Assessing Vulnerability to Natural Hazards:
An Impact-Based Method and Application to Drought in Washington State

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Abstract

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This article presents a technique for performing vulnerability assessments, using measures of exposure, sensitivity, and adaptive capacity. Historically, vulnerability assessments have focused on analyzing the hazard itself, absent information on its causes and mitigations. The Vulnerability Assessment Method (VAM), presented herein, acquires data and heuristics from affected stakeholders to assess not only the hazard, but also the causes of vulnerability, potential for adaptation, previous impacts, and ways to mitigate future impacts. We apply the VAM to a case study of Washington State, assessing drought vulnerability across 34 sub-sectors. Results indicate highest vulnerability for dryland farmers, farmers with junior water rights, select fisheries, ski area operators, and the green industry. Through validation exercises, we demonstrate the VAM's internal consistency and broader applicability. Contributions of the VAM include its incorporation of stakeholder data, quantitative assessments of underlying components, and applicability to other areas and types of hazards.

Table of Contents

List of Figures

List of Tables

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Dedication

To my parents and Shelby for all their love and support.

I. Introduction

Drought has been the nation's most costly natural disaster, inflicting $6 billion-$8 billion in annual average damages (FEMA, 2005). Further, droughts are expected to become more frequent and severe, with increasing demands, limited and uncertain supplies, and effects of climate change and climate variability. Faced with these challenges, decision-makers need information to help them prepare for droughts, allocate resources effectively, and reduce the impacts of future hazards.

Disaster management has typically focused on analyzing the hazard, such as the severity of a drought due to a shortfall of precipitation. Increasingly, however, we recognize the need to analyze not only the hazard, but also the vulnerability to the hazard, such as the impacts of that shortfall on users, the causes of those impacts, and the actions that can reduce the impacts. In addition, disaster management has been moving away from solely emergency response, initiated during or after an event, toward mitigation and preparedness, initiated before an event, in order to reduce impacts more effectively (Wilhite et al., 1987, 2000; Hooke, 2000). Both of these trends generate increased attention to vulnerability.

Although many have emphasized the importance of vulnerability assessments, and some have presented useful frameworks (Cannon, 1994; Knutson et al., 1998; Odeh, 2002; Polsky et al., 2003; Turner et al., 2003; Hayes et al., 2004; Schröter et al., 2004a; Metzger et al., 2005; Metzger et al., 2006, Wilhelmi and Wilhite, 2002; Wu et al., 2004), few have presented methods to assess vulnerability empirically. Yet empirical assessments are important to understand how vulnerability is experienced "on the ground," by those who are vulnerable, to elucidate the causes and effects of that vulnerability, and to provide data-based guidance to decision-makers. Moreover, even in empirical studies, data often focus on the hazard itself (e.g., magnitude of a water shortage) rather than overall vulnerability, which would also consider impacts (e.g., losses due to water shortages) and the ability to reduce and mitigate those impacts, both short term and long term (e.g., through water reallocation and conservation). Finally, as the literature indicates (e.g., Abraham, 2006; Hayes et al., 2004; Odeh, 2002; Turner et al., 2003; Wilhelmi and Wilhite, 2002; Wu et al., 2004), ambiguity surrounds not only the components of vulnerability, but also the measurement of those components. This work is motivated by and seeks to address those needs.

In this paper, we present a Vulnerability Assessment Method (VAM), using measures of exposure, sensitivity, and adaptive capacity. A foundation of the method is the acquisition of data and heuristics from those who are vulnerable, which permits not only quantitative assessments, but also comparisons among users, regions, and sectors. We then apply this method to the assessment of drought vulnerability in the State of Washington, examining 34 sub-sectors across the state. To validate the method, the underlying model, and the results, we conduct both internal and external validation exercises, which support the usefulness of the VAM, especially for highly vulnerable areas. We conclude with findings from the assessment and broader lessons.

II. The Vulnerability Assessment Method (VAM)

To assess vulnerability, we develop a conceptual model (Figure 1) that builds upon work of the International Panel on Climate Change (IPCC, 2001) and illustrated by Schröter et al. (2004b). In our model, vulnerability is related to three primary variables: (1) exposure, (2) sensitivity, and (3) adaptive capacity. Exposure is based on frequency and severity of drought; severity includes magnitude, duration, and spatial extent. Sensitivity is the susceptibility of the water user (individual, region, or sector) to the effects of the drought. Adaptive capacity is the ability of a water user to manage or reduce adverse effects of a drought, through actions taken before, during, or after the drought. Exposure and sensitivity determine the potential impact. Adaptive capacity determines the portion of the potential impact that becomes an actual (net) impact. The combination of the three components results in a net impact or vulnerability to the drought.

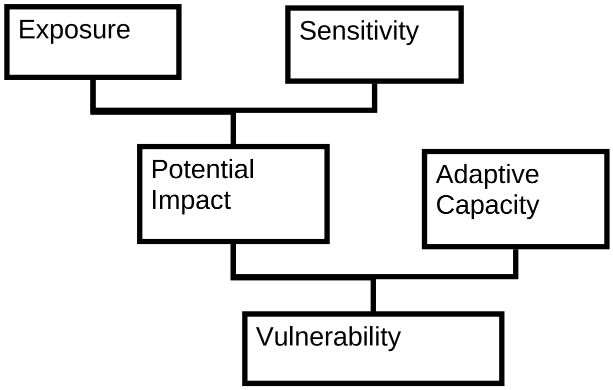

Figure 1. Conceptual Model of Vulnerability, adapted from Schröter et al. (2004b), The Allen Consulting Group, (2005), and IPCC (2001).

With this conceptual model, we then operationalize and measure the variables. In some applications, components of vulnerability, such as severity, have been assessed using drought indicators (Wilhelmi and Wilhite, 2002; Wu et al., 2004). Indicators are typically based on hydrologic, meteorologic, or water supply and demand variables, such as streamflow, soil moisture, precipitation, snowpack, groundwater levels, and reservoir storage. While drought indicators can provide useful and often objective data on a potential hazard, they can be incomplete measures of vulnerability. For instance, a one-month shortfall of spring precipitation may have severe impacts for a dryland farmer, but only moderate impacts for a municipal water supplier with multi-year storage reservoirs. Also, drought indicators often lack statistical consistency, and temporal and spatial specificity (Steinemann and Cavalcanti, 2006). For example, an "extreme drought," as classified by the Palmer Drought Severity Index, occurs less than 1% of the time in January in the Pacific Northwest, but more than 10% in July in the Midwest. Sensitivity and adaptive capacity can also vary widely among sectors and regions, and depend highly on the user. For instance, a farmer may drill a new well and reduce sensitivity significantly, whereas a new well may reduce sensitivity only slightly for a large municipal water supplier.

To generate operational and relevant measures of vulnerability, we developed an assessment approach to evaluate exposure, sensitivity, and adaptive capacity, using data and evaluations from water users themselves. This approach provides an important perspective on vulnerability by obtaining information from those who actually experience the vulnerability, and by examining links between the hazard, the impacts, and ways to mitigate the impacts.

To conduct the assessments, detailed in the next section, we performed an in-depth study of water users, using structured and semi-structured interview questions that investigate factors such as the severity of previous impacts, causes of these impacts, potential for future impacts, level of adaptive capacity, and information and resources that could help to reduce or prevent future impacts. A five-point Likert scale (0=very low, 1=low, 2=medium, 3=high, and 4=extreme) was used to assess each of the three components (exposure, sensitivity, and adaptive capacity) for each water user. Each Likert scale ranking corresponds to a score (Table 1). We then combine these component scores in a functional form of the conceptual model of vulnerability (Figure 1) to generate a vulnerability score (V):

$$V = (E + S) \times A \tag{1}$$

where E is exposure, S is sensitivity, and A is adaptive capacity. For instance, higher hazard exposure and higher sensitivity lead to higher potential impacts and higher vulnerability; higher adaptive capacity leads to lower vulnerability. In this algorithm, exposure and sensitivity are weighted equally, although weights can be easily varied. Next, with data on exposure, sensitivity, and adaptive capacity, vulnerability scores were calculated for each individual, and then averaged within sectors and sub-sectors for each region. While each individual's score was given equal weight relative to other individuals, the weighting protocol can also be easily modified. The next sections detail the application and evaluation of this method, and the interpretation and relevance of results.

Table 1. Net-Vulnerability Component Scoring System.

Ranking Scale	Score
Exposure	
Extreme	4
High	3
Moderate	2
Low	1
Very low	0
Sensitivity	
Extreme	4
High	3
Moderate	2
Low	1
Very low	0
Adaptive Capacity	
Extreme	0.6
High	0.7
Moderate	0.8
Low	0.9
Very low	1

III. Case Study: Drought in Washington State

In the last decade, Washington State has experienced two major droughts. A statewide drought emergency was declared on March 14, 2001 and on March 10, 2005; in both cases due to less than 75% of normal supply and expected undue hardship (Office of Governor Gary Locke, 2001; Office of Governor Chris Gregoire, 2005). Both droughts also inflicted significant impacts throughout the state, which included the following: increased production costs and reduced revenue in the agricultural sector, reduced deliveries to junior water rights holders, reduced power generation, increased power costs, reduced survival of adult and juvenile salmonids, and reduced visitation to ski areas (Fontaine and Steinemann, 2007). Estimates of drought damages to agriculture ranged from $270 million - $400 million in 2001 (Stephens et al., 2001) and $195 million - $299 million in 2005 (Stephens et al., 2005).

Given the significant impacts of previous droughts, and the need to prepare for future droughts, the authors conducted a statewide study, in collaboration with State of Washington agencies, to analyze impacts from recent droughts, identify the most vulnerable areas and sectors, and determine ways to reduce drought vulnerability. The report generated from this study is attached in Appendix A. Using data from this study and using the VAM developed above, we assessed the vulnerability in five sectors (agriculture, environment, municipal and industrial, recreation, and power) from six regions in the state (Figure 2) that had similar intra-regional and distinct inter-regional characteristics.

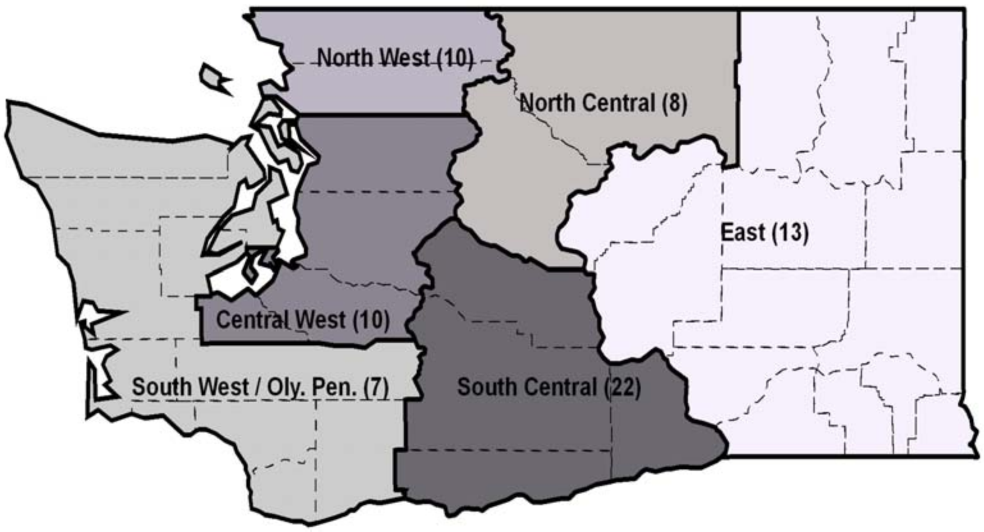

Figure 2. Identification of regions; number of interviews conducted in parentheses.

To perform the assessment, we conducted telephone interviews with 67 individuals who were designated as key representatives of each sector and region affected by previous droughts, and most likely to be affected by future droughts. These individuals included farmers, officials from agricultural trade associations, water supply system managers, fisheries agency officials, recreation operations managers, and hydropower sector officials; the combined experience of these interviewees in dealing with water supply issues exceeded 1,000 years. These individuals were identified in consultation with an advisory panel of officials from Washington State agencies, including the Department of Ecology, Department of Agriculture, Department of Community, Trade, and Economic Development, Office of Financial Management, and Washington State University.

We assessed the variables of exposure, sensitivity, and adaptive capacity using data, information, and heuristics obtained from interviews. In addition, during the interviews, we asked these individuals not only about components of vulnerability, but also about broader aspects of drought within their sector, region, and sub-sector. Methods for data elicitation and coding followed procedures as outlined in Babbie (1995) and Dillman (1978). The lead author served as the primary interviewer, data recorder, and coder; the second author served as verifier. The full interview protocol is detailed in Fontaine and Steinemann (2007). Table 2 provides an example of data used to quantify each independent variable, to calculate an overall individual vulnerability score using Equation 1. Individual vulnerability scores were combined, using the procedure detailed earlier, within each sub-sector to determine an overall vulnerability score by sector and region.

Table 2. Example of data collected and used to perform vulnerability component ranking.

Component	Interview Data Collected	Ranking	Score[1]
Exposure	Received less than 50 % of normal water entitlements during two of the past five years. Water shutdown comes at inopportune times for crops.	Extreme	4
Sensitivity	Raises primarily perennial tree fruit that commonly produce low quality fruit under sub-normal supply. Crops are very costly to replace if damaged.	High	3
Adaptive Capacity	No backup/emergency water supplies and less than ten percent of acreage in annual crops (limited ability to spread water).	Low	0.9
Total Score			6.3[2]

[1] See Table 1. for a score determination matrix
[2] Calculated from component scores using equation 1.

IV. Results

Using the VAM, we evaluated drought vulnerability in 34 sub-sectors in Washington State. Results are presented by region, sector, and sub-sector in Table 3, and rank-ordered by VAM scores for each sub-sector in Table 4.

Table 3. Sectors analyzed within each region, and average sub-sector vulnerability scores.

Region and Sector	Sub-sector	Average Vulnerability Score	Range	Number of Interviewees
North West Region				
Agriculture	Green Industry	4.5	4.5	1
Agriculture	Irrigated Berries	3.1	2.8-3.2	4
Agriculture	Irrigated Row Crops	3.6	3.2-4.0	2
Agriculture	Dairy	3.2	3.2	1
M&I	Purveyor	2.7	2.7	1
Environment	Fisheries	4.1	3.6-4.5	2
Central West Region				
Agriculture	Green Industry	4.8	4.5-5.4	3
M&I	Large Municipality Supplier	3.2	2.1-3.5	4
Environment	Fisheries	4.0	4.0	2
South West / Olympic Peninsula Region				
Agriculture	Green Industry	4.5	4.5	1
Agriculture	Irrigated Diverse Agriculture	4.0	4.0	1
Agriculture	Dairy	3.2	3.2	1
Agriculture	Irrigated Berries	4.5	4.5	1
M&I	Municipal	2.7	2.7	1
Environment	Fisheries	3.4	2.7-4.0	2
North Central Region				
Agriculture	Irrigated Fruit Trees	3.4	3.2-4.5	3
Agriculture	Cattle Ranchers	4.0	4.0	1
Environment	Fisheries	4.8	4.0-5.4	4
M&I	Municipal	3.6	3.6	1
South Central Region				
Agriculture	Irrigated Junior Rights	5.0	3.6-6.3	6
Agriculture	Irrigated Junior Rights - Wine Grapes	2.4	2.4	2
Agriculture	Irrigated Senior Right	1.8	1.8	1
Agriculture	Dryland	6.3	6.3	2
Agriculture	Cattle	4.0	4.0	1
M&I	Municipal	3.6	3.6	2

Table 3. continued

Environment	Fisheries	5.6	5.4-6.3	6
East Region				
Agriculture	Irrigated Surface Water	2.7	2.7	1
Agriculture	Irrigated Ground Water	3.0	2.7-3.6	3
Agriculture	Dryland	6.0	5.4-6.3	7
M&I	Municipal	3.7	3.6-4.0	3
Environment	Fisheries	4.3	3.6-4.8	3
No Specific Region				
Recreation	Golf Courses	2.8	2.8	1
Recreation	Ski Areas	5.4	5.4	2
Power	Hydropower	3.3	2.8-3.5	6

Table 4. Vulnerability assessment method (VAM) results for Washington State, rank ordered by VAM scores.

Category (Region, Sector, Sub-sector)	VAM Subgroup Average	VAM Ranking	Internal Validation[1]	Expert Rankings[2]	Modified VAM Scores[4]
South Central, Agriculture, Dryland	6.3	High	High	Medium	6.3
East, Agriculture, Dryland	6.0	High	High	Medum	6.0
South Central, Env, Fisheries	5.6	High	High	Medium	5.6
Recreation, Ski Areas	5.4	High	High	Medium	5.4
South Central, Agriculture, Irrigated Junior Rights	5.0	High	High	High	5.0
North Central, Env, Fisheries	4.8	High	High	Medium	4.8
Central West, Agriculture, Green Industry	4.8	High	High	Medium	3.9
North West, Agriculture, Green Industry	4.5	High	High	Medium	3.2
South West / Olympic Peninsula, Agriculture, Green Industry	4.5	High	High	Medium	3.6
South West / Olympic Peninsula, Agriculture, Irrigated Berries	4.5	High	Medium	Low	3.2
East, Environment, Fisheries	4.3	High	Medium	High	5.5
North West, Environment, Fisheries	4.1	Medium	Medium	High	5.0
Central West, Environment, Fisheries	4.0	Medium	Medium	Medium	4.0
South West / Olympic Peninsula, Agriculture, Irrigated Diverse	4.0	Medium	Medium	Low	4.0
North Central, Agriculture, Cattle Rancher	4.0	Medium	Medium	Low	4.0
South Central, Agriculture, Cattle Rancher	4.0	Medium	Medium	Medium	4.0
East, M&I, Small Municipal Supply	3.7	Medium	Low	Medium	3.7
North West, Agriculture, Irrigated Row Crops	3.6	Medium	Medium	Low	3.6
North Central, M&I, Small Municipal Suppliers	3.6	Medium	Low	Medium	3.6
South Central, M&I, Small Municipal	3.6	Medium	Low	Medium/ Low[3]	3.6
North Central, Agriculture, Irrigated Tree Fruit	3.4	Medium	Medium	Medium	3.4

Table 4. continued

South West / Olympic Peninsula, Environment, Fisheries	3.4	Medium	Medium	Medium	4.7
Power, Hydropower	3.3	Low	Medium	Medium	3.3
North West, Agriculture, Dairy	3.2	Low	Medium	Low	3.2
South West / Olympic Peninsula, Agriculture, Dairy	3.2	Low	Medium	Low	3.2
Central West, M&I, Large Municipal Supplier	3.2	Low	Medium	Medium	3.2
North West, Agriculture, Irrigated Berries	3.1	Low	Medium	Low	3.1
East, Agriculture, Irrigated Ground Water	3.0	Low	Medium	Low	3.0
Recreation, Golf Courses	2.8	Low	Medium	Low	2.8
North West, M&I, Purveyor	2.7	Low	Low	Medium	2.7
South West / Olympic Peninsula, M&I, Municipal Supply	2.7	Low	Low	Medium	2.7
East, Agriculture, Irrigated Surface Water	2.7	Low	Medium	Low	2.7
South Central, Agriculture, Irrigated Junior Rights - Wine Grapes	2.4	Low	Medium	High	2.4
South Central, Agriculture, Irrigated Senior Rights	1.8	Low	Low	Low	1.8

[1] Rankings based on internal assessment of the dependent variable, vulnerability, absent component scores.
[2] Rankings based on expert assessment of vulnerability.
[3] Sub-sector not used in statistical analysis.
[4] VAM component scores for each sub-sector recalculated based on second phase of external validation process.

Vulnerability was ranked the highest for the following sub-sectors: dryland farmers in the Eastern regions, farmers with junior water rights in the South Central region, fisheries in the Central regions, ski area operators, and the green industry in the Western regions. Dryland farmers in the East region, for example, are highly vulnerable because of high exposure, high sensitivity, and low adaptive capacity. They need to make critical decisions on crops, prior to the planting and growing season, but with limited and uncertain information on future water supplies. Farmers with junior water rights in the South Central region, for another example, are also highly vulnerable, but can have a higher adaptive capacity. They receive estimates of their water entitlements for the upcoming season, which can increase their ability to adapt to drought, especially with a formal state drought declaration that streamlines the permitting process for emergency wells and water transfers. In many cases, however, these adaptive measures come at a high cost (e.g., the costs to drill a new groundwater well, the costs to purchase water rights, or the lost revenue from fallowing fields to transfer water to more valuable or sensitive crops), which can reduce the marginal net benefit of the adaptive methods and thereby increase vulnerability.

Exposure was ranked the highest for dryland farmers, junior water right holders, hydropower generators, ski areas, and fisheries in watersheds with large surface water withdrawals. In the past, the power sector has been severely affected by drought, particularly the 2001 drought, which caused record-low streamflows across much of Washington State and coincided with increased power prices resulting from insecure Southwestern energy supplies. Since 2001, the power sector has reduced its vulnerability by reducing sensitivity (e.g., by increasing thermal power generation sources) and increasing adaptive capacity (e.g., by developing a resource adequacy standard). In this study, exposure was rated high or extreme for more than half of the interviewees, which reflects the designation of interviewees from "hot spots" in the state: sectors and regions that had severe impacts from previous droughts, and were likely to have severe impacts in future droughts.

Sensitivity was reported high for dryland farmers, junior water right holders farming exclusively tree fruit, and fisheries populations already highly stressed by surface water withdrawals and other habitat impacts. Populations of anadromous salmonids in many Washington rivers have already been decimated by dams, river channelization, reduced large wood recruitment, water quality deterioration, and hydrograph alterations resulting in reduced natural freshets and reduced flooding; consequently, these populations are highly sensitive to drought. Long rearing salmonids are especially sensitive because they may spend a year or more in the river system as juveniles before migrating out to sea.

Adaptive capacity was reported at high levels for large municipalities and hydropower generators. For municipalities, large surface water reservoirs can enable them to adapt before needing to impose water use restrictions (e.g., by storing water earlier in the spring for use in the late summer, and by performing water intensive maintenance activities in the spring rather than summer). In addition, many reservoir operators include input from fisheries commissions when developing their annual operation plans, and modify operations to minimize impacts on struggling fish populations (e.g., by using stored water to supplement natural flows during the spring to aid downstream migration of juvenile salmonids, and during the fall to aid upstream migration of mature salmonids prior to spawning). Thus, adaptations used by reservoir operators can also potentially increase adaptive capacity for fisheries.

V. Model Validation

To validate the model and results, we performed both internal validation and external validation. Internal validation checks the relationships between independent and dependent variables in the model; thus, it evaluates the internal consistency and performance of the VAM. External validation checks the model results against an outside standard; thus, it evaluates the external applicability and generalizability of the VAM.

To perform these validation exercises, we compared the overall sub-sector VAM scores, calculated from primary data for the three independent variables (exposure, sensitivity, and adaptive capacity), with the vulnerability rankings from both internal and external assessments. Internal assessments are based on the primary data, obtained from the interviewees, for the dependent variable (vulnerability). External assessments are also based on primary data for vulnerability, but obtained from an external, independent expert. This expert served as the Washington State Drought Coordinator during four major droughts (1992, 1994, 2001, and 2005), and brings nearly three decades of experience in state water resource planning.

Vulnerability rankings of high, medium, and low were assigned to each of the 34 sub-sectors for both internal and external assessment. During internal assessment, the vulnerability of each sub-sector was ranked based on primary data from the sub-sector interviewees. During external assessment, the external expert ranked the vulnerability based on his data and experience dealing with drought issues throughout the state. The results are shown in Table 4 and Figures 3, 4, and 5. Analysis of variance (ANOVA) was employed to test the equivalence of means in each of the three vulnerability ranking categories (high, medium, and low). Student-Newman-Keuls (SNK) multiple comparison test was then used to determine which categories were significantly different from the others.

Results of these analyses indicate that the VAM exhibited favorable performance in both internal and external assessments. For internal assessment, the VAM rankings were consistent with the vulnerability rankings generated from the independent variables, for 20 of the 34 sub-sectors, including the nine sub-sectors with the highest VAM scores (Figure 3). Statistically, these results are strengthened by SNK multiple comparison tests, which verify that the high vulnerability category is significantly different from both the medium and low categories ($\alpha=0.1$), in addition to ANOVA tests, $p=0.0005$ (Table 5). SNK multiple comparison tests did not identify a significant difference between the sub-sectors receiving medium and low internal vulnerability rankings (at $\alpha=0.1$), indicating that the VAM performed strongest, statistically, for the high vulnerability sub-sectors.

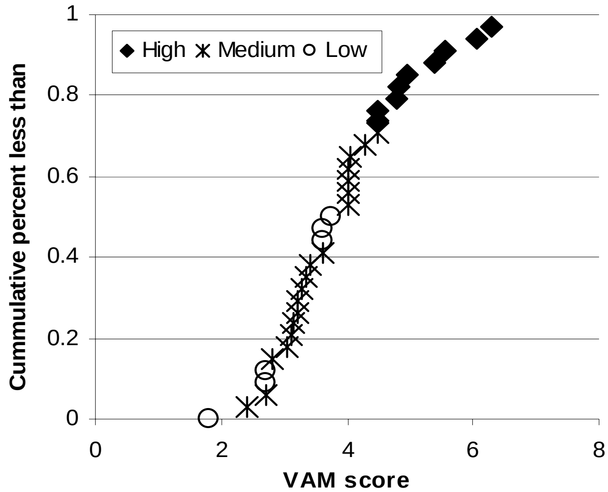

Figure 3. VAM scores based on internal assessment of vulnerability.

Table 5. Model validation: ANOVA p values and Student-Newman-Keuls multiple comparison tests[1].

Assessment Type	ANOVA p value	SNK (α=0.1)		
VAM and Internal Assessment	0.0005	H	M	L
VAM and External Assessment	0.059	M	H	L
Modified VAM and External Assessment (outlier in Figure 4 excluded from analysis)	0.004	H	M	L

[1] High, medium, and low categories indicated as "H", "M", and "L." Solid lines beneath categories indicate non-significant difference between categories.

For external assessment, the VAM rankings were consistent with the external assessment categories for 15 sub-sectors, and differed for 19 sub-sectors, specifically when the external assessment incorporated data that differed from the VAM assessment. ANOVA tests show a significant difference between external assessment categories (p = 0.059) (α = 0.1), thus indicating that there is a difference among category means.

However, the SNK multiple comparison tests identify a significant difference between medium and low categories but not a significant difference between high and medium categories or between high and low categories ($\alpha = 0.1$). To investigate reasons for the differences between the external assessment rankings and the VAM scores, we conducted a second round of evaluations with the external expert, discussing the results, and through this we acquired additional information and insights on drought vulnerability. For example, in the municipal and industrial sector in the South West / Olympic Peninsula region, the external expert noted a case where a municipality's water right is junior to that of a large paper mill on the same supply line, creating potentially high drought exposure for the junior water rights user. Thus, the expert's assessment of vulnerability was higher than the VAM results for that sector, which did not incorporate that case. As another example, for wine grape growers with junior water rights in the South Central region (outlier on Figures 4 and 5), the VAM results indicate low vulnerability to drought, based on information that wine grapes are drought tolerant (low sensitivity) and require less water, overall, than the normal entitlements of junior water users (moderate exposure). The external expert assessed a higher vulnerability to drought, given that water rights were based on consumptive use, so the reduction in water allotted to wine grape growers with junior water rights would be proportional to their normal usage, thus creating the same level of vulnerability as junior water right holders raising more water intensive crops. On the other hand, the internal assessment considered the drought tolerance of the crops, and also that the restricted water supply the growers would receive would be based on the normal supply to all junior water users. After discussion, it was decided to exclude this outlier from the next phase of assessment. This is an example of how differing interpretations can result in different assessments of vulnerability.

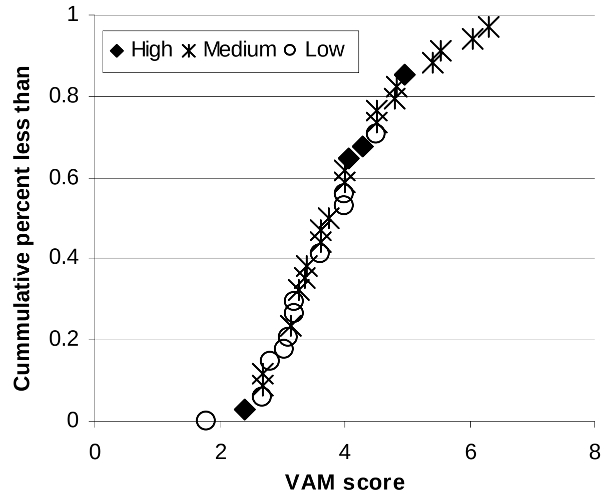

Figure 4. VAM scores based on external assessment of vulnerability.

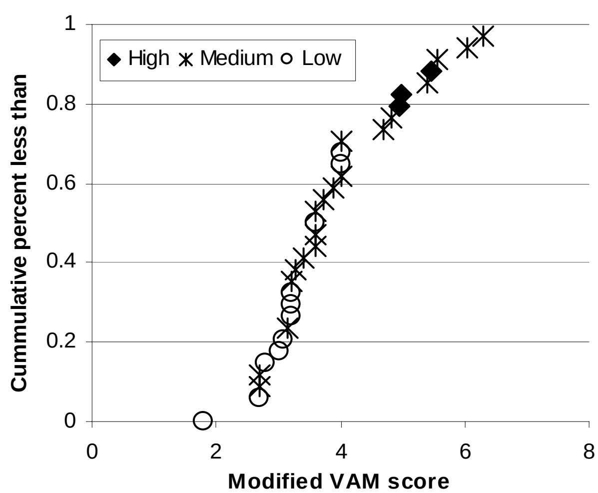

Figure 5. Modified VAM scores based on external assessment of vulnerability.

The external assessment then incorporated the additional information from the expert into the VAM scores. With the revised VAM scores, ANOVA results were significant ($p=0.004$), and SNK multiple comparison tests identified a significant difference between means for all three groups ($\alpha = 0.1$). Thus, through an iterative assessment process, and incorporating a broader base of knowledge about vulnerability, the gap between the VAM and the expert assessment narrowed (Figure 5) and the SNK and ANOVA demonstrate closer alignment between the VAM scores and external assessment rankings. This demonstrates the value of a vulnerability assessment as a process of discussion and evaluation, rather than an isolated event.

Overall, the VAM demonstrated high consistency and applicability, in both internal and external assessment. By assessing overall vulnerability through its underlying components, the VAM was able to identify the sub-sectors considered most vulnerable to drought.

VI. Discussion

From this study, we offer three main considerations for vulnerability assessments.

First, the VAM can provide a useful tool for analyzing individual components of vulnerability, from the underlying causes to the potential for adaptation, in addition to generating an overall assessment. Thus, the VAM can provide quantitative rankings for each sub-sector, in addition to the factors that influence vulnerability. This is in contrast to many vulnerability assessments that focus on the quantification of the hazard, even though the causes and mitigations are central to a goal of assessment: to prepare for and reduce effects of the hazard.

Second, the VAM process acquires local and context-specific information on vulnerability, which often cannot be gleaned by examining indicators over a large spatial or temporal scale, or by using indicators that may have little relationship to impacts. Also, the VAM provides empirical assessments that can help to identify critical areas and allocate resources to reduce impacts. Because local information is the foundation of the VAM, the model and assessment approach can be applied to other areas and other types of hazards.

Third, the VAM incorporates stakeholder input throughout the assessment process, which is essential to understanding the causes of the impacts as well as the range of adaptations. This input can also increase the credibility and relevance of results, and provide a more holistic and integrated assessment of vulnerability. As evidenced through the validation exercises, an iterative discussion can also provide key insights on drought vulnerability. Thus, a vulnerability assessment may be most useful as a process rather than just a product.

The VAM approach also has its caveats. By applying numerical methods to complex sets of data, both qualitative and quantitative, the VAM may not adequately convey all factors that are important for understanding and mitigating drought vulnerability. Also, while stakeholder data provide an essential perspective on vulnerability, the data are understandably subject to human bias, experience, and interpretation. Finally, the VAM results should be viewed as one of several inputs to decision-making, rather than the deciding factor.

The results from this case study are currently being used to help identify sectors, sub-sectors, and regions that are most vulnerable to drought, to guide drought mitigation efforts, and to identify improvements to the State of Washington drought plan.

VII.Conclusion

Drought vulnerability assessment can use information from previous droughts in order to prepare more effectively for future droughts. The VAM addresses a need to analyze vulnerability across diverse sectors and regions. In this case, the VAM is used to assess drought vulnerability, but the method can be adapted to assess vulnerability to other hazards. Using data obtained directly from stakeholders affected by the hazard, the VAM enables decision-makers to understand not only relative vulnerability to a hazard, but also the underlying sources of that vulnerability and the resources and actions that could reduce future vulnerability.

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Appendix A: University of Washington Drought Project Final Report

University of Washington Drought Project

Final Report

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In Partnership with:
Washington Department of Ecology
Washington Department of Agriculture
Washington Office of Financial Management
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Table of Contents

List of Acronyms

CPC: Climate Prediction Center
CTED: Washington Department of Community, Trade, and Economic Development
DOE: Washington Department of Ecology
DSI: Direct Service Industry
ENSO: El Niño Southern Oscillation
M&I: Municipal and Industrial
NOAA: National Oceanic and Atmospheric Administration
NRCS: National Resource Conservation Service
NWAC: North West Avalanche Center
NWS: National Weather Service
PAWS: Public Agriculture Weather System
PNSAA: Pacific Northwest Ski Areas Association
SEAFM: Seattle Forecast Model
SNOTEL: Snowpack Telemetry
SOAC: System Operation Advisory Committee
USBR: United States Bureau of Reclamation
USDA: United Stated Department of Agriculture
UW: University of Washington
WRIA: Water Resource Inventory Area
WSU: Washington State University

Executive Summary

Introduction:
The State of Washington experienced serious droughts in both 2001 and 2005, causing significant impacts throughout the economy. To understand and assess some of the primary economic impacts of previous droughts, the authors surveyed 67 water users throughout the state, representing sectors of agriculture, municipal and industrial, environment, power, and recreation. While this sample represents but a small number of those affected, the survey does provide useful information and insights about the effects of previous droughts and the potential effects of future droughts. The main results from this study, based on reports by interviewees, are summarized below.

Key Findings:

- The industry hardest hit was typically agriculture, especially tree fruit growers in the Yakima District with junior water rights, reporting losses of up to $65 per bin of apples due to reduced fruit quality during previous droughts ($130 - $150 per quality bin). Statewide, both apples and cherries reported record yields in 2005.
- Holders of proratable (junior) water rights in the Yakima received less than 50% of their entitlements (supplies) during the 2001 and 2005 droughts. Some fallowed entire fields to conserve water to use on more valuable perennial crops; others spent hundreds of thousands of dollars to drill emergency backup wells. One junior irrigation district spent $2.8 million dollars to transfer additional water supplies from senior irrigation districts.
- Dryland wheat farmers in eastern Washington reported up to 70% fewer bushels produced per acre in some fields and above-normal production in fields less than 100 miles away, demonstrating the hit-and-miss nature of dryland farming impacts. The total harvest of 139.3 million bushels of wheat in 2005 was only slightly less than the average of the previous five years.
- Green industry (landscaping, plant nurseries, garden supply, etc.) interviewees reported revenue reductions of 8% to 20% in western Washington during 2005.
- Dairy farmers reported increased feed prices of approximately 30%.
- The costs to supply adequate water to crops increased statewide—a primary drought impact.
- Municipal water suppliers reported water restriction and ad campaign costs of $3 million (drought advisory) to $15 million (mandatory water restrictions) during previous droughts.
- Higher water temperatures and poor water quality killed hundreds of Spring Chinook Salmon in the Okanogan River prior to spawning.
- Low stream discharges blocked salmon passage in the Dungeness, Yakima, and Walla Walla Rivers.
- Cooperative shutdowns of irrigation diversions enabled fish passage in the Dungeness and Walla Walla Rivers.

- Hydropower lost approximately 5,300 MW, worth an estimated $3.5 billion to Washington State, due to low river flows in the 2001 drought, primarily on the main stem of the Columbia River. These impacts were compounded by other energy shortages in the west.
- Ski area visitation decreased by approximately one million visitors in Washington State during the 2004-2005 ski season (the 10-year average is approximately 1.5 million visits).

Suggestions from Water Users to Reduce Future Drought Impacts:

- Modify western water law; specifically, eliminate the "use-it or lose-it" requirement and create a "true water market."
- Increase water storage by several different means: small storage projects, large storage reservoirs (e.g. the Black Rock project), and aquifer storage and recharge.
- Develop more accurate long-range forecasts to assist farmers in making critical decisions, such as whether to plant and the amount of fertilizer to apply.
- Increase availability of current-condition hydrologic data.
- Provide information to agricultural users on water conservation techniques, improved irrigation practices, and robust water system construction.
- Provide financial assistance to small irrigated farms for water supply improvements.
- Develop a web-based municipal water supply information system to communicate anticipated water restrictions to residents.
- Develop climate information specific to watersheds.
- Increase fisheries knowledge, including stimuli of downstream migration in juvenile salmon and the location of problem areas in rivers during drought, to support agency planning and water management decisions.
- Make drought relief funding available to fisheries agencies by February.
- Allow additional changes in hydropower system operations during drought, addressing reservoir rule curves, irrigation supply, and fish passage.

This study was conducted by the University of Washington, with funding from the Washington Department of Community Trade and Economic Development. The findings and suggestions expressed in this study are those of the interviewees, and do not necessarily reflect the views of their sector or region, the University of Washington, the Washington Department of Community Trade and Economic Development, or other state agencies.

Summary

Introduction

Drought has been the nation's most costly natural disaster, costing the US an average of 6 billion-8 billion dollars annually.[1] Recently, drought has had severe impacts throughout Washington State. Without improved drought planning and mitigation, these impacts are expected to increase, as demands increase for limited and uncertain water supplies. In the wake of the state-declared 2005 drought, the Washington Department of Community Trade and Economic Development (CTED) contracted with the University of Washington to perform a four-phase study of drought in the state. The drought study included phone interviews with 67 stakeholders across the state. Several regions were identified as having characteristic supplies and demands; thus, this study analyzed data according to these regions: North West, Central West, South West/Olympic Peninsula, North Central, South Central, and East. Figure E.1 identifies each of these regions and the number of interviews conducted in each region. The counties included in each region are listed in Table 3.1.

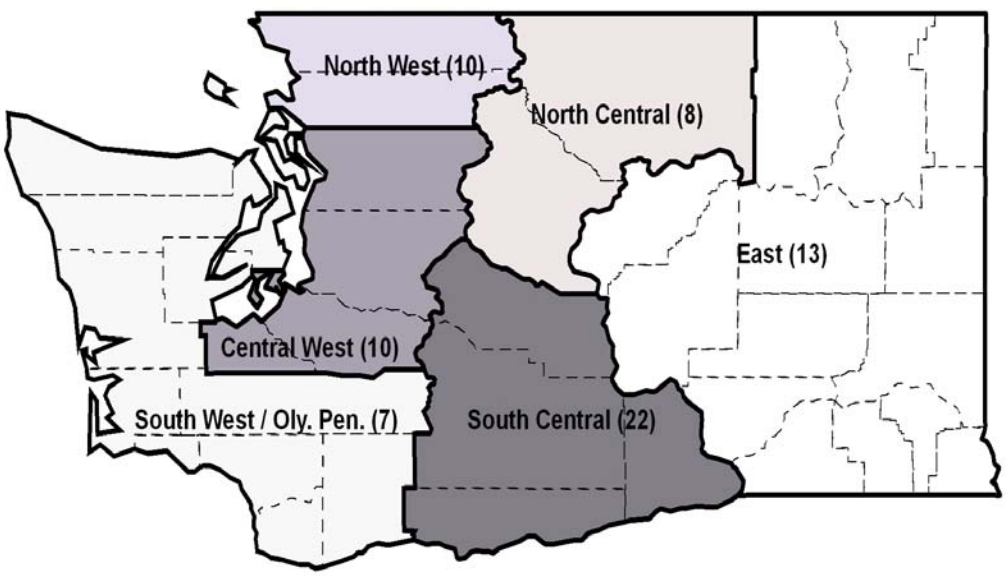

Figure 3.1 Map of Regions - total interviews conducted in each region in parentheses

This report presents the findings of the study, based on four primary objectives:

1) Assess drought potential and previous drought impacts.

1

FEMA (Federal Emergency Management Agency), 1995. *National Mitigation Strategy: Partnerships for Building Safer Communities*, Federal Emergency Management Agency, Washington, D.C., 40 pp.

   a) Identify the potential for drought by primary sectors to be affected by drought conditions.
   b) Analyze impacts from previous droughts in each sector and region, considering economic, environmental, and social factors.
   c) Evaluate these impacts according to severity, spatial extent, temporal extent, and affected public.
2) Assess vulnerability to drought.
   a) Identify the areas (sectors and regions) most vulnerable to drought in terms of exposure to drought hazard, severity of hazard, probability of occurrence, resiliency, and other factors that influence vulnerability
   b) Determine the range of actions and adaptive capacity for reducing risk for these vulnerable sectors and regions
   c) Determine the information and resources needed to implement actions;
3) Examine drought indicators.
   a) Determine the indicators that reflect the most critical drought impacts, that can track drought conditions, and that can inform decision-making.
   b) Determine temporal and spatial scales for indicator analyses, representative sites and data sources, and methods for combining and comparing indicators to characterize drought severity.
4) Identify a range of responses to reduce drought impacts.
   a) Determine actions, both strategic and tactical, that could be implemented to reduce identified impacts.
   b) Consider those actions taken during the drought, those that could have been taken but were not, and those that would be useful to take in the future.

The results are presented in four sections, each section corresponding to a primary objective of the study. The information in this report is based on hundreds of years of collective experience of individuals affected by previous droughts, and thus provides important insights on ways to mitigate future drought impacts in Washington state.

Phase 1 Summary: Drought Potential and Drought Impacts Assessment

Primary findings

The report identifies impacts of drought in all regions of the state. In the agricultural sector, impacts were greatest in cases where lack of supply reduced the quantity and quality of product. Irrigators throughout the state reported increased cost associated with water management during drought. Growers of tree fruit with proratable water rights (in the Yakima Project "proratable" refers to water rights dated later than May 10, 1905, who may receive less than normal supply entitlements during drought) commonly reported reduced fruit quality; however, impacts to quantity were not as widely reported. Many proratable water users left row crop fields fallow to ensure adequate supply for perennial crops or to supply other fields that were planted. Reduced cuttings of hay and alfalfa were also widespread. The decrease in production of feed crops increased costs of feed for livestock. Dryland farmers reported crop reductions of up to 70 percent during drought. The green industry (the industry that grows, installs, and maintains landscaping, including landscape professionals, landscape nurseries, garden centers, horticulturists, and turf grass growers) in western Washington reported severe reductions in sales due to early advisories and perceptions of drought in Western Washington. Interviewees also reported many secondary drought impacts such as reduced sales of field equipment, increased unemployment, and reductions in assessed land value per capita. Fisheries officials throughout the state reported that, in most years, fish are negatively affected by water withdrawals from streams and alteration of the natural hydrograph. These deleterious conditions can be magnified by drought, resulting in additional stress and increased mortality of adult fish migrating upstream, juvenile fish migrating downstream, and resident fish populations. The raw value of lost hydropower generation in the state was estimated to be approximately $3.4 million during the 2001 drought. In 2005, ski areas in the Washington received over 1 million fewer skier visits than average.

Summary of Drought Impacts and Costs by Region

The following table presents a summary of the major impacts reported by interviewees during the course of this study (Table E1.1). Economic quantification of these impacts is provided where possible. Detailed descriptions of impacts and economic analysis are presented in later sections of the report.

Table E1.1 Summary of Impacts by Region		
Sector	**Impacts**	**Reported Costs**
	North West	
Agriculture	Inability to supply enough water to crops with existing irrigation systems.	
	Increased plant stress.	
	Decreased production.	20% reduction in earnings.*
	Increased costs of irrigation.	

Table E1.1 Summary of Impacts by Region		
Sector	**Impacts**	**Reported Costs**
	Increased feed costs for livestock.	$70/cow/year**
M&I	Increased costs to purchase water from suppliers with more robust supplies.	
Environment	Reduced flows and high temperatures in small lowland streams.	
	Reduced access to spawning habitat and increased vulnerability to predation.	
	Increased susceptibility to disease among overcrowded fish populations.	
Central West		
Agriculture	Reduced sales in the green industry due to perception of drought by consumers.	$50,000 in lost profit*, $200,000 in lost revenue (8%)*, 20% reduction in revenue.*
M&I	Water restrictions to consumers.	
	Revenue shortfalls for water system operators from reduced sales and increased conservation costs.	
	Additional costs to implement use restrictions.	Advisory level = $3 million, Voluntary level = $11 million, Mandatory level = $15 million*
	Decreased survival of migrating juvenile fish.	
Environment	Minimum streamflows are reached earlier.	
	Increased prespawn mortality of returning adult fish.	
	Scouring and dewatering of redds.	
	Reduced fish habitat, particularly spawning habitat.	
	Decreased water quality for fish.	
	Additional pumping costs for fish hatcheries.	
South West/Olympic Peninsula		
Agriculture	Water restriction for irrigators supplied by the Dungeness River.	
	Decreased crop production.	30% reduction in production*
	Inability to supply enough water to crops with existing irrigation systems.	
	Increased plant stress.	

Table E1.1 Summary of Impacts by Region		
Sector	**Impacts**	**Reported Costs**
	Increased costs of irrigation.	
	Increased feed costs for livestock.	$70/cow/year**
	North Central	
Agriculture	Increased feed costs for livestock production.	$70/cow/year**
Environment	Increased prespawn mortality of returning adult fish, particularly in the Okanogan River basin where hundreds of fish are lost in some years.	
	Reduced fish habitat, particularly spawning habitat.	
	Decreased water quality for fish, especially increased temperature.	
	South Central	
Agriculture	Additional cost to permit and drill emergency backup wells.	
	Reduced fruit quality.	$65 less revenue per bin of apples*, $30 less revenue per bin of apples* - reported in 2001 and 2005 (equates to 20% - 50% reduction in revenue per bin)
	Reduced production of dryland wheat.	$20-$80.5 lost revenue per acre**
	Lost production from crop failure - one interviewee lost an entire cherry crop due to untimely district shut downs.	
	Lost production from fallowed fields.	
	Increased pests and disease in crops.	
	Reduced cuttings of hay and alfalfa.	
	Increased feed costs for livestock.	$70 per cow per year**
	Cost of permitting and drilling of backup wells.	$200,000 - $300,000 per well*
	Cost to purchase water from users with senior rights.	One district reported spending $2.8 million*
	One interviewee attributed a failed school bond to reduced production resulting from drought.	
Environment	Decreased survival of migrating juvenile fish.	
	Minimum streamflows are reached earlier.	

Table E1.1 Summary of Impacts by Region		
Sector	**Impacts**	**Reported Costs**
	Increased prespawn mortality of returning adult fish.	
	Scouring and dewatering of redds.	
	Reduced fish habitat, particularly spawning habitat.	
	Decreased water quality for fish.	
	Additional pumping costs for fish hatcheries.	
	Increased fisheries cost to monitor fish and maintain fish devices.	
East Region		
Agriculture	Wheat yield reductions - up to 70%.	$24.5 - 255.5 lost revenue per acre**
	Reduced purchasing of farm equipment.	
Environment	Fish stranding in WRIA 32 (Walla Walla).	
	Reduced streamflows.	
	Increased stream temperatures.	
Power Sector		
Power	Reduced hydropower production.	$3.5 billion lost generation in Washington state**
	Increased costs of meeting fish flow requirements.	
	Increased costs to buy back power and water.	$25 million spent by BPA to purchase water from the Columbia Basin Irrigation project. $861 million spent by BPA to buy back power from the direct service industry users.
	Increased costs to purchase non-hydroelectric power from other providers to meet supply agreements.	$2.3 billion in power purchased by BPA (including direct service industry buy back)
	Electricity rate increases for Washington consumers.	
	Lost jobs associated with aluminum plant closures.	
	Increased debt to revenue ratio for some power providers.	
	Reduced fish spill.	
	Increased cost to install new generation.	

Table E1.1 Summary of Impacts by Region		
Sector	**Impacts**	**Reported Costs**
	Increased air pollution related to increased thermal generation.	
Recreation Sector		
Recreation	Over 1,000,000 fewer skier visits to ski areas in Washington during 2005 (69 percent reduction from 10-yr average).	

* Costs reported by one interviewee

** Estimate made using data reported by interviewee/s

Phase 2 Summary: Vulnerability Assessment, Lessons Learned, and Information and Resources to Reduce Vulnerability

Primary Findings

All water users in the Washington State have some susceptibility to drought and many are very vulnerable. This report assesses the level of vulnerability based on results of interviews conducted with 67 water users from five sectors of the state: Agriculture, Municipal and Industrial (M&I), Environment, Power, and Recreation. Vulnerability ratings of high, medium, or low were assigned to each sector, or subsector, within each region of the state, comparing the severity and frequency of previous drought impacts and likelihood and severity of future drought impacts. The authors identify seven groups as having high vulnerability to drought: the green industry in the Central West region, the environment sector in the North Central region, proratable water users in the South Central region, dryland farmers in the South Central region, the environment sector in the South Central region, dryland agriculture in the East region, and ski area operators across the state. These sectors have all experienced the effects of severe drought impacts in the past. They also have some capacity to modify operations during drought to reduce impacts. However, during extreme drought and given current conditions, these groups are all likely to experience severe impacts again. Most other sectors fell into the moderate vulnerability category, because future impacts were expected to be moderate. Vulnerability ratings for sectors are listed in the table below.

Recommendations

Lessons learned from dealing with previous droughts can be helpful to guide strategic and tactical drought responses. A summary of lessons learned identified by interviewees is provided below (Table E2.1). In many cases, additional information and resources are needed to change current conditions and reduce vulnerability. A summary of beneficial information and resources identified by interviewees is also provided below (Table E2.2). Multiple responses are indicated by the number of times received, (#).

Table E2.1 Vulnerability Ratings and Summary of Lessons Learned by Region and Sector

Sector	Subsector	Vulnerability Rating	Lessons Learned
North West			
Agriculture	Cane Berries	Medium	Start irrigation earlier when prolonged periods of high evapotranspiration are anticipated.
	Row Crops	Medium	Have distribution systems available when needed.
	Irrigated Diverse	Medium	Cooperation between water users is effective for meeting the needs of multiple uses.
			Irrigation canal technicians (ditch riders) provide an excellent mode of communication with water users.
	Golf Courses	Medium	Advanced irrigation systems improve ability to apply the correct amount of water to turf, reducing vulnerability to drought impacts.
			Have a water conservation plan in place.
	Dairy	Medium	Have distribution systems available when needed.
M&I		Low	None identified.
Environment		Medium	Meeting streamflow goals can be difficult if water rights within the basin are not first adjudicated or if illicit water use is present.
			Long rearing species are the most vulnerable.
			Summer low streamflows are not always a clear indicator of whether drought impacts will occur.
Central West			
Agriculture	Green Industry	High	Reducing the size of the workforce during drought can help reduce impacts.
			Declaring drought regionally and improving management of media information can help prevent unnecessary impacts.
	Golf Courses	Medium	Advanced irrigation systems improve ability to apply the correct amount of water to turf, reducing vulnerability to drought impacts.
			Have a water conservation plan in place.
M&I		Medium	Having a water shortage contingency plan in place before drought hits.

Table E2.1 Vulnerability Ratings and Summary of Lessons Learned by Region and Sector

Sector	Subsector	Vulnerability Rating	Lessons Learned
			Modification of reservoir operation, e.g. using a dynamic rule curve, and modification of system operation, e.g. reduced flushing on in town reservoirs, can decrease impacts.
			Utilities need to work more closely with the green industry.
Environment		**Medium**	Maintaining instream flow flexibility minimizes impacts.
			Using reservoir storage to supplement flows benefits fish during drought.
South West/Olympic Peninsula			
Agriculture	**Cane Berries**	**Medium**	Improvements of irrigation systems are needed, but difficult to fund.
	Dairy	**Medium**	Have distribution systems available when needed.
	Golf Courses	**Medium**	Advanced irrigation systems improve ability to apply the correct amount of water to turf, reducing vulnerability to drought impacts.
			Have a water conservation plan in place.
M&I		**Low**	None reported.
Environment		**Medium**	Coordinated reductions or irrigation abstraction can effectively prevent impacts to the environment.
North Central			
Agriculture	**Irrigated**	**Medium**	Record-low flows in 2005 and minimal impacts indicate that the sector is less vulnerable to drought than had been thought previously.
			Drip irrigation is may lead to increased erosion and lower fruit quality.
			Developing agricultural land with housing doesn't always reduce water consumption.
			Heat reflective spraying and updated irrigation systems can reduce water demand.
			Removing blocks of marginal fruit trees can be an effective way to mitigate drought impacts.
	Cattle	**Medium**	Comparing historical data to current data enables better response to drought.
Environment	**Fisheries**	**High**	Administrative issues within fisheries agencies need to be worked out before drought.(2)
			Late summer droughts are more difficult to respond to than winter droughts.
			Hatcheries need response plans in place before drought.
M&I		**Low**	Ensure that water intakes will still function during extreme drought.

Table E2.1 Vulnerability Ratings and Summary of Lessons Learned by Region and Sector			
Sector	**Subsector**	**Vulnerability Rating**	**Lessons Learned**
		South Central	
Agriculture	**Proratable Irrigation**	**High**	Using high efficiency water application can lead to other complications. Drip irrigation can increase heat loading within orchards adding heat stress to crops and requiring additional overhead cooling. (3)
			Improvements of irrigation ditches can be effective for water conservation, especially improvements that allow ditches to operate at lower flows. (2)
			Pruning/Dehorning trees can be an effective way to save a fruit tree crop
			Borrowing water from one section of land to supply another can be an effective way to reduce impacts.
			Buying extra water (water transfers) may not be successful and may attract unwanted scrutiny from regulator agencies.
			Early season irrigation systems shut downs are an effective way to conserve water for later in the summer.
			Impact mitigation is more successful if proration estimates go up over the course of the year.
			Limiting water delivery in one part of a system may be necessary to pool water for deliver to another part of the system.
			Interdistrict water transfers are more complicated and less successful than intradistrict transfers.
			Use all available water by September 30th (end of water year).
			Cooperation between senior and junior water right holders is not working out due to lack of trust.
	Proratable Wine Grapes	**Medium**	Diversifying to wine grapes can be a successful method of drought mitigation.
			Grapes can be impacted by early season shortages. Avoid stress to grapes during bud break and flowering. (mid April to mid May)
			Filling the soil profile late in the season (after harvest) prevents root damage to grape plants.
	Non-	**Low**	None.

Table E2.1 Vulnerability Ratings and Summary of Lessons Learned by Region and Sector			
Sector	**Subsector**	**Vulnerability Rating**	**Lessons Learned**
	Proratable Irrigators		
	Beef Cattle	**Medium**	Comparing historical data to current data enables better response to drought.
	Dairy Cattle	**Medium**	Backup wells are critical.
	Dryland Wheat	**High**	Carry Crop Insurance.
			Use soil testing to balance nitrogen loading with available and expected water.
			Carry a low debt load.
			Maintain machinery.
			Put least productive lands into Conservation Reserve Program.
			Side dressing winter wheat in the summer won't be effective without summer rains.
			Installing field borders can help preserve top soil during drought.
Environment		**High**	Controlled pulse flows can be effective at moving juvenile fish out of the systems. Short high pulse flows are more effective than sustained medium flows. (3)
			Artificial spring freshets may not get intended response because juvenile fish receive signal to migrate from source other than just river flow.
			Administrative issues within response agencies need to be worked out in advance of drought to enable effective response.
			Get organized to confront drought early in the year and make response strategies flexible.
			Late season droughts are more difficult to respond to than winter droughts.
			Hatcheries need to have response plans in place.
			Criteria flows should be set at levels that won't adversely impact salmon.
			Trapping and hauling fish is necessary during extreme droughts.
			Be selective on which water is purchased back from agriculture to supply river flows. Don't buy warm low quality water to put back in the river.
			Maintaining higher late season pools will help maintain adequate flows over redds in the late fall.

Table E2.1 Vulnerability Ratings and Summary of Lessons Learned by Region and Sector

Sector	Subsector	Vulnerability Rating	Lessons Learned
			Balancing needs of agriculture with those of the environment can achieve a positive solution for both sectors.
M&I		**Low**	Expect supply challenges to increase as populations grow.
East			
Agriculture	**Dryland**	**High**	Adjust nitrogen fertilizer application based on precipitation expectations.
			Seed and fertilize close to normal every year, because applying too little nitrogen guarantees a below average crop.
			Newer wheat cultivars haven't proven to be as drought tolerant as older cultivars.
			Create a deeper layer of tillage mulch to conserve moisture in the soil profile.
			Only plant spring crops on especially wet years.
			Pay attention to signals of drought and be conservative.
			Crops must be planted in order to ensure that at the very least crop insurance can be collected.
	Irrigated	**Medium**	Transferring water between users or from fallow fields to crops is advantageous.
			State Drought declaration is beneficial because it allows emergency services, cost sharing, and new and expanded wells.
			Maintain all Department of Ecology Paperwork because it is necessary when applying for water transfers.
			Maintain records of groundwater levels to detect problems with supply.
M&I		**Low**	Awareness of water consumption leads to efficiency.
Environment		**Medium**	Coordinated reductions or irrigation abstraction can effectively prevent impacts to the environment.
Power			
Power	**Hydropower Generators**	**Medium**	Paying irrigators not to irrigate is an effective way to mitigate impacts, but may be difficult to implement due to enforcement challenges.
			DSI buyback was an effective way to mitigate impacts in 2001; however, the direct service industry currently makes up a much smaller portion of the power market than in 2001, making DSI buyback a less effective tool.

Table E2.1 Vulnerability Ratings and Summary of Lessons Learned by Region and Sector			
Sector	**Subsector**	**Vulnerability Rating**	**Lessons Learned**
			Curtailing fish spill during drought and manually transporting fish can be an effective way to increase generation capacity.
			A resource adequacy standard will help assure that energy shortfalls similar to 2001 do not occur during future droughts.
Recreation			
Recreation	**Ski Areas Operators**	**High**	Conserving snow by packing it in place or moving snow from parking lots to the base area is important during dry years.
			Putting up snow fencing to conserve snow on ski trails is not a cost effective way to conserve snow.
			Managing operations based on expected visits can be an effective way to reduce costs during dry years, e.g. opening fewer restaurants.
			Marketing skiing in times when snow is good by precipitation is low can be an effective way to attract visitors during dry periods
			Slope grooming during the off season (removing trees and rocks) allows areas to open with less snow.

Table E2.2. Summary of Information and Resources		
Sector	**Subsector**	**Information and Resources Needed to Reduce Vulnerability to Drought**
	North West	
	Cane Berries	Increased availability of information including more evapotranspiration data, more weather station data, and infrared and conventional satellite imagery available in real time.
		Improved irrigation technology.
	Row Crops	More accurate long range forecasts.
	Golf Courses	Correct use of information by the media.
		More accurate long range forecasts available by June, however forecasts in February and March would be most valuable.
		Elimination of "use it or lose it" water law.
	Central West	
Agriculture	**Green Industry**	A water supply dashboard needs to be available to the public that conveys water supply status of utilities and projections of water supply over the course of the growing season. This dashboard should be updated constantly.
		More accurate long range weather forecasts and more readily available snowpack information.
		Policy makers need to make the best possible decisions regarding drought based on the best available information and communicate those decisions accurately to the public. This will enable the public to make the make informed decisions.
		Water supply predictions provided during the primary hiring period from February to early March will enable operations to more accurately plan their labor force and avoid lay offs due to drought.
	Golf Courses	Correct use of information by the media.
		More accurate long range forecasts available by June, however forecasts in February and March would be most valuable.
		Elimination of "use it or lose it" water law.
M&I		Better tools produced by climate groups to meet forecasting needs of large municipal water supplies targeting forecasting on a watershed specific level would enable better risk based decision making. This includes improved 10 day forecasts and improved long range forecasting available by January.

Table E2.2. Summary of Information and Resources

Sector	Subsector	Information and Resources Needed to Reduce Vulnerability to Drought
Environment		Improved long range predictions of timing of fall rains will enable better management of water supply to meet increased fall fish flow needs.
		Increasing knowledge of relationship between river stage and problem areas for fish will improve the ability of fisheries personnel to predict, identify, and respond to fish passage problems.
		South West/Olympic Peninsula
Agriculture	**Cane Berries**	Better availability of soil moisture and evapotranspiration information.
		Programs to help relieve some of the costs of irrigation system enhancements.
		Programs to educate growers on irrigation practices.
		More evapotranspiration stations would provide increased data to aid growers' decisions.
	Dairy	Improved long term forecasts provided in early May.
		Development of more drought tolerant crop varieties.
	Golf Courses	Correct use of information by the media.
		More accurate long range forecasts available by June, however forecasts in February and March would be most valuable.
		Elimination of "use it or lose it" water law.
M&I		Better determination of the water supply status quo would enable better drought planning.
		Easy access to water rights information, possibly a water rights database, would enable better drought planning.
Environment		Increasing knowledge of relationship between river stage and problem areas for fish.
		North Central
Agriculture	**Irrigated**	Better dissemination of long term supply forecasts provided in January to February.
		More storage would help supply demands in late July, August, and early September. This storage could be achieved through small "smart" storage projects that provide water for multiple uses in sites with minimal environmental impact.
		Better determination of continuity between groundwater and surface water.
		Education in irrigation system technology and water conservation methods.
		Improved long term forecasts provided in early May.

Table E2.2. Summary of Information and Resources		
Sector	Subsector	Information and Resources Needed to Reduce Vulnerability to Drought
	Dairy	Development of more drought tolerant crop varieties.
	Beef Cattle	More accurate information aiding in the forecast of water supply.
M&I		Better determination of the water supply status quo would enable better drought planning.
		Additional information on the impacts of water shortage on water quality.
Environment		Additional mechanisms for correlating flow tracking with fish observations.
		Additional control structure agreements.
		Negotiated release patterns.
		Funding for drought relief made available by February.
		Development of a matrix that identifies the economic value of different water uses.
		Increased incentives for the agricultural community to conserve water.
South Central		
Agriculture	Proratable Irrigation	Increased storage would make the water supply more reliable. (6) Black Rock Reservoir (3)
		Accurate estimates of the total water supply available forecasted during the winter financial planning period of December and January. Estimates provided by January 1 would be best. (3)
		Better long term forecasting is needed in January to enable better financial planning. (2)
		A more open water market that allows water trading. (2)
		Assurance of permanent water supply and the necessary infrastructure to deliver the water. (2)
		A greater sense of urgency from politicians for creating a more reliable water supply.
		A better understanding of crop demands.
		Improved application technologies.
		Better and earlier estimates of proration expectation would help with financial planning including crop insurance and loans.
		More NRCS and USBR data collection sites may help by providing more information.
		Adequate supply of water during the early season will help prevent impacts to wine grape growers.
		Eliminate the "use it or lose it" portion of water law.
		Improved knowledge of techniques for water spreading (from location to location) may enable growers to more effectively manage limited water.
		More promotion of interdistrict water transfers.

Table E2.2. Summary of Information and Resources		
Sector	**Subsector**	**Information and Resources Needed to Reduce Vulnerability to Drought**
		Clarification of Ecology's role for issuing new water rights.
		Reregulation of the reservoirs in the Yakima Project.
		More robustness of the distribution system may enable more effective operation when supply is low.
		Aquifer storage and recharge would enable storage of early season supply to supplement supply later in the year.
	Beef Cattle	Any additional forecasts of water supply would be beneficial.
	Dairy Cattle	Improved long term forecasts provided in early May.
		Development of more drought tolerant crop varieties.
	Dryland Wheat	Improved long term and short term forecasting.
		A regional drought monitor would be useful.
		More money in the farm bill.
		Better understanding of the continuity between ground water and surface water.
M&I		Aquifer storage and recharge would enable storage of early season supply to supplement supply later in the year.
		Multibenefit storage projects.
Environment		Improved long range weather forecasts. (2)
		Additional storage would enable streamflows in the Yakima Project to be returned to more natural conditions.(2) Black Rock Reservoir (1)
		Improved spawning surveys combined with quantification of available water in storage and accurate forecasts of fall precipitation date would improve the ability to manage streamflows for Salmon.
		Ending inefficient diversions and eliminating conveyance losses for distribution systems will save more water for streamflows. (may make use of funding from the power sector)
		Increased efficiency in other sectors.
		Allowing more natural floods will increase flood plain storage and provide natural freshets.
		Encouraging better cooperation among irrigators will improve conditions for fish during drought.
		Improved early predictions of drought available in February.
		Funding for drought relief should be made available by February.

Table E2.2. Summary of Information and Resources		
Sector	**Subsector**	**Information and Resources Needed to Reduce Vulnerability to Drought**
		Development of a matrix that identifies the economic value of different water uses to prioritize purchasing of water rights for instream flows.
		Increased incentives for the agricultural community to conserve water.
		A better understanding of what stimulates outmigration of juvenile fish.
		More clearly defined tribal (fisheries) water rights.
		Aquifer storage and recharge would enable storage of early season supply to supplement supply later in the year.
		East
Agriculture	**Dryland**	Better long range forecasts available August 20th to September 5th for winter wheat. Forecasts in the fall would need to predict available moisture in the spring. Better long range forecasts available March 1 to April 1 for spring wheat. (4)
		More drought tolerant cultivars would improve yield during drought.
		Increased federal financial assistance.
	Irrigated	Improved short and mid range forecasts.
		More monitoring stations for streamflow and weather data.
		Better estimates of spring runoff available in April and May.
		Improved long term forecasts of precipitation in July, August, and September available in April and May.
		More education on water spreading.
M&I		Better determination of continuity between ground water and surface water.(3)
		Increased storage.
		Power
Power	**Hydropower Generators**	Better volume forecasts as early and as reliable as possible.(3)
		Better daily temperature forecasts improve abilities to forecast load.
		Leaving more water in the main stem of the Columbia River increases generation capacity.
		More available real time data on fish migration.
		Increase public utility district and independent power producer participation in development of the westwide resource adequacy standard.
		Encourage utilities to implement all cost effective conservation.

Table E2.2. Summary of Information and Resources

Sector	Subsector	Information and Resources Needed to Reduce Vulnerability to Drought
		More resources invested in exploring demand response alternatives such as centrally controlled water heaters.
		Store more water in Canada.
		Develop more non-hydro resources.
		Consider allowing more curtailments of operating restrictions such as flood protection, irrigation supply, and fish passage.
Recreation		
Recreation	**Ski Areas Operators**	More reliable forecasts available in September and October. (2)
		Additional water rights.

Phase 3 Summary: Indicators

Primary Findings

Indicators are vital to drought preparation and response. Indicators are employed to monitor and forecast drought conditions, characterize and compare drought severity, and provide a basis for triggering drought responses. This report describes indicators identified by 67 water users from five sectors of the state: Agriculture, M&I, Environment, Power, and Recreation. Interviewees identified indicators they use to monitor drought conditions, most notably soil moisture, precipitation, ground water, surface water, and temperature. Interviewees also identified indicators used to forecast future drought conditions, including snowpack, precipitation forecasts, surface water storage, and climate signals. Social and biological indicators are also used to evaluate demand, including demand forecasts and timing of fish migration. Indicators are considered by water users when making planning decisions, so the timing and availability of information is also important. The agriculture sector makes decisions about crop rotations, crop selection, cropping practices, field selection, financial planning, purchasing and selling water rights, drilling emergency wells, purchasing additional land, modifying irrigation practices, purchase seed, fuel, and fertilizer, and controling herd size. M&I supply managers make decisions on how to implement negotiated instream-flows, alternate water use between basins, change system maintenance schedules, initiate water shortage contingency plans, and adjust rule curves. Fisheries agency officials need to make decisions regarding where to monitor for stranded fish, how to allocate funding, whether to buy or lease water rights, where to allow fish migration to occur, whether to advise the agricultural community to conserve water, and when and where to undertake emergency projects. Fisheries officials must also make recommendations to water system managers including when and where to augment natural flows, at what level to set target fish flows, and how to put limited reservoir storage to the most beneficial use, including releases for pulse and flushing flows. Ski area operations in the recreation sector reported that key decisions relate to hiring and determining how soon to open ski areas at full capacity. The power sector makes decisions related to fish flows, reservoir operations, flood control storage, and power generation.

Recommendations

Indicators currently considered by water users in the state provide valuable data to state decision makers. Future development of the state drought plan should be expanded to include consideration of additional relevant data sets when creating regional drought response indicators and triggers. This work should also develop a more precise characterization of temporal and spatial scales of retrospective indicators; particular attention should be paid to temporal scales analyzed by each sector. A summary of indicators used by Washington water users is provided in Table E3.3. A key to table abbreviations is provided in Table E3.1 and Table E3.2.

Table E3.1 Abbreviation Key	
Regions	
NW	North West
SW/OP	South West / Olympic Peninsula
CW	Central West
NC	North Central
SC	South Central
E	East
Sectors	
Ag	Agriculture
M&I	Municipal and Industrial
Env	Environment
Rec	Recreation
Power	Power

Table E3.2 Range Key

Range	Definition
Current	Current conditions or retrospective cumulative amounts
Short Range	Prospective indicator that provides information relevant to short term planning
Mid Range	Prospective indicator that provides information useful for making decisions during a current season, typically indicate conditions one month to six months in advance
Long Range	Prospective indicator that provides information useful for making decisions related to expected conditions six or more months in advance

Table E3.3 Indicators

Region *	Sector *	Variable	Indicator/Source/Measurement	Range*	Source
NW	Ag	Demand	Evapotranspiration data	Current	
NC, SC, CW	Env, M&I	Demand	Demand forecasts	Short, Mid, and Long Range	
CW	Env	Fisheries	Fish migration timing	Short, Mid, and Long Range	
CW, E	M&I, Env	Ground Water	Ground water monitoring wells	Current	
NC, SC	Ag	Multiple	Weather station data	Current	http://index.prosser.wsu.edu/
NC, SC	Ag	Multiple	UW Forecast System	Long Range	http://www.hydro.washington.edu/forecast/westwide/
SW/OP	Ag	Multiple	Capital Press Agriculture Weekly Newspaper, Salem, OR	Multiple	http://www.capitalpress.com/water/
NC, SC	Ag	Multiple	USDA Office of the Chief Economist - Weather and Climate	Multiple	http://www.usda.gov/oce/weather/index.htm
E	Ag	Multiple	Data Transmission Network - forecast service	Short Range	http://www.meteorlogix.com/products/
SW/OP, SC	Ag	Multiple	Private forecast services	Short Range	
NC, SC	Ag	Multiple	Internet weather forecasts	Short Range	

Table E3.3 Indicators					
Region *	**Sector ***	**Variable**	**Indicator/Source/Measurement**	**Range***	**Source**
SW/OP	Ag	Multiple	Local news - weather forecasts	Short Range	
NW	Ag	Plant Stress	Plant stress	Current	
CW, SC	M&I, Ag	Precipitation, Temperature	NOAA CPC - Long range forecasts	Long Range	http://www.cpc.ncep.noaa.gov/products/forecasts/month_to_season_outlooks.shtml
E, NW, SW/OP, NC, SC, CW	M&I, Env, Power, Ag	Precipitation	Precipitation measurements	Current	NWS, TV networks, PAWS sites
E	Ag	Precipitation	Winter precipitation data (cumulative)	Current	
NA	Rec	Precipitation	Weather forecasts 2-3 months ahead	Mid Range	
CW	M&I, Rec	Precipitation	NOAA National Weather Service - weather forecasts	Multiple	http://www.nws.noaa.gov/
NW	Ag	Precipitation	Short term weather forecasts	Short Range	
NW, CW, SC, E	Ag	Precipitation, Temperature	Climate signals - ENSO	Long Range	
NW	Ag	Snow Pack	Snowpack on May 1st at Mount Baker	Mid Range	
SC	Ag, Env	Snow Pack	Snowpack at Mount Adams	Mid Range	
SW/OP, NC, E, CW	Ag, M&I, Env	Snow Pack	USDA NRCS SNOTEL Data	Mid Range	http://www.wcc.nrcs.usda.gov/snotel/
E	Ag, M&I, Env	Snowpack	Snowpack in the Blue Mountains	Mid Range	
CW, NW	M&I, Ag, Power, Env	Snowpack	Snowpack measurements	Mid Range	

Table E3.3 Indicators

Region *	Sector *	Variable	Indicator/Source/Measurement	Range*	Source
SW/OP, SC, E, NW	Ag	Soil Moisture	Soil moisture measurements	Current	http://index.prosser.wsu.edu/
NW, NC, SC, SW/OP, CW, E	Env, M&I	Surface Water	River gages	Current	http://wa.water.usgs.gov/data/
CW	M&I	Surface Water	SEAFM - Seattle Forecast and Analysis Model	Long Range	
NC, SC	Env	Surface Water	Flow projections	Mid Range	
NA	Power	Surface Water	Internal river forecasts	Mid Range	
SC	Ag	Surface Water	Irrigation district supply estimates	Mid Range	
CW	Ag	Surface Water	Municipal website - water supply availability	Mid Range	
NW, CW, SC	Env, M&I, Ag, Power	Surface Water	Reservoir storage	Mid Range	
SC	Env	Surface Water	Total water supply available	Mid Range	
SC	Ag, Env	Surface Water	USBR Hydromet data	Mid Range	http://www.usbr.gov/pn/hydromet/yakima/realtime_yak.html
SC	Ag	Surface Water	USBR Yakima Basin Water Supply - Monthly Forecasts	Mid Range	http://www.usbr.gov/newsroom/newsrelease/state.cfm?state=18
NA	Power	Surface Water	NWS River Forecast Center	Multiple	http://www.nwrfc.noaa.gov/

Table E3.3 Indicators					
Region *	**Sector ***	**Variable**	**Indicator/Source/Measurement**	**Range***	**Source**
NC, E	Env	Temperature	Surface water temperature	Current	http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html#4 https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp
E, NW	Ag, M&I	Temperature	Temperature measurements	Current	
SC	Env	Temperature	Long range temperature outlook	Long Range	

* Definitions are provided in Tables E3.1and E3.2 for abbreviations and terms used in the Region, Sector, and Range fields.

Phase 4 Summary: Recommendations

Primary Findings

This section of the report describes recommendations made by 67 interviewees from sectors and regions throughout the state to reduce future impacts of drought. These recommendations can help decision makers to allocate resources to mitigate drought more effectively, identify needs and resources to build capacity and reduce vulnerability, and prioritize funding and actions. Recommendations made by interviewees from the agriculture sector include the following: providing more accurate and geographically specific climate forecasts, changing water law to ease water rights trading, developing new storage projects, increasing the number of weather stations, providing farmers education on improved irrigation practices, developing financial assistance programs to improve efficiency and robustness of irrigation and distribution systems, developing more drought tolerant cultivars, and modifying the drought declaration system to reflect local conditions. From the M&I sector, recommendations include the following: developing downscaled forecasts for municipal water suppliers, determining current water usage more accurately, quantifying hydraulic continuity between surface water and ground water, developing new storage projects, and developing a water rights database. From the environment sector, recommendations include the following: developing improved forecasts, developing a system to identify where fish may become stranded based on river stage, determining the stimuli of downstream migration in juvenile salmonids, providing emergency funding to fisheries agencies earlier (February) during drought years, working with the agricultural community to reduce water use through efficiency improvements and conservation incentives, developing new storage projects, and more clearly defining fisheries water rights and control structure agreements. From the hydropower sector, recommendations include providing improved forecasts for water supply, floods, and temperature, improving real-time data on fish migration, increasing non-hydro generation, encouraging utilities to implement all cost effective conservation measures, exploring more demand response technologies, storing more water in Canada, and increasing flexibility of non power-related constraints. From the ski area operators in the recreation sector, recommendations include providing improved forecasts for the timing of fall and winter precipitation, and granting water rights to ski areas. In sum, these recommendations identify information and resources needed by water users in Washington state, and reflect decades of collective experience and expertise from those interviewed. Thus, this report provides an important foundation and guide for future efforts to mitigate drought more effectively.

1. Introduction

Drought has been the nation's most costly natural disaster, costing the US an average of 6 billion-8 billion dollars annually.[1] Washington state is not immune. The effects of drought have been felt throughout the state in the past several years. Without improved drought planning and mitigation, these impacts are expected to increase, as demand increases for limited and sometimes uncertain water supplies. In the wake of the state-declared 2005 drought, Washington Department of Community Trade and Economic Development (CTED) contracted with the University of Washington to perform a four-phase study of drought in the state. This report presents the findings of this study, which include the following components:

- identification and quantification of the primary impacts of drought across the state,
- a vulnerability assessment,
- a summary of lessons learned from previous droughts,
- a list of information and resources identified by interviewees to help decrease vulnerability to drought,
- identification of indicators of drought used by stakeholders across the state, and
- recommended information and resources to help reduce drought impacts to water users across the state.

Officials from several state agencies formed an advisory committee for this project. The officials identified the primary regions and sectors of the state that have been affected by drought. The advisory committee also identified an initial list of interviewees as the primary candidates for this study. Additional interviewees were contacted based upon recommendations from these initial candidates and research performed to identify other groups affected by drought. Candidate identification and interview procedures are described in Appendix A. The interview protocol used to guide interviews can be found in Appendix B.

The information presented in this report comes directly from 67 individuals affected by previous droughts, and provides decision makers with important insights on ways to mitigate future drought impacts in Washington State.

2. Recent Drought in Washington[2]

Drought has always been a feature of Washington's climate. While it is generally viewed as a climate anomaly, in fact drought is the dry part of the normal climate cycle. What is unusual is that droughts appear to be occurring more frequently. The state

[2] The first five paragraphs of this section of the report are taken directly from the following source: Anderson, B., Gibbs, M., Hart, C., Inman, R., McChesney, D., Slattery, K. (2006). 2005 Drought Response Report to the Legislature. Washington State Department of Ecology. (Publication No. 06-11-011.) p. iii.

experienced its second driest year on record in 2001 – and in every year since, the state has encountered at least one season with unusually dry weather conditions.

Water year 2005 (October 1, 2004, through September 30, 2005) came on the heels of a year where the mountain snowpack melted earlier than normal, followed by a warm and fairly dry summer. Water year 2005 got off to a good start. October precipitation ranged between normal to well-above normal for all but the north Puget Sound region. However, that situation abruptly changed from November 2004 through February 2005. Statewide precipitation was below average except for the extreme northwestern tip of the Olympic Peninsula and the westernmost part of Whatcom County. With few exceptions, nearly the entire southern part of the state had well-below average precipitation.

To make matters worse, the fall and winter months were extremely warm, which dramatically affected the state's mountain snowpack. The snowpack was already below average when a warm mid-January storm, commonly referred to as a "pineapple express," removed much of the remaining snowpack. When February turned out to be both warm and dry, the die was cast for a potentially serious drought in 2005.

Unlike most states, Washington has a statutory definition of drought consisting of two parts:

• An area has to be experiencing, or projected to experience, a water supply that is below
75 percent of normal, and
• Water users within those areas will likely incur undue hardships as a result of the shortage.

By early March, projections were made that Washington might be facing not just another drought – but one as bad as or worse than the 1977 drought, the worst on state record. This situation led Governor Christine Gregoire to authorize the Department of Ecology (Ecology) to declare a statewide drought emergency on March 10, 2005. The declaration expired on December 31, 2005.

Despite forecasts for continued dry weather, unusually heavy and fortuitous precipitation during the spring and summer caused conditions to improve in some regions of the state and for some sectors. In some cases, damage from heavy rains had significant impacts on crops. Despite reports of significant drought impacts by many individuals in the agricultural community, which are described in subsequent sections of this report, statewide, apples, pears, cherries, and cattle and calves reported record sales value in 2005[3] and the total wheat harvest of 139.3 million bushels[4] in 2005 was only

[3] USDA National Agricultural Statistics Service. *Record Values for Apple, Cherry, Pear and Cattle and Calf Crops Push Washington's 2005 Agricultural Value to Record High*, October 10, 2006. < http://agr.wa.gov/News/2006/topforty.pdf> December 3, 2006.

slightly less than the average of the previous five years. These figures do not necessarily convey the value to farmers who may have experienced increased costs due to drought.

3. Description of Regions and Sectors

3.1. *Region Identification*

Water supplies and demands vary greatly across the state, due to variations in land, hydrology, climate, infrastructure, water uses, among other factors. Significant variations occur between the eastern and western sides of the state, due in large part to the climatic effect of the Cascade Mountains. During the interview process, several regions were identified as having characteristic supplies and demands; thus this study analyzed data according to these regions: North West, Central West, South West/Olympic Peninsula, North Central, South Central, and East. Figure 3.1 identifies each of these regions and the counties included in each region are listed in Table 3.1.

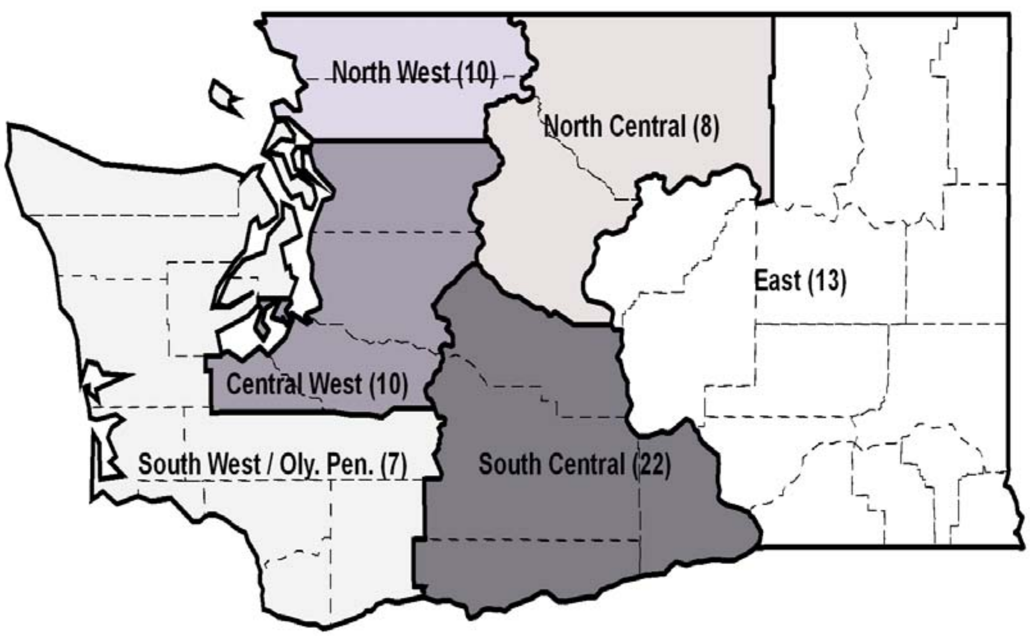

Figure 3.1 Map of Regions - total interviews conducted in each region in parentheses

[4] USDA National Agricultural Statistics Service. Quick Stats
Washington Data – Crops <http://www.nass.usda.gov/QuickStats/Create_Federal_Indv.jsp> December 3, 2006

Table 3.1 Counties in Each Region					
North West Region	Central West Region	Olympic Peninsula / South West Region	North Central Region	South Central Region	East Region
Whatcom	Snohomish	San Juan	Okanogan	Kittitas	Ferry
Skagit	King	Island	Chelan	Yakima	Stevens
	Pierce	Clallam		Klickitat	Pend Oreille
	Thurston	Jefferson		Benton	Douglas
		Kitsap			Grant
		Grays Harbor			Lincoln
		Mason			Spokane
		Pacific			Adams
		Lewis			Whitman
		Wahkiakum			Franklin
		Cowlitz			Walla Walla
		Clark			Columbia
		Skamania			Garfield
					Asotin

3.2. *Description of Primary Sector Distribution within Regions*

3.2.a. Western Regions

The three western regions—North West, Central West and South West/Olympic Peninsula—are geographically quite similar. They are all bounded on the east by the Cascade Mountains. The South West/Olympic Peninsula region also contains the Olympic Mountains to the north. These three areas experience rainy winters with relatively dry summers. Snowmelt provides surface water flows in rivers in all three regions through much of the summer. The North West Region is bounded by the highest mountains and so receives the most reliable late supply of meltwater.

The North West region is composed of Whatcom and Skagit counties. The primary sectors interviewed in this report are agriculture, M&I, and environment. Water demand is supplied by a mix of ground water and surface water. The area receives a high amount of precipitation in the winter with relatively dry summers.

The Central West region includes the counties of Snohomish, King, Pierce, and Thurston. It is the most densely populated region in the state. The demands within this region are primarily M&I with some agriculture present. The demand is met primarily by surface water supplied from several reservoirs in the region. Thurston county is a notable exception, supplying most of its need with ground water. The area receives high winter precipitation and has relatively dry summers. This area is also home to several endangered fish species, creating many challenging environmental water issues.

The South West/Olympic Peninsula region includes the southwestern counties as well as those on the Olympic Peninsula. The primary demands for water are agriculture, M&I, and environmental. Water supply comes from a mix of surface water and groundwater.

3.2.b. Central Regions

The North Central and South Central regions are geographically very similar. Both are bounded on the west by the Cascade Mountains and on the east by the Columbia River. Both regions receive little rainfall throughout the year. Most of the water demand is met by meltwater from the Cascades. The main difference between the two regions is that the South Central region contains a large Bureau of Reclamation project called the Yakima Project, which includes a system of five reservoirs and distribution infrastructure. The North Central Region has several lakes with a small amount of controlled storage.

The primary demands in the North Central region are agricultural, environmental, and M&I. The primary supply is melt water from the Cascade Mountains in the West. Groundwater is also used agriculturally and by the M&I sector.

The primary demands in the South Central region are agricultural, environmental, and M&I. The primary supply is melt water from the Cascade Mountains supplemented in the summer by storage in the five major reservoirs of the Yakima Project. Groundwater is also used agriculturally and by the M&I sector.

3.2.c. Other Regions and Sectors Considered

The East region includes the counties east of Okanogan County and east of the Columbia River and those if the far northeast part of the state. The primary demands in the East region are irrigated and dryland agriculture, environmental, and M&I. Demand in the region is met mainly by precipitation, surface water from the Columbia River (much of it from the Columbia Basin Irrigation Project), surface water from smaller tributaries, and ground water.

The Hydropower sector in Washington State is fed primarily by the flow in the Columbia River and its tributaries, such as the Snake river, as well as runoff from the Cascades. This sector is considered separately in this report because it is regional in nature and meets a very specific demand.

The Recreation sector in Washington State is a very diverse sector. Many portions of the recreation sector can be negatively affected by drought. Recreation will be considered separately in this report, and represented by ski areas.

4. Interviews by Region and Sector

Representatives from within each sector were interviewed for this report. Initial interview candidates were identified from existing contact lists provided by agency officials. The primary list used for the agricultural sector was the Drought Response Action Team list. Primary contacts for the environmental and M&I sectors were the established Water Resource Inventory Area (WRIA) teams, officials from M&I suppliers, and officials from fisheries agencies. Additional contacts within the agricultural, environmental, and M&I sectors were identified during interviews with primary contacts. Interviewees from the power sector were identified by contacting one of the major power producing entities in the Northwest. Interviewees from the recreation sector were identified by contacting representatives from various recreations companies in Washington. Figure 3.1 illustrates the break down of interviews from each region by sector. Table 4.1 identifies the number of interviews relevant to each sector within each region. The sum of all interviews in Table 4.2 is greater than 67 because some interviewees were able to address issues for several regions or sectors.

Table 4.1 Interview Distribution by Region and Sector

Geographic Region	Interviews	Distribution
North West	**10**	
Agriculture		7
M&I		1
Environmental		2
Central West	**10**	
Agriculture		4
M&I		5
Environmental		2
South West / Olympic Peninsula	**7**	
Agriculture		5
M&I		1
Environmental		3
North Central	**8**	
Agriculture		6

Table 4.1 Interview Distribution by Region and Sector		
Geographic Region	**Interviews**	**Distribution**
M&I		2
Environmental		3
South Central	**22**	
Agriculture		16
M&I		2
Environmental		7
East	**13**	
Agriculture		13
M&I		3
Environmental		3
Power	**6**	
Hydropower		6
Recreation	**3**	
Ski Industry		3
Total Interviews	**67**	

Phase 1: Water Resources, Drought Potential, and Drought Impacts Assessment

5. Drought Potential by Region

5.1. *Comparison of Supply and Demand within Regions*

The North West region relies on wet winters and springs to supply water for agricultural crops in the early part of the growing season. In the summer months, precipitation is supplemented with groundwater and surface water in some cases. The primary surface water supplies include farm ponds and snow melt from the Nooksack River and Skagit River. In addition to agriculture, surface water supplies are also important for the environment sector, including runs of several species of salmonid.

The Central West region is characterized by its dense urban population. Population centers of Everett, Seattle, Tacoma, and Olympia receive the majority of their water from surface water sources. Everett, Seattle, and Tacoma all have water supplies that include at least one major reservoir in the foothills of the Cascade Mountains. The reservoirs are managed for flood control in the winter months and water storage in the summer. Olympia supplies its drinking water demands with ground water.

The South West/Olympic Peninsula region uses water from a wide variety of sources including ground water and surface water, some of which comes from snowmelt. The supply is used for agricultural operations as well as to serve M&I needs.

The North Central region is characterized by intensive agricultural operations dominated by perennial crops. Key fish species, both resident and anadromous, are also found in the region during the year. The primary supply to the region is surface water stored by the snowpack and provided throughout the growing season as melt water. There are several small controlled reservoirs in the region that are used, in part, to meet late-season demand and to augment late summer flows.

The South Central region is characterized by intensive agricultural operations dominated by perennial and row crops. Migratory fish species are also present in the region throughout the year. The primary supply to the region is surface water stored by the snowpack. The melt water is stored in a series of five major reservoirs operated by the US Bureau of Reclamation and used during the summer to augment streamflows to meet agricultural and environmental demands. Water from the Yakima Project is distributed to farmers though infrastructure operated by several irrigation districts.

The East region is supplied by surface water and ground water. Natural precipitation also accounts for a large portion of the supply as the East region is home to many dryland farming operations. Surface water supply for irrigated agriculture in the region comes from small local tributaries, meltwater from surrounding mountain ranges, and major rivers that flow through the region. Ground water is pumped primarily from deep aquifers. Surface water supplied by the Columbia basin project contributes a large portion of the irrigation supply in this region. Demands in the region include many smaller M&I demands, irrigated and dryland agricultural demands, and environmental demands.

The power sector will be addressed separately from considerations made within specific regions. The bulk of power generated in the northwest comes from hydropower dams on the Columbia River and Snake River, extending beyond the state into British Columbia, Idaho, and Wyoming, and rivers flowing from the Cascade Mountains. Runoff from the entire northwest region is captured and managed as a single source through an extensive network of dams and reservoirs. The Columbia basin water is used for power generation, although the supply must also meet the needs of migrating fish, transportation, and flood control.

The Recreation sector will also be addressed separately from considerations made within specific regions. The primary recreation group considered in this report is ski area operators, who rely on snow. A good snowpack is necessary for ski areas to operate and attract visitors.

5.2. *Identification of Supply and Demand Challenges within Regions*

North West region supplies can be threatened by low snowpack as well as below normal precipitation during the summer months. Low snowpack can result in lower ground water recharge as well as lower flows in the major rivers of the region during the later summer months. Because the area is normally wet, irrigation systems are less common and less robust than those in areas more accustomed to dealing with dry conditions year round. A dry summer season can challenge the ability of those with limited or no irrigation systems to supply enough water to meet crop needs. Dry summers and low snowpack can also pose problems for M&I suppliers and fish populations.

Central West region supplies can be threatened by low snowpack as well as below normal precipitation during the summer months. A lower snowpack will result reduced ability to fill reservoirs after the threat of winter floods subsides. A prolonged dry period in the summer or fall can challenge municipalities' ability to meet the needs of consumers in the late-summer or fall months, and at the same time meet instream flow requirements.

South West/Olympic Peninsula region supplies are capable of meeting demands in most cases; however in extremely dry years streamflows can become low and present challenges for migrating salmonids. Agricultural challenges are commonly experienced by irrigators supplied by the Dungeness River. High evapotranspiration rates can challenge agricultural infrastructure to supply water to crops in the region.

North Central region supplies are mostly from natural river flows. In much of the year this flow provides a surplus to needs of agriculture; however withdrawals by agriculture present challenges for migrating fish species. Extremely low flow levels in streams can also present challenges in meeting demands for both agriculture and M&I needs in the late summer.

South Central region supply is a combination of natural flows and water stored in the Yakima Project. In years when the snow pack is low, there can be challenges in meeting the demands of agriculture and the environment. Supply challenges are most common for agricultural water users with proratable junior water rights.

East region's supplies are diverse, as are the demands. In many cases localized shortages can occur, especially due to locally low precipitation. Surface water levels can be drawn down by agricultural uses creating challenges for fish.

The power sector relies on water supplied from the entire Columbia River Basin; however water flowing into the Columbia River from Canada provides much of the supply. Challenges of meeting demand can occur in years when snow pack, particularly snow pack in the headwater regions of British Columbia, is low.

The main recreation sector considered here, the ski area operators, rely on supply from natural precipitation, specifically snowfall. In dry years with low snowpack the ski industry suffers.

6. Primary and Secondary Impacts by Region

6.1. *Definition of "Primary" and "Secondary"*

Impacts are defined broadly in this report as the effects caused when water supplies are insufficient to meet water demand for one or more sectors. The report will discuss both primary and secondary impacts. Primary impacts are those experienced directly by the user of the water, e.g., inadequate supply may result in the reduced fruit quality for the grower, which in turn may reduce profits for the grower. Secondary impacts result from the primary impact but are separated in time and space. For instance, if grower profits are reduced throughout an entire region (primary impact), sales of farm equipment, and supplies like fertilizer, may decline (secondary impact).

6.2. *North West*

6.2.a. Agriculture

Interviews were conducted with growers of cane berries and farmers of row crops in the North West region. In recent years overall agriculture in the North West region has not been severely affected by inadequate water supplies. Because the region typically receives high amounts of precipitation between growing seasons and some precipitation during the growing season, irrigation infrastructure in the region is often absent or less robust than that found in drier portions of the state. Farmers in the region that use irrigation have found it challenging to meet crop water needs when precipitation is low for extended periods and evapotranspiration is high. This is especially true for row crop farmers that use mobile systems such as large irrigation guns. The primary impacts of drought to agriculture in the North West region are increased electricity costs for irrigation pumping and lower crop yields. Crop yield reductions are primarily experienced as a reduction in crop weight or size due to inability of irrigation systems to supply enough water. There were also reports of irrigation wells running dry in the region.

Golf courses in the region may experience reduced turf quality when municipalities impose water restrictions or in some cases due to over watering in an attempt to compensate for increased evapotranspiration.

6.2.b. M&I

The interviewee from the M&I sector indicated that no significant drought impacts have been experienced. During particularly dry years, when user demands can not be met by existing supplies, the supplier purchases water from other jurisdictions to augment supply and transfers the water through intersystem connections. The cost of this water low enough that economic impacts on the supplier are minimal.

6.2.c. Environment

Representatives from the environment sector reported that drought impacts to fisheries are most severe for long rearing species such as Coho salmon and Cutthroat trout, as well as species where the adults spend long periods of time in the river system prior to spawning. These impacts include reduced survival of juvenile fish, passage problems for adult fish migrating upstream, limited spawning habitat, increase likelihood of disease, and increased scouring of redds. Fish kills were reported to have occurred on the South Fork of the Nooksack River during previous droughts. One representative reported that impacts are most severe in low-gradient lowland streams, particularly in cases where the riparian zone is dominated by agriculture and agricultural water withdrawals are high.

6.3. *Central West*

6.3.a. Agriculture

Representatives from the green industry (landscapers and landscape plant growers and retailers) comprise the main body of interviewees from the

Central West region. None of the green sector interviewees experienced direct impacts to their growing operations due to water shortage. Interviewees from the green sector reported extreme impacts in the form of reduced sales resulting from the statewide declaration of drought.

Most clients of the green industry in Western Washington rely on M&I supply for their watering needs. Interviewees indicate that the 2005 drought declaration severely affects residential landscaping projects causing them to be cancelled, postponed, or dramatically scaled back. This reduction affected residential landscapers who install the projects and wholesale and retail nurseries that supply the products. Spring months of April, May and June are a critical period for plant sales; interviewees report that announcement of drought affect these critical sales causing many representatives from the green industry to operate at a loss for the year. Reduced sales in the green industry also result in reduced employment and reduced capital investments in this sector.

Long term restrictions of water use were identified as a potential source of job security for a portion of the landscaping sector, as the restrictions may increase sales of professionally installed irrigation systems so irrigators can better manage their water application when conservation measures are in place.

As in the North West region, golf courses in the region may experience reduced turf quality when municipalities impose water restrictions or in some cases due to over watering in an attempt to compensate for increased evapotranspiration.

6.3.b. M&I

Impacts to the M&I sector depend greatly on the level of response that is required during the particular water shortage. In general there are four levels of response to drought in local water shortage response plans: (1) advisory, (2) voluntary, (3) mandatory, and (4) emergency curtailments. On major municipality reported reaching an advisory level during the 2005 drought. Since 2000, this municipality has enacted voluntary restrictions twice. Mandatory restrictions were implemented in 1992. The main effects of these restrictions is that consumers are affected by the reduction in available water and watering of lawns and gardens may need to be discontinued and lawns allowed to turn brown. The municipalities that implement the restrictions are affected economically by lost revenue without reductions in cost. Municipalities also incur additional cost to manage drought response program, leading them to impose surcharges to recoup costs.

6.3.c. Environment

Impacts to fisheries in the region occur during many years due to M&I diversions of surface water and the alteration of natural flows in watersheds used to supply M&I demands. As described for other regions, impacts are magnified by drought conditions. In years when surplus water supply is available to meet M&I needs, natural flows may be supplemented with water stored in reservoirs to enhance fish habitat. Impacts to fisheries in the region are best discussed by season.

In the spring, juvenile fish depend on the spring freshet, when the bulk of the snowpack melts, to transport them out to sea. This outmigration can be affected in drought years as flows below reservoirs are reduced in favor of increased summer storage. Lower spring freshets reduce survival of migrating juvenile fish as they are more at risk to predation during their migration. One migration of special concern in the region is the migration of Sockeye salmon out of the Cedar River watershed. Despite drought conditions in 2005, one interviewee indicated that outmigration survival rates were better than average. Allowing more natural spring freshets aids downstream migration and reduces impacts to fisheries, but uses water that may otherwise be conserved for use in the late summer. This increases impacts in the M&I sector.

In the summer, drought results in lower flows for resident fish, rearing juvenile fish, and those adults that migrate upstream in the spring. During drought years minimum target flows in rivers are reached earlier. These lower levels may not meet operating criteria for some of the fish ladders in the system. The need for increased monitoring and maintenance of fish devices, including fish ladders and fish screens, increases during drought. Increased stress from low flow conditions described above results in increased prespawn mortality.

As the fall season approaches, spawning flows must be set at levels that can be maintained until spring. This is necessary to ensure that fish will not spawn in areas that are at risk of being dewatered during the late fall and winter periods. This has the potential to affect spawning in two ways. Spawning can be confined to the main channel of the river making redds more susceptible to scouring during winter floods. If fall rains are not heavy or timely enough to provide water to cover redds throughout the fall after spawning, redds may dry out.

Hatcheries in the region are also affected by drought. In years when water supply is particularly low, flows may need to be supplemented by pumping. This pumping incurs additional costs. The cost is highest with fish that rear throughout the summer when natural supply is lowest.

6.4. *South West/Olympic Peninsula*

6.4.a. Agriculture

Interviews were conducted with growers of cane berries, representatives from the dairy farming industry, and Dungeness River irrigators. Overall agriculture in the southern portion of this region has not been severely affected by lack of surface water or ground water supply. Because the southern area typically receives high amounts of precipitation in the winter months and some precipitation during the growing season, irrigation infrastructure in the region is not widespread or as robust as that found in drier portions of the state. This is compounded by the small nature of many of the berry farms in the region. Many berry owners don't have the capital to invest in increased irrigation capacity. Berry farmers without robust irrigation systems are also affected when evapotranspiration losses are high. Impacts experienced include increased frost damage and when the soil profile is dry, and reduced fruit size and quality.

Most surface water irrigators near Sequim, WA are supplied by water from the Dungeness River. Because the river is used heavily for irrigation, this supply can be strongly affected by drought conditions. The 2005 drought resulted in the lowest flows in the 78 years of recorded streamflows. Irrigation districts in this area supply a wide variety of agriculture including livestock, cruciferous row crops (cabbage, broccoli, brussel sprouts, and cauliflower) all of which are grown for seed production, barley and bent grass seed production, bulbs, Christmas trees, hay, and organically grown apples and blueberries. Many of the seed crops are only minimally affected by water shortages. Hay crops, apples, and blueberries experience the most extreme impacts. On interviewee estimated that profits from these crops may be affected by as much as 30 percent during drought.

Dairy farmers who purchase feed on the open market experience large impacts during drought. Drought increases the cost of feed, thereby increasing the costs to produce milk.

6.4.b. M&I

One interview was conducted with a WRIA representative to account for multiple municipal impacts in the region. No physical impacts to municipal water supplies were reported. The only impact cited by the representative was potentially reduced ability of municipalities in-need to procure new water rights.

6.4.c. Environment

The WRIA representative did not specifically report any environmental impacts from drought in the southern portion of this region. Migrating fish species are affected in the Dungeness River in the late summer and early fall;

however, these impacts have lately been minimized by cooperative irrigators, who have reduced diversions to provide instream flows.

6.5. *North Central*

6.5.a. Agriculture

Representatives from the tree fruit industry were the primary interviewees in this region. Interviews conducted with the dairy and cattle grower sectors can also be considered valid in this region.

According to Weekly Drought Reports produced by the Washington Department of Ecology, and based on information from the US Geological Survey (USGS), several rivers in the North Central region, including the Wenatchee, Okanogan, Stehekin, Entiat, Chiwawa, and Similkameen rivers, reported record-low daily streamflows during the 2005 growing season. Several of these rivers recorded daily record-low flows over many months.[5] Some irrigation districts imposed restrictions on water usage and early cut off times for water users. Several shallow wells also reported running dry. Despite water restrictions, record-low flows, and limited water storage capacity in the region, no major impacts to tree fruit were reported. One processor of fruit even reported that the North Central region produced an increased share of the fruit crop in 2005, up to 42% from 38% in 2004. (It should be noted that this increased share of production could be due to decreased production in other regions, rather that particularly high production in the North Central region.)

Representatives from the cattle and dairy industry both reported increased feed cost as the primary impact to production. The cattle industry also reported increased costs for moving animals when rangeland water supplies run dry. In some cases the water supply ran dry before forage was used up.

6.5.b. M&I

Representatives from WRIA groups reported that some municipal water intakes, including the municipal supply for Cashmere were dangerously close to being exposed by, but no impacts were reported. Drought is reported to increase the perceived conflicts between municipal and agricultural demands in the region.

6.5.c. Environment

Several representatives from the environment sector were interviewed regarding impacts on fish in streams in the North Central region. In general

5 Washington Department of Ecology (WDOE), 2005. *Ecology News 05-128, Ecology News, 05-134, Ecology News 05-185, Ecology News 05-221, Ecology News 05-243*. Retrieved February 27, 2006, from http://www.ecy.wa.gov/news/news2005.html

fish experience drought-like conditions in the region on most years due to dewatering of streams by agricultural and M&I diversions. In unregulated streams these impacts include reduced size and quality of habitat for resident fish throughout much of the year as well as increased water temperature and reduced flow for migrating fish in the late summer and fall. This can result in increased mortality of resident fish and increased prespawn mortality of returning fish. Effects are magnified for Summer Chinook Salmon, which return to the streams earlier but don't spawn until the fall. Lake Osoyoos (and Lake Okanogan in British Columbia), contributes a large quantity of high temperature water to the river. In drought years the effects of this warm water are great because local tributaries are nearly dewatered by agricultural diversions, leaving very little cold water supply for the Okanogan River. In many years this causes the death or hundreds of Summer Chinook Salmon and Sockeye Salmon. The impacts were particularly severe in 2004. Impacts were also large in 2001 and 2005. These low flows late in the season can also limit access to spawning habitat. In general drought exacerbates existing problems, causing them to begin earlier, last longer, and become more severe.

6.6. *South Central*

6.6.a. Agriculture

Agriculture in the South Central Region includes irrigated and dryland farms. The vast majority of irrigated acres in the region receive water from the Yakima Project, operated by the US Bureau of Reclamation (USBR), which supplies water to 464,000 agricultural acres during years with full supply. Some Groundwater is increasingly pumped in the region. Users of Yakima Project water can be divided into two categories: those with senior water rights (non-proratables) and those with junior water rights (proratables). During drought years, supply to the proratable users can be restricted while non-proratables are likely to receive all of their allotted water supply every year. During the 2005 drought the proratable water users in the South Central region experienced some of the most widespread and severe drought impacts in the state. Impacts varied within the region from individual to individual. Many of the proratable water users in the region grow tree fruit and other perennial crops such as grapes and hops. There are also many hay and alfalfa farmers. Row crops are also grown in the region.

Proratable Water Users:

In early March and throughout the irrigation season, the USBR issues estimates of the Total Water Supply Available (TWSA) for the basin as mandated by a federal court order. The TWSA is an estimate of the amount of water available to meet all needs, including fish flows, in the Yakima River system for the upcoming irrigation season. Impacts to various user groups will vary depending upon decisions in response to prorationing estimates. Initial estimates given in March 2005 by the USBR were for 34 percent of normal supply to proratable users. The actual prorationing percentage at the end of the irrigation season was 42 percent of normal. [6]

The statewide declaration of drought makes several tools available for proratable water users to minimize the impacts of drought when faced with potentially low water supplies. Affected users may apply for emergency permitting of backup groundwater wells or drilling of new backup groundwater wells. Those who chose to execute these groundwater options incurred additional costs for permitting and drilling. Proratable users may also apply to lease additional water rights from non-proratable users. One 100 percent proratable irrigation district reported increasing their actual 2005 water supply from 42 percent to 49-51 percent using water purchased from non-proratable users.

Farmers with different crops or fewer perennial crops had more flexibility to respond to the drought and therefore experienced fewer impacts to crop quality. Farmers who farmed both row crops and perennial crops could fallow the row crops to make water available on their perennial crops. Row crop revenue was sacrificed in exchange for additional security of perennial crops which have a much higher replacement cost.

Proratable water users reported impacts in addition to reduced fruit production including increased costs for crop insurance, reduced ability to meet agreements to supply world markets, and impacts to long and short term financial planning. Most irrigators reported increased irrigation costs during summer.

Crop impacts will be discussed by crop type below.

Tree Fruit – Tree fruit requires several types of water during the year. In the early season frost water is applied to the ground beneath trees to prevent frost damage to the crops, water is then necessary throughout the summer to support fruit development, and finally during especially hot sunny days cooling water is applied to the fruit (mainly apples) to prevent damage from the heat and sun. The initial low proration figures led some districts to stop water supply during the spring in order to conserve supply for later in the year. One grower of cherries reported loss of an entire 2005 cherry crop (50,000 lbs in 2004) due to unavailable frost water in a field that didn't have a

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USBR (United States Bureau of Reclamation), 2002 (With 2005 edits). *Interim Comprehensive Basin Operating Plan for the Yakima Project, Washington (November, 2002)*, United States Bureau of Reclamation, Upper Columbia Area Office, Yakima, WA, 434 pp.

groundwater backup supply available. Four interviewees reported that the lack of available cooling water affected fruit quality, reducing the value per unit of fruit produced. Growers also reported increased pests and disease as a result of past droughts. Several tree fruit growers reported increased costs of managing irrigation systems during drought.

Hops – Hop growers reported some production impacts.

Wine and Juice Grapes – Minor impacts were reported by winegrape growers. One interviewee reported marginal water supply during the bud break period which may have affected fruit development. Wine grapes require much less water than tree fruit, so wine grape growers can make due with less supply. Juice grape operations may have been affected more significantly. One interviewee estimated that some juice grape growers may have experience a 10 to 20 percent reduction in production.

Row Crops – One farmer reported large impacts to row crops. Many farms reported fallowing fields that are normally used for row crop production which led to less row crop production.

Perennial Alfalfa and Hay – Interviewees reported reduced cuttings of hay and alfalfa due to reduced water supply.

Other impacts:
Cattle farmers incurred additional costs to move cattle when water supplies ran dry before forage ran out. Dairy and cattle farmers both reported increased feed prices.

Two dryland wheat farmers from the region reported greater than 70 percent reductions in crop yields during extreme drought.

Due to the large impact to proratable water users, interviewees from the South Central region described more severe secondary impacts than interviewees from other regions. These impacts included difficulty getting financing due to uncertainty of water supply, reduced equipment sales, reduction in labor force, erosion of the tax base in the region, and lost piece of mind reported by users of proratable water. One farmer attributed failure of a school bond due to revenue reductions caused by previous droughts. Another farmer reported that he was debating whether he would continue to encourage his children to pursue farming, or whether he should sell the farm and possibly relocate to an area with a more secure water supply.

6.6.b. M&I

No interviewees reported impacts to M&I water supplies.

6.6.c. Environment

Many interviews were performed with representatives from the Environment sector in the South Central Region. Impacts to fisheries in the region occur on an annual basis due to agricultural diversions of surface water and changes to natural flows. As described for other regions, impacts are magnified by drought conditions. Impacts to fisheries in the region are best discussed by season. In the spring, juvenile fish depend on the spring freshet to transport them out to sea. This outmigration can be severely affected in drought years as flows below reservoirs are reduced earlier to increase summer storage. A lower volume freshet reduce survival of migrating juvenile fish as they are more at risk to predation during their migration to the Columbia. In some cases fish are manually transported from Prosser Dam down to the Columbia River to avoid a particularly shallow slow moving portion of the river. Water may be released from storage to aid in downstream migration, but the volume of water released would probably be much less than that coming from a typical freshet. One interviewee reported that fish do not respond as well to these releases than they do a natural freshet. Because releases would come from water that might otherwise be available to junior water right holders, impacts to the agricultural sector would increase.

In the summer, drought results in lower flows for resident fish, rearing juvenile fish, and those adults that migrate upstream in the spring. During drought years minimum target flows in rivers are reached earlier. These lower levels do not meet operating criteria for some of the fish ladders in the system. In addition lower levels are accompanied by increased temperature and increased sediment and pesticide loads. In the Yakima system minimum target flows are 300 to 600 cfs over Sunnyside Dam, depending on total water supply available. Monitoring and maintenance of fish devices, including fish ladders and fish screens increases during drought. In some years fish are transported over impassable sections of the system, further increasing maintenance costs. In other years fish are simply not allowed into sections of the river for fear of stranding and dewatering of redds in upper tributaries, reducing available spawning habitat.

Fish migration is also affected in the fall. Increased stress from low flow conditions described above results in increase prespawn mortality. If low flows continue into the spawning period, spawning can be confined to the main channel of the river. This increases risk of scouring of redds during winter floods. Extremely low reservoir levels in the fall can also affect spawning of resident Bull Trout. In low water years access, to Bull Trout spawning habitat in tributaries flowing into reservoirs can be cleared manually using heavy equipment, which incurs high costs.

As the fall season approaches spawning flows must be set at levels that can be maintained until spring. This is necessary to ensure that fish will not spawn in areas that are at risk of being dewatered during the late fall and winter periods. This has the potential to affect spawning in two ways. Spawning can be confined to the main channel of the river making redds more susceptible to scouring during winter floods. If fall rains are not heavy or timely enough to provide water to cover redds throughout the fall and winter, redds may dry out. Proper management of pulse flows from reservoirs is critical to minimize impacts.

6.7. *East*

6.7.a. Agriculture

Agricultural uses of water in the East region is very diverse. The impacts of drought can be equally diverse. Farmers that irrigate with water from the Columbia River, including from the Columbia Basin Irrigation Project, are seldom affected by water shortage. In some cases in the past, water has been purchased back by the Bonneville Power Administration (BPA), both to reduce load and return water to the river for additional generating capacity. No impacts from drought were reported from the Columbia Basin Project irrigators. Farmers that irrigate with ground water are seldom affected by lack of supply. All irrigation operations are affected on dry hot summers by additional pumping costs and challenges to meet increased losses from evapotranspiration. The primary impacts in the agricultural sector were reported by the dryland farmers of the state. These farmers rely solely on precipitation, both rain and snow, to produce wheat, barley, dry peas, and other dryland crops.

The primary impacts reported were reduced yields during drought. Reductions of 74 percent were reported by one farmer, while reductions between 20 and 40 percent were more common. These yield reductions are also much localized. Farmers reported that a 20 mile separation between fields could result in a 60 percent difference in production, making drought very difficult to predict. Because dryland farming operations rely on water stored up to six feet deep in the soil profile, impacts of drought can be reflected in reduced yields for several years.

Secondary impacts within the region were described as reduced cash flow. Farmers that were affected by drought also reduced purchasing in the community, particularly of new farm equipment.

Specific impacts were also reported in WRIA's 32 and 34 (Walla Walla and Palouse). Both WRIA's reported increased cost to agriculture for drilling of additional wells. WRIA 32 reported a reduction in cuttings of hay and other grasses. WRIA 44 reported that the aquifer in the area is being drawn down, which can be exacerbated by drought. Impacts of drought are magnified across the state by increasing costs of fuel and nitrogen fertilizer. WRIA 50 (Foster) reported that drought has increased the conflict between exempt and non-exempt ground water users and that agricultural development in Moses Coulee has been halted.

6.7.b. M&I

The primary impact of drought to the M&I sector is restriction on growth. Restrictions on growth were reported in WRIA's 32, 44 (Moses Coulee), and 50.

6.7.c. Environment

Environmental impacts of drought were reported by several interviewees. Fish stranding was reported in WRIA 32. Low streamflows were reported in WRIA's 32, 35 (Middle Snake), 44, and 50. Increased stream temperatures were reported in WRIA 35.

6.8. *Power*

The power sector reports severe impacts from past droughts. The impacts are not necessarily caused by the same droughts that affect other sectors of the state. The majority of hydroelectric power generated in Washington comes from flows in the Columbia River and other Cascade rivers, therefore shortages of the high mountain snowpack has the greatest impact on hydropower generation. Since water is the fuel for hydropower, water shortage is equivalent to a fuel shortage. The most recent major shortage in the Columbia system was in 2001, when BPA declared a power emergency in conjunction with power outages being experienced in California. The level of impact is directly related to the reduction in flow. If power generation is reduced greatly enough, the impacts can be severe. Strategies for meeting demand in drought years are each accompanied by additional costs. These strategies include paying major direct service consumers, such as aluminum smelters, to stop production in what is know as industry buy back; buying additional power from smaller generation plants in the region; and paying irrigators, primarily those that use water from the Columbia Basin Irrigation Project not to irrigate.

Power production entities have agreements to supply a certain amount of power to retailers. If supply is low enough these agreements can't be met by hydropower generation alone. This requires the producer to purchase power from out of the region or from more expensive production sources such as small natural gas plants. In 2001 diesel generation plants were even used to meet local demands in Clark County. Power was also purchased on the open market. These additional costs can be extremely high and can jeopardize the ability of producers to meet treasury payments. Some utilities also increased their debt to revenue ratio during the 2001 drought, which increases the interest rate paid on loans, making future investments in capital more expensive. The increased costs of power supply and increased expenditures by utilities in 2001 resulted in rate increases for customers during subsequent years.

The increased costs of power supply and increased expenditures by utilities in 2001 resulted in rate increases for customers during 2001 as well as in subsequent years.

The operation of more thermal power sources and emergency diesel generators also increased the amount of air pollution released by the power sector.

Declaring a drought emergency in 2001 enabled BPA to curtail fish spill requirements, which resulted in additional costs to transport fish around dams as well as likely impacts to fisheries.

6.9. *Recreation*

The recreation sector was represented primarily by ski area operators. The primary impact to the ski area operators is caused by lack of snow. The lack of snow reduces the number of days ski areas are able to operate, thereby reducing the overall number of visitors the ski area attracts. Data on ski area visits in the Pacific Northwest were obtained from Pacific Northwest Ski Areas Association (PNSAA). These data indicate that during the low snow winter of 2004-2005 ski areas in Washington state averaged 69 percent fewer visits than the 10 year visitor average.[7] This dramatically reduces revenue brought in by ski areas. It also reduces the need for labor at ski areas causing lay offs. Secondary impacts are experienced in surrounding communities that receive business from skiers as well as more distant vendors of ski equipment. Ski areas also reported a reduction in capital investment at the ski area in years following low visitation. These reduced investments also have secondary impacts on contractors who would normally perform the work.

For information on impacts to the golf industry, see impacts listed in the Agricultural sector in North West, Central West, and South West regions.

7. Economic Assessment of Impacts

7.1. *Description of Economic Impacts*

Few interviewees were able to provide economic quantification of impacts. In some cases interviewees quantified impacts as percentage decrease in earnings or revenue. In other cases estimates were given for reduced value per unit of product. Where feasible estimates provided by interviewees were expanded with additional

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[7] Pacific Northwest Ski Area Associations. (2005). [Pacific Northwest annual ski area visits, 1995-2005]. Unpublished raw data.

calculations using current market values to determine lost revenue per acre. In some instances it was possible to use reported increases in costs or reductions in sales to reflect total costs to a single average operation or to estimate reduced revenue across an entire industry.

7.2. *North West*

7.2.a. Agriculture

No interviewees were able to quantify the additional electricity costs for pumping during drought years. One farmer reported approximately 20% reduction in earnings due to reduced crop size. Several farmers also reported additional labor and capital costs resulting from increased need for irrigation.

7.2.b. M&I

The increased cost of purchasing additional supply water during drought is the only economic impact identified by this sector. The interviewee did not indicate that this increased cost had significant effects on the supplier's net revenue.

7.2.c. Environment

No interviewees were able to quantify the cost of drought impacts to the environment sector.

7.3. *Central West*

7.3.a. Agriculture

The green industry reported severe profit reductions during drought years. One interviewee reported $50,000 in profit lost due to the 2005 drought declaration. The same interviewee indicated that this quantity of lost profit correlates to $200,000 in lost revenue out of $2.5 million in average revenue, an eight percent reduction of revenue. Another interviewee indicated a 20 percent reduction in supply sales and a 20 percent reduction in plant sales. This top 20 percent is reported to be the most critical portion for generating profit during a given year.

7.3.b. M&I

One municipality identified approximate costs for three response levels used in the past: Advisory ~ $3 million, Voluntary ~ $11 million, Mandatory ~ $15 million. These costs include increased program management costs as well as lost revenue due to reduced usage. No interviewees were able to identify the cost to consumers for forgone usage.

7.3.c. Environment

No interviewees were able to quantify the cost of drought impacts to the environment sector.

7.4. *South West/Olympic Peninsula*

7.4.a. Agriculture

Reduced quality and quantity of fruit causes economic impact; however, no interviewees were able quantify economic impacts due to drought.

7.4.b. M&I

No impacts were reported from the M&I sector.

7.4.c. Environment

WRIA representatives from this region didn't identify any environmental impacts resulting directly from drought.

7.5. *North Central*

7.5.a. Agriculture

The primary impact to growers was increased costs to maintain and control irrigation systems. The cattle and dairy industries reported that feed costs increased from an average of $65-85 per ton in 2004 to $85-110 dollars per ton in 2005. Each cow consumes between two and three tons of feed per year, which translates to roughly $70 dollars per cow per year cost increase. The average dairy operation in Washington has roughly 300 cows, so for operations relying on purchased feed, the expected increased feed cost for 2005 is approximately $21,000 per dairy farm.

7.5.b. M&I

No impacts were identified in this sector.

7.5.c. Environment

The economic value of environmental impacts, including those to fish, are extremely difficult to quantify. No interviewees offered data on economic impacts to fish.

7.6. *South Central*

7.6.a. Agriculture

Proratable water users in the region experience extreme impacts from drought. Few interviewees were able to quantify direct cost of impacts. Several identified reduction in fruit quality as the main impact and were able to quantify losses as value per bin of apples. High quality fruit allows production of a larger number of quality packs (most marketable fruit) per bin. Poorer fruit quality can be translated into lost revenue per bin. Table 7.1 conveys the economic impacts identified by tree fruit growers.

One interviewee identified the cost of drilling backup wells as $200,000 to $300,000 per well. This figure does not account for increased pumping costs incurred during drought years.

The cattle and dairy industries reported that feed costs increased from an average of $65-85 per ton in 2004 to $85-110 dollars per ton in 2005. Each cow consumes between two and three tons of feed per year, so this increased cost translates to roughly $70 dollars per cow per year cost increase. The average dairy operation in Washington has roughly 300 cows, so for operations relying on purchased feed, the expected increased feed cost for 2005 is approximately $21,000.

One irrigation district identified increased expenditures of approximately $2.8 million dollars to purchase water right from more senior irrigation districts. Half of this cost was met by drought relief funding provided by the state.

Dryland wheat farmers in the region reported reductions of over 70 percent. Table 7.2 shows the impacts of drought to interviewees expressed as dollars of revenue lost per acre assuming a $3.00 per bushel price for wheat.

Table 7.1 Impacts to Proratable Water Users

Crop	Impact To Production
Apples	Reduced Number of Quality Packs per Bin - Average is 20; Only 15 in 2005
Apples	10% reduction in Apple Quality - $65 lost revenue per bin
Apples	Average of $130 - 150 per bin; Reduced to $110 per bin in 2005 $50,000 dollar loss in 2005
Juice Grapes	10-20 % reduction in production

Table 7.2 Impacts to Dryland Wheat (Assumed Wheat Price of $3.00/bushel)

Location (County)	Crop	Average Yield (Bushel/Acre)	Yield During Extreme Drought (Bushel/Acre)	Percent Reduction	Lost Revenue ($/Acre)
Paterson, WA (Benton County)	Winter Wheat	31	25	19%	18
	Winter Wheat	31	8	74%	69
Bickleton, WA (Yakima County)	Winter Wheat	30	8	73%	66

7.6.b. M&I

No economic impacts were identified in the M&I sector.

7.6.c. Environment

Interviewees from the environment sector were not able to quantify the impacts of drought to the environment economically. These impacts can be described qualitatively as increased costs for monitoring and maintenance of fish devices, increased costs to transport fish, loss of individual fish, and increased costs of excavation to provide access to tributaries in that become inaccessible due to reservoir drawdown. Costs to fish are difficult to quantify for many of the same reasons that most natural resources are difficult to evaluate economically. On interviewee offered several examples of different philosophies for determining the value of one fish:

- recreational value of one fish caught = $200-800
- cost of lost generation and fish devices for each returning salmon = thousands of dollars
- value of tribal way of life lost = invaluable
- value of lost commercial asset to tribes = very high
- value of fish meat contained in one fish at the grocery store = several dollars

7.7. *East*

7.7.a. Agriculture

Agriculture is greatly affected economically by drought. Operations that use irrigation experience increased pumping costs. Dryland operations are particularly hard hit. Production can be reduced by over 70 percent. Table 7.3 conveys the impacts of drought to interviewees as dollars of revenue lost per acre assuming a $3.00 per bushel price for wheat.

Table 7.3 Impacts to Dryland Wheat (Assumed Wheat Price of $3.00/bushel)

Location (County)	Crop	Average Yield (Bushel/Acre)	Yield During Extreme Drought (Bushel/Acre)	Percent Reduction	Lost Revenue ($/Acre)
Dayton, WA (Columbia County)	Winter Wheat	100	27	73%	219
	Spring Wheat	60		100%	180
	Barley			50%	
	Garbanzo Beans			50%	
	Dry Peas			75%	
Asotin, WA (Asotin County)	Winter Wheat	75	57	24%	54

Ritzville, WA (Adams County)	Winter Wheat	43	36	16%	21
Coulee City, WA (Grant County)	Winter Wheat	55	30	45%	75
Douglas County	Winter Wheat	48	32	33%	48

7.7.b. M&I

No interviewees were able to quantify M&I impacts of drought.

7.7.c. Environment

No interviewees were able to quantify environmental impacts of drought.

7.8. *Power*

Interviewees recommended calculating the raw cost of lost generation from the Northwest regional hydropower system during 2001 by multiplying an estimate of the total lost generation (5304 MW) by the average cost of power during 2001 ($124.5 per MW). The total lost generation is estimated by using the total volume of water available for generation in 2001 (79.3 M acre•ft) and interpolating between the generation on an average year (15800 MW from 133 M acre•ft of water) and the generation on a critical water year (11780 MW from 92.3 M acre•ft of water). Figure 7.1 displays this interpolation graphically and Table 7.4 displays the estimates used to calculate the 2001 generation.

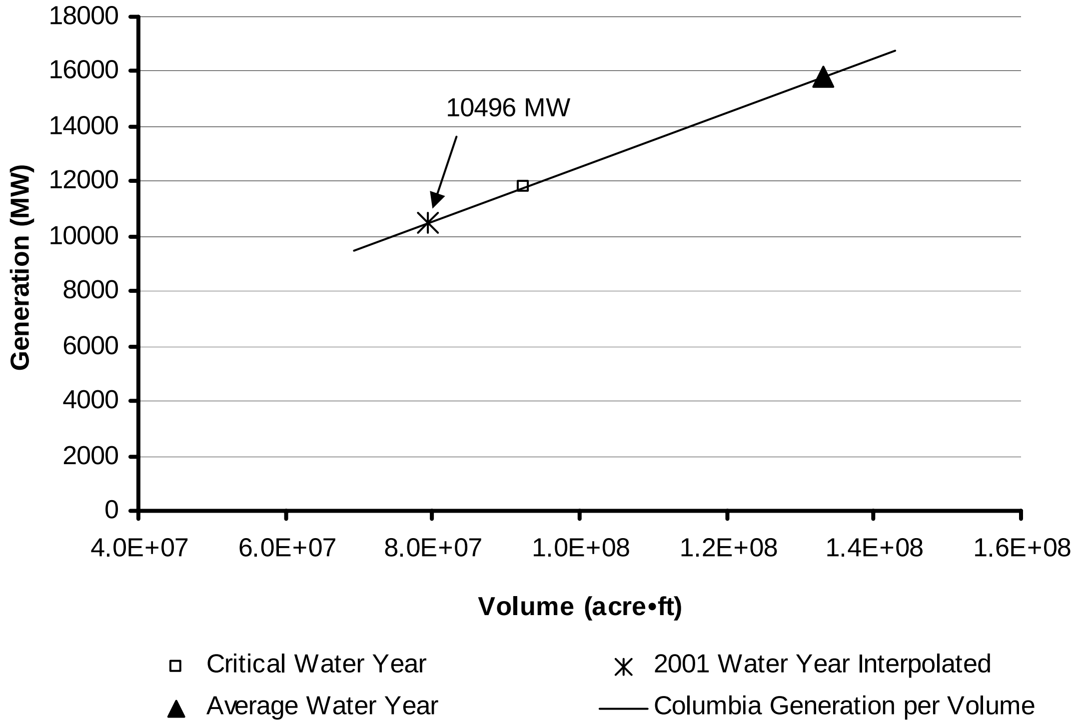

Figure 7.1 Northwest Regional Hydro-Generation – Average Water Year, Critical Water Year (1937), and 2001 Water Year (Interpolated)

Table 7.4 NW Region Hydro-Generation - Critical Water Year, Average Water Year, and 2001 Water Year		
Water Year	**Generation (MW)**	**Columbia Volume Near The Dalles, OR (acre•ft)***
Critical Year	11780	92300000
Average Year	15800	133000000
2001	10496**	79300000
2001 Average Price per MW per hr ($)	124.5***	
*Volumes for the entire water year **Interpolated based on 2001 volume and historical generation/volume ***Price based on 2001 monthly spot market sale prices at the Mid-Columbia market point		

Interviewees recommended using this estimated generation to determine the raw cost of lost generation from the Columbia River system during the 2001 drought. To do this the generation rate was multiplied by the average 2001 power price and the total amount of time in the year. Raw lost generation cost during 2001 was calculated to be roughly 5.8 billion dollars for the entire Northwest region (Table 7.5).

Table 7.5 Estimated Raw Lost Generation Cost During 2001 Drought (Departure from Average Year Generation)*	
Average NW Region Hydro-Generation Value $	17,231,796,000
2001 NW Region Hydro-Generation Value $	11,447,115,364
Departure From Average $	**-5,784,680,636**
Lost Generation in Washington $ (60%)	**-3,470,808,382**
* All generation values based on 2001 average price in Table 7.4	

Interviewees indicated that estimating the percentage of this power used by Washington is difficult; however, approximately 60 percent of the regional federal power supply is consumed by Washington, so this percentage was applied to the total regional generation, yielding a total reduction in hydro-generation for the state of approximately $3.5 billion. This method for estimating the total cost of the drought has several flaws that likely result in an overestimate of the actual figure. The first flaw is that this method uses an annual price that is an average of the monthly spot market prices and not a weighted average that considers monthly variations in generation. The second flaw is that this method applies the 2001 prices to both water years. This doesn't account for the affect that the drought had on power prices during 2001, and likely magnifies the calculated economic cost of the drought. Despite these discrepancies, this method was chosen to provide an estimate of the scale of the 2001 drought impacts to the power sector.

Generators must compensate for this reduced generation by purchasing additional power on the open market, increasing capacity for non-hydro-generation, purchasing power back from consumers, or implementing conservation measures. During 2001 BPA purchased $2.3 billion of replacement power, including $861 million in direct service industry buyback, to replace lost hydro-generation. The aluminum plant closures caused by the industry buyback resulted in loss of jobs and revenue in the state, though it is unclear whether the permanent closure of several aluminum plants is a result of the drought. BPA also spent $25 million paying Columbia Basin Project irrigators not to pump water from the Columbia River. Many utilities enacted rate increases or surcharges to pay for additional power or building/reopening generation facilities (Table 7.6). Those that chose not to increase rates were forced to borrow money, which increased their debt to revenue ratio, making it more expensive for these utilities to borrow money in the future. Table 7.7 lists some of the specific costs of the 2001 drought to the hydropower sector.

Table 7.6 Electric Rate Increases Enacted or Announced by Washington Utilities, 7/00-7/01* [8]					
Utility	**Residential**	**Commercial**	**Industrial**	**Average**	**Date**
Cowlitz Co. PUD**	29.00%	23.10%	31.60%	30.20%	10/1/2000
Tacoma Power (1)	43.00%	58.00%	75.00%	61.50%	12/20/2000
Pacificorp	3.00%	3.00%	3.00%	3.00%	1/1/2001
Grays Harbor Co. PUD**	19.00%	19.20%	26.40%	21.10%	1/1/2001
Snohomish Co. PUD	33.00%	38.00%	41.00%	35.80%	1/1/2001
Seattle City Light (1)	9.30%	5.30%	7.00%	10.40%	1/1/2001
Clark Co. PUD (1)	20.50%	25.00%	34.00%	24.10%	1/15/2001
Seattle City Light (2)	18.00%	19.00%	19.00%	18.60%	3/1/2001
Okanogan REA**	6.70%	8.70%	-	7.50%	4/1/2001
Okanogan PUD**	29.90%	27.40%	32.80%	30.00%	4/1/2001
Peninsula Power & Light**	26.50%	28.10%	42.80%	27.00%	4/1/2001
Seattle City Light (3)**	8.30%	9.40%	9.60%	9.00%	7/1/2001
Clark Co. PUD (2)	15.50%	18.20%	26.80%	20.00%	8/1/2001
Tacoma Power (2)**, ***	-26.00%	-42.00%	-52.00%	-41.50%	9/30/2001

* All percentages based on 1999 rates. Rate increases gathered from selective industries survey conducted by OTED staff and from media reports. List may not be comprehensive.
** Rate increase for specific customer classes are estimates.
*** Partial repeal of previous surcharge.

Table 7.7 Hydropower Sector Costs to Purchase Additional Power or Reduce Demand in the Northwest Region	
Adaptive Measure	**Cost ($)**
Total BPA power purchases (Including industry buyback)	2.3 billion
Industry buyback	861 million
Pay agriculture not to Irrigate (Costs for Columbia Basin Project irrigators only)	25 million
Loss of jobs associated with aluminum plant closures	Undetermined
Increased power rates across much of the state	Undetermined
Increased debt to revenue ratio for some power providers	Undetermined
Reduced fish spill	Undetermined
Installation of new generation	Undetermined

[8] Washington Office of Trade and Economic Development, August 7, 2001. *Draft Energy Q&A: The Sequel,* 11 pp.

Table 7.7 Hydropower Sector Costs to Purchase Additional Power or Reduce Demand in the Northwest Region	
Adaptive Measure	**Cost ($)**
Increased air pollution related to new generation	Undetermined

The power sector reports that the cost of lost production by meeting fish flow demands are inseparable from the lost production due to drought. This is because meeting fish requirements necessitates spilling extra water from the reservoirs; spilled water is unavailable for production. In years when supply is plentiful this impact is low; in years of drought this impact can be great. The ten year average annual cost of lost production from meeting fishery needs in the Columbia and Snake system is estimated to be $300 million per year. Despite fish spill curtailments, this cost escalated to approximately $1 billion during 2001.

By declaring an energy crisis in 2001 BPA was able to curtail some of the spillage requirements for fish. The cost of this impact on Columbia River fisheries has not been quantified.

7.9. *Recreation*

Assuming a lift ticket price of $40 and a total visitor reduction of 1,099,569 (comparing 2005 visitation to the 10 year average)[7], ski areas in Washington lost an estimated $43,982,776 in revenue due to the 2005 drought. This does not include lost revenue from rentals and restaurants or lost revenue in the nearby communities.

Phase 2: Vulnerability Assessment, Lessons Learned, and Information and Resources to Reduce Vulnerability

8. Analysis of Drought Vulnerability and Adaptive Capacity

8.1. *Vulnerability*

Vulnerability, in this study, will be defined as the susceptibility of a water user, a region, or a sector to drought hazard. The severity of drought hazards is based on the duration, magnitude, and spatial extent of drought impacts. Vulnerable sectors will be identified based on results of the impacts assessment performed in Phase 1 of this project. Vulnerability will consider two main factors: (1) frequency and severity of previous drought impacts, and (2) likelihood and severity of future drought impacts. In addition, adaptive capacity and the ability to mitigate impacts will be considered in the assessment of vulnerability.

8.2. *North West*

8.2.a. Agriculture

Prior impacts of drought to the agricultural community were described as minor. The primary challenge in meeting crop water demands during drought occurs due to limitations of existing irrigation systems or lack of irrigation systems. Members of this sector who rely on irrigation to supplement precipitation are the most vulnerable to drought. Farmers may improve their ability to cope with drought by predicting increasing plant demands in advance and making existing irrigation systems more robust.

When making decisions regarding row crops, one farmer reported planting crops in soils that have better moisture retention properties when drought is expected, though this may not be a viable option for some farmers.

Drought affects dairy farmers in the region by reducing production of feed onsite, leading to increased costs for feed if they want to maintain herd size. Dairy farmers have limited capacity to adapt to increases in feed prices.

Golf courses in the region are especially vulnerable to use restrictions in cases where water is obtained from a purveyor. Golf courses have a considerable amount of adaptability when dealing with water shortage, including prioritizing watering locations, altering watering methods, and modifying horticultural practices. Interviewees from the golf course industry report that golfers are more accepting of dry hard grass than flooded soggy turf, further enhancing adaptive capacity of courses. The primary impact reported from droughts is over-watering resulting from overcompensation for increased evapotranspiration.

8.2.b. M&I

The interviewee from this sector reported only minimal impacts from previous droughts. The interviewee indicated that all previous demands have been met using system supply and intersystem water transfers. No conservation orders have been issued in the past. The interviewee also indicated that the jurisdiction has plans to improve system reliability by drawing water from a more reliable main-stem river source. Vulnerability of this sector to drought is currently low.

8.2.c. Environment

The environment sector is vulnerable to impacts caused by low streamflows. The naturally low streamflows that occur during drought are magnified by surface water withdrawals by agriculture. Interviewees indicated that the main stem river habitats are least likely to be affected by drought and that low gradient lowland streams and headwater mountain streams are most vulnerable habitat types. Fish species that spend a long time rearing and species that return to the river systems long before spawning are the most vulnerable species. Adaptive capacity is limited in the environment sector. Fisheries agencies may undertake projects to improve fish passage, such as removing obstructions in headwater streams or channelizing lowland streams with hay bales and plastic sheeting, to reduce fisheries impacts.

8.3. *Central West*

8.3.a. Agriculture

The green industry reports severe impacts from drought during previous years. In this unique case, the green industry is most vulnerable to the expectation of drought by customers during the spring, in addition to actual shortages during the summer. The green industry cannot exert control on operations of municipal supply. When drought is anticipated, they can increase efforts to ensure that potential customers form their water supply expectations on accurate information from municipalities, rather than exclusively from perceptions (from the media).

Because nurseries plant much of their product several years in advance, they have limited adaptive capacity other than scaling back onsite operations when reduced sales are expected. Retail nurseries and residential landscape companies may adapt to drought by reducing labor costs and purchasing. These labor and purchasing reductions have secondary impacts within the community.

Golf courses in the region are especially vulnerable to use restrictions in cases where water is obtained from a purveyor. Golf courses have a considerable amount of adaptability when dealing with water shortage, including prioritizing watering locations, altering watering methods, and modifying horticultural methods. Interviewees from the golf course industry report that golfers are more accepting of dry hard grass than flooded soggy turf, further enhancing the adaptive capacity of courses. The primary impact reported from droughts is over-watering resulting from overcompensation for increased evapotranspiration.

8.3.b. M&I

The primary impact of drought on water purveyors is revenue losses from reduced sales during use restrictions. Suppliers have some ability to adapt to these potential economic losses by creating reserve funds and modifying water management strategies to reduce the necessity for use restrictions. Management strategies cited by interviewees include using a dynamic rule curve, altering maintenance schedules, and optimizing the combined use of water sources. M&I water customers are affected by use restrictions during drought. They may adapt to these conditions by changing their practices to ones that require less water, including gardening with drought tolerant plants.

8.3.c. Environment

The environment sector is vulnerable to impacts of drought during all seasons of the year. Flexibility of the environment sector is limited. Impacts can be reduced by increasing monitoring and maintenance of fish devices and using manual methods to transport fish. In some controlled watersheds environmental advisory boards have been formed to enhance coordination between M&I operations and fisheries demands. Coordinating supplemental flows from reservoirs with fish needs is another way the environment sector adapts to drought.

8.4. *South West/Olympic Peninsula*

8.4.a. Agriculture

Prior impacts of drought to the agricultural community in the southern portion of this region can be described as minor. The primary challenge in meeting crop demands for southern irrigators in the region occurs due to the limited number of irrigation systems as many growers rely on precipitation to meet their needs. Representatives from this sector with less robust irrigation systems are the most vulnerable to this type of drought impact. Farmers may enhance their ability to cope with drought by predicting increasing plant demands in advance, and making existing irrigation systems more robust. Adaptive capacity of smaller farms is limited because of less ability to finance new projects. Irrigation districts in the northern portion of this region have reported some significant impacts from drought. The primary cause for these impacts is low streamflows. Farmers of cruciferous row crops, which are often planted the previous fall and grown for seed, are drought tolerant and rarely impacted. Farmers of perennial fruit trees have the least flexibility to respond to drought conditions because these crops are perennial and require significant amounts of water late in the season to produce quality crops. In some cases decisions can be made to increase flexibility; farmers can decide not to plant additional fields or not to increase acreage of perennial crops when drought is expected.

Dairy farmers in the region are affected by increased feed costs or decreased feed production. Operations that rely solely on purchased feed are most vulnerable to impacts from drought, and also have extremely limited ability to adapt. Many dairy farmers in this region produce their own feed and have more flexibility in their own operations to avoid increased costs. One method for reducing potential impacts is to leave alfalfa crops intact for another season, instead of rotating fields to corn, or simply reducing the number of cuttings.

Golf courses in the region are especially vulnerable to use restrictions in cases where water is obtained from a purveyor. Golf courses have a considerable amount of adaptability when dealing with water shortage, including prioritizing watering locations, altering watering methods, and modifying horticultural methods. Interviewees from the golf course industry report that golfers are more accepting of dry hard grass than flooded soggy turf, further enhancing adaptive capacity of courses. The primary impact reported from droughts is over-watering, which is under the complete control of the golf course.

8.4.b. M&I

No impacts of drought were reported in the M&I sector. Vulnerability of this sector to drought is currently low. Vulnerability to drought is likely to increase in areas experiencing population growth. Difficulty in procuring additional water rights has been identified in one location.

8.4.c. Environment

Some impacts to migrating fish have been reported in the Dungeness River, where irrigation reduces natural flows during the migration period. Flexibility exists to confront this problem. Coordinated irrigation reductions have proven to be effective at providing necessary flows for returning adults to migrate upstream.

8.5. *North Central*

8.5.a. Agriculture

According to Weekly Drought Reports produced by the Washington Department of Ecology, several rivers in the North Central region, including the Wenatchee, Okanogan, Stehekin, Entiat, Chiwawa, and Similkameen

Rivers, reported record-low daily streamflows during the 2005 growing season. Several of these rivers recorded daily record-low flows in multiple months. Despite these record-low river levels, growers of tree fruit reported only minimal impacts from drought[7]. One interviewee reported that 2005 proved that water supply in the region is less vulnerable to drought than he had thought. Growers did face challenges meeting water demand during the 2005 drought. Some water use restrictions were imposed. This indicates that the agricultural sector is vulnerable to drought impacts during more extreme droughts. This vulnerability may increase as growth in the region increases. Tree fruit growers in the region have some capacity to adapt to water shortage. Options for reducing demand include increasing watering efficiency, widening weed control strips, alternating watering from one side of trees to another, limiting irrigation in the spring to reduce foliage development thereby reducing water demand in the summer, using heat reflective spraying, and removing marginal blocks of trees.

Dairy farmers in the region are affected by increased feed costs or reduced feed production. Operations that rely solely on purchased feed are most vulnerable to impacts from drought, and also have extremely limited ability to adapt. Dairy farmers that produce their own feed are less susceptible to drought impacts and have more flexibility in their own operations to avoid increased costs. In the North Central region one method for reducing potential impacts from water restrictions is to plant more drought tolerant forage crops.

Beef cattle ranchers reported experiencing some impacts from drought, including rangeland water supplies running dry before forage runs out and increased feed costs. Ranchers have some flexibility in range operations which allows adaptation to drought conditions. Herd size can be cut back to stay within the reduced carrying capacity for given range conditions, herd rotation can be increased (at increased costs), water can be supplied by truck (cattle are often inaccessible by truck), and production schedules can be altered.

8.5.b. M&I

No impacts were reported by the M&I sector; however, the water intake for the city of Cashmere was reported to be dangerously close to running out of water coverage. This indicates that future droughts could affect M&I supply in the region. Modification of intake levels or obtaining alternative supplies during extreme drought may be difficult and time consuming.

8.5.c. Environment

Impacts to fish have been reported in the North Central Region during previous droughts. These impacts include increased stress and in some years hundreds of returning Summer Chinook Salmon and Sockeye Salmon perish before spawning. The adaptive capacity of the environment sector is increased in years where emergency drought funds are made available. Impacts to fisheries can be reduced by more intensive monitoring and management of fish devices. Monitoring can also be performed on known problem areas in the river in order to identify stranded fish. Water can also be bought back from agricultural users returning some of the natural flow to rivers. When temperatures below Osoyoos Lake become high and tributaries of the Okanagan are dewatered, adaptive capacity decreases significantly.

8.6. *South Central*

8.6.a. Agriculture

The agricultural sector in the South Central region is highly vulnerable to drought impacts. In 11 of the past 35 years water supply from the Yakima Project has not fully met the demands of irrigated agriculture. According to an interviewee, the Yakima Project was able to provide 42 percent of normal water supply to proratable water users in 2005. This is the third lowest final proration estimate in the last thirty years; however, preliminary proration estimates in March of 2005 predicted only 34 percent of normal water supply for proratable users, which would have been the lowest proration in 35 years. Inability to meet agricultural demands in the Yakima Project has led to a variety of impacts to junior (proratable) water right holders. Impacts vary from farm to farm. Proratable users who farm hay or alfalfa realized fewer cuttings. Those that grew tree fruit reported reduced quality, and in some cases entire crops were lost. In general operations growing exclusively apples have the least adaptive capacity. Apples require very large amounts of water in every season: to protect from frost in the spring, to produce fruit, and to protect fruit from heat and sun during the hottest summer days. When proration is low growers may struggle to keep the orchard alive; production of high quality crop is even more challenging. On the other end of the spectrum, diverse operations have more flexibility, for example a farmer of tree fruit, wine grapes, and row crops is flexible in several ways. Firstly, wine grapes require three to four times less water than apples, so when proration is low, water from the grapes can be used to help insure tree fruit quality. In addition, row crop fields can be left fallow to concentrate water on the most profitable crops or those that represent the largest investment (fruit trees are usually both). In some cases a certain section of trees may produce a variety of fruit that is only marginally marketable. In these cases growers may opt to remove the marginal block of trees to conserve water for more marketable fruit. Growers can also invest in more efficient irrigation systems.

In addition to methods of managing water within farming operations, official drought declaration enables proratable users to apply for approval to transfer water between irrigation units on their own land, to lease water rights from others on a temporary basis, and for emergency water rights to drill new groundwater wells or reactivate existing emergency ground water wells. Farmers may also purchase extra land to fallow during drought years and transfer water to acreage with more valuable production.

Irrigation districts also have some capacity to adapt to drought conditions. Districts made up of proratable users may chose to purchase extra water from non-proratable districts, especially in situations where the proratable farmers produce more valuable crops or cases where the proratable farmers grow perennial crops. Districts may also chose to shut down irrigation operations for short periods in order to conserve water for later in the summer when water is more essential for crop development. During the 2005 drought, one proratable irrigation district was able to purchase enough water from senior districts to supply its users with approximately 49-51 percent of normal water supply rather than the normal 42 percent proration realized by proratable users who didn't obtain extra water. Trading was also used by this district during the 2001 drought, but with less success. In 2001 approximately 42-43 percent of normal supply was delivered rather than the 37 percent that would have been delivered otherwise.

Dairy farmers in the region are affected by increased feed costs or reduced feed production. Operations that rely solely on purchased feed are most vulnerable to impacts from drought, and also have extremely limited ability to adapt. Dairy farmers that produce their own feed are less susceptible to drought impacts and have more flexibility in their own operations to avoid increased costs. In the South Central region one method for reducing potential impacts from water restrictions is to plant more drought tolerant forage crops.

Beef cattle ranchers reported experiencing some impacts from drought including rangeland water supplies running dry before forage runs out and increased feed costs. Ranchers have some flexibility in range operations which allows adaptation to drought conditions. Herd size can be cut back to stay within the reduced carrying capacity for given range conditions, herd rotation can be increased (at increased costs), water can be supplied by truck (cattle are often inaccessible by truck), and production schedules can be altered.

Dryland farmers in the South Central region also experience impacts from droughts when crops don't receive adequate rain. Impact to dryland farmers may be increased if nitrogen is applied that plants can't consume due to drought. Dryland farmers have some adaptive capacity for dealing with drought. For example, quantities of nitrogen applied to crops are based on expectations for available moisture during the growing season. If more nitrogen is applied than the plant can use based on available water then investment in fertilizer is lost; if the crop cannot make use of all available water due to nitrogen deficiency, then potential yield is lost. With accurate predictions of available moisture during a growing season, farmers can avoid lost fertilizer investments or lost crop yields. In the South Central region, various dryland crop cycles are used depending on average precipitation. In some cases, a winter wheat summer fallow two-year rotation is used; in other cases, a three-year winter wheat, spring wheat, summer fallow rotation is used. Other rotations combinations are also possible, but most dryland operations in Washington State include at least one rotation of winter wheat. Depending on available moisture in the soil before planting and seasonal moisture expectations, this planting cycle can be modified to reduce impacts of drought. During winter wheat rotations, fall nitrogen applications can be reduced and, if winter moisture is higher than expected, crops can be side dressed with additional nitrogen in the spring (this practice increases application costs). Spring crop rotations can be skipped if soil moisture and precipitation expectations are too low. Dryland farmers may also place lands that perform poorly during drier conditions into the Conservation Reserve Program. In most cases, the ability of dryland farmers to adapt to drought conditions depends on accurate determination of existing soil moisture and predictions of available precipitation during the growing season. In cases where production is extremely low, farmers may chose not to harvest if operation costs of the combine will be larger than revenue from wheat sales.

8.6.b. M&I

No M&I impacts were reported by interviewees. Vulnerability of the M&I sector can be expected to increase as populations in the South Central region grow.

8.6.c. Environment

The environment sector experiences impacts from unnatural flows and reduced base flows on all years; these impacts are greatly magnified during drought. The environment sector has some ability to adapt to drought conditions. This ability is enhanced by drought declarations, which make additional funding available to fisheries personnel for mitigation of impacts. Fisheries organizations can reduce drought impacts by increasing monitoring and maintenance of fish devices, such as ladders and screens, in the system. Monitoring of trouble locations can also be increased to enhance ability to respond to stranded fish. Fish can be transported and fisheries personnel can make appropriate decisions regarding whether to allow fish migration into areas that a may become dewatered later in the fall. A Systems Operation Advisory Committee (SOAC) has been established in the South Central region to advise operations of the Yakima Project on issues regarding fish. This organization makes recommendations to the USBR on flows that should be maintained during different seasons. These recommendations include recommendations for artificial spring freshets, minimum summer base flows, recommended flows during fall spawning that determine access of spawning fish to areas outside the main channel, and winter flows required to prevent redds from being dewatered.

8.7. *East*

8.7.a. Agriculture

Agriculture in the East region is highly vulnerable to drought. Dryland farming operations in general are particularly vulnerable, as the water supply for these crops comes directly from precipitation. Impact to dryland farmers may be increased if nitrogen is applied that plants can't consume due to drought. Dryland farmers have some adaptive capacity for dealing with drought. For example, quantities of nitrogen applied to crops are based on expectations for available moisture during the growing season. If more nitrogen is applied than the plant can use based on available water then investment in fertilizer is lost; if the crop cannot make use of all available water due to nitrogen deficiency, then potential yield is lost. With accurate predictions of available moisture during a growing season, farmers can avoid lost fertilizer investments or lost crop yields. In the East region, various dryland crop cycles are used depending on average precipitation. In some cases, a winter wheat summer fallow two-year rotation is used; in other cases, a three-year winter wheat, spring wheat, summer fallow rotation is used. Other rotations combinations are also possible, but most dryland operations in Washington State include at least one rotation of winter wheat. Depending on available moisture in the soil before planting and seasonal moisture expectations, this planting cycle can be modified to reduce impacts of drought. During winter wheat rotations, fall nitrogen applications can be reduced and, if winter moisture is higher than expected, crops can be side dressed with additional nitrogen in the spring (this practice increases application costs). Spring crop rotations can be skipped if soil moisture and precipitation expectations are too low. Dryland farmers may also place lands that perform poorly during drier conditions into the Conservation Reserve Program. In most cases, the ability of dryland farmers to adapt to drought conditions depends on accurate determination of existing soil moisture and predictions of available precipitation during the growing season. Several interviewees stated that El Niño years have proven to be warmer and drier, so dryland farmers may adapt to drought by responding appropriately to the ENSO signal. This includes reduced nitrogen fertilizer application during El Niño years.

Irrigated operations in the East region are only slightly vulnerable to drought. Irrigated farming operations receive surface water from the Columbia Basin project or other smaller irrigation projects. Some pump water directly from small tributaries. Others irrigate with water pumped from groundwater. No interviewees reported impacts from supply restrictions or groundwater drawdown. The main impacts reported from irrigated farming operations were increased costs to pump water. These operations can also be vulnerable to reductions in crop quantity or quality if water supply is unable to meet demands from evapotranspiration on extremely dry years. Farmers that don't have a high percentage of perennial crops have some adaptive capacity. Crops placed within one irrigation unit can be diversified so that large amounts of water are required at different times in each field within the irrigation unit. For example, an irrigation unit that supplies water to five fields may limit potato production to two of those fields because potatoes require very large quantities of water during tuber development.

8.7.b. M&I

The M&I sector is not particularly vulnerable to drought in the East region. No interviewees identified any physical impacts of water shortage, such as water use restrictions. WRIA's 32, 44, and 50 reported restrictions of growth in the region; however, this may be an appropriate response to water supply limitations that have been identified. Growth restrictions will help limit vulnerability of the M&I sector.

8.7.c. Environment

The environment sector is affected on most years due to stream dewatering. These impacts are magnified by drought, which indicates medium vulnerability. The environment sector has some ability to adapt to drought conditions. This ability is enhanced by drought declaration, which makes additional funding available to fisheries organizations for mitigation of impacts. Fisheries organizations can reduce drought impacts by increasing monitoring of streams, particularly problem locations. This can enhance the ability of this sector to respond to stranded fish. Fish can be transported and fisheries personnel can make appropriate decisions regarding whether to allow fish migration into areas that may become dewatered later in the fall. When low spring flows are affecting outmigration of juvenile fish, coordinated irrigation reductions can provide restore more natural flows and allow fish to migrate upstream.

8.8. *Power*

Because river flow is the fuel for hydropower producers in the state, hydropower producers will always be vulnerable to drought; however, from dealing with past droughts, hydropower producers have developed strategies that increase adaptive capacity of the sector and reduce vulnerability. Some of the vulnerability of hydropower producers to drought stems from quantities agreed upon in sales agreements. In a worst case scenario, when supply agreements can't be met, power must be purchased on the open market. In 2001 the cost of purchasing replacement power was increased by inflated market prices for electricity. Other vulnerability is created by the balance of power supply and power demand in the Northwest Region. Interviewees indicate that prior to the 2001 drought there was an estimated 4000 MW supply shortage during an average water year, making the power sector more vulnerable. By 2005 this balance had shifted to an estimated 2000 MW supply surplus, drastically reducing the vulnerability of the power sector.

Using results of flow modeling simulations and climate forecasts, water managers in the hydropower sector can make decisions that make hydropower producers less vulnerable to impacts from drought similar to those experienced in 2001. If less flood control space is necessary, managers may decide to keep more water in reservoirs during the spring.

Several tactics are also available to help reduce impacts when supply is low. Water may be purchased from irrigators in order to curb demand and increase generation. Electricity may be bought back from the direct service industry. During the 2001 drought, direct service industry buyback made large quantities of electricity available to meet supply agreements; however, these customers currently make up a much smaller percentage of the regional demand, making direct service industry buyback a less effective strategy in the future. Other production units may be paid to turn generators on or alter generation schedules to produce lower priced electricity than is available on the open market.

Impacts to fisheries and hydropower generation potential are often inseparable. Many power producers have established agreements to sacrifice power generation in order to provide more water over spillways for downstream fish migration. The cost of this spilled water is magnified during drought, especially if power must be purchased to meet supply commitments. Hydropower producers have several methods for dealing with fish flow requirements during drought to decrease vulnerability. During drought, water managers may decide to pool more water in the spring and summer to increase fuel supply for the winter. This may mean that fish flow requirements are not met, in which case fish capture and transport below the dams is increased.

Since the 2001 drought, the power sector has developed a resource adequacy standard that compares energy resource availability with expected demands to determine the level of energy security. Adequacy is based on the infrastructure in the entire western interconnection which includes imports from California and transmission sufficiency. The system uses a green-light, yellow-light, red-light signal system to indicate the current level of vulnerability. The status in the summer of 2006 is green, meaning low vulnerability. This low vulnerability-assessment is largely due to an improved balance of supply to demand within this region and increased energy security in California. Impacts to the power sector during the 2005 drought were much less severe than during the 2001 drought, even though the

Columbia River flow volume for the 2005 water year was the 19th lowest on record. When asked whether current energy resources were adequate, one interviewee responded, “we’re there,” indicating that the current resources available would provide enough power for the Northwest region; even in a water year comparable to 2001, there would be no risk of brownouts and utilities would not need to activate emergency diesel generators.

8.9. *Recreation*

Many recreation industries in the state depend on adequate supply of water to meet the demands of their operations. This report focuses on the ski industry, which requires adequate snow pack to open operations and to attract customers. Low snow pack results in reduced visits and can have large impacts on profit, making the ski industry extremely vulnerable to drought. The ski industry has limited adaptive capacity. The primary method used by ski area operators is to minimize staffing and reduce operations. One interviewee indicated that early season hiring is minimized during times of uncertain supply to reduce vulnerability. Ski areas may also be opened on a limited capacity to reduce vulnerability, e.g. opening only one restaurant rather than five when snow pack is low.

9. Lessons Learned From Previous Droughts

9.1. *Lessons Learned*

Lessons learned during previous droughts guide decisions made by representatives from each sector as they prepare for and attempt to mitigate impacts of subsequent droughts. Each interviewee was asked to describe the lessons learned from dealing with drought. Responses covered both strategies that were effective and those that were not as effective. The summary of lessons learned provided in this section of the report can be useful to those considering new strategies to prevent and mitigate drought impacts. Lessons learned will be presented as tables for each region. These tables summarize the lessons learned expressed by interviewees from respective regions and sectors. Frequency of responses received multiple times within a region is indicated by a number (#) following the entry in the table.

9.2. *North West*

Table 9.1 North West Region Lessons Learned

Sector	Sub Sector	Lessons Learned During Previous Droughts
Agriculture		
	Cane Berry Farmers	Past systems were under designed. Modify existing systems and design new systems to meet greater demand.
		Design irrigation systems with capability to transfer water from unit to unit in case one supply becomes unavailable.

Table 9.1 North West Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
		Start irrigation earlier at times when prolonged high evapotranspiration rates are expected. Add more water to the soil column as reserve to avoid plant stress. Don't get behind.
	Row Crops	Improved planning will help meet crop demands. Have more distribution systems available when needed (hoses for big guns).
	Golf Courses	Use phased water reductions. Prioritize water shut off; shut off least important sections first.
		Advanced irrigation systems reduce vulnerability to impacts of drought by minimizing water usage and applying water only when needed. Avoid over watering.
		Have a water conservation plan in place.
		Good contacts for discussing water management during drought can be very helpful.
	Dairy	Successful operations must have irrigation equipment available to distribute water when necessary.
Environment		
	Fisheries	Meeting streamflow goals can be difficult if water rights within the basin are not first adjudicated or if illicit water use is present.
		Long rearing species are the most vulnerable.
		Summer low streamflows are not necessarily a clear indicator of whether drought impacts will occur.

9.3. *Central West*

Table 9.2 Central West Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
Agriculture		
	Green Industry	Layoffs and non-hiring can mitigate impacts to landscaping companies during drought.
		Base hiring decisions on good forecast information. (The primary hiring window is the month of February)
		Persuasion of Government not to declare drought on a statewide level would benefit the sector.
		Better management of media information is essential for preventing unnecessary impacts. (Provide the public with accurate and applicable information so they don't cancel landscaping projects unnecessarily.)
	Golf Courses	Use phased water reductions. Prioritize water shut off; shut off least important sections first.

Table 9.2 Central West Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
		Advanced irrigation systems reduce vulnerability to drought by minimizing water usage and applying water only when needed. Avoid over watering.
		Have a water conservation plan in place.
		Good contacts for discussing water management during drought can be very helpful.
M&I		
	Large Municipal Suppliers	Having a water shortage contingency plan completed at the onset of drought is critical.
		Utilities need to work more closely with the green industry.
		Modifying supply system operations, such as reducing the flushing frequency for in town reservoirs, can significantly reduce system demand during drought, but may increase other costs, such those for testing.
		Better snow pack monitoring is needed.
		Using a dynamic rule curve has the potential to increase supply.
Environment		
	Fisheries	Maintaining instream flow flexibility minimized impacts.
		Use of reservoir storage to supplement flows is beneficial to fish.

9.4. *South West*

Table 9.3 South West/Olympic Peninsula Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
Agriculture		
	Cane Berry Farmers	Implementation of advanced irrigation systems with drip irrigation is complicated by many factors: smaller operations with less available funding, smaller farms, older growers, poor water quality that fouls application systems. These factors make improvements difficult.
		Using ditch riders as a means of communicating from the irrigation districts to the agricultural community can be very effective.
		Expect drought to occur occasionally.
		Cooperative water use reductions, e.g. encouraging hobby farms and other uses that aren't critical to reduce consumption, can be an effective means of ensuring adequate supply for major agricultural operations.
		Communicate on a one-on-one basis until June.

Table 9.3 South West/Olympic Peninsula Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
	Dairy	Successful operations must have irrigation equipment available to distribute water when necessary.
	Golf Courses	Use phased water reductions. Prioritize water shut off; shut off least important sections first.
		Advanced irrigation systems reduce vulnerability to impacts of drought by minimizing water usage and applying water only when needed. Avoid over watering.
		Good contacts for discussing water management during drought can be very helpful.
		Have a water conservation plan in place.
Environment		
	Fisheries	Coordinated shut downs of irrigation can be an effective means of supplying adequate water for migrating fish.

9.5. *North Central*

Table 9.4 North Central Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
Agriculture		
	Irrigated	Record-low stream flow during 2005 indicates that systems can operate with less water than previously thought.
		Large drought education functions are poorly attended. Drought education needs to be focused at the individual level because drought response is so specific.
		Emergency response to drought is not effective.
		Drip irrigation is not always effective. Drip irrigation can lead to increased erosion and lower fruit quality.
		Turning orchards into housing developments doesn't necessarily reduce water consumption.
		Heat reflective spray can effectively reduce water demand.
		Updating irrigation systems can improve efficiency.
		Removing blocks of marginal fruit can be an effective way to mitigate drought impacts.
	Beef Cattle	Comparing historical data as much as possible enables better response to drought.
Environment		
	Fisheries	Administrative issues within response agencies need to be worked out in advance of drought to enable effective

Table 9.4 North Central Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
		response. (2)
		Late season droughts are more difficult to respond to.
		Winter droughts are easier to respond to.
		Hatcheries need to have response plans in place.

9.6. *South Central*

Table 9.5 South Central Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
Agriculture		
	Proratable Irrigation	Using high efficiency water application, such as drip irrigation, can lead to other complications. Drip irrigation can increase heat loading within orchards adding heat stress to crops and requiring additional water for overhead cooling. (3)
		Pruning/dehorning trees can be an effective way to save an orchard from drought.
		Borrowing water from one area to supply another can be an effective way to mitigate drought impacts.
		Irrigation ditch improvements can be effective for water conservation. Improvements that allow ditches to operate at lower flows are especially helpful.
		Buying extra water may not work.
		Diversifying to wine grapes can be a successful method of drought mitigation.
		Impact mitigation is more successful if proration estimates go up over the course of the year.
		Early season irrigation systems shut downs are an effective way to conserve water for later in the summer.
		Use all available water by September 30th (end of water year).
		Grapes can be affected by early season shortages. Avoid stress to grapes during bud break and flowering. (mid April to mid May)
		Filling the soil profile late in the season (after harvest) prevents root damage to grape plants.
		Interdistrict water transfers are more complicated and less successful than intradistrict transfers.
		Water transfers may attract unwanted attention from

Table 9.5 South Central Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
		regulators.
		Leaving land fallow to borrow water is an effective way to manage drought.
		Irrigation piping is superior to ditches.
		It may be necessary to limit water delivery in one part of a system to pool water for deliver to another part of the system.
		Cooperation between senior and junior water right holders is not working out due to lack of trust.
	Beef Cattle	Comparing historical data as much as possible enables better response to drought.
	Dairy Cattle	Backup wells are critical
	Dryland Wheat	Carry Crop Insurance.
		Use soil testing to balance nitrogen loading with available and expected water.
		Carry a low debt load.
		Maintain machinery.
		Put least productive lands into Conservation Reserve Program.
		Side dressing winter wheat in the spring won't be effective without summer rains.
		Installing field borders can help preserve top soil during drought.
Environment		
	Fisheries	Using pulse flows that mimic the natural freshet can help stimulate juvenile fish migration. (2)
		Criteria flows should be set at levels that won't adversely affect salmon.
		Natural floods create abundant fish habitat.
		Pulse flows with higher flow rates and shorter durations are more effective than sustained pulse flows with medium flow rates.
		Flexible Response strategies are more effective.
		Be selective on which water is purchased back from agriculture to supply river flows. Don't buy warm low quality water to put back in the river.
		Trapping and hauling fish is necessary during extreme droughts.
		Administrative issues within response agencies need to be worked out in advance of drought to enable effective response.

Table 9.5 South Central Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
		Get organized to confront drought early in the year.
		Late season droughts are more difficult to respond to.
		Winter droughts are easier to respond to.
		Hatcheries need to have response plans in place.
		Balancing needs of agriculture with those of the environment can achieve a positive solution for both sectors.
		Mechanically controlled pulse flows may not get intended response because juvenile fish receive additional signals to migrate from other environmental stimuli.
		Maintaining higher late season pools will help maintain adequate flows over redds in the late fall.

9.7. *East*

Table 9.6 East Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
Agriculture		
	Dryland Wheat	Adjust nitrogen fertilizer application based on precipitation expectations.
		Seed and fertilize close to normal every year, because applying too little nitrogen guarantees a below average crop.
		Newer wheat cultivars haven't proven to be as drought tolerant as older cultivars.
		Create a deeper layer of tillage mulch to conserve moisture in the soil profile.
		Only plant spring crops when soil profile has adequate moisture.
		Pay attention to signals of drought and play it safe.
		Crops must be planted in order to ensure that at the very least crop insurance can be collected.
	Irrigated	Transferring water between users or from fallow fields to crops is advantageous.
		State Drought declaration is beneficial because it allows emergency services, cost sharing, and new and expanded wells.
		Maintain all Department of Ecology Paperwork because it is necessary when applying for water transfers.
		Maintain records of groundwater levels to detect problems

Table 9.6 East Region Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
		with supply.
M&I		
		Awareness of water consumption leads to efficiency.

9.8. *Power*

Table 9.7 Power Sector Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
Power		
	Hydropower	Paying irrigators not to irrigate is an effective way to increase supply and reduce demand.
		DSI buyback is an effective way to mitigate impacts. (2)
		Paying irrigators not to irrigate is hard to implement due to difficulties with enforcement.
		Curtailing fish spill during drought can be an effective way to increase generation capacity.
		The 2001 drought exposed resource inadequacies in the western region.
		Methods of reducing drought need to be tested before good information on effectiveness is available; however, high costs can be prohibitive to testing new methods.

9.9. *Recreation*

Table 9.8 Recreation Sector Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
Recreation		
	Ski Areas	Managing facilities operations based on expected visits can be an effective way to reduce costs during dry years, e.g. opening fewer restaurants. (2)
		Reducing full time staff during drought years can reduce costs during drought. (2)
		Moving snow from parking lots to the base of the ski area is critical during dry years.
		Conserving snow by packing it in place is important during dry years.
		Putting up snow fencing to conserve snow on ski trails is not a cost effective way to conserve snow.
		Marketing skiing in times when snow is good but precipitation is low can be an effective way to attract visitors during dry periods

Table 9.8 Recreation Sector Lessons Learned		
Sector	**Sub Sector**	**Lessons Learned During Previous Droughts**
		Slope grooming during the off season (removing trees and rocks) allows areas to open with less snow.

10. Information and Resources Needed to Reduce Vulnerability

10.1. *Information and Resource Analysis*

Interviewees were each asked to identify additional information and resources that would improve their ability to adapt to drought conditions and mitigate drought impacts. Items identified by interviewees are summarized in the following tables.

10.2. *North West*

Table 10.1 North West Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
Agriculture		
	Cane Berry Farmers	More weather stations that measure evapotranspiration rates and precipitation amounts, making this information more available to farmers.
		Infrared and conventional satellite imagery of crops in real time. This will enable detection of plant stress before physical signs of stress are visible on the ground.
		Improvements in current drip irrigation technology.
	Row Crops	Accurate long range forecasts made available to farmers via the web, phone, or fax by the first week of may.
	Dairy	Improved long range forecasts provided in early May would help farmers make more accurate decisions when deciding on crop varieties and fertilizer application rates.
		Development of more drought tolerant crop varieties, particularly forage crops, would help ensure a more reliable supply of cattle feed.
		Providing better interpretation of what the current ENSO signal strength means for water supply in specific geographic locations.
	Golf Courses	Correct use of information by the media.
		More accurate long range forecasts may be helpful in some cases. Forecasts need to be available by June, however forecasts in February and March would be most valuable.
		Elimination of "use it or lose it" water law.
Environment		

Table 10.1 North West Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
	Fisheries	Improve riparian buffers to increase large wood recruitment.
		Adjudicate water rights and stop illicit water withdrawal.
		Reduce diversions from headwater and lowland streams.

10.3. *Central West*

Table 10.2 Central West Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
Agriculture		
	Green Industry	Long range weather forecasts and more readily available snowpack information.
		Better identification of the value of landscaping to the community and the environment and conveyance of this information to politicians to help guide decisions regarding drought declaration and water supply forecasts.
		Improved municipal water planning, possibly involving increased storage, could create more security for consumers.
		More progressive water restrictions would be less harmful to the industry.
		Decision making and water forecasting performed on a more local level will better enable consumers to make informed decisions.
		Accurate information communicated accurately to the public will enable more informed decisions.
		Information regarding water supply needs to be supplied to the public as soon as it is valid and constantly updated thereafter.
		An improved drought declaration system would help prevent unnecessary impacts to the green industry.
		Water supply predictions provided during the primary hiring period from February to early March will enable operations to more accurately plan their labor force and avoid lay offs due to drought.
		A water supply dashboard needs to be available to the public that conveys water supply status of utilities and projections of water supply over the course of the growing season.
		Policy makers need to make the best possible decisions based on the best available information and communicate those decisions accurately to the public.
	Golf Courses	Correct use of information by the media.

Table 10.2 Central West Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
		More accurate long range forecasts may be helpful in some cases. Forecasts need to be available by June, however forecasts in February and March would be most valuable.
		Elimination of "use it or lose it" water law.
M&I		
	Large Municipal Suppliers	Better tools produced by climate groups to meet forecasting needs of large municipal water supplies targeting forecasting on a watershed specific level would enable better risk based decision making.
		Better forecasting, particularly accurate 10 day forecasts would enable better management of the dynamic rule curve. Reliable forecasts would also enable more exact planning instead of risk based decision making.
		Improved long range forecasting available in January will help determine when to begin filling the reservoir
Environment		
	Fisheries	Improved long range predictions of timing of fall rains will enable better management of water supply to meet increased fall fish flow needs.
		Increasing knowledge of relationship between river stage and problem areas for fish will improve the ability of fisheries personnel to predict, identify, and respond to fish passage problems.

10.4. *South West/Olympic Peninsula*

Table 10.3 South West/Olympic Peninsula Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
Agriculture	**Cane Berry Farmers**	Better availability of soil moisture information and improved soil moisture sensing technology will enable growers to better manage their crops.
		Improved technical knowledge and education on monitoring soil moisture and dealing with water shortage within the agricultural community.
		Programs to help relieve some of the costs of irrigation system enhancements would enable implementation of water conservation technology.
		Programs to educate growers on irrigation practices would enable better use of water conservation technology.
		More evapotranspiration stations would provide increased data to aid growers' decisions.
	Dairy	Improved long range forecasts provided in early May would help farmers make more accurate decisions when deciding on crop varieties and fertilizer application rates.

Table 10.3 South West/Olympic Peninsula Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
		Development of more drought tolerant crop varieties, particularly forage crops, would help ensure a more reliable supply of cattle feed.
		Providing better interpretation of what the current ENSO signal strength means for water supply in specific geographic locations.
	Golf Courses	Correct use of information by the media.
		More accurate long range forecasts may be helpful in some cases. Forecasts need to be available by June, however forecasts in February and March would be most valuable.
		Elimination of "use it or lose it" water law.
M&I		
		Better determination of the water supply status quo would enable better drought planning.
		Easy access to water rights information, possibly a water rights database, would enable better drought planning.
Environment		
		Increasing knowledge of relationship between river stage and problem areas for fish will improve the ability of fisheries personnel to predict, identify, and respond to fish passage problems.

10.5. *North Central*

Table 10.4 North Central Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
Agriculture		
	Irrigated	Better dissemination of long range supply forecasts provided in January to February.
		More storage would help supply demands in late July, August, and early September. This storage could be achieved through small "smart" storage projects that provide water for multiple uses in sites with minimal environmental impact.
		Better determination of continuity between groundwater and surface water.
		Education in irrigation system technology and water conservation methods on a grower by grower basis.
	Dairy	Improved long range forecasts provided in early May would help farmers make more accurate decisions when deciding on crop varieties and fertilizer application rates.
		Development of more drought tolerant crop varieties, particularly forage crops, would help ensure a more reliable supply of cattle feed.

Table 10.4 North Central Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
		Providing better interpretation of what the current ENSO signal strength means for water supply in specific geographic locations.
	Beef Cattle	Any additional and more accurate information aiding in the forecast of water supply would be beneficial.
M&I		
		Better determination of the water supply status quo would enable better drought planning.
		Additional information on the impacts of water shortage on water quality may help provide more incentive for conservation.
Environment		
	Fisheries	Additional mechanisms for correlating flow tracking with fish observations.
		Additional control structure agreements.
		Negotiated release patterns.
		Funding for drought relief can be most effectively utilized if it is distributed by February. This enables fisheries agencies to buy water rights from irrigators before planting of new orchards or row crops.
		Development of a matrix that identifies the economic value of different water uses to prioritize purchasing of water rights for instream flows.
		Increased incentives for the agricultural community to conserve water and more efficient irrigation infrastructure will enable more water to be kept in streams. This may also make more water available for hydropower generation.
		Fishing season modifications.
		Projections of likelihood of drought by February are most useful.

10.6. *South Central*

Table 10.5 South Central Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
Agriculture		
	Proratable Irrigation	Increased storage would make the water supply more reliable. (6) Black Rock Reservoir (3)
		Accurate estimates of the total water supply available forecasted during the winter financial planning period of December and January. Estimates provided by January 1 would be best. (3)
		Better long range forecasting is needed in January to enable better financial planning. (2)
		A more open water market that allows water trading. (2)

Table 10.5 South Central Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
		Assurance of permanent water supply and the necessary infrastructure to deliver the water. (2)
		More inter-reservoir piping.
		A greater sense of urgency from politicians for creating a more reliable water supply.
		A better understanding of how much water is required during the growing season to produce good grapes.
		Improved application technologies.
		Better and earlier estimates of proration expectation would help with financial planning including crop insurance and loans.
		More NRCS and USBR data collection sites may help by providing more information.
		Better information on how much water and when it will be available (timing of water availability is most important for wine grapes).
		Better information on quality of water that can be expected from the water supply.
		Adequate supply of water during the early season will help prevent impacts to wine grape growers.
		Fixing antiquated water law by eliminating the "use it or lose it" portion of the law will encourage conservation of water.
		Improved knowledge of techniques for water spreading (from location to location) may enable growers to more effectively manage limited water.
		More promotion of interdistrict water transfers would alleviate some of the challenges faced by proratable water users.
		Clarification of Ecology's role for issuing new water rights.
		Reregulation of the reservoirs in the Yakima Project.
		Automated checks in the irrigation canals may increase efficiency of the irrigation system.
		More robustness of the distribution system may enable more effective operation when supply is low.
		Better long range forecasts, specifically flood predictions in the spring, would enable better management of storage to provide greater supply later in the season. (Reservoir levels could be raised earlier.)
		Conservative early estimates make planning easier than monthly changes of proration.
		Aquifer storage and recharge would enable storage of early season supply to supplement supply later in the year.
	Beef Cattle	Any additional and more accurate information aiding in the forecast of water supply would be beneficial.

Table 10.5 South Central Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
	Dairy	Improved long range forecasts provided in early May would help farmers make more accurate decisions when deciding on crop varieties and fertilizer application rates.
		Development of more drought tolerant crop varieties, particularly forage crops, would help ensure a more reliable supply of cattle feed.
		Providing better interpretation of what the current ENSO signal strength means for water supply in specific geographic locations.
	Dryland Wheat	Improved long range and short range forecasting would be valuable in September for fall planting.
		Improved long range and short range forecasting would be valuable in the spring for spring planting and tilling.
		A regional drought monitor would be useful.
		More accessible and localized drought forecasting would improve utility of forecasts.
		More money in the farm bill.
M&I		
		Better understanding of the continuity between ground water and surface water.
		More information on the recharge of aquifers.
		Aquifer storage and recharge would enable storage of early season supply to supplement supply later in the year.
		Multibenefit storage projects.
Environment		
	Fisheries	Additional storage would enable streamflows in the Yakima Project to be returned to more natural conditions.(2) Black Rock Reservoir (1)
		Improved spawning surveys combined with quantification of available water in storage and accurate forecasts of fall precipitation date would improve the ability to manage streamflows for Salmon.
		Ending inefficient diversions and eliminating conveyance losses for distribution systems will save more water for streamflows.
		Make use of funding available from the power sector to increase efficiencies of agricultural systems.
		Increased efficiency in other sectors will increase the flexibility available to fisheries managers during drought.
		Alter rule curves to provide a better spring freshet.
		Allowing more natural floods will increase flood plain storage and help prevent extremely low base flows during drought.
		Encouraging better cooperation among irrigators will improve conditions for fish during drought.
		Improved early predictions of drought would be helpful in

Table 10.5 South Central Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
		February.
		Funding for drought relief should be made available by February. This will enable fisheries agencies to buy water rights from irrigators before planting of new orchards or row crops.
		Development of a matrix that identifies the economic value of different water uses to prioritize purchasing of water rights for instream flows.
		Increased incentives for the agricultural community to conserve water and more efficient irrigation infrastructure will enable more water to be kept in streams. This may also make more water available for hydropower generation.
		Improved long range weather forecasts.
		A better understanding of what stimulates outmigration of juvenile fish would enable better use of limited supply during drought.
		More clearly defined tribal (fisheries) water rights would enable better operation of the Yakima Project.
		Better long range forecasts, specifically flood predictions in the spring, would enable better management of storage to provide greater supply later in the season. (Reservoir levels could be raised earlier.)
		Aquifer storage and recharge would enable storage of early season supply to supplement supply later in the year.
		Fishing season modifications.

10.7. *East*

Table 10.6 East Region Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
Agriculture		
	Dryland Wheat	Better long range forecasts available August 20th to September 5th for winter wheat. Forecasts in the fall would need to predict available moisture in the spring. Better long range forecasts available March 1 to April 1 for spring wheat. (4)
		More accurate long range forecasts would be beneficial.
		More drought tolerant cultivars would improve yield during drought.
		More reliable subscription forecasting services.
		Increased federal financial assistance.
	Irrigated	Improved short and mid range forecasts would enable better management of water in the soil profile.
		More monitoring stations for streamflow and weather data.

Table 10.6 East Region Information and Resources		
Sector	Sub Sector	Information and Resources to Reduce Vulnerability and Improve Response
		Better estimates of spring runoff available in April and May.
		Improved forecasts of precipitation in July, August, and September available in April and May.
		More education on water spreading.
		Implementation of more conservation measures would reduce demand.
		More water storage feasibility studies.
M&I		
		Better determination of continuity between ground water and surface water.(3)
		Increased storage.

10.8. *Power*

Table 10.7 Power Sector Information and Resources		
Sector	Sub Sector	Information and Resources to Reduce Vulnerability and Improve Response
Power		
		Better volume forecasts as early and as reliable as possible.(3)
		Better daily temperature forecasts improve abilities to forecast load.
		Leaving more water in the main stem of the Columbia River would make more water available for generation during drought.
		More available real time data on fish migration.
		Increased participation by public utility districts and independent power producers in development of the westwide resource adequacy standard.
		Encourage utilities to implement all cost effective conservation.
		More resources invested in exploring demand response alternatives such as centrally controlled water heaters.
		Store more water in Canada.
		Develop more non-hydro resources.
		Consider allowing more curtailments of operating restrictions such as flood protection, irrigation supply, and fish passage.

10.9. *Recreation*

Table 10.8 Recreation Sector Information and Resources		
Sector	Sub Sector	Information and Resources to Reduce Vulnerability and Improve Response
Recreation		

Table 10.8 Recreation Sector Information and Resources		
Sector	**Sub Sector**	**Information and Resources to Reduce Vulnerability and Improve Response**
	Ski Areas	More reliable forecasts available in September and October would enable more informed hiring decisions.(2)
		Additional water rights would increase snowmaking capacity and help ensure product is available.
		Anything that prevents the negative impacts of climate change.

Phase 3: Drought Indicators

11. Drought Indicators

11.1. *Indicator Identification*

Indicators are vital to drought preparation and response. Indicators are employed to monitor and forecast drought conditions, characterize and compare drought severity, and provide a basis for triggering and determining the level of drought responses. "Drought indicators are variables that describe the magnitude, duration, severity, and spatial extent of drought. Typical indicators are based on meteorological and hydrological variables."[9] This report will review indicators considered by water users in Washington state to evaluate current and future water supply. These indicators relate to a wide variety of physical variables: ground water, precipitation, snowpack, soil moisture, surface water, and temperature. Some sectors also consider societal and biological indicators: human demand and fisheries demands. The temporal and spatial scale of indicators varies across the state depending on the decision making process of sectors in each region. The report will identify these decisions and the temporal and spatial scale specific to each region. The prospective range of each indicator will be identified. The following range definitions will be used, Current - describes current conditions or retrospective cumulative amounts; Short Range – prospective indicator that provides information relevant to short term planning, e.g. weekly work load planning or crop demands; Mid Range – prospective indicator that provides information useful for making decisions during a current season, typically indicate conditions one month to six months in advance; and Long Range – prospective indicator that provides information useful for making decisions related to expected conditions six or more months in advance.

11.2. *Agriculture*

Agricultural water users consider both indicators of current water supply and indicators for future water supply when making planning decisions. Indicators of current supply include cumulative precipitation, ground water, soil moisture, temperature, and plant stress. Individual farmers measure cumulative precipitation using rain gages or refer to data from local weather stations such as those on the Washington State University (WSU) Public Agriculture Weather System (PAWS). Ground water levels are determined by measuring the elevation of the aquifer at an individual well. Soil moisture measurements are taken with tensiometers or digital soil moisture probes. Soil moisture data are also available from the WSU PAWS. Many interviewees also report physically examining soil moisture by digging test pits into the soil profile. Temperature is measured by individual farmers or at

[9] Steinemann, A.C., Hayes, M.J., Cavalcanti, L.F.N. "Drought Indicators and Triggers," In Drought and Water Crisis: Science, Technology, and Management Issues, edited by Wilhite, D.A., 71-92. Boca Raton, FL: CRC Press, 2005.

weather stations. Temperature data are also widely available on the internet. Plant stress can be detected by physical examination of plants or by using infrared satellite imagery, though farmers noted that this imagery is not currently available in realtime.

Indicators of future supply conditions include snowpack data, precipitation forecasts, and surface water supply forecasts. Snowpack data is monitored using US Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) Snowpack Telemetry (SNOTEL) Data and USDA Forest Service Northwest Avalanche Center (NWAC) Data, both of which are available on the internet. Short range precipitation forecasts are available at many different temporal scales from many different sources. Interviewees identified a variety of local television forecasts and public and private internet forecast services that provide short term weather forecasts. Mid range precipitation indicators include National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC) 30 day to 90 day forecasts. Long range precipitation indicators include data from climate signals, e.g. ENSO signal, and the University of Washington Forecast Services. Surface water supply forecasts are generally available from water supply system managers. Interviewees identified municipal supply forecasts, irrigation district supply forecasts, and USBR Yakima Basin Water Supply Monthly Forecasts as sources surface water supply projections.

Table 1 provides a comprehensive list of indicators cited by the agriculture sector, including the temporal scale associated with each indicator and a URL for each applicable indicator.

Table 11.1 Indicators - Agriculture

Region	Variable	Indicator	Range	Source
NW	Soil Moisture	Tensiometers	Current	
NW	Soil Moisture	Digital soil moisture sensors	Current	
NW	Snow Pack	Snowpack information	Mid Range	
NW	Snow Pack	Snowpack on May 1st at Mount Baker	Mid Range	
NW	Precipitation	Rain gages	Current	
NW	Precipitation	Short term weather forecasts	Short Range	
NW	Precipitation	Climate signals - ENSO	Long Range	
NW	Other	Temperature	Short Range	
NW	Other	Evapotranspiration data	Current	
NW	Other	Plant stress	Current	

Table 11.1 Indicators - Agriculture				
Region	**Variable**	**Indicator**	**Range**	**Source**
SW/OP	Soil Moisture	Soil moisture measurements	Current	http://index.prosser.wsu.edu/
SW/OP	Precipitation	Rain gages	Current	
SW/OP	Multiple	Capitol Press Agriculture Weekly Newspaper, Salem, OR	Multiple	http://www.capitalpress.com/water/
SW/OP	Multiple	Private forecast services	Short Range	
SW/OP	Snow Pack	USDA NRCS SNOTEL Data	Mid Range	http://www.wcc.nrcs.usda.gov/snotel/
SW/OP	Multiple	Local news weather forecasts	Short Range	
CW	Precipitation	Climate signals - ENSO	Long Range	
CW	Snow Pack	Snowpack information	Mid Range	
CW	Surface Water	Municipal website - water supply availability	Mid Range	
NC	Snow Pack	USDA NRCS SNOTEL Data	Mid Range	http://www.wcc.nrcs.usda.gov/snotel/
NC	Snow Pack	USDA NRCS SNOTEL Data	Mid Range	
NC	Multiple	UW Forecast System	Long Range	http://www.hydro.washington.edu/forecast/westwide/
NC	Precipitation	Rain gages	Current	
NC	Multiple	Internet weather forecasts	Short Range	
NC	Multiple	Weather stations	Current	http://index.prosser.wsu.edu/
NC	Multiple	USDA Office of the Chief Economist - Weather and Climate	Multiple	http://www.usda.gov/oce/weather/index.htm
SC	Precipitation	Rain gages	Current	
SC	Multiple	Internet weather forecasts	Short Range	
SC	Multiple	Weather stations	Current	http://index.prosser.wsu.edu/
SC	Multiple	USDA Office of the Chief Economist - Weather and Climate	Multiple	http://www.usda.gov/oce/weather/index.htm
SC	Precipitation	Rain gages	Current	
SC	Precipitation, Temperature	Climate signals - ENSO	Long Range	

Table 11.1 Indicators - Agriculture				
Region	**Variable**	**Indicator**	**Range**	**Source**
SC	Soil Moisture	Soil testing	Current	
SC	Precipitation	Rain gages	Current	
SC	Precipitation, Temperature	NOAA CPC 30-90 day outlooks	Mid Range	http://www.cpc.ncep.noaa.gov/products/forecasts/month_to_season_outlooks.shtml
SC	Surface Water	USBR Yakima Basin Water Supply - Monthly Forecasts	Mid Range	http://www.usbr.gov/newsroom/newsrelease/state.cfm?state=18
SC	Multiple	Private forecast services	Multiple	
SC	Surface Water	USBR Hydromet data	Mid Range	http://www.usbr.gov/pn/hydromet/yakima/realtime_yak.html
SC	Multiple	UW Forecast System	Long Range	http://www.hydro.washington.edu/forecast/westwide/
SC	Soil Moisture	Soil moisture measurements	Current	
SC	Multiple	UW Forecast System	Long Range	http://www.hydro.washington.edu/forecast/westwide/
SC	Multiple	Clearwest - Agricultural Forecast Company	Short Range	http://www.clearwest.com
SC	Surface Water	Irrigation district supply estimates	Mid Range	
SC	Snow Pack	Snowpack at Mount Adams	Mid Range	
E	Soil Moisture	Soil moisture measurements	Current	
E	Precipitation, Temperature	Climate signals - ENSO	Long Range	
E	Multiple	Data Transmission Network	Short Range	http://www.meteorlogix.com/products/
E	Multiple	60-100 day weather forecasts	Mid Range	
E	Precipitation	Winter precipitation data (cumulative)	Current	
E	Snowpack	Snowpack in the Blue Mountains	Mid Range	

Use of indicators is specific to each individual farmer based on supply sources and decisions made. Farmers of non-irrigated land make decisions about crop rotations, crop selection, cropping practices, field selection, and financial planning based on available soil moisture and expected precipitation. Irrigated agriculture is more dependent on surface water and ground water supply. These farmers review snowpack information, ground water levels, and surface water supply forecasts when making decisions regarding crop rotations, crop selection, cropping practices, field selection, purchasing and selling water rights, drilling emergency wells, purchasing additional land, modifying irrigation practices, and financial planning. Livestock operations make decisions related to herd size maintenance.

Timing of information availability is also critical. Table 2 summarizes when information is most valuable for members of the agricultural sector by region, water source, and primary crop type. Three general trends can be observed Table 2. Information is most valuable to irrigated agriculture of the western regions in the early spring. Information is most valuable to irrigated agriculture of the central regions in the winter. Information is most valuable to dryland farming in the central and eastern regions during the fall and spring, which reflects the fall and spring planting cycles of winter and spring wheat.

Table 11.2 Timing of Information for Decisions – Agriculture

Region	Irrigated (Y/N/NA)	Time Period Information is Most Valuable	Crop/Sub-Sector
NW	Y	By the 1st Week of May	Seed Potatoes
NW	Y	By the 1st Week of May	Multiple
NW	NA	Fall and Winter	Landscaping
NW	Y	February to May	Golf Courses
SW/OP	Y	Early Spring	Cane Berries
SW/OP	Y	End of April	Dairy Cattle
SW/OP	Y	April	Multiple
SW/OP	NA	Fall and Winter	Landscaping
CW	NA	Fall and Winter	Landscaping
CW	Y	As soon as information is valid	Landscape Nursery
CW	Y	January	Landscape Nursery
NC	NA	March to June	Fruit Processor
NC	Y	January to February	Tree Fruit
NC	Y	January	Tree Fruit
SC	N	September and Early Spring	Wheat
SC	N	Fall and Spring	Wheat
SC	NA	March (or earlier)	Irrigation District
SC	Y	Winter financial planning period	Tree Fruit
SC	Y	January 1	Tree Fruit
SC	NA	March to June	Fruit Processor
SC	Y	Earlier is better	Tree Fruit
SC	Y	January 1	Tree Fruit
SC	NA	Earlier	County Official

Table 11.2 Timing of Information for Decisions – Agriculture			
Region	**Irrigated (Y/N/NA)**	**Time Period Information is Most Valuable**	**Crop/Sub-Sector**
E	Y	Before April	Multiple
E	N	Fall and Spring	Wheat
E	N	Fall	Wheat
E	N	November to February	Wheat
E	N	April 1	Wheat
E	N	August 20 to September 5 and March 1 to April 1	Wheat
E	N	Spring and Fall	Wheat

11.3. *M&I*

The M&I sector considers indicators of current water supply and indicators of future water supply when making planning decisions. Indicators of current supply include cumulative precipitation, surface water, and ground water. Cumulative precipitation is measured at weather stations. Ground water levels are determined by measuring the water level of the aquifer at an individual well. Surface water is measured as discharge using stream gages or as reservoir storage levels.

Indicators of future supply conditions include snowpack data, precipitation forecasts, and reservoir storage. Snowpack data is monitored using USDA NRCS SNOTEL Data which is available on the internet. Short range precipitation forecasts are available at many different temporal scales from many different sources. Interviewees reported using NOAA National Weather Service (NWS) forecasts. Mid range precipitation indicators include NOAA CPC mid range forecasts. Long range precipitation indicators include NOAA CPC long range forecasts. Mid range surface water supply indicators include reservoir storage and water supply models such as Seattle Forecast/Analysis Model (SEAFM).

Table 3 provides a comprehensive list of indicators cited by the M&I sector including the temporal scale associated with each indicator and a URL for each applicable indicator.

Table 11.3 Indicators - Municipal and Industrial				
Region	**Variable**	**Indicator**	**Range**	**Source**
NW	Surface Water	Streamflow	Current	
NW	Surface Water	Reservoir Storage	Mid Range	
SW/OP	Surface Water	USGS Gages	Current	http://wa.water.usgs.gov/data/

Table 11.3 Indicators - Municipal and Industrial				
Region	**Variable**	**Indicator**	**Range**	**Source**
CW	Precipitation	NOAA National Weather Service - Short range weather forecasts	Short Range	http://www.nws.noaa.gov/
CW	Precipitation	NOAA CPC - Mid range forecasts	Mid Range	http://www.cpc.noaa.gov/
CW	Precipitation	NOAA CPC - Long range forecasts	Long Range	http://www.cpc.noaa.gov/
CW	Surface Water	SEAFM - Seattle Forecast and Analysis Model	Long Range	
CW	Surface Water	Streamflow	Current	http://wa.water.usgs.gov/data/
CW	Surface Water	Reservoir storage	Mid Range	
CW	Precipitation	Precipitation	Current	
CW	Snowpack	Snowpack	Mid Range	
CW	Consumption	Consumption	Multiple	
NC	Snowpack	USDA NRCS SNOTEL Data	Mid Range	http://www.wcc.nrcs.usda.gov/snotel/
E	Surface Water	Streamflow	Current	
E	Snowpack	Snowpack in the Blue Mountains	Mid Range	
E	Precipitation	Precipitation measurements	Current	
E	Temperature	Temperature measurements	Current	
E	Surface Water	Surface water gages	Current	http://www.wcc.nrcs.usda.gov/snotel/
E	Ground Water	Water table elevation measurements	Current	
E	Ground Water	Municipal ground water monitoring	Current	
E	Snowpack	USDA NRCS SNOTEL Data	Mid Range	http://www.wcc.nrcs.usda.gov/snotel/

Table 11.3 Indicators - Municipal and Industrial				
Region	Variable	Indicator	Range	Source
E	Ground Water	Ground water monitoring wells	Current	

Use of indicators is specific to each individual M&I water supplier based on total system demand, sources of supply and decisions that need to be made. M&I supply managers, who manage major storage systems, make decisions to negotiate implementation of instream-flows, alternate water use between water sources, change system maintenance schedules, initiate water shortage contingency plans, and adjust rule curves based on the indicators listed above.

Timing of information availability is also critical. M&I water suppliers use indicators on an ongoing bases. Good information is particularly valuable in the late winter and early spring because that is when key decisions about spring and summer operation and reservoir management are made. Information is also valuable in the late summer and early fall for negotiating fall instream-flow requirements.

11.4. *Environment*

Fisheries agencies consider indicators of current water supply and indicators of future water supply when making planning decisions. Indicators of current supply include precipitation, ground water, surface water, and temperature. Precipitation is recorded at weather stations and the data is available through a variety of sources. Ground water levels are measured at individual wells. Surface water levels are measured at river gages, including those maintained by USGS. Temperature data is also measured at weather stations and is widely available on the internet. Water temperature data is recorded at river stations around the state and is available at different temporal scales, including realtime and monthly data.

Indicators of future supply and demand conditions include demand forecasts, fisheries predictions, precipitation forecasts, snowpack data, surface water supply forecasts, and temperature forecasts. Interviewees did not identify sources for demand forecasts. Fisheries predictions are generated by fisheries agencies. Short range precipitation forecasts are available from many different sources; one interviewee reported using NOAA NWS forecasts. Interviewees reported monitoring snowpack using USDA NRCS SNOTEL Data. Several mid range surface water supply indicators include reservoir levels and streamflow projections. One interviewee reported using long range temperature forecasts, but didn’t cite a source. Another interviewee indicated that summer low streamflow levels are not necessarily clear indicators of whether impacts will occur.

Table 4 provides a comprehensive list of indicators cited by the environment sector including the temporal scale associated with each indicator and a URL for each applicable indicator.

Table 11.4 Indicators - Environment				
Region	**Variable**	**Indicator**	**Range**	**Other**
NW	Surface Water	USGS Gages	Current	http://wa.water.usgs.gov/data/
NW	Snowpack	USDA NRCS SNOTEL Data	Mid Range	http://www.wcc.nrcs.usda.gov/snotel/
SW/OP	Snowpack	USDA NRCS SNOTEL Data	Mid Range	http://www.wcc.nrcs.usda.gov/snotel/
SW/OP	Surface Water	USGS gages	Current	http://wa.water.usgs.gov/data/
CW	Fisheries	Fish migration timing	Short, Mid, Long Range	
CW	Snowpack	USDA NRCS SNOTEL Data	Mid Range	http://www.wcc.nrcs.usda.gov/snotel/
CW	Surface Water	Reservoir levels	Mid Range	
CW	Ground Water	Ground water levels	Current	
NC	Surface Water	Reservoir levels	Mid Range	
NC	Snowpack	USDA NRCS SNOTEL Data	Mid Range	http://www.wcc.nrcs.usda.gov/snotel/
NC	Surface Water	River gages	Current	
NC	Demand	Demand forecasts	Short, Mid, Long Range	
NC	Surface Water	Flow projections	Mid Range	
NC	Temperature	Surface water temperature	Current	http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html#4 https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp
SC	Surface Water	Reservoir levels	Mid Range	
SC	Snowpack	USDA NRCS SNOTEL Data	Mid Range	http://www.wcc.nrcs.usda.gov/snotel/
SC	Surface Water	River gages	Current	

Table 11.4 Indicators - Environment				
Region	**Variable**	**Indicator**	**Range**	**Other**
SC	Demand	Demand forecasts	Short, Mid, Long Range	
SC	Surface Water	Flow projections	Mid Range	
SC	Surface Water	USBR Hydromet data	Mid Range	http://www.usbr.gov/pn/hydromet/yakima/realtime_yak.html
SC	Temperature	Long range temperature outlook	Long Range	
SC	Snowpack	Snowpack at Mount Adams	Mid Range	
SC	Surface Water	Total water supply available	Mid Range	
SC	Precipitation	Cumulative precipitation	Current	
SC	Precipitation	NOAA National Weather Service Forecasts	Short	http://www.nws.noaa.gov/
East	Temperature	Surface water temperature	Current	http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html#4 https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp
East	Snowpack	Snowpack in the Blue Mountains	Mid Range	
East	Precipitation	Precipitation measurements	Current	
East	Surface Water	Surface water gages	Current	
East	Snowpack	USDA NRCS SNOTEL Data	Mid Range	http://www.wcc.nrcs.usda.gov/snotel/

Use of indicators is specific to each river system and depends on whether the river is controlled or free-flowing, and the types of decisions made and actions taken by fisheries agencies. Fisheries agency officials need to make decisions regarding where to monitor for stranded fish, how to allocate funding, whether to buy or lease water rights, where to allow fish migration to occur, whether to advise the agricultural community to conserve water, and when and where to perform emergency projects. In controlled systems, officials must also make recommendations on how to manage the system in a way that is most beneficial to fish. These recommendations include when and where to augment natural flows, at what level to set target fish flows, and how to put limited reservoir storage to the most beneficial use.

Timing of information necessity is strongly related to the nature of each decision. Information is highly valuable in February, when funding decisions are made within fisheries agencies. Information is also very important when making flow recommendations for migration periods and egg development stages. These patterns are very specific to each river and fish species, but tend towards the spring and fall.

11.5. *Power*

The power sector uses indicators of current and future conditions when making planning decisions. Indicators of current conditions include measurements of cumulative precipitation and current reservoir storage. Indicators of future conditions include snowpack measurements and river forecasts. Interviewees reported consulting river forecasts from NWS River Forecast Center as well as using internal river forecasting tools. The power sector makes decisions related to fish flows, reservoir operations, flood control storage, and power generation. Interviewees report consulting indicators on an ongoing basis. Information is particularly valuable as conditions change. Table 6 lists indicators identified by interviewees from the power sector.

Table 11.6 Indicators - Power				
Region	**Variable**	**Indicator**	**Range**	**Source**
NA	Snowpack	Snowpack measurements	Mid Range	
NA	Surface Water	NOAA River Center forecasts	Multiple	http://www.nwrfc.noaa.gov/
NA	Surface Water	Internal river forecasts	Mid Range	
NA	Surface Water	Precipitation measurements	Current	
NA	Surface Water	Current water storage	Current	

11.6. *Recreation*

The Recreation sector considers indicators of future conditions when making planning decisions. Interviewees reported that the key decisions in this sector are hiring decisions and determining how soon to open ski areas at full capacity. These decisions are based on snowpack expectations. The primary indicators used by this sector include short range precipitation forecasts, such as those from NOAA NWS and mid range precipitation forecasts that project precipitation two to three months ahead. Information is most valuable to this sector in the fall, when hiring and early season operation decisions are made. Table 5 lists indicators identified by interviewees from the recreation sector.

Table 11.5 Indicators - Recreation				
Region	**Variable**	**Indicator**	**Range**	**Source**
NA	Precipitation	NOAA National Weather Service Forecasts	Short Range	http://www.nws.noaa.gov/
NA	Precipitation	Weather forecasts 2-3 months ahead	Mid Range	

11.7. *Conclusions*

Prospective and retrospective indicators are employed by water users in Washington State to monitor and forecast drought conditions, and provide useful information for operational decision making. These indicators vary by region and sector. In the dryland agriculture sector, indicators of cumulative precipitation, future precipitation, and current soil moisture are most important, while in irrigated agriculture, indicators of snowpack and surface and ground water storage provide the essential information for decision support. M&I water users rely on good estimates of snowpack, surface water, ground water, and future precipitation to guide their system operation decisions. Environmental agency officials rely on similar indicators as well as fish run timing to manage the supply and demands of fisheries. The recreation sector uses forecasts of early season precipitation to educate hiring decisions, and the power sector uses an ensemble of snowpack and surface water supply indicators to inform hydropower system operation. These findings provide the building blocks for developing regional tools to guide water supply decisions on a statewide level. Indicators listed in this report, including cumulative precipitation, ground water levels, precipitation forecasts, snowpack, and surface water supply need to be considered in concert with sector and region specific demands to develop future drought planning tools.

Phase 4: Recommendations

12. Recommended Information and Resources To Increase Adaptive Capacity and Reduce Drought Impacts by Sector

12.1. *Information and Resources*

Previous chapters of this report have presented the potential effects of drought on many vulnerable sectors in the state. This following section presents information and resources that would enable these sectors to reduce drought impacts and aid water users and water managers in making decisions. Recommendations are provided that relate to increasing supply, improving efficiency, improving the water trading system, improving forecasting and data accuracy, and establishing more definitive instream flow requirements. The final section of this chapter describes detailed recommendations made by interviewees in the most vulnerable sectors.

12.2. *Agriculture*

Interviewees from the agriculture sector recommended many methods to reduce drought impacts. Interviewees from all regions recommended developing improved forecasts of the amount and timing of precipitation. In the Yakima Project this information could enable surface-water system managers to provide irrigators with earlier and more accurate proration estimates. Dryland farmers recommended the development of more localized long range forecasts to inform decisions on crop rotation, planting and harvest times, and fertilizer application rates. Many interviewees in the agriculture sector recommended developing additional tools to aid daily decision making, such as increasing the number of weather stations and making real-time infrared satellite imagery available to farmers. Surface water irrigators, especially those with proratable water rights, recommended altering water law in Washington and developing additional storage. South Central region interviewees commonly recommended building the proposed Blackrock Reservoir. Irrigated farmers in the North West, South West/Olympic Peninsula, and South Central regions recommended creating financial assistance programs to subsidize irrigation system improvements. The dryland farming community recommended improving the accuracy and geographic specificity of long range forecasting and developing accurate predictions of fall rain timing. The green industry recommended improving the state drought declaration system to assess drought locally and declare drought regionally; however the state already has this capability which exemplifies misperceptions that exist among water users. They also recommended improving the drought communication system's ability to educate consumers about water restrictions. Table 1 lists the specific recommendations of interviewees.

Table 12.1 Agriculture: Adaptive Measures and Recommended Actions to Increase Adaptive Capacity	
Adaptive Measures (Decisions)	**Recommended Actions to Increase Adaptive Capacity**
North West - Berries, Row Crops, and Dairy	
Increase robustness and resiliency of current irrigation systems.	Make additional funding resources available to improve irrigation systems. Develop better and more inexpensive irrigation technologies.
Plant fields with high moisture retention (require least water application) and fallow fields with low moisture retention.	
Use different irrigation techniques.	Make additional funding resources available to improve irrigation systems.
Try to predict plant demand levels in advance.	Improve forecasts. Increase the amount and quality of weather data (Evapotranspiration and Precipitation).
Increase efforts to identify plant stress earlier.	Increase the amount and quality of weather data (Evapotranspiration and Precipitation). Make real-time infrared photography available to the farming community.
Use more efficient irrigation systems.	Make additional funding resources available to improve irrigation systems.
Select plant types that require less water and are more drought tolerant.	Develop more drought tolerant cultivars.
Other Recommendations	Eliminate the use-it or lose-it portion of water law. Provide better explanations of what the current ENSO signal means for regional farmers.
Central West - Green Industry	
Develop and promote education programs to increase customer and decision maker awareness.	Advocate alternative water restrictions that allow watering of lawns and landscaping. Develop region and sector specific science. Improve the drought declaration system so drought can be declared on a regional or local level (to limit unnecessary impacts to local business). Implement progressive water restrictions. Develop a water supply dashboard to communicate utility specific water supply projections with consumers. Promote better water supply communication by the media. Identify the value of landscaping in a way that will enable decision makers to use the data.
Reduce the labor force.	
Reduce production of annual plants.	
Reduce equipment purchasing.	
Other Recommendations	Increase storage to increase security of municipal supply.
South West - Berries, Row Crops, and Dairy	

Table 12.1 Agriculture: Adaptive Measures and Recommended Actions to Increase Adaptive Capacity	
Adaptive Measures (Decisions)	**Recommended Actions to Increase Adaptive Capacity**
Increase robustness and resiliency of current irrigation systems.	Create a subsidy program to enable southwest cane fruit growers to enhance and modernize their irrigation systems. Provide more funding for water use brochures.
Predict plant stress and water demands in advance.	Develop better forecasting. Install more weather stations to provide evapotranspiration, soil moisture, and precipitation data. Improve technical knowledge and education on monitoring soil moisture and dealing with water shortage among growers.
Decide to reduce acreage or not increase acreage.	
Grow more drought resistant forage crops	Develop and test more drought resistant forage crops
Other Recommendations	Develop and fund programs to educate farmers on how to improve their existing irrigation systems. Provide better explanations of what the current ENSO signal means for regional farmers.
North Central - Tree Fruit	
Other Recommendations	Build more small multiuse storage projects. Increase irrigation education programs that focus on single users or small groups. Develop a better determination of the continuity between surface water and ground water. Develop more drought tolerant cultivars. Provide better explanations of what the current ENSO signal means for regional farmers.
South Central - Senior and Junior Irrigators and Dryland Farmers	
Decide to increase supply by drilling/activating emergency wells and buying/leasing additional water rights.	
Increase supply/acre by leaving fields fallow or removing marginal perennial crops.	
Decide to increase supply by purchasing/leasing water rights.	Clarify Ecology's role in WA for issuing new water rights. Develop a better system for water rights trading. Create a true water market program for water trading. Improve the water transfer system. Fix antiquated water law to eliminate use-it or lose-it and promote conservation. Promote more interdistrict water transfers.

Table 12.1 Agriculture: Adaptive Measures and Recommended Actions to Increase Adaptive Capacity

Adaptive Measures (Decisions)	Recommended Actions to Increase Adaptive Capacity
Decide to forgo spring wheat crops.	Develop more accessible and localized forecasting information. Develop a regional drought monitor.
Change the amount of fertilizer applied to fields.	Develop more accessible and localized forecasting information. Develop a regional drought monitor.
Change crop rotations.	Develop more accessible and localized forecasting information. Develop a regional drought monitor.
Make primary and backup irrigation systems more robust.	Make additional funding resources available to improve irrigation systems. Develop better and cheaper irrigation technologies.
Other Recommendations: General	Develop more drought tolerant cultivars. Provide more money in the farm bill.
Other Recommendations: Increase supply and improve efficiency	Develop additional water storage projects - Blackrock Reservoir (3). Use more inter-reservoir piping. Develop the Umatilla Project. Increase use of Columbia river water for irrigation. Develop more efficient emergency water delivery systems. Improve the efficiency of conveyance systems used by irrigation districts (automated checks and more pipes used as laterals). Increase storage. Increase storage in the Yakima Basin. Redistribute water supply in the Yakima Basin. Provide better supply to the Roza District in the early season.
Other Recommendations: Improve forecasting and provide better local information	Develop a regional drought monitor. Develop more accessible and localized forecasting information. Improve forecasting technology. Provide better information on when and how much water will be available from irrigation districts. Provide more reliable information on water supply expectations during the winter planning period (January 1), rather than in the spring (3). Develop more NRCS and USBR monitoring sites (SNOTEL and other stations).
East - Dryland Farmers, Senior Surface Water Irrigators and Ground Water Irrigators	
Change the amount of fertilizer applied to fields.	Develop more accessible and localized forecasting information. Develop more accurate long range forecasts. Develop a regional drought monitor.
Change crop rotations.	Develop more accessible and localized forecasting information. Develop more accurate long range forecasts. Develop a regional drought monitor.
Plant more drought tolerant cultivars	Develop more drought tolerant cultivars.

Table 12.1 Agriculture: Adaptive Measures and Recommended Actions to Increase Adaptive Capacity	
Adaptive Measures (Decisions)	**Recommended Actions to Increase Adaptive Capacity**
Decide to forgo the spring wheat crop.	Develop more accessible and localized forecasting information. Develop more accurate long range forecasts. Develop a regional drought monitor.
Other recommendations	Implement measures that reduce the prices of power, fuel, and fertilizer for farmers. Increase federal financial assistance. Improved short and mid range forecasts would enable better management of water in the soil profile. Develop more monitoring stations for streamflow and weather data. Generate better estimates of spring runoff. Develop improved forecasts that can provide more accurate estimates of precipitation for July, August, and September in April and May. Perform more water storage feasibility studies.

12.3. *M&I*

Interviewees from the M&I sector provided several recommendations to develop decision making tools, including improved forecasts and climate tools for regional planning. Improved forecasts, such as more accurate information on the timing and amount of spring and fall rains, would help inform system operation decisions. Climate tools have been developed that predict runoff from a very large area. Water managers recommended developing similar tools that can provide watershed scale runoff information for regional planning. The specific recommendations made by the M&I sector are listed in Table 2.

Table 12.2 M&I: Adaptive Measures and Recommended Actions to Increase Adaptive Capacity	
Adaptive Measures (Decisions)	**Recommended Actions to Increase Adaptive Capacity**
North West	
Improve supply reliability	Withdraw water from more reliable main stem river locations, rather than small tributaries.
Central West	
Change system maintenance schedules.	Tools from climate groups that target the needs of large metropolitan areas and provide watershed scale information. Develop downscaled versions of existing climate products. Develop improved forecasts. Develop improved early season forecasts of runoff (can reservoirs be filled?). Develop improved late season forecasts of precipitation (when will natural flows be sufficient to meet fisheries demands?).

Table 12.2 M&I: Adaptive Measures and Recommended Actions to Increase Adaptive Capacity	
Adaptive Measures (Decisions)	**Recommended Actions to Increase Adaptive Capacity**
Operate reservoirs using a dynamic rule curve.	
Optimize use of multiple water sources.	
Create reserve funds for use during water restrictions.	
South West/Olympic Peninsula	
Other Recommendations	Accurately determine the status quo and correct problems with over appropriation of the water supply. Develop an accurate water rights database. Determine the level of hydraulic continuity between surface water and ground water.
North Central	
Other Recommendations	Accurately determine the status quo. Determine the impact of water shortage on water quality.
South Central	
Other Recommendations	Determine the level of hydraulic continuity between surface water and ground water. Develop more storage - Aquifer storage and recharge, Smart Storage Projects.
East	
Other Recommendations	Determine the level of hydraulic continuity between surface water and ground water. Develop more storage.

12.4. *Environment*

Interviewees from the environment sector recommended developing several decision making tools including long range forecasts of the timing of fall and winter rains and better methods to predict where and when fish may become stranded. They also recommended the following: determining the stimuli for downstream migration in juvenile salmonids, negotiating more definitive control structure agreements for instream flows, working with the agricultural community to reduce water use through efficiency improvements and conservation incentives, funding local environmental brochures, prioritizing which water rights to lease from the agriculture sector, developing longer range drought forecasts, developing new storage projects, and quantifying the continuity between surface water and ground water. Several interviewees suggested that drought funding for fisheries agencies be provided earlier in the year (February) to purchase water rights before farmers plant their fields. Table 3 lists recommendations made by the environment sector.

Table 12.3 Environment: Adaptive Measures and Recommended Actions to Increase Adaptive Capacity

Adaptive Measures (Decisions)	Recommended Actions to Increase Adaptive Capacity
North West	
Improve habitat	Increase riparian buffers to provide shading, habitat, and recruitment of large wood.
Reduce water withdrawals and increase tools to meet streamflow goals.	Adjudicate water rights and end illicit withdrawals.
Central West	
Allow more natural pulse flows.	
Use stored water to increase natural flows.	Develop accurate long term predictions of the timing of fall and winter rains.
Increase monitoring and maintenance of fisheries devices.	Develop a real-time system that can correlate current discharge with historic discharge and location of distressed or stranded fish observations.
South West/Olympic Peninsula	
Decide to coordinate short term shutdowns of irrigation systems.	Provide more funding for environmental brochures. Develop a better understanding of the relationship between river stage and problem locations in the river.
North Central	
Increase monitoring and maintenance of fisheries devices.	
Reduce agricultural extractions by buying/leasing water rights from agriculture.	Make emergency drought funds available to fisheries earlier (by February).
Decide whether to and where to monitor for fish in distress.	Develop a real-time system that can correlate current discharge with historic discharge and location of distressed or stranded fish observations.
Decide where to allow fish migration to occur.	
Other Recommendations	Establish control structure agreements and negotiate water release patterns. Modify fishing seasons. Encourage better cooperation among irrigators to allow more water to remain in streams. Create an incentive for agriculture to conserve water in order to increase the amount of water left instream. Encourage more efficient conveyance systems and more efficient application techniques. Use available BPA funding to pay for efficiency enhancements. Develop earlier projections of likely drought scenarios. Develop a matrix to prioritize the value of water uses. Collect more information on the impacts of water use on water quality.
South Central	
Allow more natural pulse flows.	Determine what triggers downstream migration of juvenile salmonids.

Table 12.3 Environment: Adaptive Measures and Recommended Actions to Increase Adaptive Capacity	
Adaptive Measures (Decisions)	**Recommended Actions to Increase Adaptive Capacity**
Increase use of reservoir storage to supplement streamflows.	Make funding available earlier (February) for fisheries to buy back water from agriculture earlier.
Purchase additional water rights from agriculture to supply instream flows.	Make funding available earlier (February) for fisheries to buy back water from agriculture earlier.
Increase monitoring and maintenance of fisheries devices.	Make funding available earlier (February) for fisheries to buy back water from agriculture earlier.
Provide adequate streamflows for fish to access side channels.	
Provide adequate streamflows to maintain coverage of redds.	
Other Recommendations	Establish control structure agreements and negotiate water release patterns. Modify fishing seasons. Encourage better cooperation among irrigators to allow more water to remain in streams. Create an incentive for agriculture to conserve water in order to increase the amount of water left instream. Encourage more efficient conveyance systems and more efficient application techniques. Use available BPA funding to pay for efficiency enhancements. Develop earlier projections of likely drought scenarios. Develop a matrix to prioritize the value of water uses. Collect more information on the impacts of water use on water quality. Develop more storage projects - the proposed Blackrock Reservoir, Aquifer storage and recharge. Perform better spawning surveys. Develop better long range forecasts, particularly flood forecasts which could enable the storage of more water earlier. Develop more clearly defined tribal (fisheries) water rights.
East	
Coordinate agricultural shutdowns to provide necessary instream flows for short periods of time.	
Purchase additional water rights from agriculture to provide better instream flows.	
Other Recommendations:	Perform more water storage feasibility studies. Create additional small storage projects - wetland and floodplain storage. Implement more conservation measures. Determine the amount of continuity between surface water and ground water.

12.5. *Power*

The power sector already has many of their own climate and forecast specialists, so their recommendations for additional information are limited. One interviewee recommended developing earlier and more reliable supply forecasts. Another interviewee recommended developing longer range and more accurate flood forecasts to improve system operation. Several interviewees made recommendations to increase supply security including increasing non-hydro generation, encouraging utilities to implement all cost effective conservation measures, exploring more demand response technologies, storing more water in Canada, and increasing flexibility of non power-related constraints. Table 5 lists the power sector recommendations in detail.

Table 12.5 Power Sector: Adaptive Measures and Recommended Actions to Increase Adaptive Capacity	
Adaptive Measures (Decisions)	**Recommended Actions to Increase Adaptive Capacity**
Reduce fish spills and increase capture and transport of juvenile salmonids.	Develop methods to provide reliable supply information earlier.
Pay agricultural users not to irrigate.	Develop methods to provide reliable supply information earlier.
Decide whether to purchase energy from non-hydro sources.	Develop methods to provide reliable supply information earlier.
Buyback power from the Direct Service Industry.	Develop methods to provide reliable supply information earlier.
Decide whether to meet spring fish-spill requirements.	
Decide to store more water.	Develop better flood forecasts - longer range and more accurate. Enable more curtailments of operating restrictions such as flood protection, irrigation supply, and fish passage. Store more water in Canada.
Respond to energy shortage by curbing demand.	Invest more resources in exploring demand response alternatives such as centrally controlled water heaters.
Other Recommendations	Develop better daily temperature forecasts to predict load. Develop better real-time data of fish migration. Increased participation by public utility districts and independent power producers in development of the westwide resource adequacy standard. Encourage utilities to implement all cost effective conservation. Develop more non-hydro resources.

An interviewee from the power sector supplied the following list of current non-power constraints on the regional hydropower system that could be curtailed in order to reduce impacts during drought (Table 12.6). This table also includes the estimated cost of lost generation due to the current constraints.

Table 12.6 Non-power Constraints on the Hydropower Generation System[10]		
Constraint	**Power Loss**	**Estimated cost of lost hydropower generation**
Protection from flooding	Insignificant	~ $5.6 million/year - cost due to timing of sales
Opportunities for recreation	Insignificant	Insignificant
Water for irrigation	~ 625 MWa	~ $250 million/year
Water for municipal and industrial uses	Insignificant	Insignificant
Routes for navigation	Insignificant	Insignificant
Protection for Native American cultural resources	Insignificant	Insignificant
Passage for anadromous fish	~ 1035 MWa	~ $460 million/year
Protection for resident fish	Insignificant	~ $2 million/year - cost due to timing of sales
Habitat for wildlife	Insignificant	Insignificant
Control of water quality and temperature	Insignificant	Insignificant

12.6. *Recreation*

Interviewees from the recreation sector had two primary recommendations: develop improved forecasts to predict the timing and quantity of late autumn and early winter snowfall and reconsider granting water rights to ski areas for snowmaking. With improved forecasts, ski area managers could make better hiring decisions, and water rights would enable ski areas to operate with limited natural snow. Table 4 lists these recommendations in detail.

Table 12.4 Recreation: Adaptive Measures and Recommended Actions to Increase Adaptive Capacity	
Adaptive Measures (Decisions)	**Recommended Actions to Increase Adaptive Capacity**
Decide to reduce the scale of operations until conditions become good.	Develop more accurate long range forecasts of fall precipitations and temperatures.
Decide to scale back operations until ski area visitation increases.	Develop more accurate long range forecasts of fall precipitations and temperatures.
Decide to groom slopes more closely.	
Other Recommendations	Accept Water Right requests from ski areas.

[10] Northwest Power and Conservation Council, Fazio, John. Cover Memo for the Multiple Use of the River Paper, February 8, 2006.

13. Recommended Actions from Interviewees in the Most Vulnerable Sectors

13.1. *Overview*

This section will describe in detail the recommendations made by the seven most vulnerable sectors, according to assessments based on the interview data (see Phase Two report) and summarized in Table 6 below. The most vulnerable sectors are listed in bold.

Table 13.1 Vulnerability Rating Summary		
Regions	**Sector**	**Sub-sector**
High Vulnerability		
Central West	**Agriculture**	**Green Industry**
North Central	**Environment**	**Fisheries**
South Central	**Agriculture**	**Proratable Irrigation**
South Central	**Agriculture**	**Dryland Farming**
South Central	**Environment**	**Fisheries**
East	**Agriculture**	**Dryland Farming**
NA	**Recreation**	**Ski Areas Operators**
Medium Vulnerability		
North West	Agriculture	Row Crops
North West	Agriculture	Irrigated Diverse
North West	Agriculture	Cane Berries
North West	Agriculture	Golf Courses
North West	Agriculture	Dairy
North West	Environment	Fisheries
Central West	Agriculture	Golf Courses
Central West	M&I	Municipal Water Suppliers
Central West	Environment	Fisheries
South West/Olympic Peninsula	Agriculture	Cane Berries
South West/Olympic Peninsula	Agriculture	Dairy
South West/Olympic Peninsula	Agriculture	Golf Courses
South West/Olympic Peninsula	Environment	Fisheries
North Central	Agriculture	Irrigated
North Central	Agriculture	Cattle
South Central	Agriculture	Beef Cattle
South Central	Agriculture	Dairy Cattle
East	Agriculture	Irrigated
East	Environment	Fisheries
NA	Power	Hydropower
Low Vulnerability		

Table 13.1 Vulnerability Rating Summary		
Regions	**Sector**	**Sub-sector**
North West	M&I	Municipal Water Supplier
South West/Olympic Peninsula	M&I	Municipal Water Supplier
South Central	M&I	Municipal Water Supplier
South Central	Agriculture	Senior Water Rights
North Central	M&I	Municipal Water Supplier
East	M&I	Municipal Water Supplier

13.2. *Central West Region*

Green Industry: The green industry has experienced reduced sales during previous droughts. Interviewees attribute this reduction to their customers' expectations of water restrictions. The green industry is most concerned with periods when customers unnecessarily expect water restrictions. Interviewees had several recommendations to improve communications between water managers, decision makers, and consumers of green industry products. These recommendations include modifying the current drought declaration system so drought can be assessed and declared on a regional level (the state already has this capability which exemplifies misperceptions that exist among water users), encouraging water users to consult their local utilities regarding potential water restrictions, increasing efforts to communicate water-supply expectations with the public, and developing new water conservation alternatives to avoid restrictions on watering.

13.3. *North Central Region*

Environment: The largest impacts identified by interviewees were stranding and prespawn mortality of adult fish migrating upstream. These are caused by low streamflows and in some cases, poor water quality, like higher temperature. Interviewees from fisheries agencies recommended the following items to increase adaptive capacity of fisheries agencies: making drought relief funds available to agencies early enough to lease water rights from farmers before planting (February was recommended), more clearly defining fisheries water rights and control structure agreements, and working with the agricultural community to reduce water use through efficiency improvements and conservation incentives.

13.4. *South Central Region*

Proratable Irrigated Agriculture: Fruit growers in the south central region with junior water rights are highly vulnerable to drought because during bad water years, they must manage the same acreage with less than normal water supply. These farmers have received less than half of their normal supply during two of the past five years. In addition, they must plan for the upcoming year with an uncertain supply. Interviewees from this sector have made several recommendations to enhance their ability to plan for drought and adapt during drought. These recommendations can be grouped into four main categories: recommendations to increase storage or alter the way storage is used, recommendations to increase efficiency of delivery systems, recommendations to alter current water laws, and recommendations to enhance the accuracy and improve the timeliness of supply information provided to water users.

We interviewed nine individuals that were considered knowledgeable about the problems faced by junior water users; four of these interviewees were farmers with junior water rights. Six interviewees from this group suggested increasing storage in the region, three specifically recommended the proposed Blackrock project, and one recommended the proposed Umatilla project. These interviewees also recommended reregulating the reservoirs in the region, promoting more interdistrict water transfers, and constructing more interbasin piping. Four of these nine interviewees recommended efforts to increase the efficiency of the existing system by developing better application technologies, developing new techniques for spreading water, and funding improvements to the current conveyance systems such as installing more automated checks in irrigation canals and installing pipes on laterals. Recommendations to make changes to the current water laws and water appropriations system included "eliminate the use-it or lose-it portion of the law to promote conservation", reallocate water in the Yakima basin, modify water law to create a "true water market", provide further clarification to ecology on their role for issuing new water rights. Three interviewees recommended modifying the water transfer process to make trading easier. Five of the nine interviewees from this sector recommended developing better earlier proration estimates. Of these five, three specifically listed "early winter" or "January" as the ideal time to make proration estimates available so they can be used for financial planning.

Dryland

Dryland farmers in the South Central region have experienced severe impacts in the past. These farmers recommended developing better forecasting and increasing financial assistance. Their primary recommendations include improved, more accessible, and more geographically specific long range forecasting. Predictions for the spring and fall are particularly important because they dictate when to plant and whether to plant. Forecasts of total precipitation during the growing season provide insight on how to manage fields and how much fertilizer to apply.

Environment

Officials from fisheries agencies made several recommendations to improve the adaptive capacity in the South Central region including recommendations that relate to watershed system operations and modifications, increasing the amount of information available to assist system operators, and working with the agricultural community to ensure more water stays in streams. Several interviewees recommended that storage in the basin be increased by building smart storage projects, aquifer storage and recharge projects, or by constructing the proposed Blackrock reservoir. Interviewees also recommended increasing floodplain storage, restoring side channels and side channel habitat, allowing a more natural freshet in the spring, regulating flows to better resemble natural flows year round, and negotiating release patterns and control structure agreements. Many interviewees from this sector recommended keeping more water instream by increasing the efficiency of conveyance structures used for agricultural diversions, working with the agricultural community to reduce water use through efficiency improvements and conservation incentives, and increasing promotion of the water trust program. Recommendations to increase available information include developing more knowledge on fish behavior, determining stimuli of downstream migration in juvenile salmonids, quantifying the continuity between surface water and ground water, developing more concrete definitions of tribal water rights for fisheries, and developing better flood forecasting to help reservoir operators store more water. Finally, interviewees recommended having drought response plans and administrative details for fisheries agencies complete prior to drought and granting emergency drought funding to fisheries agencies by February to purchase agricultural water rights before spring planting.

13.5. *East Region*

Dryland

Dryland farmers in the East region have experienced severe impacts in the past. These farmers' recommendations indicate better forecasting and more financial assistance would be helpful. Of the five dryland farm owners we interviewed, four recommended developing improved long range forecasts. Predictions during the spring and fall are particularly important because these predications dictate when to plant and whether to plant. One interviewee indicated that forecast information is most important from March 1 to April 1 for spring wheat and August 20 to September 5 for winter wheat. These dates vary with geographic area. Fall wheat planting dates may be as late as early October in some locations. Forecasts of the timing of rains indicate when to plant. Forecasts of total precipitation during the growing season provide insight on how to manage fields and how much fertilizer to apply. These interviewees also recommended developing more drought tolerant cultivars and increasing federal financial assistance.

13.6. *Recreation*

Ski Area Operators

Ski area operators had two primary recommendations: develop improved forecasts to predict the timing and quantity of late autumn and early winter snowfall and reconsider granting water rights to ski areas for snowmaking. With improved forecasts, ski area managers could make better hiring decisions and allocate resources more economically. Water rights would enable ski areas to operate with limited natural snow.

Appendix A: Research Methods and Assessment Procedure

1. **Initial sources**
   The project managers held a kickoff meeting for the project on October 21, 2005 with officials from Washington Department of Community Trade and Economic Development, Washington Department of Agriculture, Washington Department of Ecology, Washington Office of Financial Management, University of Washington, and Washington State University. Each official has expertise in fields related to drought. This group of officials served as an advisory committee to guide the research. At the meeting, each official was given an opportunity to discuss drought concerns in their sector/region. The resulting guidance directed the research performed by the UW to identify primary sectors and geographic regions affected by drought. Phone interviews conducted by UW with representatives in the primary sectors and regions provided the primary source of information for this investigation.

2. **Interview methods**
   The authors developed an interview protocol (Appendix B) to guide phone interviews. The interviews, which included both structured and unstructured questions, focused on identifying the primary impacts of drought, decisions made by interviewees, information considered by interviewees when making decisions, additional information and resources that could better inform decisions, and lessons learned from previous droughts. Interviews ranged from 10 to 90 minutes in length. 67 Interviews were conducted between December 2, 2005 and November 13, 2006. The identity of all interviewees will be kept confidential.

3. **Hot spot identification**
   Officials identified an initial group of hot spots for investigation. In addition, the authors asked each interviewee to provide contact information for other interview candidates in their sectors/regions that were affected by water shortages or that could provide insight into additional challenges facing the sector/region. Subsequent hot spots were identified by UW during the course of interviews. The results of this report represent efforts made by UW to concentrate on hot spots identified by agency officials and by sector representatives during subsequent interviews. In general, most contacts were willing to participate in the survey; however, many were constrained by time and availability. Once a sector or region had received adequate representation in the pool of completed interviews, additional contact names were saved, and efforts shifted to those regions/sectors not yet adequately represented.

4. **Evaluations of economic impacts**

In many cases, interviewees were able to convey information on the impacts of drought based on relative approximations of how their operations were affected. For example, many wheat farmers were able to quantify impacts based on variation in production between a drought year and an average year. Several interviewees were also able to provide rough estimates on how revenue or profit was affected by drought, often given as a percentage.

In fewer cases, interviewees were able to quantify the exact economic impacts of drought to their operations or their sector as a whole. For example, impacts of a drought on fishery production may be quantifiable in terms of fish return one life cycle after a drought compared to average fish return, but it is very difficult to distinguish drought impacts from other impacts, or to determine the value of one fish. In addition, productivity of a fishery or profit on a farm is influenced by many forces in addition to precipitation. For example, higher nitrogen fertilizer cost can play a role in overall profit from a crop. In cases such as these, impacts of drought were not easily separable from other factors such as market forces.

Appendix B: Interview Protocol

University of Washington Drought Project
Interview Protocol
All Sectors

Date
Interviewer
Interviewee
Title
Phone #
Email Address
Address

1. Describe what you do.
2. Describe your primary supplies of water as well as your primary demands.
3. Describe the primary impacts that water shortages have had on your operations. Also, what are the secondary impacts?
4. Can you provide some specific examples of these impacts during previous droughts?
5. What has the economic value of these impacts been? How have you (would you) go about evaluating and quantifying these impacts?
6. What indicators do you monitor to evaluate the onset of drought and to track the progression of water shortages? (please be very specific: describe variables, timescales, and spatial scales)
7. What types of decisions do you make to mitigate the impacts of water shortage? How do you alter what you do in response to drought? In which other ways might you alter what you do?
8. What type of information is needed or desired to make these decisions? When is this information most valuable?
9. What strategies and responses have and haven't worked during previous water shortages? What do you know now, that you wish you knew then? e.g. lessons learned
10. What types of things would help mitigate drought hazards to your operations? e.g. information, resources, etc.
11. Whom else should I talk to? What questions should I ask that I haven't asked already?

Appendix C: List of Definitions[11]

Cane berries: Rubus spp., commonly known as raspberries and blackberries
Central West: the geographic area containing Snohomish, King, Pierce, and Thurston counties
Cruciferous vegetables: a family of vegetables that has four petaled flowers and includes plants with four-petaled flowers such arugula, broccoli, cauliflower, brussel sprouts, cabbage, watercress, bok choy, turnip greens, mustard greens, collard greens, rutabaga, Chinese cabbage, daikon, radishes, turnips, kohlrabi, and kale (also known as the Brassica family)
Cultivar: a type of plant that is cultivated for certain traits and that is recognized by the International Code of Nomenclature for Cultivated Plants
Dryland farming: raising crops where rain is the only water source
East Region: the geographic area containing Ferry, Stevens, Pend Oreille,Douglas, Grant, Lincoln, Spokane, Adams, Whitman, Franklin, Walla Walla, Columbia, Garfield, Asotin Counties
Freshet: a peak in the hydrograph of a river caused by a rain event and/or increased snowmelt
Green industry: the industry whose objective is to grow, install, and maintain landscaping and yards, including irrigation and landscape professionals, landscape nurseries, garden centers, horticulturists, turf growers, and golf courses
Indicator: variables that are employed to monitor and forecast drought conditions, characterize and compare drought severity, and provide a basis for triggering drought responses
Junior water right: (1) a water right dated later than another (senior) water right, based on the first date water was put to beneficial use (2) in the Yakima Project this refers to a right dated prior to May 10, 1905
Municipal and Industrial (M&I) water supplier: an entity that supplies drinking water to a city or industry
North Central Region: the geographic area containing Okanogan and Chelan counties.
North West Region: the geographic area containing Skagit and Whatcom counties
Proratable water rights: in the Yakima Project this refers to rights dated later than May 10, 1905
Purveyor: a municipality, public utility, water company, or water district that provides drinking water to customers
Redd: a depression, trench, or nest dug by a salmon in which eggs are laid
Senior water right: (1) a water right dated prior to another (junior) water right. (based on the first date water was put to beneficial use) (2) in the Yakima Project this refers to a right dated prior to May 10, 1905.
South Central Region: the geographic area containing Okanogan and Chelan counties
South West/Olympic Peninsula Region: the geographic area containing Kittitas, Yakima, Klickitat, and Benton counties
Target flows: a discharge goal below a dam or gauging station
Tensiometer: A device used to indirectly measure soil water content by measuring soil moisture tension

Vulnerability: the degree to which an individual or sector is susceptible to, or unable to cope with, the adverse affects of drought [12]