2.0 Background

2.1 Study Area

The Columbia River basin is the fourth largest watershed in North America in terms of average annual flow, encompassing all or parts of Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming, and British Columbia (BC) (Figure 5). The watershed drains approximately 258,000 square miles including nearly 40,000 square miles in British Columbia. For thousands of years, the 1250 mile long river has shaped the economy and lives of the indigenous people who lived near it. Over the past two hundred years, the basin has been developed extensively for hydropower generation, irrigation, navigation, and flood control. In fact, steamboats began operating on the river as early as 1836 and the first hydroelectric dam in the Pacific Northwest (PNW) was built on the Spokane River in 1885. The river is also managed for the protection of salmonid species listed under the Endangered Species Act, municipal and industrial supplies, maintenance of water supplies in accordance with tribal treaties, and recreation. This creates a myriad of competing demands.

Figure 1. Schematic of Columbia River Basin (Army Corps 2009).

Forecasting future water supply and demand in the Columbia River basin is further complicated by the size, complexity, and multiple jurisdictions of the river system. Nevertheless, because reliable access to water is essential for existing and future regional economic growth and environmental and cultural enhancement, resource managers are tasked with conducting such forecasts. The urgency and importance of forecasting water supply and demand continues to grow particularly as seasonal variations in water supply and demand have resulted in localized shortages with increasing regularity due to population growth, climate variability and change, and increased implementation of regulatory flow requirements. Competing demands on the region's fresh water resources will only increase in the future, particularly in summer months when demand is high. Water supply is also anticipated to decrease during these summer months of peak demand due to long-term shifts in temperature and precipitation, exacerbating summer unmet water demand.

2.2 Existing Conditions within the Columbia River Basin

This section briefly describes the most important features of current water supply and demand in the Columbia River basin. These overviews are designed to broadly characterize existing conditions with the understanding that variation exists between sub-basins.

2.2.1 Climate

Surface water flows in the Columbia River basin are dominated by the temperature-sensitive cycle of snow accumulation and melting (Leung and Ghan 1998). The average annual precipitation is quite variable across the region and ranges from less than 8 inches in central Washington to 20-30 inches near the mountain foothills across the basin and 40 or more inches in some mountain areas. The majority of the precipitation in the basin falls during the period from October through March, while summers are relatively dry. During the winter, when the majority of precipitation occurs, snow accumulates in upper elevations of the basin. This snow melts in the spring and early summer, resulting in peak flows for the year. Nearly 60% of the natural runoff to the Columbia River occurs during May, June, and July (Army Corps 1989). The actual measured USGS gage flow at the Dalles, OR (USGS 14105700) shows that the May-July 1878-2010 average discharges account for 46.5% of the total due to reservoir operations and diversions. This is followed by a characteristic low flow period in the late summer and early fall (17.4% of annual flow at USGS Dalles gage during Aug-Oct), followed by a smaller runoff peak in late fall in response to increased precipitation falling as rain (not evident in some arid regions). During the winter, flow is again low as precipitation falls as snow and accumulates throughout much of the basin.

The headwaters of the river begin in Canada's Selkirk Mountains where the source of the river (Columbia Lake) is at an elevation of 2,650 feet. Significant parts of the Columbia basin are low enough that winter precipitation falls as both rain and snow (Hamlet and Lettenmaier 1999). However, while rain events may cause short-term localized flooding, these parts of the basin have typically received much less water than higher portions of the basin that are dominated by winter snowfall. Thus, flows in the basin as a whole are dominated by the pattern described above. A major concern is that climate change is raising the elevations where winter precipitation falls as rainfall thus altering the historic runoff pattern.

2.2.2 Streamflows and Water Supplies

Water supplies in the Columbia River basin come from both surface water flows and groundwater sources. While surface water and groundwater are often physically linked, the impacts of regulations and timing on these two sources can vary greatly. Streamflows at any given location and time are influenced by the amount of precipitation coming into the system, the speed with which water moves through the system, upstream reservoir operation, diversions, and return flows. Water exits the surface system through consumptive withdrawals, losses to evaporation, and potentially through exchanges with groundwater.

Groundwater consists of water that is below the surface. This water originates as surface water that infiltrates to groundwater areas. Once there, groundwater may move laterally over long distances, including between watersheds. The amount of water available in groundwater sources and the relationships between surface and groundwater resources are not well characterized in many areas. While groundwater investigations have been conducted in several critical regions (Hseih et al. 2007; Vaccaro and Sumioka 2006; Barber et al. 2011) uncertainties even in those areas exist due to the nature and difficulty of characterizing subsurface aquifer properties and recharge zones.

Due to data and time restraints, the 2011 Forecast assessed only surface water supplies and not groundwater supplies.

2.2.2.1 Surface Water

Historically, streamflow in the Columbia River responded strongly to patterns of rain and snowfall in the basin. At the beginning of the 20th century, roughly 75% of the annual flows occurred during the summer months (April-September) as snow melted, and roughly 25% of the annual flows occurred during the winter months (NRC 2004). A look at historic discharge recorded at the USGS gage (14105700 Columbia River at the Dalles, OR) reveals that from water year 1879 through 1910, April-September flows averaged 75.1% while May-July flows averaged 52.4% of the annual total. Streamflow is significantly altered today, because numerous mainstem and tributary impoundments (dams) were built to generate hydroelectricity, store water for irrigation, and provide flood control. Today, flows on the Columbia River mainstem are managed for these needs, as well as the sometimes competing goals of fish migration, habitat protection, navigation, recreation, and municipal and industrial water supply. Management has altered the natural flow regime, smoothing out the sharp peak in flow that occurs as snow melts in late spring, and augmenting flows during the fall and winter (NRC 2004). Meanwhile, water velocity (speed) in rivers has decreased, the shape of the river's plume into the Pacific Ocean has been altered, and the limnology and nutritional pathways of the river's estuary and food web have changed (NRC 2004). Looking at the same USGS gage at the Dalles shows that from water year 1979 through 2010, April-September flows averaged 55.5% while May-July flows averaged 34.2% of the annual total.

The long-term mean average annual flow of the Columbia River at the Dalles, OR is approximately 189,400 cfs. Though historically as high as 313,600 cfs, in recent decades the recorded flows have reached 263,700 cfs in a high water year (1997), and only 117,400 cfs during a low water year (2001) (Department of Ecology 2012). Despite considerable year-to-year variability, there has been a small decrease in the average annual discharges as shown in Figure 6. Perhaps just as important, is the prolonged low flow period from 1923 to 1944 (average discharge 165,000 cfs). Although several years of discharge data may have been influenced by the completion of Grand Coulee Dam in 1942, the overall pattern indicates the system could be subject to consecutive or multiple low flow conditions.

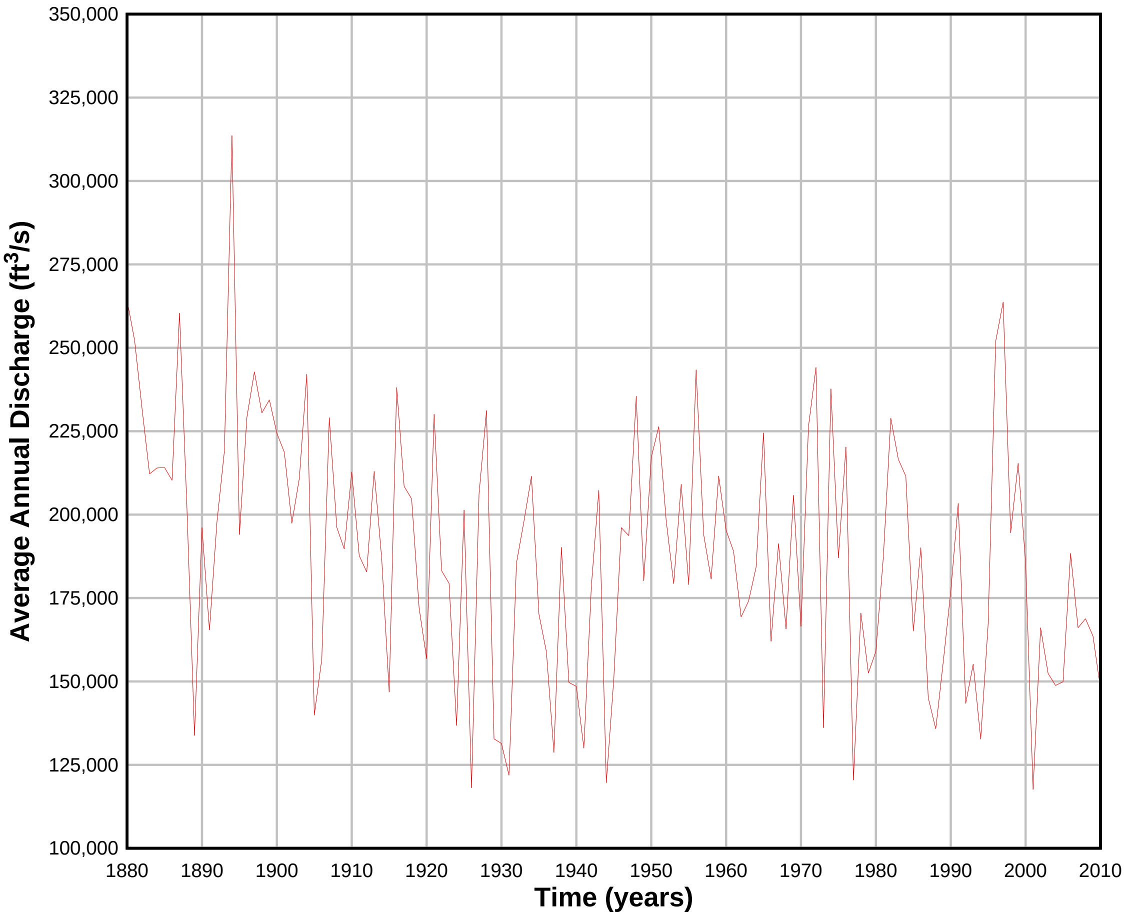

Figure 2. Average annual discharge recorded at the USGS Dalles, OR gage (USGS 2012).

It is important to note that while British Columbia accounts for less than 16% of the drainage area, nearly 40% of mean annual flow originates in Canada. Comparison of the mean annual flow at the USGS gage at the international boundary (USGS 12399500) from 1939 through 2010 indicates that the upstream gage averages about 54.8% of the downstream gage reflecting both upstream Canadian and US (Pend Oreille and Kootenai River) contributions. In other words, the river flow nearly doubles between the point where the Columbia enters Washington State and The Dalles, mainly due to the inflow of the Snake River, which comprises approximately 44% of total mean annual flow. A number of other tributaries are also important, with 30 tributaries having mean annual flows greater than 200 cfs (Golder and Anchor 2006).

Total operational water storage capacity in the entire Columbia River basin represents 42.0 million ac-ft (out of 55.0 MAF total storage), only about 30% of an average year's runoff (Bonneville Power Administration et al. 2001). This is small relative to some other river systems; for example, dams on the Missouri River can hold two to three times the total annual runoff, which gives operators more flexibility to respond to year to year variations in weather (Bonneville Power Administration et al. 2001). It is important to distinguish between operational and total storage volumes when discussing reservoir operations as most reservoirs are not designed to be drained completely. For example, Dworshak Reservoir on the North Fork of the Clearwater (in Idaho) has a total storage capacity of 3.5 MAF but since nearly 1.5 MAF is designated as dead storage, the operating pool has only about 2.0 MAF of useable storage (Army Corps 2011a). Similarly, Grand Coulee has a total storage capacity of 9.6 MAF with an operational storage capacity of 5.2 MAF within its 82 foot operating pool. Much of this type of storage is on the mainstems of the Columbia and the Snake River systems with several notable exceptions such as Libby (~5.0 MAF useable storage, Hungry Horse (~3 MAF useable storage), Dworshak (~2.0 MAF useable storage), and Duncan (1.4 MAF useable storage).

A considerable amount of Columbia River basin storage capacity exists in Canada as a result of the Columbia River Treaty between the U.S. and Canada signed in 1964. The three treaty dams built in BC account for 20.5 MAF (Mica 12.0 MAF, Keenleyside 7.1 MAF, and Duncan 1.4 MAF) with 15.5 MAF of this assigned to the treaty. Another Canadian facility (Revelstoke), not constructed under the Columbia River Treaty, has an additional 1.2 MAF of storage. Conversely, in spite of numerous run of the river hydroelectric facilities, relatively little storage occurs within the State of Washington with Grand Coulee, Lake Chelan, Chief Joe, and Cle Elum representing the most significant storage capacities.

In addition to natural flows and reservoir releases, surface waters can be augmented in locations where groundwater flows to the surface. This is particularly important in areas with extensive agriculture, as return flows can contribute significantly to late-summer stream flows. Quantification of these flows has not been widely attempted across the Columbia River basin.

2.2.2.2 Groundwater

Groundwater resources are used to meet water demand in many parts of the Columbia River basin, and are particularly important for domestic, municipal, commercial, and industrial uses (NRC, 2004). For instance, the City of Spokane receives its entire drinking water supply from a network of groundwater extractions and Yakima basin groundwater withdrawals accounted for approximately 10% of the overall water use in 2000 (Vaccaro and Sumioka 2006). Sources of groundwater vary throughout the region. Much of the basin is underlain by the Columbia Plateau regional aquifer system (Figure 7), which covers about 44,000 square miles of northern Idaho, northeastern Oregon, and southeastern Washington (Burns et al. 2010). The aquifer system comprises three major deep geologic formations: the Grand Ronde Basalt and the overlying Wanapum and Saddle Mountains Basalt. The Grand Ronde Basalt is the oldest (and therefore the deepest), and the thickest of these formations (Whitehead 1994).

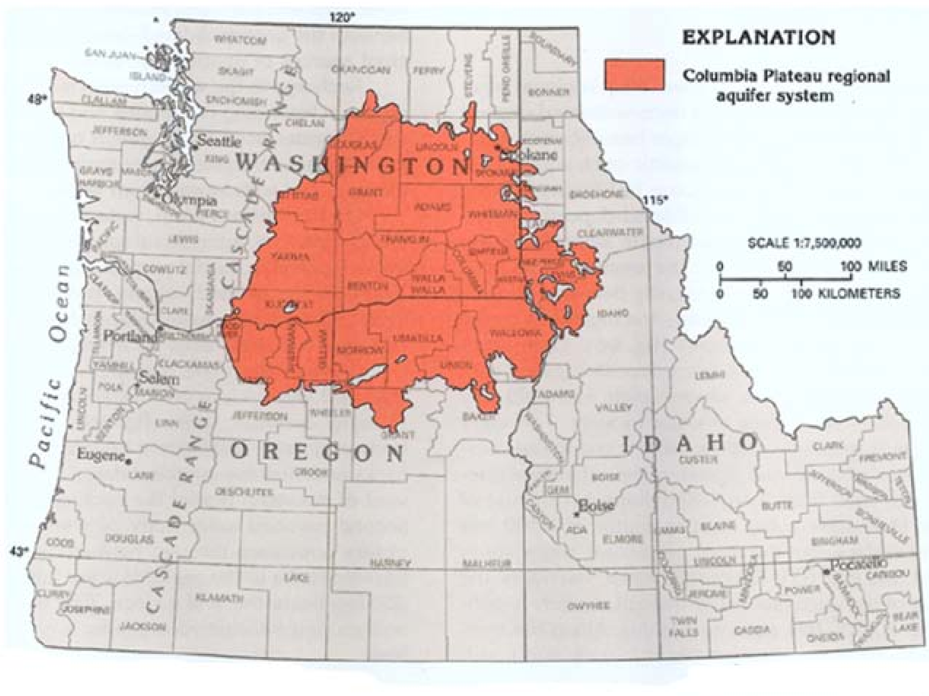

Figure 3**.** Spatial extent of Columbia Plateau aquifer system (Whitehead 1994).

Figure 7 gives the misleading impression that the aquifer behaves as a single system when in fact it has multiple subareas that may react to changes such as increased withdrawals independently (e.g., Odessa Subarea). Water flows through these basalt aquifer systems in complex ways, driven by gravity and the permeability of the geologic formations that are encountered (Burns et al. 2010). These geologic features include lithology, folding, faulting, buried granitic bedrock or vertical basalt dikes, individual interflow zones, and erosional features such as coulees (Porcello et al. 2009). In general, water enters the system from recharge areas near the edges of the plateau, and exits toward regional "drains" including the Columbia and Snake River. However, there are considerable uncertainties with respect to the exact rates and locations of both recharge and discharge. The Cascade Range in Oregon and Washington represents an important recharge area, because permeable volcanic rocks accept large volumes of precipitation, and because groundwater use is relatively light (Whitehead 1994).

Shallower, unconsolidated-deposit aquifers overlie the basalt aquifers in some areas, particularly in lowlands (Figure 8). These aquifers range in thickness, exceeding 200 feet in many areas, and reaching as much as 2,000 feet in some localized areas (Whitehead 1994). In areas where they are thick (and therefore more productive), they may be more important for water supply than the deeper basalt aquifers, providing water for public supply, domestic, commercial, agricultural, and industrial needs. These deposits may be hydraulically interconnected with surface waters, so that water flows back and forth between the ground and surface water systems in complex ways, depending on the seasonal depths of the water.

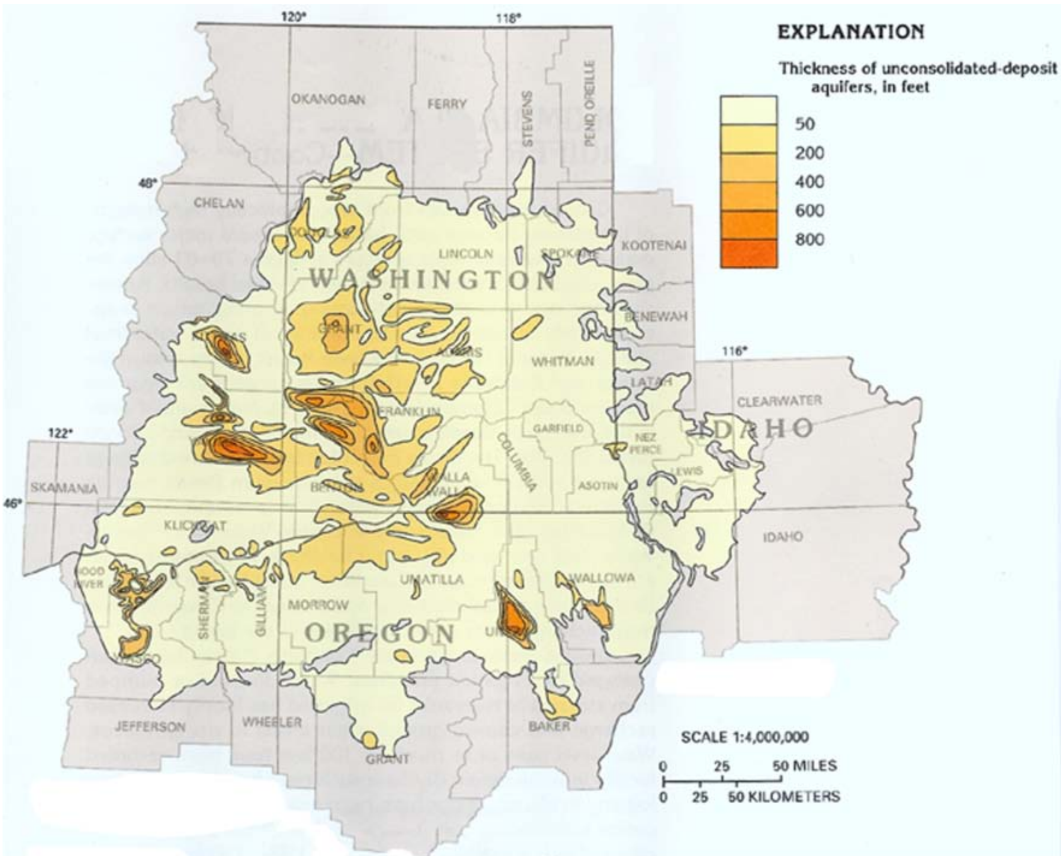

Figure 4**.** Unconsolidated aquifers in the Columbia River plateau (Whitehead 1994).

Groundwater is equally important and complex in other parts of the Columbia River basin such as the Eastern Snake Plain in Idaho. As illustrated in Figure 9, the groundwater resource covers a significant portion (approximately 10,800 square miles) of eastern Idaho. The most productive portion of the aquifer is in the upper 300-500 feet where estimates of storage range from 200 to 300 MAF. However, even with a storage volume approximately the size of Lake Erie, groundwater withdrawals and reductions in groundwater recharge resulting from more efficient irrigation have reduced discharges to springs and the Snake River prompting management concerns. Changes in Snake River flows are a concern for Washington and other downstream users.

Northeast of the City of Spokane, on the Washington-Idaho border, the Spokane Valley-Rathdrum Prairie (SVRP) aquifer is also important. Although this aquifer covers a much smaller area (approximately 370 square miles), the aquifer is designated as a sole source aquifer by the U.S. Environmental Protection Agency (EPA) and serves as the area's primary source for drinking water (both municipal and rural domestic), irrigation, and industrial (Hutson et al. 2004, as cited in Kahle et al. 2005). Concerns include the growing demands on groundwater due to rapid growth and associated development, low streamflow in reaches of the Spokane and Little Spokane Rivers, and water quality problems associated with changing land use activities (Kahle et al. 2005).

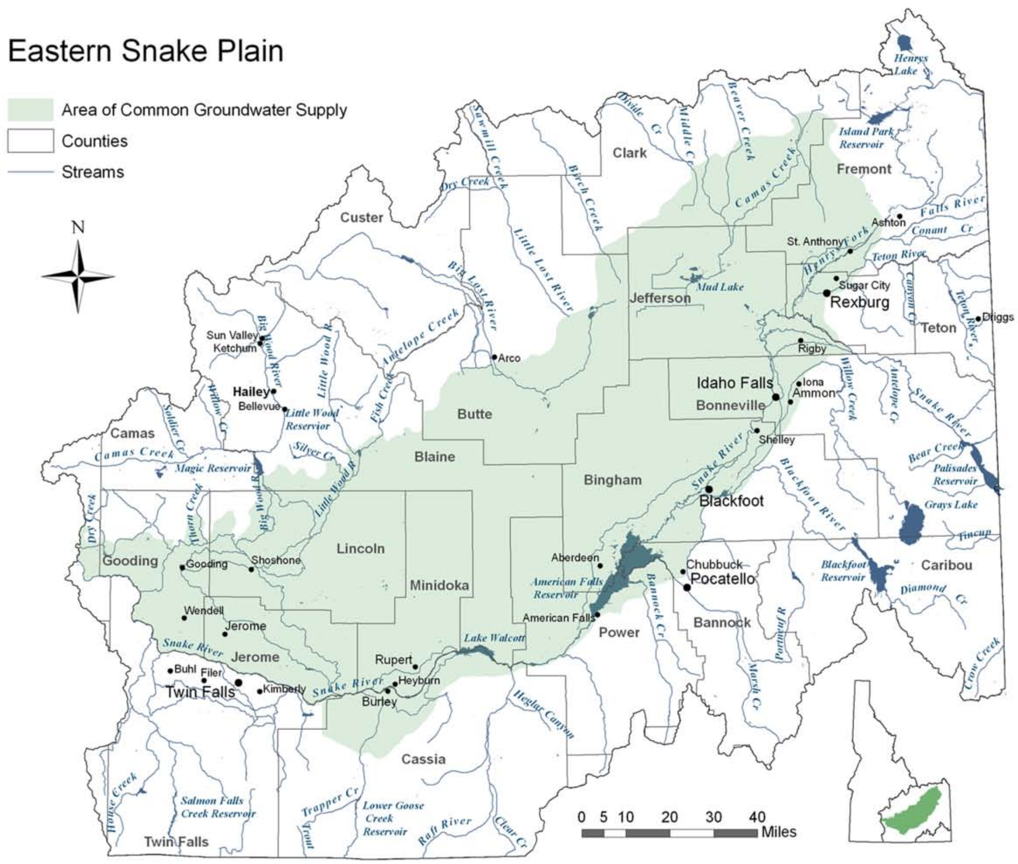

Figure 5**.** Eastern Snake Plain aquifer (Idaho Department of Water Resources 2009).

Modern water use patterns in eastern Washington have drastically altered the flows of groundwater in the Columbia Plateau regional aquifer system. In many areas, water diverted or pumped from streams or reservoirs and applied to fields has infiltrated through the soil and enhanced natural groundwater levels. Groundwater levels have risen as much as 500 feet or more in some areas of eastern Washington (Drost et al. 1997). Conversely, in other areas with substantial irrigation with groundwater, declines of as much as 180 feet have been recorded by the USGS as withdrawal rates have far exceeded recharge rates. Other groundwater issues relevant to current and future water supply and demand planning include a reduction in base flow to rivers in some areas with associated impact on temperature and water quality, and the current and anticipated effects of climate change on recharge rates, base flow, and groundwater availability (Burns et al. 2010).

2.2.3 Agriculture

Overall, about 6% of the surface water flowing through the Columbia River basin is currently removed for agricultural irrigation (Bonneville Power Administration et al. 2001). This represents the largest out-of-stream water use. Of more than 6.5 million cropped acres in Washington State, roughly 37% is irrigated (NRC 2004). Irrigated cropland currently produces tree fruit, potatoes, sugar beets, hops, fruit, vegetables, mint, wine grapes, hay, grain and many other crops (Washington also has significant non-irrigated production of hay and grain). The USGS estimated that agriculture represented 61% of out-of-stream water use statewide,[1] considering municipal, domestic, irrigation, stock water, aquaculture, industrial, mining, and thermoelectric uses (Lane 2009). Within eastern Washington, irrigation represented 82% of all uses except thermoelectric (which could not be separated regionally due to limitations in data presentation) (Lane 2009). Some of this water is used by crops, while some infiltrates through the soil and returns to the river system downstream.

Production of these crops forms a significant portion of the economy of eastern Washington. Together, irrigated and non-irrigated agriculture and related services account for more than 10% of the basin's employment (NRC 2004). Farm owners, tenants, and ranch families represent 19% of households in the basin (Quigley et al. 1997, as cited by NRC 2004).

Agricultural water uses other than irrigation, such as stock water, are important within some WRIAs, but the magnitude of these uses basin-wide is small relative to consumptive use for crops. In 2005, the USGS estimated that within eastern Washington, stock water uses represented approximately 0.4% of out-of-stream water use, considering domestic, irrigation, stock water, aquaculture, industrial, and mining (Lane 2009). If stock water represents a significant proportion of water use in the future, it may merit additional attention in future forecasts.

2.2.4 Municipal

Municipal use represents a much smaller portion of water use than agriculture in the Columbia River basin, but one that is important for supporting the continued prosperity of the region. The USGS estimated that eastern WA's domestic uses (including public and self-supplied) represented 11% of out-of-stream water use statewide, considering domestic, irrigation, stock water, aquaculture, industrial, mining, and thermoelectric uses (Lane 2009). Within eastern Washington, domestic uses represented 13% of all uses except thermoelectric (which could not be separated regionally due to limitations in data presentation) (Lane 2009).

Of the roughly 9.5 million people who live in Washington, Oregon, Idaho, and Montana (the four northwestern states that comprise the majority of the Columbia River basin), nearly 5 million live in the Columbia River basin (Volkman 1997, as cited by (NRC 2004). Since the 1980's, the basin's interior has experienced population growth in many areas. In Washington State, some of the most significant growth areas are the Tri-Cities (Richland/Pasco/Kennewick), Spokane,

[11] This includes both consumptive and non-consumptive use of water by agriculture.

Wenatchee, and Yakima (NRC, 2004). Many other areas in the Columbia River basin are sparsely populated, although some rural areas are also experiencing significant growth. Population is expected to grow and will likely increase demand for municipal water and hydroelectricity (NRC 2004).

2.2.5 Hydropower

According to the Northwest Power and Conservation Council (2010), the more than 75 major federal and nonfederal hydroelectric dams in the Columbia River basin produce upwards of 15,000 annual average megawatts (MWa) of energy. Figure 10 shows the hydropower generation capacity in the Pacific Northwest in relation to other power sources in the area as of 2010. According to the U.S. Energy Information Administration, Washington alone produced over a quarter of the nation's hydropower in 2009 at an average retail cost of $0.066/kWh, the fourth lowest in the United States.

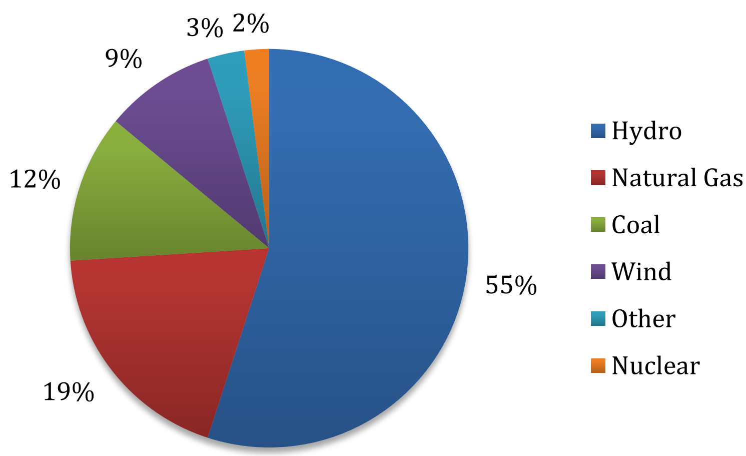

Figure 6**.** Sources of Pacific Northwest power generation by capacity as of 2010.

2.2.6 Ecosystem and Instream Flow Requirements

The waters of the Columbia River basin support a variety of fish and other wildlife important to maintaining cultural, environmental, and recreational opportunities, including both listed and non-listed species. Statewide in Washington, recreational spending associated with fishing, hunting, and wildlife viewing was estimated to be $3.1 billion in 2006 (U.S. Department of the Interior, Fish and Wildlife Service & U.S. Department of Commerce, U.S. Census Bureau, 2007).

Fish are central to the Columbia River basin. Historically, salmon were essential to Native American subsistence, culture, and religion (IEAB 2005). Prior to the building of the Dalles Dam, more than 5,000 people gathered annually near Celilo Falls to trade, fish, feast, and participate in games and religious ceremonies (IEAB, 2005). Today, salmon produced in the Columbia River system are harvested by ocean fisheries from California to Alaska. Commercial landings of salmon and steelhead harvested in the Columbia River have declined from around 20 million pounds annually in the late 1940s, to just over one million pounds in 1993. The Independent Economic Analysis Board estimated that the income generated by harvesting and preparing marketable fish, plus the secondary impacts on other economic activities generated between $40 and $142 million per year to the regional economy, depending on the assumptions made about production and harvest (IEAB, 2005). About 77% of this contribution occurs in the Pacific Northwest, while the rest occurs in Alaska and British Columbia, with a very small portion in California.

Most salmon stocks in the Northwest are at a fraction of their historical levels due to fishing pressures, blockages of fish passage, loss of freshwater and estuary habitats, poor ocean conditions, hydropower facilities, and hatchery practices (NRC 2004; Lower Columbia Fish Recovery Board 2004). Twelve evolutionarily significant populations of four species of Columbia River basin salmon and steelhead, and two resident species (bull trout and Kootenai River white sturgeon) have been listed for protection under the ESA since 1991. Figure 11 shows the distribution of ESA-listed fish in the Columbia River basin.

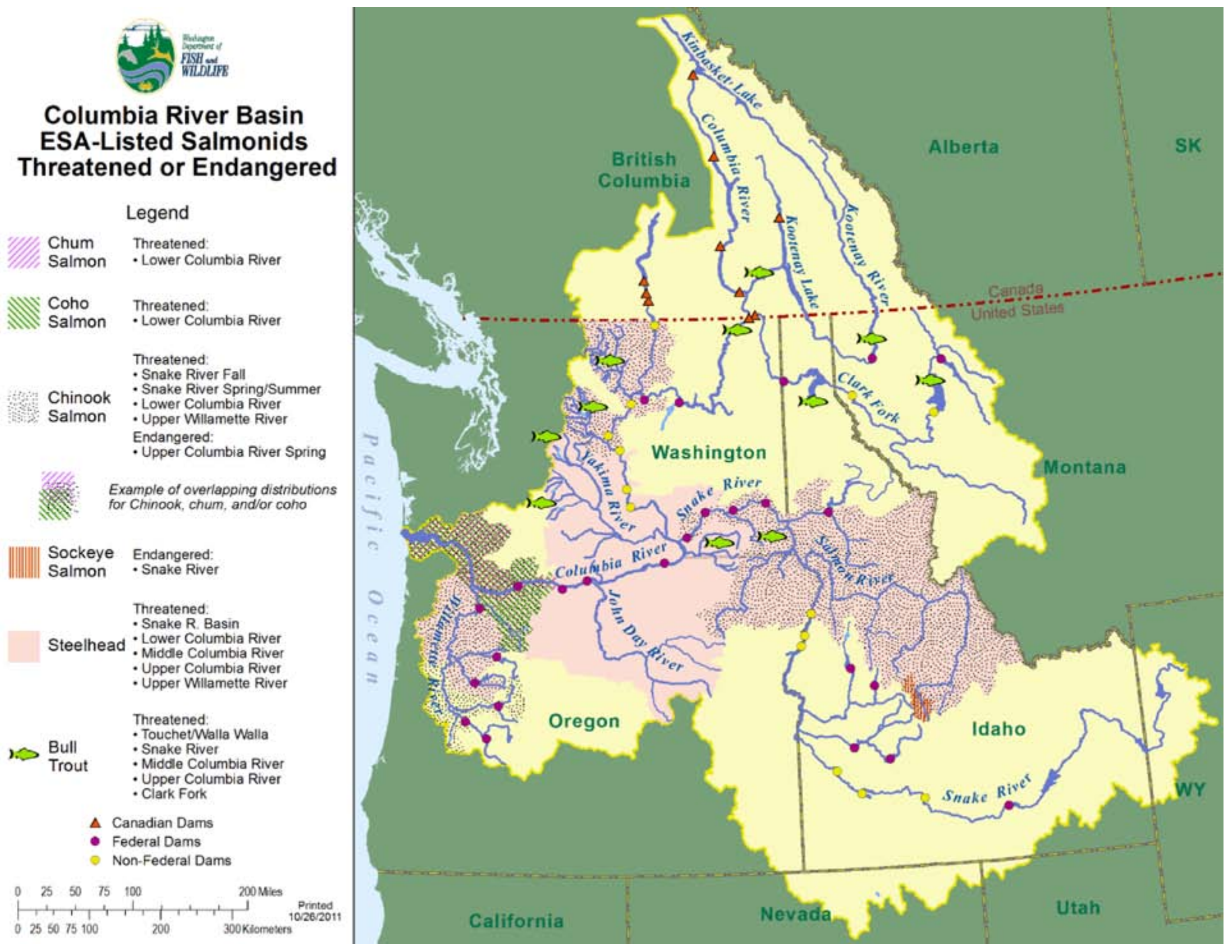

Figure 7. Distribution of fish listed under the Endangered Species Act in the Columbia River basin.

The twelve Columbia River basin salmon and steelhead ESA listings are:

- Snake River Sockeye, November 1991
- Snake River fall Chinook, April 1992
- Snake River combined spring/summer Chinook, April 1992
- Lower Columbia River Chinook, March 1999
- Upper Willamette River Chinook, March 1999
- Upper Columbia River Chinook, March 1999
- Columbia River chum salmon, March 1999
- Upper Columbia River steelhead, August 1997
- Snake River Basin steelhead, August 1997
- Lower Columbia River steelhead, March 1999
- Upper Willamette River steelhead, March 1999
- Middle Columbia River steelhead, March 1999.

As a result of concerns about declining fish populations and ESA listings, state regulatory agencies have adopted minimum instream flows in several watersheds. In eastern Washington, regulatory flows have been adopted on the Columbia River mainstem, and also within certain tributaries to the Columbia River (Walla Walla, Wenatchee, Entiat, Methow, Okanogan, Little Spokane, and Colville). These regulated flows are legal water rights with priority dates and can affect subsequently issued water rights. This means that water rights holders with later priority dates (junior water right holders), may have their water use curtailed in order to protect the regulated flows, (senior water right holders) (Rushton 2000).

The Yakima basin has de-facto federal flows, resulting from the target flows over Sunnyside and Prosser Diversion Dams described in Title XII of Public Law 103-434 (Tri-County Water Resource Agency 2003). In managing the water for the Yakima Project (a federal irrigation project covering much of the basin), the U.S. Bureau of Reclamation (USBR) calculates total water supply available (TWSA), a combined measure of unregulated flow, return flow, and stored water available for use (Tri-County Water Resource Agency 2003). Instream flow needs are met from TWSA prior to determining if pro-rationing is necessary. In water-short years, all pro-ratable users share the shortage equally, and are allotted a portion their full water supplies (Tri-County Water Resource Agency 2003).

In addition to these flows, the Department of Ecology and its predecessor agencies have established administrative low flow restrictions and closures on several surface water sources in the state, known as surface water source limitations (SWSLs). These SWSLs were generally established as a result of letters of recommendation from the Washington Department of Fish and Wildlife or their predecessor agencies (HDR 2005). The majority of these SWSLs occurred in the 1950s and 1960s, with some as early as the 1940s, and some as late as the 1980s (HDR 2005). In most cases, the low flows and closures have been in place since the letters were received by Ecology, and thus have been applied to all subsequent water right applications (HDR 2005).

2.3 Summary of 2006 Forecast

Washington's first long term Forecast was completed in 2006, as mandated by HB 2860, the legislation that created the Columbia River basin Water Supply Development Program (Golder and Anchor 2006). Because the timeline for completing this first Forecast was less than six months, the Forecast relied heavily on reviewing work carried out by others in forecasting water supply and demand. The 2006 long term supply and demand forecast focused on three objectives:

- Document existing and future demand in the basin (20 years).
- Develop an initial inventory of conservation and storage projects that could help meet future demand.
- Lay the foundation for understanding how the Columbia River is managed and what factors affect water supply.

Below is a summarization of the 2006 Forecast's report on existing and future demands for Washington.

2.3.1 Estimates of Existing Demand

2.3.1.1 Analysis of Current Water Rights on the Columbia River Mainstem

Within a one mile corridor around the Columbia River, Golder and Anchor (2006) summarized all the water rights in the Washington State Department of Ecology's Water Rights Tracking System (WRTS) database, as well as relevant data provided by the Oregon Department of Water Resources (ODWR). These databases did not include rights for water use that is federally reserved to the tribes, nor permit-exempt water use in the two states. Water rights with a purpose of "power" or "reservoir" were assumed to be non-consumptive, and were not considered. For records containing no annual quantity (Q_a) of water use, an annual quantity was calculated by assuming continuous use of instantaneous quantity (Q_i). Results are summarized for Washington and Oregon in Table 2 and Table 3 below.

Analysis of interruptible rights in Washington State revealed more than 350 interruptible water rights within 1 mile of the Columbia River mainstem, accounting for 487,104 ac-ft per year. This represents less than 5% of water rights issued by Ecology within this area.

Table 1. Washington's total number of water right documents and total annual water use allowed under claims, permits, and certificates within a one mile corridor of the Columbia River mainstem in Washington State upstream of Bonneville Dam (included in the Ecology WRTS database) (Golder and Anchor 2006).

Use Category	Total number of water documents (claims, permits, and certificates)	Total annual water use represented (ac-ft/yr)
Agricultural (dairy, frost protection, irrigation, and stock watering)	2,365	6,508,773
Commercial and Industrial (industrial cooling, commercial and industrial manufacturing, highway, mining, power, and railway)	152	623,119
Domestic (domestic, municipal, and recreation)	4,378	572,143
Environment and Wildlife (environment, fire protection, fish propagation, and wildlife propagation) (non-consumptive)	61	481,994
Undefined (water use not provided or not recognized)	131	8,557
TOTAL	**7,087**	**8,194,586**

Table 2. Oregon's total number of water documents and total annual water use allowed under claims, permits, and certificates within a one mile corridor of the Columbia River mainstem in Oregon State upstream of Bonneville Dam (included in the database of the Oregon Water Resources Department) (Golder and Anchor 2006).

Use Category	Total number of water documents (claims, permits, and certificates)	Total annual water use represented (ac-ft/yr)
Agricultural (agriculture, cranberry, dairy, frost protection, greenhouse, irrigation, livestock, and nursery)	334	561,453[a]
Commercial and Industrial (commercial, manufacturing, laboratory, mint still, log deck sprinkling, sawmill, mining shop, and road construction)	36	46,798
Domestic (aesthetic, recreation, domestic, human consumption, and municipal)	132	327,939
Environment and Wildlife (instream, fire protection, forest management, groundwater recharge, pollution abatement, fisheries, and wildlife) (non consumptive)	49	5,927,321
TOTAL (excluding environmental and wildlife non-consumptive use)	**502**	**936,190**

[a] In addition, 116,726 ac-ft per year of supplemental rights exist for agriculture in Oregon; these supplemental water rights were not included in the table above because they are not used at the same time as primary rights.

2.3.1.2 Analysis of Current Water Use in the Columbia River Basin

The 2006 Forecast also estimated existing demand by reviewing use estimates carried out by other entities: the USGS and the Washington State Department of Health (DOH) (for public water system use only).

USGS Estimate of Current Water Use

Estimated water use for the counties that make up the Columbia River basin was drawn from USGS estimations of water use in 2000 (Lane 2004), and is summarized in Table 4 below.

Table 3**.** Estimates of current water use from Lane (2004) as summarized by Golder and Anchor (2006)**.** The use categories shown here (public and self-supplied domestic, crop irrigation, golf course irrigation, and industrial) historically have accounted for 92% of use.[a]

County	Domestic (public supplied) (ac-ft/yr)	Domestic (self-supplied) (ac-ft/yr)	Crop Irrigation (ac-ft/yr)	Golf Course Irrigation (ac-ft/yr)	Industrial (ac-ft/yr)	County Total (ac-ft/yr)
Adams	2,780	1,468	209,610	123	2,500	216,481
Asotin	4,125	235	224	123	0	4,707
Benton	14,684	3,721	265,656	1,311	84,180	369,552
Chelan	6,580	2,242	56,382	818	16,253	82,275
Columbia	583	247	4,831	56	90	5,807
Douglas	3,497	594	27,462	347	3,744	35,644
Ferry	404	740	5033	45	325	6,547
Franklin	9,079	2,477	489,838	191	1,962	503,547
Garfield	314	168	572	45	11	1,110
Grant	11,075	5,941	1,042,446	2,287	3,598	1,065,347
Kittitas	7,342	1,558	223,061	516	1,580	234,057
Klickitat	2,320	1,054	29,704	146	3,116	36,340
Lincoln	1,334	706	40,241	202	11	42,494
Okanogan	4,551	4,192	81,378	370	4,237	94,728
Pend Oreille	594	785	829	0	1,031	3,239
Skamania	628	460	280	235	12,666	14,269
Spokane	88,552	13,115	10,268	1,580	48,423	161,938
Stevens	2,858	2,074	10,682	146	135	15,895
Walla Walla	6,053	1,188	138,993	258	18,271	164,763
Whitman	3,632	1,009	3,139	90	0	7,870
Yakima	28,807	14,236	637,798	1,424	7,297	689,562
Oregon[b]	52,806	NA	768,204		26,084	847,094
Use Type Totals	**252,598**	**58,210**	**4,056,944**		**235,514**	**4,603,266**

[a] Data from Lane (2004) for Washington counties and USGS (2004) for Oregon were originally reported in million gallons per day (mgd) and converted to ac-ft per year.
[b] Oregon includes water use from seven counties: Multnomah, Hood River, Wasco, Sherman, Gilliam, Morrow, and Umatilla, as reported in USGS (2004).

Estimate of Current Public Water System Use per Washington State Department of Health Data

DOH provided its 2006 water system database for Group A and Group B public water systems.[2] Total public water system use in the counties making up the Columbia River basin was estimated at 594 ac-ft per day or approximately 200,000 ac-ft annually. Average usage ranged from 92 to 300 gallons per capital per day (gpcd), with an average use of 170 gpcd per person (Golder and Anchor 2006).

2.3.2 Forecast of Future Demand

Future (2026) water demand in Washington for the one mile corridor of the Columbia River mainstem was carried out through a review of water rights applications on file with Ecology. For Washington's portion of the Columbia River basin, a projection of future water use by the agricultural and domestic/municipal sectors was conducted.

2.3.2.1 Water Rights Applications for the Columbia River Mainstem

Water right applications in Ecology's WRTS database were reviewed for Washington's 1-mile corridor along the Columbia River mainstem, and are summarized in Table 5 below.

Table 4**.** Summary of new water rights applications (ground and surface water) in WRTS in 2006 within one mile of the Columbia River mainstem upstream of Bonneville, with estimations of the total ac-ft per year associated with these rights (Golder and Anchor 2006).

Water Use	Number of Applications	Total annual ac-ft represented
Agriculture	195	211,323[a]
Domestic	214	86,849[b]
Commercial/Industrial	36	82,237[c]
Environmental	6	12,181[d]
Unidentified	4	2,211
Total	**455**	**394,801**

[a] To fill in Q_a for records that did not have this value, annual irrigation duties were calculated for the set of applications containing both acreage and Q_a. The average annual irrigation duty was 3.41 ac-ft per acre for groundwater applications and 3.83 ac-ft per acre for surface water applications.
[b] Total ac-ft were calculated from a total instantaneous use of 242 cfs, by assuming that annual use would be 50% of continuous use. This converts to a peak factor of 2, consistent with Washington State Department of Health guidance. Based on average per capita water use of 170 gallons per day per person, this is equivalent to a population of just over 450,000 people.
[c] This assumes the same peaking value as domestic water. However, this likely underestimates the amount of annual water use somewhat, because water is often used on a more continuous basis for industrial/commercial operations.
[d] Assumes continuous use of water. If these applications are intended for summer instream flow purposes, annual use would be lower.

[2] Group A water systems include those that regularly serve 15 or more connections or serve 25 or more people per day for 60 days or more (WAC 246-290). Other systems are classified as Group B systems.

Based on this method, the total annual water needed for agriculture, as represented by a combination of water right applications (211,323 ac-ft) and estimated interruptible water rights along the mainstem (163,000 ac-ft), was estimated to be 374,323 ac-ft per year (Golder and Anchor 2006).

2.3.2.2 Projections of Future Water Use for Agriculture and Domestic/Municipal

A second forecast of demand was carried out by making projections of future water use by two sectors: agriculture and municipal/domestic (including commercial and industrial).

Forecast of Future Agricultural Water Use

Changes in agricultural demand were forecasted by researchers at WSU using two contrasting methods: a Vector Autoregression (VAR) model and a survey of expert opinions (Wandschneider et al. 2006). First, a VAR model was used to determine crop production trends on a county-wide and regional basis for the top 25 crops (accounting for over 95% of farm gate revenue in the Columbia River basin), using USDA National Agricultural Statistics Service data on production and acreage from 1981- 2004 for most crops. Past trends were then used to project potential future production in 2025. This type of analysis captures factors that impact crop production that have occurred in the historical period, but will not capture factors that affect crop production that have not occurred in the historical period. Forecasts using this model can only be made if stable relationships exist between variables in the VAR equations. Unfortunately, it was not possible to forecast acreage for wine grapes or alfalfa. Overall, little or no increase in agricultural acreage was expected. However, the expected range for changes in total acreage was also quite large, with changes expected to be between an increase of nearly one million acres and a decrease of 750,000 acres at a 95% confidence level.

This general picture of stable irrigation demand was confirmed by the second analysis, a survey of experts' opinions about future crop production and water use for major crops, which suggested that participants believed that water demand would increase for wine grapes and cattle producers, but would remain stable for potatoes and apples/other tree fruit (Wandschneider et al. 2006).

Together, these estimates of future agricultural water use suggested less agricultural demand for water than the water rights applications (which suggested a growth in irrigation demand of about 211,323 ac-ft per year by 2025, 0.35% per year, or 9% by 2025). However, Golder Associates and Anchor Environmental (2006) pointed out that large projects have the potential to change this generally stable picture. Converting all interruptible rights to uninterruptible rights would require an additional 163,000 ac-ft per year. Converting the Odessa Region acreage surface water from groundwater would convert an additional 170,000 acres to surface water supply, while enlarging the Columbia basin Project to its full capacity would irrigate an additional 400,000 acres (Golder and Anchor 2006).

Forecast of Future Municipal/Domestic Water Use

Municipal/domestic (including commercial and industrial) water use growth was projected using the Washington State Office of Fiscal Management (OFM) population projections. On average, the population of all counties in the Columbia basin was projected to grow approximately 20% (350,000 people) by 2025. At an average per capita water use similar to current use levels (170 gpd), these populations would demand an extra 67,400 ac-ft per year. This is similar to the projected demand calculated by applying the OFM growth rate to the 2004 USGS estimates of current public and self-supplied domestic water use, 52,500 ac-ft per year. Assuming that the commercial/industrial water demand would grow at the same rate as population, an additional demand of 42,000 ac-ft per year is projected for 2025 for the counties within the Columbia River basin.

2.4 Overview of Anticipated Future Climate Conditions and Impacts

2.4.1 Current Evidence of Climate Change

A growing body of evidence, documents that the climate of the Pacific Northwest has changed over the last century. These changes cannot be explained by climate variability alone. The observed changes in the region are consistent with the scientifically accepted projected global and regional climate change impacts.

Average temperatures across the PNW have risen about 1.5 degrees F over the past century, with some areas experiencing increases up to 4 degrees F (Mote 2003) (Figure 12). Warming has occurred in rural and urban areas, with the highest rates of warming during the winter, and at lower elevations (Mote 2003)

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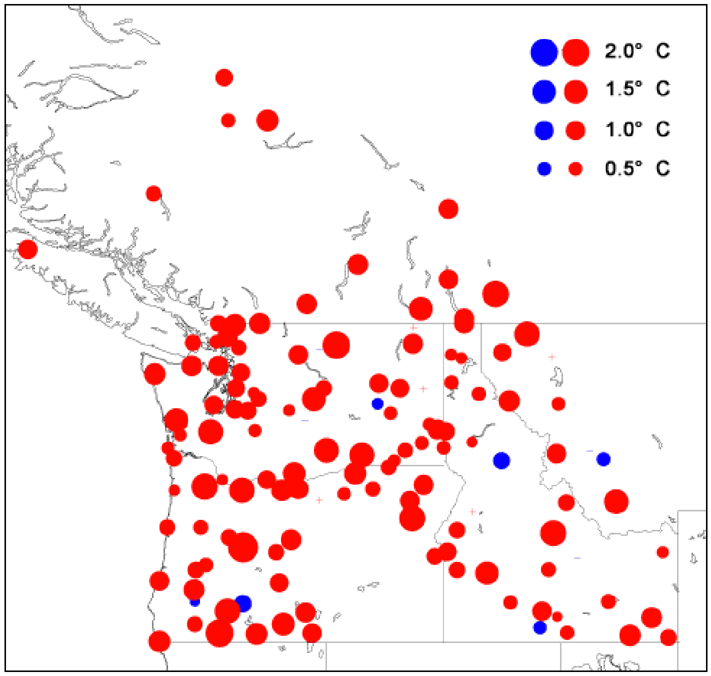

Figure 8. Trends in average annual temperatures across the Pacific Northwest, 1920-2000 (adjusted weather station data from Historical Canadian Climate Database and the U.S. Historical Climate Network) (from UW/NOAA JISAO, CSES 2011a with permission).

A warmer climate has led to changes in the timing of streamflow. In much of the Columbia River basin, a significant amount of precipitation falls during the winter as snow. As the snowpack melts in spring and early summer, this water (which can represent as much as 50-80% of annual streamflow) is released (Stewart et al. 2005). Higher temperatures mean that more precipitation falls as rain during the winter, and that snowmelt occurs earlier in the spring. Over the last 50 years, the peak of spring runoff has shifted from a few days earlier in some places to as much as 25 to 30 days earlier in others (Stewart et al. 2005; Hamlet et al. 2007). As further evidence of this same trend, average snowpack on April 1st (a key indicator of water storage available for the warm season) has already declined substantially. In the Cascade Mountains, April 1 snowpack has declined about 25% over the last 40 to 70 years, with most of this due to the increase in cool season temperatures (Figure 13; Mote 2006). This has direct implications for the availability of water because the snowpack acts as a natural reservoir in much of the Columbia River basin, storing the water for use during the summer when supply is otherwise scarce and demand from agriculture and other uses is high.

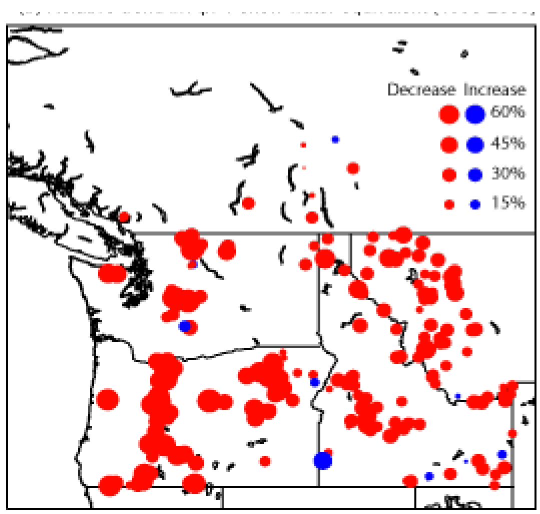

Figure 9**.** Relative trend in April 1 snow water equivalent (1950-2000) (from UW/NOAA JISAO, CSES 2011b with permission).

Overall precipitation in the PNW has changed over the last century due to regional climatic cycles, but analysis of precipitation patterns across the U.S. suggest that global warming has so far played a relatively minor role in determining precipitation patterns (Hamlet et al. 2007; Mote et al. 2005a). Variability in precipitation during the cool season has increased since about 1973 (Hamlet and Lettenmaier 2007). Although evidence to suggest what has caused this phenomenon is lacking, the effects are seen throughout the West, suggesting a large-scale climatic influence. Overall, however, flooding risks in the Columbia basin do not seem to have increased greatly in the last century, though flooding risk does seem to have increased in some costal drainage basins where winter temperatures favor a combination of rain and transient snow (Hamlet and Lettenmaier 2007).

2.4.2 Anticipated Future Changes Due to Climate Change

Climate models suggest that precipitation and temperature changes will continue and intensify in the next century. Warming is anticipated over at least the next few decades even if emission of greenhouse gasses is stabilized or reduced, due to greenhouse gases that have already been emitted (Mote et al. 2005b). Later in the century, rates of change increasingly will be influenced by whether human actions collectively accelerate or slow emissions of the gases that contribute to warming and associated climatic changes. Temperature changes are projected to be in the range of 1 degree F to 5.0 degrees F over the next 50 years, with a best estimate of about 2.5 degrees F (Mote et al. 2005b).

Although much less certain than temperature projections, precipitation changes are projected to be modest, and are unlikely to be distinguishable from natural variability until late in this century (Mote et al. 2005b). However, changes in precipitation seasonality are anticipated with increasing precipitation during the cool season and decreasing precipitation during the warm season (Mote and Salathe 2010). This change in precipitation seasonality exacerbates warming impacts on streamflow seasonality, reducing warm season flows and increasing cool season flows.

Although annual precipitation is not expected to change much in the mid-term, temperature changes will likely change water availability throughout the Columbia River basin. Specifically, higher temperatures will cause earlier snowmelt. The trend towards earlier peak spring runoff has already occurred and is projected to continue, with runoff shifting 15 to over 35 days earlier within this century (Stewart et al. 2004). April 1 snowpack is projected to decline as much as 40% by the 2040s (Payne et al. 2004). This will reduce the amount of water available during the summer and autumn, when flows are already normally low (Payne et al. 2004; Stewart et al. 2004). The summer dry period will be longer (Stewart et al. 2004) and flows will be lower in the late summer, both due to earlier snowmelt and because higher summer temperatures will lead to increased evaporation and higher water loss from vegetation. Reservoir management can compensate for some timing changes in areas of the basin with storage, but the overall level of storage in the Columbia River basin is lower (as a percentage of annual runoff) than some other major river systems in the U.S.

Simultaneously, higher summer temperatures could change demand for out-of-stream water in complex ways. Irrigated crops and natural vegetation are likely to have higher evapotranspiration (loss of water through evaporation and plant transpiration) rates and thus need more water (Stockle et al. 2010b). Decreases in summer precipitation could also increase irrigation demand because irrigation demand is the crop water requirement beyond what is provided by rainfall. Some harvested crops may be planted earlier and reach maturity earlier, which could increase demand for some crops earlier in the season, but reduce demand later in the season. Meanwhile, higher summer temperatures could also cause an increase in domestic water demand.

Demand in the summer may also be higher for instream water. Summer demand for hydropower is likely to increase due to increased use of air conditioning (Casola et al. 2005). Simultaneously, in many areas, lower summer streamflows and higher summer water temperatures will likely stress salmon, trout, and steelhead that prefer colder water temperatures (Casola et al. 2005).

These temperature-driven changes in water supply and demand have the potential to seriously stress the Columbia River basin water supply system, which was built to reliably deliver water under historical conditions. As temperature projections are more robust than precipitation projections, these highly temperature-driven impacts on surface water availability should be considered in long-term water resource planning (Barnett et al. 2005). Climate change is thus incorporated as an important feature of this Forecast, to provide information that will help legislators, water managers, and agency professionals begin to plan for future conditions that will likely be different than what we have experienced in the past.