## Addendum

# Yakima River Basin Study

## Volume 1
## Proposed Integrated Water Resource Management Plan

This report is an Addendum to the *Yakima River Basin Study, Volume 1: Proposed Integrated Water Resource Management Plan,* and is organized according to the requirements outlined in Public Law 111-11, Subtitle F – Secure Water Act, Section 9503(b).


***Prepared by***

HDR Engineering
Anchor QEA
ECONorthwest
ESA Adolfson
Golder Associates



**U.S. Department of the Interior**
**Bureau of Reclamation**
**Pacific Northwest Region**
**Columbia-Cascades Area Office**

**State of Washington**
**Department of Ecology**
**Office of Columbia River**

**August 2011**

# ADDENDUM

# YAKIMA RIVER BASIN STUDY

# PROPOSED INTEGRATED WATER RESOURCE MANAGEMENT PLAN

## INTRODUCTION AND BACKGROUND

In March 2009, Congress passed the Secure Water Act (Public Law 111-11, Subtitle F). Congress found that adequate and safe water supplies are fundamental to the health, economy, security and ecology of the United States. Additionally, global climate change poses a significant challenge to the protection and use of water resources in the United States due to an increased uncertainty with respect to the timing, form, and geographical distribution of precipitation, which may have a substantial effect on the supplies of water for agriculture, hydroelectric power, industrial, domestic uses and environmental needs.

Congress found that Federal agencies conducting water management and related activities have a responsibility to take a lead role in assessing the risks to water resources of the United States, including the risks posed by global climate change, and to develop strategies to mitigate the potential impacts of these risks. This effort is necessary to help ensure that the long-term water resources management of the United States is sustainable and will continue to ensure adequate quantities of water. Congress also found that continued and expanded research and monitoring efforts are needed to improve the understanding of the variability of the water cycle, to efficiently manage water resources, and to identify new supplies of water capable of being reclaimed. This study of water use is vital to the understanding of human impacts on water and ecological resources, and to assess whether surface and groundwater supplies will be available to meet future needs.

The Yakima River Basin is part of the Columbia River system, which is a major Reclamation river basin, as defined by Congress in Public Law 111-11(12)(A). As such, the Yakima River basin is subject to Section 9503, Reclamation Climate Change and Water Program. Section 9503 requires the Secretary to establish a climate change adaptation program to assess the effect of and risk resulting from global climate change with respect to water resources. It also requires the Secretary to ensure, to the maximum extent possible, that strategies are developed at the watershed and aquifer system scale to address potential water shortages, conflicts and other impacts to water users. The required elements of Section 9503 are outlined in Section 9503(b). The elements include an assessment of risks to water supply, an analysis of the extent to which these risks could affect water uses, and strategies to mitigate the potential impacts.

This report is being prepared as an Addendum to the *Yakima River Basin Study, Volume 1: Proposed Integrated Water Resource Management Plan* (Integrated Plan) and is organized according to the requirements outlined in Section 9503(b). Volume 2 of the Yakima River Basin Study includes technical appendices. Information for this Addendum was largely obtained from the Integrated Plan and its appendices and is being prepared to document reporting requirements in Section 9503 (b).

The Integrated Plan is a proposed approach to improving water management in the Yakima River basin. Its goals are to protect, mitigate and enhance fish and wildlife habitat, provide increased operational flexibility to manage instream flows to meet ecological objectives, and improve the reliability of water supply for irrigation, municipal supply and domestic uses.

The Integrated Plan is a culmination of studies that have been ongoing since 1979. The Yakima River basin is affected by a variety of problems that impact fish, agriculture and municipal and domestic water supplies. The Integrated Plan builds on these previous studies to propose water resource, habitat protection and habitat restoration solutions in the Yakima River basin. The Integrated Plan includes seven elements: (1) fish passage, (2) structural and operational changes, (3) surface water storage, (4) groundwater storage, (5) habitat protection and enhancement, (6) enhanced water conservation, and (7) market-based reallocation. These actions address water resource and habitat problems that currently exist and provide an adaptive management framework to address potential future changes in water needs or hydrology, including potential climate change effects.

Following is a discussion of the required elements outlined in Section 9503(b) as they relate to Reclamation facilities and operations within the Yakima River Basin.

# 1 COORDINATION WITH USGS, NOAA AND APPROPRIATE STATE AGENCIES

The Secure Water Act (SWA) Section 9503(b)(1) requires coordination with the U.S. Geological Survey (USGS), the National Oceanographic and Atmospheric Administration (NOAA), and each appropriate State water resource agency, to ensure that the Secretary has access to the best available scientific information with respect to presently observed and predicted future impacts of global climate change on water resources. The Yakima River Basin Study has been jointly led by the U.S. Department of the Interior Bureau of Reclamation (Reclamation) and Washington State Department of Ecology (Ecology), and the planning process has been closely coordinated with the National Marine Fisheries Service (NMFS) (a division of NOAA), U.S. Fish and Wildlife Service (USFWS), USGS, the Yakama Nation and several Washington State agencies. In addition to Ecology, participating state agencies include Washington Departments of Fish and Wildlife (WDFW) and Agriculture (WDA). In 2009, Reclamation and Ecology convened the Yakima River Basin Water Enhancement Project (YRBWEP) Workgroup to review studies and information produced over the past 30 years. NMFS, USFWS, the Yakama Nation WDFW and WDA all have representatives on the YRBWEP Workgroup and several of the subcommittees formed to support the planning process. The YRBWEP Workgroup members and a description can be found at http://www.usbr.gov/pn/programs/yrbwep/2010workgroup/index.html. NMFS, USFWS and WDFW played a key role in identifying instream flow needs to be met by the proposed Integrated Plan, along with habitat restoration priorities and program elements that are focused on improving conditions for listed species in the Yakima River basin and ecosystem improvements. Ultimately NMFS, USFWS, WDFW and WDA were able to join in supporting the Integrated Plan as a proposal for further consideration by Washington State and Reclamation in a planning report/programmatic environmental impact statement process.

USGS presented findings from its Yakima River basin groundwater study at several YRBWEP Workgroup meetings. Draft USGS study results were relied upon to develop a better understanding of groundwater needs and constraints. Groundwater management strategies were developed with consideration of USGS information on basin conditions.

Through the Yakima River Basin Study and interaction with the YRBWEP Workgroup and its subcommittees, these Federal and state agencies played an important role in specifying basin needs in greater detail, and helping to identify actions for inclusion in the Integrated Plan.

# 2 RISKS TO WATER SUPPLY

Section 9503 (b)(2) of the SWA requires the assessment of "specific risks to the water supply of each major Reclamation river basin, including any risk relating to a change in snowpack, changes in the timing and quantity of runoff, changes in groundwater recharge and discharge, and any increase in the demand for water as a result of increasing temperatures and the rate of reservoir evaporation."

For the Yakima River Basin Study, analyses of climate change effects were completed with the Yakima Project RiverWare (YAKRW) model using RiverWare software. Four datasets were used to analyze climate change effects. The first set, called "No Regulation No Irrigation" (NRNI), is derived from observed data and represents current or historical conditions for water years 1981 through 2005. The other three sets are derived from climate-specific hydrologic modeling conducted by the University of Washington's Climate Impacts Group (CIG) for the River Management Joint Operating Committee (RMJOC). The three climate-impacted datasets were selected from a group of 12 hybrid-delta[1] datasets using a range of assumptions about future greenhouse gas emissions and a range of different global climate models (Brekke et al. 2010). The selected scenarios represent "less adverse," "moderately adverse," and "more adverse" climate change conditions that may occur during the 2040s (Reclamation and Ecology 2011b). The RMJOC also looked at 2020 projected conditions. The climate effects were superimposed upon the historical hydrologic variations from water years 1981 through 2005. Table 1 summarizes the climate change scenarios used in the Yakima River Basin Study.

**Table 1. Summary of Climate Change Scenarios**

| SCENARIO | CLIMATE MODEL USED | RMJOC LABEL | AVERAGE TEMPERATURE CHANGE | AVERAGE PRECIPITATION CHANGE | AVERAGE ANNUAL RESERVOIR INFLOW (ACRE-FEET) |
|---|---|---|---|---|---|
| NRNI (Existing or Historical) | Historically Based | None | 0 | 0 | 1.66 M |
| Less Adverse | CGCM3.1 | None (2040s Less Warming/Wetter) | 1.8 ºC average increase | 13.4% increase | 1.86 M |
| Moderately Adverse | HADCM | Central Change (2040s C) | 1.7 ºC average increase | 3.7% increase | 1.48 M |
| More Adverse | HADGEM1 | More Warming, Drier (2040s MW/D) | 2.8 ºC average increase | 2.5% decrease | 1.38 M |

[1] Hybrid-delta datasets reflect a step-change in climate from a historical period to a future period. The datasets maintain historically based variations in hydrology, but with a consistent "delta" (or shift) based on the predicted change in atmospheric conditions from historic to 2040 conditions.

Source: Reclamation and Ecology 2011b (page 42).

Additional details of the modeling efforts are available in the *Modeling of Reliability and Flows Technical Memorandum* (Reclamation and Ecology 2011b).

The following sections present each required element as it relates to the Yakima River basin.

## 2.A Changes in Snowpack

Change in snowpack in regard to the Yakima River basin is generally described in Section 2.3 (page 31) of the Integrated Plan. Generally, increased air temperatures would cause some precipitation to fall as rain rather than snow, which would reduce snowpack. Also, higher air temperatures would cause snowpack to melt earlier than under current conditions (Reclamation and Ecology 2011a).

Studies have shown that the Yakima River basin is likely to have a 12 percent decrease in snowmelt volume given a 1°C rise in air temperature, and a 27 percent decrease in snowmelt volume given a 2°C rise (Vano et al. 2009).

Changes to snowpack were not directly modeled by the YAKRW model, due to the significant amount of additional work required to obtain this information. However, reservoir inflows and natural streamflows used in the YAKRW model accounted for changes to snowpack as determined by the UW CIG climate change models, which did simulate snowpack and were considered to adequately characterize seasonal variability in snowpack Changes to streamflows and reservoir inflows are described in the runoff discussion of this assessment (Section 2.B).

Snowpack is considered the "sixth reservoir" in the Yakima River basin because most demands in the spring and early summer are met from runoff that comes from melting snowpack. Only 30 percent of the average annual total natural runoff can be stored in the five current Yakima River basin reservoir storage system (Reclamation and Ecology 2011c). Because of this, the water supply of the Yakima River basin is susceptible to changes in snowpack due to climate change. Strategies to mitigate these impacts are discussed in Section 4.

## 2.B Changes in Timing and Quantity of Runoff

Changes in Yakima River basin runoff are described generally in Section 2.3 (page 31) of the Integrated Plan (Reclamation and Ecology 2011a) and in more detail in the *Modeling of Reliability and Flows Technical Memorandum* (Reclamation and Ecology 2011b). Generally, increased air temperatures cause some precipitation to fall as rain instead of snow, which increases winter and early spring runoff and reduces the volume of runoff from snowpack that occurs in the late spring and early summer. Additionally, higher air temperatures cause runoff from snowpack to begin earlier, shifting the peak runoff period to a point earlier in the season (Reclamation and Ecology 2011a).

To analyze changes in runoff due to climate change, total inflow into the five major reservoirs (Keechelus, Kachess, Cle Elum, Bumping and Rimrock) for NRNI and the three climate change scenarios from the YAKRW model were compared. The modeling analyses were previously described in Section 2. Figures 1, 2 and 3 compare the modeling results of runoff into the five major reservoirs of the NRNI scenario and the Less Adverse, Moderately Adverse, and More Adverse scenarios, respectively.

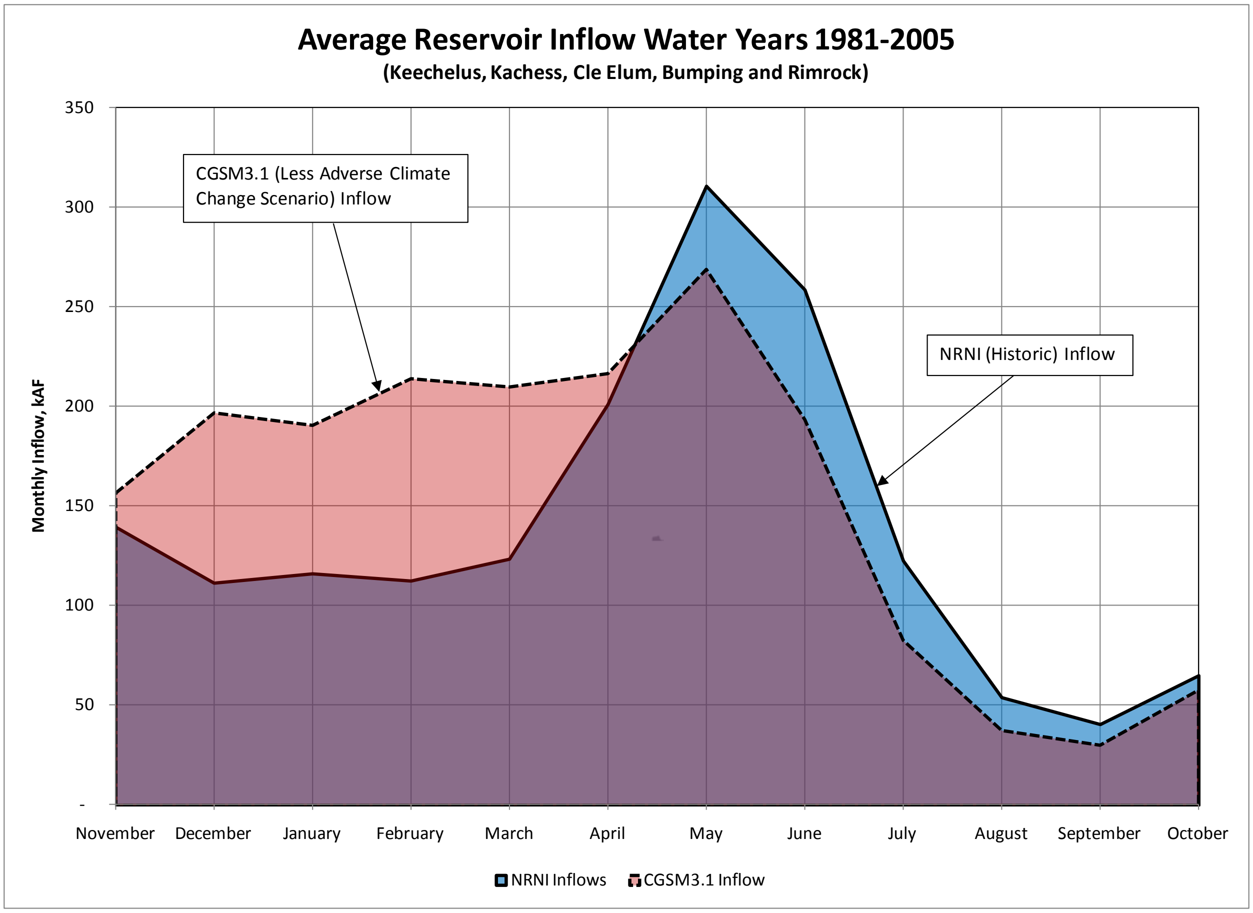


**Figure 1. Comparison of Average Monthly Reservoir Inflows between Historically Based (NRNI) and Less Adverse scenario (Source: Reclamation and Ecology 2011b)**

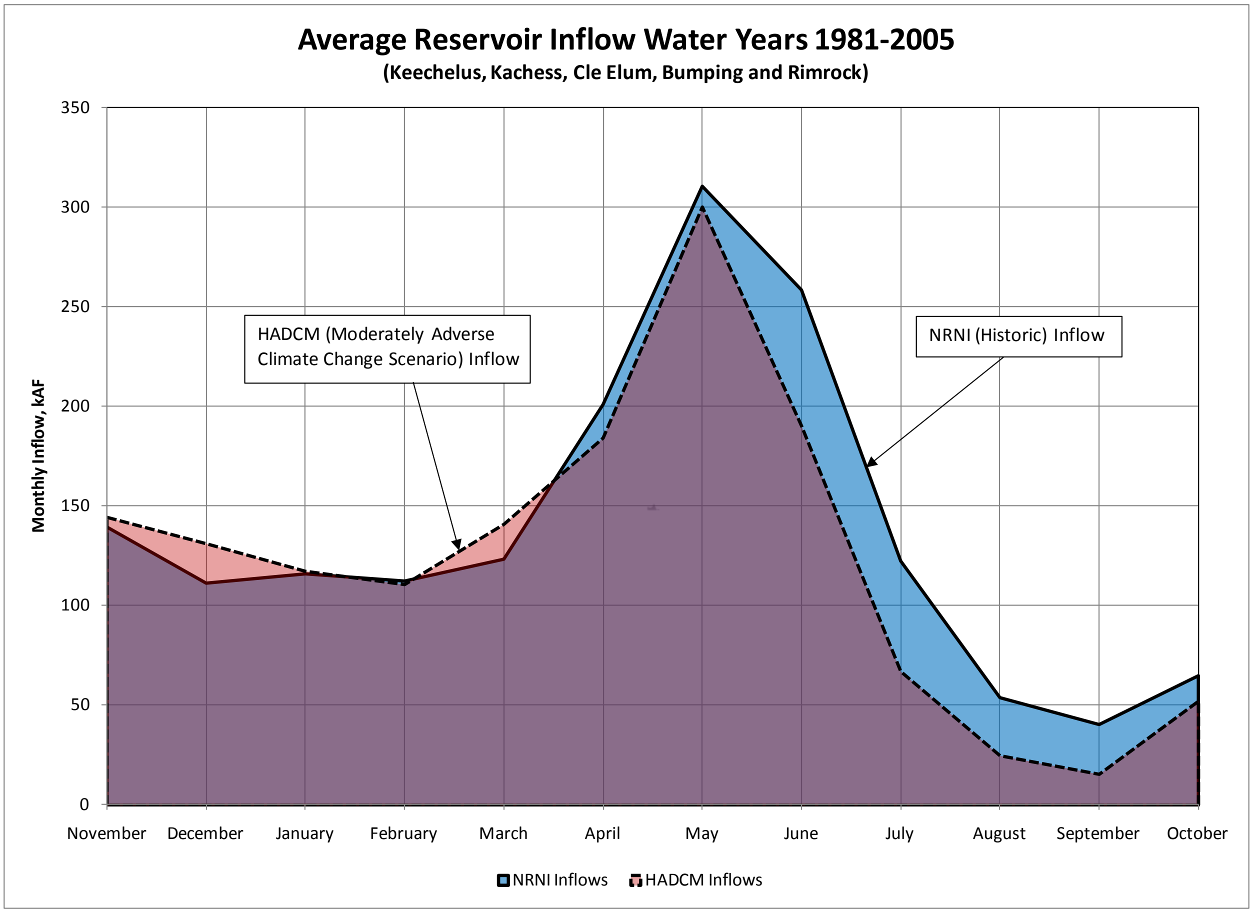


**Figure 2. Comparison of Average Monthly Reservoir Inflows between Historically Based (NRNI) and Moderately Adverse scenario (Source: Reclamation and Ecology 2011b)**

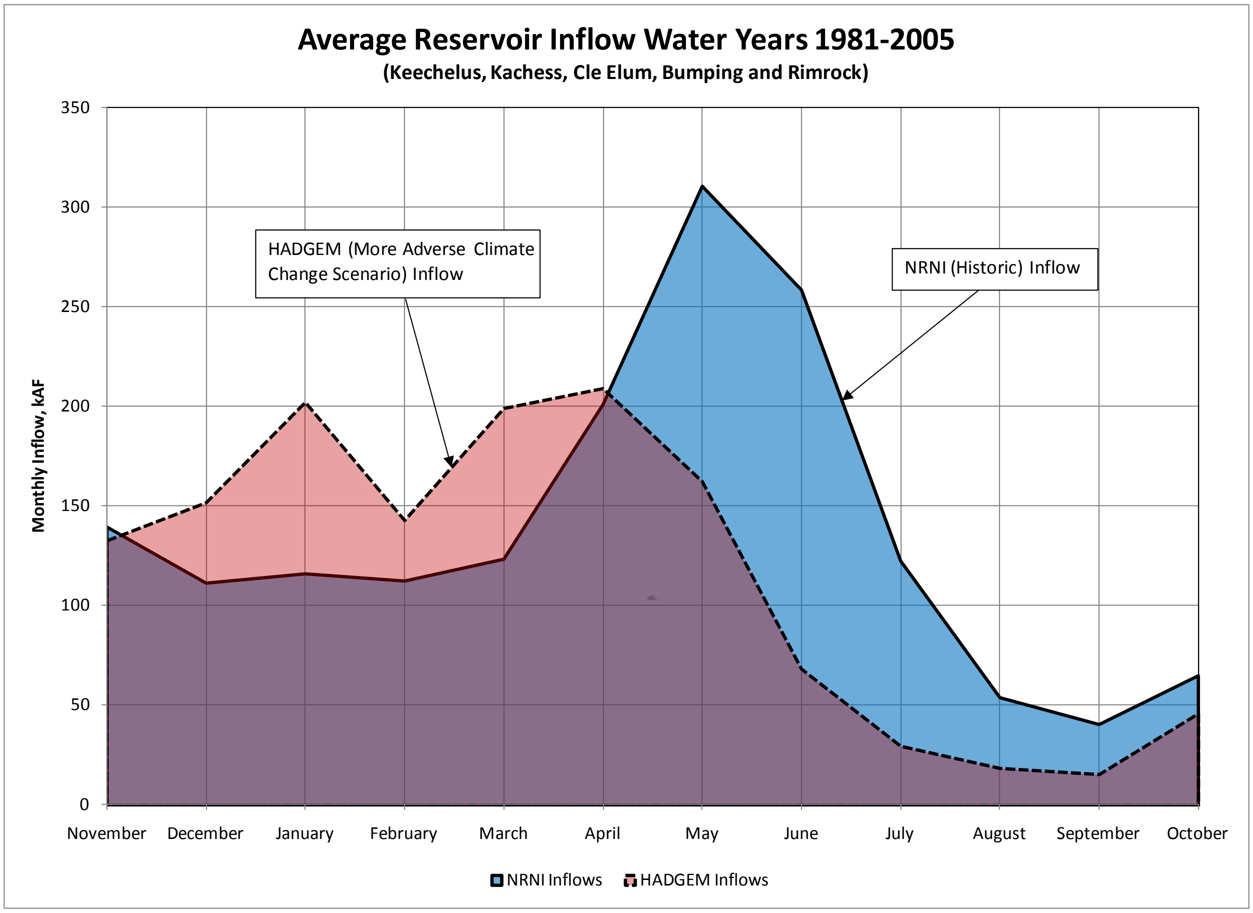


**Figure 3. Comparison of Average Monthly Reservoir Inflows between Historically Based (NRNI) and More Adverse scenario (Source: Reclamation and Ecology 2011b)**

Table 2 compares the NRNI and the three climate change scenarios for seasonal inflow into the five major reservoirs from the YAKRW model results.

**Table 2. Comparison of Average Seasonal Inflows into Keechelus, Kachess, Cle Elum, Bumping, and Rimrock Reservoirs for the Climate Change Scenarios (Results in Thousands of Acre-Feet)**

| SCENARIO | FALL (OCTOBER-DECEMBER) | WINTER (JANUARY-MARCH) | SPRING (APRIL-JUNE) | SUMMER (JULY-SEPTEMBER) | TOTAL |
|---|---|---|---|---|---|
| NRNI (Existing or Historical) | 316 | 353 | 771 | 217 | 1,657 |
| Less Adverse | 412 (+30.4%) | 615 (+74.2%) | 679 (-11.9%) | 151 (-30.4%) | 1,856 (+12.0%) |
| Moderately Adverse | 328 (+3.8%) | 369 (+4.5%) | 675 (-12.5%) | 108 (-50.2%) | 1,480 (-10.7%) |
| More Adverse | 330 (+4.4%) | 544 (+54.1%) | 440 (-42.9%) | 64 (-70.5%) | 1,378 (-16.8%) |

Based on the model results presented in Figures 1 through 3 and Table 2, changes in runoff in the Yakima River basin due to climate change are projected to be significant. For the three climate change scenarios modeled as part of the Yakima River Basin Study, the average annual change in reservoir inflow ranges from a decrease of 17 percent for the most adverse scenario and an increase of 12 percent for the less adverse scenario. For all three climate change scenarios, spring and summer runoff is projected to decrease (ranging from 12 to 71 percent of existing runoff) and fall and winter runoff is projected to increase (ranging from 4 to 74 percent of existing runoff).

The shifts in runoff quantity and timing shown in the YAKRW model results would cause significant risks to water supply. Fall and winter inflow will increase, and the reservoir system may not be able to capture and hold the increased flow for release during the high demand period (spring and summer). Additionally, a decrease in spring and summer supply will cause water stored in reservoirs to be depleted at a faster rate to meet demand. The combined effects will likely cause a decrease in overall supply during the high demand period. Mitigating these potential risks is discussed under Strategies in Section 4, and includes the major elements discussed in the Integrated Plan: structural and operational changes to the existing system, surface water storage, groundwater storage, enhanced water conservation, and market allocation.

## 2.C Changes in Groundwater Recharge and Discharge

Changes in groundwater due to climate change have not specifically been studied in the Yakima River basin. However, as noted in Section 4.5 (page 78) of the Integrated Plan, the surface and groundwater systems of the basin are interconnected (Reclamation and Ecology 2011a). Therefore it is assumed, effects on surface water (such as runoff) due to climate change would also have an effect on groundwater. As such, risks in the water supply relating to changes in groundwater discharge and recharge are similar to those described in Section 2.B.

Groundwater aquifers would likely be affected by a reduction in groundwater recharge through surface soils because of an increase in evapotranspiration (ET) from a warmer climate. As ET increases, more water is consumed by plants, and less precipitation and possibly less irrigation water may infiltrate to groundwater aquifers due to evaporation directly from the soil. In addition, riparian areas would consume more water due to increased ET, reducing groundwater flows to surface water or surface water flows to groundwater. Some of the increased ET may be offset by increased precipitation, although the timing of the precipitation will be an important factor.

The reduction in runoff quantity and change in timing described in previous sections would also impact groundwater recharge generated by application of surface water to farmland. As less water is available for irrigated agriculture, less recharge of aquifers would result, reducing groundwater discharge to surface water bodies such as the Yakima River. For example, Reclamation estimates return flow (emanating from groundwater and surface water drains) to the Yakima River above Parker using experience in operating the Yakima Project. In low runoff years, the estimated return flow that is usable for water supply is 350,000 acre-feet. In high runoff years, the estimate is 400,000 acre-feet (Reclamation 2002). A smaller surface water supply is demonstrated to reduce the amount of return flow available for water supply.

## 2.D Increases in Demand for Water

The *Water Needs for Out-of-Stream Uses Technical Memorandum* (Reclamation and Ecology 2011d), which is briefly summarized in Section 2.3 of the Integrated Plan, estimates future demand for "out-of-stream" uses, including increases in future demand due to climate change.

Rough estimates were prepared of how climate change might affect crop irrigation needs. UW estimates of future potential evapotranspiration (PET) were used for a reference crop of short grass. The ratio of future to current PET for short grass was applied to irrigation requirements listed in the Washington Irrigation Guide (U.S. Department of Agriculture 1985) for short grass and other Yakima River basin crops. Future PET rates are based on the 2040s "moderate effect" climate change model (Model 6 – HAD-CM B1). This approach allowed an estimate of the percentage increase of out-of-stream water needs by irrigation districts in the Yakima Project, and was considered a reasonable approach to provide rough estimates for the evaluation of climate change at this time.

### Increased Demand Without the Integrated Plan

Using the method described above to provide rough estimates of how climate change could affect crop irrigation needs the projected increase in consumptive use for crop irrigation throughout the basin would be approximately 95,000 acre-feet per year (a 9 percent increase), assuming current cropping patterns continue in the future. Table 3 shows the percent increase in crop irrigation requirements by irrigation district.

**Table 3. Future Crop Irrigation Requirements - Percentage Increase**

| District | Percent Increase |
|---|---|
| KRD | 9.8% |
| Roza | 9.0% |
| WIP | 8.7% |
| SVID | 9.2% |
| YTID | 8.9% |
| KID | 7.8% |

A draft of the climate change analysis (PET estimation as described above) was provided to the UW Climate Impacts Group for review. Researchers suggested that other factors (response to carbon dioxide concentrations and a shorter growing season) would cause a lesser increase of crop irrigation requirements than the HDR team projected. They estimated that, after accounting for these factors (including considerations of anticipated plant response to increased atmospheric carbon dioxide concentrations that will to some extent reduce plant water demand), the increase basin-wide would be 3 to 5 percent rather than 9 percent. A 5 percent increase would result in an increase of 53,000 acre-feet. For the purpose of hydrologic modeling, the 95,000 acre-feet figure was used.

Results from the analysis were also used to estimate the increase in water consumption due to climate change for municipal and domestic uses. It was assumed that climate change would affect only outdoor irrigation usage. A 5 percent increase in municipal and domestic consumptive use at 2040 was used. This percentage yields 2,400 acre-feet in increased need. The 9 percent increase for agricultural use and 5 percent increase for municipal and domestic use both are subject to uncertainty of at least plus or minus 50 percent.

### Increased Demand With the Integrated Plan

Existing facilities in the Yakima River Basin are not sufficient to address demand for water under current conditions. Increase in demand in the future due to climate change would further reduce the ability of existing facilities to meet water needs in the basin. The Integrated Plan would reduce the risk to future water supply from climate change by increasing the total water supply available for use. The estimated increase in water demand modeled by Reclamation was incorporated into hydrologic modeling used to evaluate the effectiveness of the Integrated Plan.

## 2.E Increases in Reservoir Evaporation

The Yakima River basin reservoirs are located in the Cascade Mountains at elevations ranging from 2,240 to 3,426 feet. Table 4 provides a list of major reservoirs and their elevations.

**Table 4. Yakima River Basin Reservoirs**

| RESERVOIR NAME | RESERVOIR VOLUME (ACRE-FEET) | ELEVATION (FEET IN NGVD DATUM) |
|---|---|---|
| Keechelus | 157,800 | 2517 |
| Kachess | 239,000 | 2262 |
| Cle Elum | 436,900 | 2240 |
| Bumping | 33,700 | 3426 |
| Rimrock | 198,000 | 2926 |

Source: Reclamation (2002)

The rates of evaporation under existing climate conditions are implicitly accounted for in the YAKRW model and in the NRNI model scenario run. The evaporation rates are not explicitly calculated in the YAKRW model, but the model uses inflow time series that are generated from reservoir outflow and reservoir stage data that reflect water supply conditions after evaporation losses.

In general, increased air temperatures would cause an increase in the rate of evaporation. An increase in evaporation rates would cause more water to be lost from storage, which would decrease the water supply available. However since the reservoirs are located at a moderately high elevation in the Cascade Mountains, the change in evaporation is expected to be small compared to other changes, such as a reduction in runoff due to a diminished snowpack (see Sections 2.A and 2.B). For example, a 10% increase in evaporation results in an approximately 3-inch drop on a 50 to 100-foot deep reservoir, which would represent less than a 1% change.

The YAKRW model runs under future climate change scenarios also implicitly account for changes in reservoir evaporation, in that the GCM-produced meteorological data used in the runoff simulations incorporated climate-impacted precipitation, temperature, and evaporation data.

Estimates of increased evaporation from reservoirs were determined for this study by analyzing data sets from UW CIG (Hamlet, 2011). The UW publication projects PET for open water at Cle Elum Lake for the three climate scenarios (less, moderate and more adverse). Those estimates were reviewed and compared to existing for this document. An increase in PET of 5.6-8.9% is projected for Cle Elum Lake. In terms of relative volume of water, the increase in PET for Cle Elum Lake ranges from about 0.38 feet to about 0.44 feet. Similar or lesser increases would be expected at the other reservoirs as they are higher in elevation than Cle Elum Lake. The change in evaporation is expected to be small compared to other changes, such as a reduction in runoff due to a diminished snowpack (see Sections 2.A and 2.B).

Because the changes in evaporation are expected to be small compared to other changes in water supply due to climate change, the risk to water supply associated with increases in the rate of reservoir evaporation is minor compared to risks associated with changes in runoff (Section 2.B).

# 3 IMPACTS FROM CHANGE IN WATER SUPPLY

Section 9503(b)(3)of the SWA requires the analysis of "the extent that the risks to water supply will impact water deliveries to the contractors of the Secretary of the Interior, hydroelectric power generation facilities, recreation at Reclamation facilities, fish and wildlife habitat, applicable species listed as an endangered, threatened, or candidate species, water quality issues, flow and water dependent ecological resiliency, and flood control management."

The following sections present each required element as it relates to the Yakima River basin and the Integrated Plan.

## 3.A Ability to Deliver Water

The ability to deliver water to the irrigation districts of the Yakima River basin is impacted by a number of factors addressed above in Section 2, including changes in snowpack, changes in the timing and quantity of runoff, increase in demand for water, and increase in the rate of reservoir evaporation (although relatively minor). These topics were analyzed in the Yakima River Basin Study and its associated technical memoranda. This section discusses the impact of climate change on the overall water supply outcomes, an analysis informed by the factors listed in Section 2. Section 4.6 of the Integrated Plan covers water supply outcomes under climate change and the Modeling of Reliability and Flows Technical Memorandum includes more detailed information on the analysis. Hydrologic inputs for four of the climate-specific scenarios were incorporated into the YAKRW model: historically based Existing Conditions, Less Adverse climate change, Moderately Adverse climate change, and More Adverse climate change. Climate change impacts on hydrology, water demands, volume and timing of water flow into reservoirs, and streamflow at diversion locations were incorporated into the model for each scenario.

## Assessment of Risk: Future Without the Integrated Plan

Two important concepts used in managing the Yakima River Basin's water supply are Total Water Supply Available (TWSA) and prorationing. TWSA is a measure of water available from the supply system, above the Parker gage, from April through September. Prorationing refers to reduced deliveries to certain users that occur in years when the water supply is inadequate to serve all legal entitlements. Water rights to federal project water are divided into two categories: proratable and nonproratable. Nonproratable rights have priority over proratable rights for receiving supplies in water-short years.

Modeling under the Existing Conditions scenario showed that, based on the average scenario for water years 1981 through 2005, the future April 1 total water supply available (TWSA) would be 2,790,000 acre-feet. Under this scenario, the irrigation proration level would be 80 percent on average. Modeling of climate change scenarios showed significant risk to Reclamation's ability to deliver water to irrigation districts in the Yakima River basin. Under the Less Adverse climate change scenario, the average TWSA would be 2,640,000 acre-feet and the proration level would be 74 percent. Under the Moderately Adverse scenario, the average TWSA would be 2,310,000 acre-feet and the proration level would be 54 percent. Under the More Adverse scenario, the average TWSA would be 1,840,000 acre-feet and the proration level would be 30 percent. Under the More Adverse scenario, in years similar to the 1994 and 2001 dry years, there would be no water available to junior water right holders (a zero percent proration level) and nonproratable water rights would not be fully satisfied.

## Assessment of Risk: Future With the Integrated Plan

Modeling results indicate that without climate change, the average TWSA would be 3,000,000 acre-feet and the proration level would be 92 percent if the Integrated Plan is implemented. The TWSA and proration levels would both be lowered under each climate change scenario, but to a lesser degree than conditions without the Integrated Plan. Table 5 shows TWSA and proration levels under each climate change scenario both with and without the Integrated Plan. In drought years similar to the 1994 (last year of a 3 year drought period) and 2001, under the Less Adverse and Moderately Adverse climate change scenarios, the Integrated Plan would ensure that nonproratable water rights would be fully satisfied and that proratable water users would receive at least a 70 percent supply. Under the More adverse climate change scenario, the modeling projections show that nonproratable users would receive a full supply, but the proratable users would receive a 14 percent supply in a year like 1994 and 10 percent supply in a year like 2001. However, the Integrated Plan contains an adaptation process that would commence prior to 2015. This process is intended to further refine metric or plan performance measures for potential plan adjustments though time. Thus the Integrated Plan can identify adjustments that may be needed if climate evolves over time to a most severe climate change scenario.

**Table 5. Climate Change Scenario Simulation Results**

| Climate Change Scenario | Condition | Average April 1 TWSA (in millions of acre-feet) | Average Irrigation Proration Level |
|---|---|---|---|
| Existing Conditions | Without Integrated Plan | 2.79 | 80% |
| | With Integrated Plan | 3.00 | 92% |
| Less Adverse | Without Integrated Plan | 2.64 | 74% |
| | With Integrated Plan | 2.79 | 88% |
| Moderately Adverse | Without Integrated Plan | 2.31 | 54% |
| | With Integrated Plan | 2.47 | 72% |
| More Adverse | Without Integrated Plan | 1.84 | 30% |
| | With Integrated Plan | 2.02 | 50% |

The Average Irrigation Proration Level refers to the proration level for an average year (average for water years 1981-2005), not specific water years such as 1994 or 2001.

The effects of climate change on snowpack, timing and quantity of runoff, increase in demand for water, and increase in the rate of reservoir evaporation would affect the proposed Integrated Plan facilities similar to the existing facilities. However, since the Integrated Plan facilities are designed to provide a greater quantity of water than the existing facilities under any climate change scenario, they would at least partly mitigate the impacts of climate change on Reclamation's ability to deliver water to irrigation districts in the Yakima River basin.

## 3.B Hydroelectric Power Generation Facilities

Hydroelectric power generation facilities in the Yakima River basin are described in the *Roza and Chandler Power Plants Subordination and Power Usage Evaluation Technical Memorandum* (Reclamation and Ecology 2011h). There are two existing facilities in the basin, at Roza and Chandler. The Roza Power Plant has a capacity of 12.9 megawatts (MW) and a rated head of 158 feet and generates approximately 61,000 MW hours per year. Roza's operation is subordinated to meet environmental goals (target streamflows), and therefore it does not operate (or it operates at a reduced capacity) during part of the year. The Chandler Power Plant is a 12 MW powerhouse coupled to irrigation pumps used to lift water into the Kennewick Irrigation District canal. The plant has a rated discharge of 735 cubic feet per second (cfs) and operates at between 106 and 122 feet of head. Chandler generates approximately 46,000 MW hours per year. The pumps attached to Chandler are operated to lift water for delivery to irrigators. Excess capacity may be used to generate electricity for sale. Chandler's electrical generation operation may also be subordinated to meet minimum instream flow needs.

The evaluation of potential risk to existing hydroelectric power generation facilities associated with climate change is performed using the YAKRW model. As documented in the *Modeling of Reliability and Flows Technical Memorandum*, the model was run under Future Without Integrated Plan scenarios under historically based and three sets of potential climate impacted hydrologic conditions (termed Less Adverse, Moderately Adverse, and More Adverse). Average annual and average monthly streamflow results were then examined and compared to estimate the potential effects of climate change on hydroelectric power generation facilities.

### Assessment of Risk: Future Without the Integrated Plan

Climate change may affect existing and proposed hydroelectric power generation facilities in the Yakima River basin by altering the volume or timing of flow available for generating energy. The YAKRW model studies suggest that average annual runoff into all of the reservoirs in the Yakima basin may be increased by up to 12 percent, or decreased by up to 17 percent. For individual months, the monthly average flow changes due to climate change range from an increase of 90 percent to a decrease of 76 percent.

The existing hydropower facilities are "run of river" plants, meaning that they generate electricity using water that is already flowing down the Yakima River, rather than by using water that is released from reservoir storage specifically in order to generate electricity. This means that the potential differences in the timing of flow in the Yakima River caused by climate change are critically important to the amount of energy that can be generated, more so than changes in the average annual volume of flow. Reductions in flow caused by climate change could affect hydropower generation by reducing the flow available to be diverted through the existing facilities below historical levels. Increases in flow caused by climate change could affect hydropower generation by increasing the flow available to be diverted, but if the historical flow is already above the plant capacity, climate-caused increases in flow would not be usable to increase generation. Because of this, an assessment of the risk is performed starting with information on the average flow in the system, then focusing on the quantity of flow available for hydropower generation under each climate condition.

The More Adverse scenario would reduce average annual (365 day) reservoir inflow by about 17 percent (386 cfs) from historical conditions. Monthly total reservoir inflows under the More Adverse scenario would increase by up to 74 percent (in January), and decrease by as much as 76 percent (in July). To a certain extent, these large flow changes into the reservoirs would be evened out by reservoir operations. However, there is little doubt that the runoff changes assumed in the More Adverse scenario would increase potential hydropower generation in the winter and decrease generation potential in the late spring through summer.

The Moderately Adverse scenario would reduce average annual (365 day) reservoir inflow by about 11 percent (244 cfs) from historical conditions. Monthly total reservoir inflows under the Moderately Adverse scenario would increase by up to 18 percent (in December), and decrease by as much as 61 percent (in September). (Months shown are the Maximum Change Months, which vary according to the scenario used.) To a certain extent, these large flow changes into the reservoirs would be evened out by reservoir operations. However, the runoff changes assumed in the Moderately Adverse scenario would increase potential hydropower generation in the winter and decrease generation potential in the late spring through summer.

The Less Adverse scenario would increase average annual reservoir inflow by about 12 percent (275 cfs) from historical conditions. Monthly total reservoir inflows under the Less Adverse scenario would increase by up to 90 percent (in February), and decrease by as much as 32 percent (in July). (As noted above, these are Maximum Change Months, which vary according to the scenario used.) To a certain extent, these flow changes into the reservoirs would be evened out by reservoir operations. However, the runoff changes assumed in the Less Adverse scenario would significantly increase potential hydropower generation in the winter and decrease generation potential in the late spring through summer.

Because the winter target flows at the locations of the Roza and Chandler Power Plants are currently met, when there is hydraulic capacity available in the plants, the increased winter flows under climate change conditions could be used to generate additional energy. The potentially decreased late spring and summer flows would be likely to produce Yakima River flows that are below the targets for this period and would therefore result in reduced generation. Because of plant capacity limitations, it is likely that the net effect of climate change would be a reduction in average generation at the existing facilities. The hydrologic modeling conducted as part of the Yakima Basin Plan Study incorporated the target flow requirements and the hydraulic capacity of the power plants and estimated that the More Adverse scenario would reduce average hydropower diversions at Roza and Chandler by 18 to 21 percent, the Moderately Adverse scenario would reduce average hydropower diversions by between 8 and 11 percent, and the Less Adverse scenario would leave average hydropower diversions essentially unchanged. The YAKRW-estimated monthly changes in average diversions to the Roza Power Plant are shown in Figure 4.

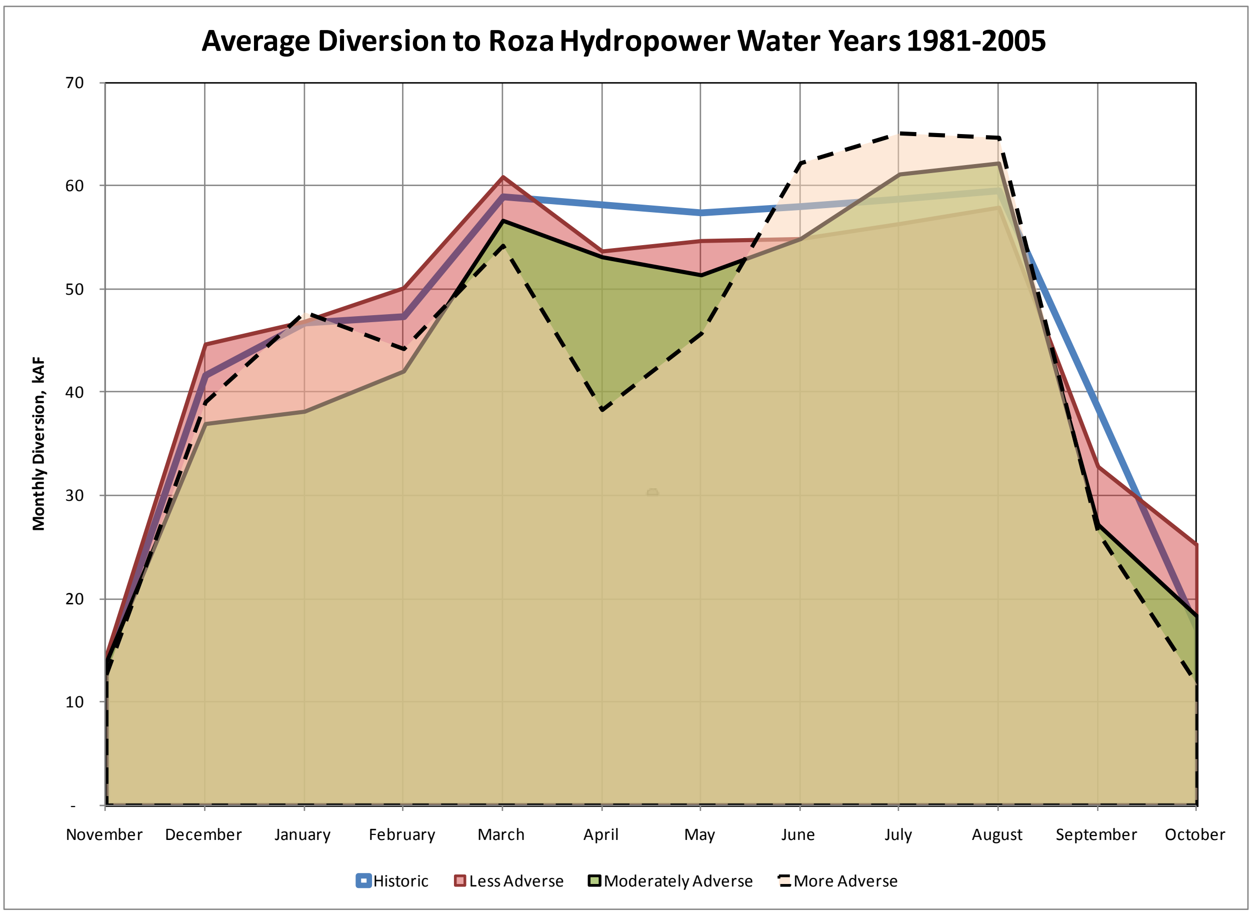


**Figure 4. YAKRW-estimated monthly changes in average diversions to the Roza Power Plant**

### Assessment of Risk: Future With the Integrated Plan

The *Hydropower Considerations and Power Subordination Technical Memorandum* estimates that historically based hydroelectric energy production at the existing plants in the Yakima River basin averages 107,000 MW hours per year. As described above, the climate change scenarios evaluated are likely to reduce summer streamflows in the Yakima River and reduce the average amount of hydroelectric energy that can be generated at these existing facilities by up to 21 percent. The Integrated Plan would include the development of new reservoir storage to maintain and increase summer flows in the Yakima River, and thus would tend to maintain energy generation capabilities at the existing facilities. The Integrated Plan also includes the establishment of new or modified instream flows to benefit anadromous fish in the Yakima River and certain tributaries, as well as the subordination of hydropower generation to benefit fish. This subordination of Roza and Chandler Power Plants would tend to reduce hydroelectric energy production apart from any effects of climate change.

The Integrated Plan may also increase the average amount of hydroelectric energy production by developing new generating plants in the basin. At the same time, the Integrated Plan will require power for pumping water into the proposed Wymer Reservoir and possibly at other locations. A range of decisions need to be made on these elements that will affect power needs and production.

## 3.C Recreation at Reclamation Facilities

The availability of water-related recreation in the Yakima River basin is impacted by a number of factors addressed in Section 2, including changes in snowpack, changes in the timing and quantity of runoff, increase in demand for water, and increase in the rate of reservoir evaporation. These topics were analyzed in the *Water Recreation Opportunity Spectrum Users Guidebook* (Reclamation 2004) as well as the Yakima River Basin Water Storage Feasibility Study. This section discusses the impact of climate change on the overall availability of recreation. Sections 4.12 and 5.12 of the *Water Storage Feasibility Study Final Planning Report/Environmental Impact Statement* (Reclamation and Ecology 2008) describe the existing and proposed recreational facilities in detail. The *Yakima River Basin Integrated Water Resource Management Alternative Final Environmental Impact Statement* (Ecology 2009) Sections 4.10 and 5.10 cover the projected effects of the proposed projects.

The *Recreation Demand and User Preference Analysis* (Reclamation 2007), regional population trends, and historical usage were used to estimate the future demand for recreational services and facilities within the Yakima River basin. The types of recreation analyzed were narrowed to activities popularly associated with reservoirs, rivers and lakes in the basin, including fishing, waterfowl hunting, rafting/kayaking, water skiing, motor-boating, developed camping, rustic/primitive camping, hiking, jet skiing, wildlife viewing, picnicking, bicycling, swimming and sailing.

The potential effects of climate change on these recreational activities were determined by looking at the changes in volume and timing of water flow in the streams and into reservoirs, as described in Section 3A.

## Assessment of Risk: Future Without the Integrated Plan

The projected demand for water-based recreational facilities is expected to increase with population, whether or not the Integrated Plan is implemented. The estimated 20-year recreation projections for the Yakima River basin, with the exception of waterfowl hunting, are expected to increase between 5 percent and 40 percent, depending on the activity. Timing and demand for recreation may be somewhat affected by changes in temperature and snowmelt patterns (higher temperatures and/or earlier snowmelt), which will change on a yearly basis extending or decreasing the length of the recreational season. Waterfowl hunting is expected to decline due to urbanization, increases in development, and losses of waterfowl habitat (Reclamation 2007).

Modeling under the Existing Conditions scenario showed that, based on the average scenario for water years 1981 through 2005, the future April 1 total water supply available (TWSA) would be 2,790,000 acre-feet. Although not specific to any particular recreational facility, this gives a generalized idea of the amount of water available system-wide within rivers, streams, and at the reservoirs for water enjoyment. Under the Less Adverse climate change scenario, the TWSA would be 2,640,000 acre-feet. Under the Moderately Adverse scenario, the TWSA would be 2,310,000 acre-feet. Under the More Adverse scenario, the TWSA would be 1,840,000 acre-feet. In general, climate change is expected to affect streamflows in both magnitude and timing, with increases in winter and early spring rainfall and earlier snowpack runoff.

More specifically, the three climate change scenarios were modeled for the reservoirs' average lake levels. The models show slight shifts in peak volume, low volume and timing for most reservoirs, with some more significant than others due to current operational strategies (timing for release of water). For example, Keechelus, Kachess and Cle Elum reservoirs show decreases in lake levels of 9 feet, 12 feet and 11 feet, respectively, under the More Adverse scenario, while Bumping and Rimrock reservoirs show almost no change. The shift in timing of peak lake levels is most significant under the More Adverse scenario, with shifts of one to two months earlier in the season.

The amount of drawdown in reservoir levels changes from existing conditions with the climate change scenarios, but does not change drastically between the scenarios. This represents the seasonal fluctuation in water level. Keechelus and Kachess would require up to 10 feet of additional drawdown each, Bumping up to 9 feet, Rimrock up to 23 feet, and Cle Elum up to 19 feet.

These changes are not expected to adversely affect overall recreational resources in the Yakima River basin because these reservoirs have always operated with fluctuating lake levels. However, some individual facilities, such as boat launches, may become stranded for portions of the year if lake levels drop to the levels predicted under the climate change scenarios.

## Assessment of Risk: Future With the Integrated Plan

Projected demand for recreational opportunities in the Yakima River basin with the Integrated Plan is expected to be the same as described above without implementation of the plan. Recreational demand will increase as the population grows, although some of the boat ramp strandings that could occur under the Most Adverse scenario may be less likely to occur with implementation of the Integrated Plan.

The Integrated Plan would provide some protection for recreational facilities against climate change. Modeling shows that without climate change, in an average year the TWSA would be 3,000,000 acre-feet with the Integrated Plan. The TWSA levels would be lowered under each climate change scenario, but to a lesser degree than conditions without the Integrated Plan. This means there would be more water resources available for recreational activities, or less impact from climate change effects, than without implementation of the Integrated Plan. Under the Less Adverse climate change scenario, the average TWSA would be 2,790,000 acre-feet. Under the Moderately Adverse scenario, the average TWSA would be 2,470,000 acre-feet. Under the More Adverse scenario, the average TWSA would be 2,020,000 acre-feet.

With implementation of the Integrated Plan, there are similar shifts in peak volume, low volume and timing for the reservoir water levels with climate change. Keechelus and Kachess reservoirs show larger drops in peak water levels under the models, with decreases of 33 and 47 feet, respectively, under the More Adverse scenario. Cle Elum shows a decrease of up to 20 feet, while Rimrock shows virtually no change. Bumping Lake would be enlarged under the Integrated Plan; thus the change in lake levels would be higher overall, even under the More Adverse climate change scenario. The shift in timing of peak lake levels is the same as without implementation of the Integrated Plan.

The drawdown in reservoir levels would still change from existing conditions under the climate change scenarios with the Integrated Plan. However, the drawdown would be less for some reservoirs and more for others. Keechelus would require up to 21 feet less drawdown, Kachess would require up to 32 feet additional drawdown, Bumping up to 13 feet additional drawdown, Rimrock up to 11 feet less drawdown, and Cle Elum up to 10 feet additional drawdown.

As discussed for the Future without the Integrated Plan, these changes are not expected to adversely affect overall recreational resources in the Yakima River basin. However, as noted above, some individual facilities, such as boat launches, may become stranded for portions of the year if lake levels drop to the levels predicted under the climate change scenarios. Measures proposed in the 2007 and 2009 EISs would sufficiently mitigate these potential impacts.

The effects of climate change on snowpack, timing and quantity of runoff, increase in demand for water, and increase in the rate of reservoir evaporation would affect the proposed Integrated Plan facilities similar to the existing facilities. However, since the Integrated Plan facilities are designed to provide a greater quantity of water than the existing facilities under any climate change scenario, they would reduce the risk and the impact of climate change on the availability of water for recreation in the Yakima River basin.

## 3.D Fish and Wildlife Habitat

Studies conducted by the Climate Impacts Group (CIG) at the University of Washington, USFWS, other Federal agencies, and the Washington State Department of Ecology were used to examine potential climate change impacts on salmonids. These studies discuss potential climate change scenarios in the Pacific Northwest and associated impacts to aquatic resources and salmonids. Results from these studies are discussed in the following sections.

## Assessment of Risk: Future Without the Integrated Plan

Climate change is expected to result in a decline in the quantity and quality of freshwater habitat for salmonid populations across Washington State (Mantua et al. 2010). Over the 20th century, temperatures in the Pacific Northwest have increased above historic records, while spring snowpack has declined (Mote et al. 2003). Studies have predicted increasing water temperatures and thermal stress for salmonids in eastern Washington that are minimal for the 2020s but increase considerably later in the century (Mantua et al. 2010). The Yakima River basin is a transient watershed, one that is dominated by a mix of direct runoff from fall rain and spring snowmelt. Simulations predict that this type of watershed will be most affected by climate change (Mantua et al. 2010).

Climate change would significantly alter the temperature, amount and timing of runoff and fish habitat in the Yakima River basin. The CIG has conducted studies assessing the impacts of climate change in Washington State. Notable temperature and precipitation findings by the CIG for the Yakima River basin include:

- Average annual air temperature is expected to increase by 2.0°C (1.5 to 5.2°F) by the 2040s with associated increased water temperatures.
- More precipitation is expected to fall as rain rather than snow, with a 38 to 46 percent decline in spring snowmelt by the 2040s, resulting in more frequent periods of high flows in the winter and low flows in the summer (Ecology 2009).

Increased air temperature would increase water temperature, negatively impacting fish habitat (Reclamation and Ecology 2011a). High stream temperatures decrease the dissolved oxygen concentration in the water and result in increased thermal stress for salmonid populations, particularly populations with a stream-type life history that utilize fresh water during the summer for either spawning migrations, spawning, rearing or seaward smolt migrations.

Elevated stream temperatures are expected to increase thermal barriers to migration (weekly average stream temperatures above 21°C) for up to 10 to 12 weeks (from mid June to early September) in the upper Yakima River by the 2080s (Ecology 2009, Mantua et al. 2010). Spawning summer-run steelhead, sockeye and summer Chinook populations are projected to be most severely impacted (Mantua et al. 2010). Elevated stream temperatures would negatively impact the quality and quantity of rearing habitat for stream-type Chinook, coho and steelhead because these salmonids spend at least one summer rearing in fresh water (Mantua et al. 2010). Higher stream temperatures would also elevate the risk of disease, resulting in increased mortality for both juvenile and adult salmonids (Ecology 2009).

As air temperatures increase, more precipitation would fall as rain rather than snow, reducing the overall snowpack. In addition, increased air temperatures would cause the snowpack to melt earlier in the season. Both of these changes would result in the reservoir system filling earlier in the year. Because the Yakima River basin reservoir system is only able to store 30 percent of the average annual total natural runoff, there would be a seasonal shift in water availability toward increased winter flows and decreased summer and fall flows (Reclamation and Ecology 2008). These conditions would adversely impact Yakima River salmonids.

Increased winter flood frequency and intensity would have a negative effect on juvenile coho, Chinook, and steelhead survival (Ecology 2009) and reduce survival rates for incubating eggs and rearing parr (Mantua et al. 2010). This includes eggs and parr of sockeye, Chinook and coho salmon. In addition, the parr-to-smolt survival rates for coho, stream-type Chinook and steelhead would be negatively impacted by increased flooding (Mantua et al. 2010).

Reduced spring snowmelt and summer and fall streamflows would impact summer-run steelhead, sockeye and summer Chinook migrations (Ecology 2009). Low streamflows would impact the availability of suitable rearing habitat for Chinook, coho and steelhead and the availability of spawning habitat for early fall spawning salmonid populations (Ecology 2009). Smolt migrations would also be negatively impacted by reduced spring snowmelt because smolt migrants time their seaward migration with peak snowmelt flows (Mantua et al. 2010).

Diminished flows in combination with increased water temperatures would increase pre-spawn mortality for summer-run and stream-type salmonids. These conditions would also limit rearing habitat for salmonids with stream-type life histories (Mantua et al. 2010) and increase stress on spawning Columbia Basin sockeye, summer steelhead, summer Chinook and coho (Tohver 2011). In addition, these stream conditions would likely alter adult migration patterns and smolt outmigration as noted above.

### Assessment of Risk: Future With the Integrated Plan

Four climate change scenarios were modeled to examine impacts to water resources associated with implementation of the Integrated Plan: Existing Conditions, Less Adverse, Moderately Adverse, and More Adverse climate change conditions that may occur in the 2040s. Demands on water (agriculture, municipal and domestic) were also adjusted to account for climate change. Implementation of the Integrated Plan would improve water supply and instream flow conditions under all three climate change scenarios (Reclamation and Ecology 2011a). Improvement in average total available water supply was observed under each of the scenarios (Table 5).

Modeling results *without* climate change show that implementation of the Integrated Plan would significantly improve flow in 6 of the 15 reaches examined, and would meet instream flow objectives in 13 of those reaches. In addition, the Integrated Plan would provide additional carryover storage of approximately 330,000 acre-feet, which would allow for increased flexibility in dam operations to meet instream flow objectives (Reclamation and Ecology 2011). Power subordination and canal modifications (which were not included in the modeling results) could also improve flow in the Yakima River basin.

These results, in light of climate change, would help enable water storage managers to work toward attainment necessary flow objectives that provide habitat conditions and habitat availability for salmonids and other fish that utilize the basin. Under climate change impacted conditions, summer runoff is more limited and some of the benefits of the Integrated Plan will need to go towards bringing flows back to non-climate impacted FWIP conditions. Improvements will still be made in meeting instream flow objectives, although less carryover storage will be available.

The Integrated Plan includes a fish habitat enhancement program. Model results for scenarios without the Integrated Plan, for restoration only, and for restoration with fish passage (Integrated Plan) were analyzed. Model results, however, did not include climate change scenarios. Results indicate that implementation of the Integrated Plan could improve habitat conditions that may increase fish production for spring, summer and fall Chinook, steelhead, coho and sockeye (Reclamation and Ecology 2011). The Integrated Plan shows increased steelhead production and spatial distribution, thereby aiding recovery efforts for this federally listed species. A qualitative analysis of Integrated Plan effects indicated both positive and negative effects on bull trout populations, also listed under the Endangered Species Act. Factoring in alterations to temperature and flow resulting from climate change, implementation of the fish habitat enhancement program could improve the likelihood of salmonid population survival and recovery.

## 3.E Listed Endangered, Threatened or Candidate Species

Studies conducted by members of the CIG, the U.S. Forest Service, and other government agencies were consulted to determine likely impacts on listed fish species (Middle Columbia River steelhead distinct population segment or DPS and Columbia River bull trout) in the Yakima River basin. These studies discuss potential climate change scenarios in the Pacific Northwest and associated impacts to aquatic resources, steelhead, and bull trout. Information on potential impacts of climate change on the federally listed western gray wolf and grizzly bear was not available; limited information on Canada lynx and spotted owl was obtained. Results from these studies are discussed in the following sections.

### Assessment of Risk: Future Without the Integrated Plan

Two listed fish species occur in the study area and would be affected by climate change. The Middle Columbia River steelhead DPS and Columbia River bull trout populations are listed as threatened under the Endangered Species Act. Potential impacts on steelhead due to climate change are discussed in Section 3.D. Potential impacts to bull trout would occur as discussed above (increased air temperature would increase stream temperatures, increase winter flood frequency, and reduce summer and early fall flows).

Climate change is expected to negatively impact bull trout distribution and abundance. Bull trout require cold water for spawning and early rearing, with temperatures greater than 59°F potentially limiting juvenile survival (Rieman et al. 2007, Salmon Recovery 2010). Bull trout occur over a large range; however, populations are fragmented and considered more sensitive to low flow and high stream temperature than most salmonids. Climate change would also interact with other bull trout stressors, such as habitat loss, non-native fish species, and disease, to reduce the quality and availability of current spawning and rearing habitat (USFWS 2010).

Western gray wolf and grizzly bear occur in the study area and are listed as endangered and threatened under the Endangered Species Act (ESA), respectively. Research pertaining to climate change and these species is not readily available. However, climate change would potentially impact western gray wolf prey availability due to warmer winters, reduced snowpack and earlier snowmelt. Warmer, drier summers could contribute to the decline in whitebark pine, which is an important food source for grizzly bear, in Washington State due to the expansion of white pine blister rust and pine beetle outbreaks, thereby negatively affecting bear populations (DoW, 2011).

Canada lynx is listed as threatened under the ESA. Climate change would result in warmer winters with more precipitation falling as rain and earlier snowmelt. These conditions could negatively impact Canada lynx, which require at least four months of continuous winter snow cover, and shift lynx habitat north, limiting their spatial distribution (Gonzalaez et al., 2007). In addition, climate change could impact the availability of their main source of food, snowshoe hare.

Spotted owl is listed as threatened under the ESA. Warmer, wetter winters associated with climate change, were found to have a negative association with the survival of fledgling owls, while hotter, drier summers could reduce the prey base of the owl, impacting the adult survival and reproductive success (OSU, 2010).

### Assessment of Risk: Future With the Integrated Plan

Under the four climate change scenarios, taking into account increased demands on water, water supply and instream flow conditions would improve with implementation of the Integrated Plan (Reclamation and Ecology 2011). In addition, end of September reservoir storage would increase under all scenarios; this water could be used to improve instream flow conditions.

As part of the Lake Kachess Inactive Storage project, the lake would be drawn down 80 feet lower than the current outlet to provide additional downstream flow during drought conditions. As part of this project, fish passage improvements would be conducted at Box Canyon Creek to improve access for bull trout.

Modeling of the Integrated Plan, *without* climate change, identified attainment of flow objectives on 13 of 15 reaches, including substantial improvement in 6 reaches. The fish passage (at Cle Elum, Keechelus, Kachess, Bumping and Tieton dams) and restoration components of the Integrated Plan would improve habitat conditions and may increase production of salmonids, including steelhead (Reclamation and Ecology 2011). To achieve these improvements while accounting for climate change, water storage managers will be required to strategically allocate water resources to meet agriculture, municipal, and domestic demands, while providing habitat conditions conducive to the recovery of listed species. Implementation of the Integrated Plan will have the greatest potential to benefit aquatic species such as steelhead and bull trout populations, with a lesser potential to benefit terrestrial species.

## 3.F Water Quality

Limited information is available correlating water quality with climate change impacts. Therefore, the discussion below is qualitative.

Currently, water quality standards for water temperature, dissolved oxygen, pH, turbidity, ammonia, dichlorodiphenyl-trichloroethane (DDT), other pesticides, and fecal coliform bacteria are not met on the mainstem Yakima River at various times (Reclamation 2008).

Climate change would have a direct impact on water temperature and probably dissolved oxygen. In general, an increase in air temperature due to climate change will cause water temperatures to increase. In the upper Yakima River, climate change models predict that the number of weeks when average water temperatures exceed 21$^{o}$C may rise from less than 5 weeks in historic conditions to over 10 weeks in the 2040s (Mantua et al. 2009).

Warmer water can hold less dissolved oxygen than cooler water, so dissolved oxygen will decrease as air and water temperatures increase due to climate change (Karl et al. 2009).

Lower summer flows resulting from less surface water runoff may cause diminished water quality conditions relative to nutrients, dissolved oxygen, and DDT due to less dilution of agriculture runoff (Reclamation 2008). The Integrated Plan includes measures to maintain increased instream flows in specific reaches of the Yakima River and tributaries. These increased flows would tend to mitigate some of the risk of adverse water quality conditions associated with climate change. Reclamation will continue to monitor study results linking climate change with water quality effects in large river systems, and incorporate results into the Yakima River supply system operations as appropriate.

## 3.G Ecological Resiliency

Information relating to this issue is limited, and the discussion below is qualitative.

An ecologically resilient environment is able to withstand disturbance or alteration caused by natural or anthropogenic forces and then recover from these impacts. Climate change has the potential to reduce flow and water dependent ecological resiliency in the Yakima River basin, primarily the ability of fish populations to adapt and survive changing habitat conditions. As noted in Sections 3.D and 3.E, fish populations and their prey are particularly vulnerable to increases in water temperatures, lower levels of dissolved oxygen, and changes in flow patterns, all of which are anticipated to occur under predicted climate change scenarios. The historical water regime of the Yakima River basin has been highly altered by the construction of dams that serve agricultural, municipal and domestic uses. Alterations to streamflows and water temperatures due to water management, in addition to habitat disturbance, loss and fragmentation, have negatively impacted the spatial distribution, productivity, abundance and diversity of fish populations that use the river basin. Climate change would result in further reductions in these indicators of population health.

The Middle Columbia River steelhead DPS and Columbia River bull trout populations are listed as threatened under the Endangered Species Act, and other salmonid populations that use the Yakima River basin have experienced significant declines over the past century. Impacts from climate change, such as more precipitation falling as rain, earlier snowmelts, reduced summer flows, and increased stream temperatures, would further hinder salmonid population recovery. These climate conditions would result in the filling of reservoirs earlier in the season and require discharge of stored water sooner than typically occurs. This early filling of reservoirs, if it results in a release of currently stored water, would benefit smolts. Increased winter flood frequency coupled with warmer, low streamflows during the summer would impact the migration, rearing and spawning of salmonids and other fish. Alterations to streamflow and temperature resulting from climate change would exacerbate existing pressures on salmonid populations, such as competition with non-native fish species, disease, habitat quality and habitat loss, resulting in decreased species resiliency.

As described in the 2011 Yakima River Basin Study, Volume 1: Proposed Integrated Plan, the Integrated Plan provides an "adaptive management framework to address potential changes in water needs or hydrology, including potential climate change effects." Adaptive water management will play an important role in ensuring the ecological resiliency of the Yakima River basin as climate change has a greater impact on the survival of fish populations. The Integrated Plan includes fish passage projects that will provide additional habitat for anadromous fish and bull trout in the upper reaches of the watershed, where temperatures are expected to remain cooler. In addition, the Integrated Plan includes programs to enhance fish habitat in the mainstem and tributary areas, which would improve spawning, incubation, rearing and migration conditions for salmonids in the Yakima River basin. The Integrated Plan also includes a land acquisition component in the riparian corridor to help link the upper and lower watersheds, providing fish passage and access to colder waters in the upper watershed as water temperatures increase in the lower reaches. These measures would help fish species withstand impacts further downstream, and help protect these species as climate changes occur.

## 3.H Flood Control Management

There is limited information available regarding the climate change impacts on flood control management in the Yakima basin. Therefore, the discussion is qualitative.

The climate change scenarios described in previous sections will generally increase the quantity of winter runoff and reduce the quantity of spring and summer runoff. A lesser snowpack and an earlier melting snowpack are forecasted.

Currently, monthly runoff forecasts are developed for the five major reservoirs for flood control and water supply purposes. Forecasts are made based on existing conditions and anticipated future precipitation levels of 50, 100 and 150 percent of normal. Reservoirs are operated using guidelines for storage and releases depending on the runoff forecast, snowpack and time of year. Generally, Reclamation operates Yakima River basin reservoirs to provide 300,000 acre-feet of storage for flood control in the winter and a variable amount of storage ranging from zero to 850,000 acre-feet for spring runoff (Reclamation 2002). Operations of the reservoirs have been adapted to water supply and flooding conditions that have been experienced in the basin (Lynch 2011).

Winter floods (November through February) have been the most damaging in the Yakima River basin, and extreme winter floods occurred in 1990, 1996 and 2009. Those events may be similar to future flood events as they were caused by an intense frontal system bringing warm rainfall (often termed a "pineapple express" or "atmospheric river") and causing snowmelt. Spring floods are more frequent than winter floods but much less damaging. They can occur when a significant rainfall event occurs during a period of rapid snowmelt, usually during May or June. The effects of climate change on spring floods are unknown, especially given the annual variability in climate and snowpack conditions.

Reclamation, through its operations of Yakima River basin reservoirs, maintains an adaptive approach to flood control management. Climate change may necessitate changes in runoff forecasting and operations to balance flood control and storage for irrigation.

# 4 STRATEGIES

Section 9503(b)(4) of the SWA requires the development of "appropriate strategies to mitigate each impact of water supply changes in consultation with non-Federal participants." The stated purpose of the Integrated Plan is to offer a proposed approach to improving water management in the Yakima River basin. The goals of the Integrated Plan are to protect, mitigate and enhance fish and wildlife habitat; provide increased operational flexibility to manage instream flows to meet ecological objectives; and improve the reliability of the water supply for irrigation, municipal supply and domestic uses. These goals are consistent with the direction provided by Congress in the SWA. The elements of the Integrated Plan provide a comprehensive framework to protect water resources and habitat that can support the Secretary in development of strategies to mitigate impacts associated with climate change.

These strategies are outlined in detail in the Integrated Plan and summarized below according to the required elements.

## 4.A Modification of Reservoir Storage or Operating Guidelines

Currently, reservoir storage and operating guidelines are managed by Reclamation's Yakima Field Office Manager. Throughout the year, the Yakima Field Office Manager can adaptively manage the reservoir storage and operating guidelines to changing conditions. As part of this adaptive management process, the Yakima Field Office Manager has monthly (or as needed) meetings with stakeholder groups to ensure the groups remain involved as part of the consultation process for Yakima River basin operations. These meetings include monthly meetings with the System Operations Advisory Committee to address fishery-related issues, River Operations monthly meetings to communicate the future month's operations plans for all interested parties, and meetings with irrigation district managers to discuss irrigation water supply (Reclamation 2002).

Reservoir operations guidelines will continue to be adapted as necessary using the process currently in place in order to respond to changing conditions, including those related to climate change.

## 4.B Development of New Water Management, Operating or Habitat Restoration Plans

The projected climate changes evaluated could impact water supplies, flood control, habitat and ecological resiliency in the Yakima River basin. The primary change projected in the three climate change scenarios evaluated is a shift in the runoff hydrograph such that more runoff enters the reservoirs in the winter and less in the summer. In addition, all three of the scenarios evaluated show that available summertime runoff will be much lower than under historical conditions and that summertime water needs will be higher. Because water use in the basin (both instream for fish and out of stream for irrigation and other use) is much higher in the summer and much lower in the winter, these changes would present difficulties for Yakima River basin water managers.

In response to these risks, Reclamation and water resource and natural resource managers have three primary strategies: (1) short-term operational approaches to reservoir management and water deliveries; (2) new facilities and features of the Integrated Plan; and (3) habitat acquisition and restoration associated with the Integrated Plan.

### Operational Approaches

The Yakima Project operations staff deals effectively with hydrologic variations every year. To a certain extent, the variations associated with climate change would be handled similarly. Each year, Reclamation staff continuously monitors reservoir levels, snowpack measurements and streamflows throughout the basin. As the snowmelt season approaches, monthly projections of runoff and total water supply available (TWSA) are developed using hydrologic models. Results from these forecasts are available to water users, to assist them in making crop planting decisions. Throughout the irrigation season, TWSA projections are updated, water deliveries may be regulated to proratable water users, and reservoir operations are modified in response to changes in hydrologic conditions. Water operational changes are made by Reclamation in consultation with the Yakima River Basin Systems Operations Advisory Committee.

Improvements in runoff forecasting are likely to occur in the future as water resources managers and hydrometeorologists increase their understanding of the effects of long-term hydrometeorological indicators on annual snow accumulation and runoff. The most important of these indicators are the Pacific Decadal Oscillation and El Nino Southern Oscillation. They have been shown to be predictable more than a year in advance and to have significant effects upon snow accumulation in the upper parts of the Yakima River basin (Scott et al. 2004).

Operational choices regarding the timing and quantity of releases from the existing five reservoirs in the basin provide some flexibility in responding to the effects of climate change, particularly with respect to tradeoffs between water supply and ecological protection. With implementation of the Integrated Plan's additional storage components, the basin's water managers would have additional operational flexibility to balance these needs.

### Features of the Integrated Plan to Increase and Protect Water Supply

Specific features of the Integrated Plan would assist in mitigating a portion of the projected impacts associated with climate change. In water supply planning, the primary solution to these kinds of hydrologic timing differences between the occurrence and the need for water has traditionally been the development of reservoir storage to alter the natural pattern of water availability so that more water is usable during the summer, when needed. Reservoirs are constructed and operated to fill during periods when runoff exceeds water needs, and then to draw down when water needs exceed runoff.

The Integrated Plan includes the development of more than 500,000 acre-feet of additional reservoir storage facilities, piloting of systems for groundwater recharge, changes in the operation of existing storage, and the development of new conveyance facilities to make better and more flexible use of existing storage while reducing some of the adverse effects of high summer-time storage releases on fish habitat. As documented in the *Modeling Technical Memorandum* (Reclamation and Ecology 2011b) and in *Modeling the Operational Response to Projected Climate Change* (Thurin et al. 2011), the Integrated Plan can satisfy existing and increased future instream and out-of-stream needs for water using the increased flexibility associated with enlarged reservoir storage capacity and an adaptive management approach to mitigate the effects of moderately adverse climate change.

### Habitat Restoration Plans

The Integrated Plan has several elements that are aimed at improving habitat for listed species:

- **Fish passage projects to make additional habitat available to anadromous fish and bull trout.** The new habitat would be provided in the upper parts of the watershed, which are expected to remain cooler as climate change occurs.
- **Programs to enhance fish habitat in mainstem floodplain and tributary areas.** These programs would improve spawning, incubation, rearing and migration conditions for all

salmonid species in the Yakima River basin and implement key strategies developed by Federal, State and Tribal agencies responsible for management of fish and wildlife. Improved habitat conditions would support protection of species in the face of climate change.

- **Land acquisition to protect and restore the watershed.** This element of the Integrated Plan would offer ecosystem, species conservation and restoration benefits in the immediate riparian corridor and would help link the upper and lower watersheds. Potential protection of lands in tributary areas such as the Teanaway River basin would provide fish passage and access to colder water that would be critically needed under the warmer temperatures associated with climate change. The Integrated Plan recommends protection of additional lands, and possible designation of wilderness areas, Wild and Scenic River designations, or other protective programs for specific areas and reaches. These designations would also help mitigate the effects of climate change on Yakima basin habitat.

## 4.C Water Conservation

Enhanced water conservation is one of the seven elements of the Integrated Plan. The water conservation element is discussed in Section 3.1.6 of the *Integrated Plan* (pages 57-58), the *Agricultural Water Conservation Technical Memorandum*, and the *Municipal and Domestic Water Conservation Technical Memorandum* (Reclamation and Ecology 2011f and 2011g).

The water conservation element of the Integrated Plan does not specifically mention climate change. However, the overall impact of climate change on the Yakima Project is a decrease in total water supply available. The water conservation element provides strategies to mitigate this change in water supply by conserving up to 170,000 acre-feet of water in good water years.

### Agricultural Conservation

Agricultural water conservation methods are described in the *Agricultural Water Conservation Technical Memorandum*. The Integrated Plan includes a programmatic approach identifying and implementing enhanced water conservation activities that build on the lessons of YRBWEP Phase 2. Projects would be selected through detailed feasibility studies and evaluation by the existing YRBWEP Conservation Advisory Group (CAG). The CAG is a workgroup composed of representatives from Reclamation, Ecology, irrigation districts and fisheries agencies to provide advice on implementation of YRBWEP Phase II. Irrigation districts would be provided funding to implement the conservation methods in the Integrated Plan.

Measures that could be implemented include the following:

- Lining or piping existing canals or laterals
- Constructing re-regulating reservoirs on irrigation canals
- Installing gates and automation on irrigation canals
- Improving water measurement and accounting systems
- Installing higher efficiency sprinkler systems, drips, or other equipment

- Implementing irrigation water management practices and other measures to reduce seepage, evaporation and operational spills

### Municipal and Domestic Conservation Program

The Integrated Plan recommends forming a multistakeholder advisory committee to carry out a municipal and domestic conservation program. The advisory committee should include local and environmental stakeholders. This program would promote voluntary, incentive-based actions focusing on landscape irrigation and other consumptive uses. The committee would focus on the following efforts:

- Education, incentives and other methods to encourage residential and commercial users to improve landscape irrigation efficiency where the source of supply is agricultural irrigation canals or ditches
- Improvements to the efficiency of consumptive uses
- Best practice standards for accessing the new supply developed through the Integrated Plan and dedicated to municipal use and municipal/domestic irrigation
- Rate structures that encourage water conservation
- Assessment of conditions for accessing the new supply that would apply to homeowners or developers seeking mitigation water for consumptive water use for homes supplied by individual household wells

Additional information on the municipal and domestic conservation program can be found in the *Municipal and Domestic Water Conservation Technical Memorandum,* which recommends creating a fund to promote water use efficiency. Assuming Reclamation is granted authority to store or deliver water for municipal and domestic purposes, the memorandum recommends that Reclamation use contracts for the new block of supply to implement the new best practice standards.

## 4.D Improved Hydrologic Models and other Decision Support Systems

As described in Section 4.A, Reclamation's Yakima Field Office Manager uses a detailed and sophisticated hydrologic monitoring and forecasting system, combined with operating guidelines and coordination with stakeholder groups, to manage existing reservoir storage, instream flows and water supply deliveries. In addition to using HydroMET-based forecasts of future runoff, this system incorporates near-real-time YAKRW modeling to permit operations staff to evaluate the consequences of any historical pattern of hydrologic conditions on existing reservoir storage.

No new hydrologic models or decision support systems were investigated as part of the Yakima basin plan study. As future improvements in runoff forecasting occur, allowing the use of long-term hydrometeorological indicators to predict snowpack farther in advance, updated decision support systems would also likely be developed to permit more efficient prediction of basin-wide water resources conditions.

## 4.E Groundwater and Surface Water Storage Needs

The needs for more surface water and groundwater storage are well recognized in the Yakima River basin, and measures are explicitly incorporated into the Integrated Plan. The plan includes the development of more than 500,000 acre-feet of additional reservoir storage facilities, and piloting of groundwater recharge systems, as well as changes in the operation of existing storage and the development of new conveyance facilities to make better and more flexible use of existing storage. These components of the Integrated Plan would improve water management in the Yakima River basin; protect, mitigate and enhance fish and wildlife habitat; provide increased operational flexibility to manage instream flows to meet ecological objectives; and improve the reliability of the water supply for irrigation, municipal supply and domestic uses. Under the impacts of potential climate change, the increased operational flexibility associated with the enlarged surface and groundwater storage will be critically important.

# 5 MONITORING PLAN

The SWA identifies that Reclamation will work with the NRCS and applicable State water resources agencies to develop a monitoring plan to acquire and maintain water data to strengthen the understanding of water supply trends, and to assist in assessment activities.

In support of this responsibility, Reclamation is working with appropriate entities to support data collection and monitoring activities in basins with Reclamation facilities. Within the Yakima River Basin, an extensive monitoring system is in place that is used to acquire and maintain water resources data. Table 6 describes monitoring systems in place in the Yakima River basin, the entity responsible for data collection, and the type of data the system collects. Additional monitoring networks not listed in Table 6 may also be available in the Yakima River basin.

**Table 6. Yakima River Basin Data Monitoring – Federal and State Operated**

| TYPE OF DATA | RESPONSIBLE ENTITY | DESCRIPTION | ONLINE AVAILABILITY |
|---|---|---|---|
| River Flow | USGS | Water Data for Washington; stream gages at various river locations throughout the basin | http://waterdata.usgs.gov/wa/nwis |
| River Flow | Reclamation | Hydromet; stream gages at various river locations throughout the basin | http://www.usbr.gov/pn/hydromet/yakima/index.html |
| Tributary Flow | Ecology | River & Stream Flow Monitoring; tributary stream gages | https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp?region=3 |
| Canal Diversions | Reclamation | Hydromet; canal diversions in the basin | http://www.usbr.gov/pn/hydromet/yakima/index.html |
| Diversions | Ecology | Reporting of individual surface and groundwater diversions | Not available online |
| Groundwater Levels | USGS | Water Data for Washington; groundwater levels at various locations throughout the basin | http://waterdata.usgs.gov/wa/nwis |
| Reservoir Conditions | Reclamation | Hydromet; reservoir water data | http://www.usbr.gov/pn/hydromet/yakima/index.html |
| Water Quality | Ecology | River water quality monitoring station data | http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html |
| Water Quality | USGS | Water Data for Washington; chemical and physical data for streams and lakes | http://waterdata.usgs.gov/wa/nwis |
| Snowpack | NRCS | SNOTEL; snowpack data | http://www.wcc.nrcs.usda.gov/snotel/Washington/washington.html |
| Precipitation/ Weather | NOAA | National Weather Service Advanced Hydrologic Prediction Service; observations, forecasts, and precipitation data | http://water.weather.gov/ahps/ |
| Weather/ Agricultural Water Demand | Reclamation | Agrimet; weather station for crop water use predictions | http://www.usbr.gov/pn/agrimet/agrimetmap/hrhwda.html |
| Weather/ Agricultural Water Demand | WSU | AgWeatherNet; weather data for crop predictions | http://weather.wsu.edu/ |
| Climate | NRCS | Climate reports | http://www.wcc.nrcs.usda.gov/climate/clim-reports.html |
| River Forecasts | NRCS/NOAA | Water supply forecasting | http://www.wcc.nrcs.usda.gov/wsf/<br>http://www.nwrfc.noaa.gov/rfc/ |

The monitoring systems currently available and operated by Federal and State agencies are extensive and cover a broad range of water resources data.

A more comprehensive water data management program that compiles and publishes water use data collected from Yakima River basin water users, both irrigation and municipal/industrial, would improve the understanding of climate change impacts to water use in the basin.

# OTHER CONSIDERATIONS

## Financial Analysis

Implementation of the Integrated Plan will have potential costs and benefits. These costs and benefits were identified in *Economic Effects of the Yakima Basin Integrated Water Resource Management Plan Technical Memorandum* (Reclamation 2011e). Sufficient quantitative information is available for estimating only some of the costs and benefits; for others it is necessary to provide a qualitative assessment.

The potential present value financial cost to implement the Integrated Plan over a 100-year period through 2110 is approximately $3.0 billion. This value is based on a discount rate of 4.375 percent. This cost primarily involves expenditures for capital, operations and maintenance of new facilities, and expenditures to implement the Integrated Plan's programs for conservation and market-based reallocation. Based on existing information, present value benefits can be estimated for three areas:

- Increased net farm earnings from irrigated crops during future severe droughts of approximately $0.4 billion
- Increased supply of up to 50,000 acre-feet of water for municipal use of about $0.1 billion
- Increased production of salmon and steelhead of $1.7 billion to $3.3 billion.

The present values for these three benefits total $2.2 billion to $3.8 billion.

In addition to costs and benefits that can be quantified, there are several categories of costs and benefits where data are not available. These include costs associated with loss of services, such as recreational opportunities and habitat from lands that would be occupied by new or expanded reservoir sites, and reduced net farm earnings for farmers who compete with those who would benefit directly from the implementation of the Integrated Plan. Benefits difficult to quantify include increases in net farm earnings from irrigated farming in drought years less severe than those quantified above, unquantifiable benefits of greater fish populations including cultural and spiritual benefits, increases in net value of recreational opportunities, increases in valuable nonsalmonid fish species, improved resiliency of the water system, and additional benefits associated with the ability to offset the impacts of climate change.

Reclamation will continue to consider the full spectrum of costs and benefits in the context of Federal guidance provided for such evaluations.

## Social/Demographic and Public Perception

Populations affected by the Integrated Plan include rural populations dependent on irrigated agriculture and urban and suburban populations around Ellensburg, Yakima, Sunnyside, Grandview Prosser and other communities in the lower Yakima Valley, and the Tri-Cities area of Pasco, Kennewick, Richland and West Richland. The Integrated Plan would provide additional water supply for irrigation that would provide significant increased net farm earnings during future severe droughts. Because water rights are fully appropriated in most areas of the basin, acquiring water rights for municipalities and housing developments is often difficult. Most communities rely on existing water rights to meet growth needs, but these rights have a limit that ultimately will be reached over time. Outside urban growth areas and in more rural areas in the basin, housing developments rely on exempt wells to meet growth needs, but there is increasing pressure to reduce the use of exempt wells. The Integrated Plan would provide an increased supply for up to 50,000 acre-feet of water for municipal and domestic use. The *Final Planning Report/Environmental Impact Statement for the Yakima River Basin Water Storage Feasibility Study* (Reclamation 2008) identified no adverse impacts to minority and/or low-income populations that could not be avoided.

Reclamation and Ecology have conducted an extensive public outreach program, in an attempt to identify and incorporate public concerns in the development of the Integrated Plan. Public outreach has largely been conducted through Workgroup and subcommittee meetings. The YRBWEP Workgroup was formed by Reclamation and Ecology in 2009 to review studies and information and formulate an integrated solution for water resources in the basin. Workgroup members include representatives of the Yakama Nation, Federal agencies, Washington State and local governments, environmental organizations, and irrigation interests. Members of the public and staff representing the State's congressional delegation also attend regularly to observe.

All meetings are open to the public with opportunities for public input. Several public comments have been made over the past two years and these comments can be viewed in meeting notes available on the Internet. Public attendance has regularly numbered 20 to 30 individuals. The YRBWEP Workgroup held its first meeting on June 30, 2009, and meetings continued every two weeks through 2009. The Workgroup reached consensus in December 2009 to move forward with finalizing the Preliminary Integrated Water Resource Management Plan. The Workgroup met in April 2010 and monthly from June through December 2010 for updates on the ongoing work on the Integrated Plan. Starting in 2011, Workgroup meetings have been held quarterly or when needed to present updates on progress and information and to make process decisions. Additionally, Reclamation and Ecology have presented information on the proposed Integrated Plan to local and regional, community and governmental organizations, as requested. Presentations have been made to service clubs, county government associations and environmental interest groups.

# 6 REFERENCES

Brekke, L., B. Kuepper and S. Vaddey, 2010. Climate and Hydrology Datasets for use in the RMJOC Agencies' Longer-Term Planning Studies. December 2010.

Defenders of Wildlife (DoW). 2011. Grizzly bear (*Ursus arctos*). Available at: http://www.defenders.org/wildlife_and_habitat/wildlife/grizzly_bear.php.

Ecology (see Washington State Department of Ecology).

Gonzalaez, G., Ronald, N., McKelvey, K, Lenihan, J., Drapek, R. 2007. Potential Impacts of Climate Change on Habitat and Conservation Priority Areas for Lynx Canadensis (*Canada lynx*). Report to Watershed, Fish, Wildlife, Air, and Rare Plants Staff; National Forest System; Forest Service; U.S. Department of Agriculture; Washington, DC and NatureServe USA. The Nature Conservancy, 4245 North Fairfax Drive, Arlington, VA 22203-1606 USA.

Hamlet, Alan F., et al. (2011). Final Report for the Columbia Basin Climate Change Scenarios Project. University of Washington. Data available at http://www.hydro.washington.edu/2860/. Accessed August 3, 2011.

Karl, T.R., J.M. Melillo, T.C. Peterson, and S.J. Hassol, eds. 2009. *Global Climate Change Impacts in the United States*. Cambridge University Press.

Lynch, Chris. 2011. U.S. Bureau of Reclamation. Personal communication, July 8, 2011.

Mantua, N.J., I. Tohver, and A. Hamlet. 2009. *Impacts of Climate Change on Key Aspects of Freshwater Salmon Habitat in Washington State*. Chapter 6 in *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate.* Climate Impacts Group, University of Washington, Seattle. June 2009.

Mantua, N.J., I. Tohver, and A. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climate Change*. doi:10.1007/s10584-010-9845-2.

Mote, P. W., E. Parson, A. F. Hamlet, W. S. Keeton, D. Lettenmaier, N. Mantua, E. L. Miles, D. Peterson, D. L. Peterson, R. Slaughter, and A. K. Snover. 2003. Preparing for climatic change: The water, salmon, and forests of the Pacific Northwest. *Climatic Change* 61:45-88.

National Oceanic and Atmospheric Administration. 2011a. National Weather Service Northwest River Forecast Center. Available at http://www.nwrfc.noaa.gov/rfc/. Accessed July 2011.

National Oceanic and Atmospheric Administration. 2011b. National Weather Service Advanced Hydrologic Prediction Service. Available online at http://water.weather.gov/ahps/. Accessed July 2011.

Natural Resources Conservation Service. 2011a. Washington SNOTEL Sites. Available at http://www.wcc.nrcs.usda.gov/snotel/Washington/washington.html. Accessed July 2011.

Natural Resources Conservation Service. 2011b. Climate Reports. Available at http://www.wcc.nrcs.usda.gov/climate/clim-reports.html. Accessed July 2011.

Natural Resources Conservation Service. 2011c. Water Supply Forecasting. Available at http://www.wcc.nrcs.usda.gov/wsf/. Accessed July 2011.

NOAA (see National Oceanic and Atmospheric Administration).

NRCS (see Natural Resources Conservation Service).

Oregon State Universty (OSU). 2010. Study Raises Concern of Potential Climate Change Impacts on Spotted Owl. August 2, 2010. Available at: http://oregonstate.edu/ua/ncs/archives/2010/aug/study-raises-concern-potential-climate-change-impacts-spotted-owl.

Reclamation (see U.S. Bureau of Reclamation).

Rieman, B.E., D. Isaak, S. Adams, D. Horan, D. Nagel, C. Luce, and D. Myers. 2007. Anticipated climate warming effects on bull trout habitats and populations across the interior Columbia River basin. *Transactions of the American Fisheries Society* 136: 1552-1565.

Salmon Recovery. 2010. *Columbia Basin Fish Recovery: Bull Trout* (Salvelinus confluentus). July 2010. Available at: http://www.salmonrecovery.gov/Files/030%20Bull%20Trout%20071210.pdf.

Scott, M.J., LW. Vail, J. Jaksch, C.O. Stöckle, and A. Kemanian. 2004. Water exchanges: Tools to beat El Niño climate variability in irrigated agriculture. *Journal of the American Water Resources Association* 40(1):15-31.

Thurin, S.M, T. Shannon, D. Minner, and C. Lynch. 2011. Modeling the operational response to projected climate change. *Proceedings of the American Water Resources Association Managing Climate Change Impacts on Water Resources: Adaptation Issues, Options, and Strategies.* Middleburg, Virginia.

Tohver, I. 2011. Climate change and future scenarios for aquatic habitats in the Northwest. *Proceedings of the 2011 Salmon Recovery Conference, Grand Mound, WA.* April 27, 2011. Available at: http://www.rco.wa.gov/documents/salmon/conference/2011/tohver_i.pdf.

U.S. Bureau of Reclamation, 2002. *Interim Comprehensive Basin Operating Plan for the Yakima Project, Washington.* November 2002. U.S. Department of the Interior, Bureau of Reclamation.

U.S. Bureau of Reclamation, 2004. *Water Recreation Opportunity Spectrum Users Handbook.* July 2004. U.S. Department of Interior, Bureau of Reclamation.

U.S. Bureau of Reclamation, 2007. *Recreation Demand and User Preference Analysis: A component of Yakima River Basin Water Storage Feasibility Study, Washington.* Pacific Northwest Region. Technical Series No. TS-YSS-10. February 2007. U.S. Department of the Interior, Bureau of Reclamation.

U.S. Bureau of Reclamation, 2008. *Yakima River Basin Water Storage Feasibility Study Final Planning Report/Environmental Impact Statement Volume 1.* December 2008. U.S. Department of the Interior, Bureau of Reclamation.

U.S. Bureau of Reclamation, 2011a. SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water 2011. April 2011.

U.S. Bureau of Reclamation, 2011b. Yakima Project Hydromet System. Available at http://www.usbr.gov/pn/hydromet/yakima/index.html. Accessed July 2011.

U.S. Bureau of Reclamation. 2011c. AgriMet, Harrah, Washington AgriMet Station (HRHW). Available at http://www.usbr.gov/pn/agrimet/agrimetmap/hrhwda.html. Accessed July 2011.

U.S. Bureau of Reclamation and Washington State Department of Ecology. 2008. *Yakima River Basin Water Storage Feasibility Study, Draft Planning Report/Environmental Impact Statement. Yakima Project, Washington.* January 2008. U.S. Department of the Interior, Bureau of Reclamation and Washington State Department of Ecology.

U.S. Bureau of Reclamation and Washington State Department of Ecology, 2011a. *Yakima River Basin Study Volume 1: Proposed Integrated Water Resource Management Plan*. Reclamation Contract 08CA10677A ID/IQ. Ecology Publication Number 11-12-004. April 2011. U.S. Department of the interior, Bureau of Reclamation and Washington State Department of Ecology.

U.S. Bureau of Reclamation and Washington State Department of Ecology, 2011b. *Yakima River Basin Study Modeling of Reliability and Flows Technical Memorandum*. Reclamation Contract 08CA10677A ID/IQ, Task 6. Prepared by HDR Engineering, Inc. and Anchor QEA. June 2011. U.S. Department of the Interior, Bureau of Reclamation and Washington State Department of Ecology.

U.S. Bureau of Reclamation and Washington State Department of Ecology. 2011c. *Yakima River Basin Study Yakima River Basin Water Resources Technical Memorandum*. Reclamation Contract 08CA10677A ID/IQ, Task 1. Prepared by Anchor QEA. March 2011. U.S. Department of the Interior, Bureau of Reclamation and Washington State Department of Ecology.

U.S. Bureau of Reclamation and Washington State Department of Ecology, 2011d. *Yakima River Basin Study Water Needs for Out-of-Stream Uses Technical Memorandum*. Reclamation Contract 08CA10677A ID/IQ, Task 2.1. Prepared by HDR Engineering, Inc. and Anchor QEA. June 2011. U.S. Department of the Interior, Bureau of Reclamation and Washington State Department of Ecology.

U.S. Bureau of Reclamation and Washington State Department of Ecology, 2011e. *Economic Effects of Yakima River Integrated Water Resource Management Plan Technical Memorandum.* Task 2.2. EcoNorthwest. U.S. Department of the Interior, Bureau of Reclamation and Washington State Department of Ecology.

U.S. Bureau of Reclamation and Washington State Department of Ecology 2011f. *Yakima River Basin Study Agricultural Water Conservation Technical Memorandum*. U.S. Bureau of Reclamation Contract No. 08CA10677A ID/IQ, Task 4.10. Prepared by Anchor QEA. March 2011. U.S. Department of the Interior, Bureau of Reclamation and Washington State Department of Ecology.

U.S. Bureau of Reclamation and Washington State Department of Ecology, 2011g. *Yakima River Basin Study Municipal and Domestic Water Conservation Technical Memorandum.* U.S. Bureau of Reclamation Contract No. 08CA10677A ID/IQ, Task 4.11. Prepared by HDR Engineering, Inc. March 2011. U.S. Department of the Interior, Bureau of Reclamation and Washington State Department of Ecology.

U.S. Bureau of Reclamation and Washington State Department of Ecology, 2011h. *Roza and Chandler Power Plants Subordination and Power Usage Evaluation Technical Memorandum*. Prepared by HDR Engineering, inc. July 2011. U.S. Department of the Interior, Bureau of Reclamation and Washington State Department of Ecology.

U.S. Fish and Wildlife Service. 2010. *Additional Information on Bull Trout and the Proposed Critical Habitat Revision.* January 2010. Available at: http://www.fws.gov/oregonfwo/species/data/bulltrout/Documents/finalQA_01.13.10.pdf.

USFWS (see U.S. Fish and Wildlife Service).

USGS (see U.S. Geological Survey).

U.S. Geological Survey. 2011. Water Data for Washington. Available at http://waterdata.usgs.gov//wa/nwis. Accessed July 2011.

Vano, J.A., M. Scott, N. Voisin, C.O. Stöckle, A.F. Hamlet, K. E. B. Mickelson, M. McGuire Elsner, and D.P. Lettenmaier. 2009. *Climate Change Impacts on Water Management and Irrigated Agriculture in the Yakima River Basin, Washington, USA.* Chapter 3 in *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate.* Climate Impacts Group, University of Washington, Seattle. June 2009.

Washington State Department of Ecology. *2009. Final Environmental Impact Statement: Yakima River Basin Integrated Water Resource Management Alternative.* Conducted as part of the Yakima River Basin Water Storage Feasibility Study. June 2009. Ecology Publication #09-11-012.

Washington State Department of Ecology 2011a. Flow Monitoring Network. Available at https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp?region=3. Accessed July 2011.

Washington State Department of Ecology, 2011b. Yakima River Basin Metering and Reporting. Available at http://www.ecy.wa.gov/programs/wr/measuring/yrbmr_home.html. Accessed July 2011.

Washington State Department of Ecology, 2011c. River and Stream Water Quality Monitoring. Available at http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html. Accessed July 2011.

Washington State University. 2011. AgWeatherNet. Available at http://weather.wsu.edu/. Accessed July 2011.