Henry’s Fork
Drought Management Plan

Prepared by
Joint Committee
Made up of Representatives from

Fremont-Madison Irrigation District
Henry’s Fork Foundation
North Fork Reservoir Company
Trout Unlimited
The Nature Conservancy
Bureau of Reclamation

Original version signed in 2005

Revised version signed December 4, 2018

Executive Summary

This report sets forth the results of the Henry's Fork of the Snake River drought management planning process that was set into motion by the Fremont-Madison Conveyance Act (Public Law No. 108-85). That act directed the transfer of title of the Cross Cut (Chester) Diversion Dam, the Cross Cut Canal, and the Teton Exchange Wells from the Bureau of Reclamation to the Fremont-Madison Irrigation District, on September 30, 2003. The Act also authorized additional Teton Project lands to receive Minidoka Project water.

Section 9 of the Act, "Drought Management Planning," reads thus:

"Within 60 days of the enactment of this Act, in collaboration with stakeholders in the Henry's Fork watershed, the Secretary shall initiate a drought management planning process to address all water uses, including irrigation and the wild trout fishery, in the Henry's Fork watershed. Within 18 months of the enactment of this Act, the Secretary shall report to Congress with a final drought management plan."

Between the fall of 2003 and the spring of 2005, advisory members representing the Fremont-Madison Irrigation District, Bureau of Reclamation, Henry's Fork Foundation, The Nature Conservancy, Trout Unlimited, and the North Fork Reservoir Company, with technical support from Idaho State University, met at regular intervals to fulfil this obligation. This process took place in the larger context of an ongoing drought, and meetings focused on both current water management needs and the larger planning effort. The winters of 2003-04 and 2004-05 were noteworthy because flows out of Island Park Dam on the Henry's Fork reflected a willingness to be inclusive of "all water uses, including irrigation and the wild trout fishery," to a significantly greater degree than has been the case in previous drought years.

With this in mind, it is the intention of those who prepared this plan to make formal the adaptive management process that was created in the 18 months after passage of the Conveyance Act and the system of regular stakeholder meetings to discuss system operations. The adaptive management process and regular stakeholder meetings constitute the Henry's Fork Drought Management Plan. The effectiveness of this plan will be evaluated and revised as needed.

Goal

The goal of the processes set forth in the Henry's Fork Drought Management Plan is to maintain or enhance watershed health and ecology, even in years of below-average precipitation, in balance with agricultural needs through flexible and adaptive water management within the context of Idaho water law.

Objectives

1. Continue to manage water out of Island Park Reservoir to optimize irrigation, fish and wildlife populations, aquatic processes, hydropower production, and long-term dam maintenance.

2. Maintain or enhance water supply for all of the above purposes.
3. Maintain functioning hydrologic regimes where they currently exist, including groundwater-surface water interactions, even if these regimes differ from the pre-European condition.
4. Provide streamflow in the Henry's Fork and its tributaries during times of year when streamflow limits fisheries or other aquatic resources, within the bounds of existing water rights, including the storage rights for Island Park Reservoir and Henry's Lake.

Drought Management Plan

The Henry's Fork Drought Management Plan, which is perhaps better and more simply described as a "water management plan," will consist of four regular meetings annually, plus additional meetings as needed. The meetings will correspond with the major cycles in a typical irrigation season, and allow for planning based on both existing/prior conditions and predicted conditions. Those meetings will include the following:

> Fall: Discuss the close of the irrigation season, begin to formulate the plan for winter flows, based on current reservoir levels, predicted demand for the remainder of the current irrigation season, and various winter precipitation scenarios.
>
> Late fall/early winter: Discuss winter flows based on reservoir carryover and current and predicted stream baseflows and precipitation.
>
> Late winter: Assess current flow/snowpack situation in Henry's Fork and whether or not adjustments need to be made to existing winter flows. Discuss Upper Snake River basin-wide precipitation levels and forecasts, Upper Snake River basin-wide reservoir levels and forecasts, and potential management scenarios for the coming year.
>
> Spring: Discuss the ongoing irrigation season, current and predicted water supply based on current/predicted demand, and formulate a recommended summer flow management strategy, including target flows in the Henry's Fork at St. Anthony.

These meetings will be open to the public. The larger watershed public will be kept abreast of water management plans through the Henry's Fork Watershed Council, the open stakeholder group co-chaired by Fremont-Madison Irrigation District and Henry's Fork Foundation.

The planning group also commits to collaborative monitoring, assessment and continued investigation and research in the Henry's Fork watershed.

Original 2005 signature sheet.

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Introduction

The purpose of the Drought Plan is to provide the policy and system for monitoring, assessing, and preparing for drought conditions, as well as for managing the Henry's Fork reservoir and irrigation system in all water years, while supporting Fremont-Madison Irrigation District (FMID) water users and the ecological resources of the Henry's Fork of the Snake River.

The following document sets forth the results of the Henry's Fork of the Snake River drought management planning process that was set into motion by the Fremont-Madison Conveyance Act (Public Law No. 108-85; Appendix A). That act directed the transfer of title of the Cross Cut (Chester) Diversion Dam, the Cross Cut Canal, and the Teton Exchange Wells from Bureau of Reclamation (Reclamation) to FMID, on September 30, 2003. The Act also legitimized Teton Project land that receives Minidoka Project water.

Between the fall of 2003 and the spring of 2005, advisory members representing the FMID, Reclamation, Henry's Fork Foundation (HFF), The Nature Conservancy (TNC), Trout Unlimited (TU), and the North Fork Reservoir Company (NFRC), with technical support from Idaho State University (ISU), met at regular intervals to fulfill Congressional stipulation to provide a Drought Plan. This process took place in the larger context of an ongoing drought, and meetings have focused on both current water management needs and the larger planning effort. The winters of 2003-04 and 2004-05 were noteworthy because flows out of Island Park Dam on the Henry's Fork reflected a willingness to be inclusive of "all water uses, including irrigation and the wild trout fishery," to a significantly greater degree than has been the case in previous drought years.

Background

The Henry's Fork of the Snake River is one of the most prominent watersheds in the West. It is situated at the top of the Snake River system, a vital and heavily scrutinized headwater drainage whose water is used to irrigate a quarter of a million acres of southeastern Idaho cropland. The Henry's Fork is also one of the world's most famous trout streams, attracting tens of thousands of anglers and other river recreationists each year, and in doing so generating millions of dollars of business for both the local economy and that of Idaho. Few rivers work as hard, and perform as well, as the Henry's Fork to serve such a diverse group of users. Due in part to ineffectiveness of adversarial approaches in resolving conflicts over water use, and in part to recognition that most water-supply concerns are common to all stakeholder groups, water management in the Henry's Fork watershed has become much more collaborative over the past two decades. For example, reservoir carryover, management of native species, and aquifer management are important to all stakeholders. In addition, rapid population growth in Idaho and surrounding states has increased demand both for river recreation and for water supply to meet growing domestic, commercial, municipal and industrial uses. These demands, when added to water already allocated to agricultural water users under Prior Appropriation, put the greatest pressure on water supplies in periods of drought.

"Drought" is defined here generally as conditions dry enough that FMID will lose some of its water allocation, and in which watershed hydrologic alteration is high. Statistical analysis of water years 1972-2003 showed that hydrologic alteration was high in one-third of those years. Analysis of the more recent 30-year period from 1987 to 2016 showed that Henry's Lake and FMID spaceholders received less than 80% of their full storage allocation in 11 (37%) of these years. Over those 11 years, water users in the Henry's Fork watershed rented an average of 24,343 ac-ft per year, most from the Water District 01 common rental pool.

Drought exposes two fundamental problems with the existing water management scenarios and infrastructure in the Henry's Fork watershed. Water in the Henry's Fork is fully appropriated in all but the very wettest years. In years of below-average precipitation some junior water-rights holders—among them many of the 1,700 irrigators served by the FMID—typically lose some or all of their storage or surface water allocations. Much of the water stored in Island Park Reservoir (more than half of it in dry years) is simply delivered through the Henry's Fork to meet senior obligations downstream, leaving the FMID to distribute their share. At the same time, from a fisheries standpoint (not to mention a more general ecological context), storing water in the winter as high in the watershed as possible for as long as possible means, in drought years, that flows in the critical winter and early spring months are lower than they should be to optimize the survival of juvenile rainbow trout and to enhance the ability of adult rainbow trout to spawn. Thus, drought has a negative impact on the productivity of the Henry's Fork watershed, both agriculturally and ecologically.

Thankfully, the Henry's Fork is also a watershed in which a wide range of stakeholders have come together to form cooperative bonds that are unheard of throughout most of the West. In 1992, HFF, a conservation organization dedicated to the protection, restoration, and conservation of the Henry's Fork watershed and its fishery, and FMID co-founded the Henry's Fork Watershed Council (HFWC, or Council), a forum to which all watershed stakeholders are welcome to come, hear ideas, screen proposals, and discuss management questions. In its first two decades, the HFWC was involved in more than 55 watershed projects, ranging from irrigation efficiency to trout habitat restoration, which brought together an amazing 80-plus cooperators.

In 1997, FMID began discussions with Idaho's federal legislators, Reclamation, and the public regarding the possible transfer of Reclamation facilities in the Henry's Fork drainage from federal to FMID ownership. Specifically, the initial proposal included Island Park, Grassy Lake, Cross Cut Diversion Dam and correlative lands, Cross Cut Canal, and the Teton Exchange Wells. The scale of the transfer was eventually reduced and in 2001 FMID, in partnership with Reclamation, began a process to transfer title to Cross Cut Diversion Dam, Cross Cut Canal, and the Teton Exchange Wells from the federal government to the irrigation district. At the same time, they began working with the Idaho congressional delegation to write proposed legislation in both the federal House and Senate that would mandate the transfer.

The initial Senate (S.2556) and House (H.R.4708) versions of the title transfer legislation focused purely on the transfer. The HFF and TU, a national coldwater fisheries conservation organization, worked with FMID throughout the summer of 2002 to include language in the legislation to benefit the river's fishery as well as the agricultural community. After numerous meetings and discussions, the focus turned to the inclusion of language that would mandate drought management planning in the Henry's Fork watershed. Both irrigation and conservation interests felt that such a planning effort could benefit stakeholders throughout the watershed. These discussions resulted in an amendment to the original legislation that included a specific section directing the Secretary of the Interior to work with stakeholders in the Henry's Fork watershed to develop a drought management plan. The provision included a specific directive to address all water issues, including irrigation and the wild trout fishery. The final language was approved by Congress on September 30, 2003 as Public Law No. 108-85.

Water Management and Fisheries in the Upper Henry's Fork Watershed

Brief history

Dams have been used to control flows in the Henry's Fork watershed since the early 1920s. The control of flows has led to changes in the river's hydrologic regime, a term defined as the magnitude, timing, frequency, duration, and rate of change of stream flow. This change to the hydrologic regime is known as hydrologic alteration, and it in turn can lead to impacts to ecological values. The impacts of two dams in particular are relevant to this drought management planning process.

Flows from Henry's Lake, in the headwaters of the Henry's Fork, have been controlled since 1923 by a dam constructed by NFRC on the Henry's Lake outlet. This dam dramatically increased the surface area and capacity of Henry's Lake. Dr. Rob Van Kirk and Boyd Burnett of ISU showed in a 2004 study (Van Kirk and Burnett 2004) that hydrologic alteration in the Henry's Lake outlet in water years between 1972 and 2002 was extreme, with high alteration in more than half of the measured years, resulting in the elimination of normal base flows, excessive sedimentation, and loss of wetland function. Alteration in this reach is the highest of any reach in the watershed. This is due to the fact that water is typically stored in Henry's Lake through the natural spring runoff period and then released in mid- to late-summer, when the outlet would have historically carried relatively little flow, effectively reversing the normal hydrograph. This situation is exacerbated by the fact that Henry's Lake's storage capacity is roughly twice the average runoff from the lake's small catchment basin, making the lake difficult to fill, and by the fact that the lake's biologically and recreationally important fishery (in particular Yellowstone cutthroat trout) makes the maintenance of high lake levels a priority for resource managers. Because Henry's Lake is operated as part of the federal Upper Snake River Reservoir system, and the stockholders in the NFRC have space in Island Park Reservoir, Henry's Lake management has varied little since Island Park Dam began to operate in 1938. This management has allowed Henry's Lake to be maintained typically at or near full pool, creating in the process a world-famous recreational trout fishery while significantly limiting the ability to provide ecological base flows in the outlet. In 1997, NFRC, Reclamation, and the Snake River Water master signed a ten year agreement that would allow for 2,200 acre feet of Reclamation water to be exchanged by the water district during the irrigation season for winter flows in the

Henrys Lake outlet. Additionally, a 1998 Memorandum of Understanding between Reclamation, Idaho Department of Fish and Game (IDFG) and TNC, provide a framework for making recommendations to Reclamation for the release of the 2,200 acre feet of the Henrys Lake exchange water when Reclamation exchange water is available. This exchange agreement did not provide benefit during drought years in the early 2000s and was not renewed upon its expiration in 2007.

The second dam, the next dam downstream from Henry's Lake, is Island Park Dam, which first stored water in 1938. Van Kirk and Burnett (2004) showed that hydrologic alteration in the river reach from the dam downstream to the confluence of the Warm River with the Henry's Fork was high (although not as high as it was in the Henry's Lake outlet). That said, water management below Island Park Dam has improved dramatically in recent years. For example, in 76% of the years between 1939 and 1971, winter flows below Island Park Dam were reduced to little more than seepage from the dam for thirty days or more in the critical (to juvenile trout survival) winter months. That figure has been reduced to only 6% of the years since 1972. Clearly, irrigators and dam operators have realized that there is room for flexible water management at Island Park Dam, and they have acted accordingly.

Changes in water management at Island Park Dam in the early 1970s were followed shortly by changes in fishery management. Prior to 1972 flow fluctuations limited the river's potential to support a self-sustaining, or "wild," native trout fishery, and the trout fishery in that reach was heavily augmented with hatchery trout and with fish (of a variety of species) that washed through the dam out of Island Park Reservoir and into the river below. In 1978, however, the IDFG ceased its stocking program in this reach. The subsequent installation of a hydropower generating facility on Island Park Dam, complete with a screened intake, limited the number of fish that are inadvertently "stocked" into the Henry's Fork below Island Park Dam. Although the original dam intake is still unscreened, the fish rescue effort undertaken in the fall of 2003 when Island Park Dam was shut down for repairs suggests that relatively few fish enter the river this way. The IDFG estimates that at least 90% of the fish biomass in Island Park Reservoir consists of "rough" fish. Observers collecting fish below the dam in 2003 saw very few non-salmonid fish species below the dam in the course of an intensive fish rescue. The rescue effort including one very large, confined pool immediately below the dam outlet that contained at least one thousand fish, almost all of them trout. If large numbers of reservoir fish were entering the river via the outlet tunnel many more rough fish should have been observed by fish rescuers. Thus, since 1978 the Henry's Fork below Island Park Dam has been managed as a wild, self-sustaining trout fishery.

Current knowledge of Island Park Dam management and the fishery downstream

Because of the popularity of the trout fishery in the 15 river miles immediately downstream of Island Park Dam, it has received a large amount of research and monitoring attention since the late 1980s. Most of this research and monitoring focused on the positive relationship between winter outflow from Island Park Dam and recruitment of rainbow trout. Oldemeyer et al. (2017) reviewed the resulting literature and data and found that between approval of the original Drought Management Plan in 2005 and water year 2016, adaptive management of fall and winter flows at Island Park enacted by the Drought Management Planning Committee resulted in a 6% increase in the rainbow trout population over what it would have been under previous management. Although positive, this increase is not statistically significant, given that the interannual coefficient of variation in population abundance is around 38%. More recently, research conducted by HFF has shown that aspects of the fishery below Island Park Dam other than trout abundance are negatively affected by high summertime flows and resulting drawdown of Island Park Reservoir (Appendix B). These include increased sediment transport out of the reservoir, decreased water clarity, decreased angler satisfaction (Laatsch et al. 2017), and warmer water temperatures (McLaren 2017). At the same time, excessive drawdown of Island Park Reservoir can also have negative consequences for FMID, since higher reservoir carryover increases the probability of full storage allocation the following year and increases the system-wide management options made possible by storing water as high in the system as possible. It should be noted that fairly precise winter management of Island Park Reservoir is possible because inflow, consisting primarily of groundwater inputs, can be predicted early in the fall with little error. In particular, winter reach gain between Henry's Lake and Island Park can be predicted at the beginning of October with a margin of error of less than 10%.

New Water-Management Issues

The original Drought Management Plan emphasized fisheries and ecological processes in the upper watershed and focused on management of Henry's Lake and Island Park Reservoir to maximize these resources when possible within the rights of spaceholders in these reservoirs. In the years between development of the original Plan and this revision, new resource concerns and administrative issues throughout the upper Snake River basin have shifted conservation priorities and added both constraints and opportunities to water management as it was practiced in the mid-2000s. These include, among many others,

- Increased recreational and angling use on Fall River, Teton River, and the lower Henry's Fork (Ashton Dam to North Fork Teton confluence);
- Adoption of the Eastern Snake Plain Aquifer Comprehensive Aquifer Management Plan, including goals for managed aquifer recharge (IWRB 2009);
- 2015 settlement agreement between groundwater and surface-water users and resulting demand for groundwater-pumping mitigation through storage rental and managed aquifer recharge; and
- Recognition that recharge incidental to irrigation has played an important role in maintaining fish and wildlife habitat in many locations for over a century.

All of these items have links to management of Henry's Lake and Island Park Reservoir and therefore should receive appropriate consideration in meeting the goals and objectives of the Drought Management Plan.

Goals and Objectives

The stakeholders set forth the following general goals and objectives as part of the drought management planning process, recognizing the rights of the FMID spaceholders.

Goal

Maintain or enhance watershed health and ecology, even in years of below-average precipitation, in balance with agricultural needs through flexible and adaptive water management within the context of Idaho water law.

Objectives

1. Continue to manage water out of Island Park Reservoir to optimize irrigation, fish and wildlife populations, aquatic processes, hydropower production, and long-term dam maintenance.
2. Maintain or enhance water supply for all of the above purposes.
3. Maintain functioning hydrologic regimes where they currently exist, including groundwater-surface water interactions, even if these regimes differ from the pre-European condition.
4. Provide streamflow in the Henry's Fork and its tributaries during times of year when streamflow limits fisheries or other aquatic resources, within the bounds of existing water rights, including the storage rights for Island Park Reservoir and Henry's Lake.

Alternatives

Within this framework, the stakeholders screened eight potential drought management alternatives when developing the original Drought Management Plan. These are listed here by name, but for the historical record, the complete, original descriptions appear in Appendix C.

1. Pumping and pipeline system for Henry's Lake Outlet.
2. Construct a new storage facility on the Teton River.
3. Stock trout into the Henry's Fork below Island Park Dam to mitigate losses of juvenile trout in drought years.
4. Mitigation Fund A (compensate storage spaceholders who lose allocation because of flows provided to fisheries).
5. Mitigation Fund B (fund incentives to reduce irrigation demand).
6. Marysville pipeline
7. Move the confluence of the Buffalo River, or some flows from the Buffalo River, to keep the upper quarter mile of the Henry's Fork below Island Park Dam wetted during maintenance or late-fall/early-winter storage season operations.
8. Adaptive management of Island Park Dam.

Of these options, number 8 has received by far the greatest attention in the regular Drought Management Planning meetings. Over the years since development of the original Drought Management Plan, operation has evolved to lower outflow from Island Park Dam as early as possible in the fall to store water prior to the onset of cold weather, usually in late November or early December. Outflow is then increased as much as possible over the coldest part of the winter while still meeting reservoir fill objectives. Actual outflow is often adjusted slightly to accommodate power generation at the Island Park hydroelectric plant. Since 2014, greater attention has been paid to spring and summer operations, and small adjustments have been made when possible to ensure that the reservoir was 100% full when storage delivery was first needed and provide flows sufficient for float fishing early and late in the fishing season. The Drought Management Planning Committee has also set flow targets at St. Anthony, which, if met, minimize delivery of storage from Island Park Reservoir.

Options 1, 4 and 7 have never been seriously pursued. The HFF conducted angler surveys in 2008 and 2014 to assess support for option 3, but survey respondents in both years overwhelmingly rejected the idea of stocking trout below Island Park Dam, and that option has not been subsequently pursued.

Some versions of options 2, 5, and 6 were assessed in the Henry's Fork Basin Study, conducted between 2010 and 2014 by Reclamation, in cooperation with the Idaho Water Resource Board (IWRB). The Henry's Fork Watershed Council served as the stakeholder workgroup for the study. After starting with 51 alternatives, the workgroup, Reclamation, and IWRB identified 12 alternatives to be assessed and analyzed in the final document. These 12 options are listed here; details are given in the Basin Study final report (USBR 2015). As of November 30, 2018, the Basin Study can be accessed online at https://www.usbr.gov/watersmart/bsp/docs/finalreport/HenrysFork/HenrysForkBasinStudyReport.pdf.

Surface storage alternatives
1. Teton Dam Replacement
2. Lane Lake
3. Upper Badger Creek
4. Island Park Dam enlargement
5. Spring Creek
6. Moody Creek
7. Ashton Dam raise

Water management and conservation alternatives
8. North Fremont Canal System pipeline
9. Managed aquifer recharge
10. Canal automation
11. Water marketing
12. Demand reduction

In the time between completion of the Basin Study and update of this document, IWRB conducted further assessment of Island Park Dam enlargement and funded enlargement of capacity at the Egin Lakes recharge site. Public and private efforts continue to expand capacity for managed recharge at Egin Lakes and elsewhere in the watershed. Three of five phases of the North Fremont pipeline conversion are complete, and the canal company plans to complete the final two phases as soon as funding allows. The concept of canal automation has received some attention, but no plans have been developed as of adoption of this document. Local and regional conservation organizations have partnered with irrigation companies and individual producers to find market-based mechanisms and other incentives to reduce irrigation demand.

Implementation and Assessment

Two main factors for the successful implementation of the Drought Management Plan are 1) involvement of all appropriate organizations and the community, and 2) the ongoing evaluation and revision of the Plan to meet changing needs. The greatest probability of negative outcomes occurs when management issues are not addressed in a cooperative and collaborative manner. Thus, the primary feature of this Plan is a formal schedule of meetings at which the signatories, as well as other interested stakeholders, discuss current and projected conditions and management over the time scale of a water year. However, long-term success depends on adaptive management, which requires monitoring, continued scientific investigation, and assessment of the Plan's effectiveness.

Schedule of Meetings

The Henry's Fork Drought Management Plan, which is perhaps better and more simply described as a "water management plan," will consist of four regular meetings annually, plus additional meetings as needed. The meetings will correspond with the major cycles in a typical irrigation season, and allow for planning based on both existing/prior conditions and predicted conditions. Those meetings will include the following:

> Fall: Discuss the close of the irrigation season, begin to formulate the plan for winter flows, based on current reservoir levels, predicted demand for the remainder of the current irrigation season, and various winter precipitation scenarios.
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> Late fall/early winter: Discuss winter flows based on reservoir carryover and current and predicted stream baseflows and precipitation.
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> Late winter: Assess current flow/snowpack situation in Henry's Fork and whether or not adjustments need to be made to existing winter flows. Discuss Upper Snake River basin-wide precipitation levels and forecasts, Upper Snake River basin-wide reservoir levels and forecasts, and potential management scenarios for the coming year.
>
> Spring: Discuss the ongoing irrigation season, current and predicted water supply based on current/predicted demand, and formulate a recommended summer flow management strategy, including target flows in the Henry's Fork at St. Anthony.

All the aforementioned meetings will be open to the public. The larger watershed public will be kept abreast of water management plans through the HFWC, the open stakeholder group co-chaired by FMID and HFF.

Assessment

Due to the unique structure of and collaborative involvement within the Henry's Fork stakeholder community, assessment and preemptive measures are part of ongoing operations. An important component of assessment is long-term monitoring of hydrological, biological, administrative, and management indicators across different types of water years. This monitoring can be most effective when results of collaborative efforts among stakeholder organizations and agencies are discussed openly at the regular meetings outlined above and at meetings of the HFWC.

The planning group also commits to continued investigation and research in the Henry's Fork watershed. Two studies of hydrologic alteration in the Henry's Fork watershed were included with original plan (Van Kirk and Burnett 2004; Van Kirk and Jenkins 2005). Several other studies of hydrology and water management in the Henry's Fork watershed have been completed since the original Drought Management Plan was written (Liegel 2010, Peterson 2011, Apple 2013, Baker et al. 2014). All received input from and were presented to the HFWC. This revision of the plan includes two more recent examples of ongoing research into water management on the Henry's Fork (Appendices B and D), including the water budget that was used in the Basin Study. These are examples of the aggressive pursuit of information that the drought management planning process has fostered and encouraged.

Drought conditions underscore the fact that the resource is limited. Therefore, during those events everyone is affected. Monitoring and scientific research are intended to identify and quantify the nature and extent of drought effects so that informed, preemptive measures can be taken to minimize the effects of future droughts. Although biological and physical quantities such as fish populations, streamflow, and reservoir carryover have been traditionally used as indicators of effects of drought, other measures such as water-rights priorities, administrative water allocation, and need for storage rental should be routinely included in assessment and prediction of drought effects. Because uncertainty is inherent in predicting and preparing for future conditions, monitoring and research are most useful when they include honest and robust estimates of uncertainty around predictions.

Even when uncertainty in predictions is included, unanticipated extreme events can occur. Response to such events includes ongoing communication and collaborative efforts of the Henry's Fork community. When necessary, emergency Drought Management Planning meetings may be held in between regular quarterly meetings to adapt current management to changing conditions, acknowledging that system-wide water rights, administrative processes, and management needs apply, regardless of conditions specific to the Henry's Fork watershed. When conditions have or are likely to have negative effects on specific resources and stakeholder groups, preemptive measures carry less uncertainty than emergency responses and after-the-fact mitigation. One example would be a market-based incentive, negotiated ahead of irrigation season, for a producer to reduce irrigation use during the upcoming season versus the necessity of renting storage water later in the summer to finish a crop already in the ground. Another example would be to maximize managed aquifer recharge during years of high water supply to increase stream baseflows during dry years that will inevitably follow.

Finally, the signatories emphasize that the core of the Plan is a series of four regular meetings involving relevant and interested parties, supported by ongoing collaborative monitoring and research efforts. Assessment of the process itself is part of adaptive management, whether that assessment results in incremental evolution in meeting format or a formal revision of the Plan itself.

The Plan will be reviewed and updated as needed. Furthermore, the plan should continue to be evaluated for effectiveness following drought events. Appendices can be added without formal review and update, as new scientific and technical information becomes available. Overall responsibility and point of contact for the Drought Management Plan resides with FMID.

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Appendix A

Fremont-Madison Conveyance Act

Public Law 108–85
108th Congress

An Act

To authorize the Secretary of the Interior to convey certain facilities to the Fremont-Madison Irrigation District in the State of Idaho.

Sept. 30, 2003
[S. 520]

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

Fremont-Madison Conveyance Act.

SECTION 1. SHORT TITLE.

This Act may be cited as the "Fremont-Madison Conveyance Act".

SEC. 2. DEFINITIONS.

In this Act:

(1) DISTRICT.—The term "District" means the Fremont-Madison Irrigation District, an irrigation district organized under the law of the State of Idaho.

(2) SECRETARY.—The term "Secretary" means the Secretary of the Interior.

SEC. 3. CONVEYANCE OF FACILITIES.

(a) CONVEYANCE REQUIREMENT.—The Secretary of the Interior shall convey to the Fremont-Madison Irrigation District, Idaho, pursuant to the terms of the Memorandum of Agreement (MOA) between the District and the Secretary (Contract No. 1425–01–MA–10–3310), all right, title, and interest of the United States in and to the canals, laterals, drains, and other components of the water distribution and drainage system that is operated or maintained by the District for delivery of water to and drainage of water from lands within the boundaries of the District as they exist upon the date of enactment of this Act, consistent with section 8.

Deadline.

(b) REPORT.—If the Secretary has not completed any conveyance required under this Act by September 13, 2004, the Secretary shall, by no later than that date, submit a report to the Congress explaining the reasons that conveyance has not been completed and stating the date by which the conveyance will be completed.

SEC. 4. COSTS.

(a) IN GENERAL.—The Secretary shall require, as a condition of the conveyance under section 3, that the District pay the administrative costs of the conveyance and related activities, including the costs of any review required under the National Environmental Policy Act of 1969 (42 U.S.C. 4321 et seq.), as described in Contract No. 1425–01–MA–10–3310.

(b) VALUE OF FACILITIES TO BE TRANSFERRED.—In addition to subsection (a) the Secretary shall also require, as a condition of the conveyance under section 3, that the District pay to the

United States the lesser of the net present value of the remaining obligations owed by the District to the United States with respect to the facilities conveyed, or $280,000. Amounts received by the United States under this subsection shall be deposited into the Reclamation Fund.

SEC. 5. TETON EXCHANGE WELLS.

(a) CONTRACTS AND PERMIT.—In conveying the Teton Exchange Wells pursuant to section 3, the Secretary shall also convey to the District—

(1) Idaho Department of Water Resources permit number 22–7022, including drilled wells under the permit, as described in Contract No. 1425–01–MA–10–3310; and

(2) all equipment appurtenant to such wells.

(b) EXTENSION OF WATER SERVICE CONTRACT.—The water service contract between the Secretary and the District (Contract No. 7–07–10–W0179, dated September 16, 1977) is hereby extended and shall continue in full force and effect until all conditions described in this Act are fulfilled.

SEC. 6. ENVIRONMENTAL REVIEW.

Prior to conveyance the Secretary shall complete all environmental reviews and analyses as set forth in the Memorandum of Agreement referenced in section 3(a).

Effective date.

SEC. 7. LIABILITY.

Effective on the date of the conveyance the United States shall not be liable for damages of any kind arising out of any act, omission, or occurrence relating to the conveyed facilities, except for damages caused by acts of negligence committed by the United States or by its employees, agents, or contractors prior to the date of conveyance. Nothing in this section may increase the liability of the United States beyond that currently provided in chapter 171 of title 28, United States Code.

SEC. 8. WATER SUPPLY TO DISTRICT LANDS.

The acreage within the District eligible to receive water from the Minidoka Project and the Teton Basin Projects is increased to reflect the number of acres within the District as of the date of enactment of this Act, including lands annexed into the District prior to enactment of this Act as contemplated by the Teton Basin Project. The increase in acreage does not alter deliveries authorized under the District's existing water storage contracts and as allowed by State water law.

Deadline.

SEC. 9. DROUGHT MANAGEMENT PLANNING.

Within 60 days of enactment of this Act, in collaboration with stakeholders in the Henry's Fork watershed, the Secretary shall initiate a drought management planning process to address all water uses, including irrigation and the wild trout fishery, in the Henry's Fork watershed. Within 18 months of enactment of this Act, the Secretary shall submit a report to Congress, which shall include a final drought management plan.

Reports.

SEC. 10. EFFECT.

(a) IN GENERAL.—Except as provided in this Act, nothing in this Act affects—

(1) the rights of any person; or

(2) any right in existence on the date of enactment of this Act of the Shoshone-Bannock Tribes of the Fort Hall Reservation to water based on a treaty, compact, executive order, agreement, the decision in Winters v. United States, 207 U.S. 564 (1908) (commonly known as the "Winters Doctrine"), or law.

(b) CONVEYANCES.—Any conveyance under this Act shall not affect or abrogate any provision of any contract executed by the United States or State law regarding any irrigation district's right to use water developed in the facilities conveyed.

Approved September 30, 2003.

LEGISLATIVE HISTORY—S. 520:

SENATE REPORTS: No. 108–62 (Comm. on Energy and Natural Resources).
CONGRESSIONAL RECORD, Vol. 149 (2003):
    June 16, considered and passed Senate.
    Sept. 16, considered and passed House.

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Appendix B

Effects of Island Park Reservoir Management on the Fishery Downstream

Effect of Delivery of Water from Island Park Reservoir on the Henry's Fork Fishery Downstream of Island Park Dam

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Summary

Henry's Fork of the Snake River supports world-class wild-trout fisheries worth around $30 million to the local economy. The most popular of these is the rainbow trout fishery in the 15 river miles immediately downstream of Island Park Reservoir. Hence, the fishery in this reach is most affected by management of the reservoir. Summer-time delivery of water out of Island Park Reservoir has five statistically significant effects on the fishery downstream.

1. Trout recruitment is positively dependent on winter outflow, which is lower when reservoir drawdown is higher.
2. Suspended sediment delivery into the river is highest when outflow is high and reservoir volume is low.
3. Turbidity in the river downstream of the dam is higher when reservoir volume is low and outflow is high, especially when most or all outflow is delivered through the dam gates.
4. After accounting for climatic effects, mean summer water temperature below the dam is higher in years when reservoir drawdown is higher.
5. The strongest environmental predictor of angler satisfaction on the Harriman State Park reach is summer-time flow; anglers are less satisfied when flow is high.

Because of these five effects, lower delivery of storage water from Island Park Reservoir benefits the fishery in terms of fish population size, water quality, and angler satisfaction.

Introduction

Henry’s Fork of the Snake River supports world-class trout fisheries for wild rainbow and brown trout from Henry’s Lake downstream to the Teton River confluence (Lawson 2012). These fisheries contribute around $30 million to the local economy (Loomis 2006, Grunder 2008). The most popular reach is the 15 river miles immediately downstream of Island Park Dam, the centerpiece of which is Harriman State Park, to which anglers travel from around the world to fish dry flies to large rainbow trout rising in flat water (McDaniel 2012). Recruitment of wild trout into this reach is limited by winter survival of age-1 fish, which is directly related to winter flow downstream of Island Park Dam (Gregory 2000, Mitro et al. 2003, Garren et al. 2006). In turn, winter flow is largely determined by carryover of storage in Island Park Reservoir, which stores 135,205 ac-ft of irrigation water for Fremont-Madison Irrigation District (Benjamin and Van Kirk 1999). This and other effects of Island Park Reservoir on fisheries and aquatic ecosystem function downstream have been studied for many years (e.g., Angradi and Contor 1989, Meyer 1995, Van Kirk and Gamblin 2000, Van Kirk and Martin 2000, Kuzniar et al. 2016).

However, the cumulative effects of the four-year drought that lasted from water years 2013 through 2016 generated concern on the part of anglers, guides, and outfitters that the quality of the rainbow trout fishery downstream of Island Park Dam—and particularly in the Harriman State Park reach—has declined substantially since the 1990s and even more so since the 1970s and 1980s. Specifically, anglers have voiced concerns about declining water quality and the effects of low winter flows. These concerns prompted the Henry’s Fork Foundation to establish a comprehensive water-quality monitoring program in 2014 and conduct statistical analyses of the dependence of the fishery on hydrology of Island Park Reservoir.

Purpose of this document

This document provides a summary of our most recent analyses of the relationship between Island Park Reservoir hydrology and key components of the fishery in the 15 river miles immediately downstream. The purpose of this summary is to state scientific results only—not to suggest alternative management strategies and actions or to compare the sociological, economic, and ecological values of the fishery with those of irrigated agriculture, which is supported in part by water stored in Island Park Reservoir. We are keenly aware of how management of Island Park Reservoir is determined by State water law, water-rights administration, and water policy—along with management objectives for the entire upper Snake River Basin. The locally based Henry’s Fork Drought Management Planning Committee fine-tunes management of Island Park Reservoir to benefit the fishery and hydroelectric power production to the greatest degree possible within the constraints of the larger water-rights and upper Snake system framework. Nonetheless, changes in management of Island Park Reservoir could result from need for both private and State-sponsored managed recharge system-wide, from new mitigation needs facilitated by the 2015 settlement between the Surface Water Coalition and groundwater users on the Eastern Snake Plain Aquifer, and from other new demands on water resources in the upper Snake River basin. In this context, our intent is simply to provide information on the effects of Island Park Reservoir management on the fishery downstream.

Published sources are cited for most of the scientific information in this document. The only unpublished scientific information that appears is analysis of turbidity and suspended sediment.

Specific Effects of Island Park Reservoir Management on the Fishery

Island Park Reservoir management affects five aspects of the fishery downstream:

1. trout recruitment,
2. suspended sediment delivery,
3. turbidity,
4. summer-time water temperatures, and
5. quality of angling experience.

Trout Recruitment

In 2006, Garren et al. (2006) found that mean December-February flow from Island Park Dam during a cohort's first winter was the best predictor of age-2 Rainbow Trout abundances in the reach below Island Park Dam. In 2016, we found that adding mean flow from the Buffalo River to the outflow of Island Park Dam increased the predictability of the earlier model because the combined flow better represents conditions in Box Canyon, where the majority of winter habitat for juvenile trout is found (Oldemeyer et al. 2017). However, Buffalo River flow is unregulated, so given the natural flow of the Buffalo River in a particular winter, total flow through Box Canyon is determined by outflow from Island Park Dam, which is a primarily a function of reservoir carryover from the previous irrigation season. Trout recruitment is a positive function of winter flow through Box Canyon (Figure 1), and 48% of the year-to-year variability in recruitment is explained by variability in winter flow.

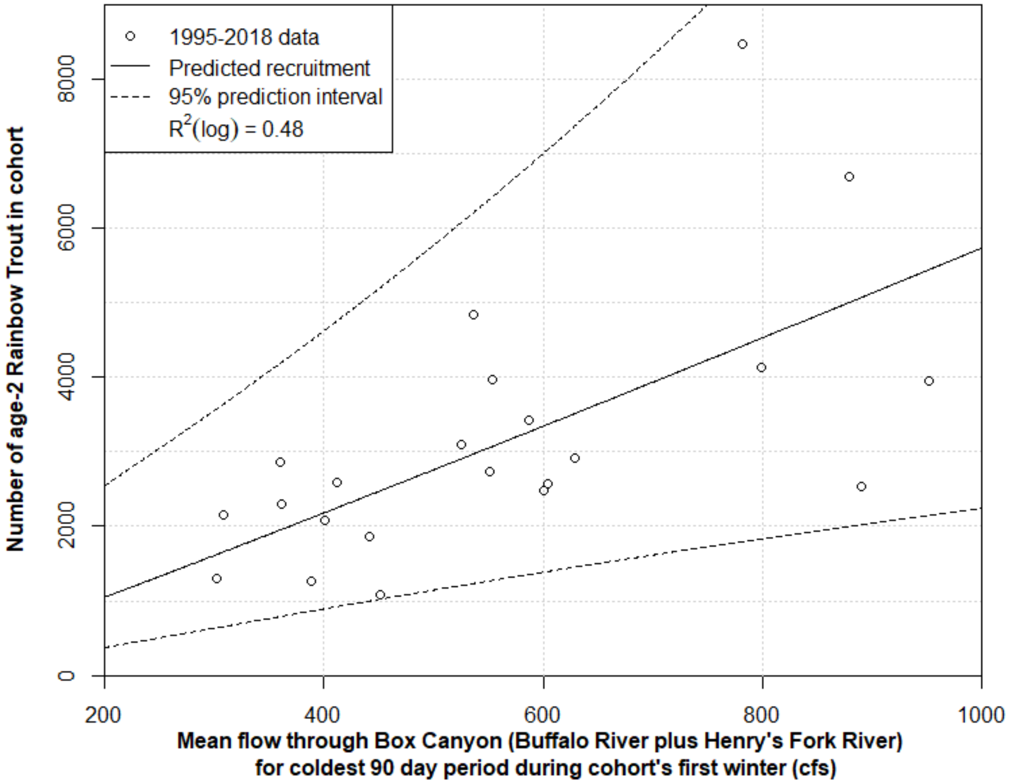

Figure 1. Dependence of trout recruitment in the population-index reach downstream of Island Park Dam on mean winter flow through Box Canyon.

Suspended sediment delivery

In excessive accumulations on the stream bottom, suspended sediment is well known to have negative effects on aquatic macroinvertebrates and trout spawning success. We began collecting suspended sediment samples from the Henry's Fork immediately downstream of Island Park Dam in August of 2013 and have continued regular sampling since then. We collect samples weekly during the summer and reduce the frequency to once every two to six weeks during the winter. Samples are analyzed at a commercial laboratory. Our statistical analysis shows that suspended sediment concentration is a decreasing function of reservoir volume and an increasing function of reservoir outflow (Figure 2; left panel). We also found that the effect of outflow on suspended sediment concentration is reduced as reservoir volume increases. In other words, suspended sediment delivery is highest during periods of high flows when reservoir content is low. These conditions occur during the late summer of years when reservoir storage delivery is high. Moderately high suspended sediment delivery occurs under two conditions: 1) when outflow is high during the spring when the reservoir is still full, and 2) when reservoir volume is low during the fall but outflow is only slightly above inflow. The lowest delivery of suspended sediment occurs when the reservoir is full or filling and outflow is relatively low. About 35% of variability in suspended sediment concentration is explained by variability in reservoir volume and outflow.

Turbidity

Although turbidity and suspended sediment are positively related (Figure 3), turbidity reflects other dissolved or suspended matter such as pigments from cyanobacteria blooms in the reservoir and decaying organic matter. Ecological effects from turbidity per se are negligible at the relatively low turbidities that occur in the Henry's Fork, but even small increases in turbidity are noticeable to anglers and have a negative effect on their fishing experience. We have measured turbidity in the Henry's Fork downstream of Island Park Dam since 2013, in conjunction with the suspended sediment samples. Using these weekly samples, the same statistical model that best explained suspended sediment concentration also explained turbidity (Figure 2; right panel). About 36% of variability in turbidity is explained by variability in reservoir volume and outflow. In particular, turbidity increases with increasing outflow and decreasing reservoir volume. Again, the effect of outflow is reduced as reservoir volume increases, so that the highest turbidity occurs when outflow is high and the reservoir is low, as in late summer of 2013 and 2016, with lower turbidity during spring runoff and during summers such as 2017 when reservoir drawdown is minimal (Figure 4).

We have also measured turbidity with continuous-recording (15-minute data) water-quality probes since 2014. We analyzed turbidity from this continuous record as a function of reservoir volume, air temperature, solar radiation, reservoir inflow and outflow, and fraction of water delivered through the bottom-withdrawal dam gates versus the power-plant siphon. The single-most important predictor of turbidity was reservoir volume. Turbidity was highest when reservoir volume was low. In addition, turbidity was higher when some fraction of water was delivered through the dam gates in addition to or instead of through the power-plant siphon. The power capacity of the power plant is 960 cfs, so when the power plant is fully operational, water is delivered through the dam gates only when total outflow from the dam exceeds 960 cfs. This is most likely to occur during periods of high irrigation demand, providing another mechanism through which high delivery of water out of the reservoir increases turbidity. When the power plant is not operating, all water is delivered through the gates. In recent years, the power plant has shut down during periods of the summer when dissolved oxygen content is low at the power-plant intake siphon, again resulting in periods of high turbidity during the fishing season.

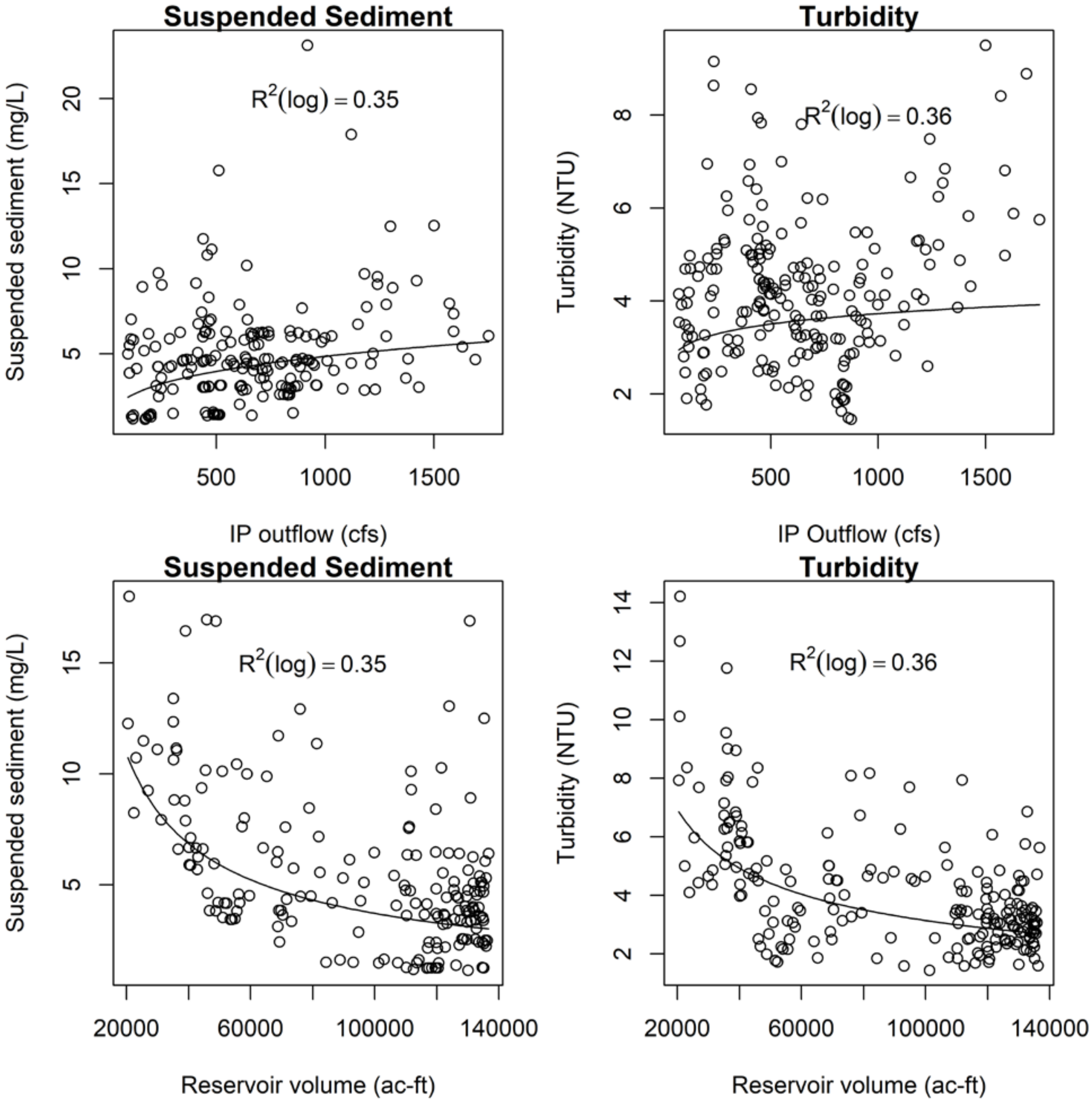

Figure 2. **Left panel**: suspended sediment concentration in the Henry's Fork downstream of Island Park Reservoir as a function of outflow (top) reservoir volume (bottom). **Right panel**: suspended sediment concentration in the Henry's Fork downstream of Island Park Reservoir as a function of outflow (top) reservoir volume (bottom). Outflow relationships are shown on data after removing the effect of volume, and volume relationships are shown on data after removing the effect of outflow.

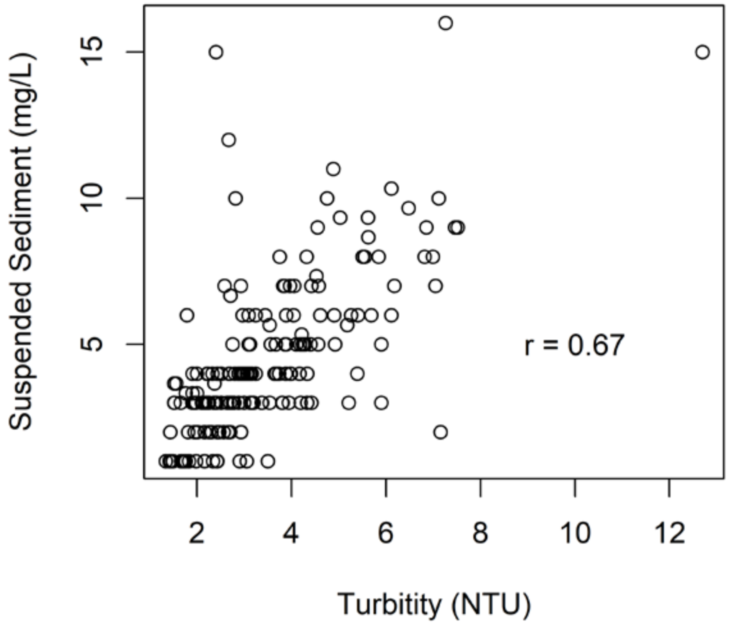

Figure 3. Relationship between suspended sediment concentration and turbidity at Island Park Dam.

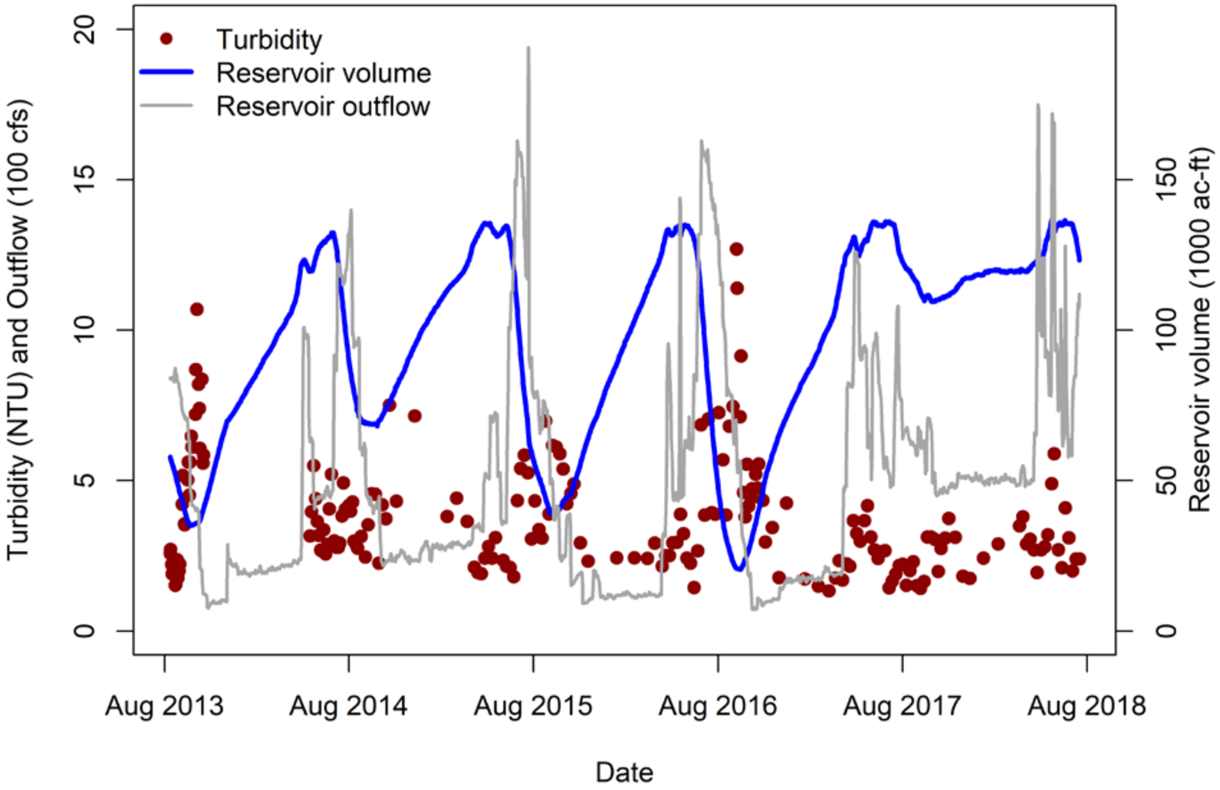

Figure 4. Time series of turbidity, Island Park Reservoir volume, and reservoir outflow from August 2013 through July 2018.

Summertime water temperature

Water temperature data for the Henry's Fork immediately downstream of Island Park Dam were collected by Fall River Rural Electric Cooperative over the period 1996-2009. We collected water temperature data in 2015 and 2017. Real-time (hourly or 15-minute) temperature data were averaged over the period from May 1 through August 31. We statistically analyzed mean water temperature as a function of solar radiation, air temperature, reservoir drawdown, and fraction of water delivered through the bottom-withdrawal dam gates versus the power-plant siphon, which is located about 30 feet up in the water column from the bottom of the reservoir (McLaren 2017). The strongest predictor was reservoir drawdown, even after accounting for the effects of solar radiation and air temperature (Figure 5). Although the correlation between reservoir drawdown and air temperature was moderately high ($r = 0.71$), indicating that higher drawdown tends to occur in warmer summers, when both air temperature and reservoir drawdown were included as predictors of water temperature, drawdown was the stronger of the two predictors. Large reservoir draft occurs when outflow greatly exceeds inflow during irrigation season, which breaks down thermal stratification in the reservoir, allowing warm surface water to be released through the dam.

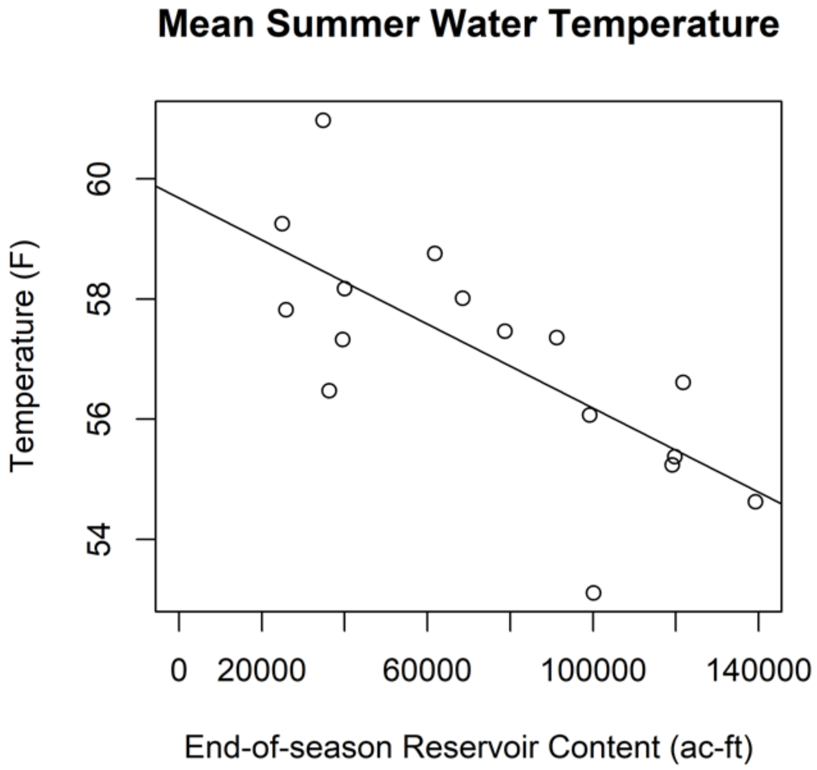

Figure 5. Mean summertime (May-August) water temperature in the Henry's Fork immediately downstream of Island Park Dam as a function of reservoir content at the end of irrigation storage delivery.

Quality of angling experience

We interviewed Harriman State Park anglers via direct, on-site surveys in 2008 and 2014, asking questions about their satisfaction with their fishing experience and about the aspects of their fishing experience they valued most. In 2016, we developed and distributed a nine-question online survey to anglers via email and social media. The electronic survey also included questions about angler satisfaction and values (Laatsch et al. 2017). We first statistically compared angler satisfaction across the three years and then correlated angler satisfaction with environmental variables. Because the observational unit for the environmental variables was year and we had only three years of data, no formal statistical inference was possible. However, we considered an environmental variable correlated with mean angler satisfaction if the rank of the environmental variable across years exactly matched (positive correlation) or was exactly opposite (negative correlation) the rank of angler satisfaction. Environmental variables used in this analysis were trout abundance, mean trout size, macrophyte cover, two indices of macroinvertebrate assemblage structure, flow out of Island Park Dam, and maximum daily temperature.

In all three years—2008, 2014, and 2016—anglers indicated that they valued more visual or aesthetic qualities (e.g., rising fish, hatches, and aesthetics) over tangible qualities like number and size of fish caught. Angler satisfaction was significantly lower in 2016 than in either 2008 or 2014 (Figure 6). The only environmental variable with the same (or opposite) rank-order as angler satisfaction was flow out of Island Park Dam from June 15 to August 15. Higher flows correlated with lower angler satisfaction (Figure 6). Anglers confirmed this in 2016 when a majority of anglers selected “high flows out of Island Park Dam” as a factor impacting fishing conditions in the Harriman reach and selected this factor twice as often as any other factor. Furthermore, in 2016, anglers were significantly less satisfied with the HSP angling experience in June and July, when flows were highest, than in other months of the year. Given that anglers report valuing aesthetic qualities more than the number or size of fish caught, we infer that lower angling satisfaction during 2016 reflects decreased aesthetic qualities of the fishing experience when flows are very high. Possible mechanisms include increased turbidity, poor hatches, and greater difficulty in wading the river.

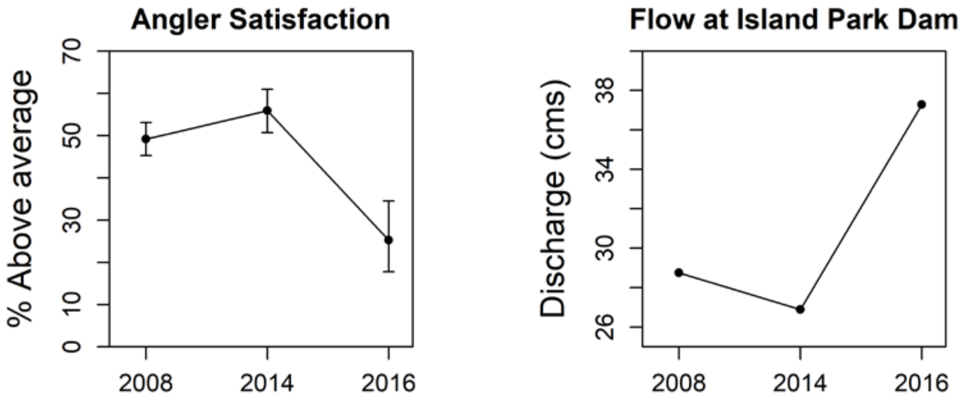

Figure 6. **Left panel**: angler satisfaction across the three survey years. Error bars indicate 95% confidence intervals. **Right panel**: mean June 15 – August 15 flow at Island Park Dam.

Conclusions

1. Trout recruitment is positively dependent on winter outflow, which is lower when reservoir drawdown is higher.
2. Suspended sediment delivery into the river is highest when outflow is high and reservoir volume is low.
3. Turbidity in the river downstream of the dam is higher when reservoir volume is low and outflow is high, especially when most or all outflow is delivered through the dam gates.
4. After accounting for climatic effects, mean summer water temperature below the dam is higher in years when reservoir drawdown is higher.
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Because of these five effects, lower delivery of storage water from Island Park Reservoir benefits the fishery in terms of fish population size, water quality, and angler satisfaction.

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Appendix C

Water-management alternatives considered in the original Drought Management Plan

Alternative 1–Pumping and pipeline system for Henry’s Lake outlet

This idea would enable water to be moved through the Henry’s Lake Outlet, only to be pumped back up through the pipe from a site below the outlet/Big Springs confluence to Henry’s Lake. This would allow Henry’s Lake to be maintained at the fullest possible storage level while simultaneously providing for a natural hydrograph in the Henry’s Lake outlet. In addition, a delivery system is needed to get excess water—that is, water above the normal volume at any given time of year—out of the outlet and to Island Park Reservoir (or a similarly stable point in the Mack’s Inn reach of the Henry’s Fork) during periods of peak irrigation demand. That delivery system could use the same pipe as the re-circulation system, or it could be an entirely separate project such as a ditch, canal, or pipe system from the outlet down to the Henry’s Fork near Mack’s Inn.

A possible solution to the problem of excess flows in the outlet could be to use overflow channels in the Henry’s Lake outlet to move above-normal flows to the Henry’s Fork. This solution does not address the need for a stabilized hydrograph outside periods of heavy irrigation demand.

A basic feasibility and cost analysis led to this alternative being rejected due to very high construction costs, maintenance costs, and the potential difficulty of acquiring land or landowner permission on which to site the infrastructure needed to make this alternative work.

Alternative 2–Construct a new storage facility on the Teton River

This would, in theory, provide sufficient flexibility to allow for less conservative management at Island Park Reservoir and Henry’s Lake. The FMID has studied the feasibility of this scenario.

The reconstruction of Teton Dam has been explored on two different occasions, once by Reclamation (1991) and once by FMID (1995). On both occasions, the idea was rejected due to the high cost, both financially and to the resource, in particular the native Yellowstone cutthroat trout fishery that would be inundated. Also, under the current water rights system the resulting storage facility would only provide water to FMID users in an estimated 30% of water years (based on historical data). For these reasons, this process rejected this alternative again.

Alternative 3–Stock trout into the Henry’s Fork below Island Park Dam to mitigate losses of juvenile trout in drought years

This alternative would artificially augment trout populations below Island Park Dam, thereby, arguably, eliminating the need for winter flows sufficient to provide over wintering habitat for juvenile trout. Some stakeholders support this idea as a management alternative to hold in reserve for use in extraordinary circumstances. The idea is opposed by other stakeholders (notably the HFF, TU, and by current IDFG policy), who argue that fisheries management should emphasize wild, self-sustaining trout populations in systems that are capable of maintaining wild populations. The IDFG's current management plan for the Henry's Fork below Island Park Dam designates the reach as a wild trout (no stocking) fishery. A stocking program would require a major revision of the Henry's Fork management program (the current plan is in force through 2006). Current IDFG managers, HFF, TU, and IDFG all note that stocking the Henry's Fork below Island Park Dam would result in considerable public outcry, given the worldwide fame of the river's wild trout fishery and the fact that it has not been stocked (intentionally) for over 25 years and even through drought cycles, the wild trout fishery remains intact.

Alternative 4–Mitigation Fund A

Create a mitigation fund to reimburse willing upper valley renters of water who lose some or all of their storage allocation. This fund would likely be crafted to address drought year—or drought cycle—realities related to operating Island Park Reservoir (and/or Henry's Lake) to provide additional fishery and ecological benefits without knowing how a specific water year is going to be; in other words, allocating flows for fishery purposes (i.e., 180-200 cfs winter base flow) and then backfilling to cover water user impacts once water year dynamics become clear during the July – October time period.

This alternative is being explored by the stakeholders. Questions that need to be answered include (but are not limited to): What would be the source for such a fund (i.e., individual donors, foundations, the federal government, etc.)? How would the fund be managed? How can storage flows be used to enhance winter base flows below Henry's Lake and Island Park Dam in light of IDWR and Reclamation Upper Snake River flow management and accounting procedures, the District One rental pool procedures, and the fact that much of the storage during drought years is owned by downstream users in the middle Snake River Basin? Who would be included as a legitimate claimant in the event of a loss of water? How frequently, according to the historical record, would a loss of water to upper valley irrigators be likely to occur? Would the fund focus on temporary or permanent transactions?

Alternative 5–Mitigation Fund B

Create a mitigation fund that deals with reducing overall irrigation demand in a manner that restores tributary flows in the Henry's Fork watershed. This fund would be a long-term mechanism to address tributary stream flow restoration issues in priority areas and could provide (a) incentives for on-farm improvements that reduce water use (projects that keep land in production but have a conserved water component that translates to stream flow and fishery benefits) and/or (b) taking land either temporarily or permanently out of production with the water use being transferred to instream fish and wildlife benefits. It could also include a federal Farm Bill ("CREP for water" as an example) type of program like that being discussed in the Mid-Snake River Groundwater negotiations. Unlike Mitigation Fund A, this fund would focus primarily on dealing with natural flow rights in high priority fishery restoration areas such as the remaining cutthroat trout spawning and rearing tributaries in the upper portion of the Teton River drainage.

This alternative is being explored by the stakeholders. Questions include many of the same issues highlighted above, including the source and management authority specifics. Further, the fund would have to be designed to dovetail with the state water supply bank and other water laws and administrative procedures to ensure that both landowner and fishery needs are addressed. The group will be cautious in pursuing either or both Mitigation Fund A and/or B because of the complexities of institutionalizing either plan and the unknown economic impacts of taking land out of production.

Alternative 6–Marysville pipeline

The Marysville pipeline is a proposal to put an existing earthen canal into a gravity pipeline to enhance water management flexibility. This alternative was not explored in any particular detail due to the same construction and maintenance costs and legal issues that led to the rejection of the Henry's Lake outlet pipeline or canal alternative.

Alternative 7–Move the confluence of the Buffalo River, or some flows from the Buffalo River, to keep the upper quarter mile of the Henry's Fork below Island Park Dam wetted during maintenance or late-fall/early-winter storage season operations

This alternative was rejected because it does not provide any significant fishery resource or water delivery benefits.

Alternative 8–Adaptive management of Island Park Dam

This alternative focuses on different approaches to moving and accounting for water out of Island Park Dam. One possible component of adaptive management includes institutionalizing last year's approach: increasing flows out of Island Park and storing the water in American Falls when there is a minimal risk that American Falls Reservoir will fill (so that FMID's proportional share on April 1 is not reduced or at risk).

This alternative is already being put into practice. In the winter of 2003-04, following a sixty day period from late October through Christmas during which flows below Island Park Dam were reduced to zero (not counting seepage) in order to allow the FMID to repair the outlet tunnel, flows were then set at 200 cfs. Although this is still lower than what historic flows would have been in this reach it represented a significant improvement over the three previous winters, in which flows had been set at 80 cfs for the duration of the winter. Those flows were also delivered in the late winter months, which studies have shown to be more critical to juvenile trout survival than the late fall and early winter months. In the current winter (2004-05), flows were set at 200 cfs for the duration of the storage season (October 1 through the start of irrigation delivery in 2005). These flows have been possible in part due to favorable circumstances (the dam closure in 2003 and a wet summer and fall in 2004 combined with low system-wide reservoir levels that necessitate the delivery of predictable amounts of water to users downstream of the Henry's Fork), but they have occurred above all because the FMID and Reclamation have been willing to take water management action outside the traditional scenario of storing all water as high in the system as possible and allowing for adaptive management of winter flows.

The winter flow regimes for 2003 and 2004 prompt a closer examination of the current management scenario as a long-term drought management strategy. How definitive are Reclamation's in-year water forecasts? Based on those forecasts, will the FMID feel comfortable enough with risk allocation to agree to move additional flows downstream of Island Park during drought years? Analysis of the historical record shows that a policy of winter flows of 200 cfs below Island Park Dam would result in a loss of water to FMID in 7-9% of years. Is it possible to manage that risk, and, if so, how do we do it? One project that could yield a very useful tool would be the development, based on the historical record, of a set of flexible, water-year based management parameters to guide the determination of flow regimes based on system-wide precipitation and reservoir levels and known downstream demand based on water rights; an integrated accounting-physical model for the upper Snake River system. Additionally, adaptive management goals and objectives could be combined with other alternatives such as the aforementioned mitigation fund to help manage the risk to irrigators caused by a more aggressive winter flow regime. Although this alternative addresses Island Park Dam it does not directly address adaptive management of flows below Henry's Lake.

Finally, questions at a watershed scale have been raised by this process, and require careful consideration. The stakeholders agree that, if possible, this process should not be limited to an examination of flows below Island Park Dam, but that it should instead address hydrologic alteration in the Henry's Fork watershed as a whole. First, stakeholders have explored, and rejected, one alternative that could have improved flow regimes in the Henry's Lake outlet (upper watershed). What other alternatives may be available or possible is a question that remains to be answered. Second, the Henry's Fork's tributaries, in particular the Teton River, are significant watersheds in their own right, and water management should be examined (insofar as water is managed in those tributaries) not only for its potential to be improved for the benefit of the Henry's Fork watershed and its users in general, but also for the sake of those individual tributaries themselves. For instance, there may be alternatives in the Upper Teton River Basin that use collaborative approaches and market-based mechanisms to ease water consumption and increase critical tributary stream flows thereby reducing the use of water exchanges in the Henry's Fork (Island Park storage water delivered via the Cross-Cut Canal to lower Teton River Valley water users).

Appendix D

Water Budget for the Henry’s Fork Watershed

Henry's Fork Watershed Water Budget

Rob Van Kirk, Humboldt State University, January 17, 2012

This document provides a brief summary of the water budget developed for the Henry's Fork Watershed as part of the USDA-funded project directed by Rob Van Kirk at Humboldt State University. Full details will be submitted for peer-reviewed publication in the future. Details of some components are explained in other accompanying documents.

Study Area

The study area is the Henry's Fork watershed, Idaho and Wyoming. Figures 1-5 depict various aspects of the watershed and summarize hydrogeologic characteristics. From a hydrologic accounting standpoint, the "bottom" of the watershed is defined to be USGS gage 13056500, Henry's Fork near Rexburg, which is downstream of all points of irrigation diversion in the watershed and all municipal wells but slightly upstream of the confluence of the Henry's Fork and the South Fork Snake River. All hydrologic calculations are applied to the basin upstream of this gage, so they exclude water in the small portion of the watershed downstream of the Rexburg gage. However, this small piece of land is irrigated primarily with water diverted from the South Fork, so excluding it has almost no effect on water budget calculations for the Henry's Fork Watershed.

Data Sources

We obtained hydrologic, basin characteristic, agricultural, water use, and other relevant data from online, government-agency databases (Table 1). Through a combination of primary field data collection, analysis of hard-copy information (e.g., annual watermaster reports from Water District 1 in Idaho Falls), and field reconnaissance via boat, ground and air, we generated new data that were used primarily to parameterize models of interaction between surface and groundwater in the watershed. Additional information came from published agency reports, technical documents, theses and dissertations, and peer-reviewed literature, which will be cited as appropriate in future, formal documents. Areas, lengths, and distances needed in the calculations were derived from Google Earth images, USGS topographic maps at 1:100,000 and 1:24,000 scales, DeLorme Topo USA© maps, and the National Hydrography Database. Measurements of linear features (e.g., canal widths, widths of canal-side vegetation strips) less than 60 feet in length were made from Google Earth images but adjusted for bias using a relationship between true and image measurements calibrated to a random sample of paired image-field measurements we made on canals in the watershed.

Time Frame

Our water budget was developed for water years 1979-2008, and reported mean figures are averaged temporally over this time frame. To the greatest extent possible, we derived estimates through analysis of daily hydrologic data over this 30-year time period. With the exception of relatively short periods of missing data, daily data were available for precipitation, evapotranspiration, stream flow, reservoir contents, and irrigation diversion. The latter data were available on a daily basis for all canal systems and most pumps diverting from the Henry's Fork, Fall River, and the Teton River downstream of Bitch

Creek. Missing data in these daily data sets were generated with temporal and/or spatial interpolation and time series regression models. Diversion data for the Teton River basin upstream of Bitch Creek (Teton Valley) were available only on a weekly or monthly basis and not during all years in the time frame. Daily diversion time series for each major Teton Valley tributary were estimated using a combination of interpolation and regression analysis of diversion rates based on supply. Daily time series of stream flow in the major Teton Range tributaries upstream of Bitch Creek were synthesized using a time series models Maintenance of Variance Extension relating flow in these tributaries to that of Pacific Creek, a tributary to the upper Snake River. Other data reported on annual or an even less frequent basis were obtained for as many years of the 1979-2008 period as possible and either averaged or interpolated, as appropriate, to obtain values compatible with the daily hydrologic data.

Models and Methods

Our conceptual models are based on detailed statistical analysis of the hydrologic data, personal communication with water managers and irrigators, personal familiarity with the watershed, and published information on hydrogeology of this and other watersheds in the intermountain region.

Water Supply

Total supply is basin area multiplied by annual precipitation, but most growing-season precipitation is lost to evapotranspiration (ET). Therefore, snowpack provides the majority of the water supply that enters the surface and groundwater systems. We assume that all November-April precipitation is accumulated in the snowpack at higher elevations (above 6200 feet) and that all November-March precipitation is accumulated in the snowpack at lower elevations. In the Henry's Fork headwaters and over much of the Fall River headwaters, most snowmelt recharges large, deep aquifers hosted in silicic volcanics and appears, greatly attenuated, as surface flow in headwater springs, including Big Springs, Buffalo River Springs, Warm River springs and many smaller ones that contribute to a large and stable base flow in the Henry's Fork and a somewhat smaller but still relatively stable base flow in Fall River. Almost all snowmelt in the Teton River basin is contributed to streams via surface flow. We define the "usable" water supply as all surface flow that reaches the lower elevations of the watershed and water that enters shallow aquifers at those lower elevations (Figure 6). These aquifers are generally hosted in relatively high-permeability surficial deposits of alluvium, basalt with interbedded sediments, loess, and glacial drift. We assume that water recharged to deep aquifers in mountainous areas does not contribute to this supply. Thus, we define total surface supply to consist of: 1) unregulated stream flow in the Henry's Fork at Ashton, Fall River at Chester, and Teton River near St. Anthony; 2) unregulated stream flow in Snow Creek, Sand Creek, and Moody Creek (the only perennial streams that flow into the surface system downstream of these three gages), and 3) direct precipitation on the low-elevation, shallow aquifers that is not already accounted for in the surface system. Unregulated flow at the three major-river gage locations was calculated by adding to regulated flow: 1) upstream net diversion (diversion minus return flow), 2) change in reservoir storage, and 3) reservoir evaporation. Where necessary, differences were smoothed with moving averages, and upstream contributions were lagged to account for travel time. Irrigation returns via groundwater are minor upstream of these three gages except the Teton River near St. Anthony, so a groundwater-surface water model of irrigation diversion, groundwater recharge, and return flow was used to generate unregulated flow estimates at that gage.

Irrigation System

We applied a detailed model of flow through the surface irrigation system in the four major regions of the watershed irrigated by canals (Figure 7). We first estimated the "nominal" area of each major branch of each of the canal systems in the four regions. This nominal area is the branch length multiplied by the width of the water surface in the canal when it is full, as estimated from Google Earth images taken during the middle of irrigation season. We then used our own measurements of canal geometry to compute actual wetted area of the canal as a function of the nominal area. In the case of Teton Valley canals, the nominal width was taken to be the wetted width. In the other three regions, we used a trapezoidal model of canal geometry based on our field measurements of canal cross sections and stage-discharge curves for these canals and derived a formula expressing wetted area as a function of canal discharge. However, additional analysis showed that the nominal area was a sufficiently good estimate of actual wetted area based on canal geometry, so in computational models, we use the latter for simplicity. We then applied our field-measured mean loss rates of 2.7 ft/day for canals in the Henry's Fork, Fall River and lower Teton areas and 3.6 ft/day for canals in Teton Valley to these canal areas to estimate total daily loss from each canal branch, up to the amount diverted. Loss was apportioned, in sequence, to canal-surface evaporation, uptake by vegetation along the canal banks, and groundwater recharge. In canal systems with surface return to either a stream or another canal system, we assumed that diversion is sufficient to result in a "full" canal system prior to irrigation delivery, where we define "full" as sufficient flow to exceed loss and surface return. All diversion beyond loss and surface return was assumed to be delivered to fields, where it is then applied using some combination of surface and sprinkler irrigation methods. Based on an extensive literature review, we assumed a 2% evaporative loss from sprinkler application. Because the majority of conversion from surface to sprinkler irrigation methods occurred during our analysis time frame, we developed and applied a model of temporal conversion from surface to sprinkler irrigation.

At the scale of the four major irrigated regions, we estimated the typical mix of crops grown in that region and then estimated the total area of each region devoted to agricultural production (gross area minus area of obvious non-agricultural areas such as water, gravel pits, towns and cities, etc.). We then calculated net crop ET demand for each day by multiplying the agricultural production area by actual demand minus precipitation (from ET Idaho). This provides a good estimate of daily volumetric crop ET demand on Egin Bench and the lower watershed (Figure 7), where almost all land devoted to agricultural production can be and is fully irrigated every season. In the North Fremont and Teton Valley areas, more junior water rights and limited supply preclude full irrigation of every parcel of agricultural land every season. Growing-season precipitation, crop rotations with fallow ground, partial-season irrigation of pasture and hay, and soil moisture retention (in the North Fremont area) all contribute to agricultural production in these areas without full irrigation. Our volumetric estimate of crop ET demand in these areas is based on the full potential of irrigated crop demand across the entire area every season and hence overestimates crop demand as it actually exists on the ground. Daily irrigation application in excess of our estimated net crop demand is assumed to recharge groundwater. In the shallow, permable soils of Egin Bench, most of the lower watershed, and Teton Valley, this is probably a reasonable assumption. In some of the lower watershed area and in much of the North Fremont area, some of this seepage is probably stored in the soil and subsequently contributes to crop ET. We also calculated the amount of daily crop demand met by daily growing-season precipitation.

Throughout most of the remaining surface-irrigated regions of the watershed, conveyance occurs in pipelines, so we assumed no return flow and no groundwater seepage. We estimated diversion in those regions based on supply, and assumed that delivery never exceeded crop demand. A few small canal systems are still used in Teton Valley west of the river, in the Conant Creek area, and in the North Fremont area west of the Henry's Fork. We extrapolated results from the canal system we modeled in detail to these small systems to estimate irrigation budgets there.

Groundwater – Surface Water Interactions

We assume three sources of recharge to the low-elevation, shallow aquifers (Figure 6): 1) direct precipitation, 2) irrigation seepage (canal seepage plus application in excess of crop demand), and 3) stream channel seepage. Based on analysis of unregulated base flow at gaged locations on Fall River and the upper Henry's Fork, we estimate that 75% of accumulated snowpack recharges aquifers and so assumed that 75% of November-March precipitation on the regions depicted in Figure 6 recharges shallow aquifers. Irrigation seepage was calculated from the model described above. In Teton Valley, a groundwater-surface water model was used to estimate recharge from stream channels. We assume that substantial interactions between groundwater and stream channels occur elsewhere in the watershed only in the Henry's Fork downstream of the Ashton gage and in the Teton River downstream of the St. Anthony gage. Recharge from stream channel seepage in these reaches was calculated directly from reach loss/gains between gages, after accounting for irrigation diversion and irrigation surface return flow. We assumed that all daily reach losses (negative gain) in these reaches represented seepage from the stream channel to the aquifer. However, we assumed that net gains over the entire water year (sum of all gains/losses) represented return of irrigation water to the surface system via groundwater pathways. The inclusion of the daily losses in this calculation is done to compensate for a small amount of gain attributable to surface runoff during snowmelt and to a few spring-fed streams that contribute some water recharged by sources other than irrigation. This model also assumes that generally, under "natural" conditions, these reaches of river would lose water to the aquifer almost all year and hence that any net gains are attributable to irrigation return. We assumed that water in the surface-shallow groundwater supply in excess of that accounted for by consumptive use and surface outflow from the basin at the Rexburg gage exits the basin as groundwater flow. The two major flow pathways are west from Egin Bench into the regional Eastern Snake Plain Aquifer and southward, parallel to the river, towards the Rigby Fan, an alluvial deposit associated with the main (South Fork) Snake River.

Groundwater and non-agricultural use

We obtained estimates of withdrawal for domestic, commercial and industrial use and for groundwater irrigation from the USGS water use database. Although it is well known that very little culinary, bathing and washing water is consumptively used, we assumed that all water withdrawn for non-agricultural uses is consumptively used. This is based on analysis of water use in a sample of residences in Rexburg, St. Anthony, and Driggs, which showed that the majority of water withdrawn for residential use was withdrawn during the growing season, and the amount withdrawn per unit area was statistically equal to the net ET demand for turf grass (lawn) over the growing season. Thus, we assumed that the majority of non-agricultural withdrawal occurs in the summer and is used consumptively for watering lawns and landscaping. We also assumed that all groundwater withdrawn for agricultural irrigation was consumptively used, and we assumed that only 10% of this was withdrawn from shallow aquifers.

Results and Discussion

Water Supply

Annual surface water supply averaged 2.6 million acre-feet; 48% was supplied by the mainstem Henry's Fork, 27% by Fall River, and 25% by the Teton River (Table 2). Because of the large (natural) groundwater contribution to the Henry's Fork headwaters, the Henry's Fork supply is most constant across within years (Figures 8 and 9). Supply in the Teton River varies greatly across years (Figure 8), and the vast majority is contributed between mid-May and mid-July (Figure 9). Interannual and intrannual variability in Fall River flow are intermediate to those in the Henry's Fork and the Teton River, reflecting a combination of groundwater sources from the southern part of the Yellowstone Plateau and runoff sources from the northern end of the Teton Range. Although total surface water supply shows clear decadal-scale oscillations, no trend is apparent in the 30-year time series (Figure 8). An additional 206,476 acre-feet not already included in the surface supply is contributed to the shallow groundwater system by direct precipitation, resulting in a total surface/shallow groundwater supply of 2,809,912 acre-feet (Tab;e 2). Mean annual contribution from direct snowmelt ranged from 3.9 inches in the Rexburg area to 6.5 inches east of Ashton.

Surface Irrigation System

The four primary surface-irrigated regions encompass 194,000 acres, which are served by 490 miles of delivery canals that divert 1.14 million acre-feet per year (Tables 3 and 4). Another 61,000 acres is irrigated by surface water in other areas of the watershed; diversions in those areas total about 26,000 acre-feet per year. Together, these areas essentially comprise the 255,000 acres in the Fremont-Madison Irrigation District. A small amount of surface-supplied pasture irrigation occurs in Island Park that is not included in these figures. By comparison, irrigation water rights (surface and ground combined) exist on over 450,000 acres in the watershed. Over all of the surface-irrigated areas combined, 70% of the water diverted into the surface irrigation system seeps into the shallow aquifer; 21% of the total amount withdrawn returns to stream channels within the watershed, and 49% exits the basin via groundwater flow (Figure 10). About 25% of the total amount withdrawn for irrigation is consumed by crop ET and evaporative losses. Although total diversion in the four main irrigated areas varies from year to year based on supply, it has decreased steadily over the last 30 years, declining about 20% since the early 1980s (Figure 11). Accordingly, both canal seepage and irrigation application seepage have declined since 1979. Application in excess of crop ET demand is highest early in the irrigation season, when natural flow rights are in priority, and lowest late in the irrigation season, when most diversion in the watershed is accounted to storage in most years (Figure 11). Except during a short period in July when crop demand is highest, the surface irrigation system water budget is dominated by canal seepage. Less than 1% of the water withdrawn for irrigation is lost to evaporation (canal evaporation, canal-side vegetation ET, and sprinkler evaporation; Tables 3 and 4, Figure 11). Surface return is also a small component of the water budget, and the vast majority of this is water diverted from the Henry's Fork that is delivered through the Crosscut Canal to the Teton River. During the winter, when diversion is used only for stock watering and aquifer recharge, almost all water diverted recharges shallow aquifers through canal seepage.

Temporal patterns in the irrigation water budget show substantial differences across the four irrigated regions. Diversion in Teton Valley is very closely tied to water supply in the upper Teton watershed, so year-to-year variability in diversion there is much larger than any temporal trend (Figure 12). Because Fall River has a more reliable water supply than the upper Teton River, diversions in the North Fremont area show somewhat less variability from year to year, but during the driest years, the low priority of water rights in the North Fremont system limits diversion rates (Figure 13). In both Teton Valley and North Fremont, application exceeds crop demand by substantial amounts only during the wettest years and only during June and July. By contrast, more senior water rights, abundant supplies, availability of storage, and delivery of water through the Crosscut Canal into the supply-limited lower Teton River allow relatively consistent diversion rates from year to year in Egin Bench and the Lower Watershed (Figures 14-15). The 30-year trend toward decreased diversion rates in these two areas outweighs year-to-year variability. Canal seepage is the single largest component of the water budget on Egin Bench. In both areas, application seepage is highest early in the season and lowest late in the irrigation season. Almost all irrigation surface return in the Lower Watershed is water diverted from the Henry's Fork and delivered through the Crosscut canal to the lower Teton River.

Despite substantial year-to-year variability in water supply, theoretical crop ET demand is relatively constant across years (Figure 16). On a watershed-scale, crop demand is generally met early in the season by a combination of precipitation and irrigation application, but between mid-June and mid-August, delivery is not sufficient to meet theoretical demand across the entire 194,000 acres that could be irrigated in the four primary irrigated regions. Deficits were greatest in dry years such as 1988, 1992, 1994, and 2001 (Figure 16). Growing-season precipitation meets about 12% of crop demand (Table 3). The fraction of theoretical crop demand that is not met by a combination of precipitation and irrigation ranges from less than 1% on Egin Bench to over 65% in North Fremont (Table 3). As discussed above, the apparent large crop ET deficits in Teton Valley (Figure 17) and North Fremont (Figure 18) are due at least in part to our inclusion of all potential surface-irrigated crop lands in the crop demand calculation on every day of every water year. In reality, only a fraction of these lands are irrigated fully each year. Furthermore, particularly in North Fremont, deeper, finer soils store both snowmelt and irrigation water during the spring and early summer, and this storage contributes to crop ET. Thus, some of the apparent deficit is actually met by a combination of precipitation and irrigated via storage in the soil. Crop ET deficit is essentially zero on Egin Bench (Figure 19) but can be substantial in the Lower Watershed in some years (Figure 20), despite a mean period-of-record deficit of less than 3%. Crop ET deficits there occur during dry years, although they have become larger and more frequent since 2000, occurring after the mid-July peak in Teton River supply (Figure 20).

Groundwater-Surface Water Interactions

Total recharge to the lower-elevation shallow aquifers in the watershed (Figure 6) averages 1.2 million acre-feet per year (Figure 21). Two-thirds of this recharge is supplied by irrigation seepage, one-quarter by direct snowmelt, and about 9% by stream channel seepage. Net stream reach gains in the lower

Henry's Fork and Teton rivers have declined substantially over the past 30 years (Figure 22) and by about the same amount (200,000 acre-feet) as total diversion has decreased (Figure 11). The decreasing trend is much more apparent in the Henry's Fork downstream of St. Anthony and in the lower Teton River than in the Henry's Fork between Ashton and St. Anthony. On average, reach gains in the Ashton-St. Anthony reach are fairly uniformly distributed throughout the year, whereas reach gains downstream of St. Anthony mirror diversion into the canal system (Figure 23). Future statistical analysis and modeling will elucidate empirical and mechanistic relationships between irrigation seepage and stream reach gains more rigorously.

Water Use

Although 1.2 million acre-feet (43%) of the total supply of water in the surface and shallow groundwater system is withdrawn for various uses, only about 12% of the supply is consumptively used (Figure 24). Over 95% of the consumptive use is related to irrigated agriculture; about 297,000 acre-feet is consumed by crop ET, and another 23,000 acre-feet is lost to reservoir, canal and sprinkler evaporation. Total domestic/commercial/industrial use averages about 15,000 acre-feet per year, about 0.5% of the total supply in the surface and shallow groundwater system. Groundwater pumping supplies all of the domestic/commercial/industrial use, and almost all of this is withdrawn from shallow aquifers. We estimate that 10% of the groundwater pumped for irrigation is withdrawn from these shallow aquifers; the remaining amount, about 168,000 acre-feet per year, is pumped from deeper aquifers (Table 5). About 53% of the total annual precipitation that falls on the watershed (4.9 million acre-feet) is realized as surface stream flow (Table 5). About 1.8 million acre-feet of the total watershed supply (37%) cannot be accounted for by recharge to the shallow aquifer system, withdrawal or crop ET. Much of this is lost to ET on forest, range, sagebrush steppe, and non-irrigated agricultural lands (e.g., seasonal pasture) during the growing season; the remainder recharges deep aquifers. About one-quarter of the surface supply cannot be accounted for by irrigation use or surface flow out of the basin and is thus assumed to flow out of the basin as groundwater (Table 5). Because our model does not account for soil moisture retention, some of this presumed outflow as groundwater is stored in soil moisture and ultimately consumed by crops, so our budget probably underestimates crop ET and overestimates basin outflow via groundwater.

Conclusions

Snowpack in the Henry's Fork watershed contributes an average of 2.8 million acre-feet of water to the upper Snake River system, about 25% of the total supply originating in the Snake River basin upstream of King Hill. Less than 12% of the surface and shallow groundwater supply is consumptively used within the Henry's Fork watershed; the remainder exits the basin as surface and groundwater flow, supplying water to various uses downstream. Only one-quarter of the water withdrawn for irrigation in the watershed is consumptively used; roughly half of the total irrigation withdrawal contributes to basin outflow as groundwater, providing a major source of recharge to the regional Eastern Snake Plain Aquifer system. Thus, the Henry's Fork watershed functions primarily as a headwater source of water for downstream uses rather than as a major area of consumptive use. Canal seepage rates in the watershed range from 2 to 3.5 feet/day, whereas evapotranspiration averages about 2 to 2.5 feet per year. Thus, water diverted into irrigation canals and applied to fields in excess of crop demand seeps into the ground at rates about 2.5 orders of magnitude faster than it can be lost to evapotranspiration. These high seepage rates limit the amount of diverted water that can be consumptively used, at least as long as the 19th-century earthen canal system in the watershed continues to be the primary conveyance mechanism for surface water diverted into the irrigation system.

Table 1. Primary sources of data.

Data type(s)	Source	URL or Reference
Stream flow and related (e.g., stage-dishcarge)	USGS Surface Water database	http://water.usgs.gov/osw/
Water use (primarily GW and non-ag use)	USGS Water Use database	http://water.usgs.gov/watuse/
Irrigation diversion and related water rights	IDWR WD1 Accounting	http://www.idwr.idaho.gov/GeographicInfo/accounting.htm
Reservoir contents and related	USBR Hydromet	http://www.usbr.gov/pn/hydromet
Climate data	Western Regional Climate Center	http://www.wrcc.dri.edu/
Evapotranspiration and crop growing season	ET Idaho	http://www.kimberly.uidaho.edu/ETIdaho/
Basin characteristics (e.g., area, slope, land use)	USGS Streamstats	http://water.usgs.gov/osw/streamstats/
Crop types, distribution, acreages, yields	USDA National Ag. Stats. Serv.	http://www.nass.usda.gov/

Table 2. Surface supply.

Source	30-year mean annual natural flow (a-f)	% of TOTAL
Henry's Lake	41,768	1.6%
HL to Island Park	439,072	16.9%
Island Park to Ashton	744,516	28.6%
UPPER HF TOTAL	1,225,356	47.1%
Sand Cr. + Snow Cr.	18,320	0.7%
MAIN HF TOTAL	**1,243,676**	**47.8%**
FALL RIVER TOTAL	**699,914**	**26.9%**
Teton ab. S. Leigh	298,458	11.5%
Teton S. Leigh to St. Anth.	346,009	13.3%
Moody Creek	15,379	0.6%
TETON RIVER TOTAL	**659,846**	**25.3%**
TOTAL	2,603,436	100.0%

Table 3. Mean annual water budget for the four main canal-served regions (all volumes are in acre-feet).

	Teton Valley		North Fremont		Egin Bench		Lower Watershed		Watershed Total	
	Volume (a-f)	% of Diversion	Volume (a-f)	% of Diversion	Volume (a-f)	% of Diversion	Volume (a-f)	% of Diversion	Volume (a-f)	% of Diversion
Diversion	92,290	100.0%	41,681	100.0%	368,351	100.0%	641,723	100.0%	1,144,045	100.0%
Surface Return	(3,501)	-3.8%	(575)	-1.4%	(11,588)	-3.1%	(53,007)	-8.3%	(68,670)	-6.0%
Canal Evaporation	(204)	-0.2%	(102)	-0.2%	(661)	-0.2%	(791)	-0.1%	(1,759)	-0.2%
Canal Vegetation ET	(219)	-0.2%	(158)	-0.4%	(637)	-0.2%	(915)	-0.1%	(1,928)	-0.2%
Canal Seepage	(43,051)	-46.6%	(22,578)	-54.2%	(176,232)	-47.8%	(218,322)	-34.0%	(460,183)	-40.2%
Delivery	45,261	59.2%	18,268	43.8%	179,235	48.7%	368,689	57.5%	611,505	53.4%
Sprinkler Evaporation	(640)	-0.7%	(250)	-0.6%	(2,201)	-0.6%	(4,898)	-0.8%	(7,990)	-0.7%
Application Seepage	(8,025)	-8.7%	(1,466)	-3.5%	(115,878)	-31.5%	(221,218)	-34.5%	(346,587)	-30.3%
Application Applied to Crop ET	(36,650)	-39.7%	(16,552)	-39.7%	(61,156)	-16.6%	(142,573)	-22.2%	(256,931)	-22.4%
	Volume (a-f)	% of Demand	Volume (a-f)	% of Demand	Volume (a-f)	% of Demand	Volume (a-f)	% of Demand	Volume (a-f)	% of Demand
Theoretical Crop Demand	124,701	100.0%	74,999	100.0%	69,846	100.0%	167,673	100.0%	437,219	100.0%
Crop ET met by Precipitation	16,249	13.0%	9,114	12.2%	8,162	11.7%	20,511	12.2%	54,036	12.4%
Crop ET met by Irrigation	36,650	29.3%	16,552	22.1%	61,156	87.6%	142,573	85.0%	256,931	58.8%
Deficit or Crop ET met by other sources	71,802	57.6%	49,333	65.8%	528	0.8%	4,590	2.7%	126,253	28.9%

Table 4. Summary of all irrigated regions. All volumes are in acre-feet.

Region	Area (ac)	Canal L (mi)	Diversion	Surf Return	Evap loss	Canal Seep	App Seep	Demand	Crop ET: Irrig.	Crop ET: precip.
Four above	194,000	490	1,144,045	68,670	11,691	460,183	346,587	437,219	256,931	54,036
NF W of HF[1]	4,000	3	2,000	60	20	530	0	9,000	1,390	1000
Sq/Conant[2]	25,000	14	7,000	0	70	3,000	0	56,250	3,930	6250
TV West[3]	25,000	5	7,000	210	70	795	0	56,250	5,925	6250
Teton Cyn[4]	7,000	0	10,000	0	100	0	0	15,750	9,900	1750
TOTAL	255,000	512	1,170,045	68,940	11,951	464,508	346,587	574,469	278,076	69,286

1=North Fremont west of the Henry's Fork; diversions from Snow and Sand creeks. 2=North Fremont south of Fall River; diversions from Squirrel and Conant creeks (almost all in pipelines now). 3 = Teton Valley west of the Teton River; diversions from Horseshoe, Packsaddle, Mahogany and other small creeks. 4 = Teton Canyon rim; diversions from Teton River (pumped up out of the canyon, all in pipelines).

Table 5. Mean annual water budget for the Henry's Fork watershed.

Component	Volume (acre-ft)
Precipitation (total supply)	4,880,480
Recharge to Shallow GW not in surface supply	(206,476)
Crop ET supplied by direct precipitation	(89,926)
Crop ET supplied by GW pumping	(186,800)
Domestic, Commercial, Industrial use	(14,766)
Other ET and deep GW recharge from precipitation	(1,779,076)
Surface Supply	2,603,436
Reservoir, canal and sprinkler evaporation	(22,929)
Surface-Irrigated Crop ET	(278,076)
Surface outflow from basin	(1,666,326)
Outflow of shallow GW from basin	(636,105)
BALANCE	0

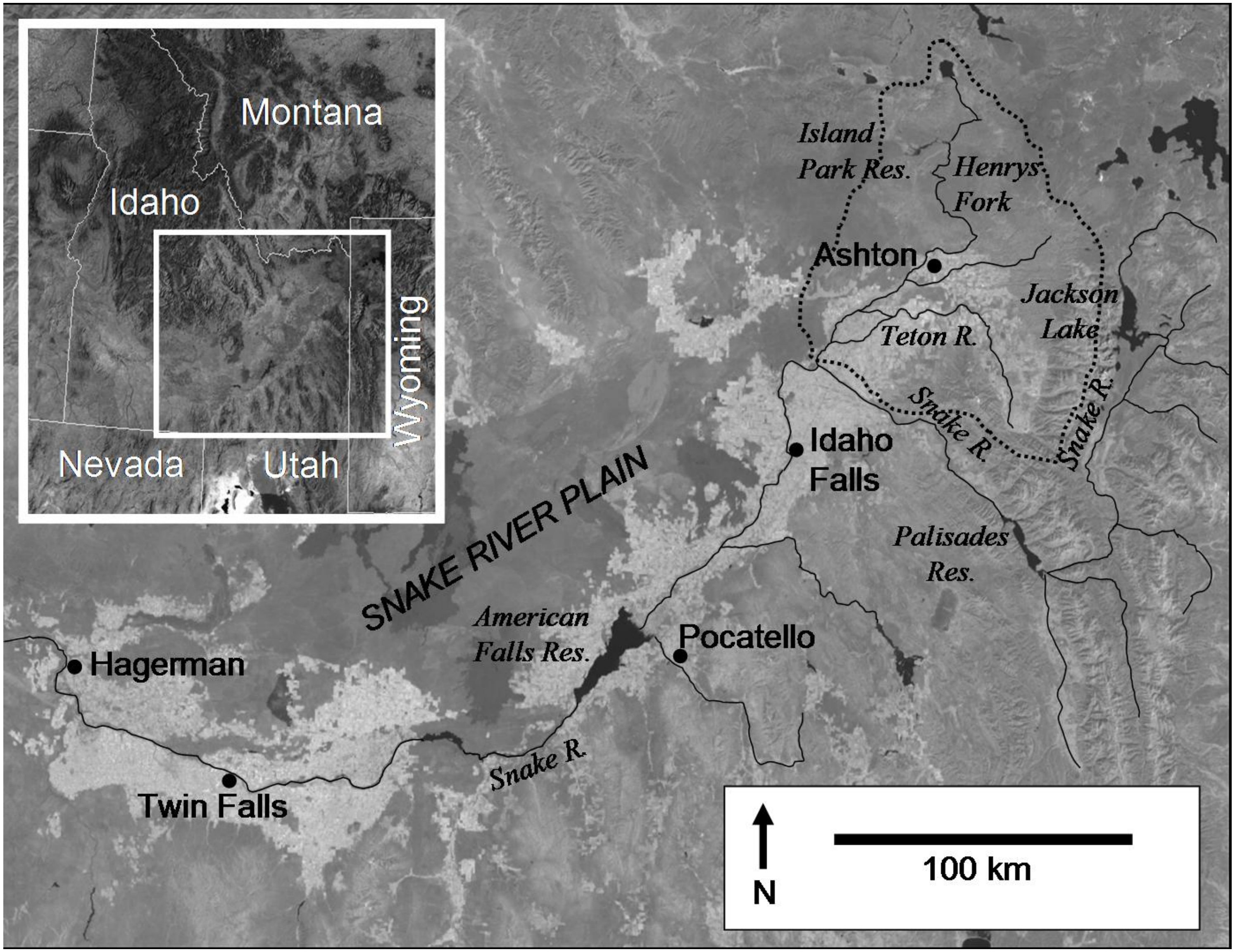
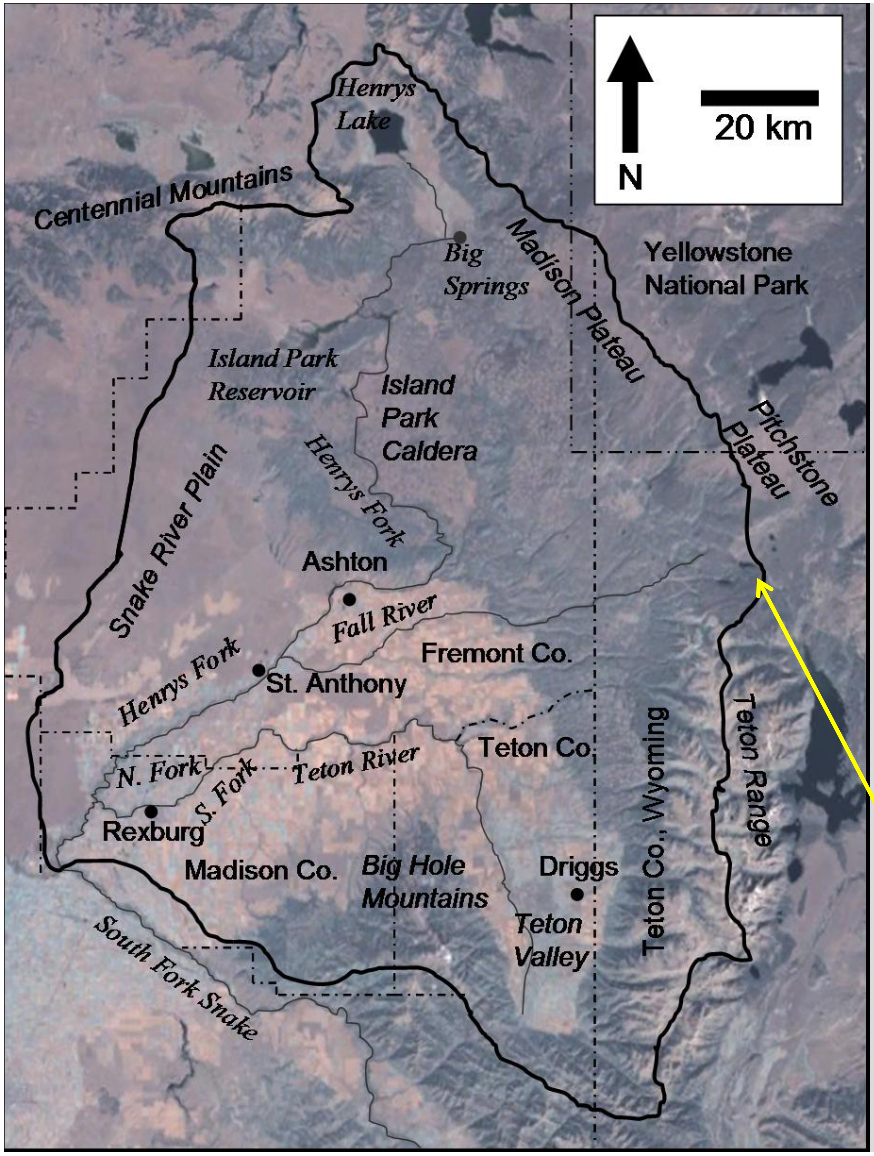


Figure 1. Location of Henry's Fork watershed within the upper Snake River basin.



- •Area: 3,250 sq. mi
- •Mean ann. precip.: 28.2 inches
- •Min. elevation: 4,820 ft.
- •Max. elevation: 11,400 ft.
- •Forested area: 36.7%
- •Agricultural land: 20.9%
- •Water & perennial snow: 1.89%
- •Urban land cover: 1.5%

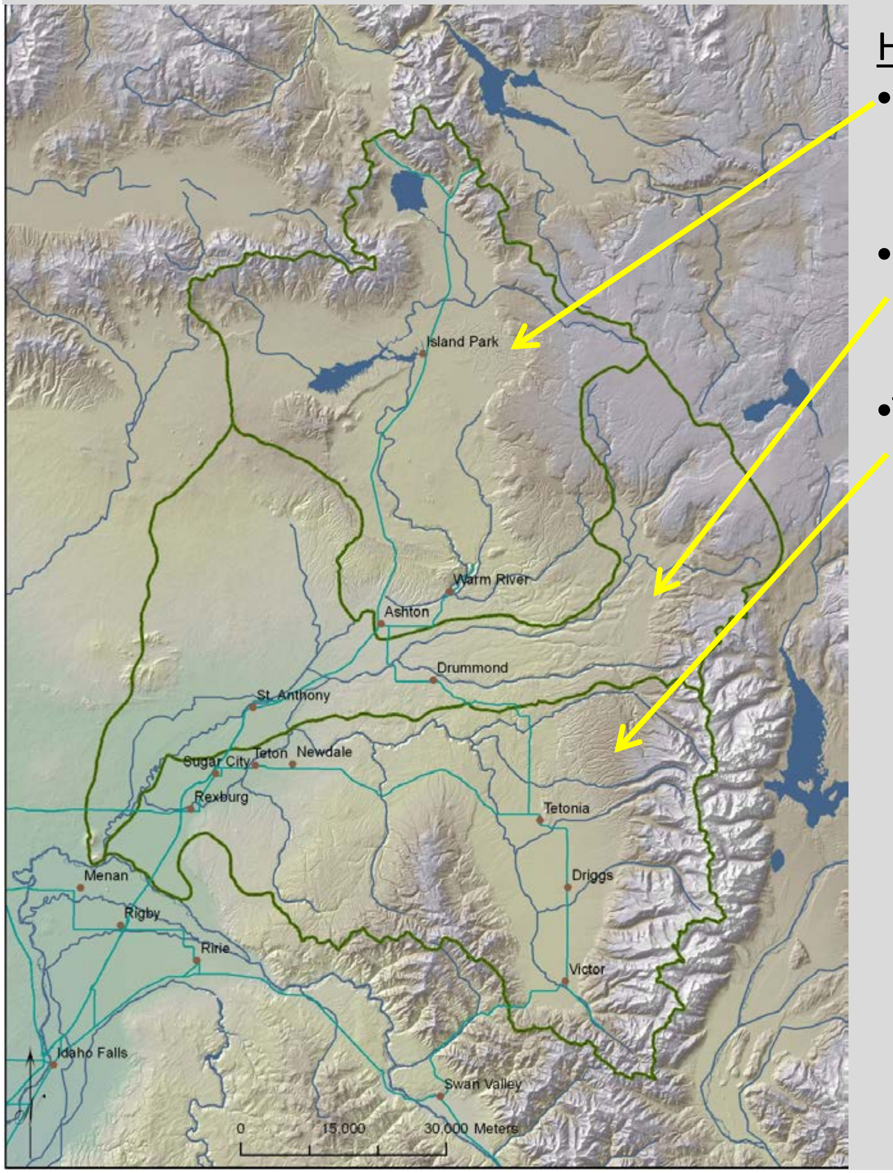
Source: StreamStats
http://streamstats.usgs.gov

Storage Reservoirs

- •Henrys Lake*: 90,000 a-f
- •Island Park Res.: 135,000 a-f
- •Grassy Lake: 15,000 a-f

*Original, natural lake held about 25,000 a-f

Figure 2. Watershed map and basin characteristics.

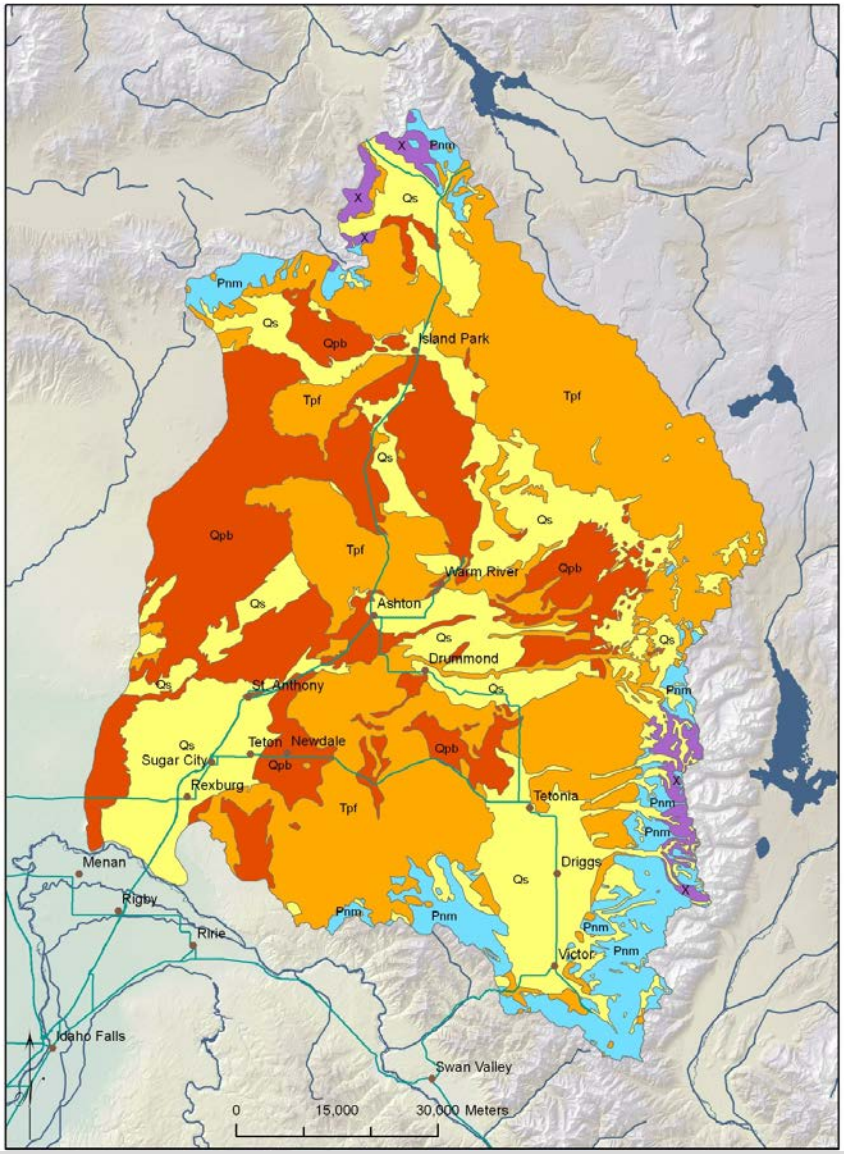


Hydrologic Units

- Upper Henrys 17040202
  - HF above Ashton
- Lower Henrys 17040203
  - Fall River and lower HF
- Teton 17040204
  - Teton River watershed

Map produced by Digital Mapping Laboratory, Dept. of Geosciences, Idaho State University

Figure 3. USGS hydrologic accounting units in the Henry's Fork watershed.



Surface lithology

🟪 Precambrian

🟦 Paleozoic and Mesozoic sedimentary

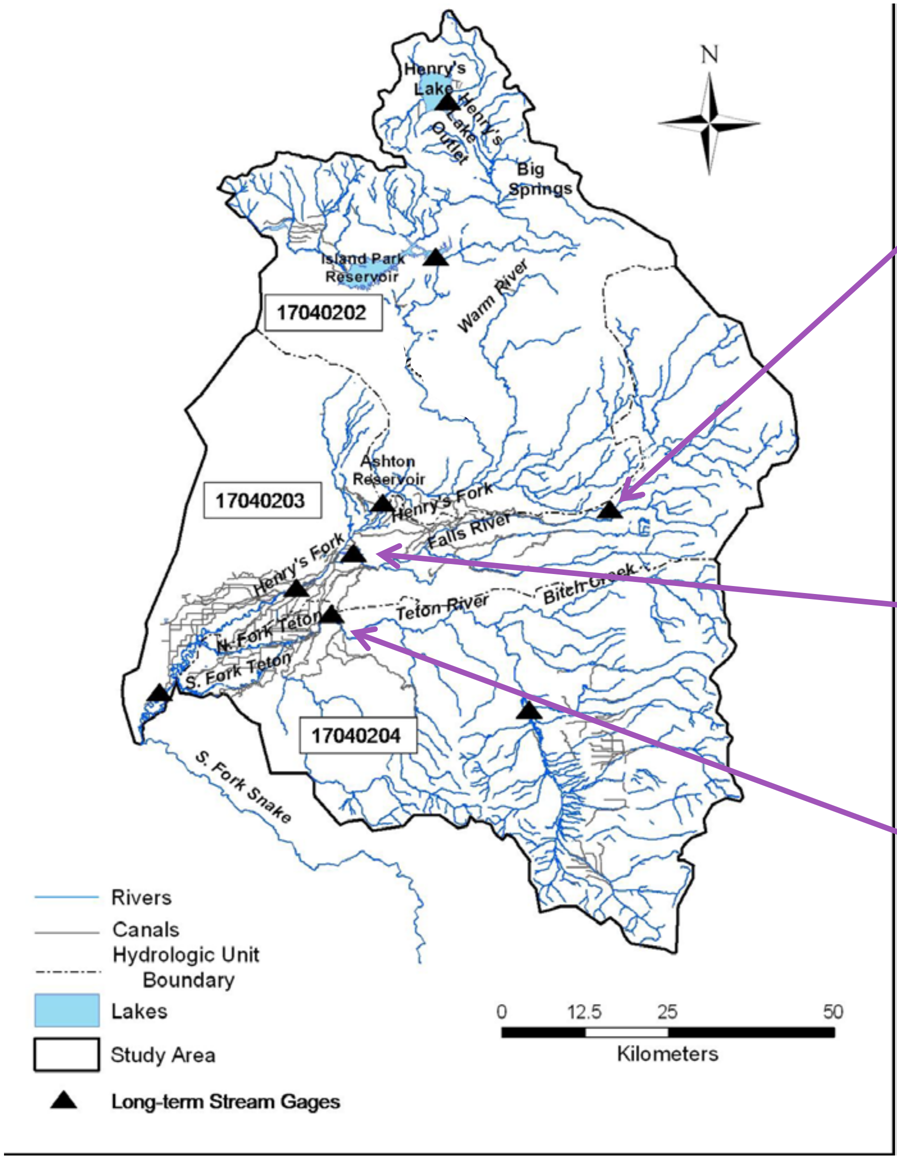
🟧 Cenozoic silicic volcanics from Yellowstone hotspot explosive eruptions

🟥 Quaternary basalts

🟨 Quaternary alluvium and glacial drift

Source: Bayrd 2006 M.S. Thesis, Idaho State University

Figure 4. Surface lithology of the Henry's Fork watershed.



Long-term USGS Flow Gages

- -Henrys Fk. nr. Lake 13039500
- -HF nr. Island Park 13042500
- -HF nr. Ashton 13046000
- -Falls River nr. Squirrel 13047500
  (between Marysville hydroelectric diversion and return since August 1993; two new gages added in WY 1994; USE CAUTION with FR flow and IDWR accounting!)
- -Falls R. nr. Chester 13049500
- -HF at St. Anthony 13050500
- -Teton R ab S Leigh Cr. 13052200
- -Teton R. ab. St. Anth. 13055000
  (immediately downstream of Crosscut canal delivery; INTERPRET CAREFULLY!)
- -HF nr. Rexburg 13056500

Figure 5. Long-term USGS stream flow gaging stations in the Henry's Fork watershed.

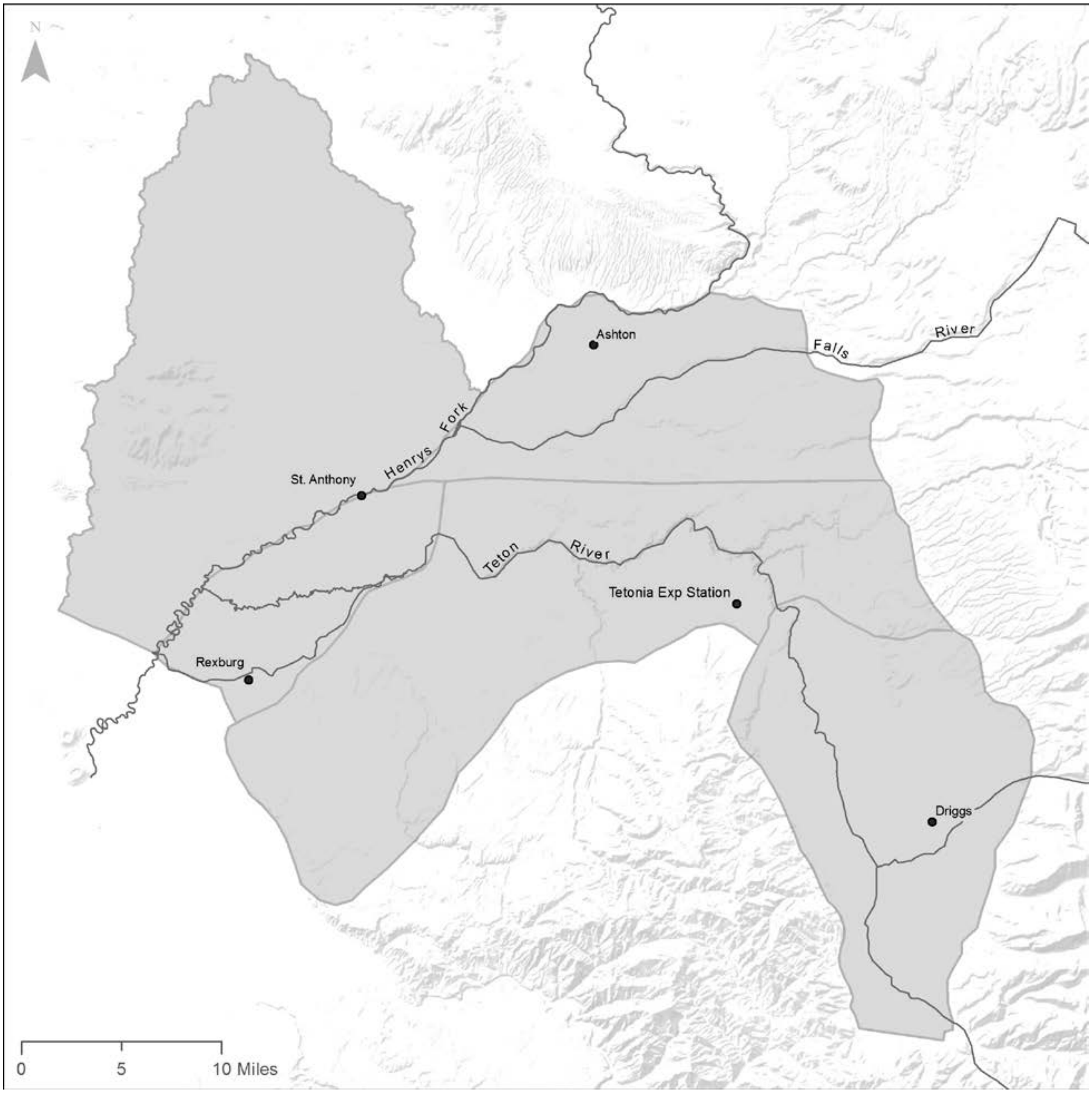


Figure 6. Extent of "low-elevation" areas as defined and used in this study, including shallow aquifers underlying these areas. Gray lines indicate boundaries of five individual geographic regions that are defined roughly by climate and topography. The climate in each region is characterized by that recorded at meteorological stations at the indicated locations.

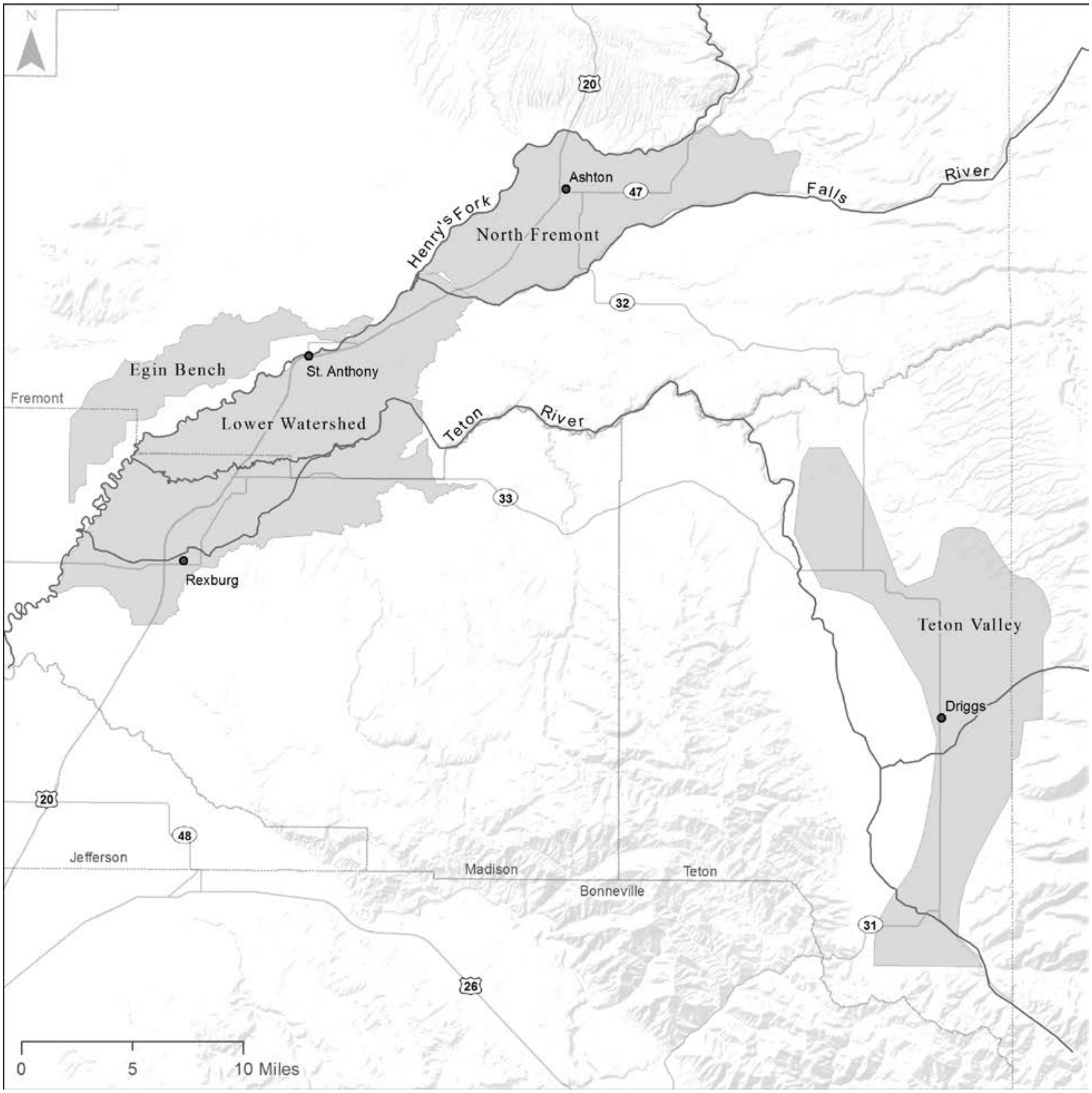


Figure 7. Map of the lower Henry's Fork watershed showing the four major irrigated regions of the watershed that are served by canal systems.

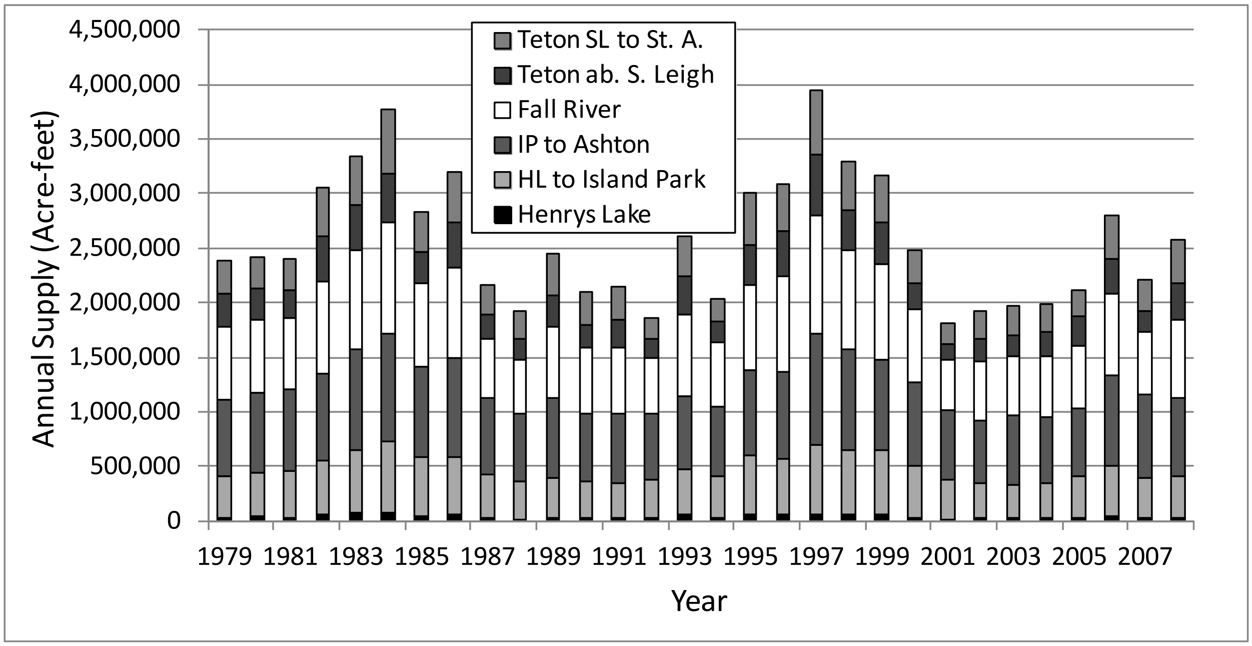


Figure 8. Time series of total annual surface supply (unregulated stream flow), WY 1979-2008.

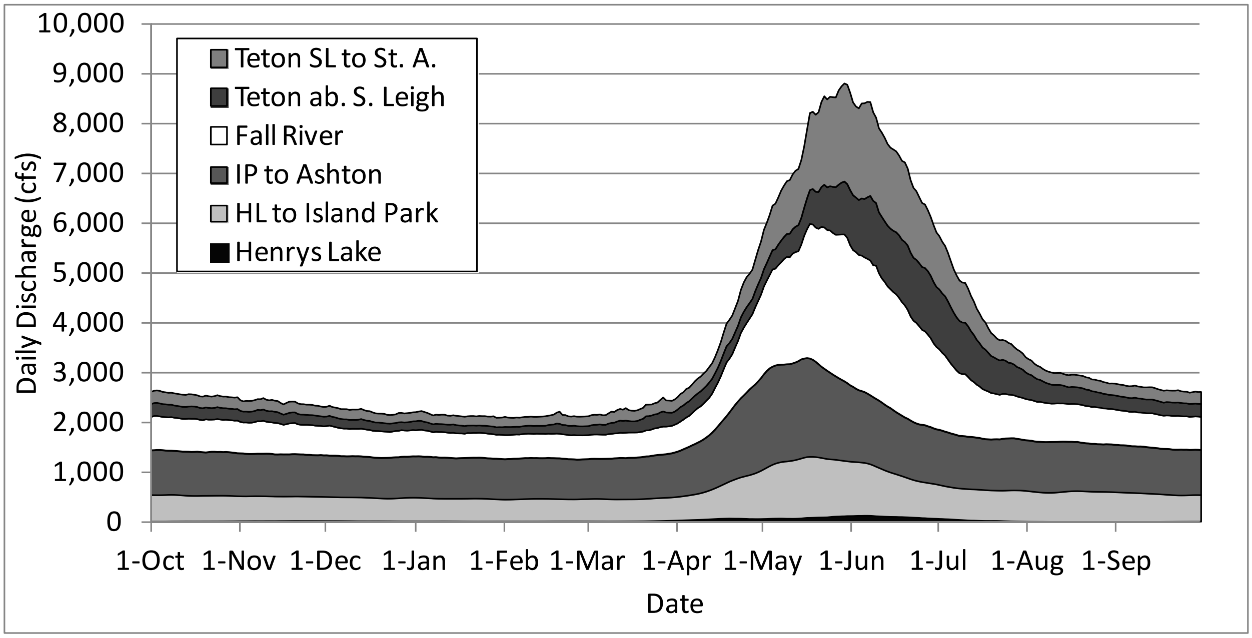


Figure 9. Mean water-year hydrograph of total annual surface supply, WY 1979-2008.

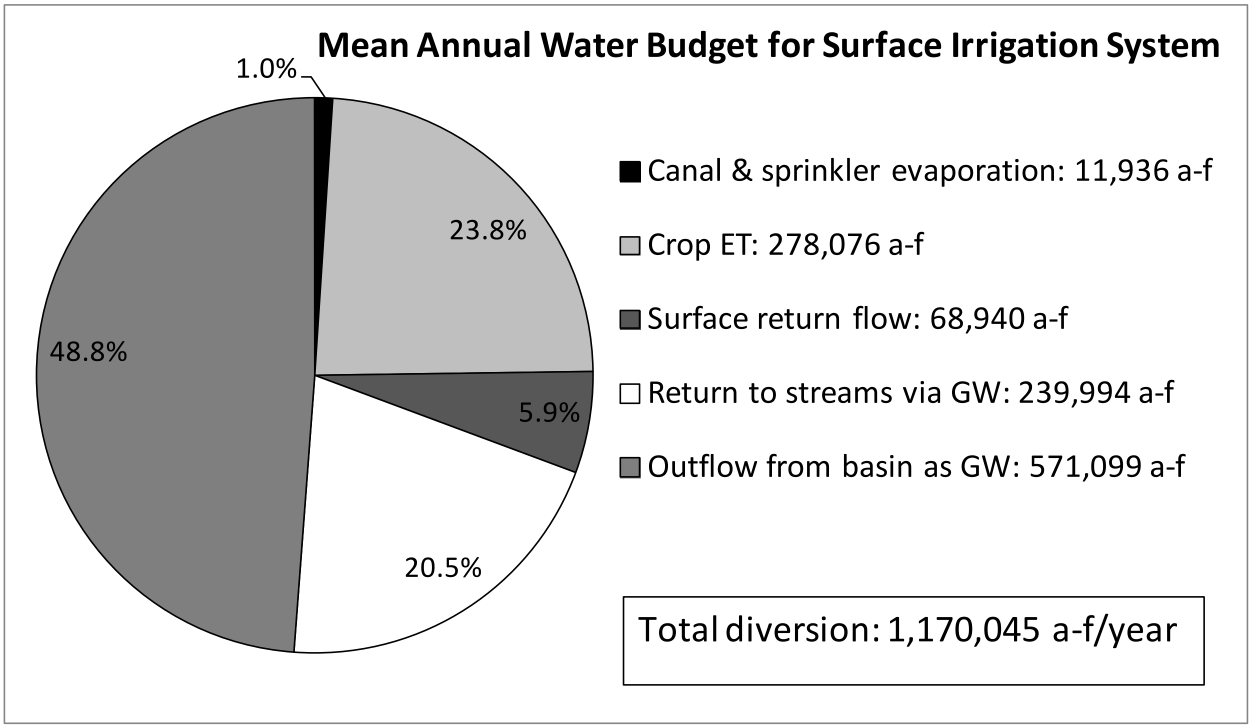
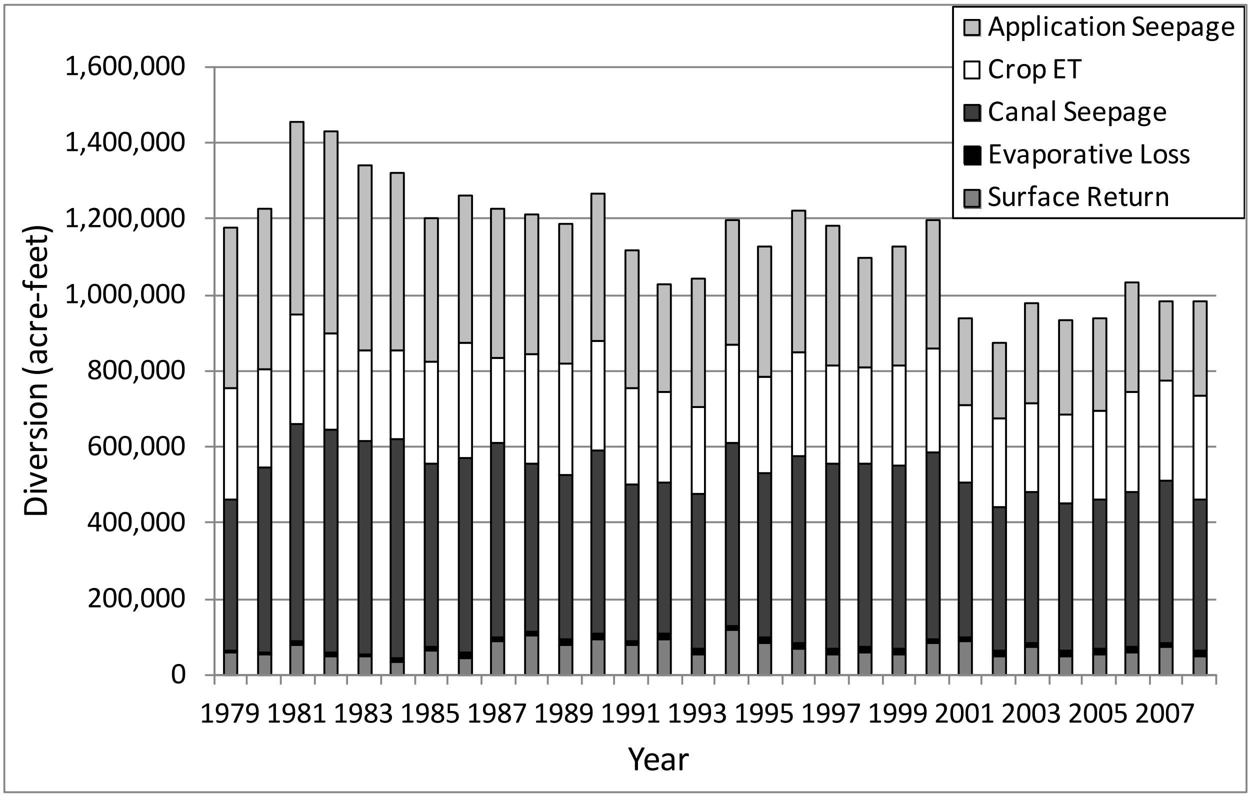


Figure 10. Water budget for surface irrigation system.



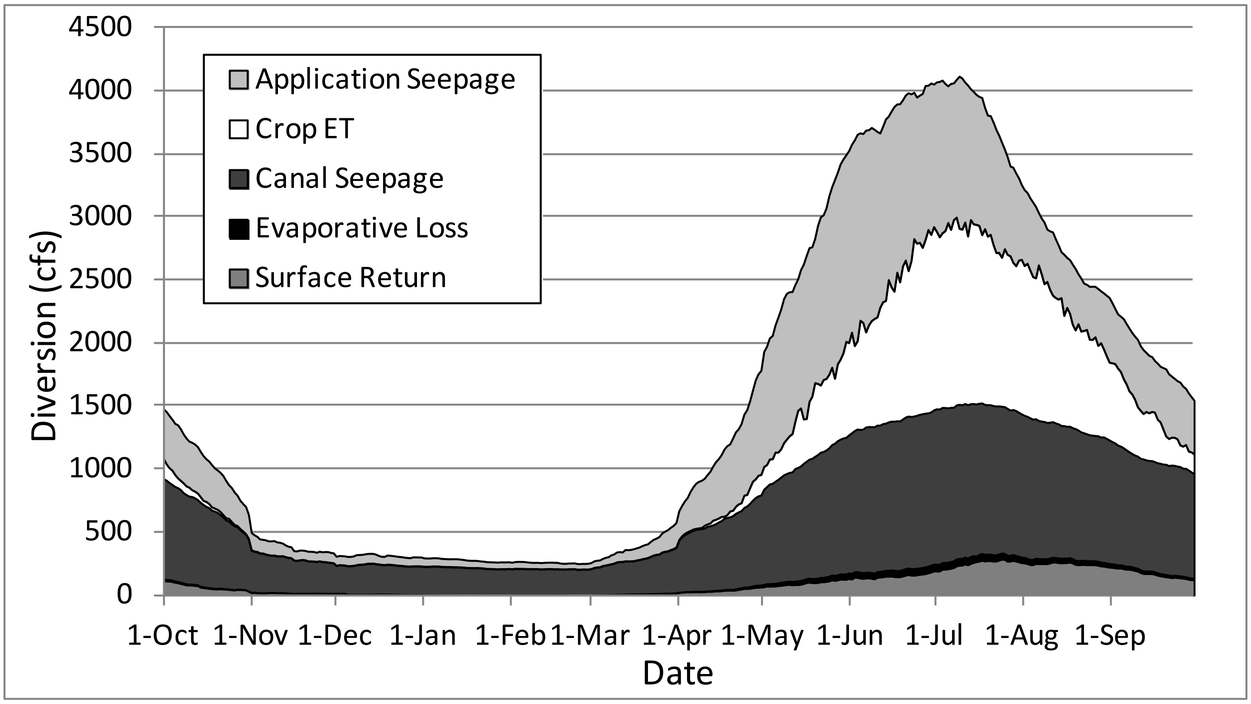


Figure 11. Time series (top) and mean 1979-2008 water-year hydrograph (bottom) of canal system water budget for the four major canal-served irrigated regions combined.

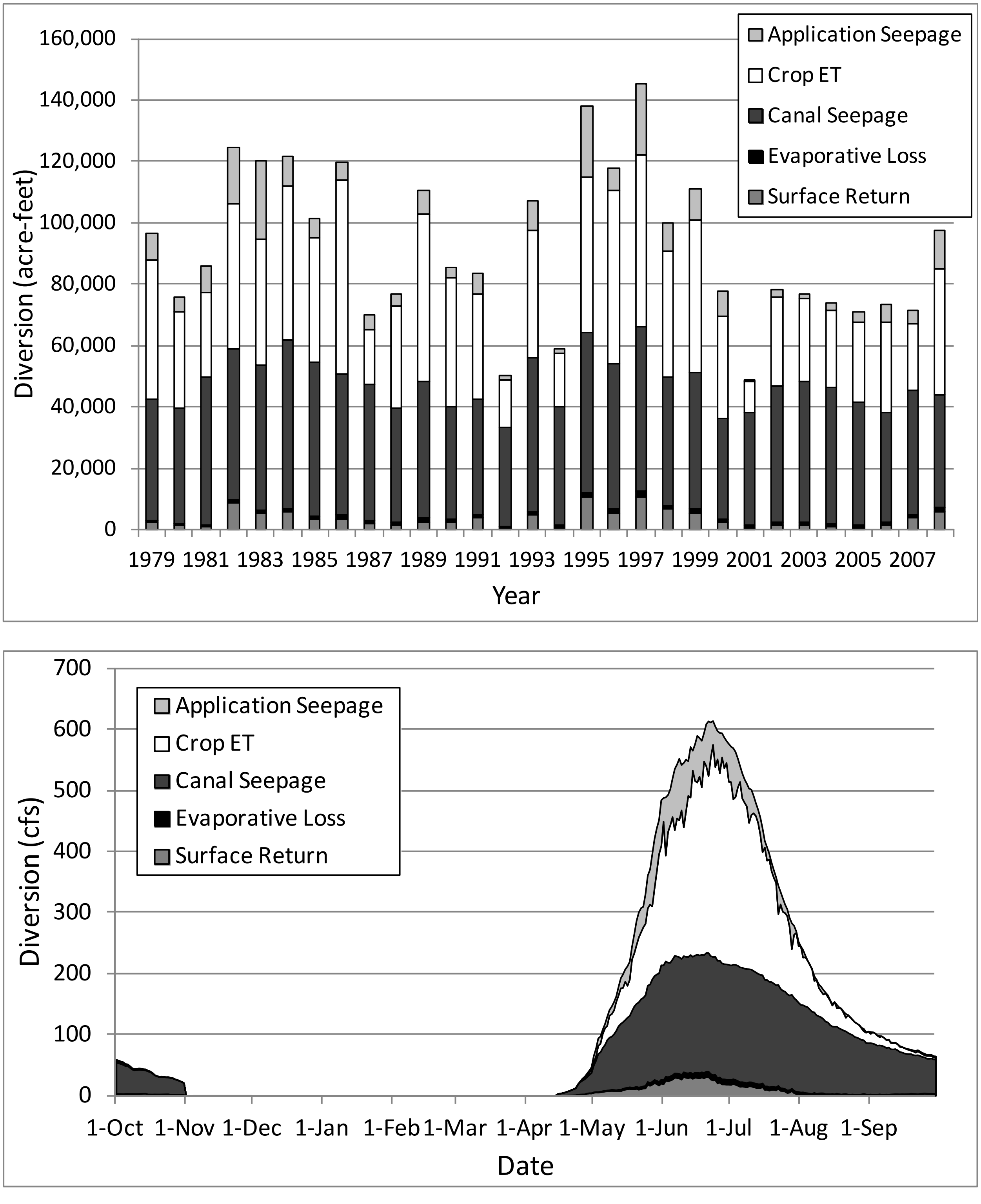


Figure 12. Time series (top) and mean 1979-2008 water-year hydrograph (bottom) of canal system water budget for Teton Valley irrigated area.

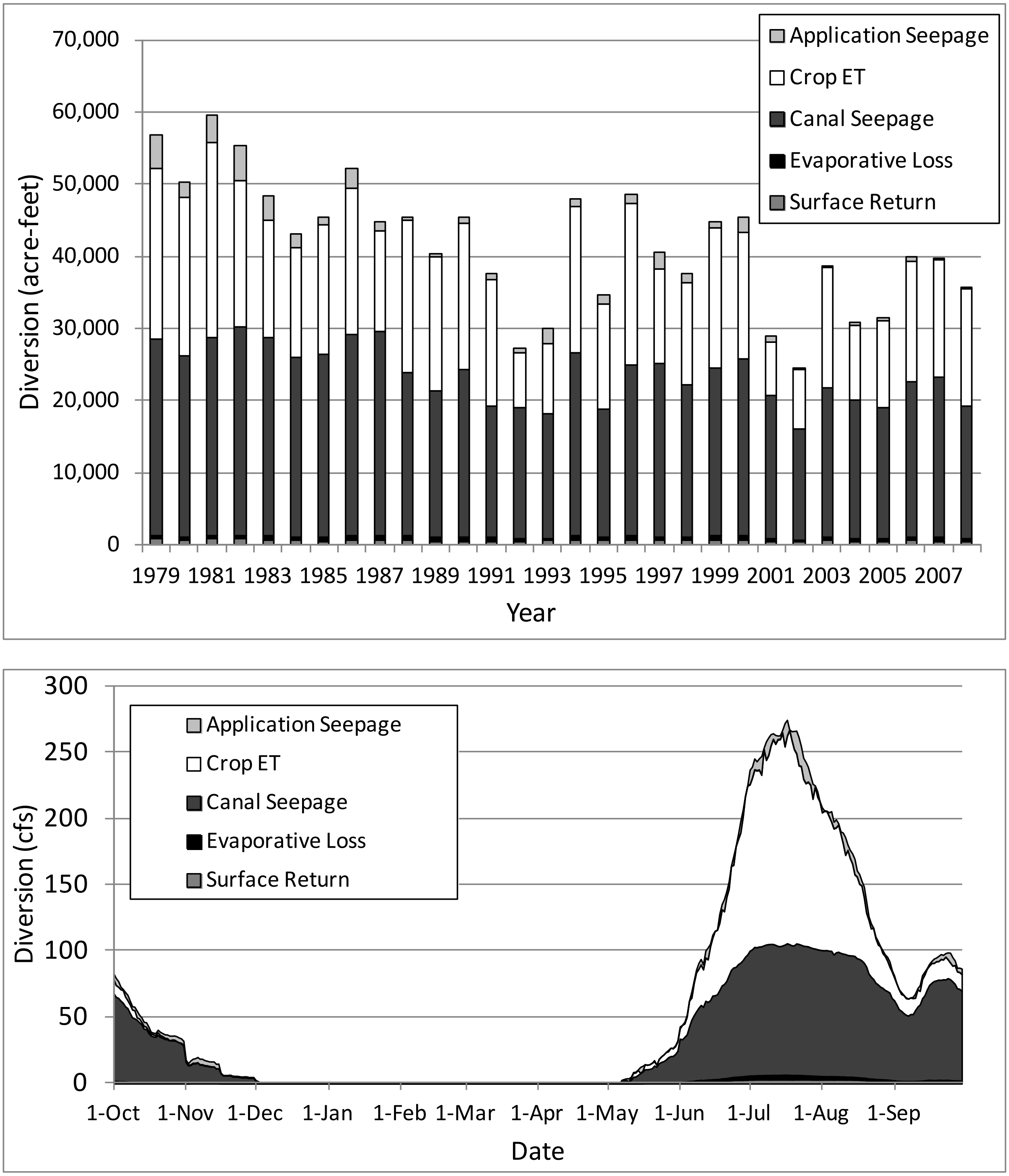


Figure 13. Time series (top) and mean 1979-2008 water-year hydrograph (bottom) of canal system water budget for North Fremont irrigated area.

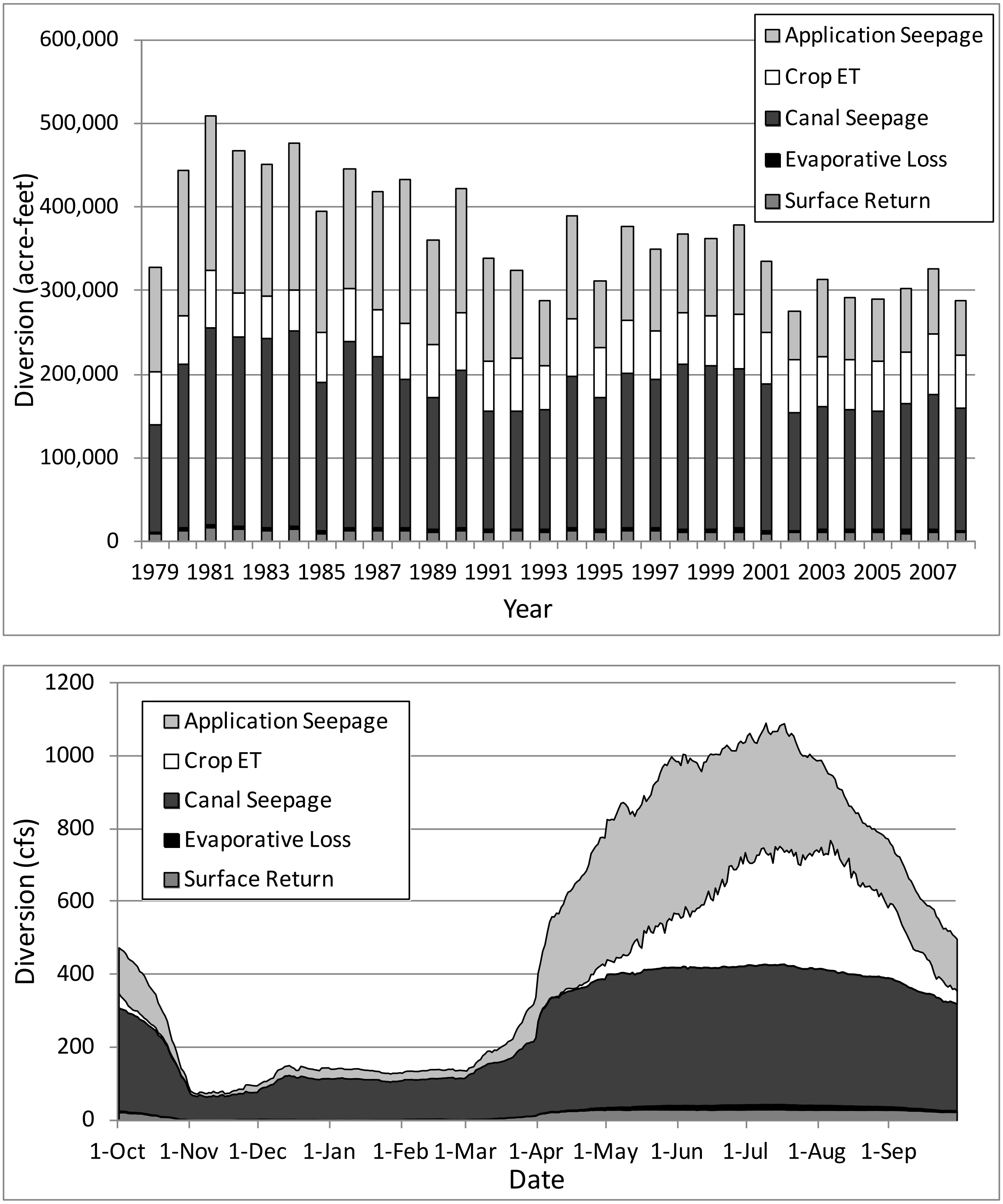
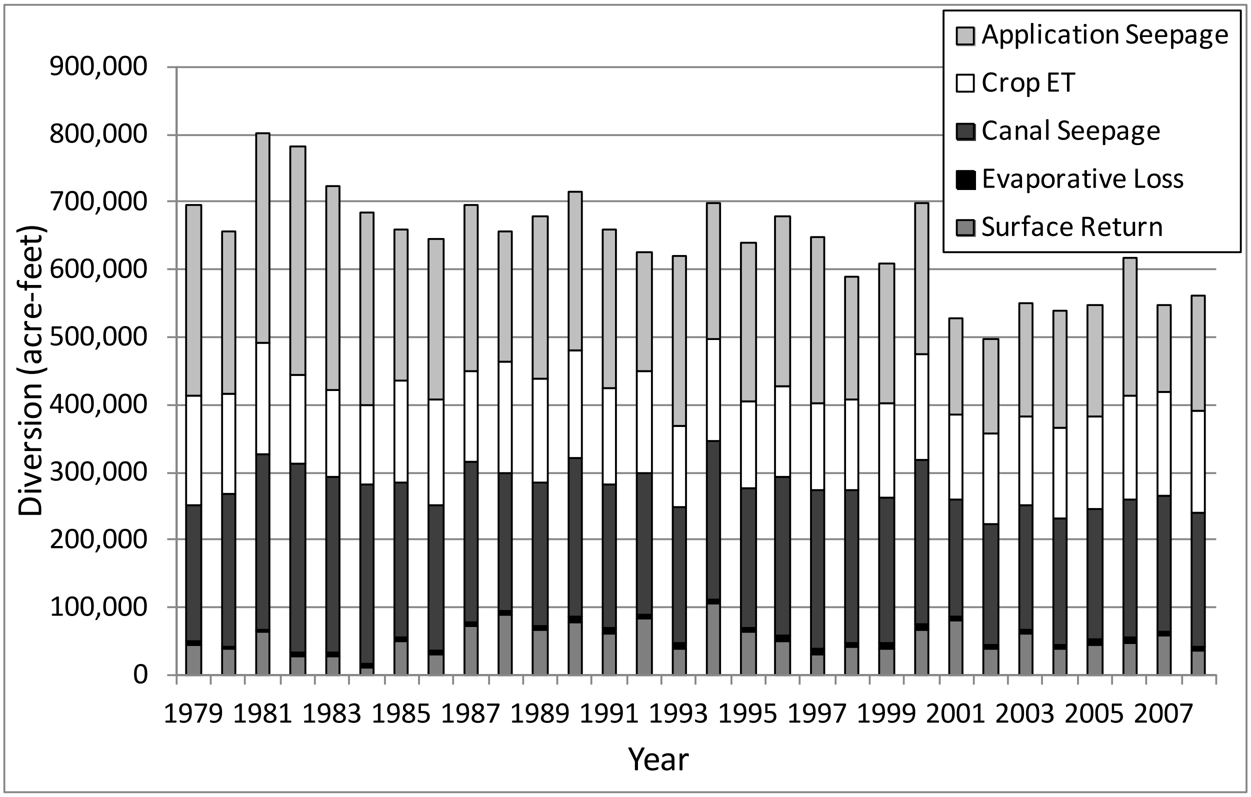


Figure 14. Time series (top) and mean 1979-2008 water-year hydrograph (bottom) of canal system water budget for Egin Bench irrigated area.



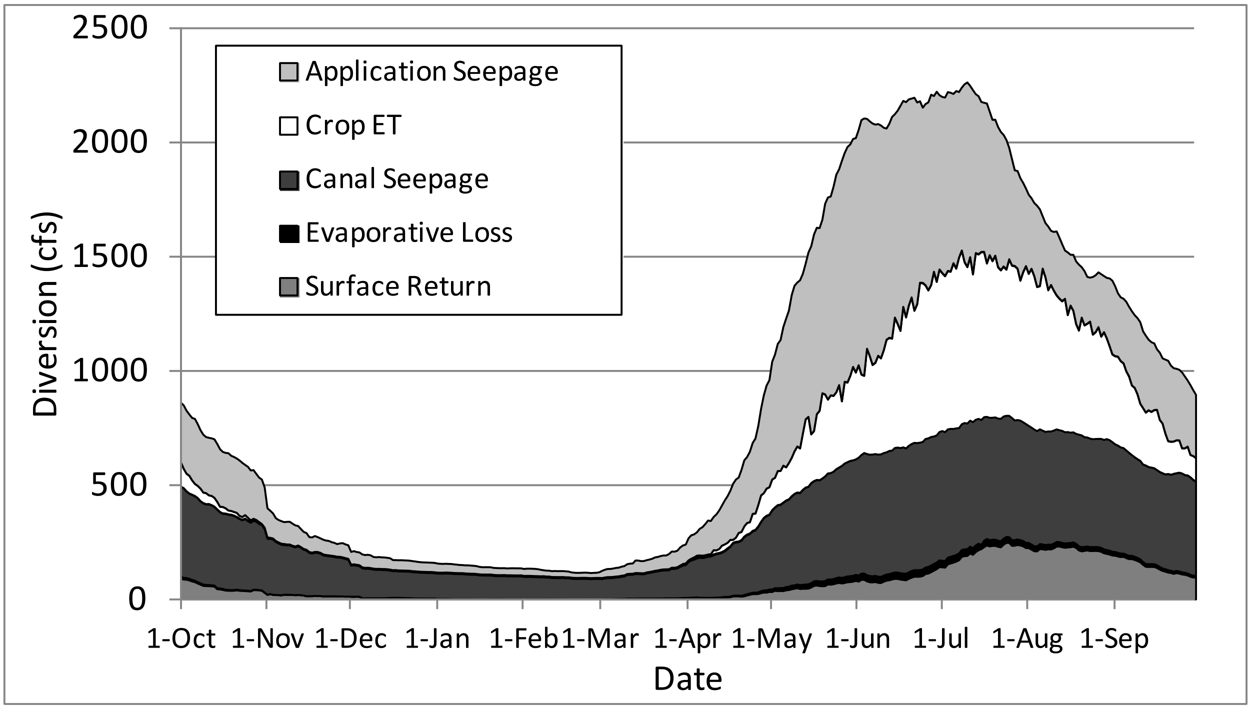
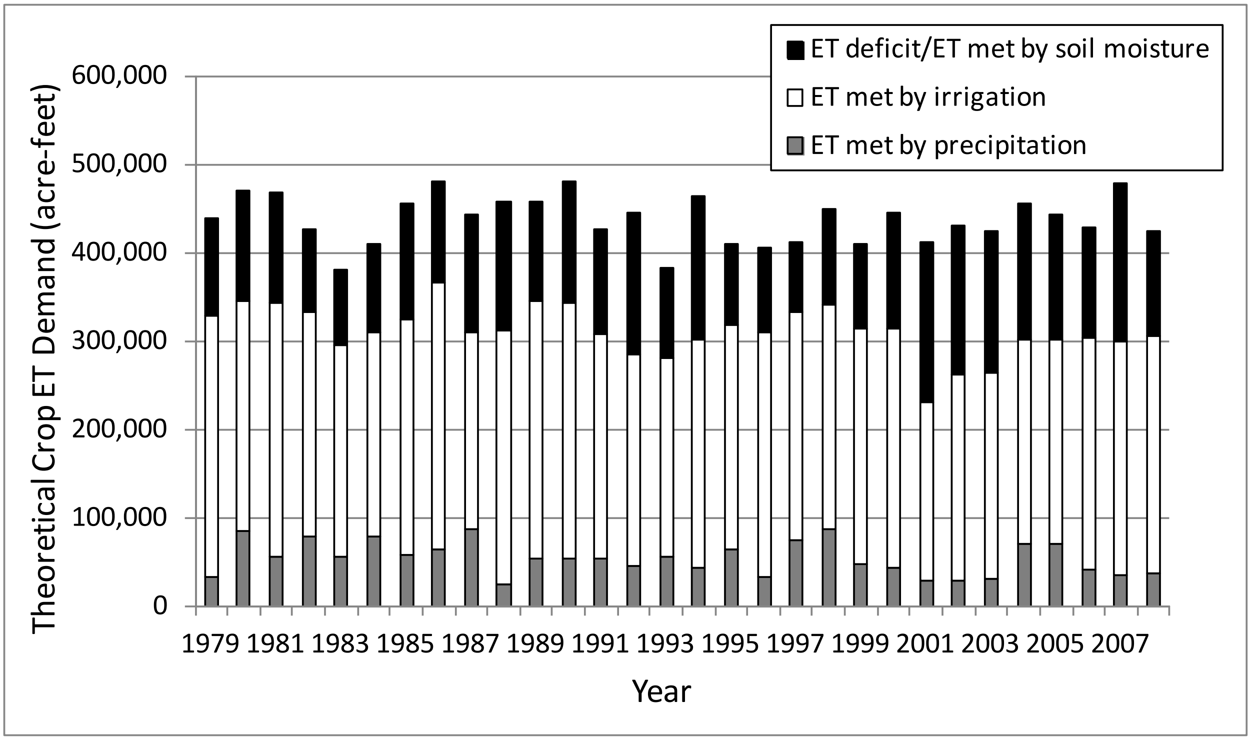


Figure 15. Time series (top) and mean 1979-2008 water-year hydrograph (bottom) of canal system water budget for Lower Watershed irrigated area.



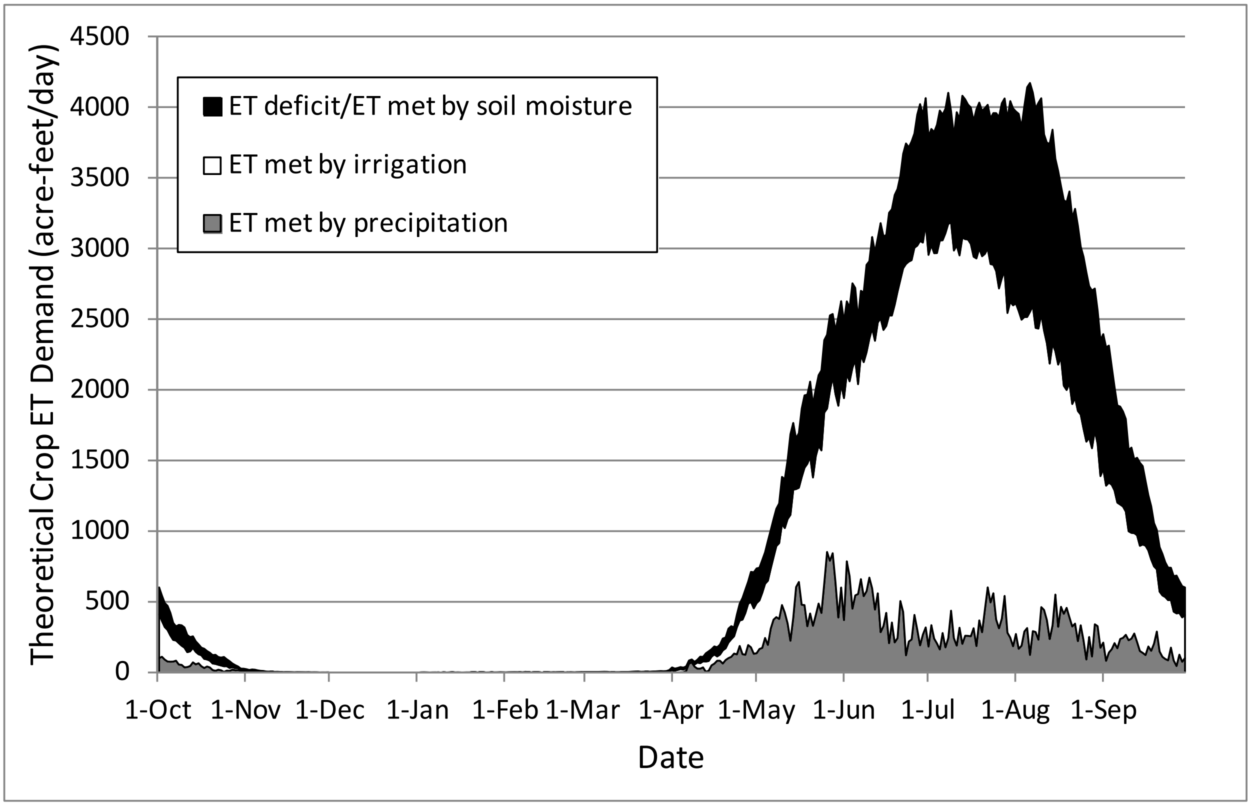
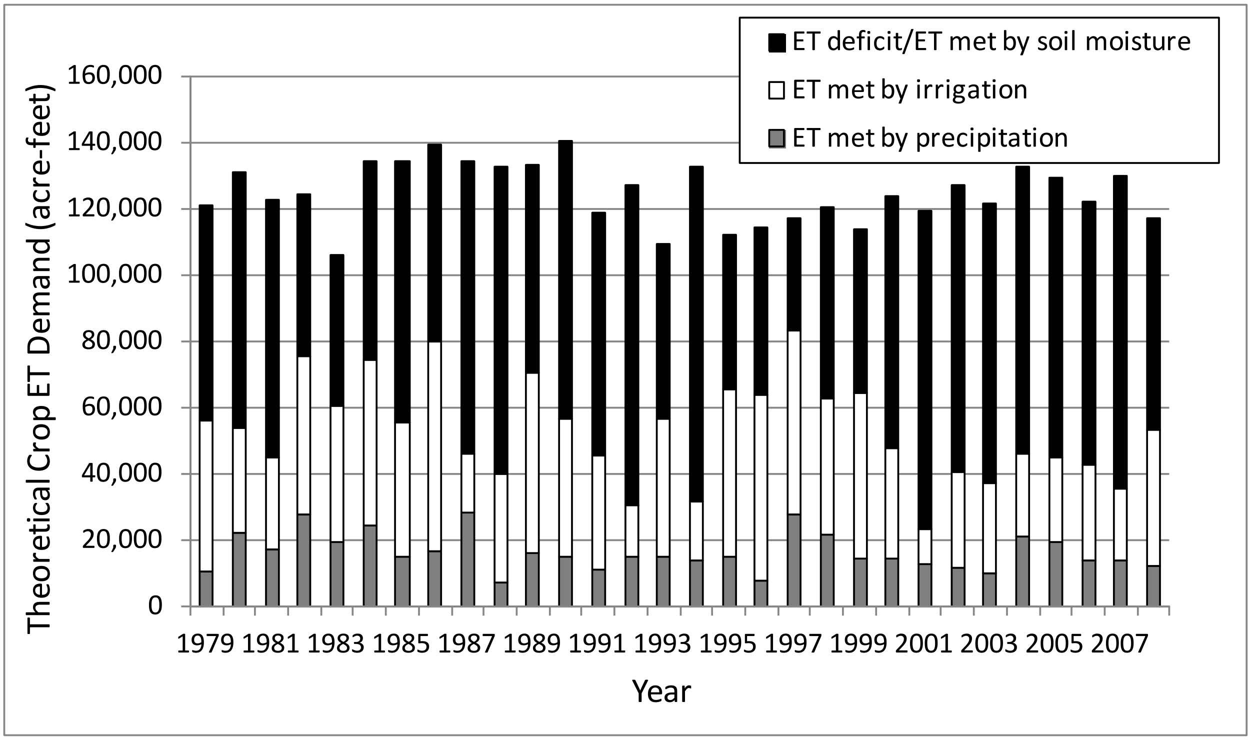


Figure 16. Time series (top) and mean 1979-2008 water-year hydrograph (bottom) of theoretical net crop evapotranspiration demand for the four major canal-served irrigated regions combined.



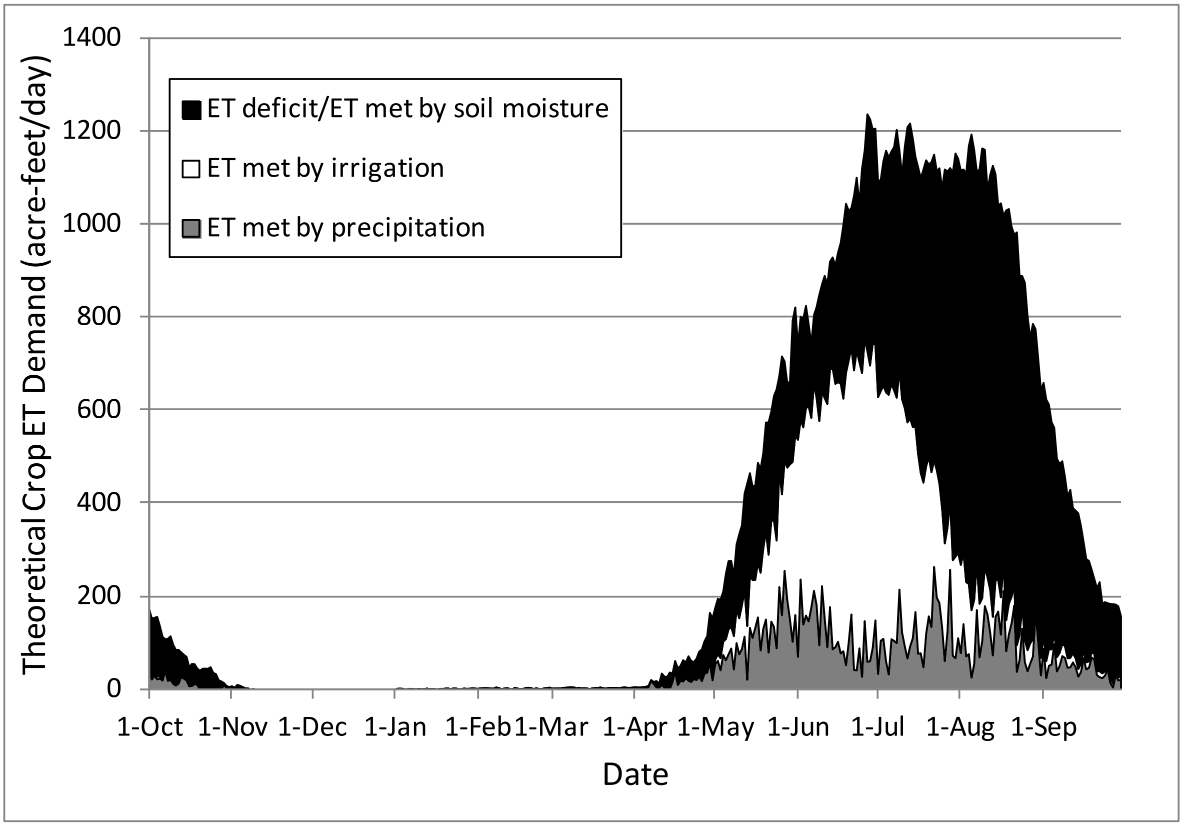
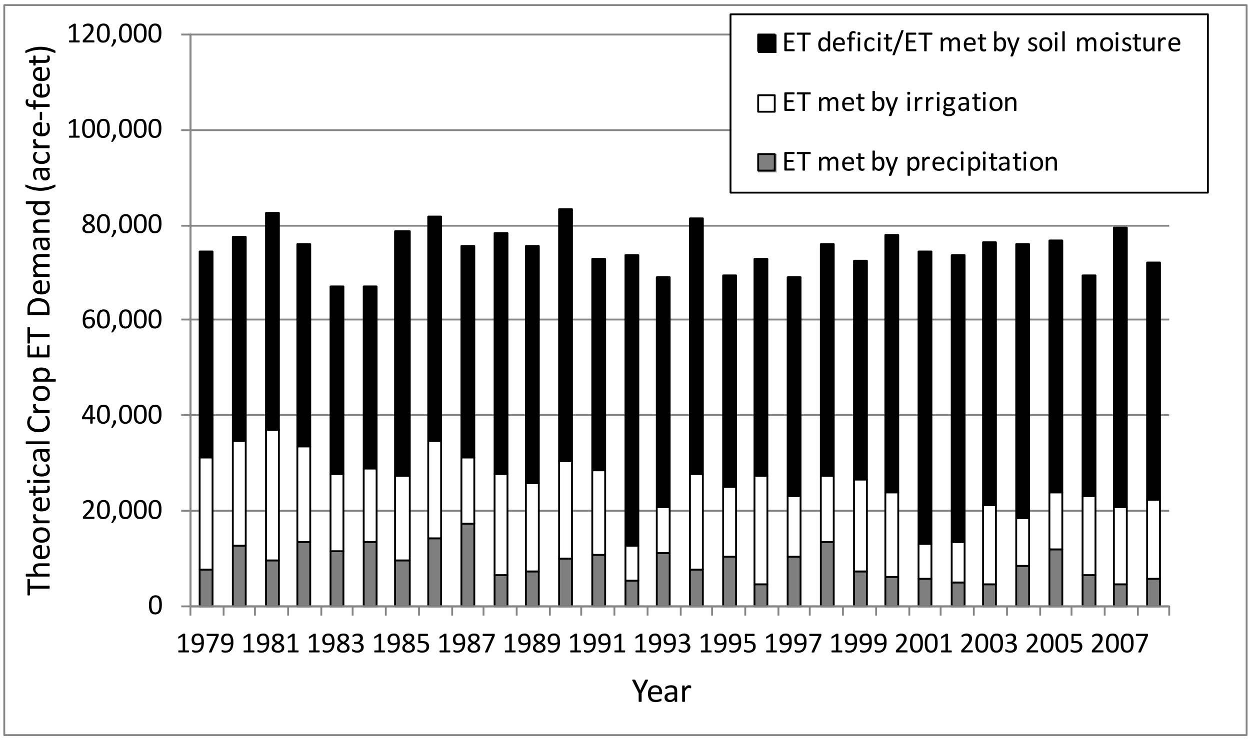


Figure 17. Time series (top) and mean 1979-2008 water-year hydrograph (bottom) of theoretical net crop evapotranspiration demand for the Teton Valley irrigated area.



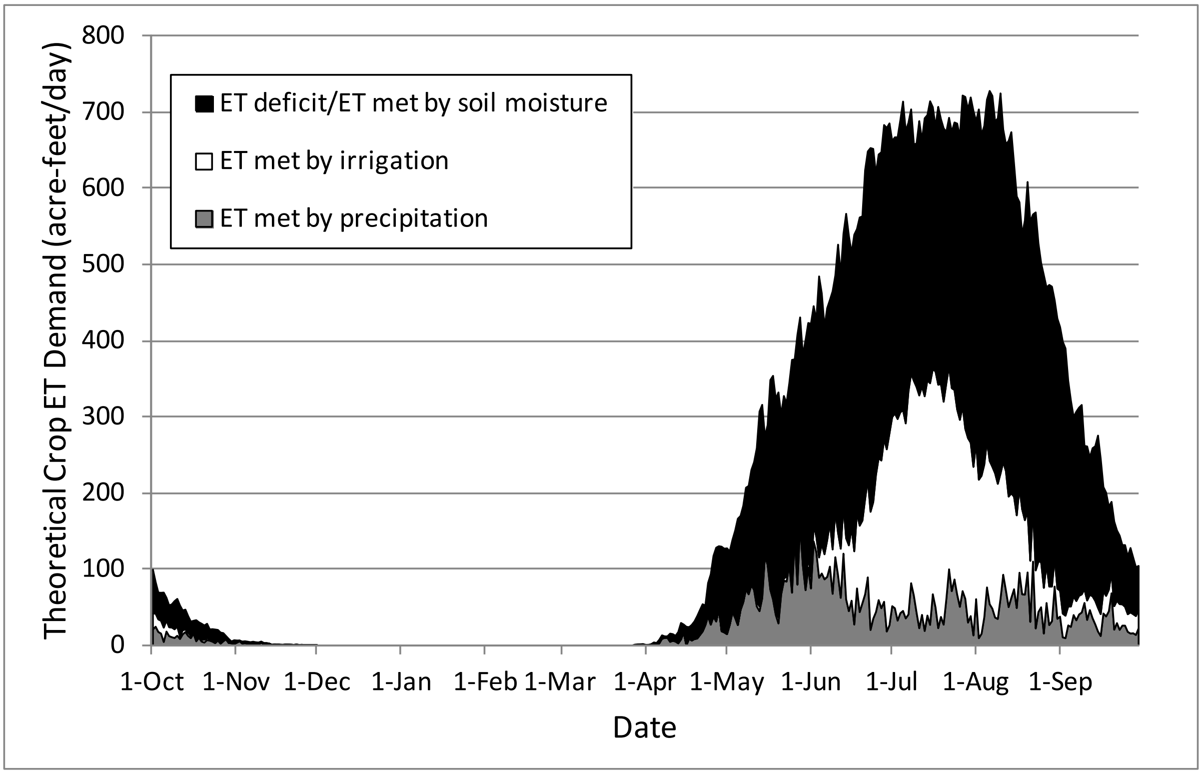
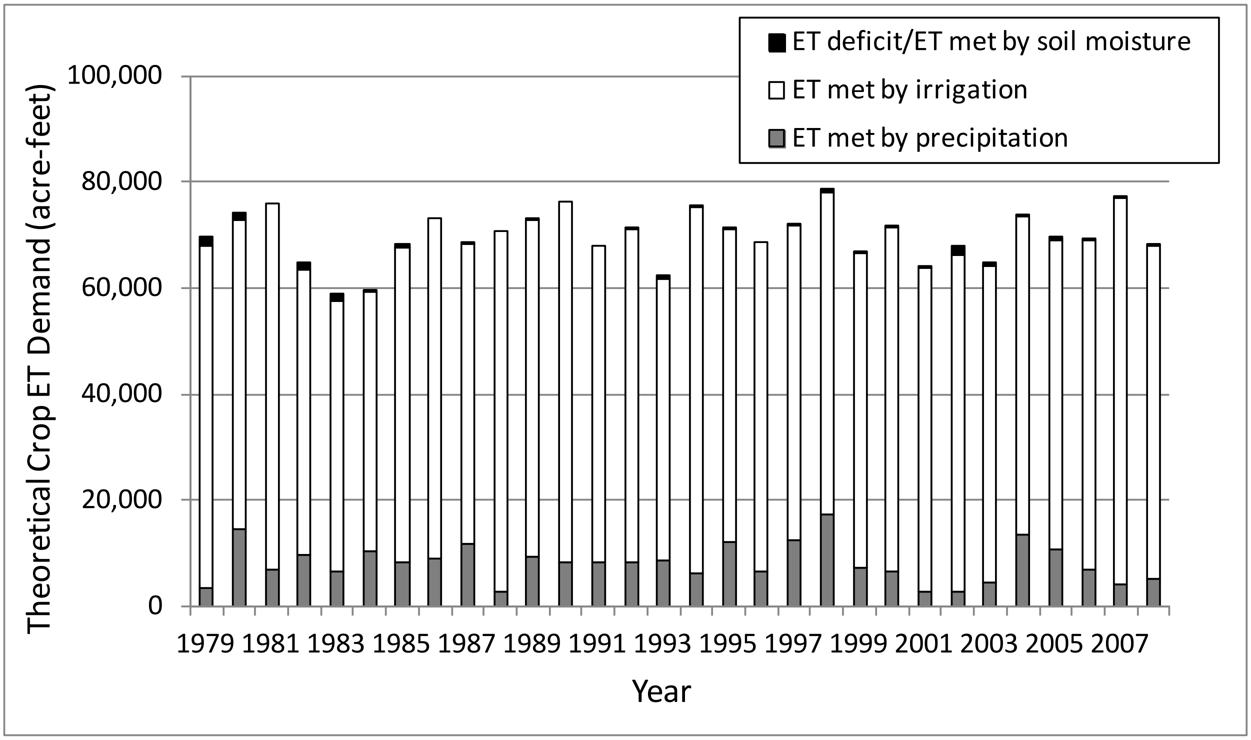


Figure 18. Time series (top) and mean 1979-2008 water-year hydrograph (bottom) of theoretical net crop evapotranspiration demand for the North Fremont irrigated area.



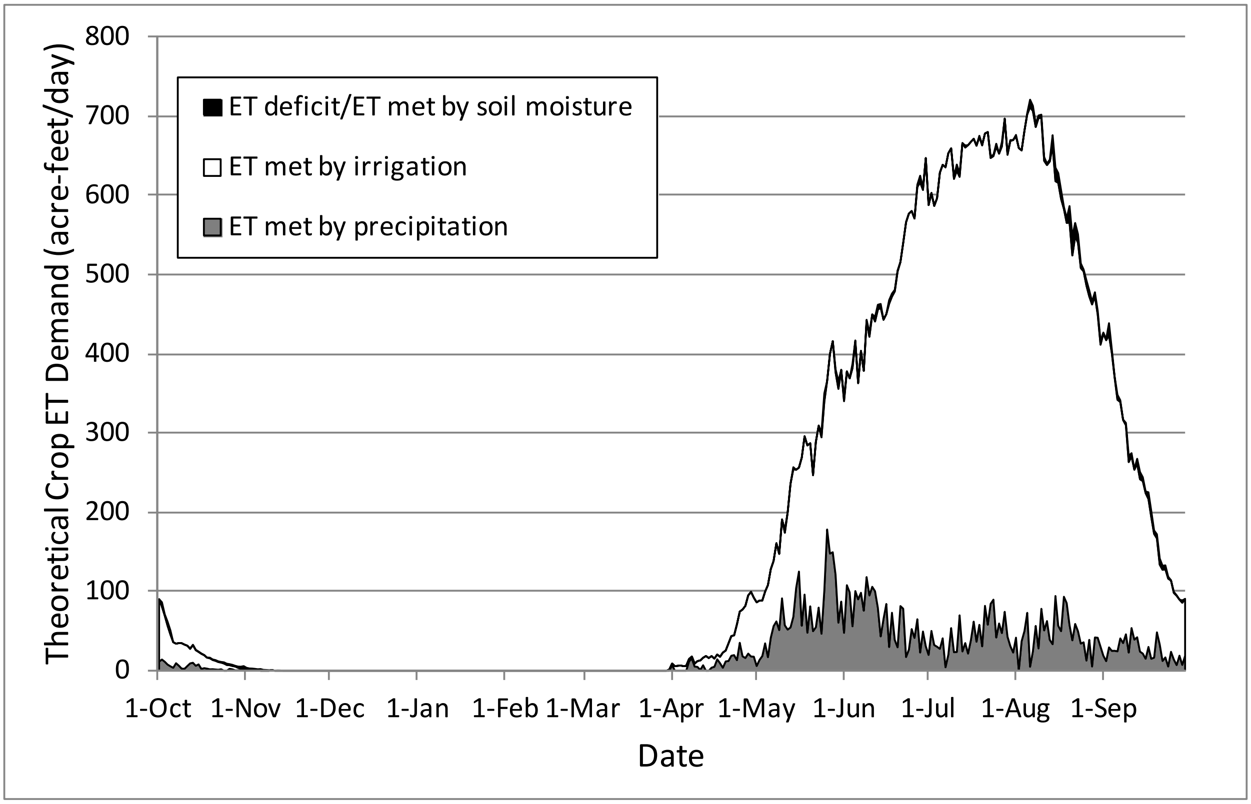
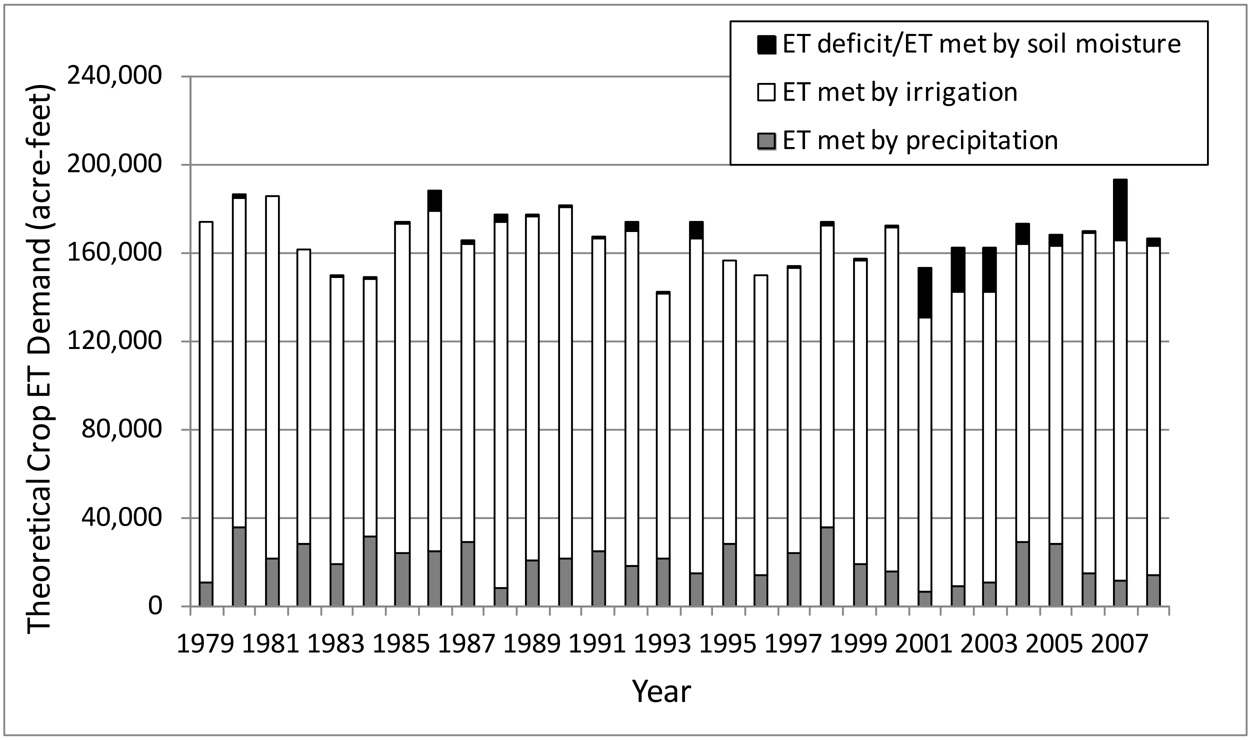


Figure 19. Time series (top) and mean 1979-2008 water-year hydrograph (bottom) of theoretical net crop evapotranspiration demand for the Egin Bench irrigated area.



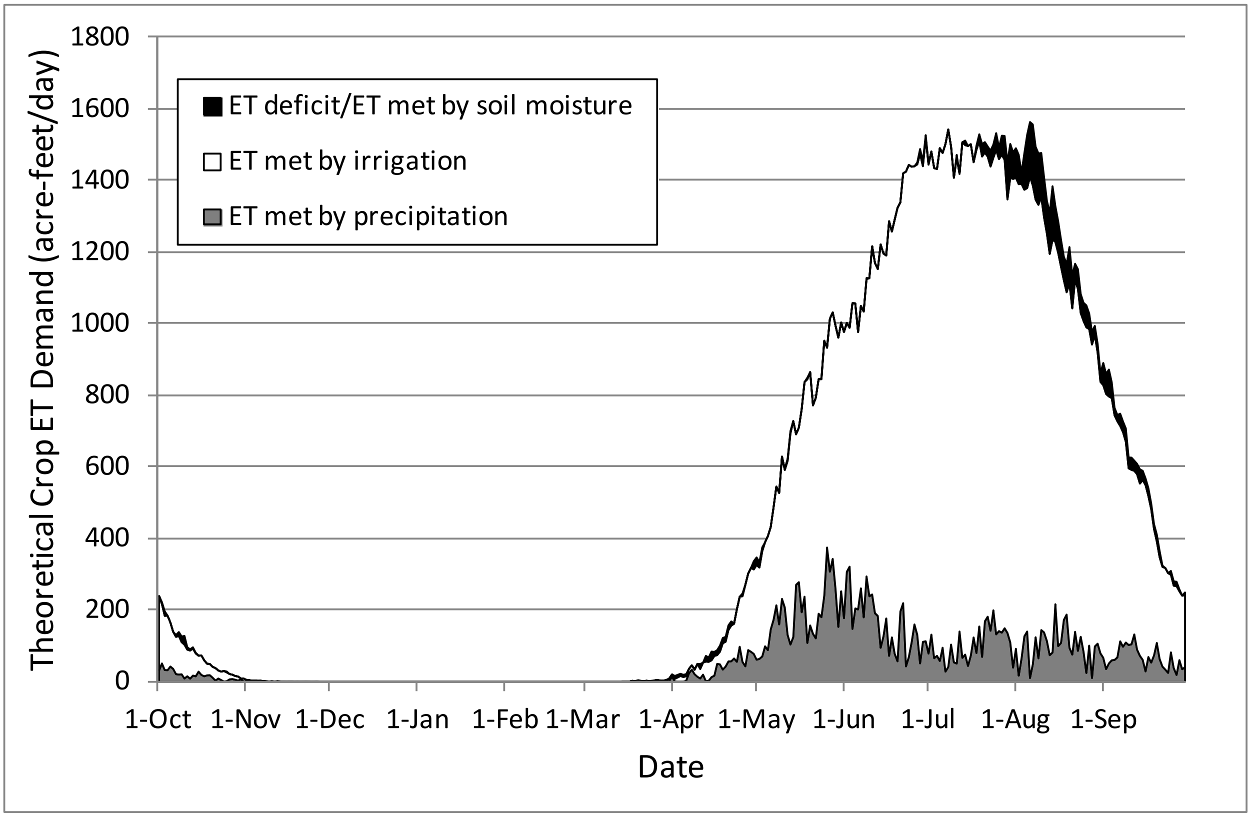


Figure 20. Time series (top) and mean 1979-2008 water-year hydrograph (bottom) of theoretical net crop evapotranspiration demand for the Lower Watershed irrigated area.

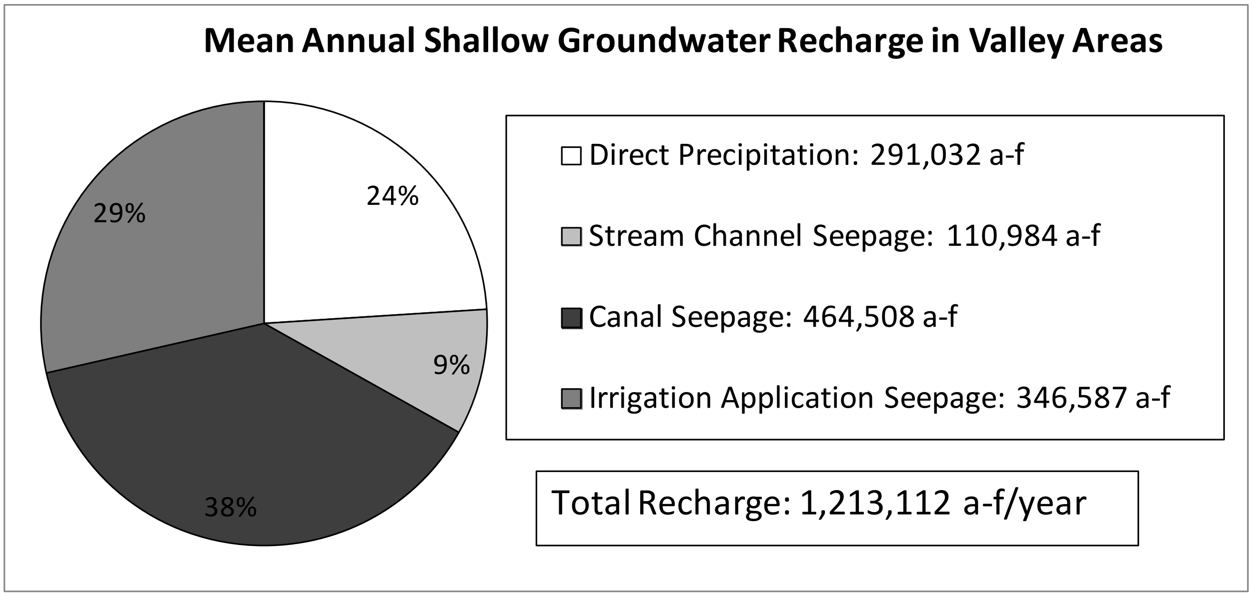


Figure 21. Distribution of sources of recharge to lower-elevation shallow aquifers in the Henry's Fork watershed.

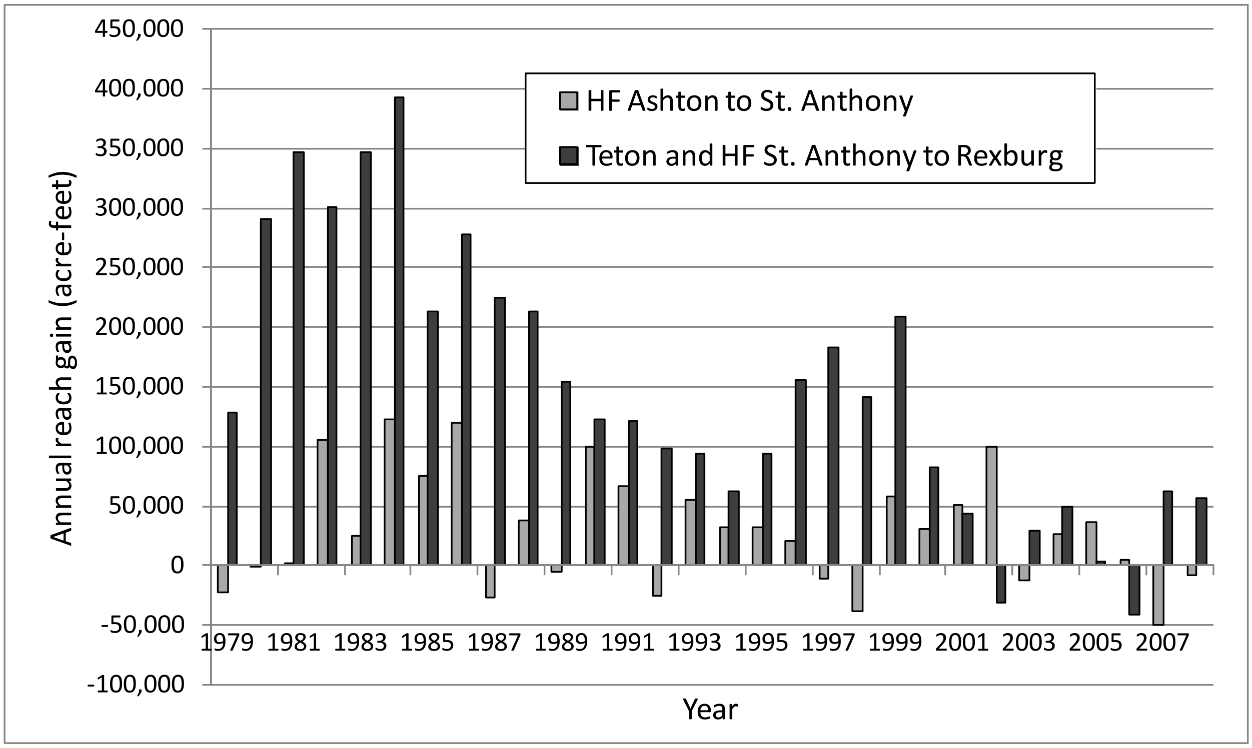


Figure 22. Annual net reach gains in the Henry's Fork and lower Teton River.

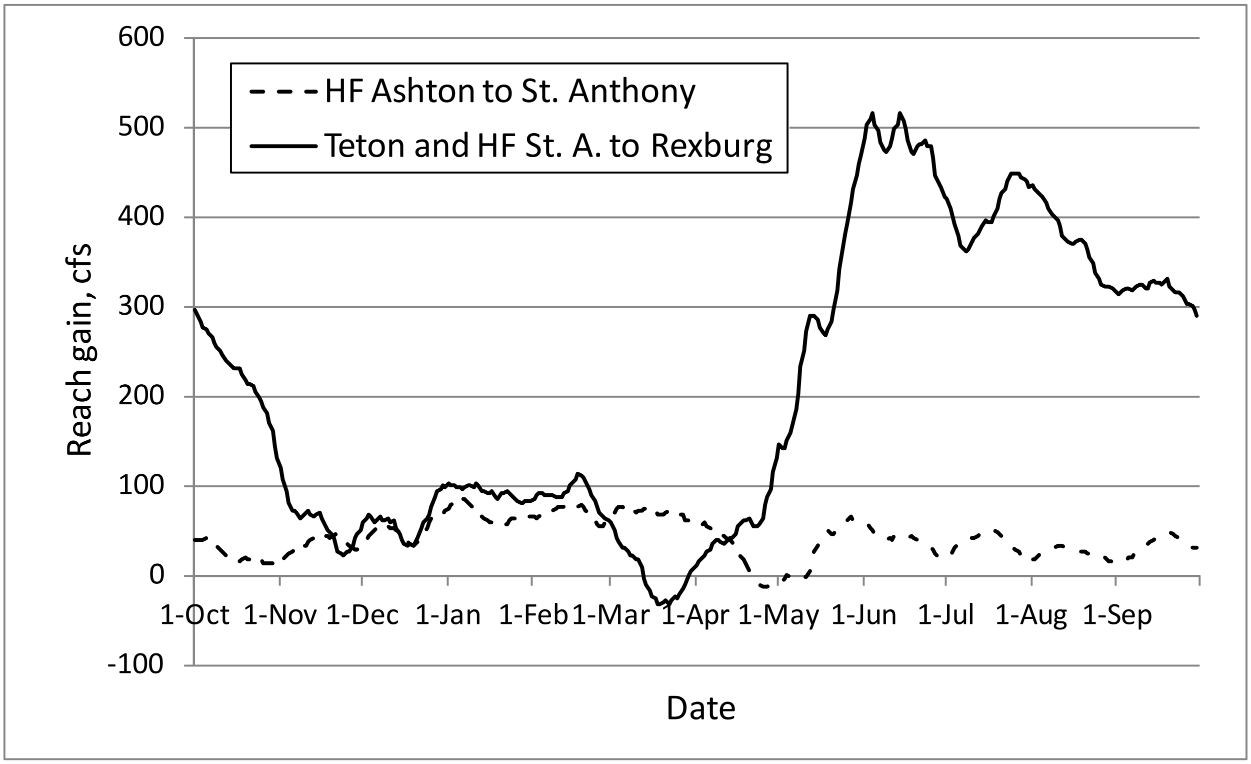


Figure 23. Mean water year hydrograph of reach gains in the Henry's Fork and lower Teton River.

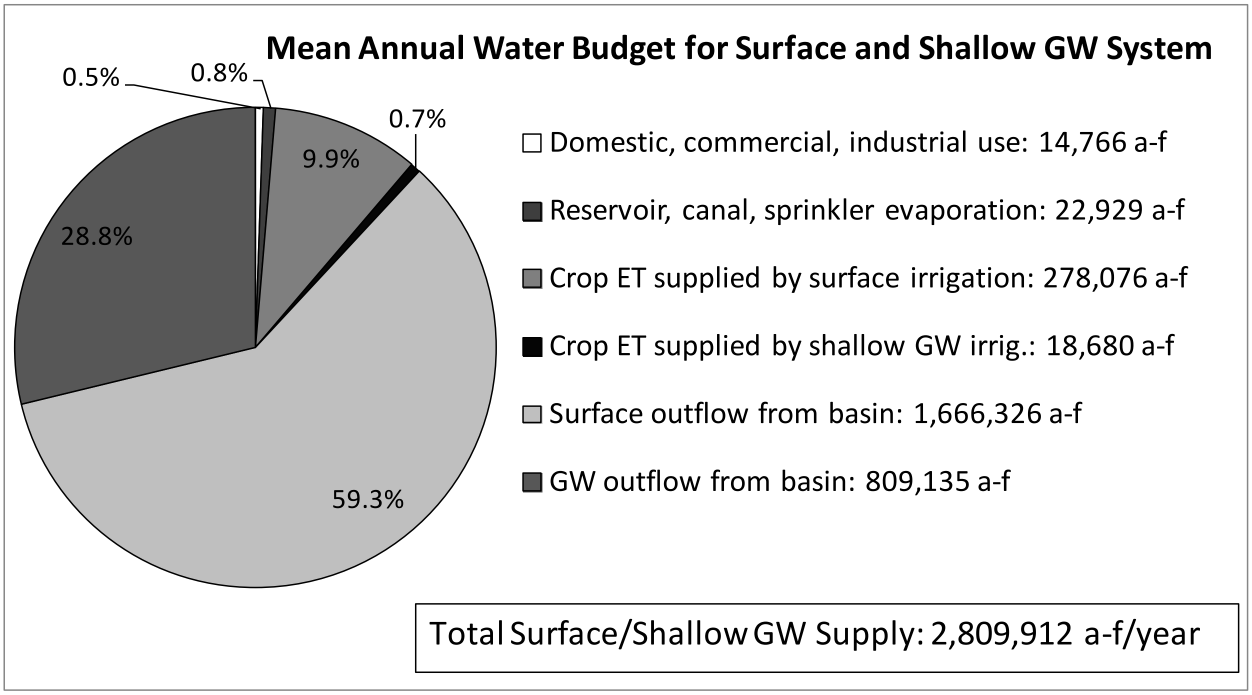


Figure 24. Water budget for the combined surface/shallow groundwater system in the Henry's Fork watershed.