Prioritization of Aquifer Recharge Sites Based on Hydrologic Benefits

Prepared for the

Idaho Department of Water Resources

and

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by

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Summary

Aquifer recharge may be performed to accomplish either of two basic objectives: a) increase spring discharges and river gains (or decrease river losses), or b) increase aquifer water levels. Increased spring discharge and river gains provide benefits by more uniformly distributing flow throughout the year or through multi-year droughts. Springs receive an additional benefit of purification of the recharge water. Increased aquifer water levels provide benefit by reducing pumping lift and potentially reducing pump lowering and well deepening in areas that are otherwise experiencing water level declines.

Seven objectives were evaluated to provide the Idaho Water Resource Board with a range of considerations for prioritizing recharge at 19 different potential sites in the Eastern Snake River Plain. The seven objectives include:

1) augmenting flow in springs below Milner Dam in the near term,
2) augmenting flow in springs below Milner Dam in the long term,
3) augmenting summer flows of the Snake River above Minidoka Dam and in the Henrys Fork,
4) augmenting winter flows of the Snake River above Minidoka Dam and in the Henrys Fork,
5) increasing flow in the Snake River above Minidoka Dam and in the Henrys Fork during extended drought,
6) increasing aquifer water levels in the A and B Irrigation District area, and
7) increasing aquifer water levels throughout the eastern Snake River Plain aquifer.

Quantitative criteria, based on Snake River Plain aquifer model simulations, were used to evaluate the effectiveness of recharge at each of the prescribed recharge sites to achieve each of the objectives. The selection of priority sites differs, depending upon which objective is considered most important. As one might expect, objectives that emphasize spring discharge benefits below Milner Dam are best served by recharge sites diverting below Milner Dam and the Lake Walcott site. Similarly, emphasis on river gains in the Snake River above Minidoka and the Henrys Fork pushes the upstream recharge sites to higher preference. Aquifer water levels tend to benefit most from recharge at the Lake Walcott site, Southwest Irrigation District, and those sites downstream of Milner Dam.

Small differences in benefits determined in this work should not be considered meaningful. The location of the actual recharge sites may differ from those represented in the models, and criteria can be developed and analyzed in a number of ways that may slightly alter the measures of effectiveness of different sites in achieving objectives.

Background

The Idaho Water Resource Board is promoting improvement in spring discharge from, and water levels in, the Eastern Snake River Plain aquifer through funding of aquifer recharge using existing irrigation canal systems. Over the next five years, the Board will provide funding to irrigation districts and companies to deliver water to recharge sites. Appropriately, the Board desires that the recharge program provide as much benefit as possible.

Artificial, or managed, recharge in the Eastern Snake River Plain may be conducted to provide any of several possible benefits. In general, increased recharge results in increased aquifer water levels and increased spring discharges (or reduced river seepage), relative to what would have occurred without the recharge. The aquifer is used as a storage vessel to redistribute recharge water from times of high river flow to times of lower flow or higher demand. Recharge also serves to distribute water to locations where river water is unavailable or of unacceptable quality, such as springs emerging along the Snake River canyon wall.

The timing, duration, and specific location of recharge benefits vary depending upon the location and timing of the recharge activities. The timing and location of the recharge activities are constrained by availability of surface water and the availability and location of infrastructure to provide the recharge. There is, however, some degree of latitude in distributing recharge water to different locations. The distribution of recharge among the many potential sites should consider the benefits that accrue from different locations. This document will attempt to provide improved understanding of the hydrologic benefits from distribution to different recharge sites within the Eastern Snake River Plain.

The two basic hydrologic benefits resulting from recharge are: 1) increased aquifer water levels, and 2) increased spring discharge and river gains or decreased river seepage. Increased aquifer water levels may reduce the need to deepen wells or lower pumps in areas where the aquifer water levels have declined, and can reduce pumping energy costs by reducing pumping lift. Increased spring discharge and river gains and decreased river seepage will occur in 11 reaches where the surface water is hydraulically interconnected[1] with the aquifer (Figure 1). Under the water-short conditions often experienced on the Eastern Snake River Plain the resulting increase in spring discharge and surface water flow can reduce shortages and consequently relieve conflict among users, increase economic productivity, and better sustain aquatic and riparian environments.

The preferred location of managed recharge should consider the effectiveness with which recharge at each site will achieve the desired objectives. Objectives need to consider both the location of benefits (increased flow or water level) and the timing of those benefits.

The purpose of this project is to prioritize potential recharge locations based upon the hydrologic effectiveness of achieving specific objectives. Potential recharge locations are limited to canal

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[1] Hydraulic connection occurs with all springs or when aquifer water levels are above the bed of a river. When the river and aquifer are hydraulically connected, spring discharge and river gains and losses vary with aquifer water level. When disconnected, aquifer water level does not affect river gains and losses.

companies and districts which have previously demonstrated ability and willingness to provide recharge. Canal systems and recharge sites evaluated and prioritized in this project include: 1) Egin Lakes (Fremont-Madison Irrigation District), 2) Canals east of the Henrys Fork in Fremont-Madison Irrigation District, 3) Canals west of the Henrys 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 Distr. #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) North Side Canal Company including Wilson Lake. Locations of the recharge sites are shown in figures 2 through 5. Hydrologic effectiveness of recharge is evaluated using the Eastern Snake Plain Aquifer Model (version 1.1) relative to specific objectives and effectiveness criteria developed below.

Not included in the scope of this project are: a) evaluation of water availability, b) evaluation of the capacity of conveyance systems and ability to accept recharge, c) water quality considerations, d) possible re-diversion and secondary recharge resulting from returns of upstream recharge, and e) monetary, legal, and political considerations.

Potential Recharge Objectives

Multiple objectives may be considered and weighed in prioritizing locations for recharge. The effectiveness of recharge at individual sites to achieve each of seven objectives is evaluated in this project. The objectives do not focus on benefits to specific water users but on reaches of the Snake River or aquifer areas where there are some common water resource needs among the many water users. Although several or all of the objectives identified below may have value, some may be more important to the water user community and to the State than others. The evaluated objectives are as follows.

Objective 1: Augment spring discharge below Milner Dam within three years.

Spring discharges below Milner have generally been declining in recent decades. Spring water uses often cannot be supplemented with river water because the places of use are elevated well above the river, and because water quality of the river may be unacceptable for some of the uses. Consequently, augmenting spring discharge is the only feasible means of sustaining these uses. Many of these uses require water year-round; consequently, augmented discharge at any time of the year may be considered effective in providing benefit. Recharge benefits cannot be targeted to specific springs so it will also have the effect of augmenting flow at unused springs, or springs only used in part of the year, potentially limiting the benefit of recharge. Augmented flow at unused springs may still provide environmental and downstream hydropower benefits. Spring users are presently facing difficulties resulting from declining flows. This objective therefore focuses on providing some relief in the relatively near term. It should be noted that "augmenting flows" does not necessarily mean spring discharge will increase. It does mean that

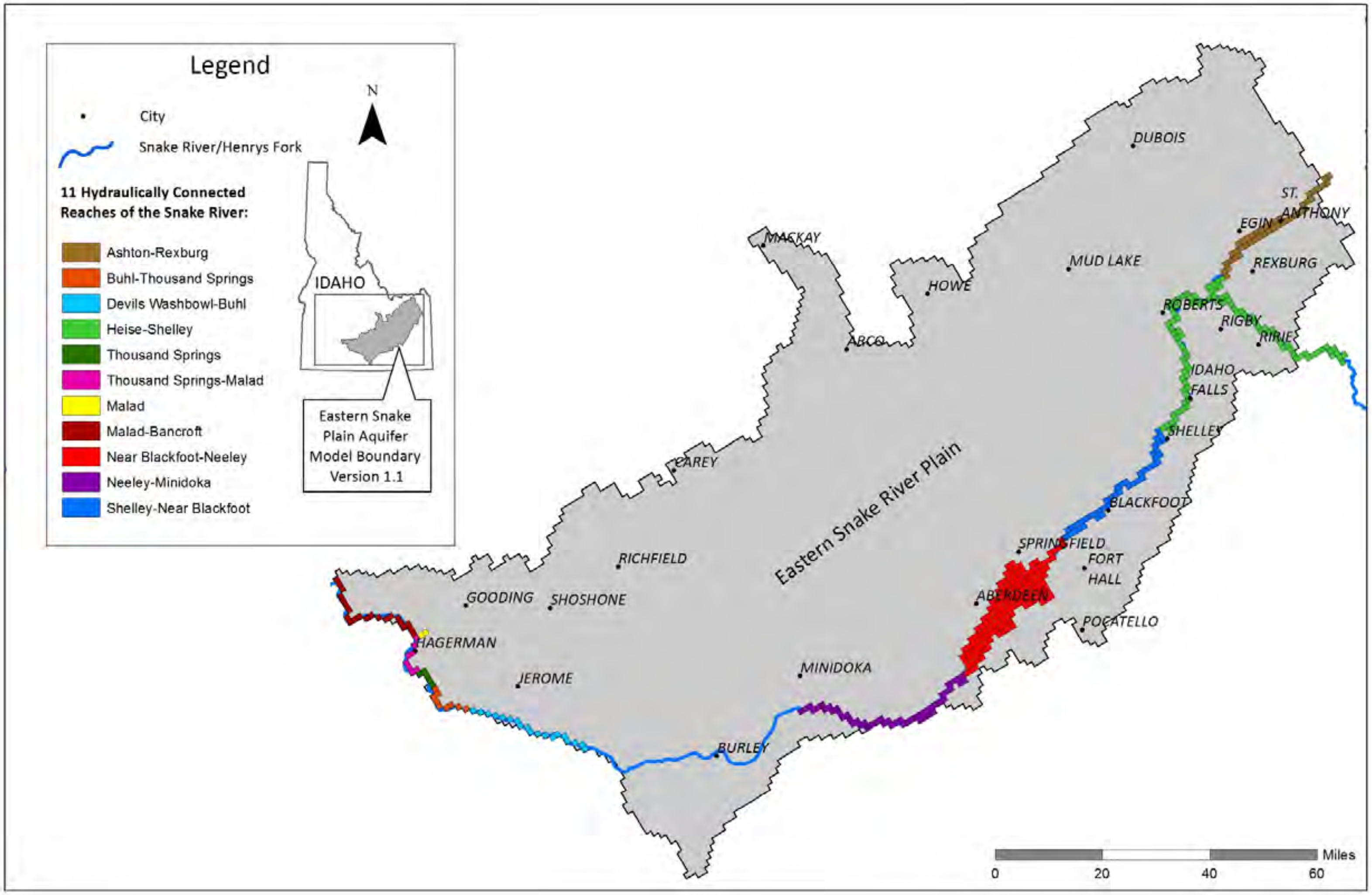


Figure 1. Snake River Plain aquifer and eleven hydraulically connected reaches of the Snake River.

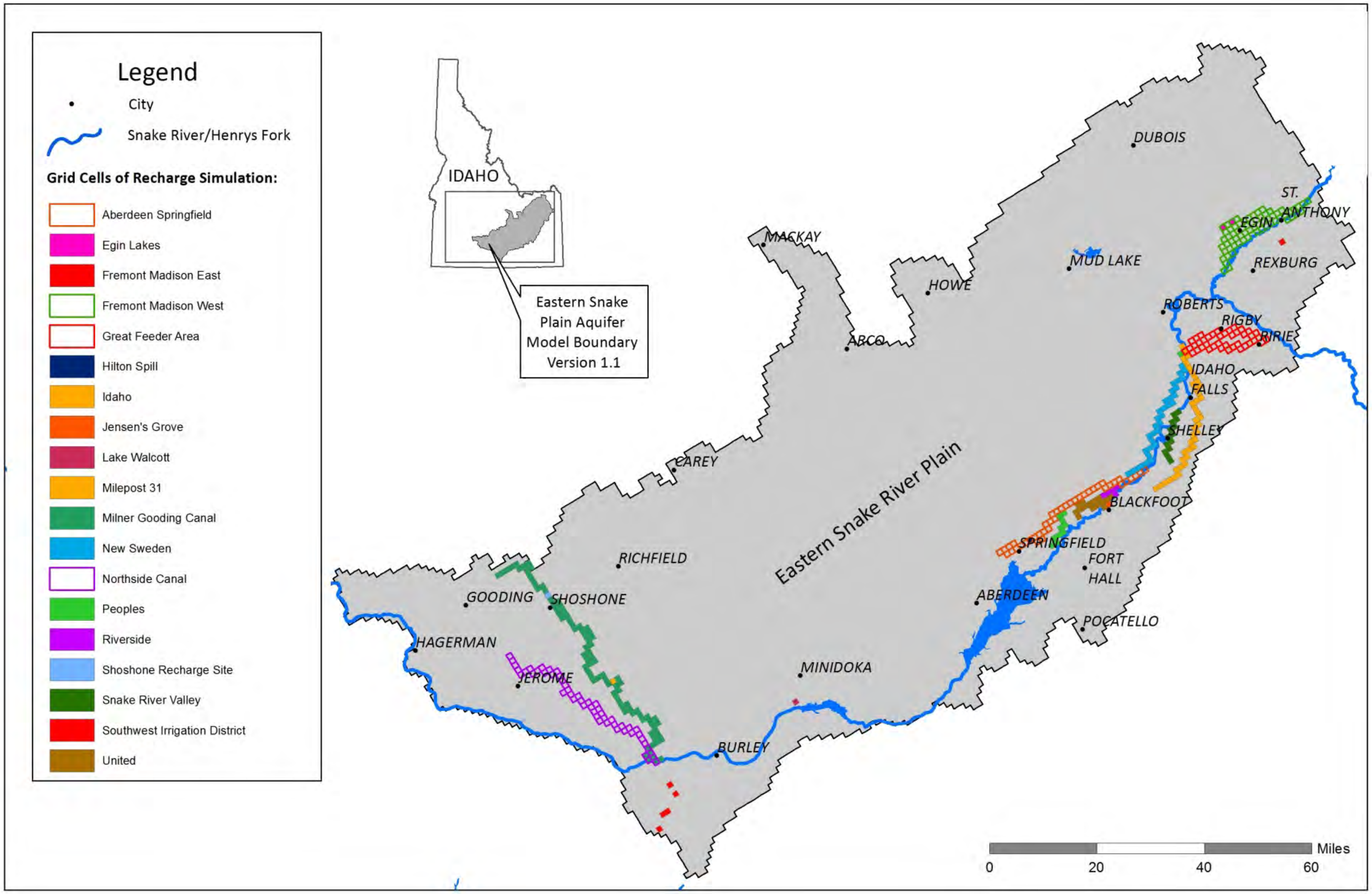


Figure 2. Recharge sites for locations considered in the recharge prioritization (from data provided by IDWR). Greater detail on individual sites in provided in figures 3 through 5.

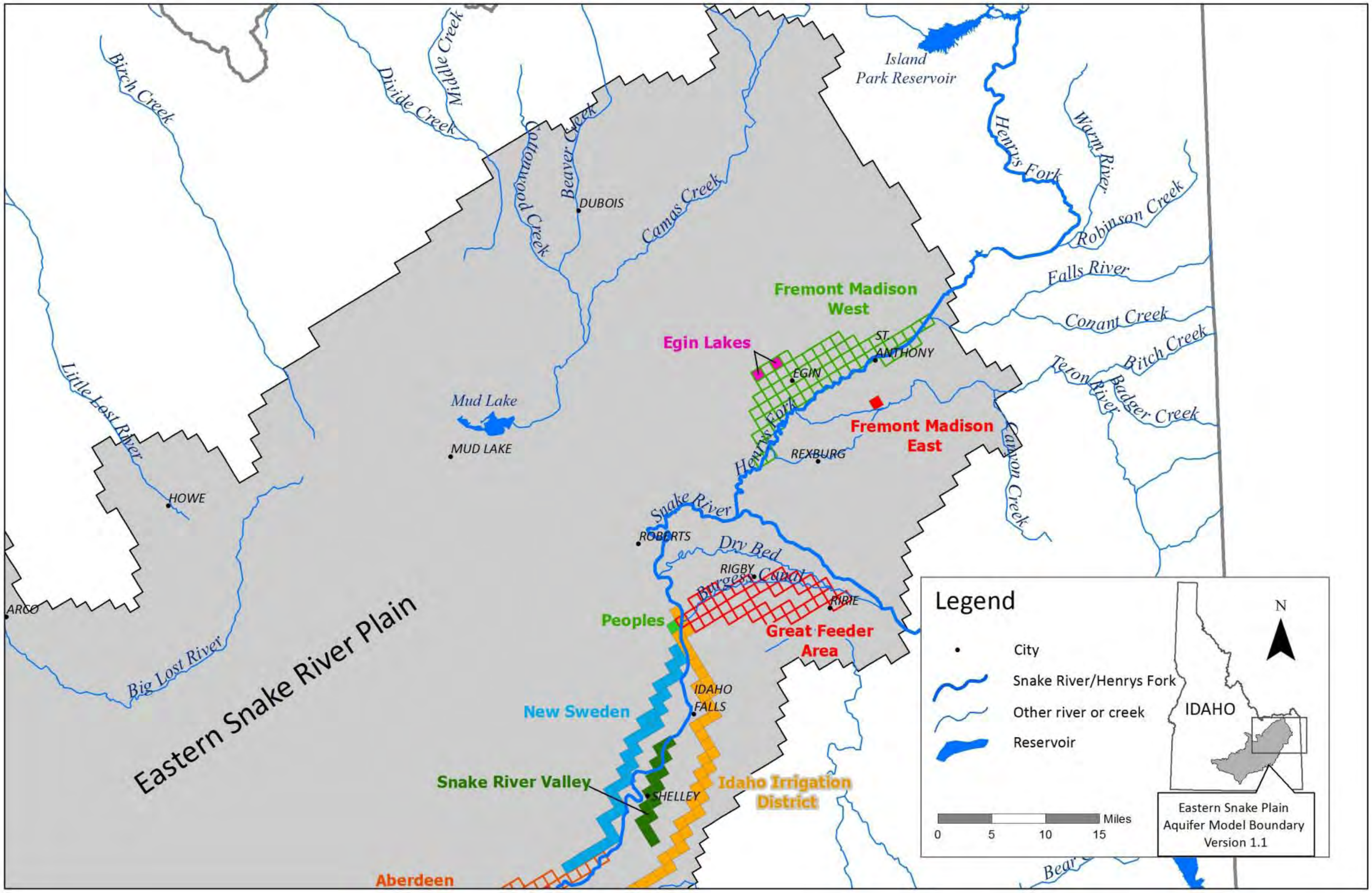


Figure 3. Evaluated recharge locations for the eastern most portion of the Eastern Snake River Plain aquifer.

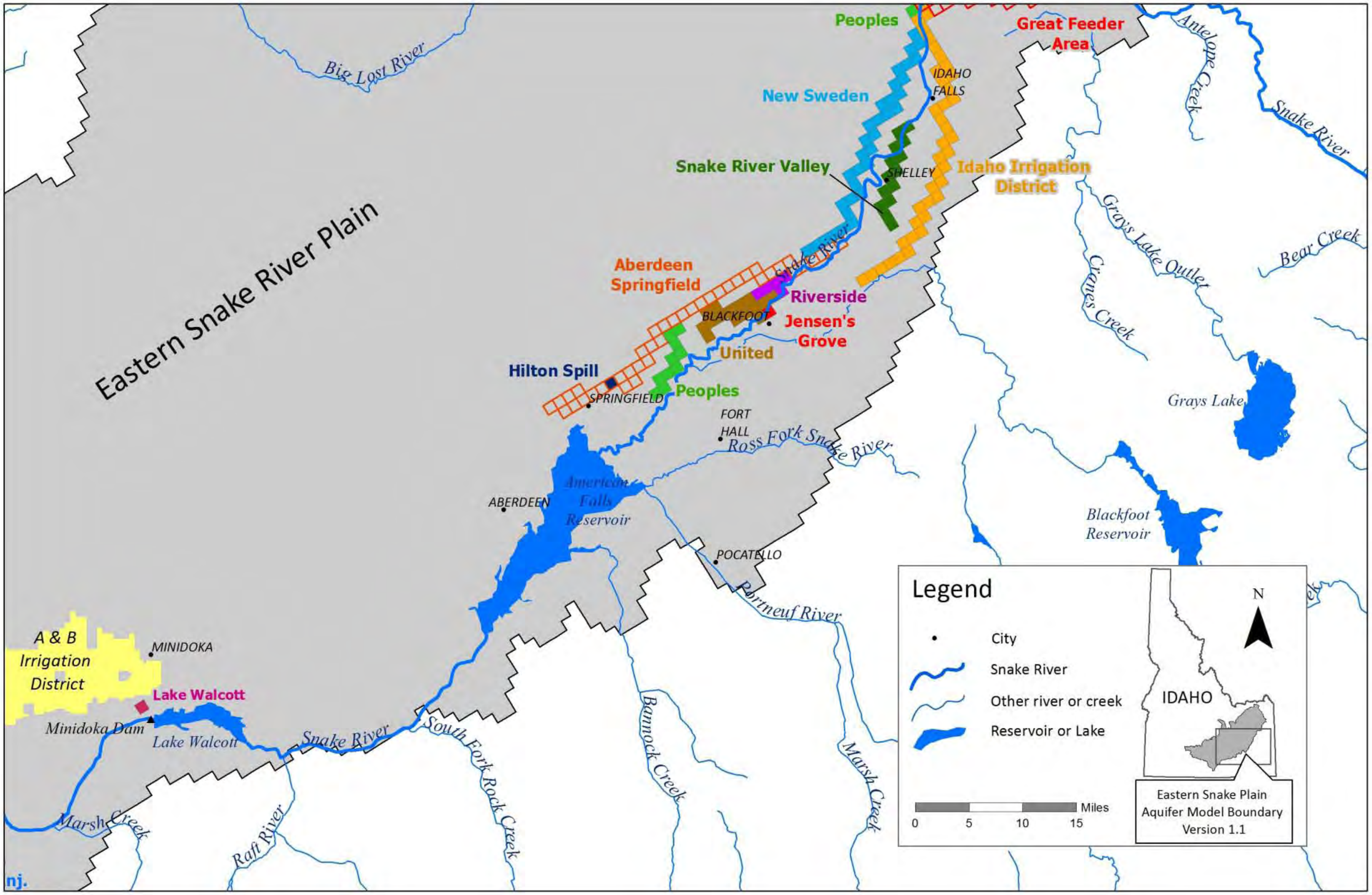


Figure 4. Evaluated recharge locations for the central portion of the Eastern Snake River Plain aquifer.

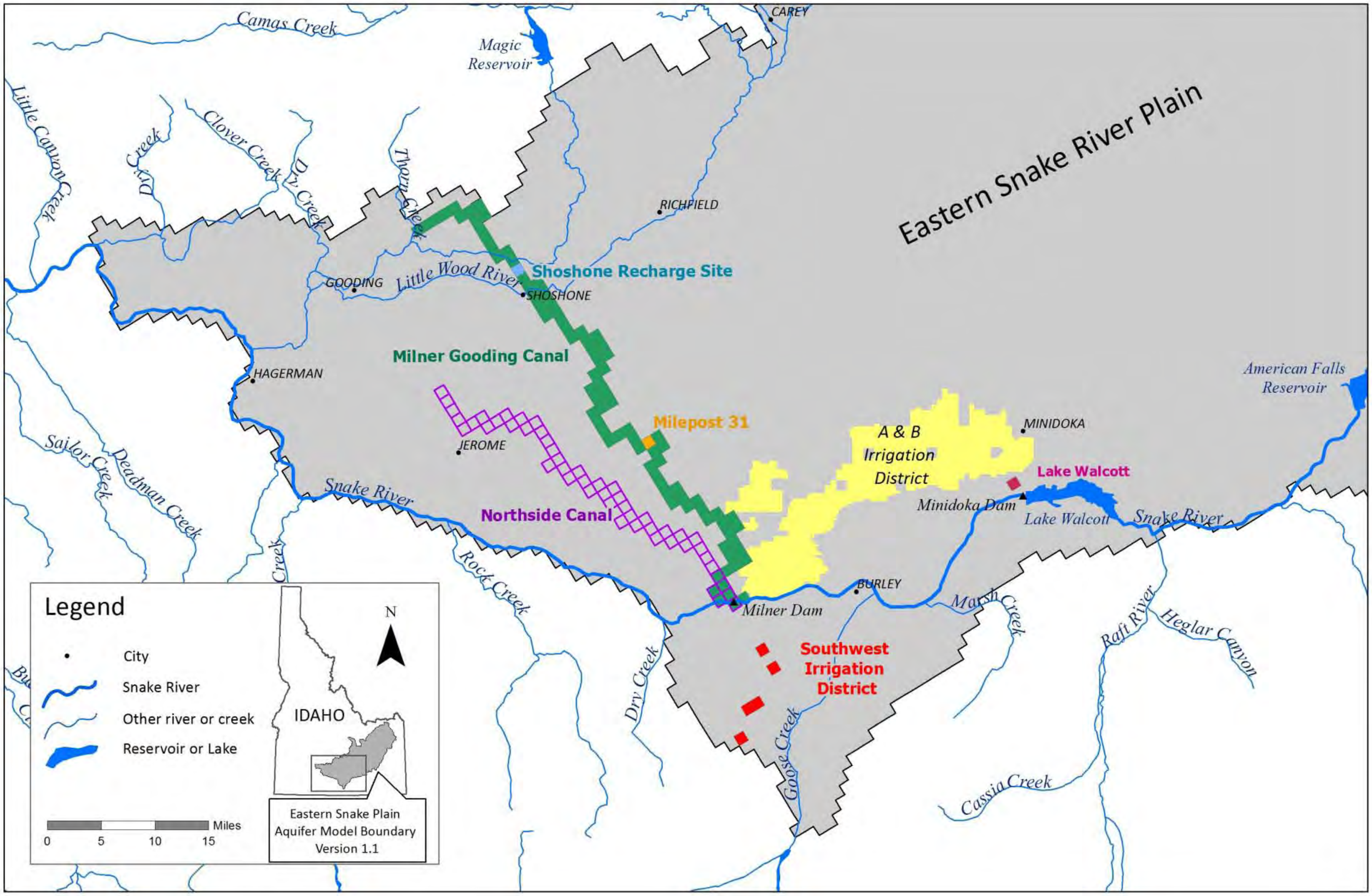


Figure 5. Evaluated recharge locations for the western portion of the Eastern Snake River Plain aquifer.

spring discharge will be greater than what it would have been had recharge not been performed.

Objective 2: Augment spring discharge below Milner over periods longer than three years.

The volume of water recharged will vary from year to year depending on available water and timing of runoff. It is reasonable to consider objectives where the Snake River Plain aquifer is used to store water over longer time periods and therefore reduce the impact of multi-year droughts on spring discharge. This objective considers the extent to which spring discharge below Milner will be sustained at least three years after the last managed recharge has occurred.

Objectives 3 and 4: Augment flow in the Snake River above Minidoka during irrigation season; augment flow in the Snake River above Minidoka during fall and winter

The Snake River and Henrys Fork are hydraulically connected with the Eastern Snake Plain Aquifer in reaches above Roberts and below about Shelley or Blackfoot downstream to Minidoka Dam. The river(s) may gain water from, or lose water to, the aquifer above Roberts depending on aquifer and river conditions, so aquifer recharge will have an effect of either enhancing river gains or diminishing losses, therefore augmenting river flows. Below Shelley the river largely gains water from the aquifer and aquifer recharge will have the effect of increasing those gains.

Aquifer recharge that focuses on enhancing river flow above Minidoka is largely just redistributing Snake River flow over time, either within a given year, or over a period of years. Recharging with water that would have traveled downstream as flood flows (or the spring freshet) stores that water for a release to the river that is more uniformly distributed over time. This is in contrast to objectives that focus on increasing spring discharge below Milner Dam where recharge not only provides a more time-constant flow to springs, but also distributes water to spring locations above river elevation and provides purification that may be needed for use in aquaculture facilities. Some springs above Minidoka Dam may also benefit from purification resulting from aquifer recharge. Recharge that returns to the river too quickly (within days or weeks) is probably of little benefit because the lag times provided by the aquifer are likely insufficient to delay flows to lower flow times of year.

Increased river gains (and decreased losses) that result from recharge will occur throughout the year, though not necessarily uniformly. The increase in river flow may be diverted for irrigation during the irrigation season, and may increase river flow and reservoir storage during the non-irrigation season. The increase in downstream diversions may subsequently increase returns to the river in following months and years, depending on the degree to which the increased diversions increase aquifer recharge. Non-irrigation season increases in flow may improve reservoir storage during dry years. In wet years, increased winter flows are likely to contribute to increased downstream flow, potentially benefitting environmental and hydropower uses.

There is probably a need for storing water in the aquifer for a few months to a few years to smooth seasonal and short-term variations in river flow. These objectives focus on that short-term need.

Objective 5: Augment flow in the Snake River above Minidoka over extended periods.

The volume of water recharged will vary from year to year depending on available water and timing of runoff. This objective considers the need for longer-term aquifer storage to supplement river flow over longer time periods and therefore reduce the impact of multi-year droughts on river flow. During extended droughts, there may be more unused reservoir capacity to store winter returns from recharge activities.

Objective 6: Increase aquifer water levels near A&B Irrigation District over extended periods.

Aquifer water levels in the A&B Irrigation District have declined in recent decades. The declines affect a large number of wells with relatively senior priority ground water rights. This objective is evaluated over extended periods because water level changes in the near term are likely to be negligible.

The effects of recharge appear as changes in water level, which obviously are not directly comparable to objectives 1-5 where effects are evaluated as changes in flow rate. This objective may be complementary to other objectives to enhance river or spring discharge.

Objective 7: Increase aquifer water levels throughout the ESRP aquifer over extended periods.

Ground water pumpers throughout the plain may benefit from decreased pumping lift resulting from increased aquifer water levels. This objective will no doubt require a sustained long-term effort to provide any possibility of noticeable changes in aquifer water level.

Effectiveness Criteria

The effectiveness of recharge at each of the 19 selected sites to accomplish each of the seven objectives is determined by simulations using the Eastern Snake Plain Aquifer Model version 1.1. Different quantitative criteria are established to determine effectiveness for achieving each objective. The approach taken relies upon the principle of superposition that allows evaluation of the effects of individual recharge activities to be evaluated independently of all other aquifer recharge and discharge occurring. This approach is generally accepted and has been used previously for the Snake River Plain aquifer and other aquifer systems. By using this approach, the model can be applied to evaluate the percentage of a recharge event that will be either discharged to specific reaches of the Snake River, or retained as additional water stored in the aquifer at any given time.

The proposed aquifer recharge is likely to be a recurring springtime event. The volumes and locations of recharge may vary from year-to-year. The distribution of benefits (increased spring discharge and increased aquifer water level) changes as the pattern of recharge changes. Three temporal recharge patterns were applied in this analysis: 1) a one-time, one-month event, 2) continuous recharge, and 3) a recurring one-month recharge event in spring of each year. These temporal patterns are intended to provide a means to evaluate effectiveness of meeting objectives and do not represent expected actual future recharge events. The one-month and the continuous events were used because results can more easily be expressed as a percentage of recharge rate or volume, while the results still reflect an appropriate measure of the objective to which they are applied.

Two criteria were applied as measures of the effectiveness of achieving **Objective 1**, augmenting spring discharge below Milner Dam in the near term (within three years). The first criterion (**Criterion 1A**) is based on simulations of a single, one-month recharge event. The percentage of the recharge volume that is discharged in springs below Milner within the first three years after the event was selected as the measure of effectiveness. For example, if 1000 AF of water are recharged at a specific site in a one-month period, and springs below Milner increase such that an additional 300 AF is discharged in the three year period following the event, then the percentage of the recharge volume that results in additional discharge (in this reach) is 30%. A second criterion is also applied to measure effectiveness of achieving Objective 1. This criterion (**Criterion 1B**) uses a simulation with a continuous recharge rate of 100 cubic feet per day. The measure of effectiveness is the increase in the collective discharge of springs below Milner Dam after one year of continuous recharge, expressed as a percentage of the recharge rate. Using simulations of recurring recharge every spring would complicate the results and would not provide any additional information relative to achieving this objective. The reader is referred to graphs in the appendices if objectives are scoped to target more specific river reaches.

The effectiveness of recharge at each site to achieve **Objective 2** (augmenting spring discharge below Milner Dam for at least three years after the last recharge event) is also evaluated using two criteria. The first criterion (**Criterion 2A**) is a measure of the percentage of the volume of a single, one-month recharge event that is discharged in the below Milner reach between 3 and 30 years after the event. For example, if 100 AF is recharged in a given month at a specific site, our interest is in the acre-feet of additional spring discharge that occurs in the 27 year period from 3 years after the recharge event to 30 years after the event. If the spring discharge is augmented by a total of 40 AF during that 27 year period, then the criterion percentage is 40%. The second criterion (**Criterion 2B**) is the percentage of a long term (30 year) continuous recharge event (flow rate) that persists three years after the recharge is ceased. This criterion is illustrated in Figure 6.

The effectiveness of achieving **Objective 3** (augmenting flow in the Snake River above Minidoka during irrigation season) is evaluated using a criterion based on simulation of recurring recharge every March over a 30-year period (**Criterion 3**). After 30 years of recurring recharge, the effects on river gains and losses develops into an oscillating pattern with little long-term trend (e.g. Figure B6 in Appendix B). The criterion selected is the percentage of the annual recharge volume (all occurring in March) returning to the river above Minidoka Dam during the months of July through September. For example, if 100 AF are recharged every March and 20 AF return to the river in the 3 month period of July through September, then the criterion percentage is 20 percent. Higher percentages mean greater effectiveness at accomplishing the objective.

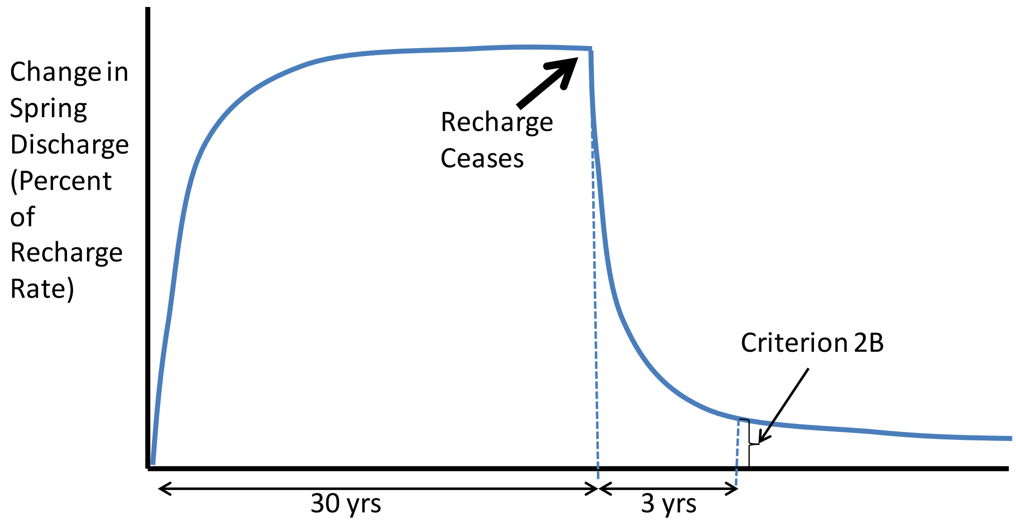


Figure 6. Illustration of Criterion 2B. The change in spring discharge, expressed as a percent of the recharge rate, three years after continuous recharge is terminated is used as the measure.

Objective 4 calls for augmenting flows above Minidoka Dam during late fall and winter. The effectiveness of achieving this objective for each site is determined by evaluation of **Criterion 4**. This criterion is based on simulation of recurring seasonal recharge in March over a 30 year period. After 30 years of recurring recharge, the effects on river gains and losses develops into a oscillating pattern with little long term trend. The percentage of the annual recharge volume (all occurring in March) returning to the river above Minidoka Dam during the months of November through February provides the quantitative measure of Criterion 4.

The intent of **Objective 5** is to increase flow in the Snake River reaches above Minidoka in the long term, providing ability to augment flows in periods of multi-year drought. The effectiveness of each recharge site to achieve this objective is determined from a quantitative score on **Criterion 5**.   Criterion 5 is based on simulation of a single, one-month recharge event. The percentage of the volume of recharged water that returns to the river above Minidoka Dam in the 27 year period between 3 and 30 years (30 years is the simulation duration) after ceasing recharge is the quantitative measure.

Objective 6 is concerned with aquifer water levels near the A & B Irrigation District. Effectiveness of recharge in increasing aquifer water levels near A & B Irrigation District is addressed by **Criterion 6**. This criterion is a measure of the average water level change in four model cells [(row,column): (75,64), (70,67), (79,73), (71,53)] distributed throughout the district that would result from 10 years of continuous recharge at 100,000 AF/year at a specified recharge site.

Aquifer water levels throughout the Snake River Plain are considered in **Objective 7**.   Water levels tend to increase when more water is retained in aquifer storage and less water is discharged to the Snake River. **Criterion 7A** is a measure of the volume of water from a one-month recharge event that is retained in aquifer storage 10 years after the event has occurred. **Criterion 7B** is the average water level change in the Snake River Plain Aquifer after 10 years of continuous recharge at a rate of 100,000 AF/yr at the selected recharge site.

Procedure

The transient ESPAM version 1.1 was used in a "superposition" mode to make quantitative evaluations of recharge effects on river gains and losses and on aquifer water levels. Superposition allows results to be expressed as a percent of recharge rate or volume, facilitating a more general understanding. Initial files for the superposition runs were downloaded from the Idaho Department of Water Resources website location:
http://www.idwr.idaho.gov/Browse/WaterInfo/ESPAM/model_files/Version_1.1_Current/. These files were modified as needed to develop simulations representing appropriate recharge locations, stress periods, and time steps. Three simulation conditions were run to evaluate the effectiveness criteria:

1) A single, one-month recharge event with a recharge of 100 cubic feet per day in the candidate recharge area (except for Northside Canal, the 100 cubic feet per day was uniformly distributed among all cells identified for the site, given in Appendix A). In Northside Canal, 2/3 of the recharge was simulated to occur above and including Wilson Lake, while the remaining 1/3 was recharge in the main canal below Wilson Lake.
2) A continuous recharge event of 100 cubic feet per day for the candidate recharge site. Again, the recharge is uniformly distributed among all model cells identified for the recharge areas listed in Appendix A, except for the case of Northside Canal. Since superposition permits scaling of effects to the magnitude of the recharge event, evaluations using different recharge rates (Criteria 6 and 7b use 100,000 AF/yr) are scaled by multiplying by the ratio of the recharge magnitudes.
3) An annually recurring recharge event of 100 cubic feet per day occurring in the month of March over a total period of 30 years. The recharge is distributed uniformly among all model cells representing a recharge site, except for the case of Northside Canal.

Superposition simulations have been used and accepted in previous model applications of the Snake River Plain aquifer and other systems. These simulations are as valid as the original ESPAM 1.1 model with the additional limitation that no portions of the river are allowed to transition from perched to interconnected with the aquifer during the simulation period. Similarly, springs are continuously flowing and not permitted to dry up. Considering that future river and aquifer conditions are unknown, this condition is reasonable.

Some of the simulations (recurring March recharge) supporting this work involved evaluation of recharge effects within several months following the recharge activity. The ESPAM 1.1 model was calibrated to six-month duration stress periods potentially raising concerns over validity of model application to shorter time periods. Although the seasonal variation of recharge effects may be slightly less than calibration stress periods, the results are valid to the degree that the calibrated estimates of aquifer transmissivity, storativity, and river conductance are correct (and the degree that the underlying conceptual model is valid). Any bias introduced through earlier calibration procedures is unknown, but it is possible that greater uncertainty exists in the recurring simulation of March recharge which involves shorter term estimates.

The location of recharge within each canal system may be distributed among multiple recharge sites (pits, depressions, engineered recharge ponds, or injection wells) and seepage in canal networks. In this work, the effects of major recharge sites were evaluated independently from those of recharge in the main canals. The model cells representing the spatial distribution of recharge is provided in Appendix A. Grid cell coordinates for recharge locations were provided by the Idaho Department of Water Resources.

Results

Three sets of simulation conditions were run for recharge at each of the 19 sites. The general results of these simulations (not specifically associated with the effectiveness criteria) are presented in Appendices B through T. The graphs in the appendices provide more detailed information of the overall effects of recharge at each of the potential sites.

The effectiveness of recharge at each potential site to achieve each objective is evaluated by comparison of values for the associated criteria that were described previously. A summary of the criteria results are presented in Table 1. Graphical presentation of the values in Table 1 and interpretation is provided for each objective in the subsections below.

Table 1. Values of criteria determined from model simulations.

Canal	Criterion									
	1A	1B	2A	2B	3	4	5	6	7A	7B
Egin Lakes	<1%	<1 %	<1%	<1%	23%	25%	41%	<0.1 ft	17%	0.4 ft
Fremont Madison East	<1%	<1%	<1%	<1%	26%	23%	16%	<0.1 ft	4%	0.2 ft
Fremont Madison West	<1%	<1%	<1%	<1%	17%	16%	23%	<0.1 ft	9%	0.3 ft
Great Feeder Area	<1%	<1%	<1%	1%	26%	24%	19%	<0.1 ft	6%	0.4 ft
New Sweden	<1%	<1%	1%	2%	23%	25%	30%	0.1 ft	10%	0.6 ft
Idaho	<1%	<1%	1%	2%	24%	26%	29%	0.1 ft	10%	0.6 ft
Snake River Valley	<1%	<1%	1%	2%	22%	24%	28%	0.1 ft	9%	0.5 ft
Peoples	<1%	<1%	2%	2%	21%	19%	20%	0.2 ft	8%	0.4 ft
Riverside	<1%	<1%	1%	2%	18%	16%	17%	0.1 ft	6%	0.4 ft
United	<1%	<1%	2%	2%	20%	18%	19%	0.2 ft	7%	0.4 ft
Jensen's Grove	<1%	<1%	1%	1%	15%	14%	13%	0.1 ft	5%	0.3 ft
Aberdeen Springfield	<1%	<1%	2%	2%	20%	19%	19%	0.2 ft	7%	0.4 ft
Hilton Spill	<1%	<1%	2%	3%	21%	20%	20%	0.3 ft	8%	0.4 ft
Lake Walcott Recharge Site	2%	<1%	26%	30%	16%	20%	47%	5.1 ft	43%	1.5 ft
Southwest Irr. District	<1%	<1%	17%	44%	4%	6%	17%	0.3 ft	96%	1.4 ft
Milner Gooding Canal	27%	8%	31%	43%	8%	11%	31%	2.5 ft	37%	1.4 ft
Shoshone Recharge Site	30%	12%	30%	37%	8%	11%	31%	2.3 ft	33%	1.3 ft
Milepost 31 Site	31%	6%	28%	45%	8%	11%	31%	2.7 ft	33%	1.3 ft
Northside Canal	28%	7%	33%	49%	7%	9%	27%	2.2 ft	40%	1.3 ft

Criterion 1A: Percent of a single, one-month recharge volume discharged in the below Milner reach within 3 years.
Criterion 1B: Percent of continuous recharge rate which appears as additional spring discharge below Milner after one year.
Criterion 2A: Percent of a single, one-month recharge volume discharged in the below Milner reach between 3 and 30 years.
Criterion 2B: Percent of a long term continuous recharge rate that persists in springs below Milner three years after the recharge ceases.
Criterion 3: Percent of annual recharge volume for recurring March recharge that returns to the above Minidoka reach of the Snake River and Henrys Fork in July through September. The values are calculated for the 30th year of recurring recharge.
Criterion 4: Same as Criterion 3 except for returns in the months of November through February.
Criterion 5: Percent of a single, one-month recharge volume discharged above Minidoka between 3 and 30 years after the recharge activity.
Criterion 6: Average water level change in four model cells in the A&B area after 10 years of continuous recharge at 100,000 AF/yr.
Criterion 7A: Percent of single, one-month recharge volume retained in aquifer storage 10 years after the recharge activity.
Criterion 7B: Average water level change in the Snake River Plain aquifer after 10 years of continuous recharge at 100,000 AF/yr.

Objective 1 (Augment Spring Discharge Below Milner Dam Within Three Years) Evaluation:

Objective 1 is to augment spring discharge below Milner Dam within three years. This objective is evaluated using Criteria 1A and 1B. Criterion 1A is the percent of one month recharge volume discharged in the below Milner reach within 3 years. Criterion 1B is the percent of continuous recharge rate which appears as additional spring discharge below Milner after one year.

The effectiveness for recharge at any of the selected locations to augment near-term spring discharges below Milner Dam is shown by the graph in Figure 7. The graph shows that the effectiveness of recharge at Northside Canal, Milepost 31 Recharge Site, Shoshone Recharge Site, and Milner Gooding Canal greatly exceed the effectiveness of other sites. Some benefit is expected from the Lake Walcott Recharge Site. Other sites provide essentially no benefit relative to this objective. Since the two criteria represent different quantities, the values of Criterion 1A are not directly comparable to Criterion 1B; but in most cases the relative differences between recharge locations are similar.

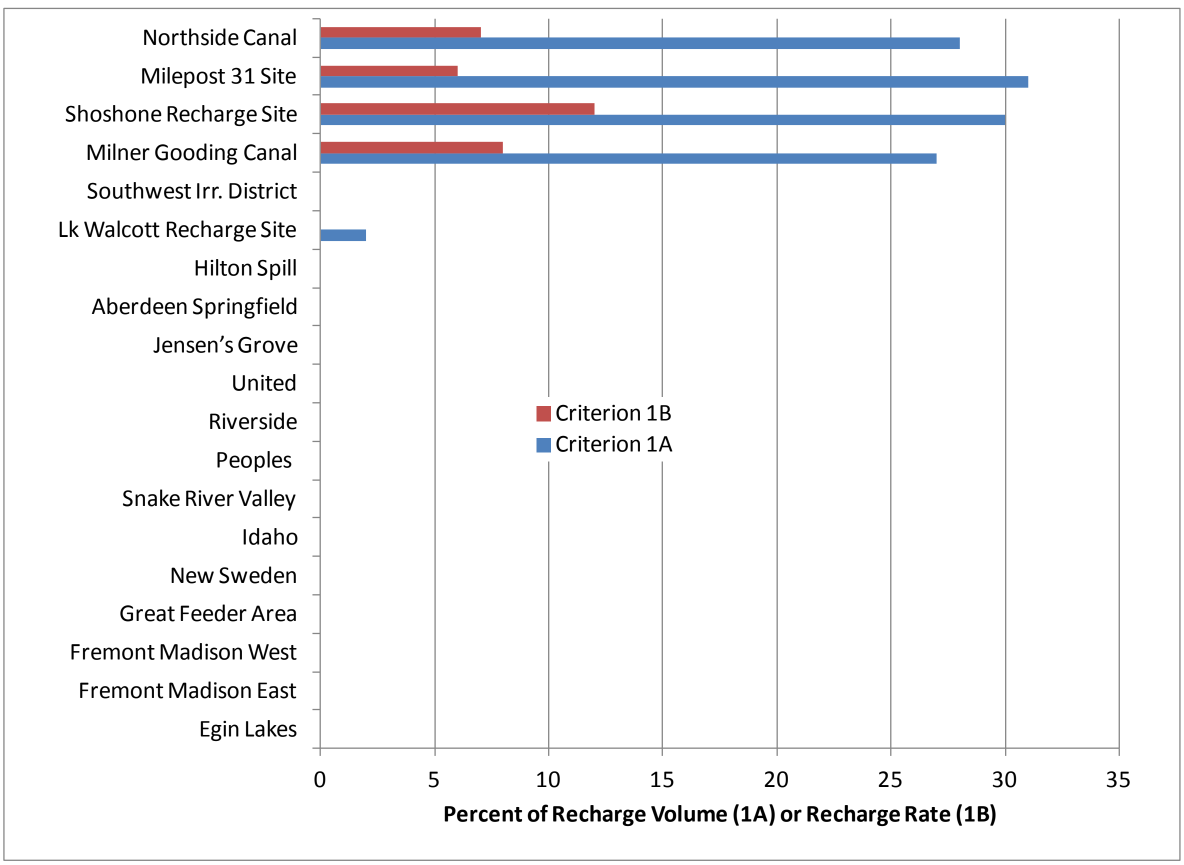


Figure 7. Objective 1 (near term spring discharges below Milner) effectiveness measures. Criterion 1A is the percent of one month recharge volume discharged in the below Milner reach within 3 years. Criterion 1B is the percent of continuous recharge rate which appears as additional spring discharge below Milner after one year.

Objective 2 (Augment Spring Discharge Below Milner Dam Over Periods Longer Than Three Years) Evaluation

Objective 2 is to augment spring discharge below Milner Dam over periods longer than three years. This objective is evaluated using Criteria 2A and 2B. Criterion 2A is the percent of a one month recharge volume discharged in the below Milner reach between 3 and 30 years. Criterion 2B is the percent of a long term continuous recharge rate that persists in springs below Milner three years after the recharge ceases.

The effectiveness of recharge at the selected sites to provide long-term augmentation of spring discharge below Milner Dam is described collectively through Criteria 2A and 2B, and illustrated in Figure 8. The results indicate that Northside Canal, the Milepost 31 Site, the Shoshone Site, the Milner Gooding Canal, Southwest Irrigation District, and the Lake Walcott Recharge Site are all similarly effective in achieving this objective. The Hilton Spill site, Aberdeen Springfield Canal, Jensen's Grove Site, United, Riverside, Peoples, Snake River Valley, Idaho, and New Sweden Irrigation systems are substantially less effective. The Great Feeder canals, Fremont Madison system, and Egin Lakes are ineffective.

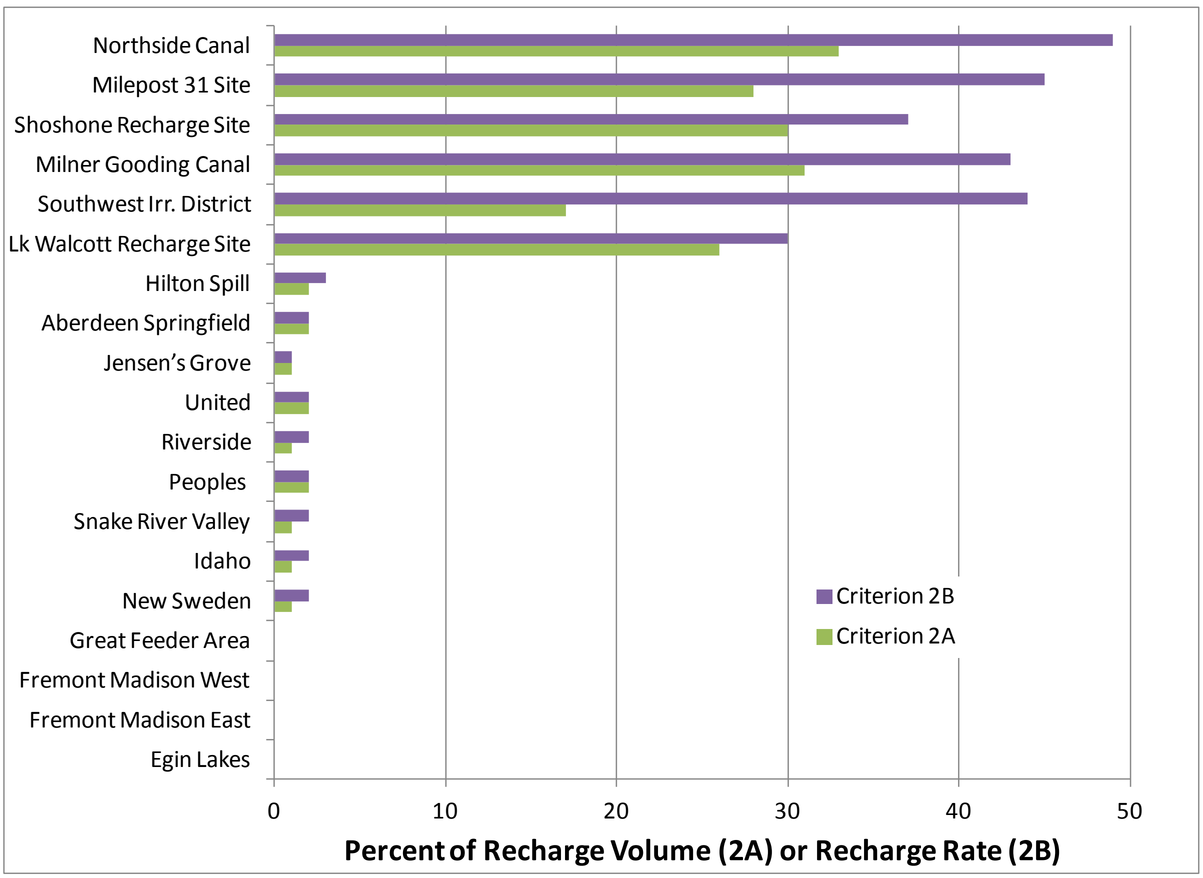


Figure 8. Objective 2 effectiveness measures. Criterion 2A is the percent of a one month recharge volume discharged in the below Milner reach between 3 and 30 years. Criterion 2B is the percent of a long term continuous recharge rate that persists in springs below Milner three years after the recharge ceases.

Objective 3 (Augment Flow in the Snake River Above Minidoka During Irrigation Season) Evaluation

Objective 3 is to augment flow in the Snake River above Minidoka Dam during the irrigation season. This objective is evaluated using Criterion 3. Criterion 3 is the percent of annual recharge volume for recurring March recharge that returns to the above Minidoka Dam reach of the Snake River and Henrys Fork in July through September. The values are calculated for the 30th year of recurring recharge.

Figure 9 shows that all sites above and including the Lake Walcott Recharge Site are more effective at inducing additional summer flows in the reach. Differences in effectiveness within this group are partially due to the selection of model grid cell locations to represent recharge events, which are uncertain in some cases. For example, the difference between Fremont Madison system canals on the east and west sides of the Henrys Fork is probably partially due to a single model cell location used to represent the east side, while modeling actual canal locations on the west side of the river. The relatively reduced effectiveness of the Fremont Madison West canals and Jensen's Grove results from a high degree of seasonal variation in river returns resulting from March recharge (very rapid response times). This rapid response is shown in the graphs of Figures D6 and L6. Recharge sites below Milner Dam are perhaps half as effective at achieving this objective, as measured by this criterion. This difference would likely be greater if a shorter (<30 year) time duration were used in the criterion. Southwest Irrigation District recharge is least effective because slow propagation of effects from this area delays many effects longer than 30 years (the duration of the simulation used for the criterion).

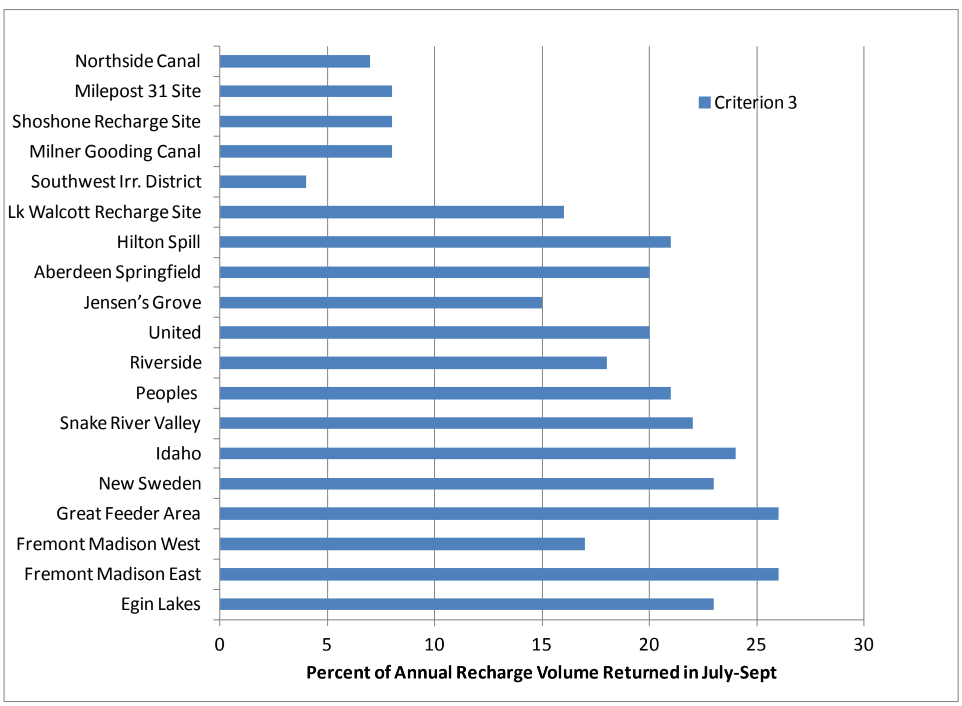


Figure 9. Objective 3 effectiveness as measured by Criterion 3. Criterion 3 is the percentage of March recharge volume returning to the Snake and Henrys Fork rivers above Minidoka Dam in July through September after 30 years of recurring March recharge.

Objective 4 (Augment Flow in the Snake River Above Minidoka During Fall and Winter) Evaluation

The effectiveness of recharge at individual sites to enhance flow in the Snake and Henrys Fork rivers above Minidoka Dam during winter is described by Criterion 4. This criterion represents the percentage of the recurring March recharge volume that returns to the Snake and Henrys Fork rivers between November and February (inclusive) after 30 years of sustained March recharge events. The results for Criterion 4 are shown in Figure 10 and are similar to those of Criterion 3. All sites above and including the Lake Walcott Recharge Site are effective at inducing additional winter flows in the reach. Some differences among these sites are apparent, and due primarily to the rate at which recharge returns to the river. For example, much of a March recharge event at Jensen's Grove is expected to return to the river before the following winter (see Appendix L, Figure L6-A). Recharge sites below Milner Dam are about half as effective at achieving this objective, as measured by this criterion. Southwest Irrigation District recharge is least effective again, because slow propagation of effects from this area delays many effects longer than 30 years (the duration of the simulation).

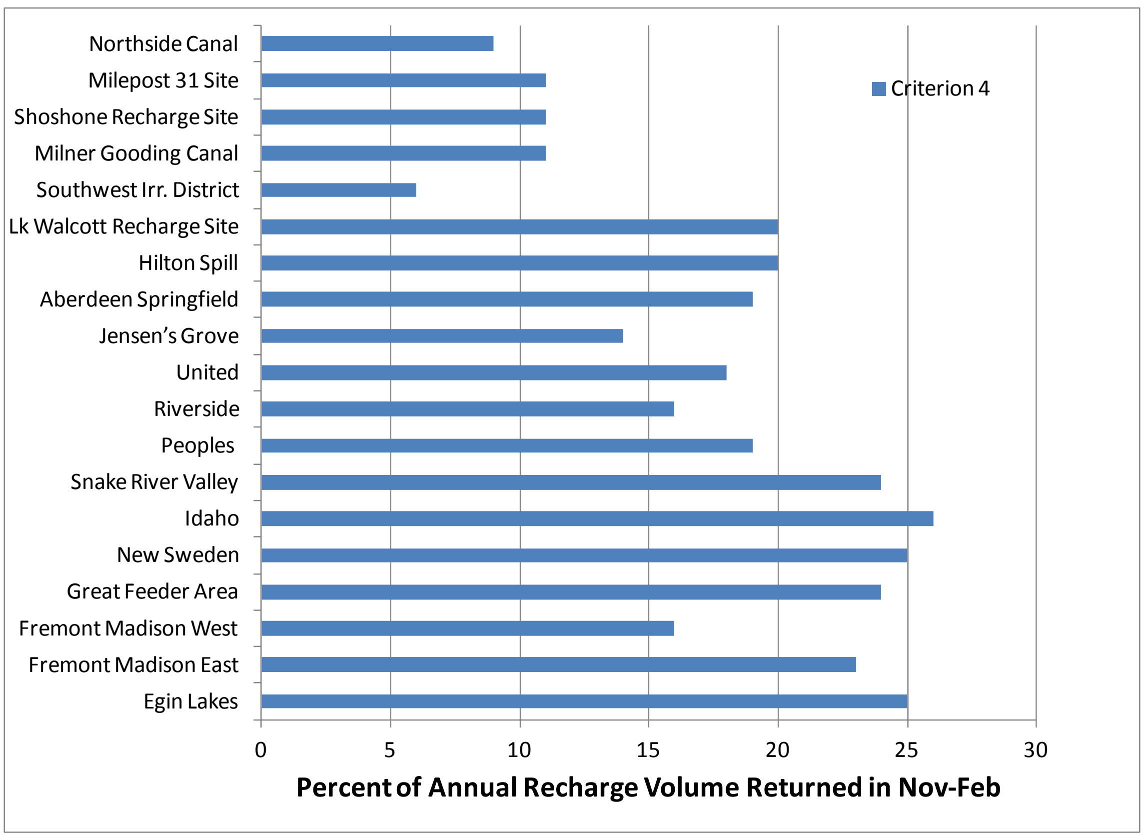


Figure 10. Objective 4 effectiveness as measured by Criterion 4. The graph shows the percentage of annual recharge volume returning to the Snake and Henrys Fork rivers above Minidoka Dam in November through February after 30 years of recurring March recharge.

Objective 5 (Augment Flow in the Snake River Above Minidoka over Extended Periods) Evaluation

The effectiveness of recharge at the prescribed sites to enhance Snake and Henrys Fork river flows above Minidoka Dam during periods of extended drought is evaluated through use of Criterion 5. Criterion 5 is a measure of the simulated percentage of the volume of recharged water (occurring only in the first month) that returns to the river above Minidoka between 3 and 30 years (30 years is the simulation duration) after ceasing recharge. Figure 11 shows that all recharge sites are somewhat effective in achieving this objective. The Lake Walcott and Egin Lakes sites are most effective. Northside Canal, Milepost 31, Shoshone, Milner Gooding Canal, Snake River Valley, Idaho, New Sweden, and Fremont Madison West display an intermediate level of effectiveness. Some of the Southwest Irrigation District effects are delayed beyond 30 years, therefore resulting in a smaller value for that system.

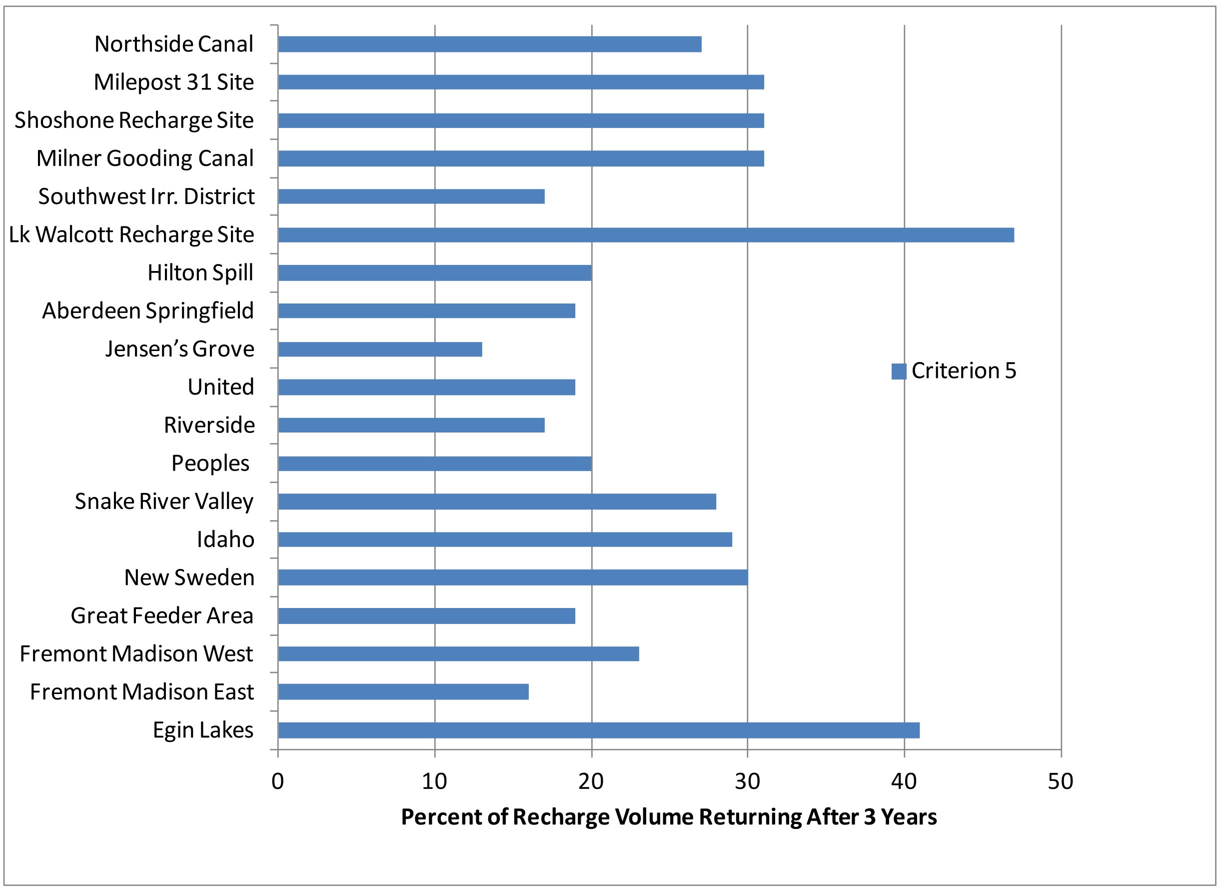


Figure 11. Objective 5 effectiveness, as measured by Criterion 5. The graph shows the percentage of one month's recharge volume returning to the Snake and Henrys Fork rivers above Minidoka Dam between 3 and 30 years after the recharge occurred.

Objective 6 (Increase Aquifer Water Levels Near A&B Irrigation District Over Extended Periods) Evaluation

The effectiveness of recharge at the prescribed sites to increase aquifer water levels in the A and B Irrigation District area is evaluated using Criterion 6. This criterion determines the average increase in aquifer water level (in feet) in four model grid cells within the A and B Irrigation District that results from 10 years of continuous recharge at a rate of 100,000 AF per year at a specified recharge site. The results are shown in Figure 12 and show three basic levels of effectiveness. The nearby Lake Walcott Recharge Site is most effective and has about double the impact of the next most effective locations. Northside Canal, Milepost 31 Site, Shoshone Site, and Milner Gooding Canal show similar levels of effect. All other recharge sites have well less than one foot of expected effect.

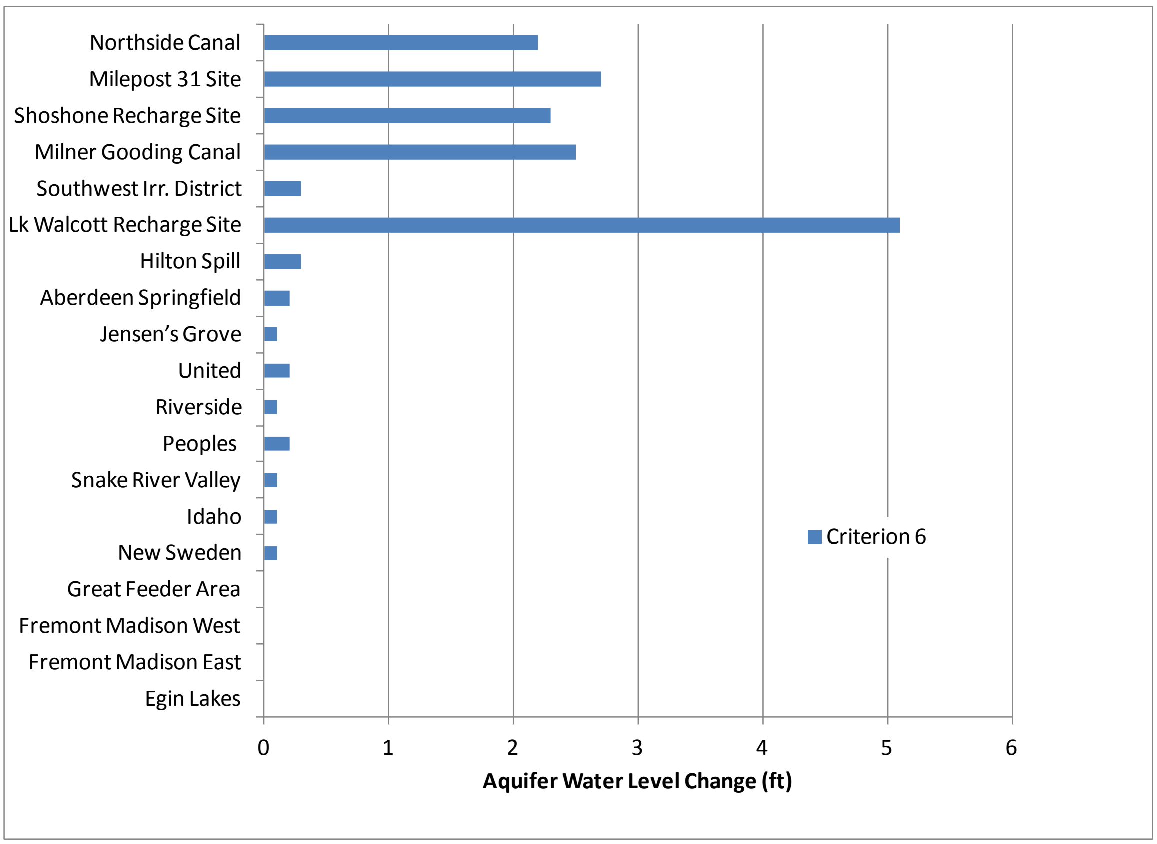


Figure 12. Objective 6 effectiveness as measured by Criterion 6. The graph shows the average water level change in four model cells within the A and B Irrigation District after 10 years of continuous recharge at a rate of 100,000 AF per year.

Objective 7 (Increase Aquifer Water Levels Throughout the ESRP Aquifer Over Extended Periods) Evaluation

The effectiveness of recharge to increase aquifer water levels throughout the eastern Snake River Plain is evaluated in Objective 7 using two criteria: Criterion 7A, the percentage of a one month recharge event that is retained in aquifer storage after 10 years; and Criterion7B, the average water level change in the Snake River Plain aquifer after 10 years of continuous recharge at a rate of 100,000 AF per year. Figure 13 shows that both of these criteria produce a similar ranking of the effectiveness of different recharge sites. An exception is Southwest Irrigation District. It is assumed that the moderate water level change relative to the extreme percent of recharge retention is due to a relatively large aquifer storativity and small transmissivity in the vicinity of the District. This has not been confirmed. Recharge sites above Minidoka produce about one third the degree of water level change as the Lake Walcott and downstream sites. Average water level changes, however, are relatively small from what may be considered as substantial levels of recharge.

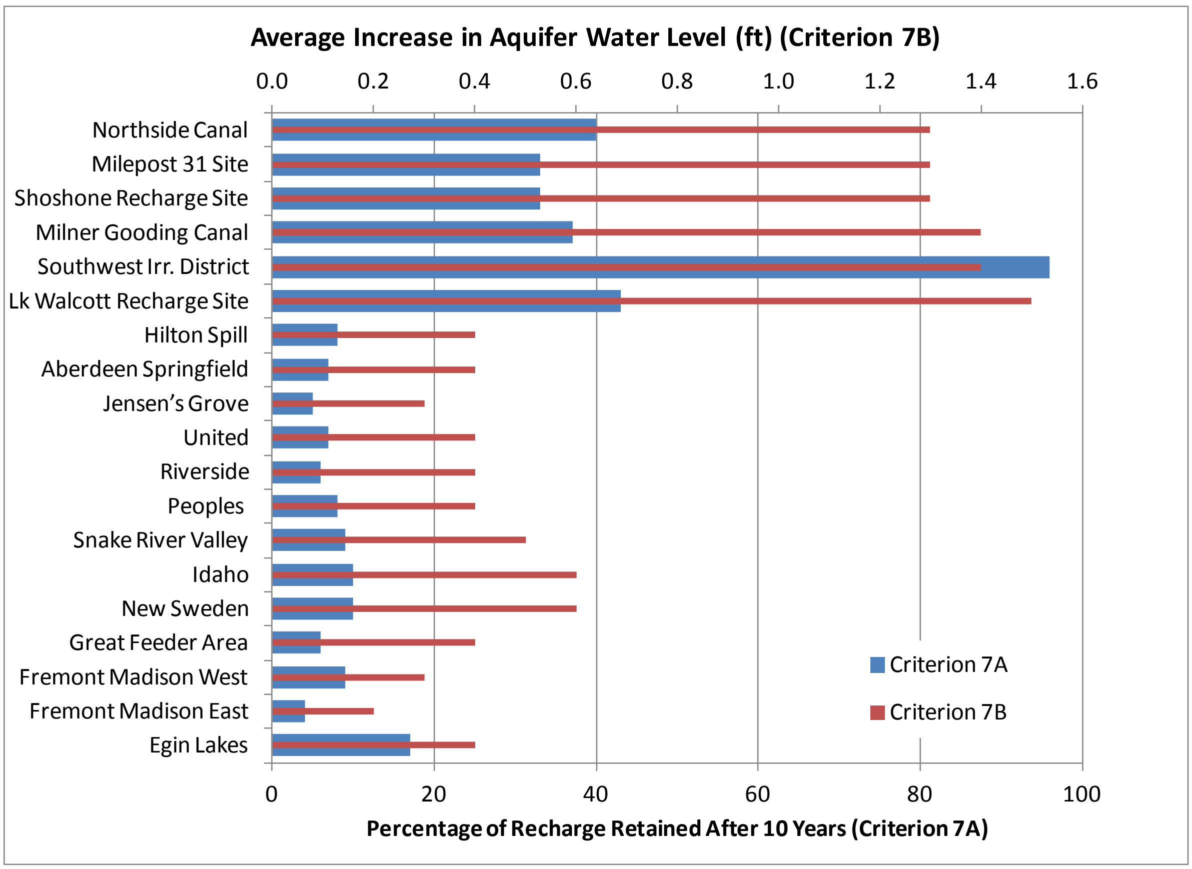


Figure 13. Objective 7 ratings according to Criterion 7A and Criterion 7B. Criterion 7A shows the percentage of a one month recharge volume that is retained in the aquifer 10 years after the recharge activity (blue bars, lower axis). Criterion 7B shows the average water level change in the Snake River Plain aquifer resulting after 10 years of recharge at a rate of 100,000 AF per year.

Summary

Aquifer recharge may be performed to accomplish either of two basic objectives: a) increase spring discharges and river gains (or decrease river losses), or b) increase aquifer water levels. Increased spring discharge and river gains provide benefits by more uniformly distributing flow throughout the year or through multi-year droughts. Springs receive an additional benefit of purification of the recharge water. Increased aquifer water levels provide benefit by reducing pumping lift and potentially reducing pump lowering and well deepening in areas that are otherwise experiencing water level declines.

Seven objectives were evaluated to provide the Idaho Water Resource Board with a range of considerations for prioritizing recharge at 19 different potential sites in the Eastern Snake River Plain. The seven objectives include:

1) augmenting flow in springs below Milner Dam in the near term,
2) augmenting flow in springs below Milner Dam in the long term,
3) augmenting summer flows of the Snake River above Minidoka Dam and in the Henrys Fork,
4) augmenting winter flows of the Snake River above Minidoka Dam and in the Henrys Fork,
5) increasing flow in the Snake River above Minidoka Dam and in the Henrys Fork during extended drought,
6) increasing aquifer water levels in the A and B Irrigation District area, and
7) increasing aquifer water levels throughout the eastern Snake River Plain aquifer.

Quantitative criteria, based on Snake River Plain aquifer model simulations, were used to evaluate the effectiveness of recharge at each of the prescribed recharge sites to achieve each of the objectives. The selection of priority sites differs, depending upon which objective is considered most important. As one might expect, objectives that emphasize spring discharge benefits below Milner Dam are best served by recharge sites diverting below Milner Dam and the Lake Walcott site. Similarly, emphasis on river gains in the Snake River above Minidoka and the Henrys Fork pushes the upstream recharge sites to higher preference. Aquifer water levels tend to benefit most from recharge at the Lake Walcott site, Southwest Irrigation District, and those sites downstream of Milner Dam.

Small differences in benefits determined in this work should not be considered meaningful. The location of the actual recharge sites may differ from those represented in the models, and criteria can be developed and analyzed in a number of ways that may slightly alter the measures of effectiveness of different sites in achieving objectives.

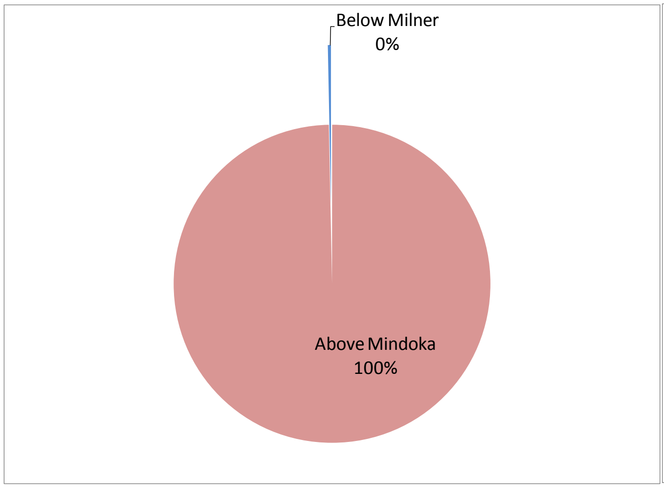
APPENDIX A: Model Cells Used to Represent Recharge Sites

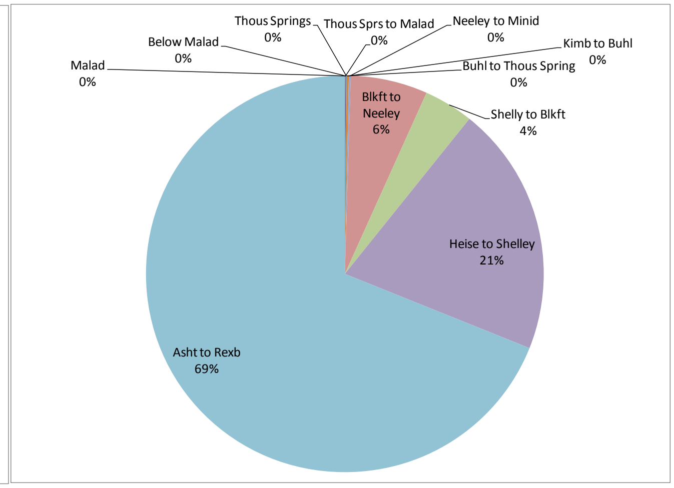
Recharge Site	**Modeled Recharge Location**	**Distribution of Recharge Flux**	**Model Cells**
Egin Lakes	Cells representing only Egin Lakes	Uniformly among 2 cells representing lakes	(49,184) (49,182)
Fremont Madison east canals	Main canals on the east side of the Henrys Fork	Uniformly distribute among cells corresponding to canals east of river	(57,190)
Fremont Madison west canals	Main canals on the west side of the Henrys 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 District	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)(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 B: Egin Lake Recharge Results





A B

Figure B1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

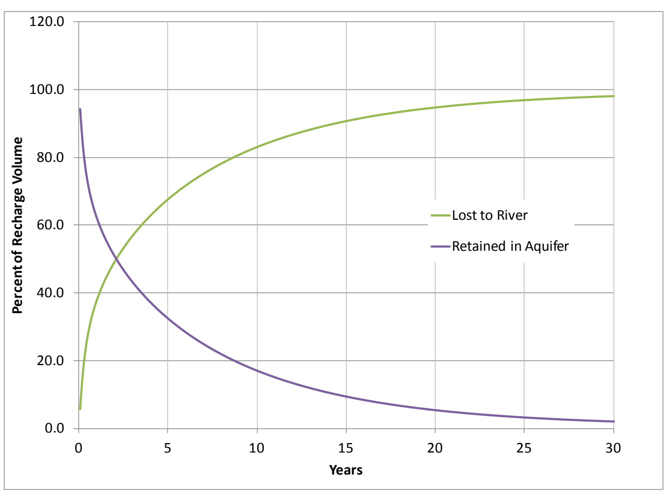


Figure B2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

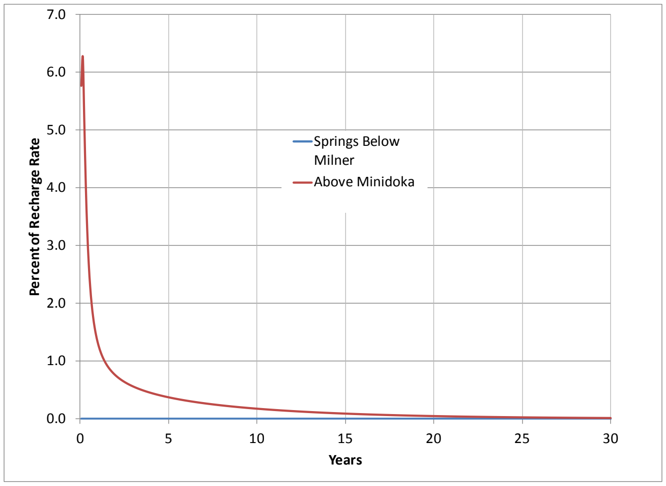
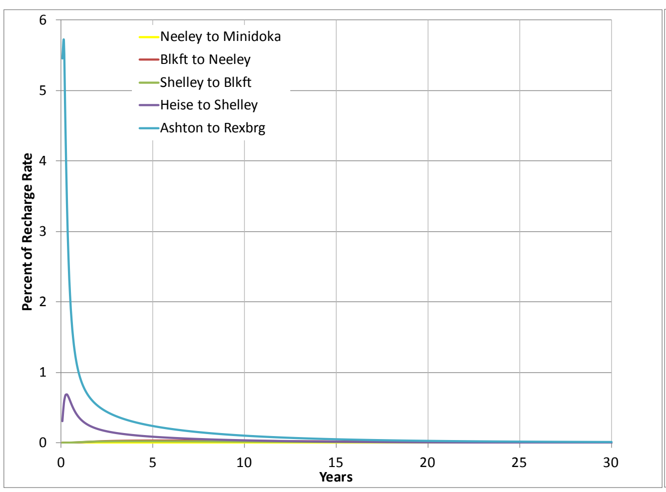
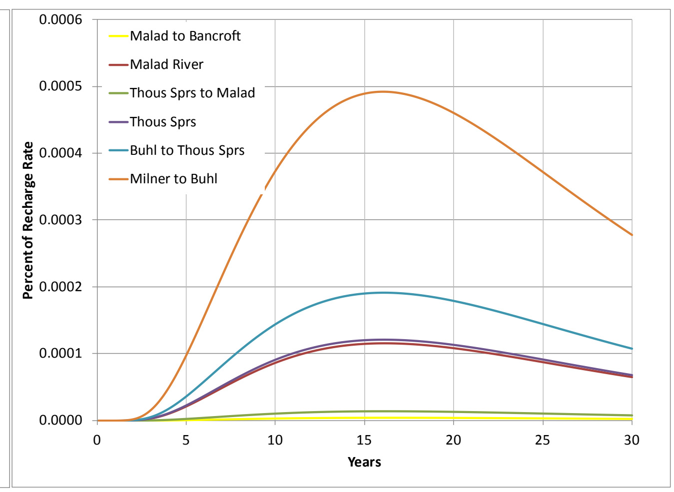


Figure B3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.



A



B

Figure B4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.

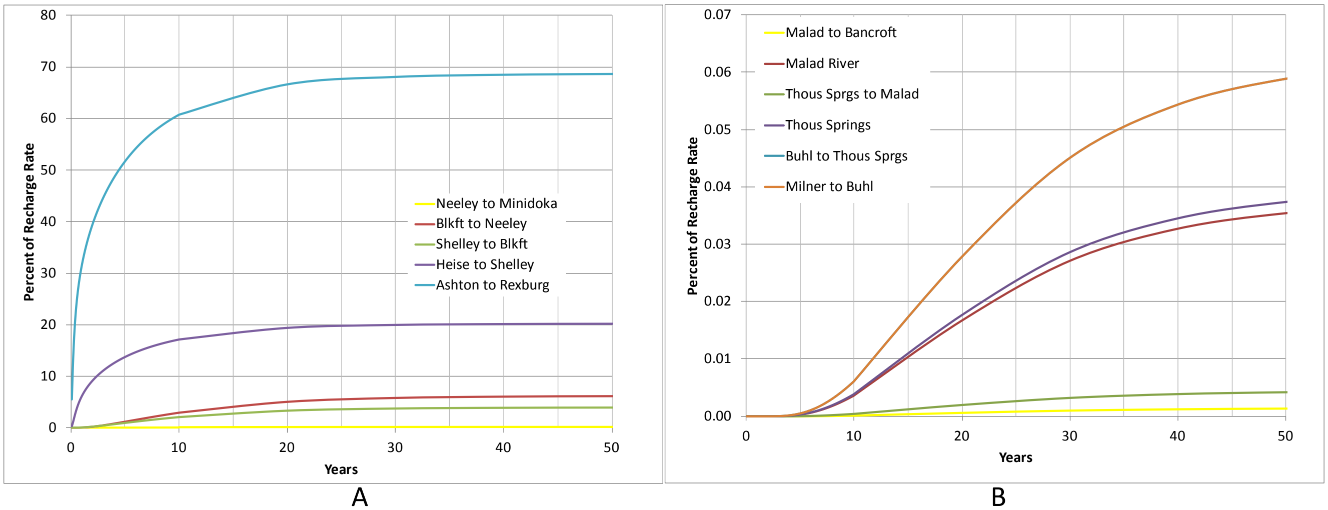


Figure B5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

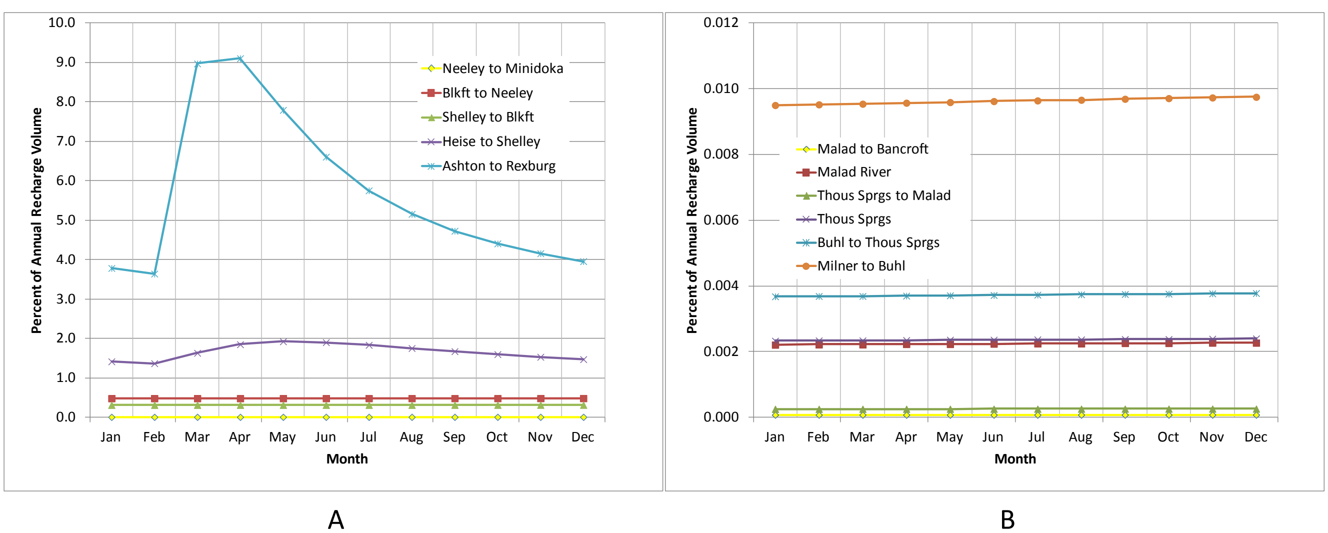
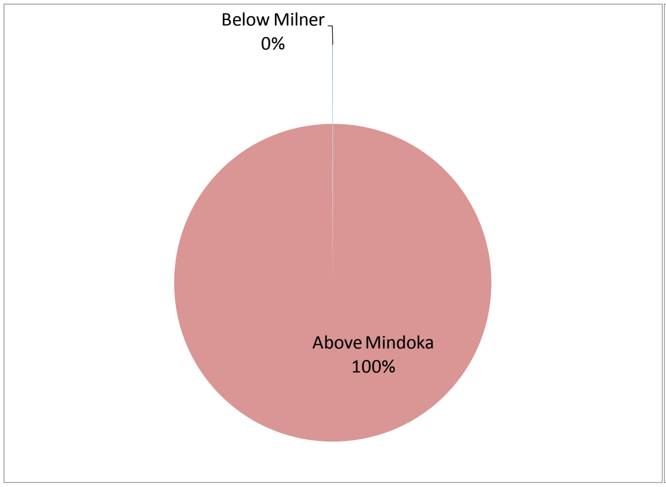
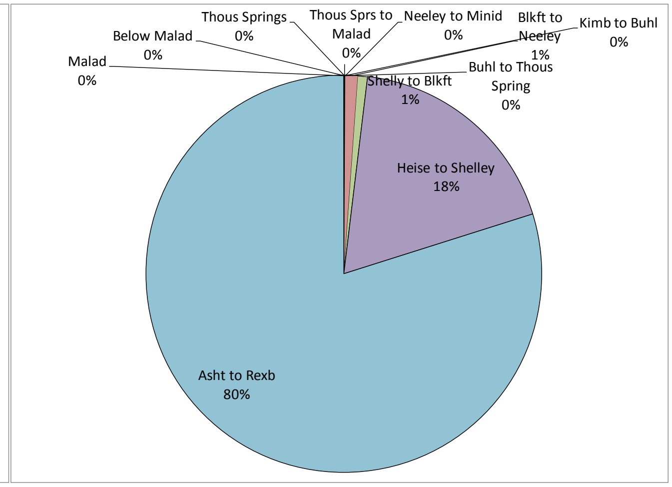


Figure B6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX C: Fremont Madison East Side Results





A

B

Figure C1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

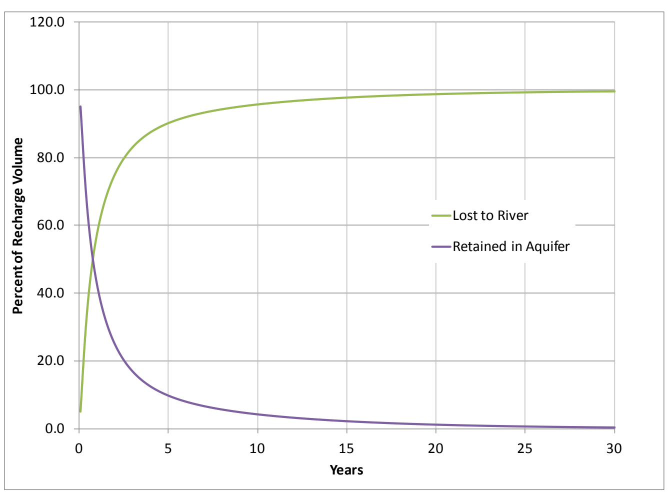


Figure C2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

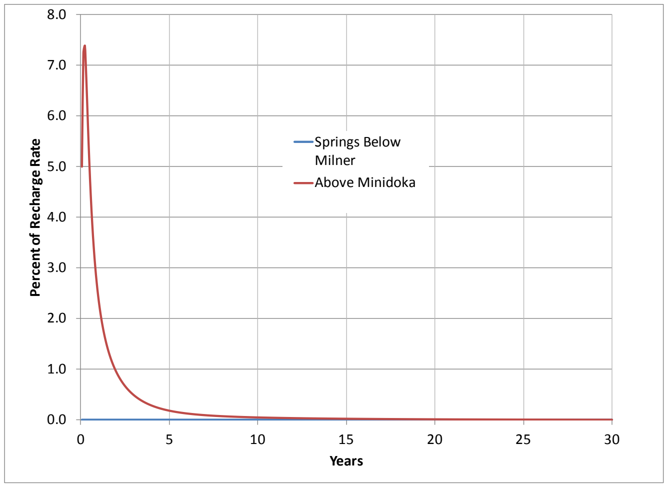
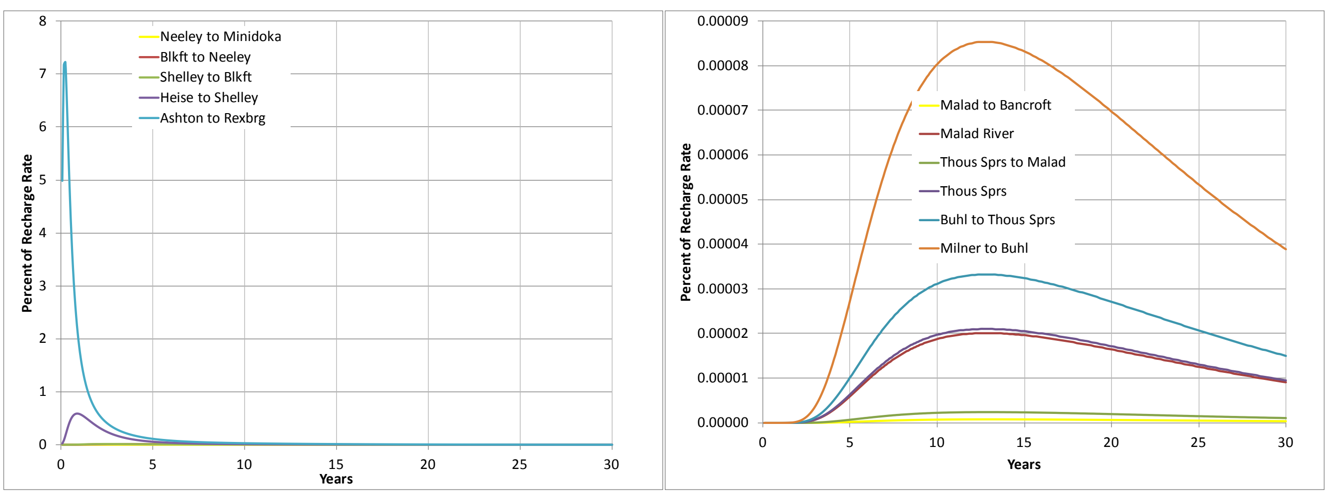
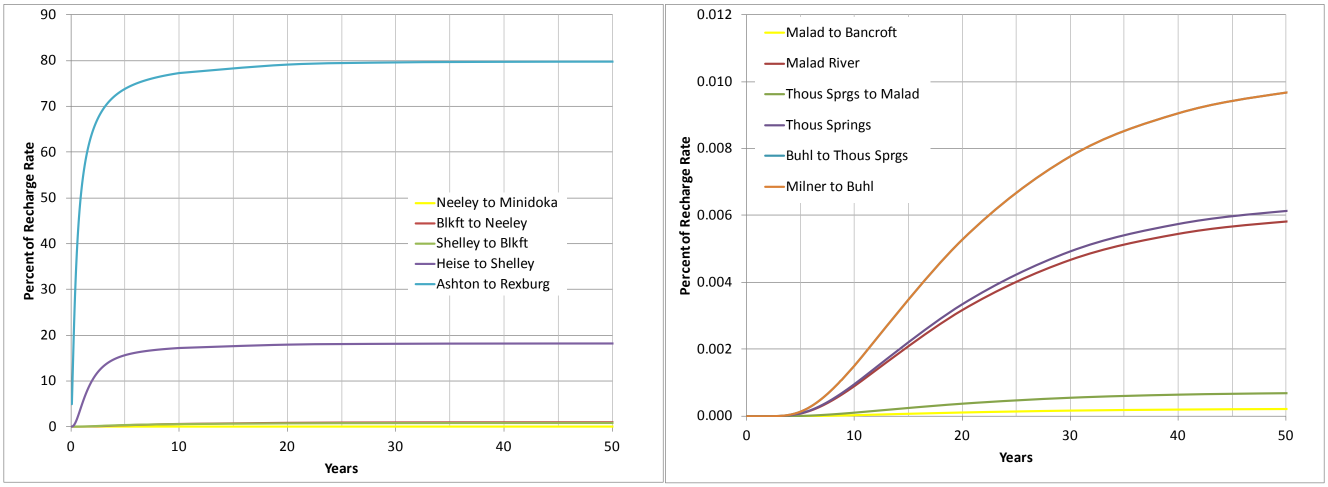


Figure C3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.



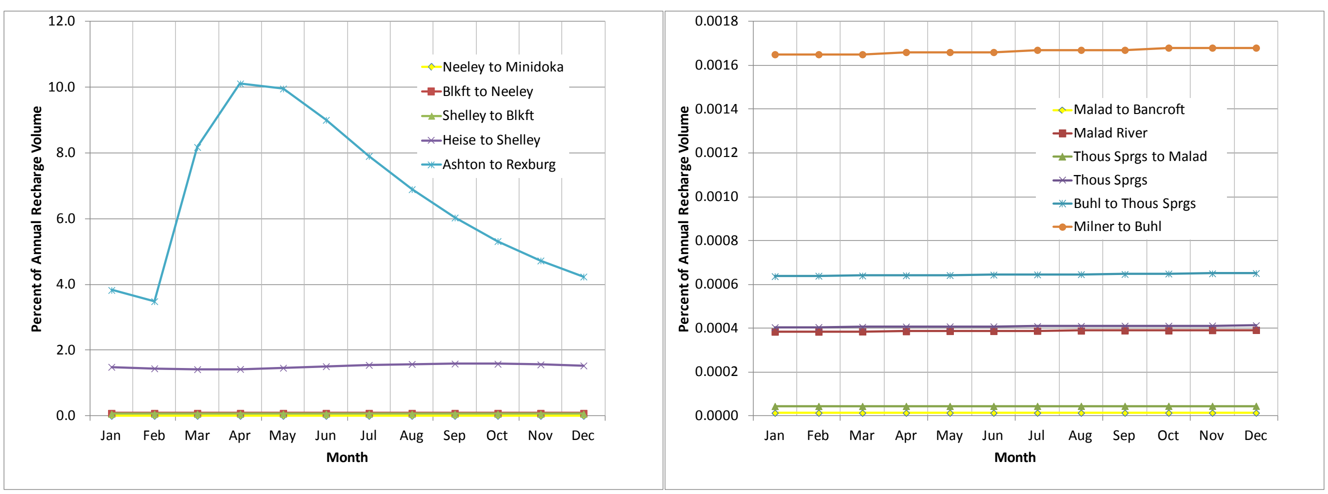
A B

Figure C4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.



A B

Figure C5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.



A B

Figure C6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX D: Fremont Madison West Side Results

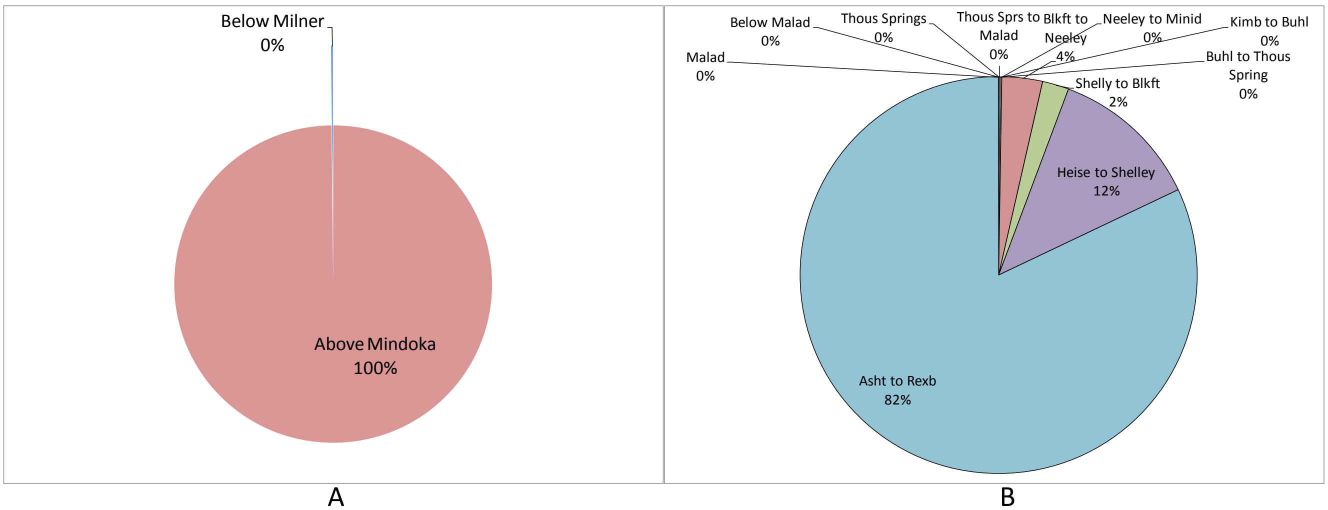


Figure D1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

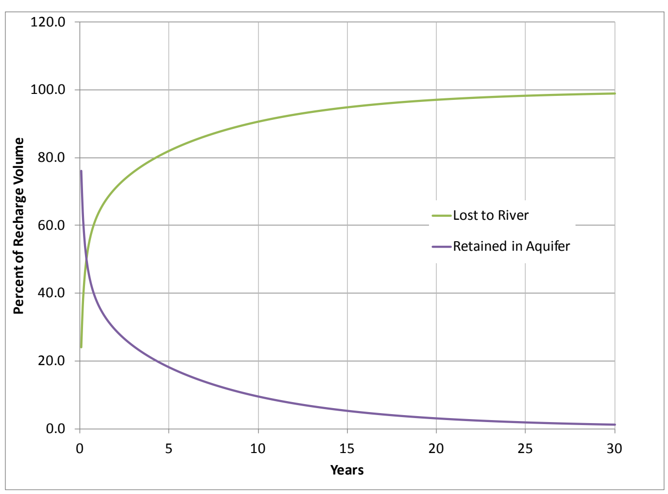


Figure D2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

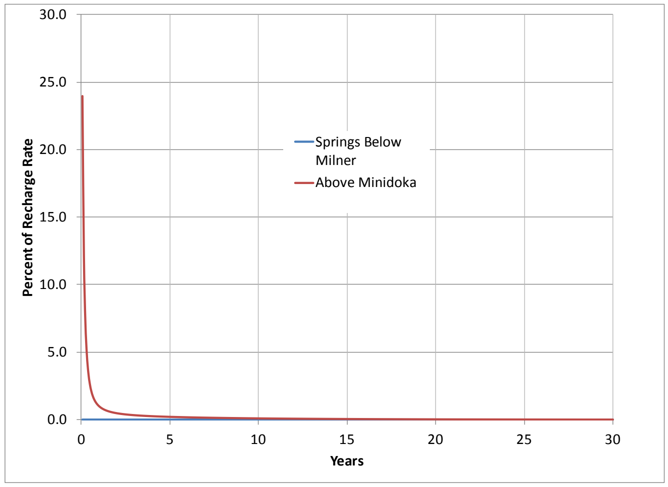


Figure D3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.

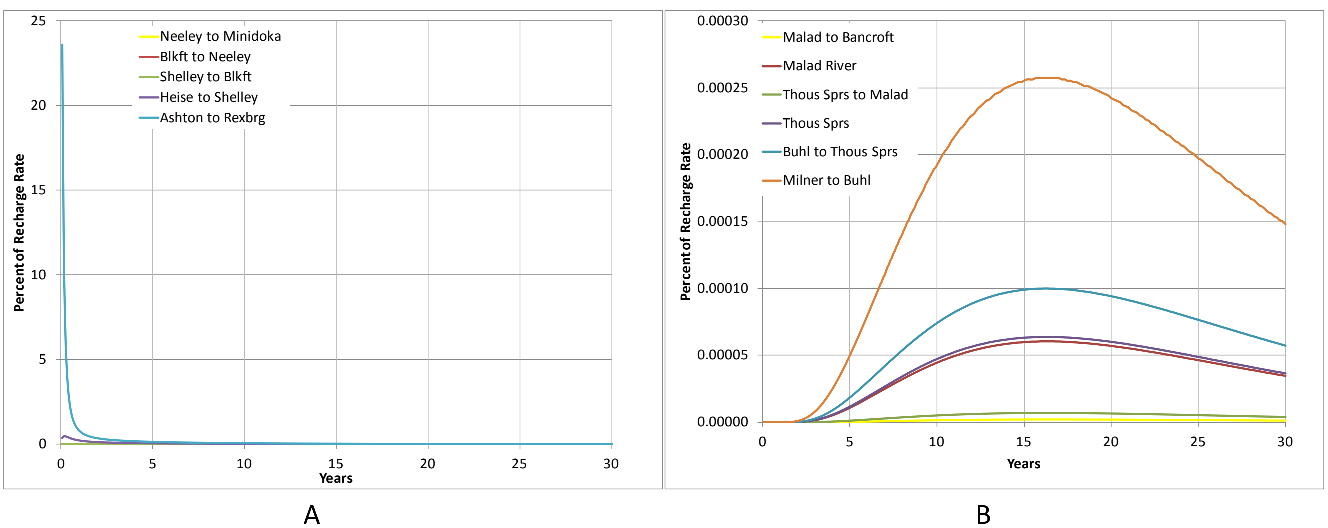


Figure D4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.

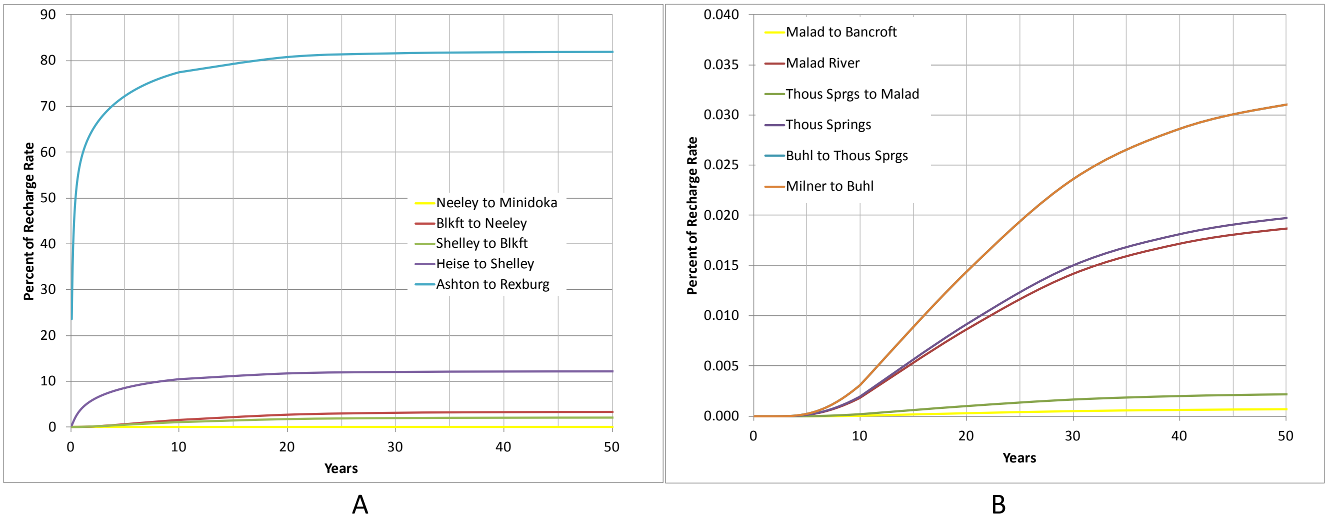


Figure D5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

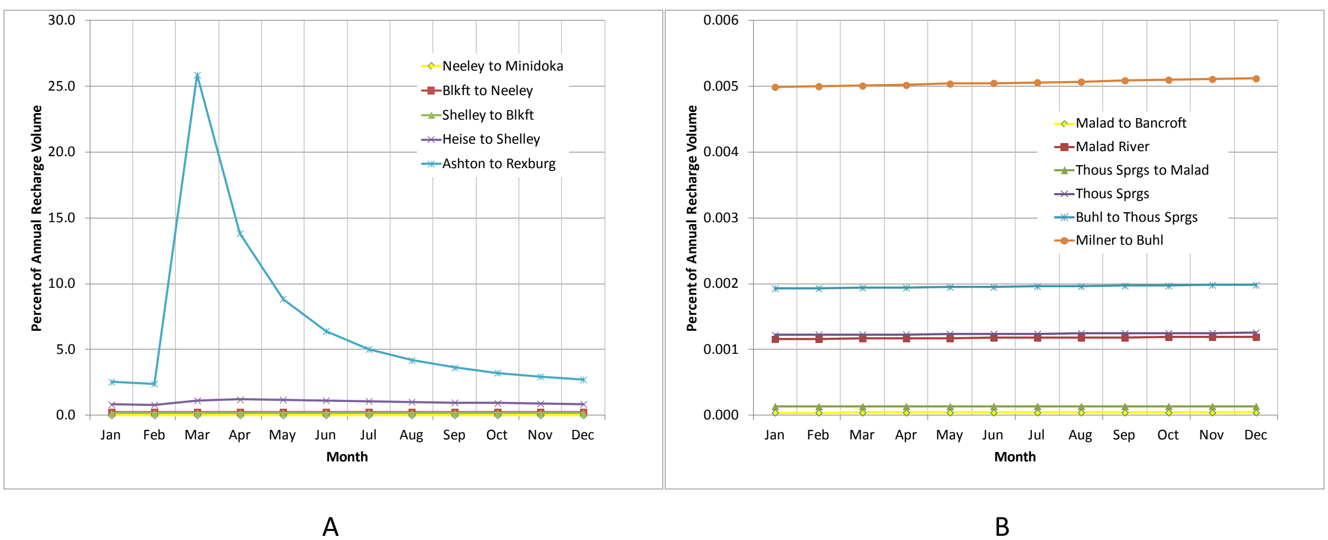


Figure D6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX E: Great Feeder Area Canals Results

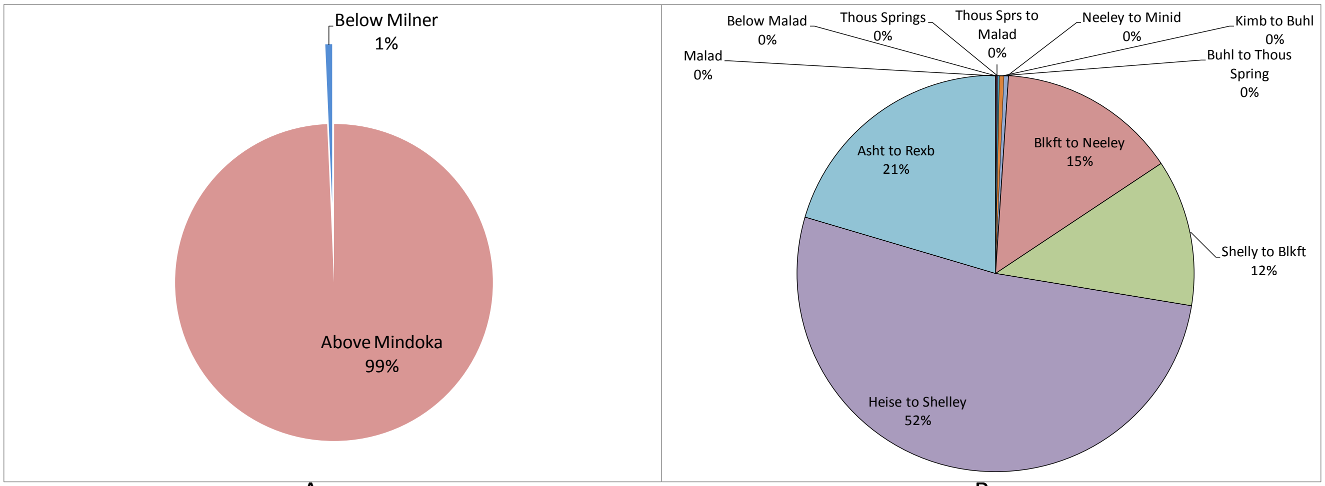


Figure E1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

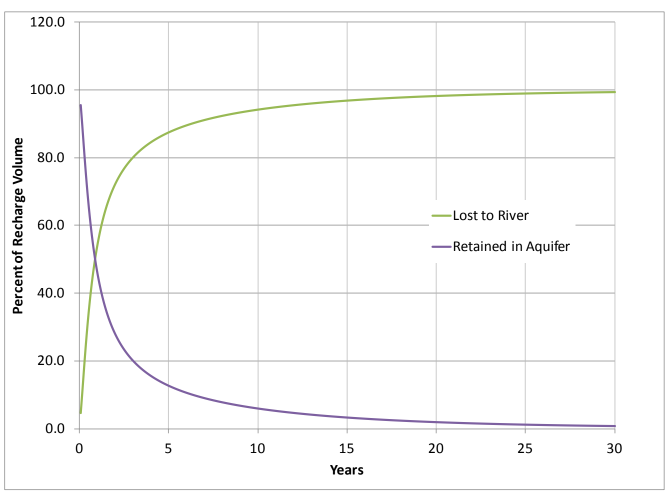


Figure E2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

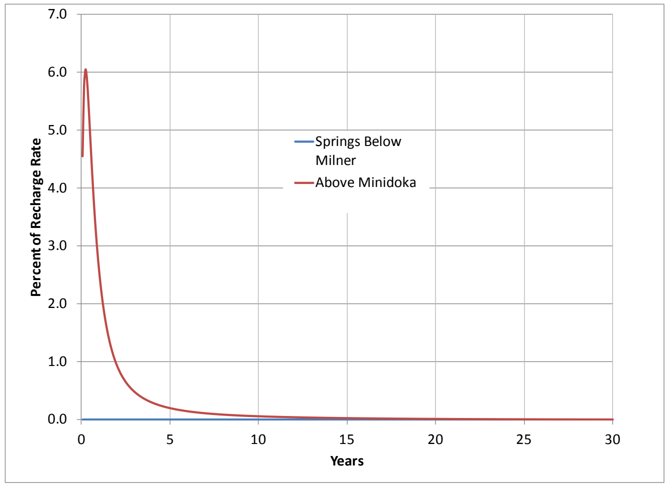


Figure E3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.

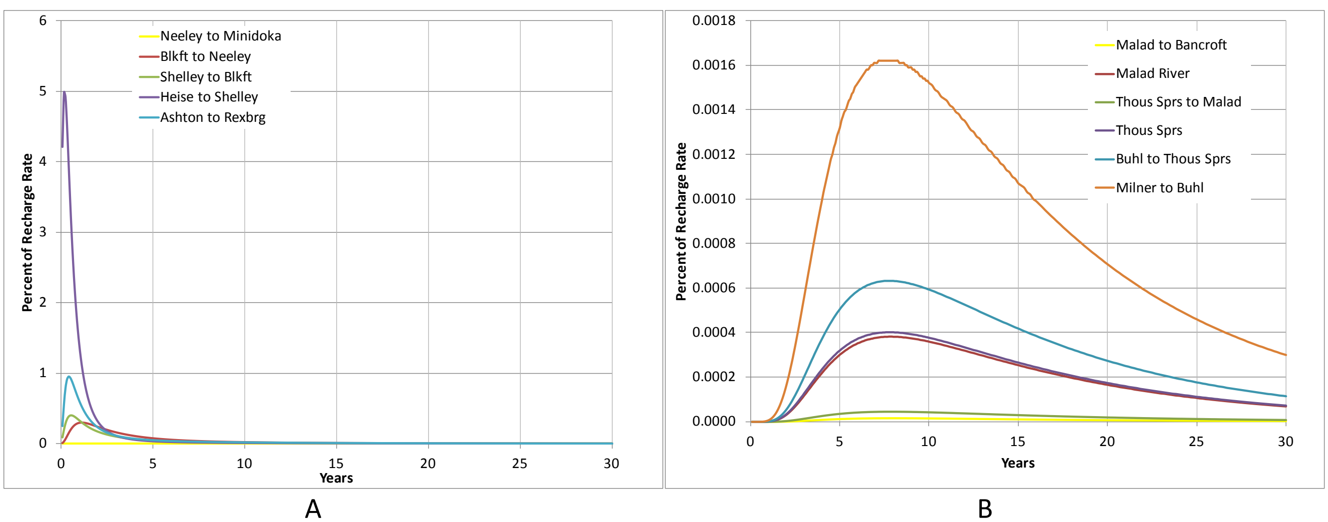
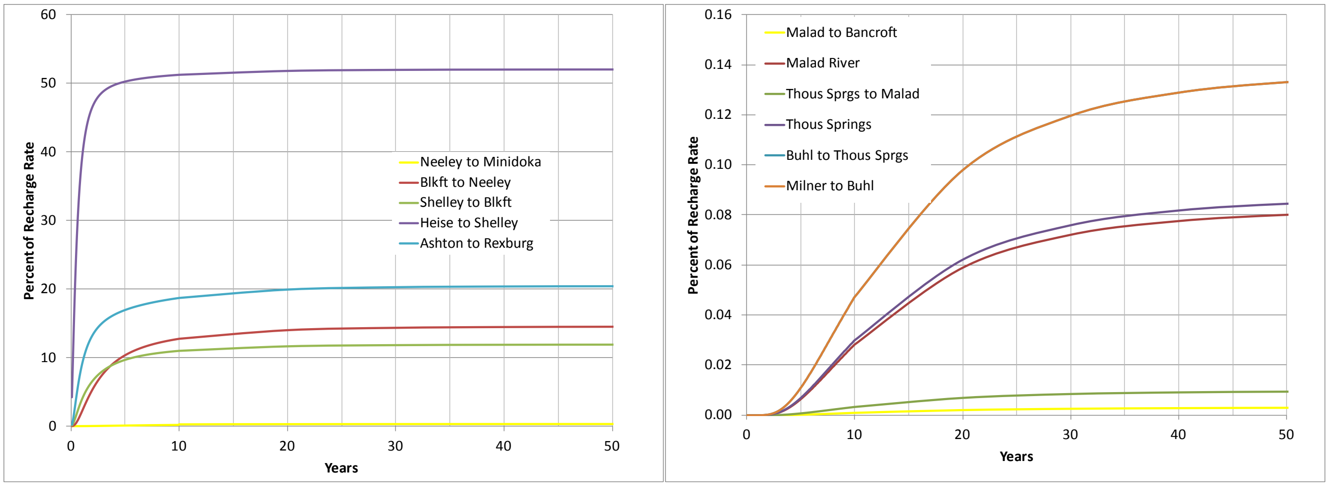
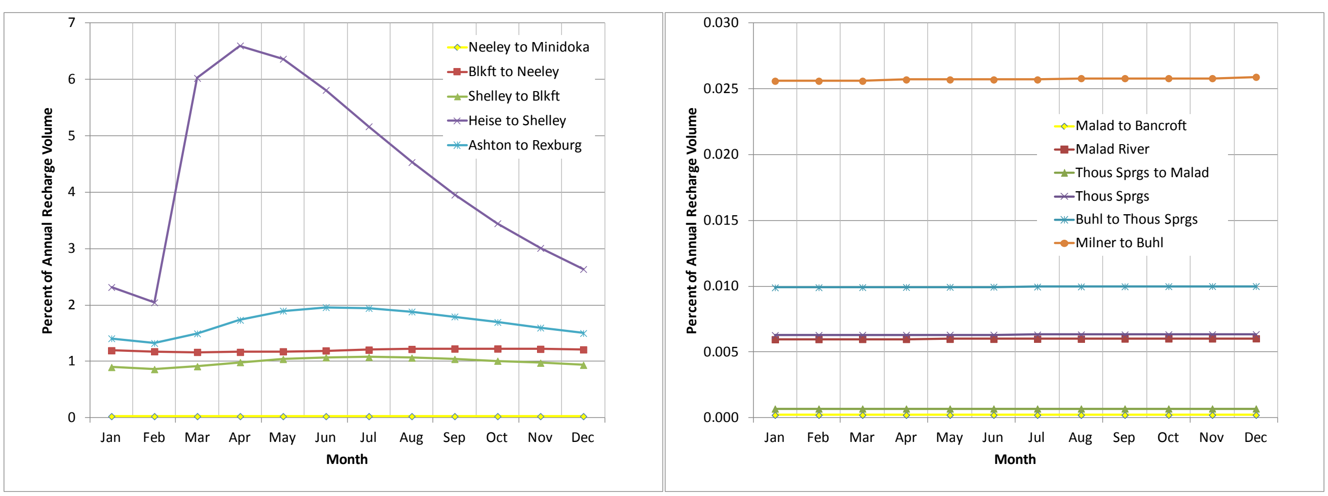


Figure E4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.



A B

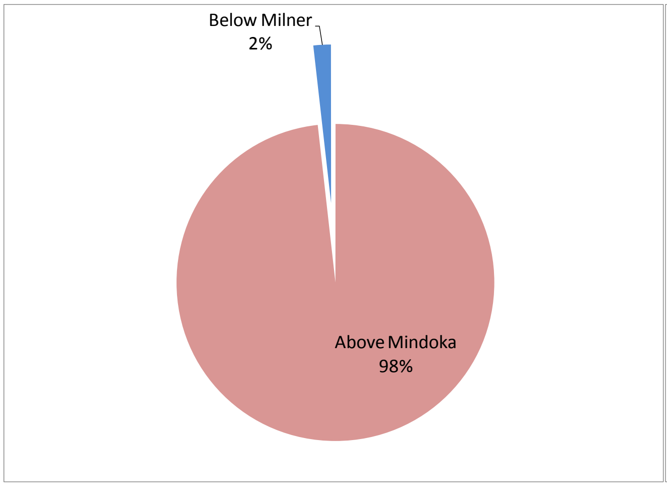
Figure E5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

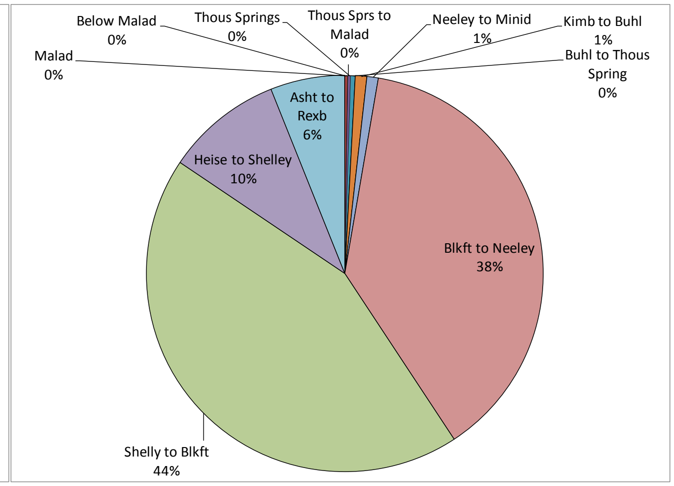


A B

Figure E6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX F: New Sweden Results





A

B

Figure F1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

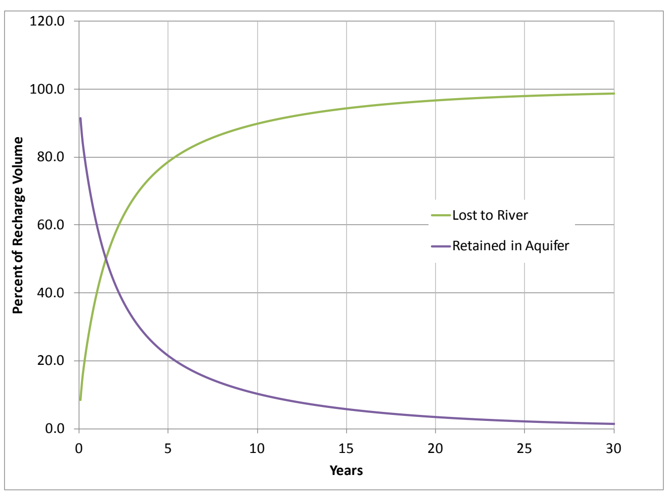


Figure F2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

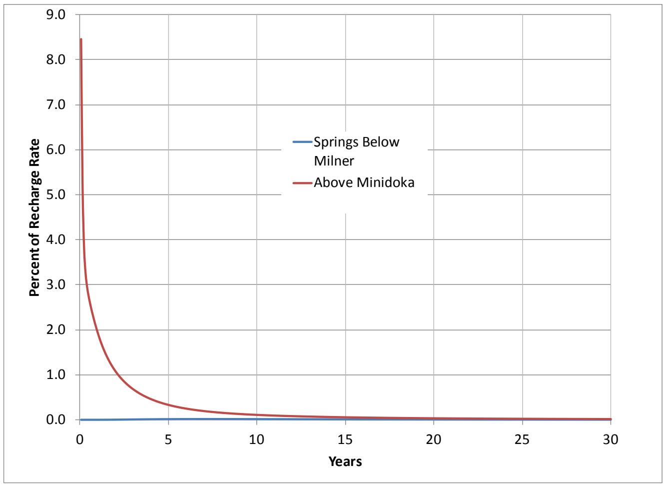


Figure F3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.

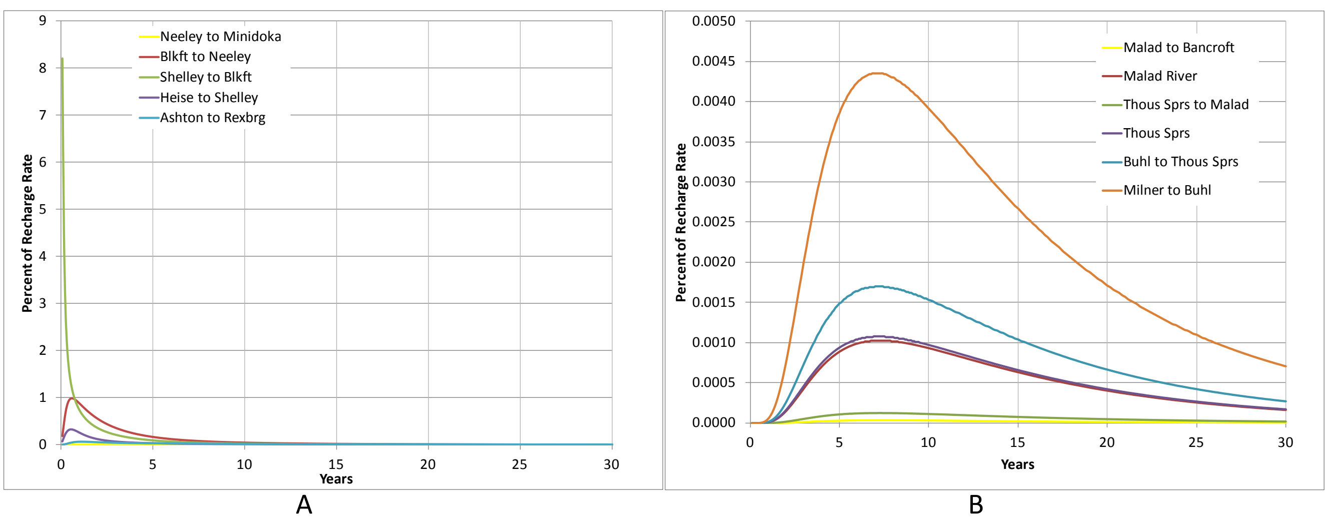
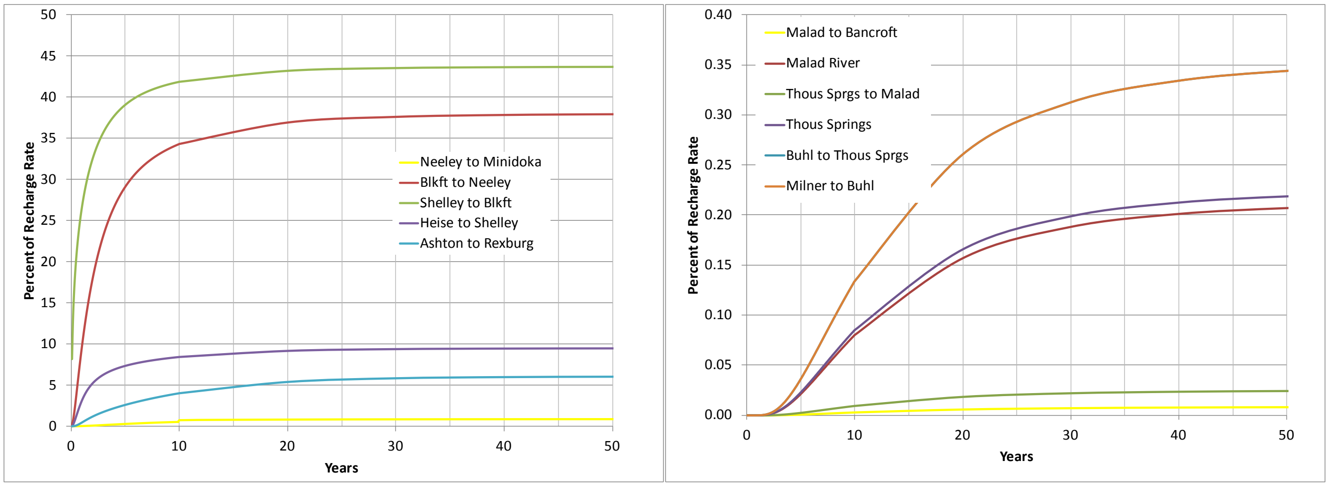
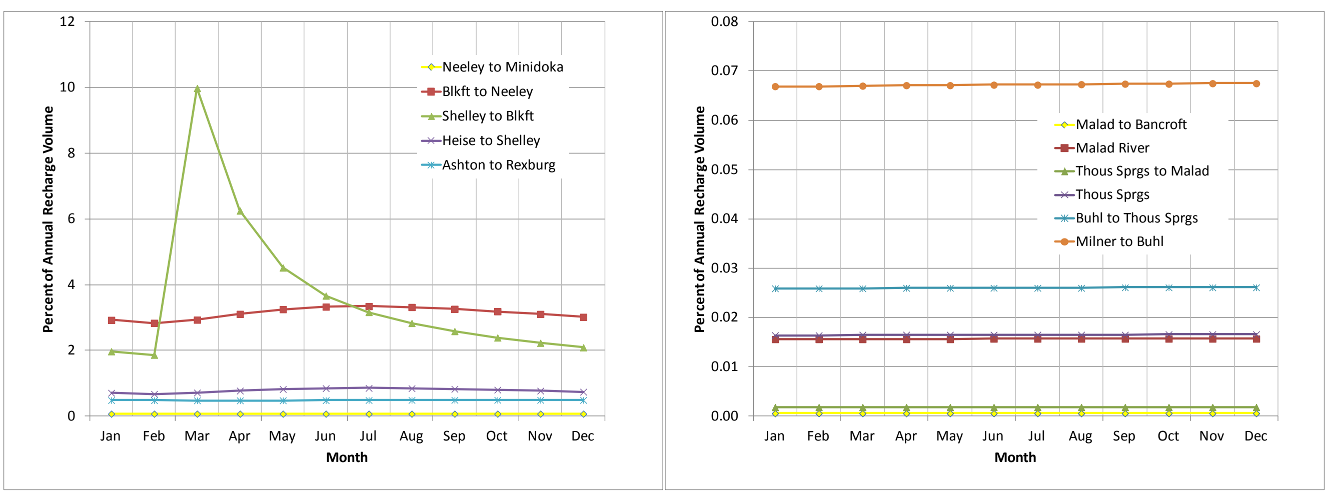


Figure F4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.



A B

Figure F5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.



A B

Figure F6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX G: Idaho Irrigation District Results

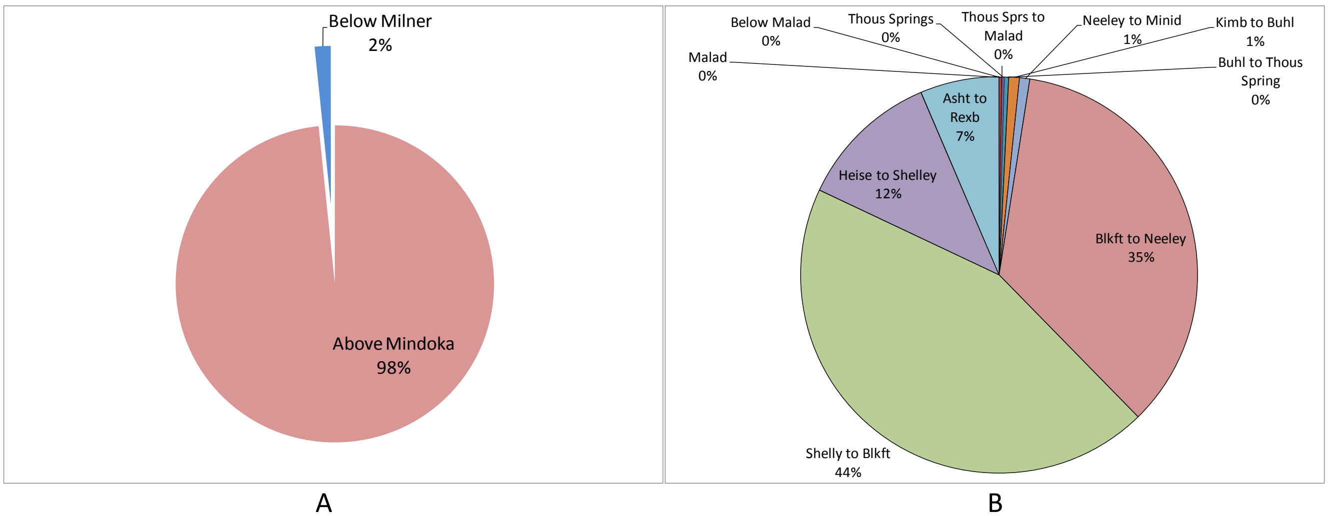


Figure G1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

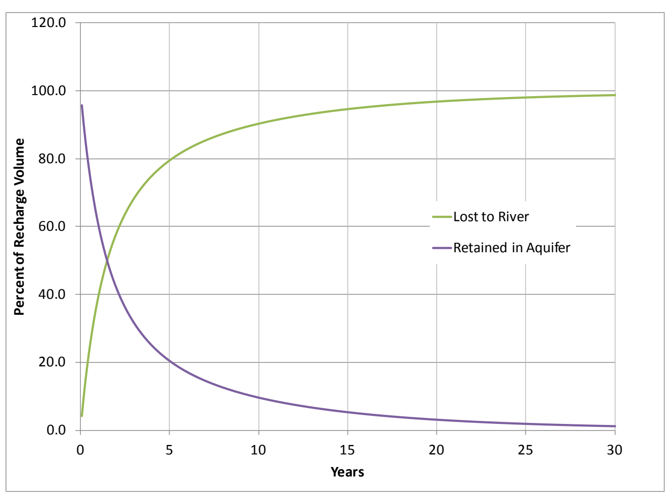


Figure G2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

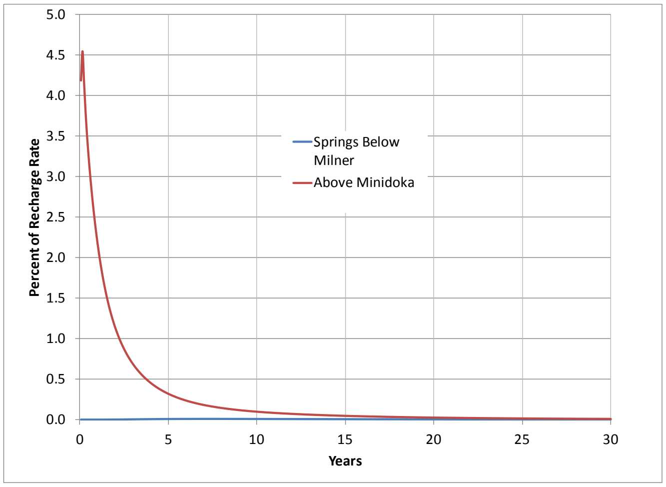
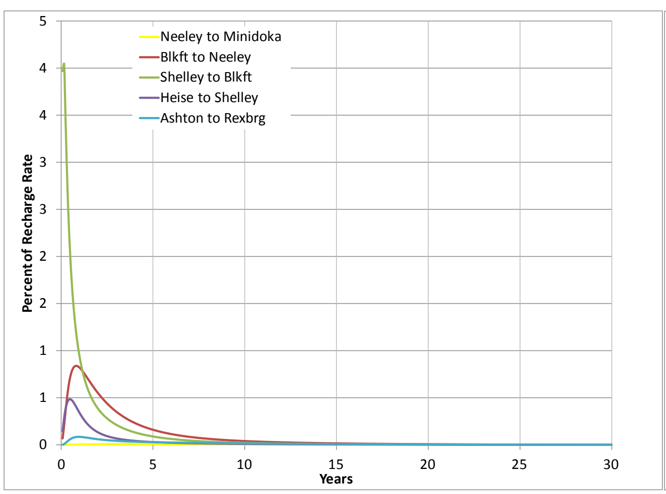
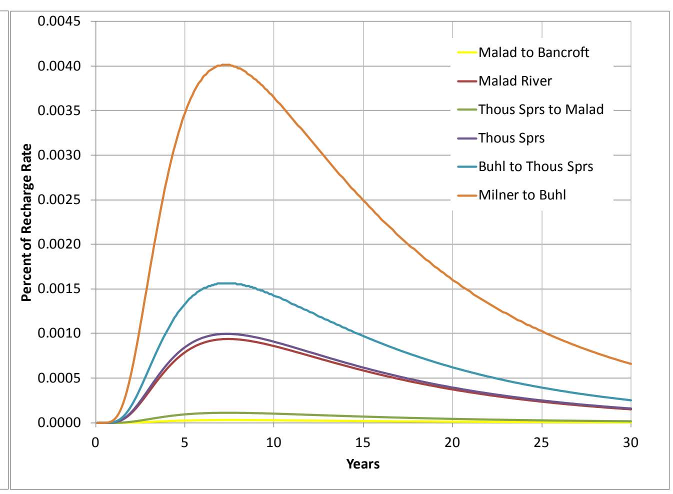


Figure G3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.

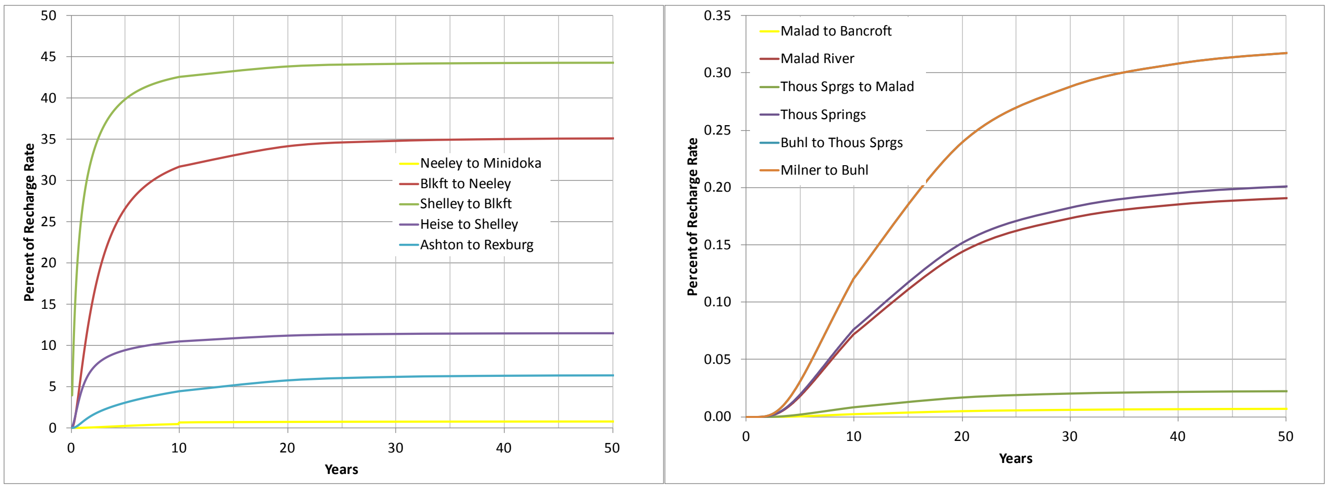




A

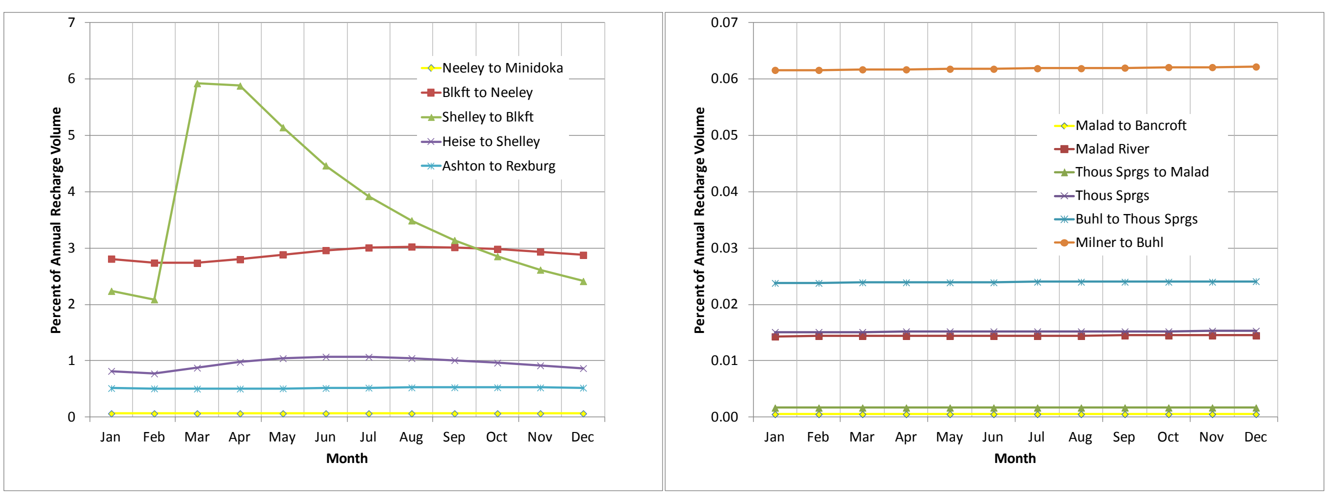
B

Figure G4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.



A B

Figure G5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.



A B

Figure G6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX H: Snake River Valley Results

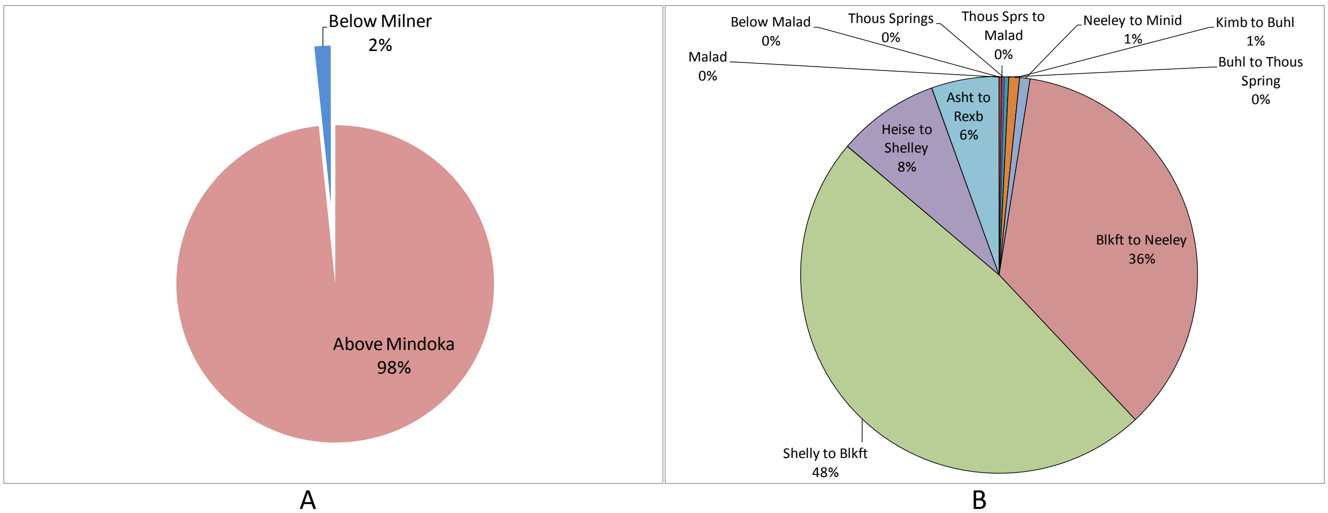


Figure H1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

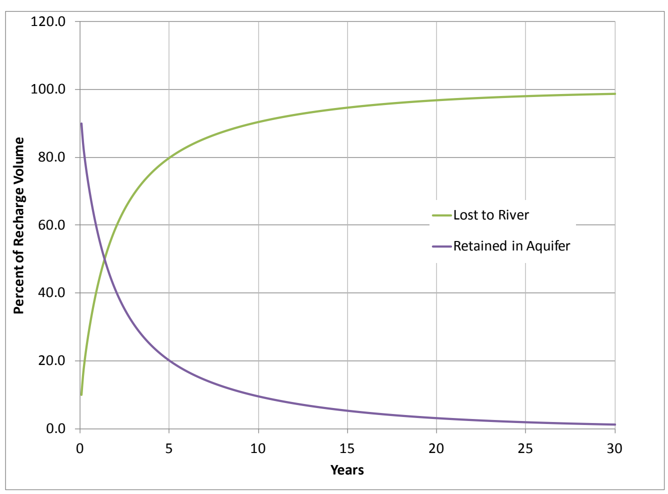


Figure H2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

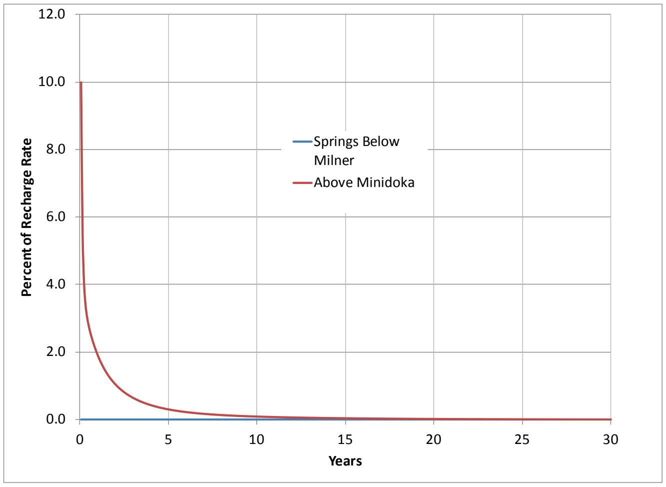
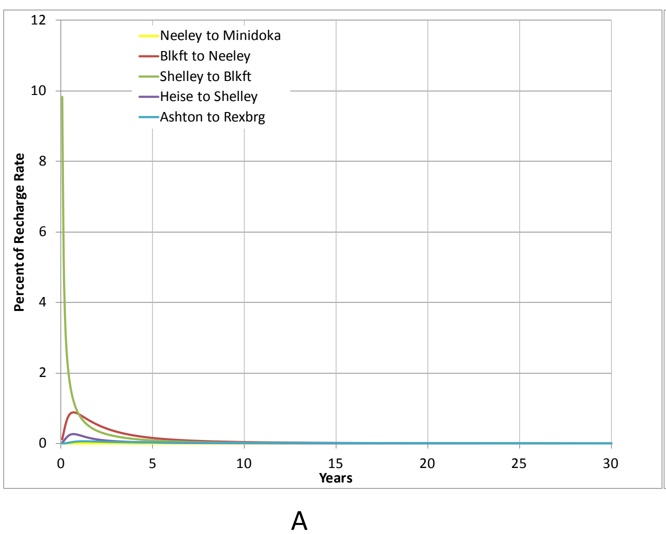


Figure H3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.



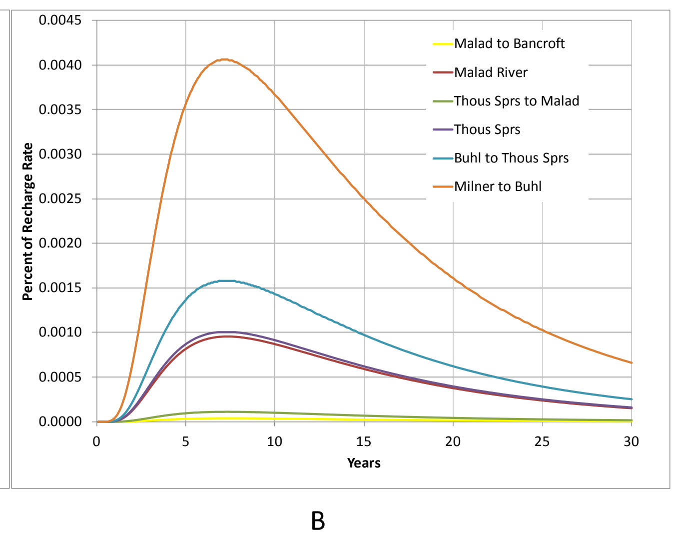


Figure H4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.

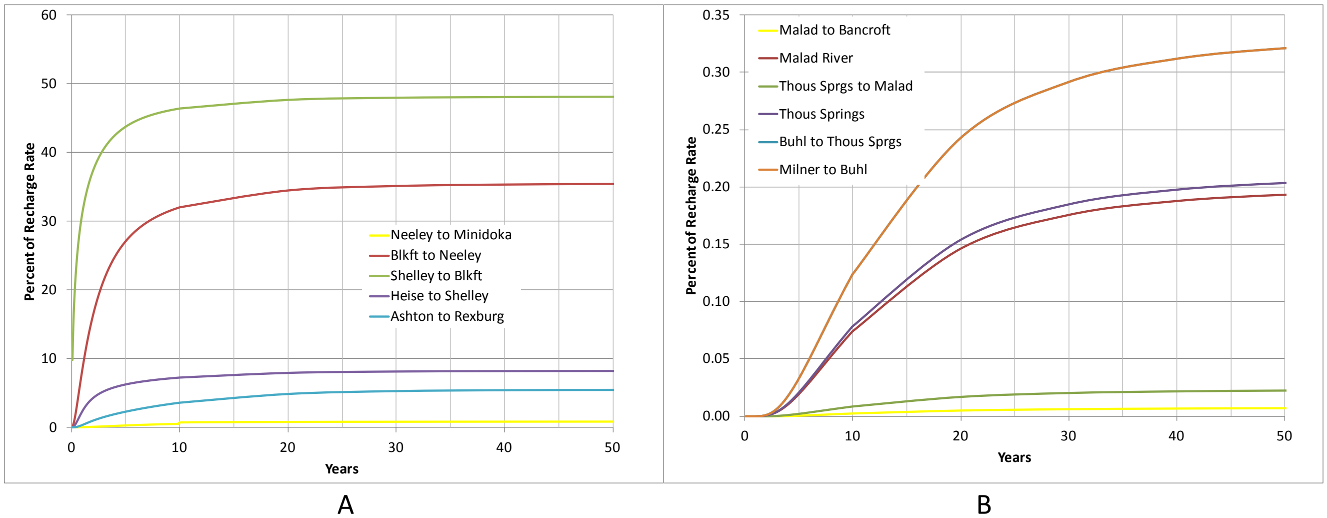


Figure H5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

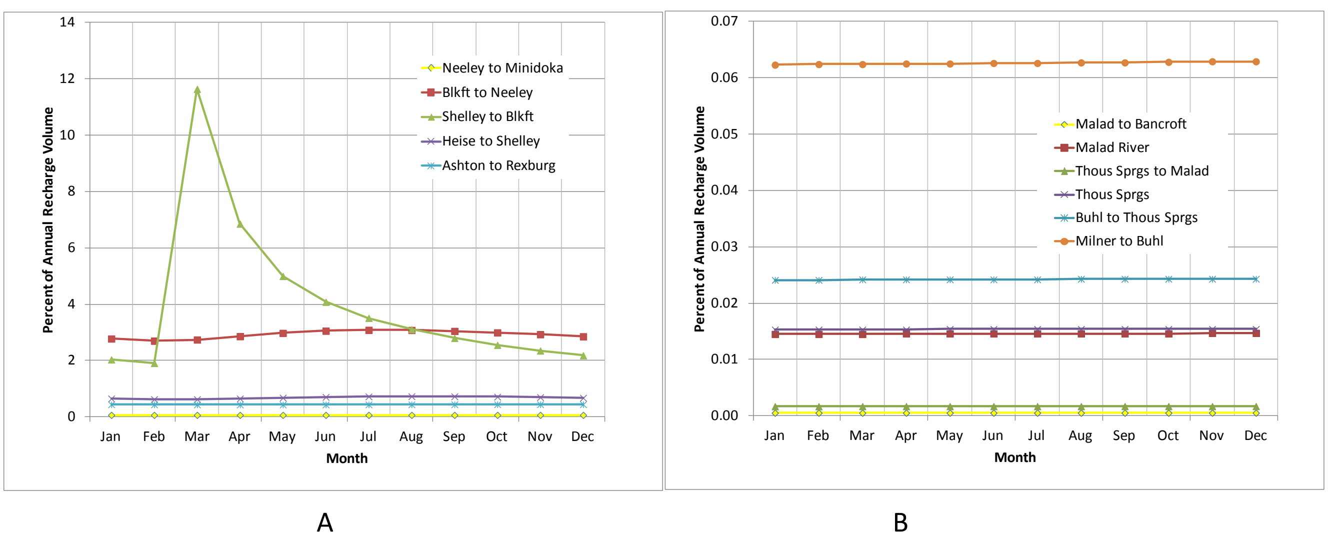
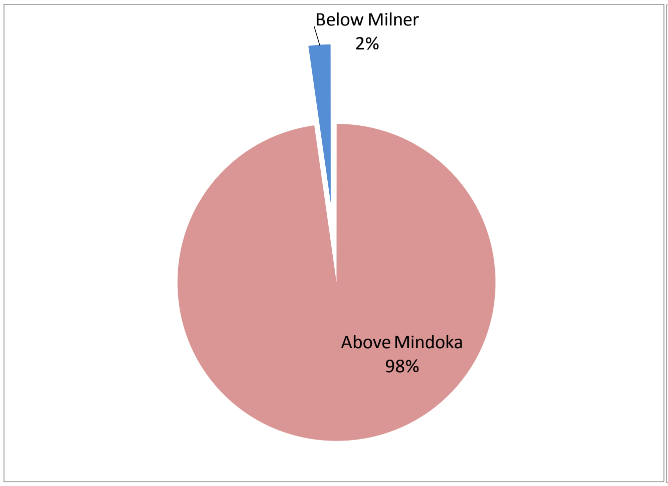
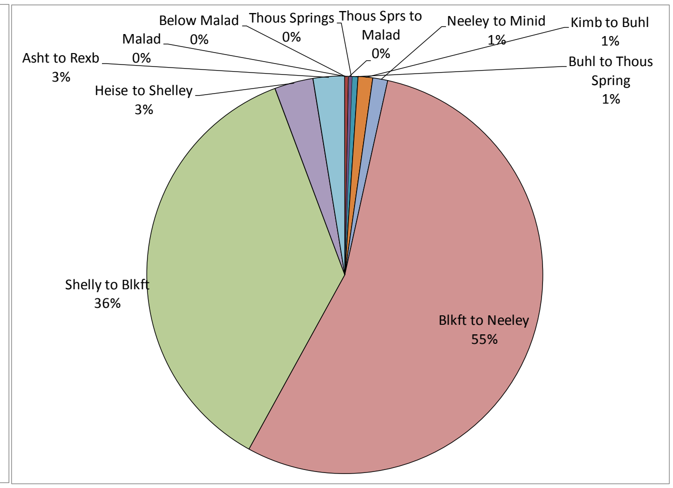


Figure H6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX I: Peoples Results



A



B

Figure I1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

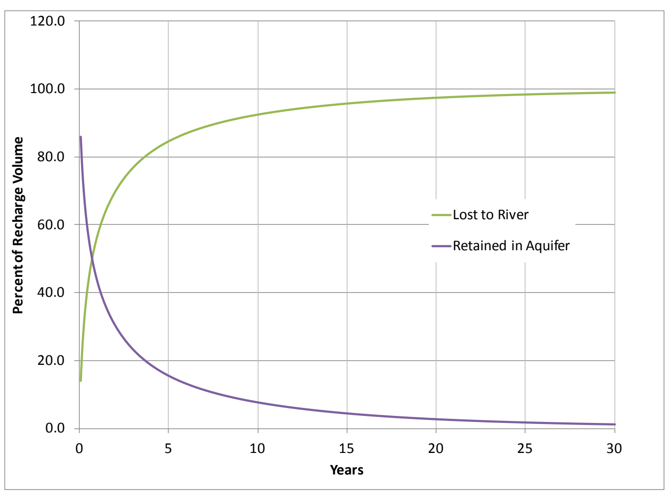


Figure I2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

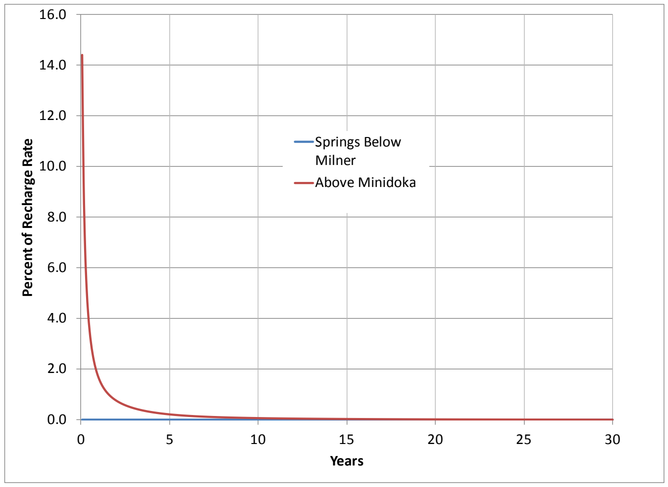
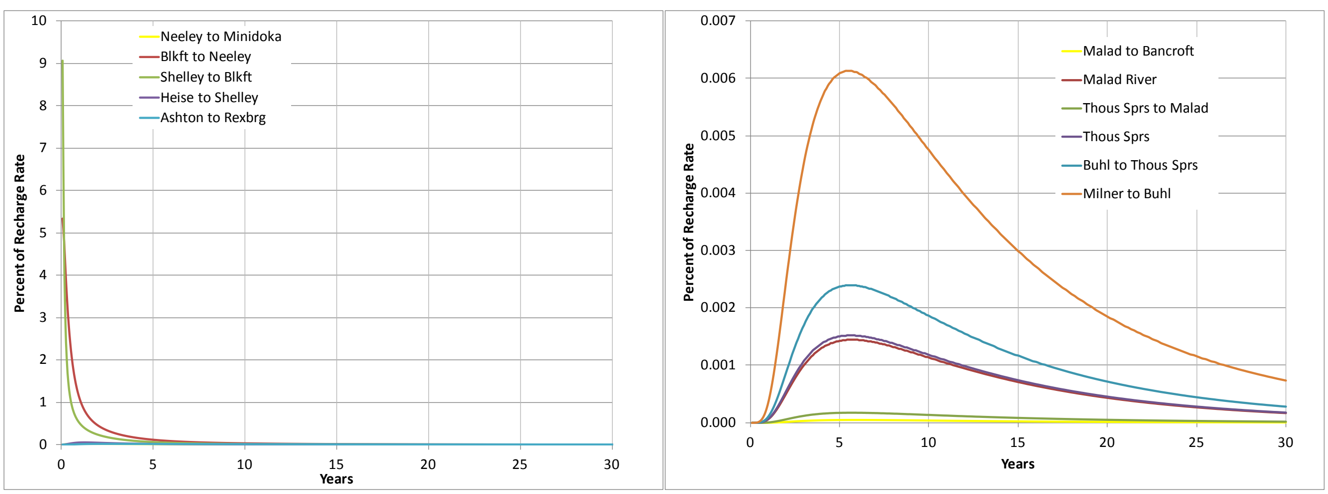


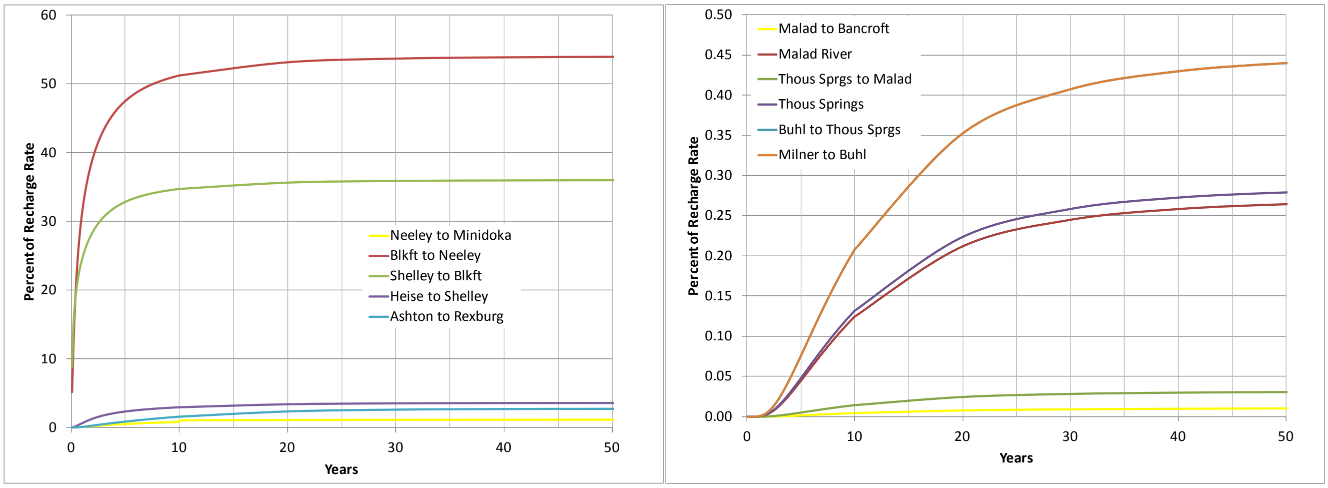
Figure I3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.



A

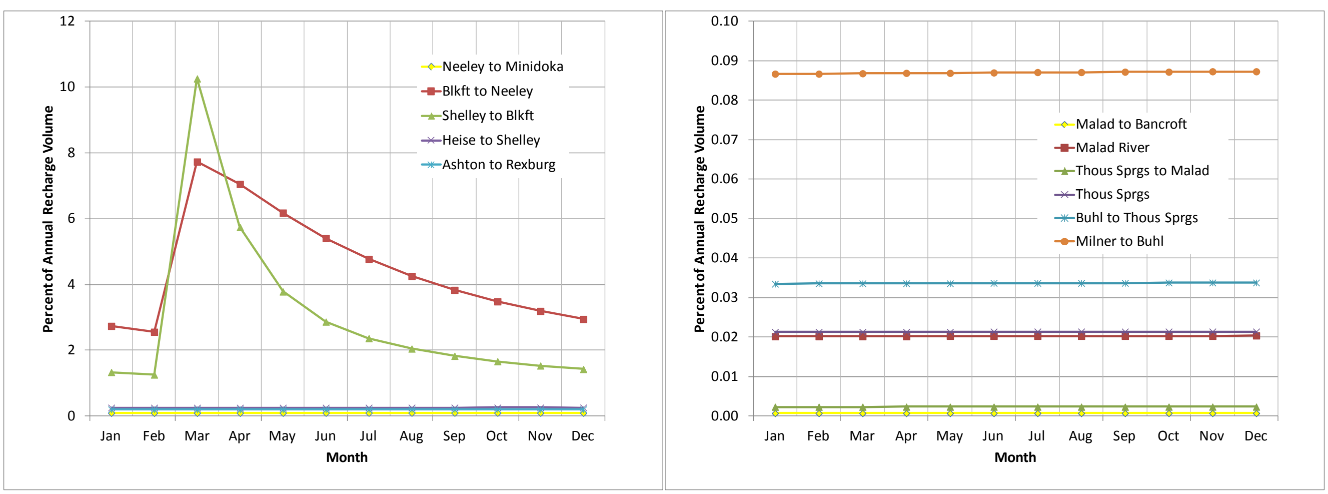
B

Figure I4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.



A B

Figure I5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.



A B

Figure I6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX J: Riverside Results

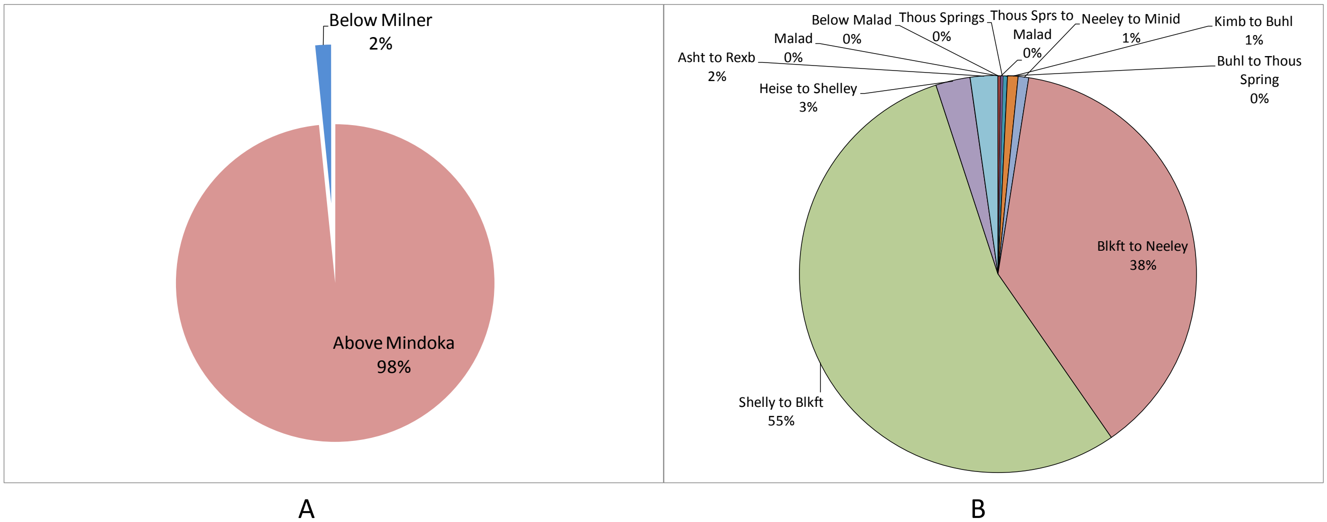


Figure J1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

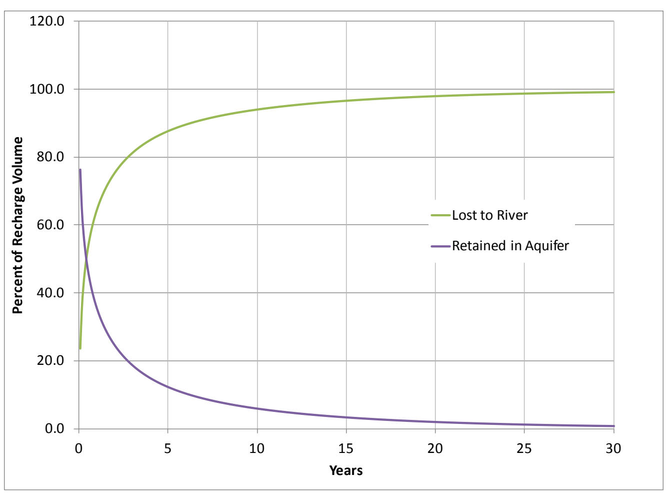


Figure J2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

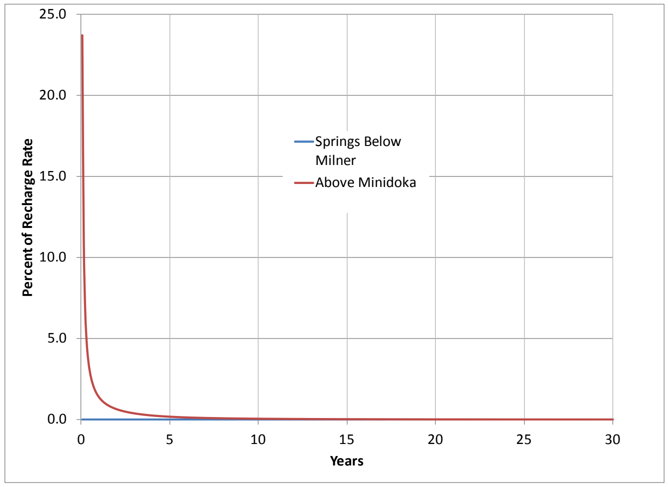


Figure J3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.

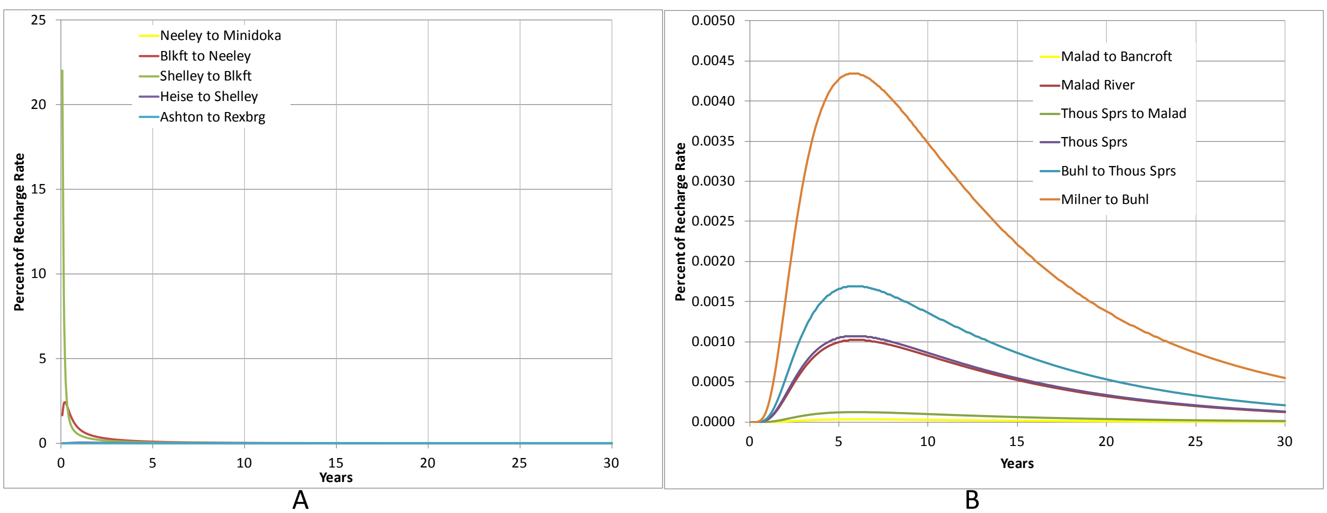


Figure J4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.

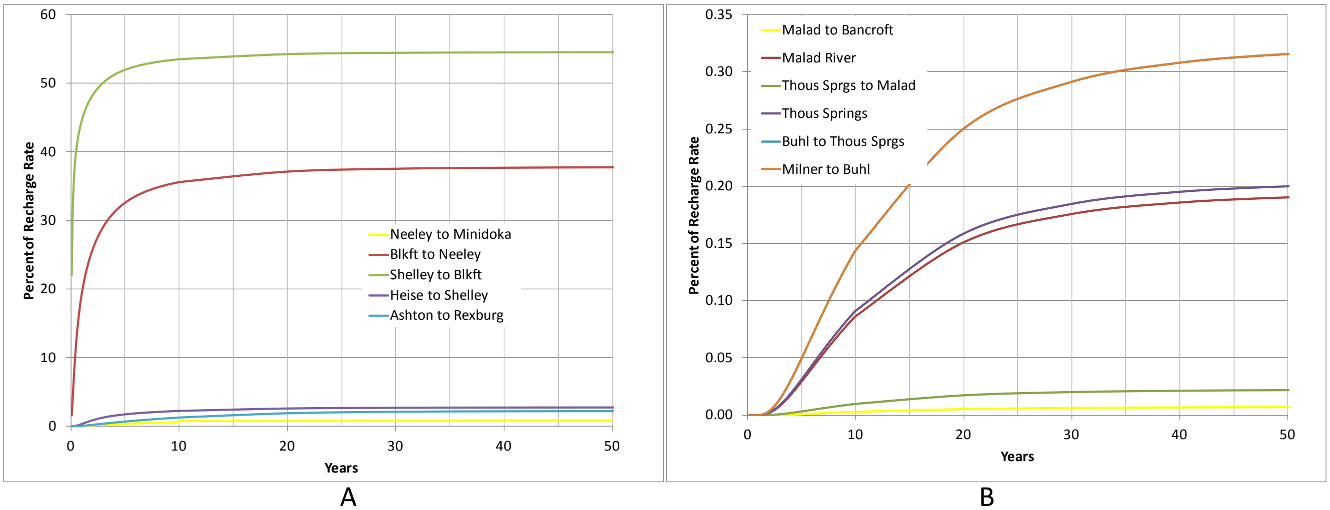


Figure J5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

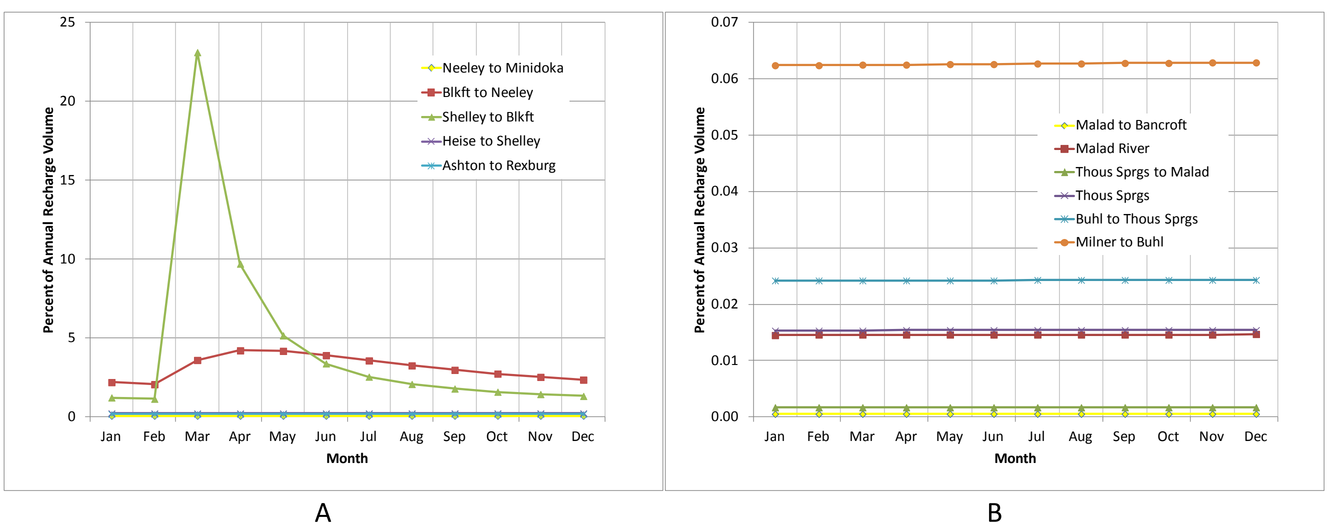
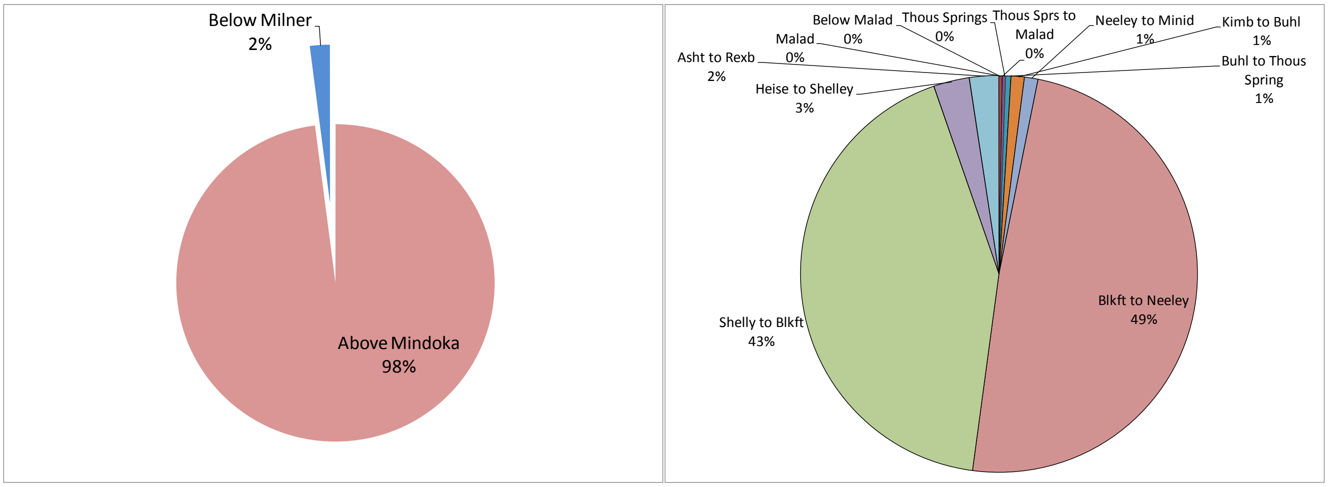


Figure J6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX K: United Results



A B

Figure K1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

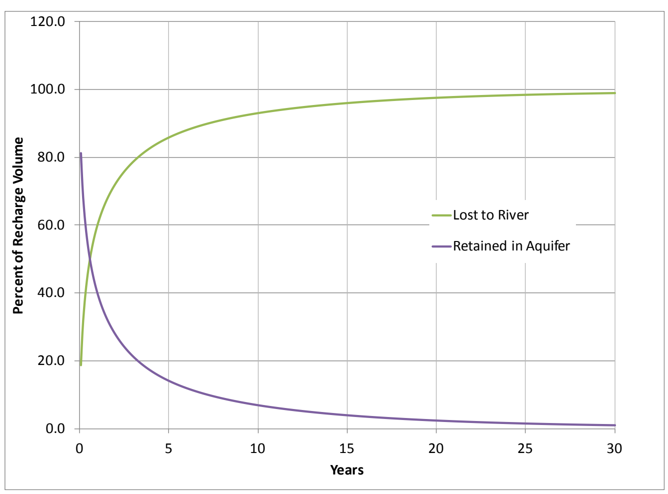


Figure K2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

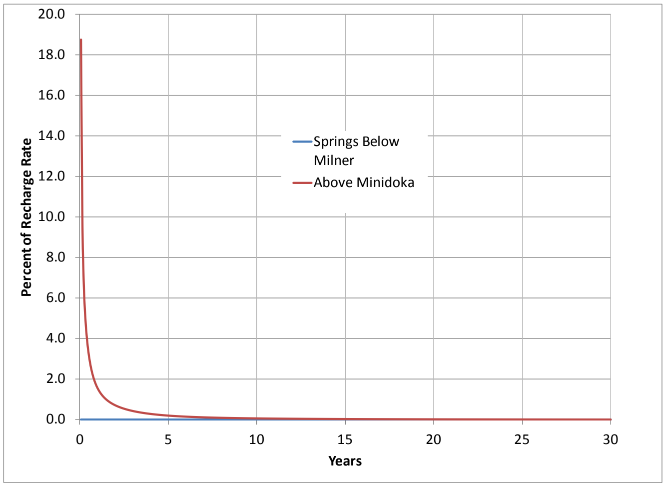
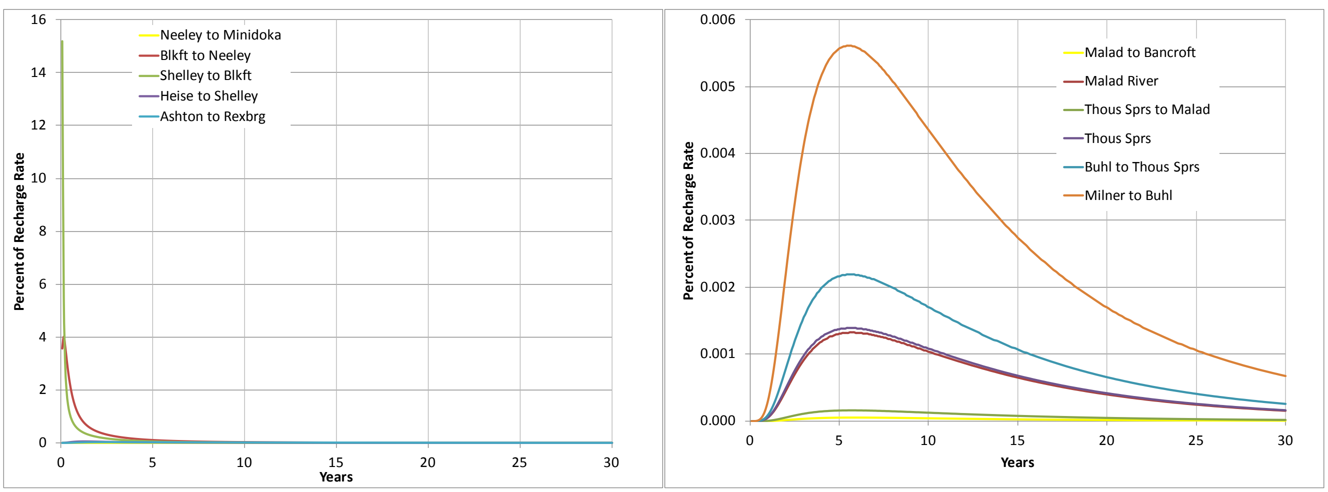


Figure K3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.



A

B

Figure K4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.

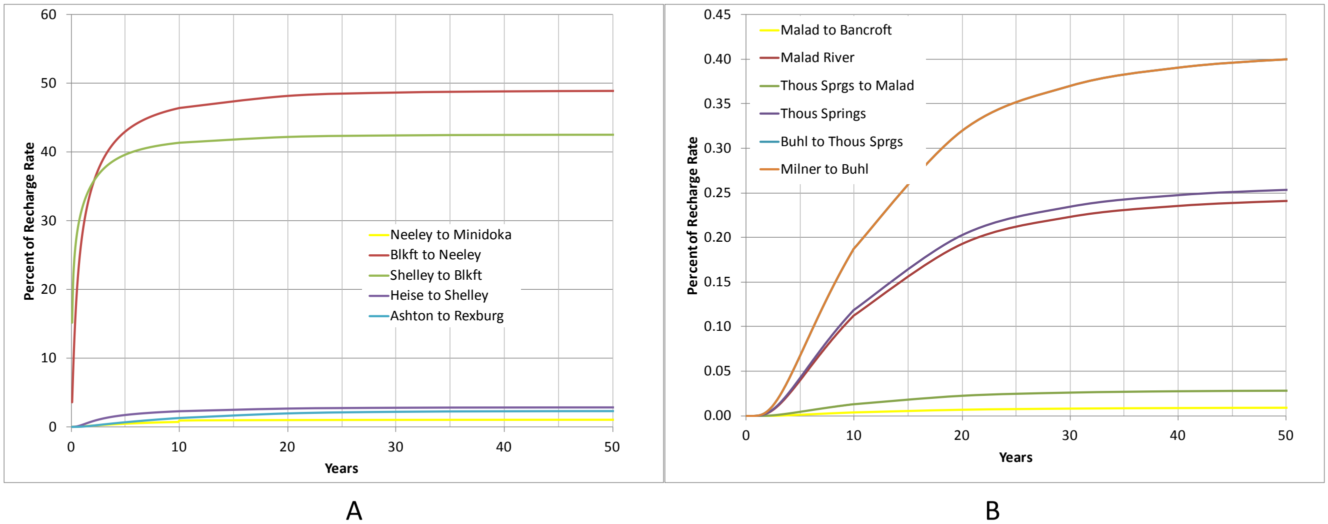


Figure K5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

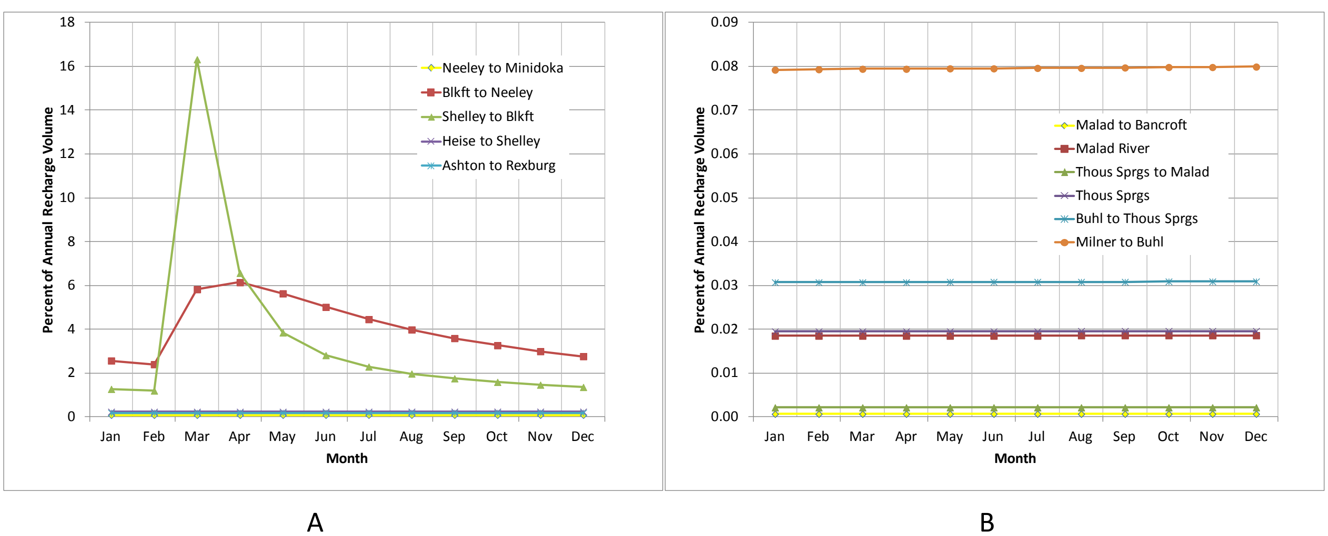


Figure K6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX L: Jensen's Grove Results

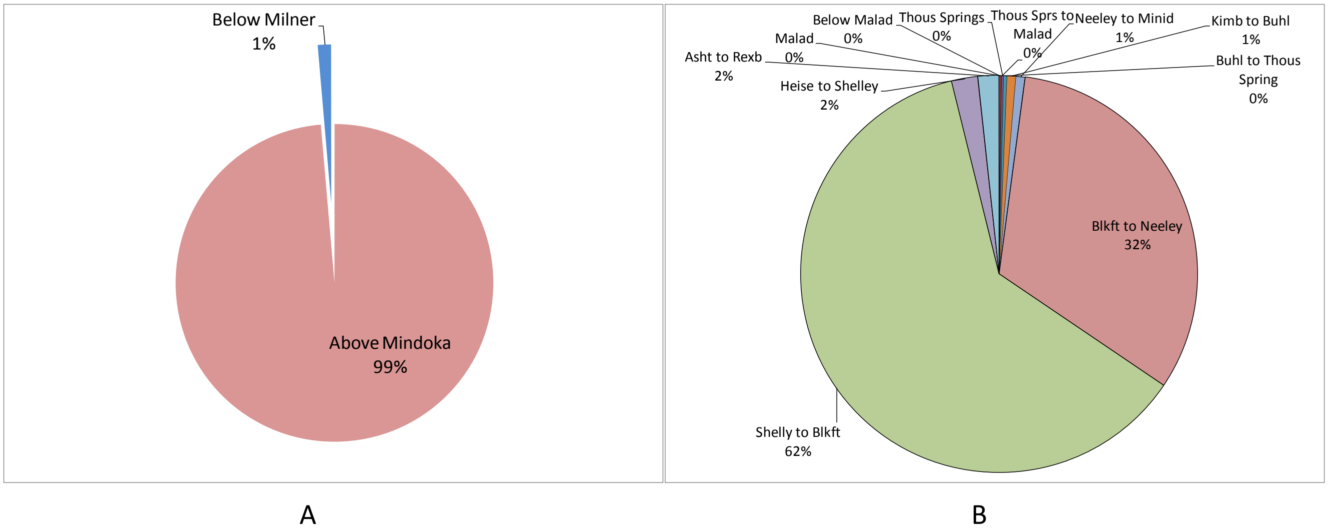


Figure L1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

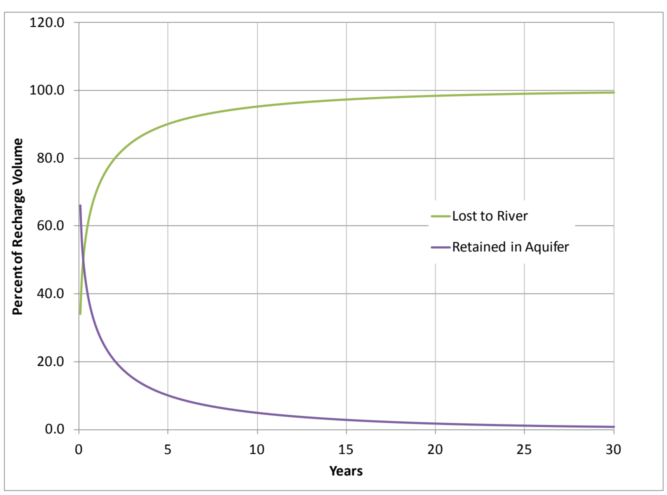


Figure L2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

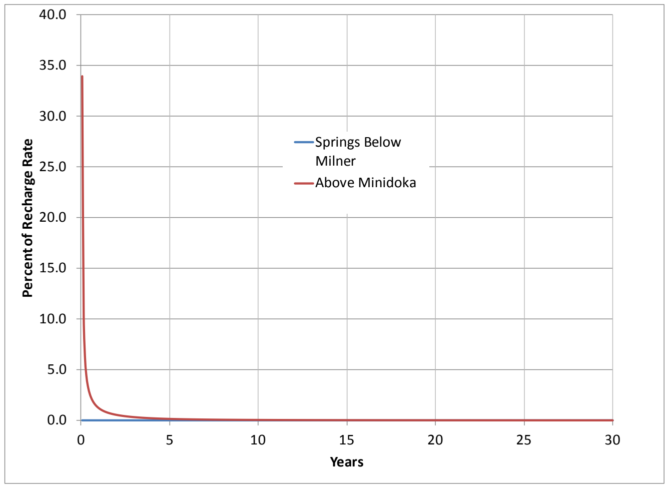


Figure L3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.

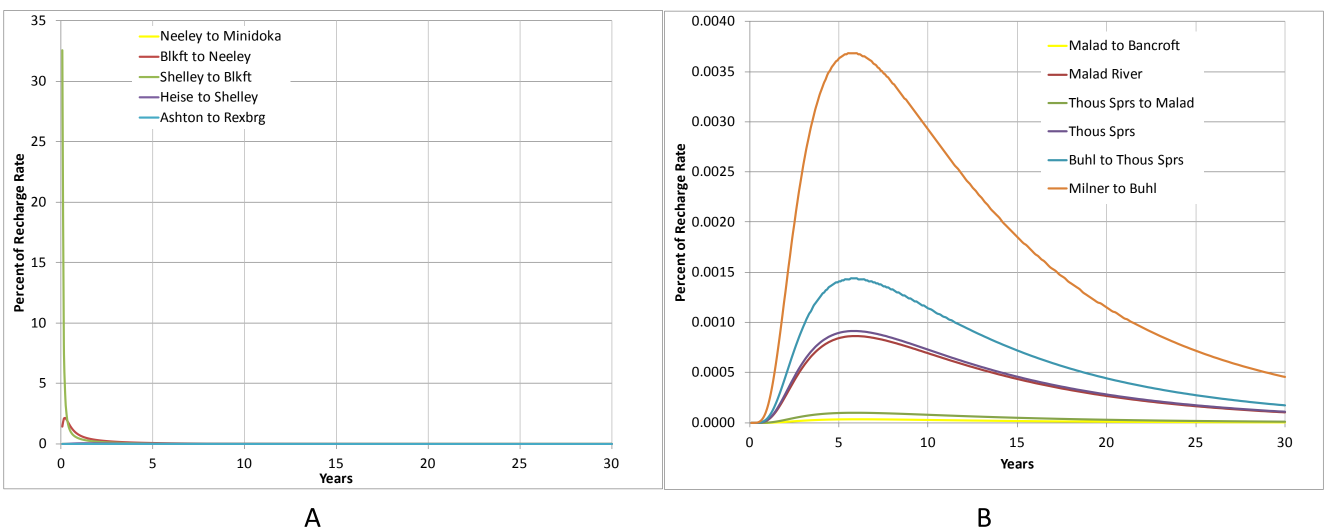


Figure L4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.

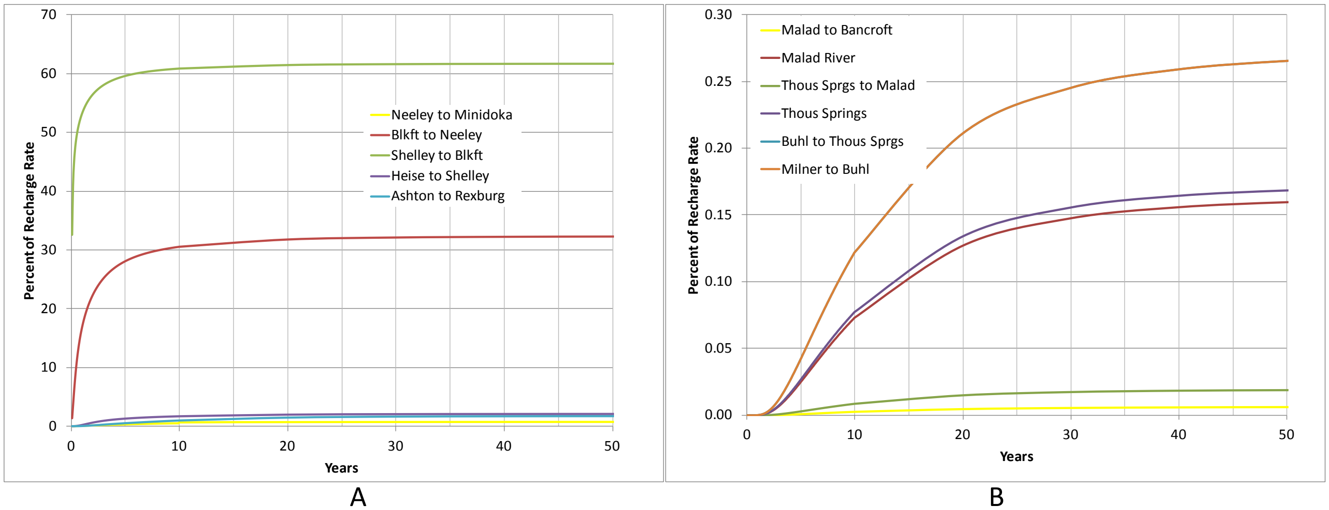


Figure L5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

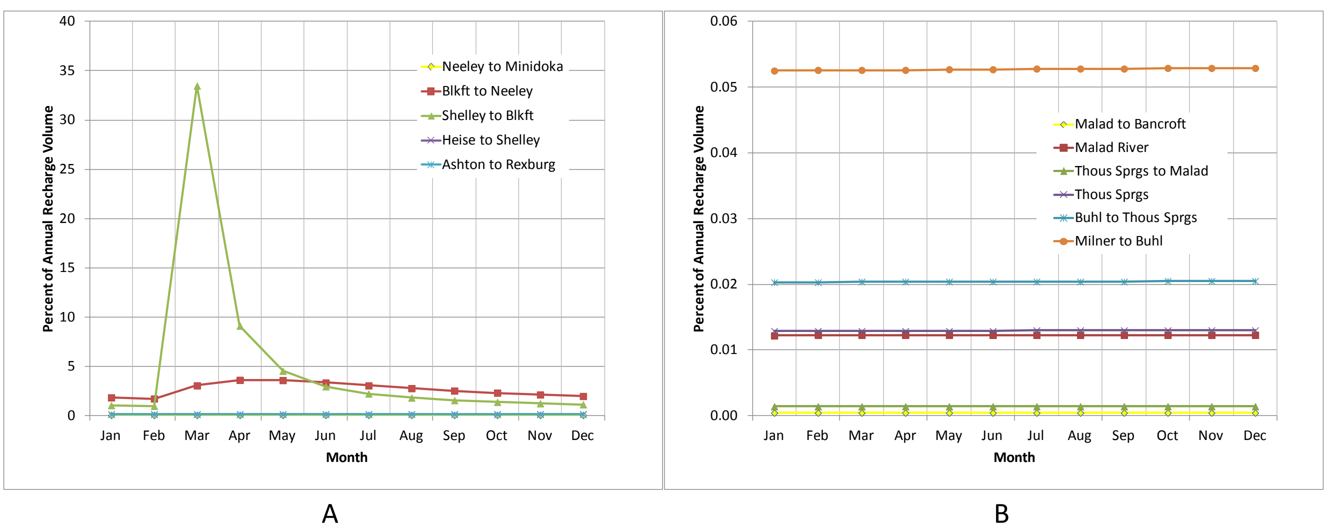
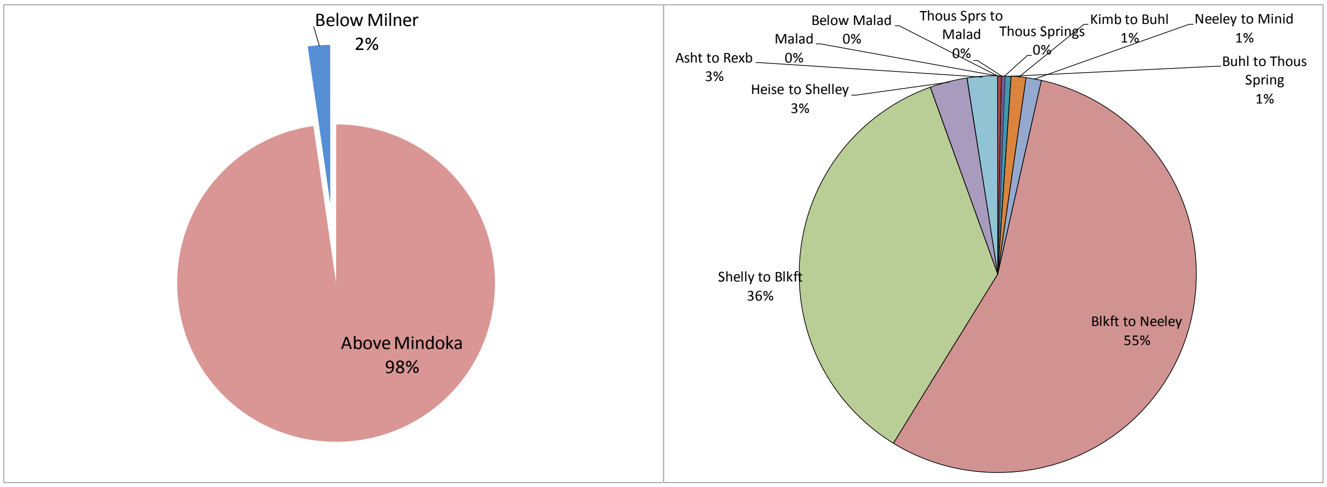


Figure L6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX M: Aberdeen Springfield Results



A B

Figure M1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

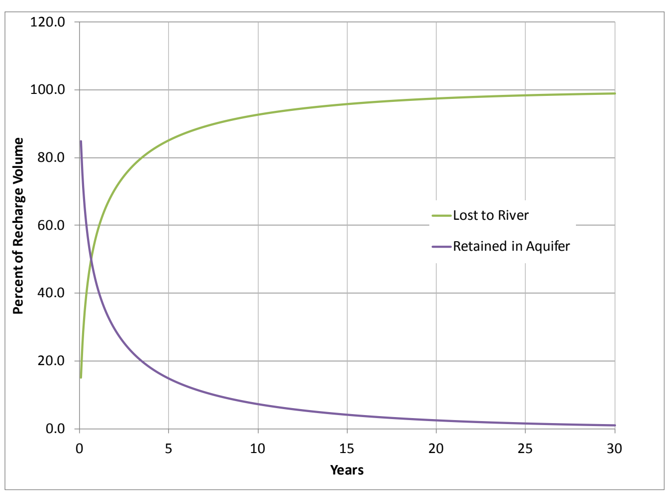


Figure M2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

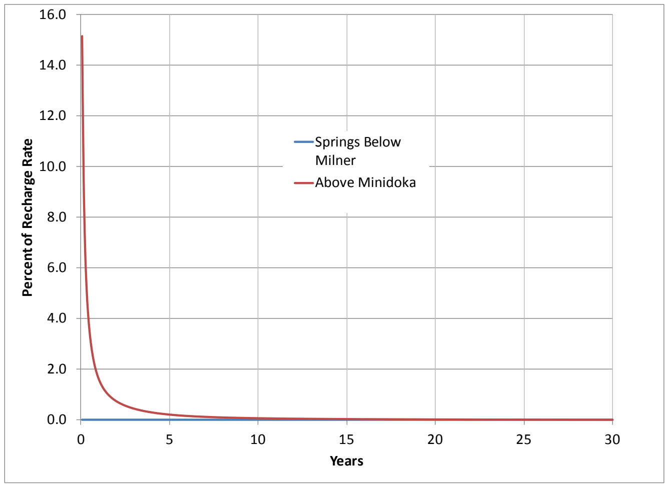


Figure M3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.

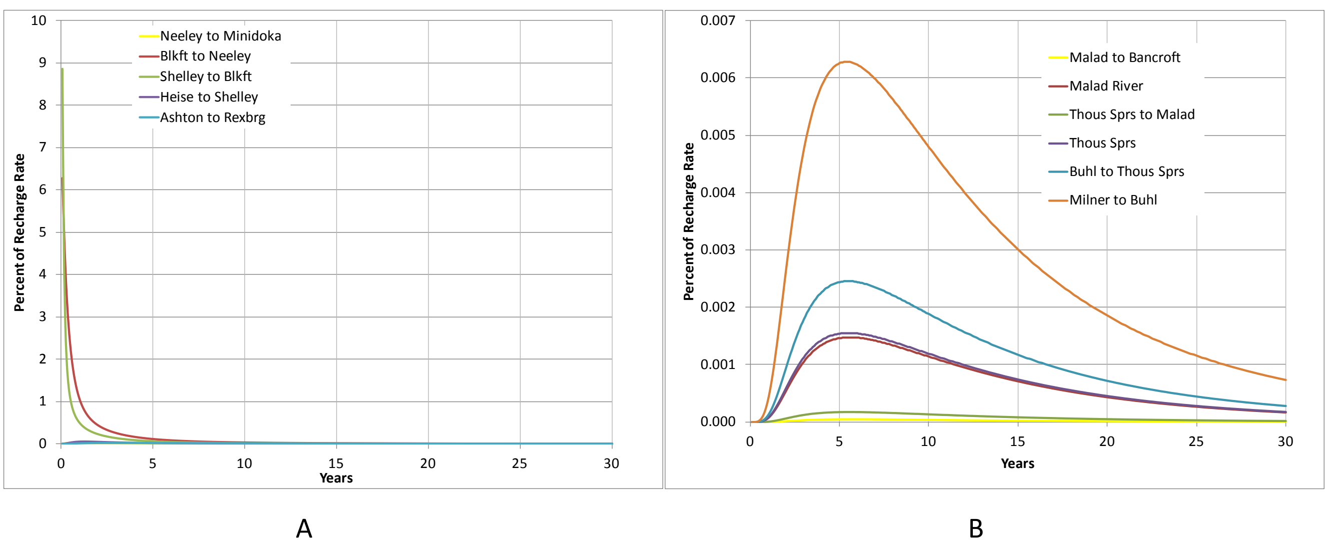
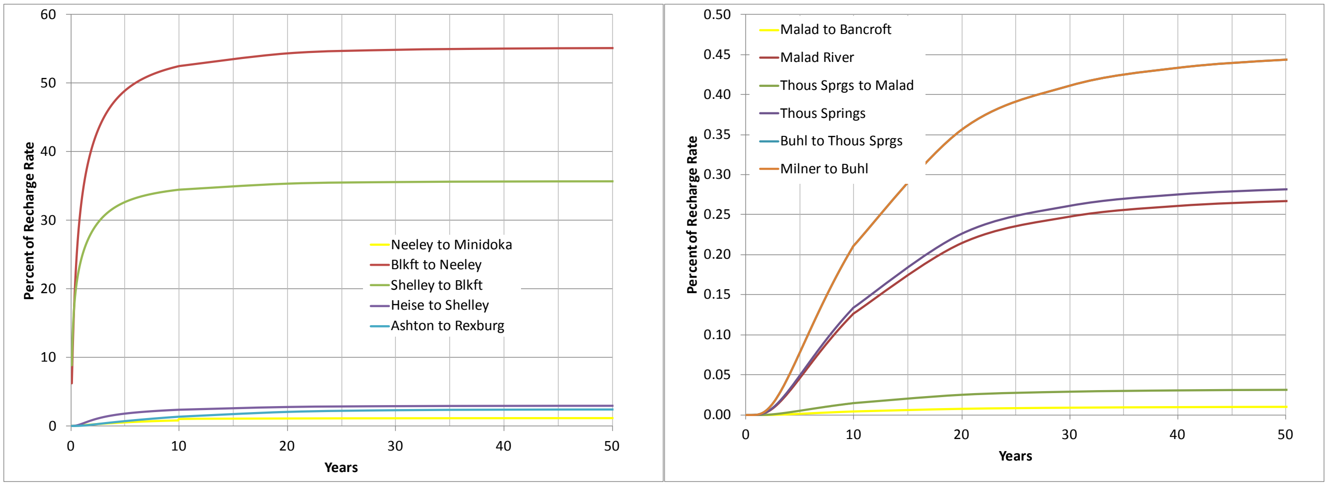
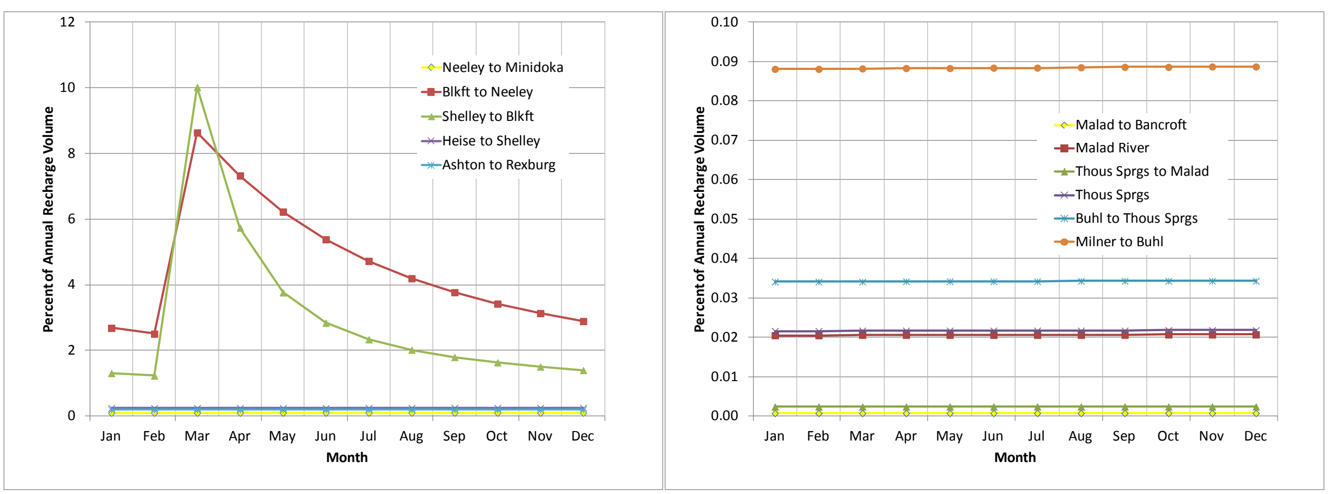


Figure M4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.



A B

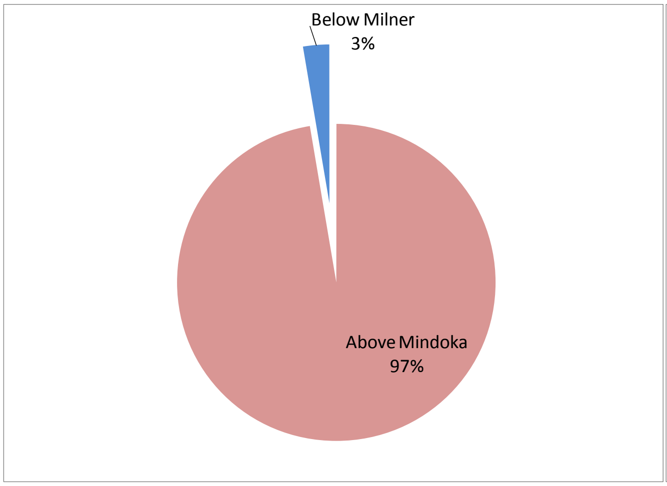
Figure M5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

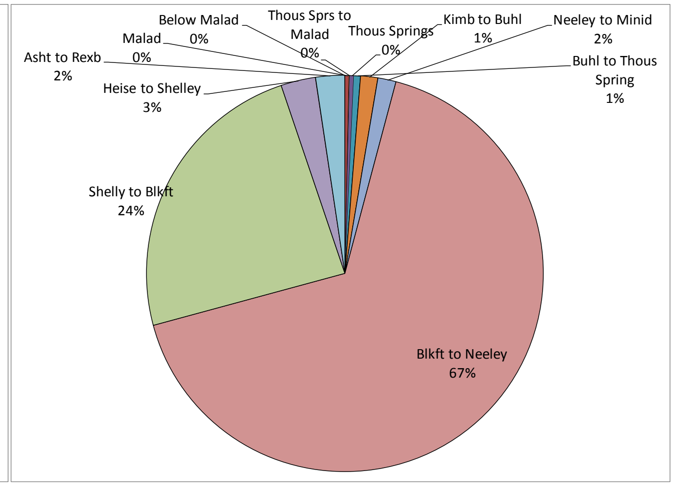


A B

Figure M6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX N: Hilton Spill Results





A B

Figure N1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

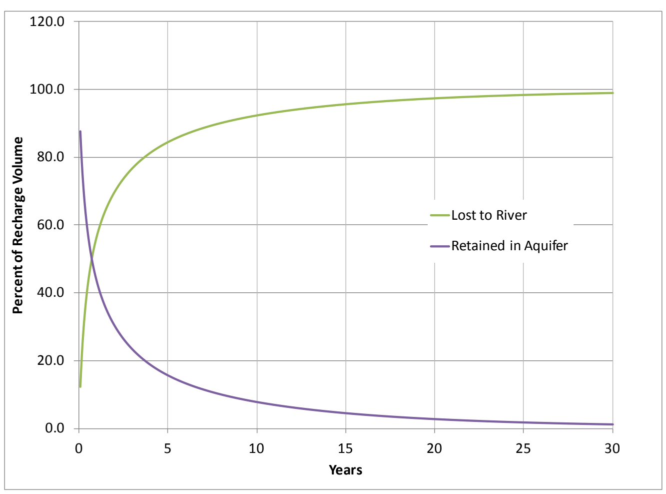


Figure N2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

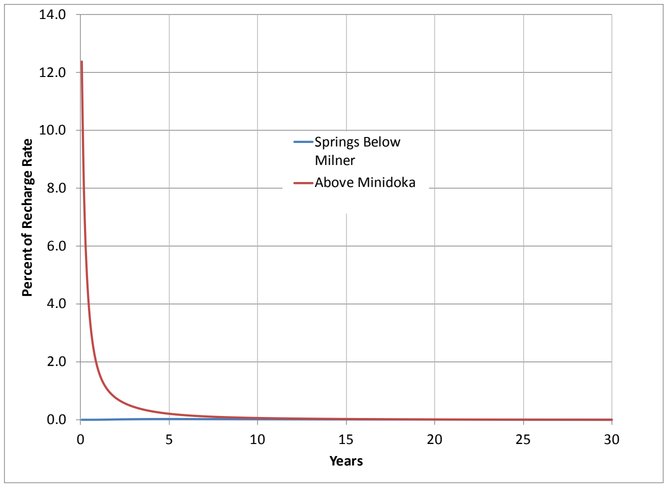
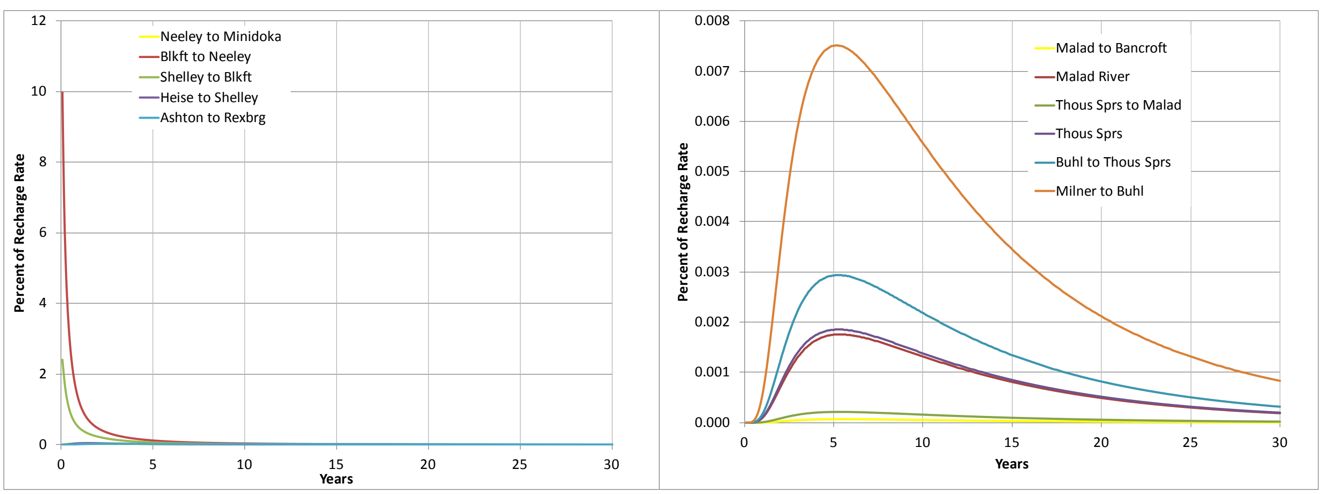
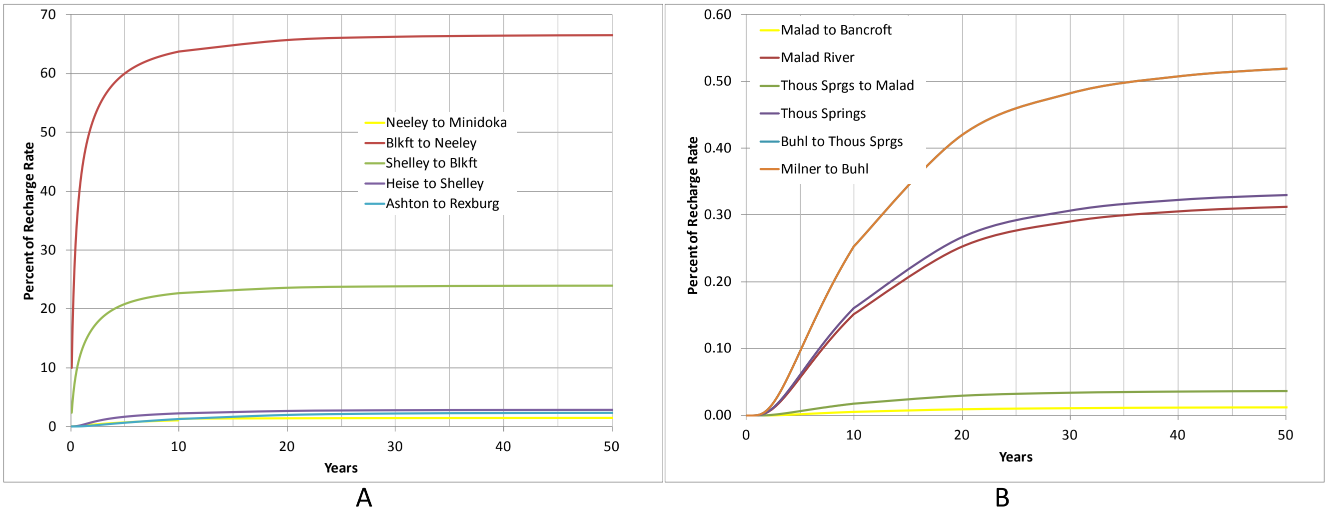


Figure N3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.



A B

Figure N4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.



FigureN5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

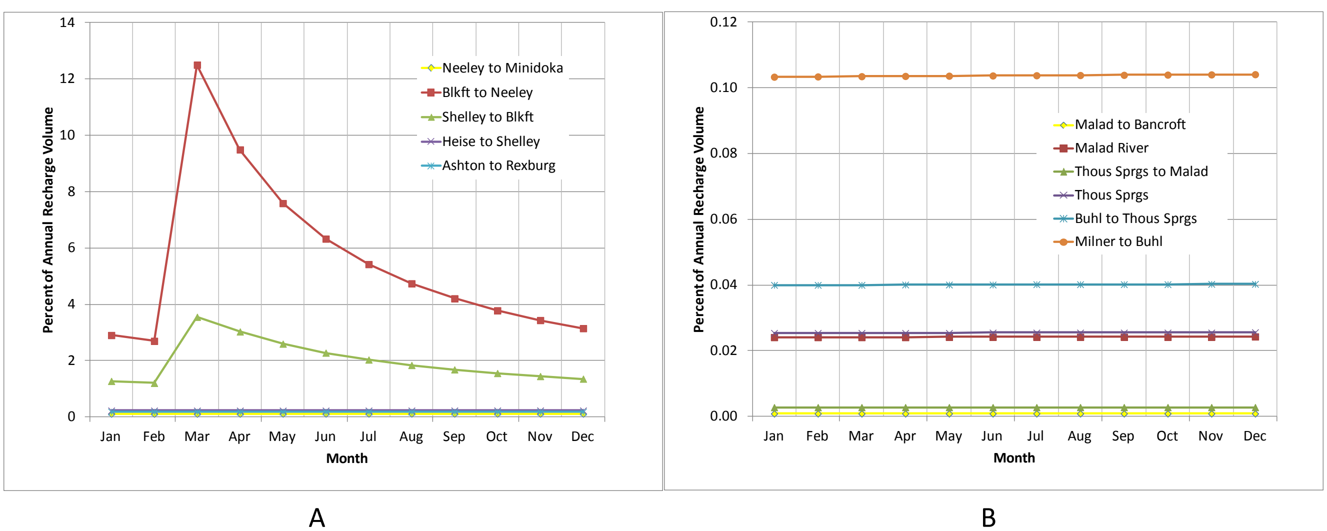
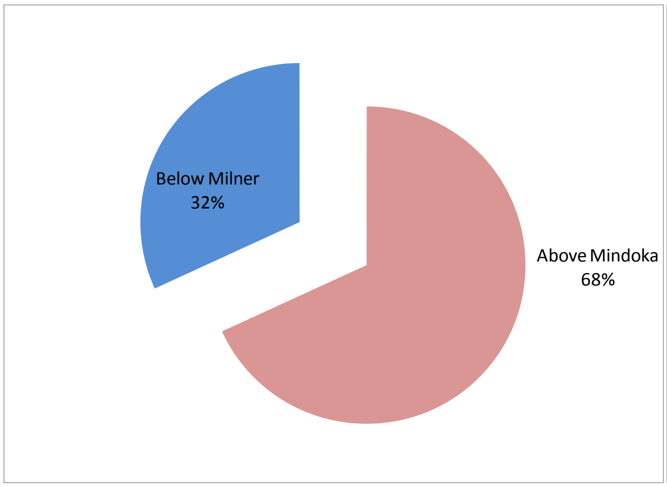
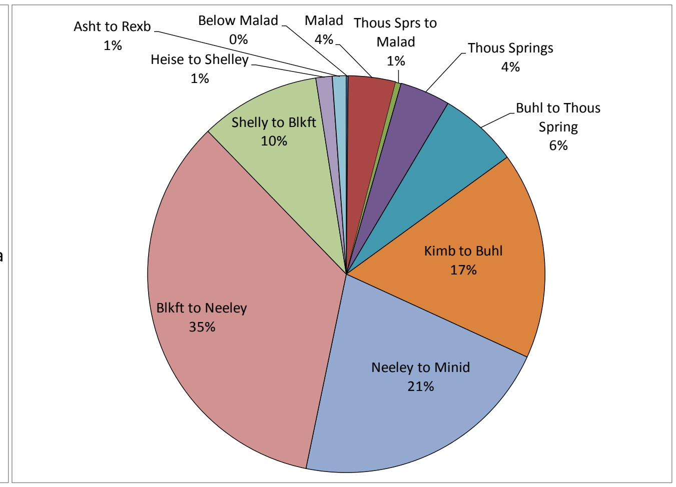


Figure N6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX O: Lake Walcott Recharge Site Results





A B

Figure O1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

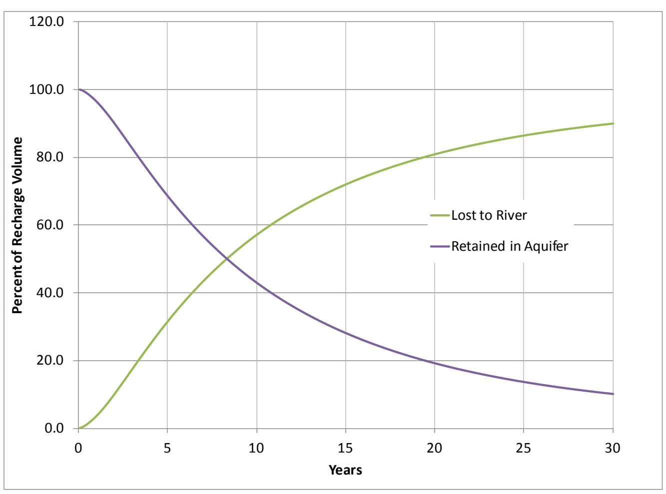


Figure O2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

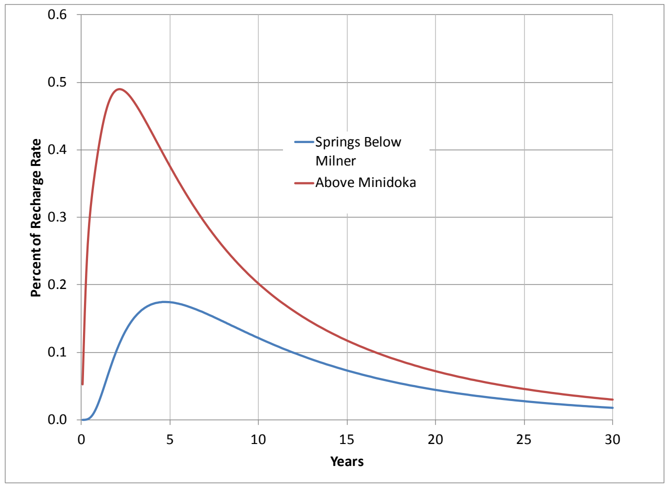


Figure O3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.

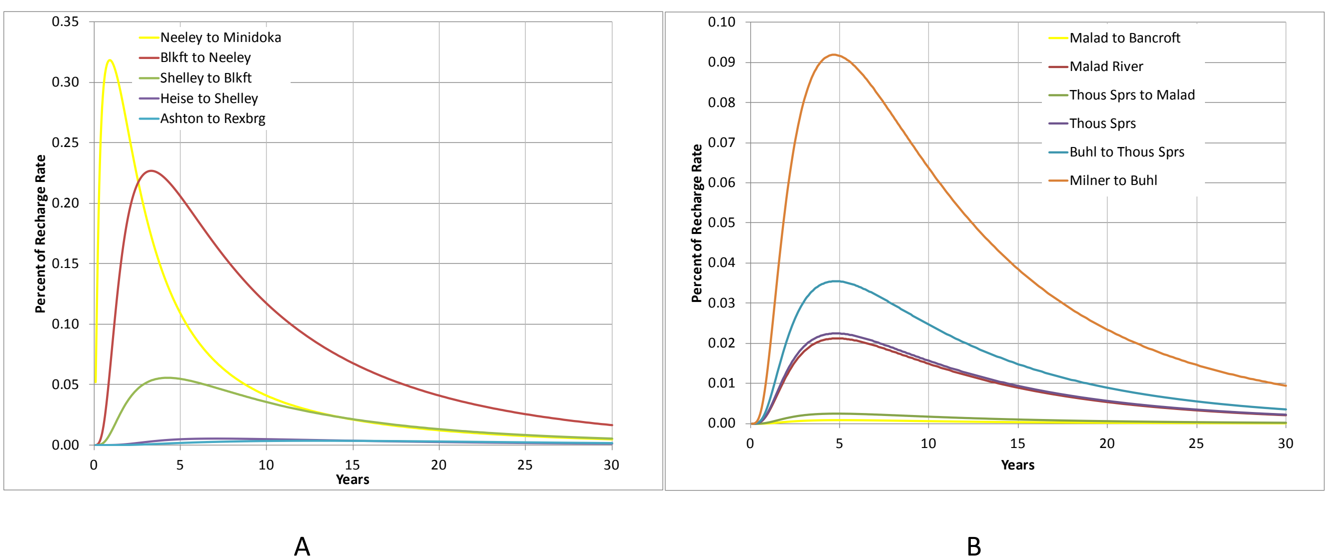
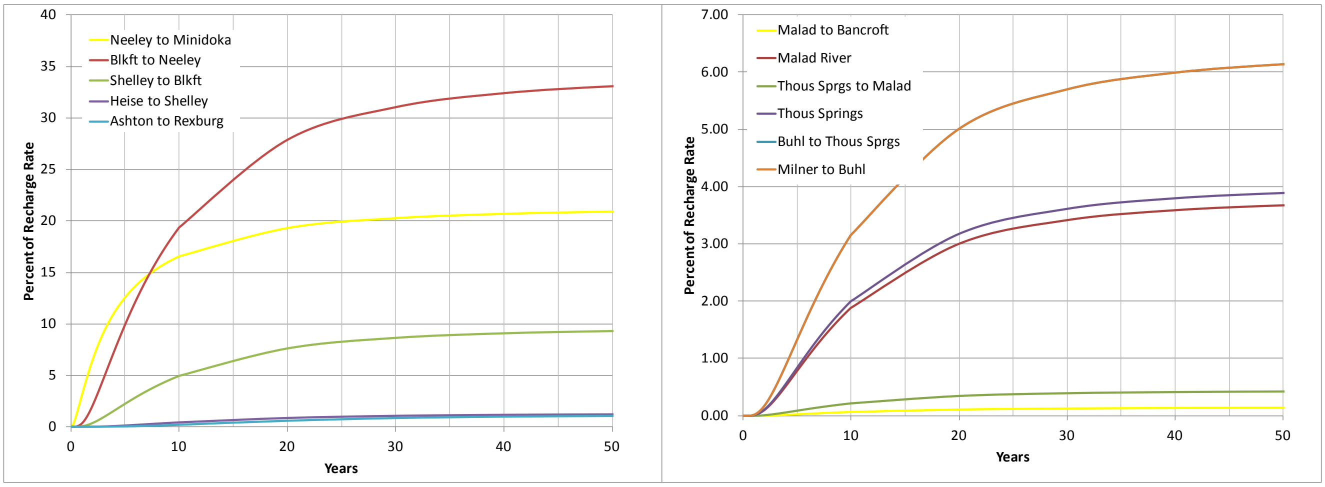
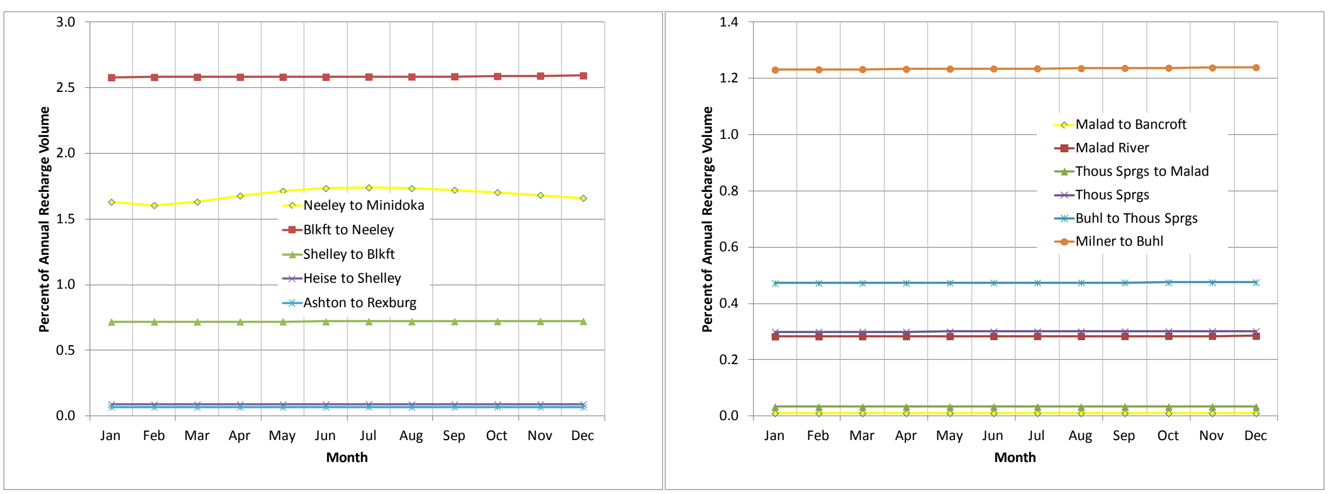


Figure O4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.



A B

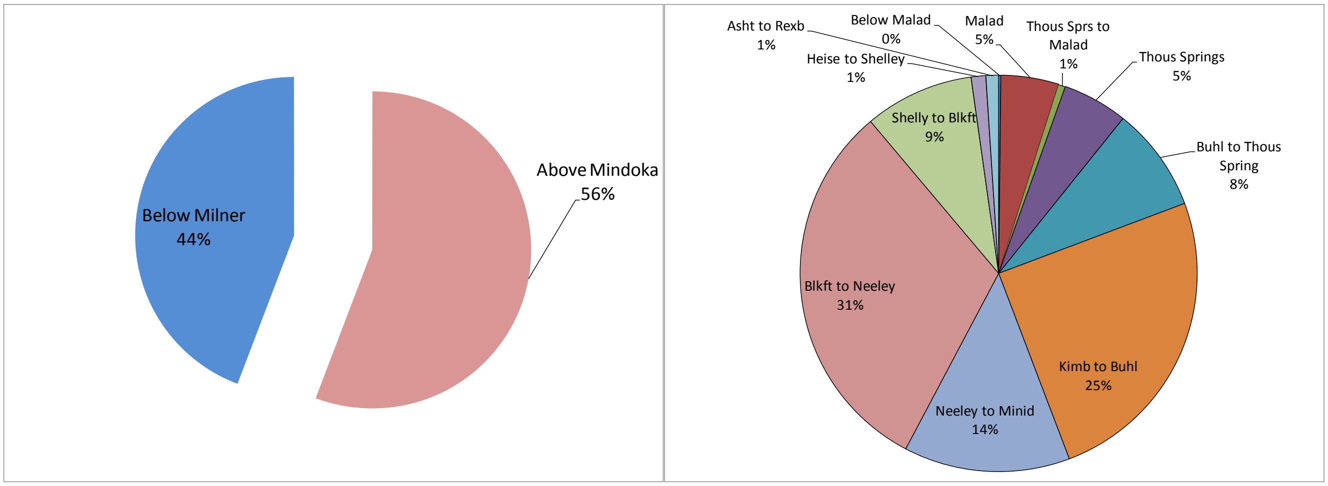
Figure O5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.



A B

Figure O6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX P: Southwest Irrigation District Results



A B

Figure P1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

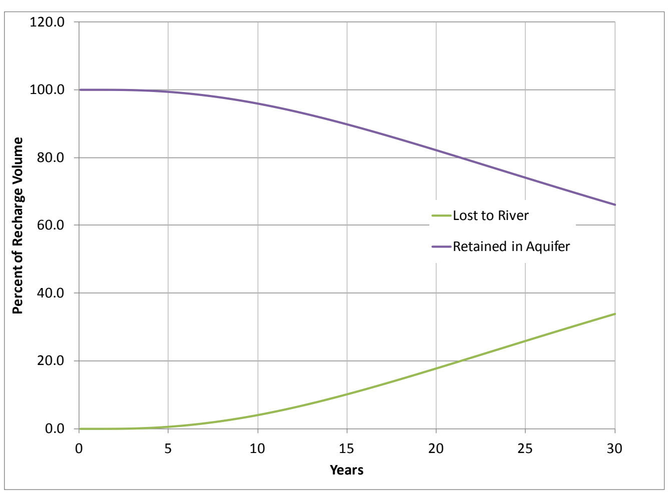


Figure P2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

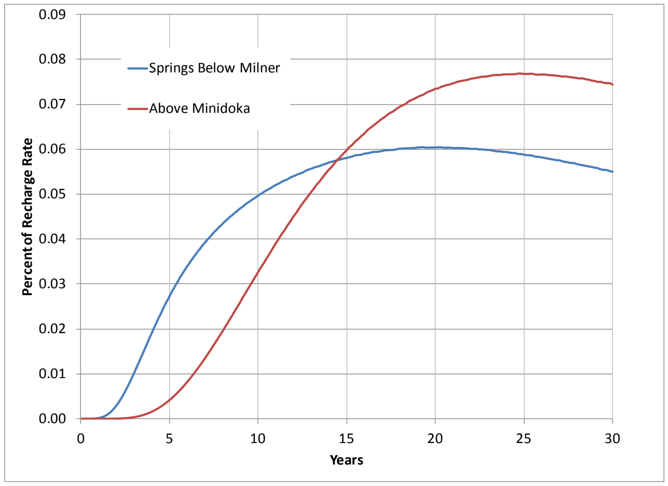
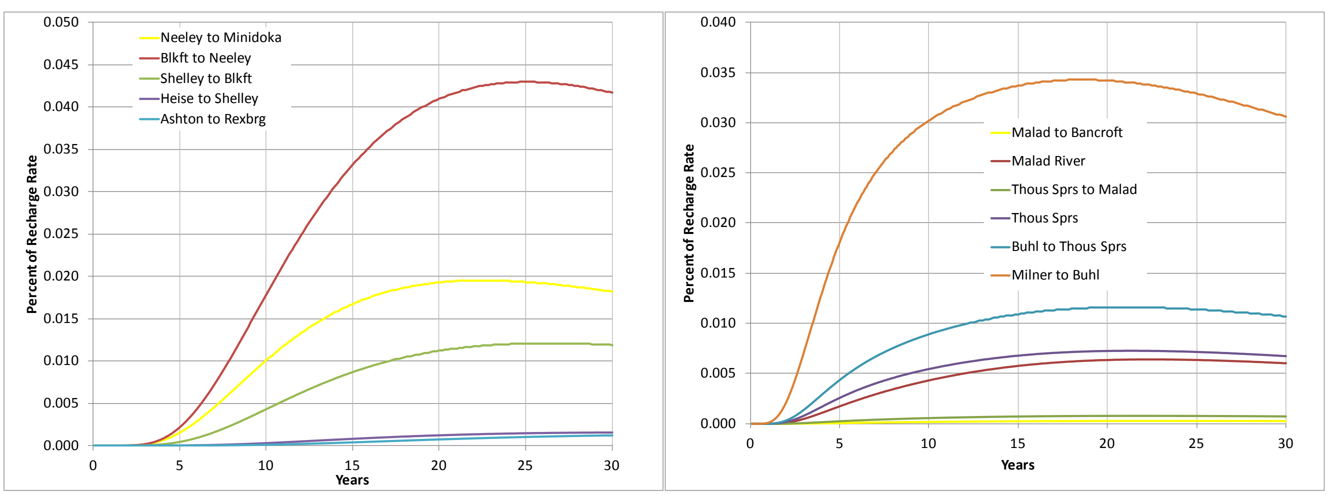


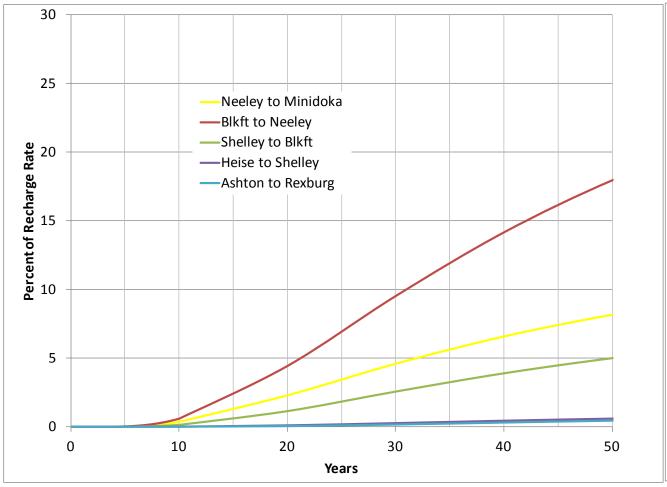
Figure P3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.

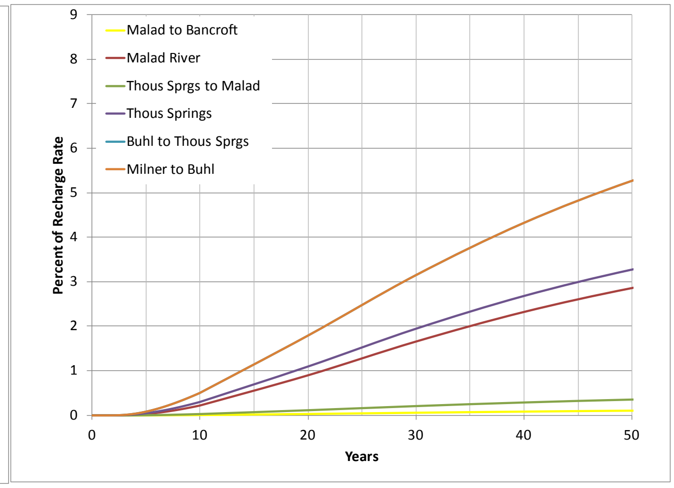


A

B

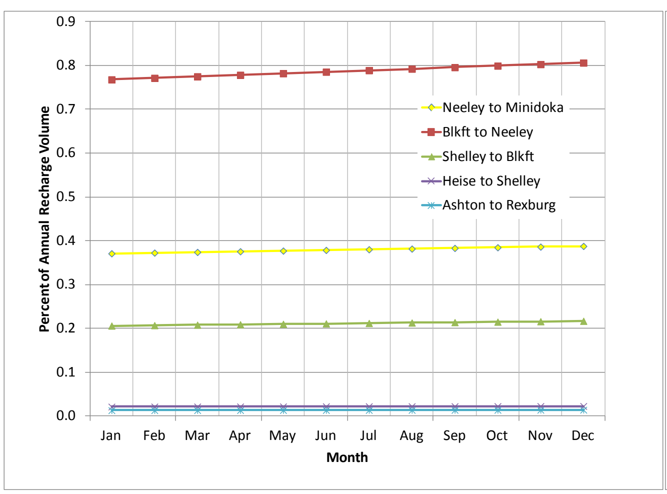
Figure P4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.

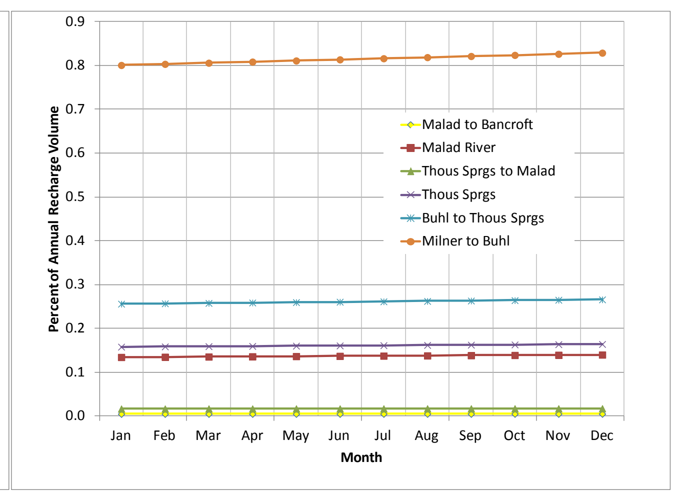




A B

Figure P5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

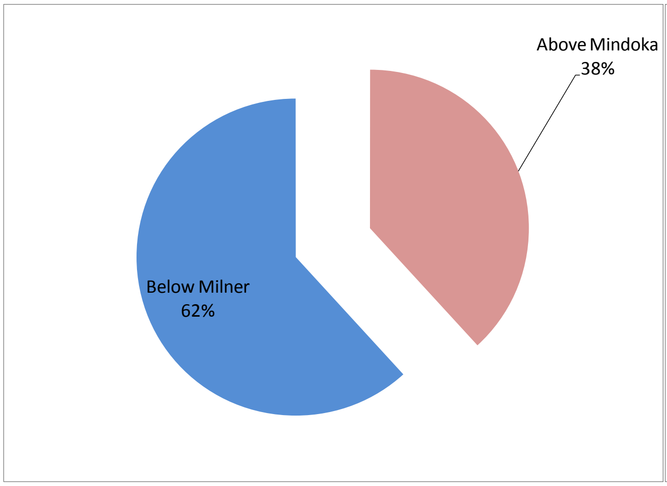


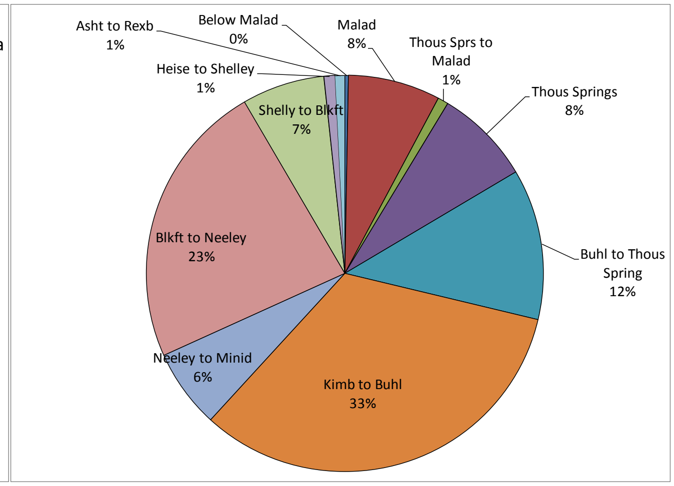


A B

Figure P6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

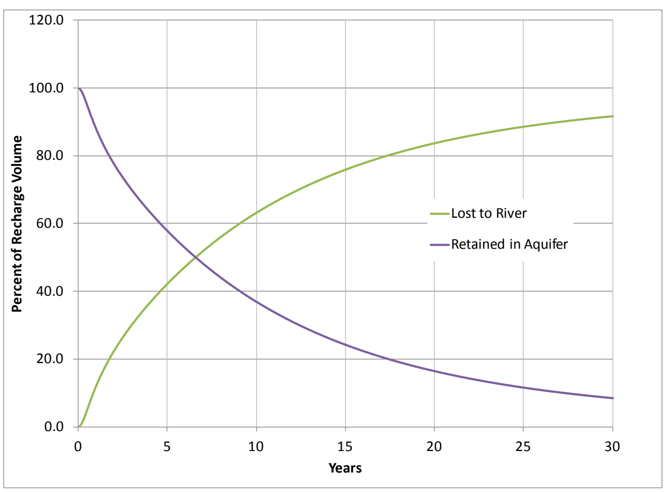
APPENDIX Q: Milner Gooding Canal Results





A B

Figure Q1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.



FigureQ2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

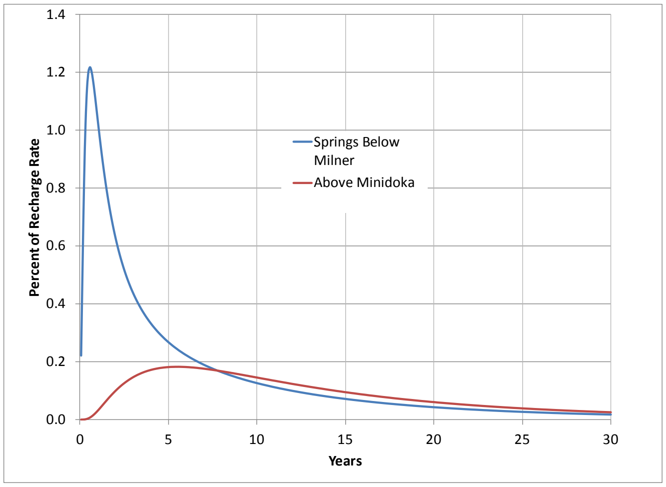
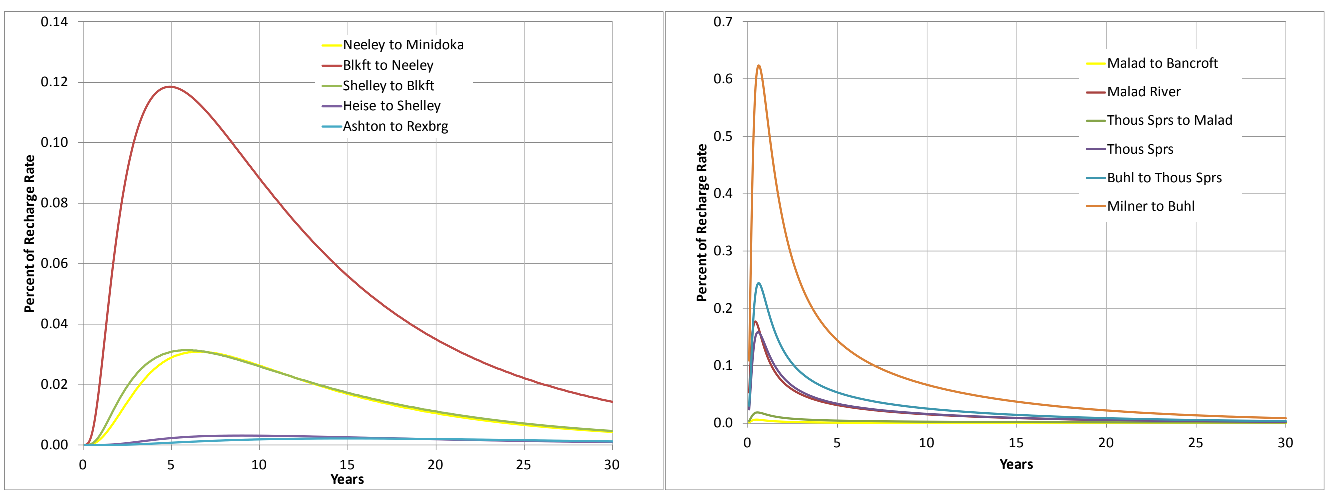


Figure Q3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.



A B

Figure Q4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.

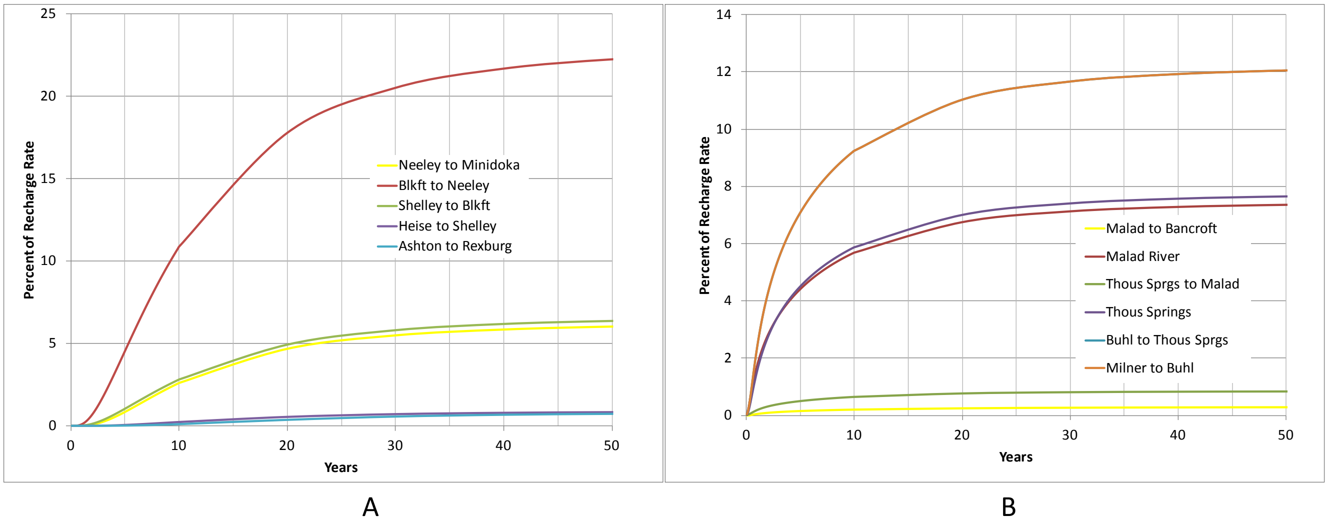


Figure Q5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

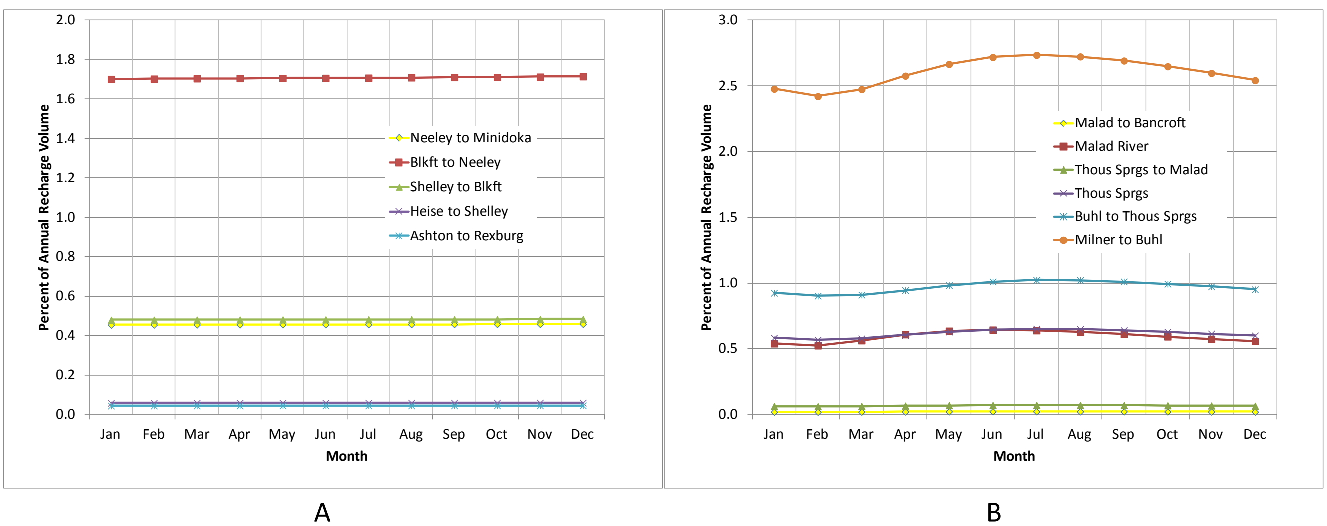


Figure Q6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX R: Shoshone Recharge Site Results

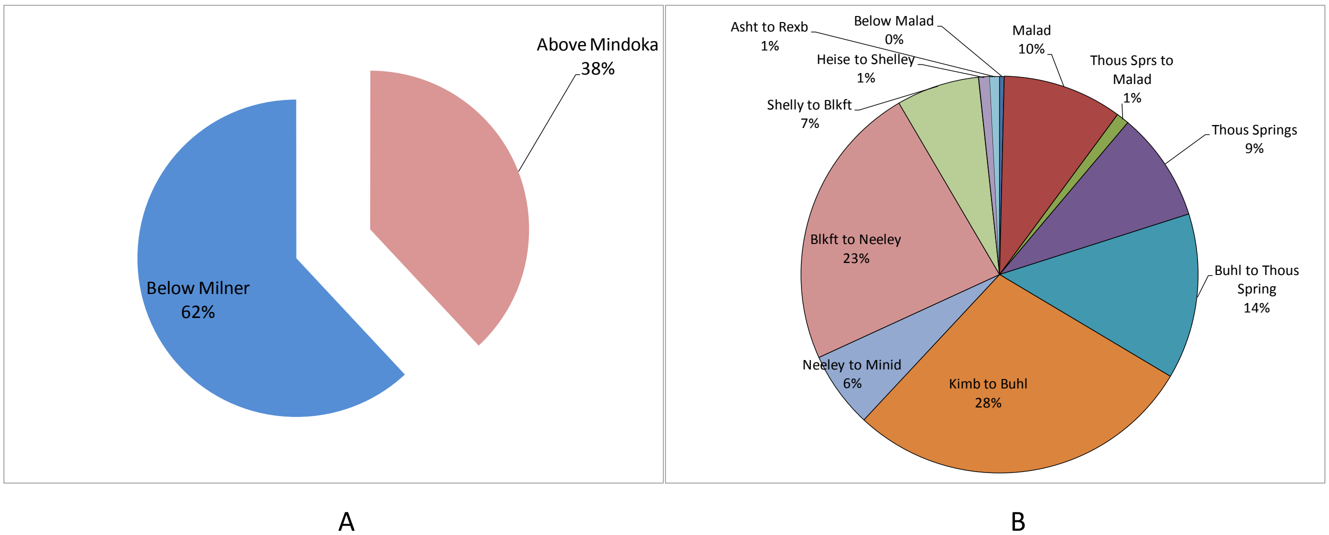


Figure R1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

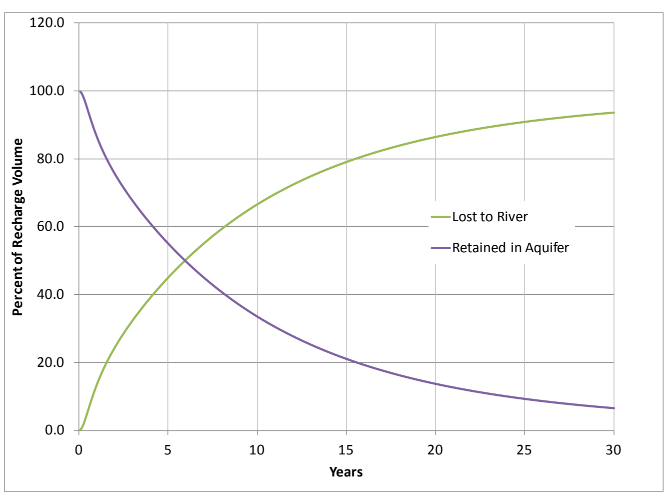


Figure R2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

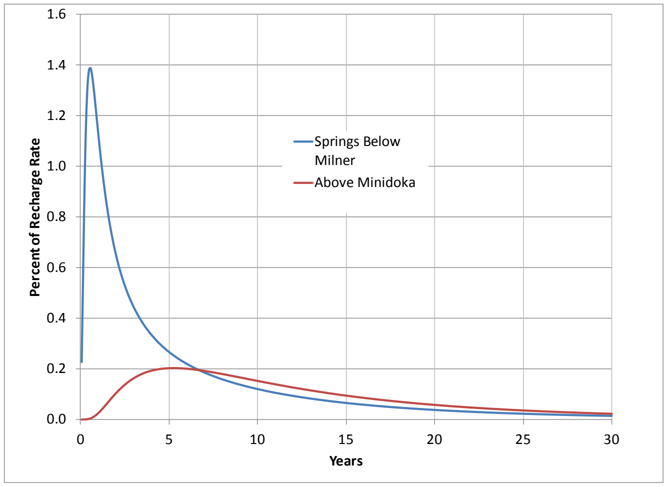
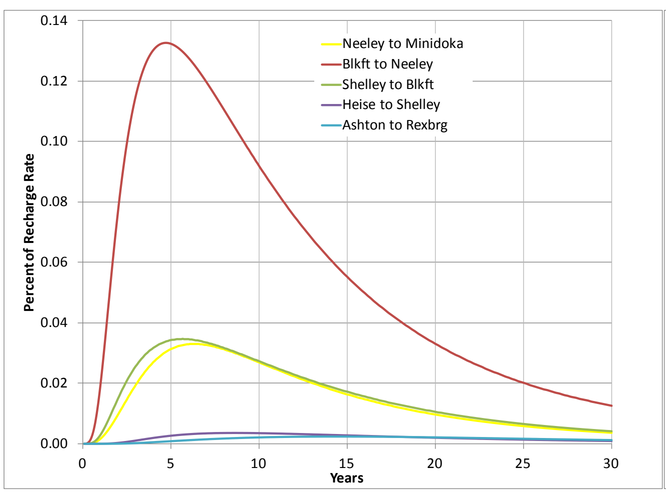
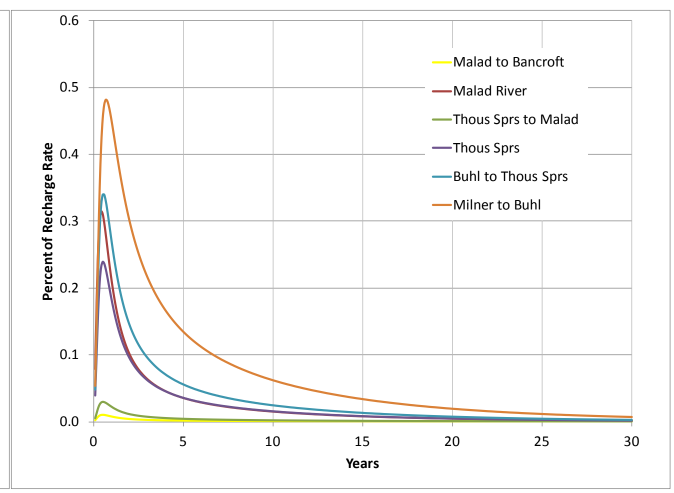


Figure R3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.





A B

Figure R4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.

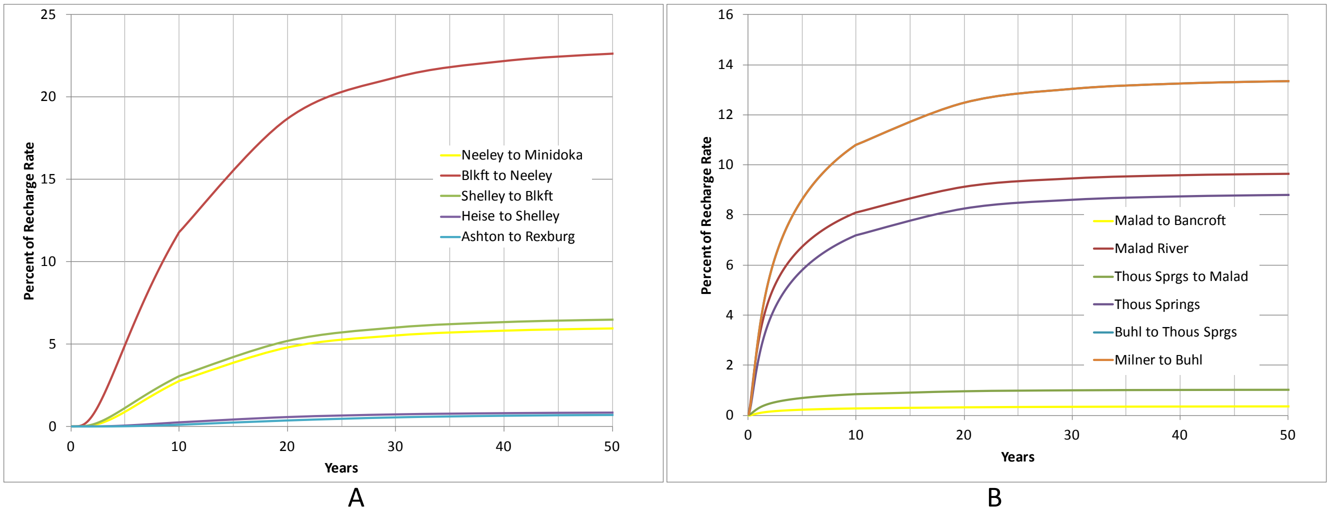


Figure R5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

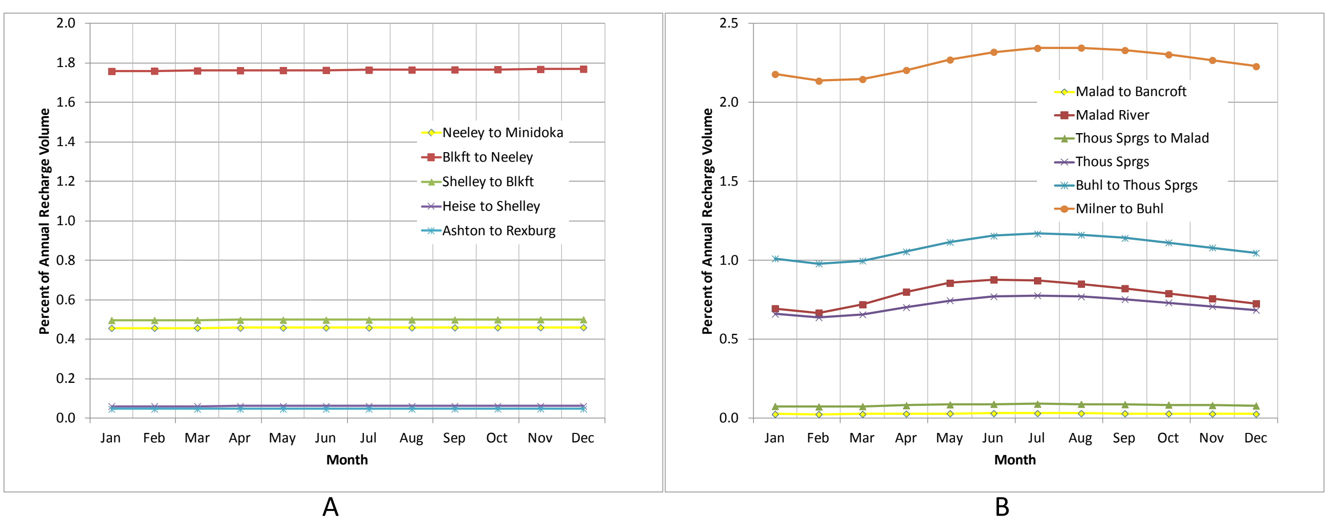
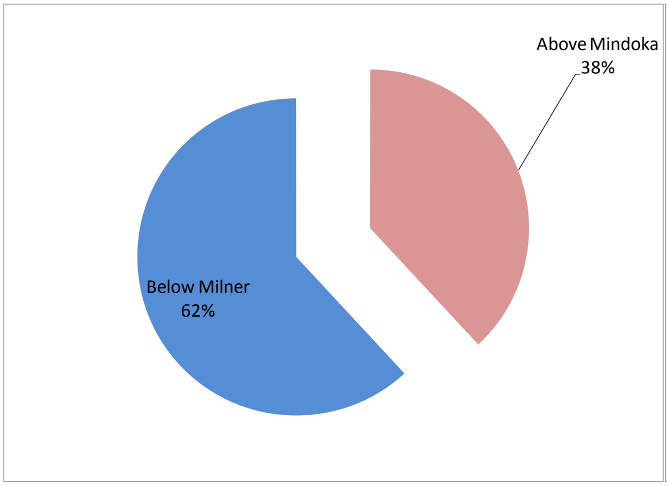
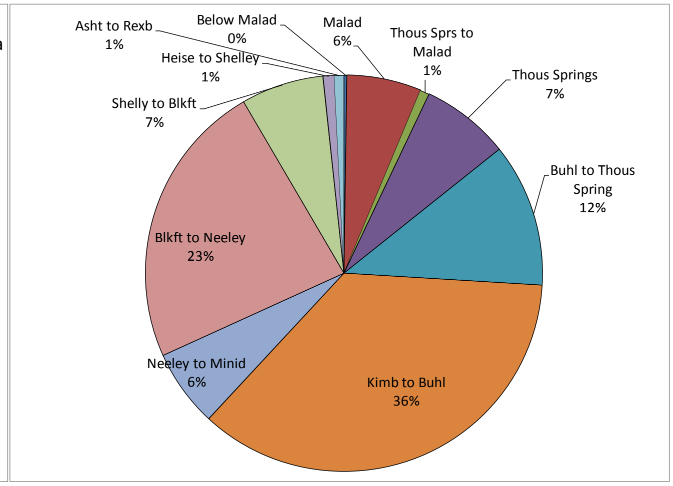


Figure R6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX S: Milepost 31 Site Results





A B

Figure S1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

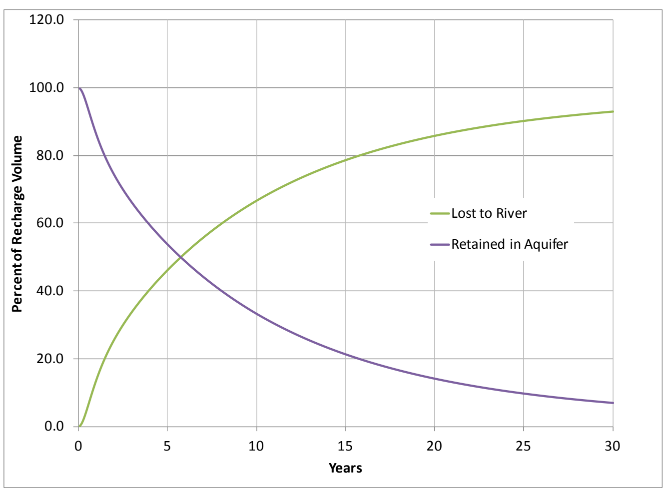


Figure S2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

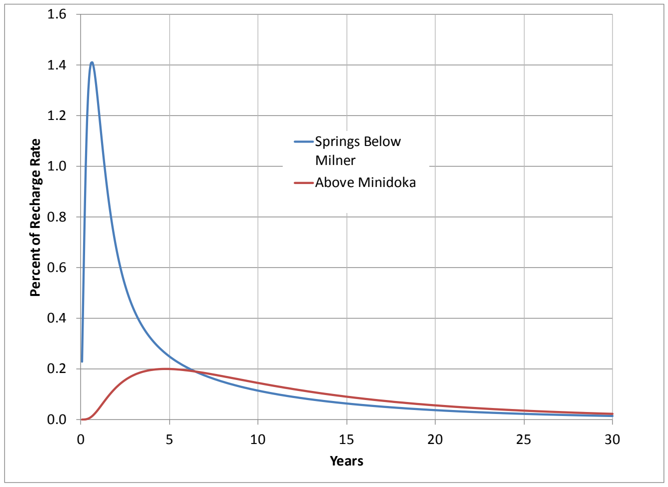
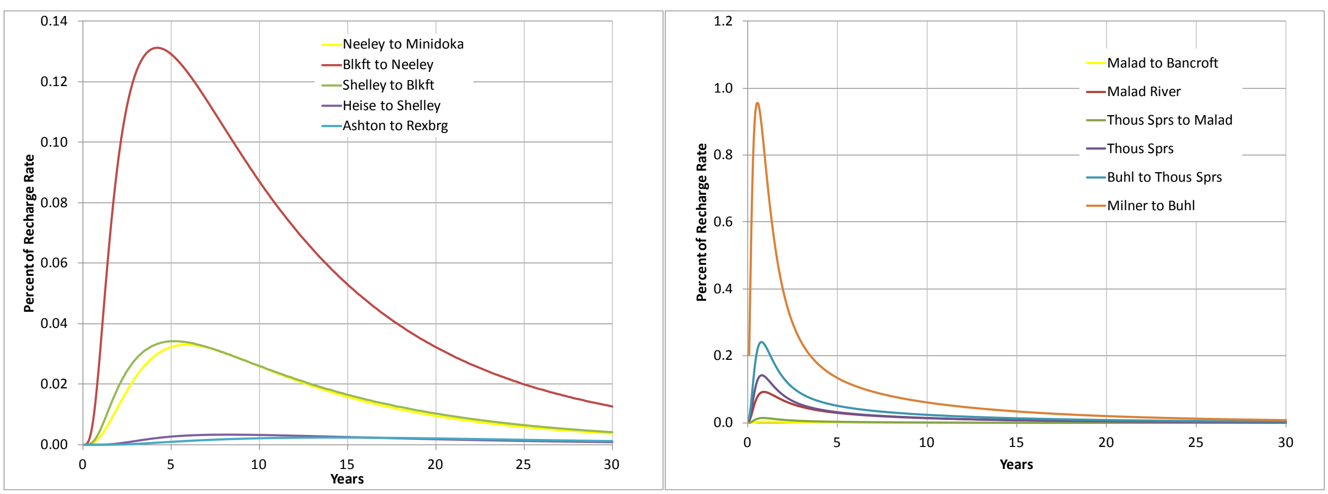
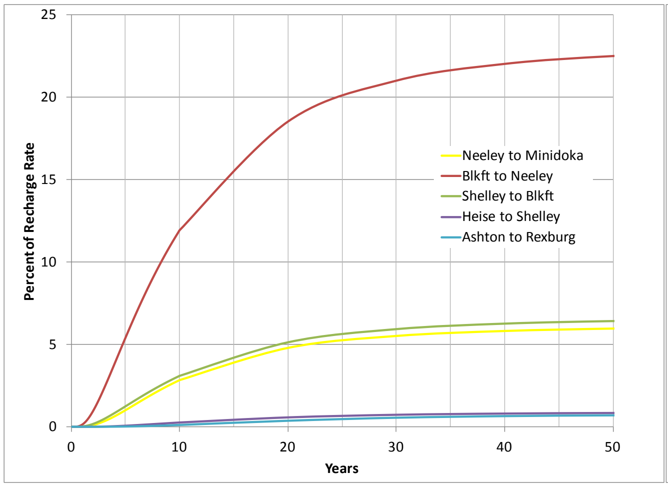


Figure S3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.

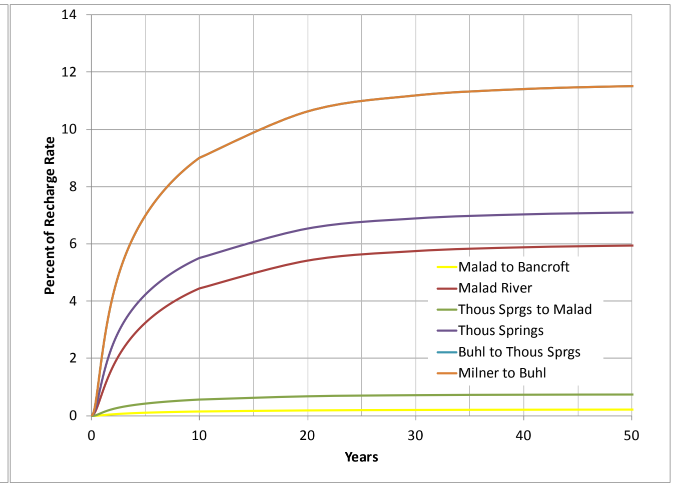


A B

Figure S4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.

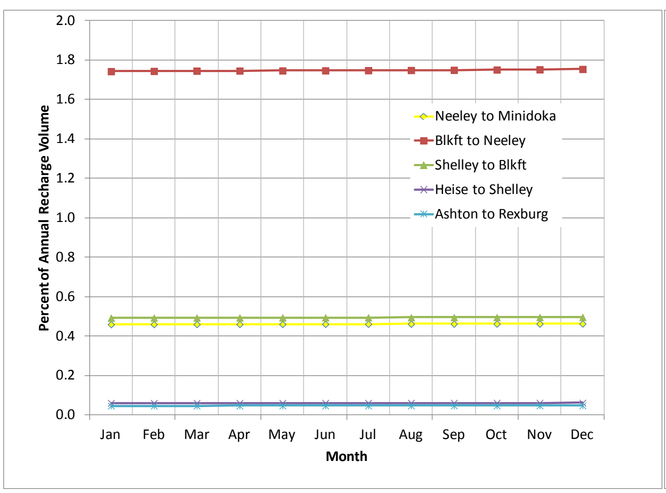


A

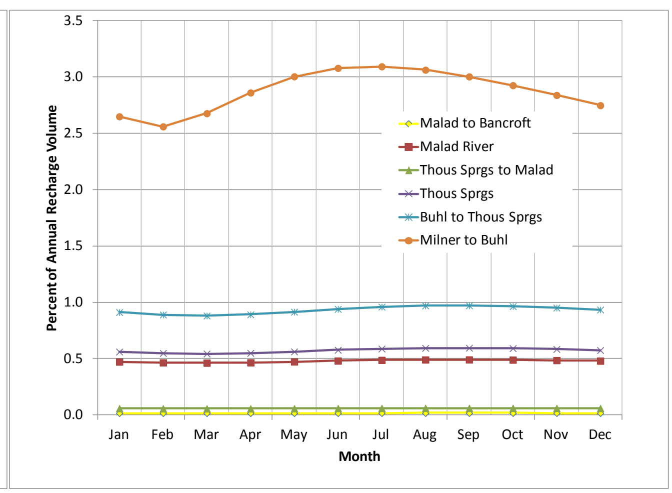


B

Figure S5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.



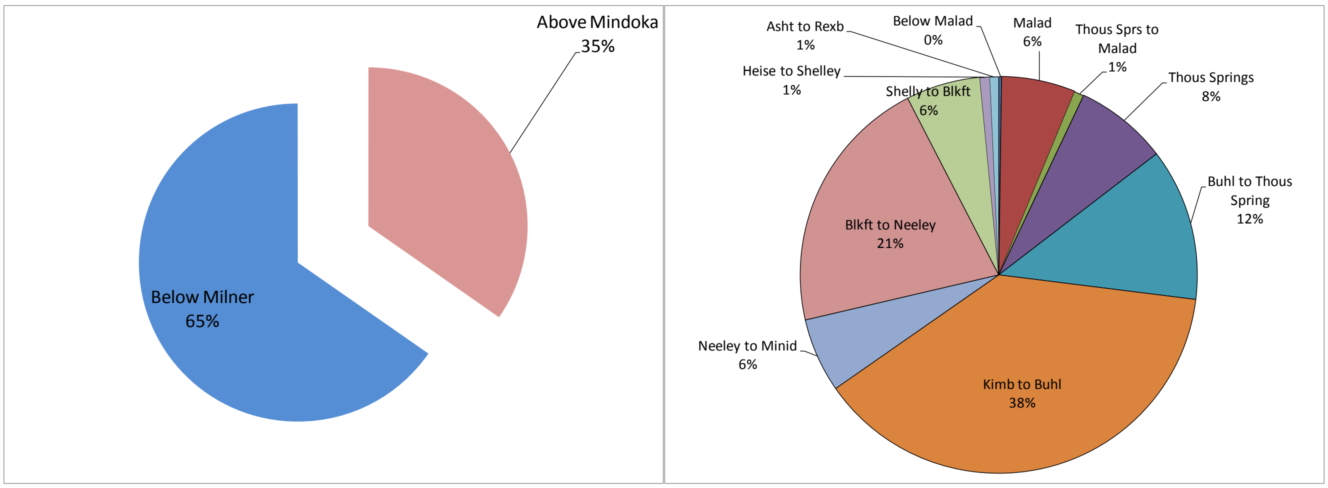
A



B

Figure S6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).

APPENDIX T: Northside Canal Results



A B

Figure T1. Pie chart showing distribution of recharge effects in Snake River A) in segments above Minidoka and below Milner and B) in individual reaches. Determined from steady state simulation of continuous stress.

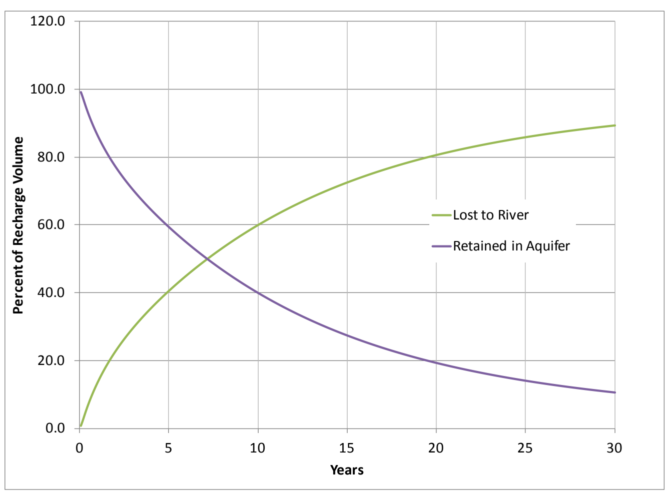


Figure T2. Change in recharge volume retained in aquifer and discharged to the Snake River over time. Determined from simulation of one month of recharge.

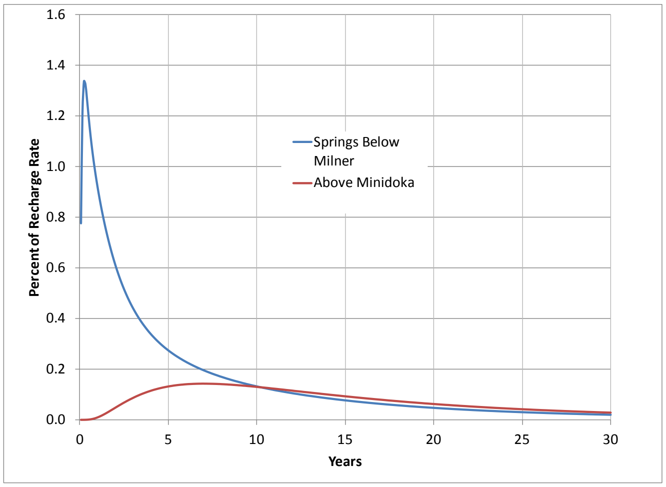
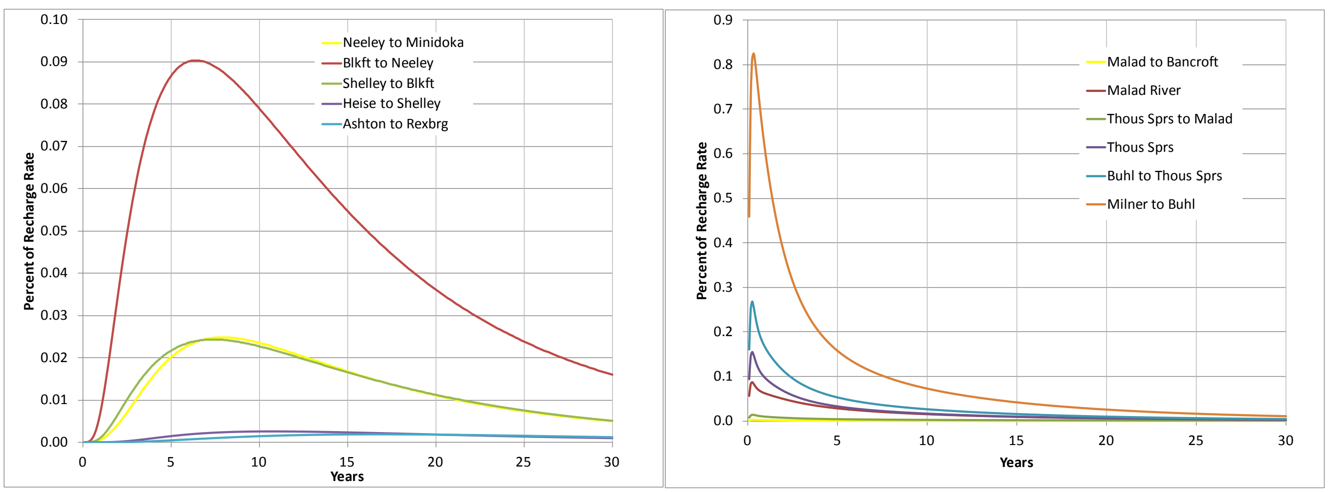


Figure T3. Change in spring discharge and river gains/losses over time in the below Milner and above Minidoka segments of the Snake River resulting from one month of recharge.



A   B

FigureT4. Change in river gains/losses for A) above Minidoka and B) below Milner reaches of the Snake River resulting from one month of recharge.

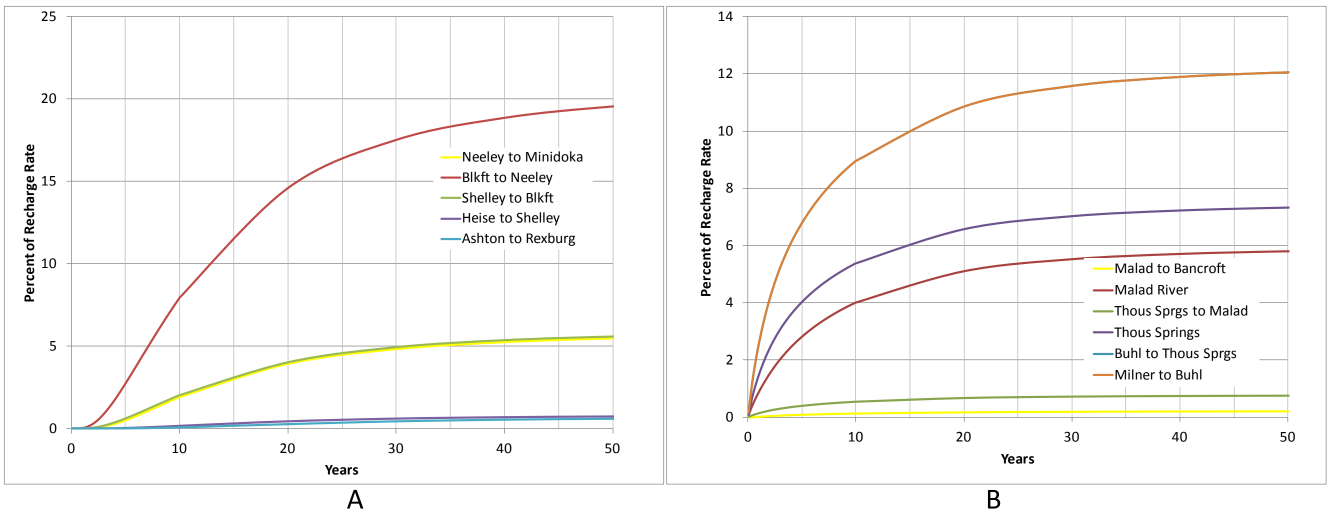


Figure T5. Change in river gains/losses and spring discharge for A) above Minidoka and B) below Milner reaches of the Snake River resulting continuous recharge.

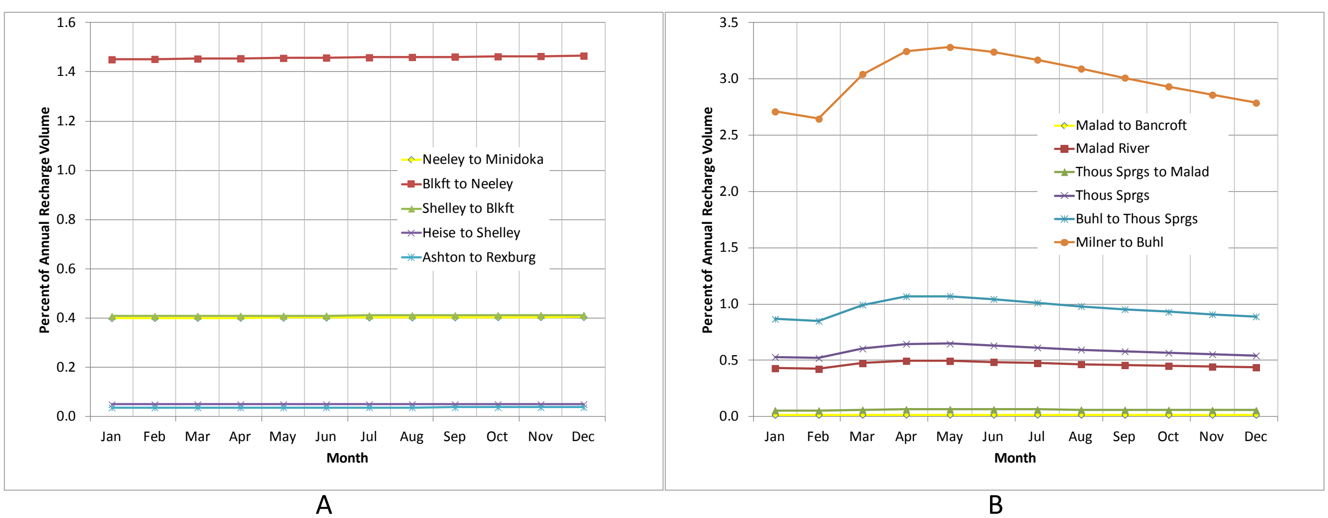


Figure T6. Change in monthly volume of river gains/losses and spring discharge for (A) above Minidoka reaches and B) below Milner reaches of the Snake River resulting from recurring spring recharge. Results represent a single year after 30 years of recurring recharge in March and are expressed as a percent (monthly volume of discharge x 100) / (annual recharge volume).