Incorporating Recharge Limitations into the Prioritization of Aquifer Recharge Sites Based on Hydrologic Benefits Using

ESPAM2.1

by

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Executive Summary

This report, *Incorporating Recharge Limitations into the Prioritization of Aquifer Recharge Sites Based on Hydrologic Benefits Using ESPAM2.1*, uses the Enhanced Snake Plain Aquifer Model version 2.1 to assess the relative effectiveness of recharge at each of 19 sites in reaching Idaho's aquifer stabilization goals. A previous modeling report prioritizes the recharge sites and provides the Idaho Water Resources Board with a range of considerations related to seven general objectives, but does not identify the primary objective for State-sponsored managed recharge.

Increasing aquifer storage is the only objective that is aquifer-wide in scope and fully aligned with the overarching ESPA Comprehensive Aquifer Management Plan goal of improving the water budget for the entire aquifer. Successfully increasing long-term aquifer storage will raise aquifer water levels, increase spring discharge, and bolster river flow throughout the aquifer/river system. For these reasons, increasing aquifer storage has been identified as the most generally useful criterion for comparing recharge sites and for optimizing recharge efforts. In short, increasing aquifer storage is the primary objective for State-sponsored recharge.

The analyses presented herein build upon previous prioritization efforts by incorporating legal and policy guidelines to the Managed Recharge Program as well as site-specific limitations to recharge. State policy limits the volume of water that can be recharge in the ESPA to a long-term average of 250,000 acre-feet annually and State law dictates that the State's recharge right must be in priority for State-sponsored recharge to occur.

The Milner Zero Minimum Flow Policy effectively divides the Snake River into two separate rivers by allowing zero flow in the Snake River at Milner Dam. Although water users below Milner Dam cannot influence water use upstream of the dam, there are established minimum flows downstream at Swan Falls Dam which the State is obligated to maintain. The State Water Plan directs that the ESPA be managed as part of the Snake River system, and that the system be managed to maintain the minimum flows at Murphy. Therefore, the success of State-sponsored managed recharge is contingent on bolstering the flows at Murphy.

There are generally four limitations to the monthly volume of recharge at a site:

1. Water Availability – Water availability is delimited by water rights and the flows past Milner and Minidoka dams. Because the flow at Milner Dam can be brought to zero to fulfill beneficial uses upstream, any natural flow past Milner Dam is available for recharge. Given that the State's recharge right is in priority, the flow past Milner can be used for recharge downstream of Minidoka Dam. Recharge upstream of Minidoka Dam is complicated by reservoir fill water rights, physical reservoir fill, and the unsubordinated USBR hydropower rights at Minidoka Dam. The USBR hydropower rights of 2,700 cfs affect managed recharge in two ways: 1) the hydropower rights are senior to the State's recharge rights, and 2) the hydropower rights are used to indicate the likelihood of physical reservoir fill. Therefore, flow in excess of 2,700 cfs at Minidoka are available for recharge upstream, but care must be taken to ensure that assumed minimum stream flows are maintained upstream of American Falls Reservoir. Water is only considered available for recharge if the State's recharge water right is in priority at the POD during the period of recharge.

2. Diversion Limitations – Diversion limitations are generally related to the size of diversion, transmission, and recharge structures; therefore, it may be possible to engineer increased diversion capacity. The diversion limitations used in this study have been developed from historic recharge activities.

3. Infiltration Limitations – Infiltration limitations are generally related to surface and subsurface geologic materials, infrastructure available at the recharge site, and the volume of water that can be delivered to the site. The infiltration limitations used in this study have been developed using a combination of published values, model-derived values, and interviews with facility managers. It may be possible to engineer increased infiltration capacity if recharge infrastructure or diversion capacity is the limiting factor.

4. Shallow Groundwater Limitations – Shallow groundwater effectively limits the space between the water table and land surface and can hinder recharge efforts by causing infrastructure damage or allowing rapid return to surface water. Limitations due to shallow groundwater have been determined using ESPAM2.1. Due to the analysis methodology and regional nature of the model, it is recommended that a hydrogeologic or engineering investigation be conducted for proposed recharge at rates greater than the shallow groundwater limitation of the site. Shallow groundwater is generally related to regional hydrogeological conditions; therefore, it is likely not possible to engineer solutions to these conditions in regards to managed recharge.

Multiple modeling scenarios have been run to evaluate the effectiveness of recharge to increase aquifer storage. Results of the modeling scenarios indicate that there are three elements to recharge that impact a site's ability to increase aquifer storage:

1. Location of the recharge site. Distance from connected reaches of the South Fork, Henry's Fork, and Snake River governs the retention of recharge in the aquifer (or how quickly water returns to the rivers). Geologic materials control how easily water infiltrates. Aquifer heterogeneities affect the distribution of recharge impacts and influence where the benefits are realized.

2. The volume of water recharged. The volume of water recharged at a site necessarily impacts how effectively aquifer storage is increased.

3. Recharge frequency. Recharge frequency is important for the development of aquifer storage. Higher recharge frequency means that more water can be recharged over time. Higher recharge frequency also means that less time passes between recharge events, during which stored water to returns to the river without replenishment by recharge. The combination of increased recharge and shorter inter-recharge periods results in the development of aquifer storage over time.

The results of the modeling and analyses indicate that water availability for recharge is most consistent at sites that divert water downstream of Minidoka Dam. Reservoir fill, water-right priority, and assumed minimum stream flows reduce availability in the upstream direction.

In general, sites located along the Henry's Fork and sites located on the main stem Snake River downstream of Minidoka Dam have the highest aquifer retention rates, while sites located along the South Fork and main stem Snake River upstream of Minidoka Dam have the lowest aquifer retention rates.

Based on modeling that considers both the site-specific recharge limitations and water availability, Northside canal system is the site with the greatest ability to benefit aquifer storage, followed closely by the Milepost 31 recharge site. The United canal system and Jensen's Grove sites provide the least benefit to aquifer storage.

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Introduction

The Eastern Snake Plain Aquifer (ESPA) is the largest aquifer in Idaho (Figure 1), and storage within the aquifer has been steadily declining since the 1950's (Figure 2). The State of Idaho (State) has determined that aquifer stabilization and recovery are the primary objectives for managed recharge, and the legislature has allocated funds to support the Managed Recharge Program (HB 547, 2014). This study uses the Enhanced Snake Plain Aquifer Model version 2.1 (ESPAM2.1) to assess the relative effectiveness in reaching aquifer stabilization goals via recharge at each of 19 sites located throughout the ESPA. The analyses presented herein build upon the prioritization efforts outlined in *Prioritization of Aquifer Recharge Sites Based on Hydrologic Benefits Revised Using ESPAM2.1* (Prioritization Report; McVay, 2015) by incorporating site-specific limitations to recharge such as water availability, diversion rate, infiltration rate, and shallow groundwater. A cursory discussion of regional ESPA hydrogeology is included to provide context to the modeling results.

The prioritizations developed in this study are not intended to preclude recharge at any site, nor do they imply a priority in monthly or annual recharge activities. Rather, this study is intended to provide understanding of the important factors governing recharge impacts so the State can develop a managed recharge program that best meets the goals of aquifer stabilization and recovery. This study illustrates the benefits and drawbacks of recharge at each site, and is intended to assist with prioritizing investment decisions and maximizing the effectiveness of recharge efforts.

Selection of Managed Recharge Sites

Potential recharge sites analyzed in this report are limited to those that were identified in the Prioritization Report (Figures 3-6). Site selection was based, in part, on the ability and willingness of the irrigation entities that operate the sites to participate in managed recharge. Managed recharge sites are defined in this report as any natural or man-made feature or location such as a basin, pond, pit, well, or canal that can accept surface water and allow it to infiltrate to the regional aquifer. Recharge sites evaluated in this project include: 1) Egin Lakes (Fremont-Madison Irrigation District), 2) Canals east of the Henry's Fork in Fremont-Madison Irrigation District, 3) Canals west of the Henry's Fork in Fremont-Madison Irrigation District, 4) Great Feeder area canals, 5) New Sweden Irrigation District, 6) Idaho Irrigation District, 7) Snake River Valley Irrigation District, 8) Peoples Canal Company, 9) Riverside Canal Company, 10) United Canal Company, 11) Jensen's Grove, 12) Aberdeen-Springfield Canal, 13) Hilton Spill on Aberdeen-Springfield Canal, 14) the Lake Walcott recharge site, 15) Southwest Irrigation District, 16) American Falls Reservoir District #2 main canal (Milner-Gooding Canal), 17) Shoshone recharge site filled from Milner-Gooding Canal, 18) Mile Post 31 recharge site filled from Milner-Gooding Canal, and 19) Northside Canal Company including Wilson Lake. Locations of the model cells used to represent the recharge sites are shown in Figures 2 through 5. Hydrologic effectiveness of recharge is evaluated with ESPAM2.1 using objectives developed for the Idaho Water Resource Board (IWRB) in the Prioritization Report.

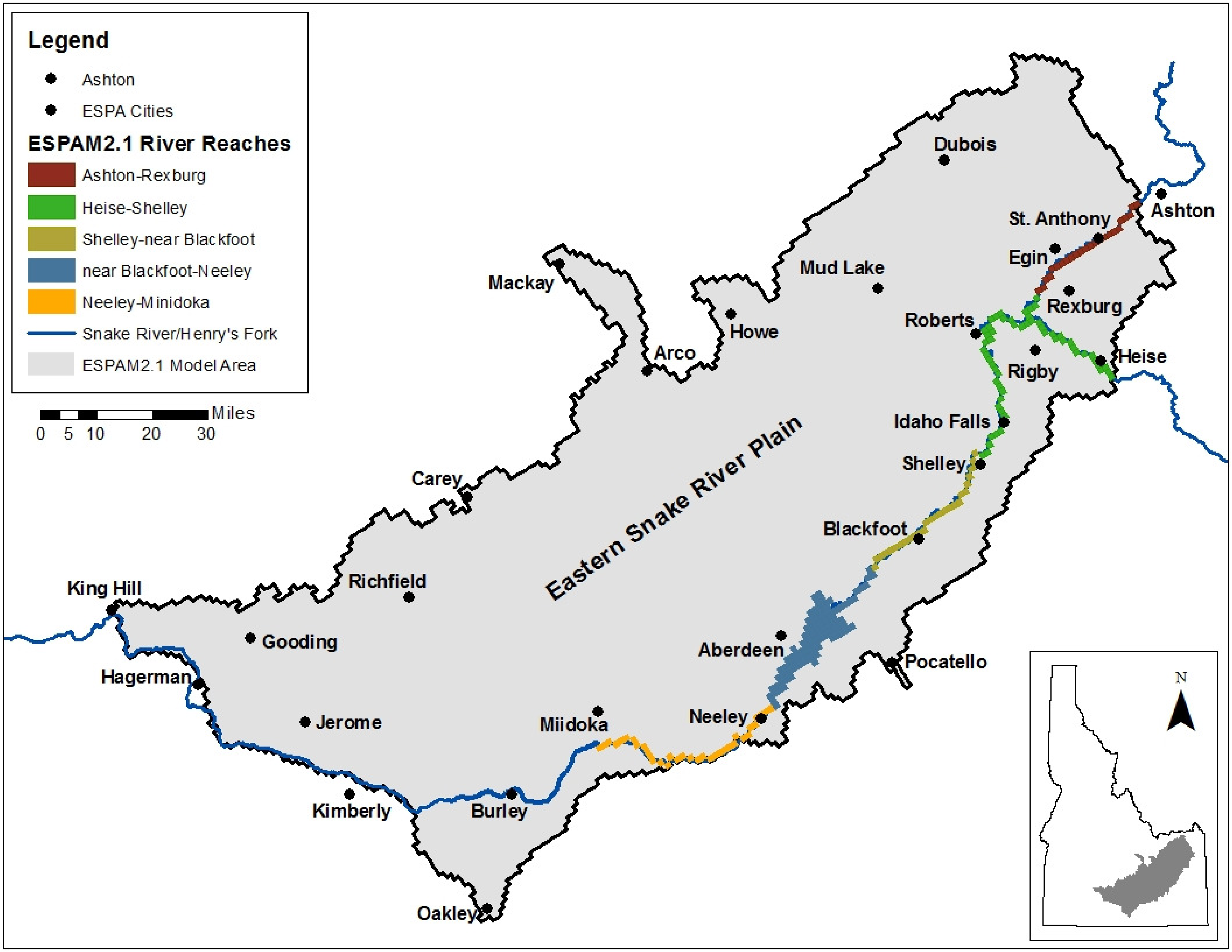

Figure 1. The ESPA and six hydraulically connected reaches of the Snake River. Figure adapted from Johnson, 2012.

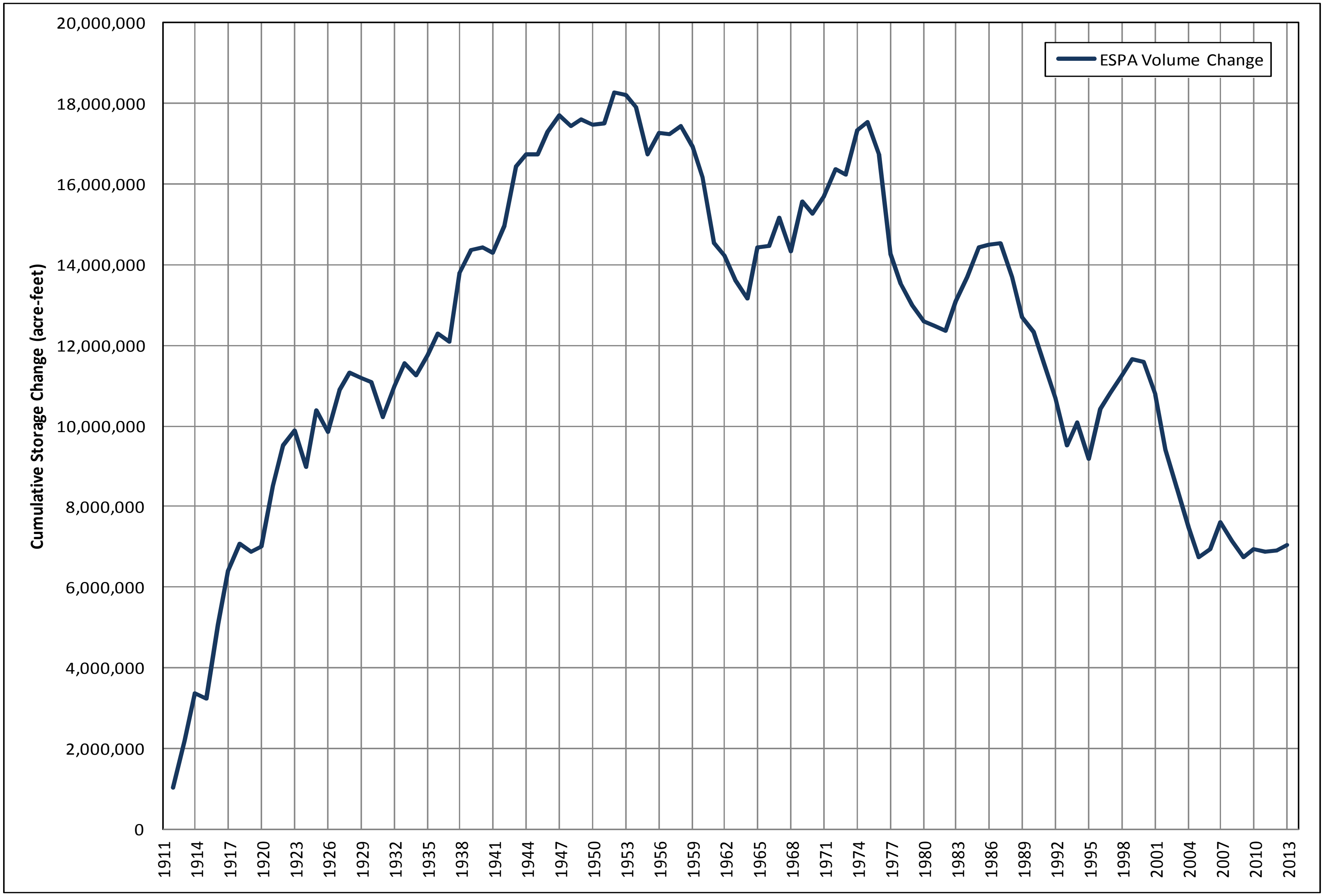

Figure 2. ESPA storage changes over time.

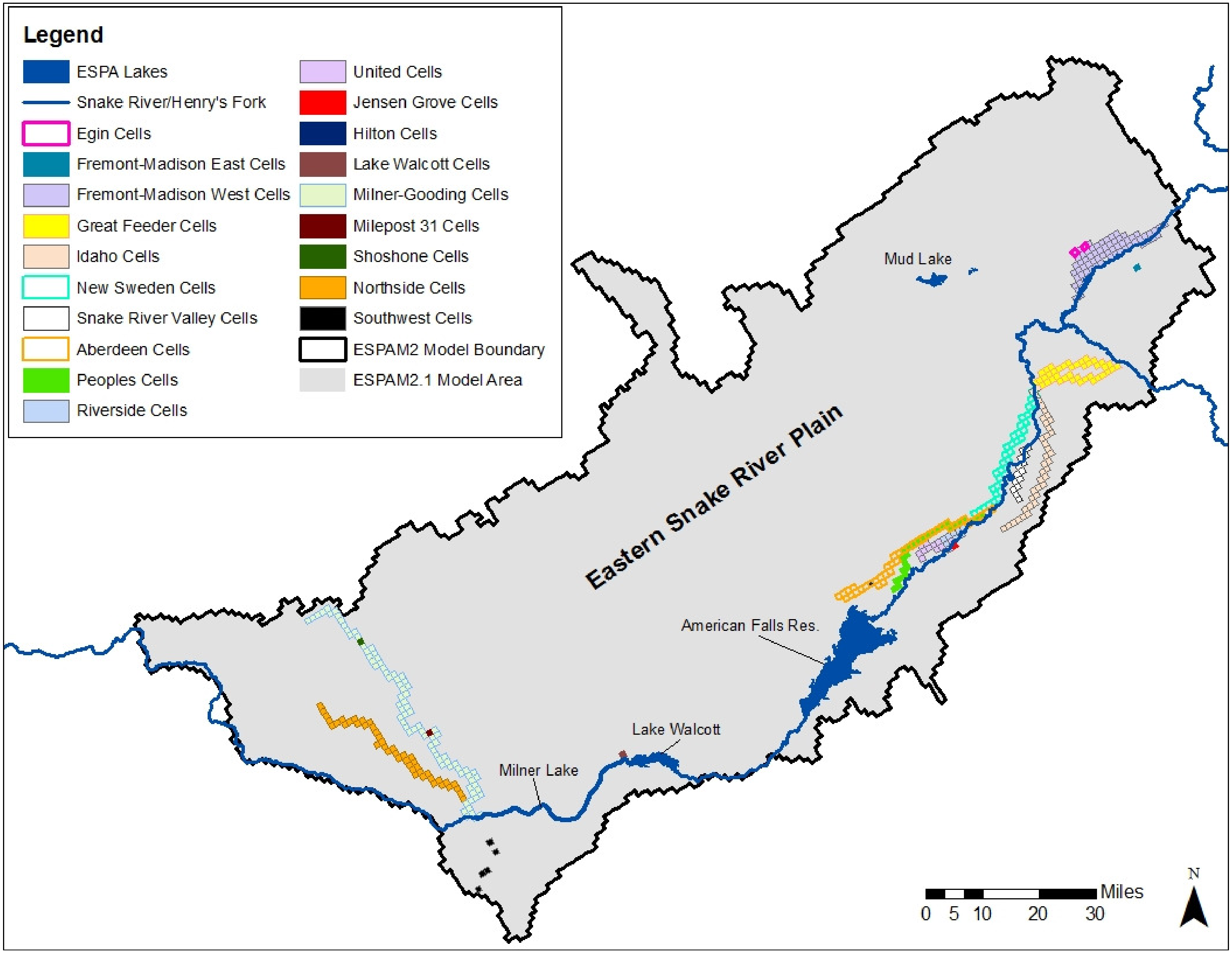

Figure 3. Model cells used to represent sites in the recharge prioritization scenarios. Greater detail on individual sites is provided in Figures 4 – 6.

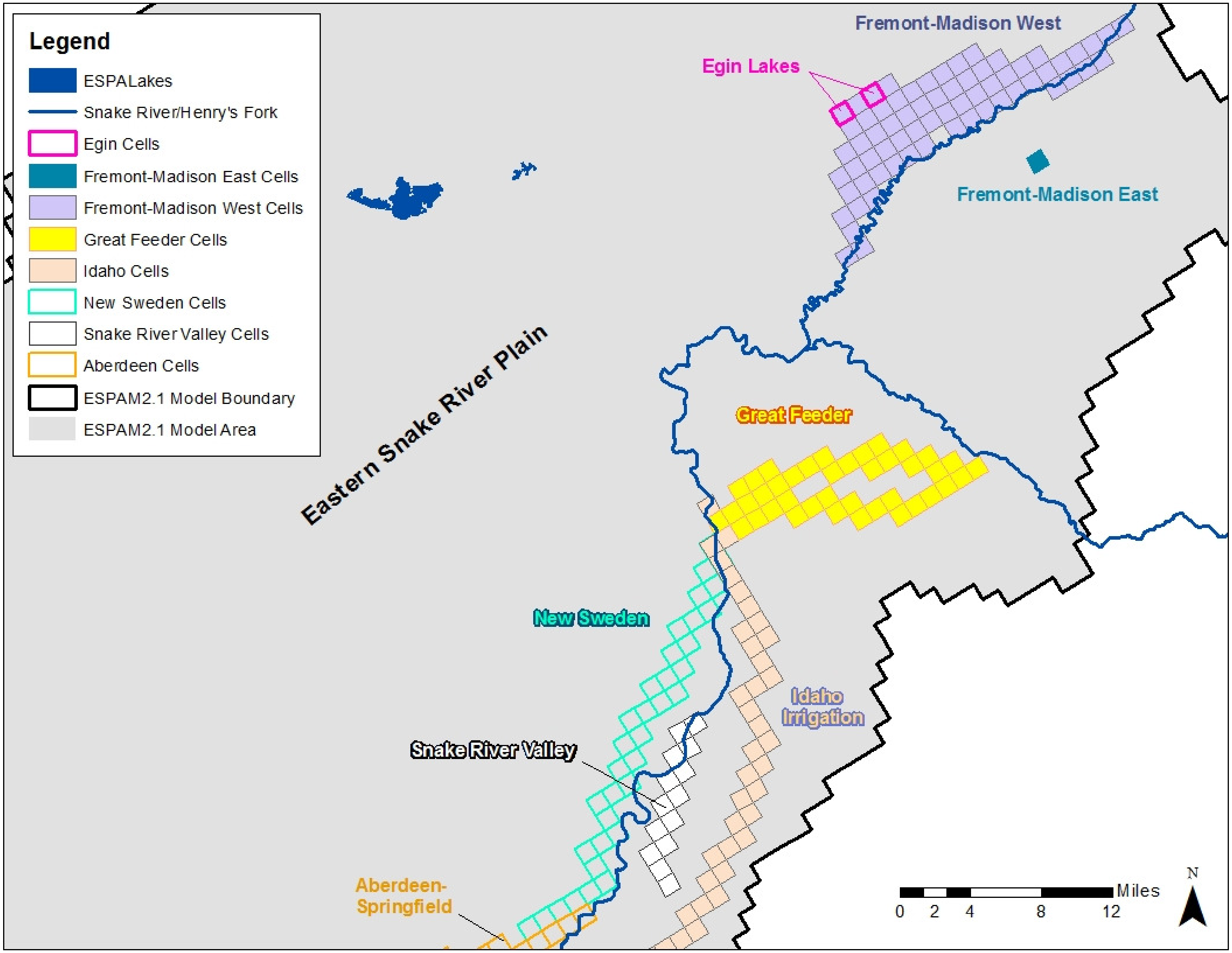

Figure 4. Model cells used to represent recharge sites for the eastern portion of the ESPA.

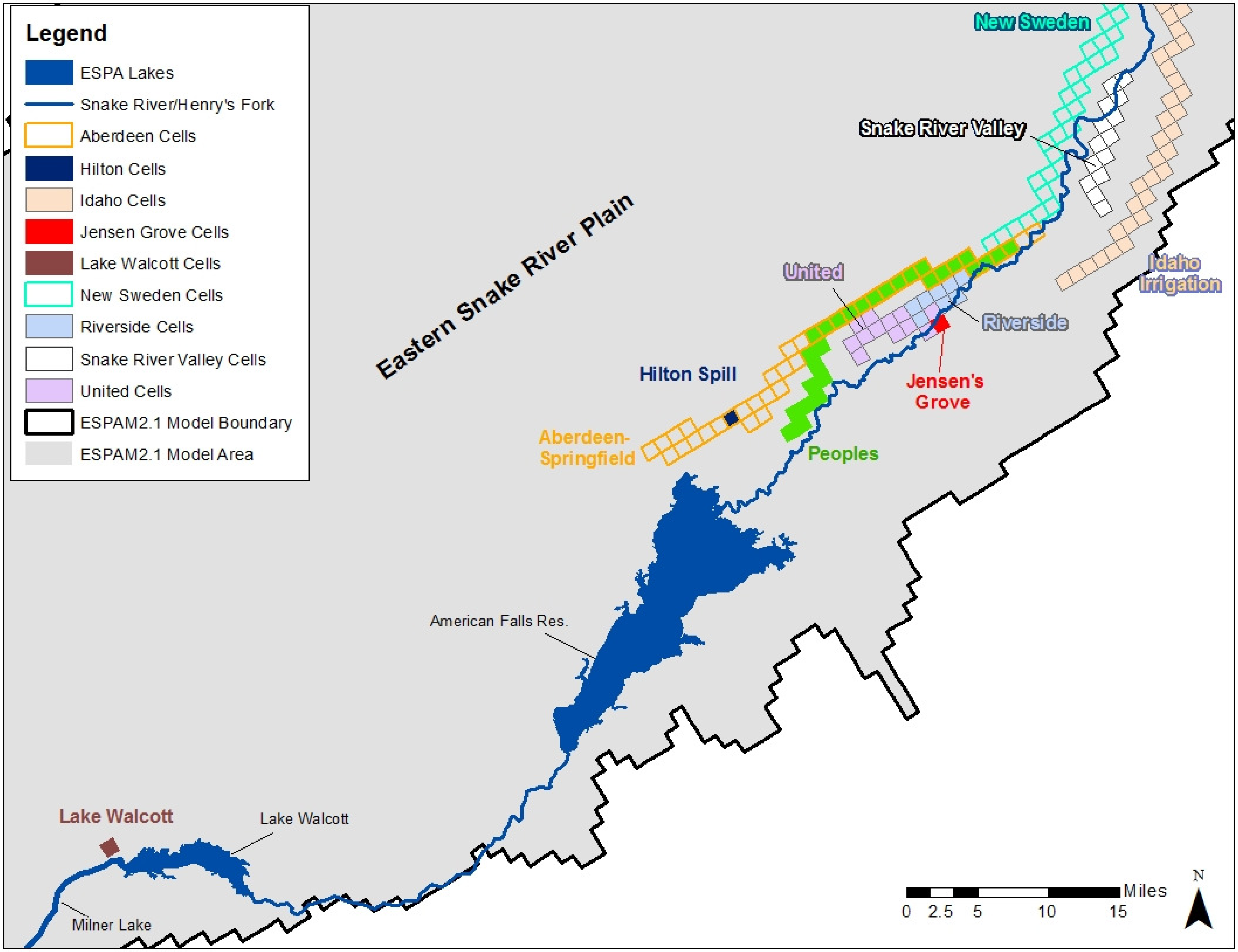

Figure 5. Model cells used to represent recharge sites for the central portion of the ESPA.

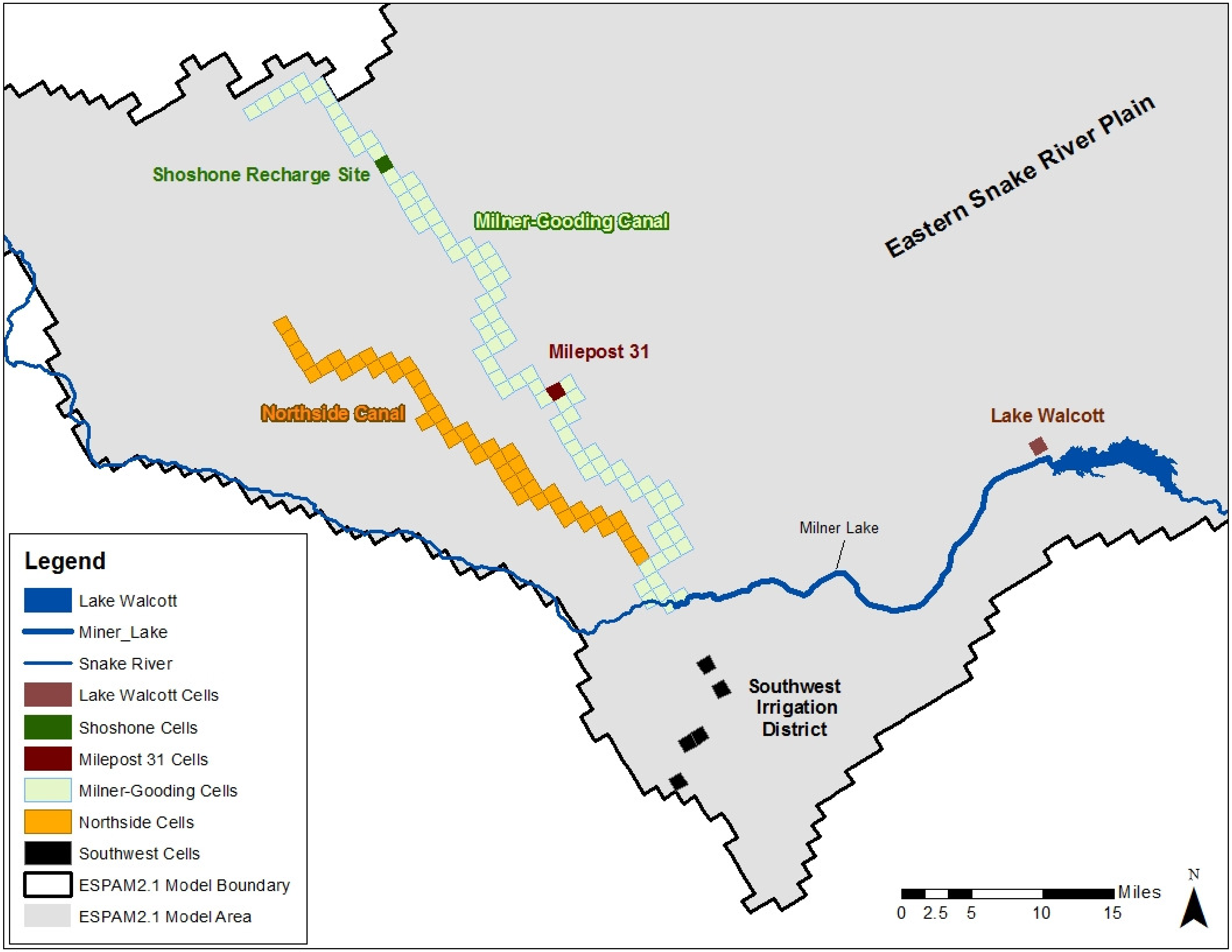

Figure 6. Model cells used to represent recharge sites for the western portion of the ESPA.

Hydrogeologic Setting

In order to fully understand the modeled impacts due to recharge, it is important to view recharge in the context of the hydrogeologic setting. The hydrogeologic setting not only influences site characteristics (e.g soil type, soil depth, depth to groundwater, and infiltration rate), but also controls the timing and spatial distribution of recharge impacts.

Geologic Framework

The surface of the Eastern Snake River Plain (ESRP) consists primarily of volcanic rocks – predominantly basalt. Most areas are covered by a veneer of windblown or fluvial sediments that vary in thickness from zero to tens of feet (IDWR, 2013). The most significant sediment deposits occur near the margins of the plain (Figure 7).

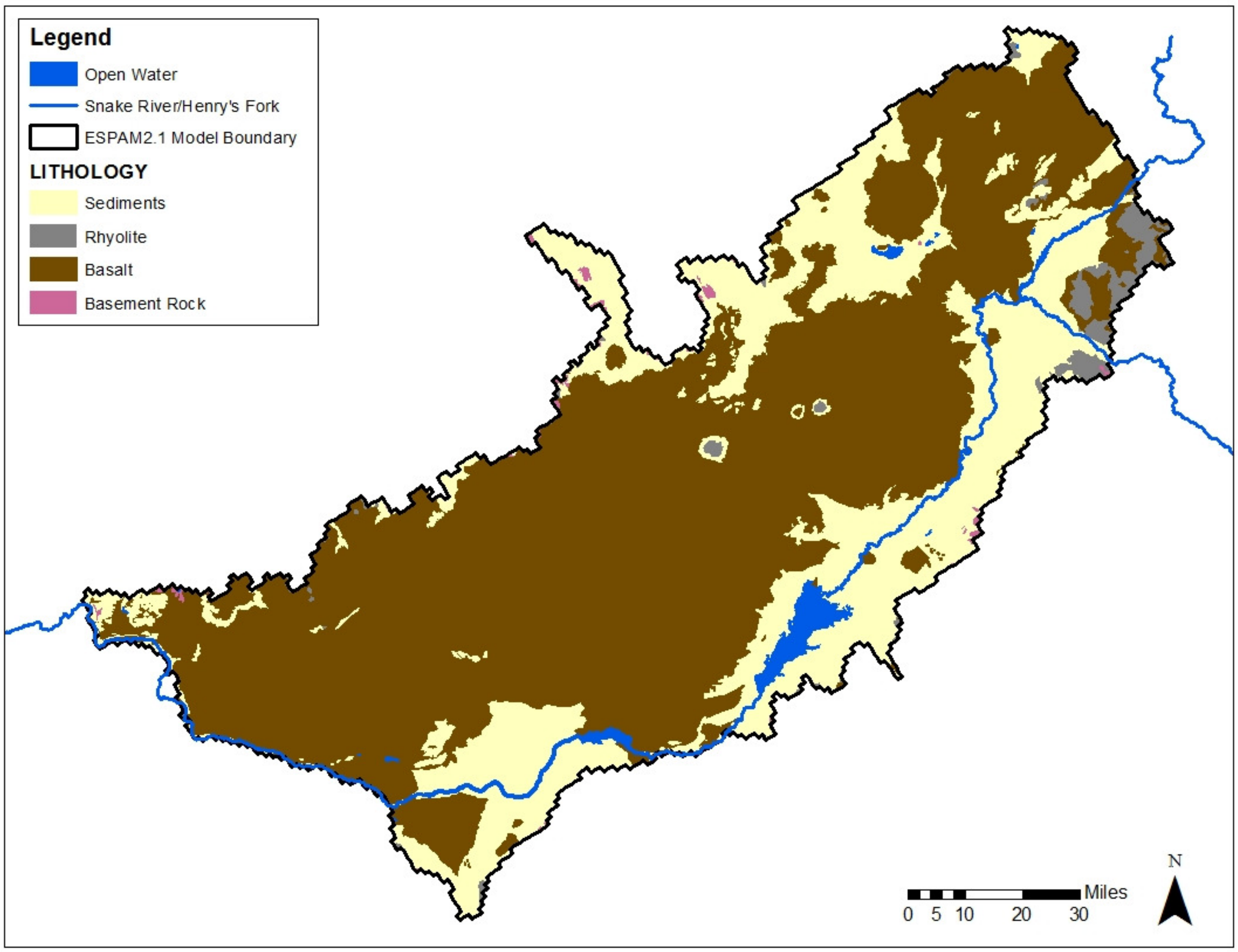

Figure 7. Generalized lithology map of the ESPAM2.1 model area.

The ESPA is composed of a series of relatively thin basalt flows and interbedded sediments, with flows ranging in thickness from a few feet to tens of feet. Individual flows typically have rubble zones at the top and bottom with flow interiors that generally are more massive. The flow interiors contain vertical fractures that form columnar basalt in some locations (Garabedian, 1992). The collective thickness of basalt flows is estimated to exceed several thousand feet in places (Whitehead, 1986). More detailed descriptions of the geology of the ESPA are provided by Anderson (1991), Whitehead (1986), and Kuntz and others (1992).

Hydrogeology

The ESPA is a highly productive aquifer comprising fractured basalt flows and interbedded sediments. Although the collective thickness of the basalt may be in excess of several thousand feet in places, the most productive portion of the aquifer is thought to be limited to the upper several hundred feet of saturated thickness (Robertson, 1974; Mann, 1986; Garabedian, 1992; de Sonneville, 1974; Lindholm and others, 1980; Cosgrove and others, 1999).

Most of the groundwater flow in the aquifer is through highly-permeable rubble zones located at the tops and bottoms of the individual basalt flows. Water-table elevation contours indicate that groundwater enters the aquifer from around the margins, the flow direction is generally parallel to the axis of the plain from northeast to southwest, and the aquifer primarily discharges via springs and reach gains in the Kimberly-to-King Hill and Blackfoot-to-Neeley reaches of the Snake River (Figure 8; Figure 1).

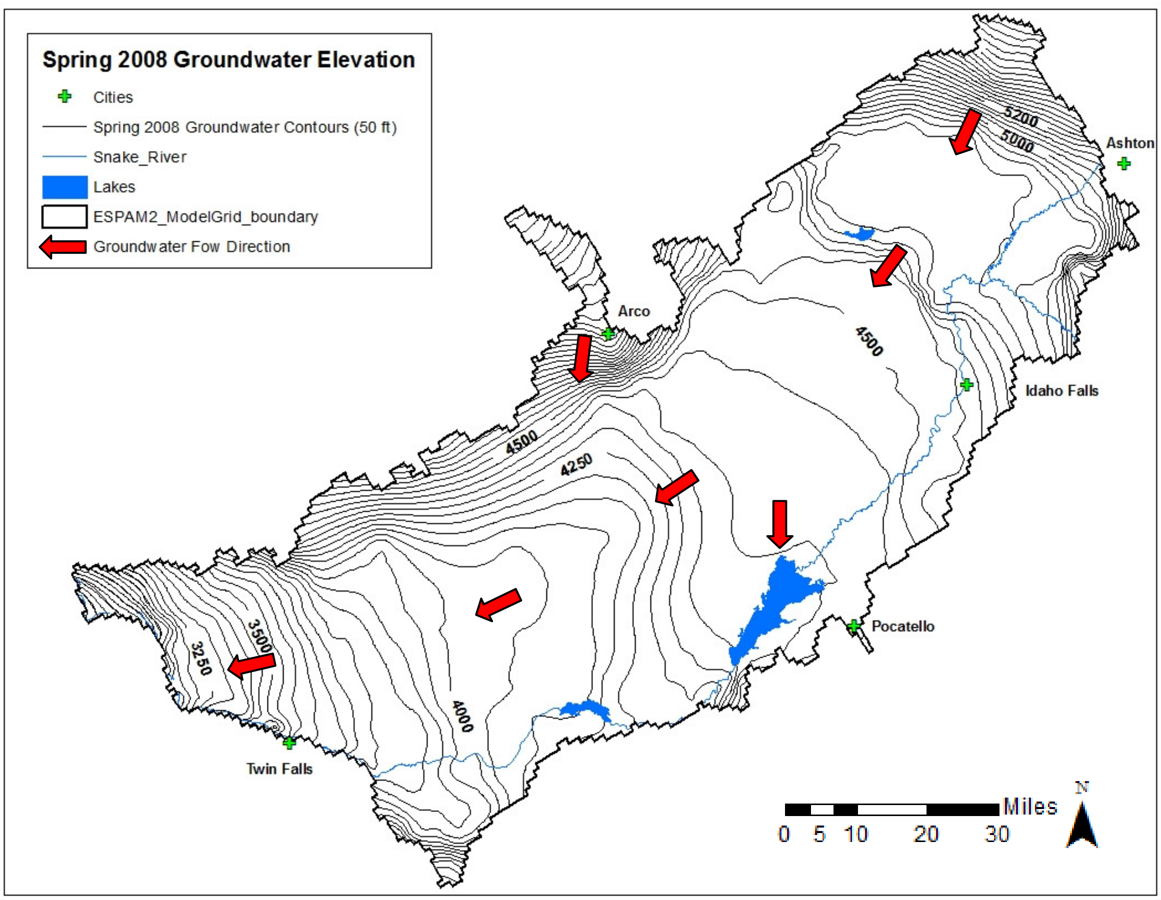

Figure 8. Water-table elevation map, spring 2008.

Managed recharge induces a stress that deforms the regional groundwater gradient; therefore, impacts due to managed recharge do not follow the regional gradient, but instead progress radially from the point of recharge until encountering hydrogeologic controls (Asano, 1985).

In the ESPA, the hydrogeologic controls that influence the progression and distribution of recharge impacts throughout the aquifer are:

1) Aquifer Boundaries: Aquifer boundaries represent the limits of the ESPA. Modeled recharge impacts do not progress beyond these boundaries (no-flow boundaries). Instead, modeled aquifer-storage impacts (expressed as water-level changes) are "reflected" back into the aquifer, which results in greater water-level changes than if the area of impact did not encounter any no-flow boundaries. The ESPA aquifer boundaries are illustrated by the black outline in Figure 9.

2) Hydraulically connected reaches of the Snake River: Hydraulic connection with the aquifer occurs with all springs and when aquifer water levels are above the bottom of a riverbed. Spring discharge and river gains/losses vary with aquifer water levels where the river and aquifer are hydraulically connected. River losses occur at rates that are unaffected by aquifer water-level changes at locations where groundwater and surface water are disconnected.

   Increase in aquifer storage is reduced as the area-of-impact encounters hydraulically connected reaches or springs. Additionally, groundwater levels near the hydraulically connected surface-water features areas experience muted increases in response to recharge. This dampening of aquifer-related impacts occurs because additional recharge water exits the aquifer as increased river gains (or decreased river losses) and spring discharge along the connected reaches instead of increasing aquifer storage.

   Hydraulic connection between the aquifer and Snake River occurs along portions of the Ashton-to-Rexburg, Heise-to-Shelley, Shelley-to-near Blackfoot, near Blackfoot-to-Neeley, and Neeley-to-Minidoka reaches. Hydraulic connection with the ESPA is strongest along the upper segments of the near Blackfoot-to-Neeley and the Heise-to-Shelley reaches, and the dampening effect on modeled recharge impacts are more pronounced in these locations. Hydraulically connected reaches of the Snake River are illustrated by green (annually losing reach) and orange (annually gaining reach) circles in Figure 9.

   The Snake River is perched above the regional aquifer system between the communities of Roberts and Shelley, and between the community of Minidoka and Milner Dam (Figure 8; IDWR, 2013). Perched reaches are not hydraulically connected to the aquifer, and lose water to the aquifer at rates that are independent of aquifer water levels. Modeled recharge impacts expand without regard to these reaches.

3) Springs: Springs occur where the water table intersects land surface and represent aquifer discharge locations that are above the elevation of the river. Discharge from springs is dependent on aquifer water levels; therefore, the flow from springs fluctuates with aquifer head. As discussed above, modeled recharge impacts to aquifer storage are dampened due to interaction between recharge-

induced water-level changes and spring discharge. Springs areas are illustrated by blue arrows in Figure 9.

4) Aquifer Heterogeneity: Non-uniform (heterogeneous) aquifer properties will cause the impacts of recharge on aquifer-storage to vary with distance and direction from the recharge site. The aquifer properties of transmissivity and storage coefficient are discussed in the following section, *Model-derived Aquifer Properties*.

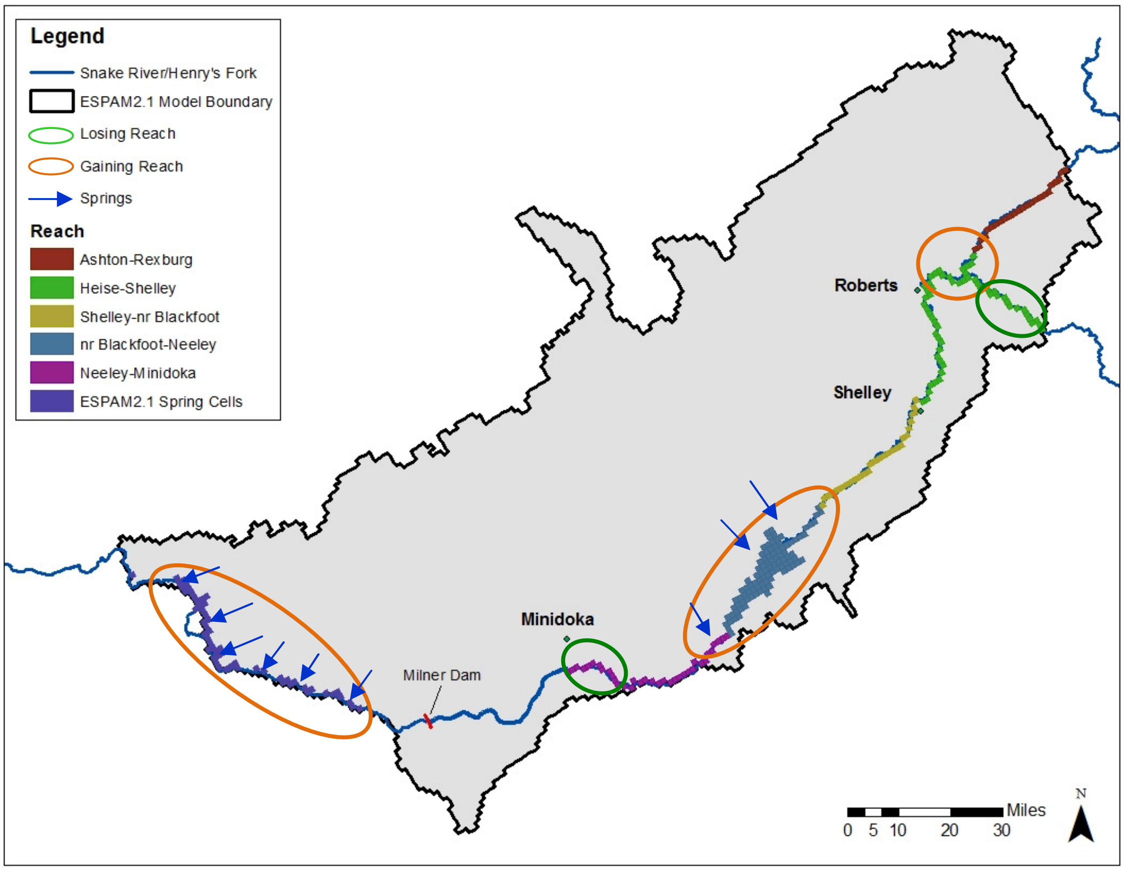

Figure 9. Approximate locations of hydrogeologic controls related to the aquifer boundaries, hydraulically connected reaches of the Snake River, and springs.

Model-derived Aquifer Properties

Calibrating a groundwater model involves relating all of the known aquifer-stress parameters (canal and perched river seepage, excess irrigation seepage, tributary underflow, evapotranspiration, and well pumping) to all measured observations (water levels, irrigation return flows, Snake River gains/losses, and spring discharge) using the governing mathematical equations for groundwater flow. Calibrating a groundwater model consists of repeatedly running the model while adjusting input parameter values until the differences between the modeled results and measured observations are sufficiently minimized. Values for the aquifer properties of transmissivity and storage are generated as a result of the ESPAM2.1 calibration process, and these properties influence the propagation and distribution of aquifer-storage impacts throughout the aquifer.

Transmissivity

Transmissivity is a measure of the ease with which water flows though an aquifer. If the aquifer is homogeneous, recharge impacts will expand radially until encountering one of the hydrogeologic controls listed above. However, aquifer non-uniformity will cause recharge induced water-level changes to preferentially follow high transmissivity zones.

The Great Rift and Mud Lake barriers are two zones of relatively low transmissivity that are important influences on the distribution of managed recharge impacts. Despite the informal moniker, these areas are not barriers to flow, but rather low-transmissivity zones that retard the flow of groundwater and hinder the progression of water-level changes due to recharge. The Great Rift low-transmissivity zone extends from north to south-southwest in the middle of the plain, and is the result of a volcanic rift zone. The Mud Lake low-transmissivity zone extends from west-northwest to east-southeast across the eastern third of plain, and is the result of thick sediment deposits. Transmissivity differences are illustrated in Figure 10.

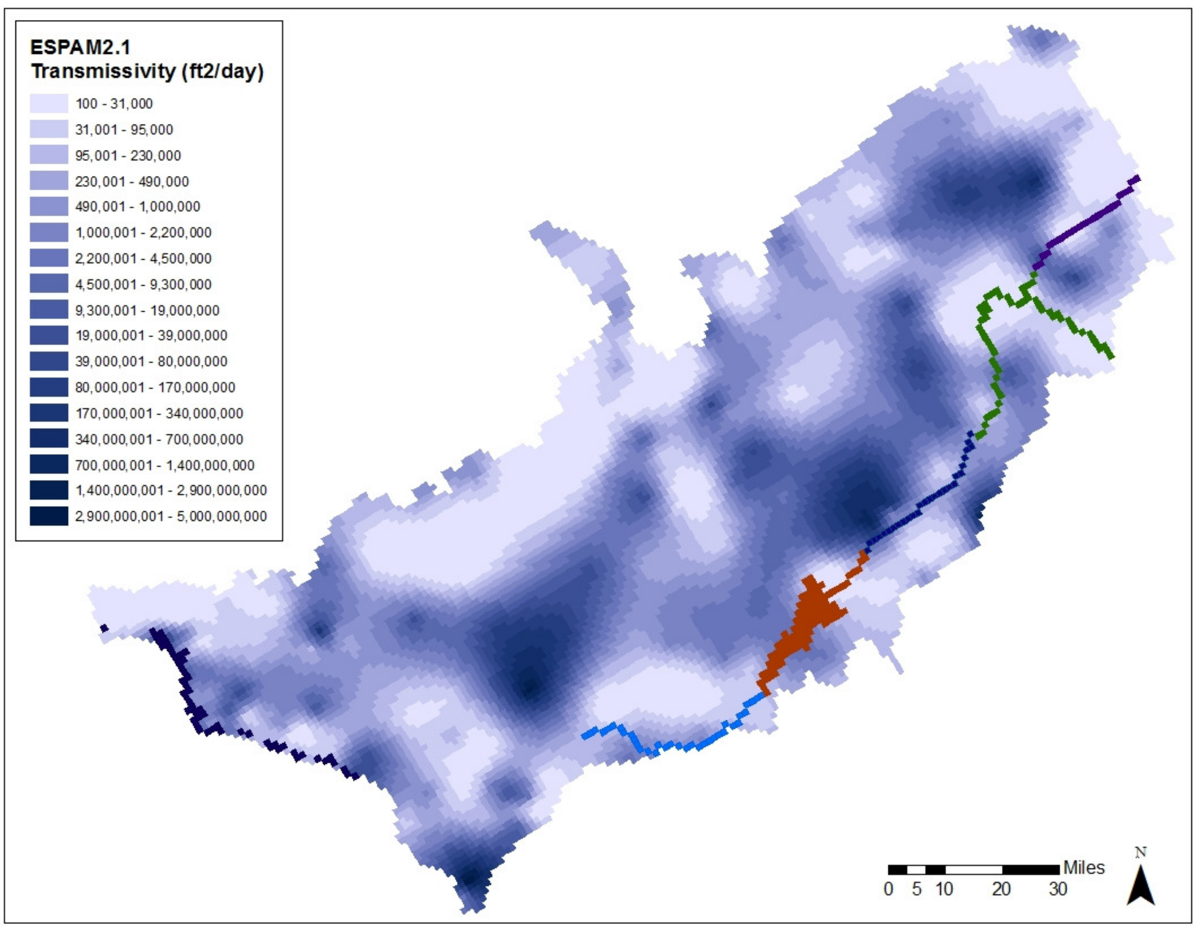

Figure 10. Distribution of calibrated ESPAM2.1 transmissivity values illustrating the Great Rift and Mud Lake low transmissivity zones.

Aquifer Storage Coefficient

The aquifer storage coefficient describes the amount of water that can be held in or released from an aquifer. In terms of recharge, it is defined as the volume of water that results a unit water-level rise over a unit area (Fetter, 1994). This means that areas with relatively large storage coefficient values require greater recharge volumes to induce water-level changes similar to those in areas characterized by smaller storage coefficient values. Therefore, recharge induced water-level changes expand more slowly in areas with large storage coefficient values than in areas with smaller storage coefficient values. The ESPAM2.1 storage-coefficient distribution is illustrated in Figure 11.

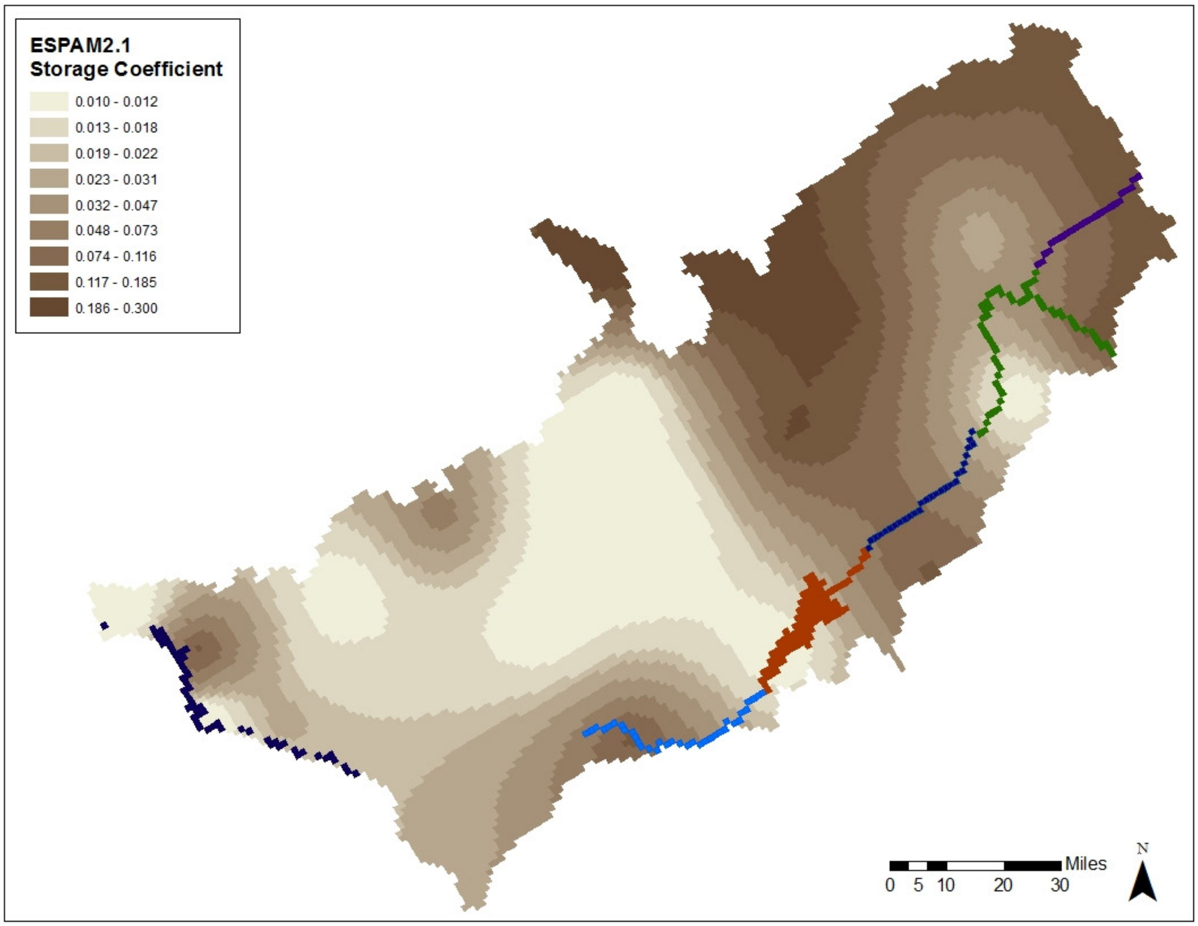

Figure 11. Distribution of calibrated ESPAM2.1 storage coefficient values.

Because water-level changes are a function of both transmissivity and storage coefficient (for a given recharge volume), the distribution of recharge induced water-level changes is dependent on the distribution of both aquifer transmissivity and aquifer storage.

State-sponsored managed recharge

The goals of the ESPA Managed Recharge Program must be defined in order to evaluate the relative effectiveness of the various recharge sites. The current ESPA Managed Recharge Program is founded on the ESPA Comprehensive Aquifer Management Plan (CAMP). The ESPA CAMP is a long-term program that directs IWRB efforts for managing water supply, and aims to stabilize and improve spring flows, river flows, and aquifer water levels across the ESRP (IWRB, 2009a). The ESPA CAMP was adopted by the IWRB in 2008 and by the Idaho Legislature in 2009 as an effort to decrease water-user conflict and reduce the need for litigious or administrative solutions (IDWR, 2015). Through stabilization of the ESPA aquifer/river system, CAMP looks to increase the predictability of water resources, and in turn, sustain the economic viability of the region. State-sponsored managed recharge is one of the mechanisms identified in the ESPA CAMP to achieve stabilization of the ESPA aquifer/river system.

Previous modeling to prioritize managed recharge sites

The Prioritization Report provides the IWRB with a range of considerations for prioritizing recharge by evaluating recharge at 19 sites relative to the following objectives and assessment criteria:

1) Augmenting flow in springs below Milner Dam in the near term.
    a. Percent of a single, one-month recharge volume which appears as reach gains below Milner Dam within three years.
    b. Percent of a continuous recharge rate which appears as additional spring discharge below Milner Dam after one year.

2) Augmenting flow in springs below Milner Dam in the long term.
    a. Percent of a single, one-month recharge volume which appears as reach gains below Milner Dam between 3 and 30 years.
    b. Percent of a continuous recharge rate which persists in springs below Milner Dam three years after recharge ceases.

3) Augmenting summer flows of the Snake River above Minidoka Dam and in the Henry's Fork.
    a. Percent of recurring March recharge which appears as reach gains above Minidoka Dam from July through September in the 30th year of recharge.

4) Augmenting winter flows of the Snake River above Minidoka Dam and in the Henry's Fork.
    a. Percent of recurring March recharge which appears as reach gains above Minidoka Dam from November through February in the 30th year of recharge.

5) Increasing flow in the Snake River above Minidoka Dam and in the Henry's Fork during extended drought.
    a. Percent of a single, one-month recharge volume which appears as reach gains above Minidoka Dam between 3 and 30 years after the recharge activity.

6) Increasing aquifer water levels in the A & B Irrigation District area.
    a. Average water-level change in four model cells in the A & B area after 10 years of continuous recharge at 100,000 acre-feet/year.

7) Increasing aquifer storage (and water levels) throughout the ESPA.
    a. Percent of a single, one-month recharge volume retained in aquifer storage 10 years after the recharge event.
    b. Average water-level change in the ESPA after 10 years of continuous recharge.

An important conclusion from the Prioritization Report is that no single site provides the greatest recharge benefit for all seven objectives. In other words, the best site for recharge depends on the objective of recharge.

Of the seven objectives that were evaluated, six are concerned with increased water availability at specific locations. Only objective seven (increased ESPA storage) is aquifer-wide in scope. As such, it is the only objective that is fully aligned with the overarching ESPA CAMP goal of improving the water budget for the entire aquifer (IWRB, 2009a). Moreover, it is accordant with the other six objectives and it does not prioritize one objective at the expense of another. Also, it is the least restrictive objective in terms of recharge limitations. For these reasons, increasing aquifer storage has been selected as the most generally useful criterion for comparing recharge sites and for optimizing recharge efforts.

Aquifer water levels are an expression of aquifer storage (IDWR, 2013) and ESPA discharge is dependent on aquifer water levels (Kjelstrom, 1986). Therefore, discharge from the aquifer increases as storage in the aquifer increases (Cosgrove et. al., 2005; Figure 12).

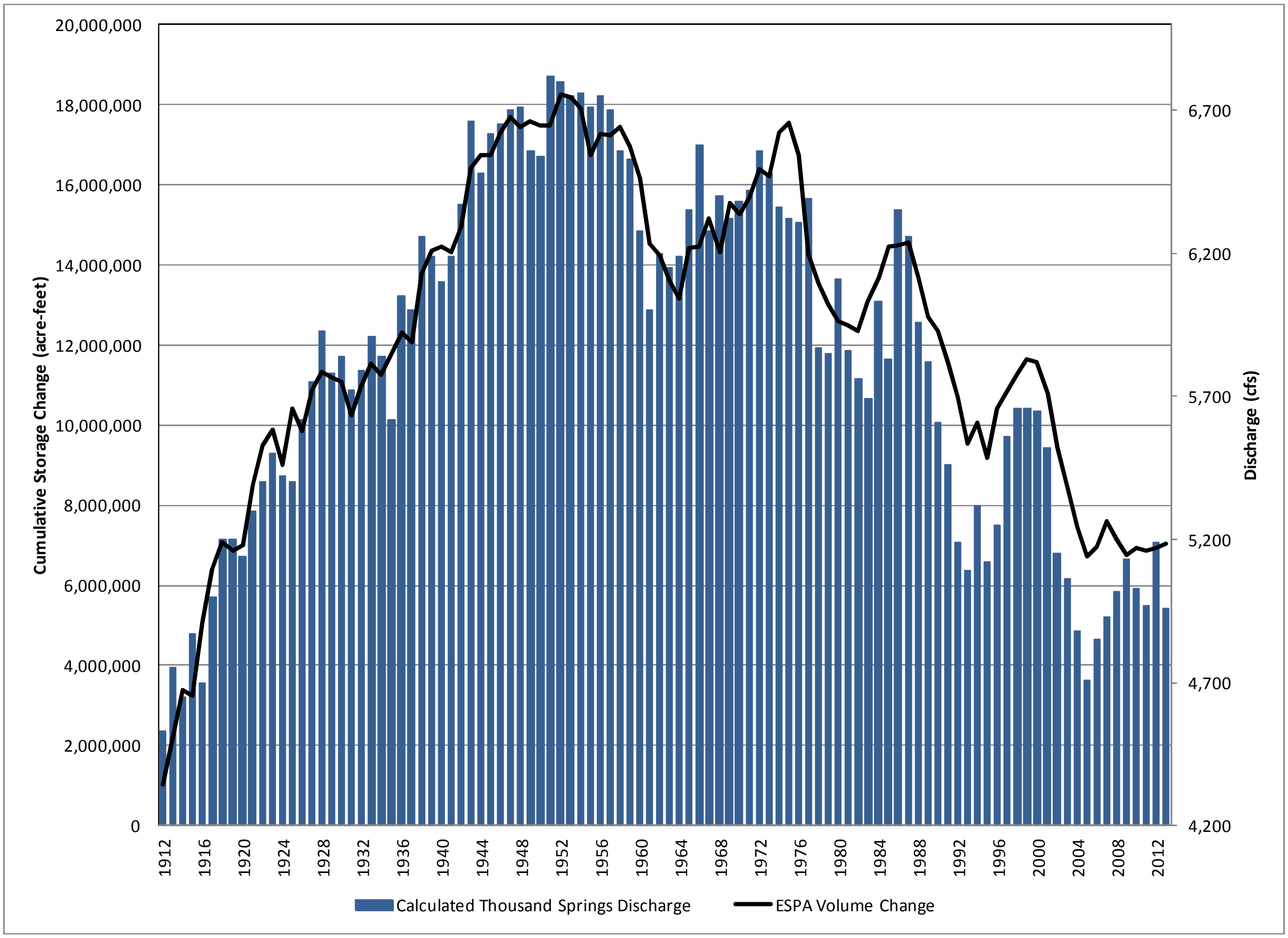

Figure 12. Cumulative changes in ESPA aquifer storage compared with calculated Thousand Springs discharge.

If managed aquifer recharge successfully increases long-term aquifer storage, aquifer-wide water levels will increase, and spring discharge and river flow throughout the aquifer/river system will be bolstered. This point is illustrated by comparing aquifer storage impacts to long-term discharge both below Milner Dam and above Minidoka Dam, as determined in the Prioritization Report (Tables 1a and 1b).

Table 1a. Long-term aquifer storage and discharge below Milner Dam.

Recharge Site	2A[1]	7A[3]
Southwest	31%	26%
Lake Walcott	21%	25%
Milner-Gooding	19%	17%
Milepost 31	19%	18%
Northside	18%	16%
Shoshone	16%	16%
Hilton Spill	3%	11%
Aberdeen-Springfield	3%	11%
Riverside	3%	10%
People's	3%	10%
United	3%	11%
Jensen's Grove	2%	9%
New Sweden	2%	11%
Snake River Valley	2%	10%
Idaho	2%	9%
Great Feeder	1%	9%
Egin Lakes	1%	36%
Fremont-Madison West	1%	26%
Fremont-Madison East	1%	22%

Table 1b. Long-term aquifer storage and discharge above Minidoka Dam.

Recharge Site	5[2]	7A[3]
Egin Lakes	65%	36%
Fremont-Madison West	50%	26%
Fremont-Madison East	45%	22%
Lake Walcott	41%	25%
Southwest	39%	26%
Milepost 31	28%	18%
Milner-Gooding	27%	17%
New Sweden	27%	11%
Shoshone	26%	16%
Hilton Spill	25%	11%
Aberdeen-Springfield	25%	11%
United	25%	11%
Great Feeder	25%	9%
Snake River Valley	24%	10%
Northside	24%	16%
Riverside	24%	10%
Idaho	24%	9%
People's	23%	10%
Jensen's Grove	21%	9%

[1]Criterion 2A: Percent of a single, one-month recharge volume discharged Below Milner 3 – 30 years after recharge.
[2]Criterion 5: Percent of a single, one-month recharge volume discharged Above Minidoka 3 – 30 years after recharge.
[3]Criterion 7A: Percent of single, one-month recharge volume retained in aquifer storage 10 years after recharge.
*Note: Blue highlight indicates recharge sites with a 10-year storage-retention value greater than 15%.

The State has determined that aquifer stabilization and recovery are the primary objectives for water-resource management, and the legislature has allocated funds for the purpose of replenishing aquifer storage (HB 547, 2014). The most efficient way to achieve aquifer stabilization is by prioritizing recharge sites with relatively high aquifer retention. Therefore, the primary goal for State-sponsored recharge is necessarily the maximization of aquifer storage.

Due to limitations in water availability and recharge resources, it is important to focus recharge efforts at locations most beneficial to the primary goal of stabilizing the ESPA. However, the success of managed recharge in the ESPA will be dependent on coordinated efforts at many locations.

State Water Law and Policy that guide State-sponsored recharge

The dedicated pursuit of aquifer-storage enhancements through the implementation of managed recharge is a reasonable strategy for stabilizing and recovering the ESPA. However, recharge must be conducted in accordance with Idaho State law and State policy.

Policy 1I of the 2012 Idaho State Water Plan provides that "[a]quifer recharge should be promoted and encouraged, consistent with state law" (IWRB, 2012). The State Water Plan also recognizes that managed recharge of the ESPA is in the public interest.

The 2012 State Water Plan (Plan) states that the "minimum stream flows provide the management framework for the optimum development of the water resources of the Snake River Basin." The Plan reaffirms that the flow of the Snake River may be reduced to zero cfs and that the minimum flow at the Murphy Gage would be 3,900 cfs from 4/1 through 10/31 and 5,600 cfs from 11/1 through 3/31. By reaffirming the Milner Zero Flow Policy, the Plan recognizes that the ground water discharge from the Thousand Springs during portions of low-water years is the primary source of water for maintaining the Murphy minimum flow. Accordingly, Policy 4D of the Plan provides that "[t]he Eastern Snake Plain Aquifer and the Snake River below Milner Dam should be conjunctively managed to provide a sustainable water supply for all existing and future beneficial uses within and downstream of the ESPA. Policy 4B calls for implementation of "a sustainable aquifer recharge program" as one of the measures to sustain the ground water levels in the ESPA (IWRB, 2012).

The State Water Plan also reaffirms the 2009 ESPA Comprehensive Aquifer Management Plan (ESPA CAMP). The ESPA CAMP identifies recharge as a mechanism for stabilizing the aquifer, and establishes a long-term hydrologic target for managed aquifer recharge from 150,000 to 250,000 acre feet on an average annual basis. The Phase 1 (through 2018) CAMP recharge target is to conduct recharge at an average of 100,000 acre-feet annually (IWRB, 2009a). Legislative approval is required if the IWRB proposes to increase the 100,000 acre-foot limit by more than 75,000 before January 1, 2019 (IWRB, 2009b; IDWR, 2015). After January 1, 2019, the CAMP recharge target is raised to an average of 250,000 acre-feet annually.

The Murphy minimum flows are an important consideration for recharge because Snake River flows at Murphy have been declining, and a shortfall in the minimum average daily flow occurred briefly during 2015 (Figure 13).

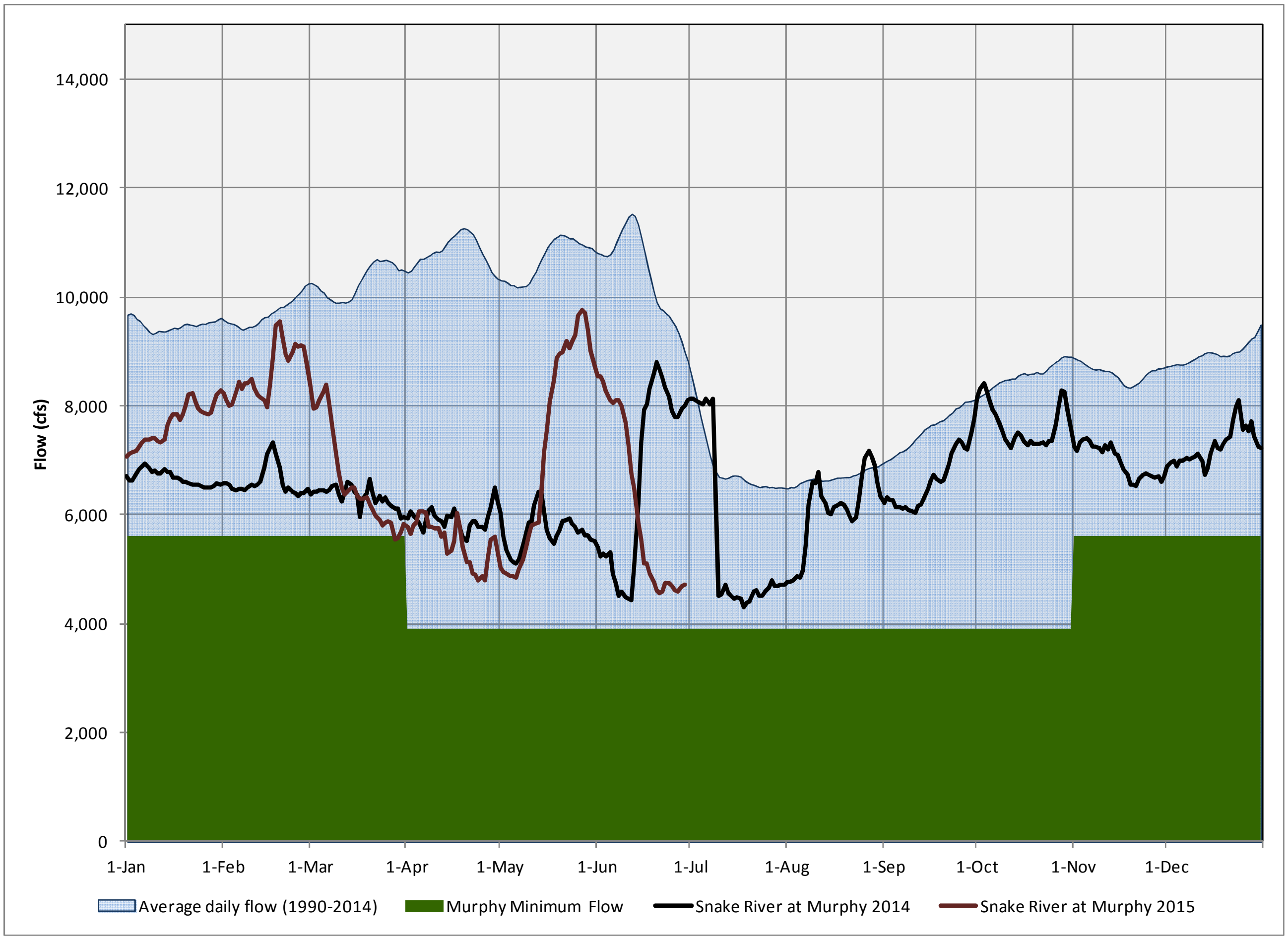

Figure 13. Seven-day average of average daily flow in the Snake River at the Murphy gage illustrating declining river flow in relation to the established minimum flows.

The State Water Plan also reaffirmed the Two-Rivers Policy, whereby the separation of water administration at Milner Dam precludes downstream calls for water above Milner. As contemplated by the Two-Rivers Policy, all flows that would otherwise pass Milner Dam are available for recharge above Milner Dam. These flows are a critical source of recharge water for the State.

Because the majority of the flow in the Snake River at Murphy is ESPA spring discharge that occurs between Kimberly and King Hill (Figure 12; Table 2; Appendix A), protecting the minimum flow water rights at Murphy requires management of the ESPA in a way that supports spring discharge along the Kimberly-to-King Hill reach of the Snake River (i.e., below Milner Dam).

Table 2. Percentage of Murphy flows due to ESPA spring discharge.

Month	Snake River at Murphy 2014[1] (cfs)	ESPA Spring Discharge 2014 (cfs)	ESPA Springs (% of Murphy Flow)
January	6,650	5,648	85%
February	6,518	5,594	86%
March	6,383	5,494	86%
April	5,913	5,441	92%
May	5,673	5,400	95%
June	4,479	5,526	123%
July	4,509	5,634	125%
August	6,183	5,918	96%
September	6,545	6,109	93%
October	7,518	6,044	80%
November	7,033	5,818	83%
December	7,206	5,724	79%

[1]Flow-augmentation releases have been subtracted from Murphy flow values to calculate June and July percentages.

Using the flows passing Milner Dam to for managed recharge to increase aquifer storage is an effective way to increase long-term, year-round spring discharge (Tables 1a and 1b). In this way, recharging to produce long-term benefits to flow at Murphy is consistent with the States recharge goal of increasing aquifer storage.

Limitations to Managed Recharge

Some recharge sites have higher recharge capacities than others. Limitations to recharge need to be understood before an effective managed recharge program can be developed. Limitations to managed recharge include:

1) Availability of surface water,
2) Rate of diversion to a recharge site (diversion capacity),
3) Rate of infiltration at a recharge site (infiltration capacity), and
4) Depth-to-groundwater at or near a recharge site (vadose-zone capacity).

Sources of information regarding recharge limitations come from several sources including: hydrogeologic studies, water-right exams, personal communications with canal managers, calibrated ESPAM2.1 parameters, and ESPAM2.1 modeling results. While many of these limitations are estimates, they are reasonable approximations that serve to help the IWRB prioritize recharge activities and develop a comprehensive managed-recharge plan.

Surface-Water Availability

The magnitude, location, and timing of surplus Snake River flow limit the amount of recharge that can take place. Surplus flow is natural flow (i.e., water not released from storage) at the point-of-diversion (POD) that is in excess of the water necessary to satisfy all in-priority water rights. Limitations to *surface-water availability* generally involve physical realities such as precipitation and reservoir storage, as well as other constraints.

In simplest terms, surface-water availability for recharge is a function of precipitation. However, in the ESPA aquifer/river system, water availability for recharge is complicated by considerations such as:

1. Water rights – The water diverted for recharge must be associated with a water right that is in priority both at the POD and during the entire period of recharge. The most senior IWRB recharge water right has a priority date of 1980, which is junior to the 1903 Minidoka (Lake Walcott), 1916 Milner, and 1921 American Falls reservoir-fill water rights, as well as the 1909/1912 unsubordinated Minidoka Dam hydropower water rights.

2. IWRB policy – The IWRB has adopted resolutions limiting recharge to the use of natural flow to avoid placing additional burden on the storage supplies above Milner Dam (IWRB, 2014). Furthermore, the IWRB has adhered to a policy that recharge should not interfere with or prevent the capture of water in the federal reservoir system (Weaver, 2012). This policy creates uncertainty as to the timing, location, and magnitude of recharge. The U.S. Bureau of Reclamation's (USBR) unsubordinated hydropower water rights at Minidoka help resolve uncertainty of the timing, location, and magnitude of recharge above Minidoka Dam. The unsubordinated Minidoka hydropower rights serve as visible and transparent indicators of whether recharge will interfere with physically filling the reservoir system. Flows in excess of 2,700 cfs at Minidoka indicate that the USBR is confident the reservoir system will physically fill, and

the diversion of water for recharge is unlikely to intercept water that could otherwise be captured in the reservoir system. Flows of less than 2,700 cfs at Minidoka indicate that the USBR is still physically filling the reservoir system, and the diversion of water for recharge upstream of the Minidoka Dam would have the potential of intercepting water that would otherwise be captured in the reservoir system (Weaver, 2012).

Determination of Water Availability for Recharge

Application of the Milner Zero Flow Policy means that only water passing Milner Dam can be considered surplus to upstream beneficial use – regardless of where the diversion occurs (IDWR, 1999). Furthermore, the Snake River flows through a canyon downstream of Milner Dam, and there is no infrastructure to divert river water onto the ESRP below the dam. Therefore, the natural flow passing Milner Dam represents the total volume of water that could be used for managed recharge if there were adequate infrastructure and administrative considerations in place to divert the water. The median 1980-2012 natural flow at Milner Dam is 964,097 acre-feet annually, which demonstrates that there is physically enough natural flow to meet the ESPA CAMP long-term recharge targets (Figure 14).

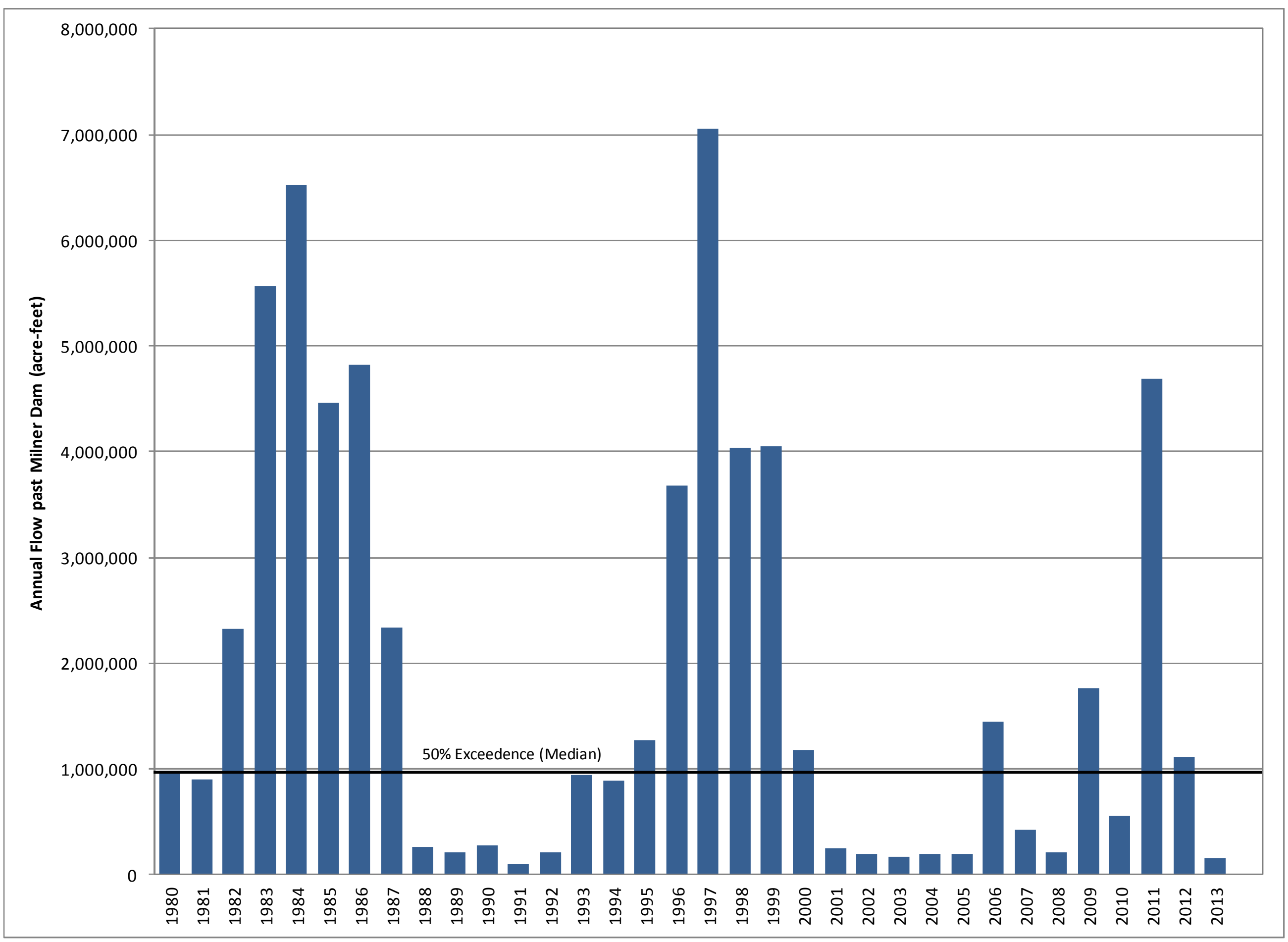

Figure 14. Annual volume of natural flow passing Milner Dam.

The median is used (instead of the mean) to describe the water availability data because it represents the skewed nature of the data more appropriately than does the mean. More extensive discussions of the water-availability data and the use of descriptive statistics are included in Appendix B.

The amount of natural flow available for recharge at a site is an important consideration for the prioritization of State recharge investment, and historic Snake River flow data is the most objective way of quantifying recharge water availability.

The determination of historic water availability is dependent on the flow at the Minidoka and Milner dams. The flow passing Milner Dam represents the total amount of water available for recharge, and the flow past Minidoka Dam serves as an indicator of the likelihood that recharge upstream of the dam will interfere with reservoir fill. Water availability is calculated using the following steps:

1. Subtract storage-release water from all minimum-flow gages used to determine water availability.
    a. Storage releases for uses such as flow augmentation for fish propagation released upstream of a recharge POD are not available for recharge.

2. Examine flow at Milner Dam (USGS 13088000 SNAKE RIVER GAGING STATION AT MILNER ID; Figure 15).
    a. If there is no flow past Milner Dam, no water is available for ESPA recharge.
    b. If there is flow past Milner Dam, recharge can take place between Minidoka Dam and Milner Dam at a rate that is less than or equal to, the flow past Milner Dam (Figure 15).

3. Assess if the State's recharge water rights are in priority at recharge PODs located between Minidoka and Milner dams.
    a. If the rights are not in priority, no recharge can take place.

4. Examine flow at Minidoka Dam (USGS 13081500 SNAKE RIVER NR MINIDOKA ID; Figure 15).
    a. Given that there is flow past Milner Dam, recharge can take place upstream of Minidoka if flow past Minidoka Dam is greater than 2,700 cfs. The 2,700 cfs is based on the USBR unsubordinated hydropower water rights.
    b. Recharge can take place between American Falls Dam and Minidoka Dam at a rate equal to the flow past Minidoka, less 2,700 cfs (Figure 15).

5. Assess if the State's recharge water rights are in priority at recharge PODs located upstream of Minidoka Dam.
    a. If the right is not in priority, no recharge can take place.

6. Examine flow at recharge PODs upstream of American Falls Dam.
    a. Because operation of the reservoir system may allow for flow in excess of 2,700 cfs at Minidoka while upstream flows are relatively low, it is important to also look at flow in the Snake River at the recharge PODs. Flows at Blackfoot, Heise, and St. Anthony are used as proxies for PODs that divert from the main stem Snake River above American Falls Dam, the South Fork Snake River (South Fork), and the Henry's Fork Snake River (Henry's Fork), respectively (Figure 15).

b. Given that the unsubordinated USBR hydropower rights are satisfied, the volume of water available for recharge upstream of American Falls Dam is limited to the smaller of either the spills past Minidoka Dam (less 2,700 cfs), or the flow in the Snake River at the recharge POD (less an assumed minimum flow).
c. Downstream limitations are applied upstream. For example, if there is not enough flow at Blackfoot to perform recharge on a given date, recharge is not permissible on the Henry's Fork or South Fork on that date.

7. Calculate recharge water availability on a daily basis at each POD.
    a. Sum to monthly and annual volumes for analysis.

A flow-chart illustrating the steps for determining water availability is located in Appendix C.

Because of the efforts required to conduct recharge activities, it has been assumed that the act of recharge does not occur if the calculated available flow is less than 10 cfs, or if water is available for less than four consecutive days (Hoekema, 2015).

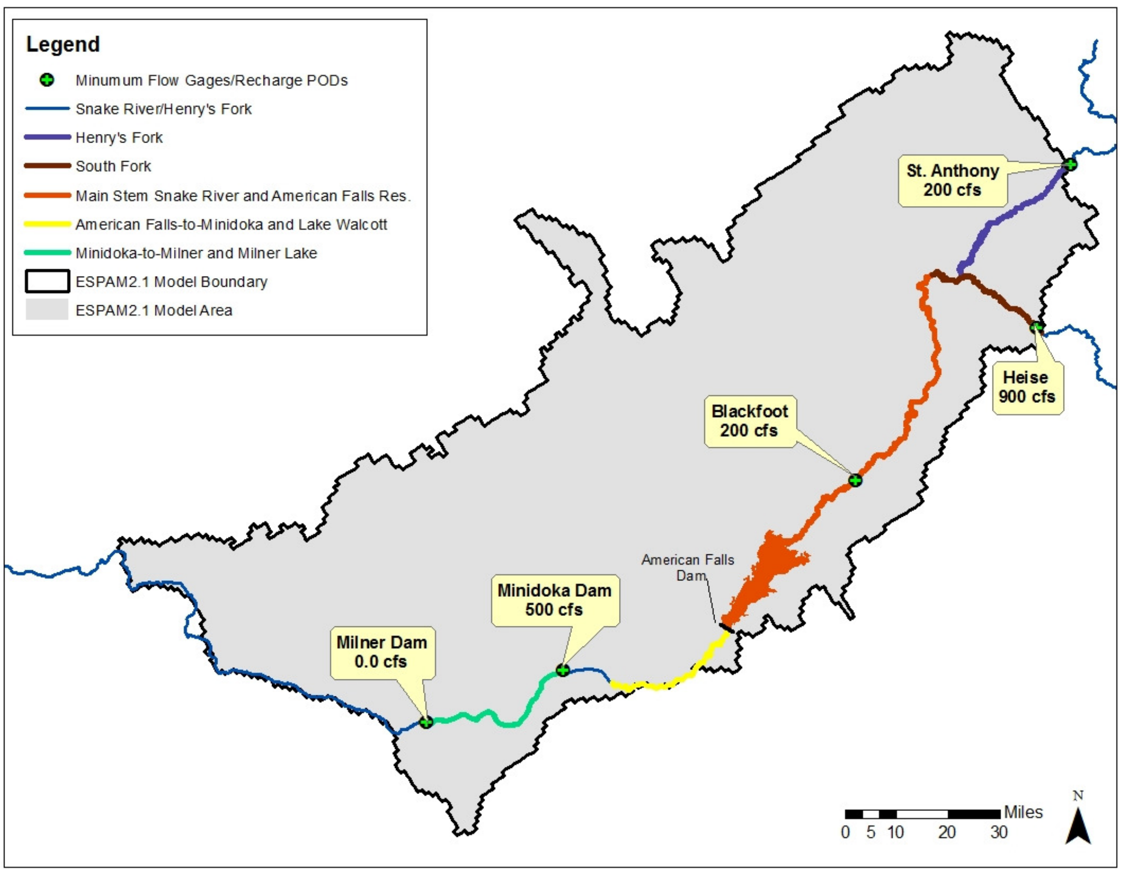

Figure 15. Locations of the minimum stream flow gages/recharge POD proxies.

These steps represent the process for determining historic water availability at each site in order to inform State recharge investment decisions. Because it is not known how much recharge will actually occur at each site, upstream recharge diversions have not been deducted from the availability at downstream sites. Calculation of real-time water availability for conducting recharge uses a similar, but iterative approach that may require adjustment of recharge diversions due to upstream recharge activities.

The minimum stream flows used in the calculation of water availability are based on Idaho Code, USBR operations, and professional judgment regarding sustainable low flows (Table 3).

Table 3. Assumed minimum stream flows for determining the availability of water for recharge.

Stream Gage	Assumed Minimum Flow (cfs)	Comments
St. Anthony (USGS 13046000)	200	Based on discussions with local water managers.
Heise (USGS 13037500)	900	Based on USBR hydropower operations.
Blackfoot (USGS 13062500)	200	Based on historic low flow.
Minidoka (USGS 13081500)	2,700	Based on USBR hydropower rights.
Milner (USGS 13088000)	0	Milner zero minimum flow policy.

The assumed minimum flows were chosen so as not to interfere with existing in-stream beneficial uses, and may not be appropriate at all times for meeting river ecosystem needs. Ecosystem-maintenance flow recommendations are discussed more thoroughly in IDWR (1999) and IDFG (2014).

Using the methodology described above, the annual recharge water availability at the minimum flow locations are illustrated in Figure 16 and Appendix B. It is important to reiterate that flows have been corrected for storage releases and reach gains.

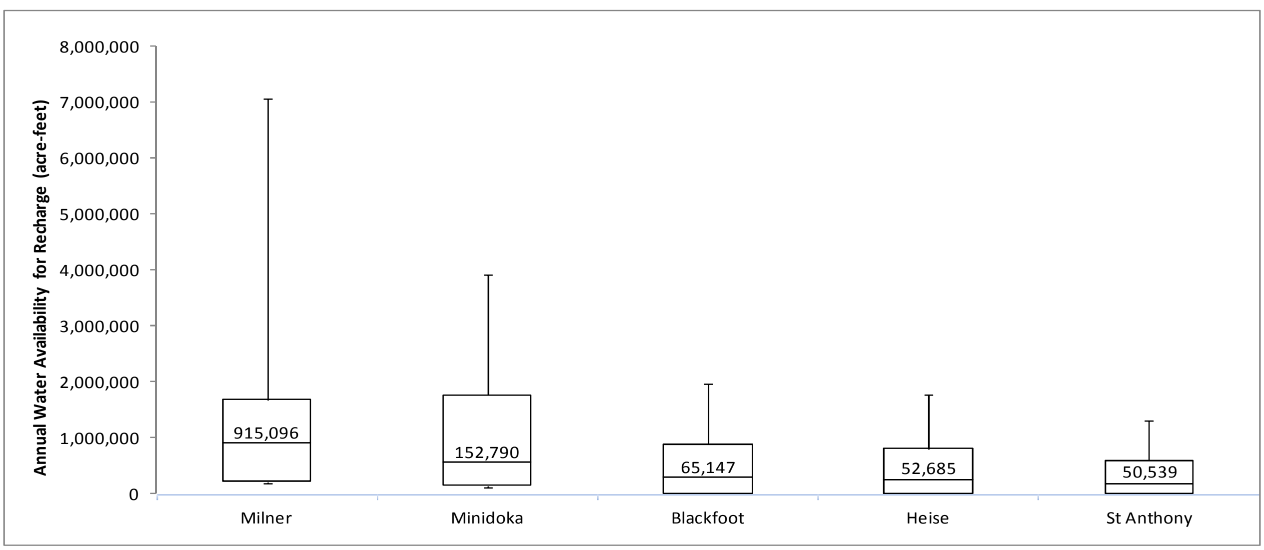

Figure 16. Box-and-whisker plots illustrating the annual water availability at the minimum streamflow locations.

The whiskers in Figure 16 represent the maximum and minimum volumes available for recharge during the analysis period, and the top and bottom box borders represent the 75th and 25th percentiles, respectively. The median volumes are labeled within the boxes.

The amount of water available for recharge downstream is significantly larger than upstream for three reasons:

1. Reservoir fill is a priority. The State has committed to prioritizing reservoir fill over recharge, and water upstream of Minidoka Dam must go to reservoir fill before it becomes available for recharge. Sites located downstream of Minidoka Dam are downstream of the combined federal reservoir system.

2. There is a constant source of water for recharge between the Minidoka and Milner dams. USBR operations provide a minimum of 500 cfs of flow past Minidoka Dam during the non-irrigation season which is available for recharge due to the Milner Zero Flow Policy.

3. Water availability at each location has been calculated independently from the other locations. Because the water availability at each location has been calculated as though no other recharge takes place, the total volume of water available for recharge is less than the sum of the water availability at all of the sites.

Monthly Water Availability

Although the median value of natural flow passing Milner Dam is greater than the annual volume necessary to meet recharge diversion objectives, the amount of recharge that can take place at any site will change over the course of a year depending on the interplay between overall water-supply conditions, reservoir fill, and water-right priorities. Therefore, it is important to look at monthly recharge-water availability at the minimum flow locations in order to determine when recharge is likely to occur during the year (Figures 17 – 21; Table 4).

Monthly water availability is affected by seasonal water use and water-right priorities related to reservoir fill and irrigation. The irrigation season is considered to be April 1 through October 31 in this study.

Monthly Water Availability: Minidoka Dam-to-Milner Dam

Due to the Milner Zero Flow Policy, the historic water availability at Milner Dam represents the total volume of water that may have been available for recharge in the ESPA aquifer/river system. The flow past Milner Dam also represents the maximum volume of water that was available for recharge between the Minidoka and Milner dams, with the assumption that no upstream recharge takes place. Figure 17 illustrates the monthly water availability at Milner Dam.

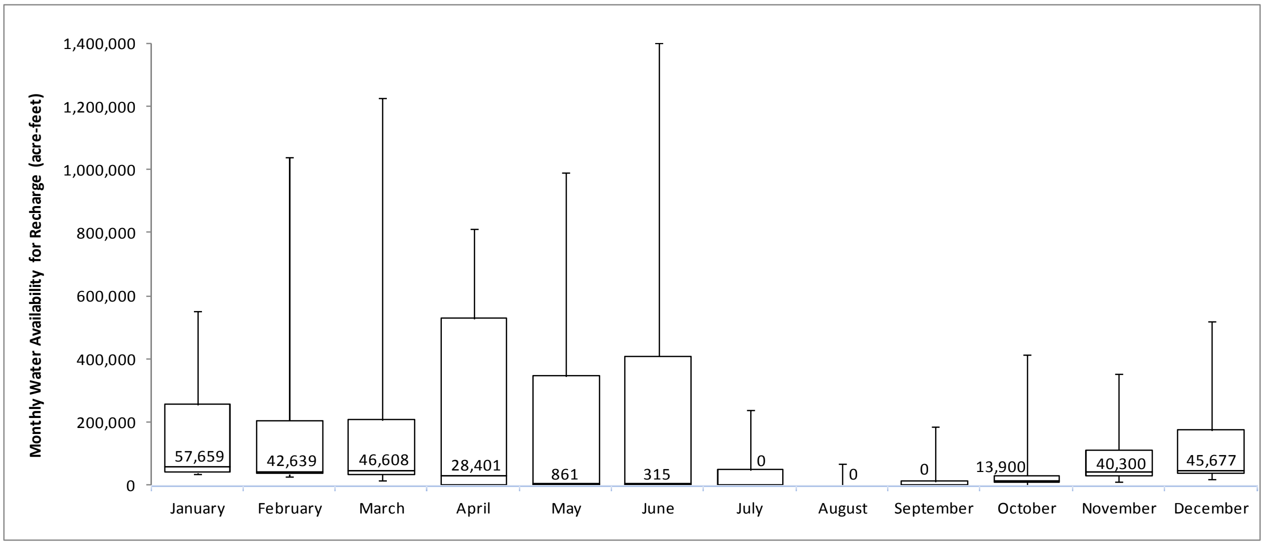

Figure 17. Monthly volumes of water available for recharge at Milner Dam.

The whiskers in Figure 17 represent the maximum and minimum volumes available for recharge during the analysis period, and the top and bottom box borders represent the 75th and 25th percentiles, respectively. The median volumes are labeled. The lack of a box indicates that no water is available in August at least 75% of the time.

Water availability for recharge is greatest during the non-irrigation season at locations between the Minidoka and Milner dams. The USBR tries to maintain a minimum of 500 cfs past Minidoka Dam during the non-irrigation season to meet river ecology needs immediately downstream of Minidoka Dam. This flow continues past Milner Dam, and is therefore available for recharge along this reach. Because the Milner Policy allows for zero flow past Milner Dam, recharge of at least 500 cfs is possible between the Minidoka and Milner dams for the entire non-irrigation season.

Significant volumes of water are also available during both early and late irrigation season months (April, May, and October). Diversions for beneficial use typically bring flows past Milner Dam to zero during the heart of the irrigation season, and virtually no water is available for recharge in June, July, August, or September in most years.

Monthly Water Availability: American Falls Dam-to-Minidoka Dam

The flow at Minidoka signals when recharge can be accomplished upstream while recharge is in priority and without interfering with reservoir fill. The historic water availability at Minidoka represents the total volume of water that may have been available for recharge above Minidoka Dam because any flow over 2,700 cfs is considered surplus to reservoir fill. The flow past Minidoka Dam also represents the maximum volume of water that was available for recharge between the American Falls and Minidoka dams, with the assumption that no upstream recharge takes place. Figure 18 illustrates the monthly water availability at Minidoka.

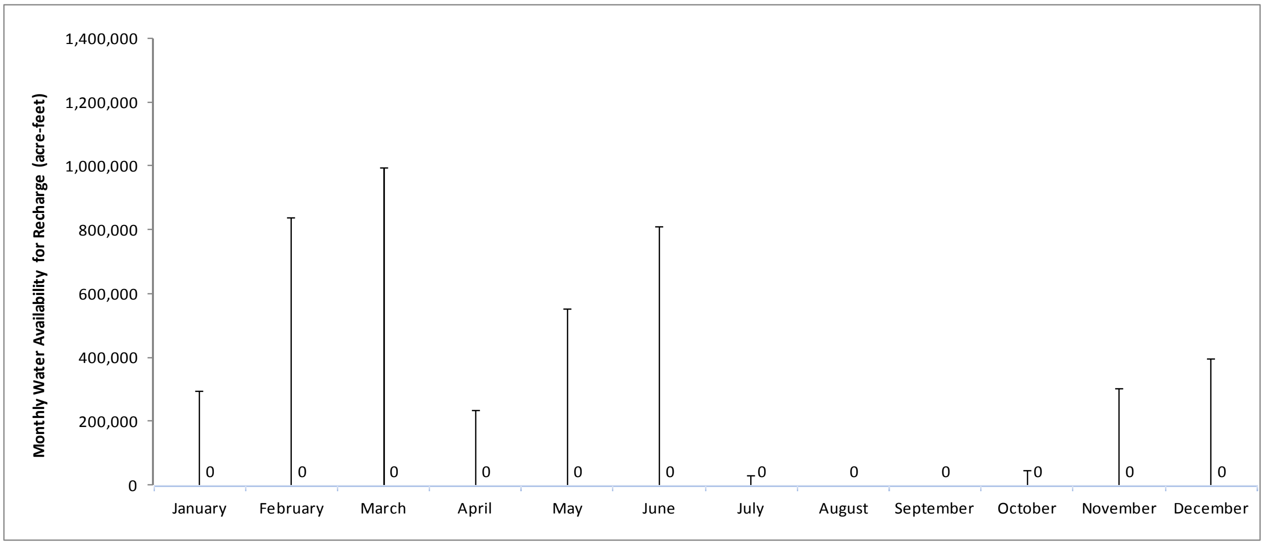

Figure 18. Monthly volumes of water available for recharge at Minidoka.

The whiskers in Figure 18 represent the maximum volumes available for recharge during the analysis period. The median volumes are labeled. The lack of a box indicates that no water is available during any month at least 75% of the time.

Because of water-right priorities, irrigation practices, and reservoir-fill precedence, water is rarely available for recharge from July through October at locations between the American Falls and Minidoka dams. Recharge water is most available November through June. However, the State's recharge water right is typically only in priority during high-flow years, resulting in a few years with very large volumes of water for recharge interspersed with many years with little or no supply.

Monthly Water Availability: Roberts-to-Aberdeen

The historic water availability at Blackfoot represents the total volume of water that may have been available for recharge at Blackfoot, and serves to represent the water-availability conditions for recharge at those sites that divert from the main stem Snake River between the communities of Roberts and Aberdeen, with the assumption that no upstream recharge takes place. Figure 19 illustrates the monthly water availability at Blackfoot.

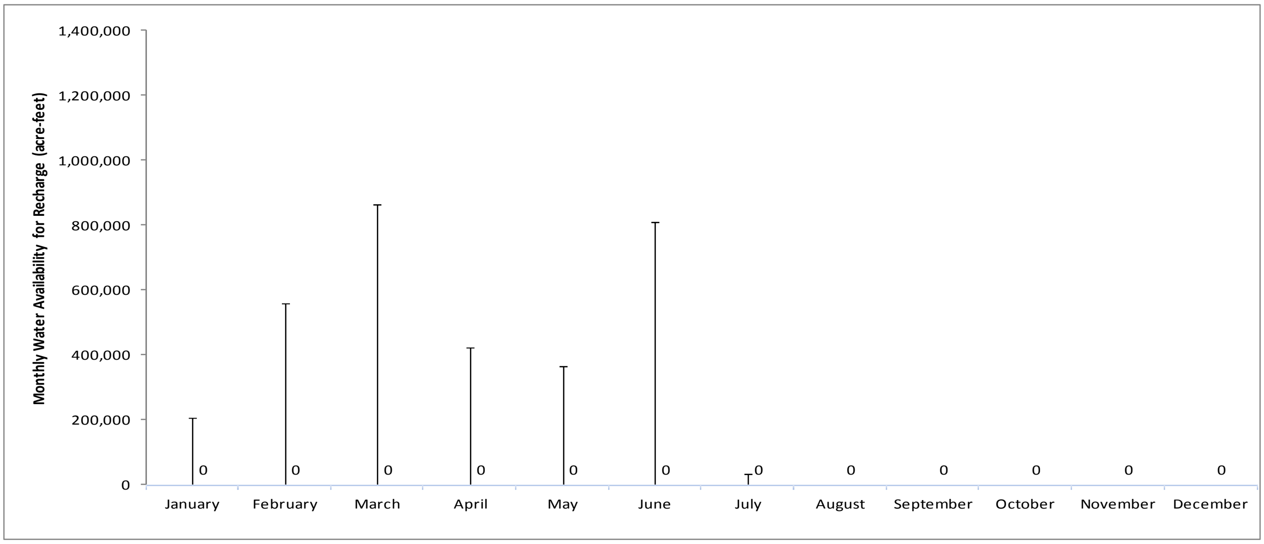

Figure 19. Monthly volumes of water available for recharge at Blackfoot.

The whiskers in Figure 19 represent the maximum volumes available for recharge during the analysis period. The median volumes are labeled. The lack of a box indicates that no water is available during any month at least 75% of the time.

Because of irrigation practices and reservoir-fill precedence, water is rarely available for recharge from July through December at locations between the Henry's Fork/South Fork confluence and American Falls Dam. Recharge water is most available from January through June. However, the State's recharge water right is typically only in priority during high-flow years, resulting in a few years with very large volumes of water for recharge interspersed with many years with little or no supply.

Monthly Water Availability: South Fork

The historic water availability at Heise represents the total volume of water that may have been available for recharge at Heise, and serves to represent the water-availability conditions for recharge on the South Fork upstream of the confluence of the Henry's Fork and South Fork. Figure 20 illustrates the monthly water availability at Heise.

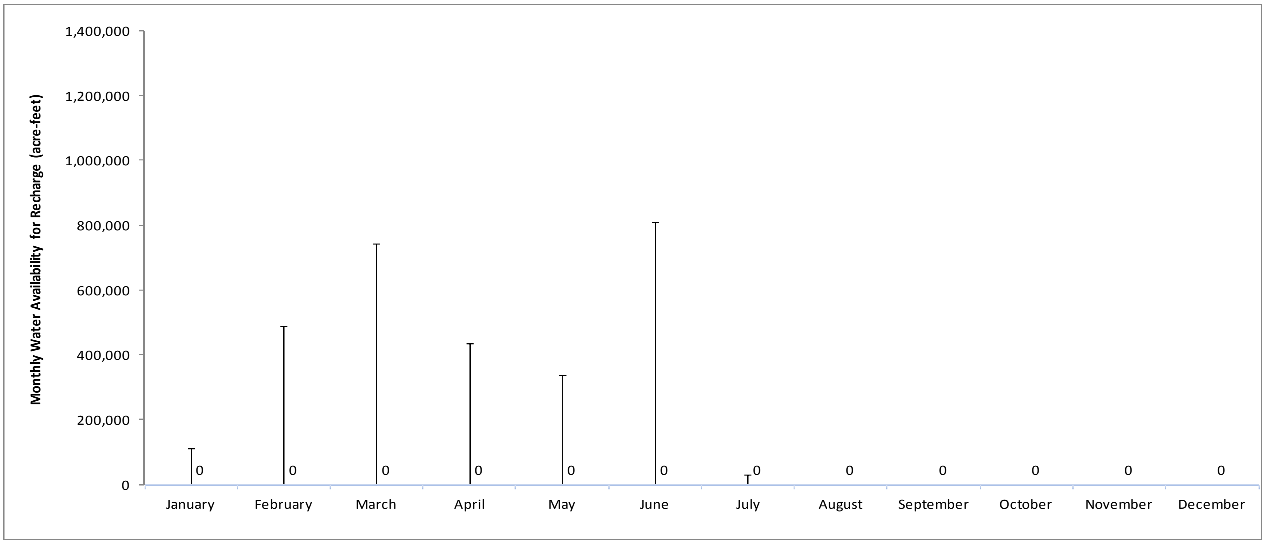

Figure 20. Monthly volumes of water available for recharge at Heise.

The whiskers in Figure 20 represent the maximum volumes available for recharge during the analysis period. The median volumes are labeled. The lack of a box indicates that no water is available during any month at least 75% of the time.

Because of irrigation practices and reservoir-fill precedence, water is rarely available for recharge from July through December at locations on the South Fork. Recharge water is most available from January through June. However, the State's recharge water right is typically only in priority during high-flow years, resulting in a few years with very large volumes of water for recharge interspersed with many years with little or no supply.

Monthly Water Availability: Henry's Fork

The historic water availability at St. Anthony represents the total volume of water that may have been available for recharge at St. Anthony, and serves to represent the water-availability conditions for recharge on the Henry's Fork upstream of the confluence of the Henry's Fork and South Fork. Figure 21 illustrates the monthly water availability at St. Anthony.

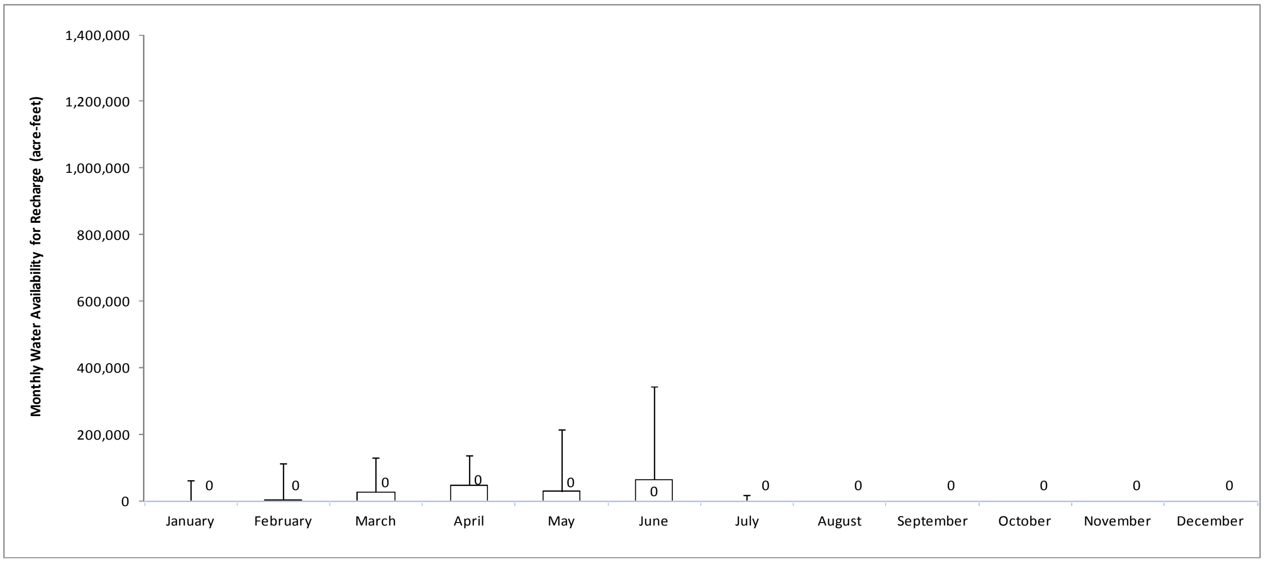

Figure 21. Monthly volumes of water available for recharge at St. Anthony.

The whiskers in Figure 21 represent the maximum volumes available for recharge during the analysis period. The median volumes are labeled. The lack of a box indicates that no water is available during any month at least 75% of the time.

Because of irrigation practices and reservoir-fill precedence, water is rarely available for recharge from July through December at locations on the Henry's Fork. Recharge water is most available from January through June. However, the State's recharge water right is typically only in priority during high-flow years, resulting in a few years with very large volumes of water for recharge interspersed with many years with little or no supply.

The data presented in Figure 17 demonstrate that significant volumes of water are consistently available at Milner Dam during the non-irrigation season, and that water is available only occasionally during the irrigation season as a result of anomalously high flows. The data presented in Figure 18 demonstrate that water is sporadically available for recharge above Minidoka Dam and availability occurs as a result of anomalously high flows. The data presented in Figures 19 – 21 demonstrate that water is only sporadically available for recharge above American Falls Dam during the early irrigation-season months and occurs as a result of anomalously high flows. Water is rarely available for recharge above Minidoka from July through December.

Visual comparison of the median annual water availability to the monthly water availabilities at a given POD indicate much larger volumes of water available annually than the sum of the monthly median values. This occurs because the annual water-availability median incorporates all monthly values – including extreme high values. Monthly water-availability medians incorporate many low values, which results in much lower monthly water-availability medians.

Median Water Availability for All Months versus Median Water Availability in Non-Zero Months

The minimum-flow locations above American Falls Reservoir exhibit median values of zero for every month of the year. However, there is water available for recharge during high-flow years. Excluding Milner, the median volumes of water when considering all years are vastly different than the median volumes for non-zero years;

indicating copious water availability during the occasional years when water is available. Table 4 illustrates the feast-or-famine nature of water availability at PODs located upstream of Minidoka Dam.

Table 4. Median monthly volume of water available for recharge for years 1992 – 2014.

	Milner		Minidoka		Blackfoot		Heise		St. Anthony	
Month	Median	Non-Zero Median	Median	Non-Zero Median	Median	Non-Zero Median	Median	Non-Zero Median	Median	Non-Zero Median
January	57,659	57,659	0	245,345	0	171,911	0	101,990	0	59,702
February	42,639	42,639	0	218,738	0	238,783	0	217,706	0	66,317
March	46,608	46,608	0	246,798	0	338,559	0	319,585	0	97,194
April	28,401	101,486	0	373,883	0	308,059	0	252,770	0	79,901
May	861	210,789	0	135,991	0	110,527	0	87,293	0	72,413
June	315	395,323	0	127,970	0	127,970	0	127,970	0	103,167
July	0	78,824	0	18,385	0	18,385	0	18,385	0	12,066
August	0	48,175	0	0	0	0	0	0	0	0
September	0	13,150	0	0	0	0	0	0	0	0
October	13,900	15,503	0	30,589	0	0	0	0	0	0
November	40,300	40,300	0	210,227	0	0	0	0	0	0
December	45,677	45,677	0	144,443	0	0	0	0	0	0

Although the median values for all non-zero years indicate that there are large volumes of water available during some years, the relatively low number of years that equal or exceed the median volume indicates the rarity of high water-availability years. Table 5 illustrates the number of years that meet or exceed the non-zero monthly median.

Table 5. Median values for years with non-zero volumes and the number of days that meet or exceed the non-zero median value during the period 1992 – 2014 (23 years).

	Milner		Minidoka		Blackfoot		Heise		St. Anthony	
Month	Non-Zero Median	Number of years >/= Median	Non-Zero Median	Number of years >/= Median	Non-Zero Median	Number of years >/= Median	Non-Zero Median	Number of years >/= Median	Non-Zero Median	Number of years >/= Median
January	57,659	12	245,345	5	171,911	2	101,990	2	59,702	2
February	42,639	11	218,738	5	238,783	3	217,706	2	66,317	3
March	46,608	11	246,798	4	338,559	4	319,585	3	97,194	4
April	101,486	10	373,883	4	308,059	4	252,770	4	79,901	4
May	210,789	8	135,991	4	110,527	4	87,293	4	72,413	4
June	395,323	7	127,970	4	127,970	4	127,970	4	103,167	4
July	78,824	5	18,385	1	18,385	1	18,385	1	12,066	1
August	48,175	1	0	--	0	--	0	--	0	--
September	13,150	6	0	--	0	--	0	--	0	--
October	15,503	11	30,589	3	0	--	0	--	0	--
November	40,300	12	210,227	2	0	--	0	--	0	--
December	45,677	12	144,443	4	0	--	0	--	0	--

Diversion Limitations

The ability to deliver water to a recharge site may limit the amount of recharge that can take place. Limitations to *diversion capacity* are generally controlled by the size of diversion and transmission structures such as gates, canals, off-canal sites, pipes, and wells. Given the general lack of recharge diversion capacity measurements (recharge diversions and surface-water returns), the preliminary diversion capacities for most sites have been estimated by reviewing historic recharge efforts.

Although the below diversion capacities (Table 6) are reasonable preliminary estimates that generally fit the recharge situation, some of the limits reported here may be lower than what can be physically diverted at the POD. Some of the diversion capacities may be refined as the recharge program develops and the relationship between recharge diversions and surface-water returns are better understood. It is also possible that some sites may be able to use different combinations of canals and off-canal features within their system to reduce returns to the river, and thus increase diversion capacity.

Table 6 lists the sources of diversion data, as well as the diversion limitations used in this study.

Table 6. Diversion capacities for recharge sites reviewed in this study.

Recharge Site	Diversion Capacity (acre-feet/month)	Comments
Aberdeen-Springfield	12,100	Based on historic recharge diversions.
Egin Lakes	15,300	Based on historic recharge diversions.
Fremont-Madison East	10,900	Based on historic recharge diversions.
Fremont-Madison West	7,200	Based on historic recharge diversions/canal manager information.
Great Feeder Area	18,100	Based on historic recharge diversions.
Hilton	7,700	Based on historic recharge diversions.
Idaho	4,500	Based on historic recharge diversions.
Jensen's Grove	1,800	Based on water-right exam data.
Lake Walcott Recharge	6,100	Based on proposed capacity of recharge wells.
Milepost 31 Recharge	18,400	Based on design capacity of diversion structure.
Milner-Gooding	46,500	Based on historic recharge diversions and MP31 design.
New Sweden	3,200	Based on historic recharge diversions.
Northside	30,700	Based on historic recharge diversions.
People's	6,000	Based on historic recharge diversions.
Riverside	5,400	Based on historic recharge diversions.
Shoshone	19,900	Based on historic recharge diversions.
Snake River Valley	4,500	Based on historic recharge diversions.
Southwest Irrigation	3,600	Based on historic recharge diversions.
United	4,500	Based on historic recharge diversions.

It may be possible to engineer larger structures to allow for greater diversion capacities at some sites; thereby increasing recharge capacity if larger recharge diversions do not result surface-water in returns to the Snake River.

Infiltration Limitations

Infiltration capacity is the physical ability for water delivered to a recharge site to seep into the aquifer. The ability to accept water is related to both the equilibrium infiltration capacity of surface soils and the hydraulic conductivity of aquifer materials. Due to the general lack of accurate infiltration measurements, preliminary infiltration capacity estimates have been garnered from several sources (Table 7).

Table 7. Infiltration capacities for recharge sites reviewed in this study.

Recharge Site	Infiltration Capacity (acre-feet/month)	Comments
Aberdeen-Springfield	7,300	Calibrated ESPAM2.1 canal seepage rate.
Egin Lakes	2,200	Published data from 2009 IWRRI recharge report.
Fremont-Madison East	6,500	Calibrated ESPAM2.1 canal seepage rate.
Fremont-Madison West	4,300	Calibrated ESPAM2.1 canal seepage rate.
Great Feeder Area	6,900	Calibrated ESPAM2.1 canal seepage rate.
Hilton	7,600	Based on historic recharge diversions.
Idaho	1,400	Calibrated ESPAM2.1 canal seepage rate.
Jensen's Grove	1,000	Based on water-right exam data.
Lake Walcott Recharge	6,100	Based on proposed capacity of recharge wells.
Milepost 31 Recharge	24,200	Based on discussion with canal manager.
Milner-Gooding	8,200	Based on discussion with canal manager.
New Sweden	1,600	Calibrated ESPAM2.1 canal seepage rate.
Northside	22,200	Published data from 1996 IWRRI recharge report.
People's	2,500	Calibrated ESPAM2.1 canal seepage rate.
Riverside	700	Calibrated ESPAM2.1 canal seepage rate.
Shoshone	21,200	Based on discussion with canal manager.
Snake River Valley	1,400	Calibrated ESPAM2.1 canal seepage rate.
Southwest Irrigation	3,600	Based on diversions, assumed due to injection.
United	600	Calibrated ESPAM2.1 canal seepage rate.

It is important to note that many of the infiltration capacities are calculated as percentages of the diversion capacities, and any inaccuracies associated with the diversion capacities will be reflected in the calculated infiltration capacities.

It may be possible to engineer certain aspects of recharge sites to allow for greater infiltration at some sites. It is also possible that some sites may be able to use different combinations of canals and off-canal features to increase infiltration capacity.

Because the Managed Recharge Program looks to recharge during the winter months in order to minimize competition with irrigation deliveries, it is important to consider temperature effects on the rate of infiltration. As temperature decreases, both the viscosity and density of water increase, making the water more resistant to flow. Therefore, infiltration rates during cold weather will likely be lower than those reported above due to the fact that the data used to develop infiltration rates are largely based on spring through fall measurements.

Differences in saturated groundwater flow based solely on temperature are calculated in Appendix D and listed in Table 8.

Table 8. Differences in saturated groundwater flow due to temperature changes.

Temperature (°F)	Percent change in flow (relative to 60 °F)
32	-37%
40	-27%
50	-14%
60	0
70	+15%
80	+31%
90	+48%
100	+65%

Limitations due to Shallow Groundwater

The depth-to-groundwater may also limit the amount of recharge that can take place (Figure 22). The term *vadose-zone capacity* is used to describe this limitation in this study. Conceptually, areas with shallow groundwater have less room to accommodate water-level changes than areas with deeper groundwater.

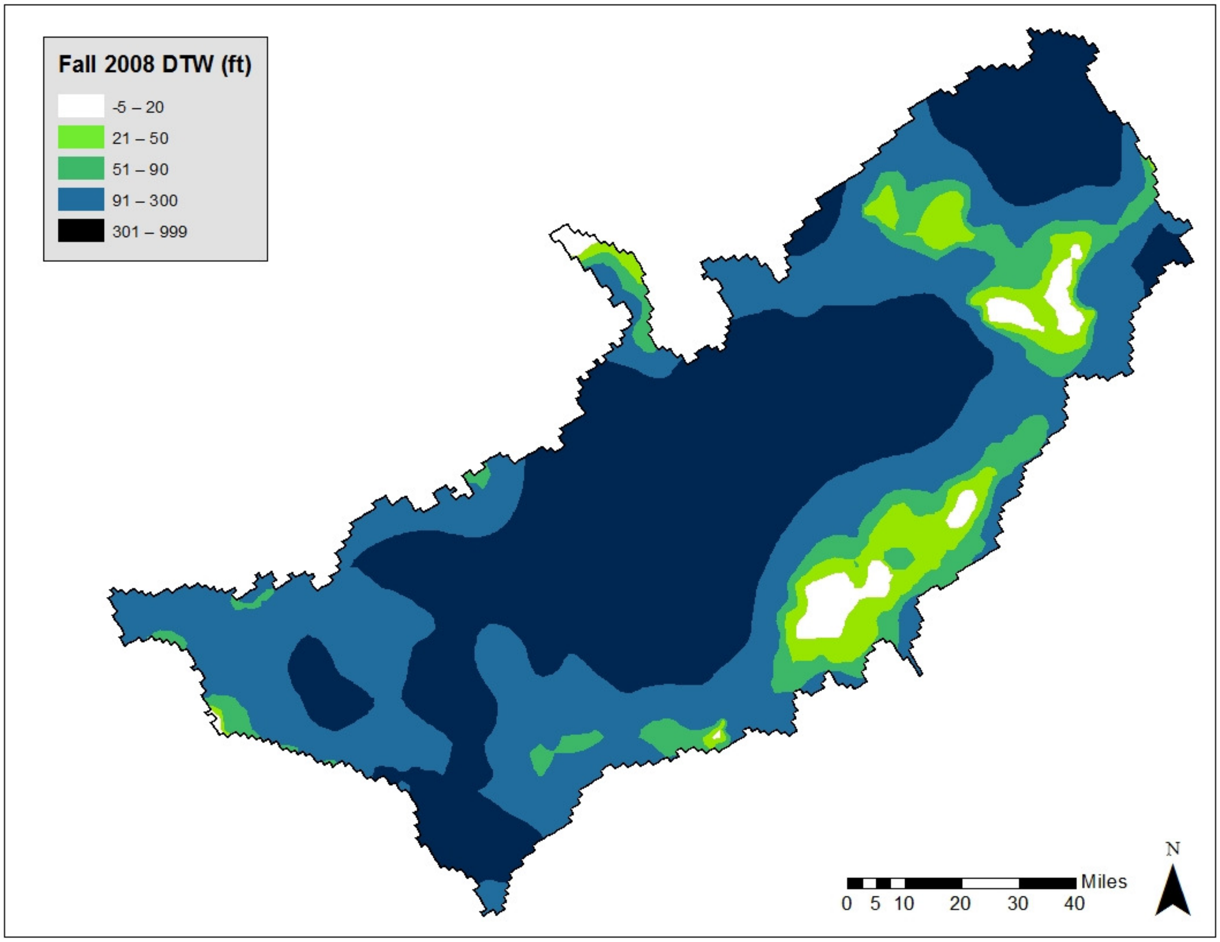

Figure 22. Depth-to-groundwater within the ESPA. Based on fall 2008 synoptic water-level measurements.

When determining how much recharge can be accommodated, some allowance should be made for man-made structures like foundations, basements, and septic/sewer systems. In addition, recharging in areas of shallow groundwater creates the risk that recharged water will not actually recharge the aquifer, but instead will exit the aquifer rapidly via drains and canals (Figures 23a – 23c).

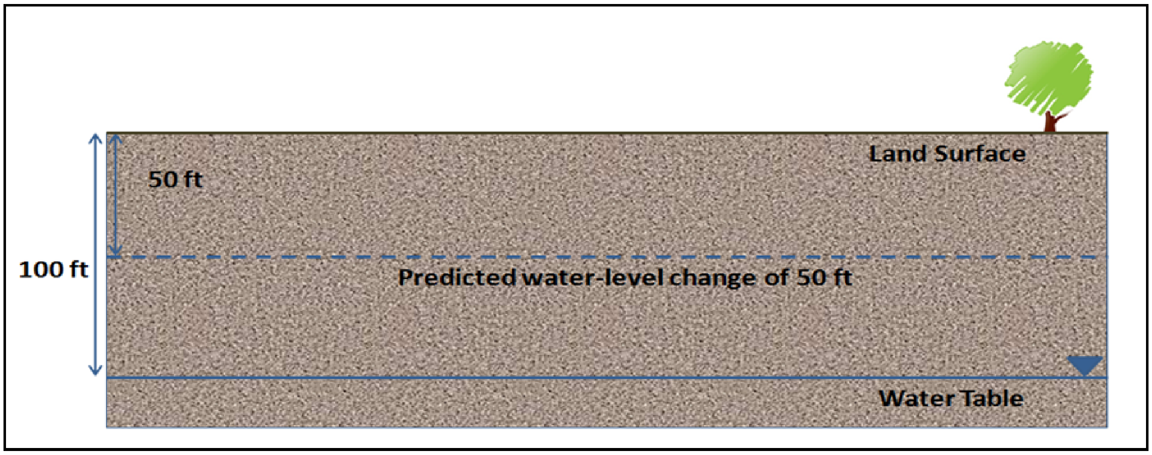

Figure 23a. Areas with sufficiently deep groundwater can accommodate recharge, and vadose-zone capacity is not a limiting factor to recharge.

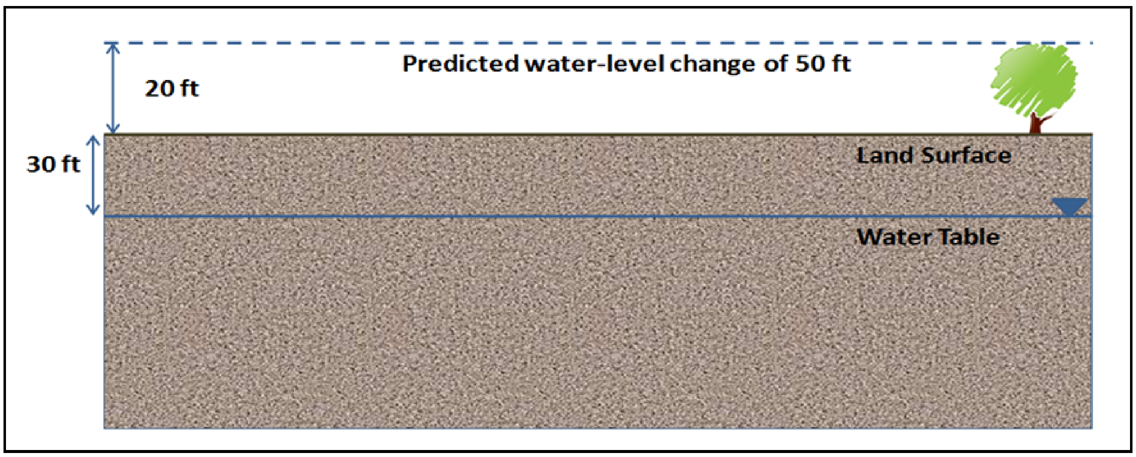

Figure 23b. Areas with insufficiently deep groundwater cannot accommodate recharge, and vadose-zone capacity is a limiting factor.

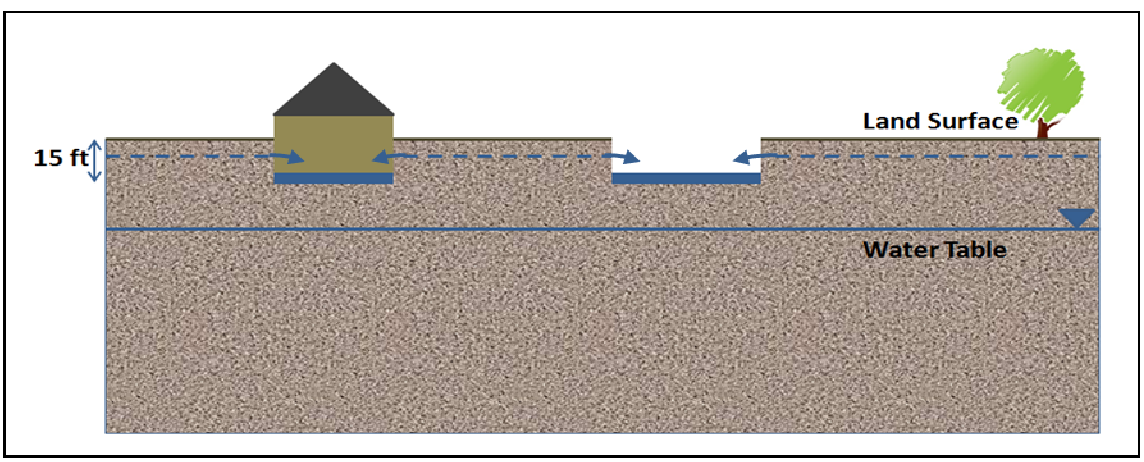

Figure 23c. To avoid wasting resources or damaging infrastructure, the determination of vadose-zone capacity should include a buffer from land surface. A 15-foot deep buffer has been implemented for this analysis.

Because no previous work has been done to quantify the relationship between managed recharge and shallow groundwater, groundwater-capacity limitations have been developed using ESPAM2.1.

For this analysis, a buffer of 15 feet below land surface has been implemented to ensure that managed recharge activities contribute to increases in aquifer storage instead of causing rapid returns to surface water or endanger infrastructure.

The calibrated EPAM2.1 does not consider shallow groundwater when running scenarios; therefore, the model has been altered by adding drains to model cells in areas with a fall 2008 depth-to-water of 20 feet or less. The drains are then used to quantify the amount of water that enters the buffer zone during a one-month recharge event. It is important to note that ESPAM2.1 river and spring cells remain as river/spring cells to avoid including water that discharges from the aquifer to the river in the estimation of vadose-zone capacity limits (Figure 24).

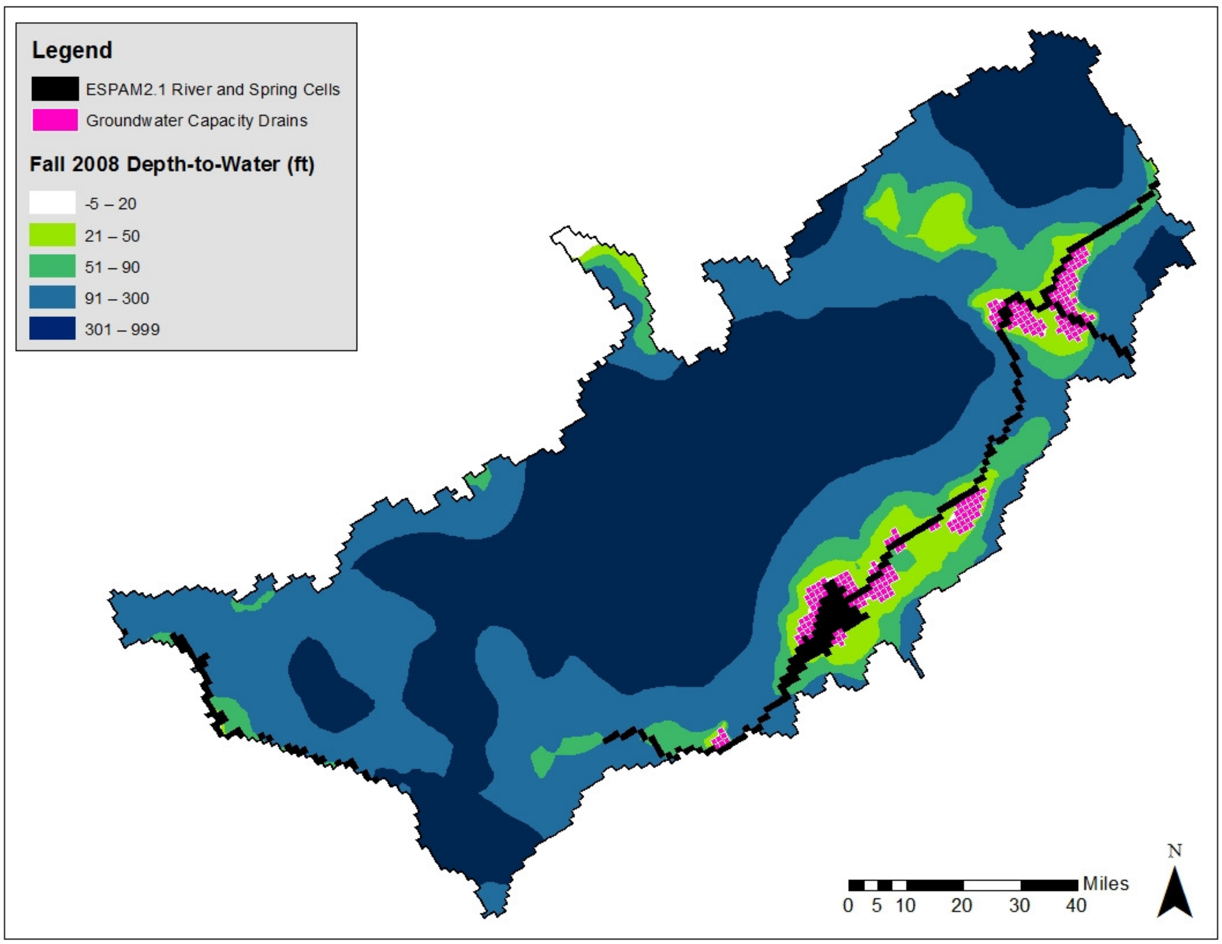

Figure 24. Drains added in locations with measured depth-to-water of 20 feet or less in the fall of 2008.

The drains have been assigned an exceedingly large conductance value of 500,000 ft^2/day to ensure that water flows easily into them when recharge-induced water-level changes raise groundwater to within 15 feet of land surface.

The following steps were taken to determine the vadose-zone capacity at each site:

1. Create seasonal depth-to-water maps using spring and fall synoptic water-level measurements.

2. Add drain boundary conditions to model cells in areas where the fall 2008 depth-to-water is 20 feet or less.
   a. Fall depth-to-water values have been employed because fall water levels are generally shallower than spring water levels, which results in a wider distribution of shallow-groundwater drain cells.

3. Run the model using increasing volumes of seasonal, one-month recharge events at each site.
   a. Seasonal analyses evaluate the spring- and fall-season depth-to-water conditions.
   b. Water is discharged into a drain when recharge raises seasonal water levels in a drain cell to within 15 feet of land surface (Figures 24 and 25).

4. Evaluate the volume of water that exits though the drains during the one-month recharge event.
   a. Vadose-zone capacity is reached when either 5% of the recharge volume or 100 AF exits though the drains during the same one-month period as recharge occurred.

It is important to note that drain cells have only been used to determine vadose-zone capacities. The use of drain cells alters ESPAM2.1, and it is not appropriate to use the altered model to assess recharge impacts. The fully calibrated model has been employed to model recharge for all analytical scenarios.

Figure 25 illustrates the selection of drain cells based on a depth-to-water of 20 feet or less, and the activation of drain cells when recharge raises water to within 15 feet of land surface. Table 9 lists the seasonal shallow groundwater limitations generated with this methodology. The distribution of seasonal vadose-zone capacities are discussed more thoroughly in Appendix E.

The shallow-groundwater recharge limits are intended to help the State prioritize recharge investment and avoid wasting recharge resources. It is important to realize that these volumes represent preliminary estimates of vadose-zone capacity that have been developed using a regional model. Therefore, it is recommended that a formal hydrogeologic or engineering investigation be performed for proposed recharge at rates greater than the vadose-zone capacity of the site. Because vadose-zone capacities are a function of the depth-to-water, it is likely not possible to increase vadose-zone capacity through engineering or construction.

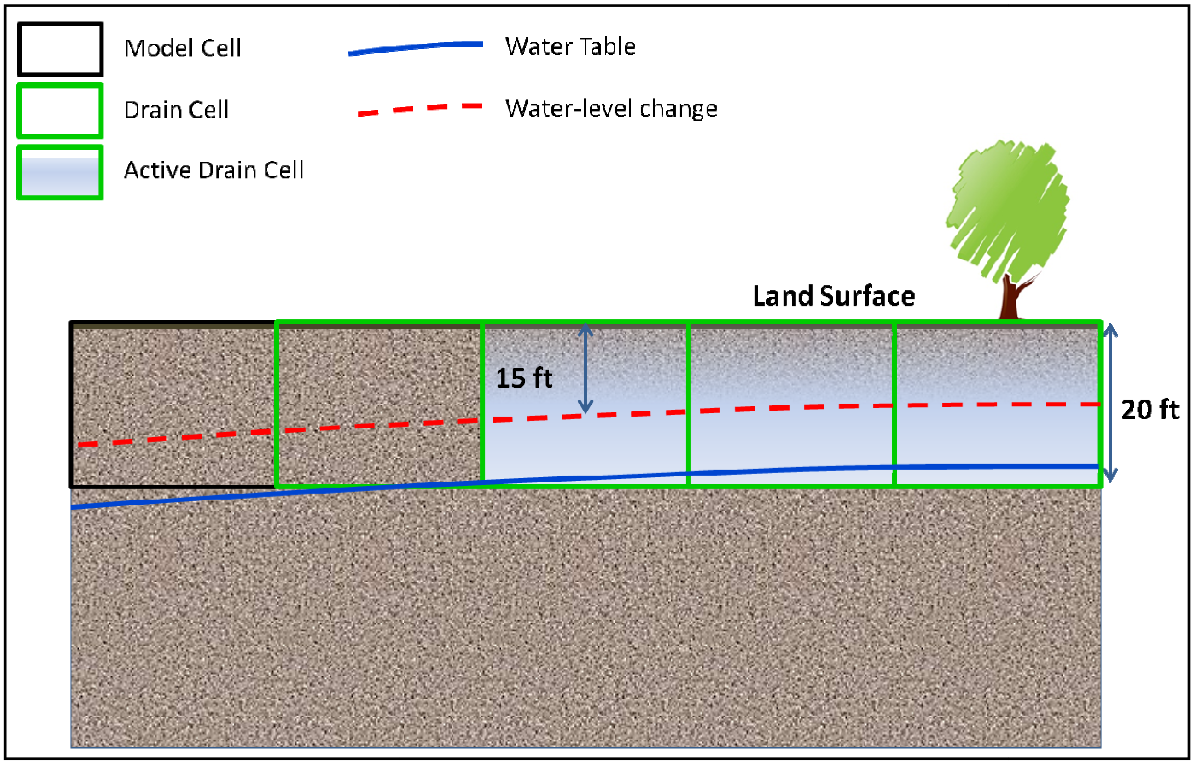

Figure 25. Illustration depicting the selection and activation of drain cells.

Table 9. Seasonal vadose-zone capacities for recharge sites reviewed in this study.

Recharge Site	SPRING Vadose-zone capacity (acre-feet/month)	FALL Vadose-zone capacity (acre-feet/month)
Aberdeen-Springfield	2,300	<100
Egin Lakes	5,000	3,800
Fremont-Madison East	17,000	12,300
Fremont-Madison West	2,600	<100
Great Feeder Area	50,000+	<100
Hilton	3,200	2,800
Idaho	8,500	<100
Jensen's Grove	6,300	3,500
Lake Walcott Recharge	50,000+	50,000+
Milepost 31 Recharge	50,000+	50,000+
Milner-Gooding	50,000+	50,000+
New Sweden	20,000	3,800
Northside	50,000+	50,000+
People's	3,400	<100
Riverside	4,300	2,200
Shoshone	50,000+	50,000+
Snake River Valley	9,400	<100
Southwest Irrigation	50,000+	50,000+
United	4,100	3,400

Recharge Capacity

The physical ability to conduct recharge at a site is termed *recharge capacity*. Recharge capacity is the lesser of diversion capacity, infiltration capacity, and the season-specific vadose-zone capacity (Tables 10 and 11). These limits represent reasonable preliminary estimates and will likely change as the recharge program matures and some values are more accurately determined.

Table 10. Spring-season recharge capacities. The recharge capacity for each site is highlighted in green.

Site	Diversion Capacity (acre-feet/month)	Infiltration Capacity (acre-feet/month)	SPRING Vadose-zone capacity (acre-feet/month)
Aberdeen	12,100	7,300	2,300
Egin Lakes	15,300	2,200	5,000
Fremont-Madison East	10,900	6,500	17,000
Fremont-Madison West	7,200	4,300	2,600
Great Feeder Area	18,100	6,900	50,000
Hilton	7,700	7,600	3,200
Idaho	4,500	1,400	8,500
Jensen's Grove	1,800	1,000	6,300
Lake Walcott	6,100	6,100	50,000
Milepost 31	18,400	24,200	50,000
Milner-Gooding	46,500	8,200	50,000
New Sweden	3,200	1,600	20,000
Northside	30,700	22,200	50,000
People's	6,000	2,500	3,400
Riverside	5,400	700	4,300
Shoshone	1,900	21,200	50,000
Snake River Valley	4,500	1,400	9,400
Southwest	3,600	3,600	50,000
United	4,500	600	4,100

Table 11. Fall-season recharge capacities. The recharge capacity for each site is highlighted in green.

Site	Diversion Capacity (acre-feet/month)	Infiltration Capacity (acre-feet/month)	FALL Vadose-zone capacity (acre-feet/month)
Aberdeen	12,100	7,300	<100
Egin Lakes	15,300	2,200	3,800
Fremont-Madison East	10,900	6,500	12,300
Fremont-Madison West	7,200	4,300	<100
Great Feeder Area	18,100	6,900	<100
Hilton	7,700	7,600	2,800
Idaho	4,500	1,400	<100
Jensen's Grove	1,800	1,000	3,500
Lake Walcott	6,100	6,100	50,000
Milepost 31	18,400	24,200	50,000
Milner-Gooding	46,500	8,200	50,000
New Sweden	3,200	1,600	3,800
Northside	30,700	22,200	50,000
People's	6,000	2,500	<100
Riverside	5,400	700	2,200
Shoshone	1,900	21,200	50,000
Snake River Valley	4,500	1,400	<100
Southwest	3,600	3,600	50,000
United	4,500	600	3,400

Recharge limitations represent relative rankings regarding the ability to conduct recharge at the sites investigated in this study. Some limiting factors can be increased via engineering and construction (e.g., diversion capacity), while little can be done to change other factors (e.g., shallow groundwater). Therefore, it is important to understand what limits recharge at any give site. The rankings are intended to help the IWRB understand the limiting factors, prioritize investment in recharge infrastructure, and coordinate recharge activities.

Recharge Modeling

ESPAM2.1 has been run in superposition mode to make quantitative evaluations of recharge effects on aquifer storage. Superposition only considers the stress that is being applied in the scenario (recharge), which allows the responses due to recharge to be evaluated separately from other aquifer stresses like precipitation, evapotranspiration, and irrigation water use.

The following scenarios represent recharge as direct injection into the aquifer, and any effects due to unsaturated sediments or perched aquifers that may exist between land surface and the regional water table are ignored. Additionally, no portions of the river are allowed to transition from perched to hydraulically connected with the aquifer during the simulation period, which may overestimate the benefit recharge has on aquifer storage at sites located near both a perched river segment and shallow groundwater.

Initial files for the superposition runs were downloaded from the Idaho Department of Water Resources website: http://www.idwr.idaho.gov/Browse/WaterInfo/ESPAM/model_files/Version_2.1_Current/. These files were modified as needed to develop simulations representing appropriate recharge sites, stress periods, and time steps. The model cells used to represent the recharge sites are shown in Appendix F. Five scenarios were run to evaluate the effectiveness criteria:

1) Continuous recharge events of 100,000 acre-feet per month in each of the candidate recharge sites to visually illustrate how the distribution of hydrogeologic features influences the distribution of impacts throughout the aquifer. Recharge has been uniformly distributed among the cells identified for the recharge sites (except for Northside Canal). In Northside Canal, 2/3 of the recharge has been simulated to occur from the POD up to, and including Wilson Lake, while the remaining 1/3 has been recharged in the main canal downstream of Wilson Lake.

2) Single, one-month recharge events of 100 acre-feet per year in each of the candidate recharge sites to quantify the influence of location on the effectiveness of recharge to increase aquifer storage. As above, the recharge has been uniformly distributed among the model cells identified for the recharge sites, except for the case of Northside Canal.

3) Single, one-month recharge events at recharge capacity in each of the candidate recharge sites to quantify the influence of both location and recharge capacity on the effectiveness of recharge to increase aquifer storage. As above, the recharge has been uniformly distributed among the model cells identified for the recharge sites, except for the case of Northside Canal.

4) Recharge simulation using recurring one-month recharge events to illustrate the importance of repetition frequency. One-month recharge events that occur each year are compared with one-month events at the same location that occur every third year. Two recharge sites (with relatively high and low 5-year retention times) have been modeled to illustrate this point. The recharge has been uniformly distributed among the model cells identified for the analyzed recharge sites.

5) A 13-year recharge simulation based on the available water from 2000 – 2012 to illustrate the combined effects of location, recharge frequency (due to water availability), and recharge capacity. The recharge has been distributed uniformly among the model cells identified for the recharge sites, except for the case of Northside Canal.

The location of recharge within each canal system may be distributed among multiple recharge features (pits, depressions, engineered recharge ponds, or injection wells) as well as seepage in canal networks. In this work, the effects of off-canal recharge sites were evaluated independently from recharge in the main canals.

Continuous recharge at 100,000 acre-feet per year

The location where managed recharge takes place is the most important factor in determining how aquifer-storage benefits are distributed throughout the aquifer. This modeling scenario investigates the influence of location on the distribution of aquifer-storage benefits that result from recharge (recharge impacts). Although none of the sites evaluated can continuously recharge at 100,000 acre-feet/year every year, the exaggerated rate illustrates how hydrogeologic features (i.e., aquifer heterogeneity, aquifer boundaries, springs, and hydraulically connected reaches of the Snake River) influence the distribution of impacts to both aquifer storage and reach gains.

Recharge for this scenario has been modeled at a rate of 100,000 acre-feet/year for ten consecutive years. Because the exaggerated, continuous recharge rate cannot be accommodated at any of the sites, impacts to aquifer storage and river flow have not been tabulated. Instead, the distribution of water-level changes have been plotted on maps to serve as visual tools that allow for a better understanding of the modeled impacts presented in the subsequent scenarios. Water-level changes provide a visual proxy for the distribution of aquifer-storage benefits.

The tenth-year water-level changes at four sites are presented in Figures 26a – 26d. These sites are generally representative of recharge-impact distributions for all sites that are located along the same reach. The tenth-year water-level changes for all sites are presented in Appendix G.

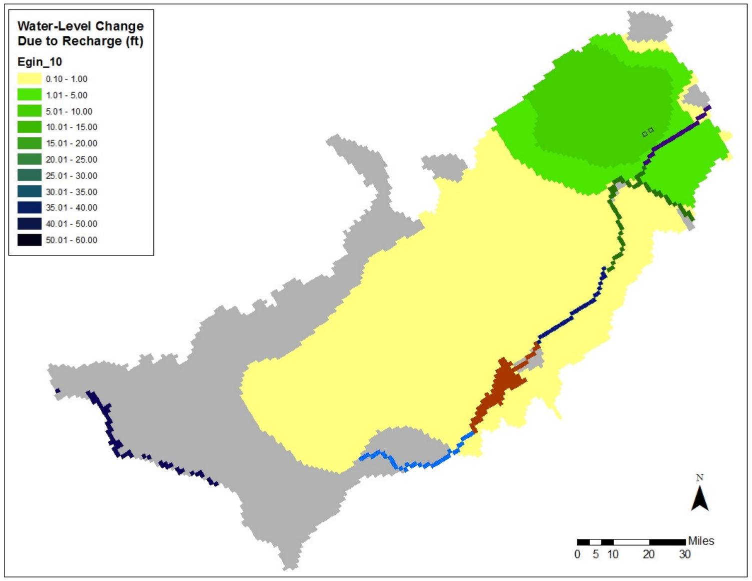

Figure 26a. Distribution of recharge impacts Ashton-to-Rexburg.

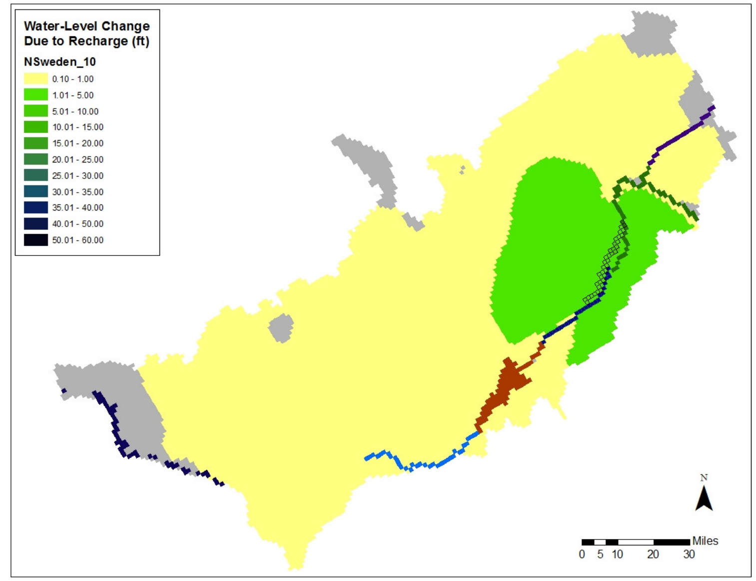

Figure 26b. Distribution of recharge impacts Heise-to-Shelley.

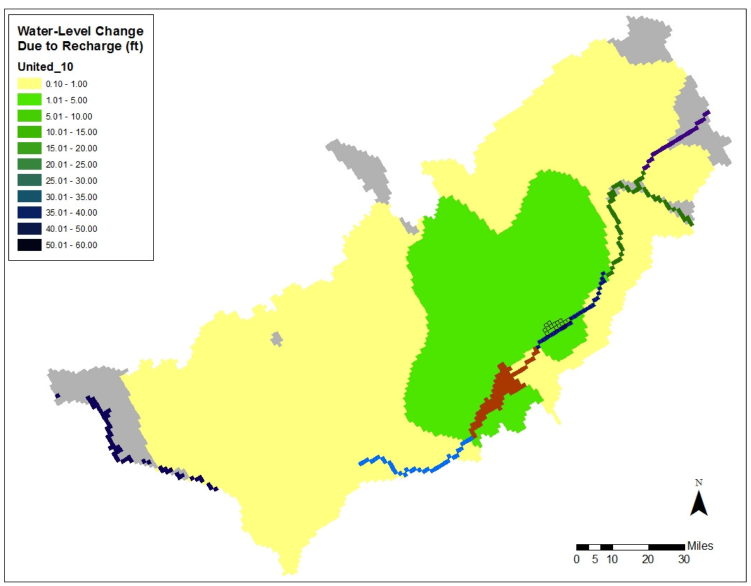

Figure 26c. Distribution of recharge impacts Shelley-to-nr Blackfoot.

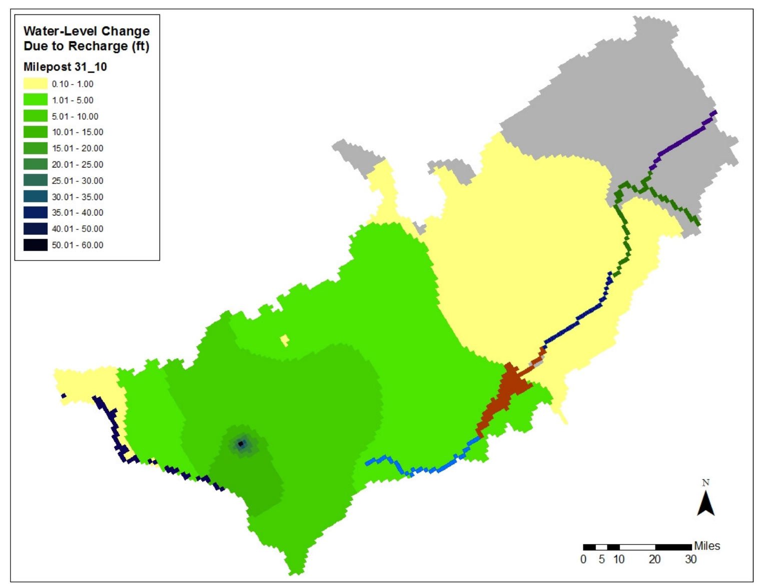

Figure 26d. Distribution of recharge impacts below Minidoka.

The common features that influence the distribution of modeled aquifer-storage impacts at sites located in the same reach are:

- Ashton-to-Rexburg: Modeled aquifer-storage impacts are concentrated in the northeast quarter of the aquifer. The presence of the Mud Lake low-transmissivity zone (Figure 10) hinders the southwesterly expansion of aquifer-storage impacts. Hydraulic connection along the South Fork and around the South Fork/Henry's Fork confluence results in surface-water discharge of recharged water that slows the further expansion of simulated aquifer-storage impacts, and prevents significant water-level changes near these reaches (Figure 26a).

- Heise-to-Shelley: Modeled aquifer-storage impacts are concentrated in an area along the Snake River between the South Fork and the upstream end of American Falls Reservoir. Hydraulic connection along the South Fork, around the confluence, and in the nr Blackfoot-to-Neeley reach results in surface-water discharge of recharged water that slows the further expansion of simulated aquifer-storage impacts and prevents significant water-level changes near these reaches (26b).

- Shelley-to-nr Blackfoot: Modeled aquifer-storage impacts are concentrated in the central quarter of the aquifer between the Mud Lake and Great Rift low-transmissivity zones (Figure 10). The Great Rift low-transmissivity zone influences the westerly and southwesterly distribution of water level-changes. Aquifer-storage heterogeneity (Figure 11) and the Mud Lake low-transmissivity zone influence the northerly and northeasterly expansion of water-level changes, respectively. Hydraulic connection along the near Blackfoot-to-Neeley reach of the Snake River results in surface-water discharge of recharged water that slows the further expansion of simulated aquifer-storage impacts and prevents significant water-level changes near the upstream segment of this reach (Figure 26c).

- Below Minidoka: Modeled aquifer-storage impacts are concentrated in southwest half of the aquifer. The sites in this reach are located at greater distances from hydraulically connected river reaches than sites in the other reaches, and the greater distance allows modeled aquifer-storage impacts to expand over a larger area. The Great Rift low-transmissivity zone (Figure 10) and aquifer-storage heterogeneity (Figure 11) influence the northeasterly expansion of water-level changes. Hydraulic connection along the nr Blackfoot-to-Neeley reach of the Snake River and discharge from the springs in the Kimberly-to-King Hill reach result in surface-water discharge of recharged water that slows the further expansion of simulated aquifer-storage impacts and prevents significant water-level changes near segments of these reaches (Figure 26d).

One-month recharge at 100 acre-feet per month

The location where managed recharge takes place is the most important factor in determining how long increased aquifer storage will persist in the aquifer, and this modeling scenario quantifies the influence that location has on the retention of water in storage. Modeling the same, achievable volume at each recharge site allows for the site-by-site comparison of recharge effectiveness.

In this scenario, a total of 100 acre-feet is recharged during a single, one-month long recharge event. Recharge only occurs in the first month of the 10-year long scenario. The results of this analysis represent the relative aquifer retention of recharge at each site (Figure 27).

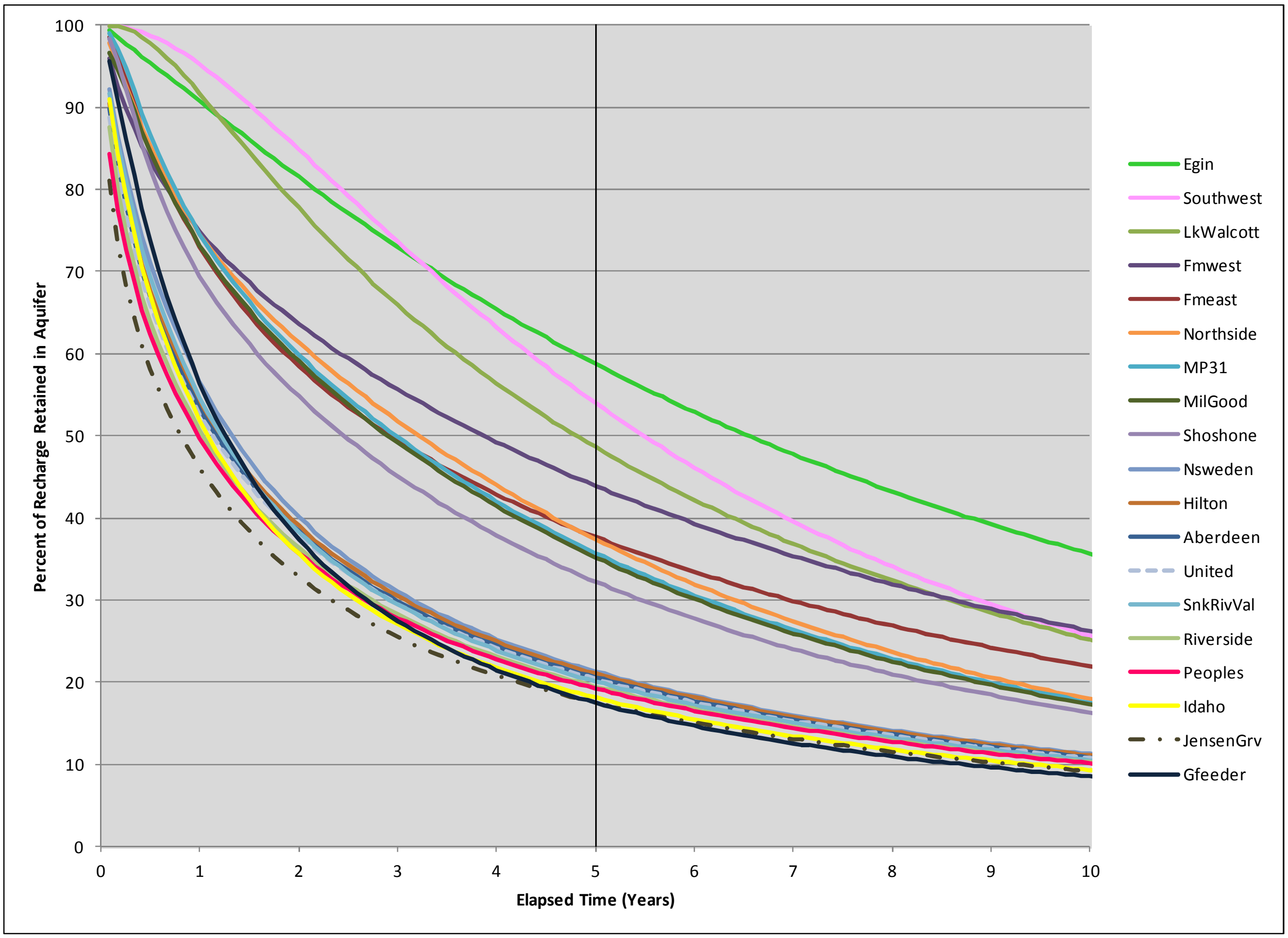

Figure 27. Retention of recharge water (recharge at 100 acre-feet during the first month) as aquifer storage over time.

The primary goal for State-sponsored recharge is the retention of water within the aquifer, and long-term retention provides the most efficient strategy for capturing surplus surface water for subsequent use in times of need. The 5-year aquifer retention provides a metric of storage-related benefits that emphasize long-term storage, while acknowledging the importance of having stored water available over a reasonable time-frame (Table 12).

Table 12. Percentage of recharged water retained within the aquifer after five years.

Recharge Site	5-Year Retention (%)
Egin	58.7
Southwest	54.0
Lake Walcott	48.6
Fremont-Madison West	43.9
Fremont-Madison East	37.7
Northside	37.4
Milepost 31	35.7
Milner-Gooding	35.2
Shoshone	32.2
New Sweden	21.3
Hilton	21.0
Aberdeen	20.6
United	20.4
Snake River Valley	20.1
Riverside	19.4
Peoples	19.2
Idaho	18.1
Jensen's Grove	17.5
Great Feeder	17.5

One-month recharge at capacity volume

The volume of water that can be recharged (recharge capacity) at a site is an important factor in determining the magnitude of aquifer-storage benefits. This modeling scenario builds upon the influence of location by including spring-season recharge capacities to quantify both the magnitude and duration of aquifer-storage benefits. Spring-season recharge capacities are greater than or equal to fall season recharge capacities; therefore, the results of this scenario represent the maximum aquifer-storage benefits due to single, one-month recharge events (Figure 28). This scenario employs recharge limitations as they are currently understood. As discussed previously, it may be possible to change some of the recharge limitations through infrastructure improvements or the collection of more detailed site-specific data.

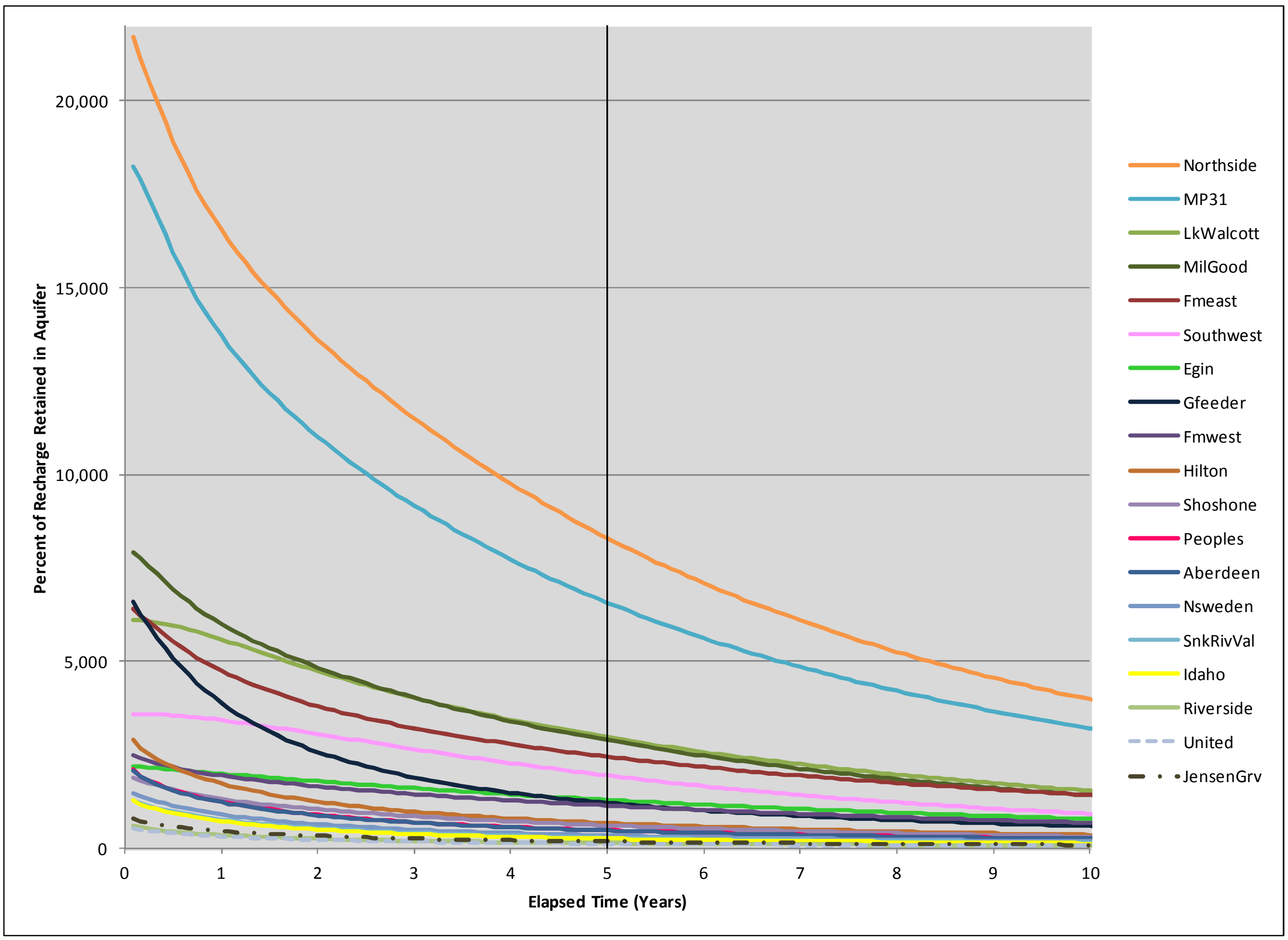

Figure 28. Retention of recharge water (recharge at spring-season capacity during the first month) as aquifer storage over time.

The 5-year aquifer retention coupled with recharge capacity provides a metric of storage-related benefits that illustrates the ability of a recharge site to affect long-term storage (Table 13).

Table 13. Volume of recharged water retained within the aquifer after five years.

Recharge Site	5-Year Retention (acre-feet)
Northside	8,301
Milepost 31	6,568
Lake Walcott	2,964
Milner-Gooding	2,885
Fremont-Madison East	2,448
Southwest	1,943
Egin	1,292
Great Feeder	1,206
Fremont-Madison West	1,141
Hilton	673
Shoshone	612
Peoples	480
Aberdeen	474
New Sweden	340
Snake River Valley	273
Idaho	254
Jensen’s Grove	175
Riverside	136
United	122

Recurring one-month recharge at 100 acre-feet per month

The frequency with which managed recharge is accomplished is an important factor in the ability for managed recharge to reach the State's managed recharge goals. This modeling scenario investigates the influence of repetition on recharge impacts.

Recharge has been modeled at a rate of 100 acre-feet/month, one month per year, at both one- and three-year recurrence frequencies, for 15 years. No recharge occurs during the final two years which results in recharge over the first 13 years.

The development of aquifer storage is related to the combination of recharge frequency and aquifer-storage retention. Therefore, this scenario investigates recharge frequency at the Lake Walcott and Idaho recharge sites due to their relatively high (48.6%) and low (18.1%) 5-year retention times, respectively (Figures 29 and 30).

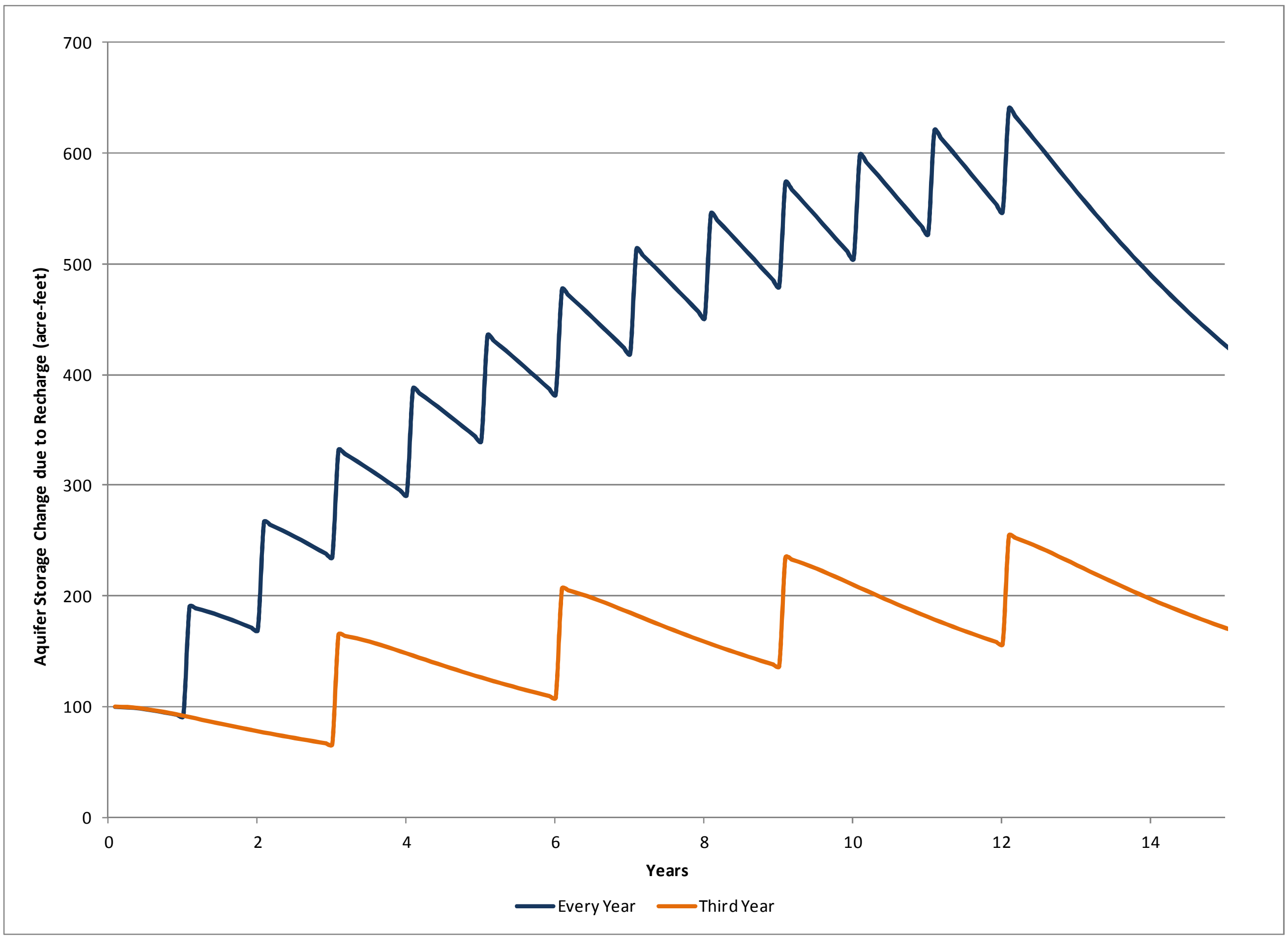

Figure 29. Comparative aquifer-storage benefit due to a one-month recharge event at the Lake Walcott recharge site recurring every year (blue) and every third year (orange).

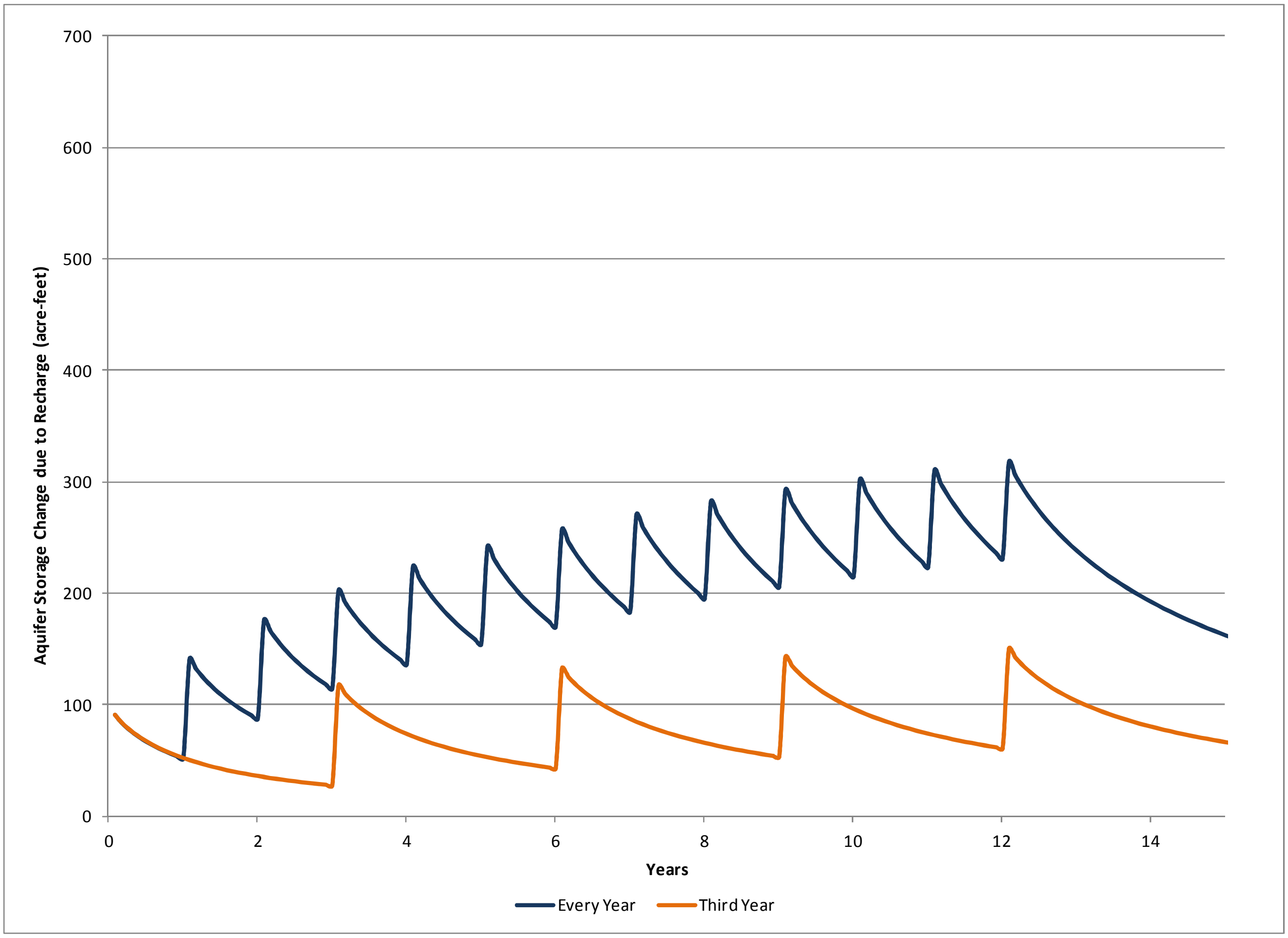

Figure 30. Comparative aquifer-storage benefit due to a one-month recharge event at the Idaho recharge site recurring every year (blue) and every third year (orange).

It is somewhat self evident that if recharge is occurring more frequently, it is possible to divert more water into aquifer storage. However, because the ESPA leaks, any aquifer-storage increases that result from recharge return to the river over time. Higher frequency recharge events produce a compounding effect that results in a greater increase in aquifer storage. Sporadic recharge frequency serves to diminish the compounding effect relative to the duration between recharge events.

Figures 29 and 30 also illustrate a conundrum regarding the recurrence of recharge. High recharge frequency is vital to maintaining aquifer-storage benefits at sites with relatively low storage-retention rates because recharged water returns to the river relatively quickly. However, high recharge frequency is less effective at building aquifer storage at low storage-retention sites because less water is left in storage between recharge events, as compared with higher storage-retention sites.

This scenario demonstrates that sites with consistent recharge water availability have greater impacts on reaching the State's recharge goals by leveraging previous recharge efforts.

Thirteen years of recharge based on water availability 2000-2012

This scenario builds upon the previous scenarios by incorporating water supply conditions for the years 2000-2012, and evaluates the influence that location, volume, and repetition have on the effectiveness of recharge. This scenario models recharge as it could have occurred at each site based on water availability, and is not representative of actual recharge efforts. As discussed earlier, it is not known how much recharge will actually occur at each site; therefore, upstream recharge diversions have not been deducted from the availability at downstream sites.

Recharge has been modeled as occurring during the same month as when water is available, and at a rate equal to the lesser of either the seasonal, monthly site recharge capacity or the available water supply. Seasonal limits are based in part on depth-to-water measurements made in April and November of 2008; therefore, seasonal recharge capacities have been distributed to the remaining ten months as indicated in Table 14. A more thorough discussion of the distribution of seasonal recharge capacities is included in Appendix D.

Table 14. Annual distribution of seasonal recharge capacities for the water-availability scenario.

Month	Seasonal Capacity
January	Spring
February	Spring
March	Spring
April	Spring
May	Spring
June	Spring
July	Fall
August	Fall
September	Fall
October	Fall
November	Fall
December	Fall

Water for recharge is often available for only a few days per month. However, ESPAM2.1 uses one-month stress periods, so recharge has been modeled by distributing the available water over the entire month during which it is available.

There are years in which water is available for recharge during the irrigation season; however, only off-canal recharge can be accredited during these months because the canals are already carrying irrigation water. This creates a potential issue because many of the locations evaluated in this study are representative of leakage from the canal system and not at discrete off-canal sites within the system. Fortunately, the differences in modeled recharge results between canal systems and associated off-canal site are often negligible. Comparisons between the Milner-Gooding canal system and the Milepost 31 site (Figures D16 and D17; McVay, 2015), as well as the Aberdeen-Springfield canal system and the Hilton Spill site (Figures D8 and D13; McVay, 2015), illustrate the similarities between modeled recharge that is distributed throughout a canal system and that modeled as occurring at an off-canal site. Therefore, any water that is available during the irrigation season has been distributed to all the cells at a recharge site in the same manner as the previous analytical scenarios.

Another potential issue is the limited capacity for canals to transmit recharge water in addition to irrigation water. A previous investigation into the potential for additional deliveries through ESPA canals indicates that the canals can generally accommodate the additional water (Figure 31; Contor and others, 2008). Therefore, this scenario assumes that all canals used in this study can accommodate recharge water every month of the year. However, it must be noted that the capacity for canals to carry recharge water during the irrigation season will depend on many factors, and additional capacity may not be available in every canal, or during the entire irrigation season.

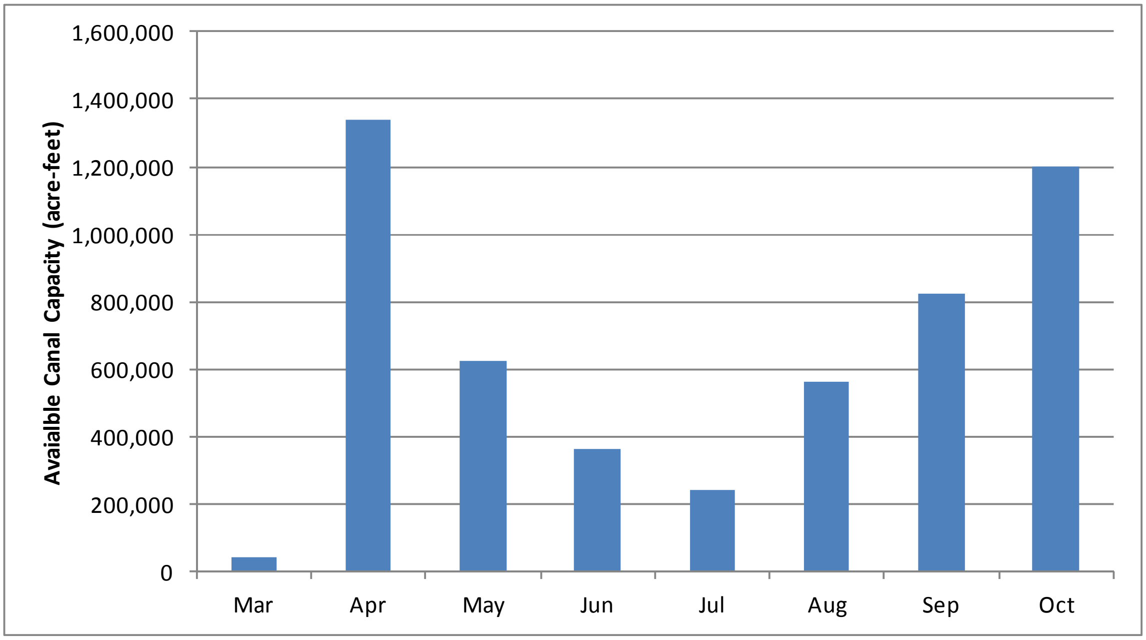

Figure 31. Irrigation-season canal capacity available to carry recharge water. Values represent the combined capacity for ESPA canals. Adapted from Contor and others, 2008.

Recharge Based on Water Availability: Minidoka-to-Milner 2000 – 2012

Water that flows past Milner Dam is available for recharge at those sites that divert between Minidoka Dam and Milner Dam. Sites analyzed in this study that are located along this reach include: Northside Canal system, Milner-Gooding Canal system, Milepost 31 recharge site, Shoshone recharge site, and Southwest Irrigation District. Figure 32 illustrates the monthly water availability at Milner Dam for the years 2000-2012 as well as the modeled aquifer-storage benefits due to the simulated recharge that occurs.

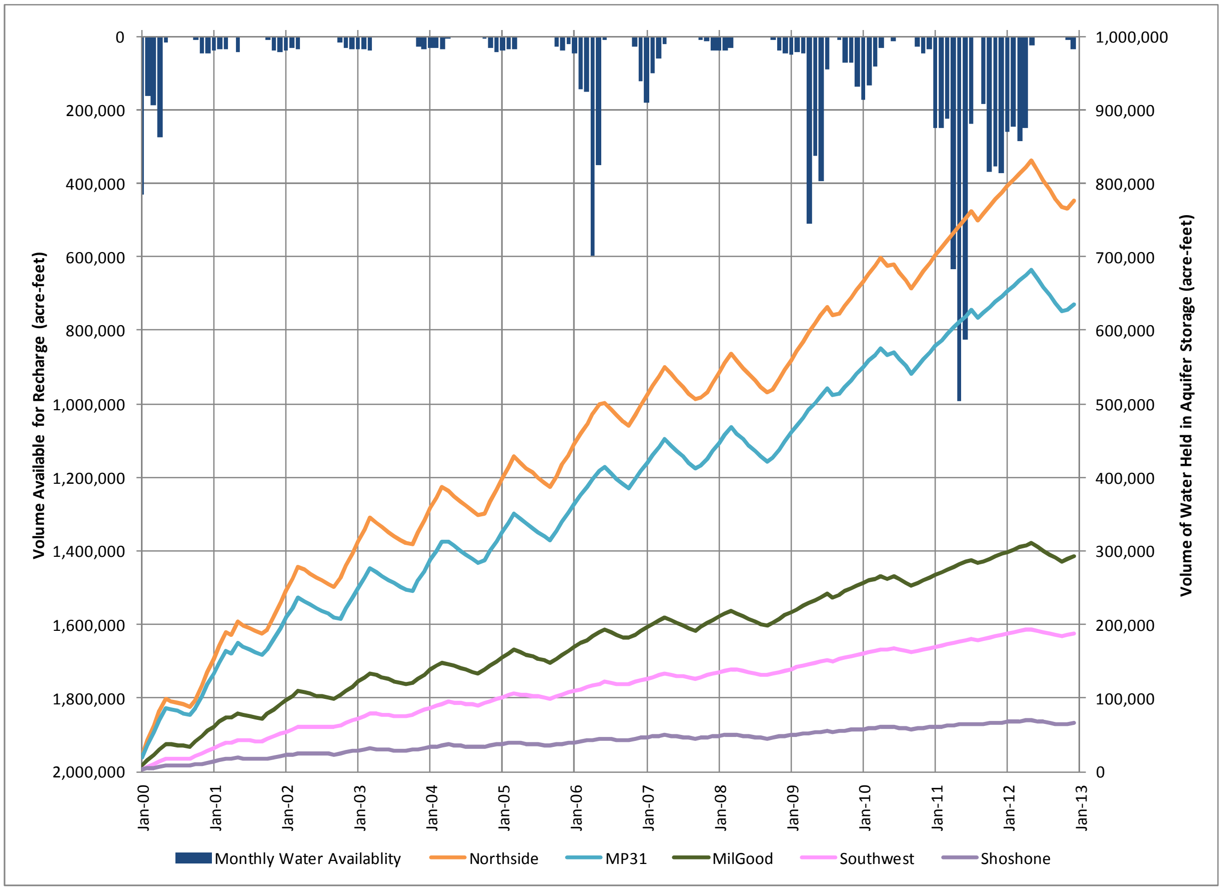

Figure 32. Water availability and aquifer-storage benefits at PODs located between the Minidoka and Milner dams.

Relatively high aquifer-storage retention combined with annual recharge frequency result in significant aquifer-storage benefits at many of the sites below Minidoka. The relatively high aquifer-storage retention combined with limited inter-recharge duration means that substantial residual storage from earlier recharge events remain in the aquifer until well after the next recharge event occurs. Therefore, successive recharge events leverage previous storage gains to build storage over time.

The 5-year storage-retention rates for sites located downstream of Minidoka range from 37.4% at Northside, to 54% at Southwest. Northside has the largest recharge capacity of all of the sites investigated for this study, and the ability to perform recharge results in Northside providing the most effective aquifer-storage benefits for recharge sites located between Minidoka Dam and Milner Dam.

Recharge Based on Water Availability: American Falls-to-Minidoka 2000 – 2012

Water that flows past Minidoka Dam (less 2,700 cfs) is available for recharge between American Falls Dam and Minidoka Dam. The calculated excess flow at Minidoka is available for recharge at those sites that divert from the main stem Snake River between Neeley and Minidoka. The only site analyzed in this study that is located along this reach is the Lake Walcott recharge site. Figure 33 illustrates the monthly water availability at Minidoka for the years 2000-2012 as well as the modeled aquifer-storage benefits due to the simulated recharge that occurs.

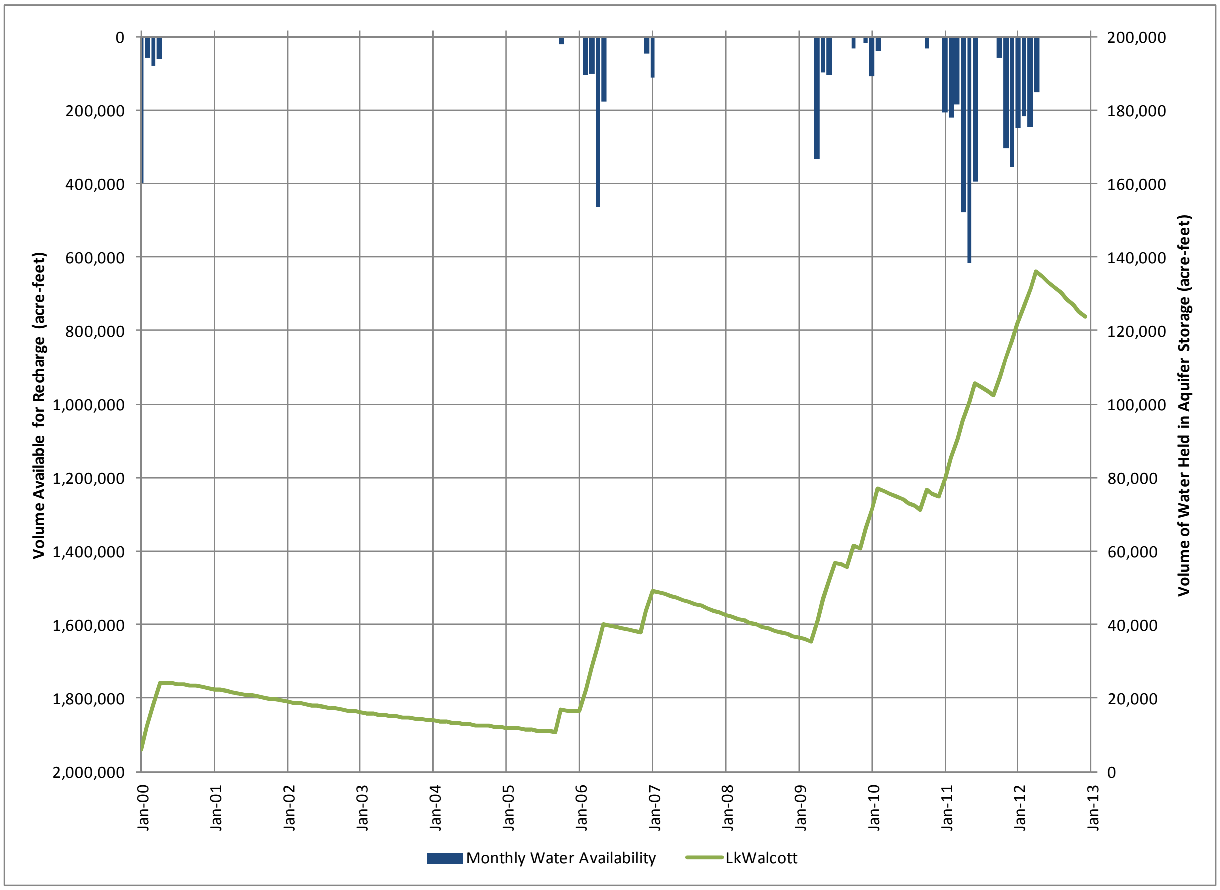

Figure 33. Water availability and aquifer-storage benefits at PODs located between the American Falls and Minidoka dams.

Inconsistent water availability between American Falls and Minidoka dams results in reduced recharge frequency, in comparison with recharge below Minidoka. However, the influence of relatively high aquifer-storage retention (48.6%) results in moderate aquifer-storage benefits. There are periods of time without recharge that allow for stored water to discharge back to the river without replenishment, but the relatively high aquifer-storage retention means that non-trivial residual storage from earlier recharge events remains in the aquifer until the next recharge event occurs. Therefore, successive recharge events build upon previous storage gains to increase storage over time.

Recharge Based on Water Availability: Roberts-to-Aberdeen 2000 – 2012

Water availability for recharge at sites above American Falls Reservoir is the lesser of either the flows past Minidoka Dam (less 2,700 cfs) or flow past the POD (less a minimum flow). The calculated excess flow at Blackfoot is used as a proxy POD for those sites that divert from the main stem Snake River between Roberts and Aberdeen. Sites analyzed in this study that are located along this reach include: Idaho Irrigation District, New Sweden canal system, Snake River Valley canal system, Aberdeen-Springfield canal system, Riverside canal system, United canal system, Jensen's Grove, Peoples canal system, and Hilton Spill. Figure 34 illustrates the monthly water availability at Blackfoot for the years 2000-2012 as well as the modeled aquifer-storage benefits due to the simulated recharge that occurs.

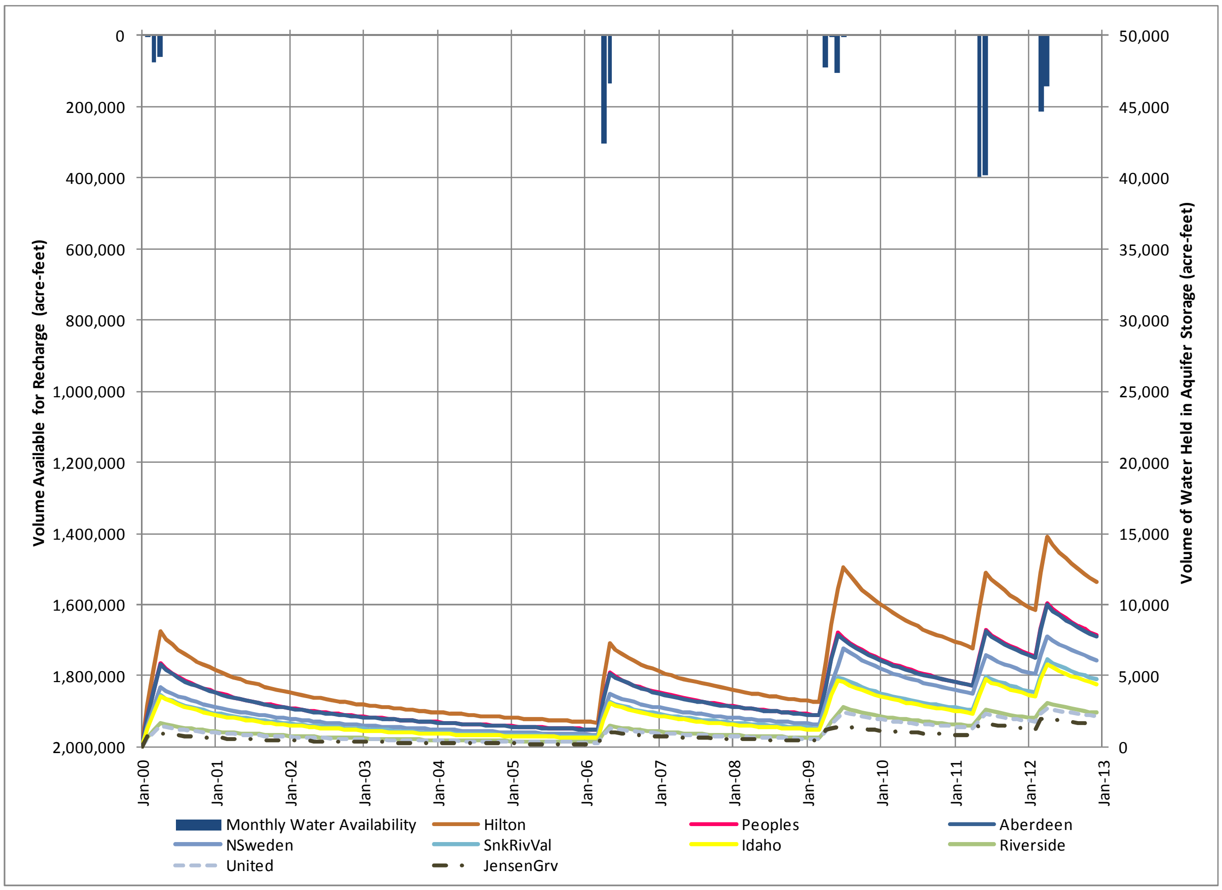

Figure 34. Water availability and aquifer-storage benefits at PODs located on the main stem of the Snake River above American Falls Reservoir.

Relatively low aquifer retention combined with sporadic recharge frequency at sites on the Snake River upstream of American Falls result in aquifer-storage benefits that are much less effective at building aquifer storage than recharge at sites below American Falls. The sporadic water availability results in lengthy periods during which stored water discharges back to the river without replenishment, and the relatively low aquifer-storage retention means that limited residual storage from earlier recharge events remains in the aquifer by the time the next recharge event occurs. Therefore, successive recharge events are somewhat unable to leverage previous storage gains, and are not as effective at building storage over time as areas with more reliable water availability.

The 5-year storage retention rates for sites located along this reach range from 21.3% at New Sweden, to 17.5% at Jensen's Grove. In comparison with the other sites located along this reach, the Hilton Spill is relatively distant from both shallow groundwater and hydraulically connected segments of the river. The distant location results in relatively high aquifer retention and recharge capacity, as compared to the other sites along this reach; therefore, Hilton Spill provides the most effective aquifer-storage benefits for recharge sites located between Roberts and Aberdeen.

Recharge Based on Water Availability: South Fork 2000 – 2012

Water availability for recharge at sites above American Falls Reservoir is the lesser of either the flows past Minidoka Dam (less 2,700 cfs) or flow past the POD (less an assumed minimum flow). The calculated excess flow at Heise is used as a proxy POD for those sites that divert from the South Fork. The Great Feeder canal system is the only site analyzed in this study that is located along this reach. Figure 35 illustrates the monthly water availability at Heise for the years 2000-2012 as well as the modeled aquifer-storage benefits due to the simulated recharge that occurs.

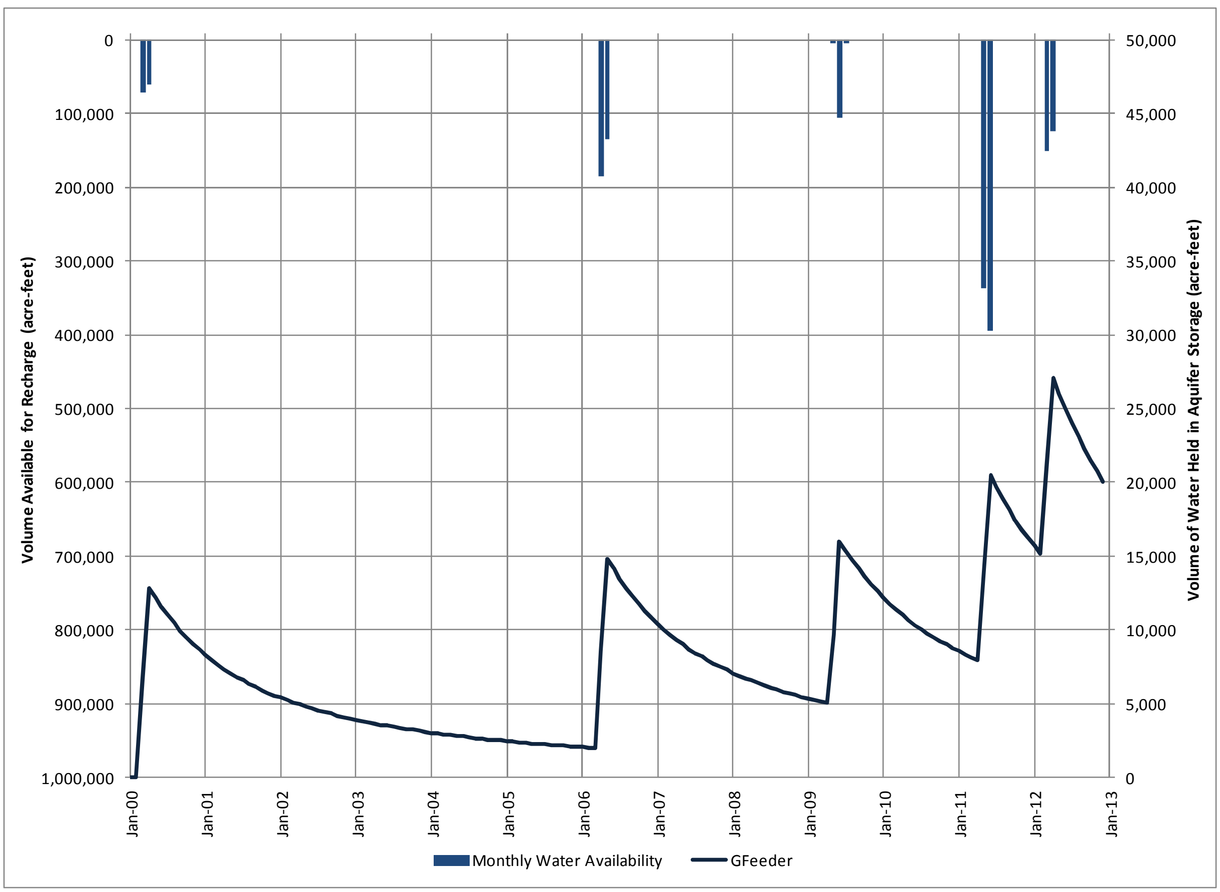

Figure 35. Water availability and aquifer-storage benefits at PODs located on the South Fork of the Snake River.

The South Fork area has the shortest retention time of any site analyzed in this study. Relatively low aquifer retention (17.5%) combined with sporadic recharge frequency at sites on the South Fork result in aquifer-storage benefits that are much less effective at building aquifer storage than recharge at sites below American

Falls. The sporadic water availability typically results in abundant time for the stored water to discharge back to the river without replenishment, and the relatively low aquifer-storage retention means that limited residual storage from earlier recharge events remains in the aquifer by the time the next recharge event occurs. Therefore, successive recharge events are somewhat unable to leverage previous storage gains, and are not as effective at building storage over time as areas with more reliable water availability and higher retention rates.

Recharge Based on Water Availability: Henry's Fork 2000 – 2012

Water availability for recharge at sites above American Falls Reservoir is the smaller of either the flows past Minidoka Dam (less 2,700 cfs) or flow past the POD (less an assumed minimum flow). The calculated excess flow at St. Anthony is used as a proxy POD for those sites that divert from the Henry's Fork. Sites analyzed in this study that are located along this reach include: Fremont-Madison canal system (east of the river), Fremont-Madison canal system (west of the river), and Egin Lakes. Figure 36 illustrates the monthly water availability at St. Anthony for the years 2000-2012 as well as the modeled aquifer-storage benefits due to the simulated recharge that occurs.

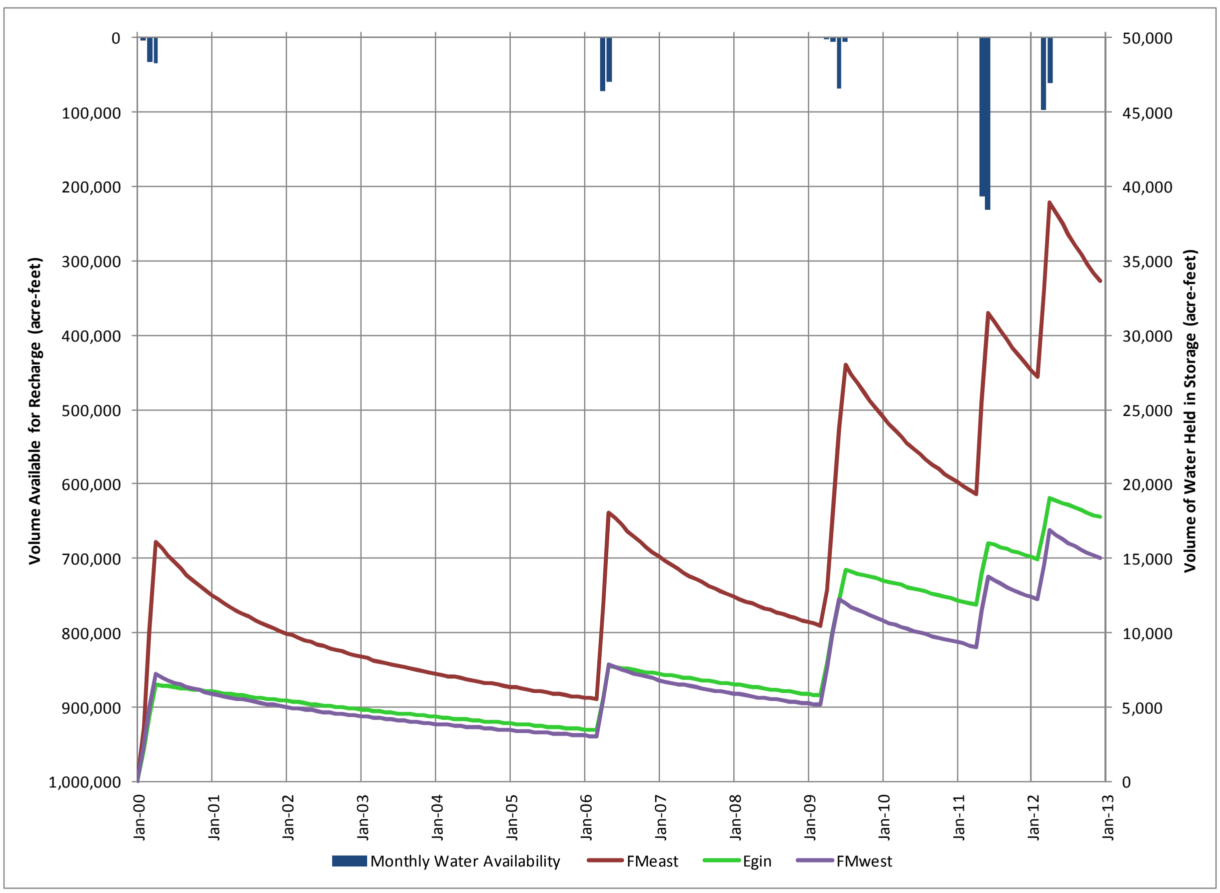

Figure 36. Water availability and aquifer-storage benefits at PODs located on the Henry's Fork of the Snake River.

The 5-year storage retention rates for sites located along this reach range from 58.7% at Egin, to 37.7% at Fremont-Madison East. Relatively high aquifer retention combined with sporadic recharge frequency at sites on the Henry's Fork result in aquifer-storage benefits that are much less effective at building aquifer storage than recharge at sites below American Falls, but more effective than recharge at sites along the Snake River upstream of American Falls and the South Fork. Although sporadic water availability results in abundant time for the stored water to discharge back to the river similar to other sites upstream of American Falls, the relatively high aquifer-storage retention at sites along the Henry's Fork means that substantial residual storage from earlier recharge events remains in the aquifer by the time the next recharge event occurs. Therefore, successive recharge events are able to build upon previous storage gains, but the development of aquifer storage over time is hampered by the inconsistent water availability.

Recharge Based on Water Availability: All Sites 2000 – 2012

The ability to augment aquifer-storage through managed recharge is based on the combination of the location of the recharge site (aquifer-storage retention), the volume of recharge that a recharge site can perform (recharge capacity), and the frequency of recharge events (water availability). Figure 37 and Table 15 illustrate the differences in aquifer-storage benefits based on location, volume, and water availability at all of the sites investigated in this study.

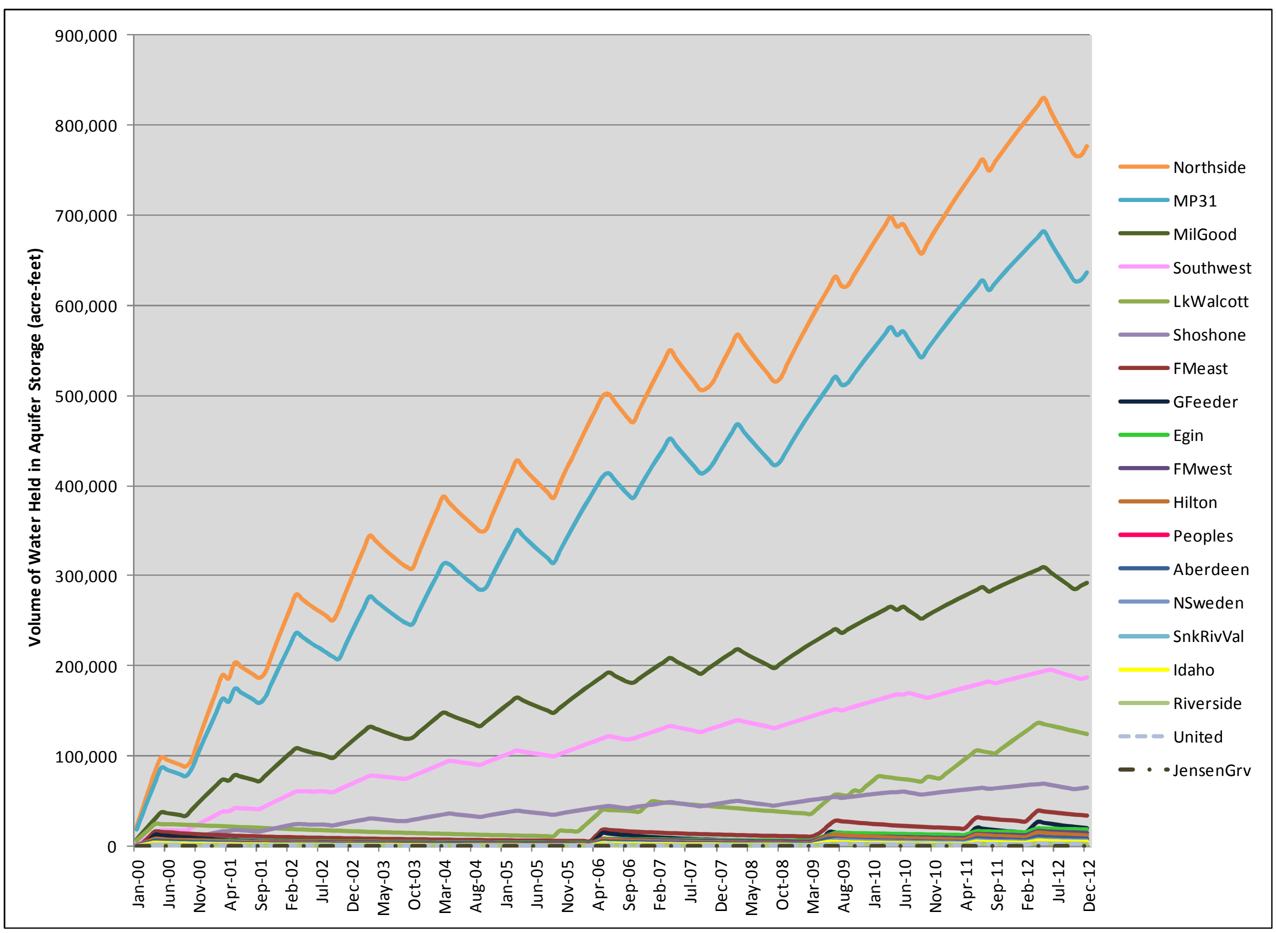

Figure 37. Comparative aquifer-storage benefit due to recharge based on water availability.

Table 15. Site ranking based on total ability to increase aquifer storage: water availability 2000 – 2012.

Recharge Site	Aquifer-Storage Benefit[1] (acre-feet)
Northside	752,404
Milepost 31	619,410
Milner-Gooding	284,763
Southwest	178,787
Lake Walcott	105,721
Shoshone	64,445
Fremont-Madison East	31,475
Great Feeder	20,498
Egin	16,031
Fremont-Madison West	13,782
Hilton	12,276
Peoples	8,224
Aberdeen	8,102
New Sweden	6,466
Snake River Valley	4,979
Idaho	4,738
Riverside	2,605
United	2,307
Jensen's Grove	1,643

[1]Aquifer-storage values represent the end of the 13th year of simulated recharge.

The combination of relatively high aquifer-storage retention and consistent water supply result in significant aquifer-storage benefits at the sites below Minidoka. Large recharge capacities at the Northside and Milepost 31 sites result in aquifer-storage benefits that far exceed the other sites.

Aquifer retention along the Henry's Fork is relatively high, but the paucity of available water hampers the ability to develop aquifer storage over time. In comparison, the combination of relatively low aquifer retention and sporadic water availability make sites on the Snake River upstream of American Falls and along the South Fork much less effective at developing aquifer storage than sites below American Falls.

Given the currently available data, Figure 37 and Table 15 provide the most objective comparison of the aquifer-storage effectiveness due to managed recharge at each of the sites.

Summary and Conclusions

Summary

State-sponsored recharge is guided by administrative policy and State law. State policy constrains the volume of water that can be recharge in the ESPA each year as the ESPA CAMP establishes targets for the amount of water that will be diverted for recharge. The CAMP targets effectively limit recharge to a multi-year average of 175,000 acre-feet annually through the year 2018, and 250,000 acre-feet annually afterward. State law dictates that the State's recharge right must be in priority for State-sponsored recharge to occur.

Idaho Statutory Code also guides managed recharge in the ESPA. The Milner Zero Minimum Flow Policy effectively divides the Snake River into two separate rivers by allowing zero flow in the Snake River at Milner Dam in order to maximize beneficial use above the dam. Although water users below Milner Dam cannot influence water use upstream of the dam, there are established minimum flows downstream at Swan Falls Dam which the State is obligated to maintain. The State Water Plan directs that the ESPA be managed as part of the Snake River system, and the system be managed to maintain the minimum flows at Murphy.

There are four general limitations to the monthly volume of recharge. First, there are limitations imposed by water availability. Water availability is delimited by water rights and the flows past Milner and Minidoka dams. Because the flow at Milner Dam can be brought to zero to fulfill beneficial uses upstream, any flow past Milner Dam is available for recharge, and represents the total available for ESPA recharge. Recharge upstream of Minidoka Dam is complicated by reservoir fill water rights, physical reservoir fill, and the unsubordinated USBR hydropower rights at Minidoka Dam. The USBR hydropower rights of 2,700 cfs affect managed recharge in two ways: 1) the hydropower rights are senior to the State's recharge rights, and 2) the hydropower rights are used to indicate the likelihood of physical reservoir fill. Therefore, flow in excess of 2,700 cfs at Minidoka are available for recharge upstream, but care must be taken to ensure that assumed minimum stream flows are maintained upstream of American Falls Reservoir. Additionally, water released as flow augmentation for fish propagation is not available for recharge and must be left in the river. Water is only considered available for recharge if the State's recharge water right is in priority at the POD during the period of recharge.

Second, there are limitations to the amount of water the recharge sites can divert (diversion capacity). The diversion limitations used in this study have been developed from historic recharge activities, and these values may be adjusted as the recharge program matures and better measurements are obtained. Diversion limitations are generally related to the size of diversion, transmission, and recharge structures; therefore, it may be possible to engineer increased diversion capacity.

Third, there are limitations to the amount of water that can infiltrate to the aquifer at the recharge sites (infiltration capacity). The infiltration limitations used in this study have been developed using a combination of published values, model-derived values, and interviews with facility managers. Infiltration limitations are generally related to surface and subsurface geologic materials, infrastructure available at the recharge site, and the volume of water that can be delivered to the site (diversion capacity); therefore, it may be possible to engineer increased infiltration capacity if recharge infrastructure or diversion capacity is the limiting factor.

Fourth, there are limitations to the amount that can be recharged at some sites due to shallow groundwater conditions (vadose-zone capacity). Shallow groundwater effectively limits the space between the water table and land surface and can hinder recharge efforts by causing infrastructure damage or allowing rapid return to surface water – both of which squander recharge resources. Limitations due to shallow groundwater have been determined by configuring ESPAM2.1 to employ drains in the areas of shallow groundwater. Because the method uses an uncalibrated version of a regional groundwater model to determine these limits, the values should be considered estimates. Therefore, it is recommended that a hydrogeologic or engineering investigation be conducted for proposed recharge at rates greater than the vadose-zone capacity of the site. Shallow groundwater is related to regional hydrogeological conditions, and it is likely not possible to engineer solutions for this managed-recharge limitation.

Multiple modeling scenarios have been run to evaluate the effectiveness of recharge to increase aquifer storage. The unaltered, calibrated ESPAM2.1 has been employed for all analytical scenarios. Results of the modeling scenarios indicate that there are three elements to recharge that impact a site's ability to increase aquifer storage:

4. Location of the recharge site. Assuming that recharge can be performed at a site, the location of the site relative to hydrogeologic controls may be the most important consideration. Distance from connected reaches of the South Fork, Henry's Fork, and Snake Rivers governs the retention of recharge in the aquifer (or how quickly water returns to the rivers). Geologic materials control how easily water infiltrates. Aquifer heterogeneities affect the distribution of recharge impacts and influence where the benefits are realized.

5. The volume of water recharged. The volume of water recharged at a site necessarily impacts how effectively aquifer storage is increased. Simply stated, increases in recharge volume result in increases in aquifer storage.

6. Recharge frequency. Recharge frequency is important for the development of aquifer storage. Higher recharge frequency means that more water can be recharged over time. Higher recharge frequency also means that less time passes between recharge events, during which stored water to returns to the river without replenishment by recharge. The combination of increased recharge and shorter inter-recharge periods results in the development of aquifer storage over time.

Conclusions

The primary goal for State-sponsored recharge is to increase long-term aquifer storage. Managed recharge should prioritize aquifer storage because it is the most efficient method of accomplishing the State's goal of aquifer stabilization and recovery. Increases in long-term aquifer storage will increase spring discharge and improve river flows.

The legal and administrative considerations that guide the Managed Recharge Program combined with the physical limitations to recharge require a coordinated, thoughtful approach to managed recharge. To build aquifer storage, the Managed Recharge Program must consider the retention rate (based on location), the potential volume of recharge (based on site capacity), and the repetition frequency of recharge events (based on water availability) in developing a plan that emphasizes continuity. However, the program needs to be flexible enough to take advantage of sporadic (but at times copious) water availability upstream of Minidoka Dam.

In general, sites located along the Henry's Fork and sites located on the main stem Snake River downstream of Minidoka Dam have the highest aquifer retention rates, while sites located along the South Fork and main stem Snake River upstream of Minidoka Dam have the lowest aquifer retention rates. Aquifer retention rates five years after recharge range from 58.7% to 17.5% at Egin Lakes and Great Feeder, respectively. The site ranking based on aquifer retention rates is located in Table 12.

Based on modeling that considers recharge capacity and water availability in addition to aquifer retention rate, Northside canal system is the site with the greatest ability to benefit aquifer storage, followed closely by the Milepost 31 recharge site. The United canal system and Jensen's Grove are the sites least capable at benefitting aquifer storage. Site rankings based on the total ability to benefit aquifer storage are located in Table 15.

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APPENDIX A

Composition of Snake River Flow at Murphy

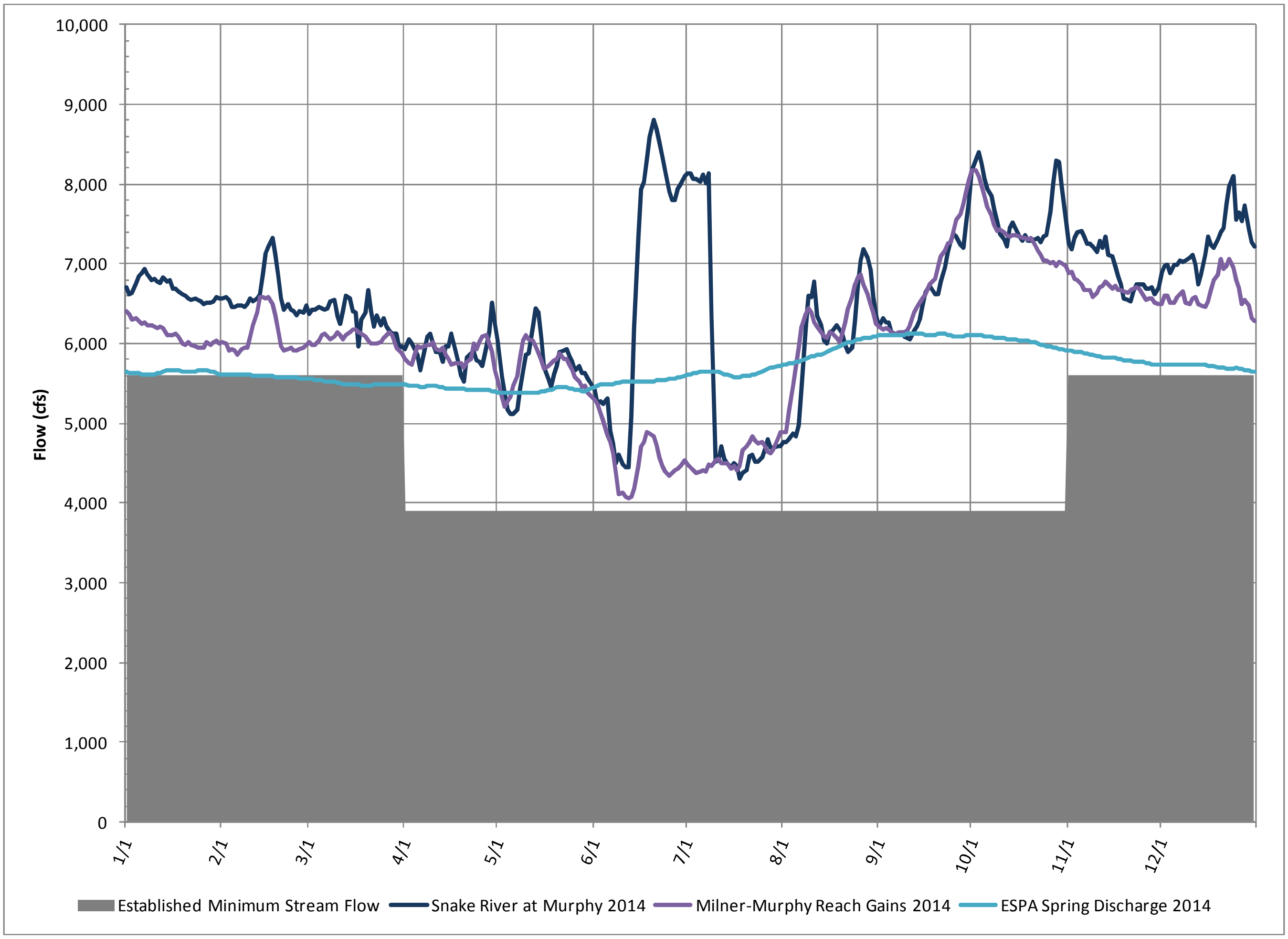

Figure A1. The relative contribution of ESPA spring discharge and reach gains to the total flow at Murphy.

Snake River flow at Murphy is a combination of reach gains between Milner Dam and Murphy, diversions, return flows, and flow-augmentation releases upstream. The pronounced spike in river flow between the middle of June and the middle of July is due to flow-augmentation releases. The differences between the reach-gain values and the Snake River flow at Murphy are the inclusion of flows past Milner Dam in the Murphy data. During the winter months and during a brief period in June-July there is flow past Milner Dam. The remainder of the time, flow at Murphy consists of mainly spring discharge and river gains between Milner Dam and Murphy.

Spring discharge from the ESPA represents the majority of flow in the river all months of the year, and exceeds river flow at Murphy for part of the irrigation season if flow augmentation releases are neglected (Table 2). Spring discharge exceeds river flow at times due to irrigation diversions that take place between King Hill and Murphy.

APPENDIX B

Water-Availability Data and Statistics

The annual water availability for recharge at each of the minimum flow locations is illustrated in figures B1-B5.

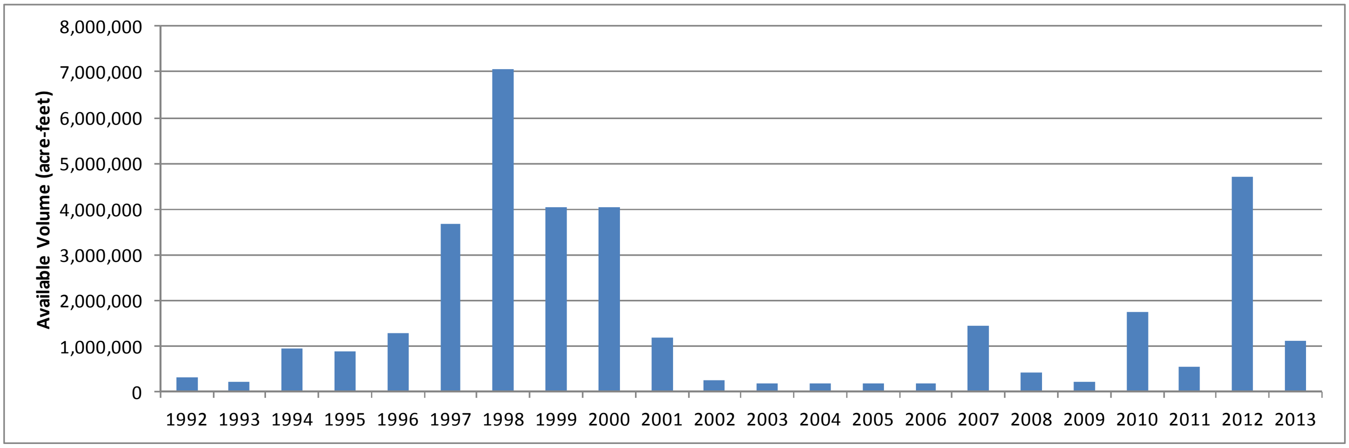

Figure B1. Annual water availability at Milner.

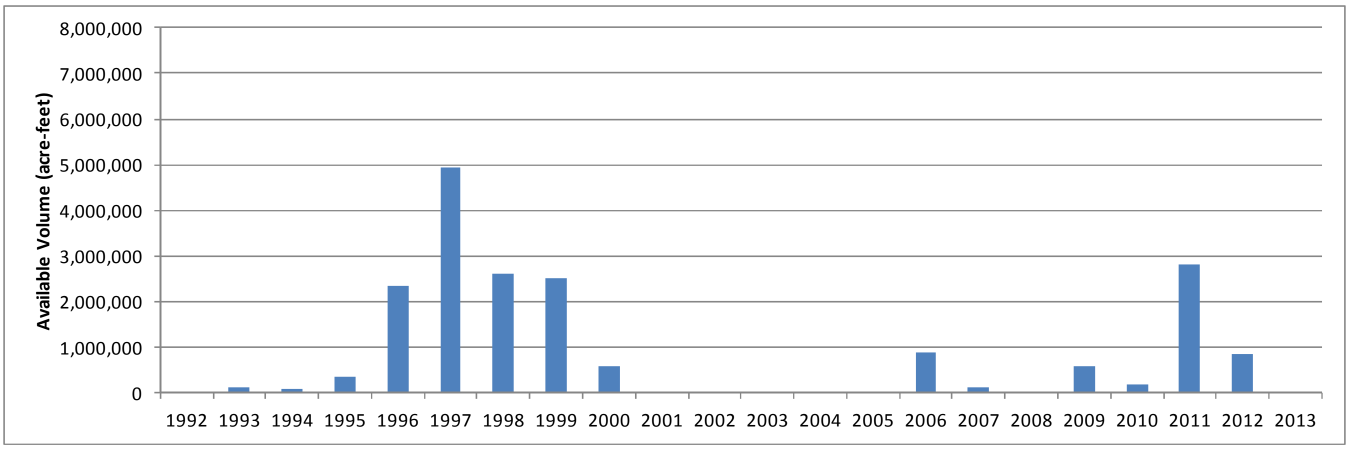

Figure B2. Annual water availability at Minidoka.

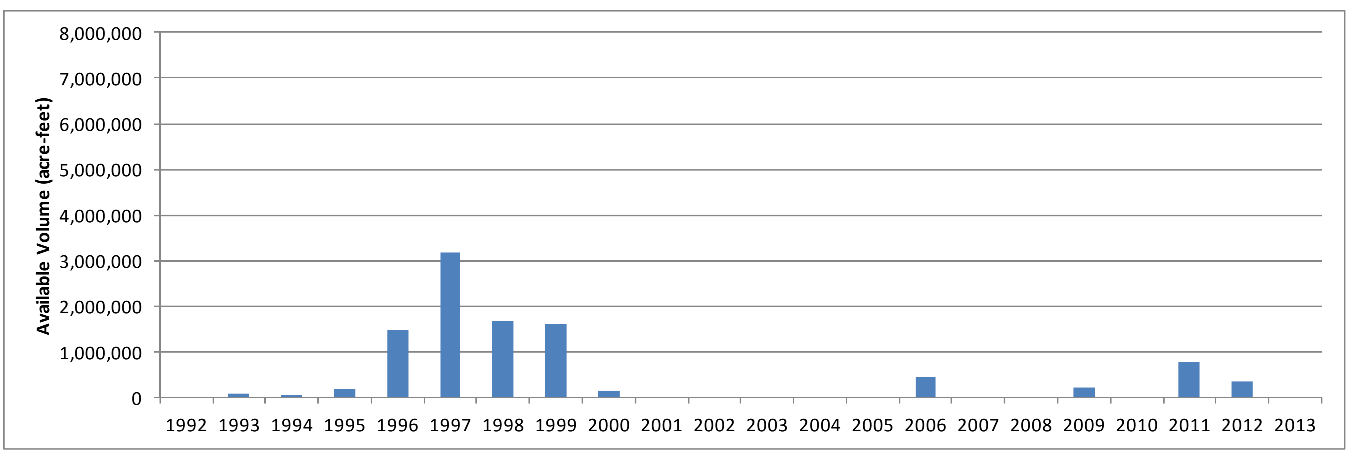

Figure B3. Annual water availability at Blackfoot.

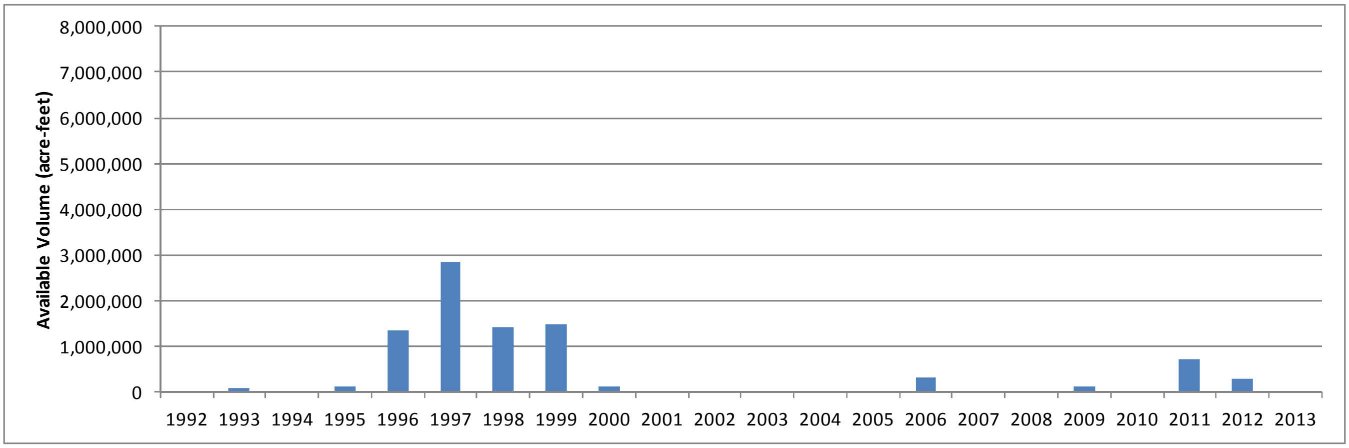

Figure B4. Annual water availability at Heise.

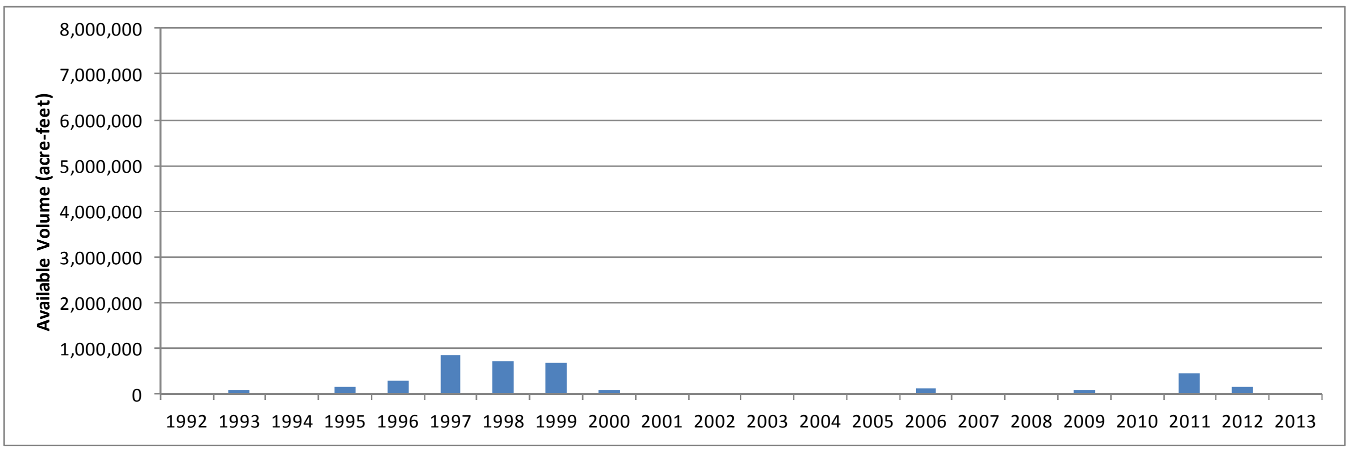

Figure B5. Annual water availability at St. Anthony.

In order to facilitate understanding of the water-availability at each minimum-flow site, a short discussion of descriptive statistics is warranted. Descriptive statistics offer a way to concisely describe the nature of a data set, and the simplification allows for quantitative comparison of data sets (Ott and Longnecker, 2001). Descriptive statistics are expressed by values describing the central tendency and spread of the data.

Central tendency is a single value used to represent a data set, and identifies a central or typical value for the given distribution of data. The mean is the sum of measurements divided by total number of measurements, and is the most familiar indicator of central tendency. However, it becomes distorted and loses descriptive value for data sets that contain very high or low values or have skewed (non-normal) distributions. In other words, the mean is not the center of the data when the data is skewed. Because the water-availability data are non-normally distributed, the mean tends to overestimate the central tendency and imply greater water availability than what the data describes (Figures B6-B10).

An alternate central tendency statistic is the median (50% exceedance). The median describes the midpoint value of a data set such that half of the data are greater than the median and half of the data are less than the median. The median is unaffected by very large or very small numbers and does not require normal data distribution to be valid. Therefore, the median is a better measure for describing water availability because it conveys useful information about both the magnitude and likelihood of future surplus flows.

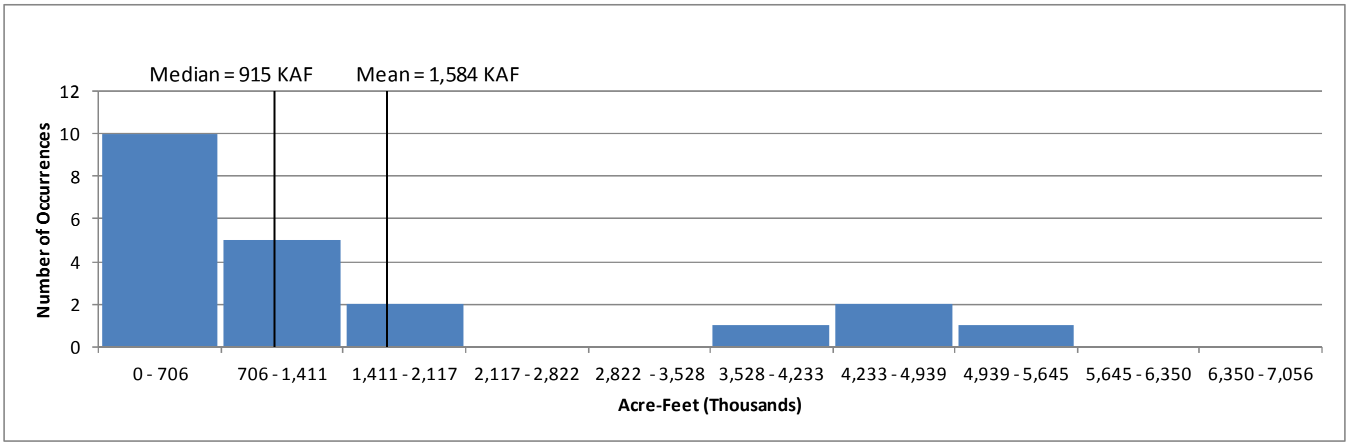

Figure B6. Frequency distribution (histogram) of water availability data at Milner.

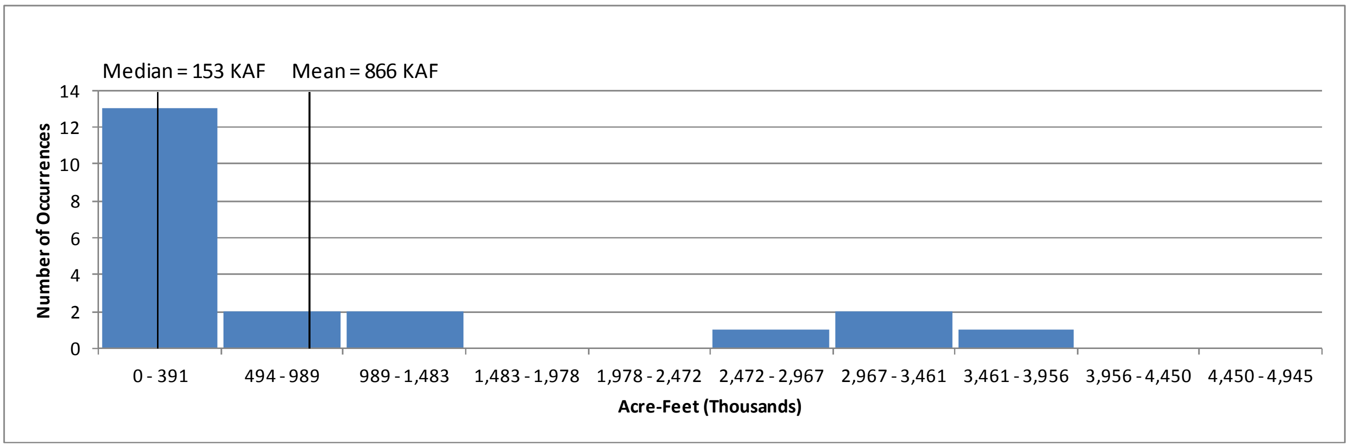

Figure B7. Frequency distribution of water availability data at Minidoka.

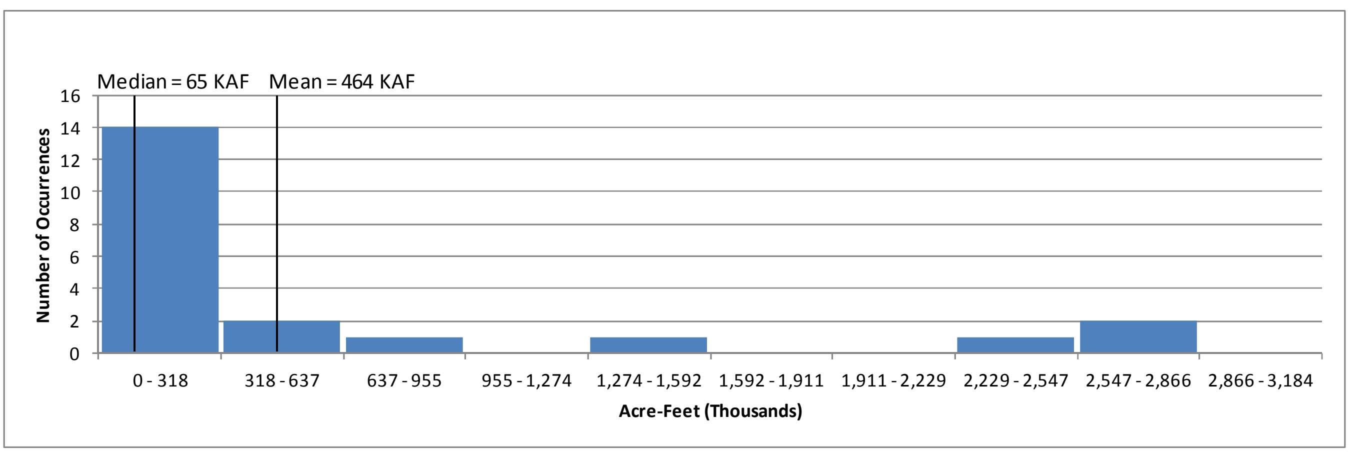

Figure B8. Frequency distribution of water availability data at Blackfoot.

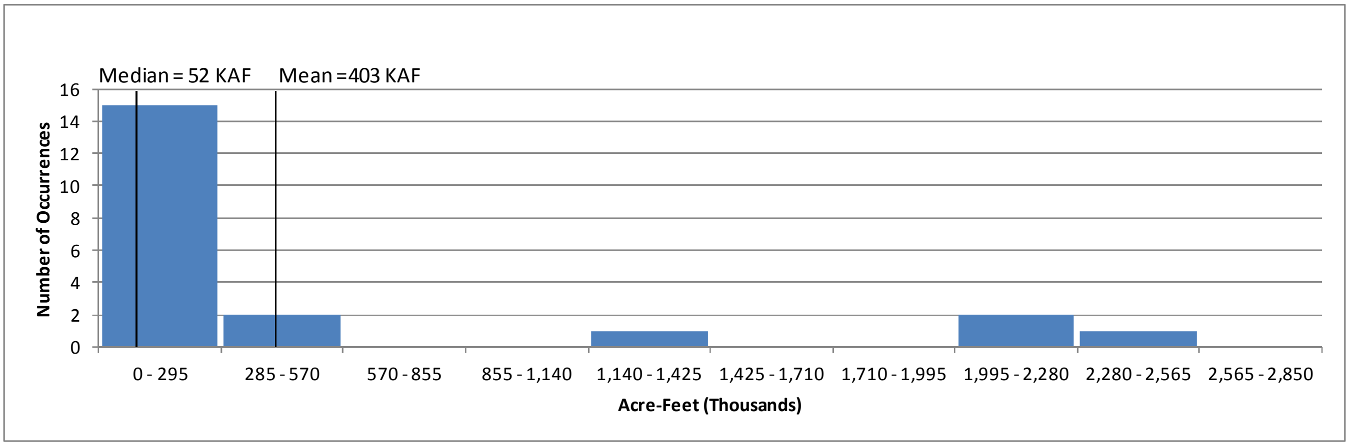

Figure B9. Frequency distribution of water availability data at Heise.

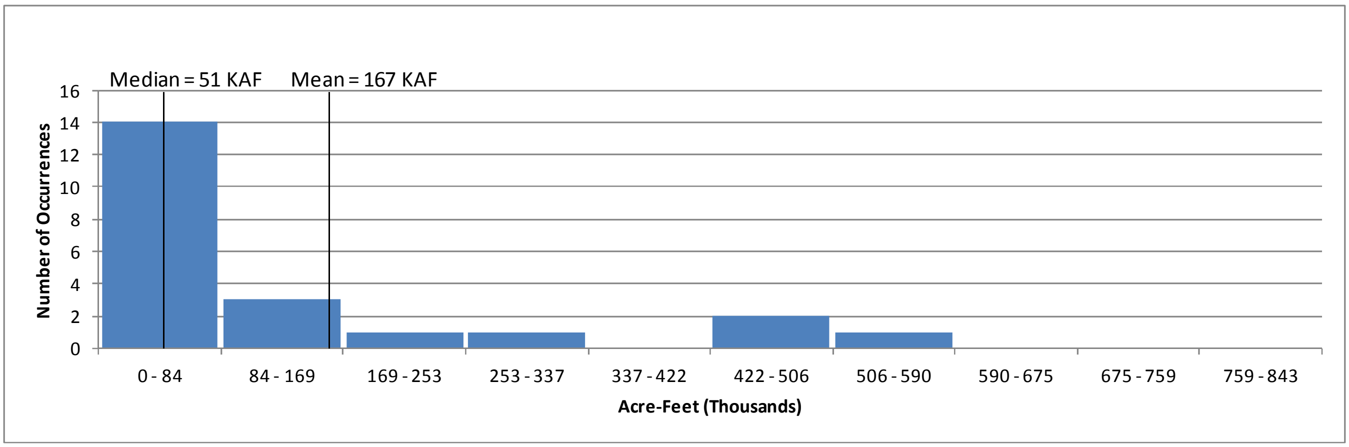

Figure B10. Frequency distribution of water availability data at St. Anthony.

Spread is a measure of variability, and describes how the data are distributed around the central tendency. Variability is readily seen on graphs of the data; however, it is difficult to make quantitative assessments of the data distribution, and impractical to make comparisons between minimum-flow locations by looking at the entirety of the data sets. Although the standard deviation is the most familiar indicator of variability, it is calculated using the mean, requires a symmetrical distribution about the mean, and is not applicable for use with the median.

An alternate spread statistic is the percentile. A percentile describes the value below which the given percentage of measurements fall, and quartiles are defined as the 25th, 50th, and 75th percentiles. Quartiles are the most useful measure of spread for skewed data, and work seamlessly with the median (the median is the 50th percentile) to create box-and-whisker plots that graphically describe the nature of a data set (University of Utah, 2015). Tops and bottoms of the boxes are the 75th and 25th percentiles, respectively. Fundamentally, this means that 75% of the data have values that are below the upper box border. The top and bottom whiskers are the maximum and minimum values, respectively.

The use of box-and-whisker plots allows for the simple, quantitative assessment of the water-availability distribution relative to the median, and facilitates the comparison of the water availability at each minimum flow location (Figure 15).

APPENDIX C

Water-Availability Calculation Flow Chart

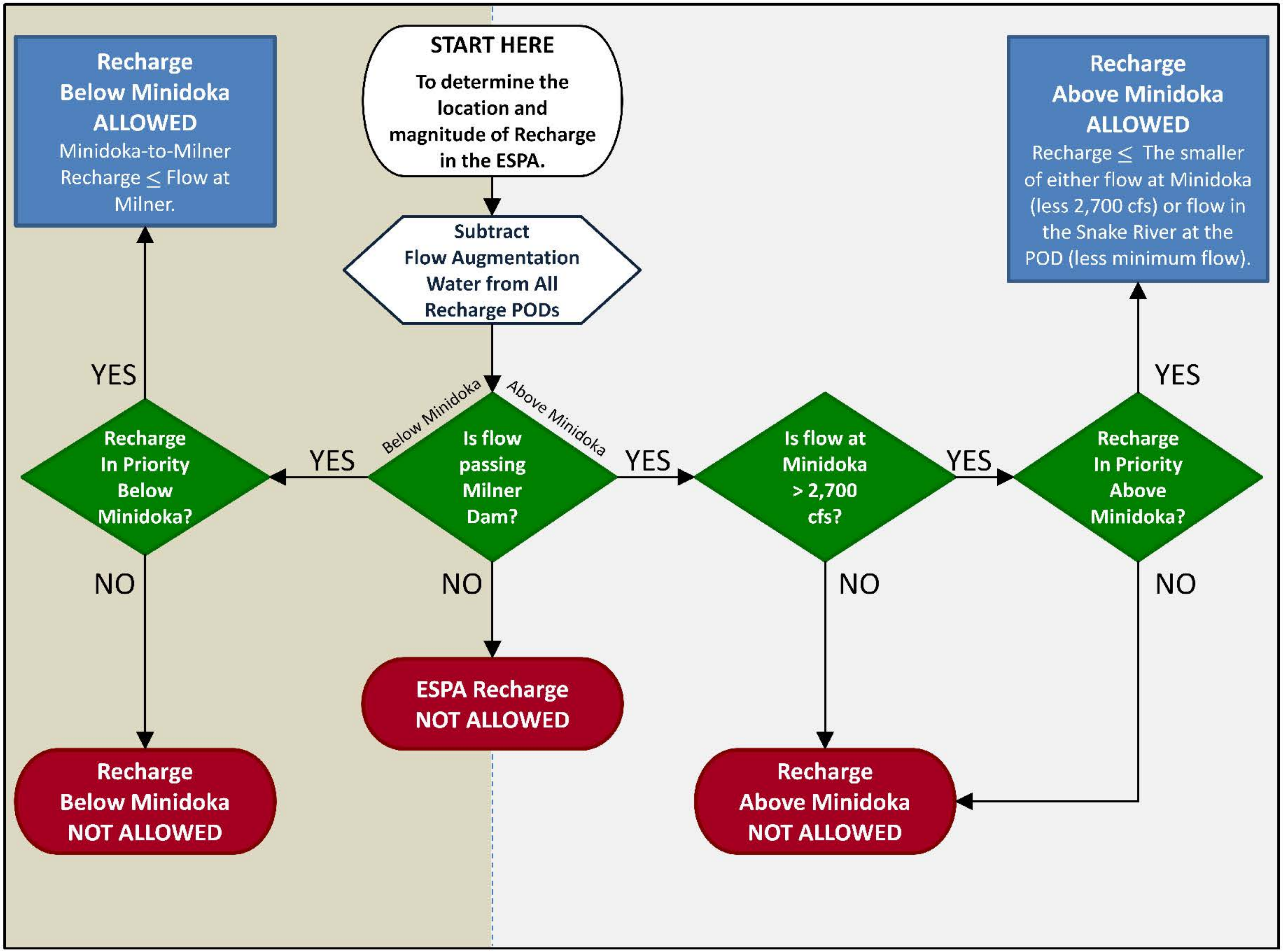

Figure C1. Flow-chart illustration of the logic behind calculating recharge water availability.

APPENDIX D

Temperature and Infiltration

Because the recharge program looks to conduct managed recharge during the winter months, it is important to acknowledge the role that temperature plays in the rate of infiltration. As temperature decreases, both the dynamic viscosity and density[1] (specific weight) of water increase, which makes the water more resistant to flow. Therefore, infiltration rates during cold weather may be lower than those based on spring through fall measurements (Table D1).

Darcy's law for flow through porous material can be written in terms of dynamic viscosity and specific weight[1] in order to estimate the effect that temperature can have on infiltration (Equation D1).

$$Q = -\left(\frac{Cd^2\gamma A}{\mu}\right)\left(\frac{dh}{dl}\right)$$ Equation D1

Were:

Q = Volumetric flow, [L^3/T].

C = Shape factor coefficient, [unitless].

D = mean grain-size diameter of aquifer material, [L].

A = Cross sectional area of aquifer, [L^2].

γ = Specific weight of water, [W/L^3].

μ = Dynamic viscosity of water, [WT/L^2].

[1]Density is calculated as mass divided by volume. Specific weight is calculated as mass multiplied by gravitational force, divided by volume.

Table D1. Changes in flow based on temperature.

Temperature (°F)	Dynamic Viscosity (μ)	Specific Weight (γ)	d (ft)	dh/dl	Area (ft^2)	C	Flow (cfs)	% Change from 60 °F
32	0.0000373	62.42	0.0006	0.01	1,000	0.0002	1.93E-05	-37%
40	0.0000323	62.43	0.0006	0.01	1,000	0.0002	2.23E-05	-27%
50	0.0000273	62.41	0.0006	0.01	1,000	0.0002	2.64E-05	-14%
60	0.0000234	62.37	0.0006	0.01	1,000	0.0002	3.07E-05	0%
70	0.0000203	62.30	0.0006	0.01	1,000	0.0002	3.54E-05	15%
80	0.0000179	62.22	0.0006	0.01	1,000	0.0002	4.02E-05	31%
90	0.0000158	62.11	0.0006	0.01	1,000	0.0002	4.56E-05	48%
100	0.0000142	62.00	0.0006	0.01	1,000	0.0002	5.06E-05	65%

Dynamic viscosity:
http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html

Specific Weight:
Finnemore, J. E. (2002). *Fluid Mechanics with Engineering Applications*. New York: McGraw-Hill.

APPENDIX E

Distribution of Seasonal Vadose-Zone Capacities

Vadose-zone capacities have been determined based on synoptic depth-to-water measurements made in the spring (April) and fall (October) of 2008. The Managed Recharge Program looks to conduct managed recharge during all months of the year. In order to understand how seasonally-derived vadose-zone capacities are distributed throughout the year, it is necessary to investigate how depth-to-water changes over time.

Water levels from well 02S35E-34BDBA1 have been used to distribute seasonal vadose-zone capacities throughout the year (Figures E1 and E2).

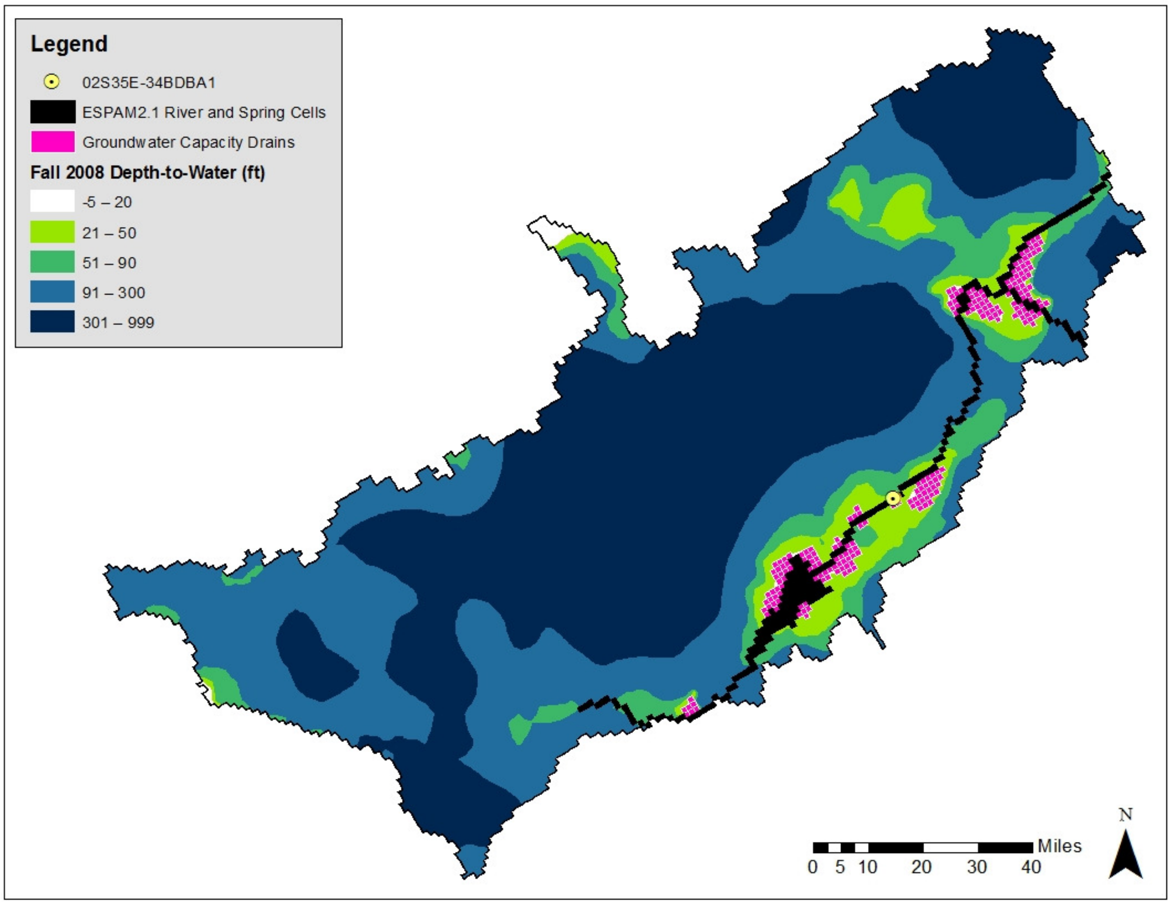

Figure E1. Location of well 02S35E-34BDBA1 in relation to shallow groundwater areas.

Areas with a depth-to-water of 20 below ground surface (bgs) or less have been represented as drain cells for the calculation of vadose-zone capacities. Drains become active when recharge raises water to within 15 feet of land surface. A value of 20 feet bgs has been used to determine when spring or fall vadose-zone capacities should be applied in modeling scenarios because recharging when ambient water levels are within 20 feet of the surface has the potential to raise the water table into the buffered area.

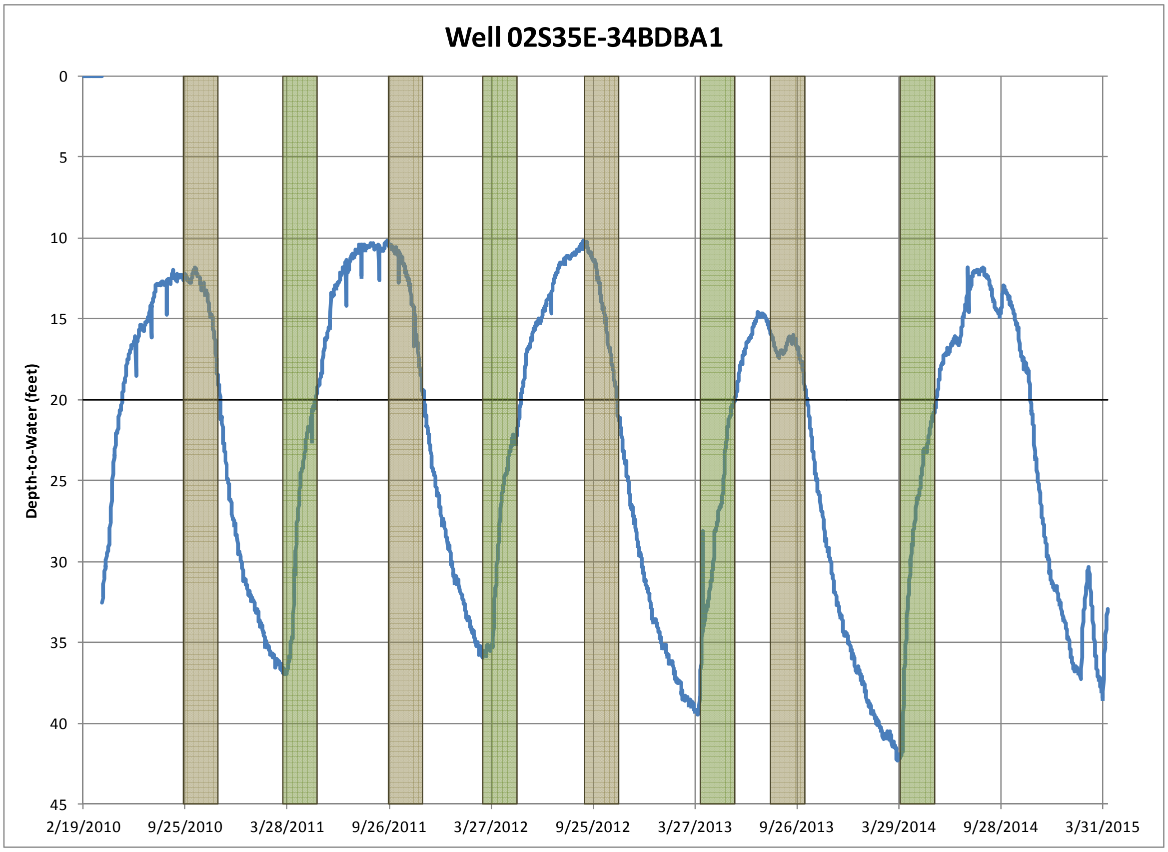

Figure E2. Hydrograph of well 02S35E-34BDBA1. Colored vertical bars delineate the time between the max/min water level and when the depth-to-water in the well falls past/rises above 20 feet below ground surface.

Figure E2 indicates that it takes approximately two months for the maximum water level to fall to below 20 feet bgs, and approximately two months for the minimum water level to rise above 20 feet below ground surface. Based on this information, spring vadose-zone capacities that were calculated for April have been applied to May and June, and fall vadose-zone capacities that were calculated for October have been applied to November and December. Table E1 lists the vadose-zone capacities as distributed throughout the year.

Table E1. Distribution of vadose-zone capacities throughout the year

Month	Seasonal Capacity
January	Spring
February	Spring
March	Spring
April	Spring
May	Spring
June	Spring
July	Fall
August	Fall
September	Fall
October	Fall
November	Fall
December	Fall

APPENDIX F

Model Cells Used to Represent Recharge Sites

Table F1. ESPAM2.1 model cells used to represent recharge sites.

Recharge Site	Modeled Recharge Site	Distribution of Recharge Flux	Model Cells
Egin Lakes	Cells representing only Egin Lakes	Uniformly among 2 cells representing lakes	(49,184) (49,182)
Fremont-Madison east canals	Main canals on the east side of the Henry's Fork	Uniformly distribute among cells corresponding to canals east of river	(57,190)
Fremont-Madison west canals	Main canals on the west side of the Henry's Fork	Uniformly distribute among cells corresponding to canals west of river	(51,183)(51,184)(51,185)(51,186) (52,183)(52,184)(52,185)(52,186) (52,187)(52,188)(52,189)(53,181) (53,182)(53,183)(53,189)(53,190) (53,191)(53,192)(54,181)(53,190) (49,182)(49,183)(49,184)(49,185) (50,184)(50,185)(50,186)(50,187) (50,188)(52,182)(52,183)(52,184) (52,185)(52,186)(52,187)(54,179) (54,180)(53,181)(53,182)(53,183) (53,184)(53,185)(53,187)(53,188) (53,189)(53,190)(53,191)(54,181) (51,190)(51,191)(50,188)(50,189) (50,190)(52,191)(52,192)(52,193) (53,193)(53,194)(53,195)(53,196) (53,197)(53,198)(54,195)(54,196) (52,185)(51,181)(51,182)(51,183) (51,184)(52,184)(52,185)(52,189) (52,190)(52,191)(53,189)(53,190) (53,191)(51,181)(51,182)(52,181) (52,182)(52,183)(54,179)(55,179) (56,178)(56,179)(53,189)(53,190) (53,188)(53,189)(53,190)(51,181) (51,182)(51,184)(51,185)(51,186) (51,187)(51,188)(51,189)(51,190) (50,182)(50,183)(50,184)(50,188) (52,180)(52,181)(52,183)(52,184) (52,185)(52,186)(52,187)(52,188) (52,190)(52,191)(52,192)(54,179) (54,180)(53,180)(53,188)(53,192) (53,193)(54,193)(54,194)(54,195) (53,190)(53,191)(53,192)
Great Feeder area canals	Locations of 14 canals	Uniformly distribute among cells corresponding to canal locations	(65,164)(65,165)(65,166)(65,167) (65,168)(65,169)(65,170)(65,171) (64,166)(64,167)(64,168)(66,171) (66,172)(66,173)(66,174)(67,173) (67,174)(67,175)(68,175)(68,176) (69,176)(69,177)(70,177)(65,164) (65,165)(68,170)(68,171)(66,165) (66,166)(66,167)(66,168)(67,168) (67,169)(67,170)(69,171)(69,172) (69,173)(70,173)(70,174)(70,175) (70,176)(70,177)(71,177)(71,178)
New Sweden	Main canals	Uniform distribution	(68,161)(69,161)(73,153)(73,154) (72,154)(72,155)(73,154)(71,156) (71,157)(70,158)(71,158)(72,156) (71,156)(72,157)(71,157)(71,158) (68,161)(69,161)(72,155)(72,156) (68,161)(69,159)(69,160)(69,161) (70,158)(70,159)(72,157)(71,157) (71,158)
Idaho Irrigation	Main canals	Uniform distribution	(75,160)(65,164)(68,163)(64,164) (72,162)(72,163)(66,163)(66,164) (67,163)(69,163)(70,163)(84,146)

District			(84,147)(84,148)(84,149)(84,150) (84,151)(74,160)(74,161)(74,162) (71,162)(71,163)(73,162)(76,160) (77,159)(77,160)(81,154)(81,155) (81,156)(78,158)(78,159)(79,157) (79,158)(80,156)(80,157)(82,153) (82,154)(83,151)(83,152)(83,153)
Snake River Valley	Main canals	Uniform distribution	(74,156)(74,157)(76,154)(76,155) (75,155)(75,156)(77,153)(77,154) (81,151)(78,152)(78,153)(79,151) (79,152)(80,151)
Peoples	Main canals	Uniform distribution	(78,132) (78,132)(78,132) (79,128)(79,129) (78,129) (78,130) (78,131)(80,128) (81,127) (81,128) (78,131) (78,132) (78,133)(78,134) (78,135) (78,136) (78,137) (78,138) (79,138) (79,139) (79,140) (79,141) (80,141) (80,142) (80,143)(80,144) (83,124) (83,125) (78,132) (78,132) (81,127)(82,127) (82,125) (82,126) (82,127) (83,125)
Riverside	Main canals	Uniform distribution	(80,136) (80,137)(81,136) (80,141)(80,142) (80,137) (80,137) (80,138)(80,139) (80,140)(80,141) (81,138) (81,139)
United	Main canals	Uniform distribution	(79,132)(79,133)(80,131)(80,132) (80,133)(80,134)(80,135)(80,136) (81,131)(81,136)(81,137)(81,138) (81,134)(81,135)(81,136)(82,136)
Jensen’s Grove	Jensen’s Grove	NA	(82,137)
Aberdeen-Springfield	Main canal extending from diversion to beyond Hilton Spill	Uniform distribution	(79,115)(79,116)(79,117)(79,118) (79,125)(79,126)(79,127)(78,127) (78,128)(78,129)(78,130)(78,131) (78,132)(78,133)(78,134)(78,135) (78,136)(78,137)(78,138)(79,138) (79,139)(79,140)(79,141)(80,116) (80,117)(80,118)(80,119)(80,120) (80,121)(80,122)(80,123)(80,124) (80,125)(80,141)(80,142)(80,143) (80,144)(80,145)(80,146)(81,122) (81,123)
Hilton Spill	Hilton spill	NA	(80,121)
Lake Walcott Recharge Site	Lake Walcott recharge site	NA	(83,68)
Southwest Irr. District	Locations of 5 specific injection wells	Uniform distribution	(90,34)(88,37)(88,36)(86,40) (84,40)
Milner-Gooding main canal	Main canal	Uniform distribution	(46,39)(46,40)(34,33)(34,34) (34,35)(34,36)(34,37)(35,37) (35,38)(35,39)(42,39)(36,38) (36,39)(37,38)(38,38)(39,38) (40,38)(40,39)(41,39)(43,39) (44,39)(44,40)(45,39)(45,40) (47,39)(47,40)(48,40)(50,40) (50,41)(49,40)(51,41)(51,42) (52,41)(52,42)(53,41)(53,42) (54,40)(54,41)(55,39)(55,40) (56,39)(56,40)(57,38)(57,39) (57,40)(58,38)(59,38)(60,38)

			(60,39)(60,40)(61,40)(62,40) (62,41)(62,42)(63,41)(63,42) (64,40)(64,41)(65,40)(66,40) (73,43)(73,44)(67,40)(67,41) (68,40)(68,41)(69,41)(69,42) (70,42)(71,42)(79,40)(79,41) (71,43)(72,43)(72,44)(74,42) (74,43)(75,42)(75,43)(76,40) (76,41)(76,42)(76,43)(77,39) (77,40)(78,39)(78,40)
Shoshone Recharge Site	Model cell located at recharge site	NA	(42,39)
Milepost 31 Recharge Site	Model cell located at recharge site	NA	(62,41)
Northside Main Canal Including Wilson Lake	Main canal and Wilson Lake	2/3 of recharge in Wilson Lake and upstream, 1/3 of recharge below Wilson Lk	(54,31)(54,32)(48,27)(50,27) (49,27)(51,27)(52,27)(52,28) (52,29)(53,29)(53,30)(53,31) (55,32)(55,32)(55,33)(56,33) (57,33)(58,33)(59,32)(59,33) (60,33)(61,33)(61,34)(62,34) (63,34)(63,35)(64,35)(64,36) (65,35)(65,36)(66,35)(66,36) (73,40)(67,35)(67,36)(68,36) (68,37)(69,37)(70,37)(70,38) (71,38)(71,39)(79,40)(72,39) (72,40)(74,40)(75,40)(76,40) (77,39)(77,40)(78,39)(78,40)

APPENDIX G

100,000 acre-feet Annual Recharge Figures

Representing the

End of the Tenth Year of Recharge

Ashton-to-Rexburg (Henry's Fork)

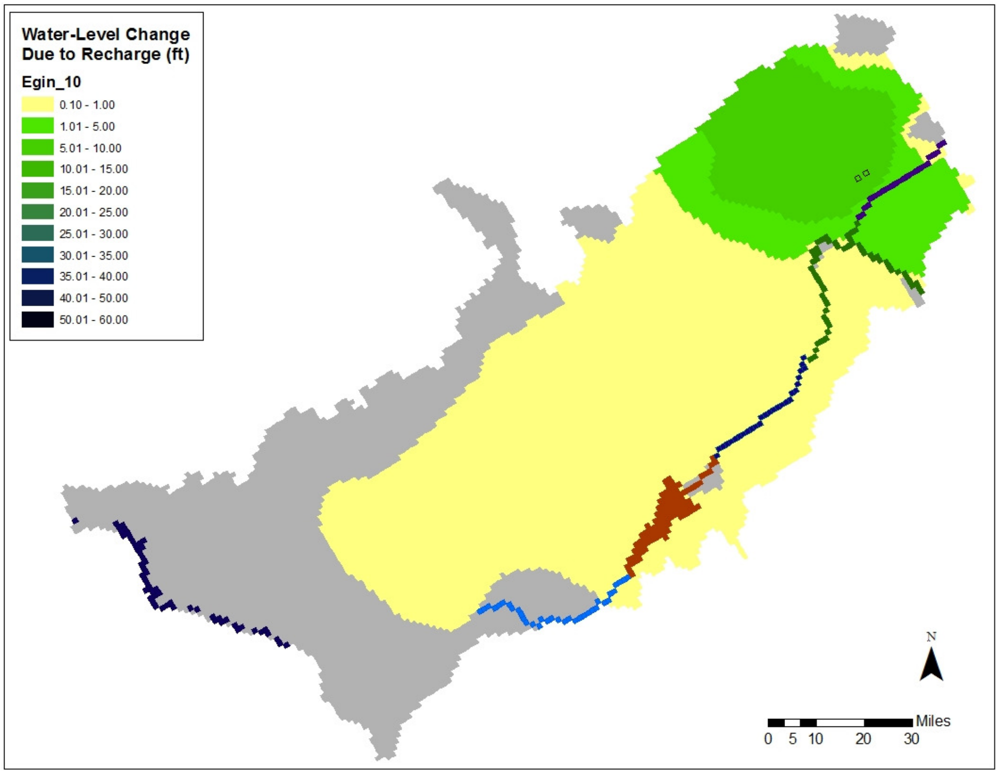

Figure G1. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Egin.

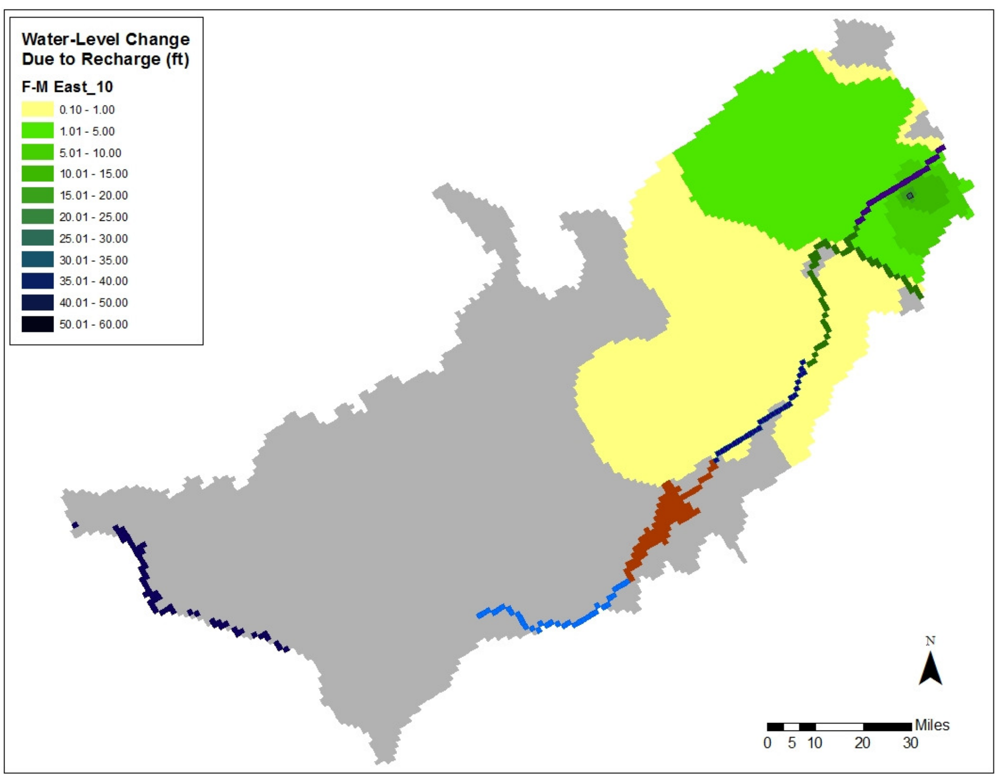

Figure G2. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Fremont-Madison East.

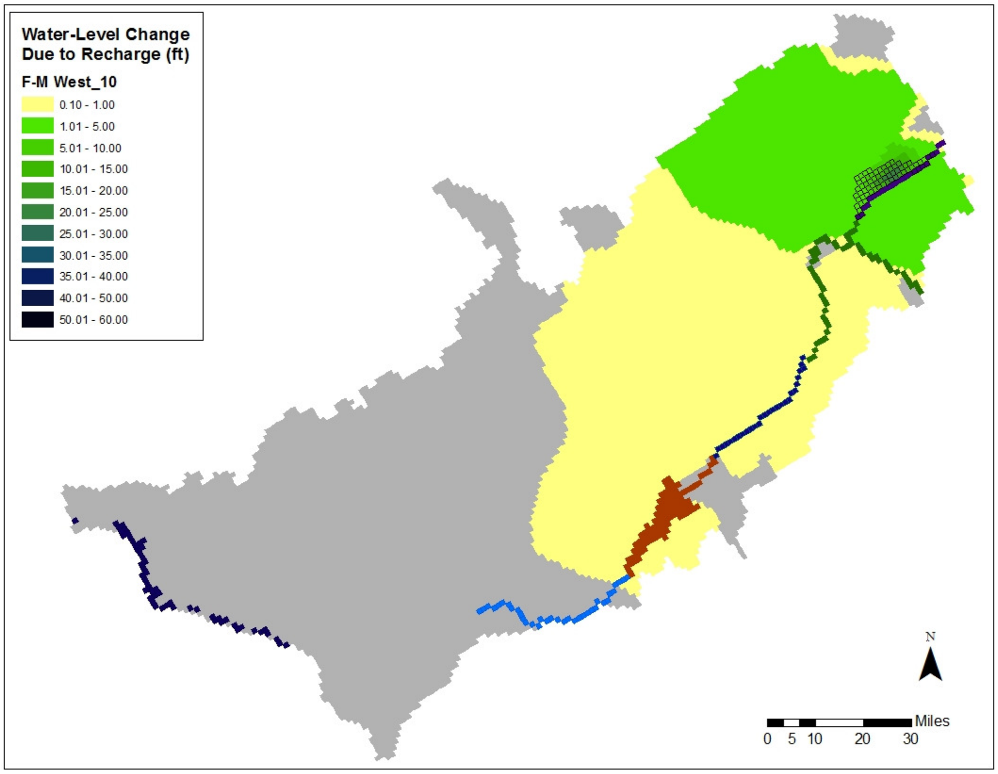

Figure G3. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Fremont-Madison West.

Heise-to-Shelley

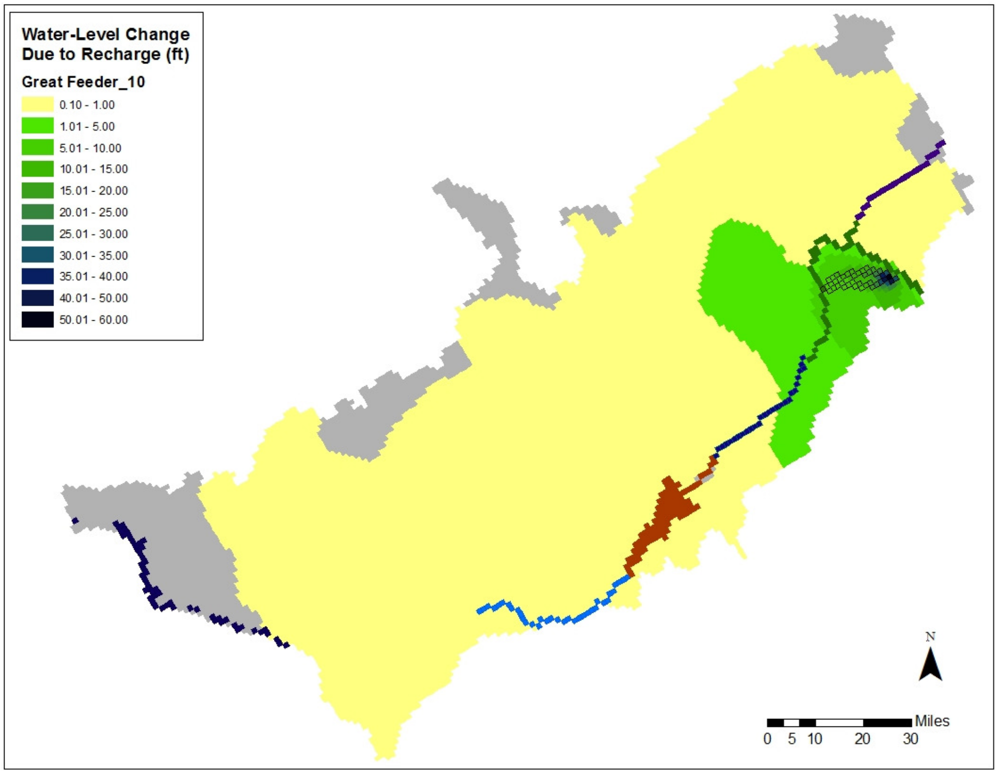

Figure G4. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Great Feeder.

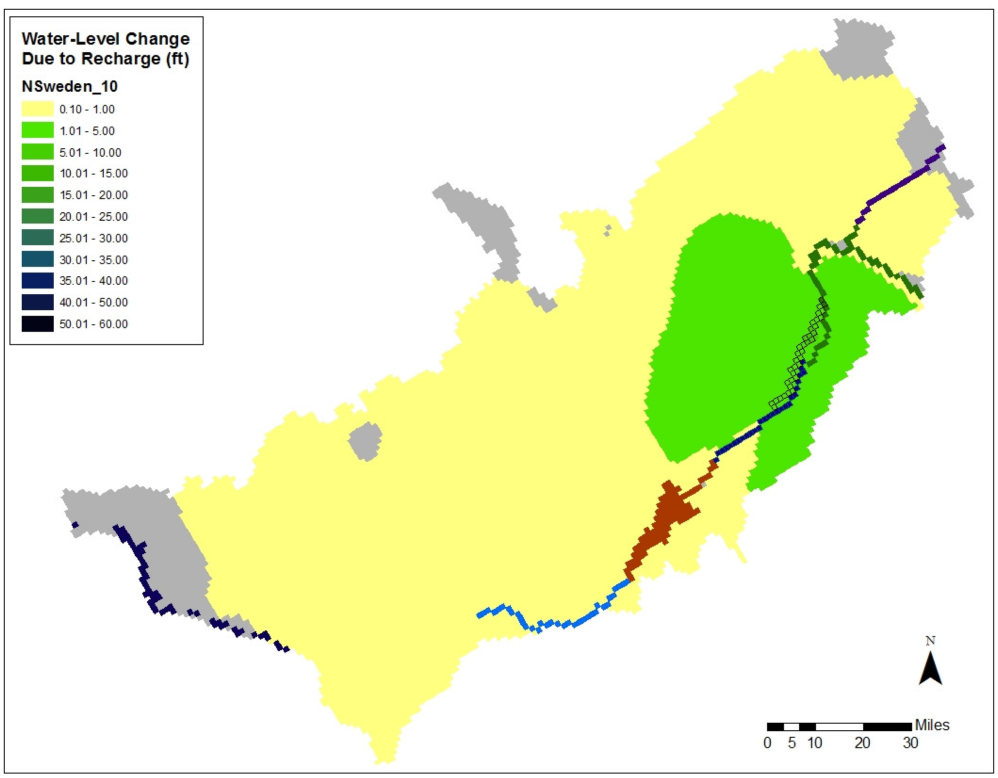

Figure G5. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at New Sweden.

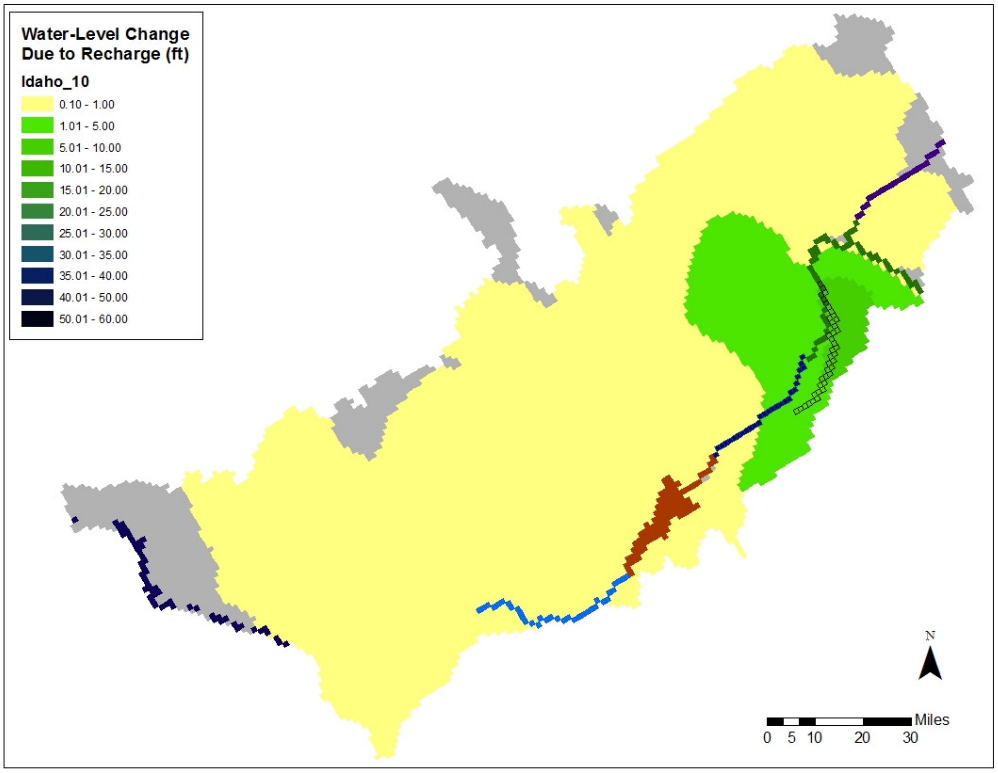

Figure G6. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Idaho.

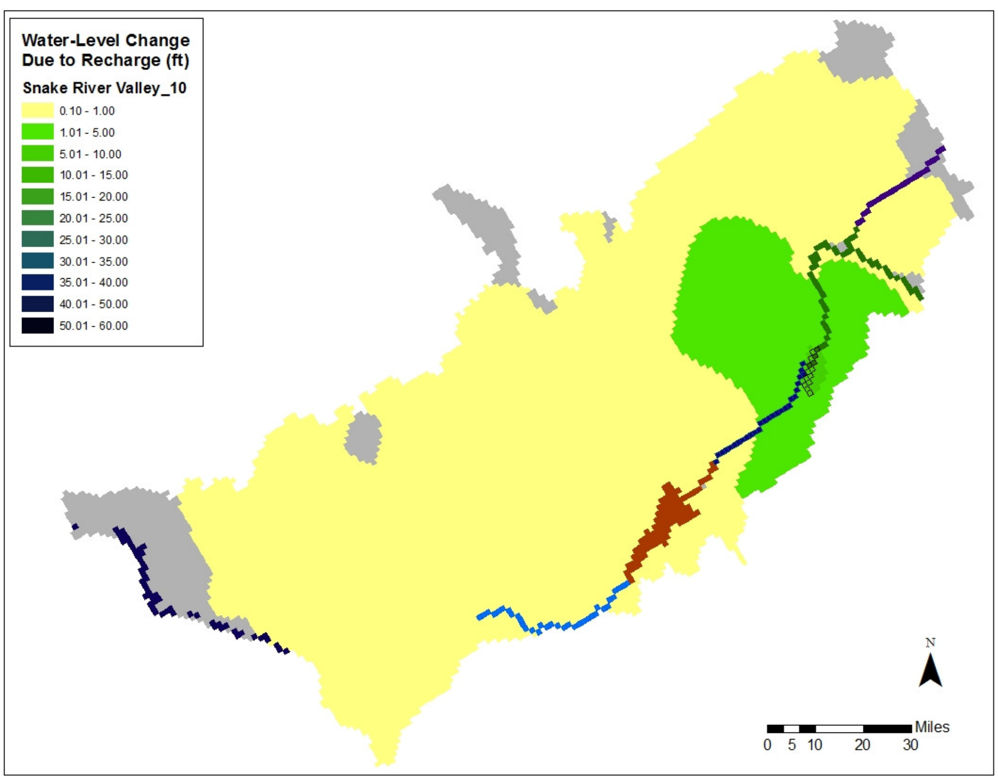

Figure G7. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Snake River Valley.

Shelley-to-nr Blackfoot

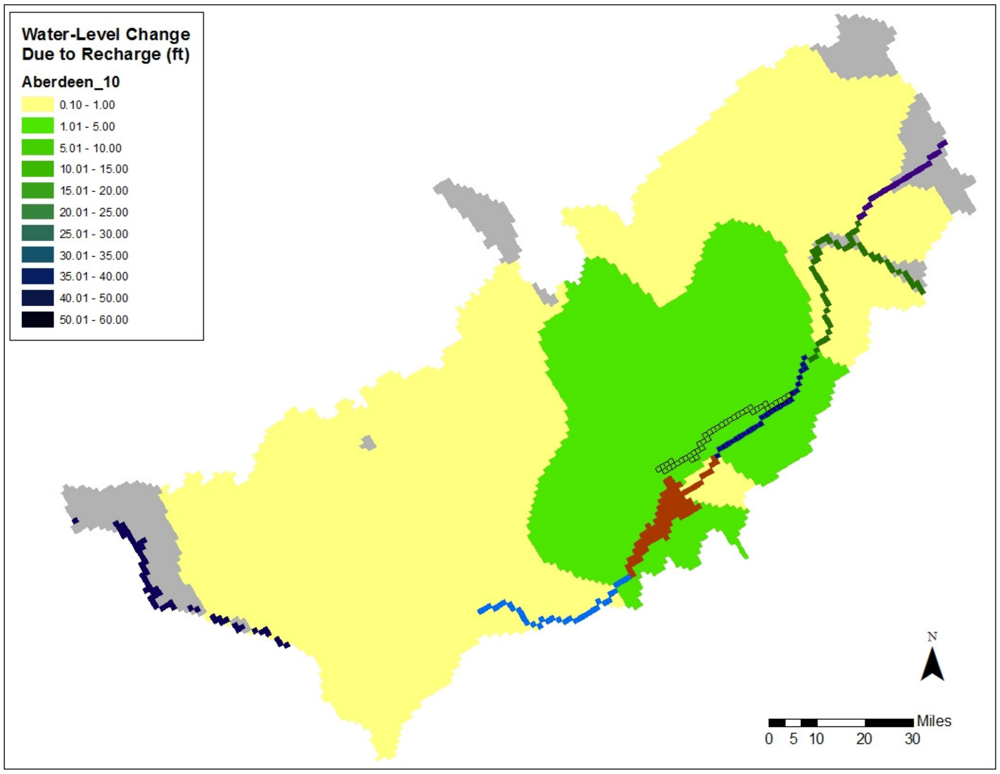

Figure G8. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Aberdeen.

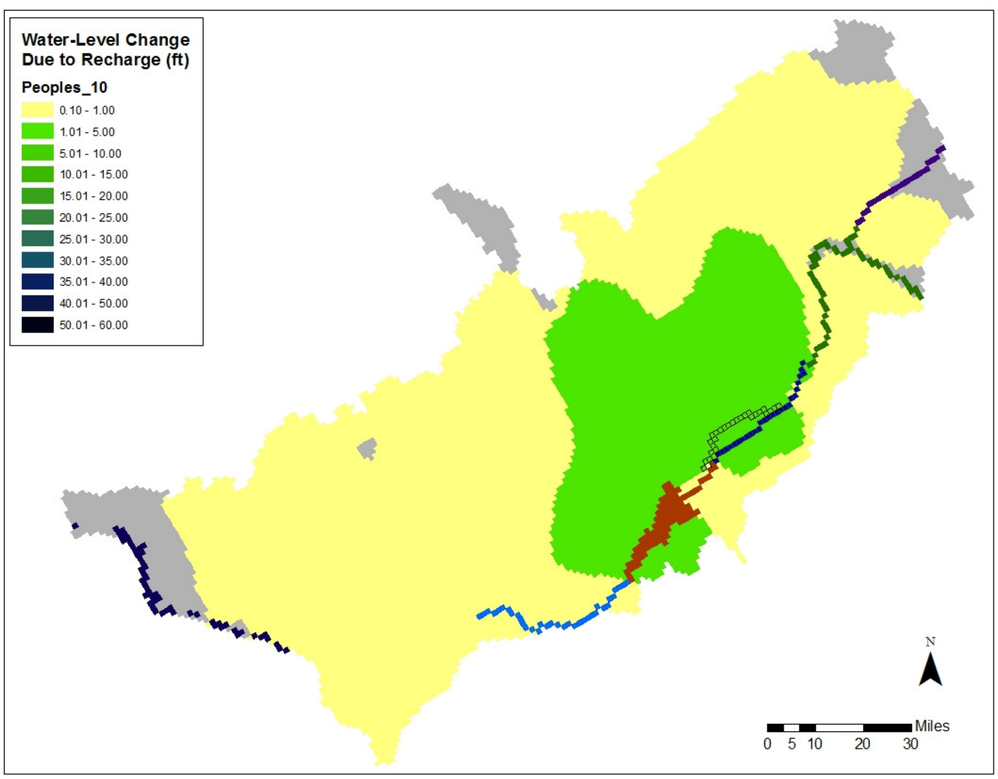

Figure G9. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Peoples.

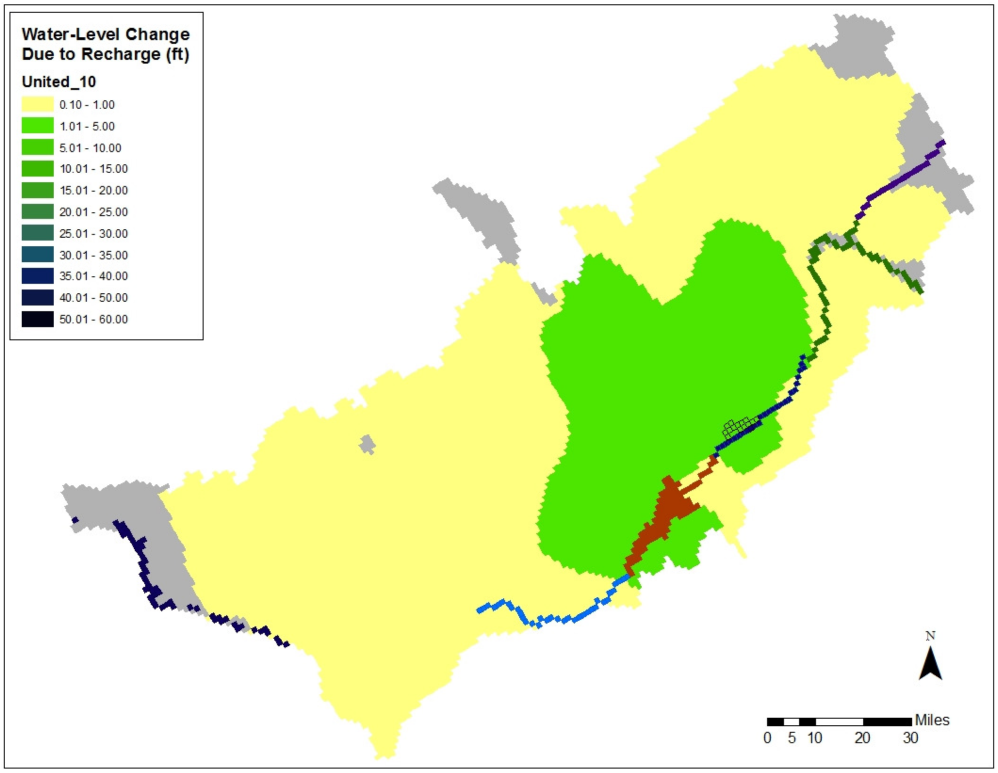

Figure G10. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at United.

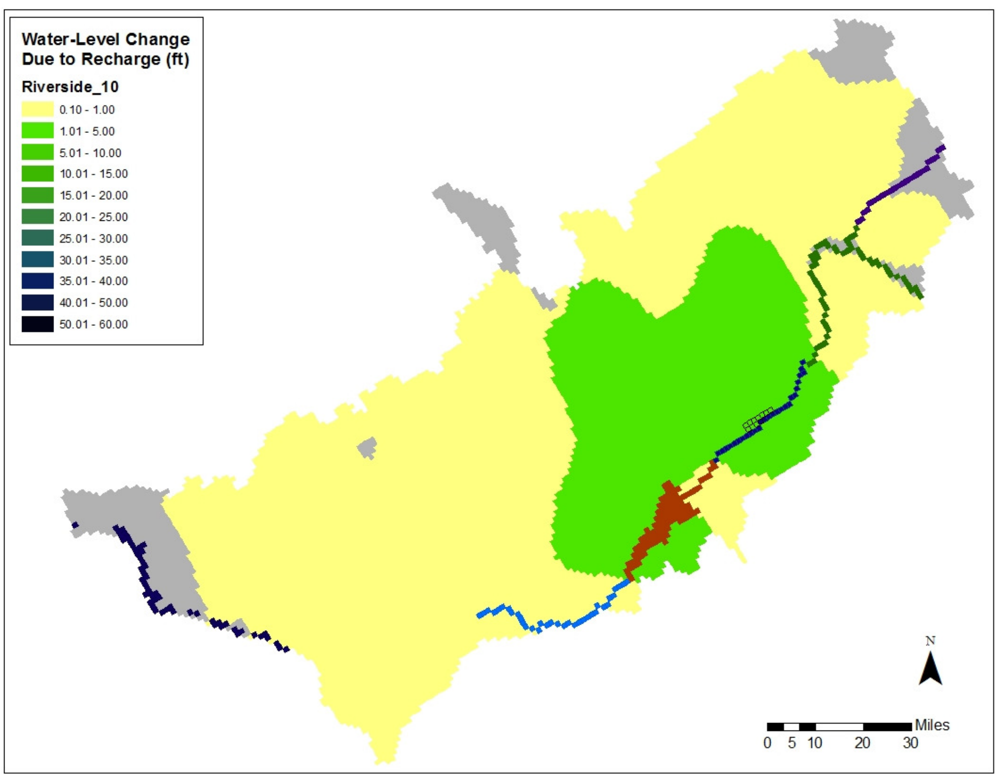

Figure G11. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Riverside.

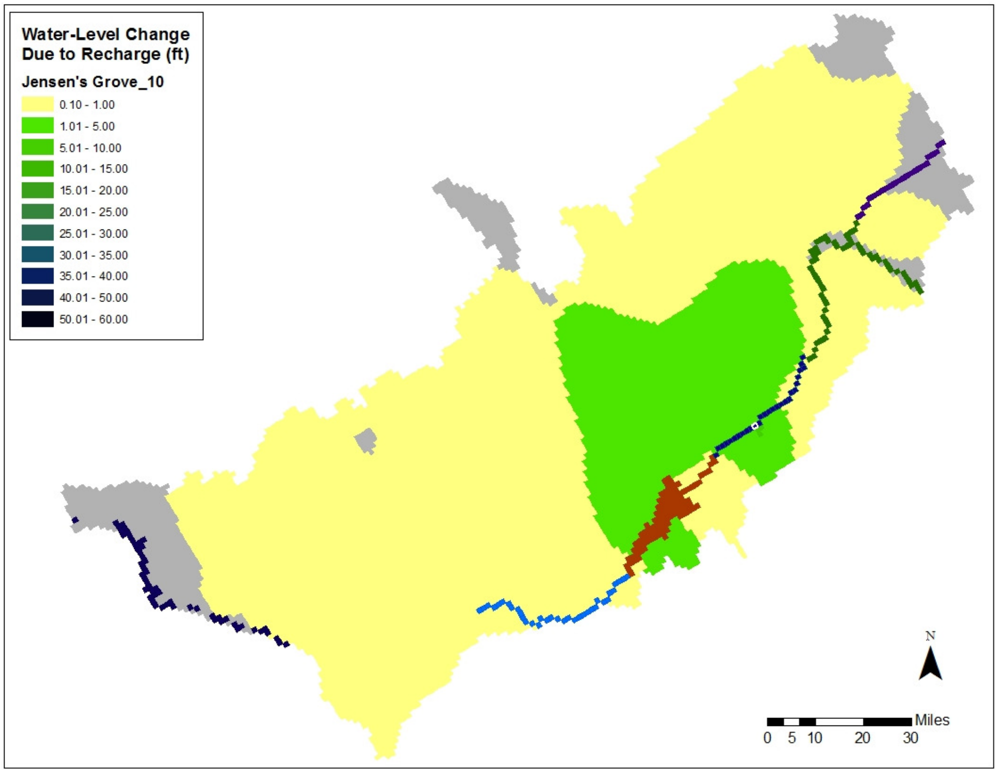

Figure G12. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Jensen's Grove.

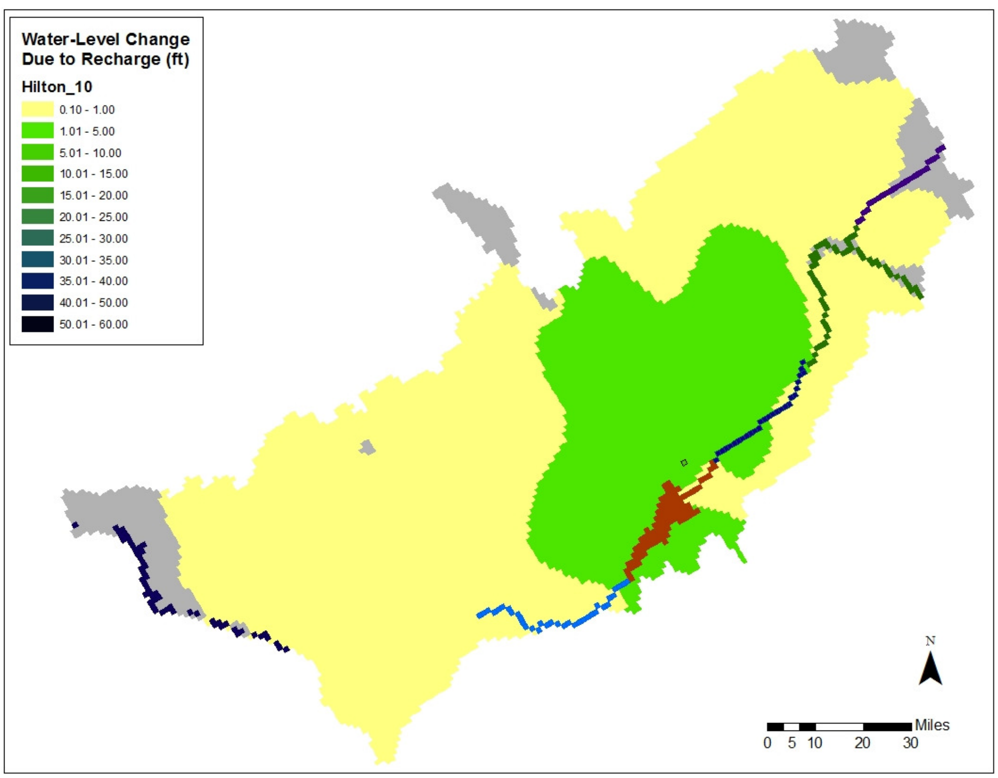

Figure G13. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Hilton.

Below Minidoka

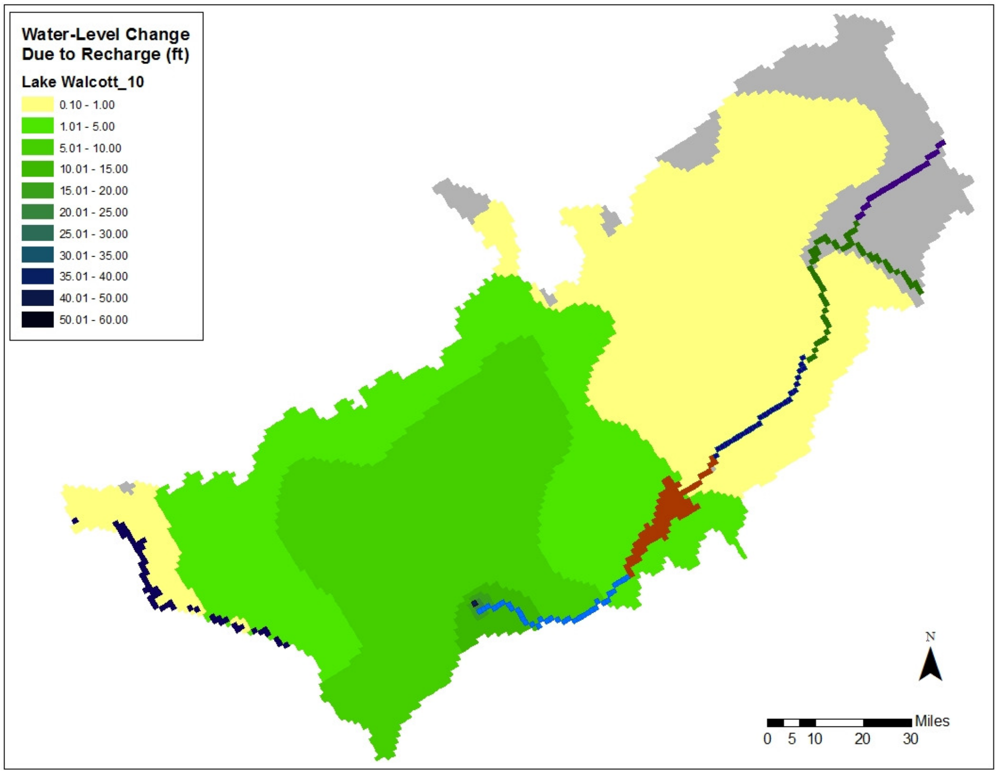

Figure G14. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Lake Walcott.

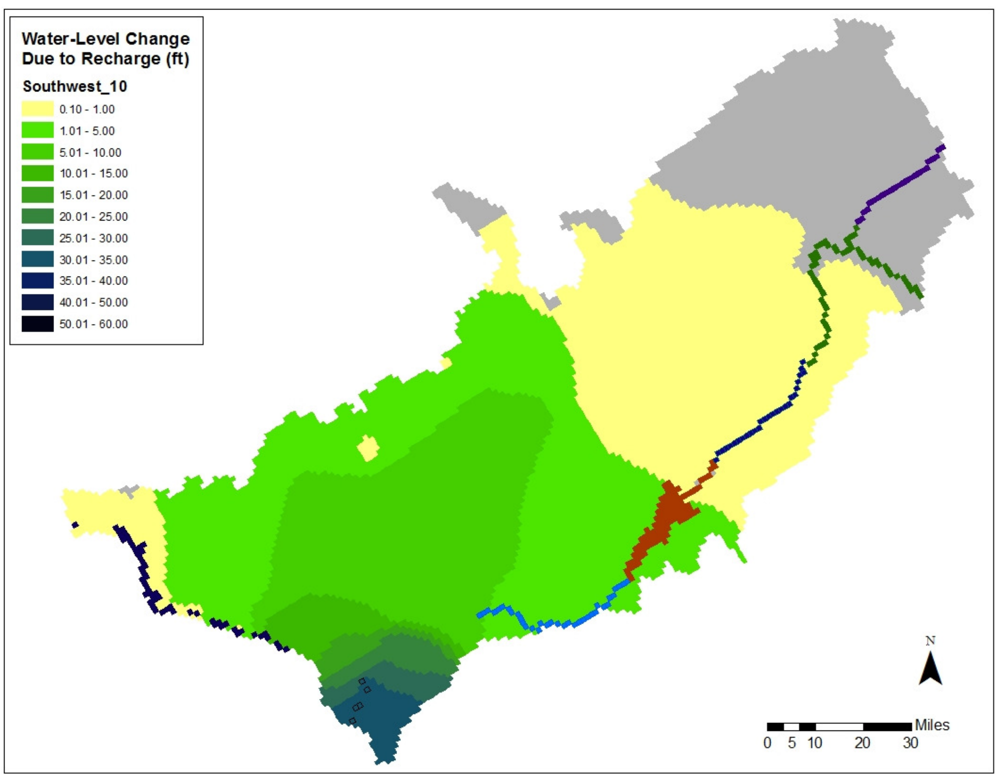

Figure G15. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Southwest.

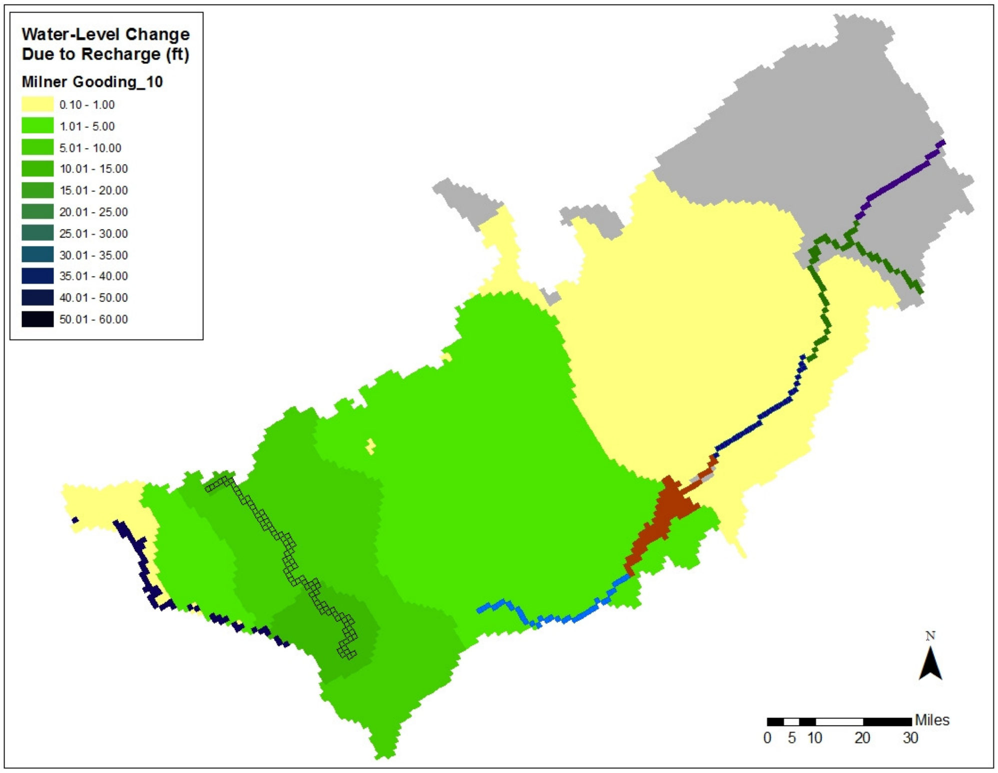

Figure G16. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Milner-Gooding.

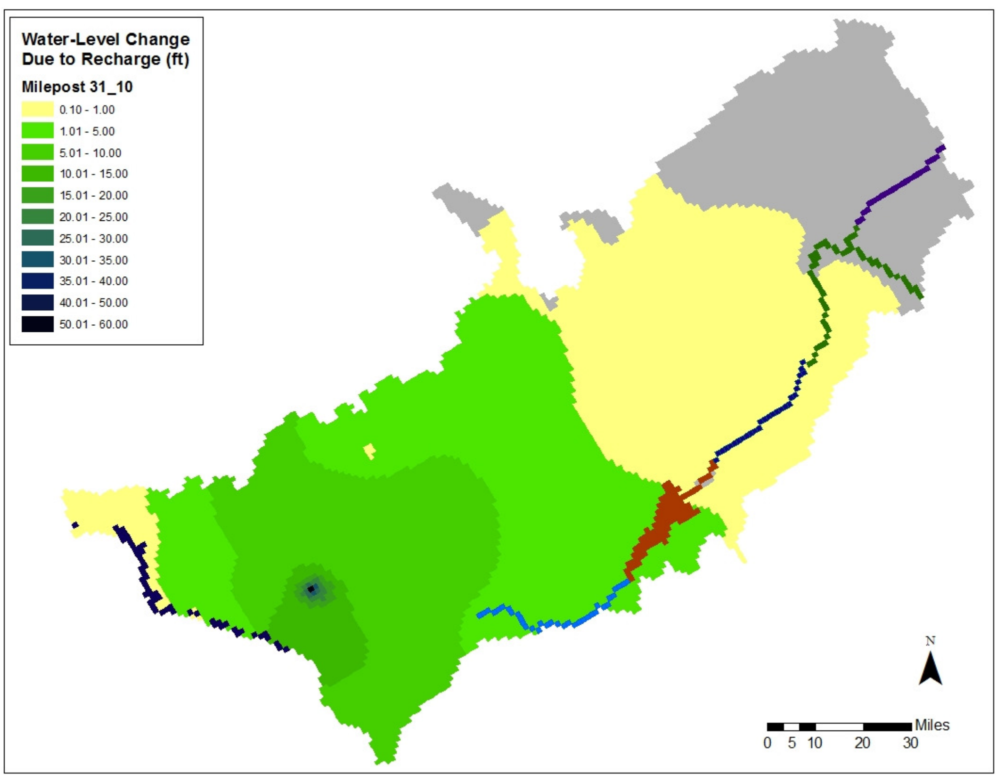

Figure G17. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Milepost 31.

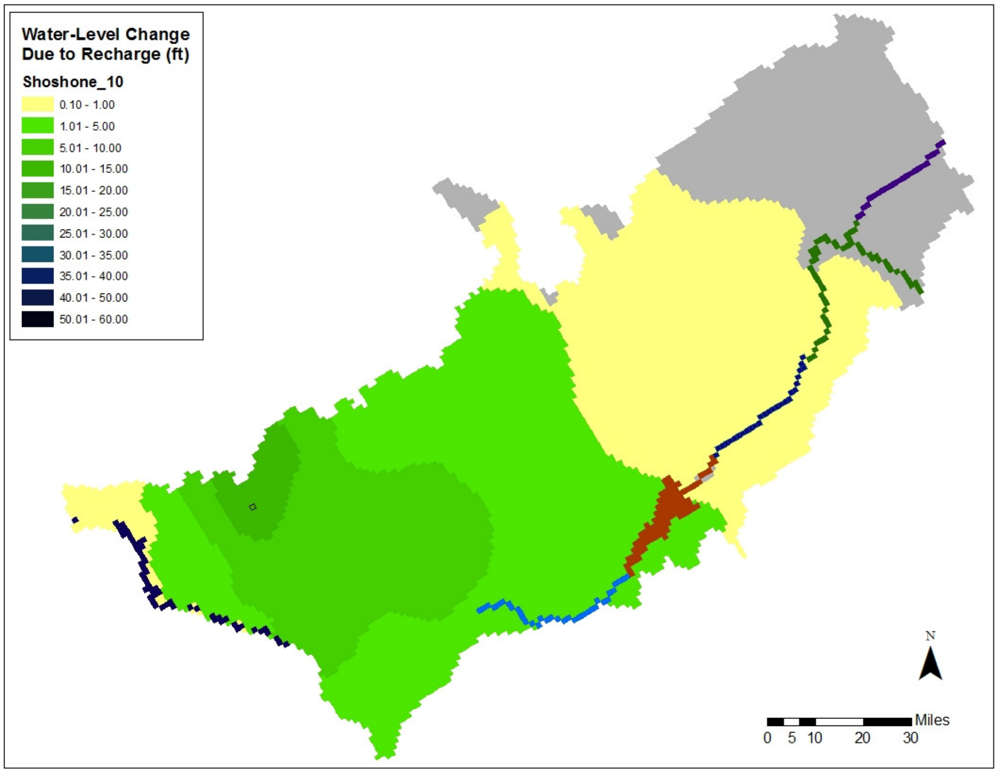

Figure G18. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Shoshone.

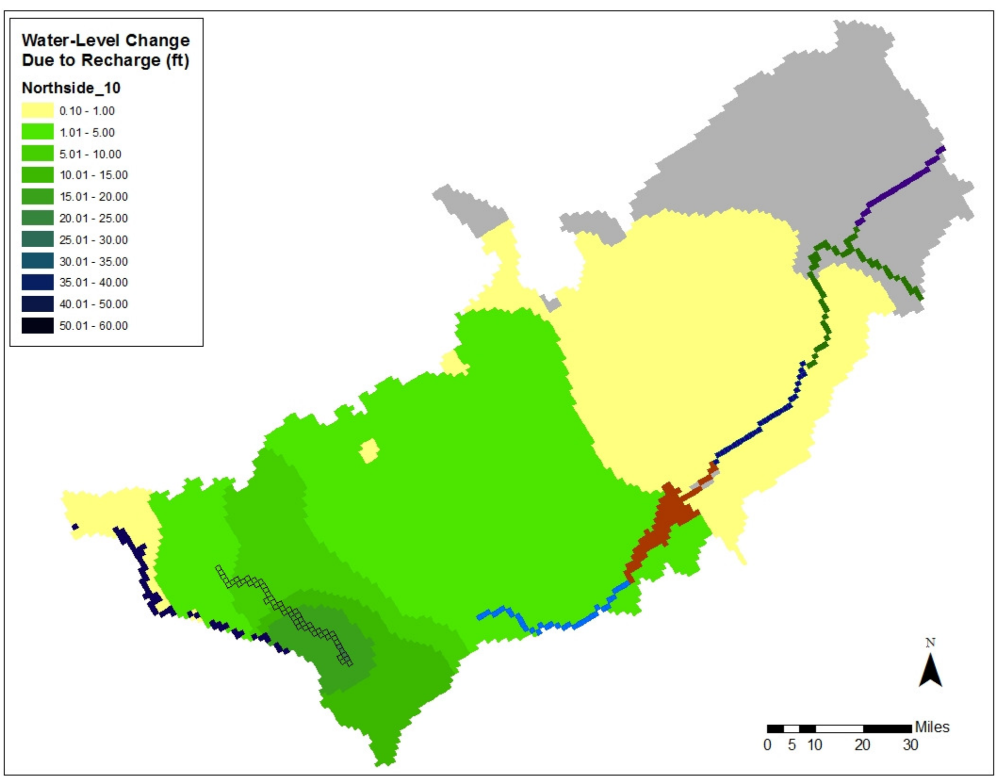

Figure G19. Water-level changes due to 10 years of 100,000 acre-feet/year recharge at Northside.