Chapter 2. Hydrologic Framework

The Water Resources Act of 1971 defined 62 Water Resource Inventory Areas (WRIAs) in Washington State for the purposes of managing state water resources, including administration of water rights. The Rock-Glade Watershed (WRIA 31) covers approximately 1,594 square miles (1,020,230 acres) located in south-central Washington. The WRIA includes portions of Benton, Klickitat, and Yakima Counties, extending from Kennewick on the east, approaching the John Day Dam on the west, and north to the Horse Heaven Hills. Approximately 50 percent of the watershed occurs within Benton County, 44 percent within Klickitat County, and 6 percent within Yakima County. From west to east, major drainages in WRIA 31 include Rock, Wood Gulch, Pine, Alder, Dead Canyon, and Glade Creeks, and Fourmile and Switzler Canyons (Figure 2-1).

Multiple interrelated characteristics of the watershed represent the framework for regional and local hydrologic conditions in WRIA 31. The most significant of these characteristics are topography, geology, soils, climate, and land use. Following a discussion of subbasin delineation, each of these general watershed characteristics is discussed in this chapter.

2.1 Subbasin Delineation

Based on topography and other considerations, WRIA 31 is divided into four subbasins for the purposes of this Level 1 Assessment. Those subbasins are, from west to east, Rock Creek, Wood/Alder Creeks, Glade/Fourmile Creeks, and Kennewick. Figure 2-1 shows the delineated subbasins for this Level 1 Assessment. Table 2-1 presents the areas of the four subbasins.

Table 2-1. Subbasin Areas

Subbasin	Area in Square Miles	Area in Acres	Areal Percentage of WRIA 31
Rock Creek	258	165,084	16%
Wood/Alder Creeks	399	255,282	25%
Glade/Fourmile Creeks	827	529,275	52%
Kennewick	110	70,596	7%
WRIA 31 Total	**1,594**	**1,020,230**	**100.0%**

To define these subbasins, drainages were initially delineated for all streams discharging to the Columbia River. This delineation was completed using GIS (ArcHydro software) and U.S. Geological Survey (USGS) digital elevation model (DEM) data on 10 meter centers. The individual delineated drainages were then combined into subbasins for the purposes of this Level 1 Watershed Assessment. The combining of drainages was based on inferred hydrologic similarities (e.g., elevation and precipitation), and general consistency with DNR's Watershed Administrative Units (WAUs). The delineated subbasins for this assessment are the same as the DNR's WAUs, except that (1) the five WAUs comprising the Rock Creek drainage are combined into a single Rock Creek subbasin, and (2) the WAU encompassing the upper portion of the Wood Gulch drainage is included as part of the Wood/Alder Creeks subbasin.

The analysis in this Level 1 Assessment is generally conducted at the resolution of these subbasins. However, conditions can vary within any subbasin and local conditions may be different than the subbasin-scale findings from this assessment

2.2 Topography

Topography is one of the most basic parameters affecting watershed hydrology. A watershed's elevation range determines to a large extent its hydrologic regime. Watershed relief determines the potential energy available to move water through the system. Both topography and relief factor into the possible effects land use may have on streamflow in a watershed.

WRIA 31 occurs within the Columbia Plateau physiographic province. The Horse Heaven Hills, a broad east-west ridge, forms the WRIA's northern boundary, and the Columbia River gorge forms the WRIA's southern boundary. Figure 2-2 is a three-dimensional elevation model of WRIA 31, showing elevation ranges as color coding developed using the USGS DEM data. The elevation model has no vertical exaggeration.

In most general terms, elevations in the watershed decrease from west to east, and from north to south (Figure 2-2). The highest elevations in the WRIA occur in the westernmost extent of the Horse Heaven Hills, and the lowest elevations along the Columbia River. The Horse Heaven Hills descend in elevation from approximately 4,700 feet at their western extent to approximately 1,600 feet near the Columbia River south of Kennewick. Table 2-2 presents elevation statistics for each of the four subbasins comprising WRIA 31. The minimum elevations are equal to Columbia River normal pool elevations adjacent each subbasin as reported by the USGS.

Table 2-2. Subbasin Elevation Statistics

Subbasin	Elevation (feet above mean sea level)		
	Average	Minimum	Maximum
Rock Creek	2,162	266	4,728
Wood/Alder Creeks	1,904	266	4,213
Glade/Fourmile Creeks	1,090	266	3,596
Kennewick	870	341	2,198

As indicated in Table 2-2, the Rock Creek subbasin is the highest elevation subbasin within WRIA 31, ranging from approximately 270 feet along the Columbia River to approximately 4,700 feet at the ridge of Horse Heaven Hills. The Wood/Alder subbasin has the second highest average elevation. The Kennewick subbasin is the lowest elevation of the subbasins in the WRIA.

The generalized pattern of decreasing elevation from west to east is similar to the general pattern for slope. Table 2-3 presents the proportion of land surface slope by subbasin. The Rock Creek subbasin, with its deeply incised canyons, has the greatest topographic relief and correspondingly greater stream velocities and erosion potential. Twenty percent of the subbasin area has slopes greater than 100 percent. Progressively flatter slopes, and less stream incisement, occur in the subbasins to the east. Glade/Fourmile is the flattest (lowest slope) of the four subbasins, resulting in relatively low stream velocities and erosion potential. Average slopes for Rock Creek, Wood/Alder Creeks, Glade/Fourmile, and Kennewick subbasins are 36, 23, 16, and 17 percent, respectively.

Table 2-3. Proportion of Land Surface Slope Angle by Subbasin

	Slope Angle in Percent				
Subbasin	<10%	10.1 – 50%	50.1 – 100%	100.1 – 500%	>500%
Rock Creek	11%	50%	19%	20%	0%
Wood/Alder Creeks	18%	54%	17%	11%	0%
Glade/Fourmile Creeks	31%	60%	7%	2%	0%
Kennewick	30%	55%	15%	7%	0%
Entire WRIA 31	**24%**	**57%**	**12%**	**7%**	**0%**

Notes: Values given as “0%” indicate less than 0.5% of the subbasin area.

2.3 Geologic Setting

The underlying geology of a watershed, or subbasin, influences to a large extent the occurrence and movement of groundwater in the area. Surface geology can also influence the magnitude and timing of surface runoff, and thus streamflow. The principal information regarding geology of WRIA 31 was obtained from Newcomb (1971), Packard et al. (1996), Brown (1979), and Drost and Whiteman (1986). The majority of available geologic information pertains to the western and central portions of the WRIA – within Klickitat County and in the Glade Creek drainage basin area. Figure 2-3 is a surficial geologic map of the watershed, from the Washington State Department of Natural Resources (2000) 1:100,000 mapping. Figures 2-4, 2-5, 2-6, and 2-7 provide four generalized geologic cross sections across the WRIA (cross section alignments depicted on Figure 2-3).

The WRIA 31 region is underlain by bedrock of the Columbia River Basalt Group (CRB) and interbedded terrestrial sediments deposited during time periods between the individual lava flows. The CRB underlies all of WRIA 31 and is the watershed’s principal source for groundwater. The CRB includes (from oldest to youngest) the Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. Older volcanic rocks underlie the CRB; however, these older rocks do not crop out and have limited relevance to groundwater resources of the WRIA. Younger (Quaternary age) volcanic rocks overlie the CRB in a very small area on the western edge of the WRIA. Given their minimal occurrence within WRIA 31, these youngest volcanics are not discussed further here.

Groundwater in the basalts occurs primarily at the tops of the individual flows ("flow top") that became vesicular (porous) as gas bubbles escaped the flows during cooling, and/or at the flow bottoms where molten lava encountered water ("pillow"). Flow tops and pillows are usually porous and permeable, and, therefore, transmit water more readily than the intervening massive portion of the basalt flow "interior." A flow top is normally present for each flow, while pillows range from relatively thick units to completely absent. Collectively, the flow tops and bottoms are referred to as interflow zones. In some locations, the interflows may be completely unproductive in terms of groundwater flow.

In many areas of the WRIA, the volcanic bedrock is overlain by unconsolidated sedimentary deposits comprised of gravels, sands, and silts of glacial or fluvial origin (collectively referred to as alluvium). Wind-blown silt and sand (referred to as loess) also covers much of the eastern portion of the WRIA. Across WRIA 31 as a whole, the surficial alluvium and loess are predominantly fine grained; where coarser grained gravels and sands are present, they typically compose discontinuous lenses with little potential as a significant source of groundwater. However, significant groundwater can occur locally where larger volumes of gravel were deposited along the banks of the Columbia River during catastrophic glacial-age floods (Missoula floods).

The major geologic structures (folds and faults) defined within WRIA 31 include the Horse Heaven Hills anticline and Columbia Hills anticline systems, which form topographically-prominent ridges along the north and south boundaries, respectively, of the WRIA. The locations of the major geologic structures are depicted on Figure 2-3. The Horse Heaven Hill anticline is broad and asymmetrical – a steeply dipping north flank and gently dipping south flank. The south flank is flat enough that it becomes more of a monocline than anticline in areas. West of Kennewick, the Horse Heaven Hills anticline system abruptly changes orientation from a southwest-northeast to a northwest-southeast trend cutting across the WRIA parallel to the eastern boundary. A series of smaller similarly east-west trending folds and faults, including the Paterson fault to the south, occur within these two dominant anticline systems. Superimposed upon these major east-west structures are a series of north-northeast trending shear faults and folds. The largest of these structures is the Central Syncline which cuts across the Glade Creek drainage basin.

The continuity and distribution of water-bearing zones within the basalts are affected by the geologic structures. Folds and faults can disrupt the continuity of the permeable interflow zones. Faults also can provide conduits for vertical groundwater flow between water-bearing zones. Across most of WRIA 31, the vertical component of groundwater flow is downward except near major surface water drainages where groundwater discharge occurs. However, upward flow along faults has been documented in some localities. For example, along some of the minor northwest trending faults in the Glade Creek drainage, groundwater is directed upward along fault planes causing artesian conditions in wells completed in the Wanapum Basalt (Garrigues 1996).

Erosional canyons can also limit lateral continuity of shallower groundwater-bearing zones. This dissection of the basalt surface can restrict lateral movement of groundwater, and thus limit the productivity of shallower aquifer systems. Since WRIA 31 is located in an area of minimal precipitation, the lack of aquifer continuity, particularly in incised stream drainages, can result in insufficient groundwater for development from a given geologic unit. This is true for many of the drainage basins within the western portion of the WRIA. For example, Rock Creek has eroded into the Grande Ronde Basalt, locally isolating water-bearing zones within the overlying Wanapum and Saddle Mountain Basalts. Deeper aquifers that underlie the canyon bottoms are more laterally extensive, and locally provide a better source of groundwater. The bulk of the major irrigation withdrawals in the WRIA occur from these deeper aquifer systems.

Where sediments interbedded between basalt flows are coarse grained, the interbeds may also transmit groundwater; however, the productivity of the interbeds is often low because of limited lateral extent and changes in composition.

The groundwater characteristics of the principal geologic units are discussed briefly below (from oldest to youngest).

Grande Ronde Basalt. The Grande Ronde Basalt forms the lower, basement geologic unit beneath all of WRIA 31, and is estimated to be as much as 3,500 feet thick in places. Within the WRIA, surface exposure of the Grande Ronde is limited to deeper portions of Rock Creek canyons and along the Columbia River valley near Towal (Figure 2-3). Interbeds of sedimentary material (silt, sand, and gravel) are rare and generally only a few feet thick within the Grande Ronde. Relatively few wells within the WRIA produce groundwater from the Grande Ronde Basalt (Packard et al. 1996). In some areas west of the WRIA (e.g., Goldendale area), deep wells completed in the Grande Ronde have had water quality unsuitable for potable use (mineralized water with high total dissolved solids).

Wanapum Basalt. The Wanapum Basalt is also present beneath almost the entire WRIA area, and is well exposed at the surface in the Rock Creek drainage, where it is truncated by the incised creek valley. It reaches a maximum thickness of greater than 1,000 feet in the central and eastern regions between the two anticline systems. The Wanapum is comprised of multiple individual basalt flows and interbedded sedimentary units of variable thickness and composition. The Wanapum is a major source of groundwater supply in the central and eastern portions of WRIA 31.

Saddle Mountains Basalt. The Saddle Mountains Basalt is present across the majority of the WRIA, and represents the final outpouring of the CRB. Its thickness increases to greater than 600 feet near the Central Syncline and Alder Creek areas. It is well exposed at the surface in the west and covered by a thin veneer of loess in the central and eastern portions of the WRIA (Figure 2-3). Sedimentary interbeds within this unit are common and rather thick, commonly greater than 50 feet. The Saddle Mountains Basalt unit commonly supplies smaller quantities of groundwater for domestic and stock watering needs. Production from the unit is restricted by the low recharge and limited lateral extent of water-bearing zones resulting from erosional dissection.

Sedimentary Interbeds within Basalt Units. Sediments between, within, and overlying the basalts occur as a result of deposition by drainage systems during time periods between individual basalt flows. The sediments are not considered part of the CRB, rather they are assigned to the Ellensburg Formation, a sedimentary deposit ranging in composition from silt to gravel and easily eroded. This unit is generally extensive, but varies considerably in thickness and yield potential for groundwater supply. The units generally have relatively higher thickness and permeability toward the center of the Central Syncline within the Glade Creek subbasin. The sedimentary interbed separating the Grande Ronde from the overlying Wanapum is sometimes referred to as the Vantage member, and the interbed separating the Wanapum and Saddle Mountains Basalt is sometimes called the Mabton member, of the Ellensburg Formation. Because the interbeds' composition, thickness, and extent are highly variable, groundwater production from these units is correspondingly variable.

Quaternary Flood Deposits and Alluvium. Much of the eastern portion of WRIA 31 is covered with thin (generally less than 50 feet thick) deposits of Quaternary loess, alluvium, and flood deposits of sands, gravels, and silts. This material is commonly referred to as "overburden" covering the CRB. Loess is composed of fine wind blown silt, and is the most widespread of the Quaternary units. Flood deposits are found in the Kennewick area, along the Columbia River predominantly between Whitcomb and Plymouth, and in the Glade Creek subbasin. During the late Pleistocene (Ice Age), water breached a dam in glacial Lake Missoula along the Columbia River, and the outburst of flood waters deposited gravels along the Columbia River, and finer-grained sand and silt overbank deposits inland from the river. Flood gravel deposits are constrained to the banks of the Columbia River between Whitcomb and Plymouth and along the northeast boundary of the WRIA where they extend inland approximately 4 miles. In the Kennewick area, the thickness of the flood gravels and younger alluvium is typically less than 30 feet, but locally can be as much as 120 feet (City of Kennewick 2002 Water System Plan). Slack-water silts and sands were deposited up to 17 miles inland from the Columbia River in the Glade Creek vicinity (Figure 2-3).

Where present in sufficient thickness and volume along the Columbia River, the flood gravels can represent significant sources of groundwater (e.g., in Kennewick and Plymouth areas). Inland from the Columbia River, the unconsolidated Quaternary deposits are generally unsaturated or in places partially saturated, and represent a marginal component of the groundwater occurrence within the WRIA.

Table 2-4. Proportion of Geologic Units by Subbasin

Geologic Unit	Rock	Wood / Alder	Glade / Fourmile	Kennewick	Entire WRIA 31
Sediments and Sedimentary Rocks					
Alluvium (Quaternary)	2%	2%	2%	4%	**2%**
Loess (Quaternary)	4%	22%	63%	31%	**39%**
Flood Deposits – Sand & Silt (Quaternary)	0%	3%	20%	11%	**11%**
Flood Deposits –Gravel (Quaternary)	1%	0%	2%	38%	**4%**
Misc. Unconsolidated (Quaternary)	4%	10%	1%	0%	**3%**
Continental Sedimentary (Miocene/Pliocene)	3%	4%	0%	0%	**1%**
Volcanic Rocks					
Volcanics (Quaternary)	2%	0%	0%	0%	**0%**
Saddle Mountains Basalt (Miocene)	19%	54%	13%	13%	**23%**
Wanapum Basalt (Miocene)	61%	6%	0%	1%	**11%**
Grande Ronde Basalt (Miocene)	3%	0%	0%	0%	**1%**

Note: Values given as “0%” indicate less than 0.5% of the subbasin area.

2.4 Soils

The hydrologic characteristics of soils present within a watershed are important in assessing the potential for infiltration and runoff within the WRIA. Maps of soil type across WRIA 31 are available for Yakima, Benton, and Klickitat Counties. The U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) has compiled the electronic Soil Survey Geographic (SSURGO) database that provides GIS soil coverage for each county. The SSURGO soil coverage for Klickitat County is currently in draft form but was provided by NRCS for this study.

The NRCS categorizes soils into four Hydrologic Soil Groups (HSGs) based on infiltration and drainage properties. Specifically, the groups are divided based on the infiltration rate at which water enters the ground surface and the transmission rate at which it moves through the wetted soil column. A description of each soil group is presented in Table 2-5.

Table 2-5. Descriptions of Hydrologic Soil Group (HSG) Properties

Hydrologic Soil Group	Typical Soil Properties	Water Infiltration and Transmission Properties
A	Deep well drained to excessively drained sands or gravels	High infiltration and transmission rates. (low run off potential)
B	Moderately deep to deep, moderately well to well drained with moderately fine to moderately coarse textures.	Moderate infiltration and transmission rates.
C	Moderately fine to fine textures or have layers that impede vertical flow.	Slow infiltration and transmission rates.
D	Clay soils with high swelling potential; soils that have a permanently high water table, clay pan or clay layer at or near the surface; shallow soils over nearly impervious material.	Very slow infiltration and transmission rates (high run off potential)

Note: Soil group descriptions taken from NRCS (2002b)

Digital HSG coverages are currently available for Yakima and Benton Counties. Although the Klickitat County soils coverage from DNR is not divided into HSGs, the soils are classified based on many other criteria, including drainage rate, in DNR’s database. Since HSGs are defined, in part, based on their drainage rate, DNR drainage categories (“very poorly drained” to “excessively drained”) were used to define HSGs for Klickitat County soils coverage for the purposes of this Level 1 Assessment. Table 2-6 presents the proportion of HSGs for each of the four WRIA 31 subbasins, based on the data available at the time of this draft.

Table 2-6. Proportion of Hydrologic Soil Groups by Subbasin

Subbasin	Hydrologic Soil Group				
	A	**B**	**C**	**D**	**Unavailable**
Rock	2%	37%	20%	36%	4%
Wood/Alder	0%	48%	34%	12%	5%
Glade/Fourmile	9%	78%	10%	3%	0%
Kennewick	12%	82%	4%	1%	0%
Entire WRIA	**6%**	**64%**	**17%**	**11%**	**2%**

Notes: Values given as "0%" indicate less than 0.5% of the subbasin area. "Unavailable" indicates areas where coverage is currently not available.

The majority of WRIA 31, where soil data are currently available, is dominated by soils of Group B which are characterized as having moderate infiltration rates and are moderately well- to well-drained (Figure 2-8). However, land adjacent to the Columbia River between Whitcomb and Berrian are dominated by Groups A and C. The central section of the Wood/Alder Creeks subbasin is predominantly Group C soils, with Group D soils lining smaller drainages and Group B soils along many of the larger drainages. Soil Group D is present in rare locations along the upper reaches of the western tributaries to Glade Creek near Horse Heaven Hills, throughout the Rock Creek subbasin, and in places along the Columbia River.

Both the Kennewick and Glade/Fourmile subbasins are dominated by Group B soils, which compose 82 percent and 78 percent of the respective total subbasin areas. The Kennewick subbasin is covered by a significant area (12 percent) of Group A (soils with high infiltration rates) and a small area (4 percent) of Group C. The Glade/Fourmile subbasin has limited occurrence of both Groups A and C (9 percent and 10 percent, respectively). The Wood/Alder Creeks subbasin has predominantly Group B and C soils (82 percent combined). Rock Creek has the highest proportion of Group D soils (36 percent) with the remainder mostly being Group B and C soils (57 percent combined).

Based on this soil group distribution, generally, infiltration rates should be lower in the western half of the WRIA (Rock and Wood/Alder subbasins) and somewhat higher throughout the eastern half of the WRIA, with areas of more variable infiltration rate along the Columbia River. In regions of most rapid infiltration, there is greater potential for groundwater recharge. In regions with slower infiltration rates, a greater proportion of precipitation would be expected to runoff to surface water.

2.5 Climate

The climate of WRIA 31 is influenced by marine air masses traveling eastward over the Cascades and along the Columbia River, as well as by continental air masses typically traveling southward from Canada. Precipitation is unevenly distributed across the WRIA, with forced uplift of marine air creating more precipitation in the higher elevation western portion of the WRIA (Rock Creek subbasin). Precipitation decreases from west to east across the WRIA. Specifically, mean annual precipitation ranges from around 24 inches along the western border of the Rock Creek subbasin to less than 8 inches near Kennewick on the east end of the WRIA. The majority of precipitation occurs between October and April, with some precipitation occurring as snow, particularly at higher elevations in the Horse Heaven Hills.

This section presents additional data about the two climatic parameters most relevant to watershed planning: precipitation and air temperature.

2.5.1 Precipitation

Precipitation is the most important climatic parameter for understanding the hydrologic response of a watershed. This section describes the available precipitation data, discusses the spatial distribution of precipitation across WRIA 31, presents the seasonal and longer-term temporal variation in precipitation, and describes the differences in precipitation type that affect the hydrologic regime in each of the WRIA 31 subbasins.

Data Availability

Precipitation data are available from Western Regional Climate Center (WRCC) for three long-term stations in WRIA 31 and an additional six stations nearby, including two potentially relevant stations in northern Oregon. Short-term (1990s to present) precipitation data are also available from seven Public Agricultural Weather System (PAWS) stations in the eastern half of the WRIA. Summaries of the information available for each station are listed in Table 2-7, and the station locations are shown on Figure 2-9.

Table 2-7. Available Precipitation Data for WRIA 31

Station ID	Station No.	Elevation in Feet MSL	Mean Annual Precipitation in Inches	Period of Record
Western Regional Climate Center Station Data				
Bickleton	450668	2,770	13.33	1931-present
Mc Nary Dam	455231	360	7.78	1954-present
Kennewick 10 SW	454159	1,500	9.23	1949-1974
Kennewick	454154	390	7.61	1948-present
Richland	457015	370	7.11	1948-present
John Day Dam	454035	190	10.22	1958-1972
Satus Pass 2 SSW	457342	2,630	22.86	1968-present
Satus Pass	457340	3,100	21.98	1956-1967
Arlington, Oregon	350265	280	8.99	1948-present
Boardman, Oregon	350858	300	8.45	1971-present
PAWS Station Data				
Alderdale	NA	736	5.26	1999-present
R. Eby	NA	1176	9.53	1989-present
Finley	NA	755	6.53	1992-present
Gramling	NA	1267	7.94	1989-present
Horrigan	NA	882	6.39	1989-present
100 Circles Farms	NA	685	4.66	2000-present
Kennewick	NA	429	10.63	1995-present

Mean annual precipitation is highest at the Satus Pass station (approximately 22 inches) located just west of the northwest corner of WRIA 31, then drops sharply and remains consistent at 5 to 10 inches for most of the stations in and around the WRIA. Using the PRISM data (1961-1990) described below, mean annual precipitation values were calculated for each subbasin in WRIA 31 and are listed in Table 2-8. The trend of decreasing precipitation to the east is apparent from the subbasin statistics – the mean annual precipitation of the Rock Creek subbasin (16.2 inches) is approximately double that of the Kennewick subbasin (8.2 inches).

Table 2-8. Mean Annual Precipitation by Subbasin

Subbasin	Mean Annual Precipitation in Inches
Rock Creek	16.2
Wood/Alder Creeks	10.8
Glade/Fourmile Creek	9.4
Kennewick	8.2

Note: Mean annual precipitation by subbasin calculated with GIS using PRISM data (1961-1990).

Although most of the precipitation stations also report snowfall and snow depth, no NRCS SNOTEL stations or USBR snow courses are located in or near WRIA 31. Snowfall and snow depth data are not as useful for understanding watershed hydrology because they do not contain information about the amount of water in the snow (termed the snow water equivalent or SWE). As an indicator of the distribution of snow through the watershed, the average monthly snowfall in inches of snow is tabulated and shown graphically on Figure 2-10.

Most of the climate stations typically receive snowfall during November through March, with peak snowfall occurring in January. The snowfall period can extend October through May for the higher elevation stations in the northwest (e.g., Satus Pass).

Spatial Distribution

The Oregon Climate Service has developed and used the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) to estimate the spatial distribution of mean annual precipitation and mean monthly precipitation for the Conterminous United States (Daly et al. 1994; 1997). The PRISM model spatially interpolates between known precipitation records based on topography and slope orientation. It has been heavily peer-reviewed and is generally well regarded for evaluating the spatial distribution of precipitation.

The PRISM spatial distribution of mean annual precipitation from 1961-1990 across WRIA 31 is shown on Figure 2-9. Precipitation estimates for WRIA 31 range from a high of 24-28 inches in the northwest corner of WRIA 31 near Satus Pass to a low of 0-8 inches in Kennewick and a small portion of the central Glade/Fourmile Creeks subbasin. Although there is a general west to east decrease in average precipitation, short-term recent records from the PAWS stations suggest that the 0-8 inch/year zone in the west-central portion of the Glade/Fourmile subbasin may be more extensive than modeled by the PRISM data (5.3, 4.7, and 6.4 inches/year at Alderdale, Hundred Circles Farms, and Horrigan stations, respectively; Figure 2-9).

Also shown on Figure 2-9 are the long-term mean annual precipitation values for the nine WRCC stations and seven PAWS stations near WRIA31. Generally, the PRISM distribution is in close agreement with the monitoring stations. This is expected because PRISM uses the monitoring station data in generating its estimates. The differences between the observed data shown on Figure 2-9 and the PRISM estimates are caused by differences in the period of record. The PRISM data shown is based on 1961-1990 data while the observed data are for the entire period of record which varies from station to station as shown in Table 2-7.

Temporal Distribution

Evaluation of the temporal distribution of precipitation includes examination of seasonal trends in mean monthly precipitation and longer-term trends in annual precipitation.

The seasonal variation in monthly precipitation for four climate stations that represent the precipitation range across WRIA 31 is shown on Figure 2-11. The monthly data are also tabulated on that figure. Precipitation at these stations exhibits the typical Pacific Northwest pattern of high precipitation in winter and much lower precipitation in summer, with rains returning in early- to mid-fall. The Satus Pass 2 SSW station receives the highest precipitation in all months and also exhibits the greatest seasonal variability. By comparison, there is less seasonal variation in precipitation for the lower elevation stations in the eastern portion of the WRIA. These stations typically receive less than 1.25 inches of precipitation in each month.

Annual precipitation at any location also changes from year to year, and can exhibit longer term trends. Two climatic cycles, the Pacific Decadal Oscillation (PDO) and the El Niño Southern Oscillation (ENSO), affect the amount of precipitation in the Pacific Northwest (Mantua 1999). The PDO is a cycle between Warm/Dry and Cool/Wet periods that occur for 20 to 30 years, with periodic shorter term reversals. Warm/Dry PDO periods reflect warmer North Pacific Ocean temperatures and are associated with warmer, drier climate in the Pacific Northwest. Cool/Wet PDO periods reflect the reverse. These impacts are similar to the El Niño/La Niña effects of ENSO, but much longer in duration. ENSO events typically last 6 to 18 months. Mantua et al. (1997) and Minobe (1997) have identified two full PDO cycles in the 20th century.

The annual variability in precipitation for four long-term climate stations near WRIA 31 is shown on Figure 2-12 along with the PDO cycle. Generally, precipitation in WRIA 31 reflects the regional trends with lower precipitation during Warm/Dry periods and higher precipitation during Cool/Wet periods. The effect of PDO appears to be less pronounced in the records from the Kennewick and McNary stations located in the eastern portion of the watershed.

The PDO cycle is also important to consider when examining streamflow records, particularly when making comparisons between rivers. If the period of record for a given stream occurs primarily within one PDO period it may not be representative of the long-term variability for that stream.

Hydrologic Regime

The timing and type of precipitation (rain vs. snow) has an important role in determining the hydrologic response of each stream in the WRIA. In particular, the combination of warm air temperatures and precipitation falling as rain onto a snowpack can result in rapid melt of the snowpack, causing peak runoff events. The Washington State Department of Natural Resources (DNR) has mapped precipitation zones which identify the dominant precipitation/runoff regime in each area based on climate, elevation, latitude and vegetation. Precipitation zones for WRIA 31 are shown on Figure 2-13.

DNR has mapped WRIA 31 as containing four precipitation zone categories: snow dominated, rain on snow, rain dominated, and lowland. The snow dominated category indicates that peak runoff is dominated by spring snowmelt. Only a small portion of WRIA 31 in the northwest corner is mapped as snow dominated. Peak runoff from rain on snow areas occurs when rain storms (and the warm air temperatures accompanying them) occur on a snowpack causing rapid melt. Large rain on snow events typically occur in November and December. Runoff from rain dominated and lowland precipitation zones is controlled by individual rain storms. The difference between these two zones is the amount of precipitation and elevation, with lowland zones receiving lower amounts of precipitation.

2.5.2 Air Temperature

Air temperature is important for watershed assessment because it affects the hydrologic regime of a watershed and is important to water quality. Minimum and maximum temperature data available for each of the climate monitoring stations are listed and depicted graphically on Figure 2-14. As with precipitation, temperature varies across WRIA 31 with higher daily minimum and maximum temperatures in the lower elevation eastern portion of the WRIA and lower temperatures in the more mountainous northwest portion of the WRIA.

Average minimum daily temperatures are typically at or below freezing for December through February, and longer in the mountainous areas. Satus Pass typically has minimum temperatures near or below freezing from October through April. The average maximum daily temperature is above freezing during all months at all stations in the WRIA.

2.6 Land Cover/Land Use

Land cover and land use can affect hydrology and water availability within a watershed. The type of land cover controls, in part, whether precipitation runs off to surface water or infiltrates to groundwater. Changes in land cover - particularly changes in impervious surface area and vegetation – can, therefore, have an affect on timing and availability of water in a watershed. Each land use (developed, cultivated, grassland, etc.) has an associated water use (natural evapotranspiration and anthropogenic), which in turn affects overall hydrology and water availability for that area. The purpose of this section is to summarize the land use in each subbasin of WRIA 31.

2.6.1 Land Cover/Land Use Data

The USGS has compiled a national database of land cover/land use coverages for each state as part of the Land Cover Characterization Program (LCCP) developed in 1995. The most recent U.S. National Land Cover Data (NLCD) map coverage available for WRIA 31 was developed from 1992 Landsat images (30 meter resolution). The USGS is reportedly completing an updated NLCD set based on 2000 Landsat imagery, and these data might be available for future watershed planning activities, if needed.

The 1992 NLCD land covers are divided into 21 distinct types. For the purposes of this Level 1 Assessment, certain similar land cover classifications in WRIA 31 have been combined. Specific combinations made were:

- The three Barren classifications are combined (bare rock/sand/clay; quarries/strip mines/gravel pits/; and transitional);
- The three Developed classifications are combined (low intensity residential; high intensity residential; and commercial/industrial/transportation);
- The three Forested Upland classifications are combined (deciduous forest; evergreen forest; and mixed forest); and
- The two Wetlands classifications are combined (woody wetlands; and emergent herbaceous wetlands).

These combined land cover classifications could be segregated for subsequent detailed assessment, if warranted.

For this assessment, we also changed the NLCD's "Cultivated – pasture/hay" category to "Cultivated – irrigated" based on information collected in this assessment and communications with the Planning Unit. Areas designed by NLCD as "Cultivated – pasture/hay" clearly correspond to irrigated lands (crop circles etc.), and those irrigated crops are primarily not pasture or hay. A more detailed evaluation of cultivated lands using 2001 imagery data was completed by IRZ Consulting to assist in estimating actual irrigation water use for this Level 1 Assessment (Section 3.5).

The four Cultivated land cover classifications in WRIA 31 (irrigated; small grains; fallow; and urban/recreational grasses) were kept separate for this assessment. Although not specified by NLCD, it appears that for WRIA 31 small grain areas generally correspond to winter wheat (dry land farming which is not irrigated). Within WRIA 31, the Cultivated fallow land occurs in close association with Cultivated small grain land. It is uncertain at what time(s) of year the 1992 Landsat imagery was collected for development of the NLCD land cover mapping; therefore, the NLCD determination of fallow land may partly be a function of the season when the imagery was collected. There are no Cultivated (row crops) or Non-Natural Woody (orchards/vineyards/other) classifications mapped within WRIA 31 based on the 1992 imagery. However, IRZ Consulting mapped both permanent crop and dryland farming areas using 2001 data, which provide the best representation of current conditions (Section 3.5). IRZ was not requested to map non-cultivated land uses across the WRIA, thus the 1992 NLCD data represent the best available information for those non-cultivated areas.

The land cover types mapped in WRIA 31 are shown on Figure 2-15 and the classifications are described in Table 2-9. Table 2-10 presents the relative proportions of land cover types by subbasin.

Table 2-9. Descriptions of Land Cover Types within WRIA 31

Land Cover Classification	Description
Developed – Various	Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g., asphalt, concrete, buildings, etc).
Barren – Various	Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.
Forested Uplands - Various	Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall).
Shrubland	Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.
Grasslands/Herbaceous	Upland areas characterized by natural or semi-natural herbaceous vegetation. Areas dominated by upland grasses and forbs. These areas are not subject to intensive management, but they are often utilized for grazing.
Cultivated – Irrigated	Areas of irrigated agriculture.
Cultivated – Small Grains	Areas used for the production of grain crops such as wheat, barley, oats, and rice.
Cultivated – Fallow	Areas used for production of crops that do not exhibit visible vegetation as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.
Cultivated – Urban/ Recreational Grasses	Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.
Wetland - Various	Areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al.

Note: Descriptions from the NLCD Land Cover Definitions. The exception is that the ‘cultivated – irrigated’ category was changed in this assessment from the NLCD’s ‘cultivated - pasture/hay’ since the latter is not an accurate descriptor of those areas.

Table 2-10. Proportion of Land Cover Types by Subbasin (1992 Data)

	Rock	Wood/Alder	Glade/ Fourmile	Kennewick
Developed – Various	0.5%	0.6%	0.7%	18.6%
Barren – Various	0.4%	0.03%	0.03%	0.02%
Forested Uplands - Various	25.8%	2.9%	0.04%	0.1%
Shrubland	46.9%	52.1%	29.9%	34.9%
Grasslands/Herbaceous	16.2%	25.4%	5.2%	1.8%
Cultivated – Irrigated	1.1%	0.4%	15.9%	11.6%
Cultivated – Small Grains	5.1%	7.0%	16.2%	12.2%
Cultivated – Fallow	3.9%	11.5%	32.1%	18.6%
Cultivated – Urban/Recreat. Grasses	0.0%	0.0%	0.0%	2.2%
Wetland - Various	0.1%	0.02%	0.01%	0.03%
Total	100.0%	100.0%	100.0%	100.0%

Note: Data based on NLCD interpretation of 1992 Landsat imagery.

2.6.2 Land Cover by Subbasin

Land cover by subbasin is summarized briefly below.

Rock Creek Subbasin. The predominant land cover in the Rock Creek subbasin is shrubland, comprising nearly 47 percent of the subbasin area. This non-forested rangeland occurs throughout the subbasin except in its highest elevation northern portion. The Rock Creek subbasin is the only WRIA 31 subbasin with a substantial proportion (approximately 26 percent) of forestland. The forestland occurs in the higher elevation areas of the upper subbasin and is mostly privately owned. Many of the riparian corridors are also forested, except in the lower elevation reaches (Figure 2-15). Ehinger (1996) reports that riparian vegetation is intact in most of the upper Rock Creek subbasin, whereas stream banks in the lower portion consist largely of cobble (hence the name Rock Creek). Agricultural land (totaling 10 percent of subbasin area) is a relatively minor land use relative to the other three WRIA 31 subbasins. Approximately 5 and 4 percent of the subbasin area is mapped as small grain and fallow cultivated land, respectively, with irrigated land comprising only 1 percent of the subbasin area. No irrigated land was mapped in this subbasin based on 2001 data (Section 3.5). All of the cultivated land occurs within the lower half of the subbasin (Figure 2-15). Developed land accounts for less than 1 percent of the subbasin area.

Wood/Alder Creeks Subbasin. The predominant land covers in the Wood/Alder Creek subbasin are shrubland (52 percent) and grassland (25 percent). Both cover types are distributed widely across the subbasin, with grassland occupying much of the Alder Creek drainage as well as the low elevation areas along the Columbia River. Forestland represents only 3 percent of the subbasin area, and is isolated to the northwest (highest elevation) portion of the subbasin. The forestland occurs primarily within the uppermost portion of the Pine Creek drainage, and some mid-elevation segments of the Pine and Wood Gulch Creek riparian corridors. Little, if any, forest occurs within the Alder Creek drainage on the east side of the subbasin. Cultivated land (small grain and fallow; dryland farming) accounts for almost 19 percent of the subbasin area, with only 0.4 percent irrigated. The proportion of dryland farmed land decreased to 15 percent, and irrigated land increased to only 1 percent, of total subbasin area based on the 2001 data (Section 3.5). The cultivated land occurs largely in the northeastern portion of the subbasin, on the southern flank of Horse Heaven Hills, but a sizeable area also occurs in the southwestern corner adjacent Chapman Creek. Developed land comprises less than 1 percent of the subbasin area.

Glade/Fourmile Creek Subbasin. Agriculture dominates the Glade/Fourmile Creek subbasin, with cultivated land comprising approximately 64 percent of the total subbasin area in 1992. Irrigated land dominates the low-elevation southern half of the subbasin, comprising 16 percent of the total subbasin in 1992. Alternating areas mapped as small grain and fallow land encompass much of the northern half and far eastern portion of the subbasin, comprising 48 percent of the subbasin area (Figure 2-15). Non-cultivated shrubland is interspersed with the cultivated land, and comprises 30 percent of the subbasin area. Developed land accounts for less than 1 percent of the subbasin area. Based on the 2001 imagery data, the proportion of irrigated land has increased to 25 percent of the total subbasin area while dryland farming has decreased to 35 percent (Section 3.5).

Kennewick Subbasin. Developed land of the metropolitan Kennewick area, the major urban area within WRIA 31, occupies approximately 19 percent of the Kennewick subbasin area based on the 1992 mapping. According to the 1992 NLCD, cultivated land covers the greatest area of this subbasin (nearly 45 percent collectively), whereas shrubland comprises 35 percent. The cultivated area is approximately 12 percent irrigated and 31 percent dryland farming. Land mapped as irrigated occurs southeast of Kennewick, where irrigation water is available from the Kennewick and Columbia Irrigation Districts. The 1992 NLCD mapped only 2 percent of the subbasin as urban grass (lawns). Dryland farming areas occupy the western portion of the subbasin, on the eastern flank of Horse Heaven Hills. Based on the 2001 imagery data, 4 and 17 percent of the subbasin area is in irrigated and dryland agriculture. The area of urban lawns (also irrigated) was not included in the IRZ Consulting evaluation (Section 3.5).