IMPACTS OF THE 2015 DROUGHT:

A STUDY OF ORCHARDISTS' IN THE

YAKIMA RIVER BASIN OF CENTRAL WASHINGTON

by

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ABSTRACT

IMPACTS OF THE 2015 DROUGHT: A STUDY OF ORCHARDISTS IN THE YAKIMA RIVER BASIN OF CENTRAL WASHINGTON

Ashlie Tainer

An extreme drought emergency was declared in Washington State in May of 2015. Consequently, a decrease of surface water and unusually high temperatures caused the state's $10 billion dollar agricultural industry to suffer losses of crop yields, crop size and marketability. The objective of this study was to identify initial patterns of physical and economic impacts that orchardists experienced in their tree fruit crops due to the 2015 drought and if and how they are adapting to future variability in surface water supply. This study analyzed a primary data set from an online survey performed by the Washington State Department of Agriculture (WSDA) over a six-week period between November and December 2015. Additionally, a set of documents deliberating on the Yakima River Basin were drawn on for supplemental data to inform the analysis, including an interim report completed by the WSDA, email conversations and interviews with two key informants. Survey results from 41 orchardists located in Central Washington revealed that 85.4% experienced yield losses due to the drought, 73.8% stated the quality or the marketability of their crop was negatively impacted, and 61.5% reported that the 2015 drought will have negative impacts on their future farming operation and 2016 crop. Overall, patterns emerged between negative drought impacts on tree fruit quality and storage in relation to implementation of infrastructure improvements. Furthermore, it was concluded that orchardists generally seek adaptations in order to mitigate drought impacts as long as they have access to the necessary resources and finances to implement such adaptations. As the effects of climate change increase and threats to surface water supplies continue, these results can help inform state agencies about how orchards in the region have been impacted by the 2015 drought, the risks the growers foresee in upcoming growing seasons, and future drought relief needs for this group of water users.

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I. Introduction

Climate change poses risks for both human and natural systems (IPCC, 2014). Change in precipitation or melting snow and ice due to warming temperatures alter hydrological systems and affect water resource quantity and quality in Washington State (Department Of Ecology, 2015). In addition, climate change models predict drought risk to increase in the Western United States, where drought events will occur more frequently and become more severe (Dai et al., 2004). As droughts increase in frequency and magnitude, and hydrologic systems change from snow dominant during the winter to mainly rain, irrigators across the region experience an unfamiliar water regime.

For example, Governor Jay Inslee declared an extreme drought emergency in Washington State on May 15th, 2015. Consequently, the 2015 crop season was among the driest on record in Washington State (Washington State Department of Agriculture, 2015). The water year, which began on October 1st, 2014 and ended on September 30th, 2015, had above average temperatures throughout the state, severely impacting snowpack and reducing streamflows. At the height of the year's drought (during the last week of August, 2015), 85% of Washington was in "extreme drought" status, as seen in (**Figure 1**) (Washington State Department of Agriculture, 2015).

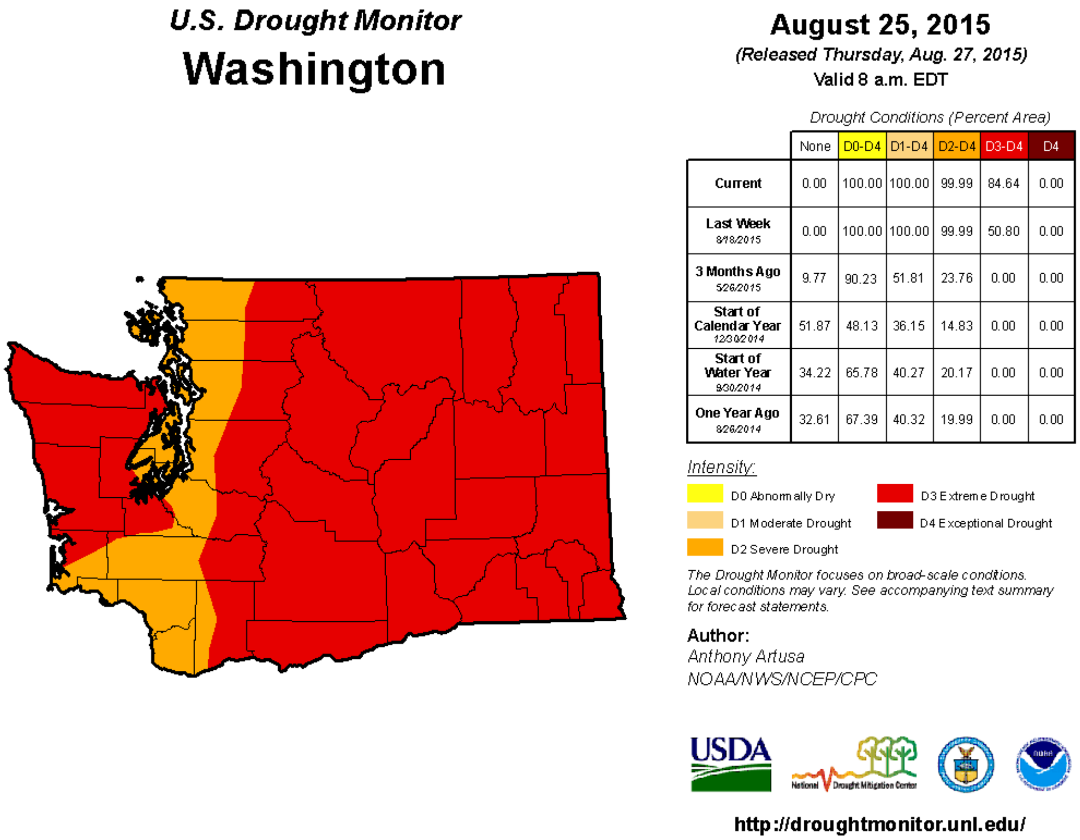


Figure 1. Washington State Drought conditions on August 25th, 2015 (OWSC, 2015)

Warm winter temperatures during the 2014-2015 season caused more precipitation to fall as rain rather than snow, decreasing snow pack levels that act as natural reservoirs during normal weather conditions. A lack of snow pack during the winter results in less snow melt and runoff during the summer and early fall when water demand is the highest. In consequence, stream levels decrease, affecting all water users. For example, fish populations and hydropower beneficiaries experience risks associated with in-access to native spawning grounds and electricity cut offs. Although, approximately 80% of Washington water withdrawals are for agricultural purposes (Washington State University, 2015). Surface water is the largest source of state agricultural water needs (compared to groundwater), accounting for approximately 75%

on average (WSU, 2015). In addition, population growth in Washington State is expected to reach 7.4 million by 2020, after jumping from 2.4 million to 5.9 million between 1950 and 2000, further pressuring the demand side of water availability (Washington State Department of Ecology, 2014). Irrigators who rely on surface water sources, and thus instream flows, to water their crops and sustain their livelihoods are impacted by a decreasing water supply while facing competition between ecological and social water demands.

A particularly vulnerable group of agricultural water users in Washington State are orchardists. In the context of U.S. production, Washington is the top producer of a wide variety of tree fruits. This includes apples, which make up 63.9% of all U.S. production as of 2015, as well as sweet cherries at 65.1% and pears with 50% (Washington State Department of Agriculture, 2015). Peaches, nectarines, and apricots also contribute to the State's tree fruit sales, collectively making up 19.6%of all U.S. production (National Agriculture Statistics Service, 2015). Apples dominate Washington's farming economic output, reaching a $2.19 billion crop value in 2013, and 22%of the state's total crop value (Washington State Department of Agriculture, 2015). The region also supports smaller fruit crops, such as wine grapes and blueberries, which will not be included in this study's analysis. Altogether, the State's central region, specifically the Yakima River Basin, has earned the name of "Washington's fruit basket" due to the successful production of these commodities (WSU, 2015).

However, tree fruits' high economic value also comes with high risk. These plants are considered perennials, or "permanent crops", because they live for more than two years and thus must withstand year-round, climate-related biotic and abiotic stresses

(Neilson et. al., 2013). Permanent crops require consistent irrigation and maintenance, and cannot be fallowed (left uncultivated for a season) during low water years due to upfront capital costs, required infrastructure, subsequent fixed costs, and replanting cost (Washington State Department of Agriculture, 2015). In fact, economic impacts listed by the State in 2015 estimated crop loss to reach 1.2 billion by the years end (Washington State Department of Agriculture, 2015). Therefore, during water-limited years like 2015, many regions of the state can experience reduced yields, quality, and produce marketability due to decreased surface water availability (Washington State Department of Agriculture, 2015).

In short, scarcity in an orchardist's water supply puts their product and income at risk, and consequently the State's economy. Environmental, social and economic impacts affect both instream and out-of-stream water users and will only be exacerbated as climate change continues to increase drought frequency in Central Washington. Therefore, this study's research question is: how were orchardists in the Yakima River Basin of Central Washington affected by the 2015 drought, and what are the implications of this knowledge for future climate adaptation planning?

Overall, the 2015 drought conditions provide an example for how the climate will be in the future in the Yakima Basin. The Washington State Department of Ecology (Ecology), the State lead on drought, acknowledged this and emphasized need for an assessment of the 2015 drought impact on Washington State's agricultural production. After the final statewide drought declaration on May 15th, 2015, subsequent completion of the state budget gave Ecology funds to conduct drought mitigation activities. At Ecology's request, the Washington State Department of Agriculture (WSDA) wrote a proposal for a 2015 drought assessment and its impact on Washington agriculture. The ensuing data collected by the WSDA through an online survey was used to prepare an economic assessment of the drought, with the purpose of better targeting future drought funding and support.

Using a subset of the data found through WSDA's ongoing online survey, as well as conversations and email correspondence with industry stakeholders, this study sought to understand the 2015 droughts overall impact on orchardists in Central Washington. In addition, historic weather patterns for the central region of the state, locally competitive water demands, and economic drivers in tree fruit production were studied to provide a thorough contextualization and analysis of the survey results. As orchardists in Central Washington plan for future growing seasons, their success relies on accessible drought mitigation options and their ability to continually implement adaptations. Therefore, this study's ultimate goal has been to identify initial patterns or trends between physical and economical impacts on tree fruit crops in Central Washington from the 2015 drought and how orchardists have adapted in order to improve future relief efforts for the region in the face of a continually changing climate.

II. Background

Chapter 1. Climate Change

Historic and Current Weather Conditions-

Water users in Central Washington experienced extreme drought conditions during the summer of 2015, signaling the first time a statewide drought emergency had been announced since 2005, and making it the hottest year on record (WSU, 2016). The most recent warm temperatures caused a decrease in snowpack, earlier average precipitation fall, and a decrease in stream levels throughout the state. As of May 2015, statewide snowpack levels were 16% of normal, which is 10% lower than the 2005 drought. Snowpack levels in the Yakima Basin were a few of the lowest in the state, with 12%in the lower basin and zero of the annual average in the upper (See **Figure 2**) (NRCS, 2015).

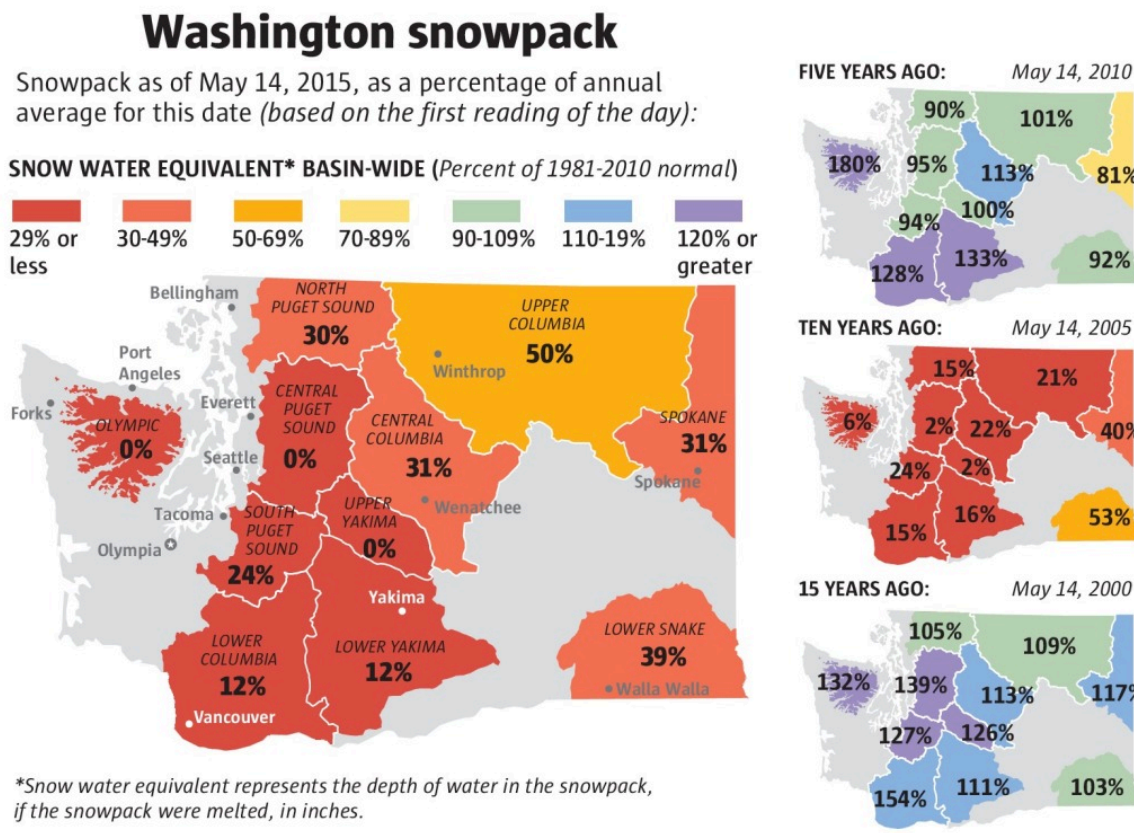


Figure 2. Washington State snow water equivalent on May 14th, 2015 (National Resources Conservation Service, 2015)

In addition, of 98 snow sites measured at the beginning of May, 66 were snow free and 11 for the first time in history (NRCS, 2015). Along with record low snowpack, the National Resources Conservation Service (NCRS) found that 17 of 34 long-term measuring sites in the state of Washington recorded their earliest snowfall peak on record, which occurred on average 48 days earlier than normal. Furthermore, Stewart et al. (2004) found that average peak runoff occurs 1 to 4 weeks earlier across much of the Western U.S. than in the 1950s. In result of earlier snowfall and less overall snowpack in 2014-15, and increasingly earlier peak runoff, 43% of rivers statewide were running at record-low levels by June 2015 (Washing State Department of Ecology, 2015). In order to understand why these changes in historic weather patterns in Central Washington are occurring, and what their impacts mean for local water users, we must first understand previous weather conditions and their characteristics.

Typical weather patterns in the arid region of Central Washington consist of warm and dry summers paired with wet winters. The unique topography of the Cascade Range and Rocky Mountains create a large inland basin, consisting of the Yakima Valley specifically. On one side, the Northern Rocky Mountains shield the inland basin from the winter season's cold air traveling southward across Canada. On the other side, the Cascade Range creates a rain shadow effect that directs most of the moisture from the atmosphere onto the west side of State (See **Figure 3**) (Shepherd, 2002).

Figure 3. Washington State Geography with the Cascade Range and Yakima River (World Atlas, accessed February 2016)

As air descends along the eastern slopes of the Cascade Range, it becomes drier and warmer, resulting in near desert conditions in the Valley. Similarly, there is a decrease in precipitation along the eastern slope of the Cascade Range as the distance from the summit increases and the elevation decreases. Although these characteristics are the average conditions experienced in Central Washington, variations due to climate change and irregular events such as El Niño can alter the region's weather patterns and make them more severe.

A unique feature of Central Washington's climate is the presence of El Niño or La Niña, together called the El Niño Southern Oscillation (ENSO). During these conditions, there is a disruption of the ocean-atmosphere system in the Tropical Pacific having important consequences for weather and climate around the globe (NOAA, 2015). El Niño is characterized by unusually warm temperatures, where as La Niña consists of unusually cool temperatures. In North America, particularly the United States, the impacts of El Niño are most dramatic in the winter. In the Pacific Northwest, El Nino winters are warmer and drier than usual, so that at a given elevation 1) less precipitation occurs, and 2) the freezing level is higher, so the type of precipitation is more likely to be rain, and 3) the accumulation season is shorter. All three conspire to produce a smaller snowpack accumulation by the end of winter in the Pacific Northwest (Western Regional Climate Center, 1998). As of November 2015, The National Oceanic and Atmospheric Administration (NOAA) stated that El Niño conditions are present in the Pacific Northwest, and will likely peak during the Northern Hemisphere winter of 2015-16. Furthermore, the World Meteorological Organization (WMO) claims that the current El Niño event is among the three strongest since 1950, out of 23 occurrences (2015). As climate change continues to lead towards a warmer atmosphere, events such as ENSO may become more extreme and result in even more severe and frequent drought events.

Future Climate Projections-

Understanding the role of mountain snowpack is key in order to understand the Pacific Northwest regions water resources and how warmer temperatures can impact their supply. During the winter, when the majority of precipitation occurs, snow accumulates in upper elevations and forms a natural reservoir that stores water during times when agricultural and environmental demands are relatively low. As the climate warms, more precipitation falls as rain and less as snow, leaving less water naturally stored in snowpack and glaciers while increasing the reliance on man-made reservoir systems, such as dams and wells. The snow also melts earlier in the spring, leaving less water available to feed streams in the late summer when demands for water are highest by irrigators, wildlife and municipalities. Therefore, climatic variations and changes that influence snowpack can have a significant impact on water resource availability in Washington State (University of Washington Climate Impacts Group, accessed Oct. 2015).

Using climate systems modeling, climate scientists predict the varying weather conditions water users in Central Washington could expect for the future due to warming temperatures. In regards to climate change, under even the low emissions scenario where the lowest amount of greenhouse gases that could be released into our atmosphere are considered, patterns of a decrease in snowpack, earlier spring runoff and less instream flows are expected to continue (IPCC, 2015) and further alter the hydrologic behavior of many watersheds in Washington. For example, snowpack across the state is projected to decrease 27% by the 2020s, 37% by the 2040s, and 53% by the 2080s (DOE, 2015). In addition, the timing of the center of mass in annual river runoff in snowmelt basins is expected to shift 30-40 days earlier in the Western U.S. relative to 1951-1980 conditions (Stewart et al., 2004). Lastly, average runoff is projected to decrease by 16-19% by the 2020s, 22-29% by the 2040s, and 33-43% by the 2080s relative to 1916-2006 conditions for the Pacific Northwest region (Elsner et al., 2010). The Yakima Basin specifically is projected to experience severe impacts on summer flows due to climate change by 2040, signifying it as one of sixteen critical basins in the State (**Figure 4**). Overall, the average annual temperature in the Pacific Northwest is projected to increase approximately 2°F by the 2020s, 3.2°F by the 2040s and 5.3°F by the 2080s relative to 1970-1999 conditions (Mote and Salathé, 2010). In addition, forecasts remain for an El Nino weather pattern that is expected to bring a warmer-than-normal winter with below normal snowfall to the Northwest during winter of 2015-16 (DOE, 2015).

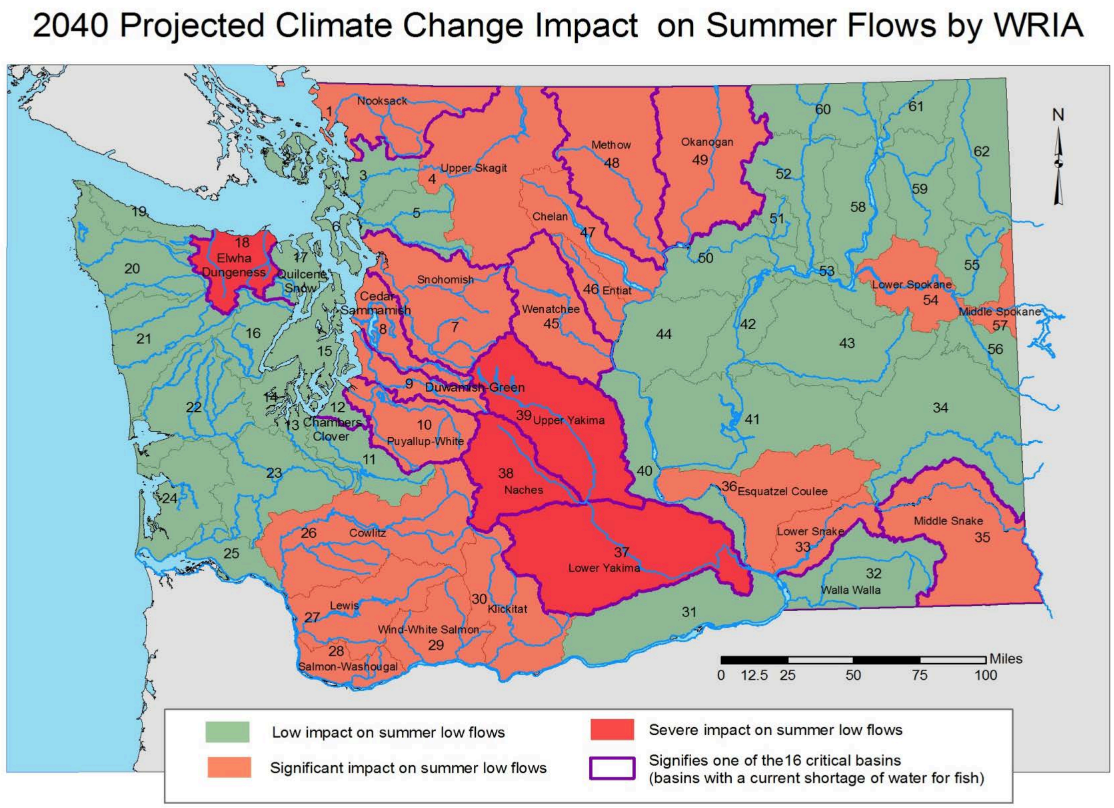


Figure 4. Projected Climate Change Impact on Washington State summer flows for 2040 (WRIA, 2015)

To summarize, the central region of Washington State is expected to experience a decrease in snowpack, less and earlier snow melt run-off, lower instream flow levels, and a continued increase in temperature over the next sixty years. These conditions are predicted to repeatedly result in extreme heat and drought. According to the National Oceanic and Atmospheric Administration (NOAA), drought is a period of below-average precipitation in a given region, resulting in an absence of water (NOAA, accessed Dec. 2015). It is a phenomenon that impacts many sectors of the economy, and operates on many different time scales. Accordingly, the climatological community has defined four types of drought: 1) meteorological drought, 2) hydrological drought, 3) agricultural drought, and 4) socioeconomic drought. Meteorological drought happens when dry weather patterns dominate an area. Hydrological drought occurs when low water supply becomes evident, especially in streams, reservoirs, and groundwater levels, usually after many months of meteorological drought. Agricultural drought happens when crops become affected. And socioeconomic drought relates the supply and demand of various commodities to drought. Meteorological drought can begin and end rapidly, while hydrological drought takes much longer to develop and then recover (NOAA, accessed Dec. 2015). For the purpose of this study, the focus is on hydrological drought, while impacts on agricultural and socioeconomic drought are considered as well.

It is important to note that analyzing the impact of drought is extremely difficult. 2015 was a year of temperature extremes across most of Washington State. By early May, temperatures were already 2-4°F above normal across Central Washington (OWSC, 2015). By the first week of July, temperatures ranged 9-15°F above normal throughout most of Washington State (OWSC, 2015). This heat exacerbated the impacts of little to no snowpack accumulated during the winter and extremely low stream flows throughout the state. Additionally, wildfires impacted a large portion of Central Washington during the summer of 2015 (for some of this region, it was the second straight year of fire damage) (OWSC, 2015). Facilities potentially affected include fruit packinghouses and orchard edges, where outcomes were either complete loss or damage during these historic wildfires (WSDA, 2015). Of the external pressures listed above, extreme heat is one that would be very difficult to isolate from standard drought conditions. Therefore, WSDA and I chose to evaluate the impact of the low water year and extreme heat in combination.

In addition to understanding past climatic variations and extreme weather events that are expected to occur in the future, it is important to consider when these affects to hydrologic changes will have the most seasonal impacts in regards to supply and demand in snow-dominated basins, such as Yakima. A reduction in peak spring streamflow can be expected, as well as an increase in winter streamflow, and a decrease in late summer flow. Substantial reductions in summer streamflow will adversely affect many water users, including farmers who rely on irrigation supply and fish and wildlife populations who rely on habitat provided by streams for spawning. Summertime hydropower production and tribal water demands could also be affected but are outside the scope of this research project. Although, changes in climate are expected to increase the risk of summer water shortages and increase demand for water (DOE, 2015), which will intensify competition and increase existing conflicts among both instream and out-of-stream water users. Overall, Washington State Climatologist Nick Bond refers to the 2015 drought as, "A test case for how it's going to be in the future" (Climate Central, 2015). It is clear that the impacts of climate change will intensify current challenges in managing water resources in Washington State.

Ecological Impacts-

Climate change will increase future variability of water supply and quality in Washington State. As warmer temperatures shift streamflow timing and volume and reduce snowpack, lower flows during the summer will make it more difficult to maintain an adequate water supply for agriculture, communities and fish and wildlife. As winter snow pack melts, annual peak flows occurring in the spring and early summer are the most important contribution to many rivers in Western North America (Stewart et al., 2004). In fact, snowmelt provides approximately 70% of annual streamflow in the

Western U.S. mountainous regions (Mote et al., 2008). Consequently, lower summer flows paired with higher temperatures will not only decrease water supply but also degrade its quality. This is specifically important for fish, considering diminishing streamflows and higher stream temperatures will be stressful for populations that have freshwater rearing periods in summer. Unfortunately, the duration of stream temperatures that cause thermal stress and migration barriers for salmon species (the icon of the Pacific Northwest) is projected to at least double by the 2080s and possibly quadruple for most streams in the Yakima River Basin (DOE, 2015). Furthermore, dams without fish passages currently block all five Yakima River headwaters (Keechulus, Kachess, Cle Elum, Bumping, and Tieton/Rimrock), preventing threatened Steelhead, Spring Chinook, Coho, and Sockeye salmon access to the Basin's extensive and cold high-elevation habitat. Access to this clean, cold habitat would greatly benefit all four of these anadromous species, with Sockeye standing to benefit in the largest numbers, as they require rearing in lakes and have not had access to any of them since the early 20th century (Garrity and Malloch, 2012). Overall, the warming summertime stream temperatures and altered streamflows combined effects will likely reduce the reproductive success for many Washington salmon populations, with impacts varying for different life history-types and watershed-types (Mantua et al., 2010).

In attempt to protect these vulnerable and in some cases endangered species, minimum instream flow levels are set for multiple rivers and streams in the Yakima Basin. An instream flow rule establishes specific stream flow levels that will protect and preserve water in streams in order to ensure an adequate amount needed for the environment and people. However, in many rivers in Central Washington, streamflows are below state or federal instream flow targets on a regular basis, particularly in late summer (DOE, 2015). Decreases in surface water in summer and early fall may lead to more weeks when instream flows are not met. When this occurs, out-of-stream water users like irrigators who rely on surface water sources no longer receive their supply. Therefore, decreasing streamflows affect endangered fish populations and create competition amongst water users.

The decrease in snowpack and resulting decrease in streamflow during future summer months will also continue to impact the State's water supply behind reservoirs and underground in aquifers. When water sits stagnant or flows at a slow rate, it's temperature increases and can result in evaporation. Again, warming temperatures will then lead to a decrease in water supply and its quality. Furthermore, warmer temperatures and reduced summer water availability may lead to decreased soil moisture and higher evaporation rates (Hamlet and Lettenmaier, 1999). Similarly, less moisture will be percolating into the groundwater system to recharge aquifers that currently remain at unstable levels (DOE, 2015). In some areas, these changes will then likely lead to increased drought frequency and severity (Mote and Salathé, 2010). This is important because a lack of soil moisture paired with increased soil temperature can be harmful to tree fruit growth (Zhou et al., 2014). In addition, unwanted pests may increase because insects are exothermic ("cold-blooded") and their surrounding temperature affects their body temperature and growth. Every insect requires consistent heat accumulation to reach certain life stages, so the more heat available to them can cause faster and more frequent than normal growth in their population (Murray, 2008). Overall, agricultural irrigators, fish and wildlife and a growing human population who all rely on Washington State's surface and groundwater supply will be impacted by future climate change and continuing warming temperatures. This study focuses on agricultural irrigators, specifically those who receive their irrigation supply from surface water sources in the Yakima Basin, and seeks to gain understanding in how they experience impacts on their tree fruit crops from exasperated drought conditions due to climate change and what it means for future growing seasons.

Chapter 2. Surface Water

Current Water Supply-

The United States Bureau of Reclamation (Reclamation) is the ultimate water purveyor in the Yakima Basin and manages more than 90% of surface water use in the area. Reclamation allocates water shares to the local irrigation districts, such as the Roza Irrigation District, Kittitas Reclamation District, Wapato Irrigation Project, Sunnyside Valley Irrigation District and Yakima-Tieton Irrigation District. These and additional contracted water entities cover the seven counties that make up the central region of Washington: Yakima, Kittitatis, Klickitat, Okanogan, Douglas, Chelan, and Grant.

The Yakima River provides surface water sources that supply the irrigation districts and reclamation entities within the Yakima Basin. The Yakima River is located in south-central Washington, and begins by the crest of the Cascade Mountain Range between Snoqualmie Pass and Mt. Daniel (Mack, 2013). The Yakima River runs southeasterly for 215 miles until it meets with the Columbia River near Richland, Washington (Mack, 2013). During its flow to Richland, the river drains an area of over 6,000 square miles, underlain by basalt flows that make up the Yakima River Basin aquifer system. Through its route, the river is fed by seven major tributaries and numerous smaller creeks and springs that allow for an annual discharge of approximately 3,700 cubic feet per second (cfs), as seen in (**Figure 5)** (Mack, 2013). The Yakima Basin watershed formation is accredited to a combination of glacier recession as well as volcanic activity occurring over millennia. These characteristics have formed deep soils in the central region of the State, compiled of glacier drift deposits and volcanic ash called tokul soils, which are among the most productive soils in the world (Von Englen, 1914 and NRCS, 2009).

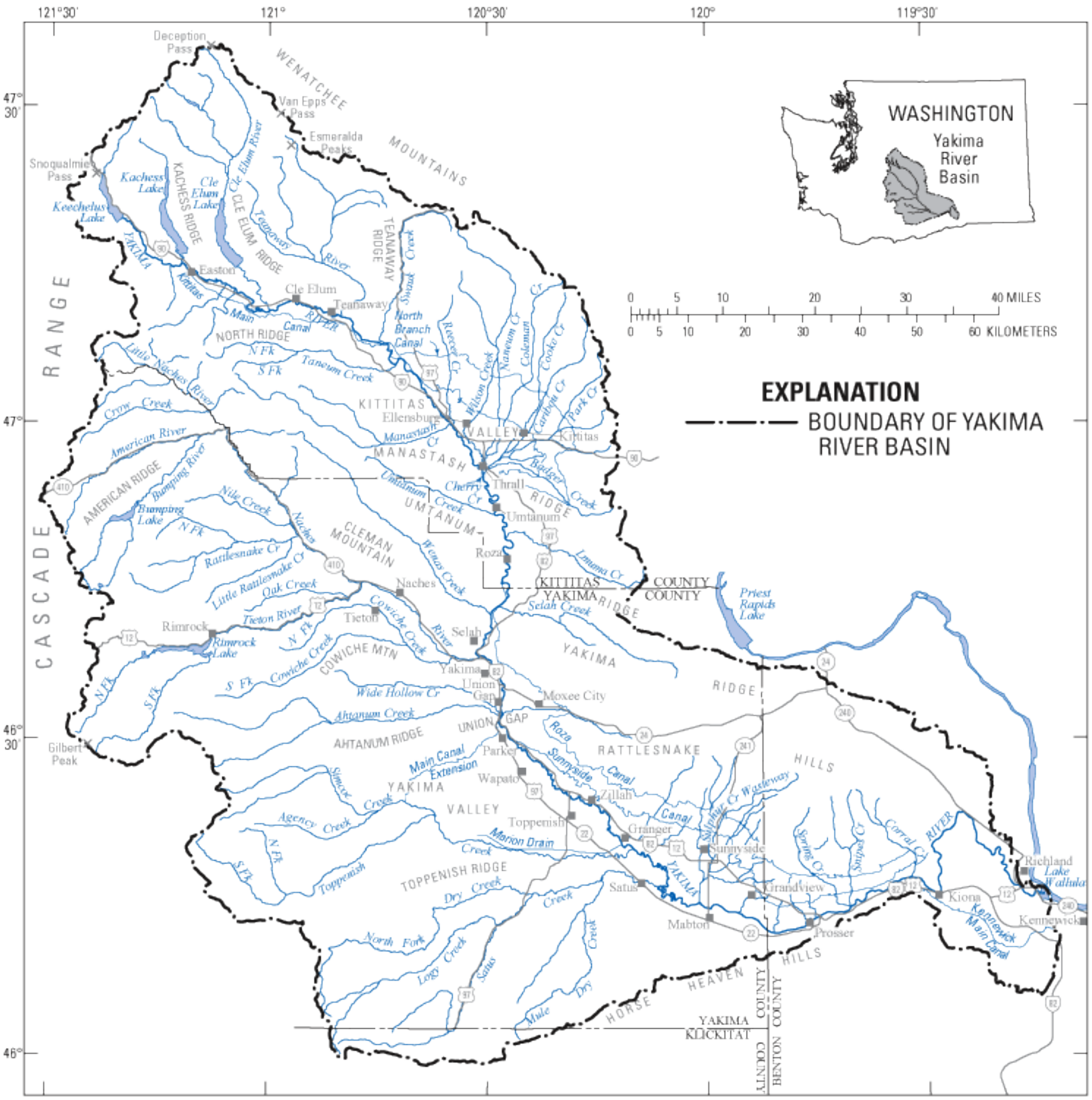


Figure 5. The Yakima River, its tributaries and the boundary of the Yakima Basin (U.S. Geological Survey, 2013).

While utilizing the fertile soil and the arid climate of the region, water development in the Yakima Basin has worked spectacularly well to grow crops and the Basin's agricultural economy over the last century. Starting in the 1850s, private (eventually including railroad-sponsored) irrigation projects were built. During this time, it was widely believed among early settlers and pioneers that water was an unlimited resource and by the turn of the century, irrigation fully consumed the Yakima River's natural flow. However, the Western United States has since been humbled to learn that water is not an unlimited resource.

By 1905 Reclamation stated that there were too many claims and not enough water available in the Central Washington's rivers and streams to provide for all the demand (DOE, 2014). In the same year, the U.S. Bureau of Reclamation developed the Yakima Reclamation Project, which created the Basin's current storage system and includes five reservoirs that store over 1 million acre-feet of water and supply irrigation to over 500,000 acres (Mack, 2013). However, the DOE projects current out-of-stream diversion demands for agricultural and municipal irrigation to increase by 2030 (DOE, 2011). Assuming no change in the amount of irrigated acreage occurs, irrigation demand met by surface water supply is projected to increase by 430,000 acre-feet per year in the State of Washington, with little difference when alternate future economic scenarios are considered (DOE, 2011). In addition, municipal demands for surface water supply are forecasted to increase by 30% by 2030 (DOE, 2011). For example, demand for energy during summer months will increase significantly due to higher electricity needs from air conditioning as temperatures and population growth continue to rise (Hamlet et al., 2010). This increased demand will likely exacerbate water supply issues, and during the summer, will make it more difficult to meet all competing demands (DOE, 2011).

Although surface water availability is forecasted to decrease during summer months, streamflows are expected to increase during winter due to earlier runoff and more precipitation falling as rain instead of snow. In this case, *annual* surface water supplies within the Yakima River Basin are expected to increase by 6%, while the water supply *timing* shifts to earlier than normal (DOE, 2011). Even though the total annual supply is increasing, water demands remain unmet during the summer growing season when water availability is decreasing due to snow drought.

The Yakima River is surprisingly sensitive to snowpack loss. Cascade snowpack is historically reliable and abundant, acting as a natural reservoir for water storage. However, Yakima Basin storage is quite limited compared to annual flow and in contrast to many other developed agricultural river basins in the West. About 30% of the Yakima's average annual runoff can be stored in human-made reservoirs, accounting for 40% of the Yakima Basin's annual water demand (Garrity and Malloch, 2012). This is much less than other major rivers in the West, such as California, where 67% to more than two times annual flow can be stored, and far less than the major storage system of the Colorado River, where several times annual runoff can be stored (Garrity and Malloch, 2012). The relatively low existing reservoir volume, paired with decreasing natural reservoirs provided by snowpack, creates unreliable surface water storage in the Yakima Basin's future and is troubling for the regions irrigators and consequently the State's agricultural economy.

Overall, altered frequencies of extreme weather events, associated with earlier winter snow melt and with consequent reduced storage of precipitation as snow, result in decreased summer water availability and significant impacts on crop yield (Mancosu et al., 2015). Thus, the compounding effects of climate change-induced drought, shifts in seasonal surface water availability, and competition from other water users require orchardists to adapt their current irrigation practices in order to remain productive. The next section examines types of adaptations orchardists can implement, considering the sensitive growth stages of a tree fruit's life cycle and the costs and benefits related to growing these high value crops in a warmer climate while facing water supply uncertainty.

III. Literature Review

Chapter 1. Growing Tree Fruits

Life Cycle-

The quantity and quality of tree fruit growth is dependent on the environment they are grown in. The principal environmental requirements for plant growth include sufficient water, oxygen, carbon dioxide, light, adequate space for root and canopy development and temperature suitable for essential physiologic processes (Iles, 2001). Oxygen and carbon dioxide are required for plant growth in order to stimulate respiration and photosynthesis. Photosynthesis converts light energy from the sun into chemical energy stored as sugars, which the respiration process then releases to fuel plant growth. Sufficient amounts of light and water are essential to these functions. In fact, no organic process occurs in the absence of water (Iles, 2001). Plants suffer more from moisture related problems than any other cause (Iles, 2001), thus temperature levels are significant as well. High temperatures are unfavorable for tree fruit growth because soil moisture decreases and their rate of photosynthesis begins to decline rapidly, slowing this important growth process (Iles, 2001). In the meantime, respiration continues and further depletes food reserves needed for growth. Additionally, leaves release water vapor into the atmosphere through transpiration, which could exceed moisture absorption by the roots if high temperatures dry out soils. Overall, fruit trees need adequate space for roots to expand and access available moisture, while the canopy needs space for development to reach sunlight. If trees are planted too close together, they will compete for water and light resources, stunting tree growth if outcompeted. Lastly, the timing of shortages of any of these principal environmental requirements also plays a critical role in tree fruit growth.

All plants go through particular growth stages depending on the climate and crop type. The main tree fruit crops grown in the Yakima Basin include apples and pears, as well as stone fruits such as sweet cherries, peaches, nectarines and apricots. These fruits all pass through similar annual growth stages, varying between seven to nine stages depending on the fruit. In general, all include a dormant stage, budding stage, bloom stage, petal fall and fruit set stage (Chapman and Catlin, 1976). Depending on the variety, full tree growth can take two to seven years to complete and bear fruit after transplanting (Hall and Perry, 2012). The annual growth cycle can then be categorized into four general stages and separated by the time of year they take place. The dormant stage, known as Stage I, occurs over winter and consists of necessary chill hours required by the tree in order to successfully bear fruit later in the year. Chill hours are the number of hours when the tree experiences temperatures below 45 degrees Fahrenheit but above freezing. Next is the flowering stage, or Stage II, which takes place during the spring and aptly when flower blossoms begin to appear. Pollinators are very important during this stage, as some tree fruits require cross-pollination in order to produce fruit from the blossoms. Stage III occurs over the summer, known as fruiting season, when the trees begin to turn blossoms into fruit. Lastly, Stage IV consists of the harvest season, which takes place in the fall, although the exact time depends on the fruit type being grown. For example, some fruits ripen on the tree while others need to be picked prior and then let to ripen in a dark, cool location, like pears. These growth stages may be seen as phenological, as they respond to and vary with season and climate (Hall and Perry, 2012). Therefore, climate change and warming temperatures can impact the onset and length of these important stages, and thus tree fruit growth.

It is crucial to recognize tree fruits' different growth stages in order to mitigate drought impacts and increase fruit production and marketability. For example, the stage III fruiting season is extremely sensitive to water deficit (Lopez et al., 2004), so trees need to be protected from excessive water loss during the dry summer months. This can be challenging if there is inadequate water supply and extreme heat conditions are present. Trees may then experience water stress, where symptoms consist of leaf discoloration and dullness, as well as sagging or drooping of growing points (Al-Kaisi and Broner, 2013). Stone fruits are particularly sensitive to water stress during the last two weeks before harvest at the end of summer (Al-Kaisi and Broner, 2013), parallel to low surface water availability.

In addition to the need for adequate water supply during the summer to ensure fruit growth, cool winter temperatures are necessary during the dormant season in stage I. If a tree does not get enough chill hours, the fruit production suffers. Most fruit trees require 600 to 900 hours and the variety of tree grown should match the regions climate in order to ensure adequate exposure time (Geisel et al., 2002). As winter temperatures in the Pacific Northwest continue to increase due to climate change, there may not be enough chill hours required by fruit trees for successful growth.

Even further benefits to tree fruit production can be accomplished by understanding their growth stages. For example, apple trees have a natural tendency to have a large crop one year and a smaller crop the next year (Schotzko, 2004). Young trees are more prone to this problem and without very careful management during the dormant stage, this alternate bearing occurs. This problem will decline as the trees mature and become more stable in producing fruit (Schotzko, 2004). In addition, treatments for various fungal diseases and pests, as well as mineral nutrient treatment application such as foliar sprays, can be achieved through monitoring and timing growth stages (Geisel et al., 2002). The stage II flowering season is a particularly important time for pollination and fertilizer application to take place, which help ensure seeding occurs to produce blossoms and necessary nutrients are provided for a tree to bear fruit. Apples, pears and sweet cherries are unique in that they are cross-pollinators rather than self-pollinators like apricots, nectarines and peaches. That is, they need to be pollinated by another tree variety with compatible pollen or bloom time. In short, fruit tree pollination equates to sexual reproduction and fruit development. Without pollination, fruit trees would not bear fruit. After pollination, the pollen germinates once it's transferred from the stamen (male) to the pistil (female), usually by bees. This results in fertilization and the seed develops. Therefore, it is important for trees to be properly pollinated to ensure successful fruit growth.

Overall, it is critical for an orchardist to recognize tree fruit growth stages in order to monitor for chill hours, pollination, water stress and harvest timing. Each stage is crucial for fruit production and increased temperatures may negatively impact their ability to grow marketable fruit commodities. As climate change models predict future warming temperatures, a lack of snowpack can result in inadequate chill hours, irrigation supply and necessary cooled storage. Furthermore, water demand and temperatures will be highest during the critical summer growing season when surface water supply is the lowest. What these conditions can mean for tree fruit crops is described in the following chapter.

Chapter 2. Drought in Orchards

Agricultural Impacts-

Irrigated agriculture is the largest single consumer of water on the planet (Fereres and Evans, 2006 and Ward and Pulido-Velazquez, 2008). A forecast performed by Ecology found that climate change will shift water availability away from the irrigation season (summer) when demands are highest (2015). Agricultural water demand represents demand for water as applied to crops, often referred to as “top of crop”. This includes water that will be used consumptively by crops, as well as water resulting from irrigation application inefficiencies such as evaporation, drift from sprinklers, or runoff from fields. Irrigation is also applied to combat pests through products diluted in the water, for frost protection of sensitive crops, to apply nutrients that are dissolved in the water, to improve the physical properties of land, to remove excess salinity from the soil and to modify the soil pH (Mancosu et al., 2015). In comparing these demands to supplies, even more water must be included to account for conveyance losses, such as occurs when transporting diverted water in unlined channels.

When irrigation water is not available to apply “top of crop”, fruit growth, quality and yield are limited (Gonzalez-Dugo et al., 2013; Miras-Avalos et al., 2013; Morandi et al., 2014). A study of the water stress affects on fresh fruit were investigated in peach trees and found that water-stressed trees with heavy crop loads had significantly reduced fruit dry weights, which were likely due to carbohydrate source limitations resulting from large crop carbon demands and water stress limitations on photosynthesis (Berman and DeJong, 1996). In addition, a multiple-year field study was conducted on 'Valencia' sweet orange trees in a commercial Florida citrus grove to determine the effect of short-term drought stress on tree health. Results found drought stress significantly increased pull force required to remove fruit, signaling immature fruit growth (Morgan et al., 2014). In addition, drought stress had no effect on leaf area, which is important to monitor considering leaf transpiration represents 95% of water loss in plants (Elfving et al., 2006). Similarly, Morandi et al. (2014) found prolonged water restriction negatively affects leaf gas exchanges, plant-water relations and overall fruit growth in pears.

Although warming temperatures will affect irrigation supply during the dry summer, studies have found one positive consequence for crops. The National Assessment Synthesis Team (2001) performed simulation models of specific crops, which indicated that a longer growing season due to warmer temperatures could improve agricultural productivity. With that said, most Pacific Northwest crops are expected to grow better in the warmer future provided 1) enough water is available, and 2) other non-climatic conditions do not change (NAST, 2001). However, as noted previously, summer water supplies for irrigation are likely to decline in many areas of the Pacific Northwest due to climate change while evaporative demand during the growing season is likely to increase (Hamlet and Lettenmaier, 1999).

Socioeconomic Impacts-

As crops become affected by a decrease in irrigation supply coupled with prolonged and stronger heat conditions, their market value is also impacted. For example, Asian-export markets desire large, brightly colored cherries and smaller crop growth could impact their value. In addition, due to food safety requirements and targeted export markets, cherries are picked immediately when ripe and kept cool to prevent spoilage. An earlier ripening season and warming temperatures could negatively impact their supply and ability to match demand periods. On the other hand, pears require long storage and are often harvested prior to being fully ripe, which eliminates some quality and storage issues seen in fruit harvested during the same time period. Therefore, pear harvest can begin one to two weeks earlier than normal and growers may not experience crop yield impacts.

In regards to apples, a 2006 study that analyzed the relationship between crop size and price of the five biggest apple varieties in Washington State found that the crops sizes have a negative impact on prices generally (Ge and Wang). That is, the smaller the fruit the less consumers are willing to pay for it. Additionally, Schotzko (2004) found consumers prefer more proportionally shaped fruit. From another perspective, a 2013 survey of U.S. apple producers asked orchardists what they perceived were the top consumer-preferred fruit quality traits in apples and found that flavor, firmness and crispness were ranked the highest over juiciness and disease resistant to name a few (Yue et al., 2013).

Overall, economic drivers in tree fruit production include traits such as large size, firmly and proportionally shaped, and brightly colored fruit. However, water deficit can prevent crops from achieving these characteristics. In order to mitigate these drought affects and successfully produce high value commodities, there are three general types of adaptations orchardists can implement.

Chapter 3. Three Themes of Adaptation

Hydrologic drought is a local and global threat to agricultural production. As orchardists in Central Washington start planning for future growing seasons, they need to be aware of their available irrigation supply and start accommodating for potential shortages. Three common ways farmers can adapt to changing water availability is through 1) decreasing their demand, 2) seeking new sources, or 3) increasing their resilience. These can be done by implementing water conservation practices such as drip irrigation, building new sources such as a rain catchment system or drilling a new well, or switching to more drought resistant crops to increase their resilience. The potential to apply any of these adaptations varies in regards to accessibility to resources, cost-benefit analysis, and location based on the climate region they are implemented in and the supplement amount of water supply needed.

Conservation-

The first instinct for many water users when facing a decrease in supply is to reassess current usage and cut back where possible in order to conserve more water for when availability is unstable. The selection of an appropriate irrigation system depends on several factors, such as local water availability, crop variety, soil characteristics (deep percolation, runoff, evaporation rate and topography) and the associated installation and maintenance costs (Mancosu et al., 2015). One practice commonly used to implement irrigation efficiency in order to conserve more supply is called drip irrigation. Drip irrigation allows for exact application of irrigated water into the root zones of plants bi-weekly (Geisel et al., 2002). Applying water at optimal times and locations in plant root zones increases crop consumptive use of water and crop yield as irrigation efficiency increases (Ward, 2008). In addition, this method results in little to no runoff and potentially deep percolation for aquifer recharge, ultimately returning to other water users (Ward, 2008). For the orchardist, efficient irrigation systems may increase crop yield and raise their income per unit of land as long as the cost of installation, cost and returns of production, and the price of water does not negatively offset the initial investment.

Additional practices have been found to help decrease demand in irrigation application by retaining moisture in soil. Soil moisture is a crucial reservoir for plants, and roots are major ways for plants to take in water (Wu et al., 2015). The most common method for retaining soil moisture is mulching, which is simply applying a protective layer of a material that is spread on top of the soil. Bark dust is commonly used as mulch and one study found that under sand covering, single fruit mass was improved obviously in a 15-year old apple crop (Zhang et al., 2010). The evaporation of the control was 156% higher than that of the crop covered in sand between March and July, suggesting that excessive ground water evaporation was the main reason to cause soil drought (Zhang et al., 2010). Another study found that seaweed extract was successful as mulch when applied directly to the root systems of citrus trees, improving drought-stress tolerance (Spann, 2011).

Overall, new water conservation practices and technologies can be a positive transformation for orchard operations. Ward (2008) adds that efficient irrigation systems minimize the demand for diverted water from streams, although Ansley (2015) warns that overall consumptive use of water can actually increase as a result of large-scale water conservation practices by having more supply to apply in additional areas. Similarly, many stakeholders question weather water conservation is truly the most direct practice for using irrigated water resourcefully and sustainably.

New Sources-

As warming temperatures decrease the amount of natural reservoirs provided by snowpack, expanding the volume of human-made storage becomes increasingly attractive to water users and managers as an adaptation strategy. Significantly increasing surface storage can be done by accessing inactive storage, expanding existing reservoirs, and building new off-channel dams and reservoirs. Although when building dams, the subsequent build up of water behind the development has to go somewhere, resulting in numerous ecological and social repercussions. Furthermore, large-scale projects such as these are costly and it can be hard to find the necessary funding and support needed to complete.

An additional adaptation irrigators can implement in order to seek new water sources include market reallocation of water or Water Banking. Both consist of a "Water Exchange", which is a tool for providing the mechanism to make water available through mitigation. Water Banking is a way to use the market to make water available for new uses, such as increasing stream flows and providing water for development. Although banking approaches may differ, the common goal is to move water to where it is needed most. For example, increasing the amount of water moved from low-value annual crops to higher-value perennial crops such as tree fruits. Building on existing efforts to reallocate current water supplies through a water market and/or water bank could do this. Under these programs, water rights are purchased, sold, or leased on a temporary or permanent basis to improve out-of-stream water supply and instream flow conditions, particularly during drought years.

As summer water supply remains variable and natural snowpack reservoirs decrease, obtaining new water sources appeals to many stakeholders. Rather than relying on action by state governmental agencies to achieve supplemental supply through large reservoir projects or water banking, some irrigators may chose to pursue additional sources on their own. One way this can be done is by drilling a well or utilizing an unused one, commonly known as an emergency well. However, accessing a new or old well is not free from governmental correspondence and requires a notice of intent, drilling fees and construction costs to name a few (DOE, accessed May 2016). Furthermore, there is no guarantee that a sufficient water supply will be provided by a well, even after accessing the bedrock compilation before drilling. Each of these methods to seek new sources can be undoubtedly time consuming, costly and rely on cooperation between stakeholders.

A smaller-scaled approach to achieving additional irrigation supply can be accomplished by installing a rain catchment system. Using this method, rainwater is collected in a water storage unit as it runs off an impermeable surface such as a roof. In fact, the average roof collects 600 gallons of water for every inch of rainfall (Begeman, 2011). Poundey et al. (2003) claims that systematic support to local innovations on rainwater harvesting could provide substantial amounts of water. For example, 2.5 acres of land in an arid region with just 4 inches of rainfall annually, could theoretically yield 1 million liters of water per year from harvesting rainwater (Poundey et al., 2003). Altogether, decentralized rainwater collection and storage can reduce the impacts of drought and increase peak flow levels, as well as decrease reliance on ground and surface water while promoting water conservation and sustainable practices (LaBranche et al., 2007 and Hicks, 2008).

Resilience-

While the ability to decrease water demand and secure more sources of irrigation supply may be limited for some orchardists due to costs and feasibility, increasing their resilience is an adaptive method that could sustain their crop production in the face of climate change and potential water shortages. Ways to increase resilience include planting drought resistant varietals or switching to more drought resistant crops altogether. Identifying characteristics of farmers who initiate such actions could then inform state agencies of factors that increase or decrease farmers' likelihood of adopting these behaviors, and could be used to direct the necessary support to positively impact their harvest and thus the state's agricultural economy.

There are relevant studies that focus on adaptive behaviors of farmers located throughout areas in the Western United States with similar arid environments to Central Washington that often face water scarcity even more severe than what the Yakima Basin has seen so far, in particular the San Joaquin Valley in California and in Colorado (Caswell and Zilberman, 1985; Green et al., 1996; Dinar et al., 1992; Schuck et al., 2005). Each of these studies identified characteristics of farms or growers that are associated with a higher probability of adopting modern or more efficient irrigation technology. Results showed that growers with more education tend to be more likely to adopt modern irrigation technology (Koundouri et al., 2006; Schuck et al., 2005), and larger farms and/or larger fields are more likely to use modern irrigation than smaller farms (Green et al., 1996; Dinar et al., 1992; Schuck et al., 2005). Lastly, studies find that the probability of adoption varies by crop (Caswell and Zilberman, 2002; Green et al., 1996; Dinar et al., 1992).

Other work has jointly considered the adoption of multiple adaptive practices in the context of climate change, such as improved irrigation and integrated pest management (IPM). Dorfman (1996) models the decision of apple (Malus domestica) growers in California, Michigan, New York, North Carolina, Oregon, Pennsylvania, Virginia, and Washington to adopt neither practice, one of the practices, or both. He finds that education increases the probability of adopting IPM and of simultaneously adopting both IPM and improved irrigation, but negatively affects the adoption of only irrigation. The amount of time the owner spends in off-farm employment decreases the probability of adopting both measures individually and simultaneously. Finally, total farm acreage increases the probability of adopting IPM and improved irrigation separately, but decreases the probability of adopting both simultaneously.

Another practice orchardists can use to increase their crop's resilience is by trimming or pruning trees. During less severe water shortages, fruit thinning is an effective means of improving fruit growth between the end of irrigation and fruit harvest (Lopez et al., 2006). Fruit thinning has two positive effects: (1) it reduces fruit-to-fruit competition, thereby improving fruit size at harvest (Johnson and Handley, 1989; Berman and DeJong, 1996; McArtney et al., 1996; Wünsche and Ferguson, 2005); and (2) it may improve a trees ability to hold water during drought conditions (Berman and DeJong, 1996; Naor et al., 1999 and 2001; Naor, 2004; Marsal et al., 2005; Lopez et al., 2006). However, summer pruning decreases canopy leaf area and may thus reduce canopy light interception (Palmer et al., 1992) and tree photosynthetic capacity (Marini and Barden, 1987), which may lower the supply of carbohydrates available to support fruit growth. Therefore, the amount of pruning is critical because it must be extensive enough to provide stress relief, but it must have only a minimal effect on the supply of carbohydrates to the fruits.

A popularized method in adapting to drought conditions by increasing resilience includes planting more drought resistant crops. For example, Li et al. (2016) performed RNA sequencing on pear samples before and after dehydration and identified potential genes that could be used for improving drought tolerance via genetic engineering. Genetic engineering is quite common in tree fruit production and has led to a variety of drought resistant crops. For example, an apple varietal known as the dwarfing rootstock has become an important trend due to its small root system that takes up less space and allows for more trees to fit in the same amount of acreage. For example, where orchardists used to plant a few hundred trees per acre, they can now plant thousands of trees per acre (Sigler, 2011). In two greenhouse experiments in 2014 and 2015, rootstocks ('Gala' and 'Fuji') with known differences in size control and potential resistance to drought were compared under conditions of reduced water availability. The study found both rootstocks provided drought resistance, where one produced higher levels of the ABA hormone that may regulate stomatal opening and improve short-term drought resistance, while the other appeared more drought hardy in the longer-term due to development of a more extensive root system (Fazio and Glenn, 2015). The difference between short and long-term drought resistance is significant because current weather trends are predicted to increase both in time and intensity. Therefore, studies that focus on more long-term adaptations and resiliency strategies will be useful. In addition to apple varietals with dwarfing rootstocks, growers have several alternatives when it comes to planting and managing their orchards with cherries and pears that are also switching to the benefits of high density. Altogether, high-density systems can produce more and better fruit with the same amount of inputs or less (Sigler, 2011).

Nowadays, many strategies are implemented to improve water productivity in orchards, starting with the optimal choice of irrigation system, followed by the application of the proper irrigation scheduling in terms of both timing and quantity of water applied, and concluding with the choice of the best crop management with regards to the variety and climate conditions (Mancosu et al., 2015). Overall, Washington State farmer's water management systems have been designed around past temperature and precipitation patterns. Preparing for and adapting to the climate change impacts will require new approaches implemented by water users that take into account how future conditions are likely to change. Many initiatives are in place and partners are engaged in addressing these challenges and anticipating future needs by using approaches such as conservation and demand management, efficiency practices, technical innovations, water transfers, markets, and water banks, infrastructure improvements, enhanced information systems and hydrologic forecasting (DOE, 2015). This study focuses on the approaches concentrated on conservation and demand management, infrastructure improvements in regards to new water sources, and efficiency practices to improve resilience against drought conditions in orchards.

IV. Methods

The Research Sample-

Irrigators in the Yakima River Basin are facing a continual decrease in surface water supply due to drought and consistently warming temperatures, and orchardists are particularly vulnerable due to the risks associated with growing high value crops like tree fruit. Perennial plants, such as apples, pears and cherries, live for more than two years and require sufficient irrigation application to survive between seasons. In addition, instream requirements for fish and domestic demands such as hydropower and population growth further complicate the amount of surface water that can be allocated to these irrigators. The demands for reliable water sources coupled with a decreasing supply and increased competition between users makes orchardists and their crops particularly at risk and is the reason this group was chosen as the sample for this study. Overall, this research study's purpose is to understand initial patterns or trends related to drought impacts on orchards in the central region of Washington State during the 2014-2015 winter season and if and how growers are adapting.

Data Collection-

The primary data used for analysis in this study originated from a 13-question online growers survey produced by the Washington State Department of Agriculture's Natural Resources Assessment Section (NRAS) in November 2015. Data collection targeted information on the 2015 drought impacts on farmers across the State and occurred over a six-week period. Of the 452 total respondents, 41 identified themselves as tree fruit farmers in the central region of Washington State. The individual survey results for the 41-person sample used in this study (n=41) were made available after issuing a public disclosure request with the WSDA. Partners of the Washington State Department of Agriculture (WSDA) promoted the online grower survey in order to recruit subject participation for the study. Such partners included the Washington State Conservation Commission, the Washington Farm Service Agency Office, and Laura Raymond from the WSDA Small Farm and Direct Marketing Program.

In addition to the primary data collected from the WSDA's online survey results, a set of select documents and interviews were drawn on to inform the analysis with additional site-specific observations and experience in the Yakima River Basin as a practice that promotes intertextuality. This supplemental data includes an interim report completed by the WSDA, email conversations and one in-person meeting with two key informants. For example, an interim report published on December 31st, 2015 by the WSDA and made accessible to the public online was analyzed for background information and quantitative data relevant to the survey questions and specific commodities. Furthermore, Stan Isley, a court appointed stream patroller in the Teanaway River Basin in Central Washington, provided first-hand accounts of low instream levels throughout the Basin during the 2015 summer through four unstructured emails and was instrumental in guiding the scope of this research project. Paul Pickett, a water resources engineer with Ecology, contributed to the story of historic and current weather conditions in this study by providing guidance towards water issues currently plaguing the State of Washington and recent studies on local climate change impacts during a two-hour long in-person meeting as well as three unstructured emails. Based on these conversations and the critical data provided by the WSDA's online growers survey, the physical and economic impacts of the 2015 drought on tree fruit crops in Central Washington, as well as analysis of if and how orchardists are changing their behaviors to adapt, are described below. Lastly, this study is not intended to completely quantify the economic losses from the 2015 drought, but rather a wide array of data types were used to look for trends or patterns regarding general effects and responses.

The Online Survey-

The 13-question online growers survey included questions regarding impacts to crop yields, quality, marketability and storage due to the 2015 drought conditions. Participant's demographic information was collected in the survey's first two questions to understand what type of crops they grow and in what region of the State. The survey respondents were only asked to identify with a crop grouping, such as tree fruits, rather than the specific types of crops they produce, like apples, pears or cherries. So for the purpose of this study, the 2015 drought impact on tree fruit crops in general (apples, pears, cherries, peaches, nectarines and apricots) is analyzed.

The survey also asked questions about infrastructure improvements, increased pest pressure, anticipated impacts to the 2016 crop, costs associated with drought wells, and estimations of total economic impact on the farm. These questions were answered in both a Likert scale and a 'Yes' or 'No' format, providing general information on adaptation themes pursued by participants. However, all survey results were returned anonymously to the WSDA, and are not tied to any specific grower. Therefore, growers were not available for further questioning, which would be desirable to gain crop and site specific information related to surface water supply availability. Respondents could also submit more than one survey to provide information about each crop they grow, although this relation would be unknown considering the anonymity of the results. Thus, the overall patterns or trends of physical and economic impacts on tree fruits is considered as well as the types of adaptations, if any, that orchardists in Central Washington implemented in response to the 2015 drought.

Introduction: The Washington State Department of Agriculture (WSDA) is compiling information about how 2015 drought conditions have affected our state's agricultural operations. The data we collect will be used to prepare an economic assessment of this year's drought and better target future drought funding and support.

Please answer the questions for your operation or farm. Your feedback is important. The survey results will be grouped by region and crop groupings, allowing individual grower operations to remain anonymous. This survey contains 13 questions and should take no more than 5 minutes to complete.

1. For this survey, I am providing information about the following: (Pick one category)
   a. Tree Fruit (apples, pears, cherries, peaches, nectarines, apricots)
   b. Small Fruit (raspberries, strawberries, wine grapes, blueberries, juice grapes)
   c. Vegetables (potatoes, carrots, sweet corn, green peas, asparagus, onions)
   d. Pulse crops (peas, lentils, chickpeas)
   e. Grain crops (wheat, barley)
   f. Herbs, etc. (spearmint, peppermint, hops, bulbs)
   g. Animal Feed crops (corn, hay, pasture, rangeland)
   h. Other (please specify)

2. I operate in the following region:
   a. Western (all counties west of the Cascades)
   b. Central (Okanogan, Douglas, Chelan, Kittitas, Yakima, Klickitat, Grant)
   c. Columbia (Benton, Franklin, Walla Walla)
   d. Eastern (Ferry, Stevens, Spokane, Pend Oreille, Lincoln, Adams, Whitman, Garfield, Asotin, Columbia)

3. The 2015 drought affected my harvest yields by this percentage range:
   a. 0%
   b. 1-10%
   c. 11-25%
   d. 26-50%
   e. Over 50%

4. The drought affected the quality or marketability of my crop or product.
   a. No
   b. Yes (If yes, what percent?)

      Fill in box

5. The drought or high temperatures affected how long I stored my crop or product.
   a. No

b. Yes

6. The drought caused me to make infrastructure improvements (i.e., shading fabric, irrigation equipment upgrades, etc.) **(Do not include drought well operation).**
   a. Yes (if yes, cost per acre and number of acres impacted)
      Cost: Fill in Box Acres: Fill in Box
   b. No

7. I expect the 2015 drought will affect my 2016 crop.
   a. Yes
   b. No

8. The 2015 drought caused a total economic impact on your farm of: (in dollars)
   Fill in Box

9. The drought and high temperatures increased pest issues on my farm operation.

   Yes/No

<u>Drought Well Questions</u>

10. I operated an emergency drought well in 2015.
    a. Yes
    b. No

11. My well required maintenance.
    a. Yes
    b. No

12. The approximate cost of running the well was: (In dollars or gpm)?
    Fill in Box

13. I ran my well for the following number of hours a day.
    Fill in Box

Figure 6. WSDA Online Growers Survey Questions (WSDA, 2015)

V. Results

In order to analyze the various impacts of the 2015 drought and its potential threats to future production for tree fruit growers in the central region of Washington State, the survey participant's responses have been broken up by question. Question **#1** and **#2** of the online grower survey collected demographic information and are described above in 'The Online Survey' portion of the Methods section.

Question #3: Yield Reduction Due to Drought

Respondents were asked to choose from a range of options for yield losses caused by the 2015 drought. The choices for yield loss were 0%, 1-10%, 11-25%, 26-50%, and greater than 50%. The majority of respondents (20) reported losses of 11-25%, six reported 0%, six between 1-10%, five responded 26-50% and four over 50%, as seen in (**Figure 7)**. A reduction in yield could be attributed to small fruit size or a decrease in overall harvest, both due to the drought conditions. Additionally, warmer than normal winter temperatures during the 2014-15 season could have caused a lack of necessary chill hours for tress and/or resulted in irrigation supply shortages due to low instream flow levels in the late summer. Overall, 85.4% of the sample experienced yield losses due to the 2015 drought.

Percent Yield Impact from 2015 Drought

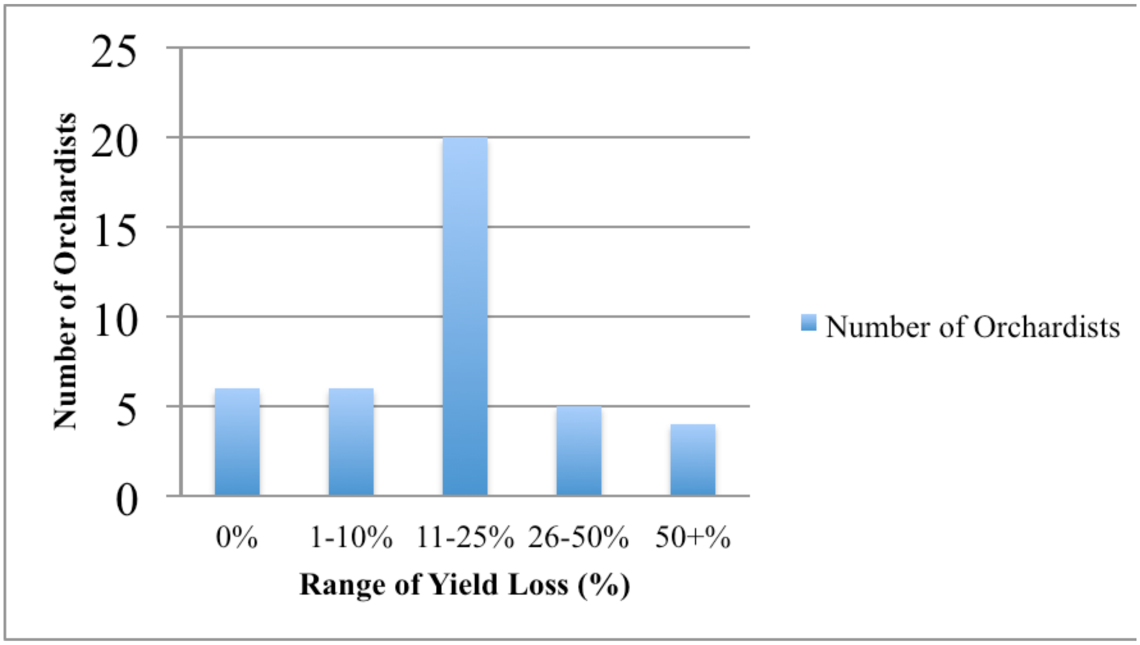


Figure 7. Crop yield losses due to the 2015 drought

Question #4: Impacts on quality and marketability

When survey respondents were questioned about whether the drought and high temperatures impacted either the quality or the marketability of their crop, 75.6% (31) stated yes and 24.4% (10) responded no (See **Figure 8)**. Of those that reported a negative impact, seven reported impacts over 50%, five reported between 26-50%, 11 for 11-25%, and five between 1-10% with another respondent recording a percent of impact between 5-15% (See **Figure 9)**. Additionally, two respondents who reported impacts provided only written data, describing a portion of their cherry crop being lost and the other slight reductions in fruit size as well as crops suffering from sunburn. These results could be attributed to a lack of irrigation supply, evapotranspiration, high soil temperatures or pests, which all cause an increase in risk for the success of fruit growth and quality in the central region of Washington State. Again, the size of each fruit could have been impacted, as well as the color, lowering its value based on consumer's demand. Without crop and site specific information, it is difficult to identify exact reasons for a negative impact on tree fruits due to the drought, yet a clear trend is apparent.

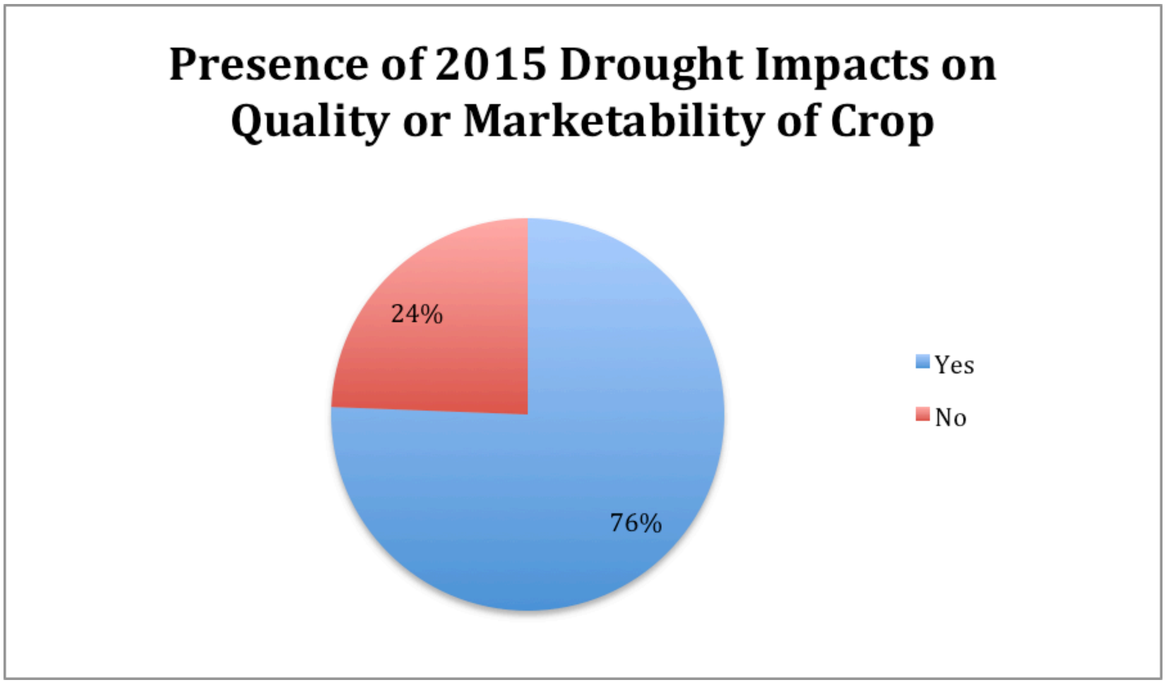


Figure 8. Presence of tree fruit crops quality or marketability impacted by 2015 drought

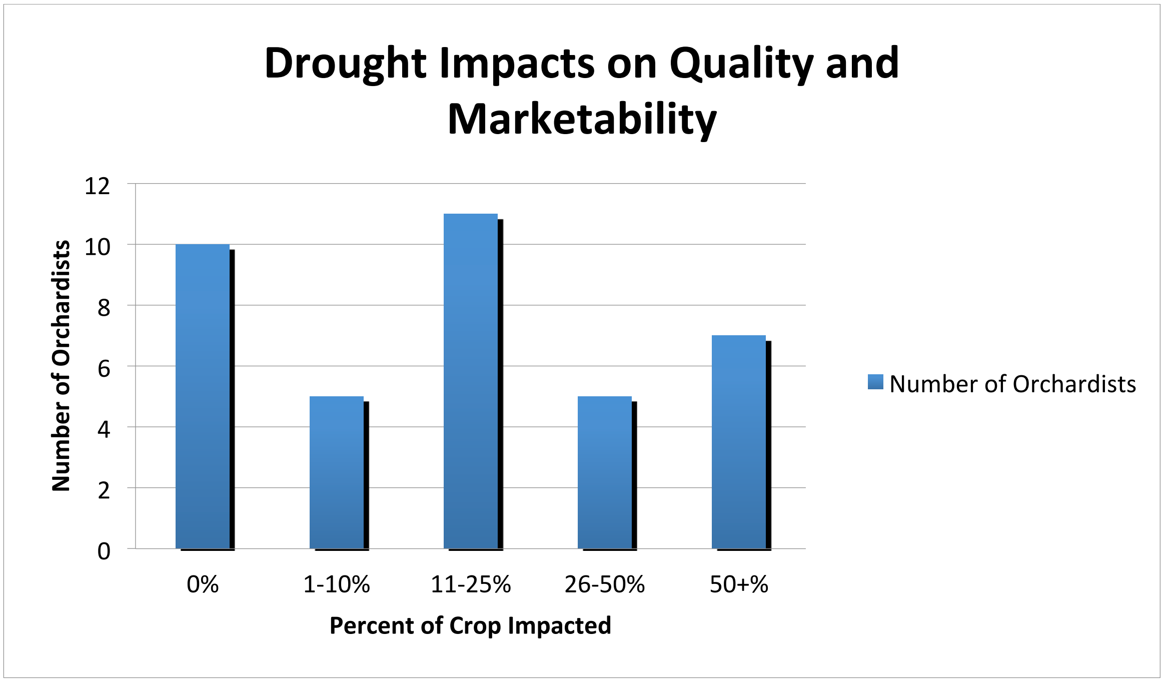


Figure 9. Percent of orchardists' crops quality or marketability impacted by 2015 drought

Question #5: Drought impacts on storage

According to the interim report, the WSDA had received anecdotal information that fruit harvested in the height of 2015's summer heat wave did not store as well as in normal weather years. To try and obtain more information, the respondents were asked whether or not they saw reduced storability caused by the 2015 drought and extreme heat. 68% of respondents (28 in total) replied that storability of their most recent crop was reduced by the drought and heat, and one did not reply (See **Figure 10)**. These results show that the drought not only impacted crop growth, but also continued after harvesting, further impacting the fruit's commodity value and affecting the grower's profit. These consequences may create additional costs for orchardist's who are forced not only to implement adaptations during tree fruit growth to prevent drought stress, but also in their distribution process.

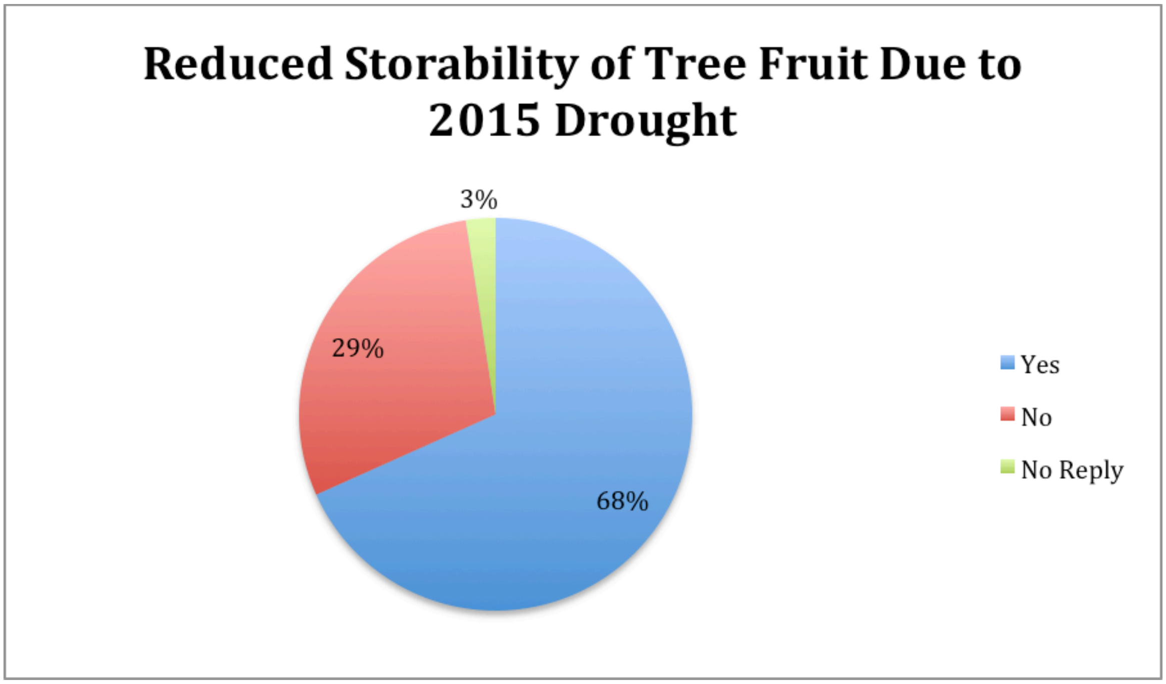


Figure 10. Percent of orchardists who experienced impacts to storage facilities due to 2015 drought

Questions #6: Drought-related infrastructure needs

Survey question number 6 attempted to determine whether or not the drought or extreme heat caused respondents to spend additional money on infrastructure improvements. This includes practices designed to decrease water demand, such as mulch or shade cloth and micro-sprinklers like drip irrigation (improvements specifically relevant to seeking new sources are considered in question number 10 and in the analysis, as is adaptations to increase resilience). 47.5% of respondents (19/41) stated that infrastructure improvements were completed in 2015 due to drought and one did not reply. Of those respondents, 48% reported cost per acre information, ranging from $10.00 to $1.5 million per acre. This is an extreme range of costs, highlighting the varying impacts drought has had in Central Washington. The same 19 participants reported acreage amounts ranging from 3 to 500 acres, although it is unclear if that is their total crop acreage or just the amount that infrastructure improvements were made on. Without knowing the total crop acreage for each grower or their specific fruit crop, it is difficult to conclude which production required more infrastructure improvements and what they consisted of. In the future, these designations, as well as the details surrounding the history of each orchard and previous infrastructure improvements made, would help determine more specific impacts for the region. For example, irrigators could have made changes to their infrastructure in recent years and are already implementing adaptation strategies, but such data would not be included in this study based on the wording of question 6. Overall, almost half of the sample experienced enough pressure from negative drought impacts to make a change. Any of the three common adaptation themes (decreasing demand, seeking a new source, or increasing resiliency) could be included among these infrastructure improvements.

Question #7: 2016 Impacts

All survey respondents were asked whether the drought conditions in 2015 would affect the 2016 harvest. These agricultural and socioeconomic drought impacts could include plant damage, yield reduction, reduced size, crop rotation changes (potentially to a lower value crop), or reduced marketability. Most respondents (39/41) answered this question, and just over two-thirds (61.5%) reported that they expect the 2015 drought to have negative impacts on their farming operation and 2016 crop. These results highlight how drought and extreme heat impacts can persist over multiple years, and may only be exasperated as climate change models predict continually increasing temperatures in

Central Washington. These conditions emphasize the need for growers to implement adaptations that increase resilience in order to sustain their production in the long-term. It is also possible that future trends of plant damage, yield reduction, decrease in crop size and reduced marketability will cause a shift in the commodities grown in the central region of the State and consequently impact Washington State's economy.

Question #8: Economic Impacts

In regards to the total economic impact of the 2015 drought on orchardists, 36 of 41 respondents provided information. Reasons for not responding to this question may include sensitivity around releasing monetary information (regardless of the anonymity of the survey results) or such information being unknown at the time of reply. Responses ranged from no economic impact to being forced to remove all crops. When asked to provide impacts of the 2015 drought in dollars, responses ranged from $0-1 million. Again, without further information regarding specific crop type or acreage amount for participants, it is difficult to conclude the direct relation between water availability and economic impact. Although, it is clear that the extreme heat conditions in 2015 caused irreversible damage to at least some orchards in the central region of Washington State. It would be helpful to learn the reasons for the one orchardist's severe actions to remove their entire crop, such as pests or acute economic deficit, and if they had attempted to implement any adaptations prior to the event.

Question #9- Pest Pressure Changes

The WSDA staff received anecdotal information that pest pressures were higher during the 2015-growing season due to unprecedented prolonged periods of hot, dry weather. To further understand whether this was a regional effect, specific to a certain commodity group, or a statement that cannot be substantiated, the online survey included a question regarding the believed impact of the 2015 drought and hot temperatures on pest pressure. Was it increased or similar to a normal year? A total of 39 out of 41 respondents answered the question, where 31.7% (13 respondents) stated that there were no changes in pest pressure during the season and 63.4% (26 respondents) stated that pest pressure increases were influenced by the drought and extreme heat (**Figure 11**).

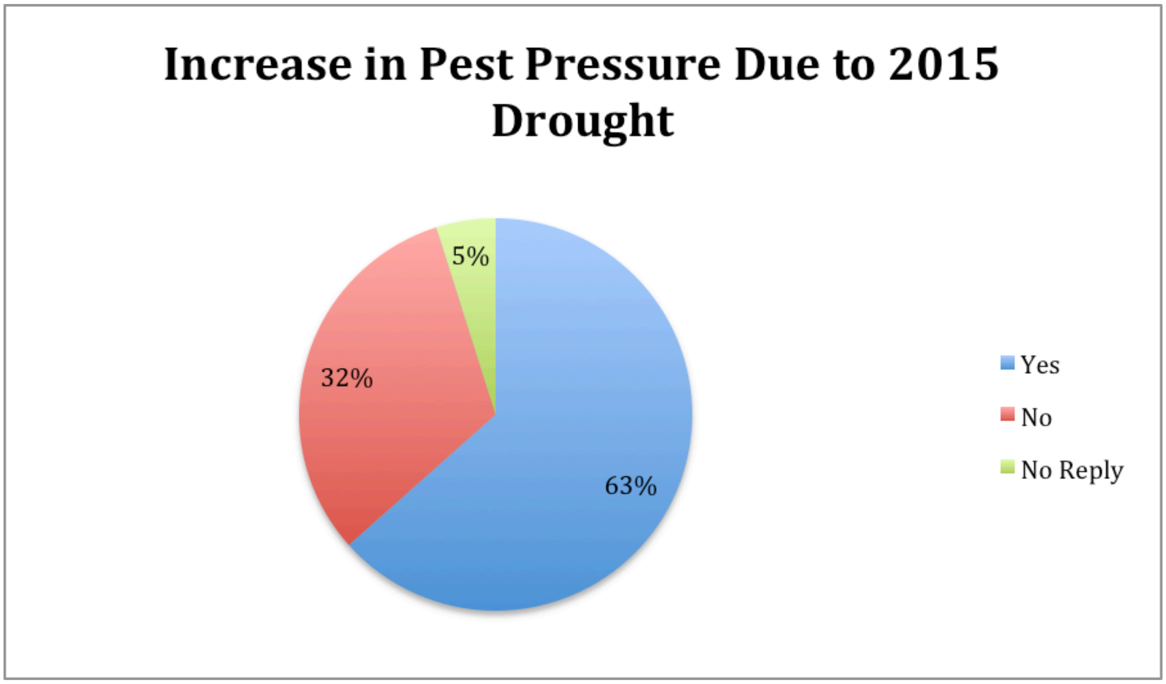


Figure 11. Percent of Orchardists who experienced pest pressures due to 2015 drought

Question #10- Drought Well questions

Of the 38 out of 41 survey respondents who replied to this question, five reported seeking a new water source by running their emergency wells. Of those five wells, each required maintenance in order to run. The approximate cost of running one of the wells was reported at $21 per hour, while two subjects stated they were still estimating the cost and the other two did not provide an amount. The well that was reported at costing $21 per hour to run was ran 24 hours a day according to the respondent. The two who claimed to still be estimating the total costs ran their emergency wells for eight hours a day and the other is unknown. One of the two respondents who did not report the hourly costs of running their emergency well did report using it for 12 hours a day, while the other claimed they were not able to run it at all because there was no water left in it after it was re-plumbed during maintenance. These responses illustrate the unknown challenges associated with securing additional water supply, particularly wells. Without a secure supply, irrigators may seek out new sources that hold hidden costs and liabilities, with little to any gain. A decrease in surface water supplies becomes an economic burden that cannot only hinder the growth of crops but also growth and sustainability of an orchardist's production capabilities.

Commodity Specific Impacts-

In addition to the online growers survey, WSDA NRAS staff conducted a number of meetings with commodity groups to gather yield and quality information throughout the state and recorded their findings in the interim report. According to their results, apple growers reported the greatest impact to their crops due to the 2015 drought conditions, while cherry and pear farmers were forced to harvest weeks earlier than normal but reported little damage to their fruit crops (WSDA, 2015).

As mentioned above, apples are the number one crop in total value in Washington State, with 180,000 acres in production (WSDA, 2015a) and a 2013 crop value of $2.19 billion (NASS, 2015b). NASS conducts analysis of expected apple yields prior to the start of each harvest season. This estimate combines an analysis of typical average yield per acre, total acres in production, and attempts to take into account any expected external stressors on the crop (WSDA, 2015). Harvest estimates in the early 2015 summer were around 125 million boxes for the entire state. In contrast, late summer harvest totals dropped to 118 million boxes. According to the findings, early harvest varieties were most affected by low water availability and high temperatures in the Yakima Basin compared to the rest of the state. Based on conversations with industry representatives (who were not identified by the WSDA in the report), the 7 million-box loss presented here is all attributed to either drought or extreme heat. In total, the known loss for the state includes 7 million boxes, each weighing 40lbs, equaling 280 million pounds of apples lost in Washington State in 2015. With a 2014 marketing year average price of $0.309/lb (NASS, 2015a), approximately $86.52 million of apple crops were lost throughout Washington State due to the 2015 drought (WSDA, 2015).

In regards to cherries, their harvest across the state started almost three weeks early on average in 2015, mostly due to high temperatures in the central region specifically. Overall, size was smaller than normal, which impacted some Asian export markets considering they desire large, brightly colored cherries (WSDA, 2015). Cherries are picked immediately when ripe and cooled to prevent spoilage due to food safety requirements and targeted export markets, and impacts to storage facilities due to the extreme heat was only recorded in the online survey and not provided in the interim report regarding information gained through commodity group meetings. Therefore, there could have been additional impacts to the quality of cherries throughout the State due to a lack of storage that was not available for analysis. Similarly, pears require long storage and are often purposefully harvested prior to being fully ripe. Therefore, growers throughout the State did not report crop yield impacts even though pear harvest began 10-14 days early in 2015. Due to long storage needs, some of the quality and storage issues seen in fruit harvested during this same time period may have been eliminated as long as adequate storage was available.

Overall, the WSDA interim report described a large economic loss to apples, earlier harvest dates for cherries and pears, and highlighted the importance of cooled storage facilities across Washington State due to the 2015 drought and extreme heat conditions. By considering these findings along with the online survey data specific to the central region, we see patterns between physical and economic impacts on tree fruits and how orchardists are choosing to mitigate further losses in the future.

VI. Analysis and Discussion

Patterns and Trends-

The 2015 drought was the hottest year on record in Washington State (WSU, 2016) and according to the online growers survey, seemed to increase the appearance of pest populations amongst orchards. Based on participants' survey responses, 66.7% of the sample reported an increase in pest pressures. Of those that saw an increase in pests, 81% (21/26) also reported impacts to their crop quality or marketability during the 2015 drought and 61.5% (16/26) claimed their 2016 harvest would be affected. This illustrates a trend between highly negative impacts on tree fruit crops and the presence of pests during extreme heat conditions, although a direct correlation cannot be made without further information. Lastly, 61.5% (16/26) of those that saw an increase in pest pressures reported implementing infrastructure improvements. Although additional information is needed to understand the type of adaptations they implemented, a pattern is revealed regarding an increase in pest pressures to the implementation of adaptations to drought based on reports of infrastructure improvements made. For example, it is possible that mulch was applied in response to high soil temperatures and pest pressures in order to retain soil moisture and prevent further pest damage.

In regards to the one grower who reported removing their entire crop, they also noticed an increase in pest pressure. Furthermore, they reported 45% of their crops quality or marketability was impacted by the drought conditions in addition to their storage being affected. They did not attempt to adapt by making any infrastructure improvements or to run an emergency well, although it is unknown if one was available. It is possible that the extreme heat and pest pressures decreased the quality of the crop and prevented adequate storage conditions. Further information regarding the specific relationships between the drought and these severe impacts are needed to understand how they could have been prevented through access to resources and instruction on adaptive strategies.

Regarding the adaptation strategy of seeking new water sources during the 2015 drought, five irrigators reported running emergency wells. Of those five, four identified the percentage of their yield loss between 11-25% and the other at 26-50%. There were four survey participants who reported yield losses above 50%, none of which reported running emergency wells, although it is possible they did not have access to one. Two of the four who experienced yield losses above 50% reported implementing infrastructure improvements, one that cost $3,000 per acre for 34 acres and the other $20,000 per acre for 100 acres. Although this is a small sample (n=2), an emerging pattern towards seeking adaptions in response to negative drought impacts on tree fruit crops is evident.

Of the five survey participants who ran emergency wells, all cited increases in pest pressures. The percent of crop quality or marketability that impacted the same five growers ranged between 10-25%, although one of the five did not provide an amount. Similarly, the four who reported negative impacts to their crop's quality also reported storage impacts while the fifth grower cited none. Based on this data, it appears that an average impact range between 10-25% of crop yield loss and crop quality was enough for growers with access to emergency wells to pursue using them and absorb the expenses. Similarly, the same four of five participants reported implementing infrastructure improvements, alluding to the possibility that they had access and financial feasibility to pursue all three common adaptation types compared to the other growers. For example, total costs for those improvements were recorded as $45,000, $750,000, $320,000 and $600 million. The same four out of five growers still reported expected future impacts to their 2016 crops, even though costly infrastructure improvements were made and emergency wells ran.

Overall, 47.5% of survey respondents (19/41) stated that infrastructure improvements were completed in 2015 due to drought and one did not reply. All but one of these 19 growers (95%) reported impacts to their storage and 16 of them (84%) reported negative impacts to the quality of their crops. Furthermore, the majority (63%) identified their crop yield loss between 11-25%. This data reveals a trend between negative drought impacts on tree fruit quality and storage in relation to implementation of infrastructure improvements. Thus, it can be concluded that orchardists generally seek adaptations in order to mitigate drought impacts. Considering 70% of the survey participants (14/20) who reported not making infrastructure improvements still cited negative impacts to their crops quality and 55% (11/20) to their storage, it could be inferred that they did not have access to the necessary resources, information or finances to implement desired adaptations in order to mitigate drought impacts. These results are important for state agencies and drought relief efforts to consider in order to work towards programs that can provide tree fruit growers with the necessary adaptation technologies and practices they desire in order to protect and sustain their tree fruit productions and Washington State's coveted $10 billion agriculture industry.

Considering the negative physical and economic impacts this study has found on tree fruit crops in Central Washington due to the 2015 drought, and general patterns highlighting a disconnect between growers' interest in adaptations and accessibility to related resources, a look at available mitigation options for this group of water users is needed. First, additional competition from other social water demands specific to the Yakima Basin is important to recognize in order to understand what hurdles orchardists may face in attempt to implement drought adaptions. While environmental pressures impact surface water volume and timing for Central Washington irrigators, Washington State water rights present challenges around who receives how much supply.

Restrictions to Water Supply-

Weather-related variables, coupled with Western water law and Washington water rights, set limits on the quantity and quality of surface water delivered to irrigators within the Yakima Valley. Western water law and Washington water rights are a defining set of laws that determines how a water rights user can legally use their irrigated water. It is important to note that water is a shared natural resource in Washington, and is therefore not owned by any individual, group, or business residing in the state. Thus, a comprehensive set of laws is necessary to ensure that the state's water resources are used in the most ecological and socially productive way. However, this distinction is subjective and causes additional frustrations for irrigators who may feel their individual demand for water use is the most important.

It is necessary to first define what a water right is in Washington State to be able to interpret the restrictive laws that govern and support it. A water right is a right to use water, not a property right. It is defined as: "A right to a beneficial use of a reasonable quantity of public water for beneficial purpose during a certain period of time occurring at a certain place" (Washington State Department of Ecology, 2014). According to RCW 90.14.031 under Washington State law, "beneficial use" shall include, but not be limited to, use for domestic water, irrigation, fish, shellfish, game and other aquatic life, municipal, recreation, industrial water, generation of electric power, and navigation (Washington State Legislature, 1969). An appropriator holding a water right may remove the water from its source and put it into beneficial use, but only from the specified place of withdrawal and place of use determined under the terms of their water right. These conditions present additional considerations for orchardists regarding not only how much water they are using, but if they are abiding by the restrictions around where and how they are using it specific to their water right. For example, a water rights holder can move irrigated water from the Yakima River under specific seasonal or monthly amounts that are determined by their water right, as long as the water is being used for a non-wasteful purpose (Ansley, 2015).

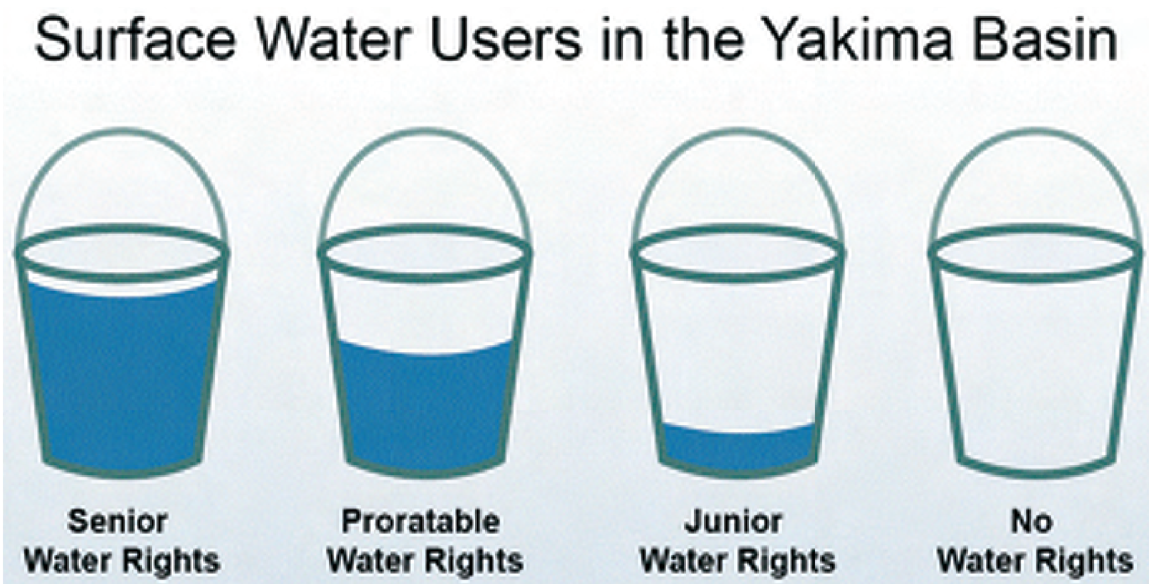
Water rights in Washington State are divided into two main types: surface water rights and groundwater rights. Water rights fall under the surface category if water is diverted from a river, stream, lake, or spring; whereas groundwater rights are classified as the right to pump water from a well (Washington State Department of Ecology, 2014). Both surface and groundwater rights are distinctly established by the elements of a water right and any special requirements recorded on water right documents. For instance, some of the elements in a water right may include "where you can take water [point of diversion, point of withdrawal], at what rate you can take water [instantaneous quantity], how much water you can use in total each year [annual quantity], what you can use the water for [purpose of use], where you can use it [place of use], and when you can use it [season of use]" (Washington State Department of Ecology, 2014). With that being said, the elements of water rights are always grounded upon state law and interpreted by a number of organizational, governmental and case law models to sustain the rights of land owners, as well as the rights of various entities involved in managing water resources. Each water right is specific to a location, source, use, amount and other parameters. Therefore, environmental regulations around surface water supply are not the only challenge orchardists in the Yakima Basin of Central Washington are concerned with when drought conditions decrease instream flow levels. Further uncertainty regarding the specificities of their water right present additional hurdles for this group of irrigators.

Water Right Curtailments-

In order to establish a water right, one must first file an application for a permit with the DOE (Washington State Department of Ecology, 2014). An application must show that water will be put to full beneficial use (See ‘Restrictions to Water Supply’ section above) before Ecology will issue a water right. Once the water rights is considered “perfected”, Ecology will provide the applicant with a water right certificate for the quantity of water, and other essential requirements that are presented on the permit. Furthermore, water is considered a public resource and is collectively owned by all people of the state. Therefore, when you acquire a water right you do not secure ownership of the water; instead, you obtain the right to use water according to the terms and conditions of the water right you have been approved for by the Washington State Department of Ecology.

Who maintains original water rights is important because a right to use water is determined by its priority date. Under Washington’s “first-in-time, first in right” legal framework, a person who established a water right before 1905 has a senior, or non-proratable water right. This gives them the right to withdraw all their water before the next person in line, who holds a right “junior” to their senior right (DOE, 2015). Water users with senior water rights hold about 46% of all the Yakima Basin surface water rights (Isley, 2016), although it is unknown how many of which participated in the online growers survey due to anonymity and there not being a direct question that asked for such information. These non-proratable water rights receive their full water supply even in serious drought years. Therefore, growing high value perennial crops like tree fruits would not pose such a high risk for these irrigators compared to proratable water rights holders due to access to a more secure water source. Further data regarding drought impacts to non-proratable surface water users would identify the severity of the 2015 drought and extreme heat conditions and should be pursued.

There are two classifications of water rights that are subject to curtailments based on their priority date. Proratable water rights hold a 1905 priority date and are cut back equally in any shortage, providing such users with one-third to the full amount of their water right depending on supply in a given year. Junior water rights are any water right established after 1905 and these users may receive no water if rationing occurs in low water years (**Figure 12**).



Pre-1905 priority date: receives full water right	**1905 priority date: receives- 1/3 to full water right depending on supply**	**Post-1905 priority date: receives no water once rationing occurs**	**Surface water use without a water right is unlawful**

Figure 12. Washington State water rights for surface water users (DOE, 2014)

Restrictions, or curtailments, of junior and proratable water right holders in their withdrawal of water from a river or from groundwater occur for two reasons: to help prevent further decline in river flows in rivers subject to instream flow rules and to protect senior water right holders from having their water use impaired by the withdrawals of water right holders with more junior ranking (DOE, 2015). An instream flow rule establishes specific stream flow levels that will protect and preserve adequate water in streams for people and the environment. They are considered a water right for the stream and all the resources that depend on it. In many rivers in Central Washington, stream flows are below state or federal instream flow targets on a regular basis, particularly in late summer (DOE, 2015). Decreases in surface water supplies in tributaries in summer and early fall may lead to more weeks when instream flows are not met. This may result in a higher frequency of curtailment for interruptible water right holders in basins with adopted instream flow rules, such as in the Yakima River Basin.

The water use of junior and proratable water right holders can be interrupted if there is a risk a water source is insufficient to meet all the water demands on it. About 54% of the surface water use in the Yakima Basin is authorized by interruptible water rights. A restriction of this study is the inability to identify grower's water rights classification and their impact on tree fruit crop production. During drought years when nature doesn't provide enough water to satisfy all the Yakima Basin surface water rights, Reclamation determines how much water is available after all senior water rights are fully satisfied. Then, Reclamation allocates proportional shares of the water that remains to all of the junior water rights. For orchardists who hold junior water rights, this could mean severe cuts to their water supply in drought years, resulting in changes to the crops they grow in order to increase resilience.

Curtailment is typically done by limiting the days the junior and proratable water right holders can withdraw water from a river or from groundwater. They receive a notification when curtailment in their basin becomes necessary, which may include a hotline number to contact for further information. In some cases, they must call the number every day and listen to the recorded message, which lets them know if they can withdraw water on a particular day. This uncertainty around water availability and supply volume prevents growers from planning necessary irrigation scheduling to prevent water stress during sensitive stages of tree fruit growth cycles. Therefore, holding a proratable or junior water right during a low water year can consequently lead to unforeseen economic contingencies and extensive loss of crops for orchardists. In this study, participants did not distinguish whether their water rights are proratable or not. Yet, the biggest and most economically productive water districts in the Yakima Basin depend on proratable rights (Garrity and Malloch, 2012). For example, interruptible water rights were cut to just 47% of Yakima irrigator's full contract water right limits during the 2015 drought (Isley, 2016). In addition, water use was curtailed in areas where it has not been done before, and curtailments came weeks or months earlier than normal (DOE, 2015).

As water demand continues to increase and water availability diminishes during critical summer months throughout the Yakima Basin, water use curtailment will become even more frequent and severe. Modeling curtailment of interruptible irrigation water rights indicates that it occurred in 90% of years between 1977 and 2006 in Washington State (DOE, 2011). Simulation of future climate scenarios predicts curtailment occurring in all the years for the middle climate scenario (DOE, 2011). That means that unmet demand will average 4,424 acre-feet per year for Washington water users (DOE, 2011). Those who hold proratable and junior water rights will be the first required to curtail their water usage, although the resulting impacts can be felt throughout the entire community. In response to this growing trend, stakeholders from multiple interest groups have been working together to find a solution to their dwindling surface water supply.

State Adaptation Programs-

There are currently programs managed by the state designed to help support irrigators mitigate drought impacts and water supply uncertainty, although access to such resources and continued funding varies by region and year. In order to decrease demand, an Irrigation Efficiencies Grants Program (IEGP) provides a voluntary solution that improves on-farm irrigation and attempts to help vulnerable salmon populations. In this program, water-right holders use program funding and resources to increase the efficiency of their on-farm water application and conveyance systems. The saved water is then returned to drought-prone streams that are home to fish species listed on the endangered species list. The IEGP is designed to pay up to 85% of total costs for landowners to implement prescribed best management practices that increase the efficiency of crop water delivery to their crops, which equates to up to $400,000 per contract. In addition, on-farm projects receive Irrigation Water Management planning and a pro-rated portion of the saved water is transferred to the state’s Trust Water Rights program to help increase in-stream flows. Since the implementation of this program started in February 2016, 62 projects have been completed, saving more than 16,000 acre-feet of water. Overall, the IEGP provides an adequate adaptation option for orchardists in the Yakima Basin seeking help to decrease their water demand as funding allows.

In addition to decreasing demand, it is apparent to many water users that additional storage will be needed for both farmers and fish considering Yakima has relatively modest surface storage and snowpack is dwindling. There is a general agreement among stakeholders that improvements should first make the best use of existing infrastructure, such as reservoirs, to meet these demands. This includes accessing inactive storage and then building economically justifiable new or expanded storage, assuming such proposals withstand National Environmental Policy Act and Endangered Species Act scrutiny.

An expansion project was authorized by Congress in 2003 to perform a feasibility study for new surface supplies involving a transbasin diversion of Columbia River water into the Yakima Basin coupled with development of a 1.3-million acre-foot off-stream storage facility known as the Black Rock Project. But the Black Rock proposal foundered in 2008, due to a cost-benefit analysis that concluded the project returned only 13 cents on the dollar and had significant potential to speed the movement of radioactive groundwater at the Hanford Nuclear Reservation Superfund cleanup site towards the Columbia River (Garrity and Malloch, 2012). Although this attempt at increasing availability of surface water supply by increasing reservoir storage never came to fruition, stakeholders and water managers throughout the Basin continue to work towards securing a more reliable supply. Exemplifying this teamwork is creation of The Yakima Basin Integrated Water Resources Management Plan, commonly known as the Integrated Plan. The Integrated Plan combines the three common drought adaptive methods. The potential for each is analyzed in the next section.

The Yakima Basin Integrated Water Resources Management Plan-

The Integrated Plan is spearheaded by the State Department of Ecology and Bureau of Reclamation and was enacted by congress in 1979. The mission of the Integrated Plan has remained to make water supply more reliable for irrigators while stimulating the economy throughout Central Washington.

The Yakima Plan consists of seven elements intended to improve the reliability of instream and out-of-stream water supplies while restoring the Basin's native fisheries in the face of climate change and population growth. Those elements are: 1) Surface Water Storage; 2) Groundwater Storage; 3) Enhanced Water Conservation; 4) Market Reallocation of Water. 5) Fish Passage; 6) Structural and Operational Changes; and 7) Habitat Protection and Enhancement (**Figure 13**).

Figure 13. The Yakima River Basin Integrated Water Resources Management Plan (DOE, 2015)

In reference to the three adaptation themes that orchardists may choose to implement in order to secure a more reliable water supply, the Plan elements referring to Surface Water Storage, Groundwater storage, Market Reallocation of Water, and Structural and Operational Changes all fall under the seeking new sources category. Enhanced Water Conservation can be categorized as decreasing demand, and the remaining element concerning Fish passage is not directly related to adaptation choices available to orchardists in the region. Adapting to increase resilience to future and more extreme drought conditions is also not specified within the Integrated Plan but is considered throughout as programs working towards best management practices and irrigation efficiencies are included.

Conservation-

In regards to decreasing surface water supply demands, the Yakima Plan's enhanced water conservation element includes agricultural, municipal, and domestic water conservation measures. In 2002, one study found that an additional 95,000 to 178,000 acre-feet of water in the Yakima Basin could be saved through on-farm efficiency programs (Columbia Institute for Water Policy, 2007). However, there has been a lack of action associated with the efficiency and conservation programs available to farmers among the Yakima Basin in the past due to under-funding (Columbia Institute for Water Policy, 2007), although the implimentation of the IEGP program in 2016 provides new hope. Regardless, Washington growers have become more efficient irrigators as cropping systems have evolved in response to external pressures like water uncertainty and increasing competition. For example, orchards using a trellis system that allows increased fruit production on the same acreage have replaced many central Washington orchards full of large trees (WSU CSANR, accessed Jan. 2016).

In the context of the Integrated Plan, agricultural irrigation conservation is projected to save up to 170,000 acre-feet of water in wet years, which will both extend existing water supplies and improve flows for salmon and steelhead in several reaches of the Yakima and Naches rivers. A drawback to this particular method is that it relies on high precipitation levels, which remain unreliable as climate change persists. Types of agricultural conservation projects slated to be funded include lining or piping existing canals and laterals, constructing re-regulating reservoirs on irrigation canals, installing gates and automation on irrigation canals, improving water measurement and accounting systems, installing higher efficiency irrigation systems on-farm, and implementing irrigation management systems to reduce seepage, evaporation, and operational spills. As noted above, these kinds of projects are already being accomplished as federal funding allows, while the Integrated Plan promises to greatly expand the funding for implementation of water conservation throughout the agricultural lands of the Basin as well as the scope of where the projects occur (Garrity and Malloch, 2012).

New Sources-

The Integrated Plan calls for significantly increasing the Basin's surface storage by accessing inactive storage at an existing reservoir, expanding another reservoir, and building a new off-channel dam and reservoir. Inactive storage behind an existing reservoir will tap the water volume below the existing dam outlet so that 200,000 acre-feet of water could be accessed during drought conditions. Expanding another already existing reservoir from 34,500 acre-feet to 200,000 acre-feet is planned, where the additional water would be used to provide drought year supplies and more natural flows during the out-migration of juvenile salmon and steelhead. This reservoir will be expanded by building a new dam about 3/4 of a mile downstream of an existing dam location. However, the expanded reservoir's footprint will be about 3,500 acres, up from roughly 1,500 acres today (Garrity and Malloch, 2012). Therefore, the reservoir expansion is the most politically controversial component of the Yakima Plan, as it will inundate about 980 acres of old growth forest, three-quarters of a mile of bull trout spawning habitat, private cabins leased from the Forest Service, and a campground

(Garrity and Malloch, 2012).

By building the new off-channel dam and storage, pumping from the Yakima River will be required to fill the 162,500-acre foot reservoir and will be stored behind a 450-foot high dam. The reservoir will have a footprint of about 1,400 acres, including 1,055 acres of shrub steppe habitat (Garrity and Malloch, 2012). Half of the water stored behind the dam will be used to improve flows for salmon and steelhead while the other half will be used to improve the reliability of the water supply for existing irrigators. While some may see new or expanded water storage as the preeminent feature of the Integrated Plan, others see it as a targeted solution that is one component of a much larger strategy to meet the specific needs of the Yakima Basin's agricultural industry and fisheries (Garrity and Malloch, 2012).

Water banking provides another option for seeking new water sources and the Integrated Plan proposes to increase the amount of water moved from low-value annual crops to higher-value perennial crops such as tree fruits, while claims will reduce the delay for such transactions. This will occur in two phases, both of which managers working on the plan admit will require more fleshing out (Garrity and Malloch, 2012). The first phase will involve a near-term effort to build on the Basin's existing water market by providing additional administrative and technical support to encourage more transactions. The second phase will require more substantial changes to law and policy to facilitate more inter-irrigation district water exchanges in addition to the intra-district exchanges that are more common in the Basin today. The initial goal for this program is to market up to 60,000 acre-feet of water supply. However, as the price of water increases and institutional barriers are reduced, some parties are estimating that much more water will be marketed on a temporary basis during low-water years (Garrity and Malloch, 2012).

As promising as the Yakima Plan sounds, securing the monetary support to fulfill the budget for its broad-based approach proves challenging for the state of Washington and will take time. The Plan in its entirety would cost the state $4 billion dollars (Garrity and Malloch, 2012). In addition to securing the necessary funding, the program will not and could not be built immediately. The Yakima Plan sets up a series of projects that will be tackled over a three or four decade time period. That makes the $4 billion dollar project a still ambitious, but much more manageable target. On the other hand, time also raises issues around the appropriate sequencing of element implementation, ability to maintain stakeholder and political support and interest, and increasingly threatening environmental changes. According to analysis of a report written by Senior Western Water Program Manager Steven Malloch and American River's Washington State Conservation Director Michael Garrity, these concerns are serious current discussion topics among Plan managers, who aim to create project groups that address enough interests to keep the political coalition together.

Future Plans and Perceived Hurdles-

Central Washington needs well-coordinated adaptation strategies across the basin to improve resilience, reduce risks, and increase water sustainability. Bottom-up integrated planning, like the Integrated Plan provides, could help prepare Washington for future changing climate and balance the states water demand with the varying seasonal water availability. The agricultural community faces both environmental and regulatory challenges when addressing this water scarcity issue. Irrigators must navigate the State's water laws and abide by the ecological and political contingencies in place in order to continue ownership of their water right. As users of "waters of the State" for irrigation, farmers are subject to regulation under the federal Clean Water Act (CWA) and Endangered Species Act (ESA). In many instances, the process of achieving and demonstrating compliance with these regulations can be particularly daunting as the pressures related to climate change and population growth further increase demand for water resources. While it is often possible for a senior water right holder or farmer with annual rather than perennial crops to overcome these issues and still make a profit, the process may not always be economically feasible for orchardists with an interruptible water right. Surface water availability and allocation for irrigation in the Yakima Basin present a culmination of various issues facing Central Washington farmers.

Lastly, the Yakima Basin is expected to experience yet another water shortfall during the 2016 irrigation season. According to scientists, in the 21st Century the Yakima Basin will, "Transition to earlier and reduced spring snowmelt as the century progresses, which results in increased curtailment of water deliveries, especially to junior water rights holders" (Vano, 2007). There are numerous sources, reports, scientific journal articles, and books about this topic that all agree that climate change will be the cause of warming temperatures for the region, and result in a recurrent decline in the Basin's snowpack.

While there are some plans and projects already in place to minimize the limited water supply impacts from 2015 on future growing seasons, there is still a great deal of uncertainty among the Basin's water users, water resource managers and all of the individuals that work diligently to maintain this precious resource. With warming temperatures, a projected increase in less reliable water resources, and the unforeseen consequences of climate change, it is vital that water users establish and implement a model for how basins everywhere can create a sustainable future for all of its inhabitants for many years to come.

VII. Conclusion

In many respects, Reclamation succeeded in its mandate to develop a robust agricultural economy in Central Washington. However, in fulfilling that mission the environmental tradeoffs have been devastating. The main conclusion from this study is that impacts on tree fruit production in the Yakima Basin due to the 2015 drought were widespread and will be ongoing. It was found from 41 orchardist's survey responses that 85.4% experienced yield losses due to the drought, 73.8% stated the quality or the marketability of their crop was negatively impacted, and 61.5% reported that they expect the 2015 drought to have negative impacts on their future farming operation and 2016 crop. Based on this data, patterns emerged between negative drought impacts on tree fruit quality and storage in relation to implementation of infrastructure improvements. Furthermore, 70% of the survey participants who reported not pursuing infrastructure improvements still cited negative impacts to their crop's quality and 55% to their storage. Therefore, it can be concluded that orchardists generally seek adaptations in order to mitigate drought impacts as long as they have access to the necessary resources, information and finances to implement such adaptations. In the agricultural industry, a drought is not a single point of impact, simply because crop growing periods, soil health, drought-damaged plants, and water supplies take time to resolve. Based on the presence of these conditions reported by survey participants and supplemental analysis of key documents, this study concludes that compounded impacts from meteorological, hydrological, and agricultural drought affected the central region of Washington State during the 2015 growing season.

This study was restricted by in-access to survey respondents, which could have provided additional data on specific demographic information for the orchardists. For example, understanding the tree fruit type they grow and on what acreage, as well as how long they have been in production and the water right classification they operate with, could provide further trends around drought impacts on orchardists in the Yakima Basin and what motivates them to seek adaptation methods during low water years.

Looking ahead, the Climate Predictions Center (CPC) states that there is a 48-54% chance (depending on the month) that the temperatures in the Yakima Basin will reach above normal conditions between May and September of 2016, compared to near or below normal temperatures. There is not much indication of how precipitation will turn out for the 2016 water year, considering the CPC outlook predicts equal chances of below, equal to, or above normal precipitation for the entire state (OWSC, 2016). As of April 16th, 2016 snowpack for the Upper Yakima Basin was recorded at 80% of normal amounts while the lower basin was recorded at 110% normal (NRCS, 2016). In fact, over one month the amount of snow that fell in the Cascade Range was higher than what fell during all of the 2014-2015 winter (WSU, 2016). Although since then, the State has seen its hottest day on record for the month of April, with temperatures reaching 89 degrees Fahrenheit, breaking the previous record set in 1976 by four degrees (National Weather

Service, 2016). This is cause for warning regarding another hot and potentially dry wildfire season in 2016, while water supplies appear to be slightly recovering. Although meteorological drought conditions may improve compared to the 2015 weather patterns, pressures from high temperatures and lasting drought effects that surround availability of surface water supply continue to compound an agricultural drought scenario. Based on the early weather and temperature conditions in Washington State, it is clear that there is an economic demand for our stewardship to protect the threatened quality of our environment and agricultural commodities.

In order to address the current problems and prepare for radically different conditions that disruption of the climate brings, stakeholders need to work together and think broadly. It is for these reasons that The Yakima Basin Integrated Water Resources Management Plan was created. By implementing the extensive Integrated Plan, Reclamation aims to establish a framework for solving a 30-year dilemma that has caused economic uncertainty, inhibited growth, and limited recovery of fisheries, while addressing Yakima's water needs today and into the future. The Yakima Plan is a comprehensive approach that involves reaching out to historical adversaries and taking a broad view of the Yakima Basin's environment, economics, and future climate. Considering The Plan incorporates each of the three adaptation themes this study used for analysis, it could provide orchardists with the necessary resources and strategies required to mitigate negative impacts from future drought scenarios and low water supply years.

Ultimately, we will not know the total impact of the 2015 drought for two to four more years, and that is only if another drought does not occur during this time. Meanwhile, farming operations will struggle to stay solvent, despite their technological innovation and adapting practices, if climate and weather changes like those seen in 2015 become more regular and even more extreme and adaptation resources are not made more accessible and feasible to orchardists in the Yakima River Basin of Central Washington.

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