INCENTIVIZING INCIDENTAL GROUNDWATER RECHARGE IN TETON VALLEY, IDAHO

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As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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Acronyms and Abbreviations

AF – acre-foot

ASR – aquifer storage and recovery

CA – conjunctive administration

CBA – cost-benefit analysis

CAMP – Comprehensive Aquifer Management Plan

CCC – Cross Cut Canal

cfs – cubic feet per second

CPR – common pool resource

CTNF – Caribou Targhee

CWAL – cold water aquatic life beneficial use

ENSO – El Niño/Southern Oscillation

ESPA – Eastern Snake Plane Aquifer

ET - Evapotranspiration

FMID – Freemont-Madison Irrigation District

FTR – Friends of the Teton River

ft - Feet

GTNP – Grand Teton National Park

GYE – Greater Yellowstone Ecosystem

HFF – Henry's Fork Foundation

IDEQ – Idaho Department of Environmental Quality

IDFG – Idaho Department of Fish and Game

IDWR – Idaho Department of Water Resources

IPR – Island Park Reservoir

IWSB – Idaho Water Supply Bank

KAF – thousand acre-feet

LWG – LegacyWorks Group

MAF – million acre-feet

RDR – rate of diversion for recharge

SNOTEL – SNOpack TELemetry

SS – salmonid spawning beneficial use

SWE – snow water equivalent

TRB – Teton River Basin

TWUA – Teton Water Users Association

USGS – United States Geological Survey

WTA – willingness to accept

WTP – willingness to pay

YCT – Yellowstone Cutthroat trout

Abstract

The Teton River in Teton Valley, Idaho supports a vibrant community of farmers, ranchers, recreationists, and wildlife species. Teton River streamflow originates as snowmelt from the mountains surrounding the Valley, and is intricately connected to groundwater. Recent increases in snowpack variability and changing irrigation practices have resulted in declining aquifer levels and a subsequent decrease in late-season streamflow. This decrease significantly impacts farmers who rely on this water for irrigation, as well as riverine and wetland ecosystems. Our client, LegacyWorks Group, aims to augment late-season streamflow in the Teton River by incentivizing changes in irrigation timing. Farmers will divert water into unlined canals early in the season, allowing water to seep into the shallow aquifer. This practice, called incidental recharge, will utilize the natural storage function of the shallow aquifer to retain early-season water and release it to the Teton River one to three months later. The objectives of this report were three-fold: 1) to model hydrologic conditions to determine the impact of recharge on streamflow and stream temperatures; 2) to quantify the economic and environmental impacts of augmented flows; and 3) to design a framework for incentivizing groundwater recharge. We found that conducting incidental recharge in Teton Valley is hydrologically feasible and, given sufficient recharge, can be cost-effective and environmentally beneficial. In order to achieve the requisite participation threshold, we recommend phasing in a recharge program that builds upon support from non-profit organizations, farmers, and the larger community. This program will encourage local farmers and environmental non-profits to work together to achieve a common goal and generate greater community benefit.

Executive Summary

The Teton River Basin is located in the southeastern corner of Idaho on the border with Wyoming. The basin lies on the western edge of Grand Teton National Park (GTNP) and just south of Yellowstone National Park (YNP). The majority of water in the Teton River Basin comes from seasonal snowmelt from the Teton Range and the Big Hole Range, both as groundwater and surface water flows in the Teton River. The Teton River flows through Teton Valley and is flanked by agricultural land to the west and wetlands to the east. These wetlands, fed by the local aquifer, provide key habitat for various migrating and wintering wildlife populations that utilize the neighboring National Parks for summer ranges (Noss, Carroll, Vance-Borland, & Wuerthner, 2002). The Teton River and its tributaries also supply irrigation water for 120,000 acres of agricultural operations in the Valley (U.S. Department of Agriculture, 2012).

As a result of the local geology, groundwater and surface water are intimately connected in Teton Valley. Some portion of precipitation and irrigation water makes its way into the groundwater and travels through the shallow aquifer to emerge one to three months later in springs that feed the Teton River. Changes in irrigation practices and increasing variability in snowpack levels over the past few decades have altered the flux of groundwater to the Teton River and have therefore changed the hydrologic regime.

Farmers in Teton Valley rely almost exclusively on surface water from the Teton River and its tributaries to irrigate their fields. Streamflow is driven primarily by snowmelt in the Teton Range. Although snowmelt and streamflow vary greatly year to year, peak streamflow typically occurs in late spring to early summer with lower flow expected in July and August once all the snow has melted. This late-season decrease in streamflow can have a significant impact on farmers who rely on this water for irrigation. Late-summer decreases in streamflow not only impact farmers but also adversely impact riverine and wetland ecosystems. Native fish need cold, clean water to survive and lower flows in the Teton River result in warmer water temperatures. The adjacent wetland and fen ecosystems, which also rely on a consistent supply of water, are part of the GYE and support dozens of important wildlife species. Decreased water availability can dry out wetland habitat and cause significant harm to the species they support.

Our client, LegacyWorks Group (LWG), has been working with stakeholders in Teton Valley to encourage community-based change focusing on social and environmental issues. As part of this larger effort, LWG aims to implement a market that will incentivize changes in irrigation practices thereby augmenting late-season streamflow in the Teton River and buffering against annual hydrologic variability. This practice, called incidental groundwater recharge, will utilize the natural storage function of the shallow aquifer to retain early-season water and release it to the Teton River one to three months later when streamflow is typically low and water temperatures are high.

Our group focused on three main objectives to meet this goal:

1. Model hydrologic conditions to determine the potential impact of recharge on streamflow and stream temperatures in the Teton River.

2. Quantify the economic and environmental impacts of augmented flows, including the costs and benefits of conducting incidental recharge.

3. Design a framework for incentivizing groundwater recharge to augment late-season streamflow in the Teton River.

It is crucial to understand the hydrologic system of Teton Valley in order to maximize the benefits of an incidental recharge program to provide augmented flows when they are needed most. We developed three methods to satisfy this objective. First, to quantify the impact of recharge on streamflow in the Teton River, a water budget was used to predict how water moves through the shallow aquifer system from recharge locations to outflow in the river. Second, to determine which recharge locations would best contribute to the goal of augmenting late-summer streamflow, a spatial site-suitability model was developed. Finally, to estimate the ecosystem benefits of recharge on fisheries, we created a model to assess the influence of increased streamflow on stream temperature. For each of these analyses, we assessed the potential impact of recharge from running water through unlined canals and allowing it to seep into the shallow aquifer.[1]

In order to garner support for an incidental groundwater recharge program in Teton Valley, we needed to determine the economic and environmental impacts of incidental recharge. We evaluated the economic impacts by conducting a Cost-Benefit Analysis of the direct costs and benefits that farmers in the Valley would incur as a result of running water in their canals for one month prior to the irrigation season. To determine the ecosystem and recreation benefits, we evaluated the effects of decreased water temperature on riverine and wetland habitat. The benefit transfer method was then used to estimate the potential economic value of improved habitat.

In addressing the first two objectives, we found that conducting incidental recharge in Teton Valley is hydrologically feasible, and has the potential to be cost-effective, and environmentally beneficial with the implementation of sufficient recharge. Crucial first steps will be on-the-ground demonstration of the connection between incidental recharge and augmented streamflow, and to garner broad-based community support for the program. In order to achieve the requisite participation threshold, we recommend a three-stage incidental recharge program:

- Stage 1: pilot project,
- Stage 2: a non-profit phase-in period,
- Stage 3: final expansion to include farmers and other community members as funders of the program.

In the face of complex challenges, a cooperative, integrated approach to water management is crucial between agricultural users, urban users, environmental non-profit organizations, and local and state government institutions. This project recognizes a common cultural value between local farmers and environmental non-profit organizations and elevates their partnership to generate greater community benefit.

[1] For reasons explained in further detail in the report, we did not assess the impact of recharge from flooding pastureland and land out of agricultural production, though the analysis could easily be expanded to include these.

Problem Statement

Farmers in Teton Valley rely almost exclusively on surface water from the Teton River and its tributaries to irrigate their fields. Streamflow is driven primarily by snowmelt in the Teton Range. Although snowmelt, and therefore streamflow, varies greatly year to year, peak streamflow typically occurs in late spring to early summer with low flow expected by July and August once all the snow has melted. This late-season decrease in streamflow can have a significant impact on farmers who rely on surface water for irrigation.

Water from the river and its tributaries is allocated to farmers for irrigation based on a system of prior appropriation. Farmers who began using water first have the oldest priority dates and, therefore, receive the most senior water rights. Water allocations are filled in order of priority dates. During the spring when there is plenty of water in the river, all users receive their full allocation of water; however, in July and August when streamflow levels are low, water is allocated based on seniority, with the most senior users getting their water first and the junior users sometimes having to curtail their water use. This can have negative impacts on crop yields and profits, especially in Teton Valley where most water rights are junior to water rights downstream.

These late-summer decreases in streamflow not only impact farmers but also adversely impact fish species and wetland ecosystems. Native fish need cold, clean water to survive and lower flow in the Teton River results in warmer water temperatures. The adjacent wetland and fen ecosystems, which also rely on a consistent source of water, are part of the Greater Yellowstone Ecosystem and support dozens of important wildlife species. Decreased water availability can dry out wetland habitat and cause significant harm to the species they support.

Ultimately, low summer flow in the Teton River has severe negative effects on the local farmers and ecosystems that depend on that water. Furthermore, increasing climatic variability will likely alter the hydrologic cycle further, resulting in even greater changes in instream flows and subsequent stress on these two stakeholders.

Project Goal and Specific Objectives

Teton Valley farmers divert water directly from tributaries into canals or pipes to transport to their fields. Water transported in unlined canals seeps into the ground and subsequently into the shallow aquifer. This water then flows through the shallow aquifer and reemerges in springs near the Teton River approximately three months later. These springs feed both the Teton River and the adjacent wetlands.

Although farmers have the right to start diverting surface water for irrigation beginning on April 15th, the planting season does not usually begin until mid-May. This leaves about one month in which farmers' rights are in priority, but not in use. Thus, the goal of this project is to augment late-summer flows by utilizing this extra month to run water through unlined canals, therefore increasing groundwater recharge. Doing so will not only benefit the ecosystems that depend on having water in the river and in the wetlands but will also benefit the farmers. With augmented streamflow in July and August from early-season recharge, it is more likely that farmers will not have to curtail their water use, or will do so at a later date, thereby lessening the associated economic impact.

Project Objective

Our client, LegacyWorks Group, aims to implement a market that will augment late-season streamflow in the Teton River and buffer against annual hydrologic variability. To do so, the market must incentivize farmers to utilize the full extent of their water rights to conduct early-season incidental recharge by running water through their unlined canals.

In order to support this goal, our group addressed three main objectives:

1. Model hydrologic conditions to determine the potential impact of recharge on streamflow and temperatures in the Teton River.

2. Quantify the economic and environmental impacts of augmented flows, including the costs and benefits of conducting incidental recharge.

3. Design a framework for incentivizing groundwater recharge to augment late-season streamflow in the Teton River.

In addressing these three main objectives, our group hoped to provide LegacyWorks Group with a recommendation for an incidental recharge program that would be both feasible and beneficial to farmers and wetland and riverine ecosystems.

Our Solution

Through our research objectives, we found that conducting incidental recharge through unlined canals in Teton Valley is hydrologically feasible, and with enough participation, it can be cost-effective and environmentally beneficial. However, despite the strong scientific and economic rationale for conducting incidental recharge, farmers are not currently undertaking this practice. We believe this is due to the abstract nature of the benefits of incidental recharge. Before farmers will be willing to invest in the costs of incidental recharge they will require physical evidence showing that incidental recharge increases late-season streamflow in the Teton River.

Our client initially envisioned the creation of a traditional market mechanism for incentivizing incidental recharge in Teton Valley. However, because augmented flows are not fully specified or exclusive, there is not a sufficient number of market participants and there is no way to exclude free riders, we have concluded that our client's original goal of developing a traditional market is implausible.

Based on our research, our final recommendation is to implement a community-based resource management program implemented in three stages.

Stage 1: Pilot Project

We recommend that our client continues with their scheduled two-year pilot project testing incidental recharge with two volunteer irrigation districts in Teton Valley. The main purpose of the pilot should be to demonstrate the feasibility of doing incidental recharge and to better understand the physical and financial challenges that farmers face in conducting incidental recharge.

Stage 2: Non-Profit Support

The short two-year duration of the pilot project will not provide enough time for the benefits of increased late-season streamflow in the Teton River to manifest. Therefore, we recommend that LegacyWorks Group set up a structure that will allow local and national non-profit groups to provide supplemental funding for conducting incidental recharge for the following three years. Additionally, funding can be used to restore historic, unused canals, and identify marginal pastureland where recharge can be pursued.

Only by conducting a significant amount of recharge beyond the capacity of the existing canal system will benefits meet the critical threshold to incentivize farmers to buy into the program. Benefits to the local fisheries and wetlands, however, will start to accrue earlier and will provide a strong case for engaging non-profits interested in augmenting river streamflow and maintaining valuable habitat for species of concern. Furthermore, incidental recharge is less expensive than other flow-augmentation schemes, such as fallowing farmland and buying water rights and will, therefore, likely be a favorable alternative.

Stage 3: Community Support and Farmer Buy-In

After the completion of the two-year pilot and non-profit expansion stages, we believe the financial benefits from augmented streamflow in the Teton River will be such that farmers will be willing to contribute funding for the program in order to ensure their cost savings into the future. At this point, we envision that the farming community will pay the costs of incidental recharge themselves and manage payments via trusted and established irrigation districts and canal companies. We also recommend that LegacyWorks Group turn over the management of the program to Teton Water Users Association (TWUA), a local governing body comprised of stakeholders in the Valley, including representation from both farmers and non-profits.

Project Significance

In the face of complex challenges, a cooperative, integrated approach to water management is crucial between agricultural users, urban users, environmental non-profit organizations, and local and state government institutions. This project recognizes a common cultural value between local farmers and environmental non-profit organizations and elevates their existing partnership. The success of such a project will prove that collaborative partnerships across sectors are not only feasible but can, in fact, generate greater community benefit.

A program like this can be replicated throughout the West as local stakeholders seek creative solutions to natural resource problems. By using existing infrastructure and avoiding costly, time-consuming legal changes to water rights, this three-phase program will be cheaper and faster to implement than many traditional managed recharge programs. It is best applied in regions where surface water provides the majority of supply and the most pressing problem is variable timing of streamflow. This project's model can be scaled up to meet the recharge goals of larger communities with a greater diversity of water needs and uses.

Backed by diligent economic and hydrologic research, the community-based resources management program proposed in this report provides the type of innovative, partnership-based solutions necessary to meet the water challenges of the 21st Century.

Chapter 1: Introduction to Teton Valley

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1.1 The Teton River Basin

1.1.1 Study Area

The Teton River Basin (TRB) is located in southeastern Idaho and is flanked by the Teton Range to the east and the Big Hole Range to the south and west. The basin straddles the border between Idaho and Wyoming and covers an area of approximately 1,118 square miles (Figure 1.1). The TRB lies within the larger Snake River Basin, which originates in Wyoming and encompasses parts of Idaho, Oregon, and Washington before joining the Columbia River.

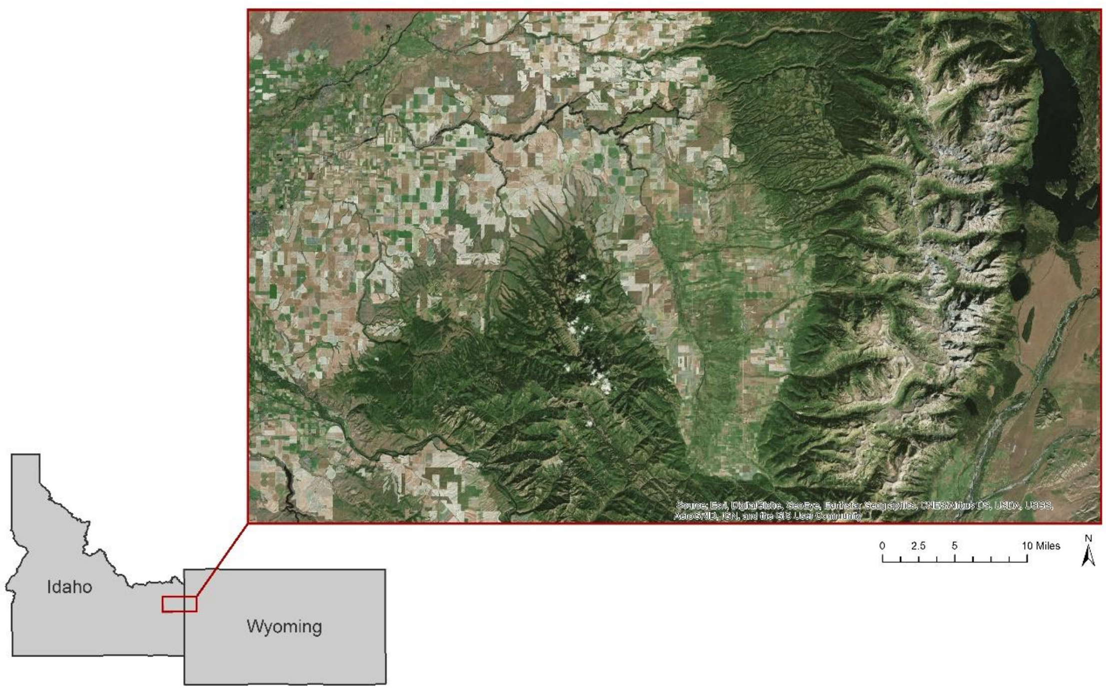

Figure 1.1: *Location of the Teton River Basin, which straddles the border between Idaho and Wyoming. Data Source: U.S. Geological Survey.*

1.1.2 Natural Landscape

Climate

The climate in Teton Valley varies temporally; summers tend to be warm and dry, while winters are cold and wet. During the winters the majority of the region's precipitation falls as snow. Climate in Teton Valley also varies spatially as a result of differing elevation. The lower elevation plains in the westernmost part of the watershed are warmest and driest, while the mountains are typically cooler and receive greater amounts of precipitation (Figure 1.2). This precipitation falls predominantly as snow and accumulates from November to April in these high elevation areas. The snowpack melts later in the season than the snow in the Valley due to the colder temperatures and greater accumulation. Mountain snowpack typically melts off during May and June during which time it flows down the mountain and into the valley (Natural Resources Conservation Service, 2016).

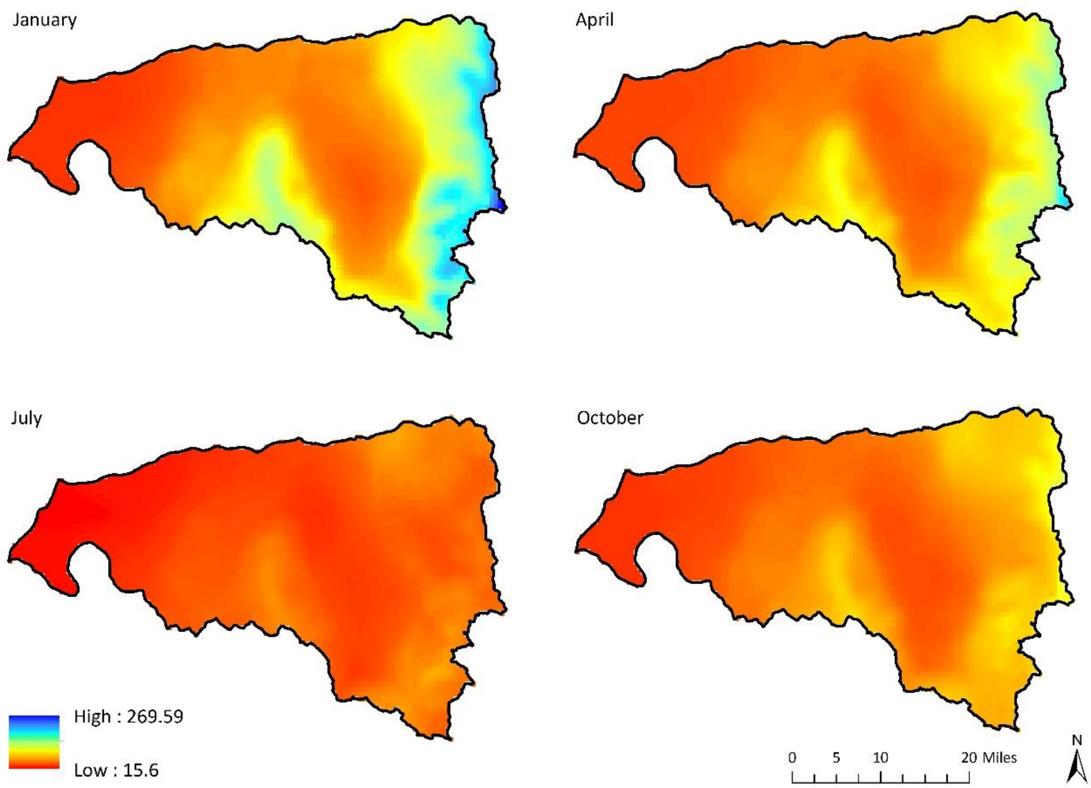

Figure 1.2: *Mean monthly precipitation (mm) in the Teton Watershed from 1981 - 2010 for January, April, July, and October. Precipitation varies spatially and temporally with the greatest amounts of precipitation falling in the winter at higher elevations. Data source: PRISM Climate Group.*

Teton River and its Tributaries

The Teton River is 81 miles long from its headwaters to its confluence with the Henry's Fork River. The main stem of the Teton River originates in the mountains near the Idaho-Wyoming border and descends rapidly into Teton Valley where it flows north for 35 miles (Figure 1.3). Throughout the Valley, the river is flanked by rangeland and extensive, ecologically significant wetlands. After it is joined by Bitch Creek at the north end of the Valley, the Teton River then flows west for 46 miles forming the border between Fremont County to the north and Teton and Madison counties to the south. The Teton River then splits into two distributaries, the Teton River to the north and the South Teton River to the south, before both joining the Henry's Fork River near Rexburg, Idaho.

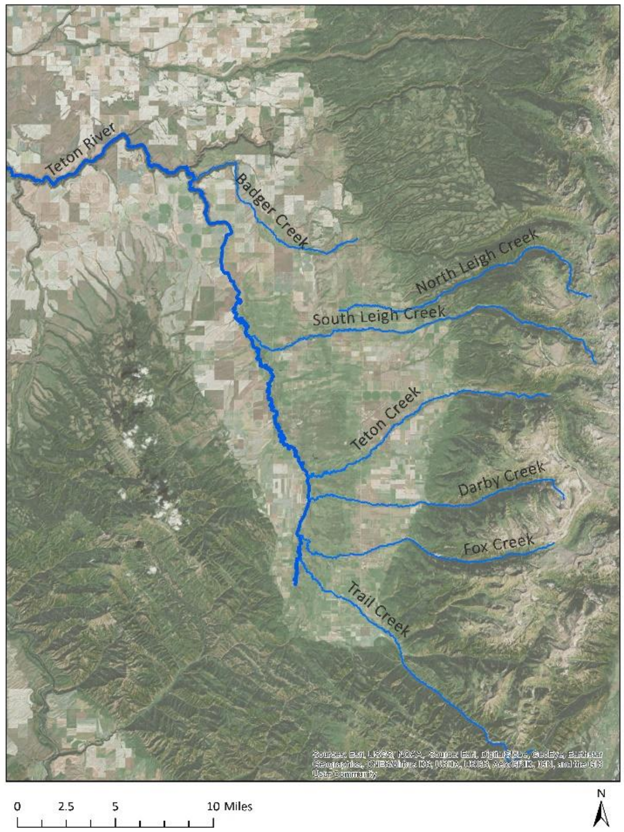

Figure 1.3: *The Teton River and major tributaries in Teton Valley. Data Source: U.S. Geological Survey.*

The majority of the flow in the Teton River originates in tributaries draining snowmelt from the western Tetons, including Trail Creek, Teton Creek, Fox Creek, and South Leigh Creek. A few tributaries also contribute water originating in the Big Hole Range to the west. As it melts, the snow flows down the mountains and into these tributaries, which then feed the Teton River. In a year with little springtime rain, the peak flow is entirely driven by snowmelt; in a wet spring with more rainfall, the peak flow is driven by a combination of snowmelt and rainfall (Natural Resources Conservation Service, n.d.). The timing and delivery of the water are largely determined by the magnitude of the mountain snowpack and the timing of snowmelt with peak streamflow occurring anytime from two to eight weeks after the beginning of the snowmelt (Figure 1.4). During this time farmers in the Valley divert water from the tributaries to use for irrigation. Given the yearly variability in snowpack and subsequent snowmelt, the agricultural season in Teton Valley can vary significantly from year to year.

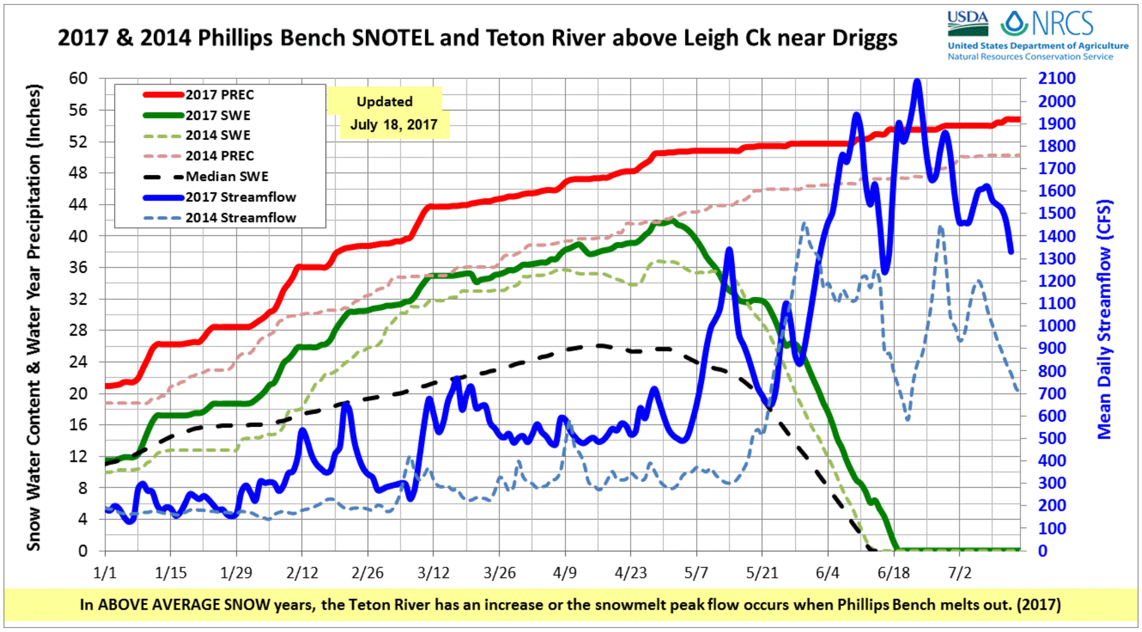

Figure 1.4: *Snow Water Equivalent (SWE inches) (green), streamflow (cfs) (blue), and precipitation (inches) (red) in the Teton River above South Leigh Creek for 2014 and 2017. Peak streamflow occurs once SWE is 0, or the snow has completely melted. Snow starts melting late-April and is completely melted by mid-June. Streamflow peaks late-June to mid-July. Source: Natural Resources Conservation Service.*

The Teton River and its tributaries have a number of beneficial uses that are designated and protected by Idaho water quality standards. The entire length of the Teton River is designated for cold-water aquatic life and salmonid spawning. The Teton River is also designated for primary contact recreation (e.g. swimming) upstream of the fork and secondary contact recreation (e.g. fishing and boating) downstream. Fox Creek, Badger Creek, and Bitch Creek are also designated as recreational waterways. Upstream of the fork, the Teton River is designated as drinking water supply and Special Resource Water (Idaho Department of Environmental Quality, 2003).

Geology & Geomorphology

The morphology of the Teton Basin is defined most notably by Basin and Range normal faulting associated with crustal extension, Yellowstone hotspot volcanism, and, more recently, two major glaciation events (Bayrd, 2006). The steep faulting of highly-competent rocks characterizes the high-relief mountains surrounding the Valley where stream tributaries have eroded through U-shaped, glacier-carved valleys (Figure 1.5). Large alluvial fan deposits in the Valley have accumulated as a result of the huge volumes of debris eroding off of the steep slopes of the surrounding mountains (Kilburn, 1964; Randle, Bountry, Klinger, & Lockhart, 2000).

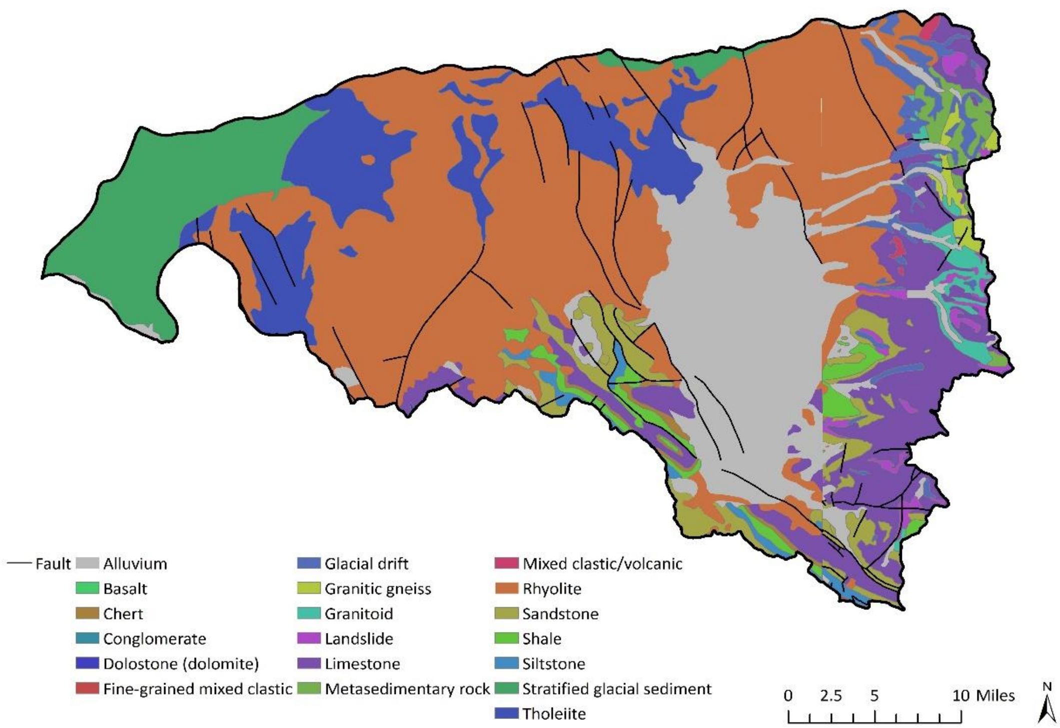

Figure 1.5: *Geology of the Teton River Basin. Black lines represent active or dormant fault locations. Data source: U.S. Geological Survey.*

The Teton Basin exhibits a range of soil textures (Figure 1.6). Topsoil grains decrease in size with further distance from the headwaters. The upper reaches of Teton Valley are dominated by stony and loam soils, while the lowest reaches in the low-relief floodplain are dominated by silts. More groundwater recharge occurs in the coarser textured, stony, and loam soils at the foot of the mountains than in the silty floodplains. Hydrologic Soils Groups (HSGs) are determined according to similar runoff potential using soil properties (Figure 1.6). HSGs in Teton Valley are fairly homogeneous, with most areas characterized by moderate infiltration, Group B soils.

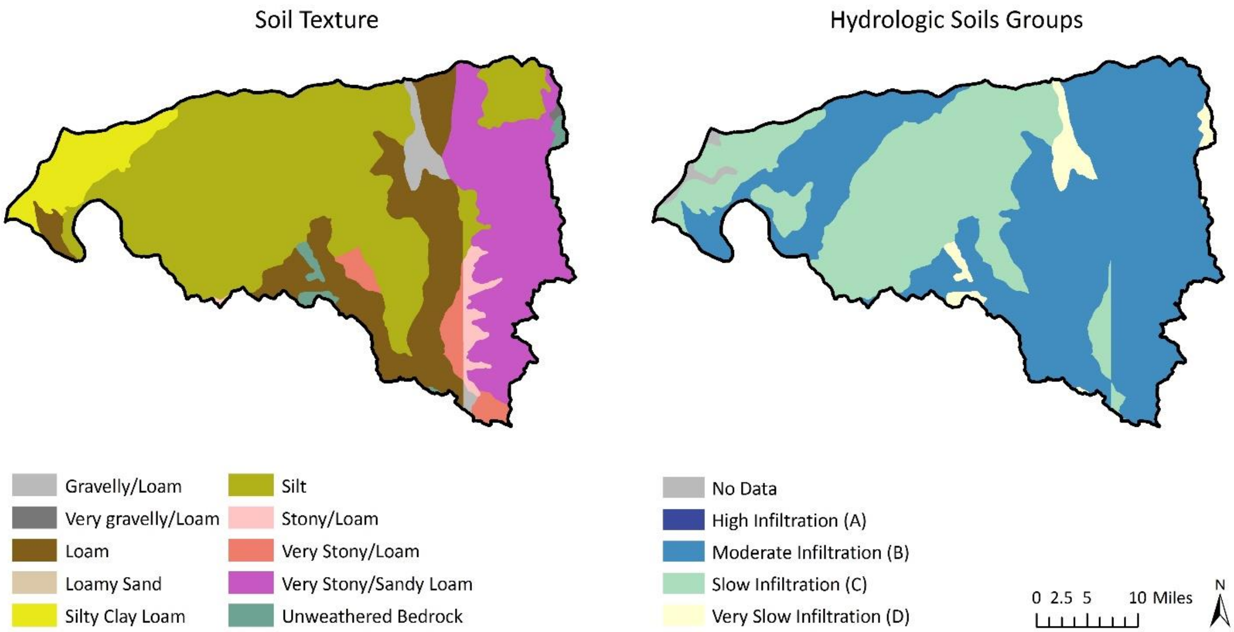

Figure 1.6*: Soil texture (left) and hydrologic soils groups (HSG) (right) in the Teton River Basin. HSG classifications of A, B, C, or D are designated based on depth to the seasonal high-water table, hydraulic conductivity under saturated conditions after extensive wetting, and depth to a low-permeability layer. Group A refers to soils with a high infiltration capacity (dark blue) and Group D refers to soils with a low infiltration capacity (yellow). Data source: Natural Resources Conservation Service.*

Groundwater

There are two main aquifer systems in the Teton Basin, a shallow aquifer with relatively-quick return flow and the deeper Teton Valley Aquifer with much longer travel times and more limited connectivity to the Teton River. The Teton Valley Aquifer, located in the upper watershed, covers approximately 90 square miles and ranges in depth from 100 to 800 feet (Bayrd, 2006). The water sits in quaternary and pleistocene alluvial fan deposits. These deposits are characterized by unconsolidated and poorly-sorted stream and glacial debris full of clays, silts, sands, and gravel above Miocene age basin fill (Kilburn, 1964). Smaller, shallow aquifers exist in the lower portions of the Teton Watershed. These likely have much shorter residence times (between one to ten years) and discharge into the Eastern Snake Plain Aquifer (ESPA) (Bayrd, 2006). Both aquifers are fed mainly by percolation from direct snowmelt through the extensive wetland and tributary creek system, as well as through incidental recharge from agricultural canals and irrigation application.

Discharge to the Teton River in this area is greater than aquifer recharge as a result of the exaggerated hydraulic gradient caused by groundwater pumping. The aquifers have been declining in recent years due to increased municipal groundwater pumping from the deep aquifer and decreased incidental recharge as a result of increased irrigation efficiency. In some places, the water level in Teton Valley Aquifer has decreased by as much as 55 feet (Lien, 2017a).

Groundwater is an important source of water supply in Teton Valley, accounting for 100% of domestic water supply and about 26% of agricultural water supply. Each year approximately 330,802 acre-feet (AF) of groundwater are withdrawn from the two main aquifers, accounting for about 23% of total water used in the watershed (U.S. Geological Survey, 2014).

Historically, the water table reaches its lowest elevation in March, though with warmer alpine temperatures, peak melt is occurring increasingly earlier. Water tables generally reach their highest levels in June and early-July. However, groundwater extraction and the impact of conservative irrigation practices have caused a significant decline in peak water levels (Figure 1.7). The deep aquifer responds very little to seasonal variation because of the long travel and residence times as the water resides in and moves through the aquifer. The shallow aquifers, on the other hand, appear to show peak water levels in September. This is likely due to elevated recharge from irrigation at the end of the irrigation season (Figure 1.8). In both cases, the timing of peak groundwater levels is shifting to earlier in the year. In the shallow aquifer, this shift affects the timing of groundwater discharge into the wetlands, rivers, and tributaries that rely on groundwater contributions to maintain water levels.

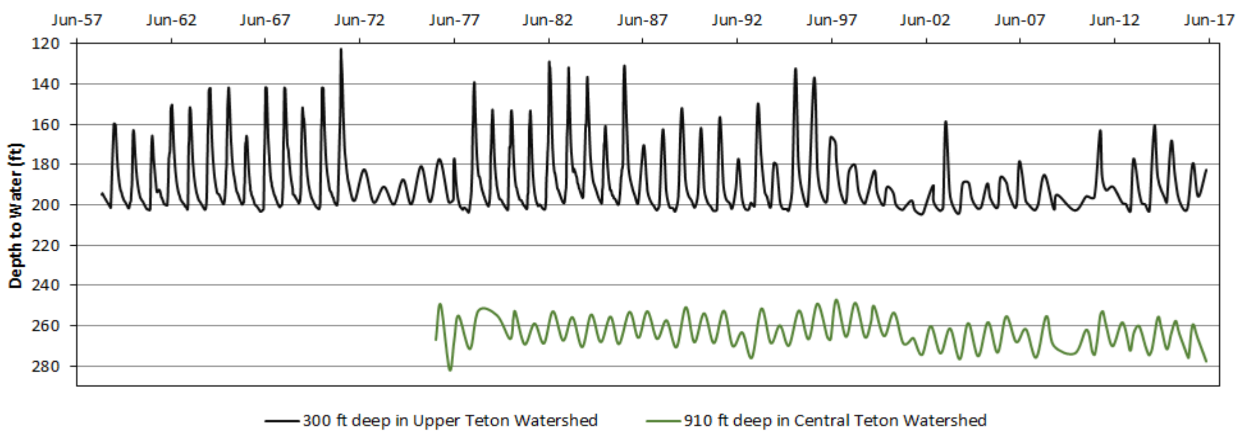

Figure 1.7: *Depth to the water table (feet) for two wells in the Teton Watershed. The 300-foot well (Well ID 04N 45E 13ADA1) is in Teton Valley between Driggs and Victor. The 910-foot well (Well ID 07N 42E 06DDA1) is in the center of the watershed upstream of Newdale. Data source: Idaho Department of Water Resources.*

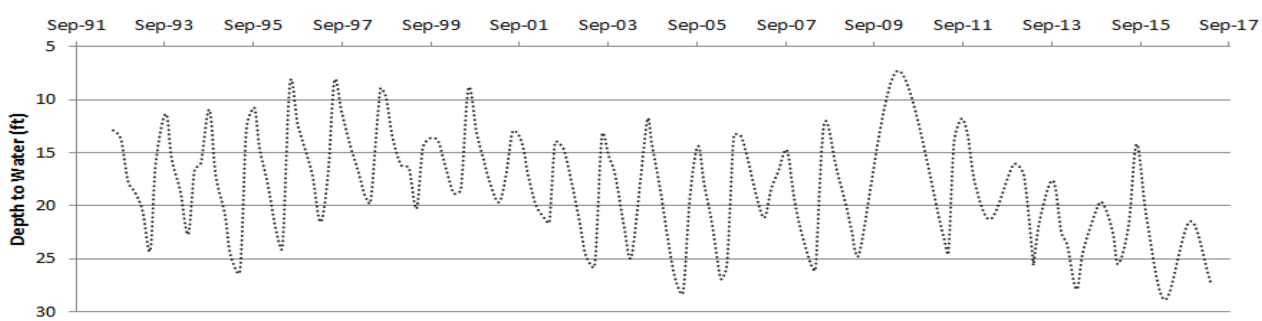

Figure 1.8: *Depth to the water table (feet) for a shallow, 55-foot well in the lower watershed. Data source: Idaho Department of Water Resources.*

Wetlands and Ecological Assets

Among Teton County's most notable ecological features are its prominent wetlands, which support a diversity of plants and animals (Idaho Department of Fish and Game, 2012). Wetlands are defined under Section 404 of the Clean Water Act as "areas that are saturated or inundated at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soils" (Merrit & Cooper, 2012). Their diverse hydrologic regimes and vegetation types provide critical habitat for waterfowl, shorebirds, and amphibians.

In Teton County, 26,760 acres are classified as wetlands, amounting to 9% of the total land area (Idaho Department of Fish and Game, 2012). This includes expansive areas of wet meadows, emergent marshes, sloughs, fens (also called peat-forming wetlands), shrub/scrub willow thickets, and less-extensive, but nevertheless-important forested wetlands dominated by aspen and cottonwood (Figure 1.9).

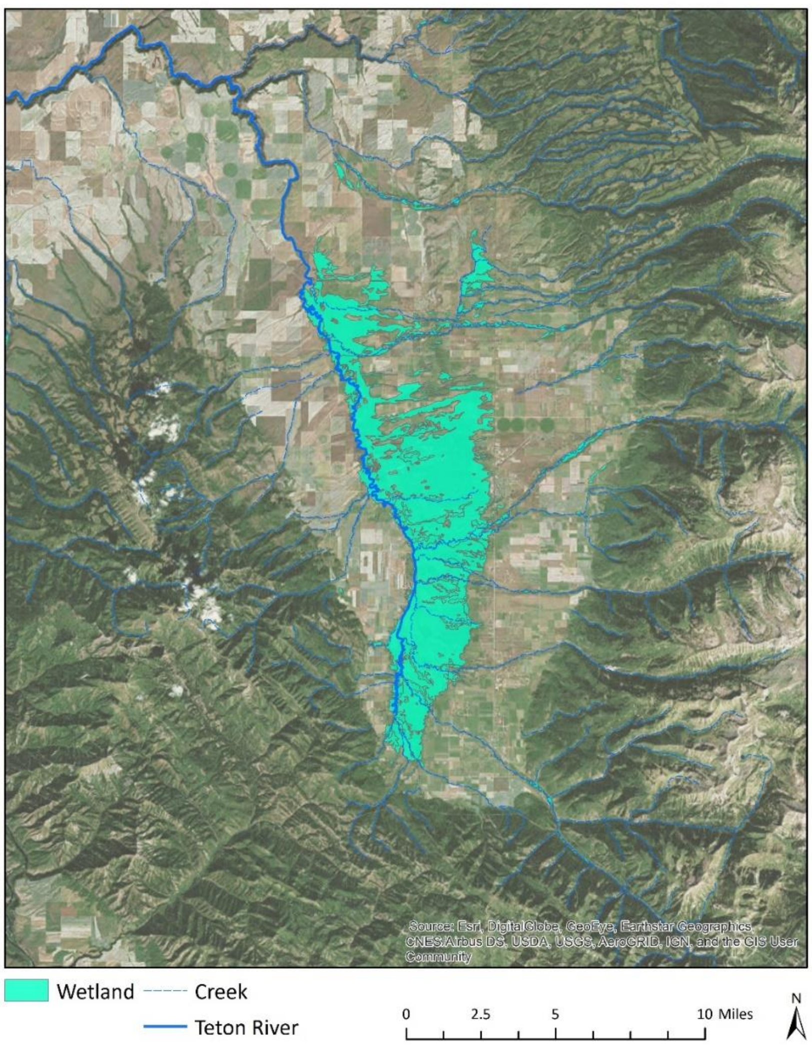

Figure 1.9: *Wetlands in Teton Valley. Data source: U.S. Fish and Wildlife Service.*

Fens are among the most floristically-diverse ecosystems in the region and can take thousands of years to form. Thus, they are considered irreplaceable by the U.S. Fish and Wildlife Service (Idaho Department of Fish and Game, 2012). Fens have perennial groundwater inflows that maintain water tables at or near the ground surface. This constant saturation retards the decomposition of organic matter and allows for the accumulation of peat, a type of organic soil. As a result, fens are less acidic than other, similar ecosystems, such as bogs and have higher nutrient levels. They are, therefore, able to support a much more diverse community of plants and animals than other, similar ecosystems. Fens form in a variety of landscapes and support many rare species (Merrit & Cooper, 2012). They also play an integral role in preventing or reducing the risk of floods and improving water quality (Idaho Department of Fish and Game, 2012).

The hydrogeologic system of alluvial fans that extend from the base of the Teton Range to the Teton River drives the hydrology of the higher-elevation wetlands, as well as the spring-fed streams and creeks (Hook, Salsbury, & Klausmann, 2005). There are three zones of wetlands in the region:

1. wetlands supported by groundwater discharge,
2. wetlands in isolated depressions, swales, and on stream courses,
3. and floodplains and backwaters of the slough and Teton River.

Each zone is hydrologically connected to groundwater in some way, although the relationships to groundwater varies for each zone. The first zone of wetlands is supported by groundwater from snowmelt. The water moves down gradient through the alluvial layer until it hits a clay layer a few miles east of the Teton River. As it hits the clay layer, it is forced upward, contributing water to the creeks that feed the river, as well as creating the spring-fed, emergent wetlands (Hook et al., 2005). Hydrologic studies confirm this process. Measurements of 33 wells indicated that water levels were consistently near or above the surface at upper- and middle-elevation sites, suggesting the presence of a steady groundwater source discharging under slight positive pressure (Hook et al., 2005). The groundwater conditions in this first zone of emergent wetlands are crucial for supporting the ecologically-significant fen and fen-like ecosystems.

Recharge from irrigation moves through the shallow aquifer throughout the growing season. Thus, groundwater recharge from agriculture also plays a prominent role in maintaining the health of the wetlands during late summer. Under the natural hydrologic pattern, it is estimated that water levels would be at or slightly above surface level in the spring and early summer, dropping in mid-summer, and then rising again in the fall. However, a study in Teton Valley found rises in mid-summer groundwater levels in some wells (Hook et al., 2005). It can thus be inferred that irrigation practices have an impact on groundwater flow and therefore on the wetland community. Van Kirk and Jenkins (2005) modeled the hydrology in the Teton Basin and found that wetlands associated with the high water table were largely created and maintained by irrigation-related groundwater recharge (Van Kirk & Jenkins, 2005).

Wetlands further to the west are more the result of local topography than groundwater conditions. Here, the wetlands exist in isolated depressions and are fed primarily by precipitation and overland runoff. However, they also rely on flooding from the nearby spring-fed streams.

Finally, the third wetland zone lies in the floodplains directly adjacent to the Teton River. When the river overtops its banks, these low-lying areas are inundated, creating the wetland habitat. River levels are directly connected to groundwater levels, which are a direct source of stream flow. These streams are spring-fed and, therefore, are impacted by groundwater levels.

There is annual hydrologic variability associated with the wetland habitat, which can greatly affect specific habitat availability throughout the year. For example, some types of wetlands may be abundant in early spring due to snowmelt runoff when migrating waterfowl and shorebirds are present, but largely dry by July when waterbird broods are plentiful. While some of this variability is natural, extreme hydrologic variability can stress wetland function and degrade habitat. Some of this extreme variability could be buffered in selected areas by implementing restoration and enhancement projects that control hydrology, such as groundwater recharge.

1.1.3 Human Landscape

History of Development in Teton Valley

The second smallest county in Idaho by area, Teton County boasts rich biodiversity, dramatic vistas, and over 120,000 acres of agricultural operations (U.S. Department of Agriculture, 2012). Farming and ranching, in addition to a growing eco-tourism industry, dominate the local economy and influence community values (Valley Advocates for Responsible Development, 2018).

Teton Valley was originally inhabited by the Shoshone-Bannock and Northern Paiute Native American Tribes (Valley Advocates for Responsible Development, 2018). The Valley was first written about and mapped in 1808 by John Colter, a former member of the Lewis and Clark Expedition. At this time, the area was known as Pierre's Hole (Green, 1974).

Teton Valley served as host to the fur trade "Rendezvous" in 1829 and 1832 but didn't begin to support permanent settlements until the second half of the century (Green, 1974). Between 1882 and 1887, the population grew from 14 to nearly 70 residents, though the first homesteads were not officially claimed until 1890. The first inhabitants were drawn to the area to raise cattle and other livestock and settled in the wetland areas, which provided good forage and easy access to water in the Teton River and its tributaries.

Within a few years, settlers began to explore agricultural crop production, despite long, cold, harsh winters and short, dry summers. As farmers expanded their acreage away from the valley floor and the wetlands, the need for irrigation became immediately apparent. The settlers began "to turn water onto the land by taking water directly from the many streams which were available… They 'just took the team and plow and went right up and plowed a ditch and took it right out of the creek. There was plenty of water'" (Green, 1974). The first canals were constructed on Darby Creek, though the practice quickly spread throughout the Valley (Green, 1974). Flood irrigation dominated during this initial period of crop raising.

Today, several fifth generation farmers farm the same land that their ancestors originally settled in the 1800s (L. Bagley, 2017b). The depth of agriculture's history in Teton Valley permeates more than the economic importance of its products. Agriculture is a way of life and the cultural driver that binds the inhabitants of Teton Valley. The open spaces and wildlife that characterize Teton Valley are partially maintained due to its agricultural heritage. Forests, rivers, grasslands, and wetlands exist on private farmland and provide critical habitat for elk, moose, mule deer, Yellowstone Cutthroat Trout, eagles, bears, and other wildlife (Valley Advocates for Responsible Development, 2018).

Land Use

Teton County ("the County") was officially established on January 26, 1915 (Green, 1974). By 1970, the County hosted a total population of 2,359 and by 1990, the population had grown to 3,458 (U.S. Census Bureau, 2016). In recent years, the cities of Driggs and Victor have become satellite cities for Jackson, Wyoming with rapidly-growing residential populations. Between 1990 and 2010, the population grew at unprecedented rates, tripling in size. This population increase contributed to a real estate boom and subsequent bust in the early 2000s that has left a "real estate disaster" in the County.[1] This planning failure was the impetus for a comprehensive planning approach with a greater push toward sustainable growth.

Despite the boom in real estate, land use in the greater Teton Watershed is still predominantly comprised of cropland and pasture (44%), coniferous forests (22%), and rangeland (21%) (Figure 1.10). The mountainous areas are dominated by coniferous forests, along with interspersed mixed forests, deciduous forests, and rangeland. In the lower elevations, forested and non-forested wetlands thrive along the rivers and creeks, with the largest areas occurring along the Teton River. These ecologically-significant wetlands only account for a small percentage of the lowland areas, as the majority of the land area in these elevations is utilized for cropland and pasture. While urban uses have increased in recent years, they are still a very small fraction of the land use in the watershed, with residential and commercial/industrial areas comprising 3.5% and < 1%, respectively.

[1] Approximately 7,200 lots in the rural valley are platted, ready for a house to be built, but currently lie vacant (Teton County, 2012). Unsold properties and incomplete subdivisions have been nicknamed "zombies" and are a burden on the County which maintains the properties and access roads (Best, 2012).

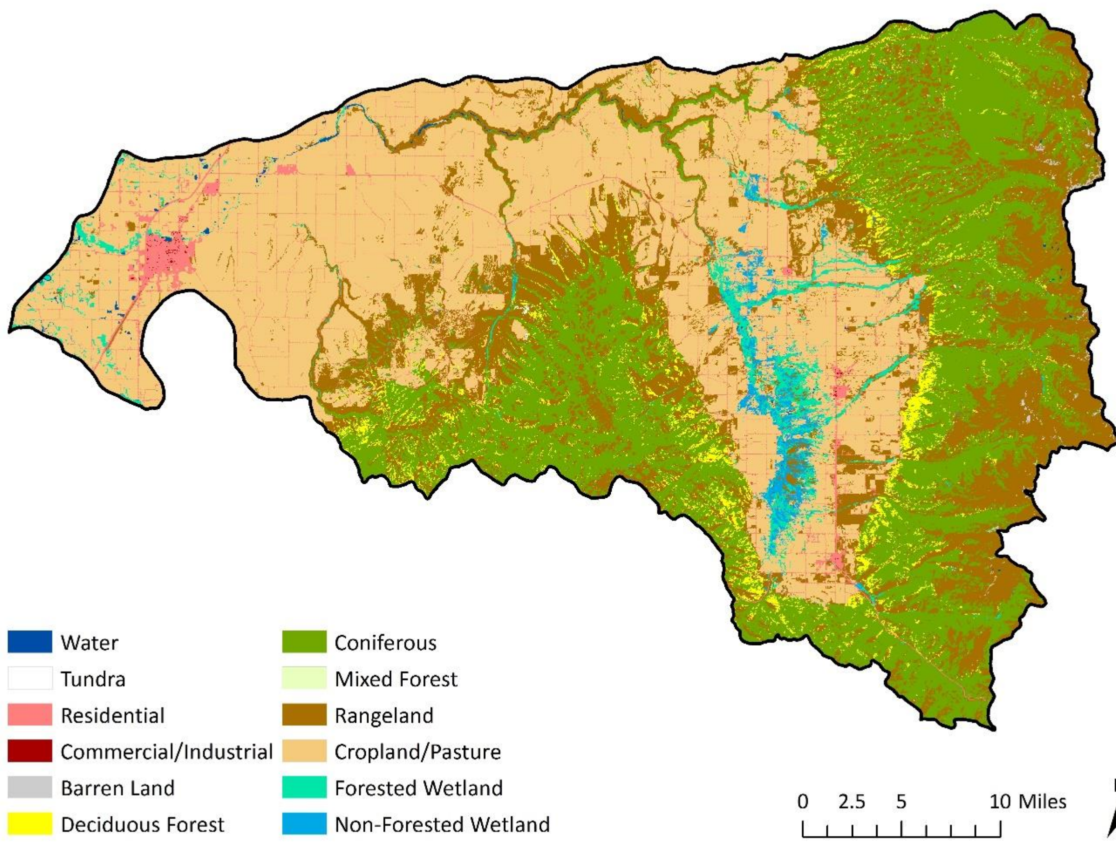

Figure 1.10: *Land use types in the Teton River Basin. Data source: U.S. Department of Agriculture.*

The upper watershed of the Teton Basin is dominated by small-scale agriculture, which accounts for 98% of all water demand (**Appendix A**). Farmers in the upper watershed primarily grow alfalfa, barley, and some heirloom varieties of potatoes. Farmers are limited in the kinds of crops they can grow due to the high elevation and relatively-short growing season. Crops in the upper watershed consume an average of 37.5 inches of irrigation water per acre per year (U.S. Geological Survey, 2014). Farmers in the upper watershed rely heavily on irrigation to ensure the viability of their crops. 74% of irrigation water comes from surface water diverted from Teton River tributaries through ditches and canals (U.S. Geological Survey, 2014). The remaining 26% of irrigation water comes from groundwater pumping through wells.

1.1.4 Threats to the Teton River Basin

Residential Development

As Teton Valley has grown in population, demand for housing has increased dramatically. As such, farmers can make more money by selling their land to developers than continuing to farm (S. Bagley, 2017). Despite the potential profit of land sales, many farmers continue to farm because of the personal importance of the work and lifestyle (L. Bagley, 2017b). However, slim profit margins and the lack of interest on the part of young family members to carry on the family farm make even the most passionate farmer have to consider selling their land for development when they retire (Verbeten, 2017).

Since the majority of the wetlands in Teton Valley are on private land, the expansion of development also greatly impacts wetlands. In a comprehensive assessment of ecological values throughout the GYE, the Teton Watershed was ranked as the number one private lands conservation priority. The study, which examined 42 other sites, acknowledged the unique combination of ecological irreplaceability and vulnerability of the Teton Watershed "megasite" (Noss, Carroll, Vance-Borland, & Wuerthner, 2002).

Over the past few decades, wetlands in Idaho have been degraded by land-use changes and alterations to the hydrologic regime, including urban development, agriculture, and irrigation efficiency practices. While a study using aerial photography of Teton Valley did not find a significant difference in wetland extent over the last 40 years (Hook et al., 2005), local farmers recall that the area was much wetter 20 to 40 years ago (S. Bagley, 2017). Water consistency, especially from groundwater springs is crucial to maintaining wetland habitat.

Climate Change

In addition to the threat of development, the health of wetland ecosystems and viability of high-elevation agriculture in Teton Valley are threatened by variability in climate and precipitation due to global climate change. Changes in the amount of snowpack and the timing of snowmelt may have critical impacts on farming operations (U.S. Environmental Protection Agency, 2016b). Teton Valley already operates within a short growing season (May-September) and increased precipitation and temperature variability from year to year will affect surface water availability and growing season length, placing increased stress on livestock and crops (U.S. Environmental Protection Agency, 2016a). The instability in growing season length will be compounded with the uncertainty of irrigation water availability.

Changing temperature and precipitation regimes in the region have contributed to variability in Snow Water Equivalent (SWE), a measurement of the amount of water contained in the snowpack. From year to year, SWE measurements associated with any given date vary greatly. It follows that timing and quantity of peak SWE also exhibit interannual variability (**Appendix B**).

Because streamflow in the Valley is heavily dependent on snowmelt, variability in SWE also makes streamflows highly variable. The 30-year average annual streamflow for 1981-2010 has decreased 7% in Driggs and 9% at St. Anthony from the 1971-2000 30-year annual averages (Natural Resources Conservation Service, 2016). Variability in streamflow could pose a threat to overall water supply in the watershed, as surface water accounts for a majority of water use in the watershed.

1.1.5 Current Conservation Efforts

Organizations such as the Valley Advocates for Responsible Development are working to create a sustainable development plan that will protect the essential character of Teton Valley while providing affordable housing for the county's residents (Valley Advocates for Responsible Development, 2018). However, the rapid rise in land value for development continues to threaten the agricultural livelihood and open space habitats of Teton Valley.

Because the majority of important wetlands fall on private land, conservation and restoration efforts have primarily been focused on protecting wetland habitat in perpetuity. For the past 25 years, the Teton Regional Land Trust has been actively pursuing wetlands protection through land purchases and conservation easements (Tear, 2011) and has worked with partner organizations to restore wetland and upland habitat on adjacent private lands (Teton Regional Land Trust, n.d.). As a result, valuable nesting, migration and wintering habitat for waterfowl in Teton Valley is being restored and protected. These actions will be critically important as subdivision and golf course development along the Teton River continues to accelerate (Idaho Department of Fish and Game, 2012).

Despite efforts to place easements on ecologically-important land, wetland conservation can be challenging because managers are at the mercy of temporal and spatial variations in groundwater levels. Furthermore, the annual hydrology is susceptible to unpredictable precipitation and natural groundwater discharge rates, which may have greater variability in the future as a result of climate change (Hook et al., 2005). Groundwater recharge may help to reduce this variability and unpredictability and, therefore, increase the resiliency of the wetlands, while maintaining higher flow in the Teton River during the late summer season.

1.2 Idaho Water Law

In order to establish a successful program to encourage incidental groundwater recharge in Teton Valley, it is critical to work within Idaho's existing legal framework. Teton Valley farmers rely on their water rights for their livelihood and will not be interested in pursuing any activities that might jeopardize those rights. This section explores Idaho state water law to inform our understanding of how to legally and effectively pursue incidental groundwater recharge in Teton Valley.

In Idaho, all waters are public property of the state (Idaho Department of Water Resources, 2015). Water rights are usufructory, meaning that rights holders don't own the physical water. Instead, a water right "is the right to divert the public waters of the state of Idaho and put them to beneficial use" (Idaho Department of Water Resources, 2015).

Idaho Department of Water Resources (IDWR) is responsible for managing all waters of the state. The state is then divided up into water districts for administrative and management purposes. Within each water district, distribution of water is overseen by the watermaster, who may be elected or appointed and reports directly to the director of IDWR (Idaho Department of Water Resources, n.d.-d). There are currently 99 active water districts in Idaho, though this number can vary from year to year. Water districts range considerably in terms of river miles, geographic area, number of water users, and budgets (Olenichak, 2018). Teton Valley is part of Water District 1, which encompasses the Snake River and all of its tributaries above Milner Dam (Figure 1.11). Water District 1 is the largest water district in the state with an annual budget of over $2 million[2].

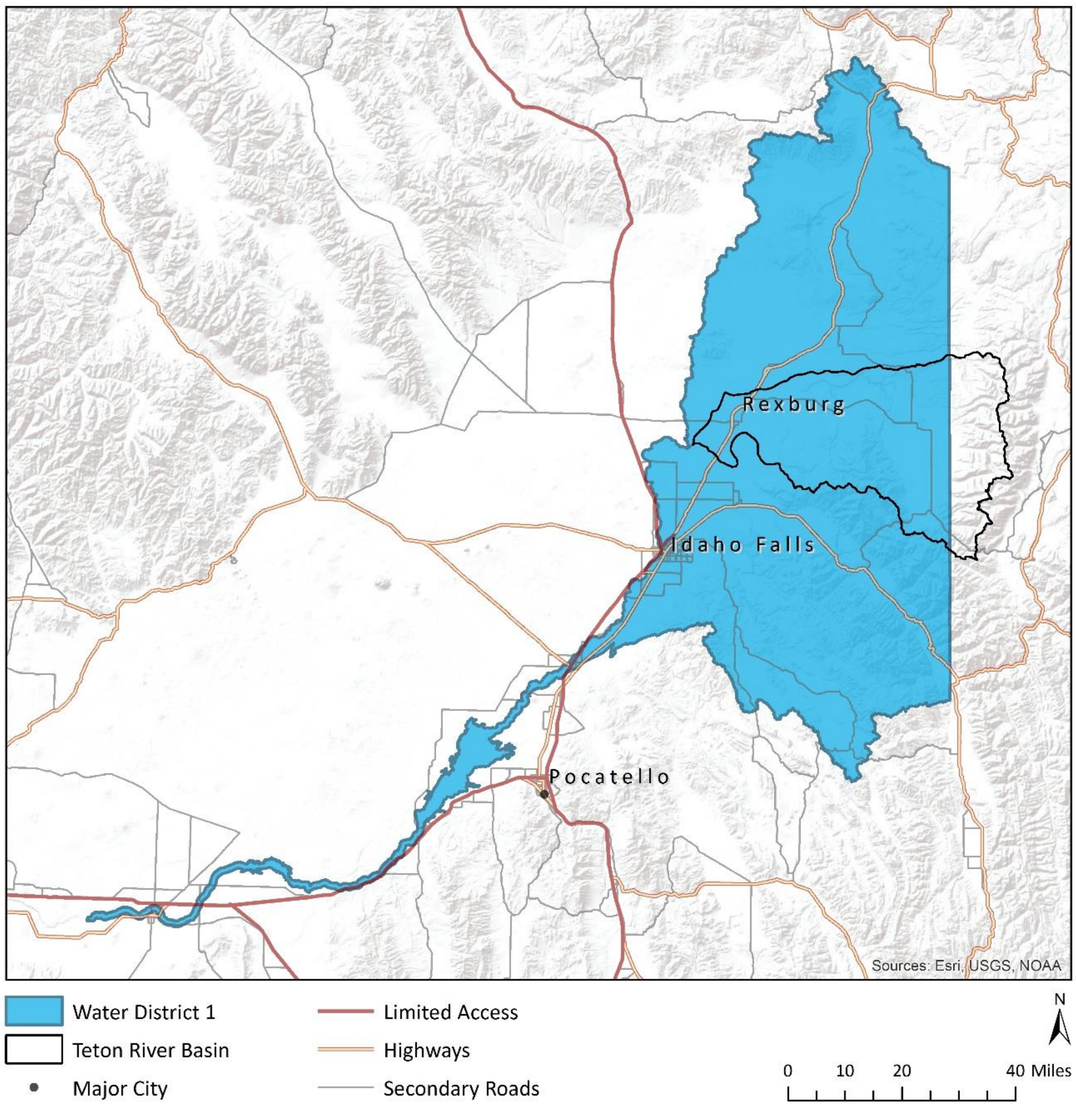

Figure 1.11: *Idaho Department of Water Resources, Water District 1. All portions of the Teton River Basin within the state of Idaho fall within Water District 1 (blue). Data source: Idaho Department of Water Resources.*

[2] For comparison, Water District #75A only regulates diversions on Jesse Creek; there are 13 water users and the district's annual budget was $3,600 in 2017 (Olenichak, 2018).

1.2.1 Doctrine of Prior Appropriation

Like all western states, Idaho subscribes to the Doctrine of Prior Appropriation.[3] Under this doctrine, often referred to as "first in time, first in right," water rights with more senior appropriation dates have priority over water rights with more junior appropriation dates. As such, in times of scarcity, senior water rights can put a "call" on the river which curtails junior water rights. Senior water rights are fulfilled in decreasing order of seniority until there is no more water or all rights have been satisfied (Idaho Department of Water Resources, n.d.-c).

Each water right has a specified priority date, an amount (in AF) or a flow rate (in cubic feet per second, cfs), a beneficial use, a point of diversion, and a point of use (POU). Beneficial uses include "domestic use, irrigation, stock-watering, manufacturing, mining, hydropower, municipal, aquaculture, recreation, as well as fish and wildlife" (Idaho Department of Water Resources, n.d.-c). Under the forfeiture statute, a water right that is not put to its beneficial use for a continuous five-year period will be forfeited (Idaho State Legislature, n.d.).

The most senior water rights in Teton Valley have a priority date of 1886, though most priority dates range from the 1890s to the 1920s (Olenichak, 2017). In general, Teton Valley water rights are junior to water rights downstream near Rexburg (Figure 1.12) (Olenichak, 2017). The most senior water rights, with priority dates of 1879 and 1880, divert at the confluence of the North and South Forks of the Teton River near Rexburg (Van Kirk, 2017).

[3] Some states utilize prior appropriation in conjunction with riparian law, or a combination of the two.

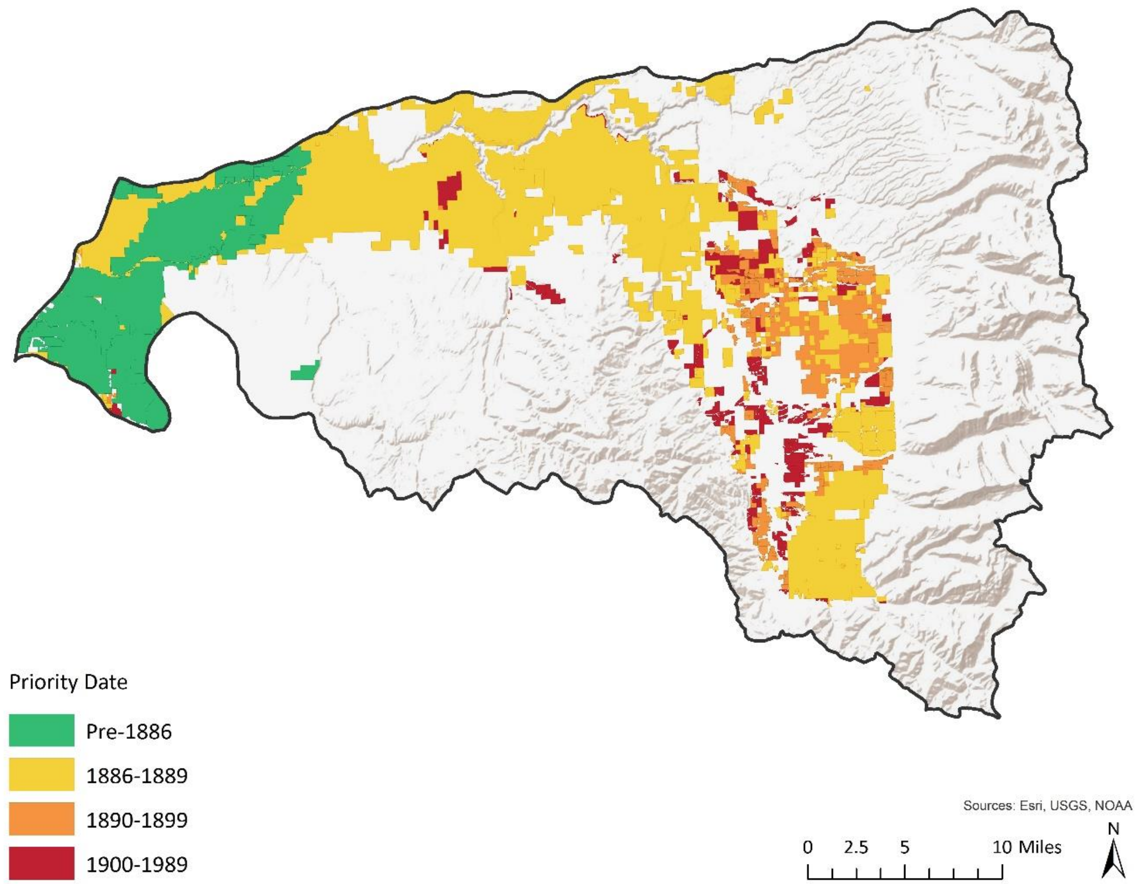

Figure 1.12: *Places of use for surface water rights in the Teton River Basin. Water rights by priority date, broken down into four categories: pre-1886 (green), 1886-1889 (yellow), 1890-1899 (orange), and 1900-2015 (red). All colors shown indicate the most senior priority date at a given location. Data source: Idaho Department of Water Resources.*

Following the spring runoff when there is plenty of water in the river, all users get their full allocation of water. However, in July and August when streamflow levels are low, water is allocated based on seniority, with the most senior users downstream near Rexburg getting their water rights filled first and the junior users in Teton Valley having to curtail their water use. This can have negative impacts on crop yields and profits in Teton Valley.

There are about 200 diversions in Teton Valley. Though this amounts to about half of all diversions in Water District 1, they account for only 5% (and maybe as little as 1%) of 4 million acre-feet (MAF) diverted annually in the district, as they tend to be small and individually used. There has been limited management and regulation of diversions in Teton Valley since IDWR does not wish to spend significant taxpayer money on one small constituency (Olenichak, 2017). There are no diversions directly off of the Teton River; all diversions are located on its tributaries (L. Bagley, 2017b).

Surface water rights for irrigation are typically in priority from April 15th through October 15th (L. Bagley, 2017a). However, farmers typically do not begin diverting water for irrigation until mid-May when fields are snow-free and temperatures are conducive to planting. Thus, there is about one month each year when the farmers' water rights are in priority but the water is not being used. This provides a window of opportunity in which water could be diverted by the farmers and transported through canals for incidental recharge.

Groundwater

As it was originally written, Idaho's Doctrine of Prior Appropriation applied only to surface water. Over time, however, hydrologists have come to understand the interconnected nature of surface water and groundwater. In 1931, Idaho's Supreme Court extended prior appropriation to include the governance of groundwater (Fereday, Meyer, & Creamer, 2017). Under Idaho Code § 42-229, "the right to the use of ground water [sic] of this state may be acquired only by appropriation…" (F. Neace, n.d.). The domestic exemption to this code (Idaho Code § 42-111) allows the drilling and use of wells for single-family homes without acquiring a water right.[4]

Two decades after groundwater was included under Prior Appropriation, the Ground Water Act of 1951 established that Idaho would employ conjunctive administration (CA) of surface water and groundwater under prior appropriation (Fereday et al., 2017). In theory, CA "merg[es] surface water and groundwater rights into a single administrative framework in hydraulically connected areas" (Ghosh, Cobourn, & Elbakidze, 2014). However, in practice, conjunctive management is only fully implemented in the ESPA (Verbeten, 2017). Outside of the ESPA, for example in Teton Valley, groundwater pumping for irrigation and other beneficial uses is not curtailed when the call goes on the river.

Teton Valley farmers to the east of the Teton River, however, rely almost exclusively on surface water for irrigation, though there are a few exceptions. To the west of the Teton River, a higher proportion of irrigation comes from groundwater, although the majority is still fed by surface water (Verbeten, 2017). As mentioned previously, 74% of total irrigation water in Teton Valley is supplied by surface water with only 26% supplied by groundwater.

While it would seem natural for irrigators to turn to groundwater pumping when surface water becomes scarce, a 1992 moratorium on "the processing and approval of presently-pending and new applications for permits to appropriate water from all surface and ground water [sic] sources within the Snake River Basin…" prevents irrigators from doing so (Higginson, 1992). As such, Teton Valley is closed to large-scale groundwater pumping; any diversion of this nature would require mitigation. However, as noted above, Idaho Code § 42-111 means that domestic wells are exempt from the moratorium and continue to be drilled in Teton Valley without restriction (Verbeten, 2017).

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[4] The rate of withdrawal for exempt wells may not exceed 13,000 gallons per day (F. Neace, n.d.).

Though the goal is to extend CA to the entire state, it is a complicated and contentious process that is expected to take many years to realize fully (Verbeten, 2017). Since CA is not fully implemented, groundwater pumping goes largely unchecked and has resulted in groundwater overdraft in many regions of Idaho. Though Teton Valley is not considered a groundwater basin in critical condition, declining groundwater levels have been documented and are of considerable concern moving forward (Lien, 2017a).

Water Administration at the Local Level

In Idaho, although water rights can be owned by individuals, it is common for irrigators to come together to form irrigation districts and private irrigation companies. These entities manage and distribute water rights on behalf of a group of people (Idaho Department of Water Resources, n.d.-a). In Teton Valley, irrigation districts are similar to school districts; they are "public, involuntary, semi-municipal, fee-collecting entities controlled by local landowners" (Idaho Department of Water Resources, n.d.-a). Members of a community petition the state "to create the boundaries for an irrigation district so monies can be raised to build and maintain canals to distribute water. "All property owners within the boundaries of the district must pay annual assessments (taxes) to the district to cover irrigation district operating costs, regardless of whether or not… [they use] water for irrigation" (Olenichak, 2018).

Irrigation companies, also known as canal companies and ditch companies, are private corporations formed by a group of irrigators who buy shares in the company. That money is used to build and maintain canals to distribute water. While canal companies have boundaries similar to irrigation districts, "only shareholders within the boundaries receive water and are responsible for paying the canal company's annual costs" (Olenichak, 2018).

Irrigation companies are the most common model used to manage water in Teton Valley, however, individuals and irrigation districts are also prevalent (Ludington, 2018). These districts and companies range in size, with some comprising dozens of water users and others as few as two (Penfold, 2017). These entities are well respected in the Valley and are very influential when it comes to decisions about how water is used and managed.

Futile Call

Under Idaho water law, a junior user cannot legally ignore a call from a senior user. However, there are exceptions to this rule, most notably the concept of a futile call. Under this doctrine, a junior user can continue diverting water when their water right is out of priority if he or she can prove that his or her foregone water would not connect to "live water," and therefore would not reach the senior user to satisfy their needs. This may happen due to seepage or evaporation in a water-short system (Carlquist, 2008). The doctrine of futile call is incorporated into the rules outlined for Idaho's conjunctive management of surface and groundwater:

> "A delivery call made by the holder of a senior-priority surface or ground water [sic] right that, for physical and hydrologic reasons, cannot be

> satisfied within a reasonable time of the call by immediately curtailing diversions under junior-priority ground water [sic] rights or that would result in waste of the water resource." (Idaho Department of Water Resources, 2008)

The concept of a futile call is intended to "lessen the harshness of prior appropriation during times of scarcity, while preserving important property rights" (Carlquist, 2008). Underpinning the idea of futile call is the belief that in these cases, it is better for the junior user to use the water than to lose it through transport to the senior user. However, IDWR may still require mitigation or staged curtailment of the junior water right (Thigpen, 2011).

The process used to determine a futile call is not an exact science. IDWR works with farmers to conduct a test to see if the would-be-diversion water will connect to live water. This test is not based on a specific flow volume since conditions vary greatly year to year. The test ranges from three to five days since the general consensus is that five days is the longest crops can go without water before incurring long-term damage. If the water does not connect to live water downstream and a futile call determination is made, the junior user may resume their diversion.

One significant problem with the futile call determination process is its impact on fish populations. Fish often migrate downstream following the test water and are then stranded when the futile call is determined and the water is again shut off (L. Bagley, 2017a). IDWR is working with nonprofits like FTR to find an alternative process that would not negatively impact fish, but at this point, they have been unable to do so (Olenichak, 2017).

In Teton Valley, the coarser textures of the stony and loam soils at the foot of the mountains allow for rapid infiltration of water into the water table and the shallow aquifer. As such, many of the tributaries of the Teton River would run dry in the summer, even without the additional pressure of agricultural diversions (L. Bagley, 2017b). For example, Darby Creek would naturally have run dry nearly every year, and it is estimated that Teton Creek would have run dry in four out of ten years (L. Bagley, 2017b). The differing hydrogeology of Trail Creek means that it is likely the only tributary in the system that would not run dry in the absence of irrigation diversions (Van Kirk, 2017).

Even in wet years, conditions are such that downstream senior users put the call on the Teton River by August. This typically curtails all water users with rights junior to 1885, which amounts to all water users in Teton Valley (Olenichak, 2017). Though there aren't any diversions on the Teton River itself, this call applies to all of its tributaries. When they are out of priority, junior users can either choose to stop diverting entirely or use stored water to offset their diversions. Teton Valley farmers rely heavily on the futile call to allow them to continue diverting without having to pay for stored water. "We kind of live and die by the futile call," says farmer Lynn Bagley (L. Bagley, 2017a).

1.2.2 Water Storage

As population and demand for water continue to grow, the question of how and where to store water has become increasingly important. The State currently has the capacity to store about 12 million AF of surface water in reservoirs (Fereday et al., 2017). This water is fully accounted for and will not be sufficient to accommodate future water supply needs.

Construction of new dams and reservoirs is costly and politically unattractive, and it is increasingly difficult to obtain a reservoir permit. As such, groundwater storage has been increasing in Idaho as it is cheaper and less controversial. This practice serves multiple purposes by storing water, reducing water losses to evaporation, and simultaneously replenishing declining aquifer levels due to overdrafting.

Idaho Water Supply Bank

Leasing and rental of water rights in Idaho dates back to the 1930s in Eastern Idaho. Through handshake deals, farmers with surplus water supplies rented their water rights to others who were in need on a short-term basis (Idaho Department of Water Resources, n.d.-b). This process was formalized in 1979 when the Idaho Legislature created the Idaho Water Supply Bank (IWSB). Administration and operation of the bank were delegated to the Idaho Water Resource Board (IWRB) under IDWR (Idaho Department of Water Resources, n.d.-b). The IWSB allows for the reallocation of water resources on a short-term basis through which all parties stand to gain. "Water rights may be leased to the Bank, if not currently in use, and rights may be rented from the Bank for beneficial uses such as commercial, industrial, irrigation, or mining" (Idaho Department of Water Resources, n.d.-e).

The IWSB consists of two distinct markets: the Board's Water Supply Bank and the rental pools. The former handles natural flow water rights, both surface and groundwater, as well as privately held stored water rights; the latter deals with water stored in specific reservoirs (Idaho Department of Water Resources, n.d.-e). The IWRB establishes a price per acre-foot, called the current rental rate. The current rental rate varies over time and by water district (Idaho Department of Water Resources, n.d.-f). The majority of ISWB activity occurs through the six rental pools in the state; the most active rental pool is Water District 1, also known as the Upper Snake Rental Pool (Idaho Water Resource Board, 2015), of which Teton Valley is a part.

Rental of Stored Water

Since Teton Valley farmers expect to have their water rights go out of priority at some point each year, some irrigation districts and canal companies own their own stored water in Island Park Reservoir (IPR). IPR is operated by the Bureau of Reclamation but the vast majority of the water rights are owned by the Fremont-Madison Irrigation District (FMID), which serves farmers in Fremont County and Madison County downstream of Teton Valley. IPR is situated on the Henry's Fork River but delivers water through the Cross Cut Canal (CCC) to the Teton River above St. Anthony's gage. Thus, Teton Valley water users don't physically use the stored water. Instead, they continue diverting water at their point of diversion and the IPR stored water is sent downstream to satisfy the needs of senior users downstream.

As mentioned above, some districts and companies own stored water that they have access to each year. The costs of delivering the stored water are factored into the fees paid annually by their constituents. Other entities must rent stored water when they are in need. In recent years, average rental prices from FMID have been around $6/AF, though they rose to $11/AF in 2015, a particularly low water year (L. Bagley, 2017a; Van Kirk, 2017). Because the CCC can only convey so much water, rentals are first transacted with FMID. Once FMID runs out of stored water, farmers then rent from the Water District 1 rental pool. As of early 2018, prices for rental pool water are as follows:

- $7.65/AF in a wet year with full reservoirs;
- $17.00/AF if the reservoirs aren't completely full but there is sufficient water for federal augmentation i.e. releasing water to the Columbia River to support fishery health;
- $22.00/AF in a dry year when reservoirs are low and there is no federal augmentation.

Even in wet years, such as 2017, the basin is overextended and junior water rights go out of priority, though later in the season and for a shorter amount of time. Excess stored water that isn't fully utilized in a wet year cannot be banked for use at a later date. However, the so-called "carryover" water means that it is easier to fill the reservoir in subsequent years which can positively impact water availability and pricing (Van Kirk, 2017).

While $6/AF and even $22/AF are relatively low prices when compared with other rental markets around the West, they can be insurmountable for farmers who operate on very slim margins. One large irrigation company reported paying around $300,000 for stored water in 2015 (L. Bagley, 2017a). Even at $11/AF, stored water is cost prohibitive and most Teton Valley water users will choose to curtail their irrigation. Augmented flow in the Teton River as a result of groundwater recharge could push the priority date back and allow farmers to continue irrigating without incurring the costs of renting stored water or forgoing additional crop yield.

Decisions about what crops to plant and how many cuttings to harvest are predicated on water availability in any given year, the perceived likelihood of a futile call, and the price of stored water (S. Bagley, 2017). To help mitigate this uncertainty, many farmers in Teton Valley supplement their incomes with second jobs and alternative operations in addition to their traditional farming practices. For example, one farmer has converted some acreage to quinoa, which grows well in the Valley and commands a higher price than other crops traditionally grown in the area (Penfold, 2017). Another farmer has a herd of domesticated elk from which he produces niche market products; the herd also serves as a tourist attraction (S. Bagley, 2017).

1.3 Groundwater Recharge in Teton Valley

As Fereday et al. (2017) put it, the purpose of groundwater recharge is not to "create new water in the hydrologic system. The issue is primarily one of timing – making water available when needed." The goal in Teton Valley is to do just that – utilize the natural storage function of the shallow aquifer to retain early-season water and release it to the Teton River one to three months later when flow is typically low and water temperatures are high. This section explores the physical process of groundwater recharge as well as its status in Idaho, both from the perspective of legality and practicality.

Groundwater recharge (or aquifer recharge) refers to water that moves from the land surface to the underlying aquifer below. Recharge is a natural part of the hydrologic cycle but can also be augmented by human activities (Alley, 2009). Natural recharge occurs through a number of pathways since surface water and groundwater are inextricably connected. These include percolation of precipitation and exchanges of water between surface features (i.e. rivers, lakes, and wetlands) and the aquifer below (Alley, 2009). Human-induced recharge can be achieved in a variety of ways, but generally falls into two categories: managed and incidental.

Recharge rates vary in different portions of Teton Valley subject to the underlying geology. Well-sorted gravels and sands transmit water far better than poorly-sorted stream debris and glacial till. However, small interbeds of sand and gravels within these units allow water to flow easily (Kilburn, 1964). The shallow aquifer discharges into the river underlain by low-permeability silts and clays that force water to emerge as springs on the surface (Figure 1.6). Extensive faulting dictates groundwater movement in the northern areas of the Valley. Nicklin Earth and Water, Inc. have estimated hydraulic conductivities that range from 14 feet/day to 330 feet/day in the shallow aquifer across Teton Valley. These values are crucial to determining which portions of the watershed have the greatest potential for recharge.

1.3.1 Managed Recharge

Managed recharge refers to the engineered delivery of water to a recharge site for the explicit purpose of contributing water to the aquifer. Managed recharge often involves the use of injection wells, land application or spreading basins, where excess surface water or reclaimed water is placed in a basin with high infiltration rates and allowed to percolate into the groundwater (Alley, 2009). These practices are becoming increasingly common in arid regions around the West.

Managed aquifer recharge was not acknowledged as a legal beneficial use until 1978 with the Idaho Ground Water Recharge Statute (Fereday et al., 2017). IDWR and IDEQ regulate and monitor surface groundwater recharge projects throughout the state. Groundwater recharge, also called aquifer storage and recovery (ASR), involves the storage of water in an aquifer for removal and use at a later date (Fereday et al., 2017). ASR projects "do not create new water in the hydrologic system. The issue is primarily one of timing – making water available when needed" (Fereday et al., 2017).

Though managed recharge is a legal beneficial use, expansion of this practice has been limited due to a lengthy regulatory and approval process. The greatest success has occurred in the Eastern Snake Plain Aquifer with the Comprehensive Aquifer Management Plan (CAMP). CAMP aims to "sustain the economic viability and social and environmental health of the Eastern Snake Plain by adaptively managing a balance between water use and supplies" (Darrington et al., 2009). Managed aquifer recharge is one part of this large and multifaceted program.

At this time, it is possible to attain a water right for managed recharge or change the beneficial use of an existing water right to managed recharge in Teton Valley. However, it isn't practical to do so because of the lengthy process involved (Ludington, 2018). Organizations such as Friends of the Teton River and the Teton Water Users Association (TWUA) are pursuing this opportunity, though it may take as long as a few decades to come to fruition (Verbeten, 2017). The process for acquisition and administration of managed recharge opportunities is beyond the scope of this report.

1.3.2 Incidental Recharge

Incidental recharge refers to the recharge of an aquifer as a secondary effect of human activity such as irrigation and seepage from water storage and conveyance. The water in excess of crop uptake is "lost" to evaporation, runoff, and infiltration into the ground, which becomes recharge. Unlined, earthen canals also provide an important pathway for incidental recharge as water seeps into the ground as it is transported to fields.

Incidental recharge is not a legally-recognized beneficial use of water since it is the secondary effect of other beneficial uses like crop and lawn irrigation. However, it can still be a significant source of recharge and can be utilized as a strategy to augment groundwater without having to go through the arduous process of changing the beneficial use of a water right.

History of Incidental Recharge in Teton Valley

Flood irrigation was the dominant practice in Teton Valley for decades, conveying substantial amounts of water to the shallow aquifer and thus the Teton River a few months later. In the 1960s and 1970s, however, farmers began to realize they could grow the same crops using less water by using new irrigation technologies, such as hand-wheel sprinklers and center-pivot systems (L. Bagley, 2018). These practices range from about 60% to 85% efficiency, meaning that only 15% to 40% of the water applied to the fields is lost to evaporation or groundwater seepage (Ashley, Neibling, & King, 1996). Flood irrigation, on the other hand, has efficiencies ranging from 15% to 30%.

While a significant portion of the cropland in Teton Valley has been converted to sprinkler irrigation, much of the Valley pastureland and some crops, such as hay, are still flood irrigated (L. Bagley, 2018). In the spring, crop water demand is satisfied by a combination of precipitation and irrigation. Later in the summer, however, irrigation plays a much larger role in sustaining crops; on average, precipitation throughout the growing season meets only 12% of total crop demand (Van Kirk, 2012).

In Teton Valley, incidental aquifer recharge actually exceeds natural rates due to the large surface area covered by agriculture. Canal seepage contributes significantly to the shallow aquifer, with about 47% of all surface diversions being lost to incidental recharge in Teton Valley (Van Kirk, 2012). Models estimate an average seepage rate of 3.7 feet/day for canals in Teton Valley (Peterson, 2011).

While increasing efficiency is generally good, falling groundwater levels in Teton Valley can be attributed in large part to the lining of these canals and increased irrigation efficiency resulting in less net recharge for the basin (Peterson, 2011), (Van Kirk, 2016). Water that once seeped into the ground and recharged the aquifer no longer does so. With increasing water demands and droughts resulting in greater groundwater pumping, a reduction in incidental recharge can have detrimental impacts on the aquifer. Studies have shown that increasing irrigation efficiency in agriculture can actually result in greater water use (Scott, Vicuña, Blanco-Gutiérrez, Meza, & Varela-Ortega, 2014). The water saved through more efficient irrigation methods does not result in more water in the rivers because it can be used for additional irrigation on the farm.

Furthermore, as the population continues to grow in Teton Valley, more pressure is exerted on groundwater resources. As mentioned above, the cities of Victor and Driggs rely exclusively on groundwater to serve their residential populations. In addition, there are hundreds of exempt wells serving single-family homes in the Valley (Verbeten, 2017). Though incidental recharge outstrips natural rates of recharge, the implementation of high-efficiency irrigation measures and increasing population have caused the aquifer to drop as much as 55 feet in some places (Lien, 2017a).

Active Pursuit of Incidental Recharge Opportunities

As mentioned previously, FTR and TWUA are pursuing managed recharge in Teton Valley, a process that is expected to take many years. In the meantime, these organizations are hopeful that a program to incentivize incidental groundwater recharge can be established in the Valley. In order to test the feasibility of such a program, the two organizations have partnered to create a pilot transaction beginning in 2018 (Lien, 2017b).

Two irrigation entities, Trail Creek Sprinkler Irrigation Company and Garden Water Company, have agreed to take part in the pilot transaction which will essentially involve them diverting water earlier in the season to run through their canals and potentially "apply to agricultural land via traditional flood irrigation methods" (Lien, 2017b). Both have water rights that are in priority from April 15th to October 15th, however, they typically do not begin diverting until approximately May 15th for irrigation purposes. This project aims to incentivize irrigators to utilize their water rights to the fullest extent within their beneficial use, thereby contributing additional water to the aquifer. FTR emphasizes that "all water utilized for the purposes of this pilot will be diverted in priority, pursuant to existing water rights, and in compliance with Idaho law" (Lien, 2017b).

The goal is for the two entities to contribute a combined additional 10,000 AF of groundwater recharge to the aquifer over a 60-day period from April 15th to June 15th. It is estimated that this will result in 4,332 AF of water contributed to the Teton River between June 15th and October 31st. Participants will be paid $3.025/AF of incidental recharge up to the 10,000 AF goal. FTR and TWUA would like to expand the project incrementally to a full build-out of 30,000 AF of recharge per year (Lien, 2017b).

As mentioned previously, incidental groundwater recharge is not a legal beneficial use but rather the indirect effect of another beneficial use. For this reason, farmers will not need to change the beneficial use of their water right in order to participate in the program. Changing the beneficial use of a water right is costly, time-consuming and unattractive to farmers. Instead, the program simply encourages farmers to change the timing of when they begin diverting water in order to utilize their water right to its full extent. This might also have the added benefit of firming up their water rights against forfeiture since the farmers currently aren't putting their water to beneficial use during the early part of the season (Ludington, 2018).

Groundwater Contamination Concerns

Groundwater contamination is a critical concern when implementing groundwater recharge. Though soils naturally filter out some contaminants, others can persist and migrate into the groundwater. Depending on the source of recharged water, this can result in elevated levels of organic material, metals, microbes, or synthetic chemicals (U.S. Environmental Protection Agency, 2015). For this reason, it is important to consider the nature and volume of recharged water, timing, and frequency of application, as well as the geologic and soil characteristics of the recharge area in question (Idaho Department of Environmental Quality, n.d.).

As discussed earlier, the vast majority of the land in Teton Valley is dedicated to cropland and pastureland. Runoff often contains elevated levels of nitrogen and phosphorus from fertilizer, pesticides, and sediment, as well as fecal coliform. Though the groundwater does not currently show signs of contamination (Cosgrove & Taylor, 2007), increased incidental recharge on active cropland could have negative impacts on water quality. However, water recharged early in the season could be less of a concern since fertilizers and pesticides will not yet have been applied to the land. It is also worth noting that recharge from canals would not be as much of a concern since farmers are not applying fertilizers and pesticides in the canals themselves. Further examination of the potential impact on groundwater quality, while important, is beyond the scope of this paper (**Appendix C**).

Chapter 2: Modeling the Effect of Recharge

CHAPTER 2: Modeling the Effect of Incidental Recharge

The first objective of this project was to model hydrologic conditions to determine the potential impact of recharge on streamflow and temperatures in the Teton River. It is crucial to know how the hydrologic system works to maximize the benefits of an incidental recharge program that provides late-season augmented flow. To satisfy this objective, we utilized three methods. First, to quantify the impact of recharge on flow in the Teton River, a water budget was used to predict how water moves through the shallow aquifer system from recharge locations to outflow in the river. Second, a spatial site-suitability model was developed to determine which recharge locations would best contribute to the goal of augmenting late-summer surface flow. Finally, we created a model to assess the influence of increased late-season streamflow on stream temperature to estimate the ecosystem benefits of early-season recharge on fisheries.

2.1 Modeling the Effect of Incidental Recharge on Streamflow

2.1.1 Model Selection

The Teton Valley Groundwater - Surface Water Model ("the model") is an analytical model of surface water and groundwater interactions designed specifically for Teton Valley. This model, published by Staff Scientist Dr. Rob Van Kirk at the Henry's Fork Foundation, combines groundwater, tributary, streamflow, and irrigation models to track Teton Valley's water. The model follows the water as it enters the alluvial fans on the far east side of the Valley, through the shallow groundwater, and out into the river upstream of Bitch Creek. These models are coded in R, an open-source programming environment. Model parameters are based on a suite of observed time series data from 1979 to 2008. The metadata for these datasets are well documented for the various publications that have used this model.

Seven primary tributary streams are considered as sources of surface flow and recharge in the model: Trail, Fox, Darby, Teton, South Leigh, North Leigh, and Badger Creeks (see Figure 1.3 "Surface Water in Teton Valley"). There is an additional tributary, Spring Creek, that is also modeled but it is primarily a gaining stream and therefore is not conducive to recharge.

Farmers exercise their existing water right by opening their headgate to divert tributary water at the top of the alluvial fan and into largely unlined irrigation canals. This water is then applied to fields for irrigation. The irrigation type (flood or sprinkler) can be specified in the model. Primary sources of recharge into the shallow groundwater that are considered in the model include irrigation application seepage, canal seepage, tributary seepage, and direct precipitation. Water is lost from the system through canal evaporation, riparian evapotranspiration, crop evapotranspiration, and groundwater pumped for domestic use. Water in excess of losses is assumed to return to the Teton River through the shallow groundwater aquifer.

This model is not a calibrated simulation model and does not have spatially predictive capabilities on any given property or stream. While some of the parameters are spatially discrete, the outputs are averaged outputs over the entire model domain. The model can predict flow effectively at two locations on the Teton River: above South Leigh Creek and at a USGS gage near St. Anthony. The model averages the impact of recharge and tributary inputs for everything upstream of these two locations. Both of these locations have 30 year plus time series records of streamflow and were used to calibrate the modeled flow. The model does not have a high enough resolution to predict daily outputs. However, annual and inter-annual trends can provide useful trends for analysis.

The model contains multiple pre-defined scenarios written into the model code. "Actual" conditions are modeled and calibrated with observed data to capture the conversion of irrigation application from flood to sprinkler. "Natural" conditions model Teton Valley without any irrigation or human impact. "Flood" conditions model Teton Valley as if flood irrigation has been the only application method for the full 30-year time series. "Current" conditions model Teton Valley after 2008 in which 90% of the Valley is irrigating using sprinkler systems. "Pipeline" models Teton Valley as if all the unlined canals were piped, assuming 100% of Teton Valley irrigates with sprinkler and there is no canal seepage, as shown in **Appendix D**. These scenarios provide flexibility in the applications the model can be used for.

Dr. Van Kirk, a former professor at Idaho State University and Humboldt State University, is a well-respected mathematical biologist/hydrologist in the region. He built this model with the intent to analyze the impact of land-use change and shifting irrigation application methods on groundwater levels and corresponding contributions to the Teton River. This model has the benefits of being both high-resolution and flexible. Though the original application is slightly different than the goals of this recharge project, the model was adapted with Dr. Van Kirk's guidance to meet the needs of this project (Figure 2.1).

Initial predictions of the impact of extra recharge in the hydrologic system were made using Dr. Van Kirk's model as impetus for the project. The fact that the model is coded in R makes for another attractive attribute as the methods used to determine impact of recharge is accessible to anyone in the Valley who is interested in participating.

Additionally, Dr. Van Kirk has strong ties to the local community and hydrology, an important asset to establish credibility and trust. This familiarity has helped him design a better model for this specific community.

2.1.2 Data and Methods

Data

The data used as inputs in the model, listed below, have been compiled or synthesized from observed data by Dr. Van Kirk and his research team (Van Kirk, 2012).

- Stream and diversion parameters: area, widths, lengths: Calculated from Google Earth Imagery

- Synthesized streamflow (cfs): Adapted from Pacific Creek in a nearby watershed
- Daily diversions from eight primary tributaries (cfs): Interpolation from available observed values
- Shallow, open-water evaporation in excess of precipitation (ft/day): ET Idaho, University of Idaho
- Riparian vegetation evapotranspiration in excess of precipitation (ft/day): ET Idaho, University of Idaho
- Gross crop evapotranspiration and gross precipitation (ft/day): ET Idaho, University of Idaho
- 30-year daily time series of:
    - Fraction of Teton Valley using sprinkler irrigation
    - Annual units of lawn evapotranspiration for Driggs
    - Time series of snowmelt recharge depth
    - Binary variable identifying whether or not it is within the official IDWR irrigation season (April 15th - October 15th)

Model Framework

The east side of Teton Valley, where the majority of irrigated land and development is upstream of Bitch Creek is the modeled region. The model is divided into two domains that generally share hydrologic characteristics - the Main Domain and the Badger Domain. The Main Domain is of more interest to the early stages of this project.

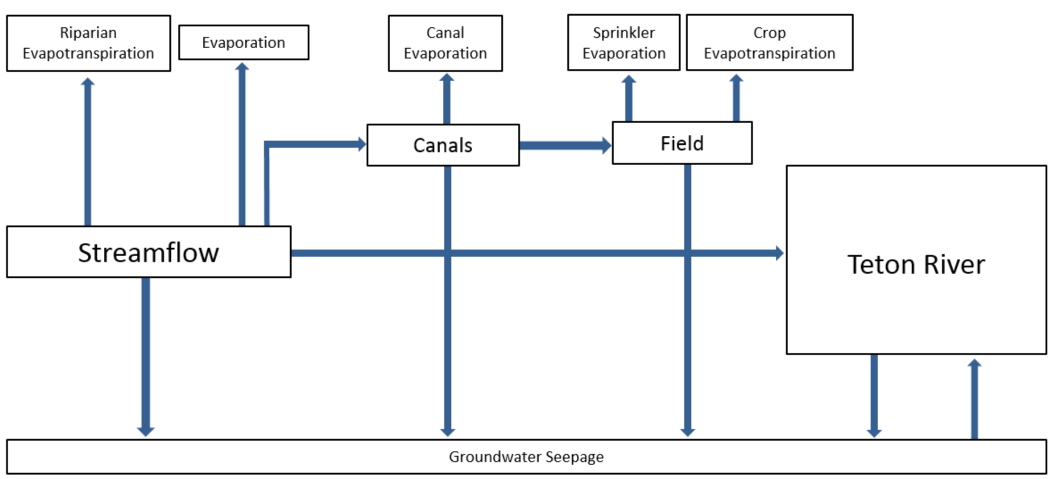


Figure 2.1: *Conceptual model of the Teton Valley Groundwater – Surface Water model.*

Net recharge in the Main Domain is calculated by adding the recharge from streams, snowmelt, and irrigation and then subtracting the amount of domestic pumping, evaporation, and evapotranspiration. The model inputs are described below as well as the relevant model outputs to this particular application.

Model Outputs

- Daily time series of total groundwater outflow to the Teton River (cfs) for reach scenario
- Daily time series of total model flow (cfs) to the Teton River above South Leigh and above St. Anthony gages for each scenario
- Daily time series of model-predicted flow in Teton River at South Leigh and St. Anthony gages for each scenario
- Mean groundwater elevation profile (ft) above spring level across Main Domain cross section for each scenario
- Mean annual totals of: diversion, evaporative loss from irrigation, canal seepage, application seepage to groundwater, losses to crop evapotranspiration, stream flow contributions to Teton River as surface flow, stream channel seepage, and net groundwater recharge (total recharge in excess of pumping) (Van Kirk, 2012)

The flow paths through the shallow aquifer in Teton Valley are predominantly east to west. Vertical movement of water was not considered because the alluvium in the Valley is underlain by silicic volcanics with hydraulic conductivities one to two orders of magnitude smaller (Nicklin Earth & Water, Inc., 2003). The shallow aquifer is assumed to be isotropic and homogeneous, thus the non-linear Boussinesq equation is used to model groundwater flow, as shown below (Van Kirk, 2012).

$$\frac{\partial h}{\partial t} = \frac{K}{S}\frac{\partial}{\partial x}\left[h\frac{\partial h}{\partial x}\right] + \frac{r(x,t)}{S},$$

All groundwater that is withdrawn through pumping is assumed to be for domestic use and withdrawn from the shallow aquifer. Water use data was used to estimate the total amount of pumping by each sector and spread proportionally throughout the year based on recorded lawn evapotranspiration from ET Idaho databases. The withdrawal of groundwater in the model is applied uniformly across each of the domains (Van Kirk, 2012).

***Table 2.1:** Canal lengths and canal areas diverting water from each tributary in Teton Valley upstream of Bitch Creek.*

	Current Canal Length (feet)	Current Canal Area ($feet^2$)
Trail Creek	78,788	682,801
Fox Creek	28,790	220,341
Darby Creek	40,251	437,383
Teton Creek	125,356	1,450,778
South Leigh Creek	107,744	708,042
North Leigh Creek	41,180	397,656
Total	422,109	3,897,001

Scenario Modeling

Dr. Van Kirk's model was adapted for the purposes of this project in order to simulate the impact of incidental recharge.

Five predefined scenarios are written into the model code, as mentioned above: Actual, Natural, Flood, Current, and Pipeline. The two most important scenarios for modeling the impact of canal recharge are the "Current" and "Pipeline" scenarios.

The current scenario models the "current" conditions following the end of the actual scenario. This assumes that 90% of the Valley irrigates with sprinklers and groundwater pumping is fixed at 2,589 acre-feet per year. The current size and capacity of the canal system are used. On the other hand, the pipeline scenario assumes that all conveyance for irrigation occurs via piped canals. Therefore, no evaporation or seepage in the conveyance occurs. In this scenario, 100% of the Valley irrigates using sprinkler irrigation (See **Appendix D** for scenario assumptions). A 2% evaporation loss rate on the sprinkler irrigation is applied. Less water is diverted under this scenario. A small amount of application seepage may occur during the growing season if precipitation meets crop demand and irrigation is applied when it doesn't need to be. **Appendix D** includes model results from the Pipeline and Current scenarios.

The total modeled groundwater outflow on a daily time step for the "Pipeline" scenario was subtracted from the daily time step in the "Current" scenario. This difference is considered the relative contribution of canal seepage to the water budget. This isolated effect is then normalized into a unit hydrograph. This unit hydrograph is multiplied by the amount of annual recharge desired to get the resulting mean groundwater discharge into the river as a result of that recharge (Van Kirk, 2018).

The recharge amounts proposed by the TWUA and FTR are modeled using this method. The goal of the pilot project is 10,000 AF of recharge per year, with full expected build-out of the recharge program at 30,000 AF per year (Lien, 2017). However, these numbers may not be feasible due to constraints on canal area, pilot participation, and number of days available to recharge before the growing season. The actual amounts and number of recharge days were estimated considering these constraints and compared to the proposed amounts.

In order to understand the recharge capacity of each canal, the diversion rate in which all diverted water is lost to seepage through the canals is calculated. This is done by multiplying the current canal area of each tributary (Table 2.1) by the canal loss rate, as shown in the equation below. "C" is a constant multiplier to represent the unit conversion.

Minimum Diversion Rate (cfs) = Canal Area (ft^2)*Canal Seepage Rate (ft/day)*C

This minimum diversion rate, subject to available tributary supply, represents the amount that irrigators can divert into the canals each day for recharge. It is important to note that this diversion rate is significantly smaller than the capacity of the canals and therefore is a conservative estimate of the recharge diversion rate. It represents the rate water will seep into the ground, with no water remaining on the ground surface of the canals. This value leaves room for irrigators to divert for recharge at the same time that they are diverting for irrigation, up to the capacity of their canals. The minimum diversion rate for Trail Creek is 28.95 cfs and for Darby Creek is 18.54 cfs. This minimum diversion rate is then multiplied by the number of days that irrigators are diverting for recharge to obtain the actual amount of water they recharge in a season.

However, to simplify the calculation, it is assumed in this analysis that irrigators are only diverting for one purpose at a given time. For example, when the "number of days of recharge" is referenced, this indicates the number of days the irrigator is diverting solely for recharge. Further, the conservative recharge rate is chosen, rather than the canal capacity, so that the number of days of continuous recharge can be a variable that is tested in the analysis. Diverting the minimum rate ensures that all water at the end of each day will have seeped into the ground.

Four different recharge scenarios were modeled to compare the effect of two possible durations of the recharge period and two levels of participation in the recharge program. The pilot participants were each modeled for recharge periods of 30 and 60 days. The scenario in which all eligible canals in the Teton Valley participate in the recharge program was also modeled for 30 and 60 days of recharge. This scenario assumes that the full extent of the canal mileage for all seven tributaries would be used for each of these time periods (Table 2.2).

2.1.3 Results and Discussion

Using the two different predefined methods and the newly defined dataset of isolated canal seepage contribution, Table 2.2 shows the additional groundwater contribution to the Teton River that results from each amount recharged. The second column in Table 2.2 indicates how much water is recharged in each scenario and the third column indicates how much additional baseflow in cubic feet per second this recharge adds to the river between June 25th and September 25th, the crucial period when flow is low and water temperatures relatively high in the Teton River.

Table 2.2: *Total additional contribution to the Teton River between June 25th and September 25th for each amount of water recharged. Proposed recharge amounts refer to amounts proposed by FTR and LWG, while estimated are those calculated that can actually be recharged using a conservative diversion rate.*

	Recharge Amount (acre-feet/year)	Additional Contribution to River June 25 - Sept. 25 (acre-feet)	Number of Days of Recharge	Scenario Description
Proposed	10000	2868	-	Pilot Goal
	30000	8605	-	Total Goal
Estimated	2826	811	30	Pilot Participants Only
	5652	1621	60	Pilot Participants Only
	11943	3426	30	All Canal Area Used
	23886	6852	60	All Canal Area Used

As expected, greater amounts of recharge results in greater groundwater contributions to baseflow in the Teton River. Figure 2.2 shows a plot of expected additional flows to the river as a result of recharge under the 4 different estimated scenarios (Table 2.2). The peaks for all hydrographs for each of the six scenarios show varying magnitudes, but occur at relatively the same time during the crucial period between June 25th and September 25th.

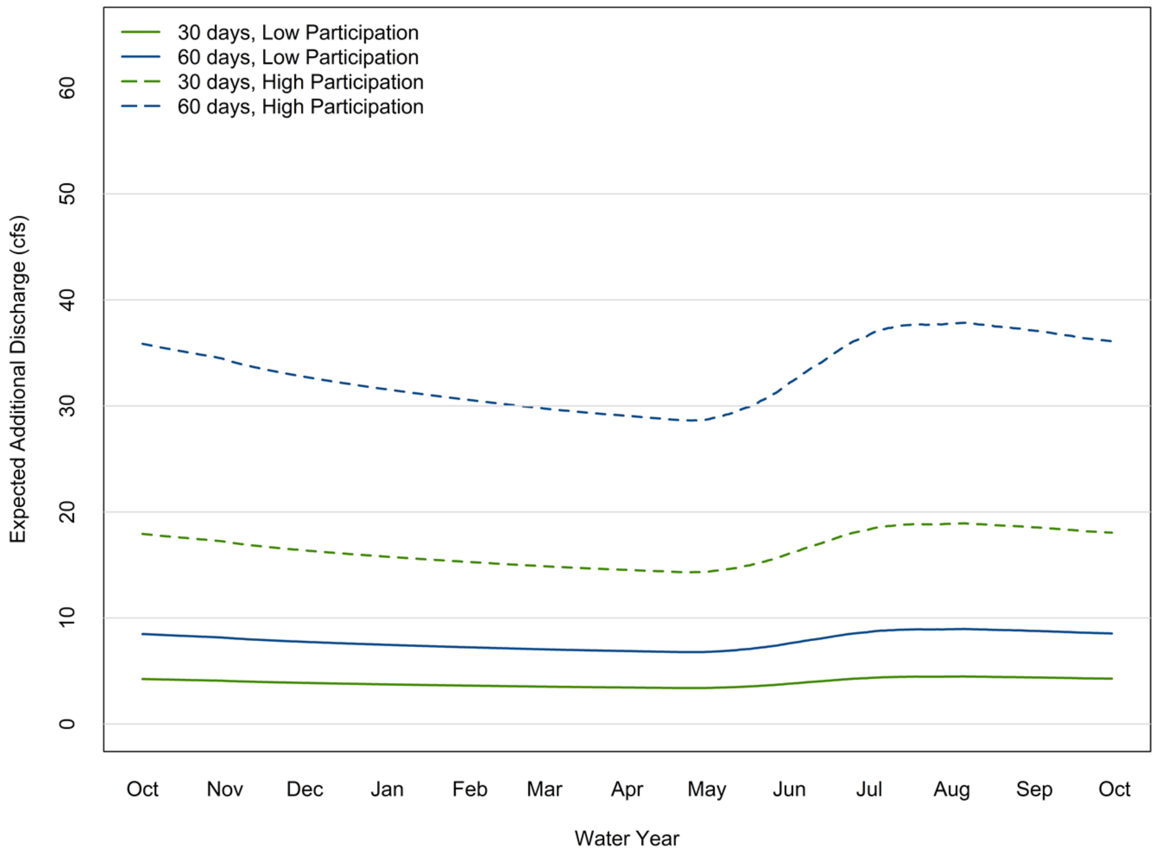


Figure 2.2: *Expected annual additional groundwater discharge to Teton River throughout the course of a water year with varying levels of participation and days of recharge.*

These results show that during the time the water is needed, approximately 29% of the recharged volume will discharge into the river. If the pilot participants are the only recharge participants, the peak elevated baseflow as a result of recharge is estimated to be about 4.5 cfs if recharging for 30 days and 9.0 cfs if for 60 days. However if the whole Valley participates, the effects of recharge are magnified. Thirty days of recharge can contribute 18.9 cfs at the peak and 60 days of recharge can contribute 37.8 cfs at the peak. These peak additional contributions correspond with approximately a 7% increase and 14% increase in annual mean baseflow in the river at the peak.[1]

[1] This assumes a mean flow in Teton River of 275 cfs over the period 2000-2018 (U.S. Geological Survey, 2018).

Model Limitations and Future Considerations

Models help scientists and decisions-makers understand the world through a simplified animation of reality. The Teton Valley Surface Water-Groundwater is an important tool in understanding potential impacts of recharge in Teton Valley, but there are some limitations to the interpretation.

The Main Domain covers a significant area and is assumed to have a constant hydraulic conductivity of 86 feet per day. This was calculated from the geometric mean of all known conductivities in the area (Van Kirk, 2012). Previous studies done by Nicklin Water & Earth (Nicklin Earth & Water, Inc., 2003) indicate conductivities within the area of the main domain to be between 14 feet per day to 330 feet per day. This project is concerned with water transport on a inter-seasonal scale. Therefore, the wide variety of conductivity rates reflected in the geology that are not included in the model may present a significant source of error.

The amount of groundwater pumped for domestic use is determined from USGS water use records. Groundwater pumped for domestic, commercial, and industrial uses is assumed to be taken from the shallow aquifer. This number may be underestimated due to underreporting or overestimated as not all groundwater pumping comes out of the shallow aquifer. To constrain the impact of pumping in the shallow aquifer in the future, a sensitivity analysis could be done to examine how influential it is on the amount of groundwater outflow to the river. If underestimated, this variable could be muting the effect of recharge by pulling the water out before it is able to get to the river.

Dr. Rob Van Kirk is also concerned with the error associated with the evapotranspiration variables in this model. However, for this application, there is an order of magnitude difference between the rate of canal loss through seepage and the rate used of canal loss through transpiring vegetation in the riparian zone along the canal. This would be a more significant concern for a project concerned with tributary seepage.

Finally, the method described above for calculating the additional contribution of baseflow to the Teton River from a specified amount of recharge applies the recharge in bulk across the entire system of canals. Therefore, conclusions about the relative impact of recharging on one farmer's property versus another cannot be made based on these results. **Appendix D** provides further explanation.

It was convenient in the pilot that the two participants owned or managed all the canal area that is diverted off of Trail and Darby Creeks. To simulate the future, the inputted canal area and diversion rates can be refined to reflect which farmers are participating along each creek. Using a less conservative diversion rate may make the recharge accounting more complicated in practice, but could have a significant impact on the amount of elevated baseflow that is estimated for each recharge scenario.

The model only is calibrated with observed data through 2008. To better reflect recent trends in the hydrologic data, group members worked with Dr. Van Kirk to gather and organize necessary observations between 2008 and 2017. Recorded diversion data since 2008 proved to be more evasive. As discussed in Chapter 1, Teton Valley accounts for approximately half of the diversions within Water District 1 but only 5% by volume of the water (Olenichak, 2017). Raw diversion data are collected manually in the field at points of diversion. All diversion readings on a given day are summed for each stream and documented. Piecewise cubic polynomial interpolation will be used to interpolate between recorded observations to obtain a smooth distribution of diversions occurring in each creek on each day throughout the irrigation season (Van Kirk, 2017).

The raw data was collected by a variety of sources and therefore lies with various authorities. This was compiled in Fall 2017 and will be used to re-calibrate the model by Dr. Van Kirk in Spring of 2018. Recent diversion data was collected from Friends of the Teton River (2009-2013), Water District 01 Office (2014-2015), and Water District 01's online data portal (2016-2017). With the new data to calibrate the model with, the model will be able to better capture the recent trends in the hydrology of the region.

Visual Indicators

The positive impacts of recharge may be seen at landmarks without requiring a complex model. For example, Teton Creek runs beneath Highway 33 just north of the Teton Regional Land Trust's office. Local Teton Valley residents claim this portion of the creek goes almost completely dry by mid summer when there is no longer enough flow to maintain surface flow (Verbeten, 2017). If the flow could be held in the upper portions of the alluvial fan for longer, this creekbed may be able to maintain more average surface flow in the summer months. Visual indicators of impact, such as streams familiar to local residents, can provide valuable feedback for this type of recharge program.

2.2 Determining Site Suitability for Incidental Recharge

2.2.1 Overview

In general, increasing early-season incidental groundwater recharge in the Teton River Basin will increase summer surface flow in the Teton River. However, physical characteristics of Teton Valley impact how well any given location will contribute to the goal of augmenting late-summer surface flow. Three physical characteristics were identified as representative determinants of recharge site suitability:

1. Distance from the Teton River;
2. Hydraulic conductivity (K), and;
3. Canal length.

The distance a recharge zone lays from the Teton River affects how quickly recharged water moves through the shallow aquifer and discharges into the Teton River. Water recharged too close to the river may begin to discharge into the river too early in the summer, when surface flow is still adequate to fill most water rights and support aquatic species. Given that the shallow aquifer lies in large alluvial fan deposits, increasing distance from the river also corresponds with an increasing unsaturated zone thickness. A thicker unsaturated zone is favorable as it provides more storage for recharged water. Hydraulic conductivity (K values), which describes the ease with which fluids move through pore spaces or fractures, also affects the speed at which recharged water will flow through the shallow aquifer. Moderate K values are preferable for this project, as areas with high K values will allow water to move too quickly, and low values will not allow water to move quickly enough. Finally, canal length determines the magnitude of water that can be recharged without requiring additional infrastructure. Based on these three physical characteristics, we create a multicriteria site suitability model was created to rank the suitability of locations for incidental groundwater recharge in Teton Valley.

2.2.2 Data and Methods

All datasets were obtained as digital spatial data files (i.e. shapefiles) or digitized for use as such (Table 2.3). Data were projected in NAD 1983 State Plane Idaho East FIPS 1101 and analyzed in ArcGIS 10.5.1.

Table 2.3: *Data sources used in the site suitability analysis.*

Dataset	Description	Source
Watershed Boundary Dataset (WBD) for HUC 17040204	HUC8 watershed boundary for the Teton Watershed	U.S. Geological Survey and Environmental Protection Agency, 2013
National Hydrography Dataset (NHD) 1:100,000 scale	Polylines defining rivers, creeks, and canals	U.S. Geological Survey, 2013
Irrigation Company Service Area Boundaries	Polygons outlining irrigation company service boundaries	Idaho Department of Water Resources, n.d.
Hydraulic Conductivity Zonation	Map of modeled hydraulic conductivity zonation, Model Layer 1	Nicklin Earth & Water, Inc., 2003

We created a multicriteria model using ModelBuilder in ArcGIS. We clipped all datasets to the boundary of the Teton Watershed and each physical characteristic was classified on a scale from 1-3, with 3 being the most suitable for our recharge goals and 1 being the least suitable (Table 2.4). The ranking scheme assumes recharge will be conducted beginning April 15th and unlined canals will be the primary mechanism for recharge.

Processing steps for each characteristic are as follows:

- **Distance from the River**: the Euclidean Distance Tool was used to calculate distances from the Teton River, with an output cell size of 100. Values were reclassified into three distance rankings using the Reclassify Tool.

- **Hydraulic conductivity**: the map of modeled hydraulic conductivity zonation (Nicklin Earth & Water, Inc., 2003) was manually digitized as a polygon shapefile. This shapefile was converted to a raster using the Polygon to Raster Tool, with an output cell size of 100. Values were reclassified into three conductivity rankings using the Reclassify Tool.

- **Canal length**: using canal data derived from the National Hydrography Dataset (U.S. Geological Survey, 2013), the Calculate Geometry Tool was used to calculate the length of each canal. The total canal lengths within each irrigation company were then summed. The shapefile was converted to a raster using the Raster to Polygon Tool, with an output cell size of 100. Values were reclassified into three canal length rankings using the Reclassify Tool.

Table 2.4: *Breakdown of physical characteristics into ranking classes. Each characteristic (distance from the River, hydraulic conductivity, and canal length) is broken down into three classes, where 3 indicates the most suitable areas and 1 indicates the least suitable areas.*

	Distance from the River (meters)	Hydraulic Conductivity (feet/day)	Canal Length (feet)
Class 1	0 - 3,000	14 - 25	7,690 - 55,877
Class 2	3,000 - 6,000	26 - 80 and 151 - 330	55,878 - 102,023
Class 3	6,000 - 15,000	81 - 150	102,024 - 702,083

Using these processes, we created a classified raster for each of the three characteristics (Figure 2.3). The Weighted Sum Tool was then used to combine the three rasters and produce a final raster with total scores summed for each cell. The total scores are delineated by irrigation company in the final raster because that is the decision-making body that will decide whether or not to participate in recharge.

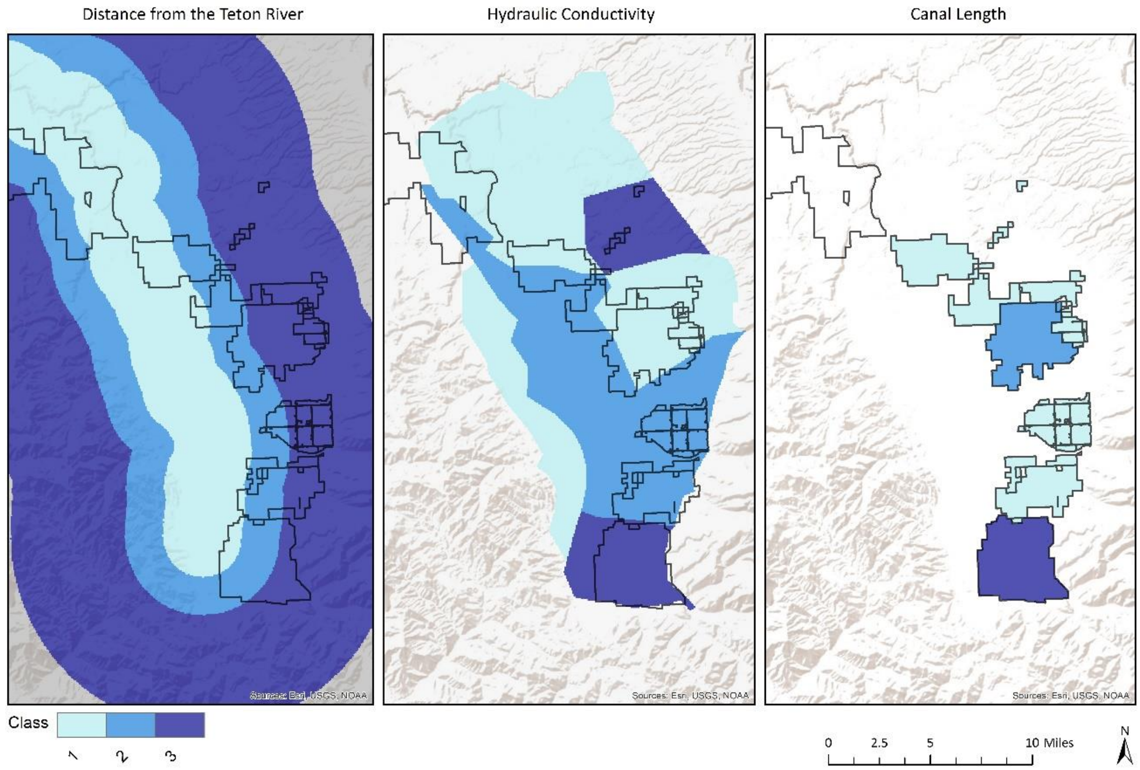


Figure 2.3: *Classifications of recharge suitability for three physical characteristics: distance from the Teton River (left), hydraulic conductivity (center), and canal length (right). Each characteristics is split into three classes from least to most suitable: 1 (light blue), 2 (blue), and 3 (dark blue). Data source: Idaho Department of Water Resources, Nicklin Earth & Water, Inc., U.S. Geological Survey.*

2.2.3 Results and Discussion

The model output shows site suitability on a scale from three to nine, where three is the least suitable and nine is the most suitable (Figure 2.4). Because no cells received a three in every category, the highest total score was eight. The results indicate that Trail Creek Sprinkler Irrigation Company is best for recharge, with scores ranging from 6 to 8 throughout the company's entire domain. While no other companies rank comparably to Trail Creek Sprinkler Irrigation Company, most irrigation companies rank favorably in at least two of the three categories.

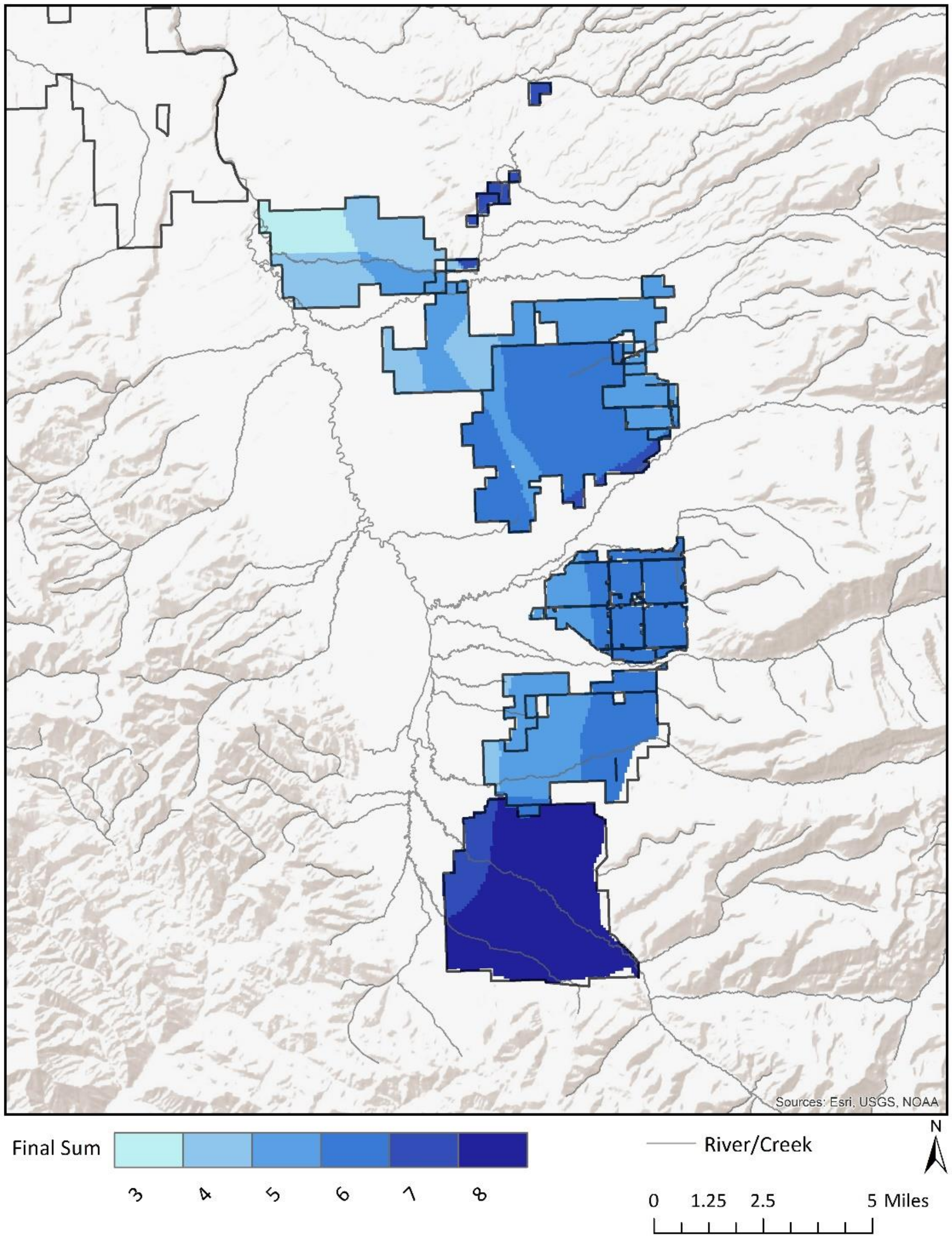


Figure 2.4: *Final recharge site suitability rankings. Site suitability is ranked from least suitable (light blue, 3) to most suitable (dark blue, 8). Black outlines show irrigation company boundaries. Data source: Idaho Department of Water Resources, Nicklin Earth & Water, Inc., U.S. Geological Survey.*

Both the intermediary and final results provide a useful tool for assessing site suitability. Each physical characteristic classification is important to look at individually as well as in aggregate. For example, while distance from the Teton River and hydraulic conductivity are factors that will remain constant over time, canal length may change. This could result from farmers decommissioning canals, lining canals, or choosing to rehabilitate decommissioned canals. Furthermore, if future expansions of recharge efforts focus on maximizing recharge area through not only canal length, but also by incorporating marginal pastureland, looking at results based on canal mileage will not provide an accurate result. Additionally, distances and conductivities that are ideal for recharging in April, may not be ideal for recharging in late May. If incidental recharge becomes feasible later into the season, perhaps areas scoring a 2 in April would score a 3 in May. Therefore, while the final ranking raster provides an idea of the most suitable sites under the currently expected recharge conditions, looking at each part individually can help answer additional questions about variable future scenarios.

Model Limitations and Future Considerations

This model provides a simple rubric for estimating site suitability. A more robust analysis should incorporate groundwater level and hydraulic head to better estimate Darcian flow through the shallow aquifer. The hydraulic conductivity measurements used in this analysis are modeled results based on previous studies conducted in the region more than a decade ago. These could be better refined by measuring conductivity in the field.

Additionally, the existing canal data does not accurately reflect the current state of canals in Teton Valley. It is likely that some canals in the IDWR dataset used for this analysis are currently inactive and that additional canals exist in the Valley beyond what is included in the dataset. Due to the many changes in irrigation practices have occurred in recent decades, it is also unknown which canals are unlined and which have been lined or piped. If there are more canals piped or lined than expected, this analysis will overestimate an irrigation company's ability to recharge. On the other hand, if there are more canals being utilized than are accounted for in this analysis, this analysis will underestimate recharge suitability. Obtaining more detailed information about conductivity, canal location, and canal type will improve the accuracy of the model outputs.

This model has been designed to allow the data to be updated and the model to be rerun to generate new results. This will provide our client with the opportunity to reassess the results when updated data becomes available in the future.

The most favorable conditions for conducting recharge in Teton Valley are farther from the river, have moderate conductivities between 81 and 150 feet per day, and a large canal network to convey recharge water. The results of this analysis can inform not only which irrigation companies will be most beneficial to involve, but also which portions of a given property will yield the best results. These rankings are intended to guide recommendations, but should not be interpreted as a means to discourage incidental recharge efforts at lower ranking sites.

2.3 Modeling the Effect of Increased Streamflow on Stream Temperature

To estimate the ecosystem benefits of early season recharge on fisheries, we created a model to assess the influence that increased late season streamflow (as a result of recharge) would have on stream temperature.

2.3.1 Background

Yellowstone Cutthroat Trout

Cutthroat trout are salmonid species native to cold-water tributaries throughout the western United States. There are 14 subspecies of cutthroat trout, each with a unique geographic range (Behnke, 1992). Yellowstone Cutthroat Trout (YCT), once abundant in Montana, Wyoming, and Idaho, now inhabit a very limited area (U.S. Forest Service, n.d.). Despite a 2006 decision to not list the YCT under the Endangered Species Act (U.S. Fish and Wildlife Service, 2006), IDFG has listed the YCT as an "Imperiled Species" and is actively working to protect remaining populations (Idaho Fish and Wildlife, 2005). The Teton River and its tributaries provide critical spawning and rearing habitat for YCT and support one of three remaining stronghold communities in the Greater Yellowstone Ecosystem (Figure 2.5).

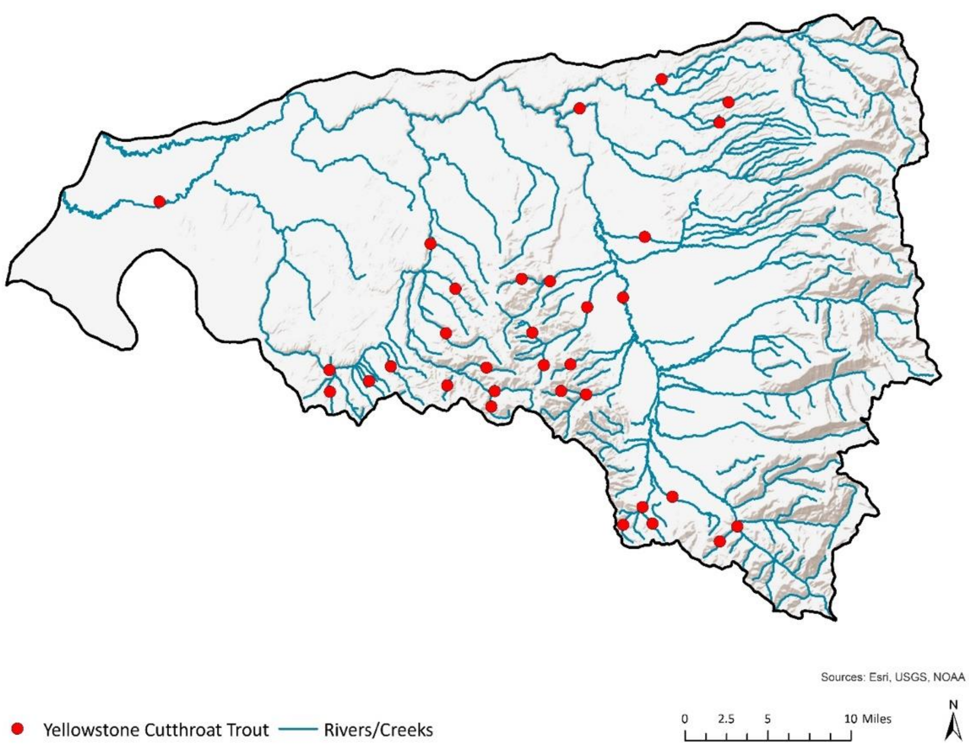


Figure 2.5: *Yellowstone Cutthroat Trout presence in the Teton River Basin. Red dots represent locations where YCT populations are known to exist. Data source: Idaho Department of Fish and Game*.

YCT populations in Teton Valley fall into two categories: resident and fluvial. The resident population lives and spawns in the perennial reaches of the Teton River and its tributaries. The fluvial population lives in the mainstem of the Teton River but spawns in the tributaries (Verbeten, 2017). Both categories rely on cold, clean water to spawn (U.S. Forest Service, n.d.). Thus, one of the greatest threats to YCT in Teton Valley are increased water temperatures. YCT populations are also threatened by competition from non-native trout species, specifically Rainbow Trout (Verbeten, 2017).

The relationship between flow levels in the tributaries, Rainbow Trout, and YCT populations is complex. The majority of Teton Valley's tributaries are losing streams and many of them dry up naturally in the summer. YCT populations are adapted for this seasonal pattern. Changes in this pattern, however, can allow for invasion by Rainbow Trout. The Rainbow Trout then outcompete and interbreed with YCT, further threatening the YCT population. Due to a combination of natural causes and human influences, tributaries of the Teton River often run dry, protecting YCT by preventing or changing Rainbow Trout migration patterns. For example, Darby Creek supports a genetically pure population of YCT because it is never hydrologically connected to the Teton River. Seasonal patterns, hydrology, and agricultural diversions result in a dry stretch of creek, thus preventing Rainbow Trout from entering the tributary (Verbeten, 2017).

Differences in the hydrology of the streams and timing of agricultural diversions affect YCT populations in different ways. In this case, increased diversions would actually maintain the population by ensuring that the stream never connects. Conversely, diversions can reduce the peak flow in connected creeks, which the YCT rely on for migrating upstream from the river. These complex relationships cannot be addressed uniformly and warrant further study that is outside the scope of this project. Ultimately, it remains undetermined as to whether additional changes in diversions from doing early season incidental recharge would hurt or help YCT populations in the tributaries. Because the relationship between YCT and streamflow in these creeks is so complicated, our study focused on the potential positive impact that incidental recharge could have on residential populations of YCT in the Teton River. More specifically, we looked at whether increased streamflow would have a significant impact on stream temperature, as YCT rely on cold water for spawning.

Impact of Stream Temperatures on Fish

Stream temperature influences both chemical and biological processes. More specifically, water temperature directly influences dissolved oxygen levels, as well as fish growth, health, behavior, reproduction, distribution, and mortality (Hillman, Miller, & Nishitani, 1999).

Alterations in hydrologic regime, and therefore temperature, can also influence interspecies competition. Declining aquifer levels have decreased late-season baseflow in the Teton River, resulting in increased stream temperatures. Although all of the fish species in Teton Valley fall under the cold-water classification, individual species have slightly different optimal temperature ranges. In general, "the critical time periods are

April through June when spring salmonid spawning occurs, July and August when maximum temperatures may exceed cold water aquatic life criteria, and September when fall salmonid spawning is most likely to be affected by higher temperatures" (Idaho Department of Environmental Quality, 2016). Based on this criteria, stream temperatures are not to exceed 9°C as a daily average and 13°C as a daily maximum from March 15 - July 15 and September 1 - November 15 for river reaches designated under Salmonid Spawning (SS) beneficial use. For the Cold Water Aquatic Life (CWAL) beneficial use, stream temperatures are not to exceed 19°C as a daily average and 22°C as a daily maximum from June 22 - September 21 (Idaho Department of Environmental Quality, 2016). When temperatures rise above these levels, fish struggle to survive and reproduce.

Due to consistently high stream temperatures during the summer months, IDEQ has established a temperature TMDL for multiple sections of the Teton River. However, little has been done to ensure that this TMDL is met. Frequently, summer stream temperatures exceed SS beneficial use standards. Temperature logger data collected by the Idaho Department of Fish and Game from 1996-2000 in the mainstem of the Teton River show regular exceedances of the SS temperature standards (Figure 2.6). Overall, temperatures exceeded the 9°C limit 100% of the time between June 21st and August 31st, in those four years. However, temperatures never exceeded 19°C during that time period.

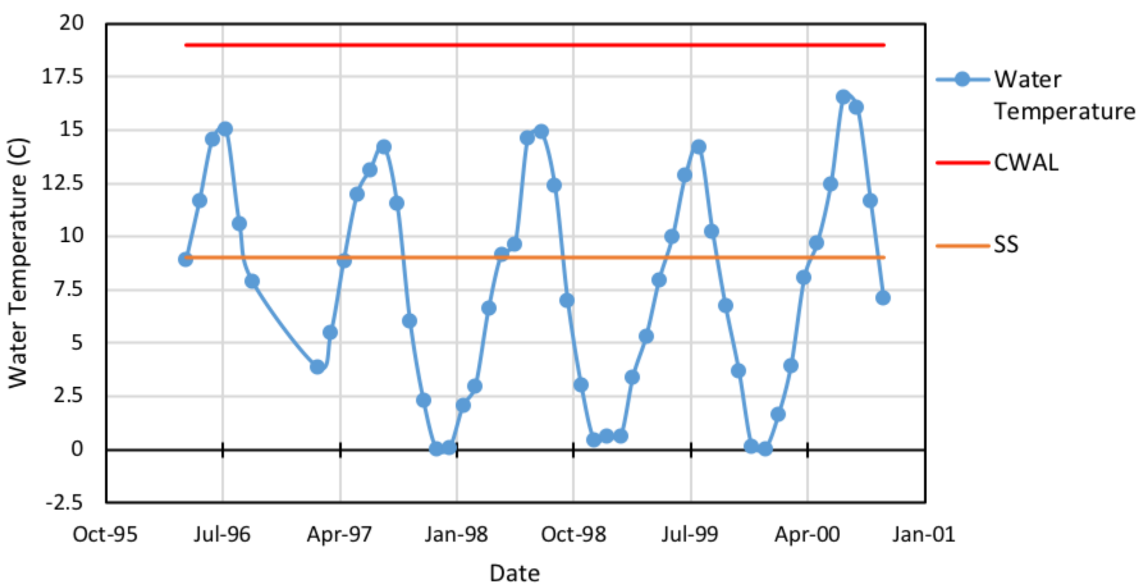


Figure 2.6: *Average monthly water temperature (°C) of the Teton River at the USGS South Leigh gauging station from 1996-2000. The maximum daily average temperature allowed for salmonid spawning (orange) and the maximum daily average temperature allowed for cold water aquatic life (red) are shown for reference. Data was collected using temperature loggers. Data source: Idaho Department of Fish and Game.*

Stream temperature is influenced by both meteorological conditions, as well as the physical and hydrological characteristics of the stream (Benyahya, Caissie, St-Hilaire, Ouarda, & Bobée, 2007). Solar energy loading plays a large role in impacting stream temperature. There are, however, many variables that influence solar energy loading, including riparian vegetation and shade cover, as well as day length. In addition to solar energy loading, meteorology, hydrology (including tributary and groundwater inflows), and stream morphology (including stream aspect, channel geomorphology, and valley topography) all play a role in influencing stream temperatures (Benyahya et al., 2007).

2.3.2 Model Selection

Although the influences of these factors on stream temperature are relatively well understood in isolation, the way in which they interact is still being investigated by the scientific community (Dugdale, Hannah, & Malcolm, 2017). Various models incorporate these variables to evaluate the overall effect on stream temperature and, therefore, ecological health. Water temperature models can be important management tools and are frequently used to determine optimum outflows for maintaining adequate temperatures in a variety of aquatic systems (Benyahya et al., 2007). There are two main types of models used to predict stream temperatures, deterministic and statistical, each of which has its own advantages and drawbacks.

Deterministic models simulate physical processes and can be useful tools for predicting stream temperatures at a large scale, but require significant data inputs (Benyahya et al., 2007). Deterministic models are based on mathematical representation of the underlying physics of heat exchange between the river and the surrounding environment and are typically carried out using an energy budget approach (Benyahya et al., 2007).

Statistical models, on the other hand, are simpler and require less data, making them more popular in many fields of study (Benyahya et al., 2007). Regression models are used for predicting or simulating water temperature at weekly, monthly, and annual time steps. These models rely on the correlation between air and water temperature (Benyahya et al., 2007), and can be expanded to include streamflow variability (Webb, Clack, & Walling, 2003).

In a review of stream temperature models, Benyahya et al. (2007) found that simple regression-based models have been successful at modeling water temperature as a function of one or more independent variables and that statistical models have played an important role in studying water resource and fisheries management issues. Thus, we selected a regression to model stream temperatures in the Teton River for our analysis.

2.3.3 Model Justification

Location. The location of our analysis is at the mouth of South Leigh Creek on the Teton River. We chose this location because it will likely be impacted by changing flow due to recharge efforts. Because it is located at the north end of the valley, recharge from most locations will contribute to streamflow at this point. Additionally, daily mean water temperature data was available for four years at this site, as well as USGS streamflow data.

The NOAA weather station at the nearby Driggs airport only has data from 2006 onwards. Therefore, we decided to use temperature records recorded at the Jackson Hole weather station. Though this weather station is 42 miles from the South Leigh USGS gage station, the difference in elevation is only 100 feet, and the climate is assumed to be representative.

Time Interval. Benyahya et al. (2007) and Webb et al. (2003) found that the water-air temperature relationship becomes less scattered as the time interval of the data increases from hourly to daily to weekly means. Thus, daily data was determined to be satisfactory for the model.

Lag. Stefan & Preud'homme (1993) found that models using daily mean values could be improved by introducing a lag into the data based on catchment size. Lag times varied from 0 days for catchments that were smaller than 300 km^2 to eight days for larger basins. However, Webb et al. (2003) found that models only need to include a lag for hourly, as opposed to daily or weekly, data. Though the size of our basin might warrant a lag, our use of daily data precluded the need for a lag term.

Time Frame. Webb et al. (2003) found that air and water temperature are more strongly correlated when flow is below median levels. Median flow in the Teton River at South Leigh Creek was 347 cfs. This threshold was not used in the model, though, as the median levels were strongly influenced by very low seasonal winter flow versus overall decreased summer flow. Instead, we used the time period from July 21st - August 31st for our analysis. Doing so reduces the influences of variability from solar energy loading, as shade from vegetation remains fairly constant during this time and day length does not vary greatly. This also captures the time period we are interested in from the standpoint of incidental recharge potential. Furthermore, Langan et al. (2001) found that the linear relationship can be partitioned on a seasonal basis and that the best fit between air and water temperature occurred in the summer.

Temperature Variation. Multiple studies show a nonlinear structure when air temperature is below 0°C or above 25°C. The former is ascribed to the release of latent heat with ice formation, which prevents water temperatures from falling much below 0°C. The latter is explained by the effect of evaporative cooling in the summer, as the moisture-holding capacity of the atmosphere increases with warmer air temperatures, promoting greater evaporation from the water surface (Webb et al., 2003). Because we are only examining data from July through September, it is inconsequential that water temperatures frequently drop below 0°C during the winter months. Additionally, temperatures during these months never exceeded 25°C over the four-year dataset.[2]

2.3.4 Data and Methods

Data

To predict how stream temperature would change as a result of an increase in streamflow, we used daily mean stream temperature (Schrader, 2004), daily mean air

[2] The maximum temperature reached was 21.2°C.

temperature (National Oceanic and Atmospheric Administration, n.d.), and daily mean flow level data (U.S. Geological Survey, 2017) (Table 2.5) from 1996-2000 to generate a regression model.

Table 2.5: *Data sources and locations used to create the stream temperature regression model.*

Station ID	Site Name	Begin Date	End Date	Latitude	Longitude	Source
USGS 13052200	Teton River above S. Leigh Creek near Driggs, ID	May 21, 1996	Oct 25, 2000	43 46'55"	111 12'33"	USGS
72577699999	Jackson Hole	May 21, 1996	Oct 25, 2000	43 60'0"	110 7'31"	NOAA Global Summary of the Day
USGS 13052200	Teton River above S. Leigh Creek near Driggs, ID	May 21, 1996	Oct 25, 2000	43 46'55"	111 12'33"	Idaho Fish and Game

Model Framework

After examining our data, we decided to use a linear function to model the relationship between air temperature and water temperature and a logarithmic function to model the relationship between streamflow and water temperature. The structure of the statistical model is as follows:

$$T_w = \alpha + \beta T_a + \gamma log(Q)$$

where T_w is stream temperature (°C), T_a is air temperature (°C), Q is streamflow (cfs), and α, β, and ϒ are coefficient constants.

2.3.5 Results and Discussion

Model Results and Future Considerations

Our model shows that while air temperature has the biggest impact on stream temperature, streamflow also significantly predicts stream temperature ($p < 0.0001$) (Table 2.6).

Table 2.6: *Regression results for summer (June 21-August 31) stream temperature (°C) at the South Leigh gauging station near Driggs, ID from 1996-2000 with two predictor variables: air temperature (°C) and streamflow (cfs). The model significantly predicts stream temperature ($F(344) = 801.4$, $P < 0.0001$, $R^2 = 0.8223$).*

	Coefficient	Standard Error	*t*	*p*	Overall Adjusted R^2
Intercept	13.8000	0.6022	31.3900	< 0.0001	0.82
Air Temperature (°C)	0.4054	0.0176	-23.2800	< 0.0001	
Log(Flow Rate (cfs))	-1.6629	0.0714	23.0500	< 0.0001	

When compared to actual water temperatures, it appears that the calibrated model does a good job at predicting water temperatures (Figure 2.7). Additional graphs for 1997-1999 can be found in **Appendix E**.

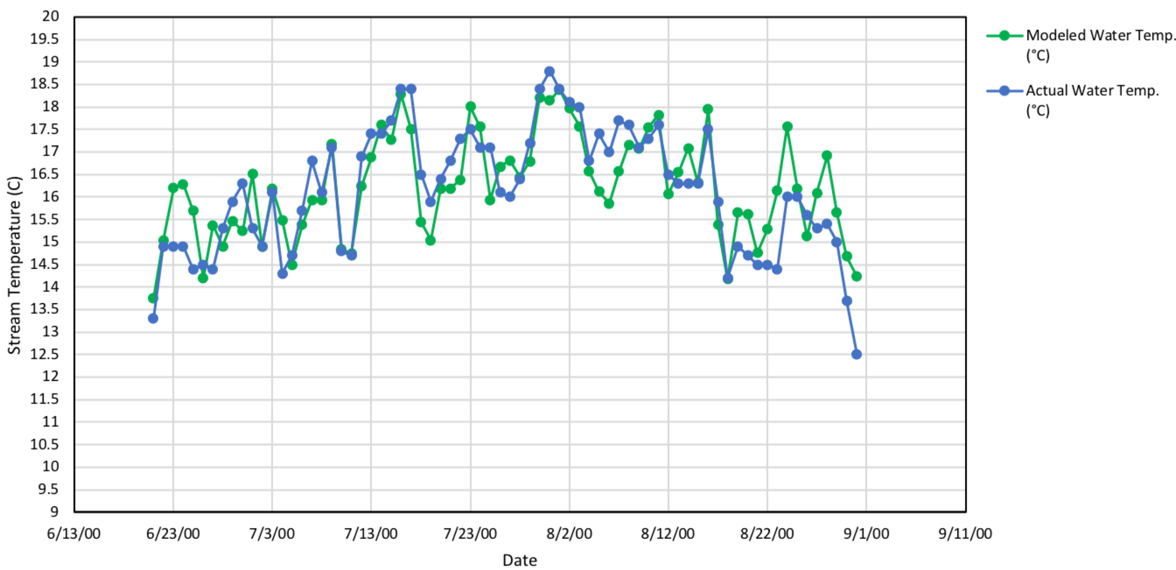


Figure 2.7: *Actual and modeled stream temperatures (°C) from June 21st-August 31st for the year 2000. The green line shows the modeled stream temperatures and the blue line shows the actual stream temperatures for that time period. Data source: Idaho Department of Fish and Game.*

Results Applied to Recharge Scenarios

We selected to model our recharge scenarios based on data from 2000. This year was a particularly dry year with lower flow and therefore higher water temperatures. We believe that recharge might play the most critical role in adjusting water temperatures during these dry periods. Therefore, we were interested in seeing the impact that recharge could have on stream temperature in dry years. Furthermore, our model was best fit to 2000 (**Appendix E**), indicating that our model is most suited for summers in which streamflow is below average.

Under our modeled recharge scenario for the year 2000, the decrease in water temperature could range from -0.61°C from 30 days of recharge with just the pilot participants to -0.73°C from 60 days of recharge utilizing all canals in the Valley (Table 2.7). Interestingly, the difference in the decrease in water temperature over the season is most significant under the highest recharge scenario, with stream temperature decreases ranging from -0.65 to -0.73°C in this scenario (Figure 2.8). More importantly, the greatest decrease in temperature in this scenario occurs at the end of August when streamflow is lowest, indicating that recharge could play a vital role in decreasing late-season summer temperatures in dry years (Figure 2.9).

Table 2.7: *Differences in stream temperatures modeled under four different recharge scenarios. Over the course of the summer season (June 21st-August 31st), changes in temperature due to recharge fluctuate. Thus, both the minimum and maximum temperature differences are given in addition to the average temperature difference over the course of the summer. Differences in stream temperatures modeled under the four different recharge scenarios for the years 1997-2000 can be found in* ***Appendix E.***

Recharge Scenario	Recharge (acre-feet/year)	Average Temperature Difference (°C)	Minimum Temperature Difference (°C)	Maximum Temperature Difference (°C)
0	0	0	0	0
1	2826	-0.61	-0.61	-0.62
2	5652	-0.62	-0.61	-0.63
3	11943	-0.65	-0.62	-0.67
4	23886	-0.69	-0.65	-0.73

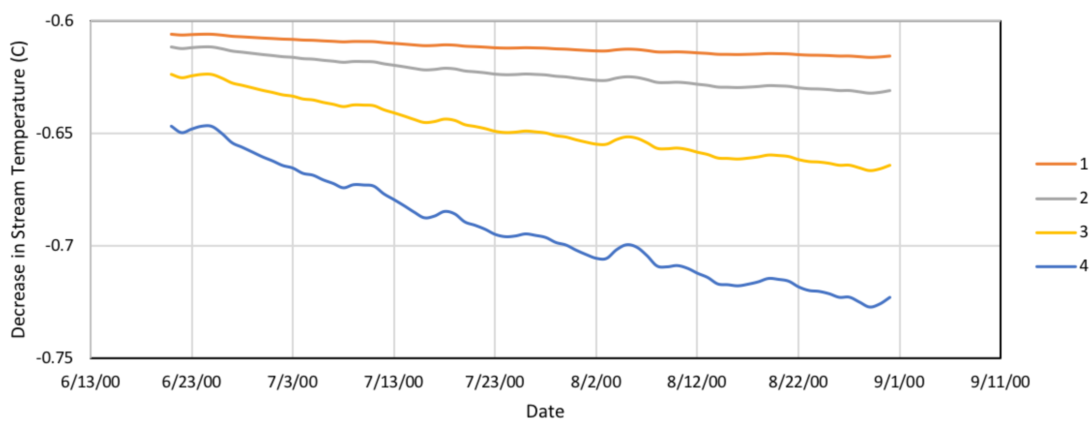


Figure 2.8. *Modeled change in stream temperature from June 21st-August 31st, 2000 under four different recharge scenarios as defined in table 2.7 above. The orange, gray, yellow, and blue lines correspond with modeled stream temperatures for 2826, 5652, 11943, and 23886 acre-feet of recharge per year respectively. While all recharge scenarios decrease water temperature between 0.6 and 0.65°C initially, the higher recharge quantities result in a much greater decrease in temperature over time, with the greatest decreases occurring late in the summer season when fish need it most.*

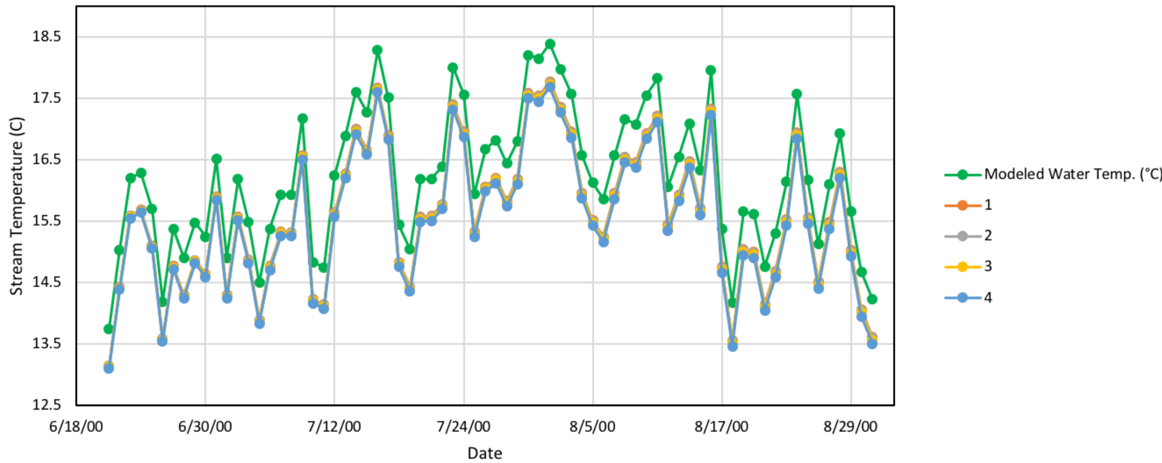


Figure 2.9: *Modeled stream temperatures for June 21st-August 31st, 2000 under four different recharge scenarios as defined in table 2.7 above. The green line shows modeled stream temperatures for this period under current conditions. The orange, gray, yellow, and blue lines show modeled stream temperatures for 2826, 5652, 11943, and 23886 acre-feet of recharge per year respectively.*

2.4 Conclusion

The three analyses discussed in this chapter satisfied our objective of modeling hydrologic conditions to determine the potential impact of recharge on streamflow and temperatures in the Teton River. The results of the scenarios we ran using the Teton Valley Groundwater-Surface Water Model show that during the time the water is needed most, approximately 29% of the recharged volume will discharge into the river (U.S. Geological Survey, 2018). Through the different scenarios, we determined that sufficient flow augmentation will be difficult to achieve, as it will require high levels of participation over more than just 30 days. Therefore, it will be critical to maximize the area used for recharge and ensure that those areas will provide the intended results. The site suitability model addressed this by evaluating site suitability based on criteria that impact both the quantity of recharge and the timing of discharge. The results of this analysis can inform not only which irrigation companies will be most beneficial to involve, but also which portions of a given property will yield the best results. Finally, the water temperature model was developed to determine if the anticipated flow augmentation would alter water temperature, and therefore benefit fish. We found that there was a significant negative correlation between streamflow and water temperature. Therefore, with higher flow in the river, we can expect lower water temperatures. When used to evaluate modeled changes in streamflow, the model predicts that the greatest decrease in temperature will occur at the end of August when streamflow is lowest, indicating that recharge could play a vital role in decreasing late-season summer temperatures in dry years.

Chapter 3: Quantifying the Benefits of Recharge

CHAPTER 3: Quantifying the Economic and Environmental Benefits of Recharge

In order to structure and garner support for an incidental groundwater recharge program in Teton Valley, the economic and environmental impacts of incidental recharge needed to be determined. We evaluated the economic impacts by conducting a Cost-Benefit Analysis of the direct costs and benefits to the farmers in the Valley. To determine the ecosystem and recreation benefits, we evaluated the effects of decreased water temperature, and increased streamflow and shallow groundwater levels, on wetland and riverine habitat. The benefit transfer method was then used to estimate the potential economic value of improved habitat. This chapter discusses the methods, results, and implications of the economic and environmental impact analyses.

3.1 Economic Analysis

3.1.1 Overview

The economic analysis evaluates the costs and benefits of utilizing the length of all irrigation canals in Teton Valley for 30 days of incidental recharge. The scenario assumes that approximately 80 miles of canal length will be used to recharge a total of 11,943 acre-feet of water from April 15th to May 15th. Using Dr. Van Kirk's model, it is estimated that the one month of incidental recharge will contribute 3,426 AF of additional discharge to the Teton River between June 25th and September 25th (see Chapter 2: Modeling the Effect of Incidental Recharge on Streamflow). The primary cost bearers are the farmers in Teton Valley who are undertaking the recharge efforts. Primary beneficiaries include Teton Valley farmers, the Teton River fishery and local economy, river and wetland ecosystems, and the individuals and groups that benefit from these ecosystem services.

3.1.2 Data and Methods

Data were obtained through informational interviews with stakeholders as well as from publicly available government records and scientific literature (Table 3.1).

Table 3.1: *Data sources used in the Cost-Benefit Analysis.*

Data	Description	Source
Canal Maintenance Cost	Costs of clearing under-maintained canals of debris, vegetation overgrowth, and headgate installation	L. Bagley, 2017a, Lien, 2017
Labor Costs	Costs of additional labor to run irrigation for one additional month	U.S. Bureau of Labor and Statistics, 2016
Market Platform Cost	Cost for Teton Water Users Association to run and maintain a market platform for incidental recharge	Lien, 2017
Loan Rate	Loan rate for farmers in Idaho, used for the calculation of an appropriate discount rate	United States Department of Food and Agriculture, 2017
Storage Water Prices	Costs to rent storage water from FMID and the IDWR rental pool	L. Bagley, 2017a, Olenichak, 2017
Water District 01: Snake River Flow Accounting	Quantification of natural flow available, natural flow use, storage use, and water rights in priority on a daily basis	Idaho Department of Water Resources, 2017

A comprehensive Cost-Benefit Analysis (CBA) model was used to analyze the economic feasibility of implementing a program to incentivize incidental groundwater recharge in Teton Valley. A list of all costs and benefits were compiled, normalized, discounted over time, and summed to determine the total net present value (NPV) over 25 years. A benefit-to-cost ratio was calculated from the NPVs of costs and benefits to evaluate the attractiveness of the project. Per unit values for costs and benefits were also compared, to evaluate the relationship between willingness to pay (WTP) and willingness to accept (WTA).

Costs

The first step in assessing the economic viability of creating this incidental recharge program was to quantify the costs associated with developing and launching the program. Costs were quantified utilizing publicly-available government data, informational interviews, and scientific literature. In addition, special care was taken to take the highest estimate of costs to ensure a conservative benefit-to-cost ratio.

Direct costs for this project include canal maintenance, farmers' time to run early-season irrigation, and program development and maintenance. To effectively recharge the groundwater, this project requires that upstream farmers begin diverting water when their water rights come into priority on April 15th instead of the usual time when weather permits irrigation to begin sometime in May.

These upstream farmers will directly bear the cost of maintaining additional canal infrastructure and the cost of their time to de-ice headgates, monitor flow, and ensure proper canal operation earlier in the season (Bagley, 2017b). Based upon informational interviews and current labor rates in Idaho, canal maintenance was quantified to cost $200.00/mile of canal with approximately 25 miles of canal requiring maintenance for a total of $5,000.00 (Bagley, 2017a). Maintenance will, however, vary by farmer depending on the condition of the canals prior to irrigation season.

In addition to paying for canal maintenance, upstream farmers also incur time cost for an extra month of running their irrigation. On average, farmers in Idaho earn $26.57/hour and will spend 20 hours of their time implementing the early-season recharge for a total time cost of $531.40 (U.S. Bureau of Labor and Statistics, 2016). This estimate accounts for additional time needed to de-ice headgates and canals.

The last direct cost quantified for this CBA was the cost to develop and maintain the platform itself. LegacyWorks Group has already secured a grant to fund the first two years of program development and implementation (Lien, 2017). After the initial two years, we suggest that the entity running the program charge a 10% fee for each acre foot of water recharged ($5,000.00). Unlike the physical costs associated with recharging water, the cost of the platform development will fall on the beneficiaries rather than the upstream farmers.

Benefits

Revealed preference methods were used to calculate the financial benefits accrued by Teton Valley farmers. Augmented surface flow in the Teton River could delay the call date from downstream senior water rights holders, thus pushing back the date at which Teton Valley farmers begin to rent stored water if they wish to continue to irrigate.

To determine how the anticipated additional flow would delay the call date, we used water rights accounting data obtained from Idaho Department of Water Resources to establish the relationship between natural flow (cfs) and water right priority (Idaho Department of Water Resources, 2017). We ran a linear regression to determine how natural flow predicts the most junior water right in priority. We bounded the regression in July and August, when Teton Valley water rights holders are often out of priority (Figure 3.1). Additionally, to better predict the trend in the priority dates that are typically most affected in this period, priority dates junior to 1940 were not evaluated. Finally, due to a high number of outliers in the data from irrigation year 2014, this year was not considered in the analysis. The analysis used daily water rights accounting data from July and August from irrigation years 2007-2013 and 2015-2017.

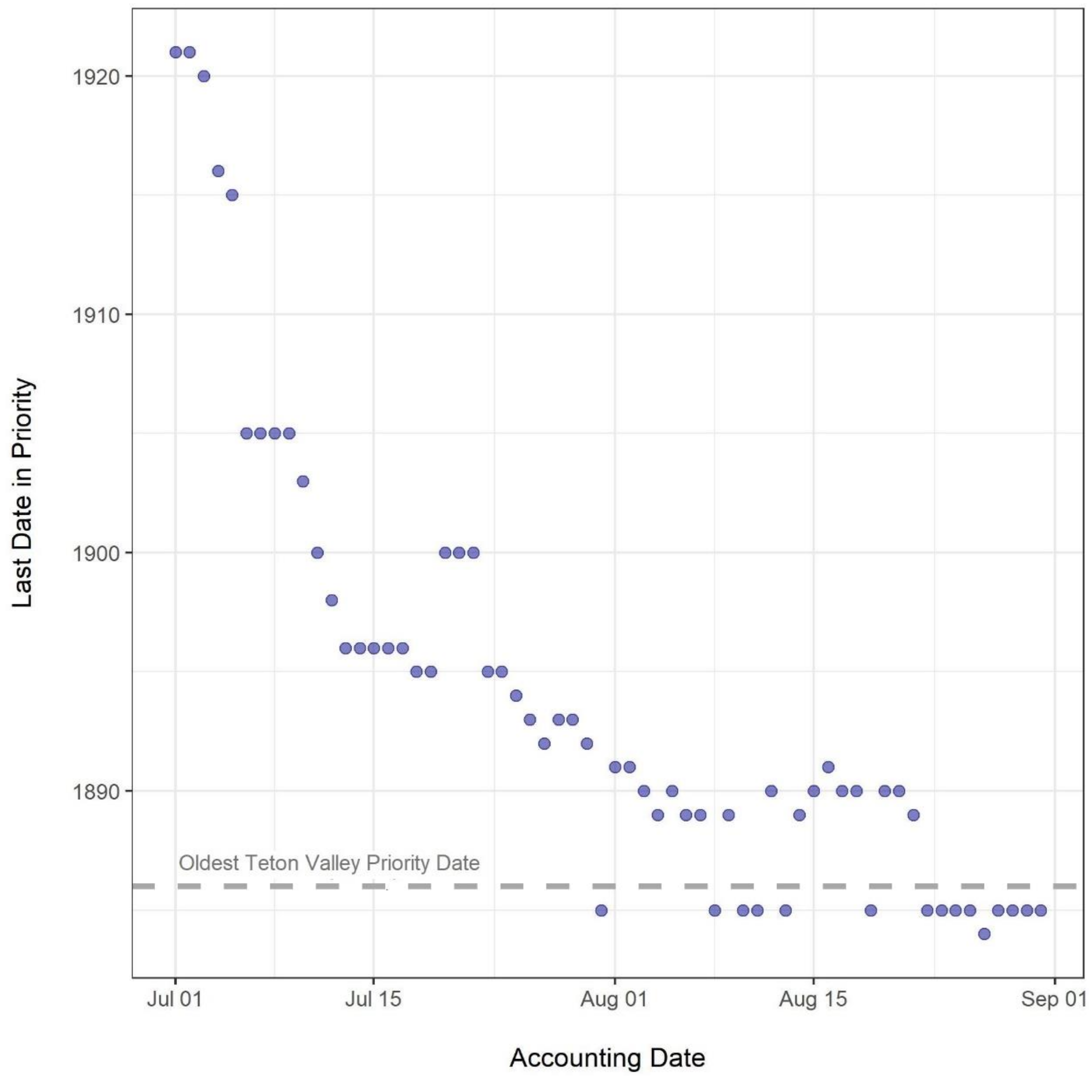


Figure 3.1: *Most junior water right in priority in July and August. Daily median values from 2007-2017. The dotted line shows the most senior priority date in Teton Valley (1886). Priority dates below the line only exist downstream of the Valley. Data Source: Idaho Department of Water Resources.*

As detailed in Chapter 1, farmers can first rent stored water from FMID and then from the Water District 1 rental pool if FMID supplies are exhausted. Depending on water levels and from whom the water is rented, the cost of stored water can range from $6/AF to $22.00/AF (Bagley, 2017a; Olenichak, 2017; Rob Van Kirk, 2017). The average cost of renting stored water from FMID was used as a proxy to estimate the value of additional water discharged into the Teton River between June 25th and September 25th. This value was used because many farmers find that when stored water is more expensive, the benefits of diverting water do not outweigh the cost of renting stored water. Therefore, if the call date is delayed by incidental recharge, the annual benefit to the farmers would be valued as the quantity of avoided stored water rentals multiplied by a rental cost of $6/AF.

Benefits to other financial beneficiaries, such as municipalities and Teton Canyon water rights holders were considered insignificant in magnitude and were not included in this analysis. The municipalities of Victor and Driggs may benefit from reduced groundwater pumping costs from a raised water table. However, recharged groundwater may take around 10 years to travel to a municipal well in the Teton River Basin, so reduced pumping costs will not be realized immediately (Friends of the Teton River, 2016), and, after discounting, these benefits would be negligible. Similarly, while farmers withdrawing water from the Canyon may benefit from higher surface water levels, and therefore reduced pumping costs, only a fraction of the additional discharge will reach the Canyon, the exact quantity of which is highly uncertain. Due to the small potential benefits and high uncertainty, benefits to municipalities and farmers in the Canyon were not incorporated.

Recreational and habitat benefits were also evaluated, but not directly quantified in this CBA. This decision was made so that feasibility could be determined based solely on actualized costs and benefits to direct participants. We determined that if the program was feasible under these conditions, then consideration of recreation and habitat values would provide additional benefits above and beyond those evaluated in this analysis.

Discount Rate

The primary cost bearers and beneficiaries are farmers in Teton Valley. Therefore, this CBA analysis uses a discount rate of 3.5% which is the equivalent of the U.S. Department of Food and Agriculture 2017 loan rate for commodity crops in Teton Valley (United States Department of Food and Agriculture, 2017).

Results

We found a statistically-significant relationship between natural flow and the most junior date in priority and this relationship explained a significant portion of variance in priority dates (Figure 3.2). The linear model predicted that every 1 cfs increase in streamflow would increase the most junior date in priority by 0.017 years. Therefore, to move the priority date by one year, an additional 58.8 cfs of flow would need to be added to the Teton River. Because we predict that the groundwater contributions from recharge will not exceed 19 cfs, we do not anticipate that this quantity of incidental recharge will result in a decrease in the amount of stored water Teton Valley farmers need to rent.

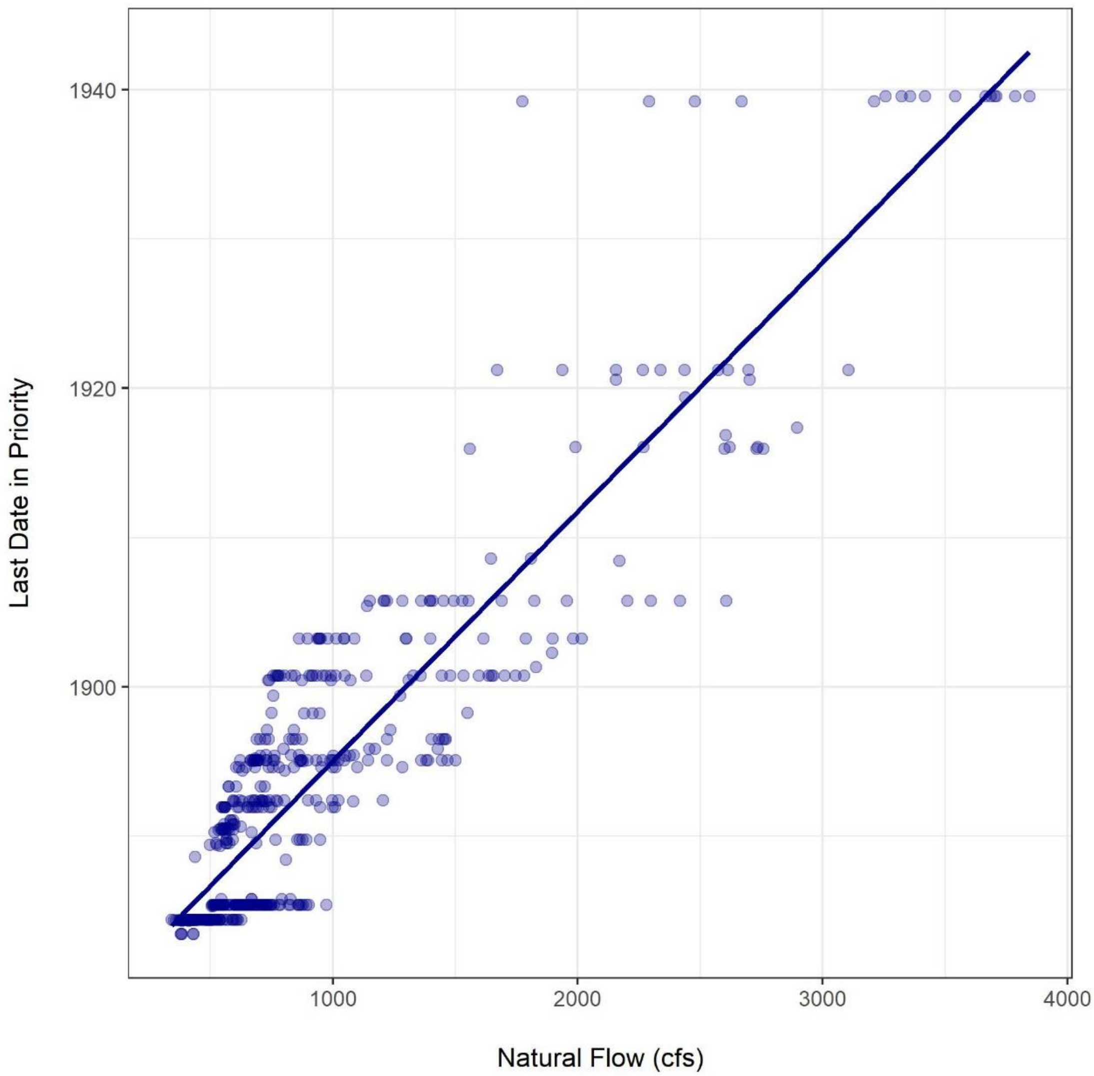


Figure 3.2: *Natural flow and the most junior date in priority (2007-2013, 2015-2017). A linear model was used to determine the relationship between natural flow (cfs) and the last date in priority. There was a statistically-significant relationship between natural flow and the most junior date in priority ($b = 0.01667$, $t(560)= 53.15$, $p < 0.001$) and this relationship explained a significant portion of variance in priority dates ($R^2 = 0.83$, $F(1, 560) = 2825$, $p < 0.001$).*

These findings were used to calculate the annual costs and benefits associated with implementing this recharge program in Teton Valley (Table 3.2). Using these costs and benefits, two descriptive analyses were performed on the aggregated data, with cash flow extending out to 25 years. The net present value of all costs and benefits over 25 years was found to be -$174,274 and $0, respectively. This results in a negative cash flow and a benefit-to-cost ratio of 0.0 (Table 3.3).

The cost calculations were also used to estimate the minimum price points for groundwater recharge. Based on estimated costs to farmers, buyers would need to pay

$1.61/AF to cover farmers' costs, or $3.07/AF to cover farmers' costs and the cost of program implementation through a program platform.

Table 3.2: *Annual costs and benefits associated with implementing a program to incentivize groundwater recharge in Teton Valley.*

Annual Cost Summary	
Canal Maintenance	$5,000
Time Value	$531
Market Platform Maintenance (Year 3 onward)	$5,000
Annual Benefit Summary	
Value of Augmented Flow	$0

Table 3.3. *Financial analysis of the costs and benefits of the recharge program over 25 years. All values were discounted at a rate of 3.5%/year.*

Financial Analysis	
NPV Costs	-$174,274
NPV Benefits	$0
NPV of Cash Flow	-$174,274
Benefit Cost Ratio	0

3.1.3 Discussion

The modeled quantity of additional flow needed to push the date in priority back by one year does not represent the actual relationship in any given year. In some years, this value is an overestimate, while in others it is an underestimate. While it is unlikely that the additional streamflow contributions from 11,943 acre feet of recharge will be sufficient to prevent Teton Valley water rights from going out of priority, it is possible that recharge could occur in a year in which less water is needed to change the date in priority. If this occurs, farmers could benefit from being able to continue diverting water. Nonetheless, the model significantly predicts the relationship between natural flow and the most junior date in priority and we believe it will be imperative to increase the volume of water recharged in order for the benefits to farmers to be realized.

Farmers currently pay an average of $6/AF to rent stored water from FMID, which is significantly greater than the estimated minimum prices of $1.61/AF or $3.07/AF. The benefitting farmers' current WTP to rent stored water is higher than the cost of reimbursing farmers for recharging. However, these prices only account for the direct costs that need to be covered and do not take into consideration that some farmers may need additional incentive to participate. If recharge efforts can be expanded to result in sufficient flow augmentation to provide savings in stored water costs, the benefits of the program would be much greater than the cost per acre-foot of covering all costs. Therefore, there would be room to establish a price that takes this into consideration and provides extra incentive to participate in recharging.

Ecosystem services and recreational benefits that would be gained from incidental recharge were not evaluated in these analyses. Incorporating these values would serve to increase the resulting net present value (assuming all costs are accounted for as well), in addition to increasing the benefit-to-cost ratio. In order to reach a benefit-cost ratio of greater than 1, the ecosystems benefits would need to exceed the costs of incidental recharge.

3.2 Ecosystem Benefits

We chose not to include recreational and ecosystem benefits in the CBA because we wanted to determine whether the actualized benefits to potential participants exceeded the costs of participation. We determined that recreation and ecosystem benefits will play an important role in the early stages of this program, as they start to accrue before the critical threshold is met at which point farmers receive benefit from augmented river flow. Thus, these benefits will increase the benefit-to-cost ratio early in the program, making it more feasible and more attractive to funders.

Though not directly quantified in this study, ecosystem benefits that result from early-season incidental recharge, including the modeled decrease in stream temperatures and subsequent benefits to the Yellowstone Cutthroat Trout fishery, as well as increased wetland resilience can have positive economic impacts. In order to determine these economic impacts, we examined existing literature to inform predictions of the benefits to fisheries and ecosystems. We then used the benefits-transfer method to estimate a value for these benefits.

3.2.1 Impact of Decreased Water Temperatures on Yellowstone Cutthroat Trout

Decreased water temperatures, especially to levels at or below the Salmonid Spawning beneficial use threshold, will likely have a positive effect on the cold water fish that rely on cooler temperatures to survive and reproduce. The thermally-suitable range of average daily temperatures for Yellowstone Cutthroat Trout from May 1st to September 30th is 5.9°C to 16.8°C (Al-Chokhachy, Alder, Hostetler, Gresswell, & Shepard, 2013). Between 1996 and 2000, Teton River mean daily summer temperatures from June 21st-August 31st exceeded this level 7.9% of the time. With augmented flow as the result of incidental recharge, however, such exceedances could be reduced. Using modeled scenarios, the temperature would exceed this critical threshold 9.0% of the time under current circumstances. With the pilot participants recharging for 30 days, the time that temperatures exceed the threshold would be cut in half, decreasing to 4.2%. With water temperatures below this critical threshold, and assuming all else remains constant, it is likely that YCT survivability will increase, as will their ability to reproduce. Thus, we predict that recharge will have a positive effect on decreasing stream temperatures and increasing YCT survival.

In addition to a growing population due to increased ability to survive and reproduce, it is possible that decreased water temperatures could also increase the metabolic rates and growth of the fish. A study by Al-Chokhachy et al. (2013) explored the potential impact of climate change and subsequent increases in stream temperature on YCT. The study found that as a group, native inland salmonids are particularly vulnerable to climate-induced changes in stream temperatures and that ambient stream temperatures strongly influence metabolic rates and growth. Changes in growth, however, are not straightforward. Study results suggested that net growth in some streams is not likely to change much, as enhanced growth during May and September will offset decreased growth during warmer periods in June through August. If, however, temperatures are lowered during that time, it is possible to see more summer growth. There are several other factors, however, that also affect growth rate, making the relationship between decreased temperature and increased growth uncertain at this time.

Limitations of the YCT Fishery Impact Assessment

While colder water is generally better for fish health, it can also change spawning times. In the Teton River, where YCT face competition from non-native Rainbow Trout, changing the stream temperature could actually have a negative impact on YCT, even if the overall number of cold water species increases. Thus, while further altering the natural flow regime through recharge may help to decrease water temperatures and meet beneficial use requirements, moving the river further from its current regime may have unintended negative consequences on the YCT population.

A study by Marchetti and Moyle (2001) examined the impact of variable flow regimes on native and non-native fish in California's Putah Creek. Similar to Idaho, streams in California naturally peak after winter rains and snowmelt and experience relatively low flow during the summer when there is little precipitation. This study found that conditions for native species improved during years with large peak flows in winter and sustained flow in summer; on the other hand, non-native species were favored during years without high peak flows and with intermittent summer flow (Marchetti & Moyle, 2001). This trend has been seen in other western streams, as high spring flows flush out non-native fish, simultaneously creating conditions that favor reproduction of native fish, which typically spawn in early spring.

In the Teton River and its tributaries, decreasing the early-season peak flow may actually favor non-native Rainbow Trout. In 2001, Van Kirk and Benjamin (2001) used a linear regression to model how trout populations in the upper Teton River have responded to annual hydrologic variability. Similar to the findings on Putah Creek, Van Kirk and Benjamin found that YCT increased in abundance relative to Rainbow Trout following years in which the hydrologic regime was dominated by surface runoff rather than groundwater. Thus, the transition of the Teton River from a runoff-dominated system to a groundwater-dominated system has favored non-native species. If the system is further shifted towards a groundwater-dominated system through additional recharge, it will make it unlikely that YCT can be restored (Robert Van Kirk & Benjamin, 2001).

It is possible, though, that the magnitude of temperature changes we expect to see from doing recharge may be helpful for YCT; a water temperature decrease of ~0.6 °C may not be enough to significantly alter spawning regimes of YCT and Rainbow Trout, but may be enough to reduce temperatures below the critical threshold for YCT half of the time that it normally exceeds it, resulting in increased survival and viability of YCT in the river.

While predicting the direct impact of lower stream temperatures on the YCT fishery is beyond the scope of this project, it is likely that there will be some positive effect. Expanding on studies that examine the relationship of stream temperatures with YCT viability will require additional telemetry studies, habitat studies, and geomorphic assessments. It will be important to study how flow regimes affect native and non-native species in the area to better understand the costs and benefits to YCT populations and the entire fishery. Additionally, monitoring YCT over the course of several years of recharge will provide insight into the relationship between temperatures and fish health.

3.2.2 Economic Benefits of a Healthy Fishery

Though we cannot predict exact changes in the fishery as a result of decreased stream temperatures, we can get a sense of the economic impact of an improved fishery by drawing on current economic values of the fishing industry. Using estimates of fish abundance and fish size, we can make predictions about the economic impact of improving the fishery.

Recreational fishing is an important sector of Idaho's economy. In 2003, a study estimated that the fishing industry contributes approximately $450 million to the economy each year through job creation and tourism (Grunder, McArthur, Clark, & Moore, 2008). In Teton County, anglers fished 12,268 days on 9,158 trips, spending an average of $106 per trip for a total of $968,332. In addition to the cost of fishing equipment and supplies, guides and outfitter fees, and access fees, this number also includes money spent on lodging and campgrounds, food and beverages in stores and at restaurants, and transportation, all of which directly impacts the local economy. Anglers also spent an additional $128,657 on fishing licenses and permits in Teton County (Grunder et al., 2008). The Teton River was the most important fishery in the County, with anglers spending a total of $688,068 on fishing-related expenses (**Appendix F**). An improved fishery in terms of more fish or larger fish in the Teton River will likely increase the economic impact as a result of an increase in angler days (Loomis, 2006). If the fishing is better, then we assume that there will be an increase in angler days on the Teton River. As a result, income from trip related expenses will increase, benefiting the local economy.

A study by Loomis (2006) using the contingent valuation method found that for three main stretches of the Snake River in Wyoming and Idaho, each additional fish caught would result in a 64.5% increase in angler days. The same study found that a 25% increase in the size of the fish caught would result in a 66.3% increase in angler days. Improvements in the Teton River fishery resulting in a 65% increase in angler days would generate about $447,200 of additional revenue for the local economy. It is also possible that increased flow will benefit fisheries below the Teton Canyon and in the Henry's Fork River, as well. The extent of this potential benefit would depend on how much streamflow levels are reduced by pumpers in and below the Canyon, which is beyond the scope of this analysis.

It is unlikely that changes in river temperature from recharge would have the impact on fish catch or size mentioned above. However, even with a modest 5% increase in angler days, associated spending would increase by about $34,400. Furthermore, there is a diminishing marginal effect of improvements, which means that the first small increment of improvement in the fishery is likely to have a larger effect than a second increment of the same magnitude (Loomis, 2006).

3.2.3 Other Recreational Benefits

In addition to fishing, there are several other recreational values of a healthy wetland and riverine ecosystem in Teton Valley. These substantial economic benefits and sources of community income are dependent on maintaining the physical habitat and other components of river and wetland habitat. Incompatible land uses, decreases in water flow at critical times, and deterioration of water quality can put these substantial economic values at risk. Conversely, using recharge to decrease variability of late-season water supply from springs can help to ensure ecosystem and economic resiliency.

In addition to fishing, boating and hunting are also popular recreational activities in Teton Valley. However, it does not appear as though incidental recharge will provide a significant economic benefit to either industry. While there is a commercial boat rental company in Driggs, it is unlikely that the popularity of floating the upper Teton River will change much with increasing flow. The upper Teton River is meandering flatwater, which people enjoy floating at all stream levels. Downstream, the Teton Narrows are popular for whitewater kayaking but are accessed mainly by private boaters, with no rafting companies running that section of the river. Therefore, while individual boaters may value higher flows downstream, the overall realized benefit would not be large and would not contribute significantly to the local economy. Hunting will also be largely unaffected by river flow and any benefit to waterfowl will be accounted for in a wetland valuation.

Wildlife viewing is another popular form of recreation in Teton Valley. A 2006 study by ECONorthwest estimated that an individual's WTP for wildlife viewing was $15/day with an average of 46 days per individual in the Intermountain West region. Average consumer surplus per person per day for wildlife viewing on public land was estimated at $37.24 from 1967 to 2003 (ECONorthwest, 2006). There is little data regarding the number of people visiting Teton Valley to view wildlife. While it may be possible to get a proxy for these numbers from other reported data (either on visitors to the region or values for wildlife viewing in other areas), it may be easier to simply include these values in the benefit to wetland habitat, as the majority of wildlife viewing takes place on the wetlands.

3.2.4 Wetland Benefits

Together, the distinctive hydrology, agricultural land use, and other factors create exceptional wildlife habitat in Teton Valley. The wetlands provide breeding habitat for 19 species of waterfowl, many of which are considered Species of Conservation Concern by various state and federal agencies (**Appendix G;** Idaho Department of Fish and Game, 2012). Waterfowl utilize the Teton River, its tributaries, and associated wetlands and uplands for nesting, brood rearing, and foraging. The Teton Watershed is also part of the migration corridors known as the Pacific and Central Flyways (Jankovsky-Jones, 1996). In fact, Teton Valley wetlands serve as one of the largest staging grounds for sandhill cranes migrating south to New Mexico in September.

The wetlands also provide critical habitat for other bird species. Approximately 39% of Idaho's conservation priority bird species depend on riparian and marsh wetlands at some point throughout the year (Idaho Department of Fish and Game, 2012). Species of Greatest Conservation Need include not only sandhill cranes, but also trumpeter swans, nesting long-billed curlews, and the sharp-tailed grouse, all of which utilize habitat in Teton Valley (**Appendix G**). Additionally, the National Audubon Society and Idaho Department of Fish and Game (IDFG) formally designated Teton Basin as a state Important Bird Area for maintaining bird populations (Idaho Department of Fish and Game, 2012).

Wetlands also provide valuable ecological functions, goods, and services, including hydrological functions, water quality functions, and functions related to direct human utilization (**Appendix H**). These functions contribute to the quality of life enjoyed by residents and visitors by improving the well-being of the people who live, work, and visit the area.

Economic Benefits of Healthy Wetlands

A portion of the groundwater recharged in the shallow aquifer will emerge in springs in the wetlands. Therefore, incidental recharge will help to maintain important wetland habitat and increase resiliency by buffering against annual variability and dry years.

In order to determine the economic benefit to the wetlands from incidental recharge, we first looked at the value of wetland functions, goods, and services. Based on a series of 39 studies from urban and coastal areas, ECONorthwest (2006) found that, on average, wetlands providing bird-watching opportunities produced services that increased the value of the land by about $1,800/acre. As mentioned in Chapter 1, 26,760 acres of Teton County are classified as wetlands (Idaho Department of Fish and Game, 2012). Therefore, wetlands in Teton County may provide up to $48.2 million in ecosystem services.

While recharge will not add much additional wetland area, it may help to maintain wetland area and, therefore, the services they provide. This would be especially important during dry years, in which wetlands may dry out by July or August and cease to provide these services. We examined streamflow in the Teton River near Driggs, and found the average one-year total flow to be 280 KAF from 1981-2010 (**Appendix I**).

Using this data, we classified dry years as those with an average below 250 KAF (National Resources Conservation Service, 2018).

This analysis determines the value of wetland functions for two months in dry years. Between 1962 and 2017, 19 years were considered to be dry years, amounting to 34% of the years examined. Because we believe value will only be added during July and August, the percent of the year that those dry years stand to benefit from additional water is 17%. Therefore, we believe that about 5.8% of the time (17% x 34%), recharge could add to the value of wetlands by extending services into July and August, when they otherwise might have dried out. Based on these assumptions, recharge may increase wetland habitat value by as much as $2.79 million by ensuring the resiliency and keeping water in wetlands during dry years so that they can continue to provide valuable services.

This method of estimating wetland value is based on a number of assumptions and incomplete data and, therefore, should not be considered final. Instead, this value should be used as a starting point to demonstrate the overall significant value that wetlands have and help to convince non-profits and other investors that there are significant benefits associated with incidental recharge.

3.3 Conclusion

There is great potential for an incidental groundwater recharge program in Teton Valley to provide ecosystem, recreational, and financial benefits. However, the full benefits will not be realized if incidental recharge does not adequately augment streamflow in the Teton River enough to keep junior water rights in priority. Small amounts of increased flow may still provide some benefits to wetland and riverine ecosystems and those who use them, but farmers will only begin accruing financial benefits from augmented flow when there is enough additional water in the river to push back the priority date.

Chapter 4: Recommendations

CHAPTER 4: Recommendations

4.1 Recommendation Overview

In addressing the first two objectives, we found that conducting incidental recharge in Teton Valley is hydrologically feasible, and has the potential to be cost-effective, and environmentally beneficial with the implementation of sufficient recharge. Crucial first steps will be to prove the connection between incidental recharge and augmented river streamflow, and to garner broad-based community support for the program. In order to achieve the requisite participation threshold, we recommend a three-stage incidental recharge program:

- Stage 1: the original pilot project,
- Stage 2: a non-profit phase-in period,
- Stage 3: final expansion to include farmers and other community members as funders of the program.

Each of the three stages will be discussed in greater detail.

4.2 Justifications for Recommendation Design

The original idea for this project was to establish a market through which farmers are paid to run water through their irrigation canals between April 15th (when their water rights come into priority) and May 15th (when they typically begin utilizing water for the growing season). This market was predicated on the assumption that downstream farmers would be willing to pay the upstream farmers for the resulting increases in "late-season" summer flow which would delay the call going on the river and allow farmers to avoid renting expensive storage water.

Water markets are a powerful tool to adequately value water and move it from low to high economic value uses. While we believe that a traditional market of this nature is possible and appealing in the long run, we have determined that it is not feasible at program creation. There are three main impediments to a traditional market:

1. increased streamflow from recharge is not fully specified or exclusive;
2. there is not a sufficient number of market participants to come together to transact with one another;
3. there is no way to exclude freeriders.

In a fully-functioning market, property rights must be fully specified, exclusive, enforceable and enforced, and transferable (Contor, 2010). While there are scientifically-robust estimates of the additional streamflow that would result from incidental recharge, we have not yet seen this in practice. The market would be, at this stage, incentivizing a management change by shifting the diversion of water a month earlier in the season. While the theoretical concept is simple, the quantifiable effect of recharge on river flow is not. This adds considerable uncertainty to the transactions between farmers (see **Appendix J**, Colorado Big-Thompson for an example of a successful market with clearly defined property rights.)

Another critical aspect of a traditional market is the concept of thickness – "that is, they need to attract a sufficient proportion of potential market participants to come together ready to transact with one another" (Roth, 2010). As a result of the limitations mentioned above, downstream farmers are unlikely to be willing to pay for this benefit until the positive impact of augmented streamflow is clearly demonstrated to them. It will also be necessary to prove to other potential sellers that undertaking this behavior change is easy and inexpensive with the potential for significant financial returns. In the current state, this market is lacking willing participants, both potential buyers and sellers. As will be explained in more detail in the following section, we recommend extending the pilot project to allow more data collection and observation before seeking out potential buyers and additional sellers. (see **Appendix J**, Eastern Snake Plain Aquifer for an example where there is sufficient market thickness).

Additionally, even if the benefits of incidental recharge were readily apparent, there is no way to exclude freeriders. Freeriders are the individuals who will benefit from the action without having to pay for it. Additional water will augment flows in the Teton River, thereby delaying the call date from downstream irrigators. This will benefit every farmer with junior water rights on the Teton River and its tributaries, but there is no way to ensure that all those receiving the benefits are contributing to cover the costs associated with doing the recharge. Farmers have an incentive to allow others to pay for the incidental recharge because they may still reap the benefits. In many cases, buyers or sellers may not even know this is happening. (see **Appendix J**, Pajaro Valley for an example of a recharge program that has successfully excluded freeriders).

In order for a traditional market to work in Teton Valley, there will need to be considerable buy-in from the community. This will not be possible unless we can demonstrate that the benefits of participation exceed the costs and the benefits and costs are direct and exclusive.

While developing a traditional market is not feasible for Teton Valley, there are alternative methods for managing common pool resources (CPR). CPRs are defined as "natural resource systems that are sufficiently large as to make it costly (but not impossible) to exclude potential beneficiaries from obtaining benefits from its use" (Ostrom, 1990). Augmented streamflow in the Teton River is a CPR because the benefits of the additional water are diffuse and the costs are only borne by a few. We used Elinor Ostrom's model, in which communities organize themselves voluntarily to manage CPRs, to inform our final recommendations for creating a management change incentive program to augment Teton River flow in the late season. By applying the principles of Ostrom's model, we believe it is possible to improve the flow of the Teton River via a community-run initiative without the exchange of private property rights or traditional market mechanisms.

Ostrom outlines seven principles for designing a successful CPR management initiative:

1. Clearly define the boundaries of the resource
2. Match rules governing use of the common resource to local needs and conditions
3. Ensure that those affected by the rules can participate in modifying the rules
4. Monitor use of the resource
5. Establish graduated sanctions for rule violators
6. Create mechanisms for conflict-resolution
7. Ensure that the right of the community to self-organize is not challenged by external governmental authorities

In developing our recommendations, we drew inspiration from Ostrom's seven principles and applied them to our working knowledge of Teton Valley gathered via literature review, interviews, and on-site visits.

In successful CPR institutions, individuals who have the right to withdraw from the resource must be clearly defined (Ostrom, 1990). If the specification of who is allowed to use a resource remains uncertain, locals face the risks that their efforts will be exploited by outsiders. Idaho water law clearly defines who (and in what quantity) is allowed to divert from the Teton River for irrigation (see Chapter 1: Idaho Water Law). All three stages of our recommendations therefore adhere to Principle 1 because those who can use the resources are legally delineated.

Principles 2 and 3 highlight one of the key benefits of a community-based CPR institution: the ability for stakeholders impacted by the rules to help shape the rules based upon the physical, cultural, economic, and political relationships that exist within the community. The Teton Valley community is a small, tight-knit community with high social capital. Because they have a common interest and understand the needs of the valley, they can be highly effective rule-makers. We recommend that farmers participating in incidental recharge be the key decision-makers of how benefits and costs of the initiative are distributed. These individuals are the most acquainted with the local culture, law, economics, and politics of the region and are best equipped to create appropriate and salient rules for governing incidental recharge incentives in Teton Valley.

Ostrom emphasizes in Principle 4 that successful CPR institutions must have monitoring and compliance efforts run by internal stakeholders rather than external enforcing bodies. Monitoring is critical to achieving sustainable programs. Internal monitoring ensures that farmers are willing to participate because they perceive that the collective goal is being achieved and that others are also complying. Specifically, we recommend that the incidental recharge program operate within the confines of the already established irrigation districts in the area. These irrigation districts already monitor the volume of water allocated to each member during the irrigation season to ensure fair fee payments. In addition to working with the irrigation districts, we also recommend that a board of directors be established to manage the program overall, including monitoring recharge practices.

In Principle 5, Ostrom discusses the importance of establishing graduated sanctions for rule violators. We recommend that payments not be distributed to farmers doing recharge until after recharge activities have been conducted. If farmers do not fulfill their obligation to meet expected recharge quantities, payments will be withheld.

All common pool resource management schemes will face conflict between members. According to Ostrom, having rapid and low-cost access to mechanisms for conflict management is key for long-term program sustainability. We aim to provide an arena for fair, robust, and quick conflict resolution by creating a governing board of directors. In addition, by recommending that the board of directors have a diverse membership representing all types of participating members, conflict can be mediated in an objective and inclusive manner.

Finally, a successful CPR institution must allow community members to self-organize without interference from governmental authorities. Because farmers will be operating within the scope of their existing water rights, it will not be necessary to legally change any rights. Therefore they can determine the most appropriate use of their water right without a need for government intervention.

Because of the high potential for market failure and the applicability of Ostrom's seven principles for managing common pool resource institutions, we recommend an incidental recharge program that more closely resembles Ostrom's management scheme than a traditional market. We believe the program would be best managed by water users in Teton Valley and should be built up in three stages, moving from a pilot project to a valley-wide program.

4.3 Detailed Recommendations

Securing community support will be paramount in the success of this program. We believe that the only way to have a noticeable impact will be to maximize the amount of area used for recharge. We also believe that it will take time to demonstrate the connection between the recharge and augmented streamflow, and therefore the benefits to potential participants. As explored in **Appendix B**, there is considerable natural variability in the magnitude of annual snowpack, and therefore variability in amount and timing of streamflow. The engineer of the model we are using believes that it will take five years to be able to discern the impact of the recharge on augmented streamflow and distinguish it from natural variation (Van Kirk, 2017). For this reason, we recommend building upon the pilot project into three distinct, incremental stages:

- Stage 1: the original pilot project,
- Stage 2: a non-profit phase-in period,
- Stage 3: final expansion to include farmers and other community members as funders of the program.

Stage 1: Pilot Project (Years 1 and 2)

We recommend moving forward with the two-year pilot project involving Trail Creek

Sprinkler Irrigation Company and Garden Water Company. This phase will be funded by the $30,000 grant the TWUA received from the Columbia Basin Water Transaction Program (Lien, 2017). This funding will be used to reimburse participating farmers for the direct costs of conducting incidental recharge on their properties (see Chapter 3: CBA). The pilot will give critical insight into the feasibility and ease of changing the timing of farmers' diversions. As with any nascent project, there will likely be stumbling blocks and unforeseen challenges that arise during the pilot. For example, there may be complications with running canals earlier, as snow and ice might limit the amount of potential recharge that can be done in the early season. Also, this will be the first time loggers at the diversion headgates will be used, and with any new equipment, there may be an experimental period. There is not an established system or central clearinghouse for recording the measurements from the loggers. Knowing the amount of water actually recharged will be critical in determining how much to pay participants. Understanding and addressing these issues will be crucial in building the program moving forward. Additionally, there may be other unexpected challenges that have not yet been identified. It will be necessary to take into consideration feedback from stakeholders throughout the process to further develop the future structure of the project.

At this time, we recommend pursuing incidental recharge through canal seepage. This is a conservative approach to avoid possible consequences of crop damage and groundwater contamination due to fertilizers and pesticides. We want to make this program as attractive as possible and fear that the potential for crop damage and groundwater contamination could drive away potential participants and funders. However, marginal pastureland may also be a viable option. Many farmers previously flood irrigated marginal pasturelands, most of which do not utilize fertilizers and pesticides. Therefore groundwater contamination should not be a concern.

We also suggest using a 30-day period of recharge, from April 15th to May 15th. Farmers generally begin diverting for irrigation in early to late May, depending upon the winter snowpack and spring temperatures (Bagley, 2018). Using May 15th as an average start date, we assume that the farmers' canals will convert to their primary purpose of transporting irrigation water and no longer be used for incidental recharge. That said, there may be additional capacity in the canals to continue a small amount of recharge while the farmers are diverting for irrigation.

Using the two irrigation districts' existing canals for 30 days, we make a conservative estimate that there will be 2,800 AF of recharge (see Chapter 2: Modeling the Effect of Incidental Recharge on Streamflow). This recharge amount is based on canal area estimates from 10 years ago and may be outdated. In order to better determine the capacity for recharge, it will be imperative to update this data. FTR has undertaken the first step towards remedying this problem by commissioning a project to map existing canals in the valley (Verbeten, 2017). In addition to understanding exactly where the active canals are, it will be important to know which canals are lined and unlined as well as where there are inactive canals that can be brought back online for the purpose of incidental recharge.

Although the amount of recharge anticipated from the pilot project will not augment flow enough to have a significant impact on farmers or ecosystems, this finding should not discourage the pilot project. The pilot project will be a critical phase of the program, demonstrating the ease and cost with which participants are able to divert earlier, the amount they can physically divert and therefore recharge, and the observed flow augmentation in the Teton River later in the season.

Robust monitoring to quantify the effect of recharge on augmented flow in the Teton River will be paramount. While we are able to simulate and estimate the impact of additional recharge, proof beyond the modeling will be necessary to garner widespread community support. Monitoring efforts must include the precise amounts of water diverted and recharged from each location, as well as streamflow and water temperatures in the Teton River throughout the year, particularly April through October. We envision Friends of the Teton River being contracted by the administrative body to take on this monitoring role. This is an innovative program and as such it will be necessary to learn by doing; this information will be used to better understand the impacts of the program and to inform necessary changes to the program moving forward.

Stage 2: Non-Profit Support (Years 3 and 4)

Capitalizing on the demonstrated success of the pilot project, the next step will be to secure additional non-profit funding to cover a portion of the costs associated with the recharge effort. These contributions could help compensate farmers to expand the amount of area being used for recharge. LWG should take on the critical task of seeking out and securing non-profit support in this stage. In addition, LWG will need to establish a program structure to facilitate the smooth transition into future years of the project.

As mentioned in Chapter 3, the wetlands and riparian ecosystem initially stand to be the largest beneficiaries of augmented flow in the Teton River. This project's cost-effective and positive impact on instream flows and wetland habitat aligns with the mission of several local and national non-profits that could be willing to further fund the project. Based on personal conversations and anecdotal evidence, we believe that local environmental non-profits will be willing to contribute to such a program. For example, in recent years, Henry's Fork Foundation (HFF) has paid farmers to fallow their land and thereby keep more water in the river (Van Kirk, 2017). The Teton River is a tributary of the Henry's Fork, which would, therefore, benefit from additional flow. Paying farmers to restore more canals, and incorporating more marginal rangeland, could increase incidental recharge enough to make a difference. This will likely be cheaper than paying to fallow land. Therefore, although recharge may not provide immediate benefits, we think non-profits like HFF can see the potential and be willing to contribute.

We also believe there is potential to engage with environmental non-profits outside of the region that have larger budgets and wider geographic scopes. Targeted partners would be those whose missions stand to benefit from the positive impacts on increased

Teton River flow, fish populations, and wetland ecosystems. Two national organizations that have already funded similar projects include The Nature Conservancy and Trout Unlimited. The Nature Conservancy (TNC) funded the national Sustainable Rivers Program focused on increasing environmental flows for fish in 11 rivers throughout the United States via changing floodplain management practices (The Nature Conservancy, 2018). In addition, Trout Unlimited actively partners with agricultural communities and farmers throughout the western United States to change irrigation usage and timing to keep needed flows in the river for sensitive fish populations (Yates, 2018).

Stage 3: Community Support and Farmer Buy-In (Year 5+)

After using the two-year pilot and subsequent non-profit funded phase as a demonstration period, we envision enough community support in Year 5 to begin engaging farmers as paying participants. The hope is that these farmers will have been receiving financial benefits from increased availability of late-season irrigation water and will therefore be willing to pay into the program to ensure continued benefits. Echoing the importance of the need for local support and trust for the program, we recommend working with and through the existing community structures of irrigation districts and canal companies. These entities are well established, respected, and trusted. Their boards and governing bodies have the power to make decisions that engage the group, and therefore all of their members.

We envision that at this stage, LWG will turn over management of the program to a local governing body. TWUA could fill this role; the organization includes representatives from multiple stakeholders such as non-profit organizations and farmers. Also, because LWG is a part of the TWUA, they will be able to help facilitate this transition. TWUA oversight would ensure farmer and non-profit participation, further strengthening community support. TWUA will contract specific recharge volumes, but not exact recharge locations, thereby giving irrigation districts critical flexibility. This framework allows each district to strategize which farmers' canals and locations within their organization would provide the most beneficial impact for the lowest maintenance cost. Contracting directly with irrigation districts reduces the transaction costs of running the program and gains much needed trust from farmers. Irrigation districts already handle the collection of dues and fees and can easily distribute credits or payments to participating farmers based upon the proportion of recharge conducted on the farmers' property. We envision a platform similar to that outlined in Figure 4.1.

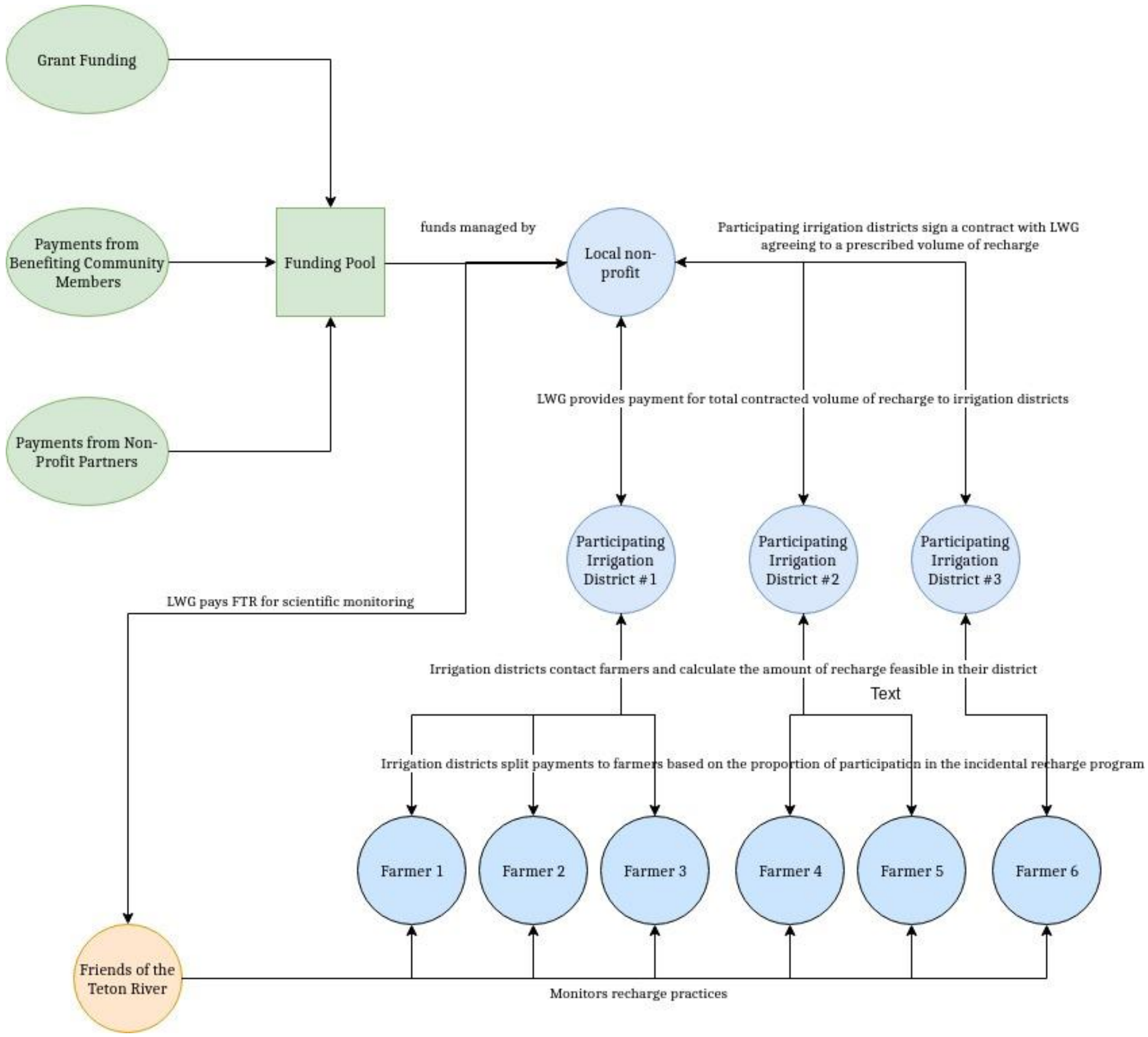


Figure 4.1: *Suggested community-based management platform for incidental groundwater recharge in Teton Valley, Idaho.*

By Stage 3, if we are able to demonstrate that it is feasible to increase incidental recharge enough to significantly benefit farmers, we think farmers will be incentivized to participate in and contribute funding to the program. Farmers that would have typically needed to pay for storage water to make it through a dry irrigation season would spend less to support this program than they would buying storage water. As detailed in Chapter 3, we estimate payments ranging from $1.61/AF to cover farmers' costs to $3.07/AF to cover farmers' costs and program administration (see Chapter 3: CBA). When compared to at least $6/AF farmers are paying for rental water, we imagine this program will be an attractive and cost-effective alternative for farmers to keep water in the Teton River and delay the call. Because of this financial benefit, we believe that in addition to non-profit contributions, farmers will eventually be willing to contribute to the larger funding pot for the project.

Other beneficiaries in the community may also be willing to provide financial support for the recharge program. Local businesses that depend on sufficient flow in the Teton River (for example outdoor adventure outfitters, fishing guides, and rafting tours) may be incentivized to contribute funding. This engagement likely won't begin unless the positive impacts of the program on streamflow are verified.

4.4 Limitations

While we think this three-stage program will allow for the transition from a pilot project to a self-sustaining program, it is not without problems of its own. Principally, it does not completely eliminate the potential for freeriding. However, by involving participants on the scale of irrigation districts and canal companies, we can rely on the strength of moral norms and social pressure, as outlined by Elinor Ostrom's principles. Additionally, if the benefits of augmented streamflow and therefore delayed call dates can be proven through monitoring, we believe the incentive to participate will be large enough to overcome some freeriding problems.

Another challenge is that this program may face funding limitations until the physical effects of the incidental recharge can be observed and verified in the river. Farmers who benefit from increased late-season flow may not see physical results in the river for two to five years. For this reason, we believe that the program will need to be supported by grants initially before it can be sustainably funded by farmers and non-profit partners.

Finally, we believe that it will be difficult to recharge enough water through just unlined canals to reach the critical threshold at which notable benefits will accrue to farmers. In order to reach that threshold, we will need to expand to more than just the existing canals. Decommissioned canals and marginal pasturelands could be used for this expansion. We think that with great effort and due diligence, a critical threshold of recharged water could be reached. In order to benefit the farmers, we recommend conducting recharge to the greatest extent possible; however, even small amounts of recharge can positively impact the wetlands and riparian ecosystems.

Conclusion

Teton Valley is a small, agrarian community that depends on sufficient streamflow in the Teton River to support its agricultural economy and unique biodiversity. Adequate late-season flow in the Teton River is critical for summer irrigation of crops and provides critical habitat for river and wetland species. Changes in irrigation practices and increases in snowpack variability have altered the flux of groundwater in the Valley, thereby changing the hydrologic regime of the Teton River. Our client, LegacyWorks Group, charged us with the task of assessing the feasibility of augmenting late-season streamflow by designing a market to incentivize incidental groundwater recharge in Teton Valley.

To address our client's goal, we formed and answered three main research objectives:

Objective 1: Model hydrologic conditions to determine the potential impact of recharge on streamflow and temperatures in the Teton River (addressed in Chapter 2).

Key findings:

- Modeling indicates that incidental groundwater recharge is hydrologically feasible in Teton Valley. Approximately 29% of the water recharged will discharge into the Teton River during the critical late-season period.
- The greater the number of participants conducting incidental recharge in their canals, the more outflow there will be to the Teton River. If the entirety of Teton Valley's canals are utilized, it is possible to see approximately a 14% increase in late-season baseflows of the Teton River.
- Certain areas of Teton Valley are better suited for conducting incidental recharge. These areas were evaluated based on the distance from the Teton River, hydraulic conductivity, and total miles of canal available for recharge.
- There is a significant negative correlation between streamflow and water temperature. Therefore, with higher flows in the Teton River, we can expect lower water temperatures. Our model predicts that the greatest decrease in temperature will occur at the end of August when streamflow is lowest (about a .7°C change), indicating that recharge could play a vital role in decreasing late-season water temperatures in dry years.

Objective 2: Quantify the economic and environmental impacts of augmented streamflow, including the costs and benefits of conducting incidental recharge (addressed in Chapter 3).

Key Findings:

- Buyers in an incidental groundwater recharge program in Teton Valley would need to pay $1.61/AF to cover farmers' costs or $3.07/AF to cover farmers' costs and the cost of program implementation. On a per acre-foot basis, we found these costs to be less than the current price paid for stored water in June-August.

- The primary environmental benefits associated with incidental groundwater recharge include improved fishery health, increased outdoor recreation opportunities, and more resilient wetland habitat, that will benefit the local economy.

- Modeling the relationship between streamflow and the last water right in priority predicts that approximately 58.8 cfs of additional discharge are needed to move the last date in priority by one year. Because it will take a large volume of recharge to reach this level of additional flow, this finding further emphasizes the importance of having a greater number of participants.
- Due to the threshold of participation necessary for farmers to reap the benefits of recharge, recreation and ecosystem benefits will play an important role in the early stages of the project, as they can start to accrue with a smaller volume of recharge.

Objective 3: Design a framework for incentivizing groundwater recharge to augment late-season streamflow in the Teton River.

Key Findings:

We conclude that because 1) augmented flows are not fully specified or exclusive, 2) there is not a sufficient number of market participants, and 3) there is no way to exclude free riders, our client's original goal of developing a traditional market is not feasible. Our final recommendation is to implement a community-based resource management program implemented in these three stages:

- Stage 1: Pilot project continuation. The main purpose of the pilot project should be to demonstrate the feasibility of doing incidental recharge and to better understand the physical and financial challenges that farmers may face in conducting incidental recharge.
- Stage 2: Non-profit phase-in period. Only by conducting a significant amount of recharge will benefits be sufficient to incentivize farmers to buy into the program. Non-profits interested in funding the earlier accruing benefits to the local fisheries and wetlands will be a critical partner for keeping the program alive until there is an incentive for farmers to participate. They may also play a crucial role in providing funding to expand recharge areas and, therefore, increase the impact of recharge.
- Stage 3: Community support and farmer buy-in. After the completion of the two-year pilot and non-profit expansion stages, we believe there will be enough physical evidence of augmented streamflow in the Teton River to rally farmer and community support to contribute funding for incidental recharge. At this point, we envision that the farming community will pay the costs of incidental recharge themselves and manage payments via trusted and established irrigation districts and canal companies.

The results of this project demonstrate that we can expect incidental groundwater recharge to augment streamflow in the Teton River, which in turn has the potential to provide benefits to farmers and ecosystems in Teton Valley. However, the anticipated magnitude of recharge may not be adequate to alter the hydrologic regime enough to see substantial benefits. For this reason, we recommend our client first assesses the feasibility of gaining widespread participation in the program before pursuing this program as the primary mechanism of augmenting streamflow in the Teton River. That said, if enough participation can be garnered and enough water recharged, we believe this program will demonstrate that agricultural landowners can provide protection and benefits to their local communities while increasing their own profitability.

Appendix A: Water Demand

After crop irrigation, the next largest consumer of water is municipal and residential demand which accounts for about 2% of total water demand. The upper watershed encompasses the cities of Driggs and Victor, both of which rely entirely on groundwater to provide water to their residents. Driggs utilizes seven wells and one groundwater spring (Aqua Engineering, 2014); Victor utilizes seven wells and one groundwater spring (Idaho Department of Environmental Quality, 2016). Average upper watershed residential demand is 265 gallons per capita per day (GPCD), well above the statewide average of 170 GPCD (Donnelly & Cooley, 2015). This could be explained by high outdoor irrigation for lawns due to low population density and therefore large properties in the upper watershed. The remaining 1% of water demand in the upper watershed is for livestock watering, golf course irrigation, and mining.

The lower watershed of the Teton Basin is also characterized by extensive agriculture, which accounts for 97% of all water demand. The mix of crop types is notably different from the mix in the upper watershed due to the lower elevation and slightly-longer growing season. The main crops found in the lower watershed are spring wheat, barley, and the Idaho potato. These farmers also rely heavily on irrigation, with 78% of irrigation water coming from surface water and 22% coming from groundwater withdrawals (U.S. Geological Survey, 2014). Crops in the lower watershed consume slightly more irrigation water than those in the upper watershed, at an average of 40.8 inches per acre per year (U.S. Geological Survey, 2014).

Municipal water use represents the next largest source of water demand at about 3%. The lower watershed includes the City of Rexburg, the most populous city in the Teton Basin. Rexburg relies entirely on groundwater pumped from six wells (City of Rexburg, 2017). At 187 GPCD, residential demand in the lower watershed is significantly lower than that of the upper watershed, though it is still slightly above the statewide average (U.S. Geological Survey, 2014). Industry, primarily in the form of crop and food processing, accounts for about 1% of water demand in the lower watershed. Trout-farming operations, mining, livestock watering, and golf course irrigation constitute the remainder of the water demand in the lower watershed.

Appendix B: Snow Water Equivalent

Historical Snow Water Equivalent (SWE) data were examined at three SNOpack TELemetry (SNOTEL) stations near Teton Valley: Grand Targhee, Pine Creek Pass, and Phillips Bench (Figure B.1).

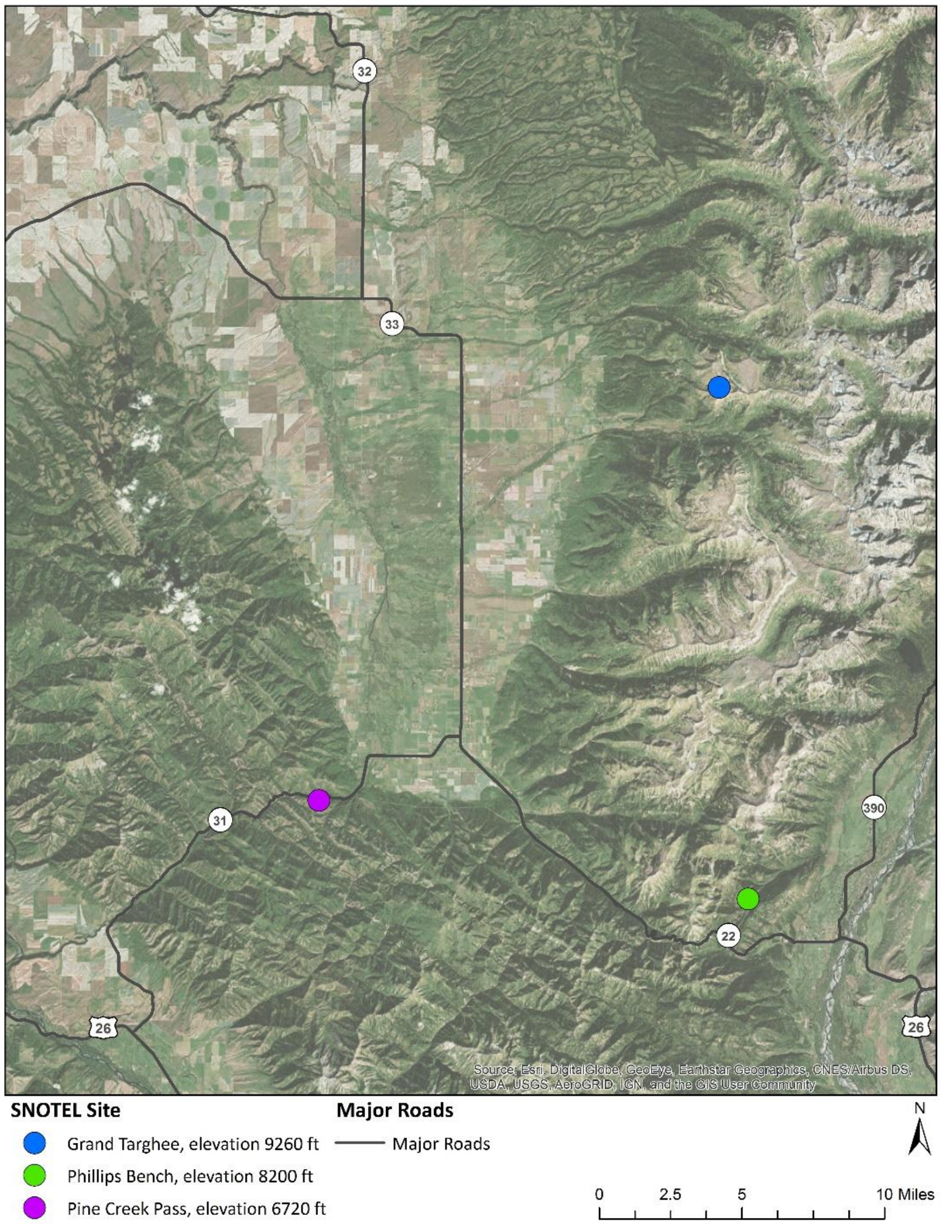


Figure B.1: *Locations and elevations (feet) of three SNOTEL sites near the Teton Valley: Grand Targhee, Pine Creek Pass, and Phillips Bench.*

Over the study periods, peak SWE ranged from 37.8 inches to 72.9 inches at Grand Targhee, from 17.3 inches to 50.4 inches at Phillips Bench and from 9.1 inches to 35.3 inches at Pine Creek Pass (Table B.1) The variability in these peak SWE measurements across the stations is largely explained by the differing locations and elevations. For example, at an elevation of 9,260 feet, the Grand Targhee station is the beneficiary of orographic lift as storms are pushed up against the mountains, causing water to condense and precipitate out as snowfall.

Table B.1: *Elevation (feet), minimum and maximum peak SWE (inches), and minimum and maximum peak SWE dates for three SNOTEL sites near the Teton Valley: Grand Targhee, Pine Creek Pass, and Phillips Bench.*

	Elevation (feet)	Minimum SWE (inches)	Maximum SWE (inches)	Minimum Peak Date	Maximum Peak Date
Grand Targhee	9,620	37.8	72.9	April 18	June 16
Phillips Bench	8,200	17.3	50.4	March 24	May 22
Pine Creek Pass	6,720	9.1	35.3	March 11	May 1

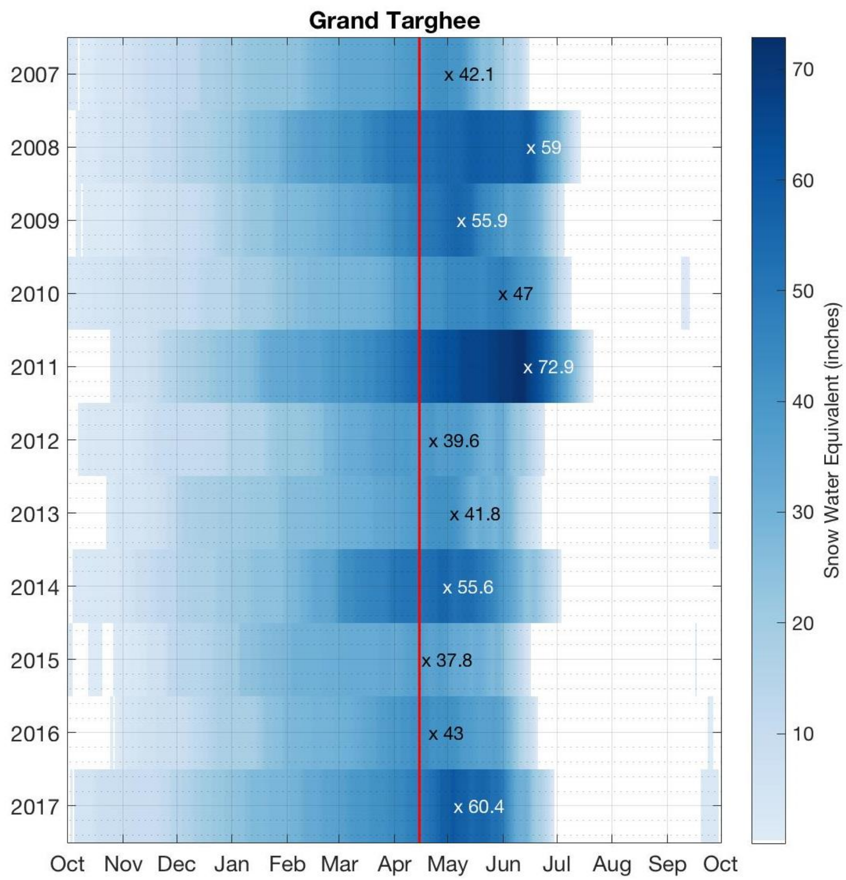


Figure B.2:. *Snow Water Equivalent (inches) at the Grand Targhee SNOTEL station, 2007-2017. Each horizontal bar represents one water year from October 1st to September 30th. The number next to each X represents the timing and amount of peak SWE in that water year. Numbers in white are greater than the median peak SWE value of 47 inches; numbers in black are less than the median peak SWE value. The red line highlights April 15th, when irrigation water rights come into priority in Teton Valley.*

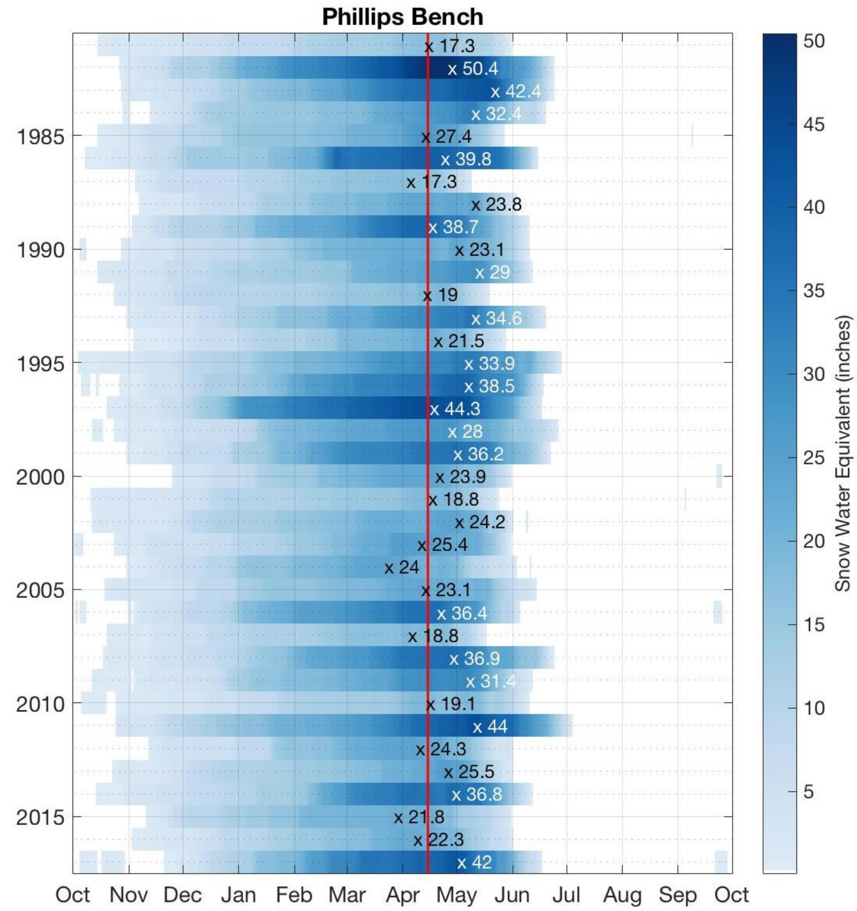


Figure B.3: *Snow Water Equivalent (inches) at the Phillips Bench SNOTEL station, 1981-2017. Each horizontal bar represents one water year from October 1st to September 30th. The number next to each X represents the timing and amount of peak SWE in that water year. Numbers in white are greater than the median peak SWE value of 27.4 inches; numbers in black are less than the median peak SWE value. The red line highlights April 15th, when irrigation water rights come into priority in Teton Valley.*

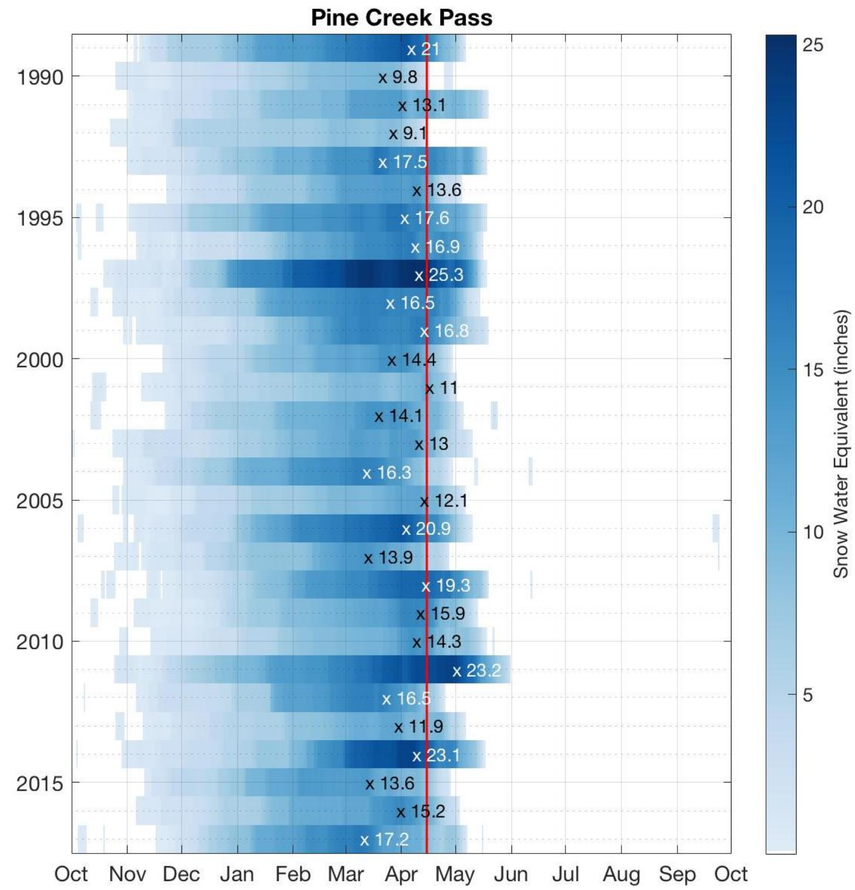


Figure B.4: *Snow Water Equivalent (inches) at the Pine Creek Pass SNOTEL station, 1989-2017. Each horizontal bar represents one water year from October 1st to September 30th. The number next to each X represents the timing and amount of peak SWE in that water year. Numbers in white are greater than the median peak SWE value of 15.9 inches; numbers in black are less than the median peak SWE value. The red line highlights April 15th, when irrigation water rights come into priority in Teton Valley.*

Appendix C: Water Quality

Water Quality Regulations

Section 303 of the Clean Water Act (CWA) requires states to adopt water quality standards pertinent to the different beneficial uses. Water quality criteria include numeric criteria for pollutants such as bacteria, dissolved oxygen, pH, ammonia, temperature, and turbidity, and narrative criteria for pollutants such as sediment and nutrients (Idaho Department of Environmental Quality, 2016). If a water body is unable to support its beneficial use and does not meet the established water quality standards, it is then listed as "water quality limited," reported to the U.S. Environmental Protection Agency (EPA), and added to the 303(d) list of impaired waterways.

Surface Water Contamination

In the Teton Watershed, the primary pollutants of concern are sediment, temperature, and fecal coliform/E. coli. While there are additional concerns with nutrients, sediment is the primary contributor of these nutrients into the aquatic system (Idaho Department of Environmental Quality, 2016). Many of the water quality concerns in the Teton Watershed can be attributed to non-point sources. Cropland and pastureland account for the majority of the land use in the watershed and runoff from these land-use types often contains elevated levels of nitrogen and phosphorus from fertilizers, pesticides, and sediment. Erosion of streambanks and uplands contributes significant volumes of sediment to the streams and rivers within the watershed. Livestock grazing in riparian areas and erosion from roads and cultivated fields are also common sources of excess sediment delivery to streams. Livestock grazing also contributes to E. coli concerns, as bacteria from domestic and wild animals (including deer, moose, and waterfowl) can be significant.

Groundwater Contamination

Despite elevated levels of nitrogen and other nutrients associated with sediment in surface water, studies have shown that groundwater in Teton Valley meets regulatory standards for these and other contaminants. Although people are concerned that groundwater can become contaminated through the percolation of irrigation water on heavily fertilized fields, it appears as though most of the water contamination occurs from overland flow across these fields. It is possible that fertilizer use is low enough and that the soil effectively filters out nutrients so that by the time water reaches the aquifer, it no longer contains high levels of these nutrients.

A study by Cosgrove and Taylor (2007) determined that groundwater contamination is not a great concern in Teton Valley. Furthermore, it showed that nitrogen levels were well below the EPA regulatory limit of 10 mg/L NO_3 as N (Figure C.1). Only 10% of the groundwater samples were between 4.96 and 8.17 mg/L NO_3 as N. All other groundwater samples were below 4.96 mg/L NO_3 as N (Cosgrove & Taylor, 2007a). Because most of the sampled wells were relatively deep, the water quality may reflect water quality deep in the aquifer and not near the surface of the aquifer. It is possible that water near the surface of the aquifer could exhibit higher concentrations of nitrate since both probable sources of nitrate are surface sources (Cosgrove & Taylor, 2007b). Thus, we believe that while further investigation should be carried out to determine any potential impact from increasing groundwater recharge on or near agricultural land, nitrogen contamination does not seem to pose an immediate threat to the region.

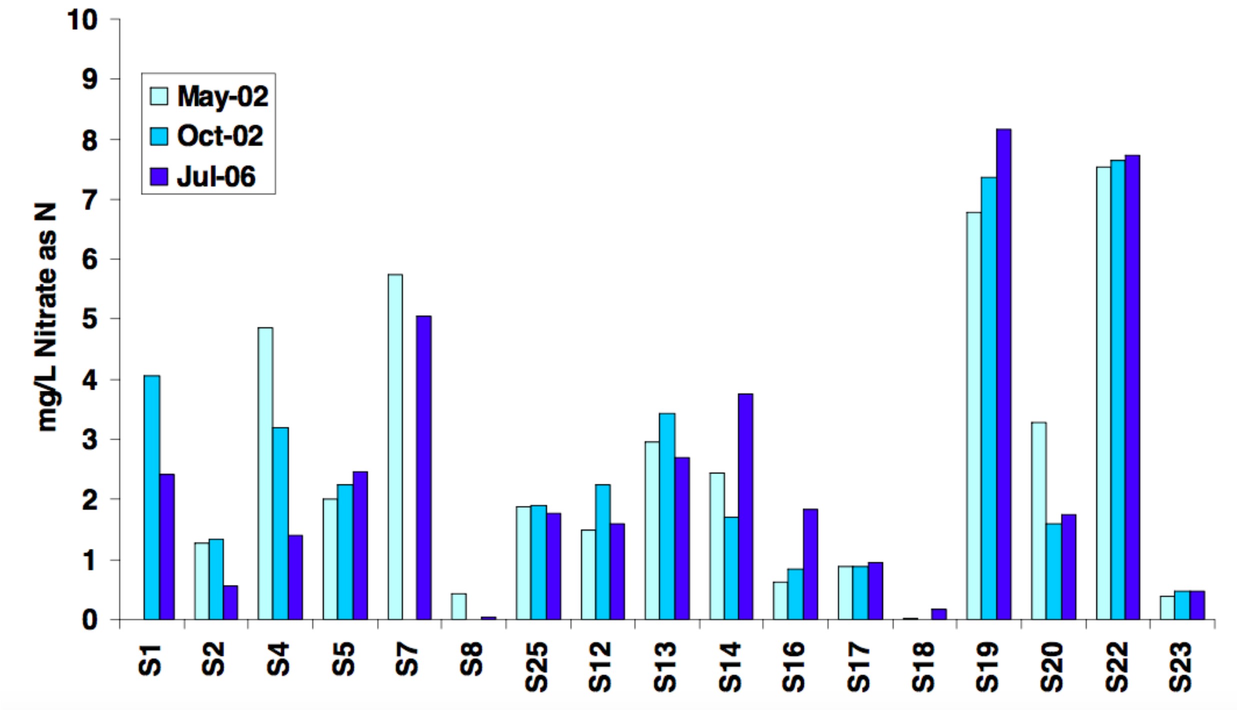


Figure C.1: *Nitrate concentrations at different wells spatially distributed throughout Teton Valley in 2002 and 2006. Source: Cosgrove and Taylor, 2007.*

Appendix D: Teton Valley Groundwater-Surface Water Modeling Results

This appendix includes more detail on the pre-defined scenarios used in the Teton Valley Groundwater-Surface Water Model. Table D.1 shows the irrigation application and canal loss rate assumptions for each of the pre-defined scenarios. Table D.2 includes the mean annual totals, in acre-feet, for the four pre-defined scenarios. The net groundwater recharge that occurs in excess of total pumping is represented in the far right column.

The two scenarios of interest when using canals for recharge are the "Current" and "Piped Canals" scenarios. There is a total contribution of canal seepage to groundwater of approximately 42,000 acre-feet in an average year in Teton Valley. This difference is also reflected in the net groundwater recharge between the two scenarios.

Table D.1: *Irrigation application and canal loss rate assumptions for each pre-defined scenario in the Teton Valley Groundwater-Surface Water Model.*

Scenario	Irrigation Application	Canal Loss Rate (feet/day)
Actual	Conversion from Flood to Sprinkler	3.663
Natural	None	0
Flood Irrigation	100% Flood	3.663
Current	90% Sprinkler	3.663
Piped Canals	100 % Sprinkler	0

Table D.2: *Mean annual totals in acre-feet generated from the Teton Valley Groundwater-Surface Water Model for each pre-defined scenario.*

	Amount of Water Diverted	Evaporation	Canal Seepage	Application Seepage	Irrigated Crop Evapotran-spiration	Surface Flow	Stream Seepage	Net Groundwater Recharge
Actual	92,290	1,063	43,051	11,514	33,161	132,105	63,440	141,187
Flood	201,584	519	67,905	79,731	49,899	57,713	30,252	201,827
Current	92,290	1,239	41,828	11,808	33,921	132,097	63,440	139,121
Piped Canals	92,091	1,772	0	12,057	74,768	138,628	57,806	91,907

As mentioned in Chapter 2.1.3, it is important to note that the “minimum” diversion rates used in the modeling in this analysis are conservative for fear of overestimating the impact of recharge in the beginning stages of this project. Once actual diversion data is collected during the pilot stage, a more accurate method of modeling the impact of recharge should be employed. The Groundwater-Surface Water model requires an input file of daily diversions across the 30-year time series. This file can be manipulated to simulate water diverted starting April 15 on each specific stream from which water is diverted early. Diversion rates derived from observed data during the pilot should be applied to each stream starting on the first day of diversion through the final day of diversion for each year across the full time series. Once actual diversion rates for recharge are recorded during the pilot, the diversion input files over the 30 years will be more meaningful and better informed. An independent "Recharge" scenario can then be constructed using this new input file.

The scope of this project was to analyze the recharge contributions from just using canals. However, expanding recharge to marginal lands, in addition to unlined canals, is a principal recommendation from our results. To provide a more accurate portrayal of the impact of a more complex recharge program in the future, individual "Recharge" scenarios should be modeled using simulated daily diversions specific to each tributary.

Appendix E: Stream Temperature Model Outputs

Table E.1: *Differences in stream temperatures modeled under four different recharge scenarios for the years 1997-2000 (tables in chronological order). Over the course of the summer season (June 21st-August 31st), changes in temperature due to recharge fluctuate. Thus, both the minimum and maximum temperature differences are given in addition to the average temperature difference over the course of the summer.*

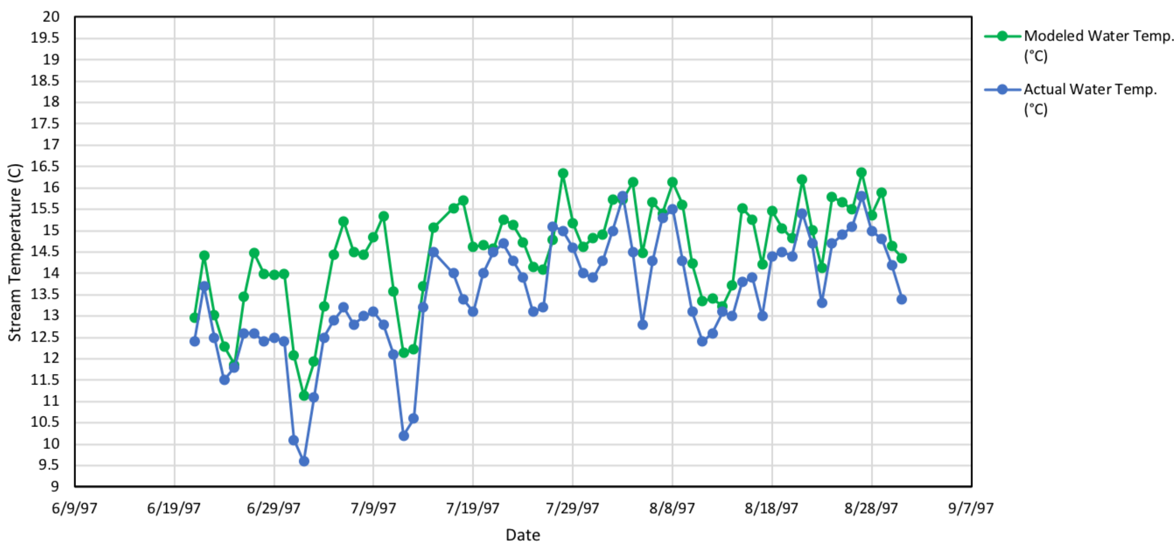
Recharge Scenario	Recharge (acre-feet/year)	Average Temperature Difference (°C)	Minimum Temperature Difference (°C)	Maximum Temperature Difference (°C)
0	0	0.00	0.00	0.00
1	2826	-0.60	-0.60	-0.61
2	5652	-0.61	-0.60	-0.61
3	11943	-0.62	-0.60	-0.63
4	23886	-0.63	-0.61	-0.65

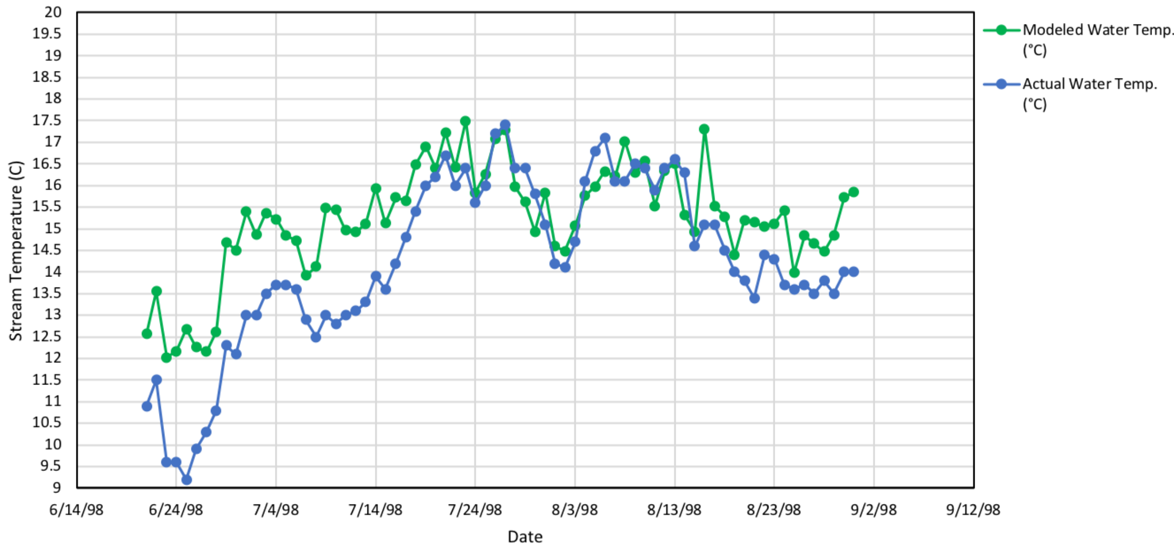
Recharge Scenario	Recharge (acre-feet/year)	Average Temperature Difference (°C)	Minimum Temperature Difference (°C)	Maximum Temperature Difference (°C)
0	0	0.00	0.00	0.00
1	2826	-0.61	-0.60	-0.61
2	5652	-0.61	-0.60	-0.62
3	11943	-0.62	-0.61	-0.64
4	23886	-0.64	-0.61	-0.67

Recharge Scenario	Recharge (acre-feet/year)	Average Temperature Difference (°C)	Minimum Temperature Difference (°C)	Maximum Temperature Difference (°C)
0	0	0.00	0.00	0.00
1	2826	-0.60	-0.60	-0.61
2	5652	-0.61	-0.60	-0.62
3	11943	-0.62	-0.61	-0.63
4	23886	-0.64	-0.61	-0.67

Recharge Scenario	Recharge (acre-feet/year)	Average Temperature Difference (°C)	Minimum Temperature Difference (°C)	Maximum Temperature Difference (°C)
0	0	0	0	0
1	2826	-0.61	-0.61	-0.62
2	5652	-0.62	-0.61	-0.63
3	11943	-0.65	-0.62	-0.67
4	23886	-0.69	-0.65	-0.73

Figure E.1. *Actual and modeled stream temperatures (°C) from June 21st-August 31st for the years 1997- 2000 (in chronological order). The green line shows the modeled stream temperatures and the blue line shows the actual stream temperatures for that time period.*

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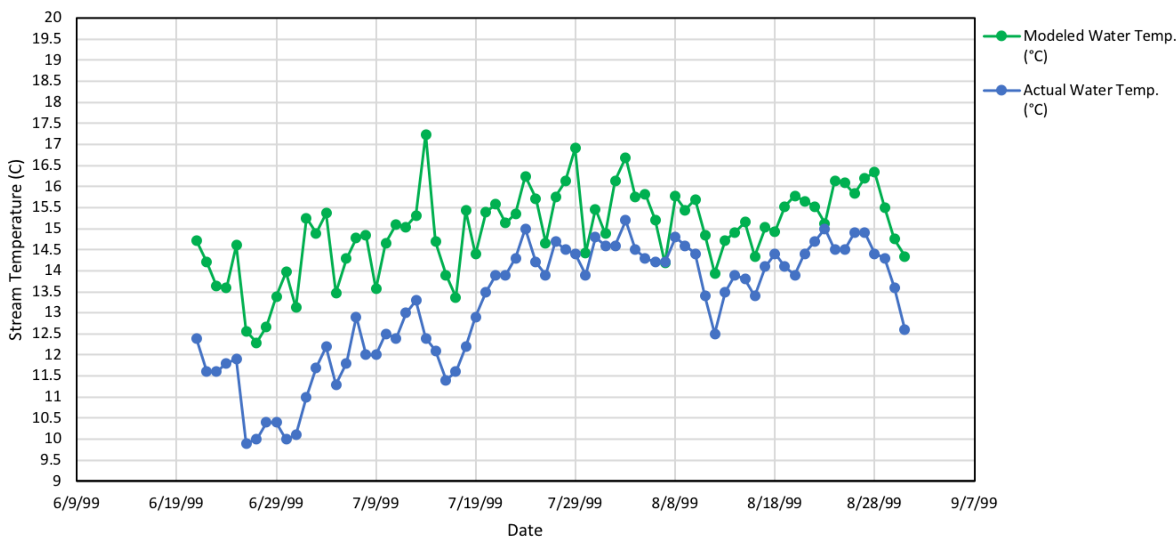
Actual Water Temp. (°C)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Stream Temperature (C)
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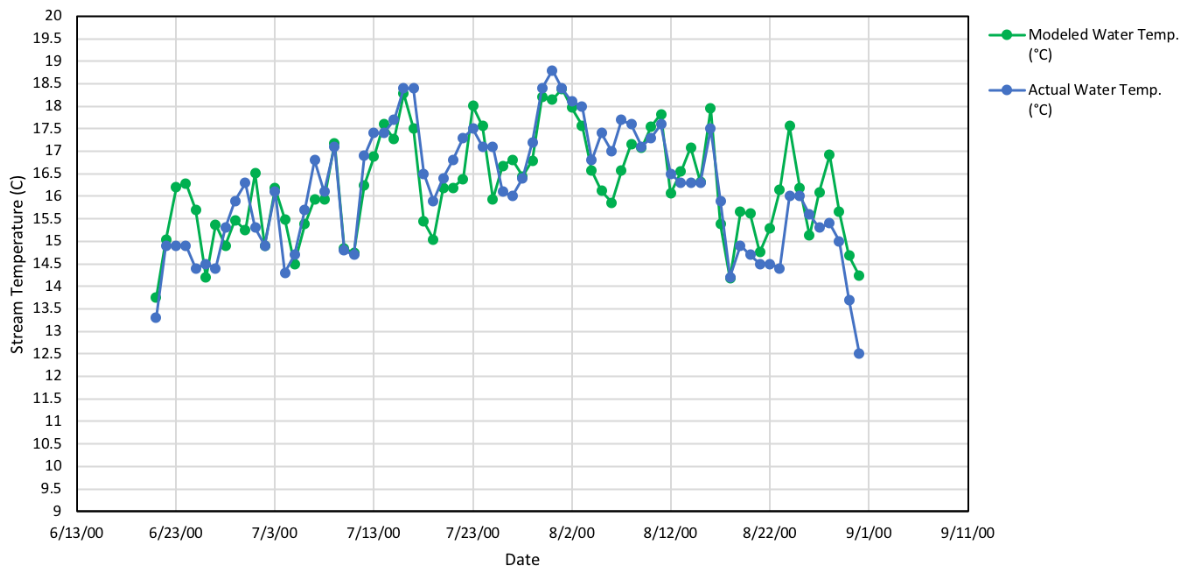
Modeled Water Temp. (°C)
Actual Water Temp. (°C)



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Stream Temperature (C)
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7/13/00
7/23/00
8/2/00
8/12/00
8/22/00
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Date
Modeled Water Temp. (°C)
Actual Water Temp. (°C)

Appendix F: Fishing Expenses

Table F.1: *Breakdown of expenditures before and during a fishing trip. Expenditures are further broken down into amounts spent on the Teton River, in Teton County as a whole, and in the state of Idaho. Source: Grunder et al., 2008.*

		Statewide Totals	Teton County	Teton River
Groceries	*Before**	$70,393,878	$111,968	$96,541
	*During**	$35,634,034	$114,926	$90,188
	Total	$106,027,912	$226,894	$186,729
Restaurants	*Before**	$9,146,659	$5,135	$4,332
	*During**	$33,094,783	$68,777	$34,906
	Total	$42,241,442	$73,912	$39,238
Fishing Supplies	*Before**	$43,766,767	$153,315	$148,689
	*During**	$18,090,390	$163,218	$150,666
	Total	$61,857,157	$316,533	$299,355
Equipment	*Before**	$46,537,648	$32,680	$26,157
	*During**	$13,444,744	$12,640	$1,903
	Total	$59,982,392	$45,320	$28,060
Transportation		$91,115,794	$271,875	$108,150
Guides/Outfitters		$31,495,818	---	---
Motels		$29,358,536	$26,536	$26,536
Campgrounds		$10,008,279	---	---
Access Fees		$5,544,405	$7,262	---
Total Spending		**$437,631,735**	**$968,332**	**$688,068**
Total Trips		2,917,972	9,158	6,824
Average Spending per Trip		$150	$106	$101
Fishing License/Permit Sales		$12,289,806	$128,657	

*"Before" is the amount of money spent "Before" going on a fishing trip and "During" is the amount of money spent "During" a fishing trip.

Appendix G: Waterfowl Habitat in Teton Valley Wetlands

The 19 species of waterbirds that utilize Teton Valley wetlands for breeding grounds are the harlequin duck, mallard, northern pintail, wigeon, northern shoveler, gadwall, green-winged teal, blue-winged teal, cinnamon teal, ruddy duck, lesser scaup, canvasback, redhead, ring-necked duck, Barrow's goldeneye, bufflehead, hooded merganser, common merganser, and Canada goose.

Different species use different types of wetland habitat at different times of the year. Table G.1 highlights a select few waterbirds that can be found in the Foster Slough wetlands and lists their seasonal habitats.

Table G.1: *Seasonal habitats used by selected waterbirds in Foster Slough. Habitats are listed in order of importance. Source: Hook, Salsbury, & Klausmann, 2005.*

Species/Group	Winter	Spring		Summer	Fall
		Migrating	Nesting		
Long-Billed Curlew			Natural and irrigated wetmeadow, cropped pasture	Wetmeadow, emergent marsh	
Waterfowl (Ducks, Geese)	Open water/aquatic bed vegetations	Open water, shallow pools	Residual wetland, upland, and shrub/scrub vegetation	Hemimarsh, open water	Hemimarsh, cut grainfields
Sandhill Crane		Wet meadows, grain stubble fields	Hemimarsh, wetmeadows	Emergent marsh, wetmeadow, upland pasture	Cut grainfields, shallow flooded wetmeadows, upland pastures
Other Shorebirds		Shallow pools/mudflats	Emergent Marsh	Wetmeadows, irrigated pastures and hayfields	Shallow pools/mudflats
Trumpeter Swan	Open water/aquatic bed vegetation				Open water/aquatic bed vegetation

Appendix H: Wetland Functions

Table H.1. *Functions, goods, and services associated with wetland ecosystems. Source: ECONorthwest, derived from Mahan, B. L. 1997.*

Wetland Services
Planetary Ecosystem Functions
Cycle elements (carbon, nitrogen, phosphorous, sulfur, methane)
Stabilize atmospheric conditions
Capture the sun's energy (convert energy to plants and other life)
Sustain biodiversity
Hydrological Functions
Convey surface water
Store surface water
Alter flood flows
Recharge aquifer
Discharge groundwater back to streams
Water Quality Functions
Stabilize and entrap sediment
Sediment/toxicant retention
Remove nutrients and toxic substances
Provide habitat (plants and animals)
Functions Related to Direct Human Utilization
Produce goods (wood, forage, fish, game, fur)
Provide recreational opportunities
Provide attractive vistas
Provide educational and research opportunities
Sustain landscapes associated with cultural heritage
Stabilize stream banks

Appendix I: Average Streamflow Volume

The annual streamflow volume is the total volume of water that flows past a given point on a river over the course of an entire year. Thus, it more or less represents the total amount of water in the watershed above that point in any given year. The 30-year average annual streamflow volume is the average of total volumes over a 30-year period and is based on streamflow, precipitation, and reservoir averages, as well as SWE medians during the given reference period. In the upper Teton Watershed near Driggs, the 30-year average annual streamflow volume for the Teton River is 280 thousand acre-feet (KAF) (Natural Resources Conservation Service, 2016). This average is based on a reference period from 1981-2010. Knowing the average yearly amount of water in the watershed over time allows us to determine in any given year whether the year is below-average, above-average, or average in terms of surface water supply. Also, knowing the yearly streamflow volume over an extended period of time can allow us to observe trends, which can help inform decisions regarding water management.

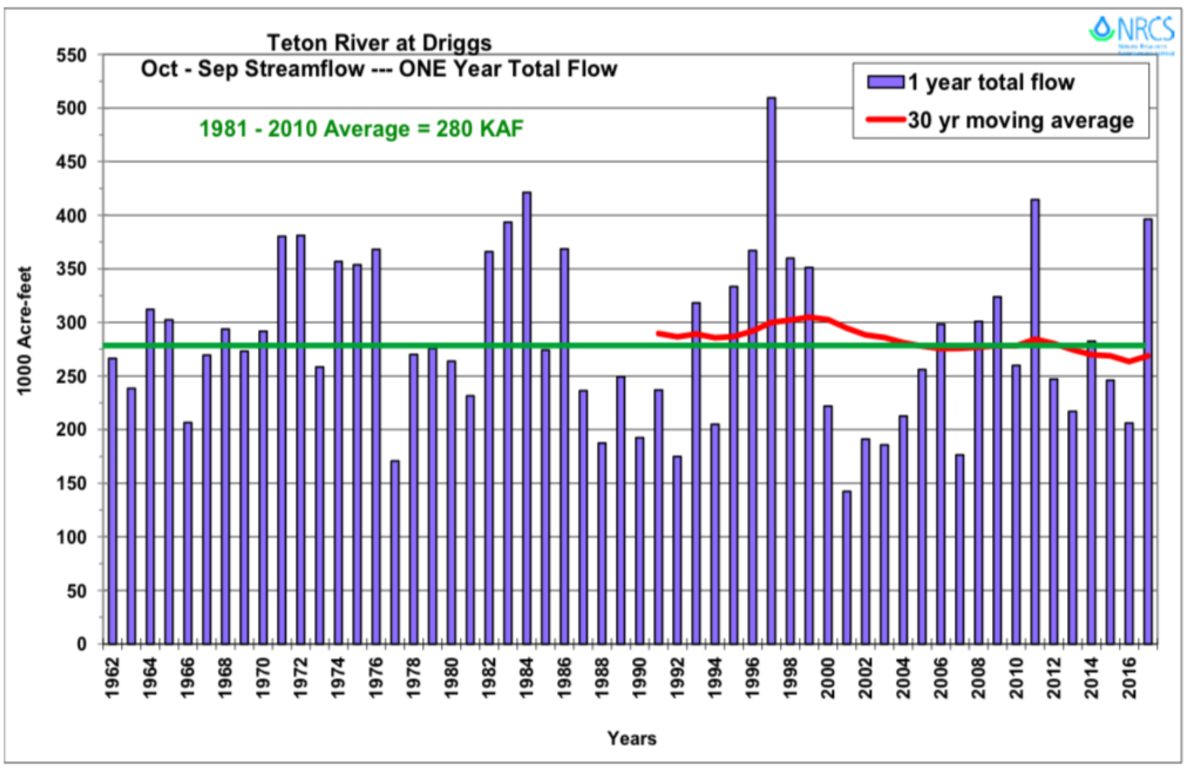

Figure I.1: *One-year total annual streamflow from October through September, 1962-2017. Total annual streamflow is a measurement of the total volume of water in a given year. The green line represents the 30-year average total annual streamflow from 1981-2010 and the red line represents the 30-year moving average. Data from Natural Resources Conservation Service.*

Appendix J: Case Studies

CASE STUDY: Colorado-Big Thompson Project

LOCATION: South Platte & Colorado River basins, Colorado

HIGHLIGHTS
Year Established: 1957 **Active?** Yes
Who are the buyers & sellers? *buyers:* predominantly Front Range municipalities; *sellers:* mostly Western Slope farmers
Who operates/manages the market? Northern Colorado Water Conservancy District (Northern Water) & the US Bureau of Reclamation
How is it funded? A portion of each water sale collected by NCWCB to fund program administration
Does it involve groundwater recharge? No **Is recharge/pumping metered?** N/A
Are water rights being exchanged? Yes; since 2010, it is also possible to lease surplus storage water when available
What is the platform for exchange? NCWCB acts as the clearinghouse for transactions
Pricing: sales: $26,000/unit or $37,000/acre-foot (2015); leases: $44/acre-foot/year (2015)
MARKET OVERVIEW
The infrastructure for the Colorado-Big Thompson Project (CBT) was built between 1938 and 1957 and funded jointly by Northern Water and the U.S. Bureau of Reclamation. The project transports water from the Western Slope to users on the Front Range via a 13-mile tunnel under the Continental Divide and Rocky Mountain National Park. It is the largest diversion project in the state, consisting of 12 reservoirs, 35 miles of tunnels, 95 miles of canals, and 700 miles of transmission lines and conveying over 200,000 AF of water annually. This water accounts for 30% of total South Platte water supply, providing water to 30 towns and municipalities and irrigating 640,000 acres of farmland (Northern Water 2017). The exchange of CBT water began in 1957 making it the oldest water market in the state. This market also works in tandem with a market for native South Platte River water. As of 2010, it is now possible to lease CBT water when there is surplus storage in the system. CBT water rights are available to the public for purchase or lease through Northern Water and through various water brokers throughout the state. The sellers are primarily agricultural users and municipalities, at 78% and 11%, respectively. The buyers are also agricultural users and municipalities, at 77% and 14%, respectively (West Water Research 2016).

IMPORTANT SIMILARITIES/DIFFERENCES FROM THE TETON BASIN
Similarities: Though different in nature, CBT and Teton Basin transfers are mainly ag to urban. *Differences:* There are a lot of differences between the CBT Project and the Teton Basin, but we chose to include this since it is an example of a successful and prolific market. The most notable differences are that the CBT deals exclusively with surface water rights and is much larger than the proposed Teton market. Also, environmental impacts are not considered in CBT water transfers, a quirk of Colorado water law concerning water imported from another major basin" (Howe & Goemans 2003)
LESSONS LEARNED FOR THE TETON BASIN
(1) The small median transfer size (16.7 AF) suggests an "efficient market with low transaction costs that allows buyers and sellers to undertake small transactions as the need arises rather than occasional larger transactions" (Howe & Goemans 2003). Low transactions costs have been critical to the success of CBT, so it is promising that water rights will not be exchanged and no external approval will be required for the proposed Teton market. (2) CBT water is characterized by homogenous units. "Each share gets the same amount of water and there are no priorities" (Howe & Goemans 2003) which simplifies pricing and the transfer process. There are concerns about the homogeneity of the incidental recharge water in the Teton Basin. (3) Quantifying environmental benefits will be paramount to ensure a functioning market in the Tetons.
RESOURCES
http://www.northernwater.org/WaterProjects/C-BTProject.aspx (Northern Water 2017) https://coloradoencyclopedia.org/article/colorado%E2%80%93big-thompson-project (Colorado Encyclopedia 2016) http://www.waterexchange.com/wp-content/uploads/2016/02/16-0217-Q1-2016-WWInsider-LO-singles.pdf (West Water Research 2016) Howe, C. and Goemans, C. 2003. Water transfers and their impacts: Lessons from three Colorado Water Markets. *Journal of the American Water Resources Association.*

CASE STUDY: Eastern Snake Plain Aquifer Managed Recharge

LOCATION: Eastern Snake River Plain, Idaho

HIGHLIGHTS

Year Established: 2006 **Active?** Yes

Who are the buyers & sellers?
buyers: Idaho Water Resource Board (IWRB);
sellers: canal companies and irrigation districts

Who operates/manages the market? IWRB

How is it funded? Primarily funded by IWRB, but opportunity for project-by-project funding

Does it involve groundwater recharge? Managed, mostly through canal seepage

Is recharge/pumping metered? Diversions are measured

Are water rights being exchanged? No

What is the platform for exchange? IWRB makes cash payments to the sellers

Pricing: $3.00/acre-foot (2009-2010)

MARKET OVERVIEW

IWRB holds 1980 priority recharge rights that permit diversion of 1,200 cfs from anywhere on the Snake River. These rights are senior to Milner Hydropower and other recharge rights, but junior to irrigation and existing reservoirs as well as Minidoka Hydropower (Patton 2015). Recharge efforts within this system primarily entail allowing water to run through the canals so it can percolate into the aquifer. Running the water incurs costs to the canal companies, so IWRB developed a cash payment system to incentivize canal companies to participate (Patton 2012). This is facilitated by a contract system in which IWRB and the canal companies enter into an annual agreement. Contracts can be obtained by almost anyone and have the potential to be renewed. The diversions are then measured by canal personnel, verified by IDWR and the Snake River Rental Pool (WD01), and submitted to IWRB. Once the submissions are approved, IWRB pays the canal companies (Patton 2011).

IMPORTANT SIMILARITIES/DIFFERENCES FROM THE TETON BASIN

Similarities: As in the Teton Basin, the ESPA managed recharge market seeks to find a new way to provide groundwater recharge that was once readily available through incidental recharge associated with regular farming practices (Johnson et al. 1999).

Differences: In the ESPA there are specified recharge rights as opposed to the use of existing agricultural water rights in the Teton Basin. The recharge rights allow recharge to occur without having to put the water towards an agricultural use such as flood irrigation and are not limited to the period in which agricultural rights are in priority. In the upper valley, recharge rights are in priority from Feb 16 - March 4 and in the lower valley October 24 - March 23 (Hipke 2015), as opposed to April 15 in the Teton Basin incidental recharge market.

LESSONS LEARNED FOR THE TETON BASIN
(1) There is concern about keeping the costs and benefits internal to the market. Recharged groundwater is intended to recharge the aquifer and it cannot be explicitly ensured that all who benefit from this action will be market participants. For example, downstream users beyond the jurisdiction of the market may benefit from the recharge efforts. IDWR has expressed concern that not all users reaping the benefits from increased groundwater levels are contributing (Patton 2011). This is a particularly important issue because IDWR is concerned about being able to provide adequate funding to pay irrigators and canal companies as proposed funding from the ESPA Comprehensive Aquifer Management Plan has not become available (Patton 2011). While the potential for freeriding is hard to avoid in this type of market, involving all identified internal players would help provide adequate funding for the market. Local municipalities, such as the cities of Blackfoot and Idaho Falls, have expressed interest in supporting managed recharge (O'Connell 2016). This bodes well for the ESPA market as well as the Teton Basin market, which hopes to engage the cities of Driggs and Victor. (2) The IDWR has realized the importance of identifying the most useful sites, as not all sites will provide the same benefits. This has been identified as an important next step and should also be considered when developing the Teton Basin market.
RESOURCES
Hipke, W. 2015. Eastern Snake Plain Aquifer Managed Recharge Update: Upper Snake River Advisory Committee Meeting. *Idaho Water Resource Board*. Johnson, G., Sullivan, W., Cosgrove, D. and Schmidt, R. 1999. Recharge of the Snake River Plain Aquifer: Transitioning from Incidental to Managed. *Journal of the American Water Resources Association.* O'Connell, J. 2016. East Idaho mayors look to cooperate with ag on water. *Capital Press.* Patton, B. 2011. Eastern Snake Plain Managed Aquifer Recharge Program: Henrys Fork Basin Study Working Group. *Idaho Water Resource Board.* Patton, B. 2012. History of Managed Aquifer Recharge Efforts on the Eastern Snake Plain: Upper Snake River Valley Recharge Symposium. *Idaho Water Resource Board.* Patton, B. 2015. ESPA Managed Recharge Program Update: Natural Resources Interim Legislative Committee Boise, Idaho. *Idaho Water Resource Board.*

CASE STUDY: Umatilla Aquifer Recharge Project & Basalt Bank

LOCATION: Umatilla Basin, Oregon

HIGHLIGHTS
Year Established: 2011 (pilot project) **Active?** No **Who are the buyers & sellers?** *envisioned buyers:* junior groundwater rights holders and other curtailed users under sustainable annual yield (SAY) allocations *envisioned sellers:* senior groundwater rights holders who can acquire water from other sources **Who operates/manages the market?** Initially the Water Commission who then turned it over to the non-profit, Northeast Oregon Water Association (NOWA), to set up the market **How is it funded?** The cost of developing alternative supply sources for senior water rights sellers would be offset by payments to the bank and grants/loans from the state water development program **Does it involve groundwater recharge?** Indirectly. For the recharge project, but not the basalt bank **Is recharge/pumping metered?** Somewhat. All groundwater users limited to a certain amount of water under SAY allocations **Are water rights being exchanged?** No. Legal challenges led the failure of the water market **What is the platform for exchange?** Could never be established **Pricing:** N/A
MARKET OVERVIEW
The Umatilla basin in Oregon has four critical groundwater areas (CGWAs). Under CGWA restrictions, the Oregon Water Resources Department (OWRD) determines the "sustainable annual yield" (SAY) of the basin and water rights are curtailed accordingly. The Umatilla Aquifer Recharge Project aimed to recharge the aquifer by pumping water from the Columbia River during the winter and applying it to recharge areas to be available for irrigation in the spring. Doing so would restore groundwater levels, make 100,000 acre-feet of water available to offset curtailed groundwater use through a banking program, and provide instream flow benefits to the Umatilla River. The basalt bank was designed to work in tandem with the aquifer recharge project by allowing senior groundwater rights holders to use alternative supply sources and lease their rights to junior users. After the pilot, they found that the aquifer could only store ¼ of the expected amount of water and that benefits to the Umatilla River were minimal (the majority of water flowed to the Columbia River instead). Also, there were not enough alternative supply sources and the cost of taking out stored water was prohibitive. Additionally, there were no effective means to authorize the banking of SAY allocations by the senior users in exchange for the use of new stored water or other sources of supply available through the bank. More specifically, an effective banking system would require significant changes in law, administrative rules, agency practices, and the enactment of a new process that allowed for the collective review and approval of multiple water use changes or other authorizations. They also discovered the need for an alternative governing structure to operate the bank with more direct involvement and control by affected water users. As a result of these factors, the market failed.

IMPORTANT SIMILARITIES/DIFFERENCES FROM THE TETON BASIN
Similarities: the goals are to recharge groundwater to stabilize aquifer, provide groundwater for users, and benefit the environment - Fully-appropriated groundwater and surface water rights (although groundwater rights are curtailed) - Storing unused winter flows for later use during irrigation season - Diminished in-stream flows a priority in the market (similar to water for wetlands) *Differences:* Water transactions required an exchange of rights, which wasn't legally feasible and could not overcome high transaction costs (transfer process includes public notice, comment and opportunity for protest) - Required additional infrastructure, but had more state and project funding for that infrastructure
LESSONS LEARNED FOR THE TETON BASIN
(1) A critical assessment of the aquifer and how much actually ends up coming out in the wetlands will be critical - both modeling and actual data collection may be necessary for this. (2) You must establish a credible, measurable, and enforceable permit system for accounting for the water that is "banked" and the water that can then be taken by buyers. Exclusion is important and will help to address the issue of freeriding. (3) A structure for running the market that involves the users is critical to success. (4) Just because it sounds like a good idea, doesn't necessarily mean it will work! We must carefully analyze all of the components. (5) The Umatilla Basin "demonstrates the importance of a thorough feasibility analysis addressing project economics as well as engineering, advance attention to the governance structure and legal mechanisms for operating a water marketing program, and the need for significant law changes to allow for efficient water transactions" (Pagel 2016).
RESOURCES
https://static1.squarespace.com/static/56d1e36d59827e6585c0b336/t/5805466815d5dbb1ab59a238/1476740731982/Oregon-Groundwater-Pagel.pdf (Pagel 2016)

CASE STUDY: North Platte Project

LOCATION: North Platte Basin, Nebraska

HIGHLIGHTS
Year Established: 2014 **Active?** Yes
Who are the buyers & sellers? Agriculture to Agriculture users
Who operates/manages the market? Mammoth Trading Works
How is it funded? $200/transaction
Does it involve groundwater recharge? No **Is recharge/pumping metered?** NA
Are water rights being exchanged? Yes, certified irrigation acreage
What is the platform for exchange? Operated by word of mouth until 2014 then smart auction platform
Pricing: $1,800 - $3,200/acre-foot
MARKET OVERVIEW
Before 2014, the Twin Platte Northern Resource District (TWNRD) licensed the amount of certified irrigated acreage (CIAs) and assessed large fines to anyone irrigating unlicensed acres. The market began because the district did not want to forbid the expansion of irrigation so it allowed trading between new landowners and those who had CIAs. Trades are based on acreage not on the amount of groundwater consumed. Compliance is monitored via flyovers. All transfers are permanent sales, not leases. Trading ratios are used to mitigate trade damages to wetlands.
IMPORTANT SIMILARITIES/DIFFERENCES FROM THE TETON BASIN
Similarities: Both aquifers are hydrologically connected to surface water sources and are experiencing groundwater and stream depletion. Similar to the Teton Basin, the North Platte supports sandhill cranes and other migrating bird species in its wetlands (Young 2016). Both counties are dominated by agriculture as the primary economic activity. Some parties are hostile to the idea of markets because they fear outside investors coming into the market. *Differences:* North Platte had experienced well moratoria and groundwater pumping limitations before market mechanisms were instituted. The area receives very little surface water inputs and almost no snowmelt.

LESSONS LEARNED FOR THE TETON BASIN
(1) The word-of-mouth "coffee shop" platform has made it difficult for buyers and sellers to negotiate and has limited the amount of transactions that could take place. The market has stagnated recently since only permanent transfers are allowed, and it is likely to continue to decline in the future as fewer sellers come to the table. (2) Regulatory compliance before approval of the deal is critical - many deals in the North Platte fall through afterwards due to regulatory oversight. (3) The smart market auction method began in 2014 and users praise the anonymity and confidentiality of the system. Anonymity removes biases between buyers and sellers and allows water to trade for the market price (Arens 2016). (4) Must keep in mind that paper water might enter the market and the government might have to buy those rights back in order to protect stream flow.
RESOURCES
https://static1.squarespace.com/static/56d1e36d59827e6585c0b336/t/5805463315d5dbb1ab599f36/1476740670534/Nebraska-Smart-Markets-Young.pdf (Young 2016) http://www.nebraskafarmer.com/management/smart-water-markets-take-local-regulations-account (Arens 2016)

CASE STUDY: Recharge Net Metering in the Pajaro Valley

LOCATION: Pajaro Valley Basin, California

HIGHLIGHTS
Year Established: 2016 Active? Yes, pilot program began in October, 2016.
Who are the buyers & sellers? *buyers:* Pajaro Valley Water Management Agency *sellers:* landowners and farmers
Who operates/manages the market? Pajaro Valley Water Management Agency; Resource Conservation District of Santa Cruz County; UC Santa Cruz
How is it funded? At this point, by grants
Does it involve groundwater recharge? Yes, managed recharge **Is recharge/pumping metered?** Yes
Are water rights being exchanged? No
How do the transactions work? Sellers receive rebates, then applied to the next year's pumping fees
Pricing: Rebate is worth 50% of the cost that PVWMA charges to pump in that area
MARKET OVERVIEW
In the Pajaro Valley, 85-90% of the basin relies solely on groundwater because the region is cut off from water imports. Because of this, groundwater overdraft is a major regional challenge. Exacerbated by this overdraft, seawater intrusion has become a major threat to this coastal aquifer. Well-drained soils, low-elevation land, and close proximity to the coastline are present challenges to controlling the seepage of saltwater into the freshwater aquifer (Hanson, 2003; Levy & Christian-Smith, 2011). In response to these challenges, water managers have adapted the idea of net metering used in the solar industry to groundwater recharge. Landowners are able to generate revenue from contributing to the shared aquifer by collecting stormwater for managed recharge systems installed on their land. The program is called "Recharge Net Metering," and after 5 years, they plan to have 8-10 systems installed that together will infiltrate 1,000 acre-feet of water annually (Fisher, 2016). Overall, this program is expected to enhance recharge of the aquifer by 10% (Yulsman, 2016).
IMPORTANT SIMILARITIES/DIFFERENCES FROM THE TETON BASIN
Similarities: No rights are exchanged through this transaction, but rather the PVWMA pays the landowners to contribute to the public aquifer. The Pajaro Valley's water demand is also dominated by agriculture. *Differences:* Pajaro Valley is using storm flow, while Teton is using water already allocated to the landowners through their water rights. In general, there is a lot more quantification of flows in the Pajaro Valley; all the groundwater pumped in this basin is strictly metered and everyone pays a fee to pump depending on where their property is in the basin. Suitable sites for managed recharge have already been identified and modeled for their recharge potential. Additionally, as this is a managed recharge program, the recharging itself is more engineered, using dry wells and designed recharge ponds. Given that the recharge is storm flow, one logistical difference is that Recharge Net Metering is ongoing throughout the entire winter rather than in a single month period.

LESSONS LEARNED FOR THE TETON BASIN
(1) Net Metering requires reliable measurement and monitoring, a formula that is used to calculate the rebate, and a strong relationship built on trust between stakeholder and agency (Fisher, 2016). The focus on quantifying the amount of water going in and out may be the most notable lesson learned from this example.
(2) There is a strong emphasis on site feasibility assessment. Long before the pilot project began, suitable sites for recharge in the basin were identified. This is a way to save money and be more efficient once the project launches.
(3) This project is starting very small with incremental goals, one site at a time. The cost of implementation will be much lower for an incidental market in the Teton Basin than for a managed recharge market, but a pilot program is likely a good model to follow.
ADDITIONAL NOTES
Many sources analyzing this program emphasize that this is not groundwater banking. “Recharge net metering incentivizes infiltration, not recharge, not storage." No water right is exchanged or defined and no recovery of water is promised through the process (Fisher, 2016). The incentive structure is based purely on rebates for the next year’s fees.
RESOURCES
https://websites.pmc.ucsc.edu/~afisher/post/Hatch/H44F-02_Fisher_1615-30.pdf (Fisher, 2016)
https://www.scientificamerican.com/article/parched-california-tries-to-grab-storm-water-before-it-escapes/ (Yulsman, 2016)
Hanson, R.T. 2003. Geohydrologic framework of recharge and seawater intrusion in the Pajaro Valley, Santa Cruz and Monterey Counties, California. *U.S. Department of the Interior, U.S. Geological Survey.*
http://www.pvwma.dst.ca.us/about-pvwma/rates.php (PVWMA, 2017)
Levy, M. and Christian-Smith, J. 2011. Groundwater management in the Pajaro Valley. *The Pacific Institute.*

CASE STUDY: Arkansas River Water Bank

LOCATION: Arkansas River Basin, Colorado

HIGHLIGHTS
Year Established: 2002 **Active?** Technically yes, but no transactions have occurred
Who are the buyers & sellers? *buyers:* predominantly municipalities *sellers:* farmers & ranchers in the Arkansas River basin
Who operates/manages the market? Upper Arkansas Water Conservancy District (originally Southeastern Colorado WCD)
How is it funded? Transaction fees collected by the water bank to fund program administration
Does it involve groundwater recharge? No **Is recharge/pumping metered?** N/A
Are water rights being exchanged? No; water bank is intended to encourage short-term leases as opposed to permanent sales
What is the platform for exchange? Upper Arkansas WCD acts as the clearinghouse for transactions
Pricing: $800 - $1,000/acre-foot/year
MARKET OVERVIEW
In 2001, the Colorado General Assembly authorized a water banking pilot project in the Arkansas River basin ("the ARWB"). The intention was to "place water in a 'bank' for lease," in both the long- and short-term, "to other users as a means to keep water in the basin and alleviate drought conditions." (Colorado Division of Water Resources 2016). This act was expanded in 2003 to include all basins in the state, and made permanent in 2006, thus ending the pilot project phase. Since 2002, a few deposits have been made into the ARWB, but no transactions have occurred. The reasons for this include: (1) high asking prices, (2) the absence of water storage facilities (it is a "virtual" rather than a "physical" bank), (3) uncertainty about the review and approval process, and (4) the fact that transactions can only occur for stored water rights, not direct flow rights. Though the scope was expanded in 2003 to allow water banks in all basins in Colorado, no other banks have been established or requested. That said, many in the state are still in favor of water banks and modifications are under consideration to further this objective. Some modifications include establishing an integrated network of firm storage options (potentially groundwater storage) and establishing the Colorado Water Conservation Board as the administrator for all water banks in the state.
IMPORTANT SIMILARITIES/DIFFERENCES FROM THE TETON BASIN
Similarities: (1) theoretically, the transfers in each program are likely to be ag to urban; (2) though not currently the case, there is talk of storing the banked water in the alluvial aquifer (Scanga Jr. 2013). *Differences:* There are a lot of differences between the two projects, but we chose to include the ARWB as an example of a largely-unsuccessful market, though one that still has potential moving forward. The most notable differences are that (1) the ARWB deals exclusively with stored water rights and (2) it encompasses a much larger area than the Teton Basin.

LESSONS LEARNED FOR THE TETON BASIN
(1) Establishing an appropriate pricing mechanism is critical. High asking prices in the ARWB have deterred participation and high transaction costs give little incentive for farmers to lease rather than sell their water outright. (Castle & MacDonnell 2016) (2) Uncertainty about the review and approval process will deter potential participants. It is critical "to create or authorize a credible institution to proactively facilitate these transactions, to actively promote interest in use of the bank, and to develop viable procedures facilitating its use and the protection of other water rights" (Castle & MacDonnell 2016). (3) Timing is a critical piece of the puzzle and "paper" water rights can undermine the viability and integrity of the market (Scanga Jr. 2013).
RESOURCES
https://www.colorado.edu/law/sites/default/files/An%20Enhanced%20Water%20Bank%20for%20Colorado.pdf (Castle & MacDonnell 2016) https://www.colorado.gov/pacific/sites/default/files/13WaterResourcesUpdateonWaterBanking.pdf (Scanga Jr. 2013) http://water.state.co.us/DWRIPub/DWR%20General%20Documents/SynopsisofCOWaterLaw.pdf (Colorado Division of Water Resources 2016)

CASE STUDY: Kern Water Bank

LOCATION: Kern County, San Joaquin Valley Basin, California

HIGHLIGHTS
Year Established: 1995 **Active?** Yes
Who are the buyers & sellers? Kern Water Bank Authority (KWBA) members have access to recharge, storage, and recovery based on their participation
Who operates/manages the market? A joint powers authority (JPA) known as the KWBA
How is it funded? Recharge and extraction costs borne by KWBA members; major infrastructure funded by grants, loans, bonds
Does it involve groundwater recharge? Yes **Is recharge/pumping metered?** Yes
Are water rights being exchanged? No. Initially, KWBA sold State Water Project (SWP) entitlements to DWR for the property
What is the platform for exchange? KWBA Board Meetings
Pricing: N/A. Access to recharge, recovery, and storage proportional to participation in the project
MARKET OVERVIEW
In 1988, the Department of Water Resources (DWR) acquired the Kern Fan Element (KFE) to develop a water bank, but countless obstacles prevented the bank from being established. In 1994 the Monterey Agreement - Statement of Principles solved many of the issues and allowed the transfer of the KFE property to water agencies in Kern and King Counties for use as a water bank. In 1996 the participating agencies acquired the property by retiring 45,000 AF (worth $5,800/AF) of their State Water Project (SWP) entitlement. The participating agencies comprise a Joint Powers Authority (JPA) known as the Kern Water Bank Authority (KWBA). Implementation of the water bank required several major infrastructure projects, which included "7,000 acres of recharge ponds, 85 recovery wells, 36 miles of pipeline, and a 6-mile long canal" (KWB n.d.).
In addition to providing water to urban water suppliers and farmers, the Kern Water Bank (KWB) also helps improve endangered species habitat by providing habitat around the recharge ponds and enhancing groundwater dependent wetlands. The land is operated under the Kern Water Bank Habitat Conservation Plan/Natural Community Conservation Plan which designate land use through 2072 (KWB n.d.).
IMPORTANT SIMILARITIES/DIFFERENCES FROM THE TETON BASIN
Similarities: (1) Recharge greatly benefits groundwater dependent ecosystems (GDEs); (2) water demand is largely agricultural, and (3) there was a heavy reliance on grants to get started.
Differences: (1) No monetary exchanges; (2) users that supply water for recharge are the same users that will benefit from recovery; and (3) high up-front costs for construction of infrastructure

LESSONS LEARNED FOR THE TETON BASIN
(1) Many agencies were not interested in participating because the potential cost/risk was high. A pilot project and quantification of costs and benefits will be critical in gaining support for a market in the Teton Basin. (2) In June and July of 2010 the Center for Biological Diversity filed two lawsuits over the KWB and the Monterey Amendments (CBD 2010). The court ruled partly in favor of the Center for Biological Diversity concluding that the original Environmental Impact Report was inadequate and DWR would have to conduct a new review (CBD 2014). One of the driving forces behind the lawsuit was the impact on downstream habitat. While the bank creates/enhances wetland habitat, it may still have negative implications for instream habitat. In the Teton Basin, the impacts on Yellowstone Cutthroat Trout should be thoroughly considered to avoid lawsuits and other controversies.
RESOURCES
http://www.kwb.org/index.cfm/fuseaction/Pages.Page/id/330 (KWB n.d.) http://www.biologicaldiversity.org/campaigns/monterey_plus_amendments/lawsuits.html (CBD 2010) https://www.biologicaldiversity.org/news/press_releases/2014/kern-water-bank-10-03-2014.html (CBD 2014)

CASE STUDY: Truckee Meadows Groundwater Bank

LOCATION: Truckee Meadows Groundwater Basin, Nevada

HIGHLIGHTS

Year Established: 2000 **Active?** Yes

Who are the buyers & sellers? Truckee Meadows Water Authority is both

Who operates/manages the market? Truckee Meadows Water Authority

How is it funded? Funded by the Truckee Meadows Water Authority

Involve groundwater recharge? aquifer storage & recovery **Is recharge/pumping metered?** Yes, both

Are water rights being exchanged? No.

What is the platform for exchange? No platform for exchange; inputs/withdrawals are managed internally

Pricing: "No pricing structure as the system is an accounting system to record the withdrawals and recharges of water by one entity." (Clifford et al., 2004)

MARKET OVERVIEW

The Truckee Meadows Groundwater Bank (TMGB) is not a bank as used in more typical terms. Rather, it is a bank in that the Truckee Meadows Water Authority manages their groundwater resources based on allotments determined by how wet or dry the year is. The TMWA does not facilitate the sale of water, but instead serves as an accounting for groundwater credits and withdrawals from the basin. Recharge is done through an extensive aquifer storage and recovery (ASR) program that has been active since 1993. Surface water is treated year round, so winter groundwater pumping is not necessary. Extra treated surface water is injected back into the ground. The baseline total withdrawal from the basin is 15,950 AF/year. Therefore, during wet years, withdrawal beneath this amount builds credits, while during dry years, withdrawals over this long term average create debits (Clifford et al., 2004). Since 1993, 19,000 AF of water has been stored (Truckee, 2009).

In a drought year, the system allows variable pumping up to 22,000 AF for three consecutive years if there is enough credit banked. Ultimately, the TMGB is a formal accounting system for the water in the basin. Information is lacking on direct success, but presumably this system allows for more water availability during dry years and more water efficiency during wet years.

IMPORTANT SIMILARITIES/DIFFERENCES FROM THE TETON BASIN

Similarities: Surface water is put in the ground at a time when there is surplus. The recharge contributes to the shared alluvial basin aquifer that is managed by the water authority, rather than directly credited to those who recharge.

LESSONS LEARNED FOR THE TETON BASIN
(1) Similar long term average baselines could be set in Teton Basin, with formal goals for how much recharge to do to meet those goals. People might be more willing to participate if they knew it would allow them to pump more during dry years. (2) There is a single entity facilitating and monitoring what goes in and what goes out.
RESOURCES
http://www.climas.arizona.edu/sites/default/files/pdfewsr-banks-final-5-12-101.pdf Clifford, P., C. Landry and A. Larsen-Hayden. 2004. Analysis of Water Banks in the Western States. Washington Department of Ecology. Publication number 04-11-011. https://tmwa.com/wp-content/uploads/docs/your_water/2030WRP/Final/2030_WRP.pdf www.westernstateswater.org/wp-content/uploads/2012/10/laws-policies-report-final-with-cover-1.pdf

CASE STUDY: Murray-Darling Water Market
LOCATION: Murray-Darling Basin, Australia

HIGHLIGHTS
Year Established: Water trading has been occurring through the '70s but market expanded significantly in early 2000s **Active?** Yes **Who are the buyers & sellers?** *Buyers:* environment (via AUS government), farmers, land developers *Sellers:* farmers with water allocations **Who operates/manages the market?** Murray-Darling Basin Commission **How is it funded?** Via fee on transactions and government subsidies **Does it involve groundwater recharge?** No, surface water only **Is recharge/pumping metered?** No **Are water rights being exchanged?** Yes, there are two different types of exchanges. Permanent water rights exchanges and annual allocation exchanges **What is the platform for exchange?** National Water Market System (online) **Pricing:** between $1,000-$3,000 AUD per megalitre
MARKET OVERVIEW
The Murray-Darling Basin Water Market is one of the world's largest and most successful water markets. The market allows for the free trade of surface water entitlements except for restrictions allowable for environmental reasons; the identical treatment of water entitlements acquired by trade or otherwise including carryover; no trade restrictions on water entitlements in terms of purpose of use; no restrictions on the volume of water that can be traded; and an allowance for recovery of damages for compensable losses if trading rules are contravened. Studies have found that water trading has increased the GDP of the MDB by $370 million AUD.
IMPORTANT SIMILARITIES/DIFFERENCES FROM THE TETON BASIN
Similarities: Area's economy is dependent on agriculture, competing urban vs. ag interests, hydrologic connectivity of the basin, impact investing is active *Differences*: Moves water between state boundaries and watershed boundaries, dry desert climate, high value agriculture, water rights are "unbundled" from land rights, cap on extraction of surface water exists for the protection of the environment, surface water rights not groundwater

LESSONS LEARNED FOR THE TETON BASIN
(1) MDBA found that water trading provided capital for farmers to increase their ventures
(2) Strong bureaucracy that supports and defends market trading mechanisms and ensures transparency and fair trades is critical to the system
(3) The Australian Government continues to expand available information about the market to facilitate wide participation (information sharing is critical to a functioning market)
(4) Significant concerns over the equity of buy and dry a lot of ag towns are dying plus many are concerned that the inflated prices of water make instream flows too expensive to buy
RESOURCES
Pricing Report for Murray-Darling Basin 2017 https://www.mdba.gov.au/report/basin-plan-annual-report-2015-16/basin-communities-industries/water-markets Water markets in the Murray-Darling Basin R. Quentin Graftona, James Horne b

CASE STUDY: Walla Walla Basin Aquifer Recharge Program

LOCATION: Walla Walla Basin, Washington and Oregon

HIGHLIGHTS
Year Established: 2004 **Active?** Yes **Who are the buyers & sellers?** No true buyers and sellers; irrigation and conservation districts are implementing the project and funds are mostly from grants and external funding, including the Oregon Watershed Enhancement Board (OWEB) **Who operates/manages the market?** Walla Walla Basin Watershed Council (Watershed Councils are comprised of members of a community representing diverse interests who work together to identify locally acceptable solutions to natural resource issues affecting their local environment) - since the basin covers two states, management differs slightly depending on state regulations **How is it funded?** Grants and state funding **Does it involve groundwater recharge?** Yes **Is recharge/pumping metered?** Recharge is measured by diverted flows and the creation of a hydrologic model with Oregon State University **Are water rights being exchanged?** Kind of. Currently, OR Limited License Application and WA Temporary Use Authorizations under local water plans serve as temporary water rights **What is the platform for exchange?** Managed differently in each state. Not a true market **Pricing**: N/A
MARKET OVERVIEW
Walla Walla Valley hydrology is largely defined by a distributary river system and an underlying unconfined alluvial aquifer system hosted by the sediments overlying basalt. In the late 1990s, began seeing dry reaches in the streams during portions of the summer and fall and the alluvial aquifer started facing declines and steelhead and bull trout were listed as threatened. Decided to reduce irrigation withdrawals by 25 cfs - rewatered summer flows. Irrigators agreed to give up portions of their water rights to leave water instream and implemented irrigation efficiency projects. However, increased efficiency meant the aquifer continued to decline and spring creeks still went dry. In 2004, the Walla Walla Basin Watershed Council (WWBWC) partnered with Hudson Bay Ditch Improvement Company, Gardena Farms Irrigation District #13, the Walla Walla River Irrigation District (WWRID), and the Walla Walla County Conservation District to create four recharge pilot projects. Combined, these multiple aquifer recharge projects are estimated to have the potential to put over 20,000 af into the aquifer during recharge season (Nov. 1 - May 31). With continued funding, several more recharge projects have been created and now the two states are working on allowing water rights to be used for AR under beneficial use.
IMPORTANT SIMILARITIES/DIFFERENCES FROM THE TETON BASIN
Similarities: Similar hydrology - shallow aquifer. Recharge ponds put water back in the ground and ultimately back in the stream; recharge is little to no cost for canal companies/farmers; need funding to implement project, however, it is not aiming to set up a market; looking at their budgets, as well as measures of success from their pilot projects could help us to do the same for Teton Valley

LESSONS LEARNED FOR THE TETON BASIN
(1) The key to success seems to be the use of temporary water rights and the ability to implement local water plans that allow for more flexibility for how water is used.
RESOURCES
http://www.wwbwc.org/aquifer-recharge-reports.html#washington-reports http://www.eastoregonian.com/eo/local-news/20170504/walla-walla-basin-watershed-council-nets-grant-for-aquifer-recharge https://fortress.wa.gov/ecy/publications/documents/0811061.pdf http://www.oregon.gov/owrd/docs/Place/NC_07_05_WallaWalla_OWRDPBPLOI_120715.pdf

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