 T15 R1W	LEWIS	Tr-Packwood Creek	PacifiCorp	1975
36	PEO Dam No. 19A	S3 T14 R1W	LEWIS	Tr-Packwood Creek	PacifiCorp	1977
37	Seeley Ski Lake	S8 T17 R2W	THURSTON	Tr-Black River		1992
38	PEO Dam No. 32B	S21 T15 R1W	THURSTON	North Hanaford Creek	PacifiCorp	1991
39	Black River Ranch	S22 T16 R3W	THURSTON	Offstream	Black River Ranch	1994
40	College Hill Reservoir	S2 T17 R10W	GRAYS HARBOR	Little Hoquiam R. - offstream		1900
41	Reilly Dam	S21 T15 R5W	LEWIS	Tr-South Fork Garrard Creek		1965
42	Kyte Dam	S20 T15 R2W	THURSTON	Tr-Skookumchuck River		1966
43	Davis Creek Dam	S4 T18 R10W	GRAYS HARBOR	Davis Creek	City of Hoquiam	1966
44	Campbell Slough	S16 T18 R11W	GRAYS HARBOR	Campbell Slough	Washington Dept. of Fisheries	1964
45	Walentiny Dam	S12 T16 R3W	THURSTON	Tr-Black River		1968
46	Borst Lake Dam	S6 T14 R2W	LEWIS	Tr-Skookumchuck River	City of Centralia	1950
47	PEO Dam No. 6	S29 T15 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1971
48	PEO Dam No. 6A	S29 T15 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1970
49	Dunlap Pond Dam	S8 T15 R2W	THURSTON	Tr-Prairie Creek		1930
50	Eagle Creek Dam	S4 T14 R3W	LEWIS	Eagle Creek	Jerguson	1950
51	Monte Vista Poultry Detention Pond	S20 T16 R2W	THURSTON	Offstream	South Sound Soils	1980
52	Wynoochee Fish Barrier Dam	S12 T22 R7W	GRAYS HARBOR	Wynoochee River	City of Aberdeen	1972
53	Stewart Dam	S4 T27 R8W	GRAYS HARBOR	Geissler Creek		1916

Table A-5 (Continued): Location of Dams in the Chehalis Basin (Source: WDOE GIS Layer Dams in Washington)

Map Number	Name of Dam	Legal Description Section Township Range	County Name	Name of Stream	Name of Dam Owner	Year Dam Completed
54	PEO Dam No. 5A	S32 T15 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1971
55	PEO Dam No. 5B	S32 T15 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1982
56	PEO Dam No. 5D	S32 T15 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1983
57	PEO Dam No. 20	S24 T15 R2W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1973
58	PEO Dam No. 45	S10 T14 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1978
59	PEO Dam No. 32	S20 T15 R1W	THURSTON	Tr-Hanaford Creek	PacifiCorp	1986
60	Schoenbachler Dam	S2 T16 R1W	THURSTON	Silver Springs Creek		1960
61	PEO Dam No. 20A	S24 T15 R2W	LEWIS	Tr-North Fork Hanaford Creek	PacifiCorp	1955
62	PEO Pit No. 7 West Sump	S4 T14 R1W	LEWIS	Tr-Packwood Creek	PacifiCorp	1974
63	PEO Dam No. 22	S30 T15 R1W	LEWIS	Tr-Hanaford Creek	PacifiCorp	1973
64	PEO Mendota East Sump	S33 T15 R1W	LEWIS	Tr-Packwood Creek	PacifiCorp	1985
65	Havvaski Waterski Pond	S2 T16 R3W	THURSTON	Tr-Black River		1992
66	Silverado Waterski Pond	S3 T13 R3W	LEWIS	Tr-Chehalis River		1992
67	Fairview Reservoir No. 2	S5 T17 R9W	GRAYS HARBOR	Wishkah River-Offstream	City of Aberdeen	1921
68	Mill Creek Dam	S23 T17 R9W	GRAYS HARBOR	Mill Creek	City of Cosmopolis	1930
69	Beacon Hill Reservoir	S12 T17 R10W	GRAYS HARBOR	Hoquiam River - offstream	City of Hoquiam	1935
70	West Fork Dam	S4 T18 R10W	GRAYS HARBOR	West Fk. Hoquiam River	City of Hoquiam	1956

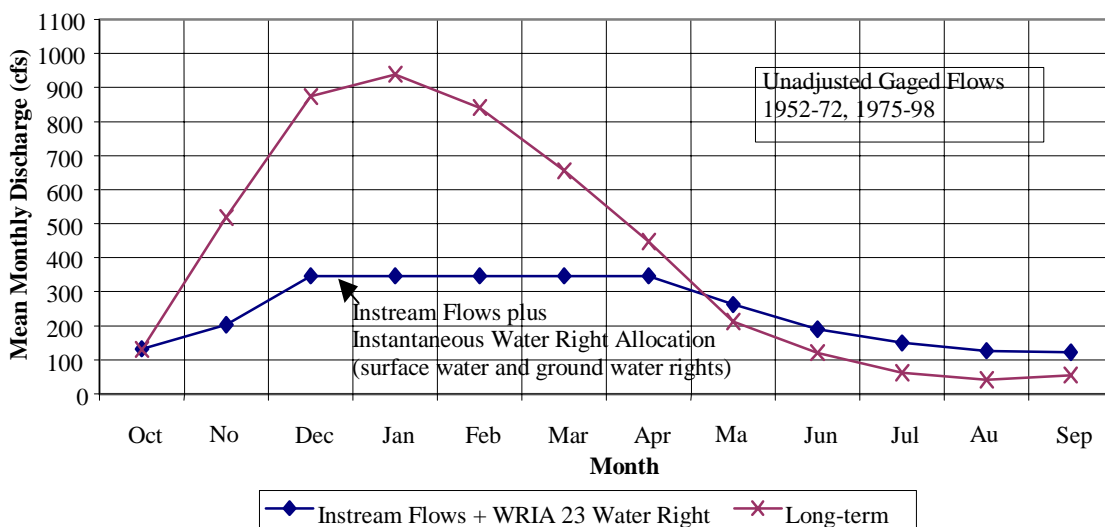
ANALYSIS OF GAGED FLOWS

In order to obtain an understanding of the flows the Chehalis River actually experiences, gaged flows at or near the mouth of each WRIA were examined. Upstream dams and myriad diversions have influenced the gaged flows along the Chehalis River. Dams typically influence the flow regime of a river by reducing the peak flows and augmenting low flows; pre-dam and post-dam data sets can represent two distinct population of flows depending on operating policies. Level 2 analyses may need to investigate the effects of streamflow regulation due to dams in the Chehalis Basin.

The Chehalis River at Porter (#12031000) is located at the downstream end of WRIA 23 and therefore reflects surface water quantity totals for this WRIA. Fifty-four dams were identified within WRIA 23, 14 of which had storage rights listed in WDOEs water rights database (WRATS). The largest dam in WRIA 23 is the Skookumchuck Dam (subbasin 9) completed in 1971. The USGS note minor effects of flow regulation from this dam on the streamflows recorded at the Chehalis River at Porter gage. At this level of analysis, the impact of this and the other dams on the flow in the Chehalis River was unknown.

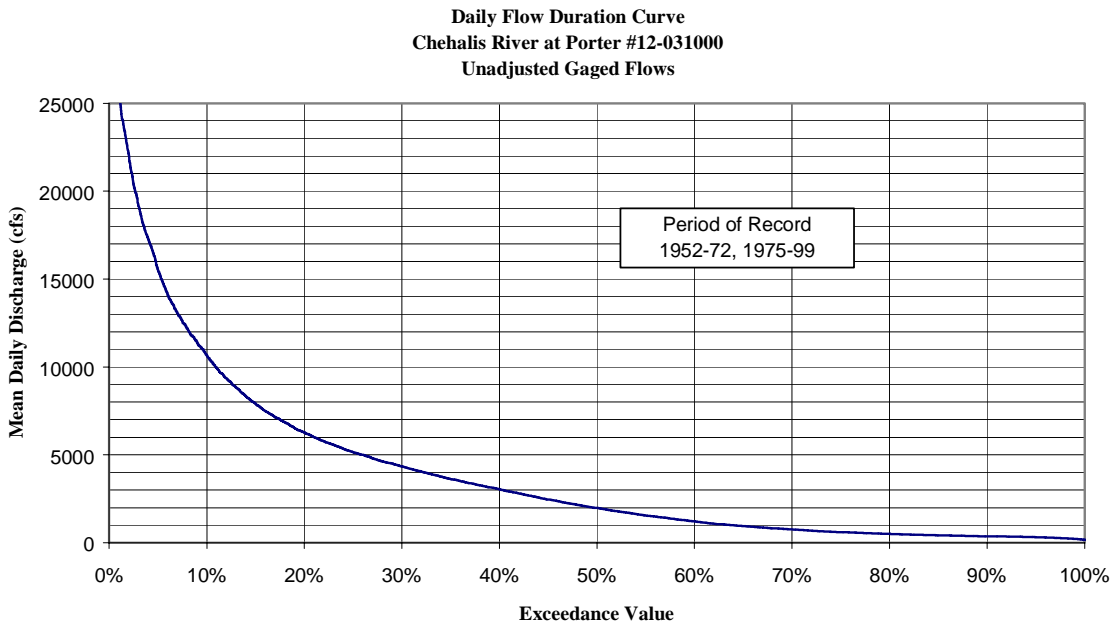
The mean monthly hydrograph for the Chehalis River at Porter (1952-72,1975-98) is displayed in Figure A-1. For perspective, the average bimonthly instream flows at the Porter control point (as set by WAC 173-522-020) were added to the total water right allocation for WRIA 23 (961 cfs) and plotted on Figure A-1. This graph indicates that the combination of the instream flow and the instantaneous water right allocation (which includes both surface water and ground water rights) exceeds the gaged mean monthly flows from May through September.

Figure A-1: Chehalis River at Porter (12-031000) Regulated Mean Monthly Hydrograph



A flow duration curve (Figure A-2) was generated for the Chehalis River at Porter using the unadjusted flows. Flow duration curves provide an indication of the frequency distribution of flows at a station. Since exceedance values are indirectly proportional to the flow, the 90% exceedance values are always less than the 50%, the median flow value of the data series (half of the flows will be less than the 50% exceedance value and half will be greater). Of the mean daily flows recorded at the Porter gage, half have been equal to or greater than 1980 cfs and 90% of the flows have been equal or greater than 370 cfs.

Figure A-2: Chehalis River at Porter (12-031000) Flow Duration Curve



Surface water quantity totals for WRIA 22 were more difficult to estimate since there was no flow data available near the mouth of the Chehalis River. Additionally, WRIA-wide totals would not be hydrologically meaningful since several of the major tributaries in WRIA 22 drain directly to Grays Harbor, not to the Chehalis River. Lower Chehalis River surface water runoff was estimated at Montesano, near the upstream end of the tidally influenced reach.

Flows at Montesano were estimated by adding gaged flows (Chehalis at Porter, Cloquallum, Satsop, and Wynoochee) and incorporating unit runoff estimates for the ungaged portions along the river valley between Porter and Montesano. Accretion flow from the 165 mi² of ungaged drainage to the Chehalis River between Montesano and the Porter Creek confluence was estimated using a combination of unit runoff values and the relationship of flows at the Chehalis at Porter gage. Mean monthly unit runoff values were generated from the 8 years of gage records available at the historic Chehalis River at south Elma station located mid-basin. These monthly unit values compared favorably to values from the longer-term base gages and therefore were used. Exceedance values for the ungaged area between Montesano and Porter were derived by using a ratio of the mean monthly to the 50% and 90% exceedance value at the Chehalis River at Porter gage. These exceedance values were then added to the accumulated values of the

gaged flows (Porter gage + Cloquallum, Satsop, and Wynoochee) to represent flows available at Montesano.

The Chehalis River at Montesano exceedance values listed in Table A-6 were based on data from 1957-72 and 76-98, the coinciding years of record at the four gages. This period did include both pre- and post-dam years on the Wynoochee and therefore the values do not represent an estimate of natural flow. Instead, the exceedance values were based on the addition of unadjusted gaged flows, which reflect the many unidentified diversions throughout both WRIA's and regulation of the Wynoochee River. There is no instream flow control point on the lower Chehalis River near Montesano.

**Table A-6
Flow Exceedance Values for Chehalis River at Montesano**

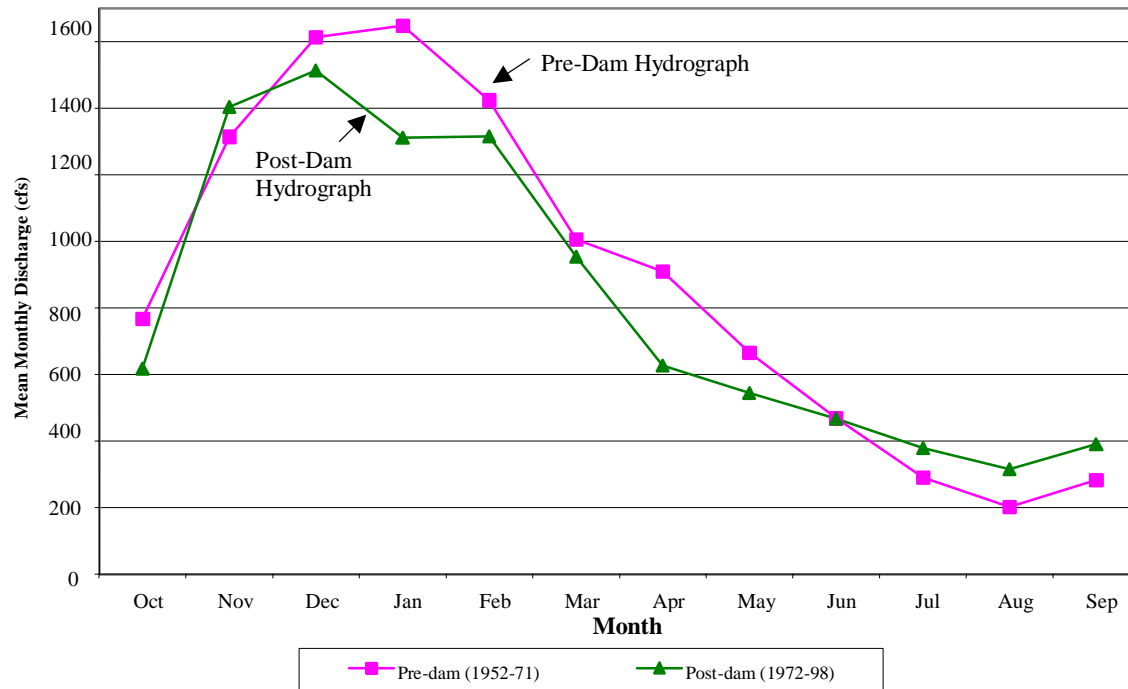
<u>Month</u>	Estimated Flow Exceedance Values ¹			
	Chehalis River at Montesano			
	50% Exceedance (cfs)	50% URO ² cfs/mi ²	90% Exceedance (cfs)	90% URO ² cfs/mi ²
October	2078	1.05	827	0.42
November	8296	4.19	2424	1.23
December	13144	6.65	5596	2.83
January	13445	6.80	5020	2.54
February	12987	6.57	6026	3.05
March	10260	5.19	5045	2.55
April	6853	3.46	3828	1.94
May	3761	1.90	2336	1.18
June	2124	1.07	1438	0.73
July	1333	0.67	893	0.45
August	915	0.46	611	0.31
September	985	0.50	627	0.32

¹ based on the addition of daily data from four gages USGS station #12-031000, Chehalis R. at Porter, Cloquallum #12-032500, Satsop R #12-035000, and the Wynoochee R. #12-037400 for coinciding record years 1957-72,76-98 + accretion flow to Montesano; drainage area = 1,978 mi²

² URO = unit runoff

Mean monthly flows at the Wynoochee above Save Creek gage (#12-036000) for the pre-dam years (1952-71) were compared to those for the post-dam years (1972-98) as displayed in Figure A-3. The post-dam hydrograph demonstrates that the dam is effective in dampening the peak flows; post-dam mean monthly flows for December through May were lower than pre-dam flows. Also, the post-dam flows show augmentation during the low flow months (July, August, and September).

Figure A-3: Wynoochee River (12-036000) Pre-and Post-Dam Hydrographs



ANALYSIS OF NATURAL CLIMATE VARIABILITY

In the Pacific Northwest, two primary patterns of climate variability occur: El Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). The cyclical patterns and physical mechanisms of ENSO have been thoroughly researched and are now fairly well understood. The physical mechanism behind the more recently discovered PDO is not as well studied, however, the cyclical nature of the PDO phases has been characterized. The ENSO effect can be determined on a year-by-year basis, however, for water allocation, planning this is not as useful as a longer-term pattern that includes cycles of dry and wet year extremes. For this study, an understanding of the decadal climate phases was most important, therefore, climatic and hydrologic data from the Chehalis Basin were analyzed and compared to the regionally identified natural climate variability as measured by PDO phases (Mote et.al., 1999).

Regional Patterns of Climate Variability

Mote et.al 1999 have defined time periods for five distinct PDO climate cycles experienced in the Pacific Northwest (Table A-7). The period of record used for water allocation studies should cover both PDO phases to adequately represent the natural variability.

Table A-7: Pacific Northwest Pacific Decadal Oscillation Cycles

Pacific Northwest PDO Climate Cycles	Time Period ¹
Cool/Wet Phase	1890-1924
Warm/Dry Phase	1925-1945
Cool/Wet Phase	1946-1976
Warm/Dry Phase	1977-1995
Cool/Wet Phase	1995 shift speculated

¹ per Mote et.al. 1999

In the Pacific Northwest, the cool PDO phase, experienced in the 1890-1924 and 1946-1976 cycles, resulted in: an average temperature decrease of 0.2 °F, an average increase in precipitation of 2%, an increase in snow depth of 17%, and a corresponding increase in streamflow of 6% (Mote, 1999). Also, during these cool phases of PDO, an increase of 19% in the annual catch of Washington Coho salmon was observed (Note: only Coho salmon catch was evaluated in Mote, 1999).

The warm PDO phase that occurred throughout the Pacific Northwest from 1925 to 1945 and from 1977 to 1995 was characterized by: an average temperature increase of 0.3 °F, an average precipitation decrease of 4%, a corresponding decrease in snow depth and streamflow (-15% and -10%, respectively), and a 16% decrease in the Washington Coho salmon catch (Mote, 1999). Scientists have speculated that a shift may have occurred from the warm and dry PDO in 1995; however, the certainty of a shift is not yet known (Mote, 1999).

Climate and Streamflow Patterns in the Chehalis Basin

Statistical techniques were applied to the annual precipitation data for the entire period of record at the Centralia and the lower Aberdeen climate stations to understand the trends in these “local” data and whether they follow the documented regional climate variability cycles.

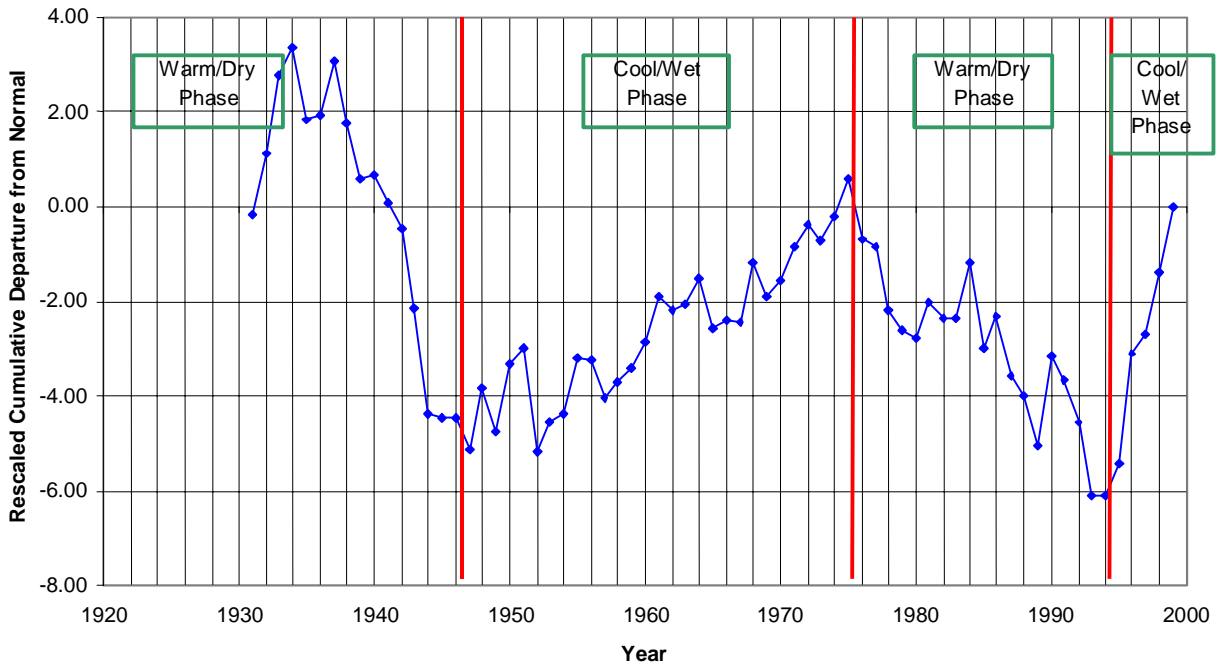
Patterns of increasing and decreasing values over time are often difficult to discern from time-series graphs because of the variation between values from month to month or year to year. The patterns become more evident by accumulating the values prior to plotting (Kresch, 1994). Departures from normal were calculated, accumulated, and then plotted for each of the climate stations. Graphs of cumulative departure from normal equal zero at the start, increasing during wet periods (positive departures indicate that the rate for a given year exceeds the long-term average) and decrease during dry periods (Kresch, 1994). To facilitate graphical comparison across the stations, the cumulative departures from normal are then standardized or rescaled (divided by the standard deviation) to illustrate the PDO pattern.

The important fact to glean from Figures A-4 to A-7 is that the trends in the data are consistently increasing or decreasing within a given regionally identified Pacific Decadal Oscillation phase (noted as vertical lines per Mote, 1999). For Centralia (Figure A-4), the pattern is distinct and coincides with the reported regional PDO patterns (Mote et.al. 1999); Figure A-4 displays a

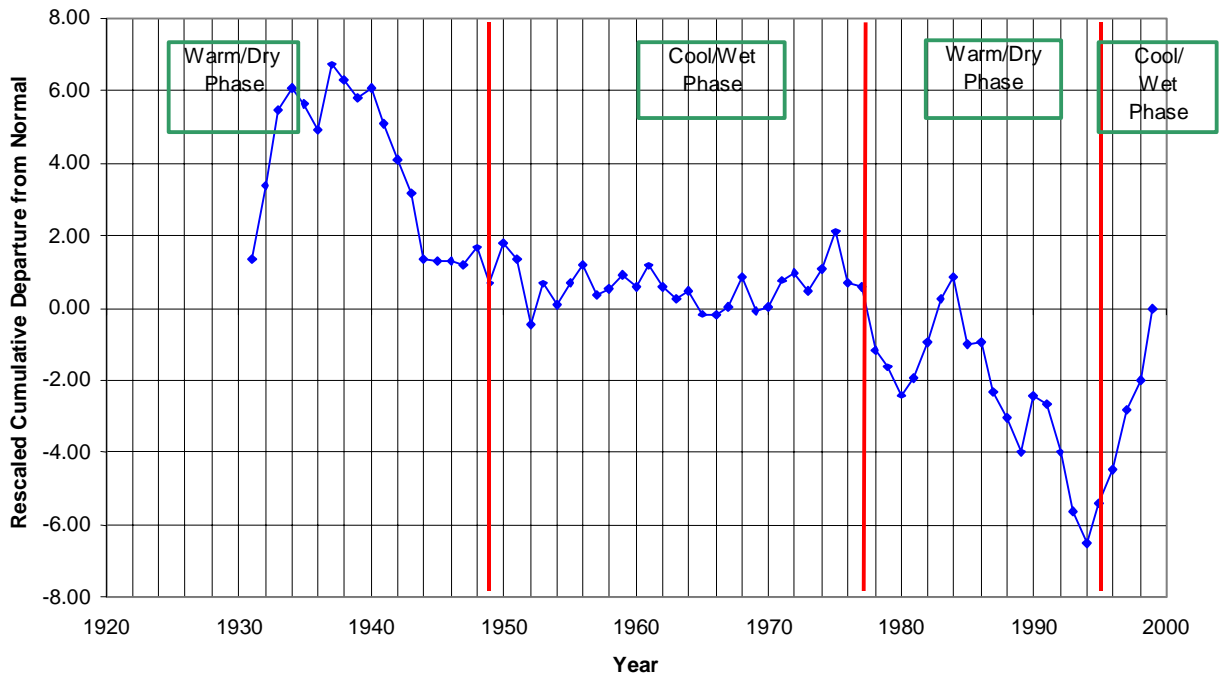
declining pattern pre-1945, moving to an increasing pattern until the mid-1970s then declining again.

The pattern during warm/dry PDO phases at the Aberdeen station (Figures A-5) is also fairly distinct and coincident with the reported regional patterns. However, the adherence to regional patterns was less clear for the cool/wet phase; a shift occurred in the rescaled departures from normal in 1945 (at the same time as the regional phase shift), however, annual values plateaued instead of increasing.

Figure A-4. Annual Precipitation for 1931-1999 for Station #451276, Centralia, WA (Elevation = 185 feet)



**Figure A-5. Annual Precipitation for 1931-1999, Station #450008, Aberdeen, WA
(Elevation = 10 feet)**



A similar analysis of departures from normal and rescaled cumulative values was undertaken with the streamflow records at the longest continuously recording gage in the Chehalis Basin, the Satsop River near Satsop station (#12-035000). Annual departures from normal, as a percentage, are displayed in Figure A-6 to distinguish wet and dry years over the long period of record at the Satsop gage. The trends in the data, evident in Figure A-7, show the pattern of climate variability at the Satsop gage distinct and coincident with the reported regional PDO patterns (Mote et.al. 1999).

Figure A-6. Mean Annual Streamflow Departures from Normal for 1931-1999, Satsop River near Satsop, WA

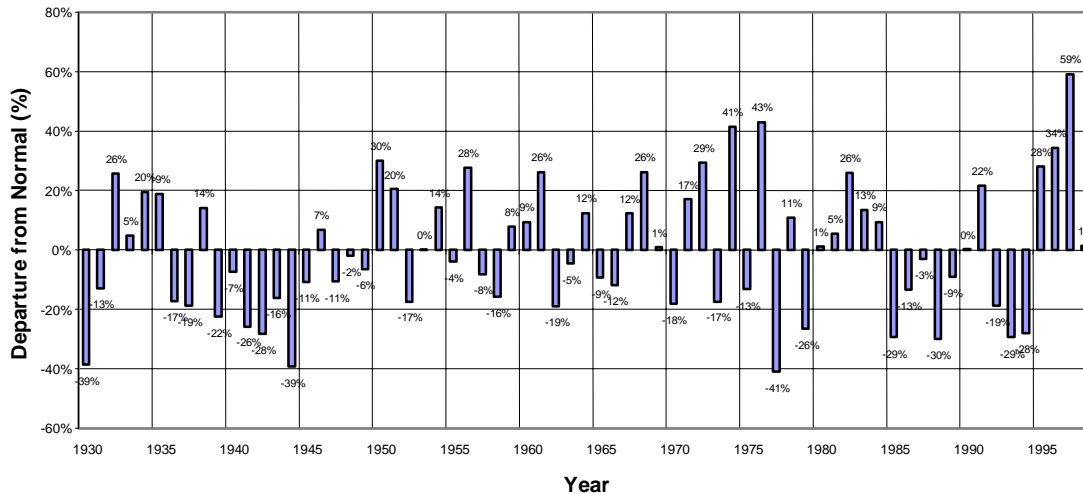
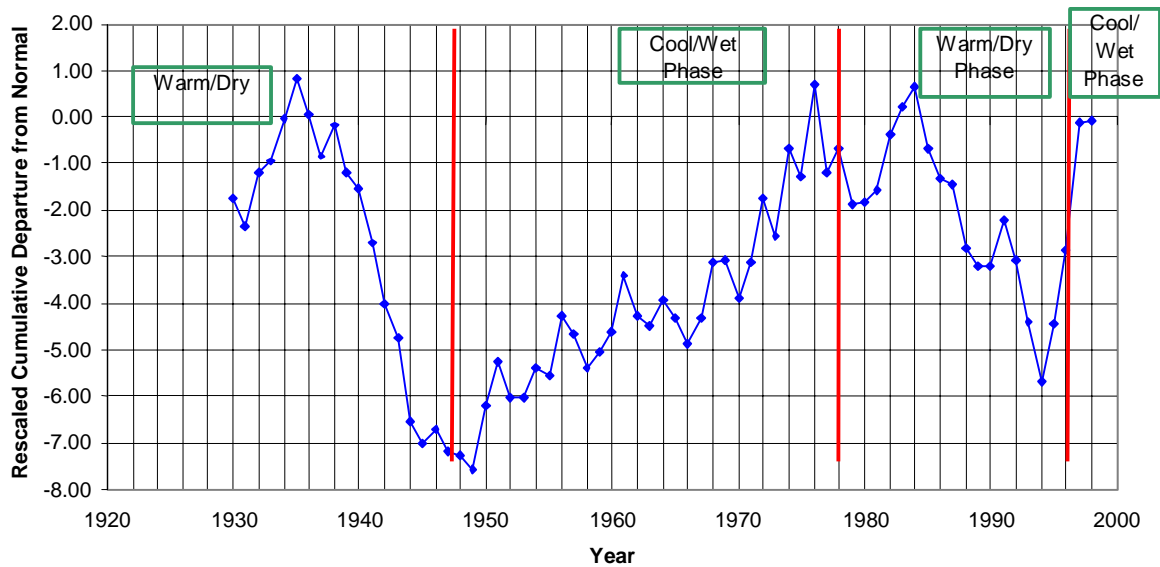


Figure A-7. Mean Annual Streamflow Cumulative Departure from Normal for 1931-1999, Satsop River near Satsop, WA



In summary, the stations analyzed in the Chehalis Basin show clear adherence to the regionally identified natural climate variability; no alternative trends in either streamflow or precipitation were identified at this level of analysis. Investigation of shorter-term gage records used in the subsequent section take this fact into consideration; the records were analyzed in the context of the mix of wet and dry years experienced at the Satsop River gage.

UNDEPLETED GAGE FLOW

Of the 30 subbasins identified in the Chehalis Basin, all but five (Decker Creek, M Fk Hoquiam, E Fk Hoquiam, Elks River, and the Chehalis Lower Reach 2 to the mouth) had some systematic streamflow records located within the boundaries. While substantial streamflow data area available, few of these streamflow stations have recorded flows unhampered by human uses. Several factors (e.g. upstream regulation/diversion, climatic conditions, land use during the period of record of the gaged flows) influence the adequacy of the gage records to represent natural or undepleted flows. Prior to using the numerous gage records to generate summary statistics representative of “undepleted” flows, two factors were investigated: 1. the extent of upstream regulation and abstraction of water, and 2. the climate variability over the period of record. A detailed streamflow depletion analysis was not conducted for any of the gages in the Chehalis Basin but could be considered for a level 2 analysis; the term undepleted is used in this report to qualify the reviewed gage records.

Base gage selection

Twenty gages located in thirteen of the 30 subbasins were identified as having sufficient streamflow data reflective of “undepleted” flows; these were termed base gages. Nine of these gages were located in lower Chehalis and eleven in upper Chehalis (Table A-8). The criteria for selection as a base gage were threefold: 1. length of streamflow record greater than 10 years; 2. little or no regulation or diversion upstream of gage, and 3. a minimum of development in the watershed upstream of the gage. The USGS remarks section in the gaging station records was reviewed for initial information on regulation/ diversions etc. occurring upstream of the gage potentially influencing the recorded streamflow data. The WDOE Water Supply Bulletin #60 (Sinclair and Pitz, 1999) was used as an additional source of information regarding the extent of potential upstream diversions for each of the base gages. Registered dams were identified (WDOE GIS Layer, Dams in Washington) and the location reviewed to assure no upstream regulation by small dams. Observations on water withdrawal (pumps, dams/ diversions) from the USFS Chehalis Habitat database (Wampler et.al., 1993) was reviewed cursorily but should be pursued in more depth in Level 2.

Table A-8. Selected Streamflow Base gages (meeting criteria of >10 years unregulated records and only small or minor diversions)

Station Number	Station Name	Period of Record	Drainage Area (mi ²) Elevation gage (ft)	Remarks on Regulation and Diversions * = USGS Water Supply Bulletin #15 , 1962 Data source for all other Earthinfo 1994 CDRom
Lower Chehalis				
12039000	Humptulips R nr Hump	1933-35 1942-79	130 mi ² 120 ft	No diversion above station Slight low flow regulation by fish hatchery on west fork*
12037400	Wynoochee R Abv Black Crk nr Montesano	1956 – current	155 mi ² 179 mi ² * 40 ft	Only used the 1956-69 unregulated portion; Small diversions for domestic and irrigation use
12036650	Anderson Crk nr Montesano	1972-85	2.72 mi ² 150 ft	No remarks
12036400	Schafer Crk nr Grisdale	1987-96	12.1 mi ² 280 ft	No regulation or diversions upstream
12036000	Wynoochee R Abv Save Crk nr Aberdeen	1925-52; 1952-current	74.1 mi ² 401 ft elev	Only used the 1925-52 unregulated portion (published as at Oxbow 12035500) and the 1952-69 unregulated portion; No diversions upstream of station
12035450	Big Crk nr Grisdale	1972-96	9.57 mi ² 600 ft	No regulation or diversions upstream
12035000	Satsop R nr Satsop	1929-current	299 mi ² sea level (0)	No regulation or diversion upstream
12034200	E Fk Satsop R nr Elma	1957-71	65.9 mi ² 205 ft	No regulation or diversion upstream
12032500	Cloquallum R at Elma	1942-72	65.8 mi ² 20 ft	Small diversions on minor tributaries Some regulation by log pond –Wildcat Crk*
Upper Chehalis				
12031000	Chehalis R at Porter	1952-72 1975- current	1,294 mi ² 23.64 ft	Only used 1952-1971 unregulated portion This station is influenced by a large Consumptive Use – (54.5 peak, 30 cfs avg) by Centralia Steam Plant
12030000	Rock Crk at Cedarville	1942-71	24.8 mi ² 70 ft	No regulation upstream Some diversion for irrigation*
12027500	Chehalis R nr Grand Mound	1928- current	895 mi ² 123.65 ft	Only used 1928-1971 unregulated portion This station is influenced by consumptive Use – (54.5 peak, 30 cfs avg) by Centralia Steam Plant; Municipal water supply 4cfs (Centralia, Chehalis) only supplemental supply. Small diversions for domestic and irrigation use
12026000	Skookumchuck R nr Centralia	1929-34 1939-69	61.7 mi ² 317.34 ft	No regulation No diversions upstream
12025700	Skookumchuck R nr Vail	1967- current	40.0 mi ² 710 ft	No regulation No diversion upstream
12025000	Newaukum R nr Chehalis	1929-31 1942-81 1982- current	155 mi ² (revised) * 190 ft	Municipal diversion of 5 cfs (cities of Chehalis and Centralia) No regulation upstream
12024000	SF Newaukum R nr Onalaska	1944-49 1957-72	42.4 mi ² 540 ft	No regulation or diversion

Table A-8 (Continued). Selected Streamflow Base gages (meeting criteria of >10 years unregulated records and only small or minor diversions)

Station Number	Station Name	Period of Record	Drainage Area (mi ²) Elevation gage (ft)	Remarks on Regulation and Diversions <small>*= USGS Water Supply Bulletin #15 , 1962 Data source for all other Earthinfo 1994 CDRom</small>
12021000	SF Chehalis R at Boistfort	1942-50	48 mi ²	No remarks
12020900	SF Chehalis R nr Boistfort	1961-66 1961-81	255 ft 44.9 mi ²	No remarks
12020500	Elk Crk nr Doty	1942-50 1968-70	280 ft 360 ft	No remarks
12020000	Chehalis R nr Doty	1939-current	113 mi ² 302.1 ft	No regulation or diversions upstream

The accuracy of frequency analysis results, and any summary statistics, is largely a function of the period of record used to generate the statistics. Statistics based on short records can be influenced by a non-representative mix of wet and dry years. Even stations with 10 years of record may not be representative of climate variations and should be extended where possible (Robison, 1991). Using the annual departures from normal for the Satsop River long-term records (Figure A-6) as an indicator of regional climate norms, tallies were taken of the number of wet and dry years over the period of record for each base gage (Table A-9). The mix of wet/dry year tallies were similar to the long-term records for most stations and, therefore, assumed representative of natural variability. For three gages (12020500, 12021000, and 12036650), the mix of wet and dry years covered within the period of record was not similar to the Satsop gage. Data generated from these gages were coded as to the respective bias based on the predominance of wet or dry years.

Table A-9. Pertinent Information on Base Gages

Station Number	Station Name	Period of Record	Drainage Area (mi ²) Elevation of gage (ft)	Mean Annual Flow (cfs) [cfs/mi ²]	Period of Record (Mixed, Wet or Dry based on Satsop record) ¹
Lower Chehalis					
12039000	Humtulpis R nr Hump	1933-35 1942-79	130 mi ² 120 ft	1337 [10.3]	Mixed +22/-20
12037400	Wynoochee R Abv Black Crk nr Montesano	1956 – 69 pre dam portion	155 mi ² 179 mi ² * 40 ft	1299 [8.4]	Mixed +24/-19
12036650	Anderson Crk nr Montesano	1972-85	2.72 mi ² 150 ft	15 [5.5]	WET +9/-5
12036400	Schafer Crk nr Gridale	1987-96	12.1 mi ² 280 ft	75 [6.2]	Mixed +4/-6
12036000	Wynoochee R Abv Save Crk nr Aberdeen	1925-52	74.1 mi ² 401 ft elev	772 [10.4]	1929-52 period +8/-15
12035450	Big Crk nr Gridale	1972-96	9.57 mi ² 600 ft	113 [11.8]	Mixed +13/-12

Table A-9 (Continued). Pertinent Information on Base Gages

Station Number	Station Name	Period of Record	Drainage Area (mi ²) Elevation of gage (ft)	Mean Annual Flow (cfs) [cfs/mi ²]	Period of Record (Mixed, Wet or Dry based on Satsop record) ¹
12035000	Satsop R nr Satsop	1929-current	299 mi ² sea level (0)	2033 [6.8]	Mixed +34/-35
12034200	E Fk Satsop R nr Elma	1957-71	65.9 mi ² 205 ft	374 [5.7]	Mixed +16/-20
12032500	Cloquallum R at Elma	1942-72	65.8 mi ² 20 ft	274 [4.2]	Mixed +19/-13
Upper Chehalis					
12031000	Chehalis R at Porter	1952-72 1975-current	1294 mi ² 23.64 ft	4107 [3.2]	Mixed +25/-20
12030000	Rock Crk at Cedarville	1942-71	24.8 mi ² 70 ft	89 [3.6]	Mixed +14/-16
12027500	Chehalis R nr Grand Mound	1928-current	895 mi ² 123.65 ft	2823 [3.2]	Mixed +34/-35
12026000	Skookumchuck R nr Centralia	1929-34 1939-69	61.7 mi ² 317.34 ft	247 [4.0]	Mixed +16/-20
12025700	Skookumchuck R nr Vail	1967-current	40.0 mi ² 710 ft	201 [5.1]	Mixed +19/-13
12025000	Newaukum R nr Chehalis (deregulated)	1929-31 1942-81 1982-current	155 mi ²	498 [3.2]	Mixed +21/-22
12024500	NF Newaukum R nr Forest	1957-66	31.5 mi ² 380 ft	103 [3.3]	Mixed +4/-6
12024000	SF Newaukum R nr Onalaska	1944-49 1957-72	42.4 mi ² 540 ft	200 [4.7]	Mixed +10/-12
12021000	SF Chehalis R at Boistfort	1942-50 1961-66	48 mi ² 255 ft	199 [4.2]	DRY +4/-11
12020900	SF Chehalis R nr Boistfort	1961-81	44.9 mi ² 280 ft	175 [3.9]	Mixed +12/-9
12020500	Elk Crk nr Doty	1942-50 1968-70	360 ft	163 [3.5]	DRY +4/-8
12020000	Chehalis R nr Doty	1939-current	113 mi ² 302.1 ft	573 [5.1]	Mixed +29/-31

¹Using the Satsop gage departure from normal graph (Figure A-6) tally of number of years that annual streamflow was above or below normal Dry = >60% of years above normal

For these 20 base gages, summary statistics were generated on a monthly basis and normalized into runoff per square mile to allow comparison of runoff production across the basin. Unit runoff characteristics representative of annual runoff, seasonal, and maximum and minimum monthly values are compiled in Table A-10 under the subbasin name in which the base gages occur.

Table A-10. Chehalis Basin Unit Runoff Characteristics

Sub-basin No.	Subbasin Name and drainage area to mouth	Base Gage within the subbasin	Mean Unit Runoff (cfs/mi ²)				
			Annual	Max Month	Winter Avg ¹	Summer Avg ²	Min Month
1	Chehalis R 116 mi ²	12020000	5	11	10	<1	<1
2	Elk Creek 60 mi ²	12020500	3	9	7	<1	<1
3	SF Chehalis 50 mi ²	12020900	4	10	8	<1	<1
		12021000	4	10	9	<1	<1
5	SF Newaukum 42 mi ²	12024000	5	10	8	1	1
7	Newaukum 82 mi ²	12025000(wit h municipal diversions added back in)	3	7	6	<1	<1
9	Skookumchuck R 177 mi ²	12025700	5	10	9	1	1
		12026000	4	8	8	1	1
10	Chehalis River - Middle Reach 1 102 mi ²	12027500	3	7	7	<1	<1
13	Chehalis River – Middle Reach 2 226 mi ²	12030000	4	9	8	<1	<1
		12031000	3	8	7	<1	<1
14	WRIA 23 WRIA 22 Cloquallum Creek 70 mi ²	12032500	4	10	9	1	1
15	EF Satsop R 57 mi ²	12034200	6	13	11	2	1
18	Satsop River 137 mi ²	12035000	7	14	13	1	1
20	Wynoochee R 198 mi ²	12035450	12	24	22	3	2
		12035500	11	21	18	3	2
		12036000	10	22	19	4	3
		(52-69 yrs)					
		12036400	6	14	12	1	1
		12036650	6	13	10	1	<1
		12037400	8	18	15	2	1
25	Humptulips R. 244 mi ²	12039000	10	21	18	3	2

¹Winter Avg. = December through March²Summer Avg. = July through September

Primarily due to the extreme variation in precipitation across the Chehalis Basin, the amount of runoff varies dramatically (up to four-fold) from 3 cfs/mi² annually along the low lying valley bottom area to more than 12 cfs/mi² in the upper watersheds draining the Olympic Mountains. Based on the unit runoff characteristics (Table A-10), in conjunction with basin characteristics (precipitation isohyets, geology, etc.), and low flow values (Sinclair and Pitz, 1999 and Cummins, 1975), the Chehalis Basin was divided into 6 hydrologically similar areas as

presented in Table A-11. Insufficient streamflow data existed on the South Bay tributaries (Johns, Elk, Charley) to determine representative unit runoff ranges in the Level 1 assessment.

Table A-11. General Areas of Hydrologic Similarity within the Chehalis Basin

Description of Hydrologically Similar Areas	Annual Unit runoff range (cfs/mi ²)	Winter Average unit runoff ¹	Summer (low flow) average unit runoff ²
North Bay/ Inner Harbor low-lying tributaries (Hoquiam, Lower Humptulips)	5-8	10-15	1-2
Humptulips to Wynoochee Upper Watersheds	10-12	21-24	3-4
WRIA 22 & 23 Low-lying valleys along Chehalis and tributaries	3-4	7-9	<1
Satsop River Basin	6-7	9-13	1
WRIA 23 Mid-basin major tributaries with headwaters in foothills of cascade range (Black, Skookumchuck, Newaukum)	4-5	8-9	1
WRIA 23 Upper Chehalis headwaters in Willapa Hills (Elk, SF, Stillman..)	3-5	7-10	<1

¹ Winter Season for this study is defined as December through March

² Summer Season for this study is defined as July through September

These regions of similarity will be useful for Level 2 analyses to produce flow estimates in ungaged basins. Level 2 analyses may also involve hydrologic techniques such as correlation analysis between miscellaneous flow measurements and concurrent gage data and normalization of flows by drainage area (per unit runoff calculations for various flow events). Additionally, a core period of record could be selected to assure that undepleted flow estimates reflect the natural variability in climatic conditions. Base station streamflow records could be extended through correlation analysis with nearby gages as appropriate to cover the selected core period of record then unit runoff calculations could be updated.

DISCUSSION OF APPROPRIATE EXCEEDANCE LEVELS

For watershed planning purposes, it is of interest to understand the amount of time that streamflow can be expected to be at different levels e.g. low flows, or median flows. Frequency analysis techniques can be used to determine exceedance percentiles representing how often a given flow value can be expected to be equaled or exceeded based on the long-term streamflow records. For instance, the 90% exceedance value is defined as that flow met or exceeded 90% of the time (e.g. in four out of five flow values). Since exceedance values are indirectly proportional to the flow, the 90% exceedance will always be less than the 50% which represents the median flow value for the data series used (half of the values will be less than the 50% exceedance value and half will be greater). In this report, the 90% exceedance flow is presented as a marker of low flows while 50% exceedance value is indicative of normal flows.

In 1991, Oregon Water Resources Dept. completed a statewide water availability study in which 80% exceedance flows were used for planning purposes to determine if a stream is over-appropriated, while the 50% exceedance flows were used for evaluation of water right applications. The State of Washington has not completed a statewide water availability study. In

the absence of state standards regarding water allocation policy, 90% exceedance values are used in this document; use of the 90% values would yield overallocated results prior to use of the 80% exceedance values.

In addition, exceedance values for this study were derived for each month based on daily flow values for the period of record available or synthesized. According to Robison's 1991 study, results from a comparison of exceedance values derived from monthly mean flow values, to those derived from daily flow time series for 88 gaged records in Oregon, showed that flow exceedance values based on daily data have a tendency to be lower than those based on monthly data.

DATA GAPS

GEOLOGY

The direct connection between shallow groundwater bodies and streamflow in portions of the Black and Middle Chehalis Rivers, as well as Scatter Creek, has been well documented. Interaction of ground and surface water elsewhere in the Chehalis Basin has not received comparable study. While the nature of the surface deposits in the major river valleys allows us to assume a high degree of ground/surface water continuity, a wide spectrum likely exists with respect to discharge/recharge timing, volumes, and relative contribution to surface flows. Due to the discontinuous nature of confining lenses within the glacial/alluvial deposits found in valley bottoms, interaction between surface and shallow groundwater bodies is variable, even in the well studied Black River area.

Given the increasing reliance on groundwater and the recognized importance of groundwater in supporting stream flow, there is a paucity of data dealing with their interaction in the Chehalis and other basins. Without this information, we can not adequately address the question of potential impacts of ground water withdrawals at the subbasin level, much less on a basin level scale.

HYDROLOGY

Hydrologic analyses rely heavily on time series of streamflow data, and the Chehalis Basin is fortunate to have numerous streamflow stations distributed throughout the basin. However, 5 of the 30 subbasins do not have any record of streamflow in the basin and several others have only a few years of record. Hydrologic analyses can be undertaken in level 2 to estimate flows in these ungaged subbasins in the absence of collecting new data. Future management decisions however, would be facilitated if streamflow gages were installed or re-instated coincident with the instream flow control points of primary fishery concern.

The only specific data gap identified for surface water hydrology was that insufficient streamflow data existed on the South Bay tributaries (Johns, Elk, Charley) to determine representative unit runoff ranges in the Level 1 assessment. If fishery concerns exist on the South Bay tributaries, more streamflow data would be helpful.

RECOMMENDATIONS

GEOLOGY

Level 2 investigations in the groundwater portion of the study need to clearly define the interaction of groundwater with surface water. Develop a hydrologic water balance for each subbasin to screen areas for issues related to ground water and stream flow interactions. Components of a water balance include precipitation, interception, evaporation, evapotranspiration, surface water runoff, ground water storage, and recharge (including septic system return flow), and losses or gains to the basin from interbasin transfers of water. These components can be estimated from available data or calculated using hydrologic techniques. This essentially dictates that some degree of three-dimensional modeling be undertaken in the basin. Modeling a subset of subbasins to infer conditions elsewhere in the basin is likely the most cost efficient method of obtaining needed information. It would make sense to focus the modeling on those subbasins, which have significant groundwater withdrawals, and aquifer/geologic systems which have been studied to some degree. Modeling of the most heavily studied subbasins such as the Black River and Scatter Creek subbasins would be a logical place to start given the plethora of available information on groundwater and geologic conditions. Other basins which may have slightly less information concerning groundwater conditions, such as the middle Chehalis and Newaukum drainages, should also be modeled. Additionally, modeling should be undertaken in those subbasins which are, after additional fisheries work, identified as low flow limiting from a habitat perspective.

HYDROLOGY

The natural flow values presented in this document were intended as preliminary or screening level to guide prioritization for Level 2; use of the exceedance values as a true representation of natural flow must be done with caution. The records generated for each of the five basins reflected some degree of anthropogenic effect. In some of the basins, (e.g. #25 the Humptulips) the estimated natural flows may be closer to the true value while in other basins, the gaged streamflow was depleted by the cumulative impact of many small diversions upstream. Deregulating a streamflow record in mixed use, high agricultural use areas (e.g. #7 Newaukum) or mainstem sub-basins (#19) would be very complex and beyond the Level 1 effort. Documenting the amount of upstream diversions may be necessary in the Level 2 assessment. In addition, in high unit runoff areas (e.g. Humptulips), the effects of neglecting a few minor water withdrawals may not substantially impact the magnitude of the flow duration curve except during the low flow season; in basins with low unit runoff, more emphasis should be placed on identifying diversions upstream of stream gages. Adequate estimates of natural flow may never be obtained short of conducting continuous hydrologic modeling.

Estimates of natural streamflow were developed for 5 of the 30 subbasins, level 2 efforts should continue developing natural streamflows for the remaining 25 subbasins. Prioritization should be based on subbasins with agricultural and rural residential development or basins with known low flow problems. Seventeen of the 30 subbasins do not have base gages within the sub-basin

boundaries and will require further hydrologic analyses for the estimation of natural flows in level 2. Hydrologic techniques such as correlation analysis between miscellaneous flow measurements and concurrent gage data and normalization of flows by drainage area (per unit runoff calculations for various flow events) can be used as necessary. USGS gage ratings for the base gages should be reviewed to reveal cases where flows, particularly low flows, are not collected with reliable accuracy due to shifting streambed control at the gaging station. Additionally, a core period of record can be selected to assure that natural flow estimates reflect the natural variability in climatic conditions (e.g. includes both warm/dry and cool/wet cycles). Base station streamflow records can be extended through correlation analysis with nearby gages as appropriate to cover the selected core period of record then unit runoff calculations could be updated.

Initial information on land use in the watershed and its possible relationship to streamflow were reviewed for watersheds draining to the identified base gages. More detailed investigation of land use changes may be necessary at a later date (during Level 2 or 3), such as a review of aerial photos to determine: 1) the changes in land use and watershed conditions over the length of the gage records; and 2) the difference between land use and historic watershed conditions.

At this level of analysis, any suspected trends in streamflow data cannot be attributed to any specific cause (e.g. regulation by upstream dams, increased water use, climate change etc.) associations can be made. Level 2 analyses will need to address the effect of the combination of water use and land use changes over time, along with streamflow regulation to detect underlying trends.

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