Hydrology, Water Right and Groundwater Modeling Evaluation
Of
Rangen Delivery Call

By

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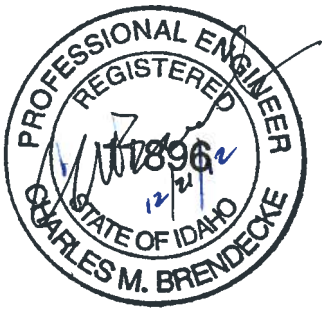

For

Racine, Olson, Nye, Budge and Bailey, Chartered
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Errata Sheet

This report is identical to the report of the same name and authorship dated December 21, 2012, with the exception of the following corrections, which have been included for the reader's convenience. There are no modifications of the report analysis or conclusions.

Table of Contents

There is no section 6.1.5.; reference has been removed from table of contents.

Page numbering for Chapter 6 has been corrected to start with 6-1 instead of 6-4.

1.0 Introduction

p. 1-3 line 3: "…curtailed water use described in conclusion 23 above…" was corrected to read "…curtailed water use described in conclusion 22 above…"

p. 1-3 line 12: "…ESPAM2, conclusion (25) above…" was corrected to read "…ESPAM2, conclusion (24) above…"

p. 1-3 line 13: "…water rights described in conclusion (25) above…" was corrected to read "…water rights described in conclusion (24) above…"

p. 1-7 line 13: "…water levels and Range spring flows…" was corrected to read "…water levels and Rangen spring flows…"

2.0 Water Development and Use on the Eastern Snake Plain

p. 2-2 line 4: "…2.1, average recharge to the aquifer…" was corrected to read "…2.2, average recharge to the aquifer…"

p. 2-2 line 32: "…(Kjelstrom, 1995)." was corrected to read "…(Kjelstrom, 1995a)."

p. 2-3 line 18: "Kjelstrom (1995)…" was corrected to read "Kjelstrom (1995a)…"

p. 2-4 line 22: "Kjelstrom (1995)…" was corrected to read "Kjelstrom (1995a)…"

3.0 Rangen Springs Development and Use

p. 3-4 line 14: "…Berkey, 2003, 2003a)." was corrected to read "…Berkey, 2003a, 2003b)."

p. 3-4 line 24: "In his May 19, 2005, Order…" was corrected to read "In his May 19, 2005, Second Amended Order…"

p. 3-4 line 28: "(Order, FF23)" was corrected to read "(IDWR, 2005, FF23)".

p. 3-5 line 12: "(Order, FF 62, 63, 72)." was corrected to read "(IDWR, 2005, FF 62, 63, 72)."

p. 3-5 line 17: "(Order, FF 84)." was corrected to read "(IDWR, 2005, FF 84)."

p. 3-5 line 31: "(Coleman, 2012)" was corrected to read "(Miller, 2012)"

4.0 Model Development

p. 4-1 line 4: "…that began in 1974 (deSonneville, 1974)." was corrected to read "…that began in 1974 by deSonneville."

p. 4-4 line 28: "…discharge data (Wylie, 2012 memo)." was corrected to read "…discharge data (Wylie, 2012a)."

p. 4-9 line 11: "…derived from Hinckley fig 19," was corrected to read "…derived from Hinckley Figure 18,"

p. 4-9 line 21: "…in the Rangen cell from curtailment is about 4 feet." was corrected to read "…in the Rangen cell from curtailment is about 6 feet." This correction was also made to Figure 4.8.

p. 4-9 line 34: "…but Johnson (2011)…" was corrected to read "…but Johnson (2010)…"

p. 4-10 line 6: "…a simulated groundwater flow of 320 cfs across…" was corrected to read "…a simulated groundwater flow of 366 cfs (on average) across…"

p. 4-10 line 31: "…using ESPAM2.1 (Sukow, 2012b)…" was corrected to read "…using ESPAM2.1 (Sukow, 2012)…"

p. 4-13 line 13: "…by the Department (Wylie, 2012c, d)…" was corrected to read "…by the Department (Wylie, 2012b, c)…"

5.0 Simulation of Curtailment of Junior Groundwater Rights

p. 5-2 line 4: "(Sukow, 2012b)…" was corrected to read "(Sukow, 2012)…"

p. 5-2 line 10: "…by Contor, et.al. (2005)…" was corrected to read "…by Contor et al. (2006)…"

p. 5-2 line 11: "…limited spatially to the the Area…" was corrected to read "…limited spatially to the Area…"

6.0 Alternative Conceptual Models

p. 6-5 line 19: "…into this lower area from the southeast…" was corrected to read "…into this lower area are from the southeast…"

p. 6-6 line 14: "Covington and Weaver note…" was corrected to read "Covington and Weaver (1989, 1991) note…"

p. 6-7 line 20: "…calibration of model #1 for…" was corrected to read "…calibration of model #2 for…"

p. 6-7 line 26: "…2 ? in recent years." was corrected to read "…2.1 in recent years."

References

The reference list has been updated to correct typographical errors and remove references that were not actually used.

Figures

Figure 6-3: "GBH Modification for Alternative Model" was corrected to read "GHB Modification for Alternative Model"

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1.0 INTRODUCTION

1.1 Objectives

The objective of this report is to review the hydrology, water rights and groundwater modeling of the Eastern Snake Plain Aquifer (ESPA) in the vicinity of the Rangen, Inc., (Rangen) aquaculture facility, as they relate to the delivery call placed by Rangen on December 13, 2011. That delivery call requests the curtailment of all groundwater rights within the domain of the Enhanced Snake Plain Aquifer Model (ESPAM) that are junior to July 13, 1962. The primary study area of focus of this report is shown on Figure 1.1.

1.2 Organization of Report

This report is organized into 6 sections, beginning with this Introduction and Summary of Conclusions. Section 2 presents an overview of hydrology and water development in the area of the Rangen facility. Section 3 provides a detailed description of the Rangen facility itself and the water rights pertinent to it. Section 4 describes development and calibration of the ESPAM Version 2.1 (ESPAM2.1) by the Idaho Department of Water Resources (IDWR). Section 5 describes analysis of the effects of curtailment of junior groundwater rights using ESPAM2.1 and its predecessor, ESPAM2.0. Section 6 presents an analysis of curtailment effects using a modified version of ESPAM2.1 that more closely reflects hydrogeologic conditions near Rangen.

A related discussion of hydrogeology of the Rangen area is presented in Hinckley (2012).

1.3 Summary of Conclusions

Based on the analyses and evaluations I carried out in preparing this report, I conclude that:

1. The Martin-Curren Tunnel is a distinct source of water separate from natural springs that also supply Rangen.
2. The July 13, 1962, Rangen water right that is the basis of the delivery call (36-2551) is sourced at the Martin-Curren Tunnel.
3. The April 12, 1977, water right (36-7694) held by Rangen is sourced at the Martin-Curren Tunnel.
4. The Martin-Curren Tunnel is an artificial excavation that was constructed to access groundwater for irrigation purposes.
5. The Martin-Curren Tunnel meets the physical definition of a well contained in Idaho Code 42-230(b).
6. Neither observed nor estimated flows from the Martin-Curren Tunnel have ever been high enough to provide water in-priority to the 1977 water right (36-7694) held by Rangen.
7. Observed flows of Billingsley Creek reported by Rangen have not been high enough to provide any water to Rangen's 1977 water right (36-7694) since October of 1976, a date which precedes the priority of the water right.
8. Inspection of Rangen facilities and diversions by the Department of Water Resources concluded, among other things, that water right 36-7694 "should not have been issued."

9. Water right 36-7694 has never been able to divert and beneficially use water in priority.
10. Neither observed nor estimated flows from the Martin-Curren Tunnel have ever been high enough to deliver the maximum rate of diversion authorized under water right 36-2551.
11. Rangen's measurement of water flows through its property underestimates actual flows by 10-12%
12. It is feasible for Rangen to make more efficient use of available flows by delivering water from Billingsley Creek to its small raceways.
13. As a result of incidental recharge from surface water irrigation, spring flows in the Milner to King Hill reach are currently 25 percent greater than natural, pre-development flows.
14. Much of the change in spring discharge in the Milner to King Hill reach since 1960 can be attributed to reduction in incidental recharge from surface water irrigation due to changes intended to reduce waste.
15. Neither ESPAM 2.1 nor its predecessors is capable of separating the effects of groundwater pumping on flows from the Martin-Curren Tunnel from the effects of groundwater pumping on flows from other springs in the Rangen complex. .
16. The predictive uncertainty analysis of ESPAM2 and ESPAM2.1 carried out by the IDWR explores only a limited aspect of model uncertainty and does not quantify overall model uncertainty.
17. Fundamental to overall model uncertainty is the uncertainty associated with the conceptual model reflected in ESPAM2.1. The predictive uncertainty analysis relies on a single conceptual model and does not explore the uncertainty that arises from improper conceptualization of local geologic and hydraulic conditions that influence discharge of specific spring complexes, such as those at Rangen.
18. Alternative conceptual models can be developed that better reflect hydro-geologic conditions near Rangen and which produce substantially different effects of curtailment than does ESPAM2.1.
19. That ESPAM2.1 can fairly closely mimic the observed past behavior of a spring complex is not proof that it represents hydrogeologic reality sufficiently to predict accurately future behaviour of that complex, especially under aquifer water use conditions (e.g., curtailment of junior groundwater pumping) that are radically different from those extant in the model calibration period.
20. The ESPAM2.1 is not sufficiently detailed in either its general formulation or its representation of hydrogeologic conditions at Rangen, to be used reliably to predict changes in flow available to water right 36-2551 due to curtailment of junior groundwater rights on the ESPA.
21. ESPAM2.1 represents the details of the Rangen spring complex and the surrounding geology in highly simplified form, omitting several key features and that would make significant differences in predicted benefits of curtailment.
22. Using ESPAM2 and ESPAM2.1, less than 3 % of the curtailed groundwater rights junior to Rangen's 1962 priority, under the 10% trimline, would accrue to the Rangen complex; the rest would accrue to other connected river reaches, springs and baseflows, including those on which there are no water rights or diversions, those on which there are no delivery calls, those on which

approved mitigation plans are already in place, and those on which diversions occur under water rights junior to those of the curtailed rights.

23. An even smaller amount of the curtailed water use described in conclusion (22) above would accrue to the Martin-Curren Tunnel.
24. Using ESPAM2, less than 1% of the curtailed groundwater rights junior to Rangen's 1962 priority over the entire model domain, such as requested by Rangen, would accrue to the Rangen complex, the rest accruing to other connected river reaches, springs and baseflows, including those on which there are no water rights or diversions, those on which there are no delivery calls, those on which approved mitigation plans are already in place, and those on which diversions occur under water rights junior to those of the curtailed rights.
25. Because the model domain, irrigated lands and water rights are the same in ESPAM2.1 as in ESPAM2, conclusion (24) above would also apply to results from ESPAM2.1.
26. An even smaller amount of the curtailed water rights described in conclusion (24) above would accrue to the Martin-Curren Tunnel.
27. Alternative calibrated models that better reflect hydro-geologic conditions near Rangen show that curtailment of groundwater rights, within the 10% trimline and junior to Rangen's 1962 right, would produce only half, and possibly as little as 5%, of the benefit to Rangen predicted by ESPAM2.1.
28. Analysis using ESPAM2.1 shows that implementation of Rangen's request for widespread curtailment will, by any reasonable standard, result in waste of the water resource.
29. If the Director uses ESPAM2.1 to quantify the benefits to water right 36-2551 from curtailment of junior groundwater uses, this quantification should reflect the substantial uncertainty of that benefit that derives from use of a regional model to predict discharge from a particular spring outlet at the edge of the aquifer system. Due to this uncertainty, any curtailment based on ESPAM2.1 should be limited to junior-priority rights for which ESPAM2.1 predicts a significant benefit to Rangen. In my opinion, to recognize uncertainty and prevent unreasonable waste, application of ESPAM2.1 should at a minimum restrict curtailment to junior rights for which ESPAM2.1 predicts at least 10% of the curtailed water will accrue to Rangen.
30. Even use of a 10% trimline results in waste of the water resource because the vast majority of that foregone use would not accrue to the benefit of Rangen.
31. Use of trimlines smaller than 10% increases the relative waste of the water resource.

Hydrology and Water Development

32. Spring discharge is closely related to incidental recharge from surface water irrigation within the service area of the North Side Canal Company.
33. The sensitivity of spring discharge to incidental recharge is likely increased near the edges of the aquifer system near the Hagerman Rim and Rangen.
34. The Winter Water Savings Program of the North Side Canal Company alone may have reduced incidental discharge to the ESPA above the Thousand Springs reach by roughly 150,000 acre-feet per year beginning in 1961.

35. Conversion of irrigated lands from flood and furrow irrigation to sprinkler irrigation has significantly reduced incidental recharge.
36. Sprinkler usage under the North Side Canal Company grew from zero percent of the service area in 1982 to 100% of the service area by 2008.
37. Approximately 24,000 linear feet of lateral off the W-canal in the area west of Wendell, in proximity to Rangen, have been lined or placed in pipe since the 1990s, primarily to reduce excessive seepage losses, which are incidental recharge.
38. All of the foregoing reductions in incidental discharge are reductions in waste of water.
39. Prior to development of irrigation under the North Side Canal Company natural flow from springs in the Milner to King Hill reach was estimated to be about 4,000 cfs. Spring flows reached a peak at about 7,000 cfs in the early 1950s and have declined since that time. The average annual discharge for the 10-year period ending in 2011 is about 5,000 cfs, which is still above the natural (predevelopment) levels
40. When significant surface water irrigation began in the NSCC area the seasonal variability of spring discharges increased in addition to the magnitude of average annual flows. Prior to development, the pronounced seasonal pattern of spring flows that currently exists did not appear to exist.
41. Reductions in total annual spring discharge are also related to drought episodes.

Rangen Water Use

42. Discharges from the Curren Tunnel are divided between Rangen pipelines, three irrigation diversions, and spills to Billingsley Creek from the Rangen Box.
43. The North Snake Groundwater District has been providing mitigation supplies to the irrigation water users through the Sandy Pipeline since 2003. This pipeline is believed to have nearly eliminated irrigation diversions from the Curren Tunnel outlet.
44. Flows in Billingsley Creek are divertible by gravity to Rangen's large raceways but not to the hatch house, upper (small) raceways, or culinary use, all of which are presently supplied only by pipelines from the Tunnel.
45. Spills from the Rangen Box may remain in Billingsley Creek and bypass the Rangen facilities under some circumstances.
46. It is feasible to pump water from Billingsley Creek to Rangen's small raceways from the same point where Rangen diverts water into the large raceways. This would increase the efficiency of use of Rangen's existing physical supplies by making the total discharge of the Rangen complex available to all of Rangen's raceways.

ESPAM2.1 Model

47. Observations of ESPA geology suggest it is highly complex, comprised of overlapping fractured basalts interspersed with sedimentary formations, with hydraulic characteristics that can vary substantially over short distances.

48. ESPAM2.1 is, like all models, a simplified representation of reality, and this leads to model uncertainty.
49. ESPAM2.1 is comprised of cells that are one mile square.
50. Within each ESPAM2.1 grid cell, aquifer characteristics are assumed to be homogenous and isotropic.
51. This assumption of homogeneity means that hydrologic and geologic details of a scale smaller than the cell cannot be explicitly represented in the model.
52. Considerable amounts of pertinent input data are not known at even the one-square mile level of spatial resolution of the ESPAM2.1 grid.
53. ESPAM2.1 is comprised of a single layer of cells of uniform thickness.
54. ESPAM2.1 assumes constant thickness throughout the model domain and constant transmissivity within each cell. These assumptions may result in substantial misrepresentation of flow conditions in some parts of the aquifer, such as the Hagerman rim, where thinning occurs and preferential flow pathways become more restricted.
55. The discharges at Rangen are represented in ESPAM2.1 as a single drain.
56. This single-drain representation does not allow ESPAM2.1 to distinguish flows emanating from the Curren Tunnel from flows emanating from natural springs in the Rangen complex.
57. The generalizations and simplifications in ESPAM2.1 can introduce significant error into model results, particularly for highly localized conditions such as those governing discharge from specific outlets of a specific spring complex.
58. ESPAM2.1 has a large number of cells and each cell has a large number of adjustable parameters, so the total number of adjustable parameters in the ESPAM2.1 model is large.
59. The large number of parameters reflected in ESPAM2.1 increases the likelihood that the model is not unique.
60. ESPAM2.1 simulates conditions that are not physically possible and conditions that are in direct opposition to observed conditions in the real system. These discrepancies reveal serious model misrepresentation of detailed aquifer behaviour in the Rangen area, and raise doubt as to the accuracy of model predictions there.
61. Many of the conceptual aspects of ESPAM2.1 fail to reflect observed characteristics of the aquifer system in the Rangen area. These failures lead to conceptual uncertainty in the ESPAM2.1.
62. Each of the input data types used in ESPAM2.1 carries its own uncertainties that can stem from, among other things, the inability to measure a condition accurately (or at all) and from the spatial or temporal resolution of measurements.

ESPAM2.1 Calibration

63. Calibration uncertainty reflects the fact that many combinations of model parameter values may lead to equally well-calibrated models.

64. The ESPAM2.1 was calibrated under the assumption that aquifer transmissivity in any given cell is constant over the calibration period. This assumption has not been validated, and there are many locations and situations in the model domain and over the model calibration period where it is probably not true.
65. ESPAM2.1 was calibrated using an automated approach implemented in a computer program called PEST.
66. ESPAM2.1 systematically under-estimates discharge at the Rangen spring in the early years of the calibration period while over-estimating it in the later years.
67. ESPAM2.1 systematically under-predicts the water level at the closest well to Rangen that was used for calibration by 20 feet. ESPAM2.1 also consistently under-predicts the water level in another nearby well.
68. The under-prediction of water levels near Rangen is partly a result of the fact that discharge targets were weighted more heavily than water level targets in the calibration process.
69. Because predicted water levels are too low, PEST increased the drain conductance to values higher than are suggested by observation, thereby embodying in ESPAM2.1 a mischaracterization of the real physical relationship between water levels and flows at Rangen.
70. This mischaracterization results in over-sensitivity of the change in drain flow to a simulated change in water level due to curtailment. This over-sensitivity is carried into the superposition model used for curtailment, with the result that changes in spring flows are over-predicted by nearly a factor of 4.
71. The calibrated drain conductances in ESPAM2.1 range over 4 orders of magnitude. This extremely large variation suggests that the set of calibrated parameters is quite fragile and that PEST can readily find alternative parameter sets that provide acceptable calibrations.
72. ESPAM2.1 differs from ESPAM2 in the correction of an error that arose in the calculation of the water budget in the Mud Lake area and overestimated aquifer recharge by approximately 89,000 acre-feet/year in that area of the model domain. This represents a change of less than one percent in the overall water balance for the ESPA.
73. Correction of this error required re-calibration of the model, so a new set of model parameters, including drain conductances were developed. These are the parameters used in ESPAM2.1.
74. The drain conductances in ESPAM2.1 differ from those used in ESPAM2 by more than the 1% change in water budget associated with the correction. The conductance for the Rangen drain decreased by about 4%, but some drain conductances in the area changed by nearly 1000%. Some cell transmissivities in the area near Rangen changed by more than 100%.
75. These changes in conductance and transmissivity are carried directly into the superposition models used to calculate the flow changes resulting from curtailment.
76. The area encompassed by the 5% trimline is substantially larger with ESPAM2.1 compared to ESPAM2, and this expansion is mainly in areas on the opposite side of the Malad Gorge from Rangen, which are hydrogeologically disconnected from the Rangen spring.

77. Large changes in calibrated parameter values and model results suggest that ESPAM2 and ESPAM2.1 may be over-parameterized, and that other comparable calibration solutions easily can be reached with only minor perturbations in model assumptions.

Estimation of Benefits from Curtailment

78. ESPAM2.1 represents the Rangen spring as a drain and the flow in that drain as a linear function of water level in the cell that contains the drain.
79. Application of ESPAM2.1 to estimate changes in spring flow due to curtailment employs the method of superposition.
80. The principle of superposition relies on the assumption that the system being modeled and the model behaves in a completely linear way.
81. If the system being simulated or the model exhibits important non-linear behaviours, a superposition model can introduce significant error into the analysis of effects of stress changes.
82. Analysis of observed water levels and Rangen spring flows by Hinckley demonstrates that the relationship of Rangen flow to water levels in nearby wells is not linear.
83. The structure of the aquifer and conditions in the aquifer along the Hagerman Rim in the region of Rangen indicate that the behaviour of the aquifer in that region is not linear.
84. The large number of parameters reflected in ESPAM2.1 increases the likelihood that the model is not linear.
85. There are a total of 406 groundwater irrigated acres relying on rights junior to Rangen's 1962 priority within the 10% trimline, using 1,445 acre-feet of groundwater. At steady state, curtailment of pumping on these lands would cause total modeled flow at the Rangen springs to increase by 0.19 cfs (141 af/y assuming year around flow). Not all of this increase would accrue to the Martin-Curren Tunnel, but the ESPAM2.1 model does not represent flows in the tunnel. It would take somewhat less than a year for discharge to reach 90% of this modeled steady state increase.
86. There are a total of 565,023 groundwater irrigated acres within the model domain relying on rights junior to Rangen's1962 priority, using 1.46 million acre-feet (MAF) of groundwater. At steady state, ESPAM2 predicts that curtailment of pumping on these lands would cause modeled discharge at Rangen to increase by 18.07 cfs. It would take approximately 16 years for modeled discharge to reach 90% of this steady state increase.
87. Because the model domain, irrigated lands and water rights are the same in ESPAM2.1 as in ESPAM2, conclusion (86) above would also be expected to apply to results from ESPAM2.1.

2.0 WATER DEVELOPMENT AND USE ON THE EASTERN SNAKE PLAIN

2.1 Hydrology

The Snake River flows along the southern edge of the Eastern Snake River Plain (ESRP), a broad arcuate plain that covers an area of approximately 10,000 square miles in southeastern Idaho. As shown on Figure 2.1, the two main branches of the Snake River are the South Fork, which primarily drains the eastern side of the Teton mountain range, and the Henry's Fork, which primarily drains the western side of the Teton Range and joins the South Fork near Idaho Falls. Several smaller tributaries enter the Snake River from the south, the largest being Willow Creek and the Blackfoot, Portneuf and Raft rivers. With few exceptions, tributaries from the mountains to the north of the plain flow out onto the plain and recharge the underlying aquifer. Because of its porous surface, there are no significant surface water features on the plain itself.

At Milner Dam, northeast of Twin Falls, the Snake River drops into a canyon making gravity diversion of river flows impossible; large irrigation canals at Milner seasonally divert all but a small amount of the river flow. The canals diverting from the Snake River at Milner Dam, as well as others diverting from the lower Big and Little Wood Rivers, deliver large amounts of irrigation water to lands in Jerome, Gooding and Lincoln Counties above the north rim of the river canyon. The Snake River itself is largely restored by the time it reaches King Hill due to spring discharges from the north wall of the Snake River canyon and tributary streams such as Rock Creek, Salmon Falls Creek and the Malad River.

The ESRP is underlain by a vast basalt aquifer system, the Eastern Snake Plain Aquifer (ESPA), formed when intermittent lava flows filled ancestral valleys and canyons of the Snake River (Stearns and Crandall, 1938). In the central part of the ESPA, these and other formations extend to a depth of more than 3,000 feet (Whitehead, 1992). The total volume of water stored in the ESPA has been estimated to be as high as 1 billion acre-feet (IDEQ, 2006).

The agriculturally productive areas of the Plain occur in sedimentary and aeolian deposits overlying the most recent (Quaternary) basalts, which outcrop in numerous places. The porous and fractured basalt formations in the upper part of the ESPA can store and transmit large amounts of water and have been developed as a groundwater resource. Lindholm (1996) estimated that the upper 500 feet of the aquifer may contain 200-300 million acre-feet, an amount approximately 50 times greater than the combined surface water storage above King Hill.

Between Milner Dam and King Hill are numerous springs that emerge from the north side of the canyon and flow to the river. In some cases there are very well-defined outlets for these springs while in other cases they discharge through talus slopes and the actual outlets in the canyon wall can't be seen. There are also some springs that emerge in the river itself. This reach of the river is often referred to as the Thousand Springs Reach, though there is also an individual spring complex named Thousand Springs. A few of the larger spring complexes along the north wall of the canyon are at Crystal Springs, Clear Lakes, Box Canyon, Thousand Springs, Billingsley Creek and the Malad Gorge.

Figure 2.2 shows the annual average water budget for the period 1981-2008 used in development of the ESPAM2.1. Note that this is not a water budget for the ESPA, as it includes surface water supplies that are consumed directly without entering the aquifer. Based on Figure 2.2, average recharge to the aquifer system from precipitation on non-irrigated lands, from tributary underflow, and from non-Snake River seepage is 2.46 million acre-feet (MAF). This relatively small component of overall aquifer recharge is still greater than the total groundwater consumption simulated in curtailment to 1870 (Sukow, 2012) indicating that groundwater use remains less than the reasonably anticipated rate of future natural recharge.

2.2 North Side Canal Company

Early irrigation development on the ESRP was concentrated in the upper portions of the basin, above Blackfoot. Irrigation development in the lower portion of the plain began in 1877 with appropriations from the lower Big and Little Wood Rivers north of Wendell and Shoshone. By 1900, surface water rights totalling more than 900 cfs had begun operating to irrigate lands above the Malad Gorge (at their confluence, the Big and Little Wood Rivers become the Malad River).

Diversions from the Snake River onto the western ESPA began in 1905 with the development of the Twin Falls Project. Small diversions by the Twin Falls North Side Land & Water Company (predecessor to the North Side Canal Company) began in 1908. Diversions quickly grew from 250 thousand acre-feet (KAF) in 1909 to 1.2 million acre-feet (MAF) in 1912 (USGS, 1956). Considerable water was diverted in the first decade of canal operation to fill the Jerome Reservoir, but that project was abandoned in 1918 after it became clear that seepage losses from the reservoir would prevent it ever being filled (Crandall, 1923; USGS, 1956). North Side Canal Company (NSCC) diversions at Milner Dam have averaged about 986,000 af/y over the last 10 years. Present acreage served by the NSCC is reported to be 154,067 acres. Figure 2.3 shows the present service area and main canals and laterals of the NSCC.

For the first half of the 20th century, the NSCC diverted water in the winter as well as during the irrigation season. This was done primarily to provide domestic and stock water to small towns and farms. There is no significant crop water demand in the winter, so considerable amounts of the winter diversions undoubtedly recharged the ESPA in Jerome and Gooding Counties or were spilled over the canyon rim at the ends of laterals.

As part of its Regional Aquifer System Analysis (RASA) study, the USGS estimated that by 1952 more than 24 MAF of water had been added to the aquifer by incidental recharge from surface water irrigation (Kjelstrom, 1995a). The importance of incidental recharge resulting from seepage losses from surface irrigation systems is evident in Figure 2.4a, b which is reproduced from the RASA study. Figure 2.4a shows the close correlation between incidental recharge and spring discharges in the Milner to King Hill reach of the river. The pattern of incidental recharge is clearly superimposed on a longer term increasing trend of spring discharge from 1912 to the mid-1950s, and is very closely related to the declining trend in spring discharge since the mid-1950s. Figure 2.4b shows the estimated change in ground water storage from this incidental recharge.

Figures 2.5 and 2.6 are from another RASA report (Goodell, 1988). Figure 2.5 shows the early 20th century increase in water levels in three observation wells, the locations of which are shown on Figure 2.6. Water levels in observation well 8S-17E-19BBB1 reflect water levels in the aquifer beneath the area irrigated by the North Side Canal Company. It can be seen that the aquifer water level in this area rose by approximately 45 feet between 1900 and 1950 as the result of incidental recharge from surface water irrigation.

Winter diversions all but ended in about 1960 as the Company participated in the Winter Water Savings Program, which sought to stop 435,000 af of "wasteful non-irrigation season diversions" and redirect this water to storage in Palisades and American Falls Reservoirs (USBR, 1946). The Palisades Winter Water Savings agreements went into operation in 1961 and generally required participating canal companies to cease diversions in the months of November through March. Figure 2.7 is derived from records of the USGS and the IDWR and shows the historical November through March diversions of the NSCC. The onset of the Winter Water Savings Program is clearly evident in this diversion record. Based on Figure 2.7, the Winter Water Savings of the North Side Canal Company alone may have reduced incidental recharge to the ESPA above the Thousand Springs reach by roughly 150,000 acre-feet per year (207 cfs).

Prior to the 1950s, flood and furrow irrigation was the primary method of water application on the ESRP. Kjelstrom (1995a) notes that by the 1970s about 20 percent of surface water irrigation distribution systems had converted from gravity application methods to sprinkler application methods and that this conversion had reduced deep percolation to the aquifer. In 1981 the University of Idaho published (Hamilton, et al., 1981) the results of a survey of the responses of irrigators to the severe drought of 1977. Table 2.1 is reproduced from the Hamilton report. It shows that many irrigators on the ESRP had installed sprinkler systems, had added gated pipe, and had lined ditches as a result of the 1977 drought.

Information provided to the IDWR by the North Side Canal Company in connection with the 2005 delivery call of the Surface Water Coalition shows that in 2004 sprinklers were the primary method of water application on 88 percent of the North Side service area. Documentation for the current groundwater model of the Eastern Snake Plain Aquifer (ESPAM2.1) reflect a growth in sprinkler usage under the NSCC from 0% of the service area in 1982 to 100% by 2008. This has undoubtedly further reduced aquifer recharge in the area of the springs.

Figure 2.8 shows the portion of the NSCC service area generally between the town of Wendell and the head of Billingsley Creek. The irrigation laterals shown in this area are part of the W-lateral system. Lateral W-40 extends nearly to the head of Billingsley Creek, ultimately reaching a spill point on the canyon rim immediately to the north of the Rangen aquaculture facility. Recent data (Sullivan, 2012) show that flows into the lower portion of the W-lateral system, have declined about 20,000 af/y since the late 1980s. Interviews of NSCC personnel (Wertz, pers. comm., 2012) revealed that approximately 24,000 linear feet of laterals off the W-Canal in the area west of Wendell have been lined or placed in pipe since the 1990s, primarily to reduce excessive seepage losses.

The spill point at the end of W-40 was visited in June, 2012, and did not show evidence of current use. As with other canal companies in the area, the NSCC has been attempting in recent years to consolidate and reduce spills to the river for water quality management purposes. The primary spill point for the W-Canal system is now into the Malad Gorge just downstream of the State Park.

2.3 Springs in the Milner to King Hill Reach

As mentioned previously, between Milner Dam and King Hill the Snake River flows in a deep canyon. There are numerous springs discharging from the walls of this canyon, the majority of them being on the north side in an area known as the Thousand Springs reach, including an individual spring complex named Thousand Springs. In some cases there are very well-defined outlets for these springs while in other cases they discharge through talus slopes and the actual outlets in the canyon wall can't be seen. There are also some springs that emerge in the river itself. Figure 2.9 shows the locations of major spring complexes in the Milner to King Hill reach.

The earliest records of spring discharge measurements in this reach of the river date back to 1902. In the spring of that year the U.S. Department of Agriculture and the U.S. Geological Survey (USGS) separately made measurements on several of the springs in this reach of the river. These and other early measurements are summarized in Nace, et al., (1958). J.D. Stannard, the investigator for the Department of Agriculture estimated the total discharge of springs on both sides of the river between a point 3 miles above Twin Falls and a point 10 miles below the Malad River (roughly the entire Milner to King Hill reach) to be 3,833 cfs. These 1902 measurements were made before irrigation development under the North Side Canal system, though not before irrigation diversions began from the lower Wood River to supply lands north of Wendell and Shoshone. Kjelstrom (1995a) estimated that the pre-irrigation (pre-1880) discharge of springs between Milner and King Hill averaged about 3.0 maf, or 4,140 cfs. Mundorff, et.al. (1964) estimated the natural discharge from the aquifer in the Thousand Springs Reach to be 4,000 cfs, and possibly less.

When significant surface water irrigation began in the North Side Canal area spring discharges changed, increasing in seasonal variability and in overall magnitude. Meinzer (1927) prepared an inventory and description of large springs in the United States, including the springs in the reach of the Snake River between Milner Dam and King Hill. Figure 2.10, reproduced from the Meinzer report, illustrates the close relationship he found between the combined spring discharges at the Blue Lakes and Clear Lakes spring complexes and the quantity of irrigation water applied to the Eastern Snake River Plain above the springs via the North Side Canal Company. Figure 2.10 shows that the monthly rise and fall pattern of North Side Canal diversion is followed, in a slightly delayed fashion, by a similar monthly pattern in spring discharge. Canal diversions were substantially smaller in 1919 (shortly after the Jerome Reservoir project was abandoned) than they were in the preceding two years, and the subsequent rise in spring discharge is also substantially smaller. A comparison of the two 1902 observations of flow at Blue Lakes given in Nace, one in April and one in August, showed almost equal flow rates. So the seasonal spring discharge pattern evident in the period 1917-1920 didn't appear to exist in 1902 at Blue Lakes and Clear Lakes, prior to major irrigation development above the springs. This emphasizes the importance of localized patterns of incidental recharge to flows of specific springs.

The IDWR prepares estimates of the annual spring discharge to the Thousand Springs Reach based on a method originally developed by Kjelstrom (1995b) and documented in USGS Water-Resources Investigation Report 95-4055. Figure 2.11 is a plot of the discharge estimates prepared by the IDWR for the period 1902-2011. The average of the annual discharge values for the 10-year period from 1902-1911 is 4,207 cfs. The average annual discharge for the 10-year period ending in 2011 is 5,019 cfs.

Also shown on Figure 2.11 is the annual value of the Palmer Drought Severity Index (PDSI) for NOAA Climate Zone 7 (NOAA Earth System Research Laboratory Physical Sciences Division 2012). The PDSI is a commonly used water supply index that incorporates precipitation, temperature, runoff and soil moisture conditions. Greater positive values of the PDSI reflect increasingly cooler and wetter conditions; greater negative values reflect increasingly warmer and drier conditions. A relationship can be seen in Figure 2.11 between drought episodes and reductions in total estimated spring discharge to the Milner to King Hill reach.

From the foregoing, it can be concluded that pre-development springs flows in the Thousand Springs Reach were probably not greater than 4100 cfs; that flows peaked in the early 1950s at approximately 6900 cfs primarily as a result of surface water irrigation development; and that flows have declined to current levels as a result of changes in surface water irrigation practices, drought and groundwater development. However, spring discharge between Milner and King Hill remains above natural (predevelopment) levels.

2.4 Groundwater Development

With the exception of shallow wells constructed in the Mud Lake area in the 1920s, ground water development of the ESPA did not begin in earnest until the late 1940s. The first project relying heavily on ground water supplies was the Minidoka North Side Pumping Division of the Minidoka Project (now the A&B Irrigation District) which began operation in 1948. While the majority of the subsequent permits were for irrigation of new lands, many were for supplemental irrigation of lands already irrigated with surface water supplies. In addition, the benefits of sprinkler irrigation have led to the conversion of some formerly surface-water irrigated lands to ground water use. Ground water development began to level off in the 1980s and a moratorium on new irrigation well development has been in place since 1992.

Farms in the Wendell area were initially supplied with irrigation water by the NSCC (Sullivan, 2012). Conversion of irrigated lands from surface to groundwater sources and development of new groundwater-supplied lands in the area began in the 1950s. Figure 2.12 shows the growth in groundwater permits in the area from 1948 until 1992, when a moratorium on further groundwater irrigation permitting went into effect. Notable increases in permitting occurred in 1960-61, just prior to Rangen's application for water right 36-2551, and in 1973-76, just prior to Rangen's application for water right 36-7469. Figure 2.13 shows the current Points of Diversion for groundwater rights in the area between Wendell and the head of Billingsley Creek; these points are color-coded to show their priorities relative to July 13, 1962.

Sullivan estimates that there were approximately 25,000 acres of irrigated land under the W Canal in 1953 and about 30,500 acres in 2009. In 1953 there was little or no groundwater irrigation under the W Canal. By 2009 roughly 10,000 of the formerly surface-water irrigated acres were supplied in whole or in part with groundwater and about 9,300 acres of new acreage was being served by groundwater (about 3,500 acres of surface water irrigation had been retired). Given the 1992 moratorium on new groundwater irrigation, it is reasonable to assume that nearly all of this groundwater use was actually in place by 1992.

Figure 2.14 shows observed groundwater levels in two wells in the area between Wendell and Rangen. Records of groundwater levels are less complete as one goes back in time, so the wells shown in Figure 2.14 do not illuminate aquifer conditions in earlier periods. It can be seen from Figure 2.14 that that seasonal fluctuations in water levels are about 5 feet in this area, with lows generally occurring in the months of March (well 992) and July (well 989). Annually, water levels have declined somewhat since 1985, with levels appearing more stable in the last 10 years. These declines are likely due to changes in surface water irrigation practices, including spill management, lining or piping of laterals, and conversions from surface to groundwater use, to drought, and to that increment of groundwater pumping brought online since 1985.

3.0 RANGEN SPRINGS DEVELOPMENT AND USE

3.1 Billingsley Creek Overview

Billingsley Creek enters the Snake River northwest of the town of Hagerman, just upstream from Lower Salmon Falls Dam. The creek is fed by a series of springs emanating from the Quaternary basalts forming the canyon rim in western Gooding County. Figure 3.1 is an aerial photo of the area showing the creek and the locations of selected spring discharge points. Figure 3.2 shows the measured flows of Billingsley Creek at the USGS gaging station (13134600) at the Highway 30 bridge just north of Hagerman. Records at this station are not continuous, and spring and creek flows are diverted both above and below the station for aquaculture, irrigation and other uses.

The Martin-Curren (aka Curran, Kearn) Tunnel and Rangen aquaculture facility are located at the upper end of Billingsley Creek. Figure 3.3 is an aerial photo of the Rangen facility showing key features of the area that will be referred to later in this section. Flows from the Tunnel and from other spring outlets and seeps in the Rangen area form the headwaters of Billingsley Creek.

The Rangen facility was constructed in 1962, apparently expanding on an earlier, smaller aquaculture operation purchased by Rangen in May of that year (Twin Falls Times-News, December 30, 1962). The facility was launched as a research center focused on trout diseases and diet, and on hatchery management problems.

The primary physical sources of water used at the Rangen facility are the Martin-Curren Tunnel and natural springs, most of which emerge from the talus slope about 45 feet in elevation below the tunnel portal (Farmer, 2009). Water from the Tunnel is divided between Rangen pipelines and three irrigation diversions. The natural springs all discharge to Billingsley Creek. Flows in Billingsley Creek are divertible by gravity to Rangen's large raceways but not to the hatch house, upper raceways, or culinary use, all of which are presently supplied only by pipelines from the Tunnel. Inspection of the Rangen facilities by IDWR personnel in 2003 concluded that some spring inflow to Billingsley Creek also occurs below the diversion for the large raceways (Berkey, 2003a).

3.2 Water Rights

Water rights for flows in the headwaters of Billingsley Creek in the area of the Rangen facility are listed in Table 3.1. The earliest rights date to 1884 and are for irrigation and domestic use.

The earliest right for fish propagation is Rangen's 1957 priority for 1.46 cubic feet per second (cfs). This may have been the primary water right for Rangen's predecessor. The present delivery call seeks administration of groundwater rights junior to Rangen's 1962 priority (36-2551), which is sourced by the Snake River Basin Adjudication (SRBA) Court at the Martin-Curren Tunnel.

The irrigation rights of Candy, Morris and Musser are also sourced at the Martin-Curren Tunnel. These diversions provide water to irrigate parcels south of Billingsley Creek. The water rights for these diversions are senior to the Rangen rights, dating to as early as 1884. Because the irrigation diversions are consumptive with respect to Billingsley Creek, they reduce the water supply available to Rangen from the Tunnel.

In 2003, anticipating that groundwater users might in the future be required to mitigate declines in Tunnel and spring flows, the North Snake Groundwater District (NSGWD) voluntarily constructed a pipeline (the "Sandy Pipeline") from ponds in Section 5 of T8S, R14E (the "Sandy Ponds") to the Curren Ditch. The pipeline was constructed so that it could also supply irrigation water to Candy, Morris and Musser, thereby reducing or eliminating those irrigation diversions at the Tunnel and increasing the Tunnel supply available for Rangen. This pipeline is in operation and is believed to have nearly eliminated irrigation diversions from the Tunnel outlet.

The Curren Ditch diverts from the creek below the Rangen facility under irrigation rights that are also senior to the Rangen aquaculture rights. However, since Rangen's aquaculture use is non-consumptive, the Curren Ditch does not call for bypass of Rangen's more junior aquaculture rights.

Groundwater development on the plain above the Curren Tunnel began in the early 1950's. Figure 2.12 showed the evolution of groundwater rights in the area east of Billingsley Creek. The earliest groundwater rights in the immediate area date to 1952. Notable increases in permitted acreage occurred in 1959-61 and in 1973-76, just prior to Rangen's applications for water rights 36-2551 and 36-7694. By the time of Rangen's 1962 water right, about 3900 acres had been permitted. At the time of Rangen's 1977 water right, about 8300 acres had been permitted. By 1992, when the moratorium on new groundwater irrigation went into effect, permits for about 10,000 acres had been issued.

3.3 Curren Tunnel Development

The Curren Tunnel is excavated into the canyon rim above the Rangen facility. It extends roughly 100-300 ft into the basalt forming the rim (Tate deposition testimony, 2012), at a depth roughly 70 feet below the ground surface above the rim (Hinckley, 2012). The tunnel is bifurcated some distance into the cliff into north and east forks. Water flows out of the Tunnel by gravity.

It appears that the Tunnel excavation had at least commenced by October of 1884 (New International Mortgage, 1932) with the aim to deliver irrigation water via a ditch (i.e., by gravity) to lands on the bench area south of Rangen. A feature article in the December 30, 1962, Twin Falls Times-News describes the source of Rangen's supply as "man-made springs on the north side of the canyon" where "early pioneers in search of irrigation water drilled a hole into the cliff and struck water." USGS Water Supply Paper 1463 (Nace, et.al., 1958) contains a Billingsley Creek flow observation made in April, 1902, with remarks that "Water emerges from a tunnel dug into brecciated, highly permeable basalt, and from the talus slope below the tunnel…" The 1932 decree from New International Mortgage Bank v Idaho Power Company, et.al., an adjudication of

water rights in Billingsley and Riley Creeks, grants 1884 priority rights to water "…developed and diverted…by means of a tunnel commonly known as the Curran Tunnel…".

According to Idaho Code 42-230(b) a "well" is defined as "an artificial excavation or opening in the ground more than eighteen (18) feet in vertical depth below land surface by which groundwater of any temperature is sought or obtained." Based on the foregoing descriptions of its development, the Curren Tunnel appears to meet this definition.

About the first 50 feet of the Tunnel is lined with large diameter corrugated steel pipe; beyond this the tunnel is unlined. It is not known when the corrugated steel lining was installed. A 6" diameter PVC pipe is laid along the bottom of the steel pipe, extending beyond it into the unlined portion to the bifurcation. This PVC pipe carries water for laboratory, culinary and landscape irrigation use at the Rangen facility. Based on a diagram produced by Rangen (RANGEN001907), it is believed that this PVC pipe was installed in 1976.

The PVC pipe does not carry all the water emerging from the Tunnel. The remainder of tunnel discharge is collected in a concrete division box (the "Farmers box") at the mouth of the tunnel, shown in Figure 3.4. The Candy, Morris and Musser pipelines deliver water from this division box to parcels south of the Rangen facility; the elevation of the Tunnel outlet allows this irrigation delivery to operate by gravity.

Two Rangen pipelines also take water from the Farmers box and water can spill from the box. The two Rangen pipelines flow into another concrete box, the "Rangen box" shown in Figure 3.5, which is further down the slope toward the Rangen facility. There they enter the pipeline serving the hatch house and research facility. Spills from the Rangen box, as well as flows from other spring outlets, flow into Billingsley Creek and can be diverted into Rangen's large raceways.

There are other spring outlets in the vicinity that also supply water to the Rangen facility. The largest of these emerges about 45 ft below the Curren Tunnel and flows to Billingsley Creek. Based on recent discharge records, discussed in more detail below, these "lower" springs produce roughly twice the flow of the Tunnel.

3.4 Discharge Records

The earliest record of discharge from springs in the Rangen area is contained in Nace (1958). Table 27 in that report shows a Billingsley Creek flow of 54.3 cfs in April, 1902, at a location where Road E2900S (aka Hagerman Highway) crosses Billingsley Creek. This observation post-dates the excavation of the Tunnel, and potentially includes discharges from other springs in the area. Other than a few subsequent measurements in the general vicinity, systematic recording of spring discharge in the area did not begin until the Rangen facility was operating.

The only measurement of discharge specifically from the Curren Tunnel was in the period between 1993 and 2009 when the IDWR operated a sonic measuring device inside the tunnel. This measured the portion of tunnel flow not conveyed in the 6" PVC pipe installed in the tunnel

by Rangen. All other historical measurements of spring discharge are derived from measurements made by Rangen at locations within the hatchery or on Billingsley Creek.

Flow measurement within the Rangen facility relies primarily on recording the depth of water flowing over the check dams in the "large" and "CTR" raceways, and depth of water flowing over the "lodge dam" in Billingsley Creek shown in Figure 3.6. Flow depth is apparently measured by a metal ruler placed on the crest of the dams as shown in Figure 3.7 (Exhibit 7a from Rangen 1st Request; Yenter, 2003). It appears that the flow from the CTR raceways reflects flow through the Rangen hatchery and, when combined with discharge over the lodge dam and diversions for irrigation, gives the total discharge of the spring complex.

Along with most other spring users, Rangen began submitting diversion records to the IDWR in 1995. In late 2003, responding to a request from IDWR Director Karl Dreher, Rangen submitted monthly flow records covering the period 1966-2003. These data, and the measurement methods used by Rangen, were subsequently reviewed by IDWR technical staff (Yenter, 2003; Berkey, 2003a, 2003b). This review included field inspection of measurement sites and methods, and verification of various estimates used by Rangen in its flow summarization. The inspection concluded, among other things, that the flow record reflected total spring complex discharge rather than Rangen diversions and found that Rangen's flow measurement methods could underestimate the total discharge by 10-12%.

Figure 3.8 shows the IDWR records of total discharge from the Rangen complex, as well as observed flows from the Curren Tunnel and IDWR records for flow in the 6" PVC pipe from the Tunnel. Seasonal variability of flow is plainly evident as are longer term wet and dry spells. In the period of overlap between total flow and Tunnel flow records, it appears the Tunnel flow is the greater source of this seasonal variability. This is to be expected as the Tunnel penetrates the aquifer at a higher elevation than that of the natural springs. In his May 19, 2005, Second Amended Order, former Director Dreher found decreases in the springs supplying the Rangen hatchery facilities to be correlated with repairs made to the facilities of the North Side Canal Company to reduce losses of surface water to ground water from the canal company's facilities above those springs in 1987, 1998, and 2000 (IDWR, 2005, FF 23). The 1992 moratorium on new irrigation wells suggests that decreases in discharge after the mid-1990's are not the result of groundwater pumping.

Figure 3.9 shows a regression analysis of total Rangen flow against observed Curren Tunnel flow. It can be seen that the relative contribution of the Tunnel is somewhat greater at higher total flow; this is to be expected from the relative elevations of the Tunnel and the natural springs that contribute to the total flow. At lower flow levels, the Tunnel may represent as little as 20% of the total Rangen flow. Over the last 10 years, the Tunnel discharge has represented roughly one-third of the total Rangen flow.

The regression shown in Figure 3.9 was used to generate estimates of Curren Tunnel flow for the entire period of record for Rangen total flow. The results of this procedure are shown on Figure 3.10, which plots both the monthly total Rangen flow and the monthly Curren Tunnel flow for the period 1966 through 2012. Also shown on Figure 3.10 are the cumulative water rights sourced at

the Martin-Curren Tunnel by the Snake River Basin Adjudication (SRBA). The cumulative rights at the Tunnel were 61.29 cfs prior to Rangen's April, 1977, appropriation. With that appropriation, cumulative rights at the Tunnel rose to 87.29 cfs.

It can be seen from Figure 3.10 that the flows from the Martin-Curren Tunnel have never been high enough to fully satisfy Rangen's 1962 priority (36-2551) and have never been high enough to provide any water to Rangen's 1977 priority (36-7694). Accordingly, it can be concluded that water was not available to water right 36-7694 at the time of its appropriation nor at any later time.

In his May 19, 2005, Order former Director Dreher found that the Department of Water Resources erred in licensing water right 36-7694 and should not have recommended it in the SRBA, because water was not available to it either at the time of its appropriation or subsequently (IDWR, 2005, FF 62, 63, 72). The foregoing analysis of Rangen discharge records shown in Figure 3.10 supports this conclusion.

Director Dreher also found that curtailment of water rights junior to July 13, 1962 (Rangen water right 36-2551) would "not at any time result in a meaningful increase in the quantity of water discharging from springs in the Thousand Springs to Malad Gorge reach of the Snake River, which includes the Curran Springs from which Rangen diverts surface water." (IDWR, 2005, FF 84). In its disclosure of June 12, 2012, the Department produced modeling results, apparently related to this finding, showing an analysis by Allan Wylie with a conclusion that Rangen could "at best expect" an increase of 0.22 cfs from curtailment.

A decomposition and back-casting of the historical monthly total discharge of the Rangen spring complex was also undertaken by Brannon (2009) apparently in anticipation of its use as a target for groundwater model calibration. This decomposition relied on Rangen measurements dating back to 1966. Figure 3.11 shows the results of this effort. Documentation of this work has not been provided by Rangen, though notes in the spreadsheet file submitted by Brannon to the IDWR allude to such documentation (Rangen Water History for IDWR.xls). Inspection of this decomposition supports the preceding conclusions that there has never been water available to water right 36-7694 since its time of appropriation.

While flows diverted from the Martin-Curren Tunnel can be delivered through the small raceways and reused in the large raceways, spring flows emerging below the Tunnel cannot. Based on a reconnaissance-level analysis (Miller, 2012), it is feasible to pump water from Billingsley Creek to the small raceways from the same point where the diversion to the large raceways is made. This would increase the efficiency of use of Rangen's existing physical supplies by making the total discharge of the Rangen complex available to all of Rangen's raceways.

4.0 MODEL DEVELOPMENT

4.1 Background

The Enhanced Snake Plain Aquifer Model (ESPAM) is the current incarnation of numerical modeling of the Eastern Snake Plain Aquifer (ESPA) that began in 1974 by deSonneville. The ESPAM was created with review and input from the Eastern Snake Hydrologic Modeling Committee (ESHMC). The ESHMC is comprised of professionals working on water issues on the eastern Snake River Plain. Regular members include agency representatives (Idaho Department of Water Resources, U.S. Bureau of Reclamation, U.S. Geological Survey, U.S. Fish and Wildlife Service), industry representatives (Idaho Power), researchers (University of Idaho, Idaho Water Resources Research Institute) and private consultants representing various water user interests. While a diversity of interests are represented on the ESHMC, the committee is constituted by request and invitation and not through election or appointment on the basis of population, water right amounts, irrigated acreage, or other such factors. Committee decisions are generally reached by consensus, though this is not always possible to achieve.

Actual development of ESPAM was carried out by the IDWR and the Idaho Water Resources Research Institute (IWRRI). Model design, construction and calibration were reviewed and in some instances redirected by the ESHMC.

From the outset of the ESPAM modeling effort, it was recognized that there would be a need for future enhancements to the model as new information and modeling approaches became available. ESPAM Version 1.0 (ESPAM1.0) was released in 2004, followed shortly by ESPAM1.1 which corrected an input data error. Discussions regarding the scope of future enhancements to ESPAM1.1 began shortly after its release (e.g., Brendecke, 2009a). ESPAM2.0 was released in the summer of 2012; correction of an input data error has recently resulted in the distribution of ESPAM2.1.

4.2 Model Structure

4.2.1 Overview

Like its predecessors, the ESPAM2.1 is developed in MODFLOW, a groundwater modeling environment developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988; 2000). In MODFLOW, aquifers are represented as a collection of rectilinear elements or “cells”. The MODFLOW code solves the equations of flow between these cells to determine how the aquifer will respond to changes in inputs or outputs. Figure 4.1 shows the grid of model cells used for ESPAM2.1.

Within each cell, aquifer characteristics (e.g., porosity, hydraulic conductivity) are assumed to be homogenous (the same throughout the cell) and isotropic (allowing flow to occur in all directions with equal ease) as would be the case if the cell were filled with clean sand of uniform grain size. This assumption of homogeneity means that hydrologic and geologic details of a scale smaller than the cell cannot be explicitly represented in the model. MODFLOW has the capability to

represent anisotropy (where flow occurs in preferential directions), but this feature has not been used in any versions of the ESPAM.

A MODFLOW model may be comprised of one or more vertical layers of cells. Multiple layers are typically used when there is more than one geologic layer that is meaningful to groundwater flow patterns. The thickness of cells in model layers can vary to reflect changes in thickness of subsurface formations, such as the thinning of water bearing formations that often occurs at the edges of aquifers.

Boundary conditions must be defined to characterize the patterns of flow into and out of the model domain, and MODFLOW provides a variety of special cell types for this purpose. River cells are used to represent subsurface flow between river reaches and the aquifer. Drain cells are used to represent aquifer discharge through springs. Constant flux cells are used to represent fixed amounts and patterns of subsurface flow into the aquifer from tributary valleys. Other special-purpose cells serve other functions.

Most of the cells in a MODFLOW model are general purpose cells. It is in these model cells that aquifer recharge from precipitation and irrigation, and aquifer withdrawals by pumping and evapo-transpiration, among other things, are represented. To carry out a groundwater flow simulation, it is first necessary to develop a water budget of aquifer inflows and outflows at each model cell and to develop, through calibration, estimates of parameters representing the aquifer characteristics at each cell.

4.2.2 General Structure of ESPAM2.1

Like its predecessors, the ESPAM2.1 is comprised of cells that are one mile square. This means that features having dimensions smaller than one mile cannot be explicitly represented in the model. However, considerable amounts of pertinent input data are not known at even this one-square mile level of spatial resolution. For example, subsurface geology on the ESPA is known with certainty only at outcrops or at locations where drilling logs are available. Crop distribution information on the ESPA is available only at a county level from annual agricultural statistics based on self-reported data. Detailed water distribution to lands within canal companies can be quite variable as shares are transferred between users; even if this information were readily available it is difficult to embody in model inputs. As a result of these latter data limitations, crop distributions in ESPAM2.1 are assumed to be uniform county-wide, and surface water distribution is assumed to be uniform across every parcel of served land within groups of canal companies.

The resolution of input data may not present a problem when doing a regional-scale analysis because local errors, if random, may effectively cancel each other in the larger context. However, the questions presented in the present delivery call are quite localized in nature and this “error cancelling” cannot simply be assumed to occur. Hinckley (2012) has illustrated some of the discrepancies that exist between the coarse simplifications of ESPAM2.1 and the details of Rangen-area hydrogeology.

Like its predecessors, ESPAM2.1 is comprised of a single layer of cells of uniform thickness. This means that substantial aquifer thinning, such as occurs in the Hagerman-Wendell, Burley-Pocatello, and Rigby Fan-Mud Lake areas (Whitehead, 1992), is not represented in the model. This is important because aquifer transmissivity (T) is a linear function of the hydraulic conductivity of the aquifer material (K) and the aquifer saturated thickness (b), as shown in the following equation:

$$T = Kb$$

As the aquifer material (in this case the Quaternary basalt) thins, the transmissivity is reduced and resistance to groundwater flow increases. Saturated thickness is also reduced by drawdown of the water table, e.g., by pumping or by spring discharge, resulting in a non-linear relationship between water level and flow. The ESPAM2.1 assumes constant transmissivity throughout the model domain. This assumption is made largely for reasons of computational convenience, as will be discussed later in this report, but may result in substantial misrepresentation of flow conditions in some parts of the aquifer, such as the Hagerman rim, where thinning occurs and preferential flow pathways become more restricted.

Like its predecessors, the ESPAM2.1 represents springs using special-purpose drain cells. As shown in Figure 4.2, discharge from a drain cell is a function of the difference in head (Δh) between the computed water level in the cell and the assumed elevation of the drain outlet, and a conductance parameter (C) that effectively acts as a throttle on the rate of discharge. The conductance parameter can be expressed in units of cubic feet per second (cfs) per foot of head difference. While it is a calibrated value in ESPAM2.1 (calibration is discussed in a later section), under certain conditions it can be estimated from field observations.

Like its predecessors, the ESPAM2.1 uses data from a variety of sources to represent the water budgets of the aquifer and of individual model cells. These data include precipitation, surface water diversions, subsurface inflows from tributary basins, stream gage records, county surveys of crop distributions, estimates of evapo-transpiration (ET), methods of irrigation water application, and assumptions about irrigation canal seepage, among others. With few exceptions, the data sources used in the ESPAM2.1 are the same as those used in its predecessors.

From the foregoing, it can be seen that the ESPAM2.1 should not be viewed as a new model of the ESPA but as a relatively modest refinement of earlier versions of ESPAM. It has the same conceptual formulation as its predecessors and relies on the same data sources as its predecessors. Its spatial resolution is the same as that of its predecessors. Like its predecessors it "…is a regional-scale model … best applied for regional-scale predictions." (IDWR, 2012).

4.2.3 Key Differences between ESPAM2.1 and Its Predecessors

The ESPAM2.1 utilizes a longer study period (1980-2008) than did ESPAM1.1 (1980-2002). The addition of six years to the study period means that more input data are used in the ESPAM2.1,

though the basic data sources used remain the same in both models. The ESPAM2.1 utilizes monthly stress periods where ESPAM1.1 used semi-annual stress periods; the increased number of stress periods also increased the amount of input data used in ESPAM2.1, since each formerly semi-annual data value was replaced with 6 monthly values. In some cases (e.g., precipitation, canal diversions) this allowed more accurate temporal representation of water budget terms, while in others (e.g., tributary underflow) it required further disaggregation of data for which only annual estimates are available.

Surface water conveyance and application efficiency are represented in more detail in the ESPAM2.1 than in ESPAM1.1. A greater number of leaky canals were explicitly represented in ESPAM2.1 (primarily in eastern portions of the plain), though canal seepage losses are still considered to be constant throughout the model study period. Farm irrigation efficiency is assumed to increase somewhat in water-short years in ESPAM2.1 through an "On-Farm Algorithm" that operates on model input data. Irrigated acreage is slightly higher in ESPAM2.1 due primarily to the use of better image processing methods than were used for ESPAM1.1 (Sukow, 2012).

The ESPAM2.1 is calibrated to a larger number of spring complexes in the Milner-King Hill reach of the Snake River than was ESPAM1.1. This stems largely from efforts to develop more complete data sets of spring discharges than were available for ESPAM1.1. In large part, these data sets are based on diversion and flow measurements reported by spring users, with extrapolation to fill missing data. The data sets were then used as targets for calibration of drain cells representing those spring complexes. Some spring complexes in ESPAM2.1 are represented by using two drains within the same model cell; in general, this was done to encompass the range of observed outlet elevations of springs falling within the cell, but in some cases the springs so represented may have little hydro-geologic relation to one another. Figure 4.3 shows the distribution of drain cells used to represent springs in the ESPAM2.1.

The more comprehensive representation of spring complexes in ESPAM2.1 necessitated the use of General Head Boundary (GHB) cells to represent observed river gains that were not accounted for in spring discharge data (Wylie, 2012a). These unaccounted for flows were implicit in ESPAM1.1 spring discharges. GHB cells work in a fashion similar to drain cells in that their discharge is a function of head difference and a calibrated conductance parameter. Figure 4.3 also shows the distribution of these GHB cells, some of which occur in cells already containing drains representing springs.

4.3 Rangen Area Representation in ESPAM2.1

While all the refinements made in ESPAM2.1 have some effect on simulated flows and impacts at the Rangen springs, two refinements bear directly on them. The first of these is the use of the Rangen springs as a specific calibration target in ESPAM2.1. Figure 4.4 shows a close-up of the ESPAM2.1 model grid in the area of the Rangen complex. In ESPAM1.1, flows at the Rangen springs were estimated as a percentage of overall spring discharge to the Thousand Springs - Malad subreach (the cells that comprised this reach are highlighted on Figure 4.4). In ESPAM2.1, historical diversions and Billingsley Creek flow measurements reported to the IDWR

by Rangen were used to derive estimates of monthly total discharge that were used as a calibration target. The discharges at Rangen are represented in ESPAM2.1 as a single drain, though discharges actually occur at multiple outlets. This single drain representation does not allow ESPAM2.1 to distinguish flows emanating from the Curren Tunnel from flows emanating from natural springs in the Rangen complex.

The second ESPAM2.1 refinement of particular consequence in the Rangen area is the elimination of the Hagerman Valley from the model domain. This was done at the recommendation of geologist Dennis Ralston, who studied the area and reported to the ESHMC that the Tertiary formations underlying the Valley were not connected to the ESPA (Ralston, 2008)[1]. As a result, the canyon rim became the westernmost extent of the model domain in the Hagerman area in ESPAM2.1. Figure 4.5 shows the changes in the model domain made with ESPAM2.1, highlighting the change in the Rangen area.

Later, after comparing the historical discharges of springs used for calibration targets with reach gains computed from river gages, it was discovered that the observed reach gains substantially exceeded, by roughly 25%, the sum of spring discharges used as calibration targets (Wylie, 2011; 2012 memo). To remedy this discrepancy, GHBs were defined through several reaches to account for the undocumented gains, or "baseflows." This at least partially undid the change in model domain, as the baseflows from the ESPA are now assumed to pass through Ralston's "unconnected formations" to reach the Snake River. As will be discussed later, this results in simulation of unrealistic groundwater flow patterns in the Rangen area.

4.4 Model Calibration Process

4.4.1 General Approach

After conceptual formulation and data development, the next step in groundwater model development is calibration. Calibration is a form of "history matching" wherein initial values of model parameters (such as transmissivity) are adjusted to achieve a better correspondence between historical targets (e.g., measured water levels and spring flows) and model-predictions. Ordinary least-squares regression may be the most familiar example of this process; in it, the parameters of the regression equation (slope, intercept) are adjusted to minimize the sum of the squared differences between the regression line and the data observations. In this context, the groundwater model can be viewed conceptually as a regression equation.

Because of the many parameters that must be adjusted (several for each model cell), groundwater model calibration is often done using special software programs that solve this "inverse problem", so called because its aim is to use observed behaviors to specify the model rather than to use the model to describe the behaviors. The software program used to calibrate

[1] In his mapping of the geohydrologic framework of the Eastern Snake River Plain, Whitehead (1992) also excluded the Hagerman Valley from the Quaternary basalt aquifer system.

all versions of ESPAM has been the model-independent Parameter ESTimation program (PEST) developed by John Doherty (Watermark, 2005).

To find the "best" solution to the inverse problem, PEST seeks to minimize an objective function that reflects the overall sum of squared differences (or "residuals") between historical aquifer observations, or "calibration targets", and model predictions. The ultimate goal of calibration is to determine the set of parameter values that produce the smallest overall value of this objective function. Historical calibration targets included observed aquifer water levels, reach gains and spring discharges over the period 1980-2008, though not all targets had continuous data over this period. While PEST produces quantitative measures of calibration success, it is ultimately a matter of judgement for the modeller to decide that a given calibration is "good enough" for the purpose at hand.

The objective function used in model calibration effectively aggregates, using weighting and indexing assumptions, all the residuals in the model calibration data set down to a single number. The weighting assumptions used in ESPAM2.1 calibration were based on judgement. Because the objective function is a single number, it is normal for PEST to identify a parameter set that provides a closer calibration to some targets than to others. As the desired use of the model focuses on ever more detailed locations and time periods, it becomes more and more important to examine calibration success in specific areas of the model.

While the calibration of models with large numbers of parameters (such as ESPAM2.1) allows consideration of more factors affecting aquifer conditions, it increases the risk that any given PEST solution (i.e., an "optimal" set of parameter values) is not unique (Watermark, 2005). This means that there may be many other combinations of parameter values could produce a similarly minimized value of overall model error. This non-uniqueness creates one dimension of overall model uncertainty, which is discussed in more detail in a later section.

4.4.2 Calibration of ESPAM2.1

The parameters that PEST was allowed to adjust in ESPAM2.1 included conventional aquifer parameters such as transmissivity, specific yield, and streambed, drain and GHB conductances. In addition, PEST was allowed to manipulate a number of terms in the aquifer water budget where precise values could not be known. For example, PEST was allowed to adjust tributary inflow estimates and surface water irrigation efficiency assumptions, among other things. Given the large number of active cells in the model and the many aquifer water budget terms considered at each cell, the number of adjustable parameters in ESPAM2.1 calibration is large.

Doherty (Watermark, 2005) cautions that "…increased parameterisation normally results in increased parameter non-uniqueness at the same time as any semblance of model linearity rapidly fades from view." As will be discussed later in this report, the assumption of linearity is fundamental to both IDWR and Rangen efforts to quantify the flow changes resulting from curtailment. The large number of parameters reflected in ESPAM2.1 increases the likelihood that the model is not linear.

Reach gain and spring discharge targets were given greater weight in the calibration of ESPAM2.1 due to the fact that there were a far greater number of calibration target values for aquifer water levels than there were for these discharges. Without preferential weighting, PEST would try to match all targets with similar accuracy, by default placing more emphasis on aquifer water level targets. The weighting applied to targets essentially determines the degree to which PEST "focuses" its effort on minimizing error in certain types of model behavior. PEST provides guidelines for such weighting, but it ultimately becomes a decision made by the modeller.

The ESPAM2.1 was calibrated under the assumption that aquifer transmissivity in any given cell is constant over the calibration period. This assumption is computationally convenient in part because it avoids iterative recalculation of transmissivity as simulated water levels change, but it can lead to overestimation of transmissivity in some areas of the model domain (Johnson, et.al., 2010). A common rule of thumb in determining whether this assumption is justified is that simulated changes in water level should not be greater than 10% of overall saturated thickness (Reilly, et al, 1987). Areas where this condition is most likely not to be met are those where the aquifer is thinnest, such as at its edges, as is the case in the present delivery call. Hinckley (2012) estimates that the saturated thickness of the ESPA in the vicinity of Rangen is on the order of 50 feet. Water level changes in wells near Rangen are on the order of 5 feet, making the assumption of constant transmissivity (and the convenient assumption of linearity that it allows) questionable. Compounding this is the fact that fractures and heterogeneities of a scale much smaller than one mile likely dominate flow hydraulics at the thin edges of the aquifer.

4.5 Calibration Results

Calibration success can be assessed in several ways besides the final objective function value produced by PEST, which is not by itself informative. The most commonly used methods for assessing calibration are visual and mathematical comparisons of simulated values and their corresponding targets. It is also useful to examine simulated and observed flow regimes to assess whether model performance reflects general observations and geological constraints that might not be represented explicitly.

4.5.1 Comparison with Calibration Targets in Rangen Area

Figure 4.6 shows the calibrated and target discharge for the Rangen spring complex from the ESPAM2.1 final calibration, along with other representations of calibration fit. In general, the broader patterns of observed discharge are reflected in the modeled values; multi-year cycles and trends are apparent in both, as are seasonal variations. However, the ESPAM2.1 systematically under-estimates discharge in the early years of the calibration period while over-estimating it in the later years.

This systematic error is more apparent by the analysis of residuals that is also shown in Figure 4.6. This analysis shows the error in monthly simulation relative to mean discharge. If simulation errors are random, this plot of residuals should vary randomly about the zero line over time. In fact, Figure 4.6 shows that that ESPAM2.1 consistently under-predicts (by as much as 15 cfs) the total flows from the Rangen complex in the early part of the calibration period and consistently

over-predicts (by as much as 15 cfs) these flows in the more recent part of the period. Since similar patterns are evident at other target springs in the area it raises the prospect of a more general problem with ESPAM2.1 representation of springs in the Hagerman area and suggests that curtailment analyses, which look forward from present conditions, may over-predict increases in spring discharge from curtailment.

Figure 4.7 shows a comparison between simulated and target water levels in calibration well #989 (7S14E29CDC1). There is no calibration well in the Rangen cell, but well #989 is in the model cell immediately northeast from the Rangen cell and is the closest well used in calibration. The simulated water level in this well is systematically more than 20 feet lower than observed level. Also shown on Figure 4.7 is a comparison between simulated and observed water levels in well 7S14E33BBB1. This well was identified as calibration well #992, but for unknown reasons was not included in the target calibration data set. Figure 4.7 shows that ESPAM2.1 also underpredicts the water level in this well.

In 2008 the IDWR completed a monitoring well (7S14E32SENW, aka the "Rangen Monitor Well") on the plain just above the Curren Tunnel (Farmer, 2009). Observations from this well could not be used in ESPAM2.1 calibration because measurements did not begin until the very end of the model calibration period. Nevertheless, the range of observed values reasonably can be compared to simulated water levels in the Rangen cell for the last few years of the calibration period. This comparison is shown in Figure 4.8. It can be seen that ESPAM2.1 predicts recent water levels in the Rangen cell that are substantially lower than what has been observed in the Rangen Monitor Well.

The underprediction of water levels near Rangen is partly a result of the fact that discharge targets were weighted more heavily than water level targets in the calibration process. If predicted water levels were too low, PEST could still meet the more important discharge target by increasing the drain conductance. This is problematic because it embodies, in the drain conductance parameter, a mischaracterization of the real physical relationship between water levels and flows at Rangen. This, in turn, results in mischaracterization of change in drain flow as a result of simulated change in water level due to curtailment. If the calibrated drain conductance parameter is too high, the benefits to Rangen from curtailment will be over-stated.

That the Rangen discharge calibration is as good as it is despite the underprediction of surrounding water levels illustrates another important modeling concept…that good calibration is not necessarily evidence of correct physical representation (Bredehoeft, 2005).

Table 4.1 lists the ESPAM2.1 drain parameters determined by PEST for target springs in the Billingsley Creek area. Drain elevation assumptions were generally chosen to reflect actual elevations, or a range of actual elevations where multiple drains were used. PEST was allowed to adjust drain conductances as needed to match spring discharge targets using simulated water levels. As can be seen in Table 4.1, the calibrated conductances range over 4 orders of magnitude. This extremely large variation suggests that the set of calibrated parameters is quite fragile and that PEST can readily find alternative parameter sets that provide acceptable calibrations.

4.5.2 Comparison to Observed Conditions in Rangen Area

The ESPAM2.1 posits a strictly linear relationship between water level in the Rangen cell and discharge from the Rangen drain. The ESPAM2.1 drain conductance has a calibrated value of 4.85 cfs/foot, meaning that a one foot increase in water level in the Rangen cell will result in a 4.85 cfs increase in drain discharge. The only water level observations close enough to Rangen to be considered within the Rangen cell are those from the Rangen Monitor Well. Hinckley (2012) demonstrates that Curren Tunnel discharge is not the simple linear function of nearby water level represented in ESPAM2.1, a fact that appears also to be acknowledged by Rangen experts (Brannon, 2009). If this relationship is in fact non-linear, the principle of superposition cannot be used to reliably determine the effects of curtailment on Rangen flows.

Even if a linear relationship were to be derived from Hinckley Figure 18, it suggests that a one foot increase in nearby water level would cause a discharge increase of 1.37 cfs rather than the 4.85 cfs embodied in ESPAM2.1. In this case the ESPAM2.1 overstates the benefit from curtailment by nearly a factor of 4.

Observed water level in the Rangen monitor well varies over a range from about elevation 3151 ft to 3166 ft (msl). Farmer (2009) estimated the elevation of the outlet of the Curren Tunnel to be 3145 ft (msl) and the elevation of the lower springs to be about 3100 ft (msl). This suggests that the saturated thickness of the aquifer above the Tunnel outlet is not greater than 6-21 feet and that the saturated thickness of the aquifer above the lower springs is in the range of 50-65 feet. Water levels in the monitor well vary seasonally by about 5 feet, and predicted (by ESPAM2.1) water level change in the Rangen cell from curtailment is about 6 feet. These changes are nearly 100% of the saturated thickness above the Tunnel and about 10% of the thickness above the lower springs, further indicating that the requirements for superposition are not met at Rangen.

Hinckley (2012) has shown that for a given water level in the Rangen Monitor well, the discharge from the Curren Tunnel can vary by 4 cfs. In other words, with *no difference* in observed water level, observed discharge varies by 100% of its average value over the observation period. Similarly, Hinckley has shown that a given level of Rangen discharge can be associated with water levels that vary over a 2.5-foot range. This casts further doubt on the accuracy with which ESPAM2.1 can predict the benefit to Rangen from curtailment.

Figure 4.9 shows the ESPAM2.1 change in calibrated values of aquifer transmissivity in the vicinity of Rangen. Notable on this figure is the fact that transmissivities increase in magnitude closer to the canyon rim above Rangen. This is the opposite of what would be expected as the aquifer thins out and saturated thickness decreases. Some of this is undoubtedly a result of the higher weighting placed on discharge targets than on water level targets, but Johnson (2010) suggests it may be a result of calibration using the assumption of constant transmissivity. It is likely that fracture or conduit flow, more than porous media flow, dominates hydraulic behavior near springs in the rim area. These other flow paradigms are not reflected in any of the MODFLOW constructs used in ESPAM2.1.

Farmer (2009) describes a geological discontinuity in the vicinity of Rangen where the Quaternary basalt forming the main aquifer effectively ends at the canyon rim. The Quaternary basalt below the rim immediately west of Rangen is postulated to have flowed down a "ramp" from the southeast. Because of this discontinuity, groundwater entering this lower basalt flow has to come from the southeast rather than directly through the Rangen area. However, in ESPAM2.1 there is a simulated groundwater flow of 366 cfs (on average) across this discontinuity from the Rangen cell into the cell containing Tucker and Stewart Springs. As a result of this high flux, simulated water level in the Tucker/Stewart cell is very high (above actual ground surface) and causes a simulated groundwater gradient sloping to the south. Hinckley (2012) points out that the observed groundwater gradient in this area is in the opposite direction from that simulated by ESPAM2.1. These discrepancies reveal serious model misrepresentation of detailed aquifer behaviour in the Rangen area, and raise doubt as to the accuracy of model predictions there.

4.5.3 Comparison of ESPAM2.1 with Previous Versions of ESPAM

ESPAM1.1 and ESPAM2.0

The IDWR carried out a comparison of ESPAM1.1 and ESPAM2.0 performance (Sukow, 2012) using the paradigm of the generic curtailment scenarios originally run by IWRRI for ESPAM1.1 (Contor, et al, 2004). This comparison utilized a steady-state version of the primary input file (the .wel file) in both the ESPAM1.1 and ESPAM2.0 and simulated the curtailment to 5 generic dates. Table 4.2 reproduces the results of this comparison for the generic curtailment date of January 1, 1961.

Table 4.2 makes two different comparisons. The first compares results from using the ESPAM1.1 input file in both the ESPAM1.1 and ESPAM2.0; this comparison illuminates the change in model results that can be attributed mainly to changes in model structure and parameters (which have been described above). The second compares results between the two models each using their own input file; this comparison illuminates the change in model results that can be attributed mainly to changes in input data. With respect to spring flows below Milner, the IDWR analysis found that flows due to 1961 curtailment increased from 352 cfs to 454 cfs using the ESPAM2. The analysis also concluded that roughly 75% of this change was the result of changes in model input data, primarily the use of more recent years for estimation of irrigated acreage and irrigation water requirements. This highlights the sensitivity of ESPAM2 results to conditions in particular years. Review of updated comparisons using ESPAM2.1 (Sukow, 2012) leads to the same conclusion.

ESPAM2.0 and ESPAM2.1

Shortly after its release, an error was discovered in the input data for ESPAM2.0. The error arose in the calculation of the water budget in the Mud Lake area and caused an overestimate of aquifer recharge of approximately 89,000 acre-feet/year in that area of the model domain. The error was corrected and the model was recalibrated creating ESPAM2.1, which was made available on November 16th of this year.

The water budget error at Mud Lake was on the order of 1% of the overall ESPAM water budget. It was expected that the relatively small size of this error and its location at the far northeastern part of the model domain would not result in significant changes to the model at its western end.

Table 4.3 shows the change in calibrated values of drain conductance parameters in the Thousand Springs reach and Rangen area, between ESPAM2.0 and ESPAM2.1. As can be seen in Table 4.3, many of the conductances in the western end of the model domain changed by amounts substantially greater than the 1% change in water budget associated with the correction. The conductance for the Rangen drain decreased by about 4%, but some drain conductances in the area changed by nearly 1000%. Figure 4.9 shows how transmissivity values changed as a result of the error correction. Some cell transmissivities in the area near Rangen changed by as much as 500%. As will be discussed in a later section, these changes in conductance and transmissivity are carried directly into the superposition models used to calculate the flow changes resulting from curtailment. Large changes in calibrated parameter values suggest that ESPAM2.0 and ESPAM2.1 may be over-parameterized, and that other comparable calibration solutions easily can be reached with only minor perturbations in model assumptions. This substantially raises the level of uncertainty in model predictions, since other models can readily be found (by PEST) that are as well-calibrated but have very different parameter values in specific locations.

Further evidence of unexpectedly large changes in ESPAM2.1 is seen in Figure 4.10, which depicts the boundary of the 5% and 10% trimlines for Rangen using ESPAM2.0 and ESPAM2.1. Figure 4.10 shows that the area encompassed by the 5% trimline is substantially larger with ESPAM2.1, but that this expansion is mainly in areas on the opposite side of the Malad Gorge from Rangen. Given the fact that the Gorge severs the Quaternary basalts that form the aquifer (Hinckley, 2012), it is difficult to see why wells west of Bliss should now be viewed as having increased effect on Rangen flows simply because of a small data error at Mud Lake.

4.6 Model Uncertainty

The ESPAM2 is, like all models, a simplified representation of reality, and this leads to model uncertainty. When viewed from a distance, the generalizations and simplifications made to construct the model may be sufficient to support regional scale analyses. However, when called upon to represent highly localized conditions such as those governing discharge from specific outlets of a specific spring complex, the generalizations and simplifications can introduce significant error into model results. Actual subsurface conditions within the ESPA are understood only in specific locations where lithology has been observed (e.g., boreholes and outcrops) and where hydraulic characteristics have been measured (e.g., pump tests). Observations of ESPA geology suggest it is highly complex, comprised of overlapping fractured basalts interspersed with sedimentary formations, with hydraulic characteristics that can vary substantially over short distances (Lindholm, 1996; Hinckley, 2012).

4.6.1 Overview - General Dimensions of Model Uncertainty

Model uncertainty has several dimensions, and these have been described in various submittals to the ESHMC (e.g., Brendecke, 2009a,b; 2012). In a nutshell, the principal dimensions of model uncertainty are those associated with model conceptualization, with model input and with model calibration. While all of these dimensions are important, conceptual uncertainty is fundamental. No amount of data improvement, re-sampling or recalibration can correct errors stemming from incorrect (or simply incomplete) model conceptualization (Bredehoeft, 2005).

Model conceptualization involves the identification and adoption of a model framework that the modeller believes can properly represent the behavior of the underlying real system. At a practical level it is the selection of a modeling code (in the present case MODFLOW) and the formulation of the model structure (e.g., defining the domain, deciding whether to operate it as a confined or unconfined system, adopting cell sizes, layering, boundary conditions, etc.). Previously in this chapter we have examined how many of these conceptual aspects of ESPAM2.1 fail to reflect observed characteristics of the aquifer system in the Rangen area. These failures lead to conceptual uncertainty in the ESPAM2.1.

Rigorous evaluation of conceptual uncertainty is difficult. There may be a large number of plausible conceptual models of an aquifer system and these models can't be rigorously evaluated until they are built. As a result, this critical dimension of model uncertainty is often "swept under the rug" in favor of more constrained and tractable evaluations that focus on input data and calibration. In the case of ESPAM2.1, this conceptual uncertainty bears directly on its suitability in the present matter.

Once a conceptual model has been identified and formulated, it must be populated with input data reflective of the important aspects of the aquifer water budget. In the case of ESPAM2.1, these data include precipitation, tributary underflows, irrigated acreage, crop distributions, surface water supplies, water application methods and efficiencies, etc. Each of these input data types carries its own uncertainties that can stem from, among other things, the inability to measure a condition accurately (or at all) and from the spatial or temporal resolution of measurements. Sometimes these uncertainties can be reduced by further data collection efforts, though these may be time-consuming and expensive. The effects of input data uncertainty can sometimes be explored through sensitivity analysis or through Monte Carlo analysis, which seeks to translate probabilistic descriptions of model input data to probabilistic descriptions of model output.

Once the conceptual model has been populated with input data, it must be calibrated. The calibration process has been addressed previously in this section. Calibration uncertainty essentially reflects the fact that many combinations of model parameter values (which in the case of ESPAM2.1 include aspects of the aquifer water budget) may lead to equally well-calibrated models. The uncertainty arises because the predictions made by these equally well-calibrated models may be significantly different.

4.6.2 IDWR Uncertainty Analysis

The uncertainty of ESPAM2.0, and selected aspects of ESPAM2.1, have been explored by the IDWR using a technique called "Predictive Analysis" that is available as part of the PEST software (Watermark, 2005). Predictive Analysis is described in the PEST documentation as

> "… the task of calculating the effect of parameter uncertainty, as estimated through the calibration process, on predictive uncertainty."

Predictive analysis essentially answers the question "If I use slightly different values for selected model parameters, do I get different values for key model results?" The analysis requires assumptions about the meaning of "slightly different" and whether such differences are small enough that the model can still be considered calibrated. The analysis does not explore alternative conceptual representations of aquifer hydrogeology, although it can be used in a limited way to explore input data uncertainty.

Table 4.3 summarizes the predictive analysis carried out by the Department (Wylie, 2012b, c) for ESPAM2.0, showing updates for selected portions using ESPAM2.1. The analysis made several simplifying assumptions to make the work computationally more efficient; for example, it assumed that pumping stress for entire Water Districts could be applied at the centroid of each District without loss of accuracy. The predictive analysis was designed to be generic, and did not examine parameter sensitivity of predictions of Rangen discharge. The conclusion that can be drawn from Table 4.3 is that parameter uncertainty variable of the model domain (e.g., the relationship between pumping in Water District 34 and reach gains between Blackfoot and Minidoka is apparently larger than that between pumping in Water District 130). The important thing to remember with this analysis is that it relies on a single conceptual model and does not explore the uncertainty that arises from improper conceptualization of local geologic and hydraulic conditions that influence discharge of specific spring complexes, such as those at Rangen.

4.6.3 Rationale for alternative models

In the uncertainty evaluation carried out for the ESPAM2.1, the model and parameter structure are assumed fixed, as are many data inputs. This approach is valuable in illuminating those parameters for which further investigation might reduce the uncertainty of the chosen model (James, et. al., 2009), but does not address larger questions of model uncertainty described above. More exhaustive evaluation approaches, such as Monte Carlo simulation, may shed greater light on the probability distributions of model errors. However, unless such approaches address all the dimensions of model uncertainty, including conceptual uncertainty, they too will be incomplete.

Conceptual uncertainty can only be addressed by considering alternative models. The poor correspondence between ESPAM2.1 assumptions about hydrogeology and aquifer behavior in the Rangen area indicate that at the very least a refined version of ESPAM2.1 is required. One very preliminary set of refinements are discussed in a later section of this report.

4.7 Limitations of ESPAM2

While it is clearly an improvement over its predecessor, several important features are the same in ESPAM1.1 and ESPAM2.1. The two are still conceptually the same regional model. Differences between them are largely the result of differences in input data and in values of calibration parameters resulting from the use of that input data. Both models represent the details of the Rangen spring complex and the surrounding geology in highly simplified form, omitting several key features and that would make significant differences in predicted benefits of curtailment.

Particularly important to the present case is the fact that ESPAM2.1 systematically underestimates water levels in the Rangen area. Because simulated heads are too low in the cells above Rangen, the calibrated drain conductances have to be made higher in order to meet the discharge calibration targets. This means that the drains are overly-sensitive to small changes in head. This over-sensitivity is carried into the superposition model used for curtailment, with the result that changes in spring flows are substantially over-predicted.

For these reasons, the ESPAM2.1 is subject to the same general limitations as ESPAM1.1, despite the increased attention given to the use of springs as calibration targets. That ESPAM2.1 can fairly closely mimic the observed past behavior of a spring complex is not proof that it sufficiently represent hydrogeologic reality to accurately predict future behaviour of that complex, especially under aquifer water use conditions (e.g., curtailment of large amounts of junior groundwater pumping) that are radically different from those extant in the model calibration period.

The ESPAM2.1 documentation describes limitations on model usage, highlighting the facts that a number of simplifying assumptions had to be made and that many components of the model water budget were uncertain. The documentation cautioned that ESPAM2.1 is a regional ground-water model best used for broad-scale predictions.

5.0 SIMULATION OF CURTAILMENT OF JUNIOR GROUNDWATER RIGHTS

5.1 Background

IDWR practice has been to create superposition versions of the ESPA groundwater model for use in evaluating curtailment (and other) scenarios. Superposition models are used primarily for reasons of convenience; it is faster and easier to perform analyses with superposition models than it is with "fully populated" models. A fully populated model contains all the water budget (input) data and parameters used in model calibration; outputs from a fully populated model can reflect simulated values of characteristics that may be directly observable in the aquifer. However, to examine effects of changes in input data, such as reduced pumping withdrawals, it is necessary to make two runs of a fully populated model and then determine effects by differencing the results of the two runs. The use of a superposition model allows this differencing to be accomplished in a single model run.

A superposition model preserves the parameters of the flow relationships between model cells but sets the initial condition of the groundwater flow regime to one of zero flux. Existing fluxes are eliminated by setting all aquifer heads and elevation differences to zero. The aquifer is converted, conceptually, into a still pool but one in which all the water molecules preserve fixed, predetermined relationships to one another. The relationships that are preserved in a superposition model are embodied in the calibrated parameters governing flow rates and responses: transmissivity, specific yield, conductance (of drains, riverbeds, and general head boundaries) and seepage rates from canals. The effect of a selected model stress, such as a reduction in groundwater withdrawal, can then be evaluated with the superposition model simply by applying that incremental stress and examining how heads and fluxes (including reach gains and drain flows) have changed from their zero condition.

The principle of superposition relies on the assumption that the system being modeled behaves in a completely linear way…that is, that flow relationships are independent of flow magnitude. In a linear model, the rate of flow caused by a half-foot difference in water level between two cells will be the same whether the cells contain water 1 ft or 1000 ft deep. Superposition models perform identically at all levels of assumed stress change, even those outside their range of calibration. If the system being simulated exhibits important non-linear behaviors, such as those that have been described in preceding sections of this report, a superposition model can introduce significant error into the analysis of effects of stress changes.

The practice of the IDWR has been to define three superposition versions of the ESPAM, a steady state version (dubbed "SuperSS"), and two transient versions (dubbed "SuperTransient10yr_monthly" and "SuperTransient150yr"). The transient versions allow simulation of how assumed stress changes evolve over time, the former reflecting a repeated seasonal pattern of conditions and the latter reflecting a constant annual pattern. The constant annual pattern is used to assess the speed at which the aquifer reaches equilibrium (steady state) conditions after introduction of a change.

Simulation of curtailment of groundwater irrigation rights junior to Rangen's 1962 Curren Tunnel water right has been carried out with ESPAM2.0 by both the IDWR and by Rangen experts. Simulation of curtailment using ESPAM2.1 has been carried out in a generic sense by the IDWR (Sukow, 2012) and for the Rangen water rights by AMEC. These simulations are briefly described and evaluated below.

5.2 IDWR Curtailment Analyses

5.2.1 Generic Curtailment Analysis

As part of the development of ESPAM2.1, the IDWR carried out a comparative analysis of the effects of curtailment as simulated by ESPAM1.1, ESPAM2.0 and ESPAM2.1. The simulated curtailments were those described by Contor, et al. (2006) for ESPAM1.1. The curtailments did not reflect priority dates of any specific water rights nor were they limited spatially to the Area of Common Groundwater defined in Rule 50 of the Conjunctive Management Rules. The curtailment dates used in the analyses were January 1 of the years 1870, 1949, 1961, 1973 and 1986. The January 1, 1870, curtailment date reflected curtailment of all groundwater use in the model domain except that occurring under tribal water right settlement agreements.

The January 1, 1961, curtailment is roughly comparable to that which would occur under the present delivery call for Rangen's July 13, 1962, water right. Table 4.2 in the preceding section showed the results of the hypothetical 1961 curtailment using ESPAM1.1 and ESPAM2.1.

5.2.2 Rangen Curtailment Analyses

In its document production of June 12, 2012, the IDWR produced model files containing results of curtailment analyses for the present Rangen delivery call. These files indicate that the Department evaluated the effects of July 13, 1962, curtailment with ESPAM2.0 using various "trimline" assumptions.

The "trimline" defines a zone of exclusion outside of which the benefits of curtailing a well are less than a threshold percentage of the amount of water use curtailed, as determined by the groundwater model. The trimline concept was originally adopted by former Director Karl Dreher in his 2005 Orders stemming from the delivery calls of Blue Lakes Trout, Clear Springs Foods, the Surface Water Coalition, Rangen, Inc., and others. Director Dreher adopted a 10% trimline and stated in hearing testimony that he viewed this as a minimum level of model uncertainty, noting that model uncertainty had not been quantified. He went on to say that:

> *"…I made the determination it was not appropriate to curtail such junior priority ground water use if, in fact, we didn't know whether curtailment would result in a meaningful amount of water reaching the calling senior right."* (Transcript at 1167: 4-80)

Table 5.1 summarizes the results of the IDWR curtailment analyses using ESPAM2.0. The analyses considered trimline thresholds between 0.2% and 10%, as well as trimlines limited only by the Rule 50 Area of Common Groundwater Supply and by the ESPAM2.0 model domain. As

the trimline threshold decreases the area encompassed by curtailment increases. As shown in Table 5.1, there are a total of 406 groundwater irrigated acres relying on rights junior to Rangen's 1962 priority within the 10% trimline; there are a total of 565,023 groundwater irrigated acres within the model domain relying on rights junior to Rangen's1962 priority.

Table 5.1 shows that curtailment of the junior groundwater rights within the 10% trimline would immediately eliminate 1,445 acre-feet of groundwater pumping and, at steady state, would cause total modeled flow at the Rangen springs to increase by 0.19 cfs (141 af/y assuming year around flow). This increase in modeled spring discharge represents 9.5% of the pumping foregone by the curtailed wells and, assuming a permitted groundwater diversion rate of 1 miners inch (1") per acre, 0.66% of the curtailed water rights. It would take somewhat less than a year for discharge to reach 90% of this modeled steady state increase.

Curtailment of the junior groundwater rights within the entire model domain would immediately eliminate 1.46 million acre-feet (MAF) of groundwater pumping and, at steady state, would cause modeled discharge from the Rangen spring complex to increase by 18.07 cfs. This increase represents 0.9% of the pumping foregone by the curtailed wells, and 0.06% of the curtailed water rights. It would take approximately 16 years for modeled discharge to reach 90% of this steady state increase.

Foregone groundwater use that is not simulated to accrue to Rangen would accrue to other connected river reaches, springs and baseflows, including those on which there are no water rights or diversions, those on which there are no delivery calls, those on which approved mitigation plans are already in place, and those on which diversions occur under water rights junior to those of the curtailed rights.

5.3 Rangen Analysis

In its December 13, 2011, delivery call Rangen included a curtailment analysis (Exhibit 11 to the petition) carried out by its experts (McGrane et.al., 2011). The details of this analysis were requested at the outset of discovery for this case, but were not produced by Rangen until November 28th of this year. Accordingly, the conclusions below are based primarily on a facial interpretation of Exhibit 11 and may be supplemented when time permits a more careful examination of Rangen's late production.

The Rangen analysis appears to be a transient analysis using average monthly stresses. The use of a transient, average monthly analysis permits the display of simulated seasonal effects of curtailment. It does not appear that the version of ESPAM2.0 used for the analysis is the final calibrated version. The analysis recommends against the use of the trimline concept and concludes with a recommendation that Rangen seek curtailment of all junior (to July 13, 1962) groundwater irrigation rights within the ESPAM2.0 domain. As noted above, this would immediately dry up 565,023 acres of groundwater irrigated land.

Figure 5.1 is reproduced from Exhibit 11 of the Rangen petition. It shows that curtailment would achieve a simulated annual average increase in total Rangen discharge of 17 cfs after 20-plus

years of curtailment. After twenty five (25) years of continuous curtailment, simulated minimum seasonal flows from the Rangen complex would increase by about 9 cfs.

Presumably the curtailed groundwater acreage and water use amounts implicit in the Rangen analysis are similar to those of the IDWR analysis with no trimline, and that similar conclusions could be drawn regarding the portion of curtailed use and water rights that would accrue to Rangen's benefit.

5.4 Rangen Curtailment Using ESPAM2.1

AMEC has carried out analyses of curtailment for Rangen's 1962 water right using ESPAM2.1. These analyses were carried out using the assumption of a 10% trimline. A 10% trimline assumption was adopted based on precedent; previous curtailment analyses and orders by the IDWR have used this assumption, which stems from Director Dreher's Orders in 2005.

AMEC compared the spatial extent of the 5% and 10% trimlines for ESPAM2.1 as defined based on steady-state response functions published by the IDWR (http://www.idwr.idaho.gov/Browse/WaterInfo/ESPAM/model_files/Version_2.1_Current). Figure 4.10 shows the 10% and 5% trimlines for ESPAM2.0 and ESPAM2.1. The 10% trimline is the same for both models, but the 5% trimline for ESPAM2.1 encompasses a larger area than that for ESPAM2.0. This is presumably the result of recalibration due to correction of the Mud Lake data error described previously, though it is difficult to see why a small change in input data in the opposite end of the model domain would cause such a large change in the trimline. It is noteworthy that the extension of the trimline occurs in the area west of Bliss, which is separated from the Rangen area by the Malad Gorge.

Table 5.2 summarizes the steady state results of the 10% trimline curtailment using ESPAM2.1. Curtailment to the 10% trimline has results nearly identical to the ESPAM2.0 analysis done by the IDWR. This curtailment would immediately dry up 406 acres of groundwater irrigated land and eliminate 1,446 acre-feet of groundwater use. Total simulated flow at Rangen would increase 0.21 cfs, which is slightly higher than the 0.19 cfs predicted by the IDWR analysis. This small difference may be attributable to changes in the transmissivity distribution that occurred in recalibration of ESPAM2.1.

6.0 Alternative Conceptual Models

This section describes the development of two alternative conceptual models (labelled #1 and #2 below) of the ESPA in the immediate area of the Rangen complex. The aim of this effort is not to present a definitive reformulation of ESPAM2.1, but to illustrate how a few relatively minor changes to its conceptual structure, suggested by detailed hydro-geologic review, could result in significantly different conclusions from a curtailment analysis. In order for either of these alternative conceptual models to be fully developed, it would be necessary to perform similar analyses at other spring complexes as were presented in the foregoing sections of this report and to extend the reach of calibration from that used herein. Nevertheless, the results of these preliminary steps at more realistic representation of local hydrogeology illustrate the potential for significant conceptual uncertainty in the application of ESPAM2.1 to localized problems.

6.1 Description of Modifications to ESPAM2.1

The alternative modeling effort focused on making small changes to the construction of ESPAM2.1 to explore what effect these changes have on simulated Rangen discharge and simulated water levels in the vicinity of Rangen. Concepts for these changes are based primarily in hydrogeologic analyses and interpretations presented in Ralston (2008), Farmer (2009) and Hinckley (2012) and on discussions with Neal Farmer on August 22, 2012.

6.1.1 Horizontal Flow Barrier

The main geologic formations that influence the groundwater flow and spring discharge near the Hagerman area are the Quaternary basalts that form the ESPA and the less permeable Tertiary formations (e.g., Glenns Ferry) that underlie it. Current geologic understanding of the Hagerman area is that the ESPA effectively terminates along the Hagerman rim and that the underlying formations restrict subsurface flow from it into the Hagerman Valley. At the south end of the rim, however, Quaternary basalt flows form a “ramp” (Farmer, 2009) creating a pathway to feed lower-elevation springs such as Tucker and Stewart as shown in Figure 6.1. Between this ramp and the rim is a geologic discontinuity, possibly faulting, that restricts groundwater movement directly from the rim to the lower elevation springs. Observed gradients indicate that groundwater flows into this lower area are from the southeast rather than the northeast.

To reflect this geological feature, a horizontal flow barrier (Hsieh, 1993) was inserted between columns 12 and 13 for the cells in rows 42 and 43 of the model domain. For model #2, this barrier was shortened to only row 42, as shown in Figure 6.2. A horizontal flow barrier restricts groundwater flow between the cells for which the HFB is defined. With this barrier in place, the preponderance of flow moving southwest through the ESPA must go around the discontinuity to reach the lower springs.

6.1.2 Multiple Drains

Groundwater flows from the Rangen complex emerge at several locations. Farmer (2009) and personal observation note at least two discharge areas, the Curren Tunnel and a set of springs emerging from the slope below it. Farmer estimated the Tunnel to be at elevation 3145 ft (msl) and the lower springs to be at elevation 3100 ft. Koreny (2011) presented spring survey data indicating a Tunnel elevation of 3150 ft "plus or minus two feet." Covington and Weaver (1991) note an elevation of 3138 ft for the "Rangen spring." Elsewhere in the Thousand Springs reach, complexes with discharge points having a range of elevations have been represented using two drains. Given the range and uncertainty in elevations of discharges at Rangen, it seems appropriate to use the same multiple drain construct to represent Rangen as was used in other nearby locations.

Accordingly, another modification made to the alternative models was to represent the Rangen complex using two drains. A new upper drain (DRN218) was added to the Rangen cell, and to the CRIV group. In both models the lower drain was given an elevation of 3100 ft. In alternative model #1 the upper drain was given an elevation of 3152 ft, while in model #2 it was given an elevation of 3148 ft, thus bracketing the upper elevation estimates for the Tunnel presented by Koreny (2011).

6.1.3 Removal of GHB Cells

As noted in Section 4, the use of General Head Boundaries (GHBs) to reflect unmeasured flows from the ESPA to the Snake River effectively undid the removal of the Hagerman Valley from the model domain. Present geologic understanding is that the Hagerman Valley is not part of the ESPA, yet the use of GHBs along the Hagerman rim implies that the ESPA continues through the valley to the river.

It is conceivable that ESPA discharges could be made to the river at the northern and southern edges of the Hagerman Valley. Covington and Weaver (1989, 1991) note the presence of springs at river level downstream of Lower Salmon Falls dam. Low elevation springs and seeps also exist in the area of the Hagerman Fish Hatchery operated by the State of Idaho.

The third modification made in the alternative models was to remove four GHB cells immediately north of Rangen to prevent simulation of ESPA flows through the Hagerman Valley. This reconfiguration is shown on Figure 6.3. This removal forces baseflows in the Buhl to Lower Salmon Falls reach to move through the remaining GHB cells defined in ESPAM2.1.

6.1.4 Increased Weighting on Recent Rangen Flows

A notable feature of the ESPAM2.1 calibration and validation is the over-prediction of Rangen flows in recent years. Given that any management action would look forward from the present, it seems appropriate that greater emphasis should be placed on simulation of current aquifer behavior. Accordingly, a further modification undertaken in Alternate Model #2 was to assign

increased calibration weight to Rangen flow observations after the year 2000. The aim of this modification was to improve the model simulation of Rangen discharge in recent years.

6.2 Calibration of Alternative Models

6.2.1 General Approach

The alternative models were calibrated using the PEST software. Calibration adjustments were limited to parameters in the CRIV group; no recalibration of model transmissivity or specific yield was done, nor were any water budget terms adjusted in the calibration.

Calibration targets for the alternative models were the same as those used in ESPAM2.1, except for the addition of water level targets for PEST well #992. This well, which lies immediately northeast of the Rangen cell, was listed as a target for ESPAM2.1 but was apparently never used. This inclusion of well #992 added 166 additional target values to the calibration data set. These were given calibration weights the same as those used in ESPAM2.1 for other transient water level targets.

6.2.2 Calibration Results Model #1

Figure 6.4a shows the results of calibration of model #1 for the Rangen discharge and Figure 6.5a shows the results for water levels in wells 989 and 992.

In ESPAM2.1, modeled groundwater levels in calibration well 989 are 20 ft lower than observed levels, and in well 992 the modeled levels are around 2 to 8 ft lower than observed levels (well 992 was apparently not used in the ESPAM2.1 calibration).

In alternative model #1, simulated water levels are higher in both wells, matching observations better than in ESPAM2.1. The most marked improvement is in well 989, which was underpredicted by approximately 20 feet in ESPAM2.1; with model #1 the underprediction is about 10 feet. ESPAM2.1 underpredicted water levels in well 992 by about 5 feet, though somewhat less in more recent years; with model #1 there is good match to water levels in well 992, though there is a slight overprediction in recent years.

The simulated Rangen discharge in model #1 is nearly identical to ESPAM2.1. From the foregoing I would conclude that the calibration of model #1 in the Rangen area is at least as good as that of ESPAM2.1.

6.2.3 Calibration Results Model #2

Figure 6.4b shows the results of calibration of model #2 for the Rangen discharge and Figure 6.5b shows the results for water levels in wells 989 and 992.

In alternative model #2, simulated water levels are not as high as with model #1, but correspondence with well 989 is still improved over ESPAM 2.1. Calibration to flow at Rangen is somewhat poorer in the early years of the calibration than is ESPAM2.1, but calibration in recent

years is much better. Model #2 appears to resolve the overprediction problem noted for ESPAM2.1 in recent years.

6.3 Curtailment Analysis with Alternative Models

Both alternative models were run to simulate curtailment of junior groundwater uses within a 10% trimline. This trimline is consistent with past practice and with IDWR water rights transfer policy. The results of these runs are shown in Table 6.1. Also shown in this table are the results of the same curtailment analysis using ESPAM2.1.

It can be seen by this comparison that the relatively minor modifications made to ESPAM2.1 to better reflect local hydrogeology have substantial effect on simulated benefits to Rangen from curtailment. In the case of alternative model #1, the benefit from curtailment is roughly half that predicted by ESPAM2.1. In the case of alternative model #2, the benefit is about 5% of that predicted by ESPAM2.1.

6.4 Conclusion

The foregoing alternative model simulations demonstrate how sensitive the predictions from ESPAM2.1 can be to the model representation of local hydro-geologic conditions. Relatively minor changes in ESPAM2.1 conceptualization, made to more closely reflect the local conditions at Rangen, result in model predictions that differ substantially from those of ESPAM2.1. The substantial differences in model predictions highlight the potential magnitude of conceptual uncertainty in ESPAM2.1, a dimension of uncertainty not addressed in the IDWR's predictive analysis.

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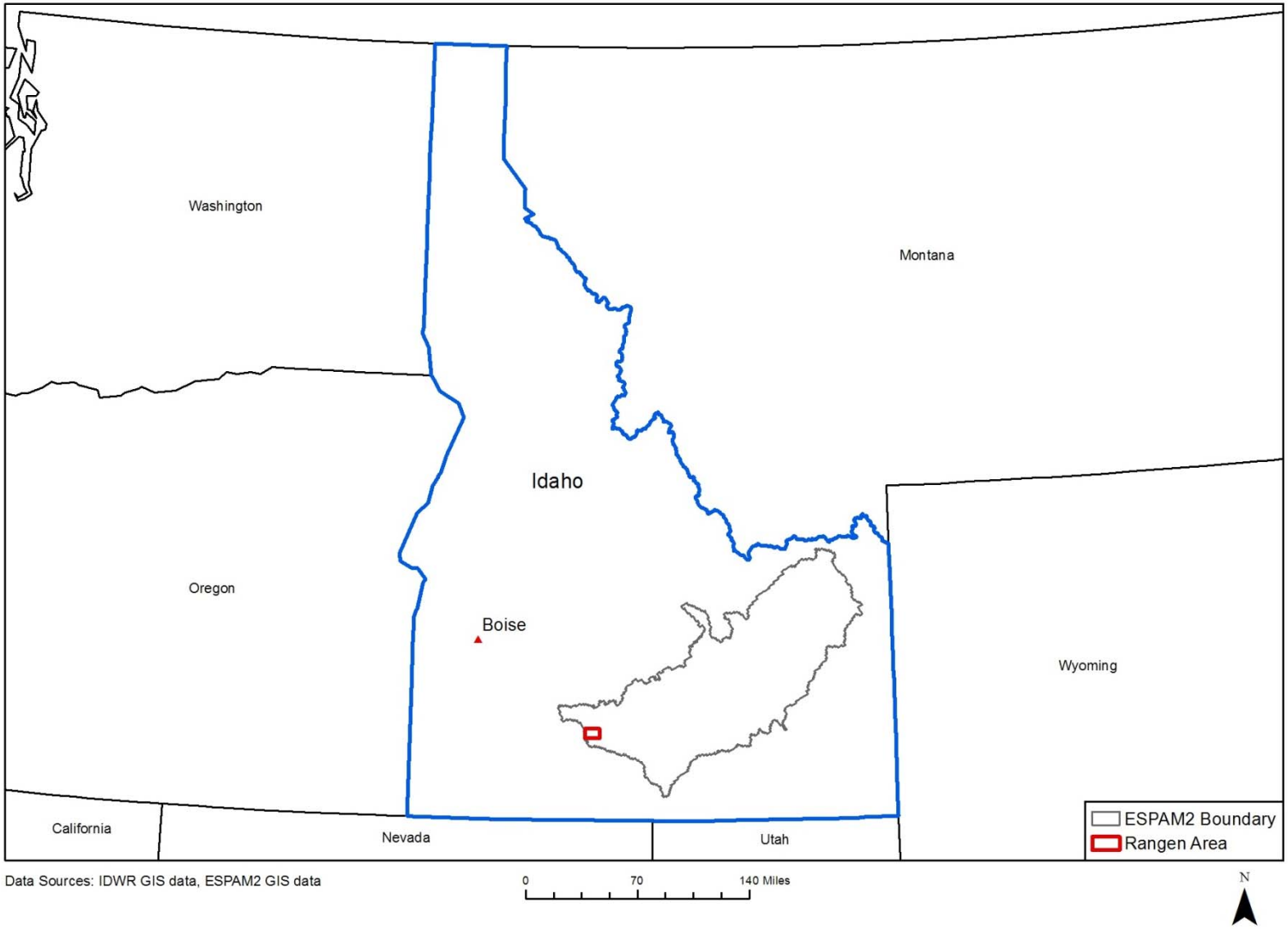


Figure 1.1: Location Map

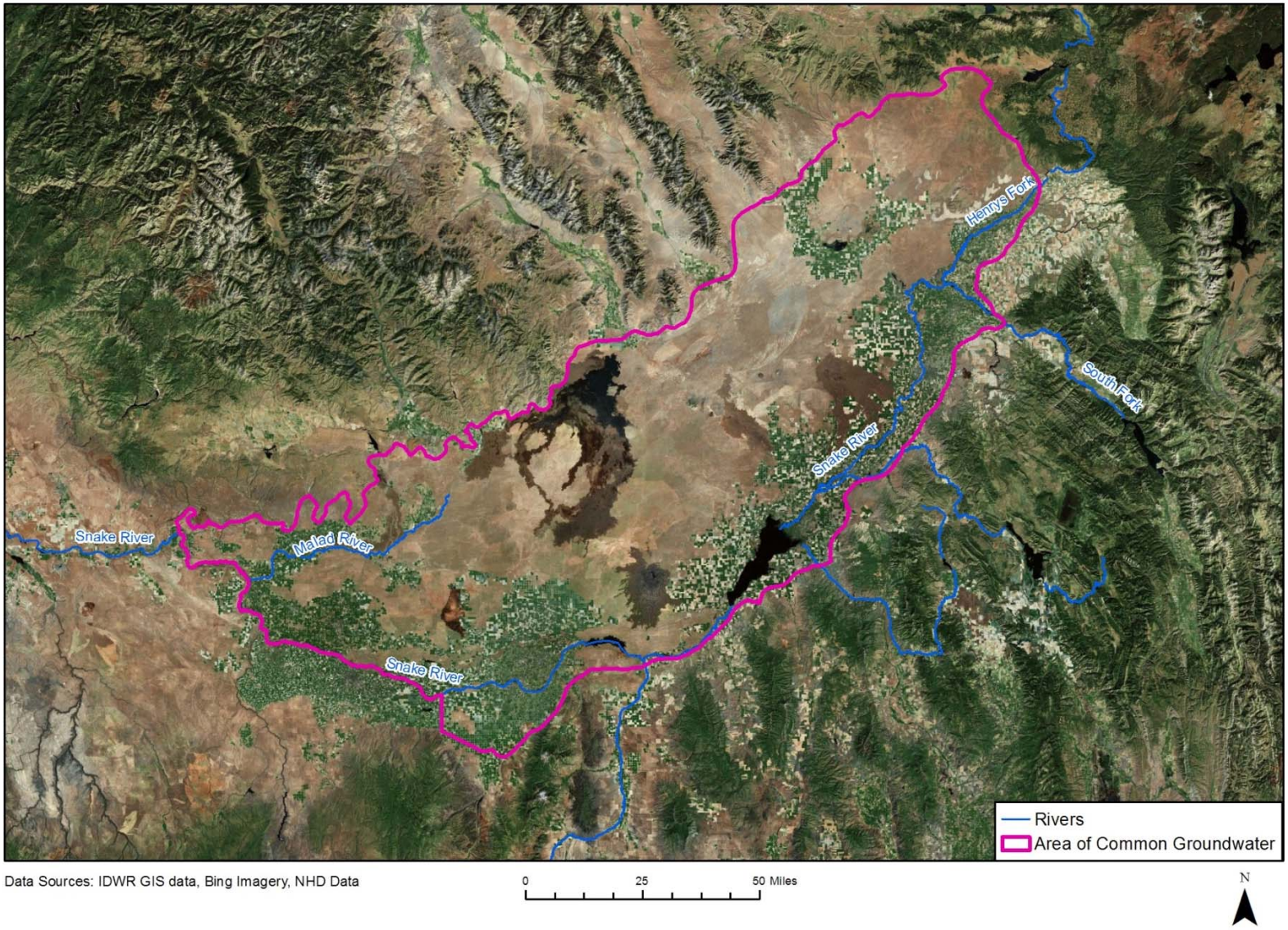
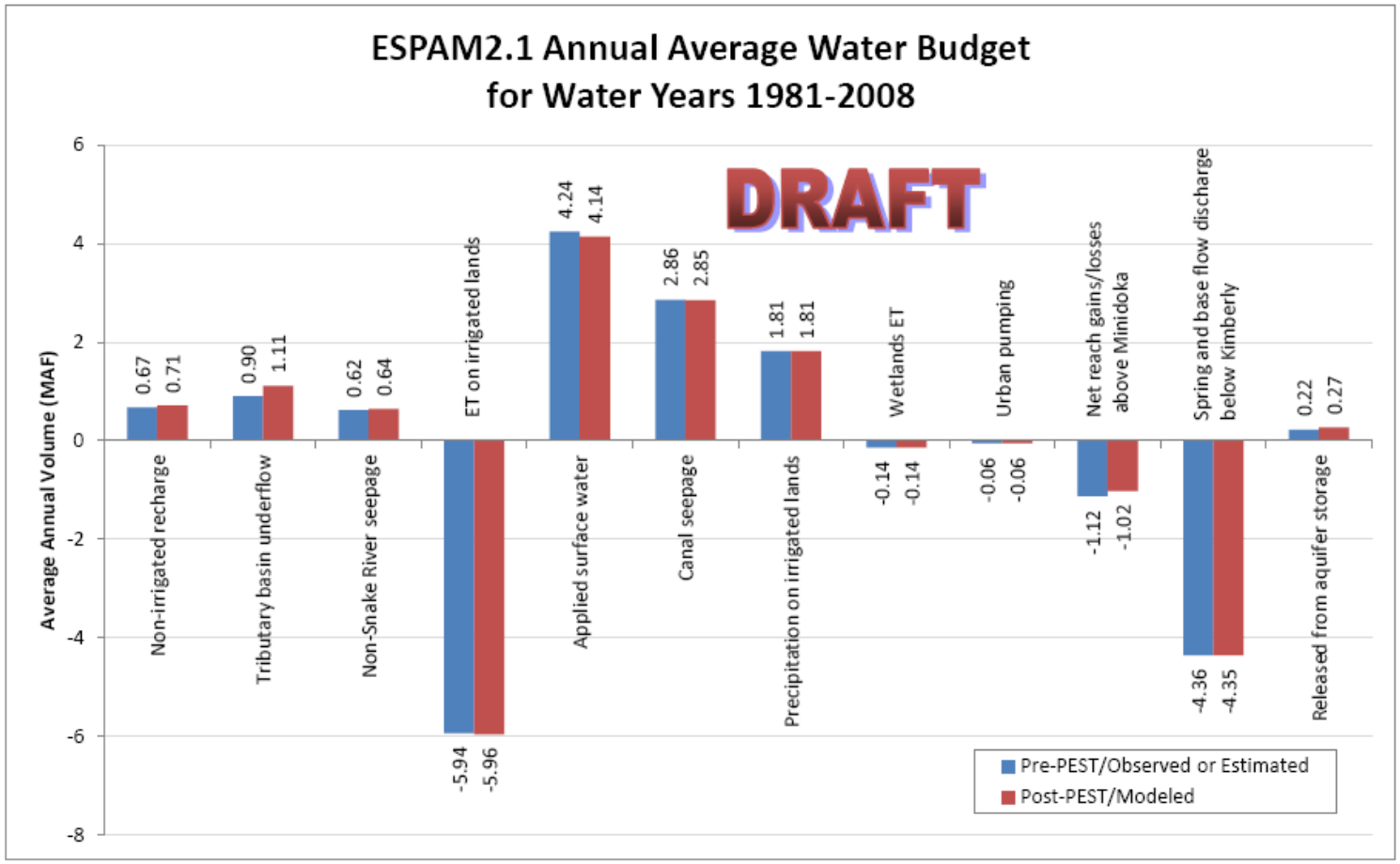


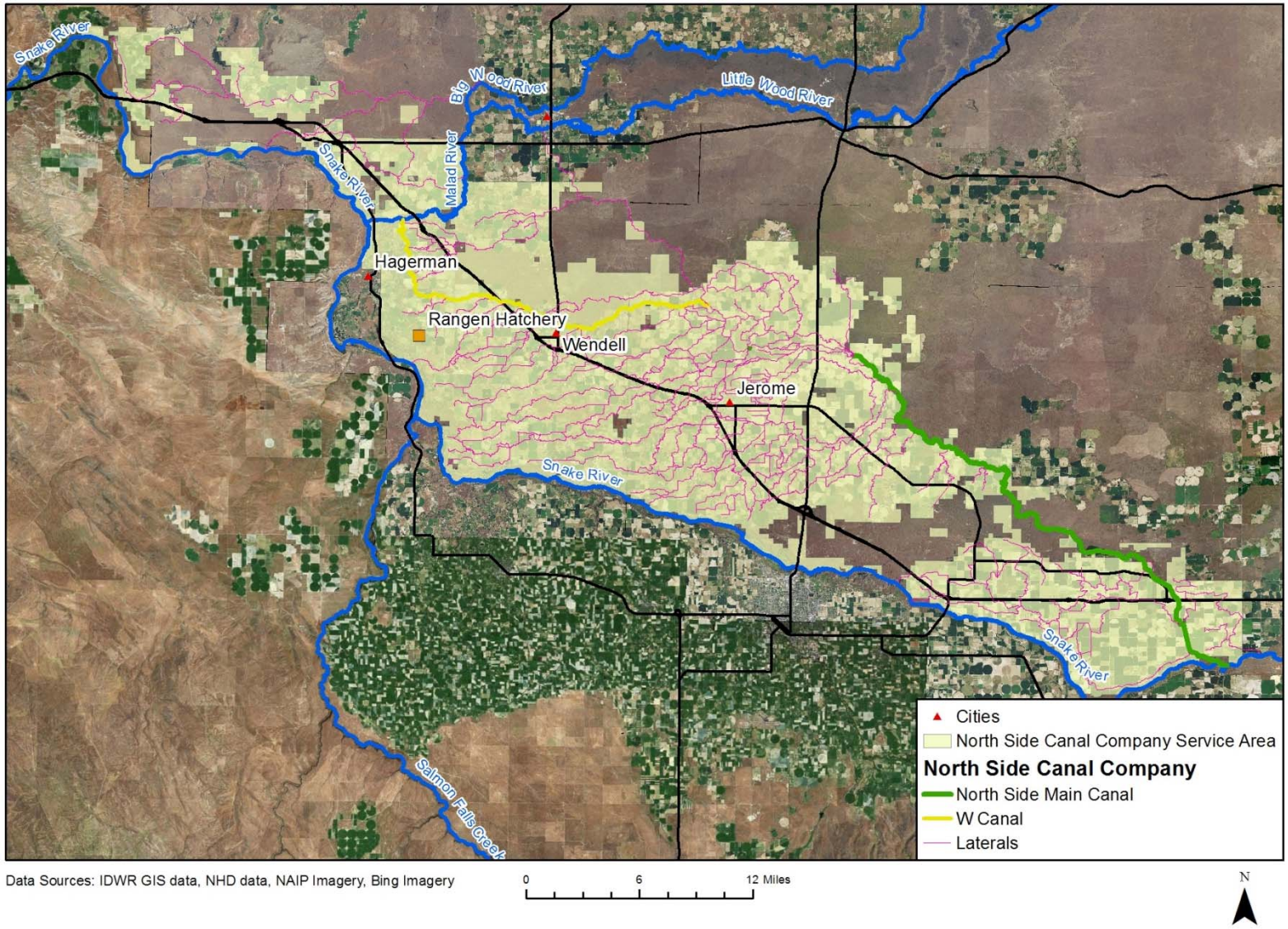
Figure 2.1: Eastern Snake Plain Aquifer



Notes: Positive values of aquifer storage represent water released from storage into the aquifer flow system. Negative values of aquifer storage represent water placed into storage. Applied surface water is defined as (Agricultural diversions – canal seepage – returns – offsite, exchange, and Mud Lake pumping). Precipitation on agricultural lands and urban pumping were not adjustable during model calibration.

Figure 2.2: Eastern Snake Plain Model Water Budget

Source: ESPAM2.1 Documentation

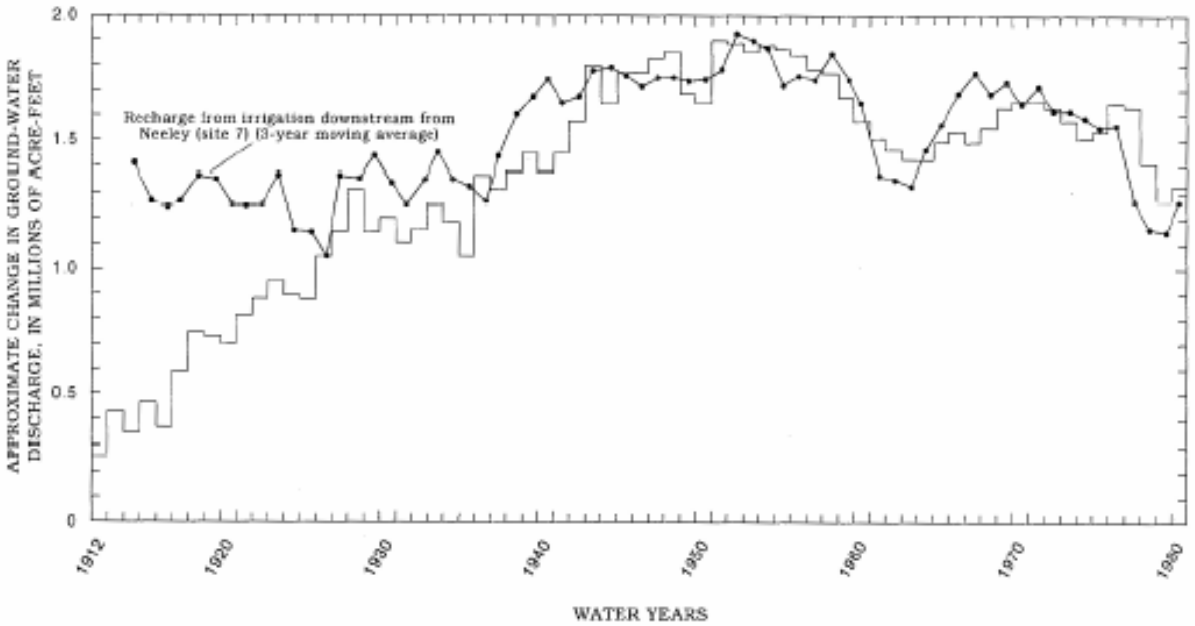


Data Sources: IDWR GIS data, NHD data, NAIP Imagery, Bing Imagery

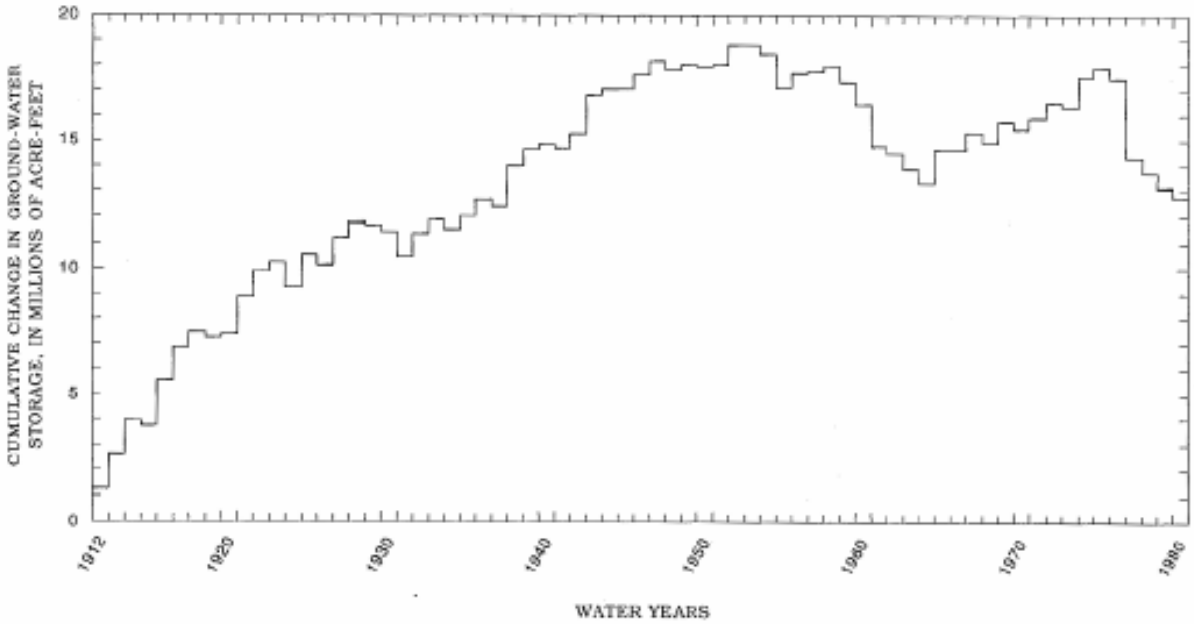
0 6 12 Miles

N

Figure 2.3: North Side Canal Company Service Area



(a)—Approximate change in ground-water discharge to the north side of the Snake River, from estimates in 1911, between Milner (site 9) and King Hill (site 13), water years 1912–80



(b)—Cumulative annual changes in ground-water storage, main part of the eastern Snake River Plain, water years 1912–80.

Source: Kjelstrom, 1995

Figure 2.4: Changes in Groundwater Storage on Spring Discharge, 1912 - 1980

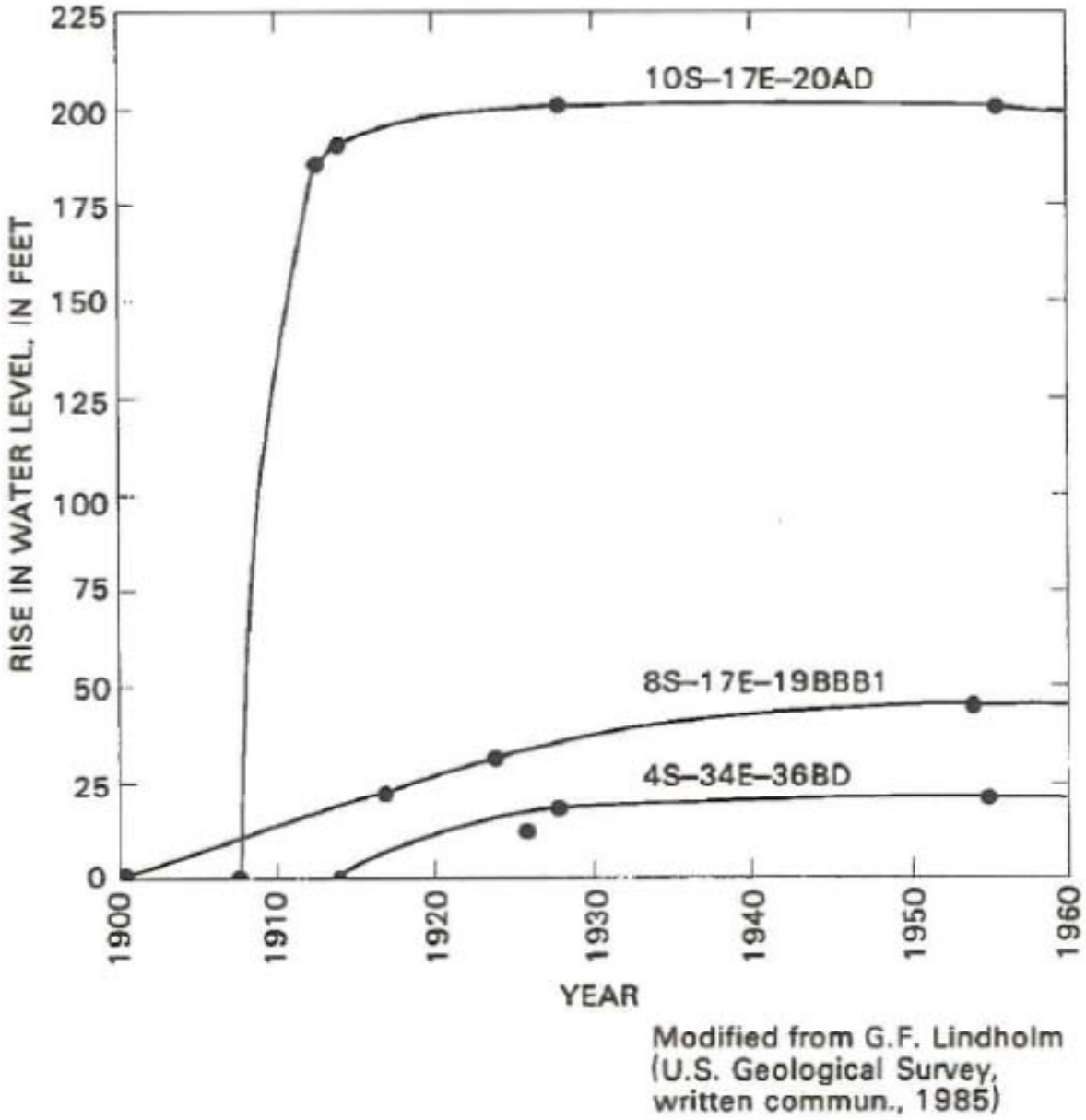


Figure 2.5: Water Level Rises in Three Observation Wells, 1900 – 1960

Source: Goodell, 1988

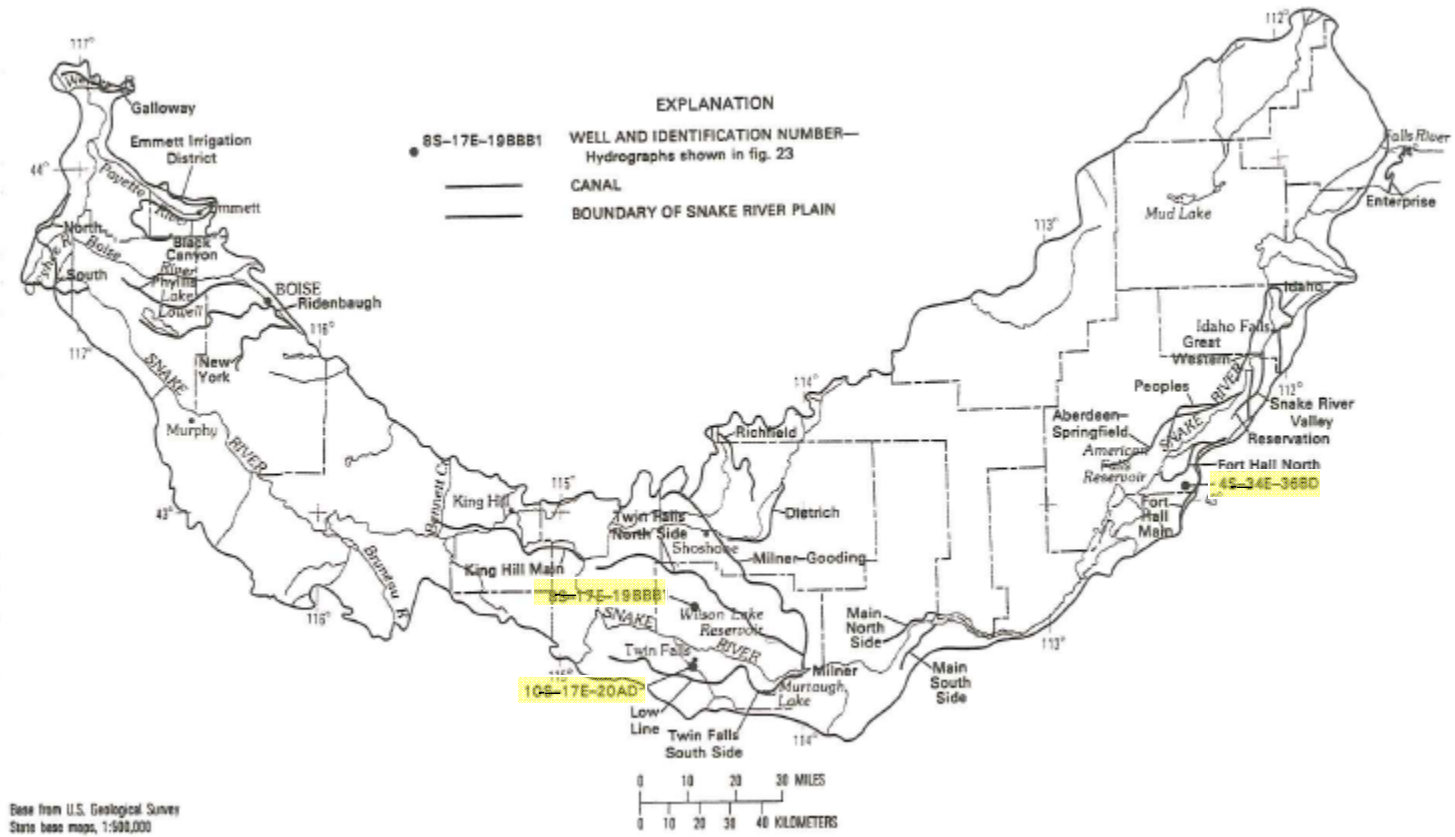


Figure 2.6: Locations of Three Observation Wells

Source: Goodell, 1988

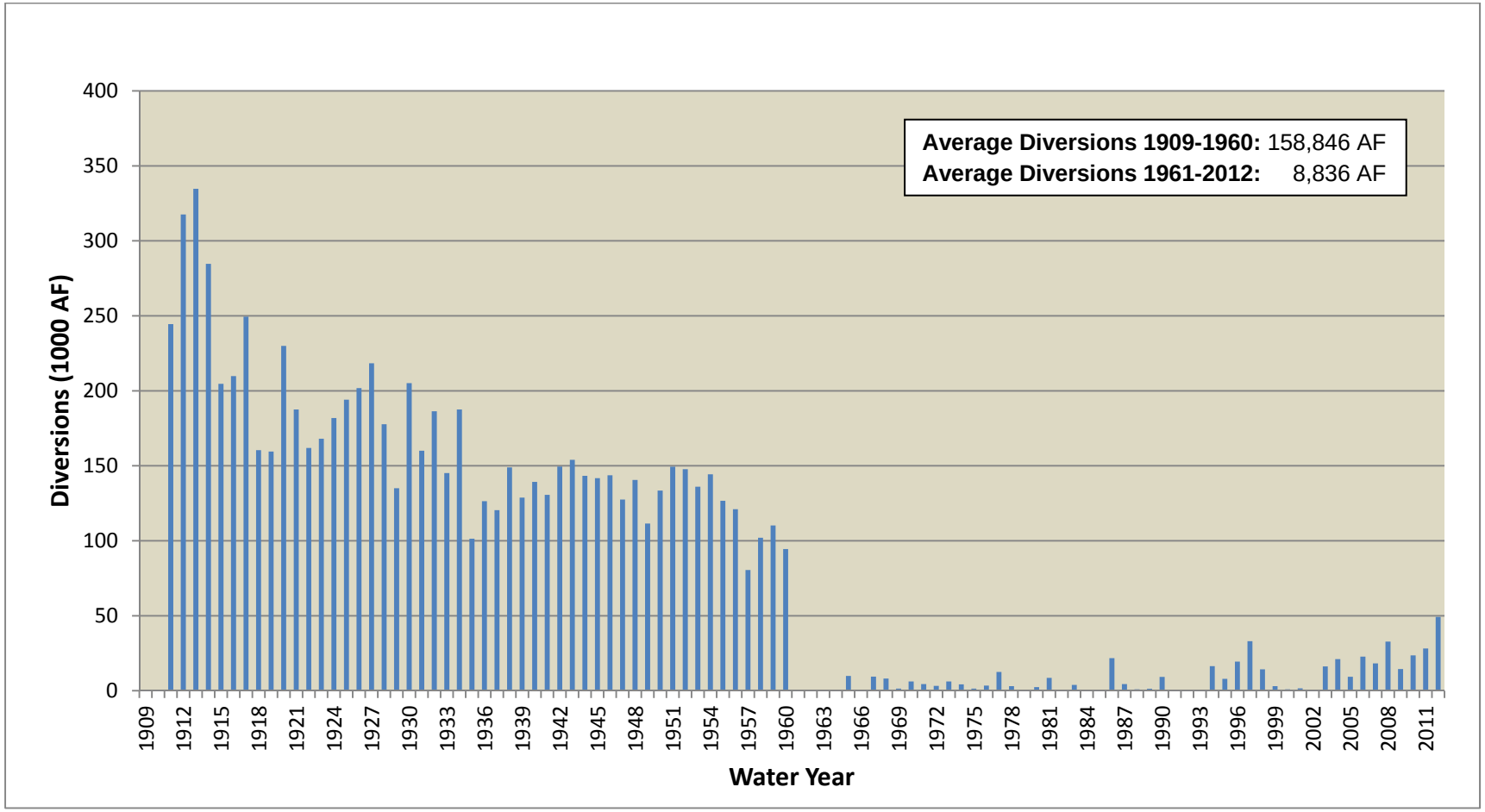


Figure 2.7: Historical Winter (Nov – Mar) Diversions, North Side Canal Company

Source: IDWR Water Rights Accounting, USGS

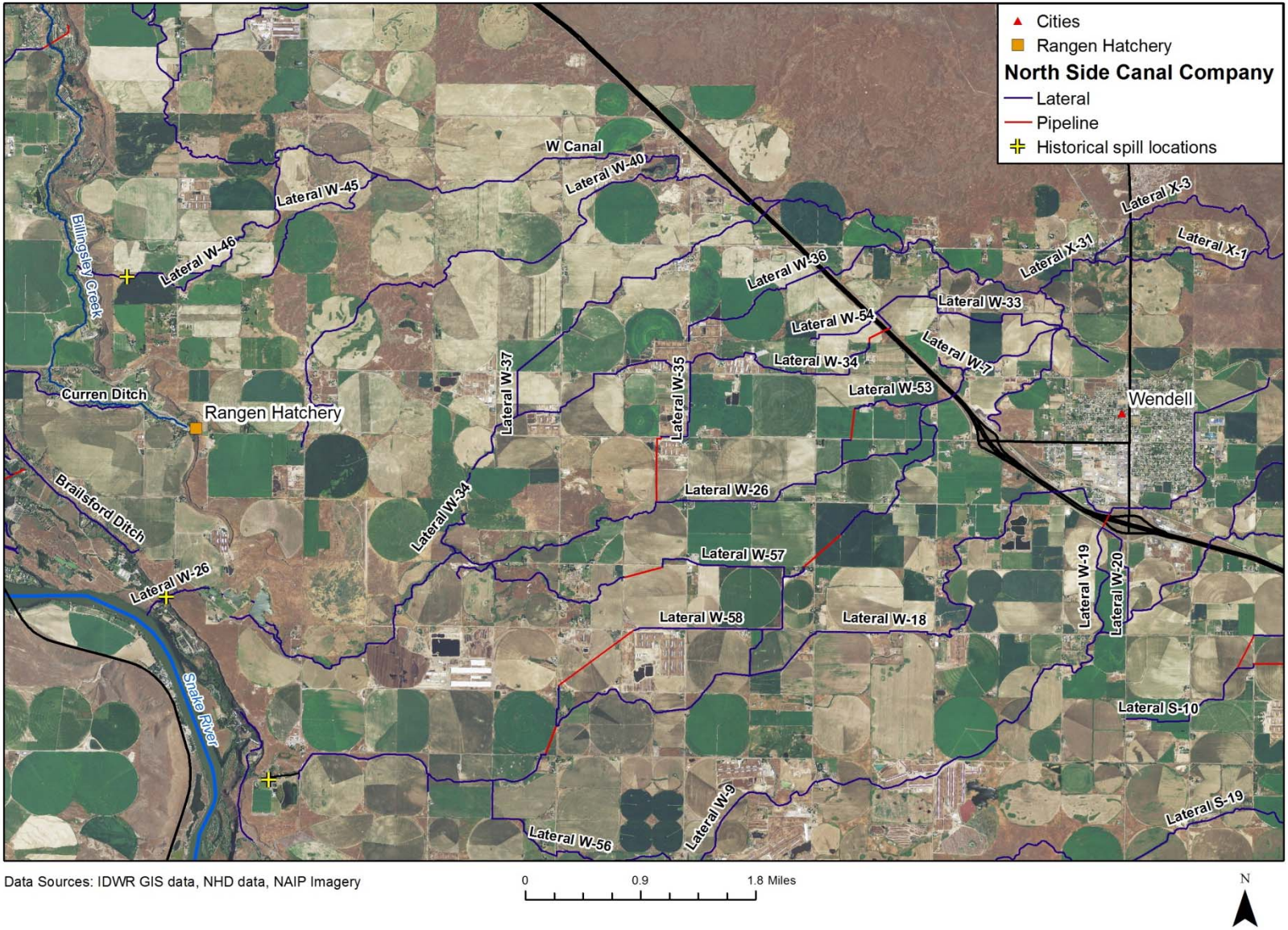


Figure 2.8: North Side Canal Company, Wendell Area Laterals and Spill Locations

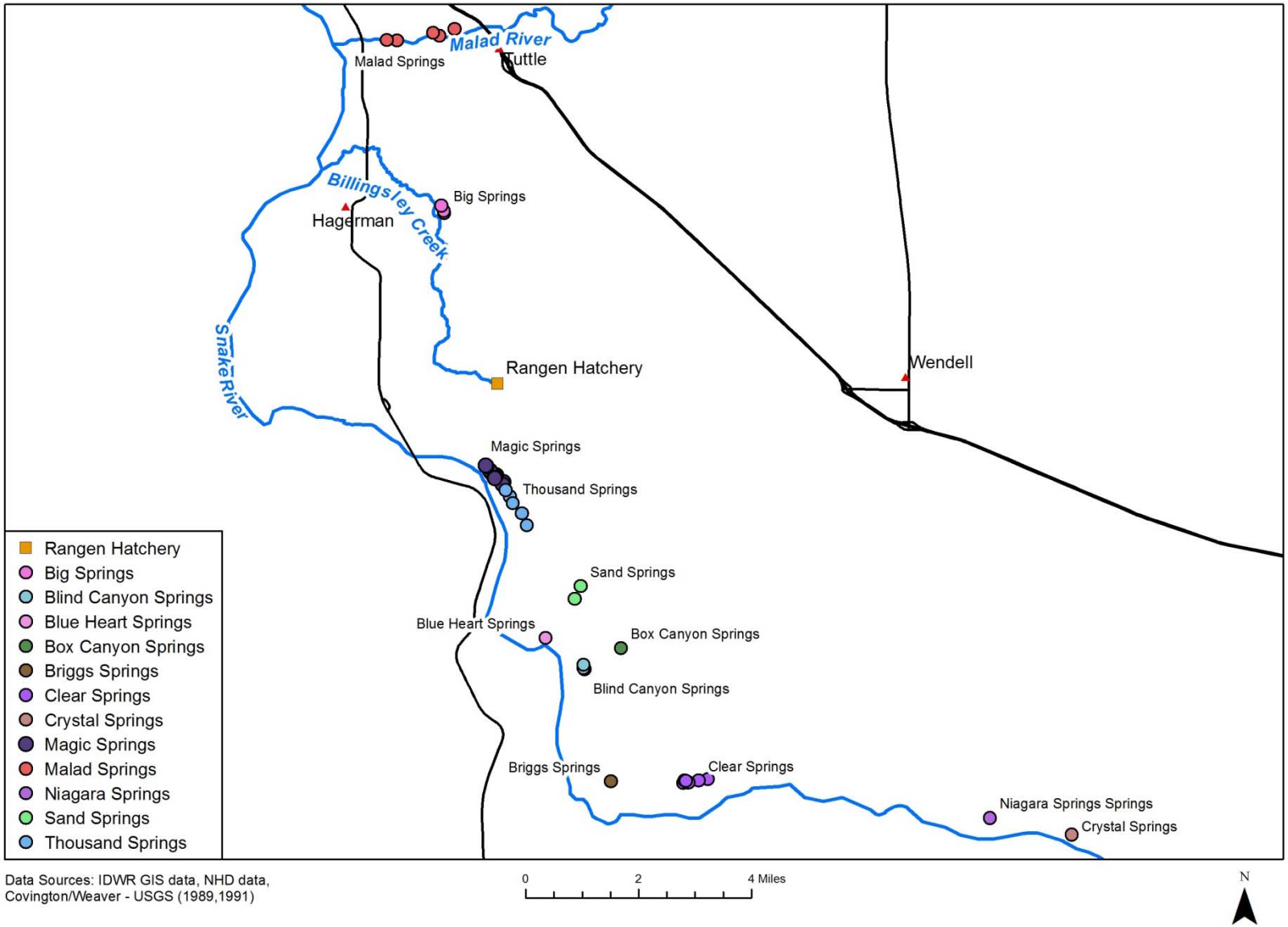


Figure 2.9 Major Spring Outlets in the Milner to King Hill Reach

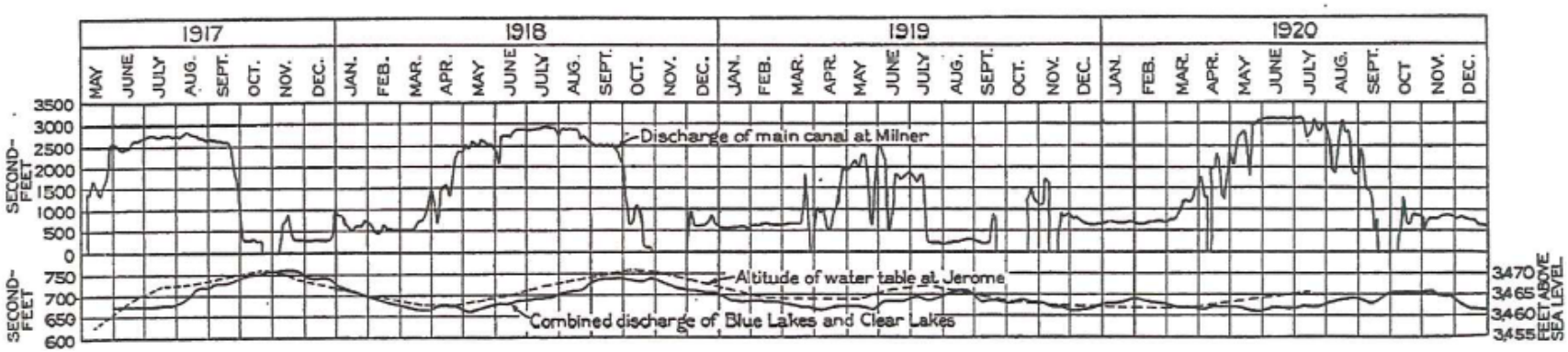


FIGURE 13.—Fluctuations in the discharge of two large springs on Snake River, Idaho (Blue and Clear Lakes), in relation to the quantity of irrigation water placed upon the upland back of these springs and to the fluctuations of the water table at Jerome, Idaho, on the upland. Diagram prepared by the engineering department of the Twin Falls North Side Land & Water Co.

Figure 2.10: Fluctuations in the Discharge of Two Large Springs on Snake River, Idaho (Blue and Clear Lakes)

Source: Meinzer, 1927

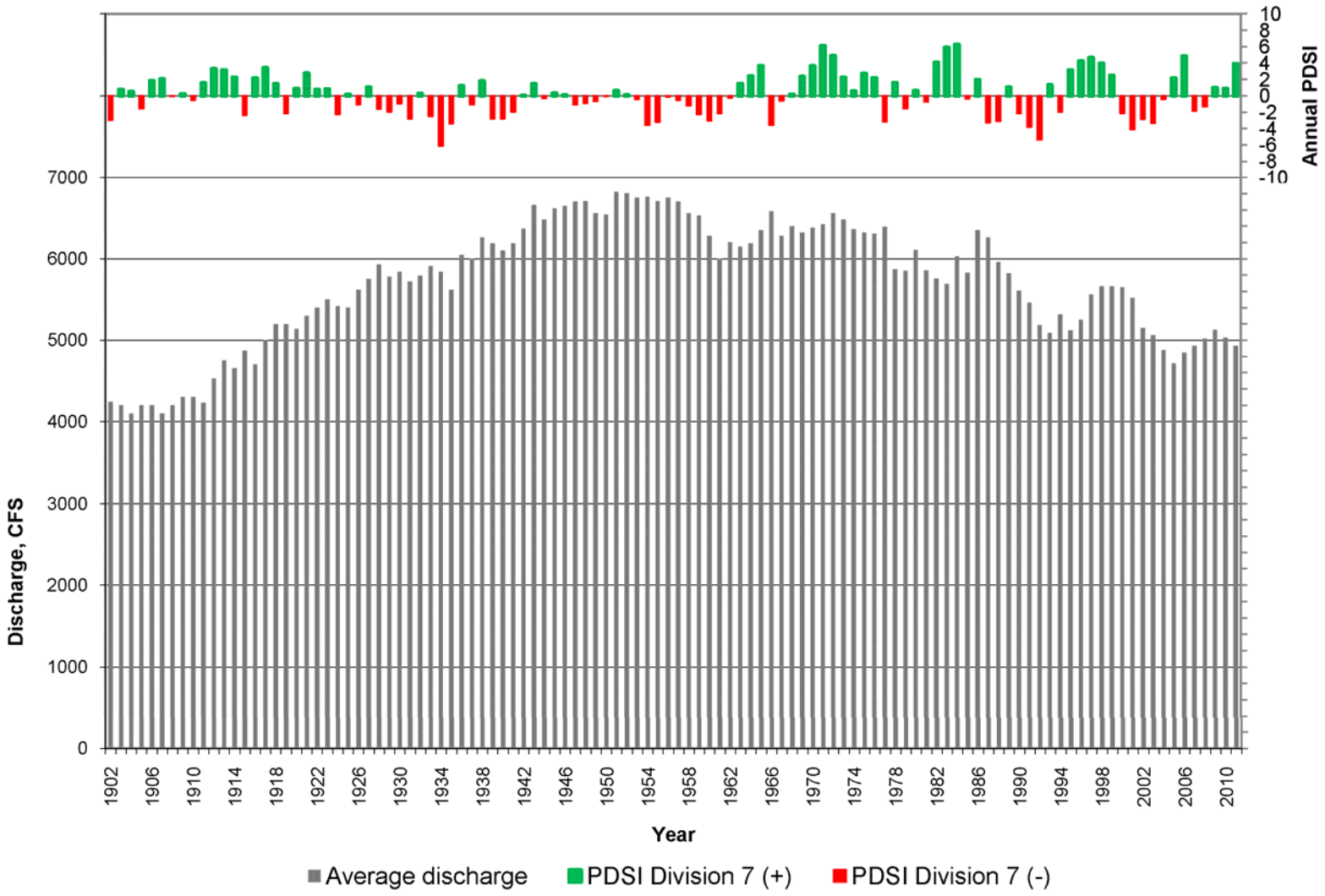


Figure 2.11: Average Annual Spring Discharge to Snake River between Milner and King Hill, 1902 to 2011

Source: IDWR, NOAA Earth System Research Laboratory Physical Sciences Division

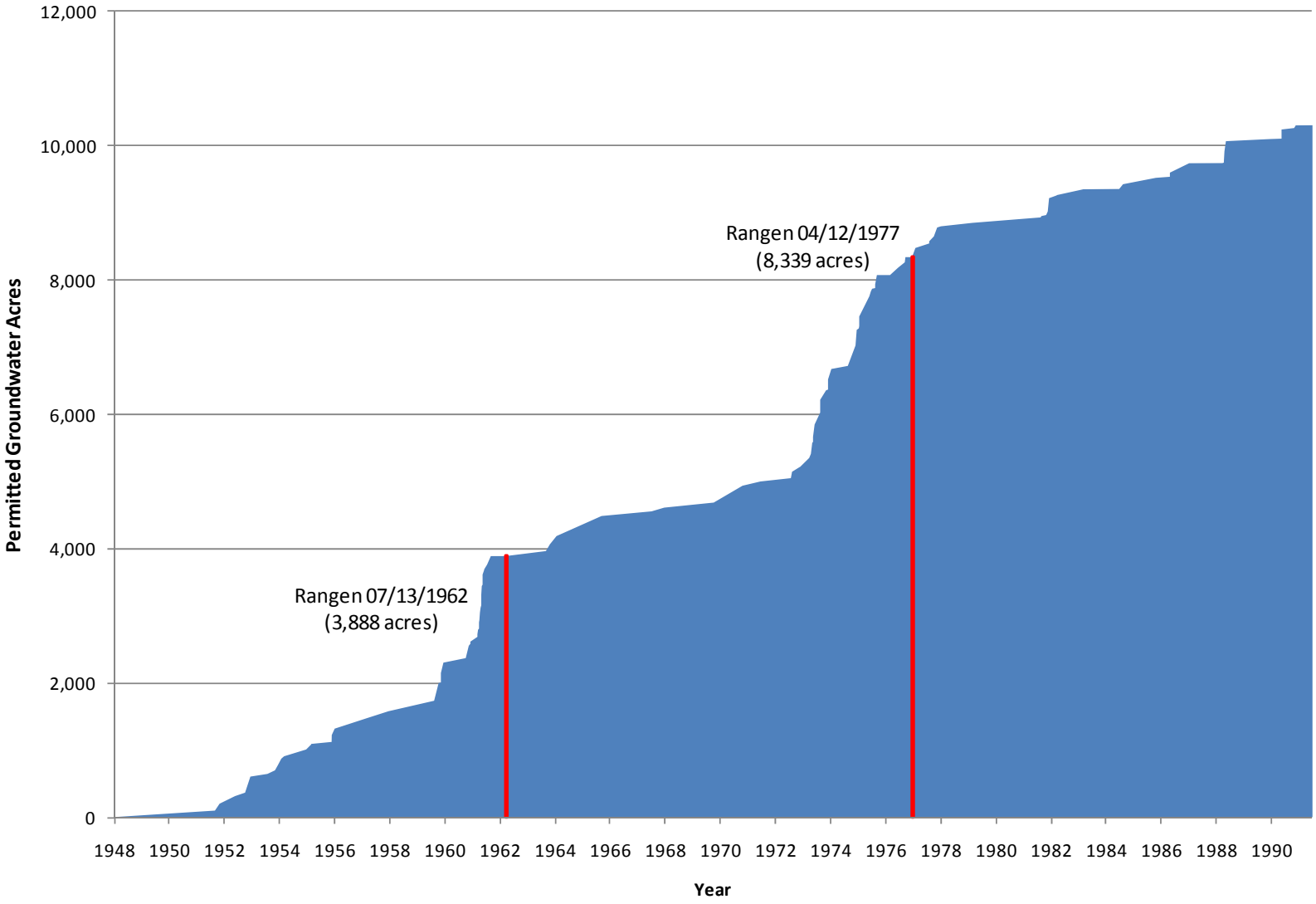


Figure 2.12: Cumulative Permitted Groundwater Acres in the Wendell Area

Source: IDWR GIS Data

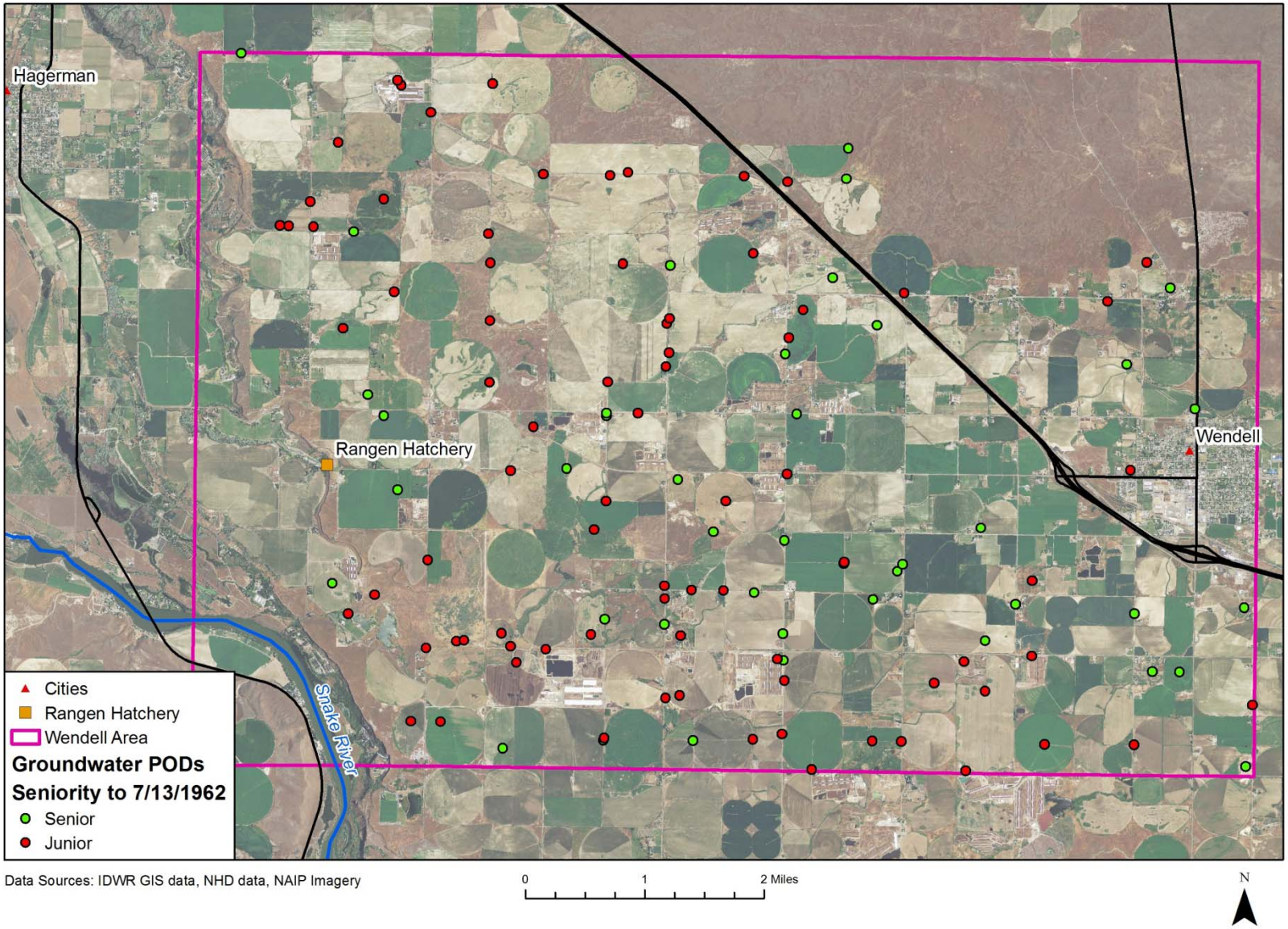


Figure 2.13: Wendell area Groundwater PODs

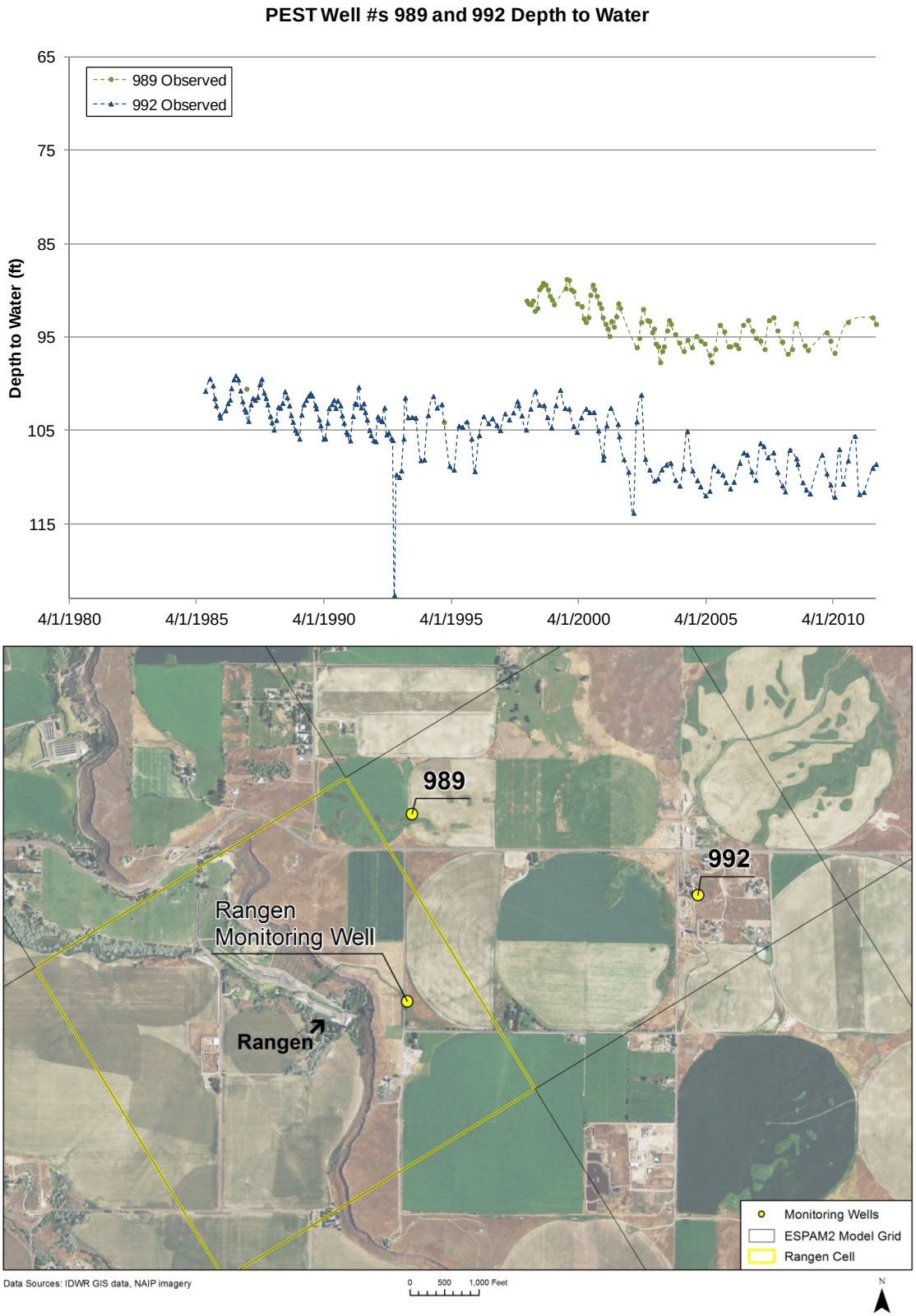
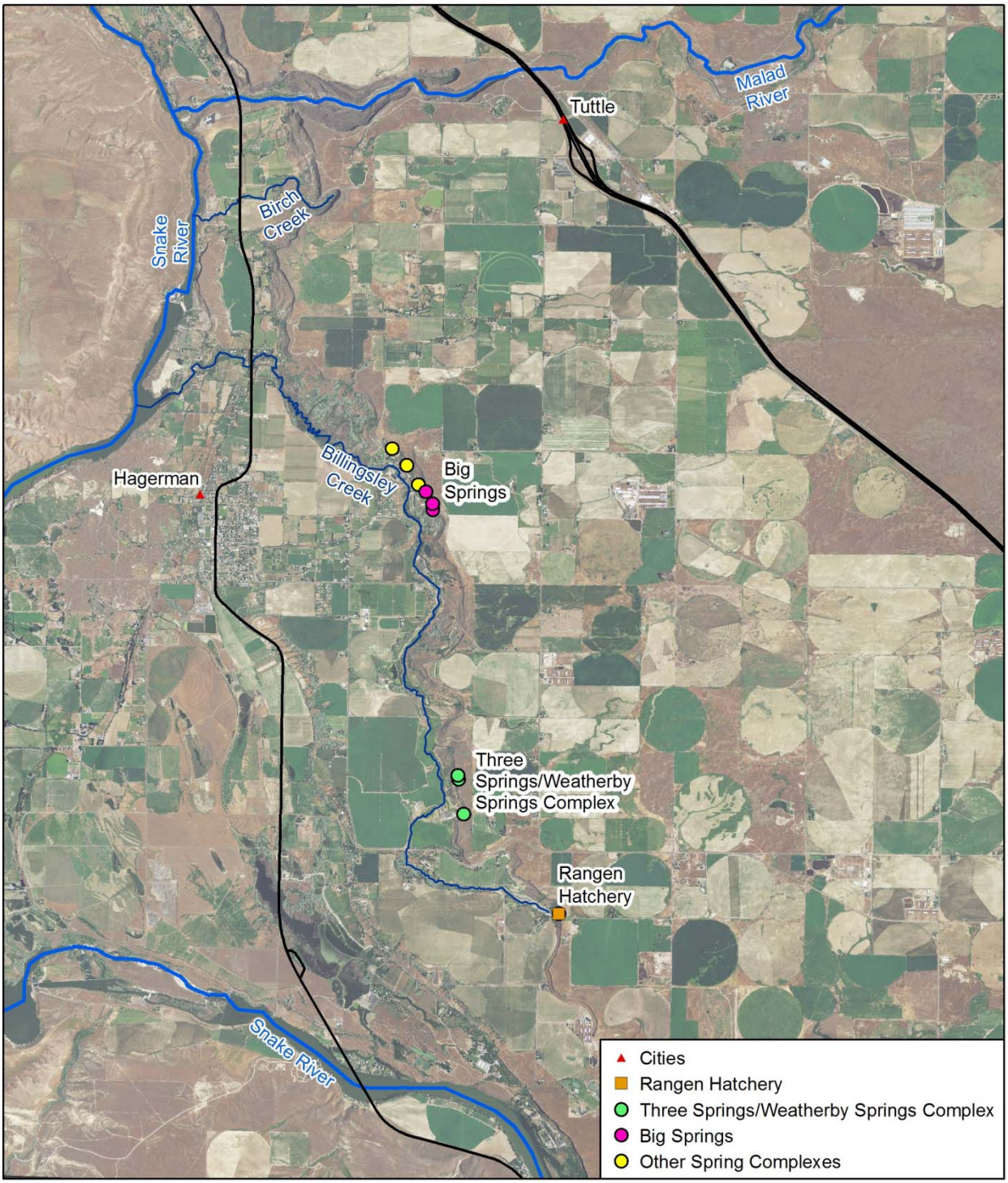


Figure 2.14: Observed Groundwater Levels in Select Wells



Data Sources: IDWR GIS data, NHD data, Covington/Weaver - USGS (1989,1991), NAIP Imagery

0 1 2 Miles

N

Figure 3.1: Billingsley Creek Area Selected Spring Discharge Points

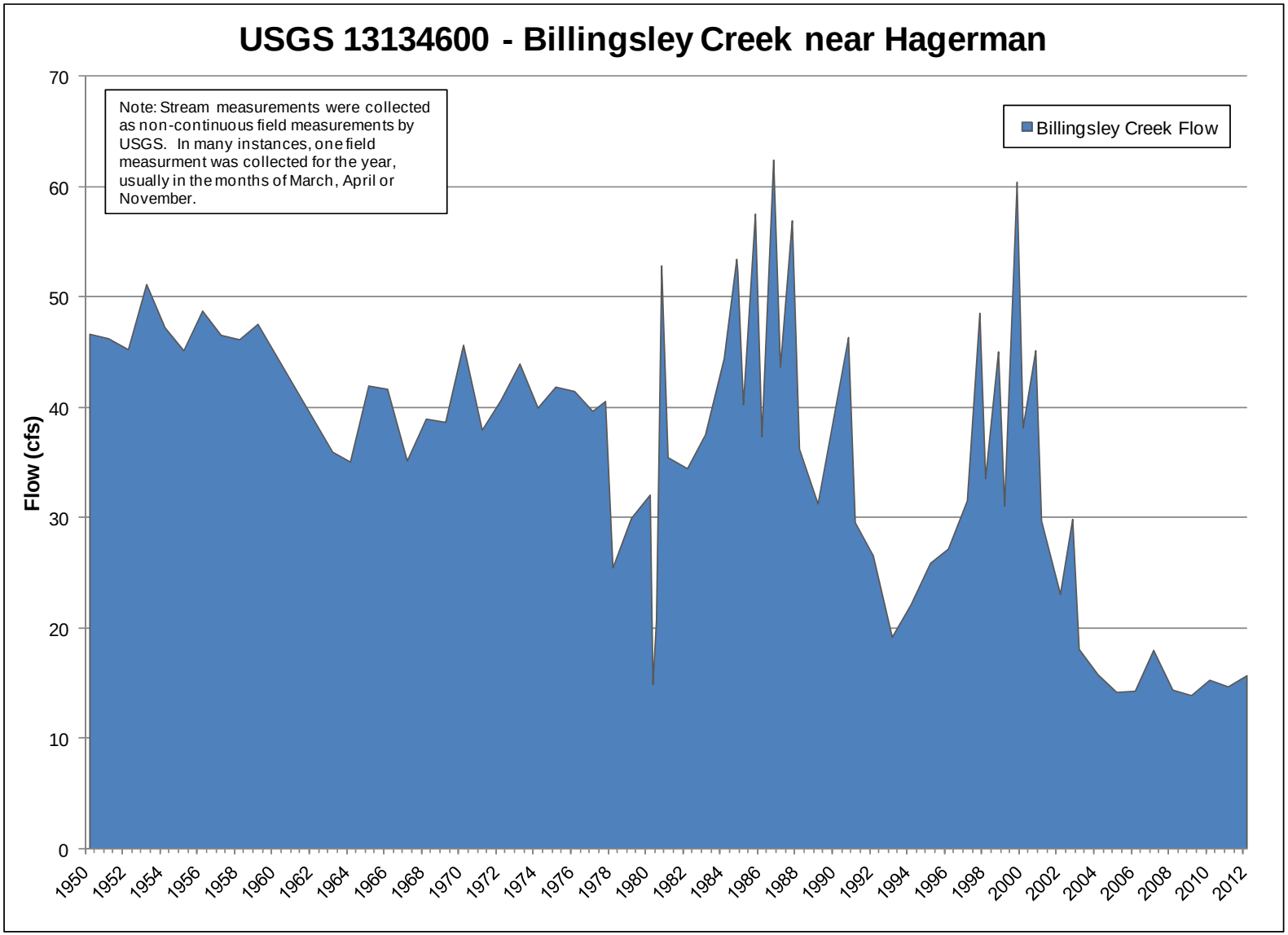


Figure 3.2: Billingsley Creek Flow

Source: USGS Gage Data

Figure 3.3: Rangen Site Map

Top photo: Water can be seen discharging from the Curren Tunnel to the Farmers Box. The Rangen 6-inch domestic pipeline can be seen exiting Curren Tunnel.
Bottom photo: Water discharges from the right side of the Farmers box to the Rangen box (not shown).

Figure 3.4: Farmers Box

Top photo: Water from the Curren Tunnel is diverted into the hatch house pipeline at the Rangen box.
Bottom photo: Water can spill from the Rangen box down the hillside to Billingsley Creek.

Figure 3.5: Rangen Box

Top photo: A view from upstream of the lodge dam on Billingsley Creek.
Bottom photo: A view from downstream of the lodge dam on Billingsley Creek.

Figure 3.6: Lodge Dam

Figure 3.7: Weir Measurement at Rangen Raceway 6

Source: “20120730 Rangen’s First Discovery Request.pdf”, Plaintiff’s Exhibit 7a

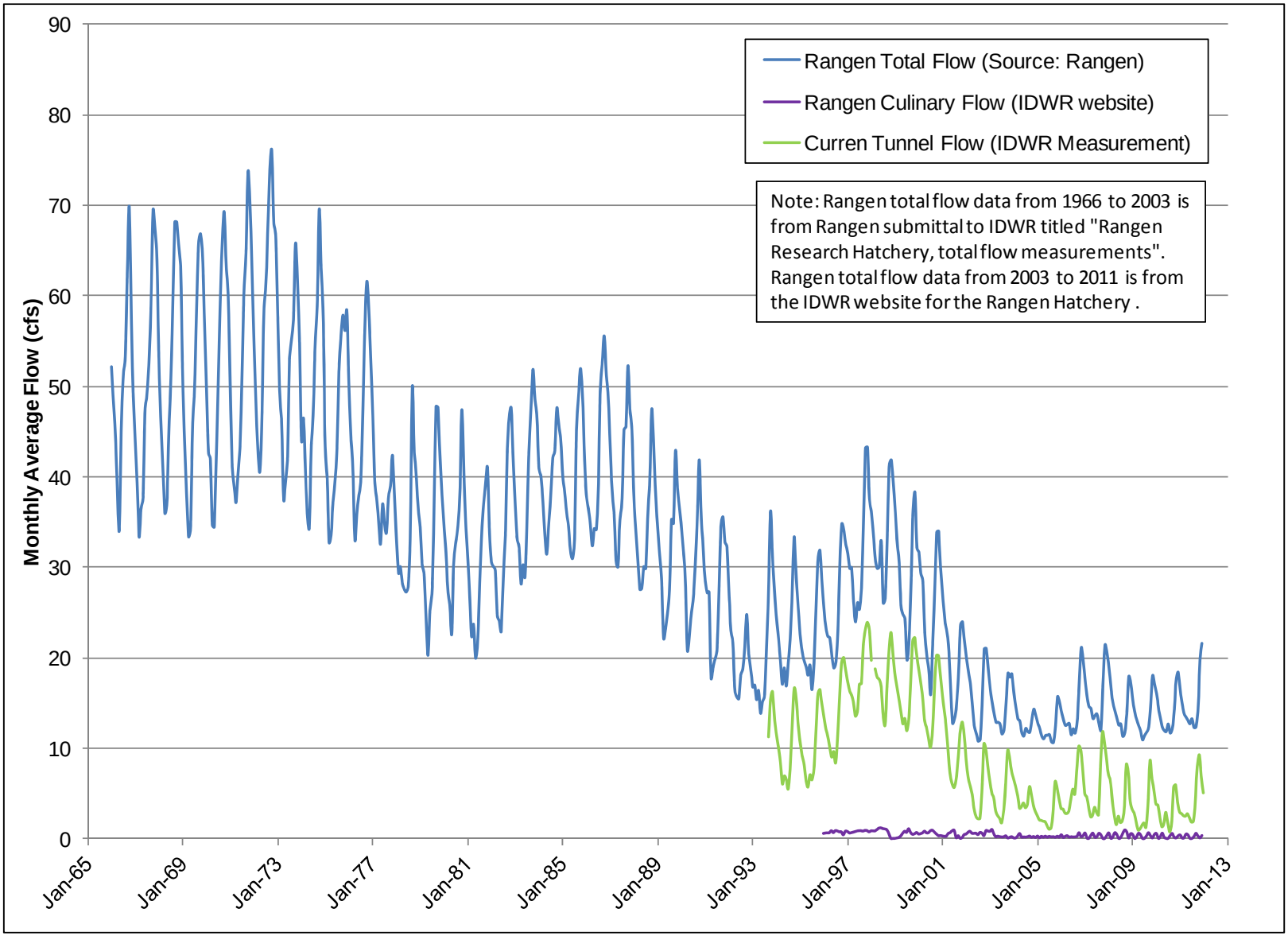


Figure 3.8: Historical Flows at Rangen Facility

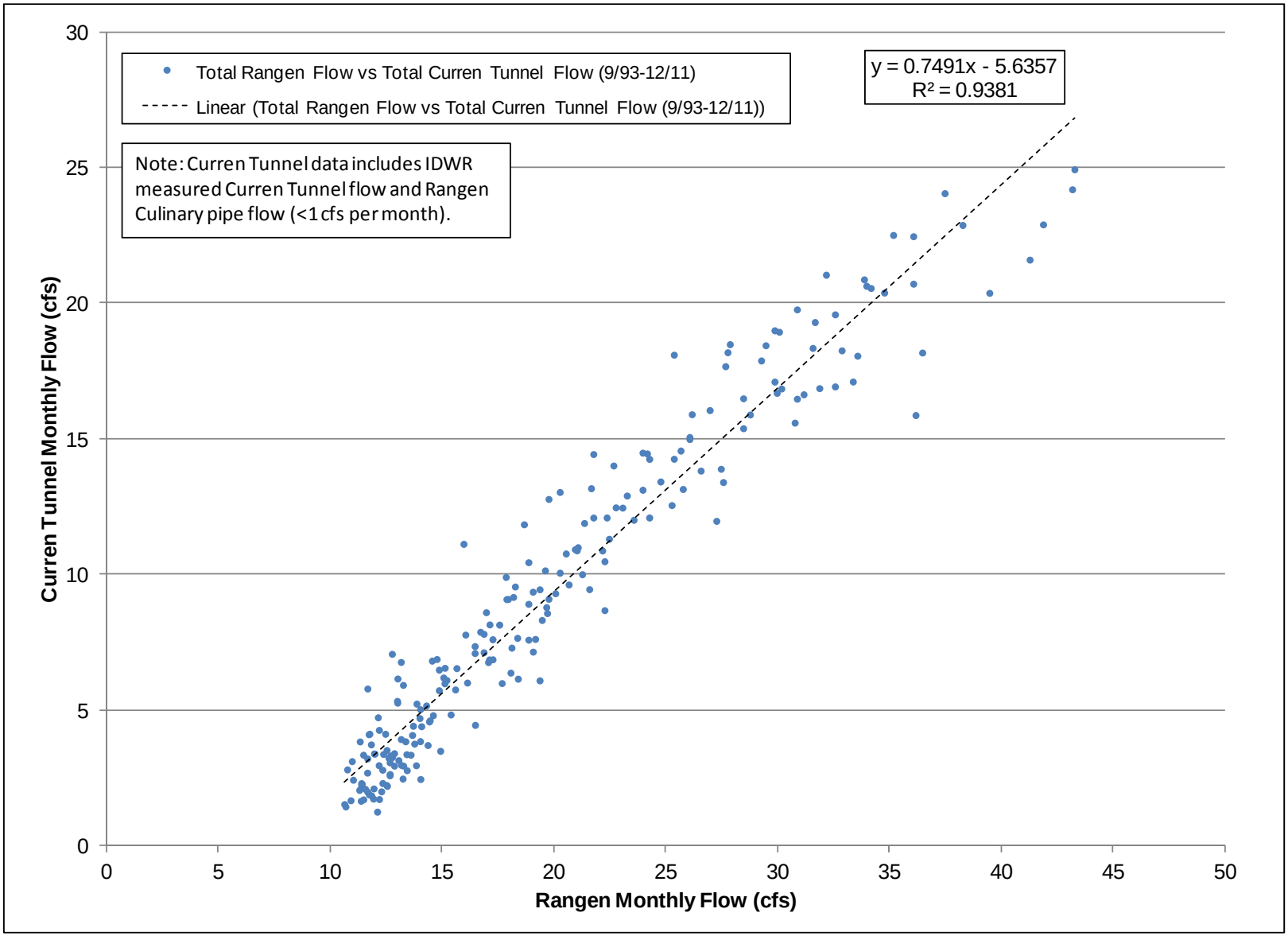


Figure 3.9: Linear Regression of Total Curren Tunnel Flow versus Total Rangen Flow

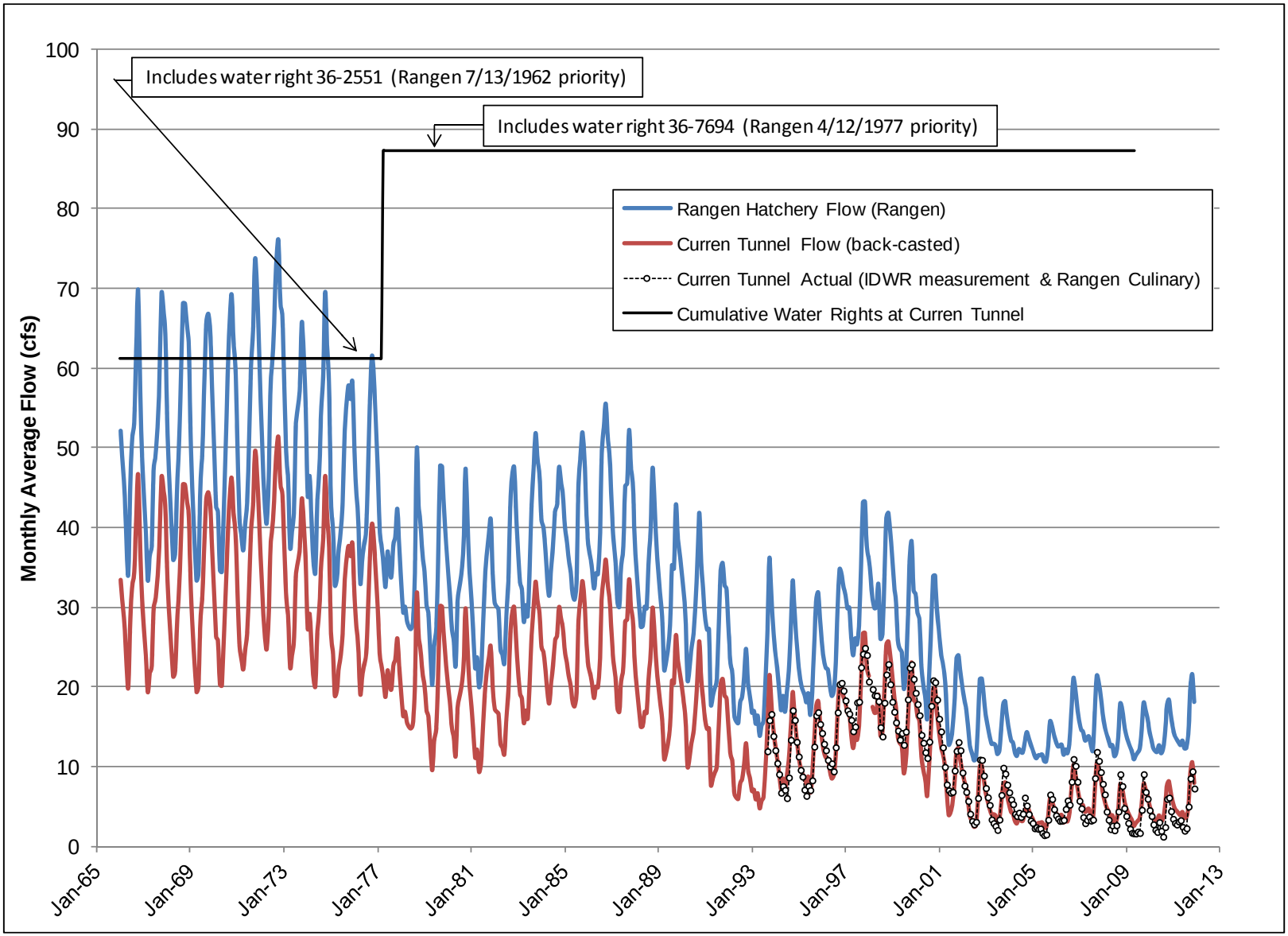


Figure 3.10: Back-casted Curren Tunnel Flow versus Total Rangen Flow

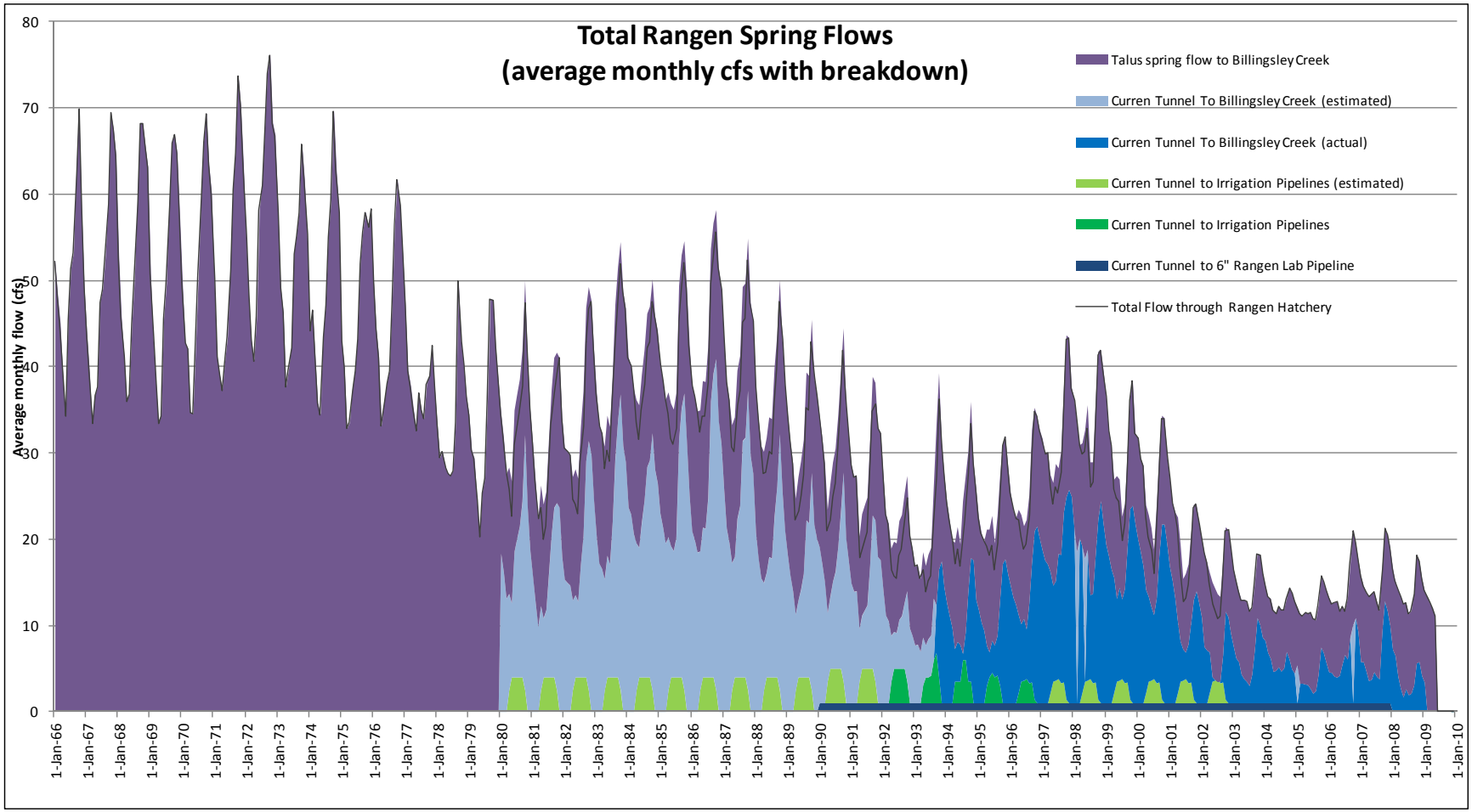


Figure 3.11: Brannon Decomposition and Back-cast of Rangen Flows

Source: Brannon, 2009. Reproduced from “Rangen Water History for IDWR.xlsx”

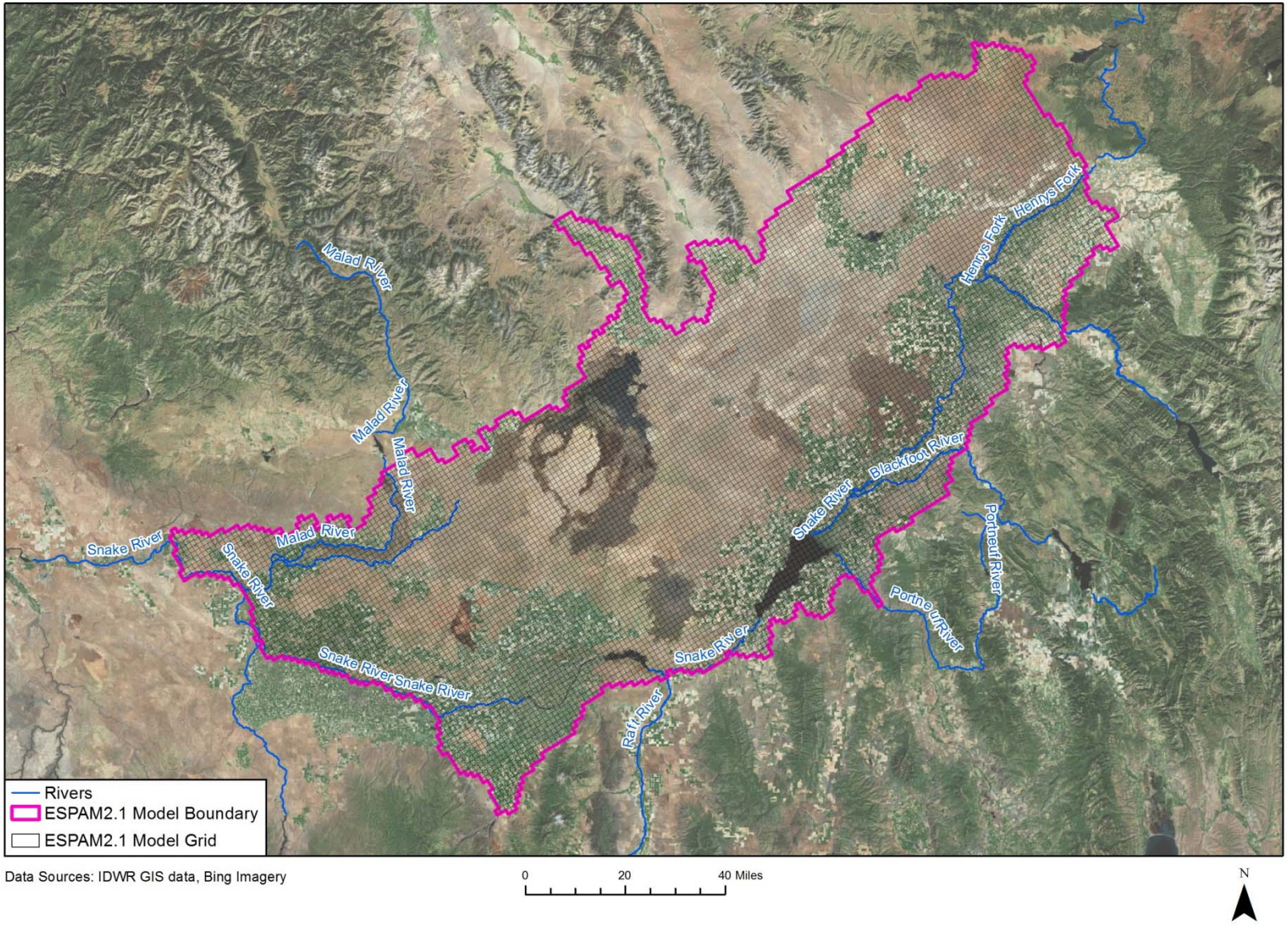


Figure 4.1: ESPAM2.1 Model Domain

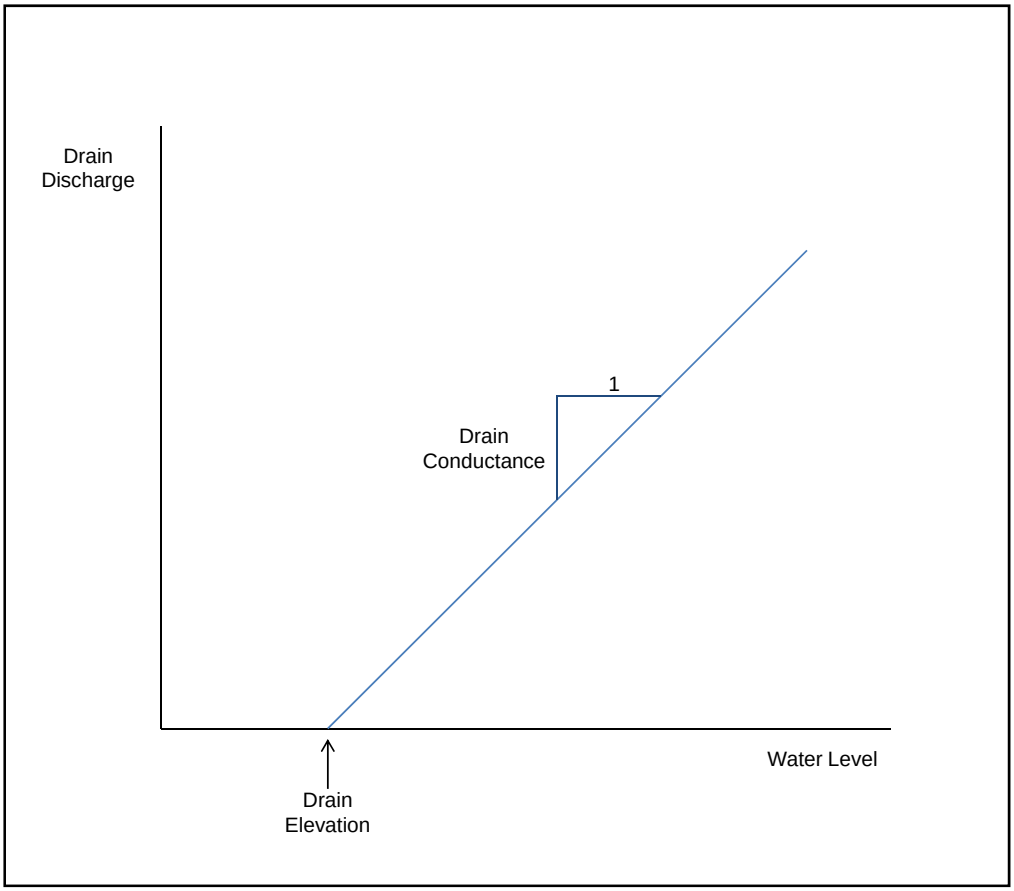


Figure 4.2: Drain Schematic

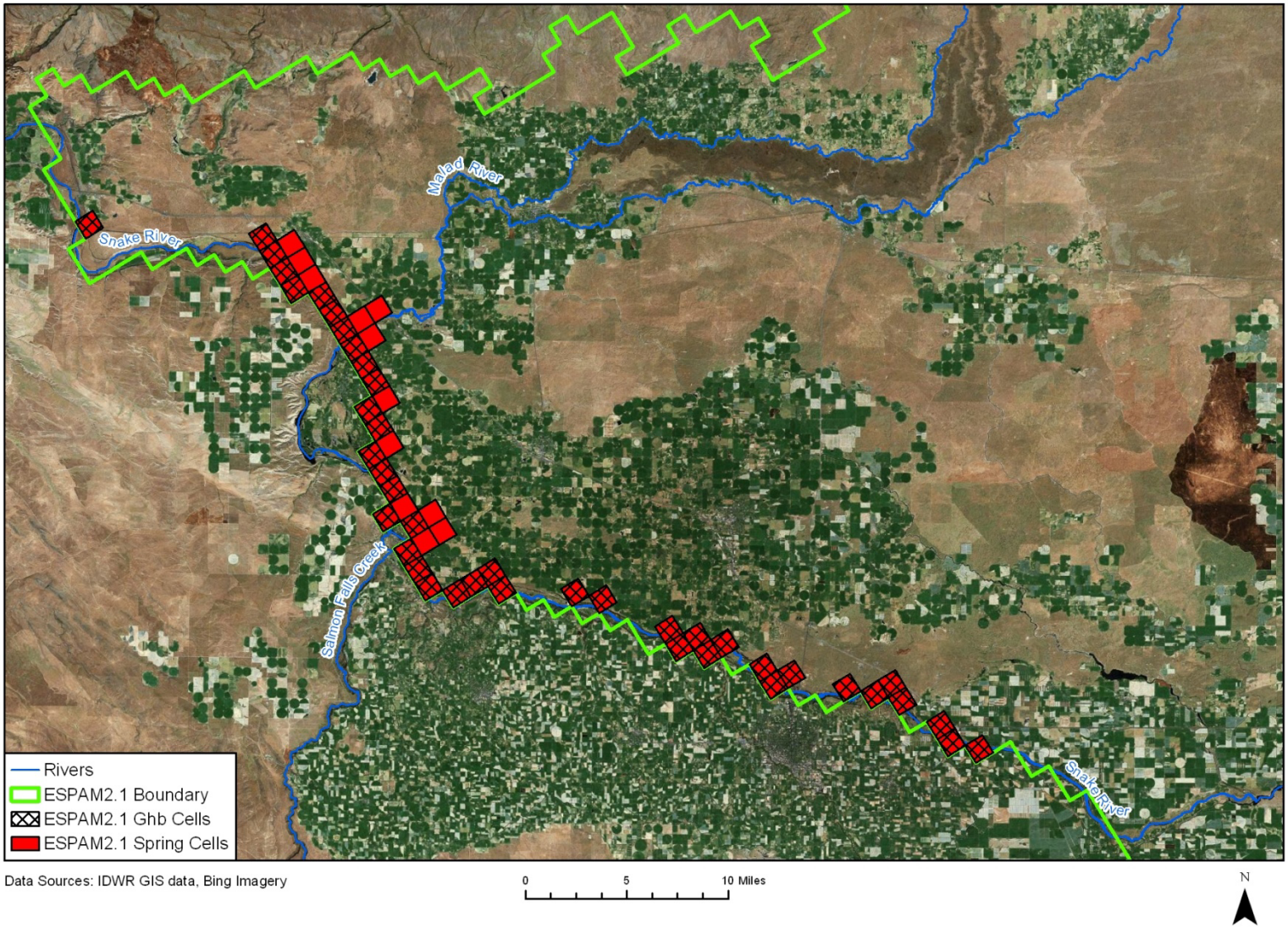


Figure 4.3: ESPAM2.1 Drain and GHB Cells

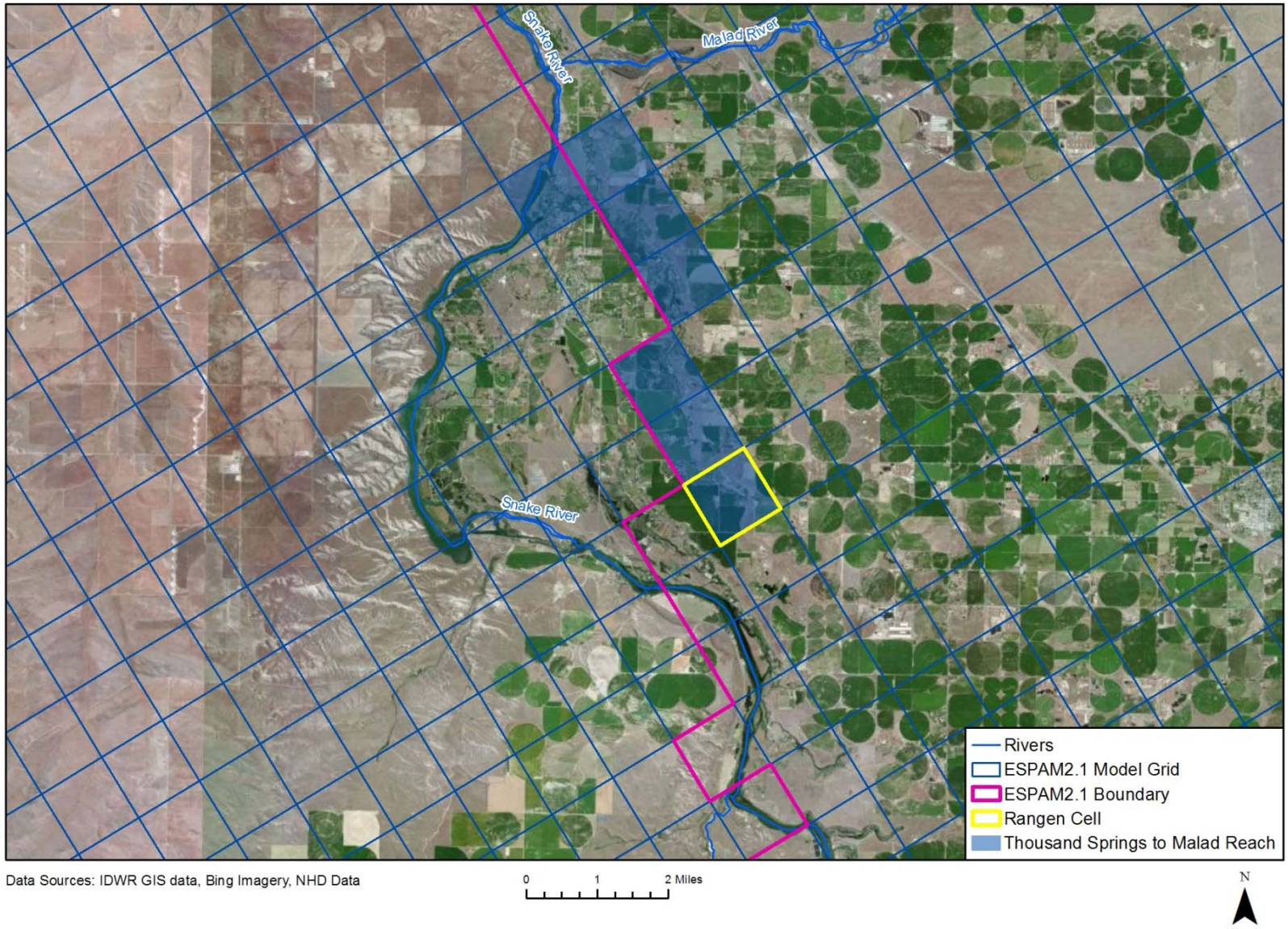


Figure 4.4: ESPAM2.1 Grid in Rangen Area

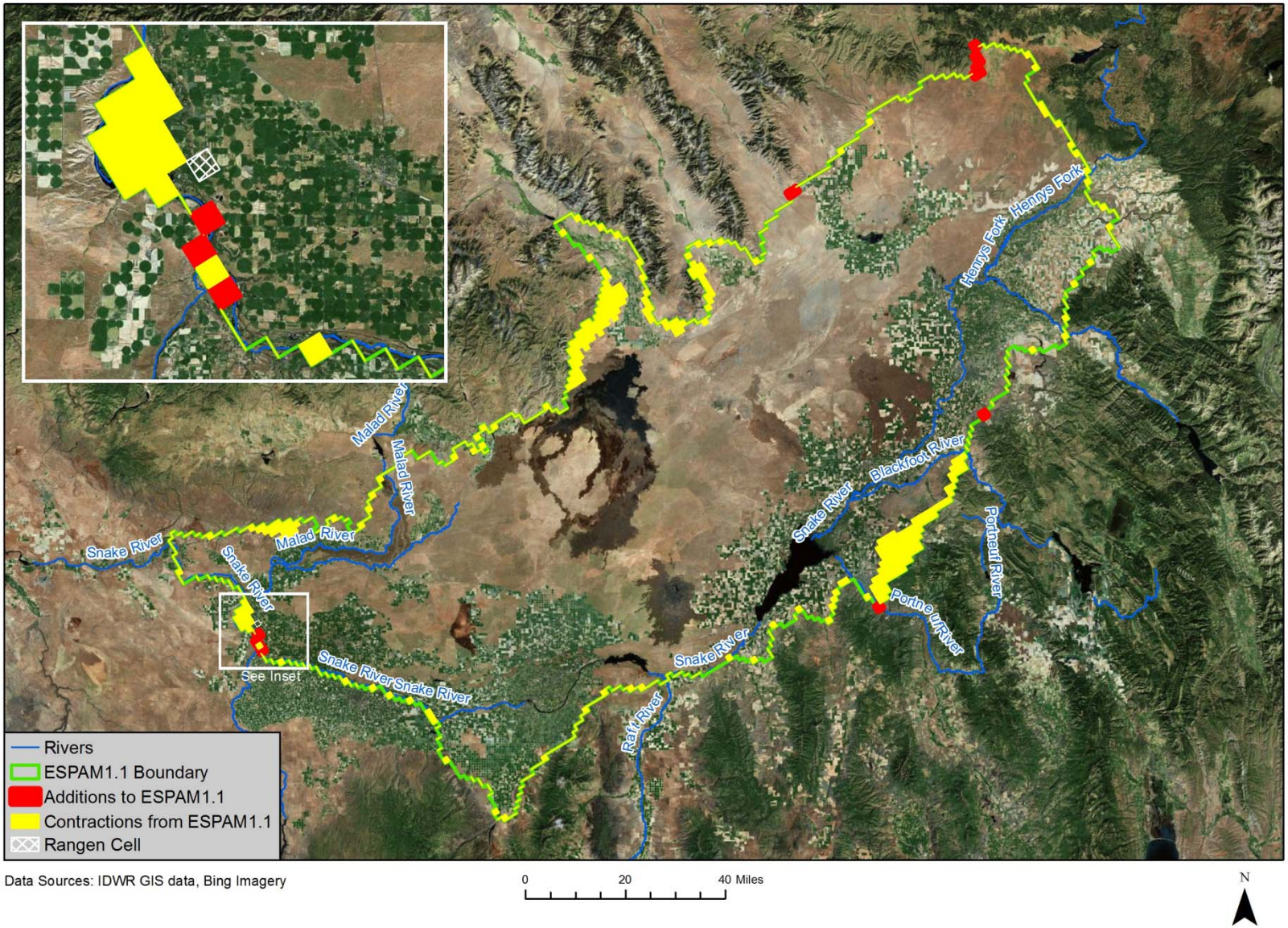


Figure 4.5: ESPAM1.1 and ESPAM2.1 Model Domain Comparison

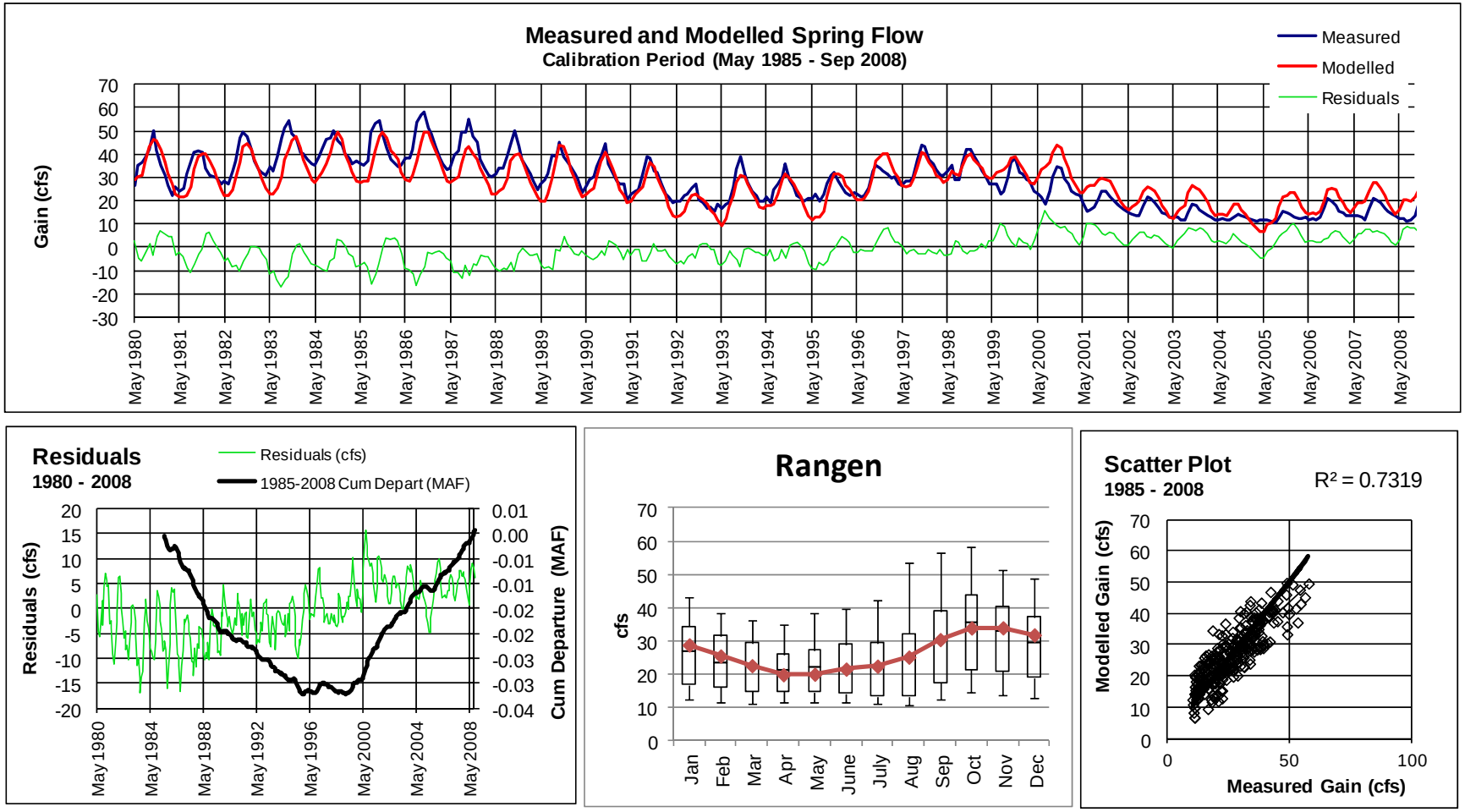


Figure 4.6: Calibrated and Target Discharge and Residuals for the Rangen Spring Complex from ESPAM2.1 Calibration

Source: ESPAM2.1 Documentation

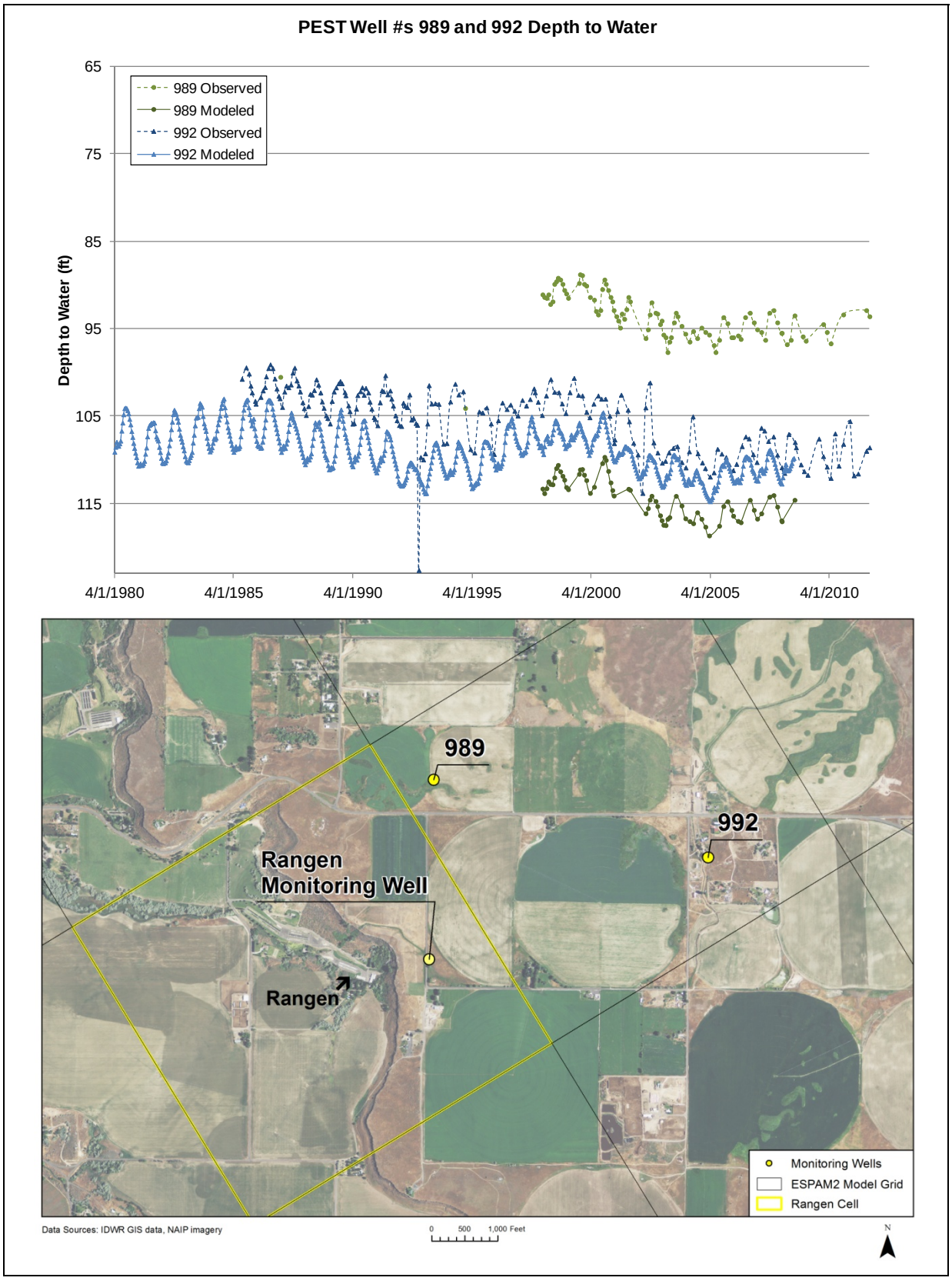


Figure 4.7: Simulated and Target Water Levels in Calibration Well #989 and #992

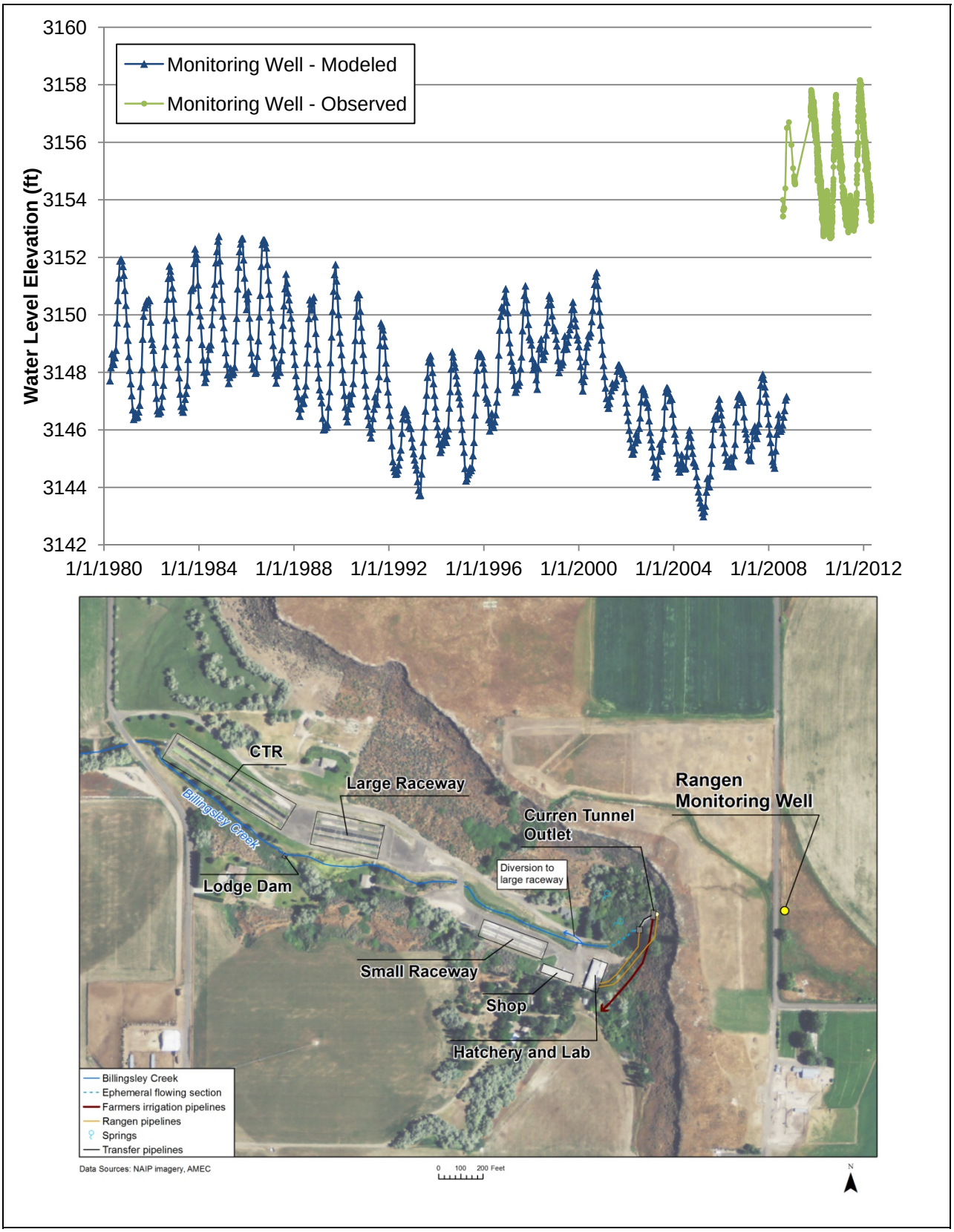


Figure 4.8: Rangen Monitoring Well Water Levels

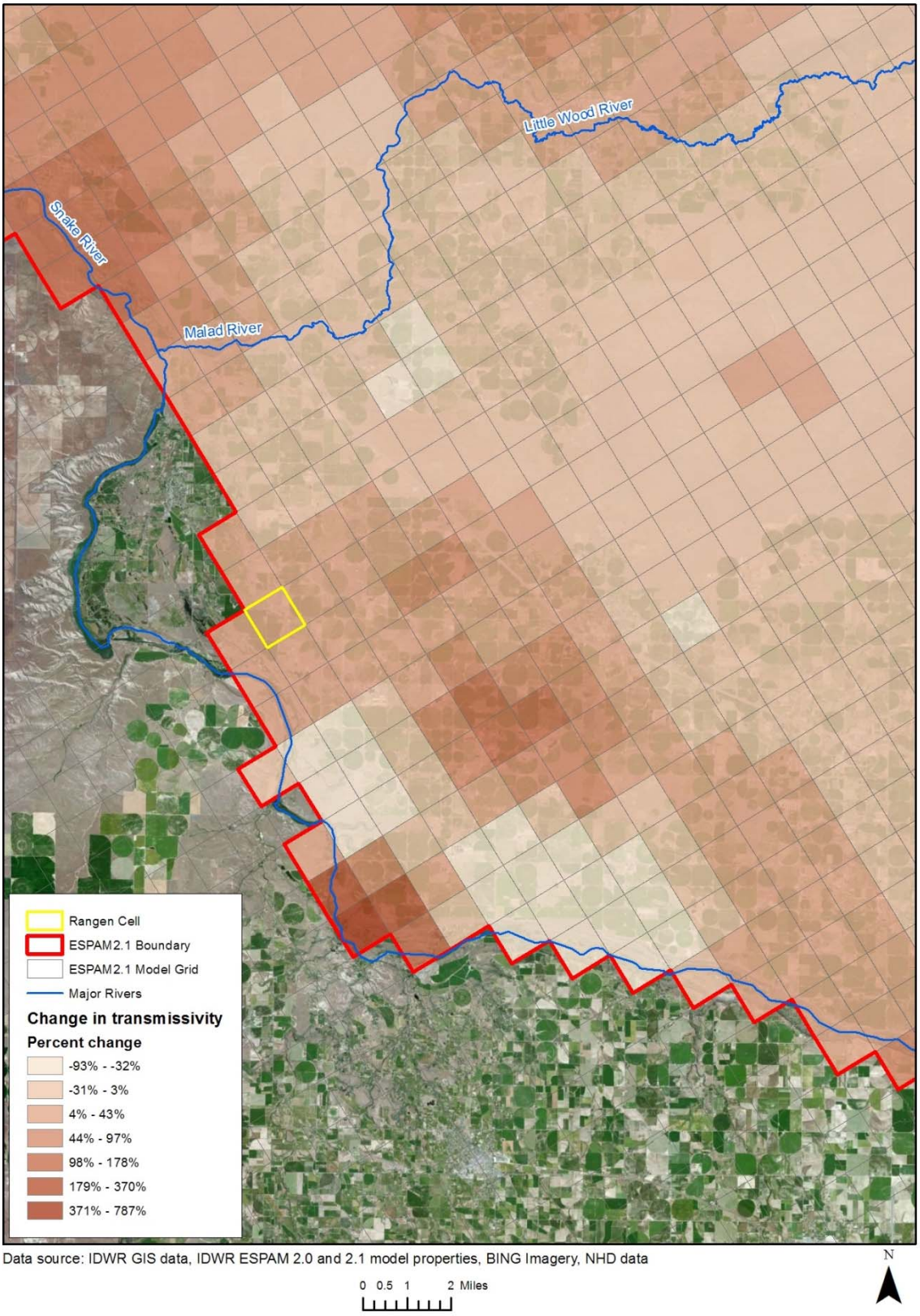


Figure 4.9: Changes in Transmissivity values in Rangen Area between ESPAM2 and 2.1
(positive % change indicates 2.1 transmissivity is greater)

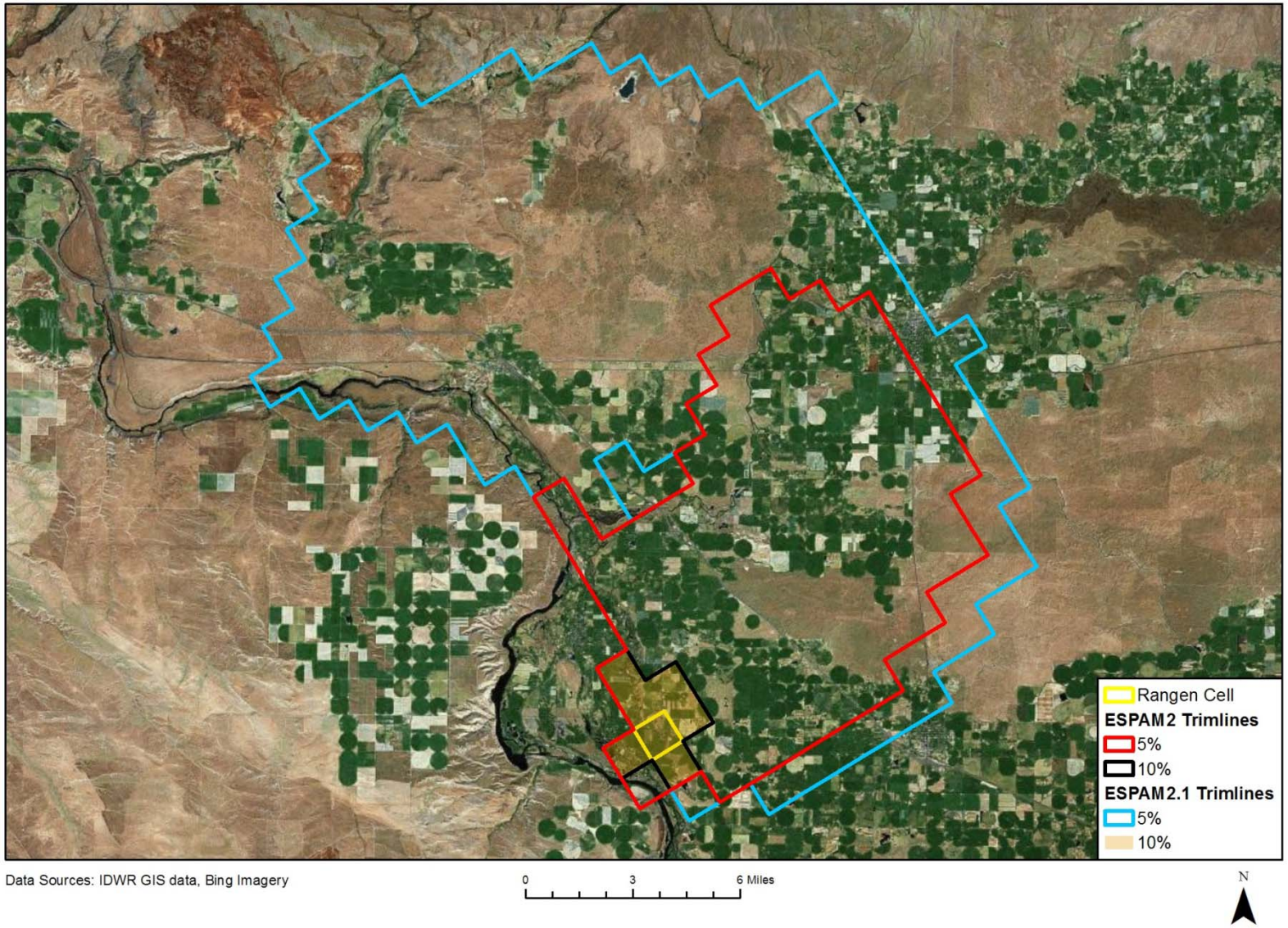


Figure 4.10: Trimline Comparisons ESPAM2.0 and 2.1

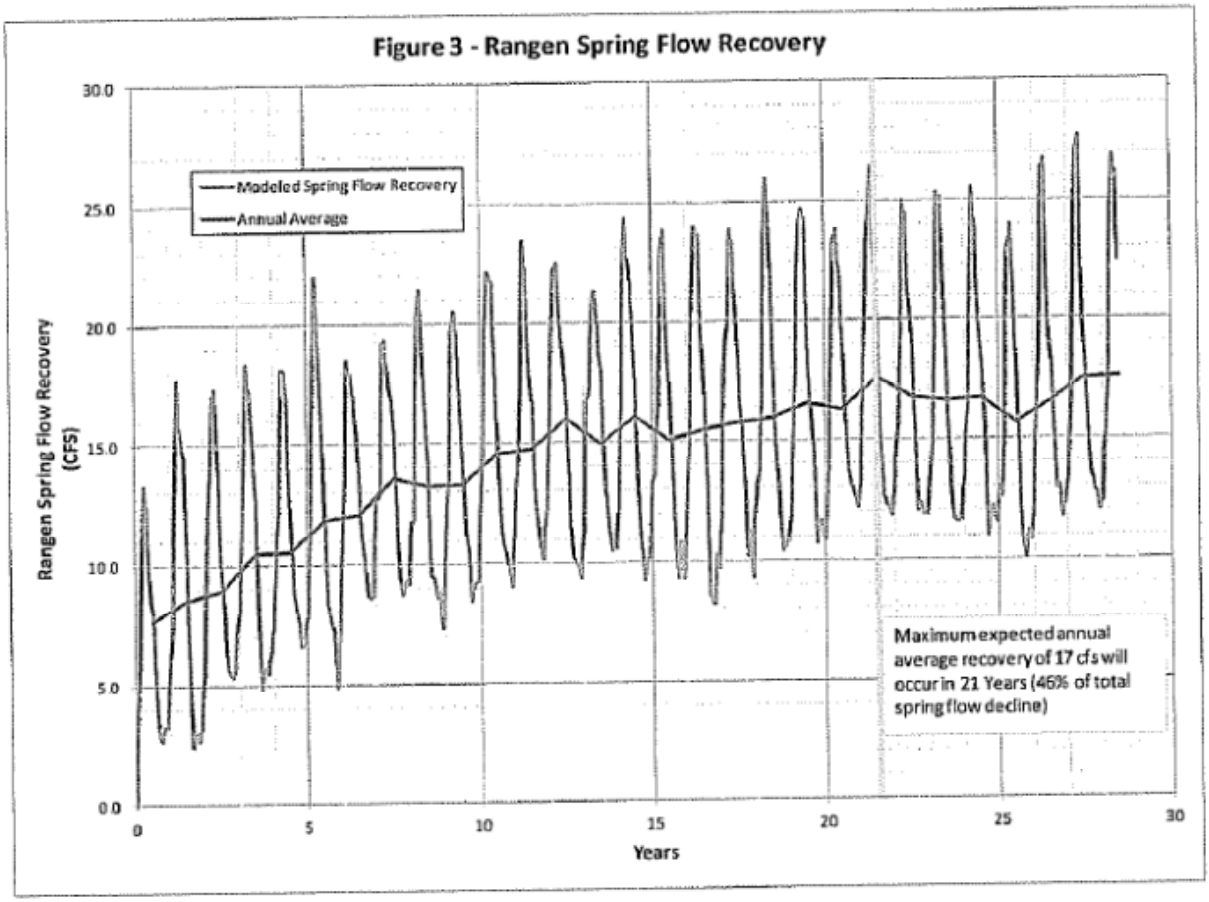


Figure 5.1: Reproduced Graph from Exhibit 11 of Rangen Petition

Source: Exhibit 11 from Rangen petition, Memorandum from Leonard Rice Engineers, Inc. to Rangen Inc., dated December 9, 2011.

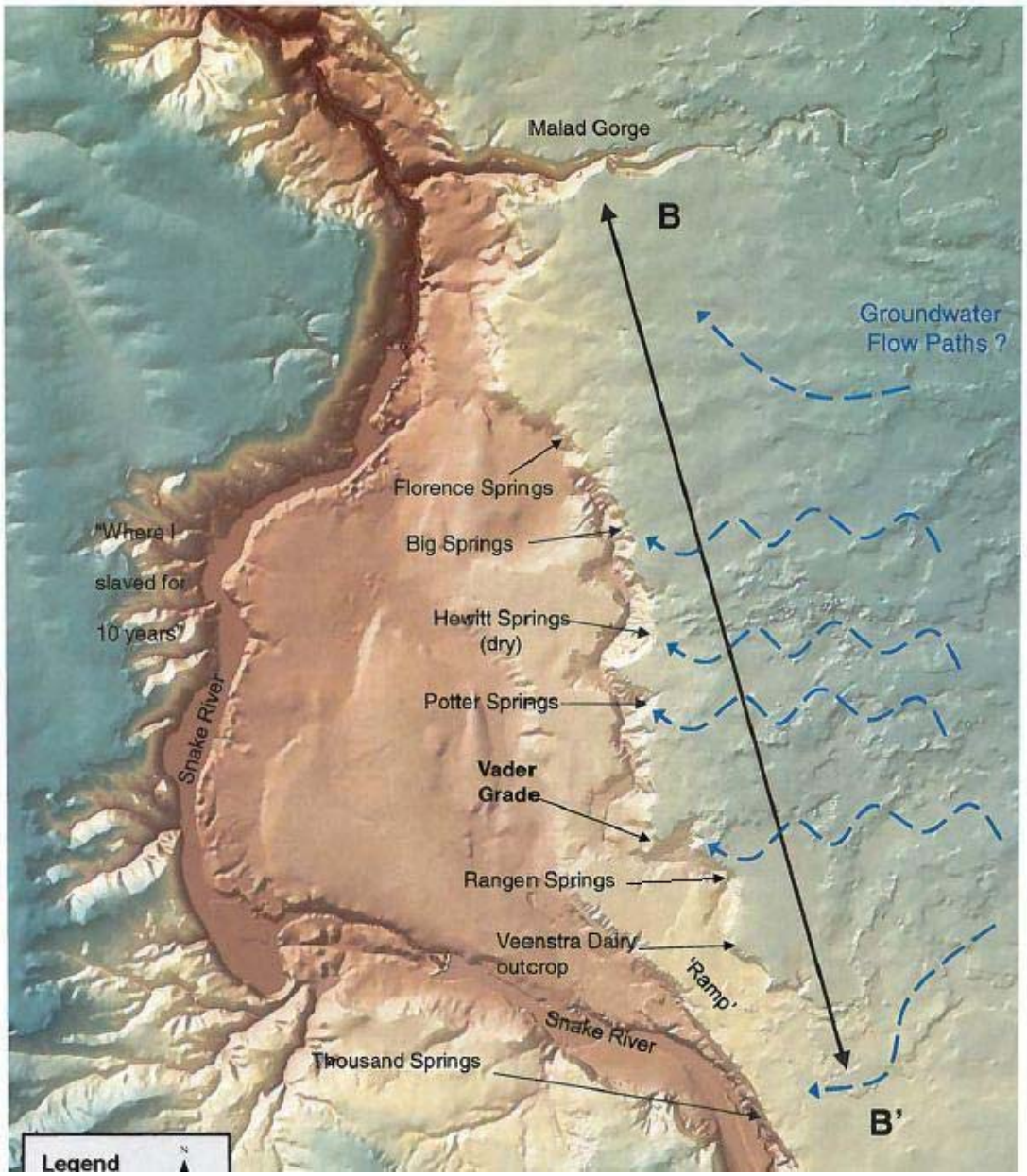


Figure 6.1: "Ramp" Formation near Hagerman

Source: Farmer pdf, no pagination, part of IDWR production dated 6/12/2012.

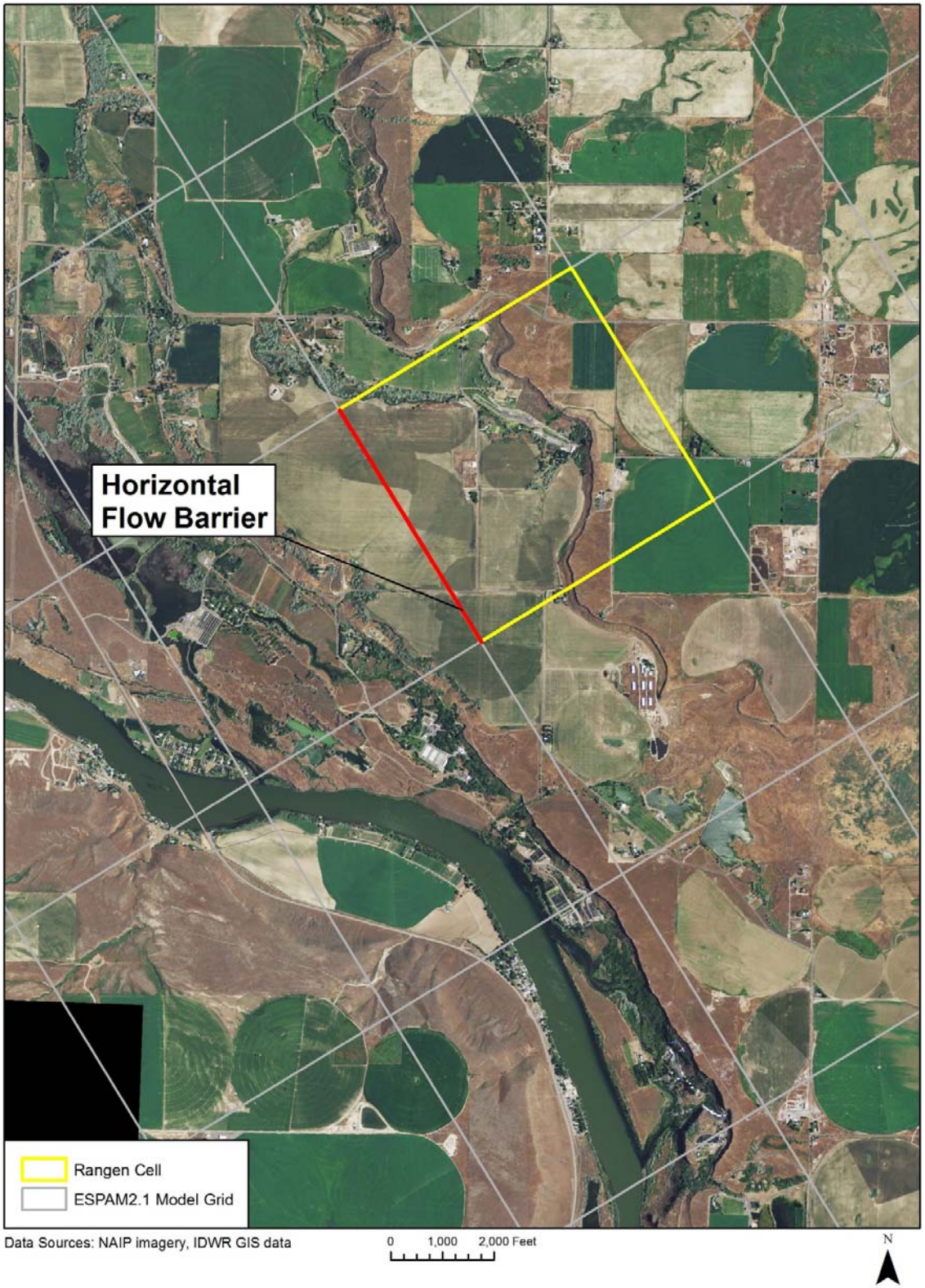


Figure 6.2: HFB Added to Alternative Model

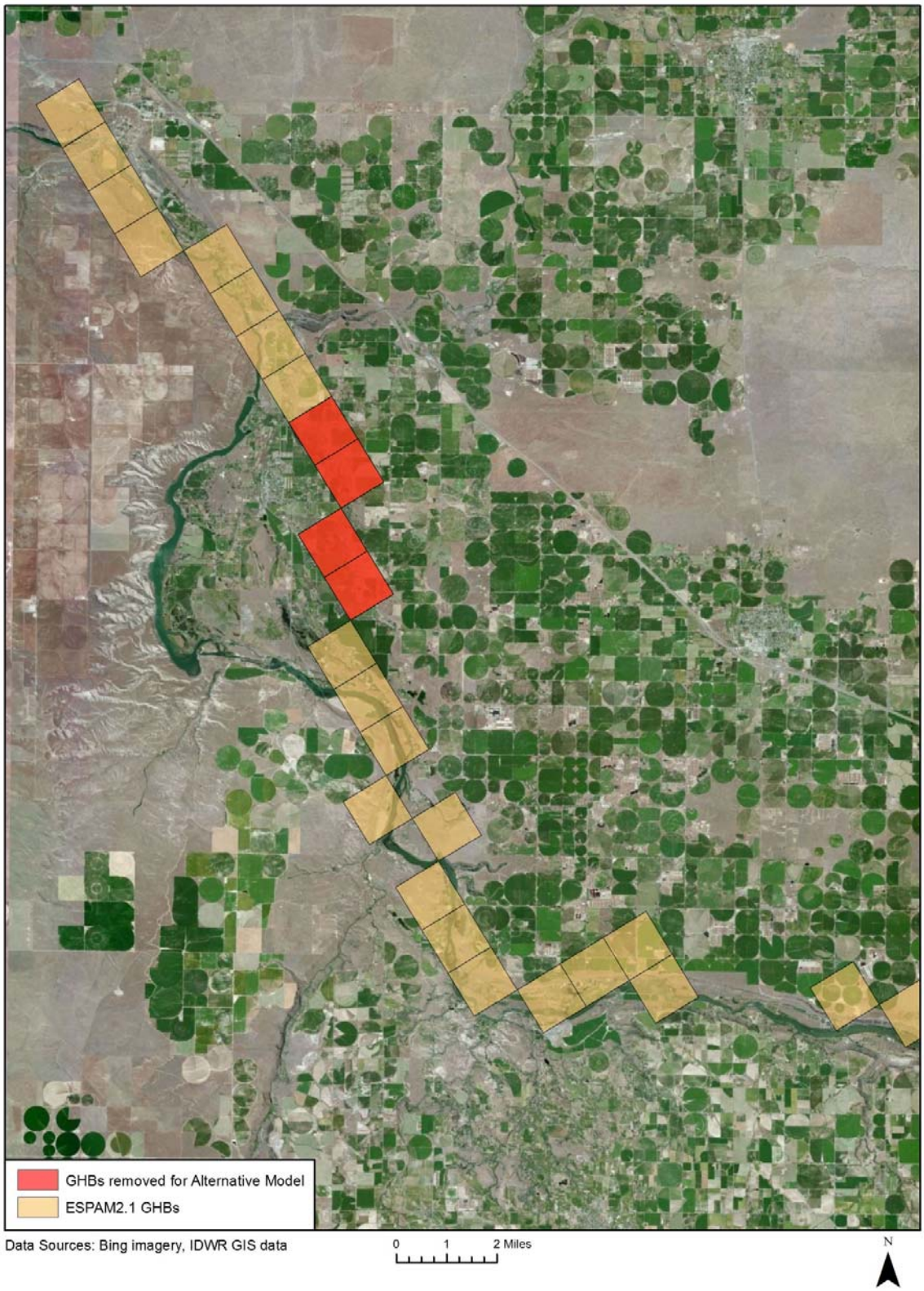


Figure 6.3: GHB Modification for Alternative Model

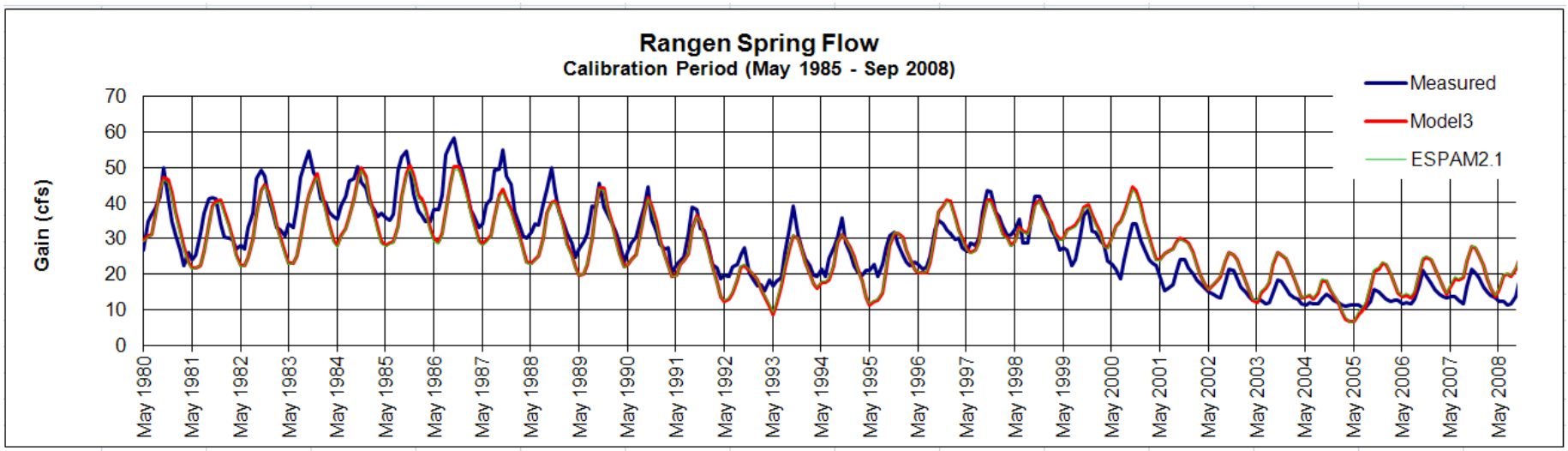


Figure 6.4a: Rangen Spring Flow Calibration Using Alternative Model #1[1]

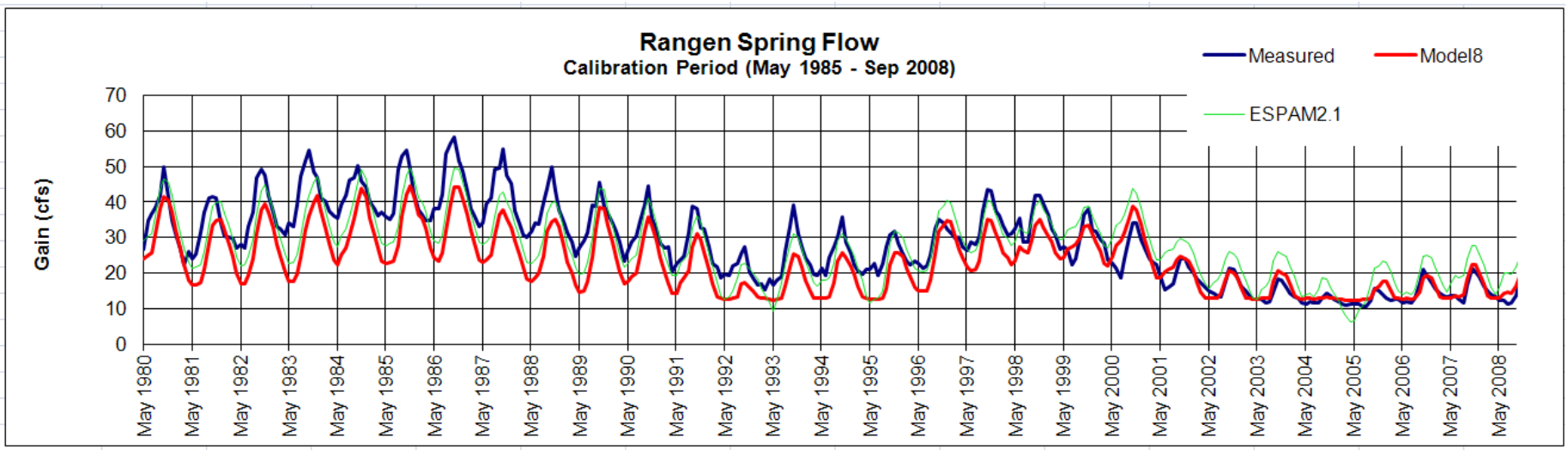


Figure 6.4b: Rangen Spring Flow Calibration Using Alternative Model #2[2]

[1] Referred to as "model #3" in supporting documentation
[2] Referred to as "model #8" in supporting documentation

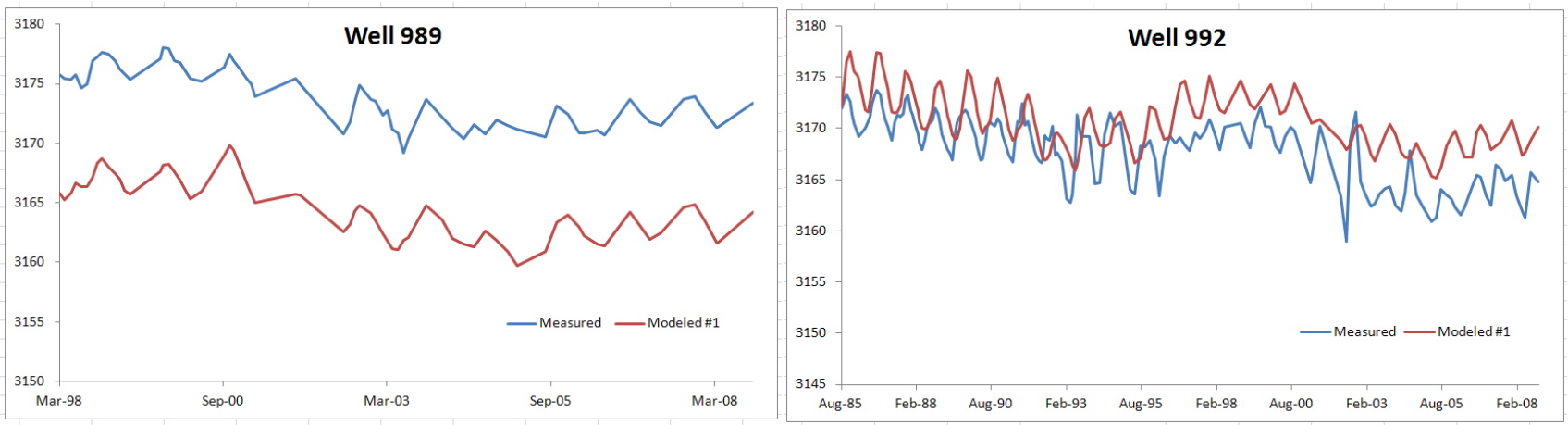


Figure 6.5a: Head Match in Wells 989 and 992 for Alternative Model #1

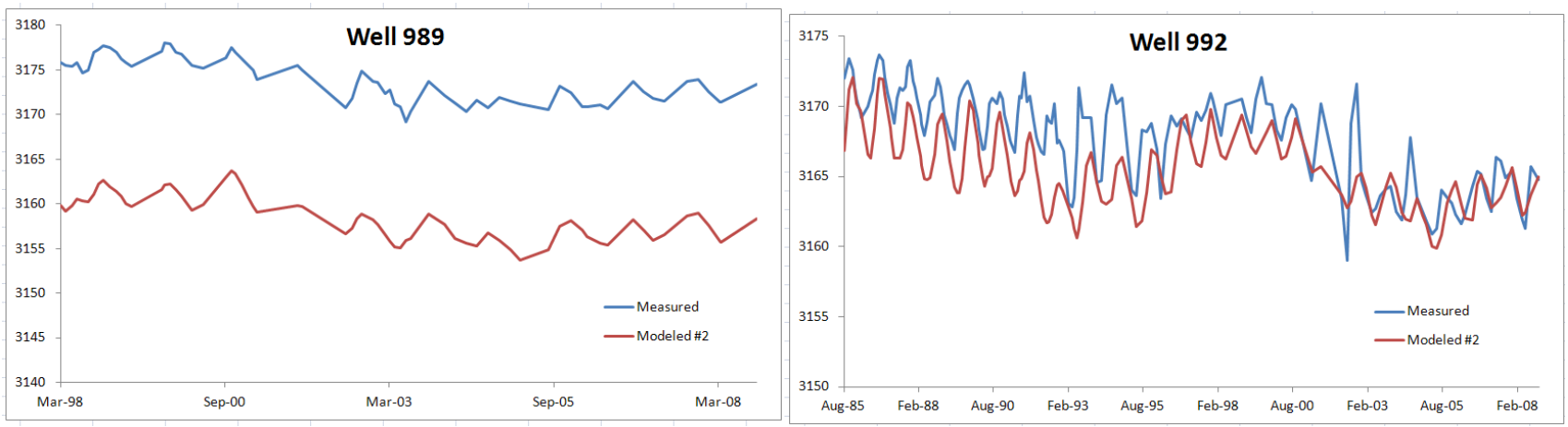


Figure 6.5b: Head Match in Wells 989 and 992 for Alternative Model #2

Table 2.1: Irrigation Improvements in Response to 1977 Drought

Table 3.41. Have You Done Anything since 1977 that Would Help Deal with Future Droughts?

	Ada-Canyon Counties		Blaine-Lincoln Counties		Bingham-Bannock Counties		All Three Areas	
	#	%[1/]	#	%	#	%	#	%
No Changes	37	52.9	12	27.9	17	44.7	66	43.7
Put In Wells	7	10.0	5	11.6	3	7.9	15	9.9
Put In Sprinklers	4	5.7	11	25.6	7	18.4	22	14.6
Added Gated Pipe	6	8.6	4	9.3	0	-	10	6.6
Lined Ditches	7	10.0	6	14.0	2	5.3	15	9.9
Land/Layout Improvements	5	7.1	3	7.0	8	21.1	16	10.6
Other	17	24.3	8	18.6	10	26.3	35	23.2
Total Reported Changes	83	-	50	-	40	-	173	-
Farmers Reporting Changes	33	47.1	31	72.1	21	55.3	85	56.3

[1/] Percent of questionnaires.

Source: Hamilton, et al. 1981

Table 3.1: Water Rights at Head of Billingsley Creek

User Name	Water Right Number	Priority Date	Amount (cfs)	Source*	Use
Candy	36-134A	10/9/1884	0.49	Martin-Curren Tunnel	Domestic, Irrigation
Rangen, Inc.	36-134B	10/9/1884	0.09	Martin-Curren Tunnel	Irrigation and domestic use
Morris	36-134D	10/9/1884	1.58	Martin-Curren Tunnel	Irrigation, Stockwater
Morris	36-134E	10/9/1884	0.82	Martin-Curren Tunnel	Irrigation, Stockwater
Musser	36-102	4/1/1892	4.1	Martin-Curren Tunnel	Domestic, Irrigation, Stockwater
Rangen, Inc.	36-135A	4/1/1908	0.05	Martin-Curren Tunnel	Irrigation and domestic use
Candy	36-135B	4/1/1908	0.51	Martin-Curren Tunnel	Irrigation
Morris	36-135D	4/1/1908	1.58	Martin-Curren Tunnel	Irrigation, Stockwater
Morris	36-135E	4/1/1908	0.82	Martin-Curren Tunnel	Irrigation, Stockwater
Morris	36-10141A	12/1/1908	0.82	Martin-Curren Tunnel	Irrigation, Stockwater
Morris	36-10141B	12/1/1908	0.43	Martin-Curren Tunnel	Irrigation, Stockwater
Rangen, Inc.	36-15501	7/1/1957	1.46	Martin-Curren Tunnel	Fish propagation use at the hatchery and research facility on Billingsley Creek.
Rangen, Inc.	36-2551	7/13/1962	48.54	Martin-Curren Tunnel	Fish propagation use at the hatchery and research facility on Billingsley Creek. (Includes 0.1 cfs for domestic use.)
Rangen, Inc.	36-7694**	4/12/1977	26.00	Martin-Curren Tunnel	Fish propagation use at the hatchery and research facility on Billingsley Creek.

* SRBA Partial Decree.
** According to a memorandum from Cindy Yenter to Karl Dreher dated December 15, 2003, Rangen's submitted historical flow numbers show that flows have not been available to support water right number 36-7694 since October 1972, which predates the priority year of the right by nearly 5 years. Additionally, during the water right development period flows did not exceed 50 cfs, which is the total of water rights 36-15501 and 36-2551.

Table 4.1: Changes in Drain Conductance

Name	Row	Column	ESPAM2.1 Drain Conductance	ESPAM2.0 Drain Conductance	Change in Drain Conductance	Percent Change in Drain Conductance (%)
White	37	14	1132.92	886.87	246.05	28%
White	37	14	1623.45	1825.01	-201.56	-11%
Birch	37	15	1259.36	1246.64	12.73	1%
	38	14	15341.51	13743.10	1598.41	12%
	38	14	1682.55	3982.91	-2300.36	-58%
Big Spg	39	14	102977.90	95434.60	7543.30	8%
Big Spg	39	14	19790.43	19441.73	348.70	2%
	40	13	1398.28	1356.85	41.43	3%
	40	13	120.39	64.08	56.31	88%
	40	14	548.53	581.12	-32.59	-6%
	40	14	13572.02	11443.99	2128.03	19%
3 Spgs	41	13	13886.21	1299.29	12586.92	969%
3 Spgs	41	13	232246.80	239273.20	-7026.40	-3%
Tucker	42	12	33531.50	34300.84	-769.34	-2%
Tucker	42	12	1219.83	1001.69	218.13	22%
Rangen	42	13	419036.20	437506.40	-18470.20	-4%
NFH	43	12	75008.54	99062.26	-24053.72	-24%
NFH	43	12	476766.10	577165.40	-100399.30	-17%
Thousand	44	12	920.37	902.42	17.95	2%
Thousand	44	12	300000000.00	300000000.00	0.00	0%
	45	11	70.22	94.58	-24.36	-26%
	45	12	816.74	840.81	-24.07	-3%
	45	12	1282.55	1114.83	167.73	15%
Sand	46	12	4.05	2.78	1.27	46%
Sand	46	13	655834.30	642687.80	13146.50	2%
	47	11	10848.44	7990.13	2858.31	36%
	47	12	8846.26	10054.27	-1208.01	-12%
Box	47	12	10447001.00	3331809.00	7115192.00	214%
Box	47	13	12761.19	17330.28	-4569.09	-26%
Banbury	48	11	257005.20	229321.50	27683.70	12%
Briggs	49	11	85472.96	86088.12	-615.16	-1%
Clr Lks	50	12	828.05	545.41	282.64	52%
Clr Lks	50	12	68061178.00	37714284.00	30346894.00	80%
Clr Lks	50	13	4551.97	1135.22	3416.75	301%
Clr Lks	50	13	362620.50	137821.40	224799.10	163%
	50	14	6.98	4.62	2.36	51%
	50	14	3.07	1.58	1.49	94%
	51	14	10.86	11.65	-0.79	-7%
	51	14	25.54	9.04	16.51	183%

Table 4.2: ESPAM1.1 versus ESPAM2.1 Simulated Curtailment Date of January 1, 1961

Reach Name	Curtailment junior to 1/1/1961					
	ESPAM2.1	ESPAM2.0	ESPAM1.1	Net change (ESPAM2.1 from ESPAM1.1)	Change ESPAM2.0 from ESPAM1.1	Change ESPAM2.1 from ESPAM2.0
Ashton to Rexburg	168	167	222	-54	-55	1
Heise to Shelley	228	234	141	87	93	-6
Sum above Shelley	**396**	**401**	**363**	**33**	**38**	**-4**
Shelley to Near Blackfoot	259	255	240	19	15	4
Near Blackfoot to Neeley	760	755	593	167	162	5
Neeley to Minidoka	24	40	84	-60	-44	-16
Sum Shelley to Milner	**1043**	**1050**	**917**	**126**	**133**	**-7**
Devil's Washbowl to Buhl	**131**	**135**	**160**	**-29**	**-25**	**-3**
Buhl to Thousand Springs	156	150	81	75	69	6
Thousand Springs	72	68	54	18	14	4
Thousand Springs to Malad	46	47	6.4	40	40	0
Sum Buhl to Lower Salmon Falls	**275**	**265**	**141**	**133**	**123**	**10**
Malad	50	51	47	3	4	-1
Malad to Bancroft	4	4	4	0	0	0
Sum Lower Salmon Falls to King Hill	**54**	**55**	**51**	3	4	**-1**
Sum of Springs below Milner	**460**	**454**	**352**	**107**	**102**	**6**
Kimberly to Buhl baseflow	11	10	--	--	--	1
Buhl to LSF baseflow	7	7	--	--	--	0
LSF to King Hill baseflow	5	5	--	--	--	0
Sum of baseflow below Milner	**23**	**22**	--	--	--	**0**
Total (cfs)	**1921**	**1927**	**1633**	**288**	**294**	**-6**
Acres curtailed	635,927	635,927	584,819	51,108	51,108	0
Curtailed consumptive use (AF/yr)	1,392,036	1,396,226	1,182,086	209,950	214,140	-4,190
Average consumptive use (ft/yr)	2.19	2.20	2.02	0.17	0.17	-0.01

Source: "Comparison ESPAM21 Appendix A: River and Spring Reach Location Maps"

Table 4.3: Predictive Analysis by IDWR

GW Use Area	Target Reach	Calibrated Impact	Maximized Impact	Minimized Impact	Range	Model Version
WD110	Clear Lakes	0.17%	0.17%	0.16%	0.000	E110712A001
WD110	nr Blackfoot-Minidoka	26.28%	26.68%	26.09%	0.006	E120116A008
WD120	Clear Lakes	0.45%	0.93%	0.39%	0.005	E110712A001
WD120	nr Blackfoot-Minidoka	66.52%	91.33%	55.02%	0.363	E120116A008
WD130	Clear Lakes	7.56%	7.84%	6.62%	0.012	E121025A001
WD130	nr Blackfoot-Minidoka	21.56%	21.67%	14.93%	0.067	E120116A008
WD130	Ashton-Rexburg	0.94%	0.96%	0.94%	0.000	E120116A008
WD34	Clear Lakes	2.73%	3.39%	0.44%	0.030	E110712A001
WD34	nr Blackfoot-Minidoka	49.19%	76.21%	43.09%	0.331	E121025A001
WD140	nr Blackfoot-Minidoka	34.86%	35.07%	34.74%	0.003	E120116A008
WD140	Clear Lakes	4.51%	4.65%	4.44%	0.002	E120116A008
WD33	Clear Lakes	0.55%	0.58%	0.53%	0.001	E120116A008
WD33	nr Blackfoot-Minidoka	61.19%	61.52%	60.60%	0.009	E120116A008
WD100	nr Blackfoot-Minidoka	19.81%	19.81%	19.78%	0.000	E120116A008
WD100	Clear Lakes	0.11%	0.12%	0.11%	0.000	E120116A008
WD99	Clear Lakes	0.11%	0.13%	0.08%	0.001	E120116A008
WD99	nr Blackfoot-Minidoka	16.44%	29.70%	3.02%	0.267	E120116A008

Source: ESPAM2 Uncertainty Analysis, IDWR

Table 5.1: Results of IDWR Curtailment Analysis using ESPAM2

Assumed Trimline Threshold	Change in Flow at Rangen Complex (cfs)	Groundwater Acres Curtailed	Curtailed Groundwater Use (af/y)	Flow Increase as % of Curtailed Water Right*	Years to Reach 90% of Steady State Increase
(1)	(2)	(3)	(4)	(5)	(6)
None	18.07	565,023	1,460,653	0.06%	16
Rule 50 Boundary	17.13	479,199	1,293,018	0.07%	15
0.20%	16.3	258,000	732,419	0.11%	15
1.00%	14.8	159,584	477,823	0.15%	13
1.50%	14.51	152,682	458,530	0.16%	13
1.70%	12.2	109,594	332,754	0.18%	11
2.00%	9.55	66,913	214,962	0.22%	9
3.50%	5.74	25,429	87,799	0.33%	5
5.00%	3.35	11,285	39,329	0.43%	3
10.00%	0.19	406	1,445	0.66%	1

Notes:
Columns (1) through (4) from IDWR production of June 12, 2012. Columns (5) and (6) by AMEC.
*Assuming 1" per acre permit amount.

Table 5.2 - Curtailment Results Using ESPAM2.1

Assumed Trimline Threshold	Change in Flow at Rangen Complex (cfs)	Groundwater Acres Curtailed	Curtailed Groundwater Use (af/y)	Rangen Increase as % of Curtailed Water Right*	Months to Reach 90% of Steady State Increase
(1)	(2)	(3)	(4)	(5)	(6)
10.0%	0.21	406	1,446	2.56%	3

Notes:
* Calculated as (2)/[(3)*0.02], assuming 1" per acre of irrigation

Source: AMEC analysis using ESPAM 2.1 Superposition Steady State version.

Table 6.1: Curtailment Results Using Alternative Model

Alternative Model ID	Assumed Trimline Threshold	Change in Flow at Total Complex (cfs)	Groundwater Acres Curtailed	Curtailed Groundwater Use (af/y)	Increase as % of Curtailed Water Right**	Months to Reach 90% of Steady State Increase
	(1)	(2)	(3)	(4)	(5)	(6)
#1	10.0%	0.11	208	740	2.69%	5
#2	10.0%	0.01	24	85	2.92%	2
ESPAM2.1	10.0%	0.21	406	1,446	2.56%	3

Notes:
* Calculated as (2)/[(3)*0.02], assuming 1" per acre of irrigation

Source: AMEC analysis using Alternative Model #1 and #2, IDWR's ESPAM2.1.