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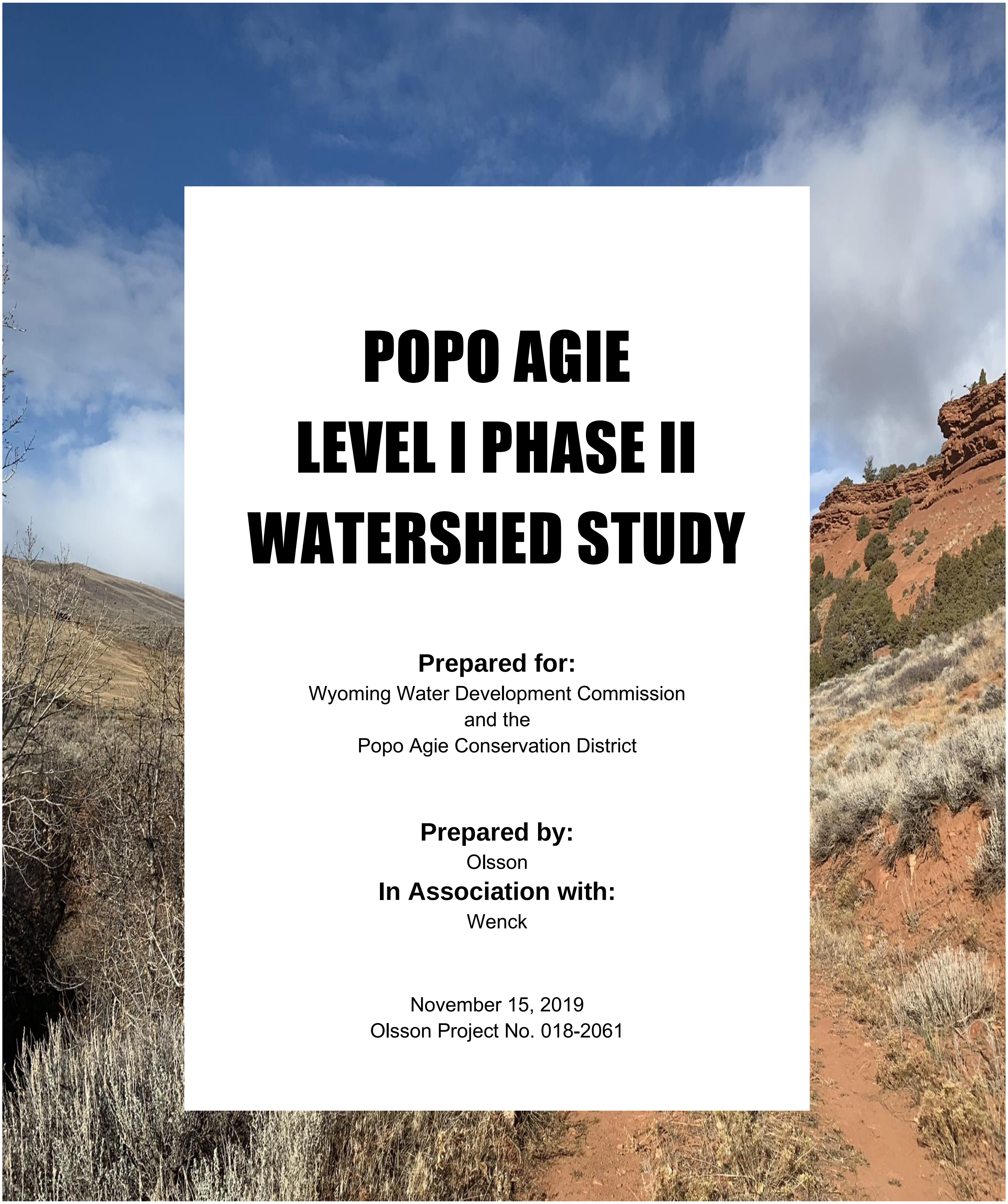

POPO AGIE
LEVEL I PHASE II
WATERSHED STUDY

Prepared for:

Wyoming Water Development Commission
and the
Popo Agie Conservation District

Prepared by:

Olsson

In Association with:

Wenck

November 15, 2019
Olsson Project No. 018-2061

Popo Agie
Level I Phase II
Watershed Study

WWDC Contract for Services
Number 05SC0297515
Olsson Project Number 018-2061

November 15, 2019

I hereby certify that this report was prepared by us or under our direct supervision and that we are duly licensed professional geologists and engineers under the laws of the state of Wyoming.

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APPENDICES

1.0 INTRODUCTION

This Level I, Phase II watershed study was prepared under contract to the Wyoming Water Development Commission (WWDC). The Popo Agie Conservation District (PACD) in Lander, Wyoming, is the project sponsor, and the plan was prepared on behalf of the landowners, land managers, stewards, and visitors of the Popo Agie Watershed (**Photo 1**). The scientists and engineers of Olsson completed the study in collaboration with Wenck.

Photo 1. The Sinks at the Sinks and Rise State Park in the Popo Agie Watershed.

1.1. Watershed Study Overview

A watershed study is a holistic evaluation of an area that is interconnected by water. A Level I watershed study evaluates the current condition of an area and looks at opportunities for water improvement projects that will restore, maintain, and enhance healthy watershed function. Specifically, a Level I watershed study looks for projects, programs, or activities that support sustainable, beneficial water use for current and future watershed residents – be they human, animal, or plant. The study is comprehensive in that it evaluates many aspects of the natural setting to ensure that any proposed projects that are beneficial to one water user, are indeed beneficial to the entire watershed. The WWDC made a holistic approach to watershed management a keystone when the watershed program was developed.

Since the program was initiated, the Wyoming Legislature has authorized watershed studies across the state of Wyoming. The studies are initiated to assist project sponsors, prioritize watershed management improvements, and ensure that any proposed projects are feasible, cost effective, and will indeed provide a positive benefit to the area.

In a WWDC newsletter, the four key issues for consideration in a watershed study were identified and included water storage, irrigation infrastructure, upland water development, and stream channel condition. As stated in the newsletter, "A watershed study, providing management and rehabilitation plans for water storage, irrigation systems and upland water development, can help empower a community to proactively enhance their watershed. Conservation by watershed can be an effective holistic approach to embracing the natural resource challenges and opportunities facing a community. A watershed study can provide the information to meet those challenges" (WWDC 2009).

1.1.1. What is a Level I Phase II Watershed Study?

In 2003, Anderson Consulting Engineers prepared a comprehensive Level I watershed study for the Popo Agie Watershed (ACE 2003). That study was prepared in response to a four-year planning effort completed by the Lander 2020 Water Planning Committee, who recognized the growing pressures on the area's natural resources (LWPC 1999). In the 1999 report, the committee summarized the planning area's demographics, surface and groundwater quality and quantity, aquifer sensitivity and vulnerability, important aquatic life, habitat quality, and riparian area conditions. In the Level I watershed study (ACE 2003), specific recommendations were made to proactively address the water issues the community was going to face over the 10-year planning horizon.

As stated in the 2003 Level I watershed study:

> *"The objective of this study is to generate a watershed management and irrigation rehabilitation plan that is not only technically sound, but also one that is practical and economically feasible. Formulation of the plan also includes providing the Popo Agie Conservation District with the data required to facilitate the planning process and make informed decisions regarding potential mitigation of several key issues/problems that presently exist within the watershed. The key issues/problems that were previously identified are summarized below:*
>
> - *Augmentation of the low flows within various reaches of the Popo River system.*
> - *Mitigation of flooding within the Popo Agie River watershed.*
> - *Monitoring potential changes in water quality within the watershed.*

- *Mitigation of impaired reaches within the Popo Agie River watershed that presently experience problems with channel stability/degradation.*
- *Limited supplies to satisfy the needs of agricultural, municipal and industrial uses within the watershed (i.e., over-appropriation of water supply within the watershed)."*

Previous reports had presented information that the watershed's water supply was not capable of fully satisfying the requirements of all water users, especially those in the Middle Popo Agie River. The Level I watershed study (ACE 2003) confirmed this. Potential improvement projects were grouped into the following five categories:

- Irrigation system conservation and rehabilitation
- Storage opportunities
- Stream channel condition and stability
- On-farm improvements
- Water quality

Most water usage within the watershed is associated with irrigation. To address water quantity issues, it was reasonable to assume that irrigation will play a vital role in conserving existing water supplies and in augmenting low flows (ACE 2003). Specifically, 46 irrigation system rehabilitation projects were proposed along with nine storage opportunities, four stream channel restorations, and several on-farm improvements (**Photo 2**).

Since 2003, most of the proposed projects listed in the Level I watershed study (ACE 2003) have been completed (see Section 4.0 and Table 4.1 for a description of the completed projects). Unfortunately, the impact has not been sufficient to address the low-flow conditions in the Middle Popo Agie River in the late summer.

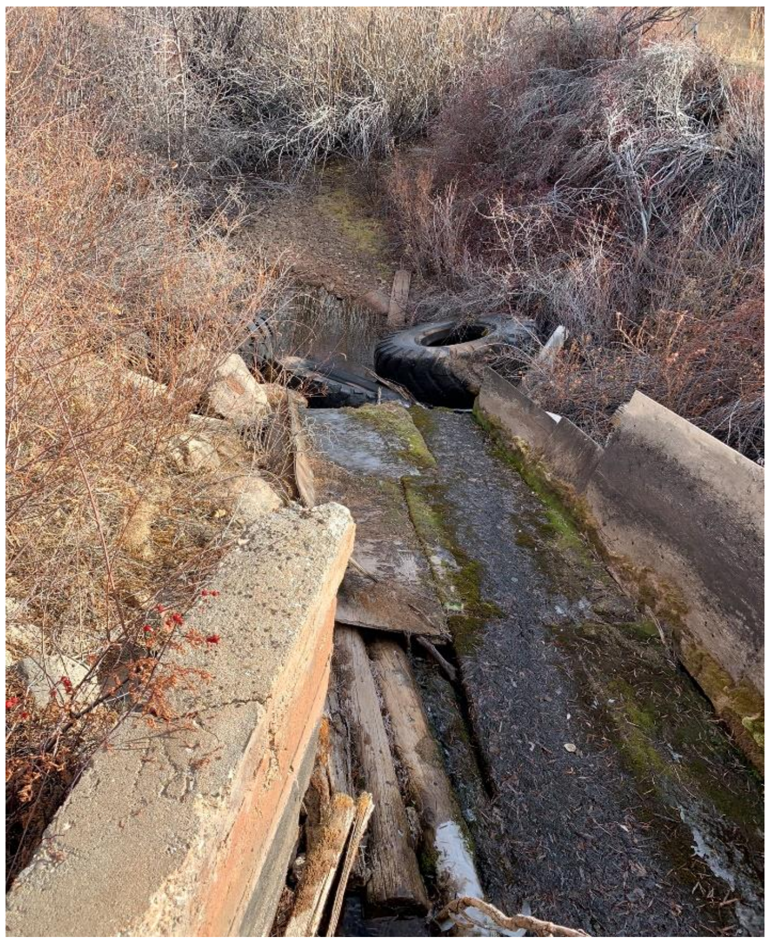


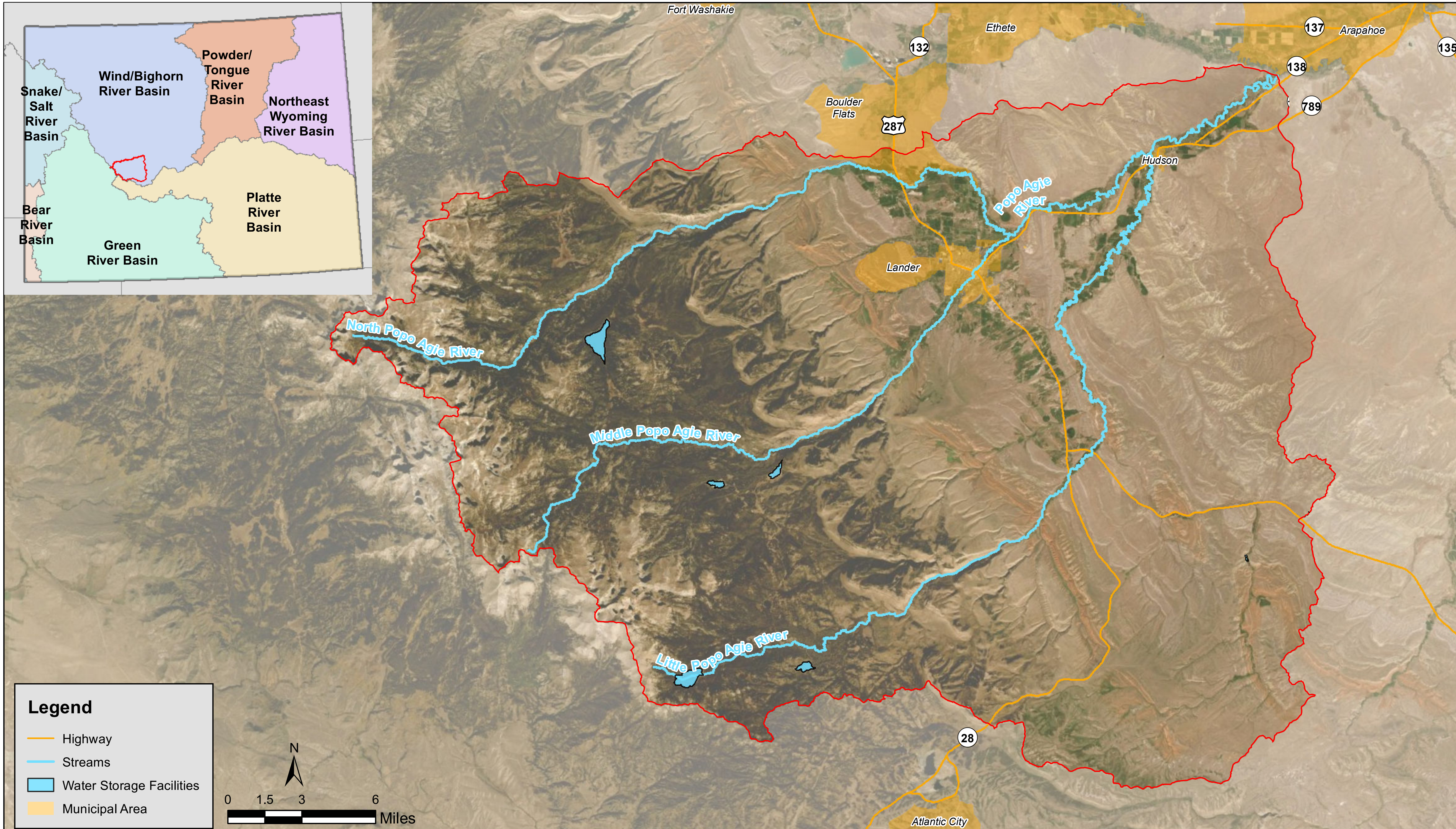
Photo 2. Example Irrigation Infrastructure Identified for Repair in ACE 2003.

In response to the ongoing water issues, the Popo Agie Watershed Healthy Rivers Initiative (HRI) was established in 2016 to build a working group that encompasses all stakeholder groups within the Popo Agie Watershed that are interested in water resources. The working group was formed to help strategize and build upon past efforts while working toward the long-term solution of improving the water quality and quantity of the Popo Agie Watershed.

One of the first things the group did was pursue funding to analyze the viability of three specific ways to address the late-season flow issues in the watershed. Since the majority of proposed irrigation improvement projects listed in the 2003 Level I watershed study (ACE 2003) were completed, the group applied for an update to the 2003 study that addresses the three specific types of projects the group proposed as most likely to be successful in the Popo Agie: (1) additional irrigation infrastructure improvements; (2) microstorage opportunities; and (3) potentially, aquifer storage and recovery (ASR) projects. But before the specific projects were identified, the HRI group asked that the water budget developed in 2003 be updated to help drive project prioritization. The WWDC funded the application. Since this study is a follow-up to the 2003 Level I watershed study (ACE 2003), the title Level I, Phase II was coined.

1.1.2. The Popo Agie Watershed

A full description of the Popo Agie Watershed was provided in the 2003 Level I watershed study and is not repeated here (ACE 2003). The following provides a brief description of the watershed. The Popo Agie Watershed is located on the eastern slope of the Wind River Range in Fremont County, Wyoming (**Figure 1.1**). The watershed can be subdivided into three subbasins – the North, the Middle, and the Little Popo Agie rivers – as illustrated in the PACD's watershed map (**Figure 1.2**). As described on the PACD website, popoagie.org, these streams are fed by annual snow melt and seasonal precipitation. The headwaters begin at the Continental Divide in the Wind River Range, and the watershed ends near Riverton, where the Popo Agie River joins the Little Wind River.



POPO AGIE WATERSHED STUDY	olsson WENCK	FIGURE
Project Location		1.1

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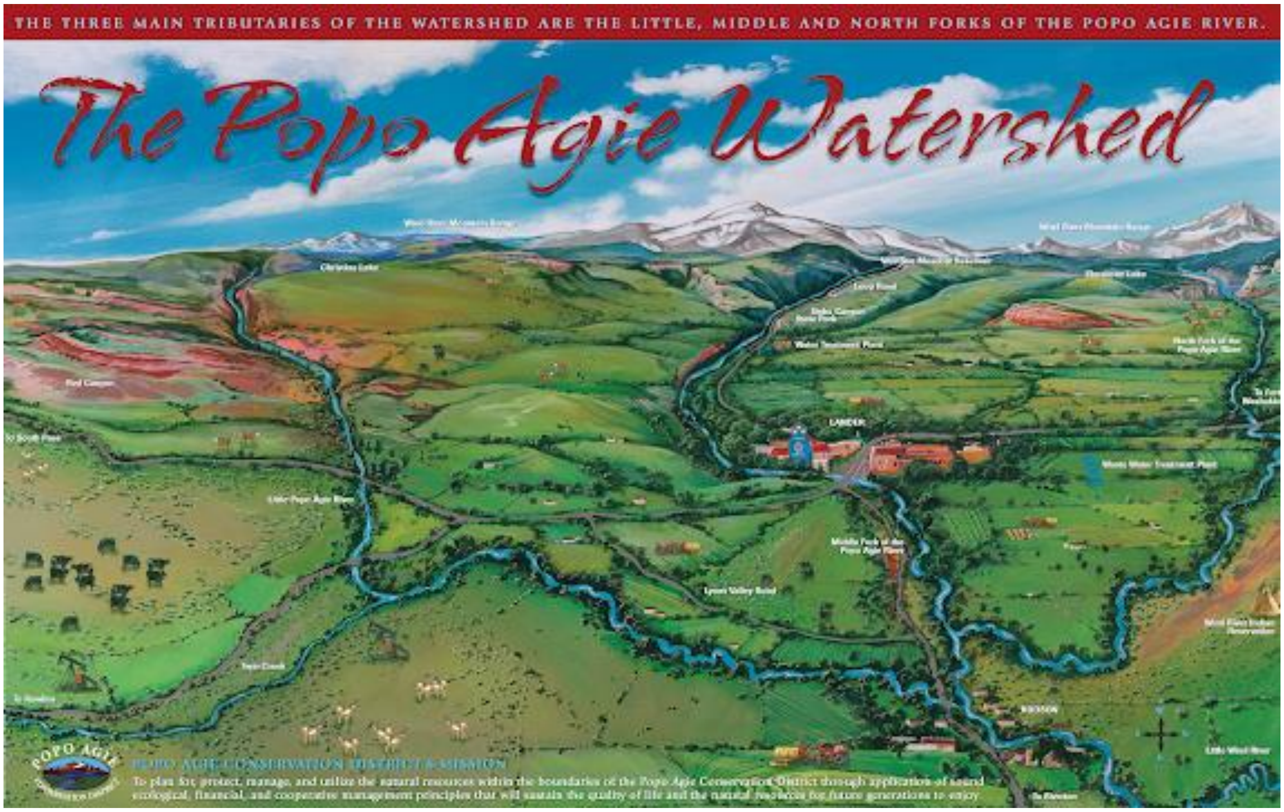


Figure 1.2 The Three Main Tributaries of the Popo Agie Watershed (PACD 2014).

Climate within the Popo Agie Watershed varies, depending on the elevation and season. Elevation ranges from over 13,000 feet above sea level at Wind River Peak (13,976 feet), to 5,000 feet above sea level near the town of Hudson. The Wind River Range creates a “rain shadow” effect by blocking moisture arriving from the Pacific Ocean, creating a semiarid climate. On average, the Lander area receives approximately 13.2 inches of annual precipitation, most of which arrives when upslope conditions are present. Temperatures also vary, with summer extremes reaching 100 degrees Fahrenheit and winter lows plunging well below zero.

The geology of the Popo Agie Watershed is widely varied and unique. The three main tributaries of the Popo Agie River originate in the igneous and metamorphic rocks of the Wind River Range. Precambrian granite is found in abundance at the high elevations and forms the peaks of the Wind River Range (PACD 2019). Much of the Popo Agie Watershed was eroded and partially covered with colorful sedimentary deposits of shale, claystone, and sandstone. The formations include the pink and orange Nugget Sandstone and the vibrant red Chugwater Formation, which form the spectacular cliffs and valleys of Red Canyon (**Photo 3**).

Photo 3. Sedimentary Rocks Exposed in Red Canyon.

The geology of the Popo Agie Watershed includes important natural features including a unique feature called the "Sinks and Rise." The Sinks, located in Sinks Canyon State Park, is where the Middle Fork of the Popo Agie River disappears into a fractured limestone deposit called the Madison Formation (**Photo 1**). The river then runs underground for an estimated one-quarter mile, where it reappears in a large, trout-filled pool known as the Rise. The Sinks and Rise and nearby waterfalls are popular tourist destinations in the area.

1.2. Key Issues in the Watershed

The Popo Agie Watershed faces some significant water issues. This watershed study was initiated to address late-season low-flow conditions in the Middle Fork of the Popo Agie River and conversely, high-water table issues causing flooded basements and city road maintenance issues. Specifically, for this project, there are three explicit technical focuses: (1) a water budget investigation and irrigation infrastructure upgrades; (2) microstorage opportunities; and (3) the feasibility of groundwater storage and recovery. Each of these topics was identified to help address the water issues, which range from too much water in some areas to too little in others. But that is not all. The project is not only a technical challenge that involves understanding the interconnections between groundwater and surface water, but it also requires a deep understanding of the interconnections of the people, plants, and animals that live and thrive in this watershed.

At the outset of the project, the PACD and the HRI's many partners (including the City of Lander, The Nature Conservancy, the Wyoming Department of Environmental Quality [WDEQ], and Wyoming Game and Fish) said they would identify this project a success if the project:

- Identifies ways to increase late-season flows in the Middle Fork of the Popo Agie River
- Includes an updated water model that incorporates all the new water gaging data
- Includes an understanding of how return flows affect the water budget
- Uses data as the foundation for water management decision making
- Engages all representatives of all water users including all those participating in the HRI
- Incorporates water management solutions that recognize that irrigation ditches are interconnected and that making a positive change to one may negatively affect another
- Identifies opportunities to move water from under-allocated areas to over-allocated areas
- Identifies data gaps so they can be filled in the future

1.3. Purpose and Scope

1.3.1. Review of Existing Data

The first step of every watershed study is to collect and review existing scientific and engineering data on the watershed. Specifically, for the Popo Agie Watershed, the area has been studied extensively because of its unique geologic, environmental, and ecological aspects. Since this is a Level I, Phase II watershed study, the evaluation was based on information gathered since 2003. The primary sources of information used in this study were published scientific reports and datasets from the following federal and state agencies and local organizations:

- U.S. Environmental Protection Agency (EPA)
- U.S. Department of the Interior
  - Bureau of Land Management (BLM)
  - U.S. Geological Survey (USGS)
  - U.S. Fish and Wildlife Service (USFWS)
  - U.S. Bureau of Reclamation
- U.S. Department of Agriculture (USDA)
  - Farm Service Agency (FSA)
  - Forest Service (USFS)
  - Natural Resources Conservation Service (NRCS)
- Wyoming Department of Environmental Quality (WDEQ)
- Wyoming Game and Fish Department (WGFD)
- Wyoming Geographic Information Science Center (WyGISC)
- Wyoming Oil and Gas Conservation Commission
- Wyoming State Engineer's Office (WYSEO)
- Wyoming State Geological Survey (WSGS)
- Wyoming Water Development Commission (WWDC)
- Wyoming Wildlife and Natural Resources Trust

A reference list is provided at the end of this report that includes the reports, studies, websites, and databases used as the foundation of this study.

1.3.2. Three Focus Areas

Since this project is a follow-up to the Level I study completed in 2003 (ACE 2003), the scope is narrowly focused on the three areas identified by the project sponsor that will provide the needed updates based on new technologies and updated datasets. The three focus areas for this Level I, Phase II watershed study as defined in the scope of work included:

- Water Budget Investigation and Irrigation Infrastructure Assessment
- Microstorage Facilities Investigation
- Aquifer Storage and Recovery

The primary goals of each topic are as follows:

- Update the water budget with recent water monitoring data and use the new water budget to describe the hydrology of the Popo Agie River watershed including quantification of significant natural and anthropogenic inputs to, and outputs from, the system.
- Use the water budget to identify where and when there are water surpluses and deficits in the Popo Agie Watershed and to prioritize both future implementation projects to address water quantity issues, and identify future study needs.
- Identify potential irrigation improvements that will deliver the greatest increases in efficiency and provide the water to address the deficits identified in the updated water budget.
- Identify potential locations for microstorage facilities off main river channels that will enable irrigators to hold water in the system for use later in the irrigation season.
- Assess the potential for capturing surface water at certain times of the year to store underground, to recharge the groundwater resource, and to enhance late-season water availability.

1.3.3. Geographic Information System (GIS)

Much of the information gathered as part of the watershed study is compiled into a geographic information system (GIS) dataset. The GIS dataset is an electronic repository of the information gathered during the investigations and analysis for the project. The information includes mapped datasets on soil, geology, vegetation, and infrastructure that is represented in a series of layers that can be evaluated spatially. A list of the GIS layers developed for this project is provided in **Table 1.1**. The GIS datasets will be provided to the PACD and WWDC. With the datasets, the PACD and agencies that manage the public lands in the Popo Agie Watershed will have the opportunity to overlay a series of maps to discern patterns, site proposed projects, and/or refine project plans based on the information presented in the digital map sets.

Table 1.1 GIS Datasets and Layer Information

Data Name in Map	Directory in Geodatabase	Filename in Geodatabase
U.S. Census Bureau (USCB)		
County Border	Administrative	TIGER_Counties
Major Road	Infrastructure	TIGER_Roads
Municipal Area	Administrative	TIGER_Place
State Border	Administrative	TIGER_States
U.S. Department of Agriculture (USDA)		
SSURGO Soils	Geology	SSURGO_Soils
U.S. Geological Survey (USGS)		
Gaging Station	Hydrology	GagingStation
Major Waterbody	Hydrology	WaterStorageFacilites
PACD Tributaries	Hydrology	PACD_Tributaries
Rivers and Streams	Hydrology	NHD_PopoAgieFeatures
U.S. Fish and Wildlife Service (USFWS)		
National Wetland Inventory	Hydrology	NationalWetlandInventory
Anderson Consulting Engineers (ACE, 2003)		
Ditches	Hydrology	Ditches
Ditch Link	Hydrology	DitchLink
Siphon	Hydrology	Siphon
Irrigated Acreage	Hydrology	IrrigatedAcreage
Subwatershed Boundaries	Hydrology	SubwatershedBoundaries
Bedrock Geology	Geology	BedrockGeology
ASR Location	Hydrology	ASR_Location
Water Treatment Plant	Hydrology	WaterTreatmentPlant
Test Well	Hydrology	TestWell
Infiltration Gallery	Hydrology	InfiltrationGallery
Distance from River for ASR	Hydrology	DistanceFromRiverForASR
Developed for Project (Olsson/Wenck, 2019)		
Approximate Water Surface	Improvements	MicrostorageWaterSurface
Ditch Improvements	Improvements	DitchImprovements
Lining Extent	Improvements	LiningExtent
Popo Agie Watershed Boundary	Hydrology	PopoAgieWatershed
Potential Microstorage Site	Hydrology	PotentialMicrostorageLocation
Top of Dam	Improvements	MicrostorageTopOfDam
Unsuitable Soils	Geology	SSURGO_Soils_Unsuitable
WTP Top of Dam	Improvements	WTP_TopOfDam
WTP Water Surface Extent	Hydrology	WTP_WSE_WaterSurface

2.0 PROJECT MEETINGS AND PUBLIC PARTICIPATION

2.1. Healthy Rivers Initiative

HRI was established in 2016 to build a working group that encompasses all stakeholder groups within the Popo Agie Watershed interested in water resources. These local leaders, landowners, and water users have been the core stakeholders in this watershed project. Since its inception and with the funding provided by the LOR Foundation, HRI has:

- Brought water users together to identify, develop, and implement voluntary measures and best management practices for managing water during low flows in ways that honor existing water rights.
- Supported existing partnerships and new opportunities that seek to reduce levels of E. coli contamination in the Popo Agie River on a consistent basis.
- Enhanced community education and outreach regarding healthy rivers and the importance of understanding the watershed.
- Synchronized project priorities to successfully compete for limited resources.

For more information on the HRI, visit the website:

https://sites.google.com/view/popoagieconservationdistrict/healthy-rivers-initiative

HRI

The Vision: The Popo Agie River and its tributaries are free from water quality impairment and sustain healthy flows that support all uses of the watershed for future generations.

The Mission: To facilitate a strategic, stakeholder-driven initiative that ensures the vitality of the Popo Agie River by improving water quality, quantity, and the biological health of the river so that it better supports domestic, agricultural, recreation, fish, and wildlife uses.

Healthy Partnerships Support Healthy Rivers

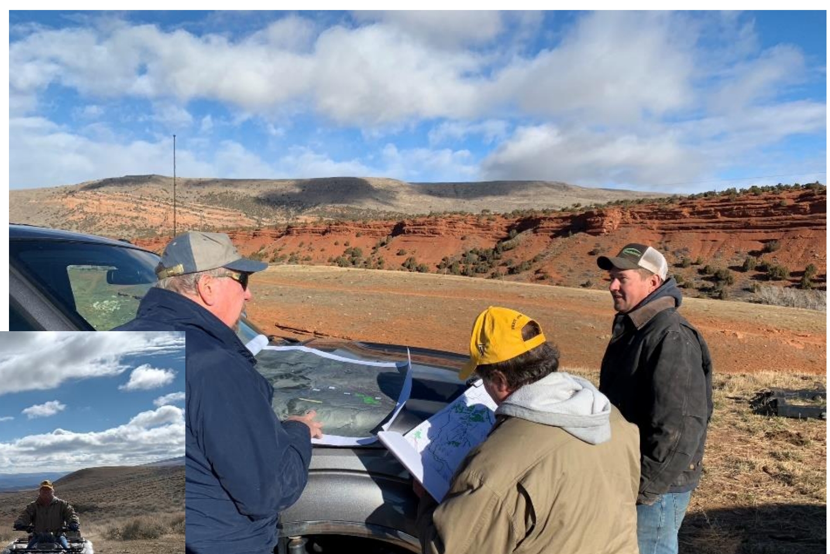
2.2. Project Meetings

Word got out about this Level I, Phase II watershed study at a public forum organized and sponsored by HRI in March 2018. At the forum, the public was invited to learn about the water issues facing the Popo Agie Watershed and some of the opportunities for improvement. Topics presented at the forum included the following:

- Understanding your irrigation system
- Microstorage opportunities for your operation
- Groundwater storage and recovery opportunities
- Fisheries of the Popo Agie River
- Popo Agie subbasin: environmental and recreational use
- Water regulation in Wyoming
- Subdivisions and water law in Fremont County

As listed above, the first three items on the forum's agenda match the three topics of focus for this project. And so, it was the forum, attended by over 200 local water users, that began the public engagement that has been the cornerstone of this watershed study.

For this project, a formal scoping meeting was held in June 2018, and two project meetings open to the public were held in the fall of 2018. Throughout the winter, conference calls were conducted with the HRI working group to discuss progress on the project and to provide a forum for discussion and project refinement. In early summer 2019, another project meeting was held at the Lander Community Center, where a synopsis of the project findings on microstorage and aquifer storage and recovery were discussed.



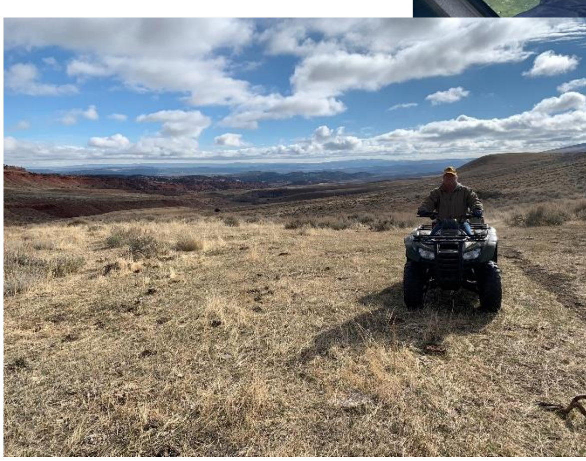


Photo 4. Two photographs from the site visit to the Enterprise Irrigation Ditch.

These project meetings and conference calls have been invaluable to the project's technical team in ensuring that improvement opportunities identified in the watershed study will be accepted and supported by the local landowners. After each project meeting, the Olsson/Wenck technical team members visited some of the proposed irrigation improvement sites with local landowners and land stewards (**Photo 4**). These site visits were critical for the Olsson/Wenck team members to understand the broader context of the water issues and to hear directly how improvements might enhance watershed function.

For more information on the project meetings, see **Appendix A** for the project meetings minutes. Figure 2.1 provides an example of a meeting announcement. The meeting minutes for the HRI conference calls are on the HRI website:

https://sites.google.com/view/popoagieconservationdistrict/healthy-rivers-initiative

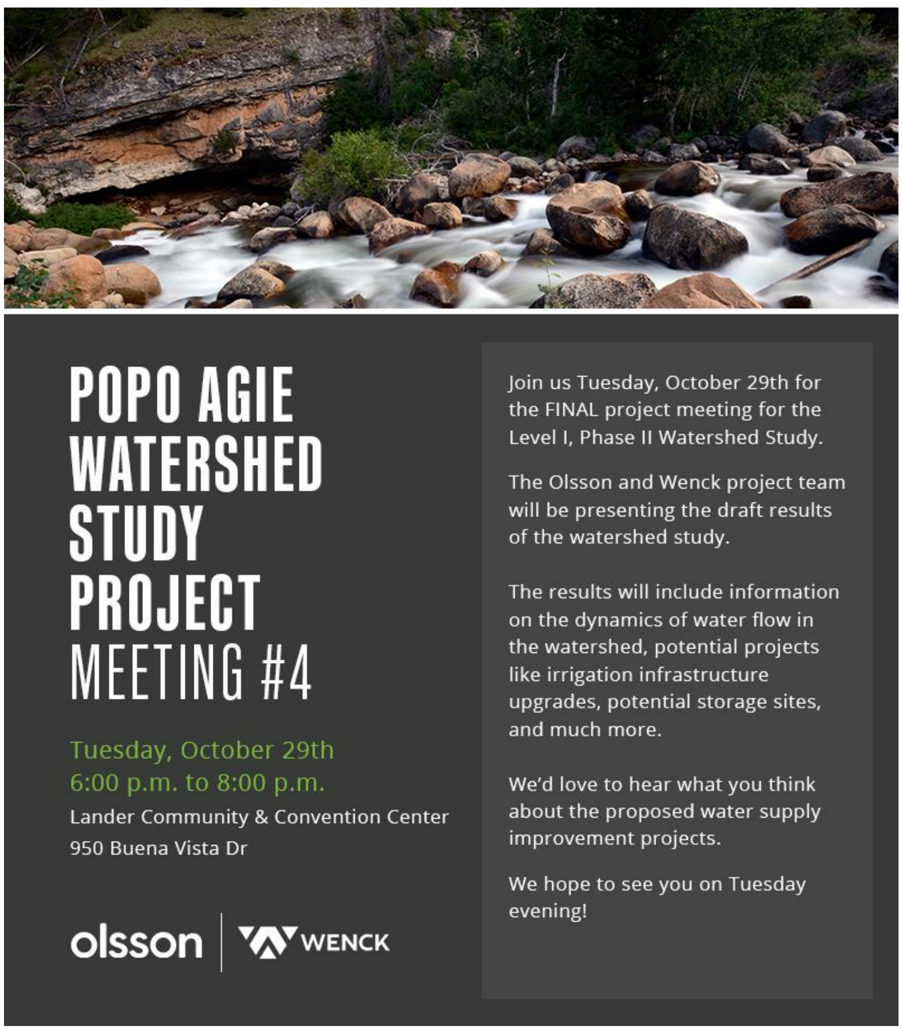


Figure 2.1. Example Meeting Announcement.

3.0 WATER BUDGET INVESTIGATION

One of the first items the HRI stakeholder group wanted to better understand was, "Does our watershed have excess water that could be used to address the seasonal water shortages facing irrigators and other water users across the Popo Agie Watershed?" For this reason, the first part of the study focused on updating the water budget model presented in the Phase I Level I watershed study (ACE 2003) (**Figure 3.1**).

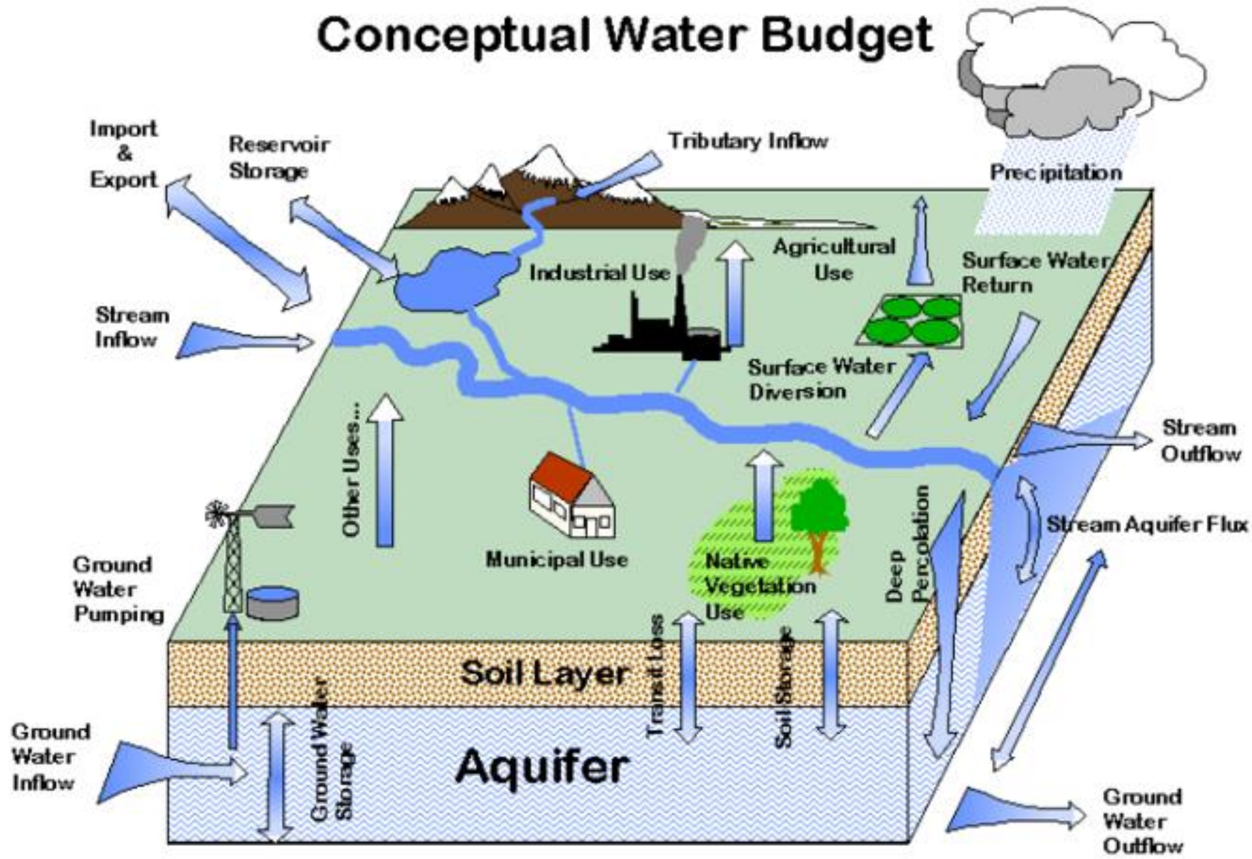


Figure 3.1 Conceptual Water Budget (Oram 2014).

This section documents the updates completed by the Olsson/Wenck team to the water budget model (Model) that was developed for the 2003 study (ACE 2003). The Model was updated based on information developed from the previous studies, data collected during the site assessment task for this project, and guidance from the sponsor and the WWDC project manager. Such updates include, but are not limited to, incorporation of new USGS gage data; new hydrologic information on ditch systems; inflows and outflows; seepage losses; and withdrawals.

Please refer to the Popo Agie River Watershed Study, Level I, Final Report Technical Memorandum for detailed information on Model development (ACE 2003). For this Level I, Phase

II Study, ACE's Model was refined with the incorporation of new information to better assess current water availability within the Popo Agie Watershed. Model results were used to assist in the microstorage reservoir evaluation and location selection as well as the ASR portion of this watershed study. In addition, the PACD, Popo Agie Watershed water users, and the State of Wyoming can use the Model as a planning tool when considering future water use and development.

A conceptual water budget model is an accounting of water stored within and water exchanged between hydrologic and man-made compartments of a watershed, such as aquifers, surface water, diversions, or reservoirs. Conceptual water budgets are useful tools in developing an understanding of how and where water moves within a system to meet the goals of rehabilitation, storage opportunities, water use development, and planning.

An illustration of a conceptual water budget is presented in **Figure 3.1**. As can be seen from the figure, many different water uses can be incorporated into a conceptual water budget. The updated Model does not include every conceivable aspect of a conceptual water budget, but it rather focuses on a few key pieces such as stream flows, diversions, and return flows.

Updates to the Model were included where new data were available and are discussed further in Section 3.1.2. Otherwise, the Model was used as is, assuming Model calculations, processes, and assumptions are accurate. The Model *does not* account for water rights appropriation. It is assumed that flow is available for upstream diversions despite the existence of downstream senior water rights. Additionally, the Model does not account for antecedent moisture conditions. Information presented herein was communicated to the PACD, members of the HRI, the City of Lander, and the public through a series of public meetings. Public information meeting notes and a list of attendees can be found in **Appendix** A.

3.1. Popo Agie River Watershed Model

3.1.1. Model Overview

The Model is a series of water accounting spreadsheets that incorporate streamflow, consumptive use, diversions, and irrigation returns data. Each spreadsheet in the Model represents one calendar year of streamflow data assessed monthly. The Model is divided into 16 subreaches and four reaches (**Figure 3.2**) based on the availability of flow data and geographic features (stream confluences, major tributaries, etc.) discussed in the 2003 ACE report. Furthermore, the three versions of the Model reflect each of the hydrologic conditions: wet-, normal-, and dry-year water supply for a study period of 1971 to 2016. More information is provided in Section 3.1.2.1 regarding the determination of wet, normal, and dry years.

Model reaches are comprised of nodes which consist of USGS gaging stations, synthetic gages, points of diversion, and stream confluences. Eighty-one nodes are incorporated into the Model (**Figure 3.3**). A water balance is performed at each node to determine the volume of inflow to the downstream node. The water balance accounts for tributary inflow, imports/exports, and irrigation diversion and return flows. Where water demands for a downstream node exceed available flow, the Model will divert all available flow to the diversion, creating a water shortage. Water shortages result in zero flow (inflow) available for the downstream node. If this occurs, the Model will alert the user of a shortage. An example of water balance for two Model nodes is shown in **Figure 3.4**.

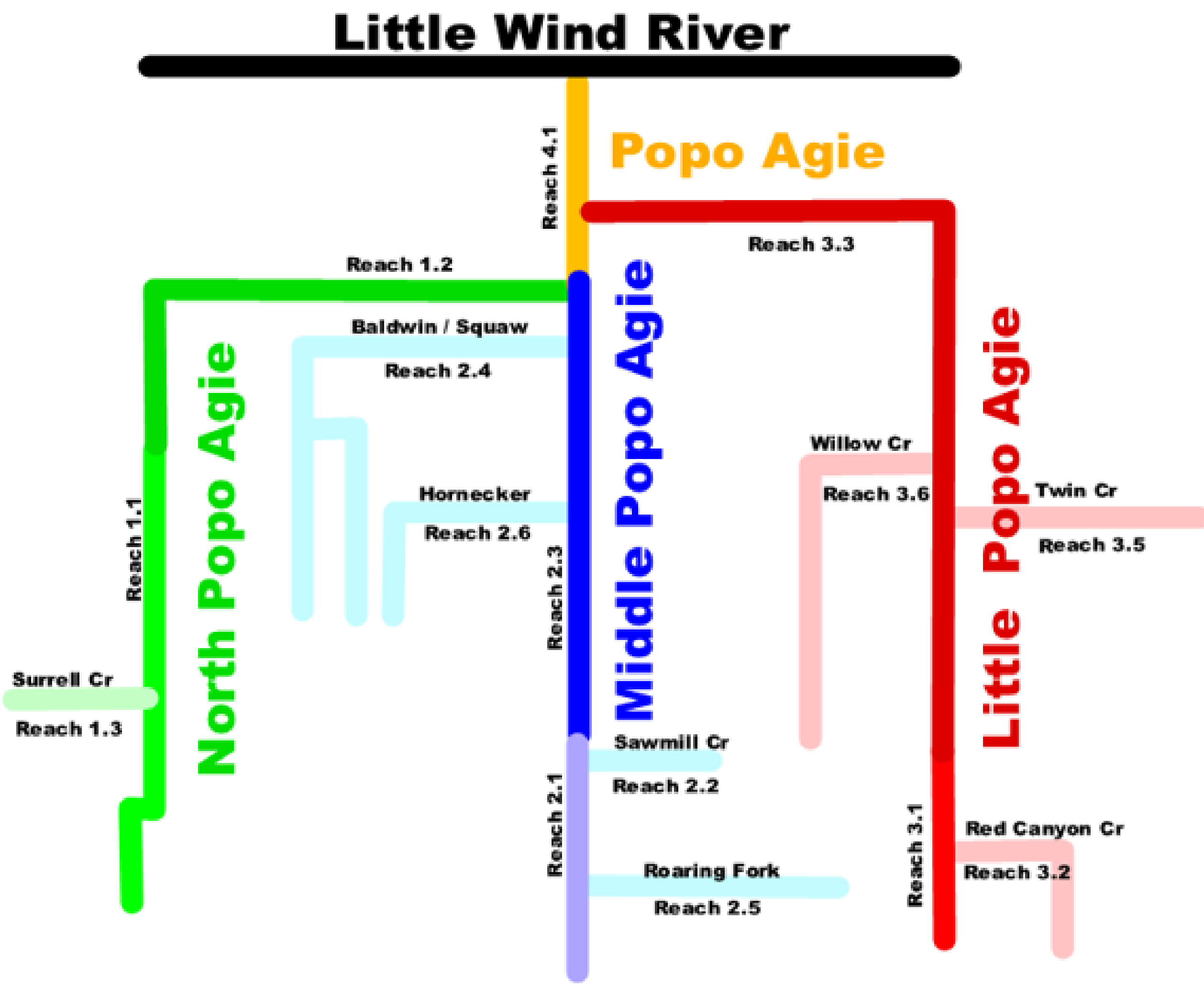
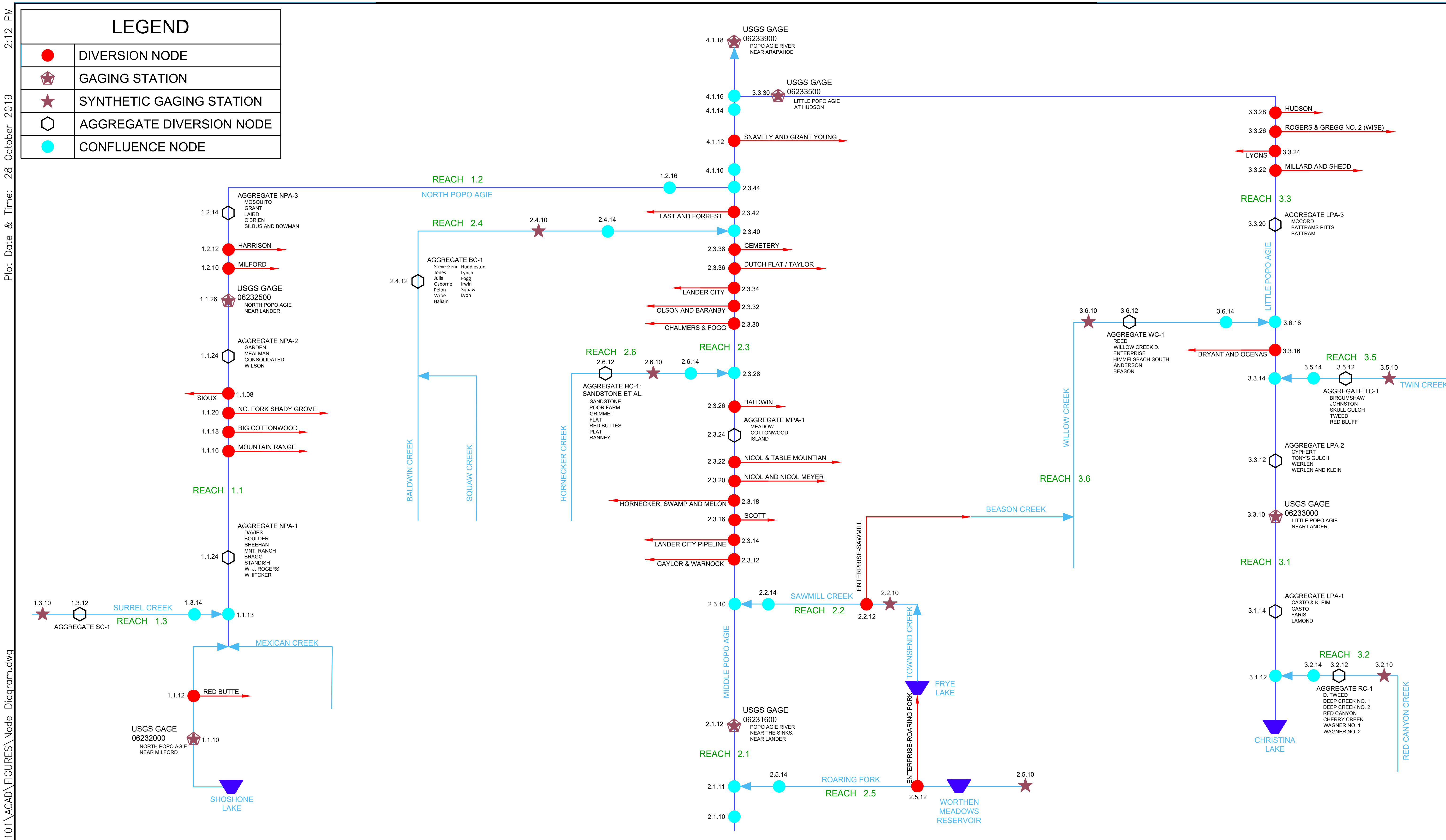


Figure 3.2 Model Reach Diagram from ACE 2003.



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DWN BY	CHK'D	APP'D	PROJECT	SHEET TITLE
NRA	CMJ		POPO AGIE LEVEL I WATERSHED STUDY, PHASE II	MODEL NODE DIAGRAM
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Oct–19			WYOMING WATER DEVELOPMENT COMMISSION	FIGURE 3.3
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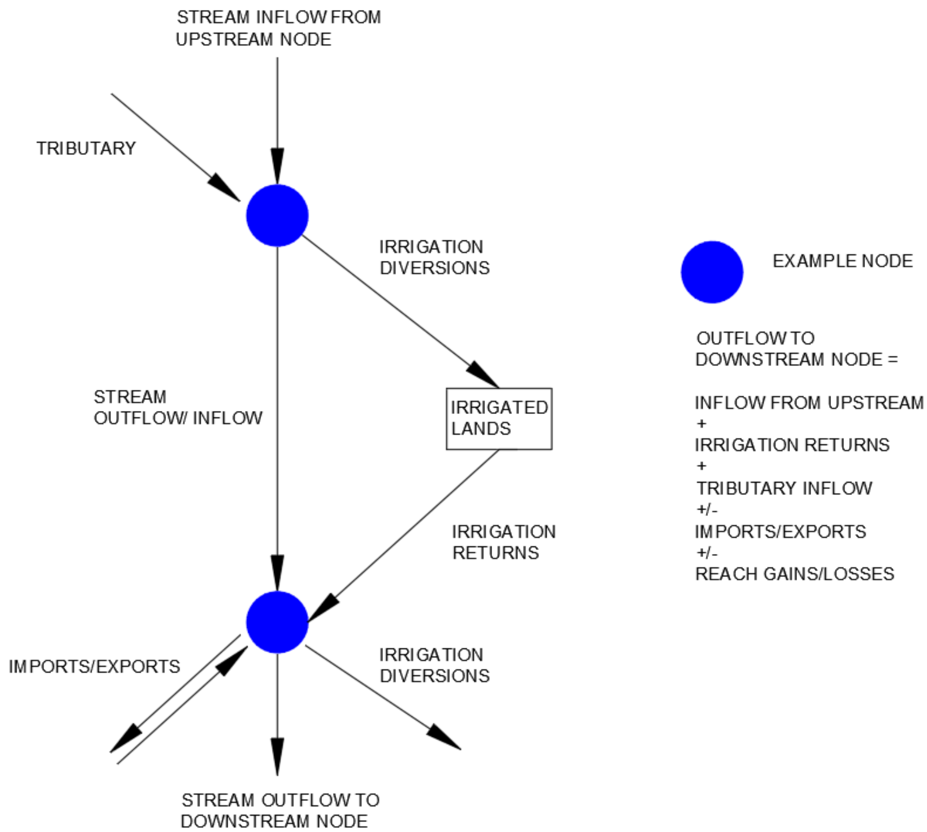


Figure 3.4 Water Balance Computation.

Ungaged stream gains (ungaged tributaries, groundwater inflow, and irrigation return flows from unspecified diversions) and losses (seepage, evaporation, and unspecified diversions) for individual reaches are computed as the difference between average historical gage flows. Losses and gains are added and subtracted respectively at the beginning and end of a reach.

Model output spreadsheets document the computed outflows and diversions for each reach and individual node. Should the Sponsor choose to progress to a Level II study, the Model can be used to evaluate impacts of specific irrigation infrastructure improvements, storage development, and other water-related projects.

3.1.2. Model Updates

Where new data were available, the Model was updated to reflect this data. Model updates discussed in the following sections include incorporation of USGS streamflow data, and updates related to diversion estimates. After updates were completed, the Model was validated by comparing the observed monthly flow volumes with Model predictions for normal years. For example, for the latter part of the irrigation season, the measured flow in the Middle Popo Agie River through Lander during normal years is 430 acre-feet per month or an approximate average daily flow of 7.0 cubic feet per second (cfs). For August of a normal year, the Model predicts a monthly volume of 433 acre-feet or an average daily flow of 7.1 cfs. Thus, with the data updates, the Model predicted normal flow conditions to within 1 percent of the actual measured conditions.

3.1.2.1. Streamflow Data

A statistical analysis of existing monthly gage hydrologic data was conducted for the determination of wet-, normal-, and dry-year flows in the Popo Agie River Watershed. First, annual streamflows were assessed for key stream gages to determine which years (1971-2016) are statistically considered wet, normal, or dry. Next, monthly stream gage data for each hydrologic condition (wet, normal, and dry) was averaged for input into the Model.

Surface water flow data from the USGS National Water Information System: Web Interface was used for the analysis. The period of record from 1971 to 2000 from the 2003 ACE report was extended to include available gage data from 2001 to 2016. Regression methods recommended in the Wyoming Integrated River System Operation Study (WIRSOS) model were employed to fill in missing data or to complete records. Key stream gages used in the hydrologic assessment are listed in **Table 3.1** and are identified geographically in **Figure 3.5**. It was assumed that annual flow variability would be consistent throughout a given tributary. Key gages were therefore chosen based on quality of data (i.e. greatest temporal extent, minimal data gaps and recent data) and spatial distribution (at least one gage per tributary). In instances where no one gage on a tributary offered a quality dataset, two gages were used in the determination of annual variability for that tributary.

Table 3.1 U.S. Geological Survey Stream Gage Data for the Popo Agie River Basin.

		Period of Record in Calendar Years Discharge	
Station Number	Station Name	Average Daily	Annual Peak
06231600	Middle Popo Agie River below the Sinks, near Lander	1959-68 1998-2017*	1960-74
06232000	North Popo Agie River, near Milford	1945-63	1946-63
06232500	North Popo Agie River, near Lander	1938-53	1938-53
06233000	Little Popo Agie River, near Lander	1964-2019	1946-2017
06233900	Popo Agie River, near Arapahoe	1990-95	1980-95

* Data from 1998 to 2017 was obtained from the WYSEO database.

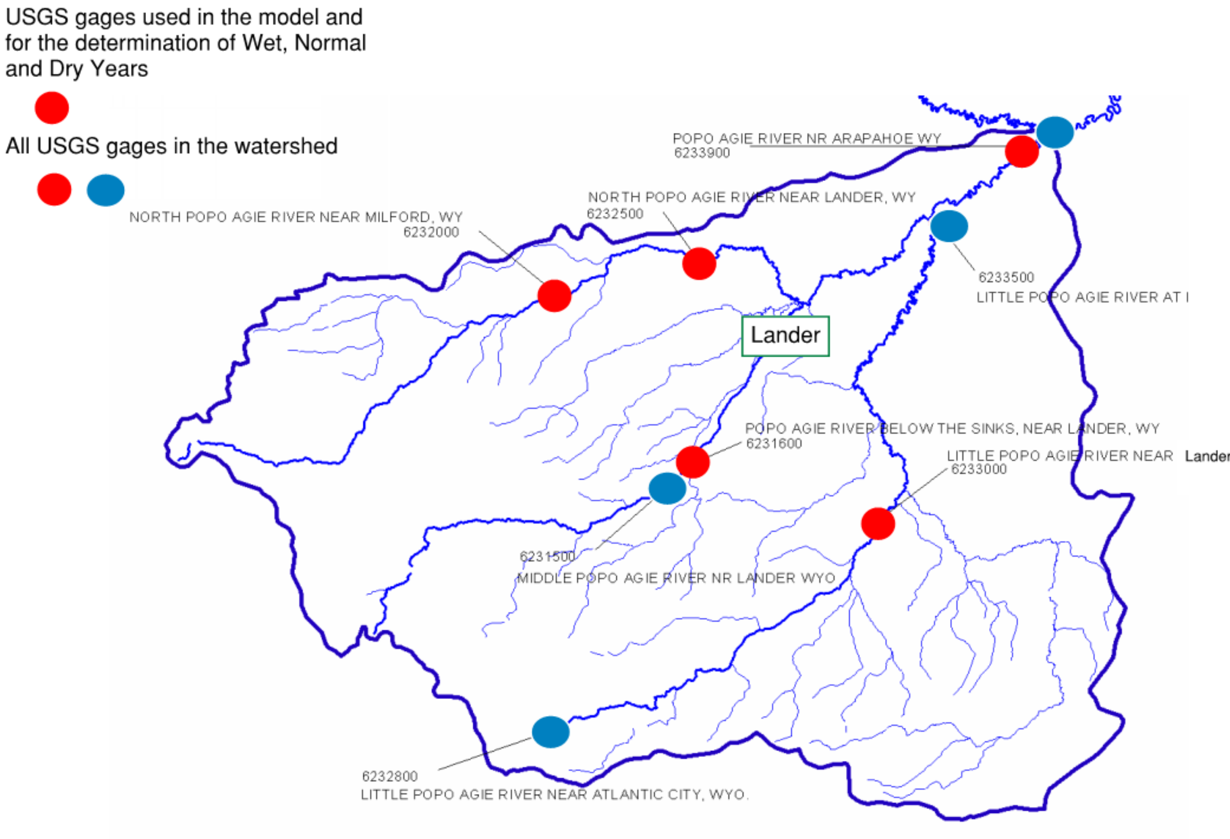


Figure 3.5 Watershed U.S. Geological Survey Gages, Modified from ACE 2003.

As an example**, Figures 3.6 and 3.7** show the available monthly mean discharge data (cfs) for the period of record for two of the USGS gages, 06231600 and 06233900 used in the analysis of wet, normal and dry years. As can be seen in the graphs, some data within each year is incomplete and there are entire years for which no gaging data was available. Incomplete and missing data was filled in for the study period of 1971 to 2016 using the regression methods described above. The graphs below illustrate how monthly mean discharge can vary from year to year. For instance, for USGS gage 06231600, monthly mean discharge in June of 1961 is approximately half of the monthly mean discharge in June of 1965. Furthermore, the graphs demonstrate how mean monthly discharges change throughout the year. For example, for USGS gage 06233900, peak flow generally occurs in the month of June, with substantial decreases in flow throughout the late summer due to irrigation diversions and decreasing snowmelt. It is through the statistical analysis that the Olsson/Wenck team was able to classify the hydrologic condition of the Popo Agie Watershed and identify typical wet, normal and dry year flows for use in the water budget model.

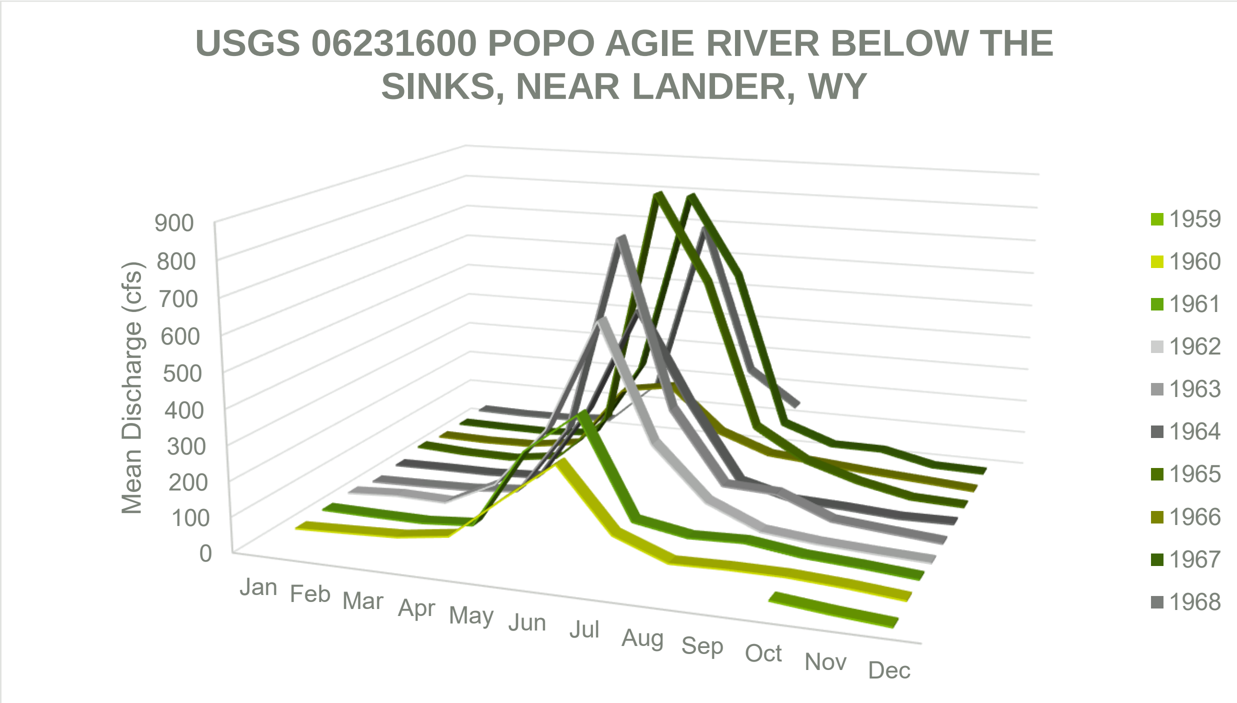


Figure 3.6 U.S. Geological Survey Stream Gage Data (06231600)

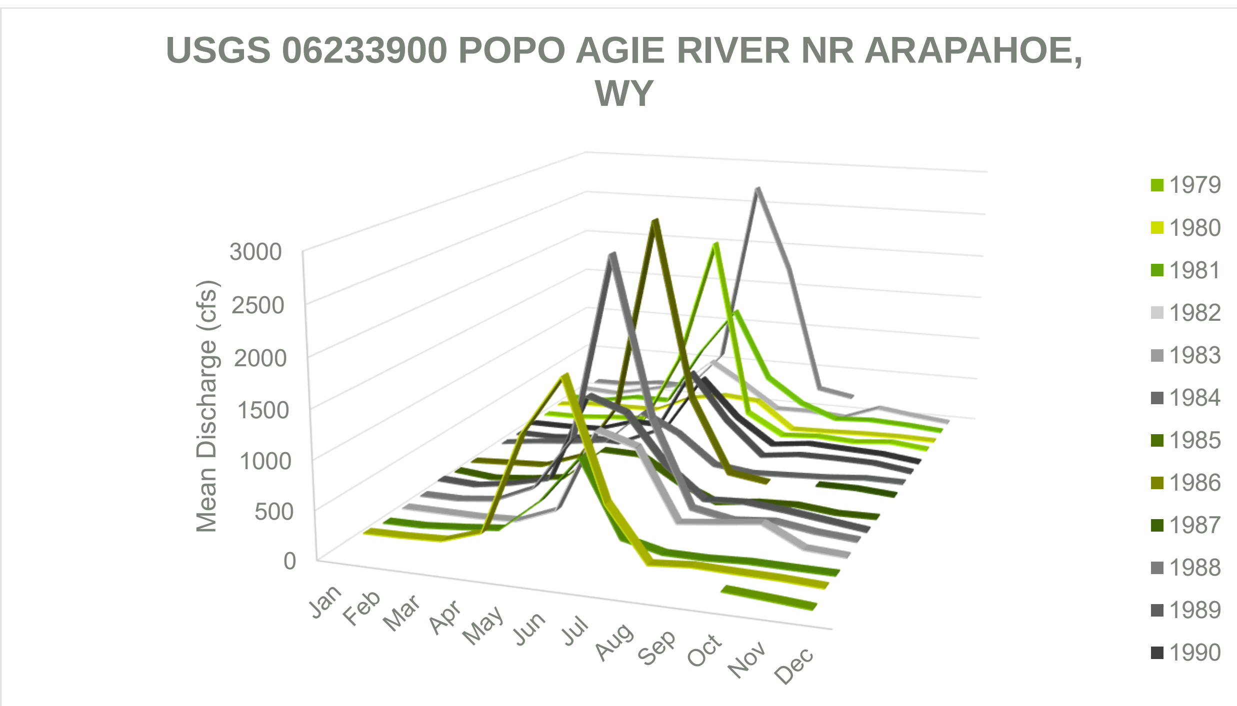


Figure 3.7 U.S. Geological Survey Stream Gage Data (06233900)

To determine the wet, normal, and dry years, the total annual flow in acre-feet per year that passed each of the key gage stations was ranked from largest to smallest. A graphic representation of this ranking for one of the gages (USGS gage 06231600) is shown in **Figure 3.8**. Ranks were used to determine the nonexceedance probability of a given annual flow volume at each gage. For example, the 1995 annual streamflow volume for USGS gage 06231600 (170,869 acre-feet per year) has a nonexceedance probability of 97.9. This means that the probability of the flow volume exceeding 170,869 acre-feet per year in any given year is 2.1 percent (100 minus 97.9).

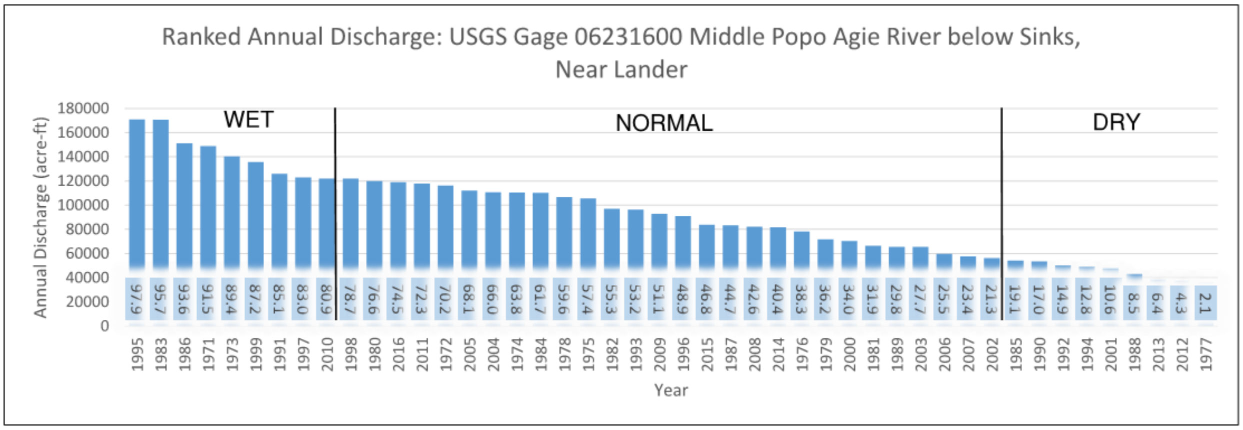


Figure 3.8 Ranked Annual Streamflow.

Years in the bottom 20 percent of ranked values were considered dry years, years in the top 20 percent were considered wet years, and the remaining middle 60 percent were considered normal years. Using this method, the wet, normal, and dry years were determined for each of the key gages. Next, the average monthly flow volumes for each gage were computed for each hydrologic condition and input into the model. **Table 3.2** provides the results of the hydrologic assessment.

Table 3.2 Hydrologic Condition for Key Stream Gages.

	Little Popo Agie River near Lander	Middle Popo Agie River below Sinks near Lander	Popo Agie River near Arapahoe	North Popo Agie River near Lander	North Popo Agie River near Milford	Basinwide Condition
Year	USGS 6233000	USGS 6231600	USGS 6233900	USGS 6232500	USGS 6232000	
1971	Wet	Wet	Wet	Wet	Wet	Wet
1972	Normal	Normal	Normal	Normal	Normal	Normal
1973	Wet	Wet	Wet	Wet	Wet	Wet
1974	Normal	Normal	Normal	Normal	Normal	Normal
1975	Normal	Normal	Normal	Normal	Normal	Normal
1976	Normal	Normal	Normal	Normal	Normal	Normal

	Little Popo Agie River near Lander	Middle Popo Agie River below Sinks near Lander	Popo Agie River near Arapahoe	North Popo Agie River near Lander	North Popo Agie River near Milford	Basinwide Condition
Year	USGS 6233000	USGS 6231600	USGS 6233900	USGS 6232500	USGS 6232000	
1977	Dry	Dry	Dry	Dry	Dry	Dry
1978	Normal	Normal	Normal	Normal	Normal	Normal
1979	Normal	Normal	Normal	Normal	Normal	Normal
1980	Wet	Normal	Normal	Normal	Normal	Normal
1981	Normal	Normal	Normal	Normal	Normal	Normal
1982	Normal	Normal	Normal	Normal	Normal	Normal
1983	Wet	Wet	Wet	Wet	Wet	Wet
1984	Normal	Normal	Normal	Normal	Normal	Normal
1985	Normal	Dry	Normal	Normal	Normal	Normal
1986	Wet	Wet	Wet	Wet	Wet	Wet
1987	Normal	Normal	Normal	Normal	Normal	Normal
1988	Normal	Dry	Dry	Dry	Dry	Dry
1989	Normal	Normal	Normal	Normal	Normal	Normal
1990	Normal	Dry	Normal	Normal	Normal	Normal
1991	Normal	Wet	Normal	Normal	Normal	Normal
1992	Dry	Dry	Normal	Normal	Normal	Dry
1993	Normal	Normal	Normal	Normal	Normal	Normal
1994	Normal	Dry	Dry	Dry	Dry	Normal
1995	Wet	Wet	Wet	Wet	Wet	Wet
1996	Normal	Normal	Normal	Normal	Normal	Normal
1997	Normal	Wet	Normal	Normal	Normal	Normal
1998	Normal	Normal	Wet	Wet	Wet	Wet
1999	Wet	Wet	Wet	Wet	Wet	Wet
2000	Normal	Normal	Normal	Normal	Normal	Normal
2001	Dry	Dry	Dry	Dry	Dry	Dry
2002	Dry	Normal	Dry	Dry	Dry	Dry
2003	Dry	Normal	Dry	Dry	Dry	Dry
2004	Normal	Normal	Normal	Normal	Normal	Normal
2005	Normal	Normal	Normal	Normal	Normal	Normal
2006	Dry	Normal	Dry	Dry	Dry	Dry
2007	Dry	Normal	Normal	Normal	Normal	Normal
2008	Normal	Normal	Normal	Normal	Normal	Normal

	Little Popo Agie River near Lander	Middle Popo Agie River below Sinks near Lander	Popo Agie River near Arapahoe	North Popo Agie River near Lander	North Popo Agie River near Milford	Basinwide Condition
Year	USGS 6233000	USGS 6231600	USGS 6233900	USGS 6232500	USGS 6232000	
2009	Normal	Normal	Normal	Normal	Normal	Normal
2010	Wet	Wet	Wet	Wet	Wet	Wet
2011	Normal	Normal	Normal	Normal	Normal	Normal
2012	Dry	Dry	Dry	Dry	Dry	Dry
2013	Dry	Dry	Dry	Dry	Dry	Dry
2014	Normal	Normal	Normal	Normal	Normal	Normal
2015	Normal	Normal	Normal	Normal	Normal	Normal
2016	Wet	Normal	Wet	Wet	Wet	Wet

3.1.2.2. Diversion Data

Estimates of monthly diversion volumes for each of the hydrologic conditions were computed for 38 diversion nodes. The "Diversion Estimates" spreadsheet in the Model incorporates the following irrigation components:

- Irrigated Acreage
- Irrigation Water Usage
  - Climate Data Collection
  - Crop Irrigation Requirement
  - On-farm Delivery Requirement
  - Ditch Diversion Requirement

Additionally, the "Diversion Estimates" spreadsheet uses conveyance and application efficiency to determine monthly diversion volumes where conveyance efficiency is the ratio of the volume of irrigation water delivered by a distribution system to the water introduced into the system, and application efficiency is the ratio of the average water depth applied and the target water depth during an irrigation event.

As a part of Model updates, the Olsson/Wenck team reviewed irrigation infrastructure improvements throughout the watershed and updated ditch conveyance efficiencies and irrigation methods as applicable in the Model. Additionally, the Olsson/Wenck team reviewed and incorporated pertinent diversion gage data from the WYSEO website (https://sites.google.com/a/wyo.gov/seo/).

Conveyance Efficiencies

Since the development of the 2003 Model, several irrigation diversions within the Popo Agie Watershed have had portions of their lengths lined to help improve conveyance efficiencies. The impact of these projects on ditch conveyance efficiency were assessed and the "Diversion Estimates" spreadsheet was updated to reflect the benefit of each improvement project. The following ditches' conveyance efficiencies, shown in **Table 3.3**, were updated in the Model.

Table 3.3 Model Nodes with Improved Conveyance Efficiency.

Model Node	Irrigation Diversion Ditch Name	Conveyance Efficiency (ACE 2003)	Current Conveyance Efficiency
2.2.12	Enterprise - Sawmill	50	56
2.3.12	Gaylor and Warnock	55	60
2.3.38	Cemetery	75	78
3.3.26	Rogers and Gregg No. 2 (Wise)	60	62
3.6.12	AggDev WC-1	60	62

Irrigation Methods

The Model applies different application efficiencies to different types of irrigation. Three types of irrigation are included in the Model: flood, side roll / hand line, and center-pivot irrigation. Irrigation efficiency percentages are an estimated average of published values reported in Section 6.3.3, Table 6.3 of the ACE report (2003). The efficiency of each method is as follows:

- Flood: 55 percent
- Side Roll / Hand Line: 85 percent
- Center Pivot: 85 percent

At the time of the previous study (ACE 2003), flood irrigation was the primary method of irrigation in the Popo Agie Watershed. Since then, several center-pivot irrigation systems have been installed. Irrigated acreage was examined geographically to identify farm areas where irrigation method improvements have been made. Using Google Earth imagery from 2018, the acreage associated with pivot irrigation systems for each diversion ditch was tabulated. This data was used to determine the percentage of irrigated lands using center pivots, and new percentages were input into the "Diversion Estimates" spreadsheet. Model nodes / irrigation ditches with new center pivot installations and associated percent coverages for each irrigation method are shown in **Table 3.4**.

Table 3.4 Model Nodes with Improved Irrigation Application.

Model Node	Irrigation Diversion Ditch Name	Irrigated Area (Acres)	Flood Irrigation (percent)	Side Roll/ Hand Line Coverage (percent)	Center Pivot Coverage (percent)
2.1.08	Sioux	400	50	5	45
2.3.22	Nicol and Table Mountain	2,472	91	5	4
3.3.22	Millard and Shedd	1,069	84.5	5	10.5
3.3.24	Lyons	771	49	5	46
3.3.26	Rogers and Gregg No. 2 (Wise)	827	70	5	25
3.6.12	AggDev WC-1	215	93	5	2
4.1.12	Snavely and Grant Young	1,203	82.5	5	12.5

Wyoming State Engineer's Office Diversion Data

The WYSEO began monitoring several of the irrigation diversions within the Popo Agie Watershed in 2002. Data obtained from WYSEO for the purposes of this Study included spot measurements (points of diversion not measured on a regular basis) and continuous measurements compiled by the State (Division 3). Continuous records can be found at the WYSEO website at the following address (https://sites.google.com/a/wyo.gov/seo/); spot measurements are not publicly available.

Where appropriate, WYSEO monitoring data was used instead of Model estimates of monthly diversion volumes. Ditches along the Middle Popo Agie that are considered influential (diverting a substantial amount of water) were compared to monthly Model diversion estimates. While the Enterprise ditch is a large diversion, it was not updated to reflect WYSEO monitoring data because of information presented below in Section 3.2.1. Point flow measurements from the state for all years on record were used to estimate average monthly flow volumes. Where Model monthly flow volumes exceeded monitoring data, Model estimates were replaced with the monitoring data. The Model information for the following diversion nodes were updated:

- Scott
- Hornecker, Swamp, and Melon
- Nicol and Nicol Myer
- Nicol and Table Mountain
- Baldwin
- Gaylor and Warnock
- Dutch Flat / Taylor
- Cemetery

3.2. Model Results

One goal of the water budget analysis was to evaluate flow availability within the Popo Agie Watershed and how flows vary annually throughout stream reaches. This analysis will also help identify water storage opportunities for the watershed. Wenck assessed watershed outflows on a monthly and annual basis for each hydrologic condition. Results have helped identify when and where water is available for storage to help augment flows in drier months. Additionally, the Model has identified deficiencies in water delivery and application methods (discussed in Section 0).

3.2.1. Water Availability and Storage Opportunities

The key to water storage is determining the correct time and location to collect water for future use. Reaches of the Middle Popo Agie have been known to have considerably low flow, less than 10 cfs during the late irrigation season months. In fact, August flows through Lander have been observed at and below 7 cfs. Both the PACD and the HRI are invested in maintaining the ecological health of the river system. Based on recommendations from the U.S. Fish & Wildlife Service in the 2003 Level I study, a minimum flow of 25 cfs is desired to sustain fish populations in the Middle Popo Agie River. Future studies may determine a different amount of flow is necessary, but for the purposes of this Level I, Phase II study, 25 cfs is the best available recommendation and was used as the minimum flow desired in the Middle Popo Agie River. 25 cfs equates to a supplemental volume of 1,100 acre-feet during the month of August. From an annual perspective, the Model shows that water is available for storage. **Table 3.5** lists the average annual stream discharge as measured at USGS Gage 06233900 (Model node 4.1.18) and tributary diversion volumes for wet, normal and dry years. This is shown graphically in the pie charts below (**Figure 3.9**).

Table 3.5 Stream Discharge near Arapahoe, WY and Tributary Diversion Volumes.

Tributary Diversions	Wet Years (acre-feet/yr)	Normal Years (acre-feet/yr)	Dry Years (acre-feet/yr)
North Popo Agie	34,608	34,488	35,878
Middle Popo Agie	50,206	57,199	55,598
Little Popo Agie	18,483	18,419	20,123
Total Tributary Diversions	103,297	110,106	111,599
Total Stream Discharge	375,237	230,535	96,750

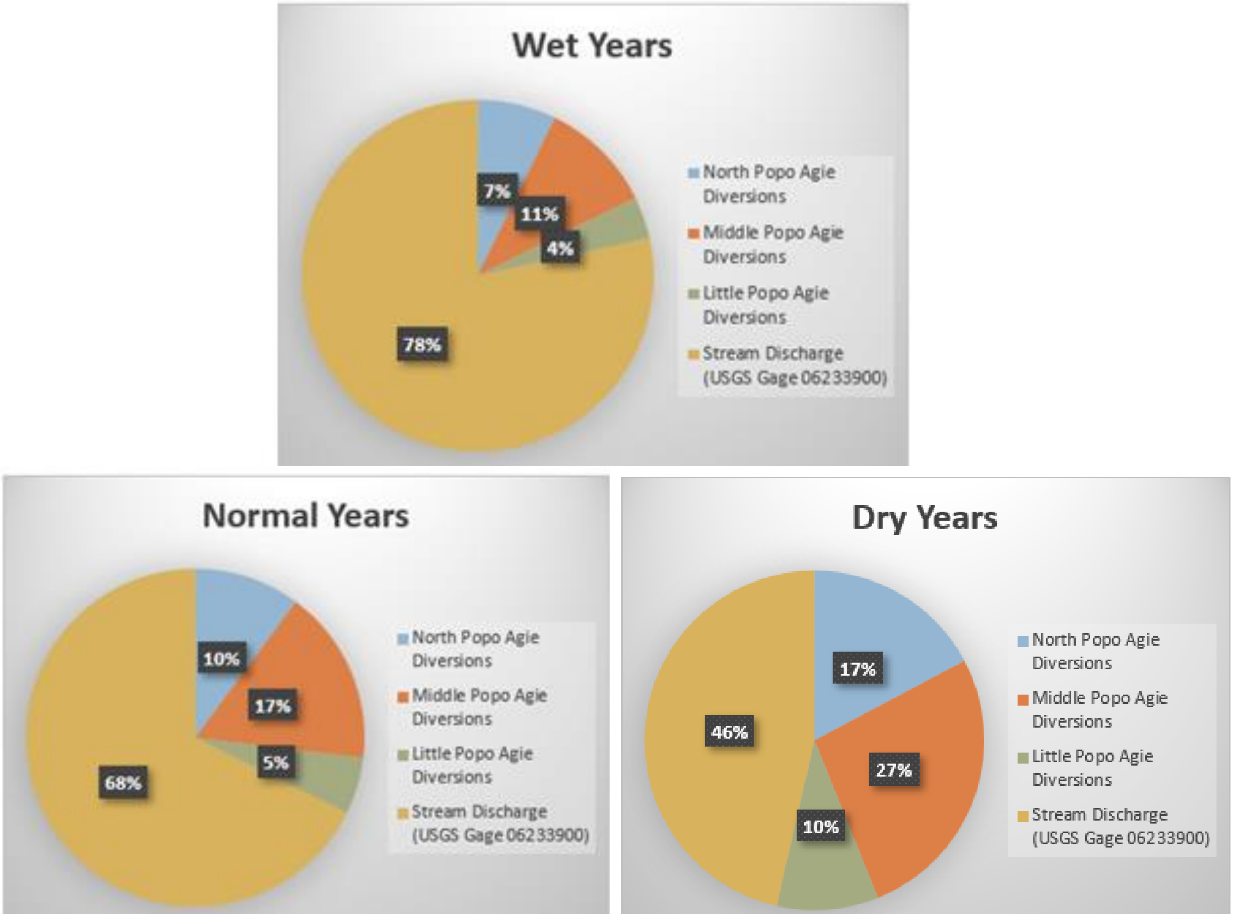


Figure 3.9 Total Annual Diversions vs. Watershed Outflow for Wet, Normal and Dry Years.

As **Figure 3.9** shows, even during a dry year, 46 percent of stream flows are not consumed by diversions, and during a wet year, only 22 percent of total in-stream flows are diverted. Examination of the watershed on an annual basis shows that water is available for storage. Of course, consideration must be given to downstream water right appropriations of the Little Wind River. Therefore, subtracting downstream water rights, 68 percent of the annual flow (230,535 acre-feet per year) is available for storage during a normal year.

To determine when flow is available for storage, the Model was examined on a monthly basis. The Model summarizes monthly outflows by node and reach in acre-feet. On a by-reach basis for normal years, 67,214 acre-feet per year is available in the North Popo Agie, 116,630 in the Middle Popo Agie, and 71,338 in the Little Popo Agie as is summarized in Table 3.6. In addition to the reach outflows, a single node near Lander (Cemetery Node 2.3.38) was included for spatial reference. Refer to **Figure 3.3** for the relative location of this node within the watershed.

As is expected, Model results show low flow volumes during the winter months (December, January, and February) and high flow volumes as snowmelt occurs (April, May, and June). Finally, as the late irrigation season is reached, flow volumes decrease significantly, especially close to Lander. This is partly caused by the high density of diversions near and upstream of Lander.

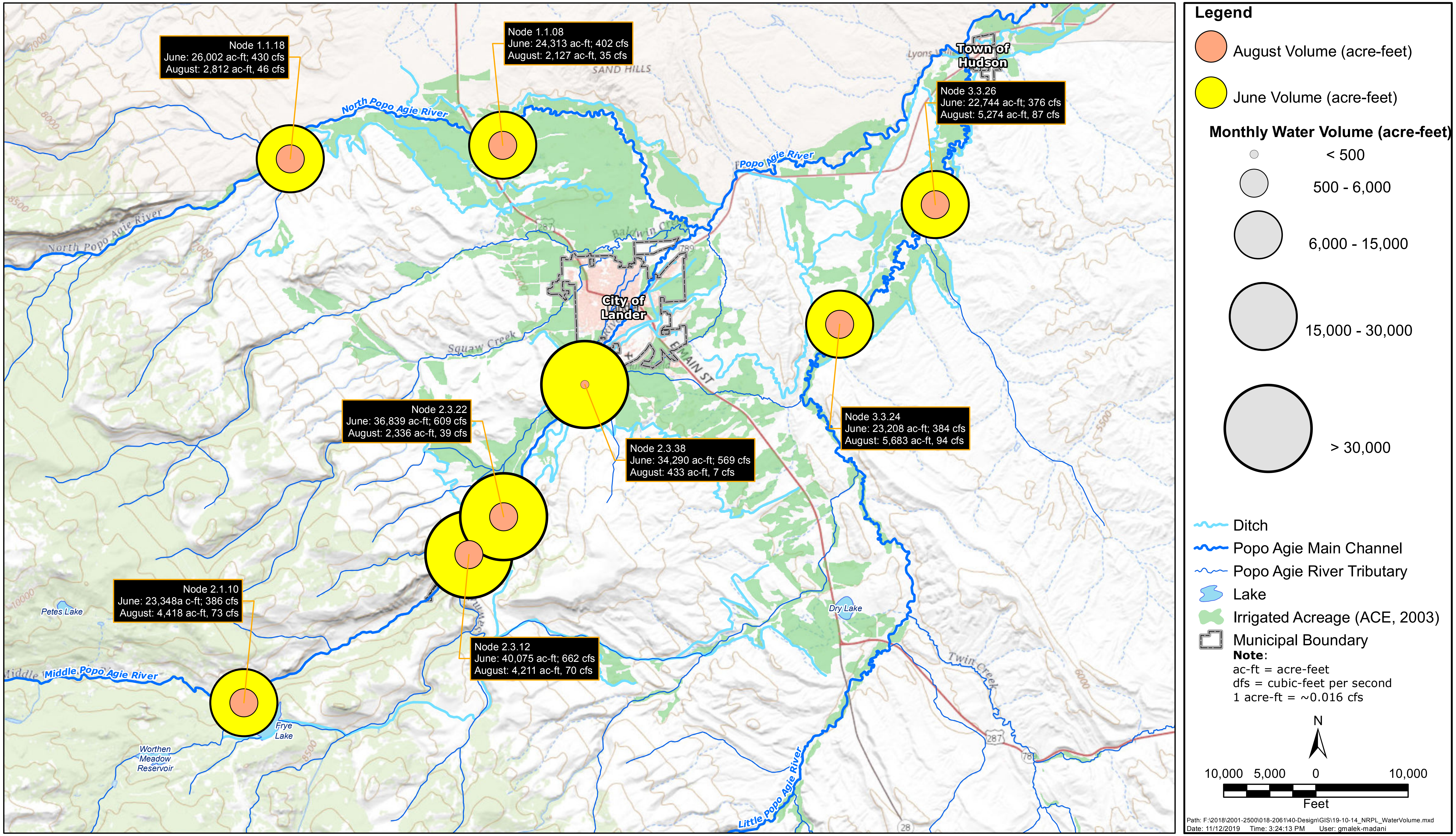
For instance, during August of a normal year, the flow volume at the Cemetery node is predicted as 433 acre-feet, or an average daily flow of 7 cfs. During a dry year, the Model predicts no available flow at the Cemetery node. However, for a normal year, the Model results predict a monthly flow volume of 34,290 acre-feet or an average daily flow of approximately 576 cfs two months prior. **Figures 3.10 and 3.11** show a geographical comparison of water availability for the months of June and August of a normal year. As can be seen from the figures and **Table 3.6,** the timing of water availability for storage occurs during spring runoff months (May and June) in the upper reach of the watershed. During this time (harvest season), flows in the Middle Popo Agie are available in excess of what is needed to maintain 25 cfs during the mid to late irrigation season through Lander.

A full account of water volume at each Model node for each hydrologic condition is presented in **Appendix B**.

According to the Model, Node 2.5.12 (Enterprise Roaring Fork) experiences a volume (flow) shortage in the months of August and September. In terms of the Model, this raises two questions:

(1) How does this shortage affect the Enterprise Sawmill Diversion (Node 2.2.12)?
(2) How does this shortage affect flow into the Middle Popo Agie at the confluence of the Roaring Fork (Node 2.1.11)?

For the first question, during the months of August and September, the Enterprise Sawmill Diversion relies on storage from Frye Lake and is therefore unaffected by the 0 acre-feet per month outflow from Node 2.5.12. Furthermore, the flow upstream of this diversion is ultimately determined by the synthetic gage downstream of Frye Lake. For the second question, USGS Gage 06231600 is directly downstream of the confluence (Node 2.1.11); therefore, any deficiencies in flow are corrected by this gaging station. Because of the self-correcting nature of the Model brought on by the downstream gaging station and synthetic gage, state data for the Enterprise was not incorporated into the Model.

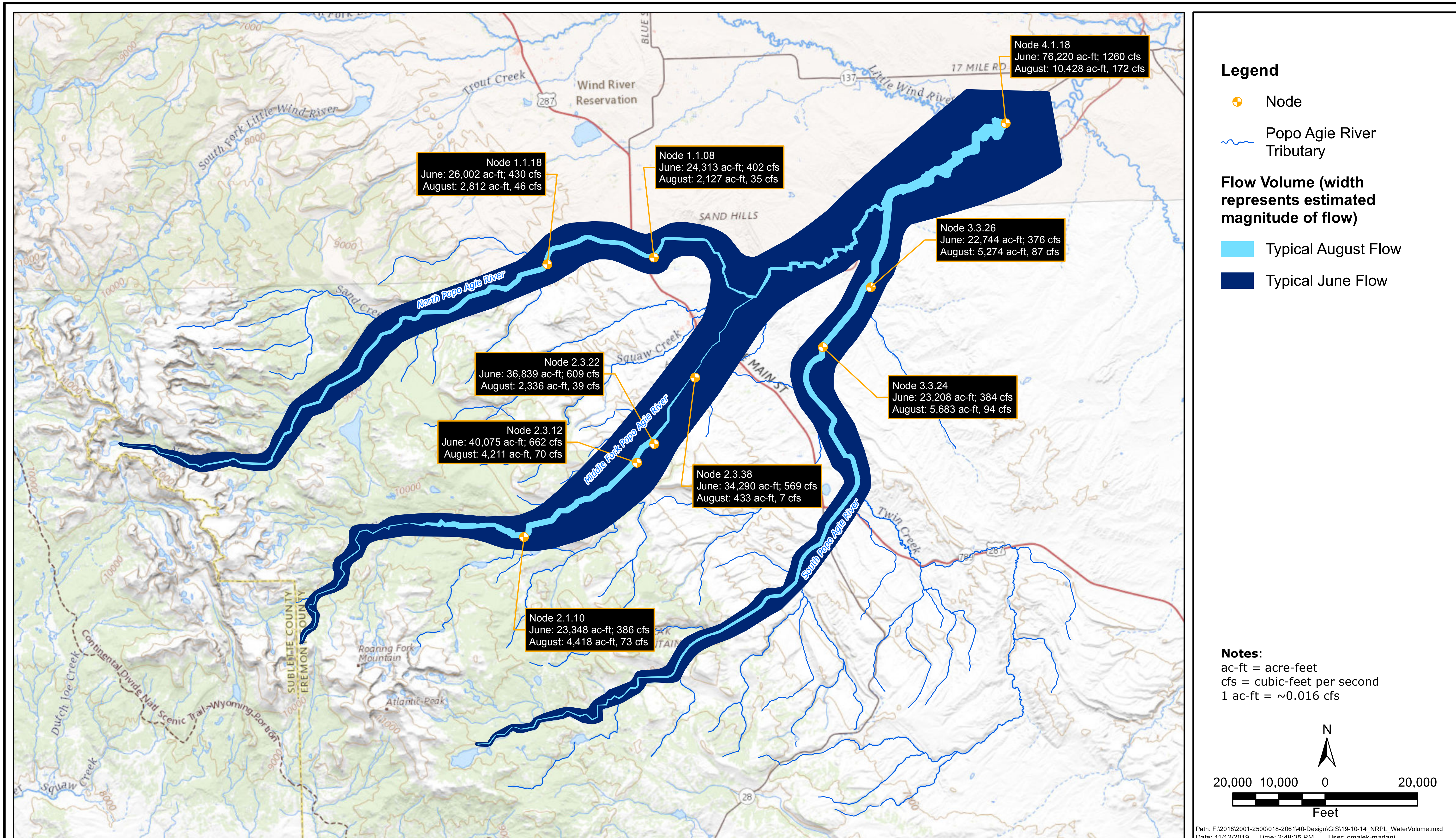


WWDC/POPO AGIE CONSERVATION DISTRICT

Water Availability June and August

olsson WENCK

FIGURE 3.10



WWDC/POPO AGIE CONSERVATION DISTRICT	olsson WENCK	FIGURE
Watershed Water Availability June and August (Normal Years)		3.11

Table 3.6 Model Outflows Summarized by Reach (Acre-Feet).

Wet				(Acre-Feet/month)												
Reach		Node	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
North	Reach 1.1	1.1.26	USGS 06232500	1,402	1,682	2,958	6,233	19,762	50,138	19,192	3,160	4,308	4,608	3,877	2,493	119,813
	Reach 1.2	1.2.16	North Popo Agie Outflow	1,402	1,682	2,958	6,168	19,654	50,153	19,451	3,789	5,160	5,155	4,039	2,511	122,120
Middle	Reach 2.1	2.1.12	USGS 06231600	2,580	2,765	3,529	5,703	19,428	62,117	22,606	5,247	5,752	5,223	4,586	3,242	142,777
	Reach 2.3	2.3.38	Cemetery	3,989	4,127	5,255	6,991	24,290	75,803	23,246	1,890	4,201	4,630	6,638	4,871	165,931
	Reach 2.3	2.3.44	Conf Middle and North Popo Agie	5,787	6,200	8,727	14,178	47,682	134,996	48,032	8,360	11,284	11,008	11,392	7,889	315,535
Little	Reach 3.1	3.1.10	Little Popo Agie North Fork	1,752	1,713	2,183	2,731	14,115	30,731	11,787	3,432	2,518	2,782	2,306	1,950	78,000
	Reach 3.3	3.3.30	USGS Gage 06233500	2,798	2,709	3,392	4,924	13,959	36,740	17,978	3,354	2,883	4,412	3,614	3,121	99,884
Big	Reach 4.1	4.1.18	USGS Gage 06233900 - End	5,421	5,563	8,129	19,950	65,269	156,212	56,608	12,934	14,488	11,228	11,739	8,599	376,140

Normal				(Acre-Feet/month))												
	Reach	Node	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
North	Reach 1.1	1.1.26	USGS 06232500	1,377	1,599	2,172	2,761	12,272	24,492	9,888	2,126	1,683	2,760	2,321	1,464	64,916
	Reach 1.2	1.2.16	North Popo Agie Outflow	1,377	1,599	2,172	2,688	12,150	24,559	10,164	2,773	2,502	3,277	2,473	1,480	67,214
Middle	Reach 2.1	2.1.12	USGS 06231600	2,158	2,326	2,970	3,530	16,278	32,079	14,480	4,418	3,316	3,940	3,309	2,394	91,197
	Reach 2.3	2.3.38	Cemetery	3,630	3,747	4,912	4,170	17,476	34,290	11,054	433	1,504	4,376	5,396	4,079	95,066
	Reach 2.3	2.3.44	Conf Middle and North Popo Agie	5,439	5,775	7,689	7,731	32,538	64,529	25,064	5,769	5,912	8,802	8,546	6,051	183,844
Little	Reach 3.1	3.1.10	Little Popo Agie North Fork	1,675	1,606	2,266	2,223	9,895	14,922	6,325	2,622	2,330	2,537	2,245	1,897	50,543
	Reach 3.3	3.3.30	USGS Gage 06233500	2,732	2,633	3,576	4,013	10,858	20,869	9,505	3,190	3,284	4,090	3,526	3,062	71,338
Big	Reach 4.1	4.1.18	USGS Gage 06233900 - End	5,900	6,084	8,147	14,722	42,575	76,220	34,587	10,428	8,226	8,460	8,404	6,497	230,248

Dry			Location	(Acre-Feet/month))												
	Reach	Node		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
North	Reach 1.1	1.1.26	USGS 06232500	905	1,157	1,785	2,422	6,246	5,204	273	0	0	1,534	1,455	1,180	22,159
	Reach 1.2	1.2.16	North Popo Agie Outflow	905	1,157	1,785	2,319	6,130	5,299	1,350	1,293	876	2,067	1,638	1,204	26,022
Middle	Reach 2.1	2.1.12	USGS 06231600	2,237	2,386	3,086	4,100	9,354	9,138	3,994	1,524	1,798	2,913	2,742	2,252	45,525
	Reach 2.3	2.3.38	Cemetery	3,467	3,539	4,625	4,567	7,423	3,496	708	0	0	2,716	4,381	3,646	38,567
	Reach 2.3	2.3.44	Conf Middle and North Popo Agie	4,751	5,081	6,946	7,701	15,936	12,505	5,100	3,664	2,544	5,769	6,610	5,285	81,892
Little	Reach 3.1	3.1.10	Little Popo Agie North Fork	1,449	1,404	1,917	2,439	6,853	6,329	2,791	1,848	1,408	1,770	1,796	1,650	31,653
	Reach 3.3	3.3.30	USGS Gage 06233500	2,454	2,304	3,024	3,228	6,431	8,608	3,818	1,149	1,403	2,781	2,844	2,683	40,727
Big	Reach 4.1	4.1.18	USGS Gage 06233900 - End	4,545	5,020	7,066	13,133	22,201	19,272	4,311	1,818	3,161	5,161	5,760	5,090	96,437

* 1 acre-foot per month = an average daily flow of 0.016 cfs

Note: The values in this table are approximate and do not account for return flows or specific downstream diversions.

3.2.2. Water Delivery and Application Efficiency

Delivery efficiency describes the effectiveness of a diversion in terms of application and conveyance. For example, conveyance losses occur when water seeps into the adjoining ground through unlined ditches. Similarly, application losses occur when more water is applied to crops than can be used for transpiration. Water that is “lost” during conveyance and application is water that could have remained as streamflow. As such, application and conveyance inefficiencies can have a significant impact on the total volume of diverted water. This is especially noticeable in the Popo Agie Watershed during July and August, when in-stream flows are naturally lower than during spring runoff months. The following sections discuss conveyance and application efficiencies as they apply to the Popo Agie Watershed.

3.2.1.1 Conveyance Losses

According to the “Diversion Estimates” spreadsheet, anywhere from 20-45 percent of total annual diversion flow volumes are lost to inefficiencies in conveyance. For example, of the 9,553 acre-feet Nicol and Table Mountain diverts during a normal year, 40 percent – or 3,821 acre-feet (average daily flow of 15.8 cfs for a 4-month irrigation season – is lost during conveyance. Conveyance losses either percolate deeply into the alluvial aquifer (often referred to as return flows) or are returned to the river as surface runoff farther downstream. While percolated water will eventually return to the river, it can take several months or even years to travel through the aquifer. Improving conveyance efficiencies can reduce the amount of water needed at the point of diversion. Improvements could include lining ditch sections or piping, and/or replacing dilapidated headgates and conveyance structures that do not provide accurate flow regulation.

Diversions along the Middle Popo Agie and their associated conveyance efficiency losses for normal years over a 4-month irrigation season are presented in **Table 3.7**. A full documentation of each tributary, for each hydrologic condition, is provided in **Appendix B**.

Table 3.7 Conveyance Efficiency Losses for the Middle Popo Agie (Four-Month Irrigation Season for Normal Years).

Diversion Ditch	Total Diversion Volume (acre-feet)	Percent Loss to Conveyance Inefficiencies	Total Losses (acre-feet)	Average Daily Losses (cfs)
Enterprise – Sawmill**	8,182	45%	3,682	15.2
Gaylor and Warnock*	3,332	40%	1,333	5.5
Scott and Melon*	191	40%	77	0.3
Hornecker and Swamp*	1,763	40%	705	2.9
Nicol and Nicol Meyer*	724	40%	290	1.2
Nicol and Table Mountain*	9,553	40%	3,821	15.8
Meadow, Cottonwood, and Island	1,511	40%	604	2.5
Baldwin*	2,567	40%	1,027	4.2
Dutch Flat / Taylor*	7,804	20%	1,561	6.4
Cemetery*	3,311	22%	728	3.0
Last and Forrest	319	40%	128	0.5
AggDev BC-1	4,799	40%	1,919	7.9
Enterprise - Roaring Fork**	8,346	40%	3,339	13.8
AggDev HC-1	3,882	40%	1,553	6.4

* Diversions that have been updated to reflect state data.

** The "Diversion Estimates" spreadsheet overestimates the monthly diversion volumes based on monitoring data.

3.2.1.2 Applications Losses

Currently, most irrigated lands in the Popo Agie Watershed use flood irrigation. This method of irrigation has a low application efficiency of 55 percent compared to that of center-pivot irrigation (85 percent). Given the high percentage of flood irrigation in the Popo Agie Watershed, the "Diversion Estimates" spreadsheet estimates approximately 20-30 percent of water is lost during application. In other words, 20-30 percent of applied water exceeds that which is needed for crop growth. For example, Nicol and Table Mountain diverts 9,553 acre-feet of water per year,, of which 32 percent or 3,068 acre-feet (average daily flow of 12.7 cfs for a 4-month irrigation season) could be conserved if application was 100 percent efficient. Of course, 100 percent efficiency is not plausible; however, installing and using pivot irrigation systems instead of using flood irrigation could help conserve water by reducing application losses.

Table 3.8 presents the application losses during normal years for diversions along the Middle Popo Agie over a 4-month irrigation season. A complete documentation for each hydrologic condition of each tributary can be found in **Appendix B.**

Table 3.8 Application Efficiency Losses for the Middle Popo Agie (Four-Month Irrigation Season for Normal Years).

Diversion Ditch	Total Annual Diversion Volume (acre-feet)	Percent Loss to Application Inefficiencies	Total Losses (acre-feet)	Total Losses (cfs)
Enterprise – Sawmill**	8,182	34%	2,743	11.3
Gaylor and Warnock*	3,332	34%	1,117	4.6
Scott*	191	34%	64	0.3
Hornecker, Swamp and Melon*	1,763	34%	591	2.4
Nicol and Nicol Meyer*	724	34%	243	1.0
Nicol and Table Mountain*	9,553	32%	3,068	12.7
Meadow, Cottonwood, and Island	1,511	34%	507	2.1
Baldwin*	2,567	34%	861	3.6
Dutch Flat / Taylor*	7,804	34%	2,617	10.8
Cemetery*	3,311	34%	1,110	4.6
Last and Forrest	319	34%	107	0.4
AggDev BC-1	4,799	34%	1,609	6.6
Enterprise - Roaring Fork**	8,346	34%	2,799	11.6
AggDev HC-1: Sandstone et al.	3,882	34%	1,302	5.4

* Diversions that have been updated to reflect state data.
** The Diversion Estimates" spreadsheet overestimates the monthly diversion volumes based on monitoring data.

Table 3.9 shows the combined losses due to inefficiencies in conveyance and application over the 4-month irrigation season for diversions along the Middle Popo Agie. A complete documentation for each hydrologic condition of each tributary can be found in **Appendix B**.

As can be seen in **Table 3.9**, conveyance and application losses can be significant. While it is not feasible to recover all losses, improvements to conveyance and application can help decrease losses and increase flow and water availability. Section 4.0 presents improvement projects that could help conserve water and alleviate low flows during the late irrigation season.

Table 3.9 Combined Efficiency Losses for the Middle Popo Agie (4-month Irrigation Season for Normal Years).

Diversion Ditch	Total Diversion Volume (acre-feet)	Total Combined Losses (acre-feet)	Combined Average Daily Losses (cfs)
Enterprise – Sawmill**	8,182	6,425	26.6
Gaylor and Warnock*	3,332	2,450	10.1
Scott*	191	141	0.6
Hornecker, Swamp and Melon*	1,763	1,296	5.4
Nicol and Nicol Meyer*	724	533	2.2
Nicol and Table Mountain*	9,553	6,889	28.5
Meadow, Cottonwood, and Island	1,511	1,111	4.6
Baldwin*	2,567	1,888	7.8
Dutch Flat / Taylor*	7,804	4,178	17.3
Cemetery*	3,311	1,838	7.6
Last and Forrest	319	235	1.0
AggDev BC-1	4,799	3,528	14.6
Enterprise - Roaring Fork**	8,346	6,138	25.4
AggDev HC-1: Sandstone et al.	3,882	2,855	11.8

3.3. Recommendations for Model Improvements

WWDC watershed studies have been applying water budget models to watersheds to aid in determining inflows, outflows and return flows throughout a watershed for approximately 15 years. To enhance model predictions of inflows, outflows and return flows, for the purposes of advancing this study, additional gaging data for the watershed would be beneficial. To accurately represent wet, normal and dry years a minimum gaging period of 10 years is recommended. For instance, if USGS gages 06231600 and 06233900 could be put back into service, this would provide additional insight into the hydrology of the Middle Popo Agie. Additionally, to supplement hydrographer data, collection of additional diversion data during the irrigation season of large ditches would increase the accuracy of the monthly diversion volume estimates. To better asses conveyance/seepage losses along the ditches it is suggested that seepage be evaluated for the larger ditches.

4.0 IRRIGATION INFRASTRUCTURE IMPROVEMENTS

This section documents the irrigation system evaluation completed to identify improvements to existing infrastructure to enhance water delivery and conservation. As reported in the ACE Level I study (2003), and based on water rights recorded with the WYSEO, more than 100 irrigation ditches are in the Popo Agie River Watershed. The ACE report (2003) identified a significant number of irrigation improvement items that could be implemented to improve water delivery for many of the irrigation ditches. Since that time, many projects have been completed with assistance from the WWDC, PACD, NRCS, and the irrigation districts. At the onset of this study, the PACD worked with many of the irrigation districts and water users to document projects that have been completed since 2003. The projects are listed in **Table 4.1**.

Table 4.1 Improvement Projects Completed since 2003.

Irrigation System Improvements*	Description	Project Completion Date
Enterprise Ditch	Replaced Crooked Creek Headgate	2007
	Replaced Sawmill Creek Headgate	2009
	Sawmill Canal Lining - Diversion to Rock-Cut	2012
	Splitter Box, Bifurcation	2011
	Wood Flume Canal Piping	2014
	Lined Reach ED-a**	2015
	Piped the lower reach, Beason Creek Bank Erosion	2015
	Installed Measurement Devices	Unknown
	Replaced Farm Turnouts (8-10)	Unknown
Cemetery Ditch	Installed 2 Wasteways	2008
	Installed New Headwall and Headgate and Repaired Sill Dam	2011
	Rehabilitated Headgate and Winter Bypass	2015
	Replaced 5 Farm Turnouts	2006-2015
Dutch Flat / Taylor	Installed 4 Measurement Devices	Unknown
Gaylor and Warnock	Rehabilitated Parshall Flume (Poured New Apron, Removed Obstruction from Channel)	Unknown
	Lined Reach GW-a**(Lined 2,000 LF*** and piped 200 LF)	Unknown
Nicol and Table Mountain	Abandoned Inverted Siphon on North Lateral and Installed Division Box, Enlarged Ditch, Installed 300 LF of Pipe and Installed Spillway	2007

Irrigation System Improvements*	Description	Project Completion Date
	Replaced Diversion Structure	2010
	Installed Ramp Flume	Unknown
	Replaced 3 Farm Turnouts	Unknown
Rogers and Gregg No. 2 (Wise)	Replaced Headgate and Wasteway	Unknown
	Rehabilitated Parshall Flume (Poured New Outlet Apron, Removed Obstruction from Channel)	Unknown
	Lined Reach WD-a ** (Approximately 1000 LF Using Bentonite)	Unknown
	Little Popo Agie River-Bank Stabilization Using Rock Weirs	2005

* Table 4.1 is not likely a complete listing of all projects that have been completed in the past 15 years but is comprised of all available information as provided by PACD.

** Reach names are identified in ACE 2003.

*** LF = linear feet

At the outset of this study, the Olsson/Wenck team solicited input from various interested parties at the project scoping meeting and subsequent public meetings to identify irrigation structures and ditch sections that needed repair and/or upgrades. Site investigations to evaluate ditches and structures were conducted on three occasions: (1) after the scoping meeting; (2) after the second public meeting; and (3) after the third public meeting. Site visits were well-attended with representatives from WWDO, PACD, NRCS, WDEQ, the City of Lander, WYSEO, and the irrigations district members.

The initial site visit was conducted on July 18, 2018, and the following ditches and areas were evaluated:

- Cemetery Ditch
- Dutch Flat / Taylor Ditch
- Nicol and Table Mountain Ditch
- Lyons Ditch

The second site visit was conducted on September 11, 2018, and included looking at the larger reservoirs of the Middle Fork of the Popo Agie River:

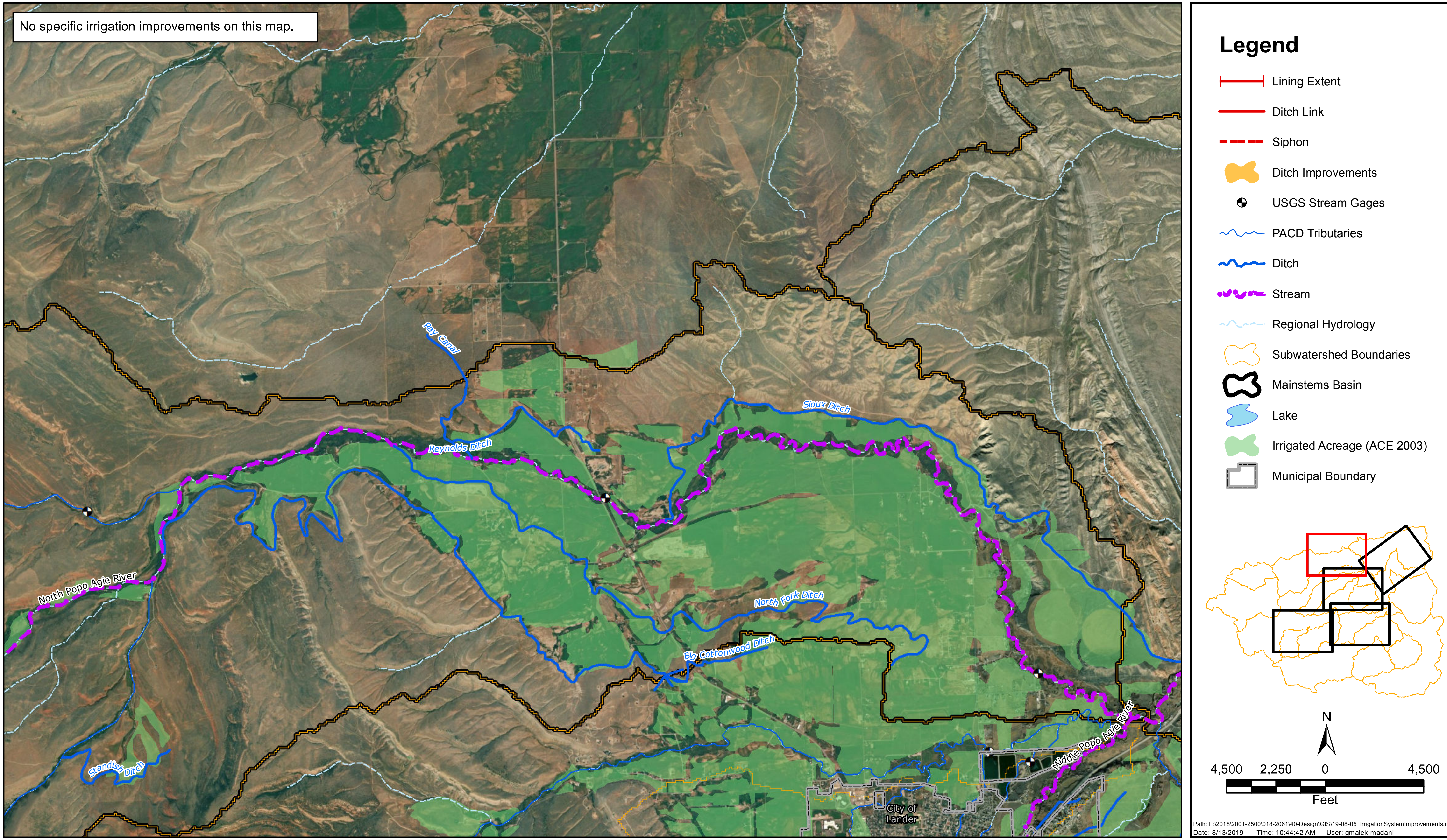
- Frye Lake
- Worthen Meadow Reservoir
- Enterprise Ditch: upper and lower section

The last site visit was conducted on November 7, 2018. During this site visit, the middle area of the Enterprise Ditch was evaluated with representatives from the Enterprise Ditch in attendance. The PACD provided valuable assistance in developing an understanding of the ditch delivery systems including coordinating the site visits and providing insights regarding the irrigation ditches and structures. Irrigation district members and staff and the PACD helped conduct site investigation tours and helped identify locations and ditch sections that should be evaluated. Structure information and conditions were recorded during the site investigations, and a pictures were taken of each structure. The irrigation systems are illustrated on a series of five maps that are referred to throughout this section (**Figures 4.1a – e**).

Various types of structures were evaluated during the site investigations and typically included the following:

- Diversion Structure and Diversion Dam, if applicable
- Diversion Flow Measurement Structures
- Wasteways
- Regulating / Check Structures
- Delivery Ditch

The following maps are presented to give the general location of the irrigation infrastructure and surrounding area. Section 4.1 presents the results of the irrigation system assessments. The assessments are followed by a description of the proposed improvements (Section 4.2) and a cost estimate for each proposed improvement (Section 4.3). **Figures 4.1a – e** illustrate the proposed improvements discussed in Sections 4.2 and 4.3. Note that **Figure 4.1a** does not have any improvements illustrated because there were no projects defined along the North Fork of the Popo Agie River. Based on information reviewed during the site investigations with the project team members, a list of potential improvement projects was developed. Projects that were selected for evaluation were based on information gathered during the site visits, potential benefits, costs, and conservation. Section 4.4 provides a method of prioritization that may be useful to the PACD for project implementation.



POPO AGIE WATERSHED STUDY

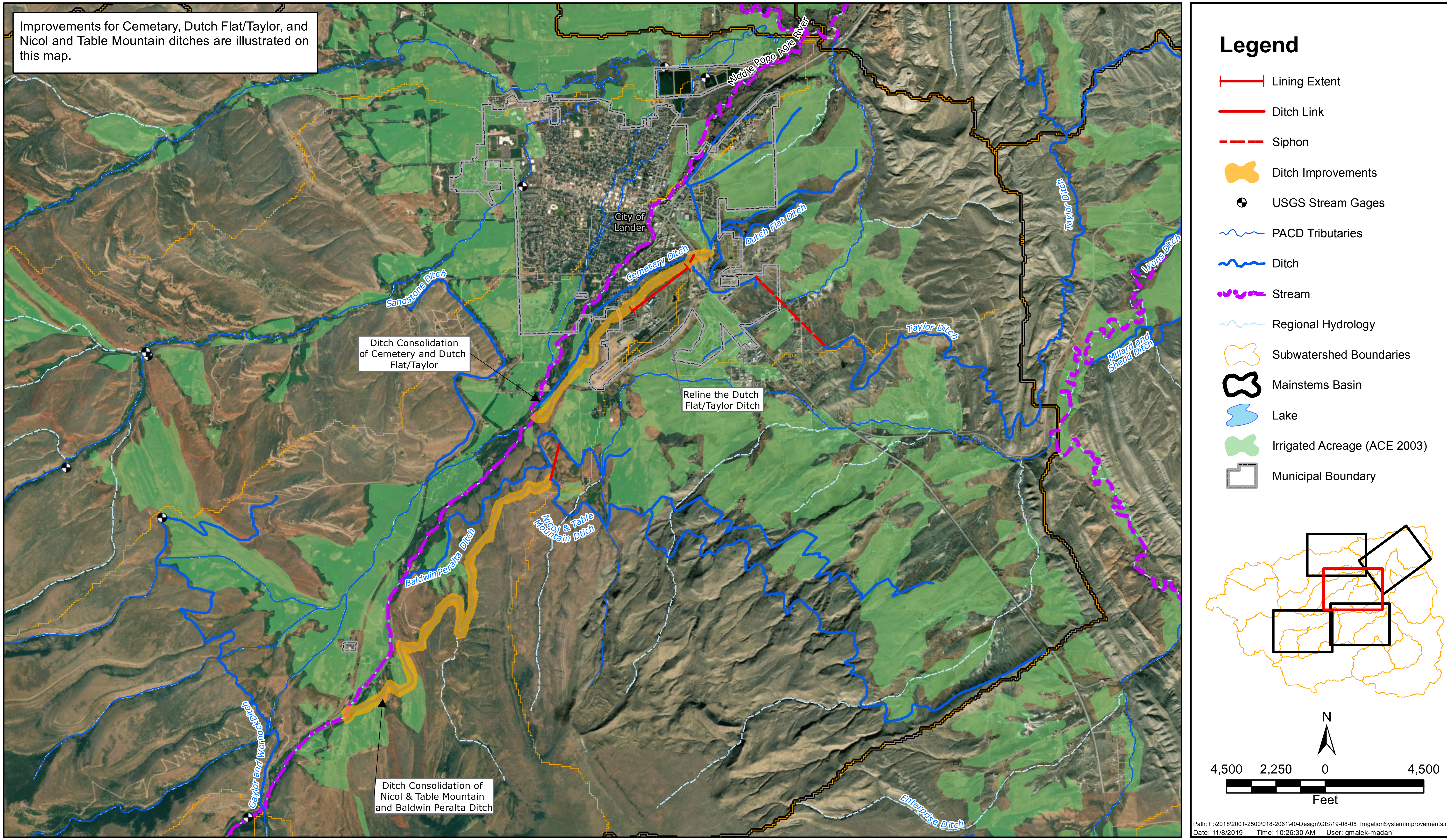
Irrigation System Improvements (1 of 5)

olsson

WENCK

FIGURE

4.1a



POPO AGIE WATERSHED STUDY

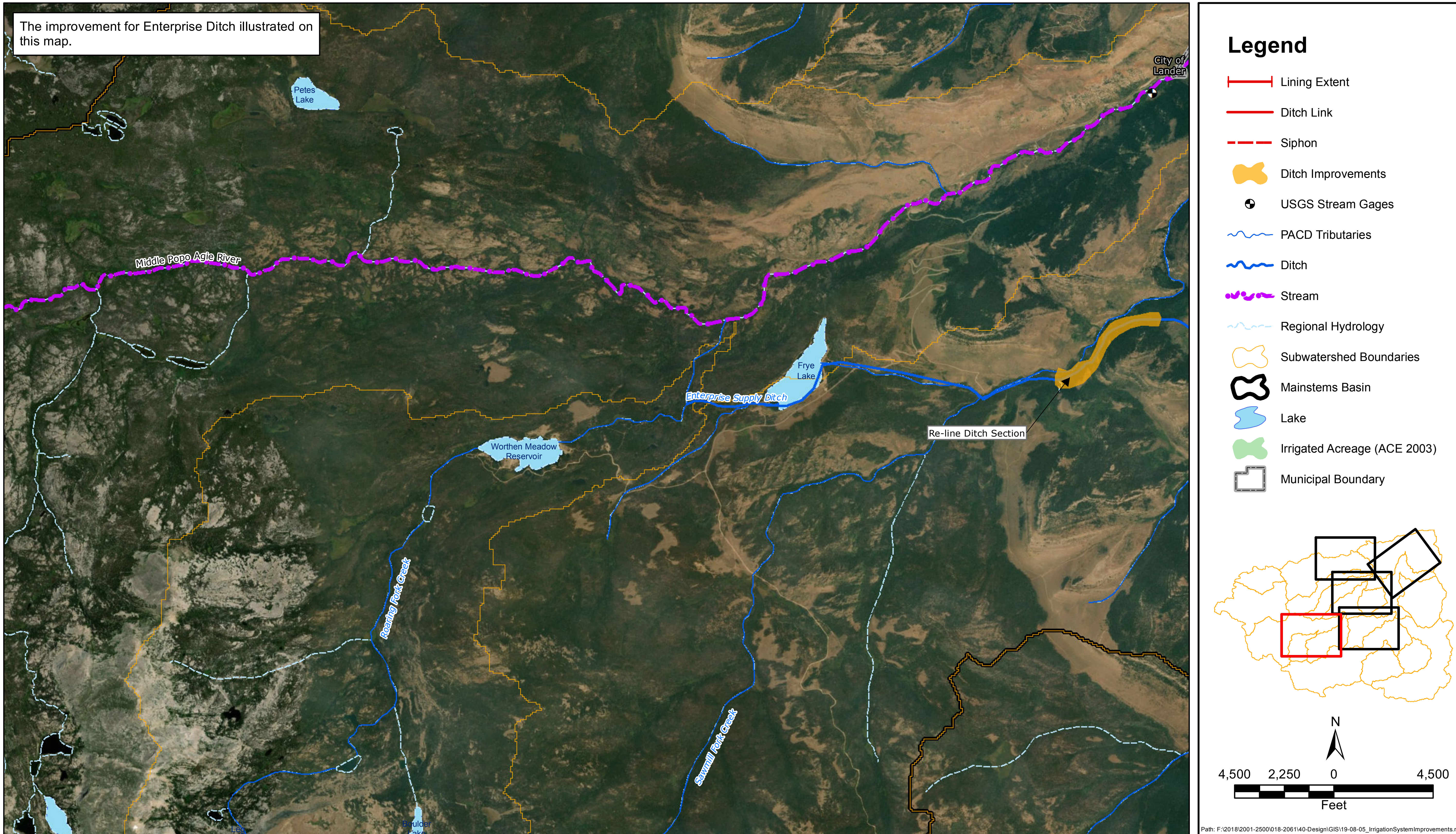
Irrigation System Improvements (2 of 5)

olsson

WENCK

FIGURE

4.1b



POPO AGIE WATERSHED STUDY

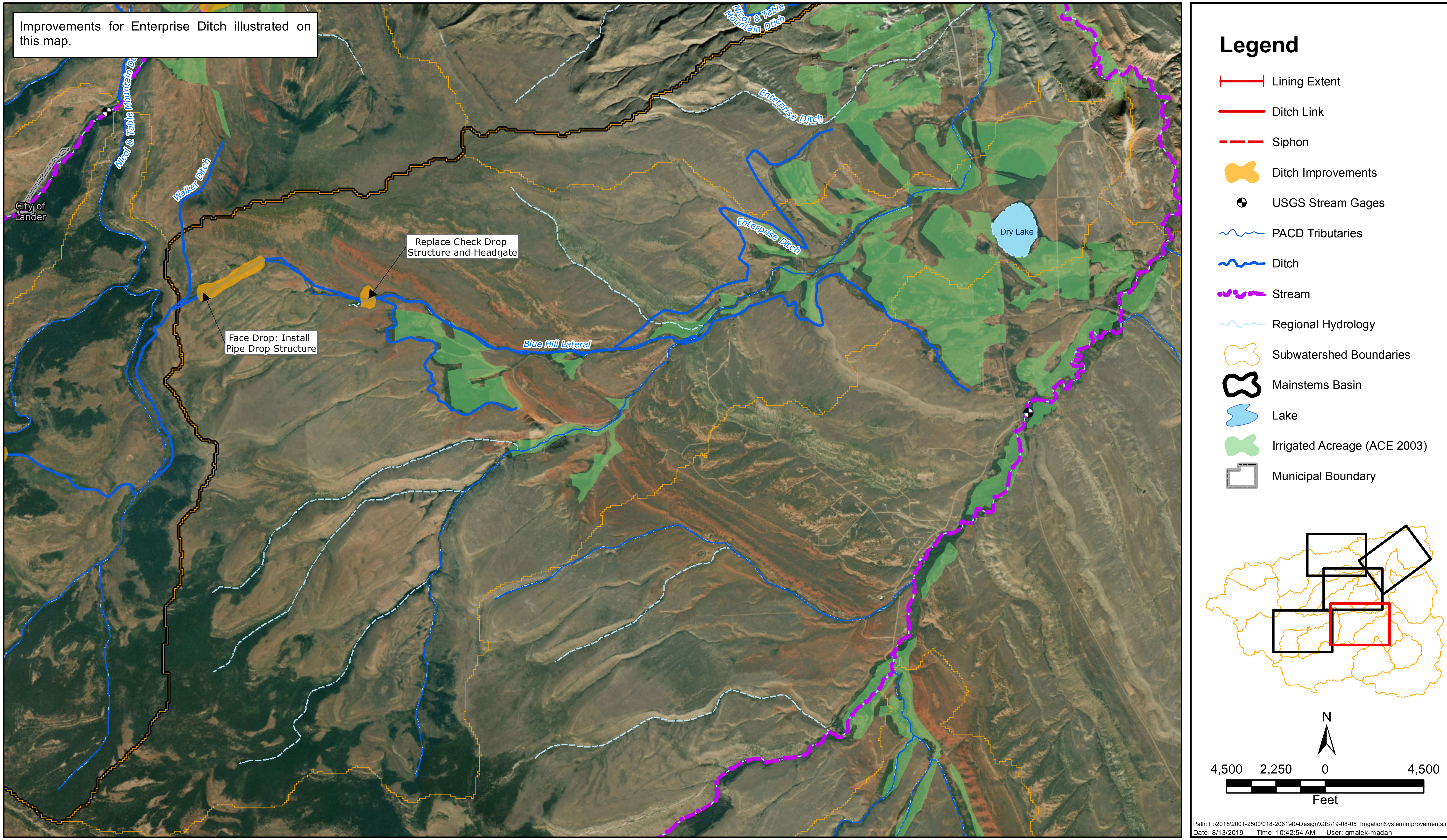
Irrigation System Improvements (3 of 5)

olsson

WENCK

FIGURE

4.1c



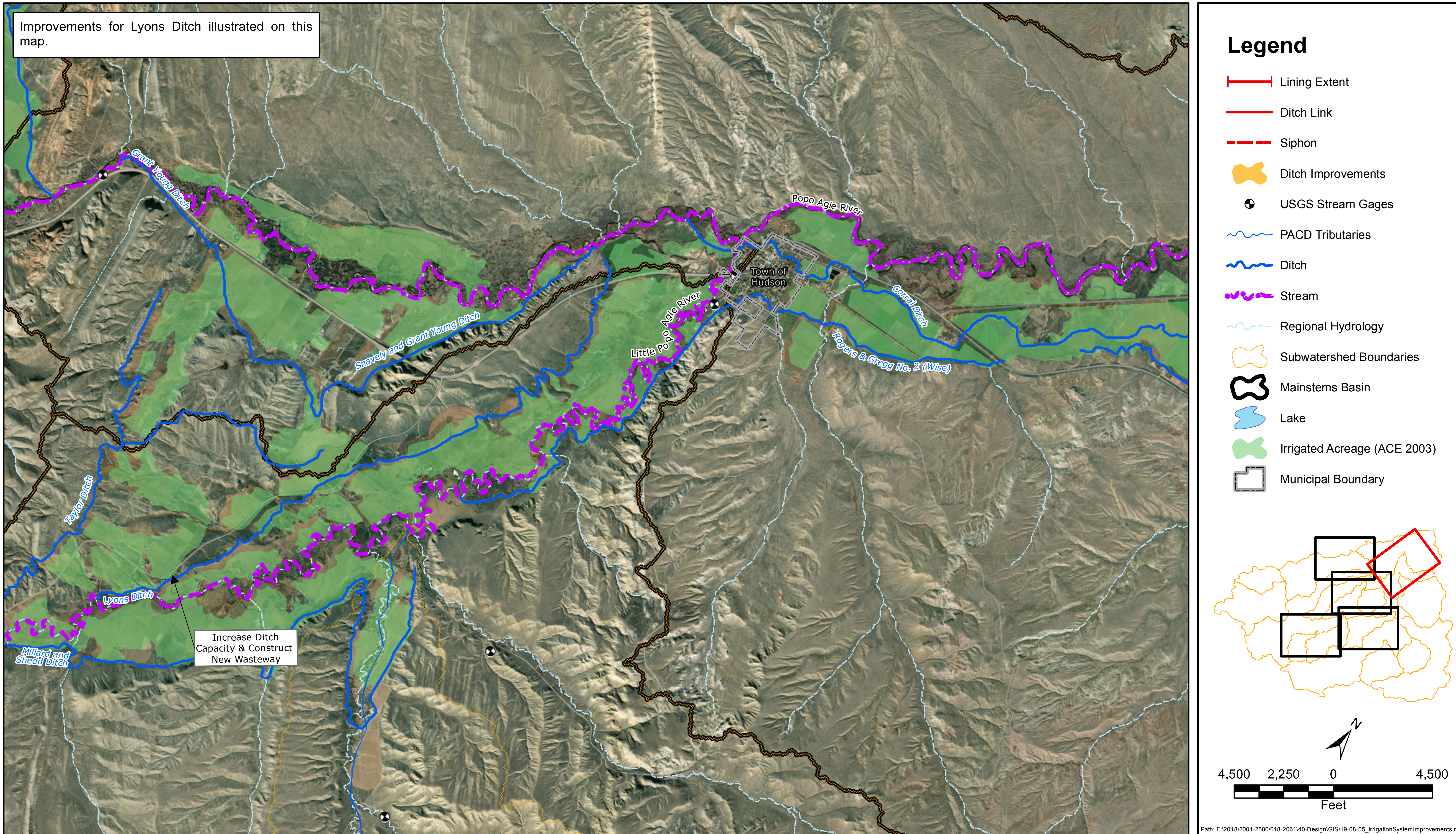
POPO AGIE WATERSHED STUDY

Irrigation System Improvements (4 of 5)

olsson

WENCK

FIGURE 4.1d



POPO AGIE WATERSHED STUDY

Irrigation System Improvements (5 of 5)

olsson

WENCK

FIGURE

4.1e

4.1. Irrigation System Assessment

4.1.1. Cemetery Ditch

The Cemetery Ditch diverts water from the Middle Popo Agie River from a headgate located just upstream of the City of Lander (**Figure 4.1b**). The ditch flows through several subdivisions in town and through the Lander Municipal Golf Course. The main irrigation areas are located east of Highway 287. High flows in the Middle Popo Agie River in 2011 damaged the diversion structure for the Cemetery Ditch. The diversion was rebuilt in 2015, and a new diversion headgate was constructed. Additionally, the sill dam at the diversion and the wasteway structure located downstream of the diversion were also repaired. **Photo 5** shows the replacement headgate and dam. A portion of the ditch that flows through the Lander Municipal Golf Course has been lined with a high-density polyethylene (HDPE) half pipe.

Since Cemetery Ditch flows through the City of Lander, operation and maintenance of the ditch is more difficult because of the proximity to homes and urban infrastructure. There are numerous culvert crossings (streets and driveways), some of which are undersized and likely restrict the conveyance capacity of the ditch. Additionally, discussions with City of Lander staff have indicated that there are areas of high-water table and seepage. The City has been replacing some of the sewer lines and are seeing benefits in some areas. Monitoring of water levels near the Cemetery Ditch should aid in determining if the ditch is contributing to the elevated water table.

Near the Old Ford auto dealership, where the ditch crosses Highway 287, there is an unstable hillslope area (Ford Slip). A previous WWDC Level II study (GEI 1988) identified one of the factors affecting the hillslope instability as seepage from the Dutch Flat / Taylor Ditch. Slumping of the soils has been noted frequently at this location and may affect the Cemetery Ditch's stability.

Photo 5. Cemetery Ditch Diversion Floodgate.

4.1.2. Dutch Flat / Taylor Ditch

The Dutch Flat / Taylor Ditch is located on the Middle Popo Agie River. The ditch's headgate is located approximately 1 mile upstream of the City of Lander (**Figure 4.1b**). Where the ditch crosses Highway 287, the Dutch Flat / Taylor Ditch splits into two ditches, the Dutch Flat (northern channel) and the Taylor (southern channel). The Dutch Flat Ditch irrigates lands closer to the Middle Popo Agie River, whereas the Taylor Ditch flows to the east and south and irrigates lands along the Little Popo Agie River. The diversion on the Middle Popo Agie River consists of two 48-inch-diameter slide gates. An 8-foot flume is located approximately 500 feet downstream of the headgate (**Photo 6**).

Photo 6. Dutch Flat / Taylor Ditch 8-foot Flume.

According to the ACE Level I report (ACE 2003), the portion of the ditch that runs adjacent to the City of Lander Municipal Golf Course had been lined with a geosynthetics liner. This was likely installed to eliminate seepage within the reach since a high-water table has been identified as a concern in this area. During the July 18, 2018, site visit, it was noticed that the liner had been removed. This is shown in **Photo 7**, where a portion of the remnant liner edge can be seen on the higher portion of the ditch bank.

As discussed in Section 4.1.1, the Ford Slip is located between the Dutch Flat / Taylor Ditch and the Cemetery Ditch. **Photo 8** shows the area where slumping of the slope has been occurring for an extended period. This section of the ditch should likely be lined or piped to eliminate the seepage water from the unstable hillslope area.

Photo 7. Dutch Flat / Taylor Ditch Adjacent to Golf Course (Geosynthetic Liner Has Been Removed).

Photo 8. Hillslope Instability Below Dutch Flat / Taylor Ditch near Highway 287.

4.1.3. Nicol and Table Mountain Ditch

The Nicol and Table Mountain Ditch is located on the Middle Popo Agie River, and the diversion is located approximately 1.5 miles downstream of Sinks Canyon (**Figure 4.1b**). The canal parallels the Middle Popo Agie River for approximately 1 mile and then flows in an easterly direction toward most of the irrigated lands, located in the Little Popo Agie Watershed. **Photo 9** shows the 8-foot flume located near the headgate structures. Limited structures were evaluated on the Nicol and Table Mountain Ditch.

Photo 9. Nicol and Table Mountain 8-foot Flume.

As indicated in **Table 4.1**, several improvement projects have been completed for the Nicol and Table Mountain Ditch, including projects at the diversion, the flume below the diversion, and the main ditch diversion split structure. The ACE Level I study (2003) indicates that there were areas of erosion in the ditch and sedimentation issues downstream. Additionally, seepage was noted in some segments of the ditch constructed in bedrock. Furthermore, because of the proximity to the Baldwin Peralta Ditch, there is potential to consolidate a portion of the Baldwin Perala Ditch into the Nicol and Table Mountain Ditch.

4.1.4. Enterprise Ditch

The Enterprise Ditch is the longest ditch in the Popo Agie Watershed. The Enterprise diversion is below Worthen Meadow Reservoir and extends to the Little Popo Agie River near Dry Lake (**Figures 4.1a-d**). Water is diverted from Roaring Fork Creek and irrigated lands are located within the Little Popo Agie Watershed. To deliver water to the irrigated lands, a long conveyance system in many different creek drainages is needed.

Water is diverted from Roaring Fork Creek and conveyed to Frye Lake via a delivery ditch that is approximately 0.5-mile-long and includes a stream segment of Frye Lake. Frye Lake is in the Townsend Creek Watershed, and WYSEO records indicate a permitted storage volume of 1,700 acre-feet. From the Frye Lake outlet, water is conveyed in a ditch to the Sawmill Creek channel. At this location, a diversion on Sawmill Creek (**Photo 10**) diverts water to another ditch segment that parallels Sawmill Creek. This ditch segment is approximately 2.5 miles long and outlets into

Crooked Creek. From here, flow is conveyed a short distance to another diversion located on Crooked Creek (**Photo 11**). The next ditch segment is approximately 2.5 miles long and conveys water from the Crooked Creek Watershed to Beason Creek. In this reach is a ditch section known as the Face Drop, or Cascade Drop, that drops approximately 1,000 feet across a 3,800 foot long hillslope to Beason Creek. The ditch slope is controlled by a shale and sandstone bedrock that lines the channel bottom. Erosion at this location has been occurring for more than 100 years. **Photo 12** shows a section of the ditch at the lower portion of the Cascade Drop.

Once the ditch enters the Beason Creek drainage, it reaches the irrigated lands area and conveys water to the diversion structures where flow is split into two laterals, the Deadman Gulch Lateral and the Blue Hill Lateral. Eventually, the ditch laterals cross Highway 287, where the ditch delivery system ends.

Photo 10. Enterprise Ditch – Sawmill Creek Diversion.

Photo 11. Enterprise Ditch – Crooked Creek Diversion.

Photo 12. Enterprise Ditch – Cascade Reach Ditch Section.

Several reports have documented the condition of the Enterprise Ditch system and have provided recommendations for improving water delivery and conveyance structures. These reports include the ACE Level I Watershed Study (ACE 2003), the WWDC Level II Study, (Aqua Engineering 2008) and a USDA study (SCS 1986). Since these reports have been completed, the Enterprise Ditch has completed several improvement projects, including replacement of the Sawmill Creek and Crooked Creek diversion structures, the lateral diversion structure, some wasteway structures, turnout headages and flow measurement structures, along with lining of ditch segments.

The Olsson/Wenck team identified and recommended the following primary areas for improvement during the site investigation:

1. Sawmill Creek Ditch Section: This section of ditch includes a reach that is approximately 3,000 feet long where liner material is degrading, allowing water to leak through the seams. Also, a pervious geotextile material is present that allows water to permeate the liner. In some locations, the liner material was visible in the ditch. **Photo 13** shows a portion of the ditch where the liner has been dislodged. In this reach, seepage zones were identified on the slope below the ditch.

2. Crooked Creek Ditch Section: This section of ditch includes reaches that were approximately 0.5 mile in length. The liner material for this section was an impermeable material that is likely 50 to 60 millimeters thick. The liner for this section of the canal is functioning better than the liner in the Sawmill Creek ditch section. The ditch company has made some repairs to the liner where leaks have been identified.

3. The Headgate Lateral for the Thompson Ditch: This headgate is in the upper portion of the Beason Creek ditch section and is an older structure in poor condition. Various materials have been placed below the drop structure to stabilize the ditch/creek area including tires, plywood, and other material (**Photo 14)**. Based on the condition of this structure, the Olsson/Wenck team recommends replacing it to improve accurate flow diversion to the lateral and to mitigate stability issues at the outlet of the drop structure.

4.1.5. Lyons Ditch

The Lyons Ditch diverts water from the Little Popo Agie River (**Figure 4.1e**). The diversion is located approximately 1 mile east of the intersection of Highway 789 and Lyons Valley Road. The ACE 2003 report indicates that there are some locations along the ditch where seepage may be occurring. During the July 18 site investigation, the Olsson/Wenck team identified that the wasteway had insufficient capacity and that an area with inadequate freeboard for the ditch is located where the ditch crosses to the northwest side of Lyon Valley Road. At the time of the investigation, the ditch was overtopping upstream of the second culvert crossing along the Lyons Valley Road. The ACE Level I report (ACE 2003) also indicated additional areas where freeboard was limited along the ditch.

Photo 13. Enterprise Ditch – Sawmill Creek Reach Channel Lining.

Photo 14. Enterprise Ditch Thompson Lateral Headgate and Drop Structure

4.2. Irrigation System Improvements

This section presents information that was developed for conceptual irrigation system improvements for irrigation structures and ditches that were evaluated as part of the Phase II watershed study. The objective of the proposed improvements is to recommend projects that will result in conservation of water for the Popo Agie Watershed and/or reduce losses that occur. Each improvement project is identified in **Figures 4.1b - e**.

As potential irrigation improvements are evaluated and implemented it would be beneficial to conduct pre- and post-monitoring to evaluate the effectiveness of the improvement project. This could aid the PACD and other entities in determining which projects have the best potential benefits regarding water conservations and cost effectiveness.

4.2.1. Cemetery Ditch and Dutch Flat / Taylor Ditch

The Cemetery Ditch and the Dutch Flat / Taylor Ditch are in proximity to each other, and operational issues affect the ditches (noted below):

- Sections of the Cemetery Ditch are located within the City of Lander, which makes it difficult to access and perform maintenance activities. Several culvert crossings for streets and driveways in this area restrict the ditch’s conveyance capacity.
- Seepage from the Cemetery Ditch and the Dutch Flat / Taylor Ditch affect the elevated water levels that occur in this part of the city during certain times of the year.
- An unstable hillslope area is between the two ditches just west of where the ditches cross Highway 287, near the Old Ford Dealership Slip.

Consolidating the ditches would eliminate these issues. The upper section of the Cemetery Ditch would still be used to provide irrigation water to lands near the diversion. The middle section of the ditch that flows through the City of Lander could be abandoned. To facilitate the ditch consolidation, the following improvements would need to be made.

- Enlarge approximately 3,800 linear feet (LF) of the Dutch Flat / Taylor Ditch so that extra water for the Cemetery Ditch can be conveyed.
- Line the Dutch Flat / Taylor Ditch segment along the golf course reach.
- Install a new headgate lateral to convey water from the Dutch Flat / Taylor Ditch to the Cemetery Ditch at the Highway 287 crossing. This will also require installing a pipe drop from the Dutch Flat / Taylor Ditch to the Cemetery Ditch to convey water to the lower half of the Cemetery Ditch and installing an energy dissipater at the outlet of the pipe drop.
- There are a limited number of culvert crossings on the Dutch Flat/Taylor Ditch that may require enlargement, that were not evaluated, this would need to be investigated as part of a Level II Study.

4.2.2. Nicol and Table Mountain Ditch and Baldwin Peralta Ditch

The Nicol and Table Mountain Ditch and Baldwin Peralta Ditch are also located close to each other. The Baldwin Peralta Ditch includes a small area of irrigated lands near the diversion structure and then a long ditch length to the area where most of the irrigated lands are located. It would be beneficial to consolidate the two ditches so that the lower portion of the Baldwin Peralta Ditch could be served by the Nicol and Table Mountain Ditch:

- Maintenance efforts for the consolidated ditch section would be reduced as only one ditch would be used for conveyance.
- Less water would be lost to conveyance since the overall ditch length of the Baldwin Peralta would be reduced.

The Baldwin Peralta Ditch would still be used to irrigate lands in the upper section of the ditch; however, the middle section could be abandoned. Consolidating the Baldwin Peralta Ditch into the Nicol and Table Mountain Ditch would require the following improvements:

- Enlarge approximately 7,500 LF of the Nicol and Table Mountain Ditch to convey the extra water for the Baldwin Peralta Ditch. Based on observation during site investigations, it appears that enlarging this section of the ditch should be straightforward since cleaning and excavated materials can be placed adjacent to the ditch.
- Install a new headgate lateral to convey water from Nicol and Table Mountain Ditch to the Baldwin Peralta Ditch. This will also require installing 1,250 LF of pipe.
- There are a limited number of culvert crossings on the Nicol and Table Mountain Ditch that may require enlargement, that were not evaluated, this would need to be investigated as part of a Level II Study.

4.2.3. Enterprise Ditch

The Enterprise Ditch includes various features that could be upgraded and/or improved to increase the conveyance efficiency of the ditch. Recommended improvements for the ditch include relining ditch sections where the existing liner has deteriorated and replacing a dilapidated headgate lateral and drop structure. Previous reports have also suggested stabilizing the steep ditch section located at the Cascade Drop in the Sawmill Creek reach. These improvement projects can help reduce conveyance losses that occur along the Enterprise Ditch. Improvement recommendations are described below:

- As previously noted, the lined ditch section for the upper reach of Sawmill Creek has deteriorated, and the liner material is a semipermeable geotextile. Replacing 3,000 LF of ditch lining will significantly reduce seepage loss that occurs in this reach. Ditch lining materials such as reinforced polyethylene or ethylene propylene diene monomer (typically referred to as RPE or EPDM, respectively), and concrete canvas can be used to line the ditch to eliminate seepage. Because of the remote location of the Sawmill Creek Ditch section, and based on installation requirements, the concrete canvas lining material could be a preferred material.

- The headgate and drop structure for the Thompson Lateral in the Beason Creek section of the Enterprise Ditch needs replacing. Installing a new lateral headgate and check drop structure will allow for better regulation of flows delivered to the lateral.
- The Cascade Drop section of the ditch has seepage occurring along the steep channel. Additionally, erosion is likely occurring and causing sediment loading into Beason Creek. Installing a pipe drop at this location would eliminate these two issues.

4.2.4. Lyons Ditch

A section of the Lyons Ditch overflows where it crosses the northwest side of the Lyons Valley Road. A gated wasteway should be installed at this location for spilling excess flows. Additionally, the ditch capacity should be increased upstream of the culvert crossing so that the ditch does not overtop. Cleaning the ditch and elevating the bank (~2,000 LF) should eliminate the overtopping problem.

4.3. Cost Estimates

Cost estimates have been developed for each of the improvements described in the previous section. Based on the estimated cost and other factors, most of the recommended improvements are eligible for WWDC funding. The following cost tables (**Table 4.2 through Table 4.7**) summarize costs for each recommended irrigation system improvement project.

Table 4.2 Cost Estimate Cemetery Ditch and Dutch Flat / Taylor Ditch Consolidation.

Item	Unit*	Quantity	Unit Cost	Total Cost
Mobilization	LS	1	$10,000	$10,000
Dutch Flat / Taylor Ditch Enlargement: includes removal of excess earth material	LF	3,800	$12	$45,600
Headgate for Cemetery Ditch delivery	LS	1	$5,000	$5,000
Pipeline from Dutch Flat / Taylor to Cemetery includes stabilization hillslope soils	LF	300	$75	$22,500
Ditch lining through golf course	LF	3,000	$12	$36,000
			Subtotal	$119,100
			Construction Administration 10%	$11,910
			Contingency 15%	$19,652
			Engineering and Design	$18,000
			Total Cost	$168,662

* LS = Lump Sum, LF = Linear Foot

Table 4.3 Cost Estimate Nicol and Table Mountain and Baldwin Peralta Ditch Consolidation.

Item	Unit*	Quantity	Unit Cost	Total Cost
Mobilization	LS	1	$10,000	$10,000
Nicol and Table Mountain and Baldwin Peralta Ditch Consolidation Enlargement	LF	7,500	$4	$30,000
Headgate for Baldwin Peralta delivery	LS	1	$5,000	$5,000
Pipeline from Nicol and Table Mountain and Baldwin Peralta Ditch	LF	1,250	$50	$62,500
			Subtotal	$107,500
			Construction Administration 10%	$10,750
			Contingency 15%	$17,738
			Engineering and Design	$16,000
			Total Cost	$151,988

* LS = Lump Sum, LF = Linear Foot

Table 4.4 Cost Estimate Enterprise Ditch; Reline the Upper Portion of the Sawmill Creek Reach.

Item	Unit*	Quantity	Unit Cost	Total Cost
Preparation of Final Designs and Specifications	LS	1	$10,000	$10,000
Permitting and Mitigation	LS	1	2,000	$2,000
Legal Fees (Title of Opinion Only)	LS	1	500	$500
Acquisition of Access and Rights of Way	LS	0	0	$0
			Pre-Construction Costs (Subtotal 1)	$12,500
Cost of Project Components				
Mobilization	LS	1	$12,000	$12,000
Install Ditch Liner, Concrete Canvas	LF	4,600	$33	$151,800
			Total Component Cost (Subtotal 2)	$163,800
			Construction Engineering Cost (Subtotal 2 x 10%)	$16,380
			Components and Engineering Costs (Subtotal 3)	$180,180
			Contingency (Subtotal 3 x 15%)	$27,025
			Construction Cost Total (Subtotal 4)	$207,205
			Total Cost (Subtotal 1 + Subtotal 4)	$219,705

* LS = Lump Sum, LF = Linear Foot

NOTE: The cost estimate in Table 4.4 includes permitting and legal fees at the request of PACD.

Table 4.5 Cost Estimate Enterprise Ditch; Replace the Thompson Lateral Headgate and Check Drop Structure.

Item	Unit*	Quantity	Unit Cost	Total Cost
Mobilization	LS	1	$7,500	$7,500
Lateral Headgate	LS	1	$4,000	$4,000
Check Drop Structure: formed concrete	CY	20	$750	$15,000
Pipe, Reclamation, Material Disposal	LS	1	$8,000	$8,000
			Subtotal	$34,500
			Construction Administration 10%	$3,450
			Contingency 15%	$5,693
			Engineering and Design	$5,000
			Total Cost	$48,643

* LS = Lump Sum, CY = Cubic Yard

Table 4.6 Cost Estimate Enterprise Ditch Cascade Reach – Pipe Drop Structure.

Item	Unit*	Quantity	Unit Cost	Total Cost
Mobilization	LS	1	$40,000	$40,000
Pipeline Inlet Structure	LS	1	$25,000	$25,000
30-inch HDPE Pipe	LF	3,800	$130	$494,000
Access Manhole and Pipe Restraint	LS	6	$6,000	$36,000
Pipeline Outlet Structure and Energy Dissipater	LS	1	$40,000	$40,000
			Subtotal	$635,000
			Construction Administration 10%	$63,500
			Contingency 15%	$104,775
			Engineering and Design	$100,000
			Total Cost	$903,275

* LS = Lump Sum, LF = Linear Foot

Table 4.7 Cost Estimate Lyons Ditch Wasteway and Increase Ditch Capacity.

Item	Unit*	Quantity	Unit Cost	Total Cost
Mobilization	LS	1	$7,500	$7,500
Wasteway	LS	1	$8,000	$8,000
Ditch cleaning and increasing ditch bank height	LF	1500	$10	$15,000
			Subtotal	$30,500
			Construction Administration 10%	$3,050
			Contingency 15%	$5,033
			Engineering and Design	$5,000
			Total Cost	$43,583

* LS = Lump Sum, LF = Linear Foot

4.4. Improvement Project Prioritization

Irrigation system improvements discussed in the preceding sections should improve ditch conveyance efficiency and conserve water in the watershed. To aid in determining which of the projects may have the most benefit for the watershed, a rating matrix was developed. Various factors were used to evaluate improvement projects, and the criteria are detailed below. Each criterion is rated from one (1) to three (3), where improvement projects with the most benefit to the watershed received a higher criterion rating.

- **Existing Condition**: The rating of the condition of the structure or ditch. Structures or sections of ditches that are in poor condition will affect water delivery and conveyance efficiency. Structures and ditches with the greatest need for replacement and rehabilitation received a higher rank.
- **Conservation Potential**: The rating of an improvement project's ability to conserve water by reducing diversions and reducing conveyance and efficiency losses. Projects are essentially rated for their conservation benefit, which can be achieved by improving structure functionality and conveyance efficiency of the ditch. Projects with a greater conservation benefit received a higher ranking.
- **Location Priority:** The rating based on project proximity to the river. Projects that would affect the Middle Fork of the Popo Agie River were assigned a higher ranking. This criterion was added since Middle Fork of the Popo Agie experiences very low flows in the summer and projects that could aid in keep or returning water in this reach were determined to have a higher rating based on recommendations from the project sponsor.
- **Cost:** The rating of relative cost of a project. High cost projects will receive a lower rating. The cost ranking can be subjective and a more expensive project could have significant

conservation potential; and it may warrant evaluating project even though the rating could be lower than another project..

Irrigation system improvement projects were evaluated and rated according to these criteria. The ratings are shown in **Table 4.8**. Projects were then ranked as the sum of their criteria rating. Projects with a higher ranking should be given a higher priority. Rankings for most of the projects were similar. The highest priority project is lining the Enterprise Ditch, and the lowest priority project is Enterprise Ditch Cascade Reach Pipe Drop. It should be noted that priorities do change over time, and that this method of prioritization is not meant to be the only way to identify project implementation priorities.

Table 4.8 Irrigation System Improvement Project Ratings.

Ditch	Project	Existing Condition	Conservation Potential	Location Priority	Cost	Ranking
Enterprise	Ditch Lining: Sawmill Creek Reach	3	2	3	3	11
Cemetery - Dutch Flat / Taylor	Ditch Consolidation: Cemetery and Dutch Flat / Taylor	3	2	3	2	10
Enterprise	Beason Creek Reach: Headgate and Drop	3	2	2	3	10
Nicol and Table Mountain – Baldwin Peralta	Ditch Consolidation: Nicol Table Mountain and Baldwin Peralta	2	2	3	2	9
Lyons	Ditch Capacity upgrade and Wasteway	3	2	1	3	9
Enterprise	Cascade Reach: Pipe Drop	2	2	2	1	7

5.0 MICROSTORAGE FACILITIES INVESTIGATION

One of the three key objectives of this watershed study was to identify potential locations for microstorage facilities off the main river channels that will enable irrigators to hold water in the system for use later in the irrigation season. The 2003 watershed study (ACE 2003) identified 33 storage sites from previous studies and newly proposed sites. These were narrowed to 18 sites for further investigation as part of the study. The smallest potential reservoir site had a volume of 450 acre-feet. The microstorage sites provide an alternative that supplements the larger structures in the Phase I study.

The updated water budget described in Section 3.0 showed that at least 1,000 acre-feet of water would be available in May and June in each of the Little Popo Agie, Middle Popo Agie, and North Popo Agie subwatersheds and that this water could be stored and used later in the irrigation season. All three subwatersheds were evaluated for potential microstorage sites.

The microstorage investigation focuses on the selection and evaluation of sites that are physically suitable for the construction of a dam and storage of water. It then ranks the sites based on criteria discussed in Section 5.4. In addition to the potential benefits of additional storage, negative consequences can also result from dam construction. They include, but are not limited to, adverse impacts to fish and aquatic life, reduced habitat connectivity, increased water temperature, and altered sediment transport. Dams can promote development wetland upstream of the structures but can also negatively alter the hydrology of wetlands and riparian areas downstream of the structures.

5.1. Location Selection

The following location selection parameters were used during initial reconnaissance of the watershed:

- Sites would be located outside of wilderness areas.
- Sites would not be located on the mainstem of the three river branches.
- Existing reservoirs were generally not evaluated, with Worthen Meadows Reservoir and Pete’s Lake as exceptions.

The 33 sites identified in the 2003 watershed study were examined for potential for microstorage sites. The locations were narrowed down to 18 potential sites by eliminating sites on the mainstem sites and existing reservoirs/lakes.

The study area was then examined for locations that appeared physically feasible on which to construct a dam to impound a suitable volume of water. These sites must also have a large enough tributary area to yield enough water to be stored or can be supplied by an irrigation ditch. To determine potentially available tributary water, the USGS stream gage that included the potential microstorage site dam and its drainage area was identified for each site. For each USGS gage, the wet, normal, and dry flows for May and June were obtained from the water budget model. The flows were divided by the published tributary area for each gage to determine the acre-foot per square mile unit watershed yield. These values are shown in **Table 5.1**.

The tributary area and potential yield for each potential dam site were determined. The tributary areas for the sites included in the 2003 watershed study were taken from the GIS files that showed each dam and its contributing drainage area. For sites newly identified in this study, the drainage areas were delineated using USGS topographic quadrangle map contours. Some potential locations that looked feasible for a dam were eliminated because of very small tributary areas. The resulting long lists of previously and newly identified sites are shown in **Tables 5.2 and 5.3** . The proposed microstorage sites are illustrated on **Figure 5.1.**

5.2. Target Capacity

A target capacity was developed to evaluate the sites. The target volume of desirable water was based on an example calculation, like one presented during the HRI workshop held during the Popo Agie Watershed Forum in March 2018. In that example, the goal was to irrigate a 100-acre alfalfa field in August. With evapotranspiration of 7.54 inches in August in Lander, Wyoming, and an irrigation requirement of 7.1 inches in a normal year, the net irrigation requirement would be 0.59 acre-foot of water per acre of alfalfa. Assuming 50 percent irrigation efficiency for flood irrigation, the crop water need would be 1.18 acre-feet per acre. For a 100-acre field, the total water needed would be 118 acre-feet.

If the water were diverted and stored starting in May and needed in August, evaporation and seepage losses must be considered. Evaporation and precipitation from May through August in Lander are 19.8 and 7.2 inches, respectively, for a net loss of 12.6 inches. If a storage site had a surface area of 22.5 acres, the result would be an approximate evaporative loss of 23.6 acre-feet. Seepage over that time could be approximately 3 inches, for a loss of 5.6 acre-feet. Adding the crop water requirement plus the losses to seepage and evaporation gives a total of 147.6 acre-feet of water needed to irrigate the 100-acre alfalfa field. This volume does not consider transmission losses from the location where the water is stored to the location where it would be used. Based on this example, the need to compensate for transmission losses, and adding volume for flexibility, a volume of 300 acre-feet was used as the target volume. The sites could be larger or smaller but achieving the same volume at each potential site yielded a like comparison. Based on this analysis, not every location could achieve the full 300 acre-feet, but most could.

Table 5.1 Available Water at USGS Stream Gages

USGS Gage	Name	Drainage Area, sq mi	Model Node	Wet Year						Normal Year						Dry Year					
				Average Streamflow, ac-ft		Average Streamflow, cfs		Average unit Streamflow, ac-ft/sq mi		Average Streamflow, ac-ft		Average Streamflow, cfs		Average unit Streamflow, ac-ft/sq mi		Average Streamflow, ac-ft		Average Streamflow, cfs		Average unit Streamflow, ac-ft/sq mi	
				May	June	May	June	May	June	May	June	May	June	May	June	May	June	May	June	May	June
6231600	Popo Agie River Below the Sinks nr Lander, WY	87.5	2.1.12	19,428	62,117	316	1,010	222.0	709.9	16,278	32,079	265	522	186.0	366.6	9,354	9,138	152	149	106.9	104.4
6232000	North Popo Agie River near Milford, WY	98.4	1.1.10	23,254	58,671	378	954	236.3	596.3	14,985	29,344	244	477	152.3	298.2	8,886	9,211	145	150	90.3	93.6
6232500	North Popo Agie River near Lander, WY	134	1.1.26	19,731	50,656	321	824	147.2	378.0	12,272	24,492	200	398	91.6	182.8	6,246	5,204	102	85	46.6	38.8
6233000	Little Popo Agie River near Lander, WY	125	3.1.16	18,675	36,617	304	596	149.4	292.9	13,428	20,374	218	331	107.4	163.0	9,296	8,715	151	142	74.4	69.7
6233500	Little Popo Agie River	384	3.3.30	14,115	30,731	230	500	36.8	80.0	10,948	21,006	178	342	28.5	54.7	6,743	8,768	110	143	17.6	22.8
6233900	Popo Agie River near Arapahoe, WY	796	4.1.18	58,363	139,875	949	2,275	73.3	175.7	41,545	85,866	676	1,396	52.2	107.9	22,214	20,172	361	328	27.9	25.3

Table 5.2. Long List of Potential Micro-Storage Sites, Previously Identified in 2003 Level I Report

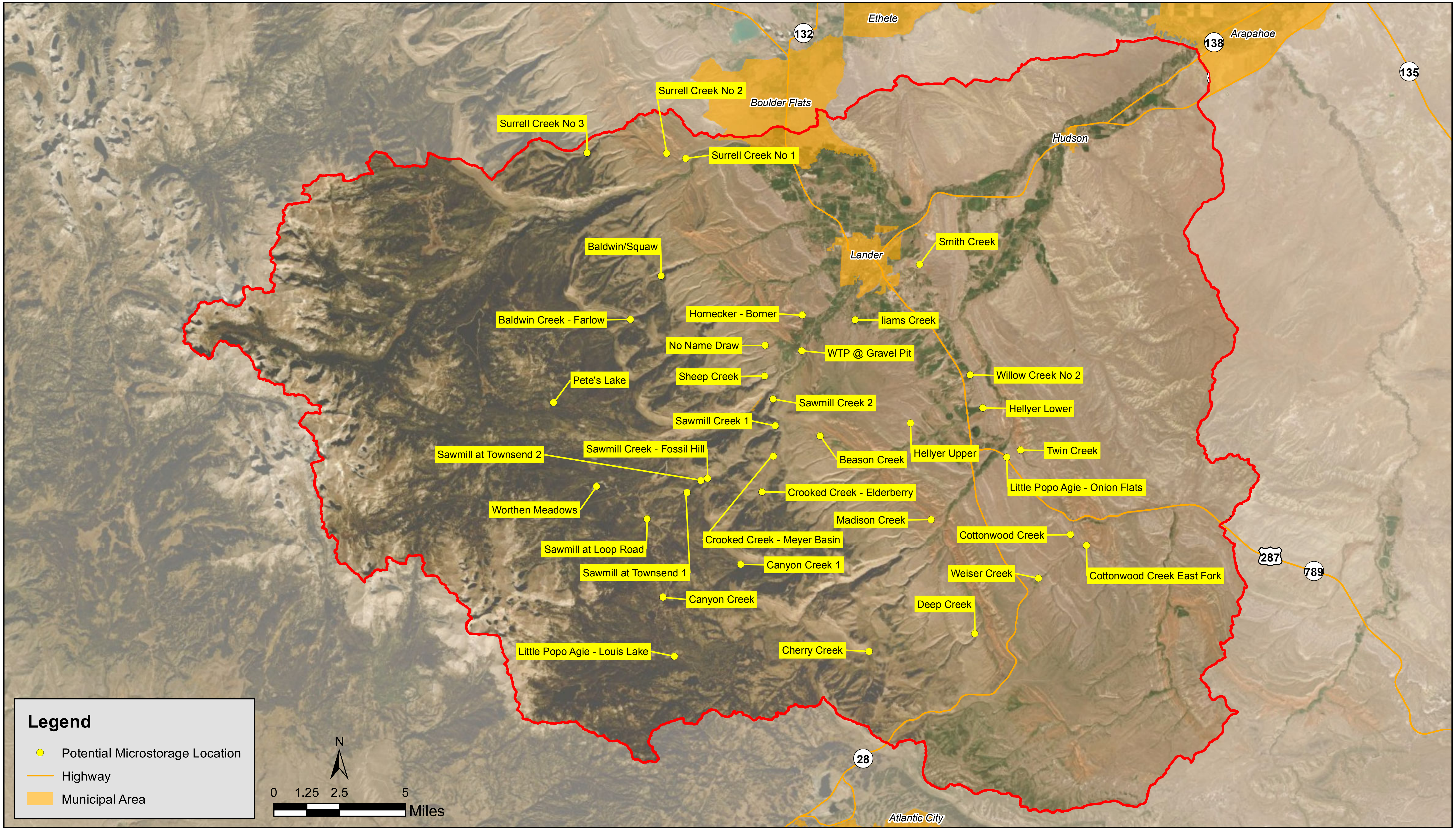
	Site Name	Source	Trib. Area, mi^2	Ownership	USGS Gage from which Unit Discharge Was Used	Model Node	Available Flow, acre-feet: Normal Year May	Normal Year June	Normal Year May + June	Dry Year May	Dry Year June	Dry Year May + June
North	Surrel Creek No. 1	North Popo Agie	12.2	Wind River Reservation, Private	06232500	1.1.26	1,113	2,222	3,335	567	472	1,039
North	Surrel Creek No. 2	North Popo Agie	12.2	Wind River Reservation	06232500	1.1.26	1,113	2,222	3,335	567	472	1,039
Middle	Baldwin - Farlow	Baldwin Creek	13.3	Private, BLM	06233900	4.1.18	692	1,431	2,123	370	336	706
Middle	Crooked Creek - Elderberry	Crooked Creek	4.1	National Forest	06231600	2.1.12	761	1,500	2,262	437	427	865
Middle	Crooked Creek - Meyer Basin	Crooked Creek	6.3	Private, BLM	06231600	2.1.12	1,166	2,298	3,464	670	655	1,325
Middle	Hornecker - Borner (MPA diversion)	Middle Popo Agie	87.5	Private	06233900	4.1.18	4,567	9,439	14,006	2,442	2,217	4,659
Middle	Hornecker - Borner (tributaries)	Middle Popo Agie	9.7	Private	06233900	4.1.18	504	1,042	1,546	270	245	514
Middle	Middle Popo Agie - Mid Valley	Middle Popo Agie	131.2	Private, State	06233900	4.1.18	6,850	14,158	21,007	3,663	3,326	6,989
Middle	Pete's Lake	Un-named	1.2	National Forest	06231600	2.1.12	219	432	652	126	123	249
Middle	Sawmill Creek - Neff Park	Sawmill Creek	7.1	National Forest	06231600	2.1.12	1,329	2,618	3,947	764	746	1,509
Middle	Sawmill Creek - Fossil Hill	Sawmill Creek	17.8	National Forest	06231600	2.1.12	3,308	6,519	9,827	1,901	1,857	3,758
Middle	Smith Creek	Middle Popo Agie	3.0	State	06233900	4.1.18	154	318	472	82	75	157
Middle	Thompson Creek (divert from MPA)	Middle Popo Agie	114.1	Private	06233900	4.1.18	5,953	12,303	18,256	3,183	2,890	6,073
Middle	Worthen Meadows Reservoir	Roaring Fork	13.0	National Forest	06231600	2.1.12	2,416	4,762	7,178	1,389	1,357	2,745
Little	Canyon Creek 1	Canyon Creek	6.8	National Forest	06233000	3.1.16	731	1,109	1,839	506	474	980
Little	Little Popo Agie - Onion Flats	Little Popo Agie	9.7	BLM, Private	06233500	3.3.30	275	528	804	170	221	390
Little	Onion Flats - from Devils Creek	Devils Creek	9.7	BLM, Private	06233500	3.3.30	275	528	804	170	221	390
Little	Twin Creek	Little Popo Agie	114.5	Private	06233500	3.3.30	3,263	6,262	9,525	2,010	2,614	4,624
Little	Willow Creek No. 2	Willow Creek	29.2	Private	06233500	3.3.30	832	1,596	2,427	512	666	1,178

Shaded sites indicate they were eliminated from further consideration

Table 5.3. Long List of Potential Micro-Storage Sites, Newly Identified

	Site Name	Source	Trib. Area, mi^2	Ownership	USGS Gage from which Unit Discharge Was Used	Model Node	Available Flow, acre-feet					
							Normal Year			Dry Year		
							May	June	May + June	May	June	May + June
North	Kimball Draw	Kimball Draw	0.8	Private	06232500	1.1.26	75	150	226	38	32	70
North	Sioux Ditch Trib	Trib. to North Popo Agie	0.4	Trust for Tribes of the Wind	06233900	4.1.18	20	42	62	11	10	21
North	Surrel Creek No 3	Surrell Creek	4.9	Wind River Reservation	06232500	1.1.26	450	898	1,348	229	191	420
Middle	Baldwin/Squaw	Baldwin/Squaw Creek	16.0	BLM	06233900	4.1.18	837	1,729	2,566	447	406	853
Middle	No Name Draw	Gaylor Warnock Ditch	1.3	Private	06231600	2.1.12	236	466	703	136	133	269
Middle	Sawmill Creek 1	Sawmill Creek	28.1	BLM, Private	06231600	2.1.12	5,232	10,311	15,543	3,007	2,937	5,944
Middle	Sawmill Creek 2	Sawmill Creek	28.9	State, Private	06231600	2.1.12	5,376	10,595	15,971	3,089	3,018	6,107
Middle	Sawmill at Loop Road	Sawmill Creek	7.1	National Forest	06231600	2.1.12	1,321	2,603	3,924	759	741	1,500
Middle	Sawmill at Townsend 1	Sawmill Creek	11.7	National Forest	06231600	2.1.12	2,185	4,307	6,492	1,256	1,227	2,483
Middle	Sawmill at Townsend 2	Sawmill Creek	15.9	National Forest	06231600	2.1.12	2,963	5,840	8,803	1,703	1,664	3,366
Middle	Sheep Creek	Sheep Creek	3.0	State, Private	06233900	4.1.18	156	322	477	83	76	159
Middle	Thompson Creek - Gaylor	Thompson Creek	0.5	Private	06233900	4.1.18	27	55	81	14	13	27
Middle	WTP @ Gravel Pit (Minimum Size)	Div. from Middle Popo Agie	87.5	State	06231600	2.1.12	16,278	32,079	48,357	9,354	9,138	18,492
Middle	WTP @ Gravel Pit (Maximum Size)	Div. from Middle Popo Agie	98.4	State	06231600	2.1.12	16,278	32,079	48,357	9,354	9,138	18,492
Little	Beason Creek	Beason Creek	2.1	Private, State	06233500	3.3.30	60	114	174	37	48	84
Little	Blue Hill Lateral	Trib near Blue Hill Lateral	0.5	Private	06233500	3.3.30	15	30	45	9	12	22
Little	Canyon Creek	Canyon Creek	0.8	National Forest	06233000	3.3.16	83	127	210	58	54	112
Little	Cherry Creek	Cherry Creek	6.0	Nature Conservancy	06233000	3.3.16	644	977	1,621	446	418	864
Little	Cottonwood Creek	Cottonwood Creek	23.3	Private	06233500	3.3.30	665	1,276	1,941	410	533	942
Little	Cottonwood Creek East Fork	Cottonwood Creek East Fork	29.8	Private, Nature Conservancy	06233500	3.3.30	850	1,631	2,480	523	681	1,204
Little	Critnan Creek	Critnan Creek	2.3	Private	06233500	3.3.30	66	127	193	41	53	93
Little	Deep Creek	Deep Creek	5.7	Nature Conservancy	06233000	3.3.16	617	936	1,553	427	400	827
Little	Iiams Creek	Iiams Creek	0.6	Private, State	06233500	3.3.30	16	31	46	10	13	23
Little	Little Popo Agie - Louis Lake	Little Popo Agie	19.9	National Forest	06233000	3.3.16	2,142	3,250	5,393	1,483	1,390	2,873
Little	Madison Creek	Madison Creek	4.8	Private	06233000	3.3.16	512	777	1,289	355	332	687
Little	Millard Ditch	Trib US of Millard Ditch	1.9	Private	06233500	3.3.30	54	104	158	33	43	77
Little	Weiser Creek	Weiser Creek	3.8	Wind River Reservation	06233500	3.3.30	109	210	319	67	88	155
Little	Willow Creek Lower	Willow Creek	22.7	Private	06233000	3.3.16	2,434	3,693	6,126	1,685	1,580	3,264
Little	Willow Creek Upper	Willow Creek Tributary	1.6	Private, BLM	06233000	3.3.16	175	266	442	121	114	235

Shaded sites indicate they were eliminated from further consideration



POPO AGIE WATERSHED STUDY

Potential Microstorage Location Overview

FIGURE

5.1

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Date: 11/8/2019 Time: 9:54:59 AM User: gmalek-madani

Tables 5-2 and 5-3 in **Appendix C** show the available flow at each potential microstorage site for the normal and dry years in May and June, when water would be collected and stored. During a conference call in March 2019, the long lists of sites were discussed with members of the HRI. It was decided that sites not having at least 100 acre-feet of available water would be eliminated from further consideration. The sites are indicated with gray shading in **Tables 5-2 and 5-3** and consist of Kimball Draw, Sioux Ditch Tributary, Thompson Creek – Gaylor, Blues Hill Lateral, Critnan Creek, and Millard Ditch. Two sites eliminated based on this criteria, Beason Creek and Iams Creek, were later added back to the list. The storage in these locations, along Beason Creek and Iams Creek, can be provided or supplemented by irrigation ditches and is not solely dependent on the contributing watershed area. Beason Creek could be filled by the Blue Hill Lateral and Iams Creek by the Nicol and Table Mountain Ditch.

After discussing the sites during a May 2019 conference call, the sponsors requested analysis of additional locations: Hellyer Draw Lower, Hellyer Draw Upper, No Name Draw, Sawmill at Loop Road, and Sawmill at Townsend 1 and 2. Some of these sites can be filled by irrigation ditches. Hellyer Upper could be filled by the Enterprise Ditch; Sawmill at Townsend 2 could be filled by the Enterprise Supply Ditch; and No Name Draw by the Gaylor and Warnock Ditch. At 15 cubic feet per second for the Gaylor and Warnock Ditch, it would take approximately 81 hours, or three to four days to fill to 100 acre-feet.

It was assumed that the sites could capture the water needed to fill each reservoir. Consideration was not given to potential needs to keep a certain flow in the drainageways for environmental or other purposes.

5.3. Dam Volumes and Costs

At each location, stage-storage relationships were developed, and the required heights of the dam embankments were determined. The dams were assumed to have a 14-foot crest width and 4-foot horizontal to 1-foot vertical (4:1) faces on the upstream and downstream sides. It may be feasible to design and construct the dams with 3:1 slopes. The flatter slopes are more conservative from a costing and design standpoint and were appropriate at this high-level conceptual stage. The WYSEO regulations regarding dams indicate that all of the dams would be under the jurisdiction of the WYSEO, unless the dam height was under 6 feet, as indicated in **Figure 5.2**. The dams are required to have 5 feet of freeboard above the normal pool, which adds significant volume and cost to the structures.

The term “microstorage” can be misleading. A 300-acre-foot structure is not a small structure, which may be implied by the term “micro.” Without the additional 5 feet of freeboard, the heights of the 300-acre-foot structures range from 6 to 94 feet, with the median at 38 feet. For comparison, the existing Frye Lake has 1,700 acre-feet of storage.

During the stage-storage and dam estimation, three additional sites were eliminated based on the proximity to existing structures and infrastructure: Middle Popo Agie – Mid Valley, Sawmill Creek – Neff Park, and Thompson Creek.

The dam volumes that represent storage of 300 acre-feet, if possible, with 5 feet of freeboard above the 300 acre-feet, were estimated. A unit cost of $15 per cubic yard of fill was applied to the dam volume. The cost has been used in previous studies to capture the construction cost of the dam, outlet works, spillway, etc. A check with the WWDC dams and reservoir group indicated that the cost is still reasonable, though it could potentially be higher. It allows for judgement of all the sites on the same basis, for a relative comparison of cost. RS Means Historical Cost Indices would indicate that the 2003 construction cost would be 0.581 percent of a January 2019 construction cost (RS Means 2019). In order to bring the cost forward using this index, the $15 per cubic yard would become $26 per cubic yard. The index has not been validated by Wyoming Department of Transportation or other local data. The estimated costs range from $124,000 to $14 million, with most structures at less than $2 million.

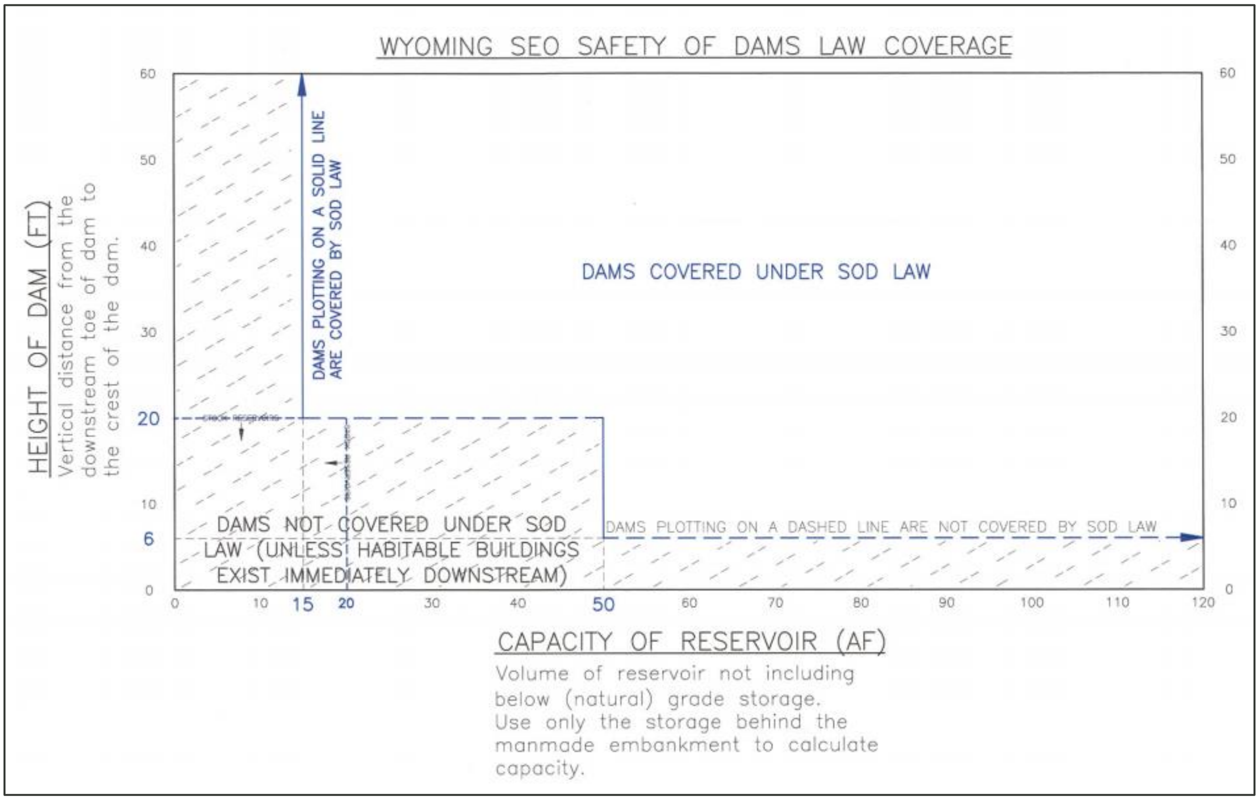


Figure 5.2 Wyoming State Engineer's Office Safety of Dams Coverage Graphic (WYSEO 2019).

Because of the high cost of many of the structures, dams that would hold closer to 150 acre-feet were estimated by relating the dam height to the cross-sectional area on a relative basis. The estimated volumes of the dams were approximated by a percentage reduction in the cross-sectional area. The purpose of this estimate was to provide a feel for the scale of the costs for the smaller structures.

The construction costs and costs per acre-foot of water for the 300 acre-feet and 150 acre-feet scenarios are included in **Table 5-4**. The per acre-foot cost was based on the initial construction and one year of use, not projected over the lifetime of the structures, which would typically be designed for 25 to 50 years of use. Future sedimentation and loss of volume have not been considered as part of this investigation.

A storage area was evaluated at the water treatment plant. The City of Lander is interested in building a settling pond, and the location can also be used for infiltration. This infiltration alternative is discussed more fully in Section 6. The desirable minimum infiltration rate was estimated to be 400,000 gallons per day, or 1.2 acre-feet per day. A storage reservoir that can hold and infiltrate the 1.2 acre-feet was graded into the open area east of the water treatment plant. A maximum size structure based on site topography was also estimated. The structure could hold up to 441 acre-feet of water below 5 feet of freeboard. The costs were approximately $50,000 for the smaller structure and over $6 million for the maximum size structure. The actual structure would fall between the two, based on the desires of the sponsors. The water treatment plant gravel pit is included in the costing tables but would not be used for microstorage, because the geology is unfavorable. It could be used for sedimentation or infiltration.

Table 5.4 presents the dam volume estimates and associated total costs, along with costs per acre-foot of water for the evaluated structures. The **Index Map** in **Appendix C** is an overview that shows all the sites in **Table C-4**. They are the sites for further consideration for microstorage or infiltration. The sites presented in this analysis store a minimum volume of 300 acre-feet of water, in general. Smaller sites in alternate locations may be beneficial and should be analyzed on a case-by-case basis.

Figures C-1a through C-36a in **Appendix C** show each of the sites in **Table C-4**, along with the potential dam centerline and approximate inundation area at 300 acre-feet, or the maximum volume the site can hold, leaving room for freeboard. The inundation areas were based on GIS contours and may not necessarily line up precisely with the aerial imagery used in the figures. The figures also show mapped soils units surrounding the sites. **Figures C-1b through C-36b** show each of the sites plus irrigated acreage from the 2003 study and wetlands from the National Wetlands Inventory (NWI) layer.

The potential microstorage sites differ in terms of the dam geometries and reservoir surface areas. Sites with larger surface areas will experience higher losses of water because of evaporation and seepage. **Table 5.5** shows estimates of the volumes of water that could remain at the end of the season after accounting for evaporation and seepage losses. Evaporation was considered for June, July, and August. A net evaporation value of 18.1 inches for these months was obtained from Table 10.B of the Wyoming Climate Atlas (Curtis and Grimes 2019). Three inches of loss caused by seepage were assumed. The timing of when the reservoirs will fill and be used will vary, but the calculation is intended to indicate when greater losses will occur.

Table 5.4. Short List of Potential Micro-Storage Sites Dam Volumes and Costs

		Dam and Reservoir Information											
		300 acre-feet of storage						150 acre-feet of storage (approximate values)					
	Site Name	Dam height, feet	Dam height plus 5 feet of freeboard, feet	Surface area, acres	Dam volume, cubic yards	Cost @ $15/cubic yard	Cost, $/acre-foot of water	Dam height plus 5 feet of freeboard, feet	Height difference	Approx. area (volume) difference	Approx. dam volume, cubic yards	Cost @ $15/cubic yard	Cost, $/acre-foot of water
North	Surrel Creek No. 1	54	59	13	117,976	$1,769,641	$5,899	42	71%	54%	63,199	$947,984	$6,320
	Surrel Creek No. 2	44	49	23	112,463	$1,686,943	$5,623	40	81%	68%	76,269	$1,144,042	$7,627
	Surrel Creek No 3	81	86	8.4	357,176	$5,357,644	$17,859	62	72%	55%	195,001	$2,925,010	$19,500
Middle	Baldwin - Farlow	50	55	12	101,668	$1,525,022	$5,083	39	72%	54%	55,169	$827,537	$5,517
	Baldwin/Squaw	82	87	9.1	234,687	$3,520,305	$11,734	67	77%	62%	145,010	$2,175,145	$14,501
	Crooked Creek - Elderberry	54	54	12	131,444	$1,971,660	$10,269	49	90%	82%	107,260	$1,608,906	$10,726
	Crooked Creek - Meyer Basin	52	57	14	91,148	$1,367,220	$4,557	39	68%	49%	44,572	$668,573	$4,457
	Hornecker - Borner (MPA diversion)	21	26	25	117,928	$1,768,923	$5,896	18	69%	50%	58,999	$884,992	$5,900
	Hornecker - Borner (tributaries)	21	26	25	117,928	$1,768,923	$5,896	18	69%	50%	58,999	$884,992	$5,900
	No Name Draw	43	48	16	261,429	$3,921,441	$13,071	34	71%	53%	138,246	$2,073,691	$13,825
	Pete's Lake	6	11	58	8,251	$123,758	$413	8	74%	58%	4,801	$72,012	$480
	Sawmill Creek 1	90	95	9.5	105,987	$1,589,808	$5,299	75	79%	65%	68,793	$1,031,901	$6,879
	Sawmill Creek 2	87	92	8.8	963,521	$14,452,813	$48,176	71	77%	63%	605,846	$9,087,695	$60,585
	Sawmill Creek - Fossil Hill	52	57	18	62,940	$944,101	$3,147	69	120%	126%	79,238	$1,188,573	$7,924
	Sawmill at Loop Road	24	29	32	58,246	$873,689	$2,912	21	74%	58%	33,644	$504,656	$3,364
	Sawmill at Townsend 1	41	46	17	108,355	$1,625,320	$5,418	34	73%	57%	61,695	$925,432	$6,170
	Sawmill at Townsend 2	66	71	14	256,459	$3,846,879	$12,823	54	77%	62%	158,254	$2,373,809	$15,825
	Sheep Creek	90	95	9.4	745,791	$11,186,858	$37,290	74	78%	64%	479,995	$7,199,931	$48,000
	Smith Creek	15	20	40	35,566	$533,485	$1,778	12	63%	41%	14,719	$220,779	$1,472
	WTP @ Gravel Pit (Minimum Size)	4	6	0.8	3,217	$48,252	$161	---	---	---	---	---	---
	WTP @ Gravel Pit (Maximum Size)	37	42	22	424,900	$6,373,500	$21,245	---	---	---	---	---	---
	Worthen Meadows Reservoir	---	---	---	---	---	---	---	---	---	---	---	---
Little	Beason Creek	33	38	21	133,517	$2,002,758	$6,676	26	68%	49%	65,402	$981,028	$6,540
	Canyon Creek	34	39	19	68,561	$1,028,413	$3,428	29	75%	59%	40,221	$603,312	$4,022
	Canyon Creek 1	38	43	15	116,628	$1,749,415	$5,831	24	56%	31%	36,475	$547,126	$3,648
	Cherry Creek	32	37	25	95,636	$1,434,543	$4,782	28	77%	62%	58,828	$882,414	$5,883
	Cottonwood Creek	26	31	28	55,165	$827,469	$2,758	26	84%	72%	39,608	$594,121	$3,961
	Cottonwood Creek East Fork	38	43	24	41,337	$620,056	$2,067	35	81%	68%	28,209	$423,129	$2,821

Site Name		Dam and Reservoir Information											
		300 acre-feet of storage						150 acre-feet of storage (approximate values)					
		Dam height, feet	Dam height plus 5 feet of freeboard, feet	Surface area, acres	Dam volume, cubic yards	Cost @ $15/cubic yard	Cost, $/acre-foot of water	Dam height plus 5 feet of freeboard, feet	Height difference	Approx. area (volume) difference	Approx. dam volume, cubic yards	Cost @ $15/cubic yard	Cost, $/acre-foot of water
Little	Deep Creek	94	99	9.1	325,367	$4,880,505	$16,268	78	78%	64%	209,359	$3,140,384	$20,936
	Iiams Creek	38	38	15	279,329	$4,189,928	$22,648	37	98%	94%	261,872	$3,928,078	$21,233
	Little Popo Agie - Louis Lake	13	18	37	44,887	$673,306	$2,244	13	74%	58%	25,813	$387,190	$2,581
	Little Popo Agie - Onion Flats	29	34	42	29,019	$435,281	$1,451	27	81%	68%	19,833	$297,490	$1,983
	Madison Creek	N/A	N/A	9.8	N/A	N/A	N/A	26	0%	0%	16,481	$247,217	$1,648
	Onion Flats - from Devils Creek	29	34	42	29,019	$435,281	$1,451	27	81%	68%	19,833	$297,490	$1,983
	Twin Creek	20	25	31	22,570	$338,555	$1,129	19	77%	62%	13,969	$209,536	$1,397
	Weiser Creek	40	45	20	87,441	$1,311,617	$4,372	34	75%	59%	51,889	$778,333	$5,189
	Willow Creek No. 2	18	23	42	22,381	$335,708	$1,119	18	78%	64%	14,365	$215,480	$1,437
	Willow Creek Lower	15	20	50	70,232	$1,053,478	$3,512	14	70%	52%	36,321	$544,812	$3,632
	Willow Creek Upper	43	48	16	98,816	$1,482,239	$4,941	35	74%	58%	57,250	$858,747	$5,725

Notes:

Use of Worthen Meadows Reservoir was not specifically evaluated with this study, but its use is recommended for evaluation with other ongoing studies

Storage at the WTP would be used for infiltration rather than micro-storage

Crooked Creek - Elderberry can achieve a maximum of 192 acre-feet (leaving 5' for freeboard)

Iams Creek can achieve a maximum of 185 acre-feet (leaving 5' for freeboard)

Madison Creek can achieve a maximum of 77 acre-feet (leaving 5' for freeboard)

Table 5.5. Potentially Available Water at the End of the Season

	Site Name	Surface area, acres	Starting storage June, acre-feet	Net Evaporation, June through August, acre-feet	Seepage, acre-feet	Remaining Volume, acre-feet	Cost, $/acre-foot of remaining water
North	Surrel Creek No. 1	13	300	19	3	277	$6,381
	Surrel Creek No. 2	23	300	34	6	260	$6,477
	Surrel Creek No 3	8.4	300	13	2	285	$18,782
Middle	Baldwin - Farlow	12	300	19	3	278	$5,485
	Baldwin/Squaw	9.1	300	14	2	284	$12,396
	Crooked Creek - Elderberry	12	192	18	3	171	$11,550
	Crooked Creek - Meyer Basin	14	300	21	3	276	$4,952
	Hornecker - Borner (MPA diversion)	25	300	38	6	256	$6,916
	Hornecker - Borner (tributaries)	25	300	38	6	256	$6,916
	No Name Draw	16.2	300	24	4	272	$14,443
	Pete's Lake	58	300	88	15	197	$627
	Sawmill Creek 1	9.5	300	14	2	283	$5,613
	Sawmill Creek 2	8.8	300	13	2	285	$50,796
	Sawmill Creek - Fossil Hill	18	300	27	4	268	$3,517
	Sawmill at Loop Road	32	300	48	8	245	$3,573
	Sawmill at Townsend 1	17	300	26	4	270	$6,020
	Sawmill at Townsend 2	14	300	21	4	275	$13,979
	Sheep Creek	9.4	300	14	2	283	$39,469
	Smith Creek	40	300	60	10	230	$2,317
	WTP @ Gravel Pit (Min Size)	0.8	---	---	---	---	---
	WTP @ Gravel Pit (Max Size)	22.2	---	---	---	---	---
	Worthen Meadows Reservoir	---	---	---	---	---	---
Little	Beason Creek	20.6	300	31	5	264	$7,591
	Canyon Creek	19.2	300	29	5	266	$3,863
	Canyon Creek 1	15	300	22	4	274	$6,381
	Cherry Creek	24.8	300	37	6	256	$5,594
	Cottonwood Creek	28.1	300	42	7	251	$3,302
	Cottonwood Creek East Fork	23.8	300	36	6	258	$2,402
	Deep Creek	9.1	300	14	2	284	$17,189
	Iiams Creek	15.4	185	23	4	158	$26,540
	Little Popo Agie - Louis Lake	36.9	300	56	9	235	$2,863
	Little Popo Agie - Onion Flats	42	300	64	11	226	$1,927
	Madison Creek	9.8	77	15	2	60	$4,132

Table 5.5. Potentially Available Water at the End of the Season

	Site Name	Surface area, acres	Starting storage June, acre-feet	Net Evaporation, June through August, acre-feet	Seepage, acre-feet	Remaining Volume, acre-feet	Cost, $/acre-foot of remaining water
Little	Onion Flats - from Devils Creek	42	300	64	11	226	$1,927
	Twin Creek	31	300	47	8	245	$1,381
	Weiser Creek	20.2	300	30	5	264	$4,960
	Willow Creek No. 2	42	300	63	10	227	$1,480
	Willow Creek Lower	50.4	300	76	13	211	$4,984
	Willow Creek Upper	16.2	300	24	4	271	$5,460

Notes:

Net evaporation was considered to be 18.1 inches for June through August, taken from Table 10.B of the Wyoming Climate Atlas

Seepage was estimated to be 3 inches over the time frame of June through August

5.4. Ranking of Sites

With 36 potential microstorage sites to be compared, criteria were developed so that the sites could be ranked. Eight criteria categories were developed and scored from 1 (lowest) to 3 (highest). Water availability, versatility of benefit, and cost were considered the most important criteria and were given twice the weight of the other categories. The categories and weights of the scoring criteria are shown in **Table 5.6**. **Table 5.7** summarizes the criteria, weight, and scoring in more detail.

Table 5.6 Ranking Criteria and Weight.

Criteria	Weight
Water availability	2
Versatility of benefit	2
Cost	2
Bedrock geology and soils	1
Proximity to irrigation	1
Proximity to structures	1
Wetlands	1
Property ownership	1

Table 5.8 shows the scores and ranking for the sites, in alphabetical order, by subwatershed. **Tables 5.9 and 5.10** show the scores and rankings for each site sorted into approximate thirds by color, with green being the most favorable third, yellow the middle third, and red the least favorable third. The thirds are not

Table 5.7. Criteria for Evaluation of Popo Agie Micro-Storage Sites

Criteria	Weight	Explanation	Score	Description	Comments
Water availability	2	Available water for May and June in a dry year	1	<500 acre-feet	Sites with less than 100 acre-feet of available water in a dry year are included in the long list but no further evaluation will be completed.
			2	More than 500 acre-feet and less than 1,000 acre-feet	
			3	More than 1,000 acre-feet	
Versatility of benefit	2	Can the water be used for multiple purposes/ benefits? The general distinction was can the water be used on nearby fields, be directed into an existing ditch, or be directed into the mainstem of one othe three branches.	1	One of the three uses	Can the water be used for multiple purposes/benefits? Specifically, can it benefit agricultural use by providing water for irrigation, can it benefit fish/wildlife by increasing stream flow during low flow periods, can it benefit industrial/municipal by providing source water during periods of high demand? One point is given for each time a benefit is identified.
			2	Two of the three uses	
			3	All three of the uses	
Cost	2	Approximate construction cost of the structure, based on dam volume at $15 per cubic yard	1	Over $2 million for 300 acre-feet	
			2	Between $1 million and $2 million for 300 acre-feet	
			3	Under $1 million for 300 acre-feet	
Proximity to irrigation	1	Are irrigated fields close to the storage site?	1	>1 mile from irrigated acreage	The farther the site from the irrigated acreage, the more potential loss to the place of use. One site is approximately 5500 feet from irrigated acreage and was assigned a 2.
			2	0.5 to approx. 1 mile from irrigation	
			3	Less than 0.5 mile or in the midst of irrigated acreage	
Proximity to structures	1	Are structures located nearby that could be impacted by storage or a dam failure?	1	Structures nearby downstream	A specific distance was not defined. Structures could be either downstream or close to a potential pool inundation area
			2	Structures either upstream or downstream but not close	
			3	No structures nearby	
Property ownership	1	Ownership of the property on which a dam and the storage pool would be located	1	Federal and reservation	If a site was on more than one category, the lower ranking was given. State and private were given 3 and 2, respectively in modified ranking.
			2	State	
			3	Private	
Bedrock Geology and Soils	1	Any potential fatal flaws for geology or soils?	1	Madison Deposits or Sinkson or Thermopolis soils present	Seepage rates may be too high in areas overlying the Madison or other limestone units. Other fatal flaws include areas with faults and/or landslides. Sinkson and Thermopolis soil types are unfavorable.
			2	Partially located on Sinkson or Thermopolis soils	
			3	Madison Deposits or unfavorable soils are not present	
Wetlands	1	Presence of wetlands, according to the National Wetland Inventory	1	>5 acres of wetlands are present	The presence of wetlands will be linked to the permitting of a particular site. Wetlands would be inundated by the storage pool or under the dam footprint.
			2	Up to 5 acres of wetlands are present	
			3	No wetlands are present	

Table 5.8. Micro-Storage Sites Scoring

	Site Name	Branch	Water Availability*	Beneficial Uses*	Cost*	Bedrock Geology and Soils	Proximity to Irrigation	Proximity to Structures	Wetlands	Property Ownership (Original)	Total	Property Ownership (Revised)	Total (with Revised Property Ownership)
North	Surrel Creek No. 1	N	3	3	2	1	3	1	3	1	17	1	17
	Surrel Creek No. 2	N	3	3	2	1	2	1	3	1	16	1	16
	Surrel Creek No 3	N	1	3	1	3	1	3	3	1	16	1	16
Middle	Baldwin - Farlow	M	2	2	2	3	1	1	3	1	15	1	15
	Baldwin/Squaw	M	2	2	1	1	1	1	3	1	12	1	12
	Crooked Creek - Elderberry	M	2	3	2	1	1	3	3	1	16	1	16
	Crooked Creek - Meyer Basin	M	3	3	2	3	1	3	3	1	19	1	19
	Hornecker - Borner (MPA diversion)	M	3	3	2	1	3	1	3	3	19	2	18
	Hornecker - Borner (tributaries)	M	2	3	2	1	3	1	3	3	18	2	17
	No Name Draw	M	1	2	1	1	3	1	3	3	15	2	14
	Pete's Lake	M	1	1	3	3	1	3	1	1	14	1	14
	Sawmill Creek 1	M	3	3	2	1	1	3	3	1	17	1	17
	Sawmill Creek 2	M	3	3	1	2	2	1	3	2	17	3	18
	Sawmill Creek - Fossil Hill	M	3	3	3	3	1	3	2	1	19	1	19
	Sawmill at Loop Road	M	3	2	3	3	1	3	2	1	18	1	18
	Sawmill at Townsend 1	M	3	2	2	3	1	3	2	1	17	1	17
	Sawmill at Townsend 2	M	3	2	1	3	1	3	3	1	17	1	17
	Sheep Creek	M	1	3	1	3	2	1	3	2	16	3	17
	Smith Creek	M	1	2	3	3	3	2	1	2	17	3	18
Little	Beason Creek	L	1	3	1	1	3	2	3	2	16	3	17
	Canyon Creek	L	1	1	2	3	1	3	1	1	13	1	13
	Canyon Creek 1	L	2	1	2	3	1	3	3	1	16	1	16
	Cherry Creek	L	2	1	2	3	1	3	1	2	15	3	16
	Cottonwood Creek	L	2	1	3	2	3	1	3	3	18	2	17
	Cottonwood Creek East Fork	L	3	1	3	2	3	2	2	2	18	3	19
	Deep Creek	L	2	1	1	3	3	2	3	2	17	3	18
	Iiams Creek	L	1	3	1	3	3	1	2	2	16	3	17
	Little Popo Agie - Louis Lake	L	3	3	3	3	1	3	1	1	18	1	18
	Little Popo Agie - Onion Flats	L	1	2	3	1	3	1	3	1	15	1	15
	Madison Creek	L	2	2	3	1	2	1	3	3	17	2	16
	Onion Flats - from Devils Creek	L	1	2	3	3	3	1	3	1	17	1	17
	Twin Creek	L	3	2	3	1	3	1	3	3	19	2	18
	Weiser Creek	L	1	1	2	1	3	1	2	1	12	1	12
	Willow Creek No. 2	L	3	2	3	3	3	2	3	3	22	2	21
	Willow Creek Lower	L	3	3	2	2	3	3	1	3	20	2	19
	Willow Creek Upper	L	1	2	2	3	3	1	3	1	16	1	16

Notes:

*Category is weighted twice
1 = Poor score, 3 = High score

Table 5.9. Micro-Storage Sites Scoring and Ranking with Original Property Ownership

Site Name	Branch	Water Availability*	Beneficial Uses*	Cost*	Bedrock Geology and Soils	Proximity to Irrigation	Proximity to Structures	Wetlands	Property Ownership (Original)	Total
Willow Creek No. 2	L	3	2	3	3	3	2	3	3	22
Willow Creek Lower	L	3	3	2	2	3	3	1	3	20
Crooked Creek - Meyer Basin	M	3	3	2	3	1	3	3	1	19
Hornecker - Borner (MPA diversion)	M	3	3	2	1	3	1	3	3	19
Sawmill Creek - Fossil Hill	M	3	3	3	3	1	3	2	1	19
Twin Creek	L	3	2	3	1	3	1	3	3	19
Cottonwood Creek	L	2	1	3	2	3	1	3	3	18
Cottonwood Creek East Fork	L	3	1	3	2	3	2	2	2	18
Hornecker - Borner (tributaries)	M	2	3	2	1	3	1	3	3	18
Little Popo Agie - Louis Lake	L	3	3	3	3	1	3	1	1	18
Sawmill at Loop Road	M	3	2	3	3	1	3	2	1	18
Deep Creek	L	2	1	1	3	3	2	3	2	17
Madison Creek	L	2	2	3	1	2	1	3	3	17
Onion Flats - from Devils Creek	L	1	2	3	3	3	1	3	1	17
Sawmill at Townsend 1	M	3	2	2	3	1	3	2	1	17
Sawmill at Townsend 2	M	3	2	1	3	1	3	3	1	17
Sawmill Creek 1	M	3	3	2	1	1	3	3	1	17
Sawmill Creek 2	M	3	3	1	2	2	1	3	2	17
Smith Creek	M	1	2	3	3	3	2	1	2	17
Surrel Creek No. 1	N	3	3	2	1	3	1	3	1	17
Beason Creek	L	1	3	1	1	3	2	3	2	16
Canyon Creek 1	L	2	1	2	3	1	3	3	1	16
Crooked Creek - Elderberry	M	2	3	2	1	1	3	3	1	16
Iiams Creek	L	1	3	1	3	3	1	2	2	16
Sheep Creek	M	1	3	1	3	2	1	3	2	16
Surrel Creek No 3	N	1	3	1	3	1	3	3	1	16
Surrel Creek No. 2	N	3	3	2	1	2	1	3	1	16
Willow Creek Upper	L	1	2	2	3	3	1	3	1	16
Baldwin - Farlow	M	2	2	2	3	1	1	3	1	15
Cherry Creek	L	2	1	2	3	1	3	1	2	15
Little Popo Agie - Onion Flats	L	1	2	3	1	3	1	3	1	15
No Name Draw	M	1	2	1	1	3	1	3	3	15
Pete's Lake	M	1	1	3	3	1	3	1	1	14
Canyon Creek	L	1	1	2	3	1	3	1	1	13
Baldwin/Squaw	M	2	2	1	1	1	1	3	1	12
Weiser Creek	L	1	1	2	1	3	1	2	1	12

Notes:
*Category is weighted twice
1 = Poor score, 3 = High score

Table 5.10. Micro-Storage Sites Scoring and Ranking with Revised Property Ownership

Site Name	Branch	Water Availability*	Beneficial Uses*	Cost*	Bedrock Geology and Soils	Proximity to Irrigation	Proximity to Structures	Wetlands	Property Ownership (Revised)	Total (with Revised Property Ownership)
Willow Creek No. 2	L	3	2	3	3	3	2	3	2	21
Cottonwood Creek East Fork	L	3	1	3	2	3	2	2	3	19
Crooked Creek - Meyer Basin	M	3	3	2	3	1	3	3	1	19
Sawmill Creek - Fossil Hill	M	3	3	3	3	1	3	2	1	19
Willow Creek Lower	L	3	3	2	2	3	3	1	2	19
Deep Creek	L	2	1	1	3	3	2	3	3	18
Hornecker - Borner (MPA diversion)	M	3	3	2	1	3	1	3	2	18
Little Popo Agie - Louis Lake	L	3	3	3	3	1	3	1	1	18
Sawmill at Loop Road	M	3	2	3	3	1	3	2	1	18
Sawmill Creek 2	M	3	3	1	2	2	1	3	3	18
Smith Creek	M	1	2	3	3	3	2	1	3	18
Twin Creek	L	3	2	3	1	3	1	3	2	18
Beason Creek	L	1	3	1	1	3	2	3	3	17
Cottonwood Creek	L	2	1	3	2	3	1	3	2	17
Hornecker - Borner (tributaries)	M	2	3	2	1	3	1	3	2	17
Iiams Creek	L	1	3	1	3	3	1	2	3	17
Onion Flats - from Devils Creek	L	1	2	3	3	3	1	3	1	17
Sawmill at Townsend 1	M	3	2	2	3	1	3	2	1	17
Sawmill at Townsend 2	M	3	2	1	3	1	3	3	1	17
Sawmill Creek 1	M	3	3	2	1	1	3	3	1	17
Sheep Creek	M	1	3	1	3	2	1	3	3	17
Surrel Creek No. 1	N	3	3	2	1	3	1	3	1	17
Canyon Creek 1	L	2	1	2	3	1	3	3	1	16
Cherry Creek	L	2	1	2	3	1	3	1	3	16
Crooked Creek - Elderberry	M	2	3	2	1	1	3	3	1	16
Madison Creek	L	2	2	3	1	2	1	3	2	16
Surrel Creek No 3	N	1	3	1	3	1	3	3	1	16
Surrel Creek No. 2	N	3	3	2	1	2	1	3	1	16
Willow Creek Upper	L	1	2	2	3	3	1	3	1	16
Baldwin - Farlow	M	2	2	2	3	1	1	3	1	15
Little Popo Agie - Onion Flats	L	1	2	3	1	3	1	3	1	15
No Name Draw	M	1	2	1	1	3	1	3	2	14
Pete's Lake	M	1	1	3	3	1	3	1	1	14
Canyon Creek	L	1	1	2	3	1	3	1	1	13
Baldwin/Squaw	M	2	2	1	1	1	1	3	1	12
Weiser Creek	L	1	1	2	1	3	1	2	1	12

Notes:
*Category is weighted twice
1 = Poor score, 3 = High score

even, given the multiple sites with the same scores. The scoring categories are explained in the following subsections.

5.4.1. Water Availability

Water availability takes into consideration the volume of water potentially available at each potential microstorage site for the normal and dry years in May and June, when water would be collected and stored. The scoring for water availability was based on the total volume of water available for May and June combined during a dry year. Sites with a combined May and June volume of less than 100 acre-feet were generally eliminated from future consideration, in accordance with discussions with members of the HRI. The water availability calculation does not take into consideration the potential need to leave a specific flow in the system and allow it to bypass the storage structures. For the water availability category, points were assigned to each site as follows:

- 1 point was assigned to sites with less than 500 acre-feet
- 2 points were assigned to sites with more than 500 and less than 1,000 acre-feet
- 3 points were assigned to sites with more than 1,000 acre-feet

5.4.2. Versatility of Benefit

Stored water can be used for multiple purposes and benefits. It can benefit agriculture by providing water for irrigation; fish and wildlife by increasing stream flow during low-flow periods; and municipal/industrial needs by providing source water during periods of high demand. The scoring does not directly address these three benefits, but it scores the versatility of where the water can be used or directed after it is stored. One point was given for each of the following instances: whether it could be applied to a nearby field, whether it could be directed into a nearby irrigation ditch for use downstream, or whether it could ultimately be conveyed back to a mainstem channel. For the versatility of benefit category, points were assigned to each site as follows:

- 1 point was assigned to sites with one of the three uses
- 2 points were assigned to sites with two of the three uses
- 3 points were assigned to sites with all three of the uses

5.4.3. Cost

The cost represents construction costs and is based on the estimated dam volume for each structure at a unit cost of $15 per cubic yard. **Table C-4** in **Appendix C** shows the total construction costs along with cost per acre-foot. For the cost category, points were assigned to each site as follows:

- 1 point was assigned to sites with a cost estimate over $2 million for 300 acre-feet
- 2 points were assigned to sites with a cost estimate between $1 million and $2 million for 300 acre-feet
- 3 points were assigned to sites with a cost estimate under $1 million for 300 acre-feet

5.4.4. Bedrock Geology and Soils

The study area contains bedrock geology units that may be unsuitable for dam construction and water storage. Seepage rates may be too high in areas overlying the Madison Formation or other limestone units. Similarly, some mapped soil types (Sinkson and Thermopolis) are unfavorable because of their propensities for piping and development of sinks. **Figure 5.3** illustrates these areas across the watershed. The ability for structures in these areas to hold water would be questionable. It was pointed out to the project team that these soils are like those in the area of the Anchor Dam in Wyoming's Big Horn Basin (Don Gaddie, personal communication, July 2019). That reservoir was not able to serve its intended use because of its inability to store enough water. The following sites are located on or near the Madison Formation: Baldwin/Squaw, Crooked Creek-Elderberry, Sawmill Creek 1, and Weiser Creek. The following sites are located over or near the Sinkson or Thermopolis soils: Beason Creek, Cottonwood Creek, Cottonwood East Park, Hellyer Lower, Hornecker-Borner, Little Popo Agie – Onion Flats, Madison Creek, No Name Draw, Surrel Creek No. 1, Surrel Creek No. 2, and Twin Creek. **Figures C-1a – C-36a** in **Appendix C** show the sites in relation to the mapped soil units. For the bedrock geology and soils category, points were assigned to each site as follows:

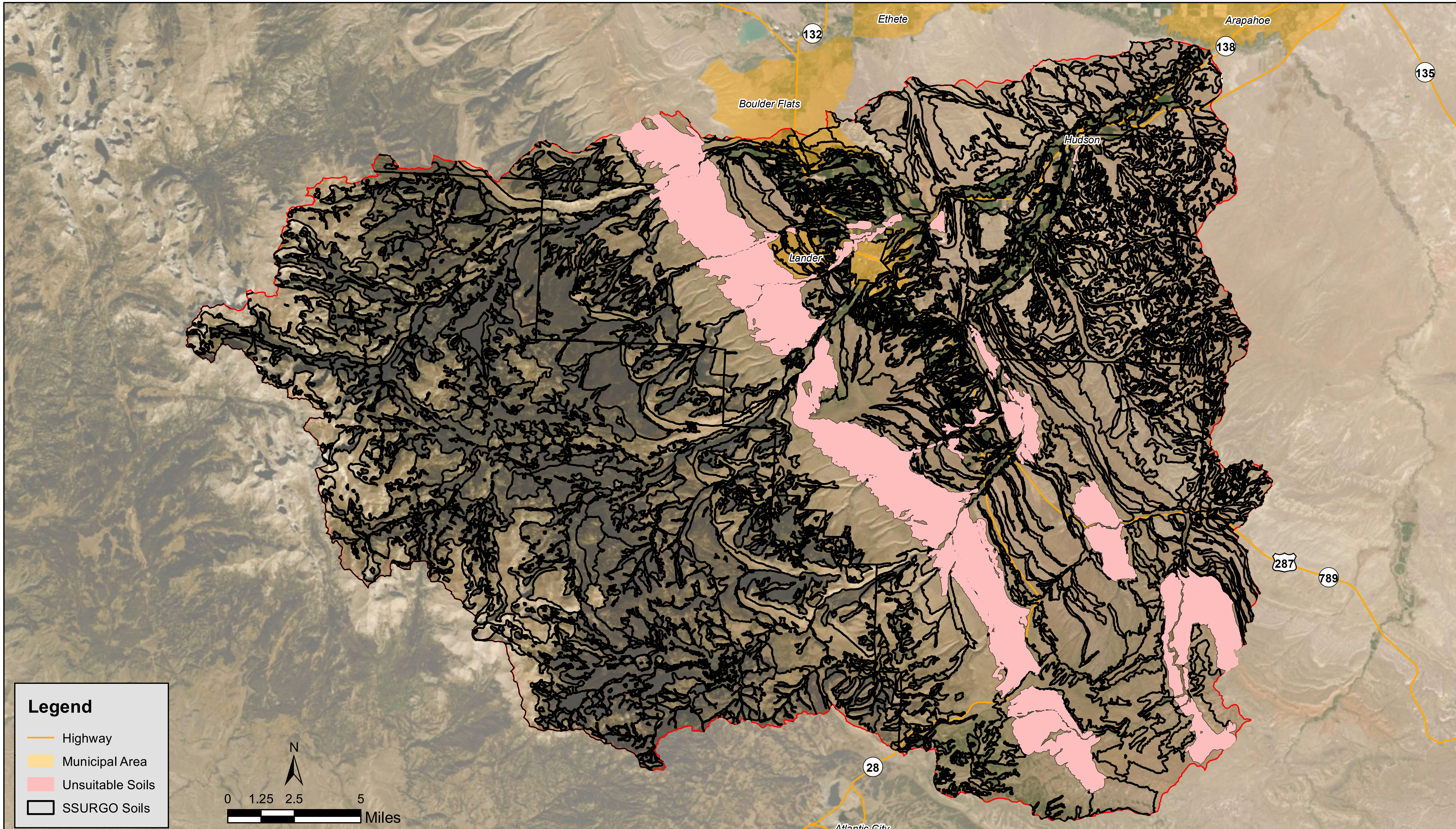
- 1 point was assigned to sites with the Madison Formation or Sinkson or Thermopolis soils present
- 2 points were assigned to sites partially located on Sinkson or Thermopolis soils
- 3 points were assigned to sites where Madison Formation or unfavorable soils are not present

5.4.5. Proximity to Irrigation

The scoring category takes into consideration whether irrigated fields are located close to the storage site. Storage sites that are closer to irrigated fields will result in direct agricultural benefits and less loss of water because of transmission to its location of use. **Figure 5.4** illustrates the irrigated acres across the watershed. The proximity of irrigation was based on comparing the storage site to the irrigated acre's layer in GIS. **Figures C-1b – C-36b** in **Appendix C** show the sites in relation to the irrigated acre's layer. For the proximity to irrigation category, points were assigned to each site as follows:

- 1 point was assigned to sites where irrigated acreage is more than one mile downstream
- 2 points were assigned to sites that have irrigated acreage between one half and approximately one mile downstream .
- 3 points were assigned to sites that are in the midst of irrigated acreage or have irrigated acreage a half mile or less downstream of the site

Surrel Creek No. 2 is approximately 5,500 feet upstream of irrigation. Although the distance is slightly over one mile, it was assigned a score of 2. Seven of the identified locations show irrigated acres, according to the GIS layer, within the footprint of the storage area. The irrigated areas would be inundated by either a 300 acre-foot structure or a 150 acre-foot structure. These sites may be deemed unsuitable by the project sponsors or landowners, but were not penalized in the scoring due to the presence of irrigated areas.



POPO AGIE WATERSHED STUDY	olsson WENCK	FIGURE
Unsuitable Geology and Soils Overview		5.3

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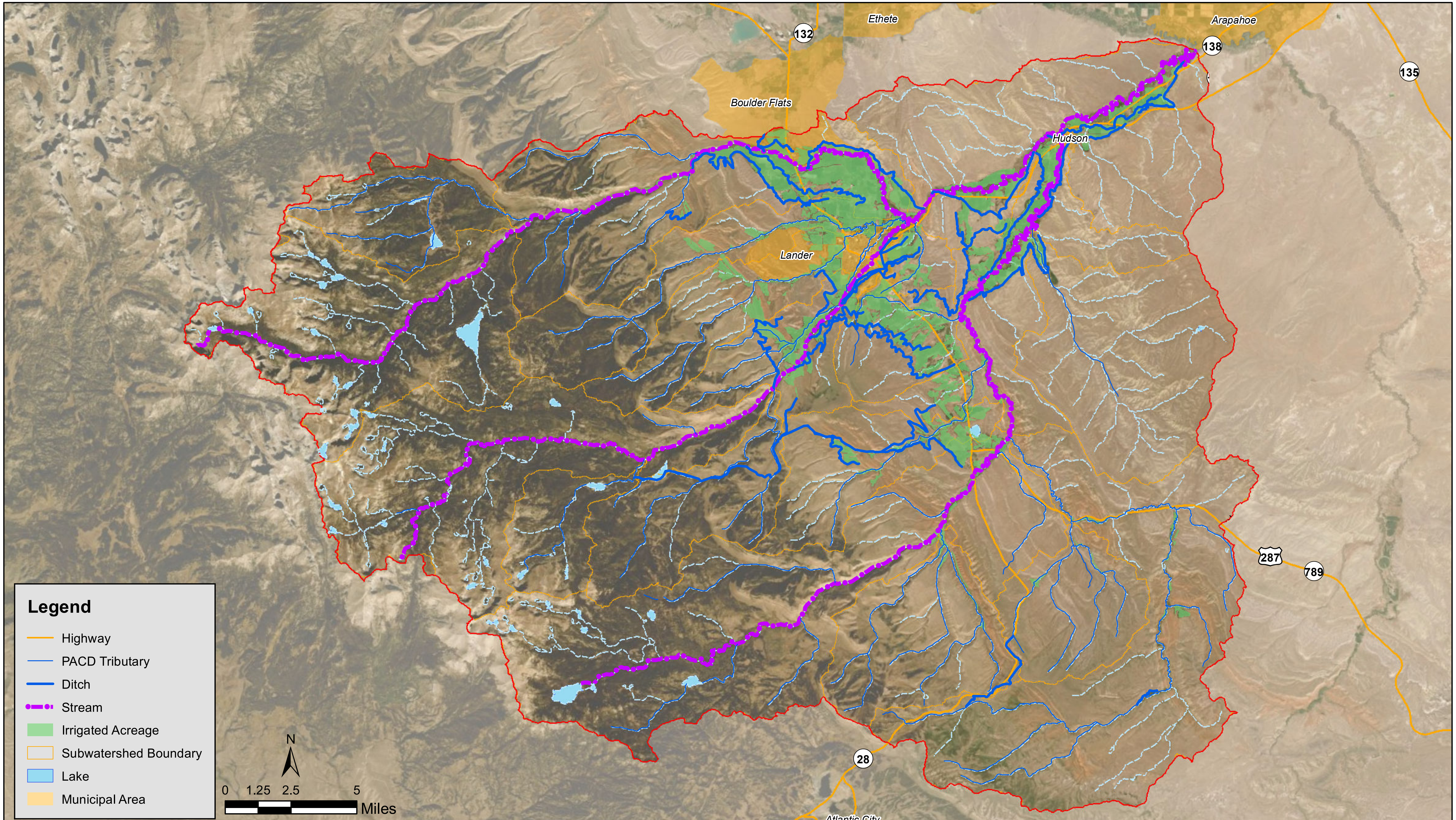

POPO AGIE WATERSHED STUDY

Irrigated Acres Overview

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FIGURE

5.4

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5.4.6. Proximity to Structures

Several sites were eliminated from consideration based on the presence of structures, particularly houses, within the storage pool or immediately downstream of a potential site. Additional sites show structures close to the storage pool or downstream of the dam, where they could be affected by a dam failure. A specific distance was not defined. For the proximity to structures category, points were assigned to each site as follows:

- 1 point was assigned to sites with structures nearby downstream
- 2 points were assigned to sites with structures either upstream or downstream but not close
- 3 points were assigned to sites with no structures nearby

5.4.7. Wetlands

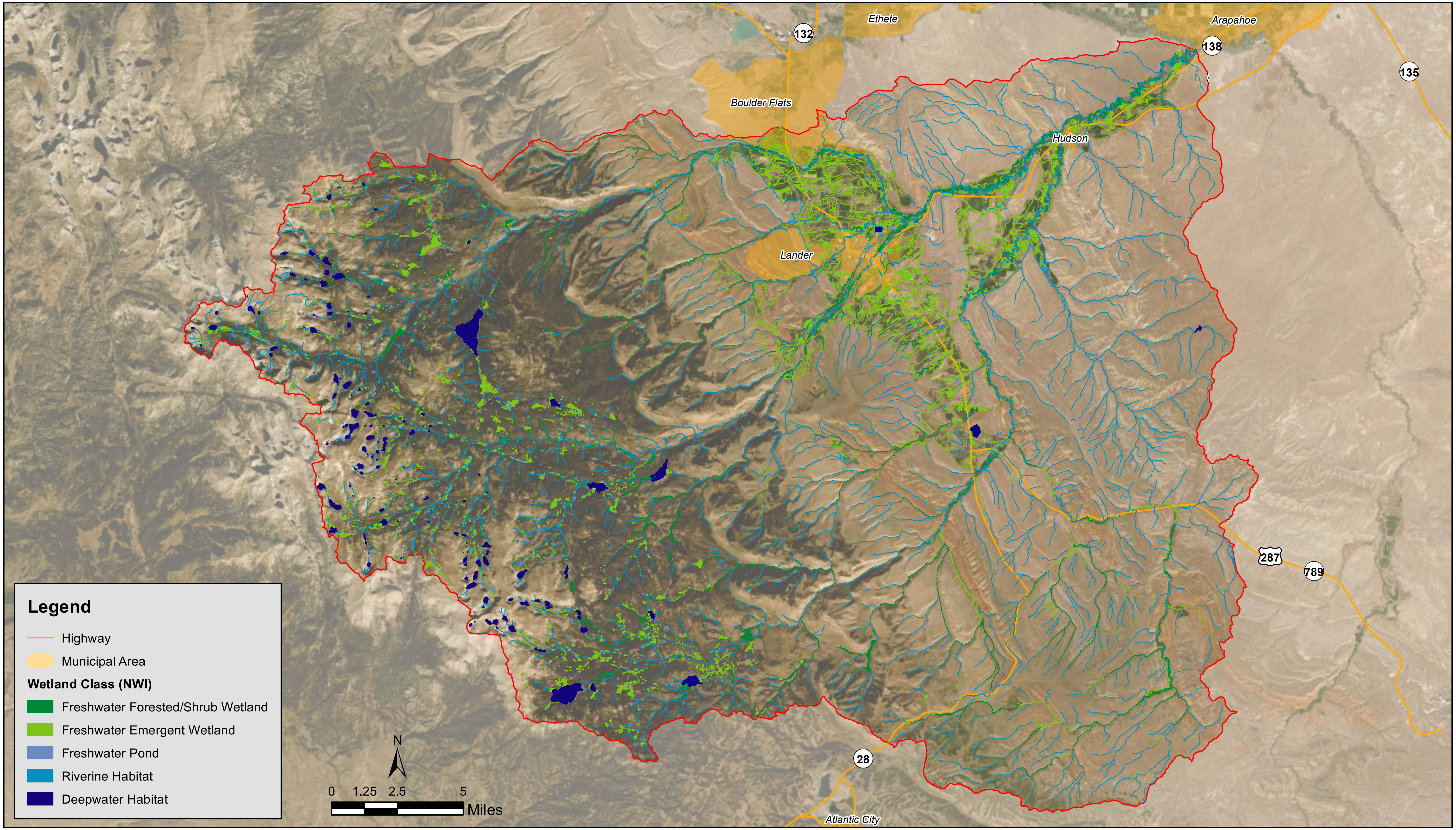
The presence of wetlands can present permitting challenges for a dam and reservoir site. **Figure 5.5** illustrates the National Wetlands Inventory across the watershed. Mitigation of the wetlands can be difficult to achieve. The sites were evaluated based on the National Wetlands Inventory (NWI) layer and whether wetlands were located where the dam embankment and storage pool would be located. Potential impacts on downstream wetlands were not considered in this ranking. **Figures C-1b – C-36b** in **Appendix C** show the sites in relation to the NWI layer. For the wetlands category, points were assigned to each site as follows:

- 1 point was assigned to sites with over 5 acres of wetlands present
- 2 points were assigned to sites with up to 5 acres of wetlands present
- 3 points were assigned to sites with no wetlands present

5.4.8. Property Ownership

Each potential site was evaluated based on who owned the property the dam would be constructed and where the storage pool would be located. Initially, federally owned land or reservation-owned land was considered least favorable, with state-owned land second, and privately-owned land most favorable. If the anticipated dam and storage area encompassed more than one land ownership type, the score associated with the least favorable ownership type was given. As listed in Table C-8, for the land ownership category, initially points were assigned to each site as follows:

- 1 point was assigned to sites located on Federal and reservation land
- 2 points were assigned to sites located on state owned land
- 3 points were assigned to sites located on privately-owned land



POPO AGIE WATERSHED STUDY

National Wetlands Inventory Overview

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FIGURE

5.5

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The rankings were completed a second time with the scores for the state and private ownership categories switched, indicating that state-owned land would be most favorable. As listed in Table C-9, for the land ownership category, points were assigned to each site as follows:

- 1 point was assigned to sites located on Federal and reservation land
- 2 points were assigned to sites located on privately-owned land
- 3 points were assigned to sites located on state owned land

Input from residents and stakeholders in the watershed is invaluable in helping determine the sites with the best potential for advancement and where additional water would prove to be most beneficial. Information regarding the sites was submitted to the PACD and distributed to the HRI. A small group of HRI members reviewed the sites and provided input, which is included in **Appendix C** as **Table C-1**. The input consists of pros, cons, and general comments regarding 24 sites, and it raises location suitability questions in some instances. The feedback does not necessarily provide endorsement of one site versus another, but it should be taken into consideration along with the information presented in this report.

5.5. Worthen Meadows Reservoir

Worthen Meadows Reservoir is included in this report as a potential, and very promising water storage site, but was not evaluated in the same way as the other sites. A study of the City of Lander's water supply is documented in the draft technical memorandum *Water Supply Evaluation and Groundwater Development Alternatives, Lander Test Well Level II Study* dated April 2019 by Wyoming Groundwater LLC. As part of the study, "the management and reliability of the Worthen Meadows Reservoir in providing a late-season water supply was evaluated using a basic reservoir operations model" (Wyoming Groundwater 2019). The model was used as a cursory for "what if" scenarios. Appendix A of the draft technical memorandum contains the document *Draft Worthen Meadows – Reliability Evaluation* by WWC Engineering and Hinckley Consulting. Two conclusions of the draft reliability evaluation are discussed in the draft Level II study and are particularly relevant to this Popo Agie Level I Phase II study. They are:

- "Short of reservoir failure, there is little reason to expect the reservoir cannot continue to meet the historical levels of demand into the foreseeable future."
- "Under the assumptions of this relatively simple model, Worthen Meadows Reservoir could release quantities approximately twice those experienced historically and still not completely empty the reservoir in any model year."

These results appear promising regarding the possibility of releasing additional water late in the season. The study notes that Worthen Meadows Reservoir is typically operated to release water down to 750 acre-feet in late September / early October and that flows during the winter are bypassed. Using Worthen Meadows Reservoir to provide late-season water should continue to be investigated in conjunction with the City of Lander's water supply study (Wyoming Groundwater 2019). Worthen Meadow Reservoir remains a top prospect for additional water storage in the watershed.

Photo 15. Outlet structure at Worthen Meadows Reservoir.

A test release from Worthen Meadows Reservoir was made in August 2018 to investigate the impact of the release on flows at downstream locations of the Middle Fork Popo Agie. The City released 20 cfs for one week starting August 23, 2018. The volume of water over that time period would be equivalent to 278 acre-feet. Popo Agie HRI reported that the drawdown in the reservoir was approximately 3 feet (Popo Agie HRI 2019). The goal was an increase in flow in the river of 5 cfs at the City's lagoon outlet. Monitoring showed that the increase was 2 cfs. Additional testing can be conducted while the Level II study is finished, or additional studies are conducted (**Photo 15**). This information would be valuable to help determine whether releasing more water from Worthen Meadows Reservoir late in the season would prove to be beneficial.

In addition to changing the reservoir operations, expansion of Worthen Meadows Reservoir can be considered. A 1988 study by ARIX Corporation titled "*Lander Rehabilitation Project Level II Feasibility Study Phase II: Geotechnical Investigation and Rehabilitation Plan for Worthen Meadows Dam and Reservoir*" (ARIX Corporation 1988) presented recommendations that included enlarging the existing dike section; raising the primary dam, secondary dike, and spur dike embankments to pass the probable maximum flood; and constructing an emergency spillway on the north side of the reservoir. A substantial rehabilitation project was completed in 1995.

A second modification that increases the storage of Worthen Meadows Reservoir can be evaluated. Based on available contours, it appears that the dam could be constructed higher.

Based on Google Earth imagery from 2014, an expanded pool could negatively impact existing recreational facilities such as boat ramps, access, and camping areas (**Photo 16**). Additional storage rights may be required. Expansion of the reservoir would be expensive due to the need to modify all of the dam controls and potential impacts to existing facilities. The potential option of drawing down the reservoir lower late in the season would be much less expensive and is recommended to be explored and tested prior to considering physical reservoir modifications.

Photo 16. Worthen Meadows Reservoir

6.0 AQUIFER STORAGE AND RECOVERY (ASR)

6.1. What is Aquifer Storage and Recovery?

6.1.1. Background

First implemented in the 1960s, ASR is a process through which water is stored in underground reservoirs during times when demand is low and extracted later when demand increases (Pyne 1995). Often used to refer to dual-purpose groundwater injection and recovery wells, ASR technology also includes several additional processes including infiltration basins, vadose zone wells, and injection wells with passive recovery at nearby surface water bodies. ASR technology has been used throughout the country to store treated sewage effluent, limit the extent of coastal seawater intrusion, serve as an alternative to surface reservoir storage, and to increase the resiliency of water supplies (Maliva et al. 2011; Misut and Voss 2007; Petkewich et al. 2004).

6.1.2. Aquifer Storage and Recovery (ASR) in Wyoming

In Wyoming, several feasibility studies assessing the viability of ASR have been conducted; however, to date, no ASR facilities have been built in the state. An ASR feasibility study was conducted for the Cheyenne Board of Public Utilities to investigate the ability of select ASR technologies to increase the long-term sustainability of its Ogallala aquifer well fields (Lytle Water Solutions 2011). The investigation included a pilot study, which examined the performance of both an injection/recovery well and enhanced rapid infiltration basins. It was determined that both approaches had significant potential to slow or reverse declining groundwater levels in the Cheyenne water supply wells. A separate study examined the feasibility of using ASR technology to dispose of treated water produced from oil and gas operations in the state (Tuwati and Fan 2015). Using a contaminant-leaching model and geologic samples collected from a site near Laramie, the study determined that water could be stored in buried sandstone aquifers without causing increases in metal concentrations beyond drinking water standards, and that ASR could serve as an alternative to surface water reservoirs for water storage in the area.

6.2. General Approach

The goal of this ASR analysis was to assess the feasibility of using ASR to retime the water supply in the Popo Agie Watershed to increase late-season river flow. Several selection criteria, including regulatory, operational, hydrogeologic, and cost, were considered and used to evaluate potential ASR technologies, locations, and storage aquifers. The focus of the ASR analysis was on the Middle Fork of the Popo Agie based on the water budget analysis and the need to address the late-season low flow conditions within the sub-watershed.

As will be described in more detail below, the shallow alluvial aquifer was chosen as the primary aquifer for potential ASR projects, after the deeper Tensleep, Flathead, and Madison aquifers were rejected because of the increased cost of drilling wells in these deeper formations and other technical reasons. It should be noted that this was a desktop study that did not include any new field investigations. The analysis relied on aquifer properties and subsurface hydrogeologic information presented in previous investigations as noted in the following subsections.

6.2.1. Aquifer Storage and Recovery (ASR) Technologies

The four ASR technologies considered in this analysis included:

- Injection/recovery wells
- Injection with passive recovery
- Infiltration basins
- Enhanced ditch infiltration

An **injection/recovery well**, also known as a traditional ASR well, is a groundwater well where water can be injected and extracted at the same location **(Figure 6.1)**. A typical ASR well may be appropriate for Lander because when demand increases, water stored in the aquifer can be pumped to the surface where it could be discharged directly to the river or used to supplement Lander's water supply. This technology is typically implemented in deep aquifers, where the speed of groundwater flow is slow, and the injected water can be recovered before it moves far downgradient and cannot be recovered. In aquifers with faster moving groundwater, modified injection/recovery systems can be implemented that use two wells, one for injection and a separate downgradient well for recovery.

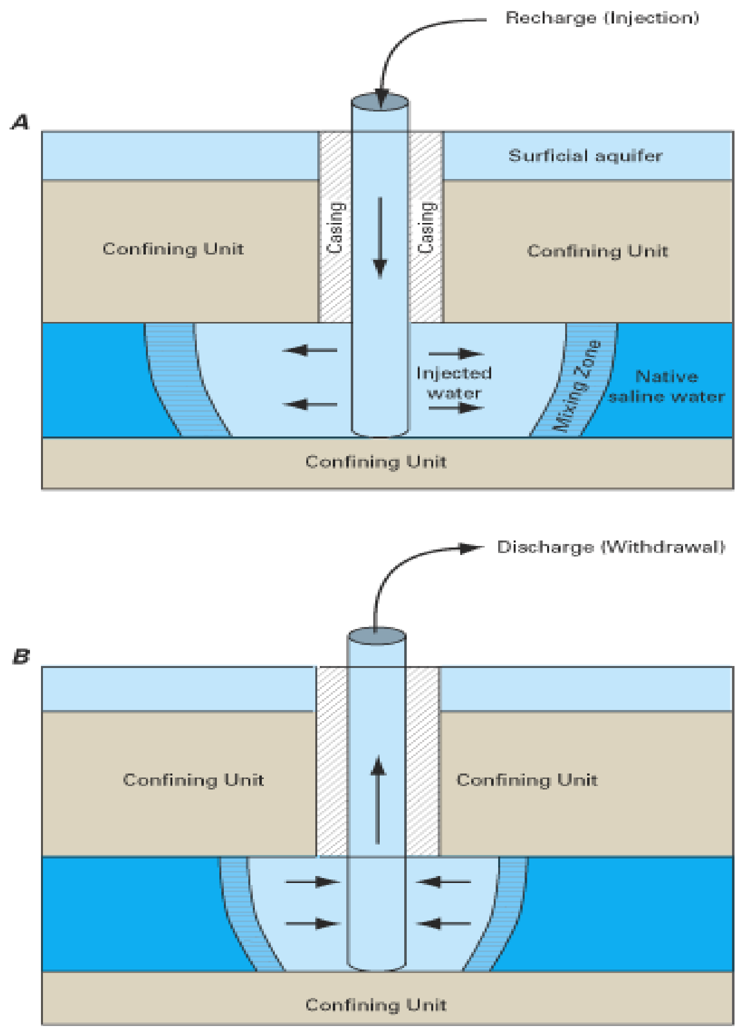


Figure 6.1 Injection and Withdrawal from a Typical Aquifer Storage and Recovery Well (USGS 2003).

An **injection with passive recovery system** uses a groundwater well to inject groundwater for storage and recovers the water at a downgradient collection location without a recovery well and without the input of additional energy. These collection locations are typically rivers, lakes, or areas of low topography where groundwater naturally gathers and interacts with surface water. In the Popo Agie Watershed, shallow groundwater is in contact with surface water throughout much of the year, so the river was chosen as a logical collection location for passive recovery. This ASR technology takes advantage of groundwater movement and must be implemented in shallow aquifers where the groundwater table intercepts the ground surface for at least a portion of the year.

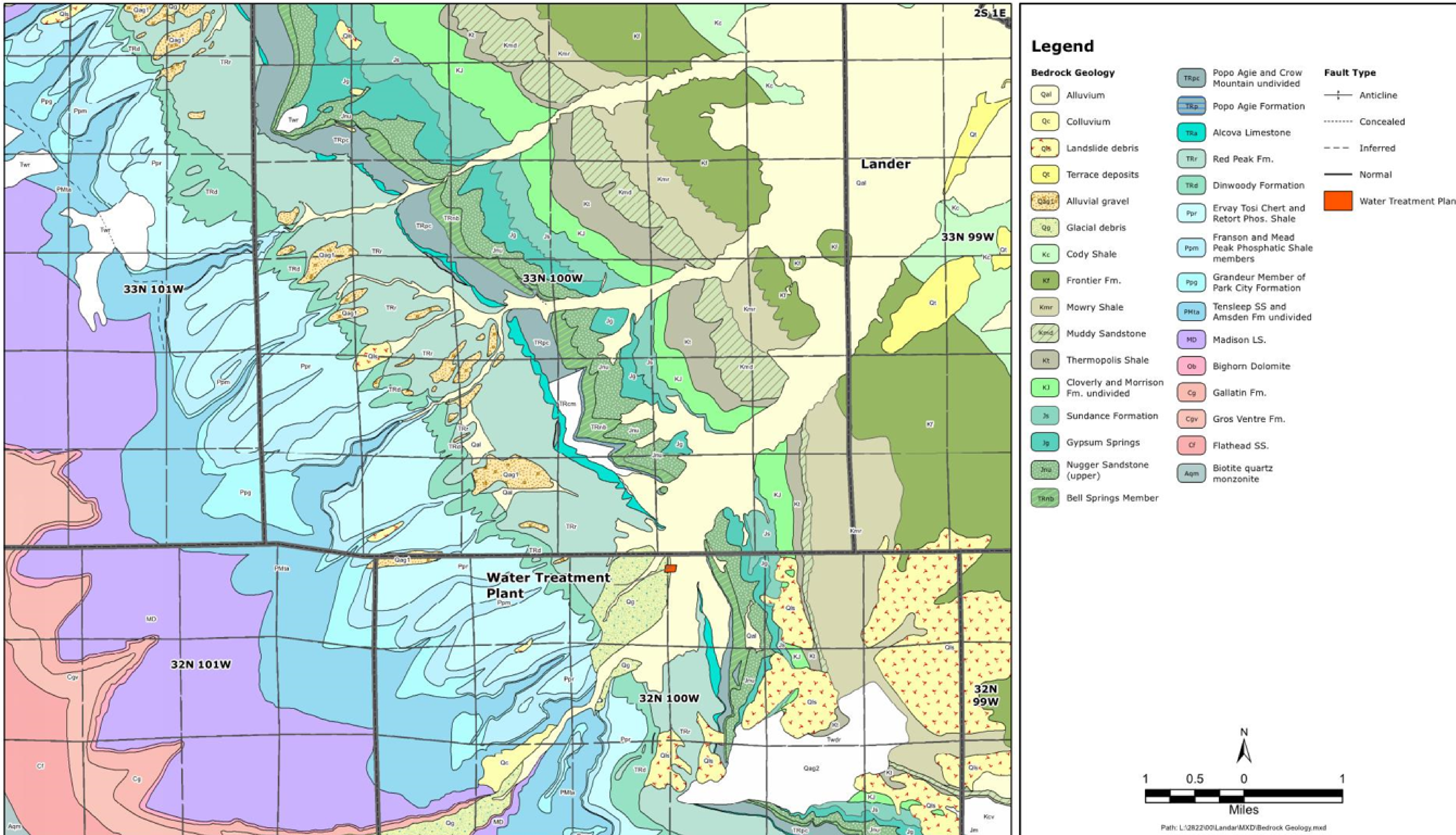
An **infiltration basin** replaces an injection well by allowing ponded water to slowly percolate downward under the force of gravity instead of recharging groundwater through injection. Infiltrated groundwater is stored in whichever aquifer is encountered first, typically the shallowest, and can be recovered passively at a downgradient location. An **enhanced ditch infiltration system** performs similarly but uses existing infrastructure or water conveyance systems as an alternative to constructing a basin.

6.2.2. Local Aquifer Considerations

The Popo Agie Watershed is a very large area and at the beginning of the analysis, the hydrogeology played a significant role in narrowing down the options for the ASR analysis. **Figure 6.2** illustrates the bedrock geology of the area that consists of a nested system of confining and transmissive geologic layers. Several of the deeper aquifers, including the Tensleep and the Flathead, were discounted as options for ASR development because of the high cost of drilling and operating an injection/recovery system in these deep aquifers. The Madison Formation was also discounted from the analysis because of the connection with Sink's Canyon State Park. As noted by all HRI team members, any ASR project proposed for the Popo Agie Watershed must not negatively affect the Sink and Rise system. With these considerations in mind, the shallow alluvial aquifer, which is the most cost-efficient aquifer to access and is connected to the Middle Popo Agie River, became the focus of this ASR analysis.

6.2.3. Potential ASR Project Site Considerations

After the initial aquifer conditions were taken into consideration, the Olsson/Wenck team met and conducted a site visit with Lander's City Engineer, Lance Hopkin. Mr. Hopkin confirmed the desire to evaluate a potential ASR site near the water treatment plant (Lance Hopkin, personal communication, November 18, 2018 and June 26, 2019). There were several reasons that a potential ASR site near the water treatment plant was considered including the fact that with some modification, the infrastructure at the treatment plant could supply water to an ASR well in the spring for injection into the alluvial aquifer for either active or passive recovery. Furthermore, the area around the water treatment plant and another site downstream closer to town, had the most available hydrogeologic data, including borehole logs, aquifer testing results, and groundwater level readings from previous studies (Lidstone and Associates 1999). For these reasons, the



POPO AGIE WATERSHED STUDY

Bedrock Geology Map

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FIGURE

6.2

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Olsson/Wenck team focused on an evaluation of ASR systems conceptually shown on **Figure 6.3**, as an upstream and downstream location using information gathered during the 1999 investigation at Lander test wells 2 and 3.

6.3. Site Evaluation Criteria

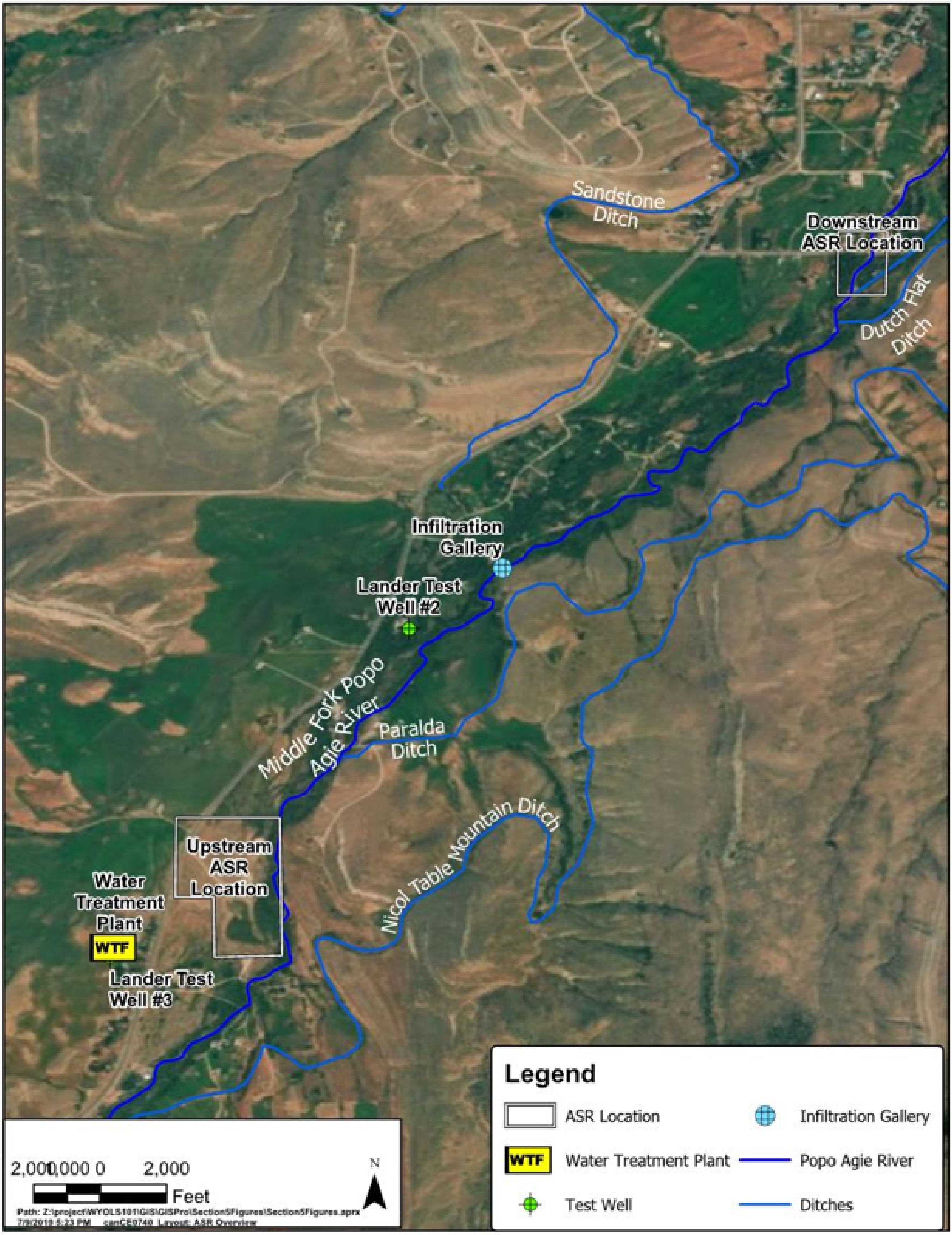
There are several different criteria that must be taken into consideration when evaluating potential ASR sites. The following discussion provides the primary criteria used in this desktop analysis of ASR sites in the Middle Fork of the Popo Agie River.

6.3.1. Regulatory

As aquifer recharge facilities, ASR wells are covered under the EPA's Underground Injection Control (UIC) program (Bloetscher et al. 2014). These wells are designated as Class V wells and, specifically, as Class 5B2 facilities. Chapter 27, Section 11 of the WDEQ Rules and Regulations states that Class 5B2 facilities pose a minimal threat to groundwater quality, do not require an individual permit, and are instead permitted by rule. In order to meet the requirements for a Class 5B2 facility, a proposed ASR facility could only be used for groundwater production and as an alternative to surface reservoir storage. While ASR technology has been used in other states to store treated sewage effluent or to limit the extent of saline water intrusion, these applications are not covered in Wyoming under a permit by rule. Infiltration basins or ditch enhancements that are engineered to increase infiltration into the underlying aquifer are also covered by the UIC program and would require an individual permit.

Wyoming requirements for ASR facilities also include water quality guidelines, which state that the injected or infiltrated water must meet the suitability class of the receiving groundwater. While no water quality data was collected for this study, based on the discussions with the City Engineer, it is assumed that both groundwater and surface water at the treatment plant meet WDEQ Chapter 8, water quality standards for Class I drinking water supplies. Because it is assumed that the suitability classes of the recharging and receiving waters are already the same, treatment of the recharging groundwater was not considered as part of this study.

Additional requirements for the evaluation of potential ASR sites are not regulatory but were put in place through coordination with PACD and HRI. These requirements state that ASR activities should have no negative impact on native river species and no impact on existing infrastructure or homes.



POPO AGIE WATERSHED STUDY

Aquifer Storage and Recovering Project Site Considerations

olsson WENCK

FIGURE 6.3

6.3.2. Operational Considerations

Potential sites were eliminated along the Middle Fork of the Popo Agie River because of operational considerations. Because ASR facilities should not be built in proximity to groundwater production wells, which can divert injected water from its intended path to the river, land parcels with existing groundwater wells were not considered as potential ASR locations. Of the remaining parcels, only those owned by Lander, the State of Wyoming, or by landowners willing to agree to limits on the placement of future wells should be considered.

Some ASR technologies, including injection/recovery wells and infiltration basins, have the potential to be used for multiple purposes. An injection/recovery well built near the water treatment plant could be used as a groundwater production well during certain times of the year and could serve as an emergency water supply for Lander. Similarly, an infiltration basin near the water treatment plant could be used as a settling basing for removing large particulates from spring runoff. These added benefits were taken into consideration when evaluating upstream locations for ASR, and preference was given to locations near the water treatment plant.

The presence of downstream users was also taken into consideration during site selection, since water that is returned to the river upstream could be intercepted by irrigation ditches. While an upstream ASR location could benefit ditch owners, it may be less effective at increasing late season flows through the central part of Lander. To account for the different uses for the added flow, a second location, downstream of the ditch diversions, was selected for consideration. The two potential ASR locations, one upstream of the diversion ditches and one downstream, are shown on **Figure 6.3**.

The availability of water for storage was also taken into consideration when evaluating potential ASR locations. As discussed in Section 3.0, the watershed model indicates that, during normal years, approximately 230,000 acre-feet of water is available for storage. This volume likely exceeds what can be stored in the shallow alluvial aquifer, as discussed in Section 6.3.3. The amount of water available for storage differs between the upstream and downstream locations because of the ditch diversions that lie in between; however, both locations have a sufficient volume of water available to operate an ASR facility.

Climate is that final operational factor that affects the selection of ASR technologies and the timing of storage. While injection wells can operate year-round, infiltration galleries or ditches can only operate at temperatures above freezing. In Wyoming, this eliminates the use of these technologies during the winter and for a portion of the spring. If water becomes available for storage during these periods, injection wells may be able to achieve more storage and longer storage times than infiltration-based methods. As discussed in the next section, the difference in storage time ultimately affects the distance between the river and where the ASR facility should be built.

6.3.3. Hydrogeologic Characteristics

For ASR technologies that use passive recovery, including injection wells, infiltration basins, and enhanced ditch infiltration, the distance the ASR facility is sited from the river is dependent upon the hydrogeologic characteristics of the alluvial aquifer, particularly the transmissivity and groundwater gradient. Transmissivity is a way to quantify groundwater movement as a rate of flow through a unit width of a vertical aquifer (Sterrett 2007) and is typically measured through aquifer testing. In 1999, two aquifer tests were performed along the Middle Fork as part of the Lander Water Supply Project Level II, Phase III study (Lidstone and Associates 1999). One of these tests was performed near the water treatment plant and estimated the local transmissivity to be 5,580 square feet per day (ft^2/day). This transmissivity was lower than expected, but is within the range needed for ASR operation, which is typically considered to be between 5,000 and 30,000 ft^2/day (Gibson et al. 2018). The second test, which was performed downstream at Lander Test Well #2, as shown on **Figure 6.3**, estimated the transmissivity to be 1,085 ft^2/day. This transmissivity was much lower than expected but, since there was no other aquifer testing data available, it was assumed to be representative of the downstream locations. This data suggests that transmissivities downstream are not high enough to support an injection well but could potentially sustain ASR through infiltration.

Along with transmissivity data, the localized groundwater gradient is used to calculate the velocity of water moving through the formation. The groundwater gradient was estimated using static water level data measured prior to the 1999 testing, in addition to well locations and groundwater measurements available from the USGS and the WYSEO. The calculated groundwater travel velocities were approximately 3.1 and 0.28 feet per day at the upstream and downstream sites, respectively.

The amount of time the injected or infiltrated water will spend in storage is dependent upon the timing of water availability. As discussed in Section 3.0, the Middle Fork typically has water available for storage in the spring and much lower flows through the central part of Lander during the late irrigation season, beginning in August. Assuming water storage through ASR begins in February with a goal of discharging to the river in August, a storage time of six months (181 days) was used for this study. Using this length of storage and the calculated groundwater velocities, the distance from the river at which the ASR facility should be constructed is 561 and 51 feet at the upstream and downstream sites, respectively. These distances from the river are illustrated in **Figure 6.4** and **Figure 6.5.** The timing of storage or discharge can be adjusted depending on water availability and climate factors and the resulting distance between the ASR facility and the river will vary accordingly.

Given the calculated distances from the river, a suitable site for enhanced ditch infiltration could not be identified in the upstream portion of the Middle Fork. Given the location of the existing ditches, enhanced ditch infiltration ASR would only possible if the allowed storage time in the alluvial reservoir were increased beyond six months. Basically, in the upstream location, the ditches are too far from the Middle Fork of the Popo Agie river to deliver water to the river within

POPO AGIE WATERSHED STUDY	olsson WENCK	FIGURE
Upstream Aquifer Storage and Recovery Location		6.4

POPO AGIE WATERSHED STUDY

Downstream Aquifer Storage and Recovery Location

olsson WENCK

FIGURE 6.5

the desired six-month period. Downstream, enhanced ditch infiltration ASR could potentially be performed near the diversion for the Cemetery Ditch. However, given the already high groundwater levels associated with this ditch, this location does not have the storage zone thickness necessary to support ASR, and it may exacerbate problems associated with a high water table within Lander.

In order to maximize the amount of water that can be stored through ASR, while still meeting the regulatory selection criteria which states that ASR activities should have no impact on existing infrastructure or homes, the thickness of the storage zone in the alluvial aquifer must be taken into consideration. The size of this zone depends on both the vertical thickness of the alluvium and the depth to groundwater below the ground surface. Data collected in support of the Lander Test Well, Level II Study (Wyoming Groundwater 2019) indicate that seasonal groundwater levels in the alluvium vary between 19 and 31 feet below ground surface. The vertical extent of alluvial deposits is variable throughout the watershed (Nelson Engineering 1998) but is assumed to be approximately 60 feet at both the upstream and downstream ASR locations.

Using Equation 1, a modified Copper Jacob equation for pumping in unconfined aquifers, the amount of water that can be injected given a certain increase in groundwater levels can be calculated.

Equation 1: Cooper Jacob Equation for Unconfined Aquifers

$$Q = -\frac{4\pi T * (\frac{s - s^2}{2b})}{2.3 * \log(\frac{2.25Tt}{r^2 S})}$$

Where:

Q=Injection capacity (cubic feet per day [ft^3/day])
T= Aquifer transmissivity (ft^2/day)
s=Groundwater level increase because of injection (feet)
b=Aquifer thickness (feet)
t= Time over which water is injected (days)
r= Well radius (feet)
S= Storativity (unitless)

To avoid affecting surface structures, groundwater levels during injection were not allowed to be shallower than 4 feet below the ground surface. Therefore, the maximum allowed groundwater level increase caused by injection was estimated using the seasonal depth to water and subtracting 4 feet. Assuming an aquifer thickness of approximately 60 feet, an injection time of 90 days, a well radius of 14 inches, and a conservative storativity estimate of 0.1, the injection capacity at the upstream location ranges between approximately 58,000 and 92,000 ft^3/day (or between 1.3 and 2.1 acre-feet/day; or between 0.7 and 1.1 cfs), depending on the seasonal groundwater level. At the downstream location, this range is lower because of the lower transmissivity, and it ranges between approximately 13,000 and 20,000 ft^3/day (or 0.3 and 0.5 acre-foot/day; or 0.15 and 0.2 cfs).

6.3.4. Cost Estimates

The cost to build an ASR facility was estimated for each of the possible technologies, aquifers, and locations. The cost to build an ASR well was evaluated using Colorado State University's (CSU) Screening Level Cost Estimates for ASR Wellfields tool (Alqahtani and Sale 2017). The tool provides estimated costs for ASR based on average power and construction material costs in 2017. The tool accounts for costs associated with well drilling and installation, water transmission pipes, and power. Features of the tool that estimate land acquisition and water treatment costs were not used since those were not considered likely expenses for this application. The cost to build an infiltration basin or to enhance infiltration along existing ditches was estimated based on average 2019 excavation and gravel prices (Home Advisor 2019). Actual construction and material costs are likely to vary with time and by location but are presented here for comparison purposes.

Well drilling and installation costs were estimated to be approximately $38,250 for a shallow well drilled to 60 feet below ground surface in the alluvial aquifer. This installation price includes 30 feet of 14-inch stainless steel screen and 10 feet of 30-inch protective surface casing. Price was a major consideration in the decision to focus the ASR study on the alluvial aquifer, instead of the deeper confined aquifers in the area. The price to install a well into the Tensleep aquifer, which is the next shallowest aquifer and extends to approximately 1,300 feet below ground surface, was calculated to be $497,000.

The cost to power an injection with a passive recovery well is based on an estimated injection rate of 92,000 ft^3/day for 90 days. The CSU cost estimate tool calculates the power requirements, in kilowatt hours (kWh) to maintain an injection head 4 feet below ground surface. It then assumes a cost of $0.08/kWh to estimate the power requirements for the well at approximately $722 a year. The cost to run a traditional ASR with injection and recovery into the alluvial aquifer would be twice this amount. Because of the greater injection head, the power cost to run an injection and recovery well into the deeper Tensleep aquifer would be approximately $15,500 a year.

Because of the presence of Lander's unused infiltration gallery, power costs for bringing water from the river to the ASR facility are not considered by the CSU cost estimate tool and may not be a factor in this study. This gallery, which is shown on **Figure 6.3**, used to provide the water supply for Lander before a new system was built upstream. The older gallery is still functional and tied into a system of pipes, which were also used to deliver water from the gallery to town. These pipes, if they are still in good condition, could be used to deliver infiltrated water from the gallery to an ASR facility without the added cost of pipes or power. If the system needs to be expanded or repaired, however, this could represent an added cost.

If the existing piping connected to the old infiltration gallery is not used, water transmission pipes would be needed to bring water from the source point along the river to the injection or infiltration location. The CSU cost estimate tool assumes a pipe diameter of 8 inches and an average cost of $65 per foot of pipe. It then estimates the cost of piping, given the calculated distance of the

ASR facility from the source. At the upstream location, based on a distance of 561 feet, the cost for piping would be approximately $36,500. At the downstream location, based on a distance of 51 feet, the cost would be approximately $3,300.

The cost to build an infiltration basin or to enhance infiltration along existing ditches includes the price for earthwork and excavation as well as the price for gravel to line the bottom. Earthwork and gravel prices are generally measured in cubic yards (CY). To infiltrate up to 20,000 ft^3/day of water at the downstream location, where transmissivity is too low for an injection well, the minimum size of the basin would be approximately 1,109 CY, with at least 0.1 yard of gravel at the bottom. Estimating the prices for earthwork and rounded gravel to be $25/CY and $90/CY, respectively, the total price for construction of an infiltration gallery would be about $44,500. Because enhancing ditch infiltration would require only minimal earthwork, the price would be less but would still include gravel. These prices are approximate, and engineering drawings for an infiltration basin or enhanced ditch infiltration in this area would likely be heavily modified from the preliminary designs presented here.

Summarized costs for each option are summarized in **Table 6.1**. These costs are approximate and assume that the existing infiltration gallery piping is not used. They do not include some additional costs, such as land acquisition, water treatment, electrical lines.

Table 6.1 Estimated Costs for Aquifer Storage and Recovery (ASR) Options

Project Description	Earthwork / Excavation	Pipes	Gravel	Operation and Maintenance	Estimated Total Cost
Infiltration Gallery	$27,725	$3,300	$16,650	$222	$47,897
Enhanced Ditch Infiltration	$6,931	$0.00	$16,650	$118	$23,699
Alluvial Passive Recovery Well	$38,250	$36,465	$721	$30,374	$105,810
Tensleep Injection and Recovery Well	$496,990	$36,465	$15,458	$30,374	$579,287

7.0 PERMITS

The following sections present the potential federal, state, and local regulatory permits that could be required for the watershed management plan and rehabilitation activities proposed in this watershed study. This section is intended to characterize the potential environmental permitting requirements for the proposed activities and to summarize the environmental documentation, permits, agency clearances and approvals, and other agency requirements that may be necessary to implement the proposed activities, depending on the final planning and design. The applicability of the federal, state, and local permits, clearances, and approvals will depend upon the project sites selected and the potential permitting implications of each of those sites.

Irrigation projects and activities on private lands are generally not subject to federal, state, and local agency review and/or approval. However, the projects proposed in this study are likely to require some amount of review and/or approval from the appropriate agency(ies) depending on the locations and features of the proposed projects.

7.1. National Environmental Policy Act

The 1969 National Environmental Policy Act (NEPA) requires federal agencies to assess potential environmental effects of projects an agency proposes to undertake, fund, or approve. NEPA is triggered when an action occurs on federal land, when federal funds may be used for the undertaking, and/or when federal agency action is necessary for a project to move forward. The NEPA process is intended to avoid, minimize, and mitigate adverse environmental effects of federal actions, and it requires analysis and documentation of potential effects (adverse and beneficial) of a proposed action and any alternative actions. NEPA mandates an open public involvement process throughout the NEPA timeline.

If the watershed projects proposed in this watershed study occur on federal lands or if federal funds will be used for the undertaking, NEPA will be triggered, and the respective federal agency will be the lead agency charged with providing compliance with NEPA and related environmental statutes. Federal regulations dictate the permitting requirements and review process of water-related projects. The timeframes for securing the necessary permits from federal agencies for such projects vary, and in some cases, could take multiple years depending on the location and complexity of the proposed activities.

7.2. Permitting/Clearances/Approvals

7.2.1. Wild and Scenic Rivers Act

The Wild and Scenic Rivers Act, enacted in 1968, protects selected rivers and their surrounding environments for the purpose of protecting the water quality and the free-flowing conditions of the rivers. The selected rivers are administered by federal or state agencies and are classified as wild, scenic, or recreational. Any project that proposes the installation of dams or other similar construction within a protected river requires a complementary policy that preserves the water quality and natural flow of the river. Under the Wild and Scenic Rivers Act, federal support for the construction of dams or other in-stream activities that have the potential to alter streamflow is prohibited within protected rivers. There are no wild and scenic-designated rivers in the Popo Agie Watershed.

7.2.2. Wilderness Act of 1964

The Wilderness Act of 1964 was enacted to designate certain wilderness areas and protect them from being impaired by human habitation. The Wilderness Act of 1964 defines wilderness as an area that has not been substantially altered by man and remains generally untouched except by the forces of nature. Wilderness areas are designated by Congress and signed off by the president. Congress also directed federal agencies to evaluate lands for suitability as wilderness in addition to designated wilderness areas. Lands being evaluated for suitability as wilderness are categorized as *designated*, *recommended*, *proposed*, *suitable*, or *study area*. These areas are managed so that their suitability as wilderness is not diminished. The Popo Agie Wilderness was designated by Congress in 1984 and stretches over 101,870 acres of the Wind River Range. The Popo Agie Wilderness lies within the Popo Agie Watershed study area, and any proposed projects would be required to follow the strict regulations associated with the wilderness designation.

7.2.3. Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act (FWCA) requires federal agencies involved in actions that will result in the control or structural modification of any natural stream or body of water for any purpose to take action to protect the fish and wildlife resources that may be affected by the action. The FWCA requires federal agencies or applicants to consult with state and federal wildlife agencies to prevent, mitigate, and compensate for project-induced losses of wildlife resources and to enhance those resources.

7.2.4. Migratory Bird Treaty Act

The Migratory Bird Treaty Act (MBTA) requires avoiding construction activities in grassland, wetland, stream, and woodland habitats and on bridges that may result in the taking of migratory birds, eggs, young, and/or active nests. The definition of take includes pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, molest, or disturb. In Wyoming, most migratory bird activity occurs during the period of April 1 to July 15. The USFWS has indicated that if a proposed construction period is planned to occur during the primary nesting season, or at any other time that may result in the taking of the nests of migratory birds, a survey should be performed. A qualified biologist must conduct the field survey of the affected habitats and structures to assess the presence of nesting migratory birds during nesting season. The survey results need to be maintained with the project files and made available to the USFWS upon request. The USFWS should be contacted immediately if active nests are identified within the construction area and within a 0.5-mile line of sight that cannot be avoided. If active nests are observed that cannot be avoided until after the birds have left the nest and no practicable or reasonable avoidance measure is identified, including delay of construction, a Federal Fish and Wildlife License/Permit must be obtained from the USFWS for the work to proceed.

7.2.5. Bald and Golden Eagle Protection Act

Bald and golden eagles are federally protected under the Bald and Golden Eagle Protection Act of 1940 (BGEPA). The BGEPA prohibits anyone, without a permit issued by the Secretary of the Interior, from the take, possession, and commerce of bald and/or golden eagles, including their parts, nests, and eggs. Compliance with the BGEPA is part of the NEPA documentation. As with the MBTA, if construction activities fall within the primary eagle nesting season, a survey of eagle nesting sites should be conducted following the guidelines set forth by the USFWS.

7.2.6. USACE Section 404 Permit

The Wyoming Regulatory Office of the U.S. Army Corps of Engineers (USACE) administers and enforces Section 404 of the Clean Water Act (CWA) in Wyoming for the Omaha District. Under the CWA, a Section 404 permit is required for discharging dredged or fill material into waters of the United States. Constructing or rehabilitating a diversion structure (e.g., a headgate, weir, or diversion dam) and associated in-stream or streambank work would involve discharging dredged or fill material into waters of the United States and would require permitting under Section 404 of the CWA.

Because many waterbodies and wetlands are considered waters of the United States, they are subject to the USACE's regulatory authority. Depending on the nature and extent of activities proposed, a nationwide permit (NWP or regional general permit) or individual permit may be required. NWPs are a type of general permit issued by the USACE on a nationwide basis for activities having minimal impacts. The USACE's *2017 Nationwide Permits, General Conditions, District Engineer's, Decision, Further Information, and Definitions* document provides an index of the current list of NWPs based on the nature of the proposed activity (USACE 2017). The permits are designed to provide timely authorization for certain activities in waters of the United States while protecting the nation's aquatic resources. Smaller projects with minor impacts typically qualify for general permits, while larger projects with greater impacts may require an individual permit (which requires more review, including an environmental analysis that documents efforts to avoid, minimize, and mitigate impacts—in that order). The USACE can only issue individual permits for the least environmentally damaging practicable alternative. Some agricultural exemptions from Section 404 permitting exist for constructing or maintaining irrigation ditches, including siphons, pumps, headgates, wingwalls, weirs, screens, or other facilities that are appurtenant and functionally related to irrigation ditches; the USACE should be contacted to discuss such exemptions.

Permit applications can be obtained by contacting the USACE's Wyoming Regulatory Office in Cheyenne at 307.772.2300 and by accessing

http://www.nwo.usace.army.mil/Missions/Regulatory-Program/Wyoming.

7.2.7. Endangered Species Act

The Endangered Species Act (ESA) Section 7 requires federal agencies to protect threatened and endangered species by avoiding impacts, including destruction or modification, to potential habitat. A project funded by a federal agency is required to consult with the USFWS, informally or formally, to discuss potential impacts to threatened and endangered species. The federal agency will typically request a biological assessment early in the project planning to determine whether the project is likely to adversely affect a threatened or endangered species or its habitat. If there are no anticipated impacts, an informal consultation is typically conducted with the USFWS to determine whether the USFWS is in agreement that the project will not affect or is unlikely to adversely affect threatened or endangered species, and to confirm that no avoidance or mitigation measures need to be taken. If impacts are anticipated, the federal agency typically requests a formal consultation with the USFWS to determine whether avoidance or mitigation measures need to be taken with respect to threatened and endangered species habitat impacts (USFWS 2013); the USFWS' decision is rendered in a biological opinion.

7.2.8. Other Federal and State Permits

Wyoming State Engineer's Office (WYSEO)

Surface Water Storage Permit

The WYSEO administers the water rights system of appropriation within the state. For construction to occur on state lands, the required permits for water rights for the diversion and storage of the state's surface water must be obtained. Most of the projects proposed in this watershed study would require a permit from the WYSEO. A water right would have to be obtained or modified for proposed wells, livestock/wildlife water, irrigation rehabilitation, and water-storage projects in accordance with WY Statute 41-3-101.

Permit to Construct/Dam Safety Review

The WYSEO also administers Wyoming's Safety of Dams Program. Wyoming Dam Safety Law (W.S. 41-3) requires any persons, public company, government entity, or private company proposing to construct a dam greater than 20 feet high or which will impound more than 50 acre-feet of water, or a diversion system that will carry more than 50 cfs, to obtain approval for construction of the dam or ditch from the WYSEO. Proposed construction, enlargement, major repair, alteration, or removal of a dam or diversion system with headgates or diversion structures that carry more than 50 cfs require plans and specifications prepared by a Wyoming-licensed registered professional engineer to be submitted to the WYSEO for approval pursuant to W.S. 41-3-308.

Other WYSEO Permits

Depending on the nature of work being performed, additional permits may have to be secured from the WYSEO, including the following (and others listed at http://seo.wyo.gov/applications-forms#Surface):

Ditches, Pipelines, Water Hauls: This permit authorizes new diversions from streams (including ditches, pipelines, and temporary water hauls), and for special application stock or domestic diversions from a stream not exceeding 25 gallons per minute.

Enlargement of Ditches, Pipelines: This permit is for enlarging an existing ditch, pipeline, or water haul to allow the diversion of more water.

Reservoirs: This permit is used to allow new reservoirs or to enlarge existing reservoirs.

Applications, regulatory information, and instructions for dam safety reviews can be accessed at https://sites.google.com/a/wyo.gov/seo/regulations-instructions. WYSEO permits can be accessed via the state's e-Permit website at http://seoweb.wyo.gov/e-Permit/ (a username and password are required).

Some of the proposed activities discussed in this watershed study may include drilling a water well or rehabilitating an existing water well. In such cases, the following permit may apply:

Appropriate Groundwater: This permit requires any person to obtain a water right appropriation prior to drilling a water well. Drilling and pump contactors and well owners must comply with W.S. 41-3-909. The water quality of a completed well must be suitable for livestock and cannot exceed certain suitability constituents for groundwater standards (W.S. 35-11-302). Groundwater applications, regulatory information, and form instructions are available at https://sites.google.com/a/wyo.gov/seo/regulations-instructions, https://sites.google.com/a/wyo.gov/seo/ground-water/water-wellconstruction, and http://deq.wyoming.gov/wqd/groundwater/resources/rules-regs/.

Wyoming Department of Environmental Quality (WDEQ)

Wyoming Pollutant Discharge Elimination System (WYPDES) Program

The EPA has oversight responsibility for the federal CWA delegated to and administered by the Wyoming Water Quality Division (WQD). Stormwater discharges are regulated under the CWA by the WDEQ's Wyoming Pollutant Discharge Elimination System (WYPDES) program. Project sponsors for proposed activities occurring within the watershed should contact the WDEQ to determine whether a construction general permit (CGP) is required. Construction activities that disturb five or more acres must obtain a large CGP, and those that disturb one acre or more (but less than five acres) must obtain a small CGP. Large CGPs must be accompanied with a stormwater pollution prevention plan. Construction activities associated with the proposed activities in Section 4 can result in the requirement to temporarily discharge pumped water. Temporary discharges must comply with the terms of the CGP and any stipulations applied.

The WDEQ has the authority to authorize temporary increases in water turbidity above the numeric criteria of Section 23, Chapter 1, in Wyoming Surface Water Quality Standards (W.S. 35-11-101) for some short-term, construction-related activities performed in live water. The proposed activities discussed in Section 4 that include irrigation diversions and/or streambank work would require a temporary turbidity waiver.

Section 401 Certification

A Section 401 certification is Wyoming's approval that activities authorized under Section 404 of the CWA meet state water quality standards and do not degrade water quality. For a proposed activity that requires a USACE Section 404 permit, preconstruction notification (PCN) must be submitted to the USACE. The PCN is then forwarded to the WDEQ for review under Section 401 of the CWA to determine compliance with the state's surface water quality standards (W.S. 35-11-101). Discharges of pollutants into waters of the United States must be authorized by permit issuance from the WQD in accordance with the WQD's rules and regulations. Those rules and regulations set forth the classification of surface water and groundwater uses and establish Wyoming's water quality standards. Any activity involving a discharge of fill to a Class 1 water or adjacent wetland requires a 401 certification from WQD, regardless of the type of Section 404 permit used to authorize the activity. A 14-day public notice and comment period is also required. WDEQ may issue special conditions with a 401 certification to provide compliance with surface water quality standards or total maximum daily loads.

Additional information and forms are available by contacting the WDEQ at 307.777.7781 and by accessing http://deq.wyoming.gov/wqd/ and http://deq.wyoming.gov/wqd/401-certification/.

Wyoming Board of Land Commissioners and Wyoming Office of State Lands and Investments

The Wyoming Board of Land Commissioners has responsibility for regulating all activities on state lands. The Office of State Lands and Investments grants rights-of-way (ROWs). Projects to be constructed on state or school lands require a ROW grant per the *Rules and Regulations Governing the Issuance of ROW* (W.S. 36-20 and W.S. 36-202).

Some of the projects proposed in Section 4 of this report could occur on Wyoming state lands. For a project to occur on state land, a grazing and agricultural lessee must obtain permission from the Wyoming Board of Land Commissioners prior to construction in accordance with W.S. 36-2-107. The lessee must submit an Application for Construction of Improvements on State Land to the Office of State Lands and Investments for review and approval. Information and applications are available by contacting the Office of State Lands and Investments at 307.777.7331 and by accessing http://lands.wyo.gov/lands/leasing/agricultural.

Wyoming Department of Fire Protection and Electrical Safety

For proposed activities within the Popo Agie Watershed that involve the installation of electrical equipment, the Wyoming Department of Fire Protection and Electrical Safety should be contacted before commencing construction to determine whether a wiring permit is required. A wiring permit is required when electrical equipment is installed in new construction or the during the remodel of a building, mobile home, or premises. The electrical installation must be performed in accordance with W.S. 35-9-120 and -123. Certain exemptions apply. Additional information and an application for a wiring permit can be obtained by contacting the Wyoming Department of Fire Protection and Electrical Safety at 307.777.7288 and by accessing http://wsfm.wyo.gov/electrical-safety/wiring-permits.

Special Use Permits/Rights-of-Way (ROWs) / Easements

Special use permits, ROWs, and/or easements may be required where access across the lands of others is required for construction and/or operation of a project. These permits can be temporary or permanent. Typically, privately owned lands that will be rendered permanently unavailable will be purchased unless the owner and sponsoring entity concur on a permanent easement.

Bureau of Land Management (BLM)

Permanent use of BLM lands would likely be administered under a grant with an appropriate term issued under the BLM's ROW process.

U.S. Forest Service (USFS)

Permanent use of USFS lands would likely be administered under a special use authorization with an appropriate term issued under the USFS' special use process.

Wyoming Department of Transportation

An easement or ROW from the Wyoming Department of Transportation could be required for some of the projects proposed in this report.

Conservation Easements

A conservation easement is a voluntary legal agreement between a landowner and a land trust or government agency that permanently limits uses of the land in order to protect its conservation values. Landowners retain many of their rights, including the right to own and use the land, sell it and pass it on to their heirs. As an example, in the Popo Agie watershed, there is a conservation easement on the land adjacent to the water treatment plant. The site was reviewed as a potential ASR project location. After consultation with representative from the City of Lander, it was clear that installation of ASR wells could be limited to a certain type based on the site-specific requirements of the conservation easement. This illustrates how conservation easements are unique to each situation. Should a project be proposed on conservation easement lands, it is important to review the proposed project and the land use restrictions of the easement on a case-by-case basis.

Property Access and Ownership

Permission should always be obtained from a landowner, lessee, or management agency before any fieldwork is performed on a property for a proposed activity within the watershed. Verbal permission from landowners may be sufficient for some site visits; if project-specific field data needs to be collected, written permission should be acquired. The Enterprise Technology Services' Wyoming Statewide Parcel Viewer is available at http://gis.wyo.gov/parcels/ and can be used to determine parcel ownership of land that will be affected by a proposed undertaking. Information regarding state land parcels and surface leases is accessible from the Office of State Lands and Investments at the following websites:

http://gis.statelands.wyo.gov/GIS/OSLIGIS/StateLandAccess/
http://statelands.wyo.gov/surfaceplatbook/

Other

In addition to the above, other permits, authorizations, and clearances may be required for the proposed activities in this report, some of which may be covered or provided by the construction contractor (e.g., air quality permit, trash/slash burning permit, utility / One-Call of Wyoming, etc.).

County

Fremont County may require other local/county zoning ordinances and permits (e.g., building construction, floodplain development, wastewater, and road or utility access). Specifically, a local floodplain permit for activities occurring in the floodplain will be required. Information on Fremont County can be found at www.fremontcountywy.org.

Special Districts

Two watershed improvement districts are located within the Popo Agie Watershed. The Taylor and Enterprise districts both have a board of directors and are governed by W.S. 41-8-101 through 41-8-126. If a project involves the property and/or facility of a special district, permission or a permit should be obtained before commencing construction.

7.3. Environmental Considerations and Mitigation

7.3.1. Wetland Resources

A formal wetland delineation in accordance with the USACE's guidelines has not been conducted across the Popo Agie Watershed. GIS digital mapping from the NWI exists and is available for review. However, some areas identified as wetlands on the NWI map may not qualify as jurisdictional wetlands upon field investigation, and wetland areas not mapped by the NWI may exist. This is because the methodology used to prepare the NWI maps changes, and wetlands also change and develop over time because of natural events. A formal wetland delineation should be conducted once project sites are selected to determine potential impacts to wetland areas and appropriate avoidance, minimization, and mitigation measures, as appropriate.

7.3.2. Mitigation

Mitigation may be required for impacts to resources, including wetland vegetation, stream channel habitat, cultural resources, fish and game resources, and threatened and endangered species. To address impacts, avoidance and minimization measures are preferred over mitigation. If mitigation is required for wetland or stream channel impacts, a mitigation plan will be required and will need to be approved by the USACE in order to obtain a Section 404 permit. Any potential mitigation for threatened and endangered species impacts will coincide with formal consultation with the USFWS.

7.4. Cultural and Paleontological Resources

To protect and enhance Wyoming cultural resources as important links to the human history of the river corridors in the Popo Agie Watershed, including historical and archaeological sites, cultural landscapes, and ethnographic resources, additional cultural records searches and fieldwork would need to be completed prior to construction of any of the recommended projects to identify and record such resources that could be inundated or otherwise affected by the projects.

Before undertaking construction/rehabilitation activities, the Wyoming State Historic Preservation Office (SHPO) should be contacted, and a formal search of Wyoming cultural resources records for previous projects and known historic buildings and archaeological sites within the study area should be performed. This search will help determine whether additional properties need to be evaluated and/or whether there are areas that need to be surveyed to assess the likelihood of those project activities having impacts on historically significant cultural resources. For activities on federal lands, consultation with the Wyoming SHPO will be required (and Class I cultural resources surveys may be needed prior to ground-disturbing activities). If a cultural resources mitigation plan needs to be developed, it would likely culminate in a memorandum of understanding or agreement between the Wyoming SHPO and the lead federal agency, with concurrence by the project sponsor(s) and potentially affected Native American tribes.

Federal approvals may be involved with some of the recommended projects for the Popo Agie Watershed, and in such cases, potential impacts on cultural resources must be considered (i.e., Section 106 consultation). If the proposed projects occur on federal lands, the National Historic Preservation Act (NHPA) and Native American Graves Protection and Repatriation Act (NAGPRA) may apply. The NHPA requires federal agencies to evaluate the impact of federally funded or permitted projects on historic properties. The NAGPRA requires federal agencies and institutions that receive federal funding to return Native American cultural items to lineal descendants and culturally affiliated Indian tribes. It also establishes procedures for the unanticipated discovery or planned excavation of such items on federal or tribal lands.

Wyoming contains many paleontological resources (or fossil specimens) throughout the state where fossiliferous sedimentary bedrock is exposed at the surface. Collection of fossils on public lands is not allowed unless special permits are obtained. While the collection of fossils on private land is not prohibited, collection and preservation should be performed by a trained paleontologist.

7.5. Greater Sage-Grouse Core Area Protection

Although the greater sage-grouse is not protected as a federally threatened or endangered species by the USFWS, the USFS, in coordination with the BLM, have implemented measures to protect greater sage-grouse and their habitat (**Photo 17**). The conservation of the greater sage-grouse is a top priority for the state of Wyoming, and Wyoming is a national leader in greater sage-grouse conservation efforts. The USFS has identified priority habitat management areas, general habitat management areas, and sagebrush focal areas. Priority habitat management areas have the highest habitat value and highest conservation priority for maintaining sagebrush habitat for the greater sage-grouse. General habitat management areas require some habitat management to maintain greater sage-grouse populations within those areas. Sagebrush focal areas are areas with a large amount of sagebrush, creating ideal habitat for greater sage-grouse.

The state of Wyoming's Executive Order 2015-4, Greater Sage-Grouse Core Area Protection, and Order 2019-3, Supplement to Greater Sage-Grouse Suitable Habitat Definitions (a supplement to 2015-4) determine state actions related to the greater sage-grouse. The State's established greater sage-grouse core areas are essential for the preservation of sagebrush habitat and greater sage-grouse populations (**Figure 7.1**).

Photo 17. Greater Sage-Grouse

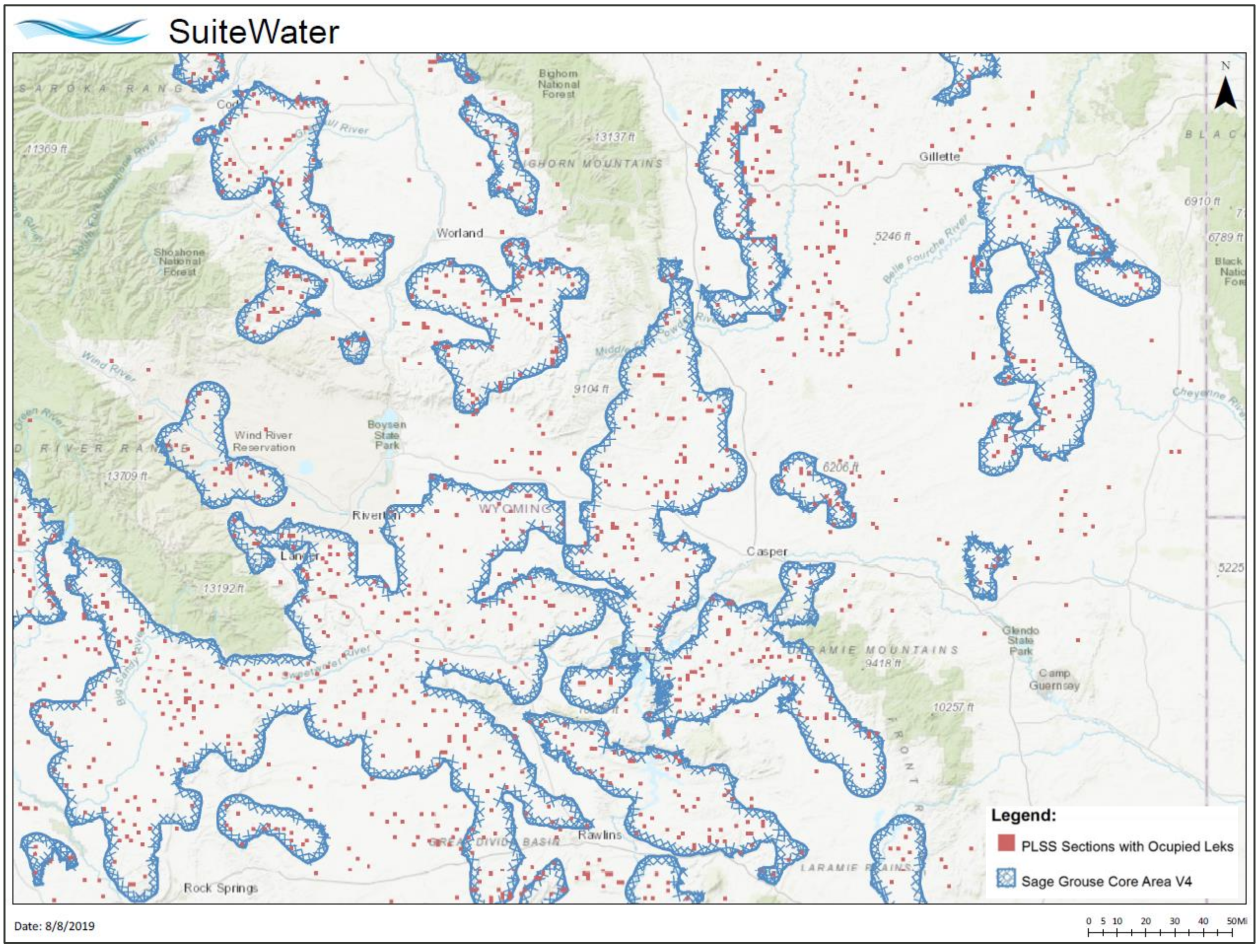


Figure 7.1 WY Sage-Grouse Core Areas (WACD 2019).

Coordination with the WGFD is recommended for any project activities that have the potential to affect greater sage-grouse habitat. The WGFD cites general and specific stipulations for avoidance, minimization, and compensatory mitigation for development in core versus non-core greater-sage grouse areas. Providing or increasing water to areas where water is limited may create a beneficial impact for this species and should be considered when evaluating the net potential impacts to this species. Sage-grouse core areas are identified in the Popo Agie Watershed along and north of Baldwin Creek and along the Little Popo Agie. An occupied lek was mapped near Table Mountain south of Lander (**Figure 7.2**).

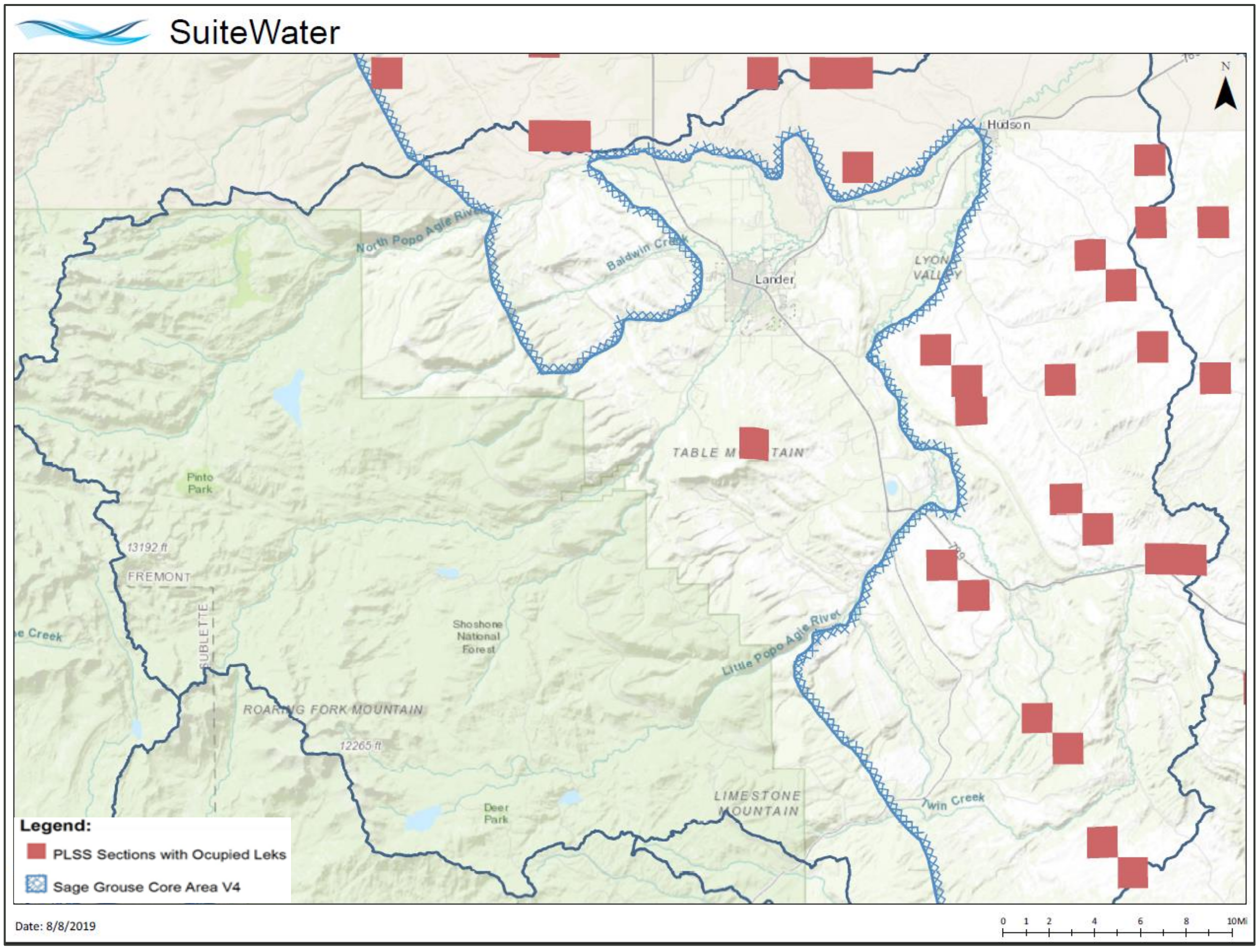


Figure 7.2 Sage-Grouse Core Areas near Lander, WY.

7.6. ASR Permitting Requirements

On September 11, 2018, the Olsson/Wenck team contacted Chris Brown at WDEQ to discuss permitting requirements for an ASR well. According to Mr. Brown, an ASR well for water augmentation in Lander would likely be designated a UIC Class V well. It would be an aquifer recharge facility (Class 5B2) and would be permitted by rule (Chapter 27, Section 11) instead of as an individual permit. According to Mr. Brown, securing individual permits is more time consuming with public notice and other requirements.

The water quality standards that would need to be met would be based on the suitability class of the groundwater. Since the Middle Fork of the Popo Agie River is a Class I river, the drinking water quality standards would apply, and injection water would need to meet those standards listed in Chapter 8, Quality Standards for Wyoming Groundwaters, **Table 7.1**. The list does not include the EPA's national drinking water standards or maximum contaminant levels because they are included by rule.

When permitting ASR sties, if an infiltration basin is used instead of an injection well, and the basin is engineered to enhance infiltration with gravel or other means, the site would likely require a UIC permit. If the infiltration basin is built with no engineered enhancement for increased infiltration, the facility would be permitted with WYPDES and through the water/wastewater division. Paul Lohman (307.777.7088) is the point of contact for discussing the requirements of an engineered basin.

Table 7.1 Water Quality Standards by Class of Underground Water.

	UNDERGROUND WATER CLASS		
	I	II	III
Use Suitability Constituent or Parameter	Domestic* Concentration**	Agriculture Concentration**	Livestock Concentration**
Aluminum (Al)	---	5.0	5.0
Ammonia (NH_3-N)	0.5[7]	---	---
Arsenic (As)	0.05	0.1	0.2
Barium (Ba)	2.0	---	---
Beryllium (Be)	---	0.1	---
Boron (B)	0.75	0.75	5.0
Cadmium (Cd)	0.005	0.01	0.05
Chloride (Cl)	250.0	100.0	2000.0
Chromium (Cr)	0.10	0.1	0.05
Cobalt (Co)	---	0.05	1.0
Copper (Cu)	1.0	0.2	0.5
Cyanide (CN)	0.2	---	---
Fluoride (F)	4.0	---	---
Hydrogen Sulfide(H_2S)	0.05	---	---
Iron (Fe)	0.3	5.0	---
Lead (Pb)	0.015	5.0	0.1
Lithium (Li)	---	2.5	---
Manganese (Mn)	0.05	0.2	---
Mercury (Hg)	0.002	---	0.00005
Nickel (Ni)	---	0.2	---
Nitrate (NO_3-N)	10.0	---	---
Nitrite (NO_2-N)	1.0	---	10.0
(NO_3+NO_2)-N	---	---	100.0

	UNDERGROUND WATER CLASS		
	I	II	III
Oil and Grease	Virtually Free	10.0	10.0
Phenol	0.001	---	---
Selenium (Se)	0.05	0.02	0.05
Silver (Ag)	0.10	---	---
Sulfate (SO_4)	250.0	200.0	3000.0
Total Dissolved Solids (TDS)	500.0	2000.0	5000.0
Vanadium (V)	---	0.1	0.1
Zinc (Zn)	5.0	2.0	25.0
pH	6.5-8.5s.u.	4.5-9.0s.u.	6.5-8.5s.u
SAR	---	8.0	---
RSC	---	1.25 meq/L	---
Combined Total Radium 226 and Radium 228	5pCi/L	5pCi/L	5pCi/L
Total Strontium 90	8pCi/L	8pCi/L	8pCi/L
Gross alpha particle radioactivity including Radium 226 but excluding Radon and Uranium	15pCi/L	15pCi/L	15pCi/L

* This list does not include all constituents in the national drinking water standards. They are included by rule.
** Units are milligrams per liter (mg/L) unless otherwise indicated.
s.u. = standard unit; meq/L = milliequivalents per liter; pCi/L = picocuries per liter

8.0 RESULTS, RECOMMENDATIONS, CONCLUSIONS

As a follow-up to the Level I study completed in 2003 (ACE 2003), the scope of this Level I Phase II watershed study was narrowly focused on the three areas. The three focus areas as defined in the scope of work included:

- Water Budget Investigation and Irrigation Infrastructure Assessment
- Microstorage Facilities Investigation
- Aquifer Storage and Recovery

The primary goals of each topic were as follows:

- Update the water budget with recent water monitoring data and use the new water budget to identify where and when there are water surpluses and deficits in the Popo Agie Watershed.
- Identify potential irrigation improvements that will deliver the greatest increases in efficiency and provide the water to address the deficits identified in the updated water budget.
- Identify potential locations for microstorage facilities off main river channels that will enable irrigators to hold water in the system for use later in the irrigation season.
- Assess the potential for capturing surface water at certain times of the year to store underground, to recharge the groundwater resource, and to enhance late-season water availability.

This section provides the results and recommendations for each of the areas of focus.

8.1. Water Budget Investigation Results

One of the first items the HRI stakeholder group wanted to better understand was, "Does our watershed have excess water that could be used to address the seasonal water shortages facing irrigators and other water users across the Popo Agie Watershed?" For this reason, the first part of the study focused on updating the water budget model presented in the Phase I Level I watershed study (ACE 2003).

For this Level I, Phase II Study, ACE's Model was refined with the incorporation of new information to better assess current water availability within the Popo Agie Watershed. Model results were used to assist in the microstorage reservoir evaluation and location selection as well as the ASR portion of this watershed study. In addition, the PACD, Popo Agie Watershed water users, and the State of Wyoming can use the Model as a planning tool when considering future water use and development.

The results of the water budget model analysis indicate that even during a dry year, 46 percent of stream flows are not consumed by diversions, and during a wet year, only 22 percent of total in-stream flows are diverted. Examination of the watershed on an annual basis shows that water is available for storage. Of course, consideration must be given to downstream water right appropriations of the Little Wind River. Therefore, subtracting downstream water rights, 68 percent of the annual flow (230,535 acre-feet) is available for storage during a normal year.

To determine when flow is available for storage, the Model was examined on a monthly basis. The Model summarizes monthly outflows by node and reach in acre-feet. On a by-reach basis for normal years, 67,214 acre-feet is available in the North Popo Agie, 116,630 in the Middle Popo Agie, and 71,338 in the Little Popo Agie. As is expected, Model results show low flow volumes during the winter months (December, January, and February) and high flow volumes as snowmelt occurs (April, May, and June). Finally, as the late irrigation season is reached, flow volumes decrease significantly, especially close to Lander. This is partly caused by the high density of diversions near and upstream of Lander.

Another aspect of the water budget analysis was an assessment of conveyance and application losses associated with the current irrigation delivery system infrastructure and on-farm irrigation application systems. Conveyance and application losses were estimated using the Model and while it is not feasible to recover all losses, improvements to conveyance and application can help decrease losses and increase flow and water availability. The following section presents improvement projects that could help conserve water and alleviate low flows during the late irrigation season to improve the ecological health of the watershed.

8.2. Irrigation Improvement Recommendations

The objective of the proposed improvements is to recommend projects that will result in conservation of water for the Popo Agie Watershed and/or reduce losses that occur. The Olsson/Wenck project team recommends the following irrigation improvements after review of the water budget analysis, field visits with landowners, and feedback from PACD and HRI.

8.2.1. Cemetery Ditch and Dutch Flat / Taylor Ditch

The Cemetery Ditch and the Dutch Flat / Taylor Ditch are in proximity to each other, and operational issues affect the ditches (noted below):

- Sections of the Cemetery Ditch are located within the City of Lander, which makes it difficult to access and perform maintenance activities. Several culvert crossings for streets and driveways in this area restrict the ditch’s conveyance capacity.
- Seepage from the Cemetery Ditch and the Dutch Flat / Taylor Ditch affect the elevated water levels that occur in this part of the city during certain times of the year.
- An unstable hillslope area is between the two ditches just west of where the ditches cross Highway 287, the Ford Slip.

Consolidating the ditches would eliminate these issues. The upper section of the Cemetery Ditch would still be used to provide irrigation water to lands near the diversion. The middle section of the ditch that flows through the City of Lander could be abandoned.

8.2.2. Nicol and Table Mountain Ditch and Baldwin Peralta Ditch

The Nicol and Table Mountain Ditch and Baldwin Peralta Ditch are also located close to each other. The Baldwin Peralta Ditch includes a small area of irrigated lands near the diversion structure and then a long ditch length to the area where most of the irrigated lands are located. It would be beneficial to consolidate the two ditches so that the lower portion of the Baldwin Peralta Ditch could be served by the Nicol and Table Mountain Ditch:

- Maintenance efforts for the consolidated ditch section would be reduced as only one ditch would be used for conveyance.
- Less water would be lost to conveyance since the overall ditch length of the Baldwin Peralta would be reduced.

The Baldwin Peralta Ditch would still be used to irrigate lands in the upper section of the ditch; however, the middle section could be abandoned.

8.2.3. Enterprise Ditch

The Enterprise Ditch includes various features that could be upgraded and/or improved to increase the conveyance efficiency of the ditch. Recommended improvements for the ditch include relining ditch sections where the existing liner has deteriorated and replacing a dilapidated headgate lateral and drop structure. Previous reports have also suggested stabilizing the steep ditch section located at the Cascade Drop in the Sawmill Creek reach. These improvement projects can help reduce conveyance losses that occur along the Enterprise Ditch. Improvement recommendations are described below:

- As previously noted, the lined ditch section for the upper reach of Sawmill Creek has deteriorated, and the liner material is a semipermeable geotextile. Replacing 3,000 LF of ditch lining will significantly reduce seepage loss that occurs in this reach.
- The headgate and drop structure for the Thompson Lateral in the Beason Creek section of the Enterprise Ditch needs replacing. Installing a new lateral headgate and check drop structure will allow for better regulation of flows delivered to the lateral.
- The Cascade Drop section of the ditch has seepage occurring along the steep channel. Additionally, erosion is likely occurring and causing sediment loading into Beason Creek. Installing a pipe drop at this location would eliminate these two issues.

8.2.4. Lyons Ditch

A section of the Lyons Ditch overflows where it crosses the northwest side of the Lyons Valley Road. A gated wasteway should be installed at this location for spilling excess flows. Additionally, the ditch capacity should be increased upstream of the culvert crossing so that the ditch does not overtop. Cleaning the ditch and elevating the bank (~2,000 LF) should eliminate the overtopping problem.

The results of the water budget analysis and irrigation assessments were presented at the November 2018 project meeting in Lander. At the meeting, another aspect of the recommendations that was discussed included using the Model to estimate the impact of specific improvements on river flow in Lander. Two hypothetical situations were evaluated. The first included increasing the conveyance efficiency of half the irrigation ditches along the Middle Fork of the Popo Agie. The other was to increase the efficiency of irrigation by fifteen percent across the watershed by converting half the irrigated fields to pivot irrigation. Clearly, both hypothetical options would be costly and difficult to achieve but based on the Model analysis, implementing either one of these options could increase river flows through Lander by approximately 25 cfs. The intent of the Model analysis was to illustrate that by implementing a combination of conveyance system improvements along with conversions to more efficient irrigation systems, the goal to retain a minimum of 25 cfs in the Middle Popo Agie River through the City of Lander may be achievable.

8.3. Microstorage Recommendations

Another of the key objectives of this Phase II watershed study was to identify potential locations for microstorage facilities off the main river channels that will enable irrigators to hold water in the system for use later in the irrigation season. The updated water budget showed that at least 1,000 acre-feet of water would be available in May and June in each of the Little Popo Agie, Middle Popo Agie, and North Popo Agie subwatersheds and that this water could be stored and used later in the irrigation season. For this reason, all three subwatersheds were evaluated for potential microstorage sites.

8.3.1. Microstorage Capacity and Location Recommendations

A target capacity was developed to evaluate the sites. The target volume of desirable water was based on an example calculation. The goal was to irrigate a 100-acre alfalfa field in August when surface water supplies are low. Considering all aspects of the water budget and the need to compensate for evaporation, seepage and transmission losses, and adding volume for flexibility, a volume of 300 acre-feet was used as the target volume for the microstorage sites. It should be noted that if a site is selected for construction, the actual storage volume could be larger or smaller but for evaluation purposes, using the same volume at each potential site yielded a like comparison.

Thirty-six sites were identified across the entire watershed using the following primary selection parameters for potential microstorage site location:

- Sites would be located outside of wilderness areas.
- Sites would not be located on the mainstem of the three river branches.
- Existing reservoirs were generally not evaluated, with Worthen Meadows Reservoir and Pete's Lake as exceptions.

8.3.2. Microstorage Site Ranking

With 36 potential microstorage sites to be compared, criteria were developed so that the sites could be ranked. Eight criteria categories were developed and scored from 1 (lowest) to 3 (highest). Water availability, versatility of benefit, and cost were considered the most important criteria and were given twice the weight of the other categories. **Table 8.1** shows the scores and rankings for each site sorted into approximate thirds by color, with green being the most favorable third, yellow the middle third, and red the least favorable third. Along with the microstorage site ranking, input from residents and stakeholders in the watershed is invaluable in helping determine the sites with the best potential for advancement and where additional water would prove to be most beneficial. For this reason, information regarding the 36 sites was submitted to the PACD and distributed to the HRI. A small group of HRI members reviewed the sites and provided input. The input consists of pros, cons, and general comments regarding 24 of the sites, and it raises location suitability questions in some instances. The feedback does not necessarily provide endorsement of one site versus another, but it should be taken into consideration along with the information presented in this report. This input is presented in **Appendix C**.

Table 8.1 Microstorage Site Scoring and Ranking

Site Name	Branch	Water Availability*	Beneficial Uses*	Cost*	Bedrock Geology and Soils	Proximity to Irrigation	Proximity to Structures	Wetlands	Property Ownership (Original)	Total
Willow Creek No. 2	L	3	2	3	3	3	2	3	3	22
Willow Creek Lower	L	3	3	2	2	3	3	1	3	20
Crooked Creek - Meyer Basin	M	3	3	2	3	1	3	3	1	19
Hornecker - Borner (MPA diversion)	M	3	3	2	1	3	1	3	3	19
Sawmill Creek - Fossil Hill	M	3	3	3	3	1	3	2	1	19
Twin Creek	L	3	2	3	1	3	1	3	3	19
Cottonwood Creek	L	2	1	3	2	3	1	3	3	18
Cottonwood Creek East Fork	L	3	1	3	2	3	2	2	2	18
Hornecker - Borner (tributaries)	M	2	3	2	1	3	1	3	3	18
Little Popo Agie - Louis Lake	L	3	3	3	3	1	3	1	1	18
Sawmill at Loop Road	M	3	2	3	3	1	3	2	1	18
Deep Creek	L	2	1	1	3	3	2	3	2	17
Madison Creek	L	2	2	3	1	2	1	3	3	17
Onion Flats - from Devils Creek	L	1	2	3	3	3	1	3	1	17
Sawmill at Townsend 1	M	3	2	2	3	1	3	2	1	17
Sawmill at Townsend 2	M	3	2	1	3	1	3	3	1	17
Sawmill Creek 1	M	3	3	2	1	1	3	3	1	17
Sawmill Creek 2	M	3	3	1	2	2	1	3	2	17
Smith Creek	M	1	2	3	3	3	2	1	2	17
Surrel Creek No. 1	N	3	3	2	1	3	1	3	1	17
Beason Creek	L	1	3	1	1	3	2	3	2	16
Canyon Creek 1	L	2	1	2	3	1	3	3	1	16
Crooked Creek - Elderberry	M	2	3	2	1	1	3	3	1	16
Iiams Creek	L	1	3	1	3	3	1	2	2	16
Sheep Creek	M	1	3	1	3	2	1	3	2	16
Surrel Creek No 3	N	1	3	1	3	1	3	3	1	16
Surrel Creek No. 2	N	3	3	2	1	2	1	3	1	16
Willow Creek Upper	L	1	2	2	3	3	1	3	1	16
Baldwin - Farlow	M	2	2	2	3	1	1	3	1	15
Cherry Creek	L	2	1	2	3	1	3	1	2	15
Little Popo Agie - Onion Flats	L	1	2	3	1	3	1	3	1	15
No Name Draw	M	1	2	1	1	3	1	3	3	15
Pete's Lake	M	1	1	3	3	1	3	1	1	14
Canyon Creek	L	1	1	2	3	1	3	1	1	13
Baldwin/Squaw	M	2	2	1	1	1	1	3	1	12
Weiser Creek	L	1	1	2	1	3	1	2	1	12

Notes:
*Category is weighted twice
1 = Poor score, 3 = High score

8.3.3. Recommendations Regarding Worthen Meadows Reservoir

Worthen Meadows Reservoir is included in this report as a potential, and very promising water storage site, but was not evaluated in the same way as the other sites. A study of the City of Lander's water supply is documented in the draft technical memorandum *Water Supply Evaluation and Groundwater Development Alternatives, Lander Test Well Level II Study* dated April 2019 by Wyoming Groundwater LLC. As part of the study, "the management and reliability of the Worthen Meadows Reservoir in providing a late-season water supply was evaluated using a basic reservoir operations model" (Wyoming Groundwater 2019). Two conclusions of the draft reliability evaluation are discussed in the draft Level II study and are particularly relevant to this Popo Agie Level I Phase II study. They are:

- "Short of reservoir failure, there is little reason to expect the reservoir cannot continue to meet the historical levels of demand into the foreseeable future."
- "Under the assumptions of this relatively simple model, Worthen Meadows Reservoir could release quantities approximately twice those experienced historically and still not completely empty the reservoir in any model year."

A test release from Worthen Meadows Reservoir was made in August 2018 to investigate the impact of the release on flows at downstream locations of the Middle Fork Popo Agie. Additional testing can be conducted while the Level II study is finished, or additional studies are conducted. This information would be valuable to help determine whether releasing more water from Worthen Meadows Reservoir late in the season would prove to be beneficial.

In addition to changing the reservoir operations, expansion of Worthen Meadows Reservoir should be considered. A 1988 study by ARIX Corporation titled "*Lander Rehabilitation Project Level II Feasibility Study Phase II: Geotechnical Investigation and Rehabilitation Plan for Worthen Meadows Dam and Reservoir*" (ARIX Corporation 1988) presented recommendations that included enlarging the existing dike section; raising the primary dam, secondary dike, and spur dike embankments to pass the probable maximum flood; and constructing an emergency spillway on the north side of the reservoir. A substantial rehabilitation project was completed in 1995.

A second modification that increases the storage of Worthen Meadows Reservoir should be evaluated. Based on available contours, it appears that the dam height could be increased. It should be noted that an expanded pool could negatively impact existing recreational facilities such as boat ramps, access, and camping areas and additional storage rights may be required. These and other aspects of increasing the storage capacity of Worthen Meadows Reservoir could be considered during a Level II feasibility study.

8.4. Aquifer Storage and Recovery

The goal of the ASR analysis was to assess the feasibility of using ASR to retime the water supply in the Popo Agie Watershed to increase late-season river flow. Several selection criteria, including regulatory, operational, hydrogeologic, and cost, were considered and used to evaluate potential ASR technologies, locations, and storage aquifers. The focus of the ASR analysis was on the Middle Fork of the Popo Agie based on the water budget analysis and the need to address the late-season low flow conditions within the sub-watershed.

The four ASR technologies considered in this analysis included:

- Injection/recovery wells
- Injection with passive recovery

- Infiltration basins
- Enhanced ditch infiltration

8.4.1. Aquifer Storage and Recovery (ASR) Results

Results of the ASR analysis indicate that ASR could be a potential storage option for retiming water supply and increasing late-season flow along the Middle Fork of the Popo Agie River. Analysis of the available data indicates that an ASR facility could contribute up to 1.1 cfs of water if the facility is located strategically within the basin and operated during periods that take advantage of the storage space available within the alluvial aquifer. Storage in the deeper aquifers was not considered a viable option because of the price. To achieve a higher contribution to late-season flow, multiple ASR facilities could be constructed, or ASR could be used in conjunction with other storage options, such as microstorage reservoirs.

Two potential areas for ASR facilities were identified as a part of this study: one upstream near Lander's water treatment plant and another downstream of irrigation users. The upstream location could host either an infiltration basin or an ASR well and, if built near the water treatment plant, has the capacity to serve dual purposes. The downstream portion of the Middle Fork could sustain an infiltration basin, which could potentially contribute up to 0.2 cfs of flow. An ASR facility in this location could potentially benefit from the water supply provided by Lander's unused infiltration gallery. A suitable location could not be identified for enhancing infiltration along an existing ditch. Cost analysis for the different storage options indicated that enhancing ditch infiltration would be the least expensive of the ASR technologies because it makes use of existing infrastructure and infiltrates water without the need for additional power. However, this technology is also the least flexible of the options and is highly dependent upon the locations of existing ditches. An injection and recovery well is the most expensive option, discounting a deeper Tensleep aquifer well, but it is also the most flexible. Because of the smaller footprint, it can be built on most parcels and can be used as a groundwater production well when emergency supply is needed.

8.4.2. Aquifer Storage and Recovery (ASR) Recommendations

Should the Sponsor choose to pursue ASR as part of a Level II study, the data used here would need to be updated and used to refine the analysis of ASR suitability and location. The presented results are highly dependent upon the hydrogeologic characteristics of the alluvial aquifer, including the transmissivity, seasonal groundwater levels, and groundwater gradient. Transmissivity data from the 1999 testing (Lidstone and Associates 1999) was conducted in two locations, and these results were extrapolated along the rest of the Middle Fork. If locations are selected for further study of ASR, each aquifer site should be retested to obtain representative transmissivity values. The available transmissivity data for the two testing locations was also much lower than expected, which had a substantial impact on the selection process for ASR locations. If updated transmissivity values are higher, which would fit more closely with expectations, then ASR facilities should be moved farther from the river. This could open potential locations for enhanced ditch infiltration or could place ASR facilities closer to the water treatment plant, where they can more easily be used for dual purposes.

The operation of ASR facilities is also highly dependent upon water level data, which should be used to ensure water is being stored not just when it is plentiful, but also when there is room available in the aquifer. To proceed with an ASR investigation, seasonal groundwater data should be collected in multiple locations to help better define the water table and the local groundwater gradient.

Surveying should also be conducted to establish land surface and riverbank elevations. This data, in conjunction with seasonal groundwater levels, should be used to refine the timing of injection and to ensure injected water will be intercepted by the river. Data from surveying can also be used to study whether regulatory selection criteria, which state that injected water should not affect the land surface or existing infrastructure, can be met.

ASR locations and the estimated costs presented in this watershed study assume that water treatment is not necessary for ASR permitting and that both the groundwater and river water meet WDEQ Water Quality Class I Guidelines. Both surface water and groundwater samples should be collected to confirm this assumption.

At this time, only the Middle Fork of the Popo Agie River was identified as a potential ASR location. If demand for water storage along the other branches of the Popo Agie River increases, the data discussed above should also be collected along the North and Little Popo Agie River locations to enable a similar analysis of ASR suitability.

8.5. Conclusions

At the end of this study, the primary question posed by the project sponsor was, “What project should we implement first?” And truthfully, the answer is, it depends. As presented earlier, there are several criteria that can be used to prioritize project implementation but, in the end, several factors will come into play. Important factors like what landowner, irrigation district, or agency is interested in completing a project and what funding source is available? However, the answer to this question may have already been answered because currently, an application for Level III funding is pending approval by the WWDC.

In 2008, the upper Sawmill reach of the Enterprise Ditch was identified as having significant seepage approximately three times higher than leakage on other areas of the irrigation system (Aqua Engineering 2008). This seepage represents approximately 50 percent of the total seepage loss on the entire system. Lining or piping this section was recommended to reduce losses. What has changed since the study was completed is that now, there is an opportunity to partner with the Popo Agie Conservation District and NRCS to provide technical assistance and funding to help contribute to this project. For a comparison of the different projects presented in this study, the following information is offered:

- For an estimated cost ranging from $44,000 to $900,000, the irrigation system conveyance system improvements presented in this report could facilitate water conservation, due to water conveyance efficiency, ranging from 0.3 to 3.5 cfs (Table 8.2).
- For an estimated cost ranging from $50,000 to $14 million, the microstorage sites presented in this report could provide additional water storage for use during late season low-flow conditions. The cost per acre foot for the stored water ranged from $630 to $50,800 for the first year of operation.
- For an estimated cost ranging from $25,000 to $500,000, an estimated 1.1 cfs of water could be returned to the river during late season low-flow conditions.

Table 8.2 Proposed Irrigation System Improvement and Estimated Water Savings

Proposed Irrigation System Improvement	Estimated Water Savings (cfs)
Enterprise: Ditch lining Sawmill Creek Reach	3.5 cfs
Cemetery & Dutch Flat / Taylor Ditch Consolidation	2.0 cfs
Enterprise: Beason Creek: Thompson Headgate	0.3 cfs
Lyons: Ditch Capacity upgrade and Wasteway	0.3 cfs
Nicol and Table Mountain / Baldwin & Paralta: Ditch Consolidation	0.5 cfs
Enterprise: Cascade Reach-Pipe Drop	1.5 cfs

With several of the proposed projects, there are data gaps that should be addressed prior to and potentially after implementation. The following list provides insight into these data gaps identified as part of this investigation:

- As potential irrigation improvements are evaluated and implemented it would be beneficial to conduct pre- and post-monitoring to evaluate the effectiveness of the improvement project. This could aid the PACD and other entities in determining which projects have the best potential benefits regarding water conservations and cost effectiveness.
- During this project and under a separate contract, the PACD and HRI initiated several seepage studies along segments of the irrigation ditches in the area. These studies should continue to determine where significant losses occur and will aid in project prioritization. Based on the improvements presented in this report, seepage studies for the Sawmill and Crooked Creek reaches of the Enterprise Ditch and the Nicol Table Mountain Ditch are recommended.
- For microstorage, the Olsson/Wenck team recommends gaging at the highest priority location(s) to better understand the hydrology and available water at the site
- Regarding ASR, additional aquifer tests and groundwater monitoring are required before ASR projects can be evaluated further. Pros and cons of the ASR projects are highly dependent on aquifer conditions and based on information currently available, the amount and timing of return flow to the river needs to be validated.

9.0 ACRONYMS AND ABBREVIATIONS

ASR .... aquifer storage and recovery
BGEPA .... Bald and Golden Eagle Protection Act
BLM .... Bureau of Land Management
CGP .... construction general permit
cfs .... cubic feet per second
CWA .... Clean Water Act
ESA .... Endangered Species Act
ft^2/day .... square feet per day
ft^3/day .... cubic feet per day
EPA .... Environmental Protection Agency
FWCA .... Fish and Wildlife Coordination Act
GIS .... Geographic Information System
HRI .... Healthy Rivers Initiative
LWPC .... Lander Water Planning Committee
MBTA .... Migratory Bird Treaty Act
NAGPRA .... Native American Graves Protection and Repatriation Act
NEPA .... National Environmental Policy Act
NHPA .... National Historic Preservation Act
NRCS .... Natural Resources Conservation Service
NWI .... National Wetlands Inventory
NWP .... nationwide permit
PACD .... Popo Agie Conservation District
PCN .... preconstruction notification
ROW .... right-of-way
SHPO .... State Historic Preservation Office
UIC .... Underground Injection Control
USACE .... U.S. Army Corps of Engineers
USDA .... U.S. Department of Agriculture
USFS .... U.S. Forest Service
USFWS .... U.S. Fish and Wildlife Service
USGS .... U.S. Geological Survey
WACD .... Wyoming Association of Conservation Districts
WDEQ .... Wyoming Department of Environmental Quality
WQD .... Water Quality Division
WYPDES .... Wyoming Pollutant Discharge Elimination System
WYSEO .... Wyoming State Engineer's Office
WWDC .... Wyoming Water Development Commission
WWDO .... Wyoming Water Development Office

10.0 REFERENCES

Alqahtani, A. and T. Sale. 2017. Screening Level Cost Estimates for ASR Wellfields. Colorado State University.

Anderson Consulting Engineers (ACE). 2003. Popo Agie River Watershed Study, Level I, Final Report. Prepared for the WWDC and the Popo Agie Conservation District, Lander Wyoming. July 9, 2003.

Aqua Engineering, Inc., 2008, Enterprise Conservation Program Level II Study, Final Report, Submitted to the Wyoming Water Development Commission.

Bloetscher, F., C.H. Sham, J.J. Danko III, and S. Ratick. 2014. Lessons Learned from Aquifer Storage and Recovery (ASR) Systems in the United States. Journal of Water Resources and Protection. Scientific Research.

Curtis, J. and Grimes, K. 2019. Wyoming Climate Atlas. http://www.wrds.uwyo.edu/sco/climateatlas/. Accessed July 2019.

GEI Consultants, Inc., 1998, City of Lander Taylor Ditch Rehabilitation Project, Level II Feasibility Study, Final Report, Submitted to the Wyoming Water Development Commission

Gibson, M.T., M.E. Campana, and D. Nazy. 2018. Estimating Aquifer Storage and Recovery (ASR) Regional and Local Suitability: A Case Study in Washington State, USA. Hydrology 2018: 5,7.

Groundwater Encyclopedia. 2019. Aquifer Storage and Recovery. http://www.waterencyclopedia.com/A-Bi/Artificial-Recharge.html. Accessed July 2019.

Home Advisor. 2019. Project Cost Estimator. https://www.homeadvisor.com/cost/garages/gravel-driveway-road/#pebbles. Accessed July 2019.

Lander 2020 Water Planning Committee (LWPC). 1999. Lander 2020 Water Planning Report. Completed for the City of Lander, Wyoming.

Lidstone and Associates. 1999. Lander Water Supply Project Level II, Phase III, Final Report 1998. Prepared for the Wyoming Water Development Commission

Lytle Water Solutions LLC. 2011. Final Report Managed Aquifer Recharge Storage and Recovery Project. Prepared for the Cheyenne Board of Public Utilities, Project No. 1175-08.

Maliva, R.G., T.M. Missimer, F.P. Winslow, and R. Herrmann. 2011. Aquifer storage and recovery of treated sewage effluent in the Middle East. Arabian Journal for Science and Engineering, 36(1), 63-74.

Misut P.E. and C.I. Voss. 2007. Freshwater–saltwater transition zone movement during aquifer storage and recovery cycles in Brooklyn and Queens, New York City, USA. J. Hydrol. 337:87–103.

Nelson Engineering. 1998. Lander Water Supply Project Level II, Phase II, Final Report 1998. Prepared for the Wyoming Water Development Commission

Oram, B. 2014. Water Research Center – The Hydrologic Cycle – Water Budgets. https://water-research.net/index.php/the-hydrological-cycle-water-budgets. Accessed July 2019.

Petkewich, M.D., D.L. Parkhurst, K.J. Conlon, B.G. Campbell, and J.E. Mirecki. 2004. Hydrologic and geochemical evaluation of aquifer storage and recovery in the Santee Limestone/Black Mingo aquifer, Charleston, South Carolina, 1998-2002, Scientific Investigations Report 2004-5046. Reston, Virginia: U.S. Geological Survey.

Popo Agie Conservation District (PACD). 2014. The Popo Agie Wateshed. Available on the PACD website: popoagie.org. Accessed July 2019.

Popo Agie Conservation District (PACD). 2019. Popo Agie Wateshed Geology. popoagie.org. Accessed July 2019.

Popo Agie Healthy River Initiative. 2019. Bulletin 05: July 2019.

Pyne, R.D.G. 1995. Aquifer storage recovery: a guide to groundwater recharge through wells. ASR Systems, Gainesville, FL.

RSMeans 2019. Historical Cost Indices. https://www.rsmeansonline.com/references/unit/refpdf/hci.pdf Accessed July 2019.

Soil Conservation Service and Wyoming State Engineers office, 1986, Wyoming Cooperative Irrigation Water Conservation Study: Enterprise Irrigation System Report, Fremont County Wyoming

Sterrett, R.J. 2007. Groundwater and Wells: Johnson Screens, New Brighton, MN.

Tuwati, A. and M. Fan. 2015. Development of a contaminant leaching model for aquifer storage and recovery technology. Cogent Environmental Science, 1: 1066177

U.S. Army Corps of Engineers (USACE). 2017. Nationwide Permits, General Conditions, District Engineer's, Decision, Further Information, and Definitions.

U.S. Fish and Wildlife Service (USFWS). 2013

U.S. Geological Survey (USGS). 2003. Ground Water in Freshwater-Saltwater Environments of the Atlantic Coast. Circular 1262. https://pubs.usgs.gov/circ/2003/circ1262/, Accessed July 2019.

Wyoming State Engineer's Office. Wyoming SEO Safety of Dams Coverage Graphic. http://seo.wyo.gov/surface-water/safety-of-dams Accessed July 2019.

Wyoming Association of Conservation Districts (WACD). 2019. SuiteWater web-based GIS planning tool available at https://suitewater.wygisc.org/. Accessed August 2019.

Wyoming Groundwater LLC. DRAFT Proposed Work Plan for Alluvial Aquifer Field Evaluation; Lander Test Well, Level II Study. 1 May 2019. Letter to Wyoming Water Development Office.

Wyoming Water Development Commission (WWDC). 2009. Water News, Conservation and Watershed Studies — what's the connection? Prepared by the WWDC, Fall.

APPENDIX A
PROJECT MEETING MINUTES

MEETING MINUTES

Popo Agie Watershed Study – Scoping Meeting

	Overnight
	Regular Mail
	Hand Delivery
x	Other: Email

NAME OF PROJECT:	Popo Agie Watershed Study, Level I, Phase II
PROJECT LOCATION:	Lander, Wyoming
MEETING LOCATION:	Lander Community Center, 950 Buena Vista Dr
DATE & TIME:	July 17, 2018, 6:00 – 8:00 PM MST
PROJECT #:	018-2061

Attendees

NAME	ORGANIZATION (if noted)	EMAIL
Anjie McConnell	---	amcconne@wyoming.com
Barbara Speyer	Enterprise Irrigation	none
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Bob Tipton	Healthy Rivers Initiative	tiptonwyo@gmail.com
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Deanna Crofts	---	deanna.crofts@wyo.gov
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Gene Dehnert	---	genedehnert@gmail.com
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Ivan Laird	---	ivanlaird@gmail.com
Jean Armstrong	---	---
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Steve Baumann	---	---
Steve Dutcher	---	sdutcherwyo@gmail.com
Tina Cunningham	---	tinajcunningham@gmail.com

Welcome and Introductions

The meeting began with a welcome and introductions by Kelsey Beck, manager of the Popo Agie Conservation District. Kelsey described the Healthy Rivers Initiative, the goals of the group and how the watershed study fits into the bigger picture of water resources management across the district.

Watershed Study Overview

Karen Griffin, Olsson Associates, began by introducing the project team including Jodee Pring of the Wyoming Water Development Office who is providing funding for the watershed study and project management, Kelsey Beck and the Popo Agie Conservation District who is the project sponsor and the combined Olsson Associates/Wenck team of engineers and scientists completing the watershed study.

The highlights of the project presentation are included in the attached PowerPoint presentation.

Speakers for each section included:

Water Budget Investigation and Irrigation Infrastructure Assessment

- Marty Jones, Wenck

Micro-Storage Facilities Investigation

- Deb Ohlinger, Olsson Associates

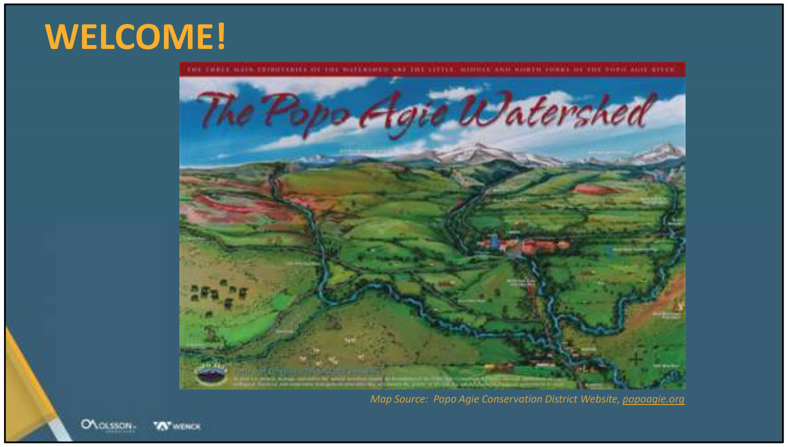
Aquifer Storage and Retrieval (Groundwater Use and Opportunities)

- Chris Lidstone, Wenck

After the presentation and Q&A, the group moved to a round table discussion format where the team answered questions from the meeting attendees and learned about issues related to water management in the area.

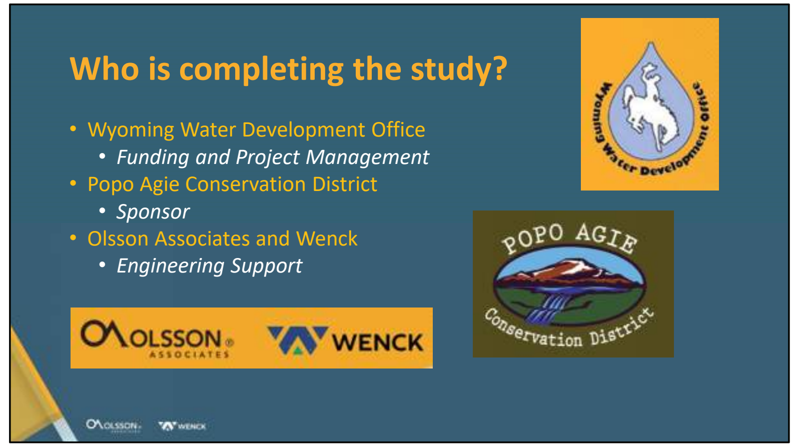
Attachment – PowerPoint presentation with notes

Title Slide



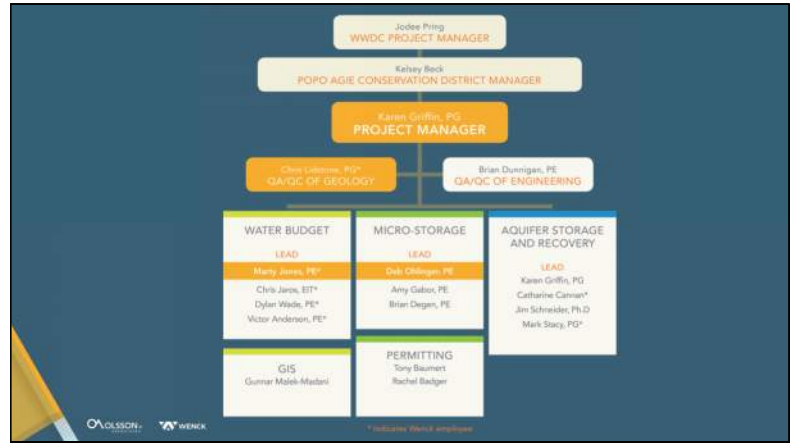
Presenter – Karen Griffin, Olsson Associates
Major Points
• Welcome to the scoping meeting for the Popo Agie Watershed Study.

Presenter – Karen
Major Points
• This is a very exciting time for the Popo Agie Watershed.
•It was truly an honor to be a part of this forum and At the forum, I talked about how in Nebraska, we are using existing irrigation ditches to recharge the aquifer and retime return flows to the river. These projects like the issues in the Popo Agie, are about low late season flows.
• Today, three of our top technical team leaders are going to describe how they can bring practical solutions to the community so that there is a collaborative approach to addressing these problems.



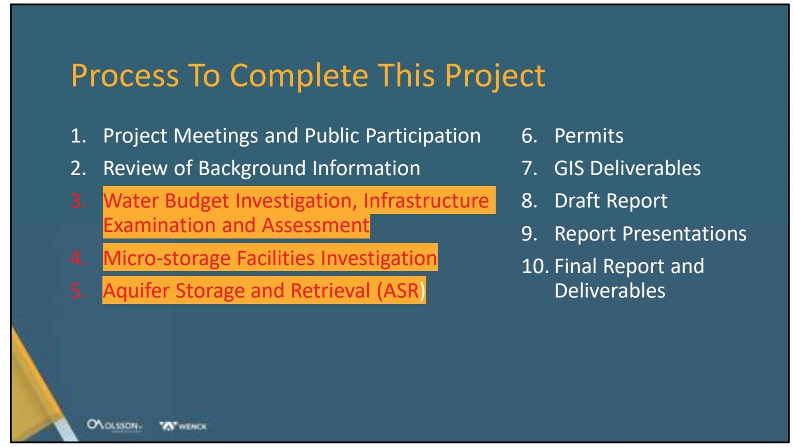
Presenter – Karen
Major Points
- Project lead agencies and roles introduced

Presenter – Karen
Major Points
- Our companies have offices across the Midwest
- For this project, our team is out of Lincoln, GI, Denver FC, Cheyenne and Lander



Presenter – Karen
Major Points
•We have a team of scientists and engineers selected to fit the needs of this project and the needs of your area.

Presenter – Karen
Major Points
• Our experts know that the only way to really get to know the issues and find technically feasible solutions is to meet with the landowners and stakeholders that know the area, we've got Cal Delmer that Lives in Lander that will be available to meet with folks along with the technical team we just listed.



Presenter – Karen
Major Points
• With the time we have in our scoping meeting today. We are going to outline our approach to this project by delving into the details of the three main aspects of potential watershed improvements we are focused on.
• The other tasks are important elements of the project but we will get to them later.
• We have the team leads for each of the three tasks here today to discuss the approach to evaluating water improvement projects.

Water Budget Model

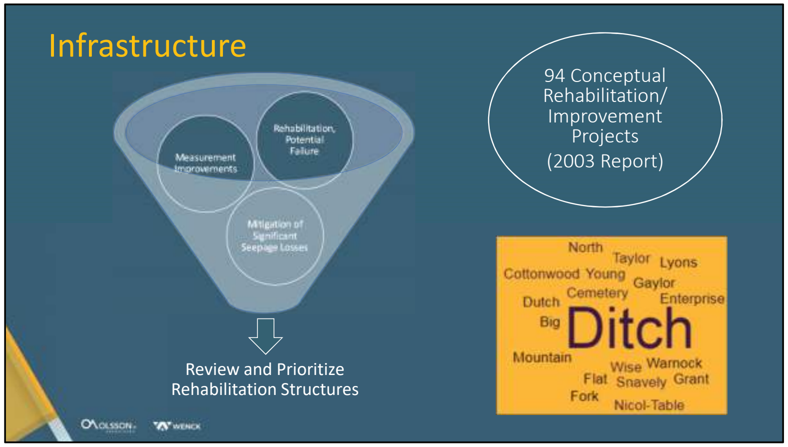
Figure 6.2 Popo Agie River Model Reach Diagrams.

Presenter – Marty Jones, Wenck
Major Points
• A water budget assessment was completed as part of the previous watershed study

Water Budget Model Update

- Additional stream flow data is available, original study time period was 1971-2000, 17 years of additional flow can be utilized.
- Additional studies have been completed in the area including projects by the WWDC that may provide additional data.
- Identify other sources of information that can be utilized to improve the model, specifically return flows and irrigation water use.

Presenter – Marty Jones
Major Points
- This task is intended to provide the foundational understanding we need to proceed with all of the other tasks
- Discuss info that can be used to update the model



Presenter – Marty
Major Points
• Wenck will review and prioritize irrigation infrastructure improvements in the watershed

Presenter – Marty
Major Points
• After review of issues identified with irrigation systems, five proposed improvement projects will be further evaluated
•Conceptual designs and cost estimates will be prepared

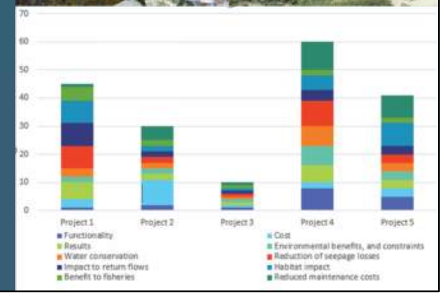
Multi-Variate Decision Matrix Tool (MVDMT)

Multiple Alternatives	Rank Priority of Multiple Criteria	Multiple Evaluators
• Project 1 • Project 2 • Project 3 • Project 4 • Project 5 • Project #s	• Functionality • Cost • Results • Environmental Benefits, and Constraints • Water Conservation • Reduction of Seepage Losses • Impact to Return Flows • Habitat Impact • Benefit to Fisheries • Reduced Maintenance Costs • Etc.	• Popo Agie Conservation District • WWDC • City of Lander • Tribes • WY DEQ • Wy Geological Survey • Fish and Game • Nature Conservancy • Ag Producers • Etc.

Presenter – Marty
Major Points
• Wenck has developed a decision matrix tool to help prioritize improvement projects.

Common Results

• Collect Opinions in a Meaningful Way
• Build Alignments Around Priorities
• Understand Different Views on the Options
• Identify and Manage Disagreements
• Transparency for Stakeholders

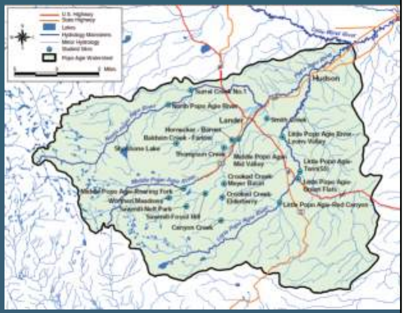


Presenter – Marty
Major Points
• Results of the evaluation

Questions on Water Budget/Irrigation

- Are there data gaps that can be addressed with this study?
- What areas do you see as focus areas?

Micro-Storage



2003 Level I Study: Larger Storage

- 33 Storage Sites, Narrowed to 18
- Smallest Site = 450 ac-ft

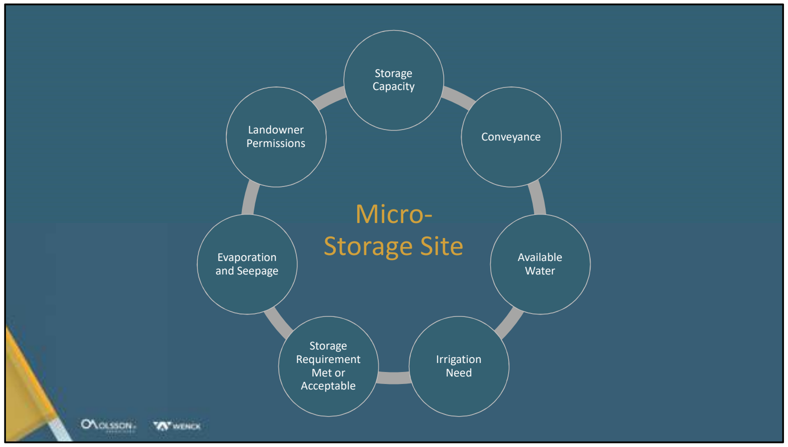
Micro-Storage

- Supplement the Phase I Study
- Late-season water
- Off-line
- Based on outcome of water budget

Presenter – Deb Ohlinger, Olsson Associates

Major Points

- The 2003 study identified 33 storage sites from previous studies and newly proposed sites. They were narrowed to 18 sites for further investigation as part of the study. The reservoirs were physically possible, but didn’t necessarily make sense for the watershed.
- The smallest potential reservoir site had a volume of 450 acre-feet.
- Micro-storage sites will be another alternative that will supplement the larger structures in the Phase I study
- Main purpose will be to store water off-line and make it available for use later in the irrigation season. The off-line storage would mean we don’t intend to dam up creeks or rivers.
- Once the water budget is complete, it will be used to identify areas where micro-storage would be desirable



Presenter – Deb
Major Points
- Suitability of sites will depend on a number of factors.
- Can we physically store water and what volume can we store?
- Can the water get to the location and to the field that needs irrigation
- If the location physically works, how much water can we expect to be available, based on the hydrologic analysis of Task 3?
- What are the irrigation needs of the field and crop to be irrigated?
- Is the amount of water available to be stored enough to meet the requirement?
- Could it provide at least some of the requirement and enough to make it worthwhile?
- Would we have enough water after accounting for seepage and evaporation?

Presenter – Deb
Major Points
- Potential locations could be close to existing ditches, in low spots not cultivated
- Next to the channel in an oxbow – potential permitting / wetland issues. Both might require pumping.
- Ideally look for areas with more elevation relief – could store water upstream and let it flow to the desired site.

Taylor Ditch

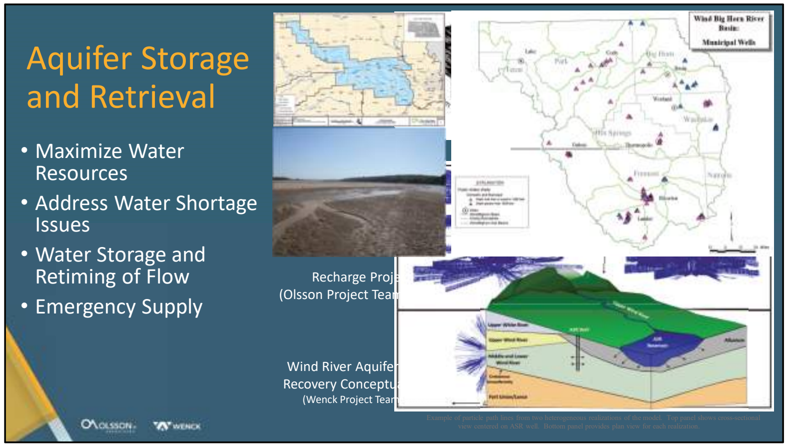
Enterprise Ditch

Presenter – Deb
Major Points

- The topography of the Taylor and Enterprise Ditches may lend itself to some feasible sites, if enough water is available.
- No sites have been pre-determined. These are a couple examples of areas that might have potential.

Questions on Micro-Storage

- Are there data sources, reports we should be aware of?
- Are there sites you have identified for micro-storage?



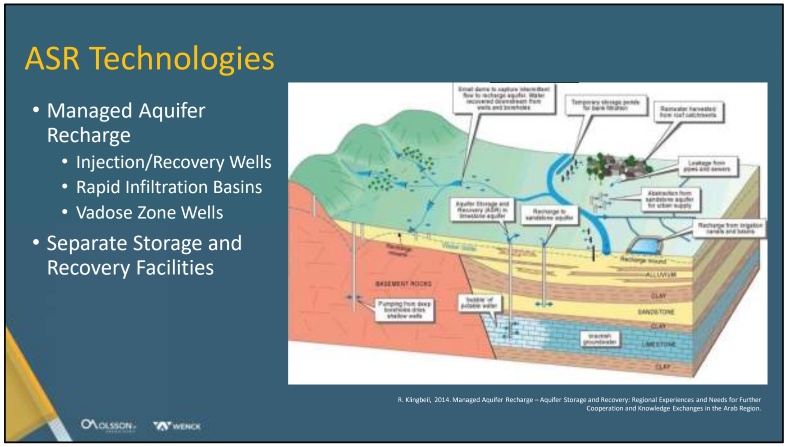
Presenter –Chris Lidstone, Wenck

I'd like to talk about some potential objectives and benefits of ASR

- *We recognize that the goal of the watershed study is to maximize both GW and SW resources in the basin*
- *ASR can be a part of this by helping to address seasonal water shortages, in conjunction with surface reservoirs. and micro-storage options*
- *A lot like micro-storage, ASR can be used to store excess water, that can be recaptured or timed to return to the stream, later in the irrigation season.*
- *ASR also experiences fewer losses to evaporation and is more resilient to natural disasters than surface storage, which makes it a good option for emergency or supplemental supply*

To the right are figures from a past project in the Denver Basin

The project team has also worked on identifying potential ASR sites for the City of Riverton and on using ASR to retime flow to the Lower Platte River in Nebraska



Presenter –Chris

To insure the most appropriate and cost effective alternative can be identified for selected sites our team will use ASR as a broad term that incorporates several methods of MAR

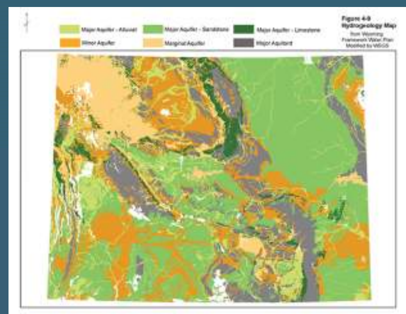
This includes traditional definition of a dual purpose injection/recovery well

We will also consider other methods of water banking such as rapid infiltration basins or vadose zone wells

These are pieces that can be used in combination, since our options are limited to those where recovery occurs at the same location water was stored

The Olsson/Wenck Approach: Evaluation Process

- Extent and Stratigraphy
- Hydrogeologic Characteristics
- Water Quality
- Current and Past Use
- Regional Flow Regimes
- Proximity to Surface Water Sources



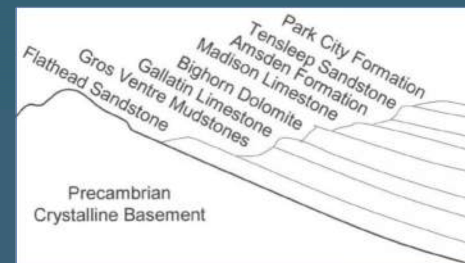
Presenter –Chris

Use existing data from the Wyoming Geological Survey State Engineer's Office, Water Development Commission River Basin Plan

As well as data collected in previous tasks to Evaluate:

- *Aquifer extent and stratigraphy*
- *Hydrogeologic characteristics such as yield, transmissivity, WQ*
- *Current and historical Water use*
- *Regional flow regimes*
- *Proximity to surface water sources*

Popo Agie Geologic Formations



Presenter –Chris

An important first step of the evaluation is understanding the underlying geology of the watershed.

The Olsson/Wenck Approach: Evaluation Process

- Excess Storage Capacity
- Recharge Water Supply, Availability, and Quality
- Proximity to Service Lines
- Potential Benefit to the Aquifer
- Dominion and Control
- Upgradient Injection

OLSSON WENCK

Presenter –Chris
The team will use an extensive process to screen and compare the aquifer's suitability for ASR projects

Questions on ASR

- Are there data sources, reports we should be aware of?
- Are there questions you have about ASR?

OLSSON WENCK

Presenter: Karen

- Describe project schedule focused on proposed project meeting dates…

Presenter - Karen
- What we love about these project is that we get to work directly with the folks living in the watershed.
- The Healthy Rivers Initiative has engaged the citizens of this watershed.
- Our team will bring engineering solutions that will sustain and improve the quality of life for the residents of the Popo Agie Watershed.

We look forward to making the same things happen here in the Popo Agie.


QUESTIONS?
OLSSON ASSOCIATES
WENCK

olsson

MEETING MINUTES

	Overnight
	Regular Mail
	Hand Delivery
x	Other: Email

Popo Agie Watershed Study - Project Status Meeting

NAME OF PROJECT:	Popo Agie Watershed Study, Level I, Phase II
PROJECT LOCATION:	Lander, Wyoming
MEETING LOCATION:	Lander Community Center, 950 Buena Vista Dr
DATE & TIME:	November 5, 2018, 6:00
PROJECT #:	018-2061

Attendees

NAME	ORGANIZATION (if noted)	EMAIL
Adam Keifeneheim	---	adamkeifenheim@gmail.com
Anjie McConnell	---	amcconne@wyoming.com
Barbara Speyer	---	None
Barbara Speyer	Enterprise Irrigation	none
Bill Lee	---	Bslee35@gmail.com
Bill Sniffin	---	bsniffin@wyoming.com
Bill Yankee	Enterprise Irrigation	LL77@wyoming.com
Bob Tipton	Healthy Rivers Initiative	tiptonwyo@gmail.com
Brendan Thomas	---	brendan@gosesengineers.com
Bryan Hamilton	Popo Agie CD Board Member	bkhamilton@wyoming.com
Chris Bove	NRCS	
Coleman Griffith	---	---
Corinne Griffith	---	---
Dave Morneau	Popo Agie Conservation District	dcmorneau@wyoming.com
Dennis Oberlie	---	doberlie@gmail.com
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Karen Griffin	Olsson	kgriffin@olsson.com
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Lloyd Larsen	---	llarsen@wyoming.com
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Mark Sanderson	---	Msm81@outlook.com
Marty Jones	Wenck	mjones@wenck.com
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Nancy Litchy	---	nllichty@gmail.com
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Rajean Strube Fossen	City of Lander	rsfossen@landerwyoming.org
Ruth Law	---	rlaw@usgs.gov
Ryan Mikesell	Wyoming State Engineer – Division 3	ryan.mikesell@wyo.gov
Steve Dutcher	---	sdutcherwyo@gmail.com

Welcome and Introductions
The meeting began with a welcome and introductions by Kelsey Beck, manager of the Popo Agie Conservation District. Kelsey thanked everyone for coming to the meeting and then described the Healthy Rivers Initiative, the goals of the group and how the watershed study fits into the bigger picture of water resources management across the district.

Watershed Study Overview and Status Update
Karen Griffin of Olsson began with a description of the meeting agenda followed by introductions of the project team including Jodee Pring of the Wyoming Water Development Office who is providing funding for the watershed study and project management, Kelsey Beck and the Popo Agie Conservation District who is the project sponsor and the combined Olsson/Wenck team of engineers and scientists completing the watershed study.

Karen explained that this is the second meeting for the watershed study and the focus today is a description of a water budget developed to better understand the dynamics of the water cycle in the Popo Agie watershed followed by a status update on the two other major topics of the project, micro-storage and Aquifer Storage and Recovery or ASR.

The highlights of the project presentation are included in the attached PowerPoint presentation.

Speakers for each section included:

Water Budget Investigation and Irrigation Infrastructure Assessment
- Marty Jones, Wenck

Micro-Storage Facilities Investigation
- Karen Griffin, Olsson

Aquifer Storage and Retrieval (Groundwater Use and Opportunities)
- Karen Griffin, Olsson

After the presentation an interactive Q&A continued the conversation and the team answered questions from the meeting attendees. The next watershed meeting will be schedule in the spring of 2019 and the main topic of discussion will be the micro-storage site evaluation.

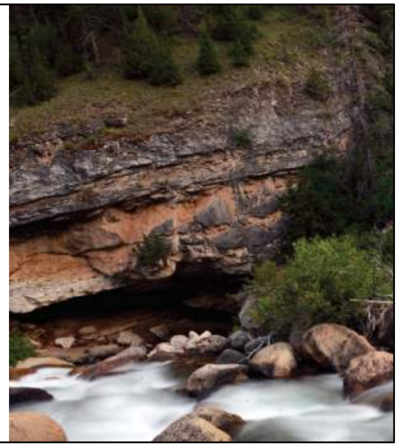
Attachment – PowerPoint presentation with notes

Popo Agie Level I Watershed Study, Phase II

Project Meeting

November 6, 2018

olsson | WENCK

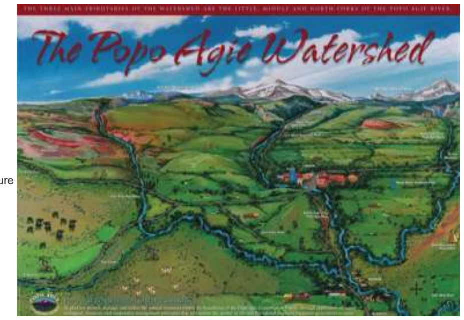


Title Slide

WELCOME!

Meeting Topics

1. Introductions
2. Watershed Study Status Update
   - Water Budget and Irrigation Infrastructure Assessment
   - Micro-storage
   - Aquifer Storage and Recovery
3. Q&A
4. What's next?



olsson | WENCK

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Presenter – Karen Griffin, Olsson

Major Points

- Meeting agenda

INTRODUCTIONS

Wyoming Water Development Office	Popo Agie Conservation District	Olsson	Wenck
Funding and Project Management	Sponsor	Engineering Support	Engineering Support

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Presenter – Karen Griffin, Olsson
Major Points
- Roles and Responsibilities

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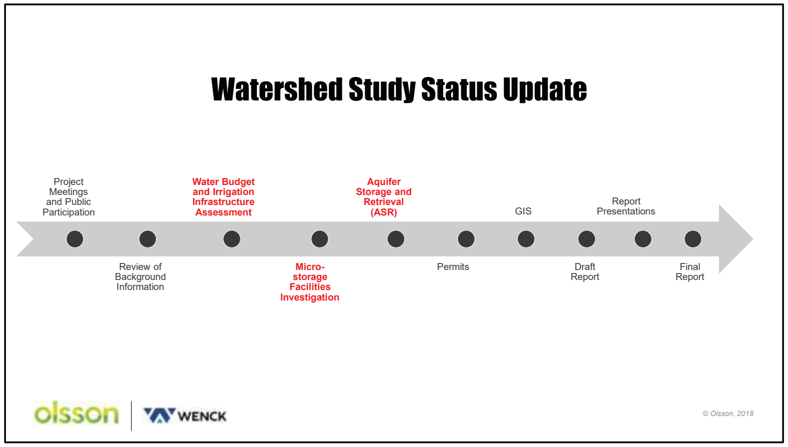
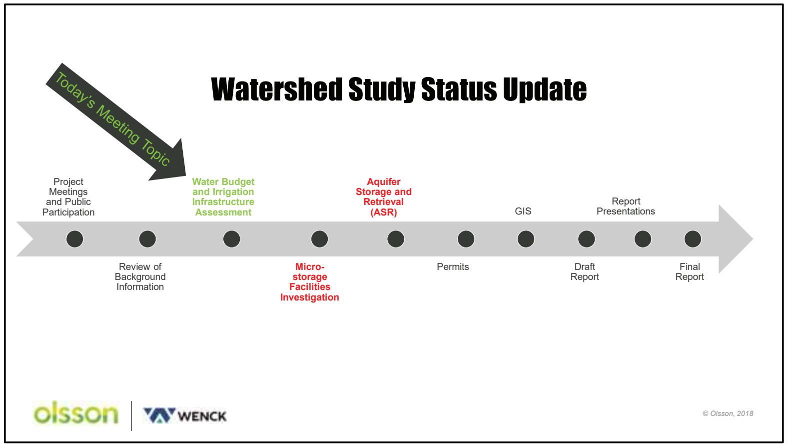
Presenter – Karen Griffin, Olsson
Major Points
- Olsson/Wenck Team Offices



Presenter – Karen Griffin, Olsson
Major Points
- Project Status timeline



Presenter – Karen Griffin, Olsson
Major Points
- Project Status timeline with current meeting topic

WATER BUDGET AND IRRIGATION INFRASTRUCTURE ASSESSMENT

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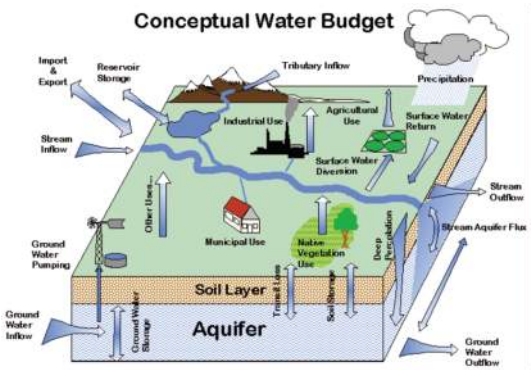
Presenter – Marty Jones, Wenck
Major Points



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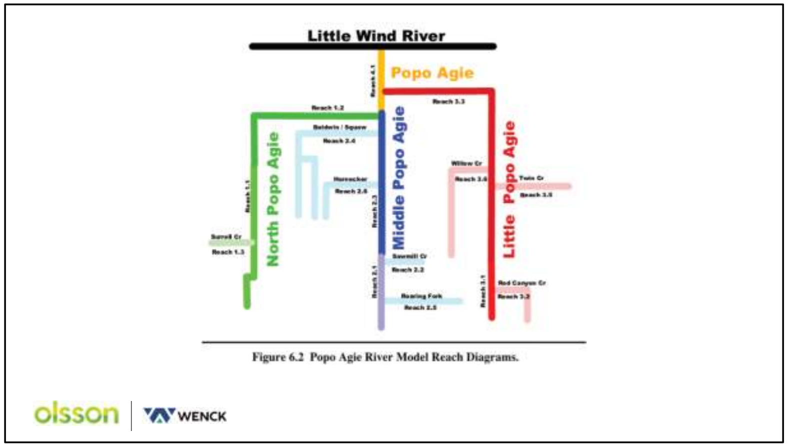
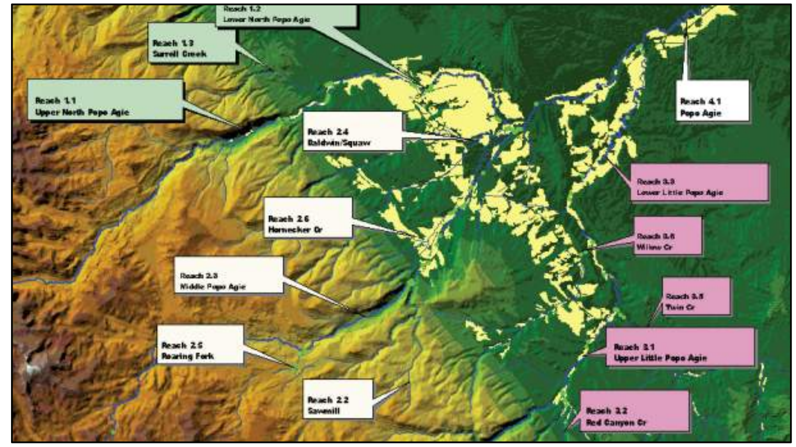
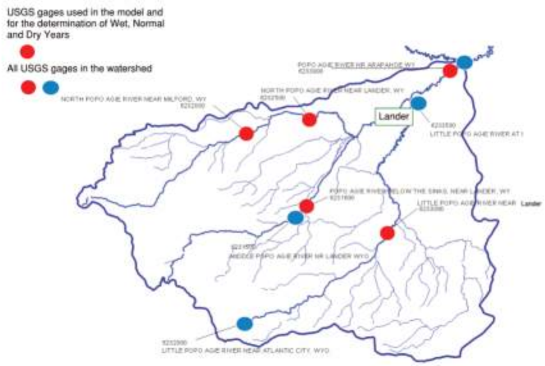
Presenter – Marty Jones, Wenck
Major Points
- Water Budget Inputs



Presenter – Marty Jones, Wenck
Major Points
- The model has 3 reaches, broken into sub-reaches.



Presenter – Marty Jones, Wenck
Major Points
- Nodes: 80 of which 6 are USGS gages
- Each reach/subreach has multiple nodes (green dots) that represent one of three notes. A gauging station (Streamflow Node), a Diversion Node (water/flows are removed from the creek to a ditch/water user), or a Confluence Node (two waterbodies joining and flows are added).
- The yellow area denotes Irrigated Acreage (ACE, 2003).
- Popo Agie Conservation District: Watershed Acreage: 522,350 Irrigated Acreage: 25,245 (~5%)



Source: Level I Study (ACE 2003

Presenter – Marty Jones, Wenck

Major Points

- We extended the Record Period for all of the Gauges. (1971-2016)
- All of the USGS Stream Gauges required some data interpolation.

Normal, Wet and Dry Years

Year	Little Popo Agie River near Lander USGS 6233000	Middle Popo Agie River below Sinks near Lander USGS 6231600	Popo Agie River near Arapahoe USGS 6233900	North Popo Agie River near Lander USGS 6232500	North Popo Agie River near Milford USGS 6232000	Basin Wide Condition
1971	Wet	Wet	Wet	Wet	Wet	Wet
1972	Normal	Normal	Normal	Normal	Normal	Normal
1973	Wet	Wet	Wet	Wet	Wet	Wet
1974	Normal	Normal	Normal	Normal	Normal	Normal
1975	Normal	Normal	Normal	Normal	Normal	Normal
1976	Normal	Normal	Normal	Normal	Normal	Normal
1977	Dry	Dry	Dry	Dry	Dry	Dry
1978	Normal	Normal	Normal	Normal	Normal	Normal
1979	Normal	Normal	Normal	Normal	Normal	Normal
1980	Wet	Normal	Normal	Normal	Normal	Normal
1981	Normal	Normal	Normal	Normal	Normal	Normal
1982	Normal	Normal	Normal	Normal	Normal	Normal
1983	Wet	Wet	Wet	Wet	Wet	Wet
1984	Normal	Normal	Normal	Normal	Normal	Normal
1985	Normal	Dry	Normal	Normal	Normal	Normal
1986	Wet	Wet	Wet	Wet	Wet	Wet
1987	Normal	Normal	Normal	Normal	Normal	Normal
1988	Normal	Dry	Dry	Dry	Dry	Dry
1989	Normal	Normal	Normal	Normal	Normal	Normal
1990	Normal	Dry	Normal	Normal	Normal	Normal
1991	Normal	Wet	Normal	Normal	Normal	Normal
1992	Dry	Dry	Normal	Normal	Normal	Dry
1993	Normal	Normal	Normal	Normal	Normal	Normal

Year	Little Popo Agie River near Lander USGS 6233000	Middle Popo Agie River below Sinks near Lander USGS 6231600	Popo Agie River near Arapahoe USGS 6233900	North Popo Agie River near Lander USGS 6232500	North Popo Agie River near Milford USGS 6232000	Basin Wide Condition
1994	Normal	Dry	Dry	Dry	Dry	Normal
1995	Wet	Wet	Wet	Wet	Wet	Wet
1996	Normal	Normal	Normal	Normal	Normal	Normal
1997	Normal	Wet	Normal	Normal	Normal	Normal
1998	Normal	Normal	Wet	Wet	Wet	Wet
1999	Wet	Wet	Wet	Wet	Wet	Wet
2000	Normal	Normal	Normal	Normal	Normal	Normal
2001	Dry	Dry	Dry	Dry	Dry	Dry
2002	Dry	Normal	Dry	Dry	Dry	Dry
2003	Dry	Normal	Dry	Dry	Dry	Dry
2004	Normal	Normal	Normal	Normal	Normal	Normal
2005	Normal	Normal	Normal	Normal	Normal	Normal
2006	Dry	Normal	Dry	Dry	Dry	Dry
2007	Dry	Normal	Normal	Normal	Normal	Normal
2008	Normal	Normal	Normal	Normal	Normal	Normal
2009	Normal	Normal	Normal	Normal	Normal	Normal
2010	Wet	Wet	Wet	Wet	Wet	Wet
2011	Normal	Normal	Normal	Normal	Normal	Normal
2012	Dry	Dry	Dry	Dry	Dry	Dry
2013	Dry	Dry	Dry	Dry	Dry	Dry
2014	Normal	Normal	Normal	Normal	Normal	Normal
2015	Normal	Normal	Normal	Normal	Normal	Normal
2016	Wet	Normal	Wet	Wet	Wet	Wet

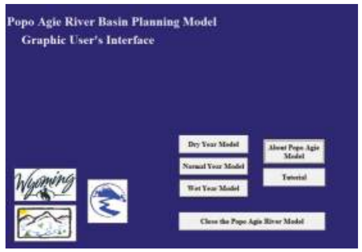
Presenter – Marty Jones, Wenck

Major Points

- Analysis of Normal, Wet and Dry Years

New Information Incorporated into the River Model

- Extended the USGS gauge period of record to 2016.
  - Determined the Normal, Wet and Dry years.
- Updated conveyance efficiencies for ditches according to improvement projects.
- Revised irrigation practices for systems upgraded to pivots.



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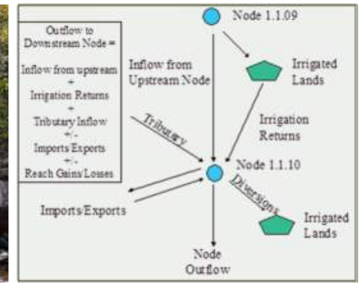
Presenter – Marty Jones, Wenck
Major Points
- What's new with the water budget.

Example Node



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Presenter – Marty Jones, Wenck
Major Points
- Outflow to Downstream Node =
- Inflow from upstream +
  Irrigation Returns+
- Tributary Inflow+/-
- Imports/Exports+/-
- Reach Gains/Losses

Model Assumptions

- Water rights priority
- Crop irrigation requirement
- Antecedent moisture conditions
- Node shortages

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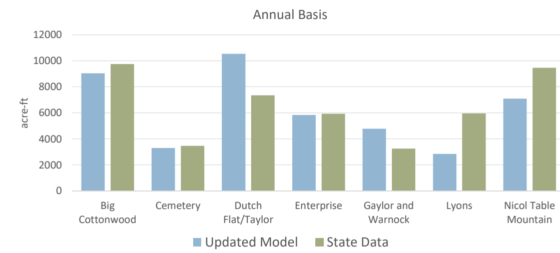
Presenter – Marty Jones, Wenck

Major Points

- Doesn't account for water rights and prioritization: All ditches are diverting during all months and all years.
- Uses the CIR to determine irrigation requirements: theoretical amount of water needed for growth.
- Has no way of quantifying water stored in the soil from the previous season therefore the model assumes higher diversion requirements in April.
- When demands exceeds water availability the model treats inflow to the next node as zero, skewing downstream results.

Comparison of Model to State Water Office Data (Normal Years: 2003 -2016)



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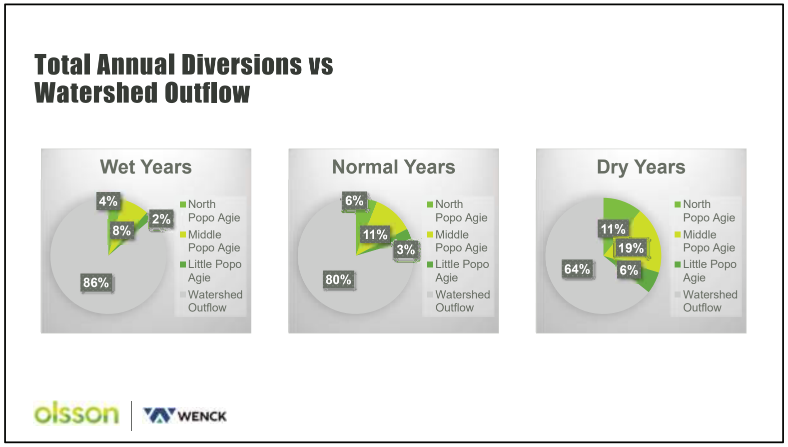
Presenter – Marty Jones, Wenck

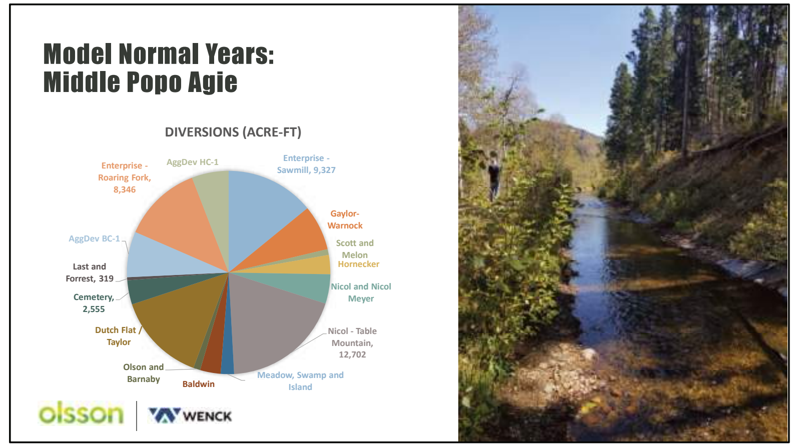
Major Points

- There is variability for each ditch. There are no consistent trends.
- Cemetery has users that actively irrigate in April. This is not true for some of the other ditches we will look at.
- For the main part of the irrigation season, the model's predicted water use is higher than the Division 3 diversion data.



Presenter – Marty Jones, Wenck
Major Points

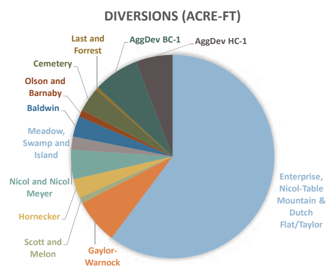
- This shows that there is water available in the basin on an annual basis.
- Primarily due to timing: high spring runoff flows and offseason flow.
- There are shortages during the critical summer months.



Presenter – Marty Jones, Wenck
Major Points

- Ditch diversions

Model Normal Years: Middle Popo Agie



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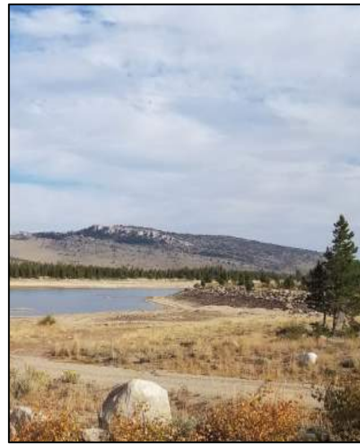
Presenter – Marty Jones, Wenck
Major Points
- Major ditches account for 60%.



August of a Normal Year

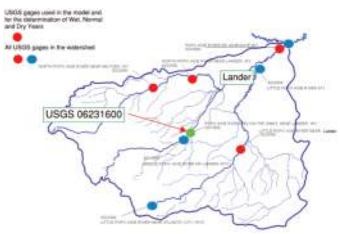
Flow in Lander:
- Estimated Desired Flow: 25 cfs
- Model Prediction: 0 cfs
- Adjusted Model: 7.5 cfs

- Goals:
  - Supplemental Flow: 17.5 cfs
  - Supplemental Volume: 1080 acre-ft

*Does not account for river losses

Presenter – Marty Jones, Wenck
Major Points
- 25 cfs: Ecological Integrity
- Need 17.5 cfs of additional flow
- Used State Water Office Data for Cemetery, Dutch Flat, Nicol Table Mountain
- Adjusted the conveyance efficiency of the Enterprise and Nicol Table Mountain

Water Availability: Middle Popo Agie



	April	May	June	July	August	Apr-Aug Total
	(acre-ft)					
USGS 06231600	3,530	16,278	32,079	14,480	4,418	70,784
Ditch Diversions	734	4,828	8,440	7,668	5,071	26,742
Excess Volume	2,796	11,450	23,638	6,812	-653	44,043
			Desired Volume		1,080	acre-ft

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Presenter – Marty Jones, Wenck
Major Points
- Negative value: This doesn't account for irrigation return flows
- Data includes both conveyance and irrigation updates

Hypothetical Improvements:

Nicol Table Mountain & Enterprise

Increased the conveyance efficiency by 25%
- Lining ½ of the length

Results
- August: 25 cfs in Lander

Increased the Irrigation efficiency by ~15%
- 50% pivot coverage

Results
- August: 23.5 cfs in Lander

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Presenter – Marty Jones, Wenck
Major Points
- Used the adjusted model to also look at improvements regarding conveyance efficiency and irrigation practices.

Take Away

Storage:

Water is available for storage in the early months of the season.

Conveyance Efficiency & Irrigation Practices:

Improvements have a significant effect.
~25 cfs

Combination Effort?

Presenter – Marty Jones, Wenck
Major Points
- Good news, water is available in the system
- Through conveyance and irrigation practices, improvements in late season flow can be realized
- The effort will be significant but combining multiple options will likely be best

Questions so far?

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Presenter – Marty Jones, Wenck
Major Points

MICRO-STORAGE

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Presenter – Karen Griffin for Deb Ohlinger, Olsson
Major Points

Micro-Storage

Data for analysis acquired

- Topography
- Hydrology
- Soil types

Analysis will begin now

- Water budget data analysis
- Timing and location of water availability

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Presenter – Karen Griffin for Deb Ohlinger, Olsson
Major Points
- Describing process for micro-storage site selection

AQUIFER STORAGE AND RECOVERY

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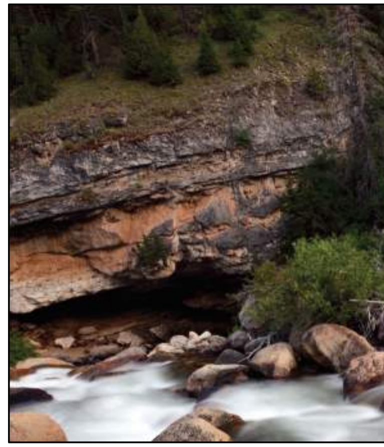
Presenter – Karen Griffin for combined Wenck/Olsson effort
Major Points



ASR

Continuing evaluation of hydrogeology

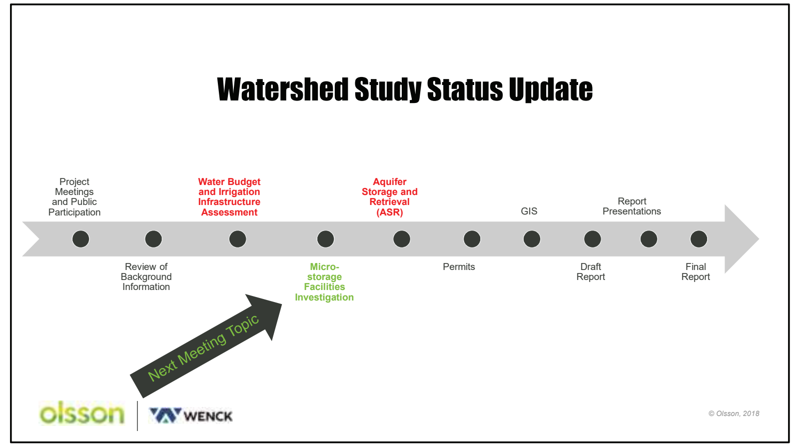
- Focus on shallow alluvial aquifer
- Used available pump test data to calculate groundwater flow rates
- Collected well data from SEO for 3-D aquifer characterization

Began evaluation of potential injection areas

- Current goal is to identify site that would provide an 8-month delay between injection and retrieval

Presenter – Karen Griffin for combined Wenck/Olsson effort
Major Points

- update on Wenck's hydrogeologic work



Presenter – Karen Griffin

Major Points

- Next meeting will be scheduled in the spring of 2019
- Topic will be micro-storage sites

MEETING MINUTES

	Overnight
	Regular Mail
	Hand Delivery
x	Other: Email

Popo Agie Watershed Study - Project Status Meeting

NAME OF PROJECT:	Popo Agie Watershed Study, Level I, Phase II
PROJECT LOCATION:	Lander, Wyoming
MEETING LOCATION:	Lander Community Center, 950 Buena Vista Dr
DATE & TIME:	June 25, 2019, 6:00 – 8:00 PM
PROJECT #:	018-2061

Attendees

NAME	ORGANIZATION (if noted)	EMAIL
Adam Keifeneheim	WDEQ Air Quality	adamkeifenheim@gmail.com
Barbara Speyer	Enterprise Irrigation	none
Bill Yankee	Enterprise Irrigation	LL77@wyoming.com
Bob Tipton	Healthy Rivers Initiative	tiptonwyo@gmail.com
Catherine Cannan	Wenck	ccannan@wenck.com
Cathy Rosenthal	WACD	cathyrosenthal@com
Chris Bove	NRCS	chris.bove@usda.gov
Dave Morneau	Popo Agie Conservation District	dcmorneau@wyoming.com
Deb Ohlinger	Olsson	dohlinger@olsson.com
Gerald MCasken	---	gmcaskey@hotmail.com
Ivan Laird	---	ivanlaird@gmail.com
Jake Hogan	NRCS – Douglas, WY Office	jake.hogan@usda.gov
Jen Lamb	The Nature Conservancy	jennifer_lamb@tnc.org
Jodee Pring	WY Water Development Office	jodee.pring@wyo.gov
Joe Kenney	KDLY Kove	Radio1@wyoming.com
Jon Crofts	---	---
Karen Griffin	Olsson	kgriffin@olsson.com
Kathi Wegner	---	---
Liz Kidner	---	lkidner@gmail.com
Mike Jensen	---	mjensen@strike-cg.com
Mike Jones	---	Mjones31957@gmail.com
Rajean Strube Fossen	City of Lander	rsfossen@landerwyoming.org
Ron Steg	WDEQ	ron.steg@wyo.gov
Ryan Mikesell	Wyoming State Engineer – Division 3	ryan.mikesell@wyo.gov
Steve Baumann	Fremont County Planning Department	steve.baumann@fremont county.wy.gov
Steve Dutcher	---	sdutcherwyo@gmail.com
Tim Wilson	---	twilson@wyoming.com
Tina Cunningham	---	tinajcunningham@gmail.com
Travis Shoopman	---	---

Meeting Minutes:

Welcome and Introductions

The meeting began with a welcome and introductions by RaJean Strube Fossen, of the City of Lander and Jennifer Lamb of The Nature Conservancy. They are filling in for Kelsey Beck, manager of the Popo Agie Conservation District (PACD) who is on maternity leave until mid-August. RaJean and Jenn thanked everyone for coming to the meeting. They described that the first part of the meeting is a Healthy Rivers Initiative (HRI) Working Group Meeting and the second part of the meeting is an update on the Wyoming Water Development Commission (WWDC) Watershed Study.

The following topics were discussed for the HRI Working Group Meeting:

HRI Working Group Agenda Topics

1. Funding Progress -
    a. $100k National Association of Conservation District's grant awarded to PACD which will allow all 8 of 8 Regional Conservation Partnership Program (RCPP) stream bank restoration sites to be engineered.
    b. RCPP update
2. Potential for Worthen Release for supplemental water this fall
    a. New Gauging locations in Basin Partnership with City and WY State Engineer's Office
    b. Parameters for release – Water supply, river level, irrigators voluntary
3. LOR programs
    a. Seepage Studies on Cemetery and Taylor ditches
    b. Purchase of Flowtracker for PACD use in the watershed
4. Outreach and communication
    a. WYO10 proposal
    b. Houlihan narratives and video promotions

Watershed Study Overview and Status Update

Karen Griffin of Olsson began with introductions of the project team including Deb Ohlinger, senior engineer on the project from Olsson, Catherine Cannan, lead hydrogeologist on the project from Wenck, and Jodee Pring of the Wyoming Water Development Office who is providing funding and project management for the watershed study.

Karen explained that this is the third meeting for the watershed study and the focus today is a description of two major topics of the project, Micro-storage and Aquifer Storage and Recovery or ASR. She provided a synopsis of the project scope and briefly described the timeline for the project. As the third project meeting, this is the time for the project team to describe the initial sites identified for micro-storage and for ASR. The information on micro-storage was presented by Deb Ohlinger and on ASR by Catherine Cannan. The highlights of the project status update are included in the attached PowerPoint presentation.

After the presentation an interactive Q&A continued the conversation and the team answered questions from the meeting attendees. Some of the questions/comments included:

- The ASR may need to provide more water to the river to be cost effective. It was noted that additional wells or infiltration areas could be added to enlarge the system.
- A question was raised about whether this study and the current WWDC project on an additional water supply well for the City of Lander overlap. Karen noted that the two consulting teams have been in contact throughout the projects to ensure that efforts are not being duplicated and that information is shared where appropriate.
- A question was raised about how one knows where the groundwater flows. Catherine noted that monitoring wells can be used to document groundwater flow direction and speed.
- A request was made to provide a link to the HRI Houlihan narratives mentioned in the HRI working group update and so the following link is provided to watch the videos:

  https://drive.google.com/file/d/1IQK6s2HQBN_7slmFy-Djbg7q3ag2MM92/view

- Additional information about this and other HRI meetings is available on the PACD website: www.popoagie.org

The next watershed meeting will be schedule in the September 2019 and the meeting will include a synopsis of the watershed study results and recommendations.

Attachment – PowerPoint presentation

Popo Agie Level I Watershed Study, Phase II

Project Meeting

June 25, 2019

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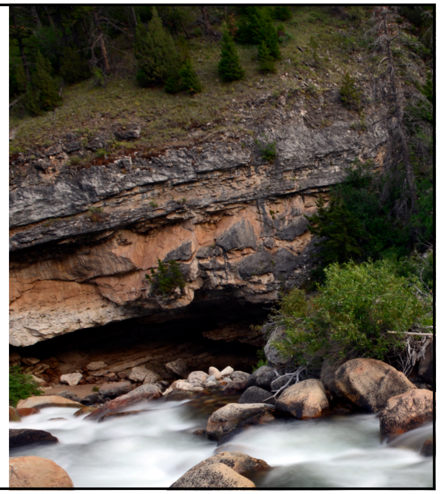
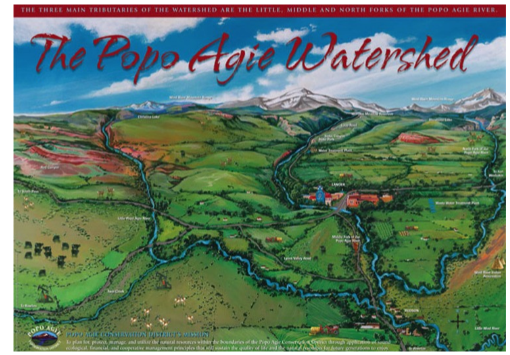


WELCOME!

Meeting Topics

1. Introductions
2. Watershed Study Status Update
   - Micro-storage
   - Aquifer Storage and Recovery
3. Q&A
4. What's next?



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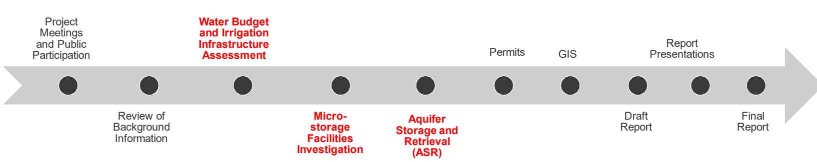
Watershed Study Status Update



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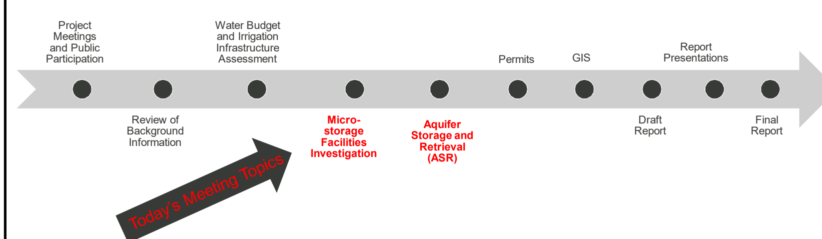
Watershed Study Status Update



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MICRO-STORAGE ASSESSMENT

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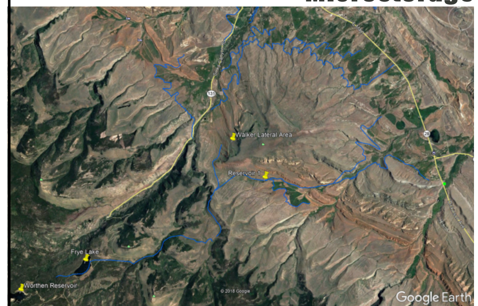
Microstorage



Water availability

- Water is available in May and June on all three branches
- For 100-acre hay field, need approximately 150 acre-feet plus additional for transmission loss to satisfy August irrigation need
- Overall watershed examined

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Microstorage

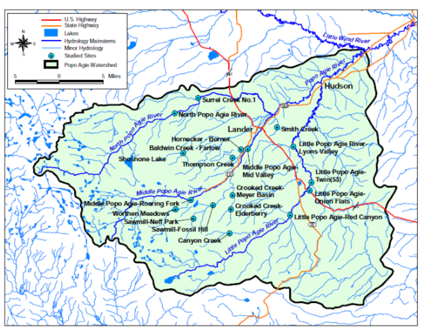

Figure 7.6 Reservoir Sites Included in Popo Agie River Watershed Study.

Two groups of locations

- 2003 Level I Study long list (18)
- New sites (22)

Compiled Information

- Tributary areas ⟶ available flow
- Other parameters – irrigation, land ownership, geology, wetlands

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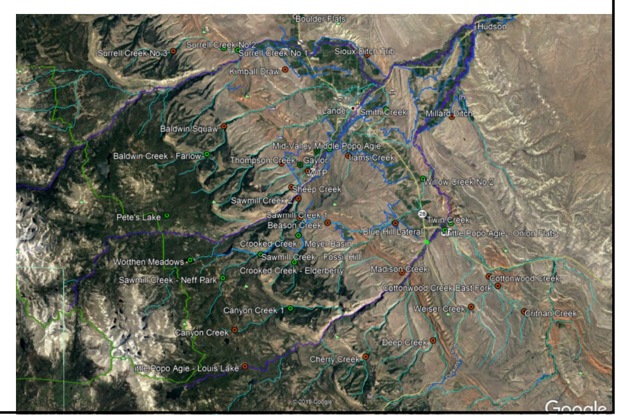
Microstorage

Exclusions (general)

- Wilderness area
- Mainstem storage
- Existing reservoirs
  - (Worthen included)
- Oxbows in lower Popo Agie



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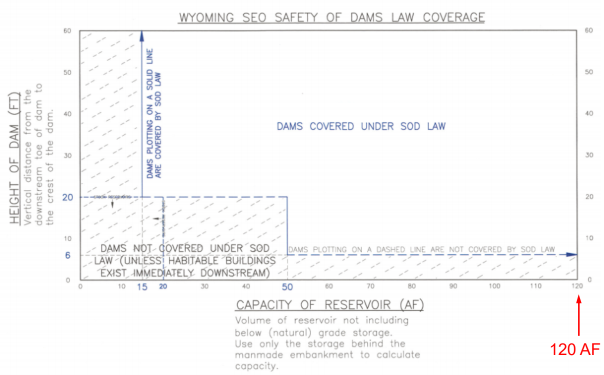
Microstorage



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Microstorage

Table 1. Potential Micro-Storage Sites, Previously Identified in 2003 Level I Report

	Site Name	Source	Trib. Area, mi^2	Ownership	Available Flow, acre-feet: Normal Year May	Normal Year June	Normal Year May + June	Dry Year May	Dry Year June	Dry Year May + June
North	Surrel Creek No. 1	North Popo Agie	12.2	Wind River Reservation, Private	1,113	2,222	3,335	567	472	1,039
North	Surrel Creek No. 2	North Popo Agie	12.2	Wind River Reservation	1,113	2,222	3,335	567	472	1,039
Middle	Baldwin - Farlow	Baldwin Creek	13.3	Private, BLM	692	1,431	2,123	370	336	706
Middle	Crooked Creek - Elderberry	Crooked Creek	4.1	National Forest	761	1,500	2,262	437	427	865
Middle	Crooked Creek - Meyer Basin	Crooked Creek	6.3	Private, BLM	1,166	2,298	3,464	670	655	1,325
Middle	Homecker - Borner (MPA diversion)	Middle Popo Agie	87.5	Private	4,567	9,439	14,006	2,442	2,217	4,659
Middle	Homecker - Borner (tributaries)	Middle Popo Agie	9.7	Private	504	1,042	1,546	270	245	514
Middle	Middle Popo Agie - Mid Valley	Middle Popo Agie	131.2	Private, State	6,850	14,158	21,007	3,663	3,326	6,989
Middle	Pete's Lake	Un-named	1.2	National Forest	219	432	652	126	123	249
Middle	Sawmill Creek - Neff Park	Sawmill Creek	7.1	National Forest	1,329	2,618	3,947	764	746	1,509
Middle	Sawmill Creek - Fossil Hill	Sawmill Creek	17.8	National Forest	3,308	6,519	9,827	1,901	1,857	3,758
Middle	Smith Creek	Middle Popo Agie	3.0	State	154	318	472	82	75	157
Middle	Thompson Creek (divert from MPA)	Middle Popo Agie	114.1	Private	5,953	12,303	18,256	3,183	2,890	6,073
Middle	Worthen Meadows Reservoir	Roaring Fork	13.0	National Forest	2,416	4,762	7,178	1,389	1,357	2,745
Little	Canyon Creek 1	Canyon Creek	6.8	National Forest	731	1,109	1,839	506	474	980
Little	Little Popo Agie - Onion Flats	Little Popo Agie	9.7	BLM, Private	275	528	804	170	221	390
Little	Onion Flats - from Devils Creek	Devils Creek	9.7	BLM, Private	275	528	804	170	221	390
Little	Twin Creek	Little Popo Agie	114.5	Private	3,263	6,262	9,525	2,010	2,614	4,624
Little	Willow Creek No. 2	Willow Creek	29.2	Private	832	1,596	2,427	512	666	1,178

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Microstorage

Table 2. Potential Micro-Storage Sites, Newly Identified

	Site Name	Source	Trib. Area, mi^2	Ownership	Available Flow, acre-feet: Normal Year May	Normal Year June	Normal Year May + June	Dry Year May	Dry Year June	Dry Year May + June
North	Kimball Draw	Kimball Draw	0.8	Private	75	150	226	38	32	70
North	Sioux Ditch Trib	Trib. to North Popo Agie	0.4	Trust for Tribes of the Wind	20	42	62	11	10	21
North	Surrell Creek No 3	Surrell Creek	4.9	Wind River Reservation	450	898	1,348	229	191	420
Middle	Baldwin/Squaw	Baldwin/Squaw Creek	16.0	BLM	837	1,729	2,566	447	406	853
Middle	Sawmill Creek 1	Sawmill Creek	28.1	BLM, Private	5,232	10,311	15,543	3,007	2,937	5,944
Middle	Sawmill Creek 2	Sawmill Creek	28.9	State, Private	5,376	10,595	15,971	3,089	3,018	6,107
Middle	Sheep Creek	Sheep Creek	3.0	State, Private	156	322	477	83	76	159
Middle	Thompson Creek - Gaylor	Thompson Creek	0.5	Private	27	55	81	14	13	27
Middle	WTP @ Gravel Pit (Minimum Size)	Div. from Middle Popo Agie	87.5	State	16,278	32,079	48,357	9,354	9,138	18,492
Middle	WTP @ Gravel Pit (Maximum Size)	Div. from Middle Popo Agie	98.4	State	16,278	32,079	48,357	9,354	9,138	18,492
Little	Beason Creek	Beason Creek	2.1	Private, State	60	114	174	37	48	84
Little	Blue Hill Lateral	Trib near Blue Hill Lateral	0.5	Private	15	30	45	9	12	22
Little	Canyon Creek	Canyon Creek	0.8	National Forest	83	127	210	58	54	112
Little	Cherry Creek	Cherry Creek	6.0	Nature Conservancy	644	977	1,621	446	418	864
Little	Cottonwood Creek	Cottonwood Creek	23.3	Private	665	1,276	1,941	410	533	942
Little	Cottonwood Creek East Fork	Cottonwood Creek East Fork	29.8	Private, Nature Conservancy	850	1,631	2,480	523	681	1,204
Little	Critnan Creek	Critnan Creek	2.3	Private	66	127	193	41	53	93
Little	Deep Creek	Deep Creek	5.7	Nature Conservancy	617	936	1,553	427	400	827
Little	Iiams Creek	Iiams Creek	0.6	Private, State	16	31	46	10	13	23
Little	Little Popo Agie - Louis Lake	Little Popo Agie	19.9	National Forest	2,142	3,250	5,393	1,483	1,390	2,873
Little	Madison Creek	Madison Creek	4.8	Private	512	777	1,289	355	332	687
Little	Millard Ditch	Trib US of Millard Ditch	1.9	Private	54	104	158	33	43	77
Little	Weiser Creek	Weiser Creek	3.8	Wind River Reservation	109	210	319	67	88	155

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Microstorage

Refined Sites

- Eliminated sites with <100 acre-feet of available water
- Eliminated 2 sites for road and house proximity
- Determined dam geometry and potential storage
- Developed estimated costs
- Ranked sites

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Microstorage

Assumptions

- Achieved 300 acre-feet of storage for flexibility
- 5 feet of freeboard required per SEO Safety of Dams law
- Embankment volume based on 300 acre-feet plus 5 feet of freeboard, also estimated for 150 acre-feet of storage – relative comparison for rankings
- Cost = $15/cubic yard, consistent with Anderson and previous studies
- Overall costs for 300 acre-feet: $50,000 - $14M; most $2M or less

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Microstorage

Table 1. Potential Micro-Storage Sites, Previously Identified in 2003 Level I Report

					Dam and Reservoir Information for 300 acre-feet of storage									
					300 acre-feet of storage					150 acre-feet of storage (approximate values)				
	Site Name	Source	Trib. Area, mi^2	Ownership	Dam height, feet	Dam height plus 5 feet of freeboard, feet	Surface area, acres	Dam volume, cubic yards	Cost @ $15/cubic yard	Dam height plus 5 feet of freeboard	Height difference	Approx. area (volume) difference	Approx. dam volume, cubic yards	Cost @ $15/cubic yard
North	Surrel Creek No. 1	North Popo Agie	12.2	Wind River Reservation, Private	54	59	13	117,976	$1,769,641	42	1	1	63,199	$947,984
North	Surrel Creek No. 2	North Popo Agie	12.2	Wind River Reservation	44	49	23	112,463	$1,686,943	40	1	1	76,269	$1,144,042
Middle	Baldwin - Farlow	Baldwin Creek	13.3	Private, BLM	50	55	12	101,668	$1,525,022	39	1	1	55,169	$827,537
Middle	Crooked Creek - Elderberry	Crooked Creek	4.1	National Forest	54	54	12	131,444	$1,971,660	49	1	1	107,260	$1,608,906
Middle	Crooked Creek - Meyer Basin	Crooked Creek	6.3	Private, BLM	52	57	14	91,148	$1,367,220	39	1	0	44,572	$668,573
Middle	Hornecker - Borner (MPA diversion)	Middle Popo Agie	87.5	Private	21	26	25	117,928	$1,768,923	18	1	1	58,999	$884,992
Middle	Hornecker - Borner (tributaries)	Middle Popo Agie	9.7	Private	21	26	25	117,928	$1,768,923	18	1	1	58,999	$884,992
Middle	Middle Popo Agie - Mid Valley	Middle Popo Agie	131.2	Private, State	9	14	45	71,142	$1,067,130	14	1	1	68,268	$1,024,018
Middle	Pete's Lake	Un-named	1.2	National Forest	6	11	58	8,251	$123,758	8	1	1	4,801	$72,012
Middle	Sawmill Creek - Neff Park	Sawmill Creek	7.1	National Forest	0	0	0	0	$0	0	0	0	0	$0
Middle	Sawmill Creek - Fossil Hill	Sawmill Creek	17.8	National Forest	34	39	16	43,501	$652,520	23	1	0	15,772	$236,580
Middle	Smith Creek	Middle Popo Agie	3.0	State	15	20	40	35,566	$533,485	12	1	0	14,719	$220,779
Middle	Thompson Creek (divert from MPA)	Middle Popo Agie	114.1	Private	0	0	0	0	$0	0	0	0	0	$0
Middle	Worthen Meadows Reservoir	Roaring Fork	13.0	National Forest	0	0	0	0	$0	0	0	0	0	$0
Little	Canyon Creek 1	Canyon Creek	6.8	National Forest	38	43	15	116,628	$1,749,415	24	1	0	36,475	$547,126
Little	Little Popo Agie - Onion Flats	Little Popo Agie	9.7	BLM, Private	29	34	42	29,019	$435,281	27	1	1	19,833	$297,490
Little	Onion Flats - from Devils Creek	Devils Creek	9.7	BLM, Private	29	34	42	29,019	$435,281	27	1	1	19,833	$297,490
Little	Twin Creek	Little Popo Agie	114.5	Private	20	25	31	22,570	$338,555	19	1	1	13,969	$209,536
Little	Willow Creek No. 2	Willow Creek	29.2	Private	18	23	42	22,381	$335,708	18	1	1	14,365	$215,480

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Microstorage

Table 2. Potential Micro-Storage Sites, Newly Identified

					Dam and Reservoir Information for 300 acre-feet of storage									
					300 acre-feet of storage					150 acre-feet of storage (approximate values)				
	Site Name	Source	Trib. Area, mi^2	Ownership	Dam height, feet	Dam height plus 5 feet of freeboard, feet	Surface area, acres	Dam volume, cubic yards	Cost @ $15/cubic yard	Dam height plus 5 feet of freeboard	Height difference	Approx. area (volume) difference	Approx. dam volume, cubic yards	Cost @ $15/cubic yard
North	Kimball Draw	Kimball Draw	0.8	Private										
North	Sioux Ditch Trib	Trib. to North Popo Agie	0.4	Trust for Tribes of the Wind										
North	Surrell Creek No 3	Surrell Creek	4.9	Wind River Reservation	81.5	86.5	8.4	357,462	$5,361,926	62.1	72%	55%	195,379	$2,930,686
Middle	Baldwin/Squaw	Baldwin/Squaw Creek	16.0	BLM	82.0	87.0	9.1	234,687	$3,520,305	66.7	77%	62%	145,010	$2,175,145
Middle	Sawmill Creek 1	Sawmill Creek	28.1	BLM, Private	90.2	95.2	9.5	105,987	$1,589,808	75.0	79%	65%	68,793	$1,031,901
Middle	Sawmill Creek 2	Sawmill Creek	28.9	State, Private	87.1	92.1	8.8	963,521	$14,452,813	71.3	77%	63%	605,846	$9,087,695
Middle	Sheep Creek	Sheep Creek	3.0	State, Private	89.9	94.9	9.4	745,791	$11,186,858	74.5	78%	64%	479,995	$7,199,931
Middle	Thompson Creek - Gaylor	Thompson Creek	0.5	Private										
Middle	WTP @ Gravel Pit (Minimum Size)	Div. from Middle Popo Agie	87.5	State	4.0	6.0	0.8	3,217	$48,252	---	---	---	---	---
Middle	WTP @ Gravel Pit (Maximum Size)	Div. from Middle Popo Agie	98.4	State	37.0	6.0	0.8	3,217	$48,252	42.0	---	---	424,900	$6,373,500
Little	Beason Creek	Beason Creek	2.1	Private, State										
Little	Blue Hill Lateral	Trib near Blue Hill Lateral	0.5	Private										
Little	Canyon Creek	Canyon Creek	0.8	National Forest	34.1	39.1	19.2	68,561	$1,028,413	29.2	75%	59%	40,221	$603,312
Little	Cherry Creek	Cherry Creek	6.0	Nature Conservancy	31.7	36.7	24.8	95,636	$1,434,543	28.1	77%	62%	58,828	$882,414
Little	Cottonwood Creek	Cottonwood Creek	23.3	Private	26.2	31.2	28.1	55,165	$827,469	26.0	84%	72%	39,608	$594,121
Little	Cottonwood Creek East Fork	Cottonwood Creek East Fork	29.8	Private, Nature Conservancy	37.7	42.7	23.8	41,337	$620,056	34.7	81%	68%	28,209	$423,129
Little	Critnan Creek	Critnan Creek	2.3	Private										
Little	Deep Creek	Deep Creek	5.7	Nature Conservancy	94.2	99.2	9.1	325,367	$4,880,505	77.8	78%	64%	209,359	$3,140,384
Little	Iiams Creek	Iiams Creek	0.6	Private, State										
Little	Little Popo Agie - Louis Lake	Little Popo Agie	19.9	National Forest	13.2	18.2	36.9	44,887	$673,306	13.4	74%	58%	25,813	$387,190
Little	Madison Creek	Madison Creek	4.8	Private	N/A	N/A	9.8	16,481	$247,217	26.0	0%	0%	16,481	$247,217
Little	Millard Ditch	Trib US of Millard Ditch	1.9	Private										
Little	Weiser Creek	Weiser Creek	3.8	Wind River Reservation	40.4	45.4	20.2	87,441	$1,311,617	34.1	75%	59%	51,889	$778,333

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Microstorage

Ranking

- Property ownership considered two ways, state and private scores
- Consideration – eliminate some categories? Change weighting?
- Divided into three groups for visual ranking

Criteria	Weight
Water Availability	2
Beneficial Uses	2
Cost	2
Proximity to Irrigation	1
Proximity to Structures	1
Property Ownership	1
Bedrock Geology	1
Wetlands	1

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Microstorage

- Worthen Meadows Reservoir not evaluated in this manner but recommended for advancement and evaluation with other ongoing studies
- Water Treatment Plant
  - Minimum size to accommodate 400,000 gallons/day (1.2 acre-feet)
  - Maximum size on site (up to 440 acre-feet)

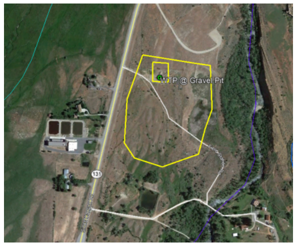

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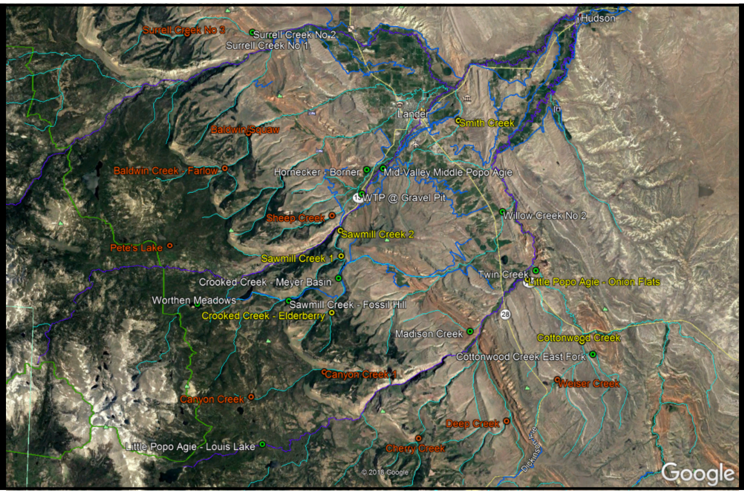
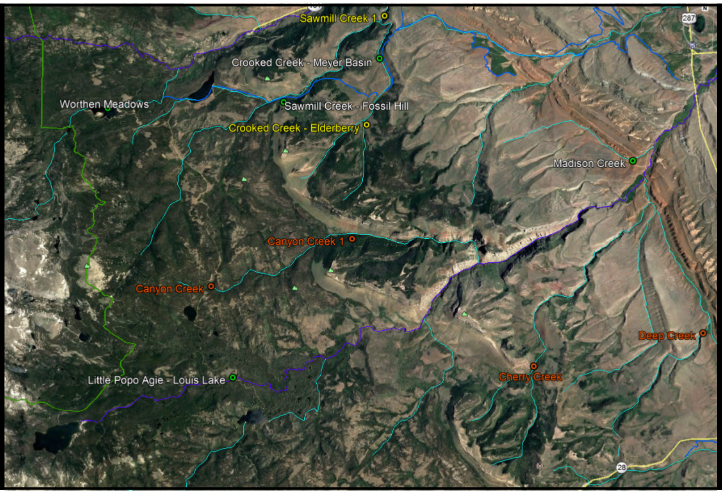
Table 5. Ranking of Micro-Storage Sites using Original Property Ownership Criteria

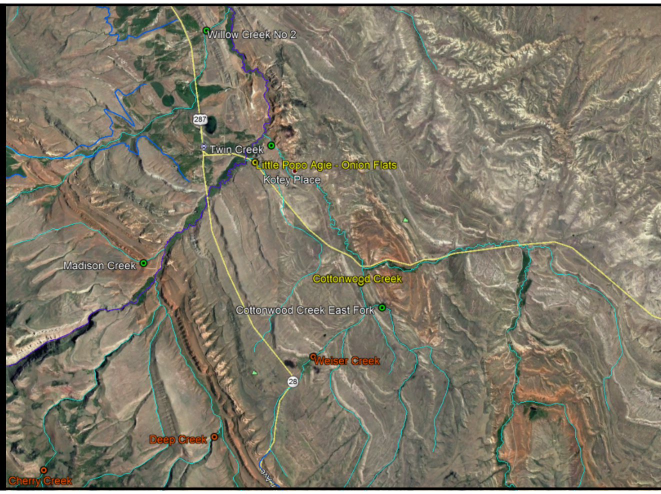
Evaluation Criteria using Original Property Ownership

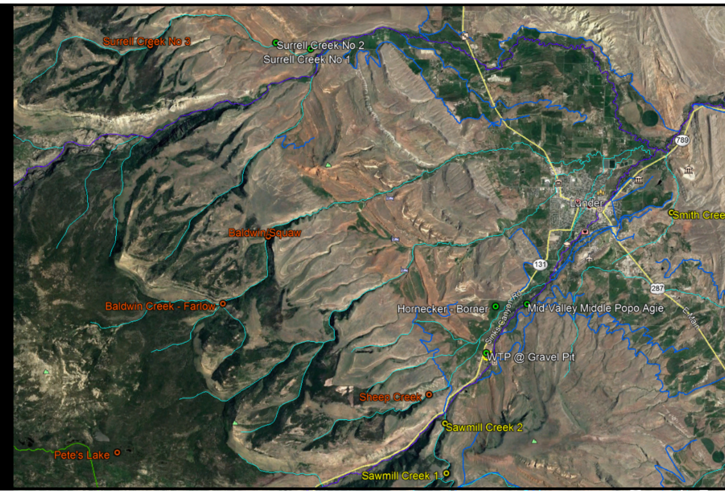
1 = Poor score, 3 = High score

Site Name	Branch	Water Availability*	Beneficial Uses*	Cost*	Proximity to Irrigation	Proximity to Structures	Property Ownership (Original)	Bedrock Geology	Wetlands	Total
Willow Creek No. 2	L	3	2	3	3	2	3	3	3	30
Twin Creek	L	3	2	3	3	1	3	3	3	29
Sawmill Creek - Fossil Hill	M	3	3	3	1	3	1	3	2	28
WTP @ Gravel Pit (Minimum Size)	M	3	3	3	3	1	2	3	1	28
Surrel Creek No. 1	N	3	3	2	3	1	1	3	3	27
Crooked Creek - Meyer Basin	M	3	3	2	1	3	1	3	3	27
Hornecker - Borner (MPA diversion)	M	3	3	2	3	1	3	3	1	27
Little Popo Agie - Louis Lake	L	3	3	3	1	3	1	3	1	27
Surrel Creek No. 2	N	3	3	2	2	1	1	3	3	26
Middle Popo Agie - Mid Valley	M	3	3	2	3	1	2	3	1	26
Cottonwood Creek East Fork	L	3	1	3	3	2	2	3	2	26
Madison Creek	L	2	2	3	2	1	3	3	3	26
Hornecker - Borner (tributaries)	M	2	3	2	3	1	3	3	1	25
Sawmill Creek 1	M	3	3	2	1	3	1	1	3	25
Sawmill Creek 2	M	3	3	1	2	1	2	3	3	25
Cottonwood Creek	L	2	1	3	3	1	3	3	3	25
Smith Creek	M	1	2	3	3	2	2	3	2	24
WTP @ Gravel Pit (Maximum Size)	M	3	3	1	3	1	2	3	1	24
Crooked Creek - Elderberry	M	2	3	2	1	3	1	1	3	23
Little Popo Agie - Onion Flats	L	1	2	3	3	1	1	3	3	23
Onion Flats - from Devils Creek	L	1	2	3	3	1	1	3	3	23
Baldwin - Farlow	M	2	2	2	1	1	1	3	3	21
Canyon Creek 1	L	2	1	2	1	3	1	3	3	21
Surrell Creek No 3	N	1	3	1	1	3	1	3	3	21
Sheep Creek	M	1	3	1	2	1	2	3	3	21
Cherry Creek	L	2	1	2	1	3	2	3	1	20
Pete's Lake	M	1	1	3	1	3	1	3	1	19
Deep Creek	L	2	1	1	2	2	2	3	2	19
Baldwin/Squaw	M	2	2	1	1	1	1	1	3	17
Canyon Creek	L	1	1	2	1	3	1	3	1	17
Weiser Creek	L	1	1	2	1	1	1	1	2	14

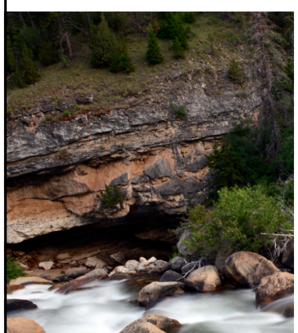








Next Steps



- Incorporate feedback
- Document in report

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AQUIFER STORAGE AND RECOVERY

Preliminary Results/Discussion

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Outline

General Approach

- Types of ASR
- Locations
- Aquifers

Selection Criteria

- Regulatory
- Operational
- Hydrogeologic
- Cost

Next Steps

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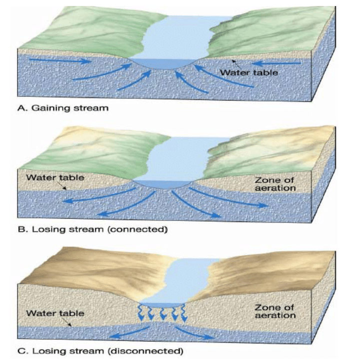
General Approach



Pearson Education, Inc., 2014

Types of ASR

- Traditional, injection and passive recovery, infiltration basin

Location

- Middle Fork Popo-Agie, South Fork, North Fork

Aquifer

- Alluvial, Tensleep, Flathead

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Regulatory

DEPARTMENT OF ENVIRONMENTAL QUALITY WYOMING

Permitting

- Underground Injection Control Class V Well

Water Quality

- Class I Water Quality Standards
- No contaminants of concern

Impact on Species

- Avoid protected habitat areas
- Positive impact on river species

Impact on Infrastructure

- No impact on homes or roads

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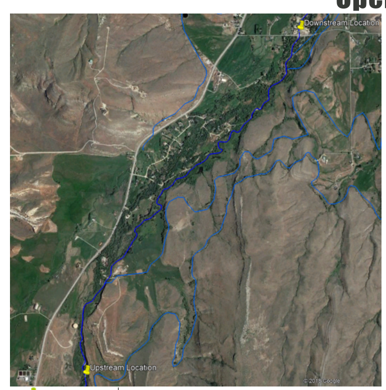
Operational



Well Proximity

- Avoid building near or upgradient of production wells

Distance from Source

- Build near river

Distance from Destination

- Build near water treatment plant or Mortimore Lane bridge

Water Supply

- Excess water during high flows

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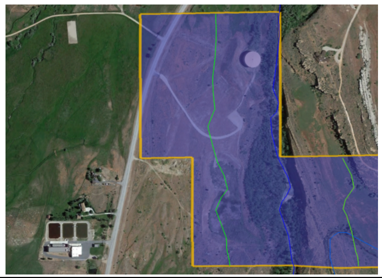
Hydrogeologic



Transmissivity

- Between 5580 and 1085 ft^2 per day
- Upstream within acceptable range

Distance to River

- Travel time of 3.1 to 0.28 ft/day, storage for 6 months

Storage Zone Thickness

- Water level approximately 19 ft. b.g.s

Injection Capacity

- Lower in Spring- 400,000 gallons per day

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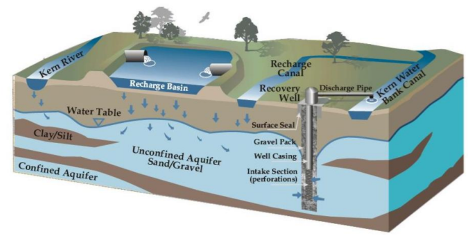
Cost



Well Installation

- For traditional wells and injection with passive recovery
- Deeper well costs 8 times more

Water Collection and Discharge Pipes

- For wells and recharge basins
- Cost depends on location

Operation and Maintenance

- For all options
- Traditional ASR well as the most expensive

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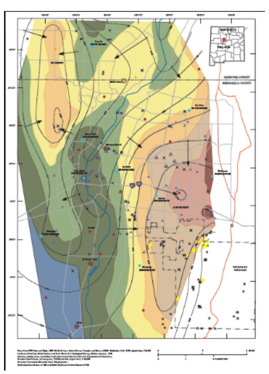
Next Steps



Water Levels

- Collect seasonal data

Groundwater Gradient

- Collect data at multiple locations

Test Boreholes

- Investigate lithology

Re-visit other options

- Traditional ASR on treatment plant property
- Recharge/Settling basin
- Existing ditches

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Questions?

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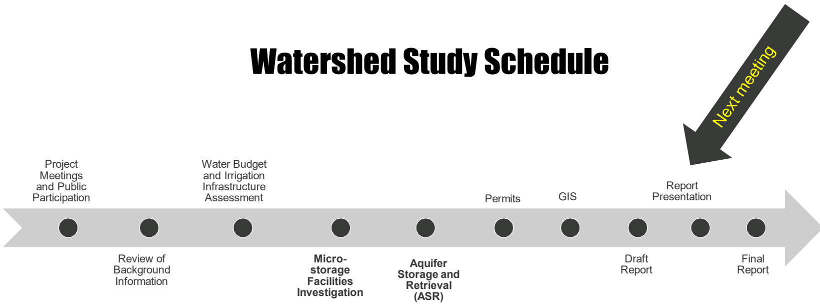
Watershed Study Schedule



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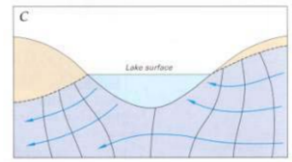
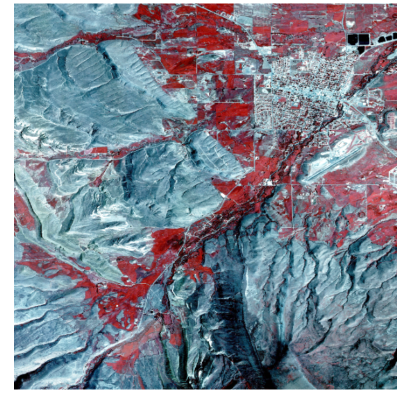
Supplementary Slides





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MEETING MINUTES

	Overnight
	Regular Mail
	Hand Delivery
x	Other: Email

Popo Agie Watershed Study – Draft Report Presentation Mtg

NAME OF PROJECT:	Popo Agie Watershed Study, Level I, Phase II
PROJECT LOCATION:	Lander, Wyoming
MEETING LOCATION:	Lander Community Center, 950 Buena Vista Dr
DATE & TIME:	October 29, 2019, 6:00 – 8:00 PM
PROJECT #:	018-2061

Attendees*

NAME	ORGANIZATION (if noted)	EMAIL
Barbara Speyer	Enterprise Irrigation	none
Bill Lee	---	Bslee35@gmail.com
Bob Tipton	HRI	tiptonwyo@gmail.com
Brandon Reynolds	---	---
Caryn Throop	---	carynthroop@gmail.com
Chris Bove	NRCS	chris.bove@usda.gov
Dave Peterson	---	dpeterse@wyoming.com
Deb Ohlinger	Olsson – Via teleconference	dohlinger@olsson.com
Dennis VanDenbags	---	dennis@dgvan.us
Don Reynolds	---	---
Doug Anesi	---	danesi@wyoming.com
Eva Crane	---	evacrane@wyoming.com
Gary Trantman	---	gtrantman@wyoming.com
Gerald MCasken	---	gmcaskey@hotmail.com
Ivan Laird	---	ivanlaird@gmail.com
Jean Armstrong	---	---
Jeff Hermansky	---	---
Jen Lamb	The Nature Conservancy	jennifer_lamb@tnc.org
Jim Corbett	---	---
Joanne Harter	Wyoming Game and Fish	joanna.harter1@wyo.gov
Jodee Pring	WY Water Development Office	jodee.pring@wyo.gov
Joe Kenney	KDLY Kove	Radio1@wyoming.com
John Burrows	---	---
Karen Griffin	Olsson – Via teleconference	kgriffin@olsson.com
Kelsey Beck	PACD	kbeck@pacd.org
Mark Hogan	U.S. Fish and Wildlife Service	mark_j_hogan@fws.gov
Mark Moxly	---	mgdmosly@gmail.com
Marty Jones	Wenck – via teleconference	mjones@wenck.com
Mary Jones	---	---
Patty Trantman	---	---
Paula McCormick	---	paulamccg@gmail.com
Rajean Strube Fossen	City of Lander	rsfossen@landerwyoming.org
Scott Harnsberger	---	---
Scott Simms	---	---
Sharon Corbett	---	---
Steve Baumann	Fremont County Planning Department	steve.b@fremont county.wy.gov
Thomas Jones	---	---
Tina Cunningham	---	tinajcunningham@gmail.com

* note there were 41 people counted at the meeting, only 35 signed in.

Meeting Minutes:

Welcome and Introductions

The meeting began with a welcome and introductions by Kelsey Beck, Manager of the Popo Agie Conservation District (PACD). Kelsey thanked everyone for coming to the meeting, especially because of the weather. She explained that because of the weather, the Olsson/Wenck project team will be participating via teleconference. They described that the first part of the meeting is a Healthy Rivers Initiative (HRI) Working Group Meeting followed by the final project meeting for the Wyoming Water Development Commission (WWDC) Watershed Study.

The following summarizes the topics discussed during the presentation on the Popo Agie Watershed Study:

Karen Griffin, Project Manager from Olsson began with introductions of the project team including Deb Ohlinger, senior engineer on the project from Olsson, Marty Jones lead engineer on the project from Wenck. Karen explained that this is the final meeting for the watershed study and the presentation today provides the draft results and recommendations presented in the Draft Watershed Study Report. The attached PowerPoint presentation includes the slides shown at the meeting. The main topics discussed included:

1. Watershed Study Methods and Results
    - Water Budget
    - Irrigation Infrastructure
    - Microstorage
    - Aquifer Storage and Recovery
2. Watershed Study Recommendations
3. What's next?

Specific questions asked by the attendees included:

- Are there any recreational benefits for the microstorage sites? The response was that there may be based on the location and size although the recreational benefits were not analyzed as part of this study.
- There was a question whether the size of Worthen Reservoir needed to be increased. Rajean from the City explained that there is another consultant conducting a study for the City. The reservoir could hold more water without increasing the size but further evaluations of the reservoir are underway.
- Will the public be able to access the final report? Kelsey noted that when the final report is complete, it will be available in hard copy at the Conservation District office and Jodee Pring from WWDC said that an electronic copy will be available for download from the WWDC website. http://wwdc.state.wy.us/
- Will the HRI group prioritize projects for funding application to WWDC? Yes, with input from project participants.
- Were sites in the North Fork of the Popo Agie River Watershed evaluated? Deb Ohlinger responded that yes, sites in all three sub-watersheds were evaluated for microstorage and water budget. The Middle Fork was the focus for irrigation and ASR due to landowner requests and data availability.

Attachment – PowerPoint presentation

Popo Agie Level I Watershed Study, Phase II

Project Meeting

October 29, 2019

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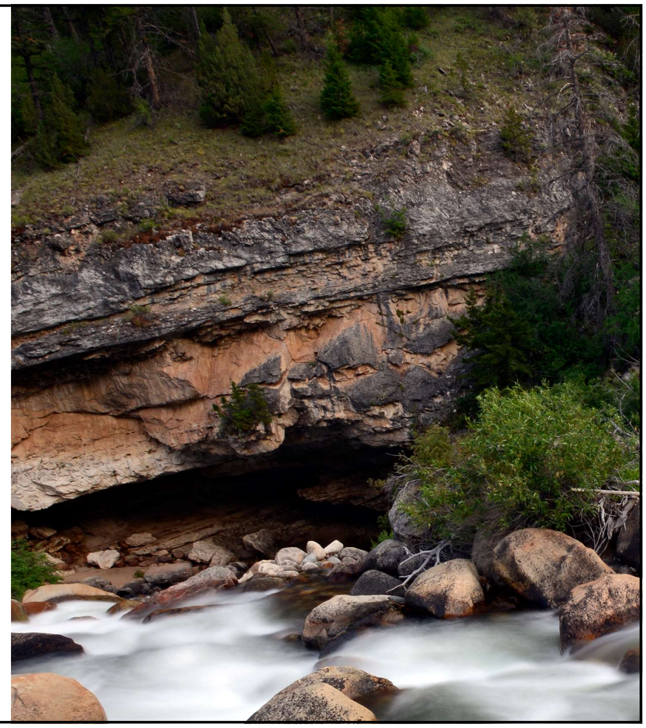
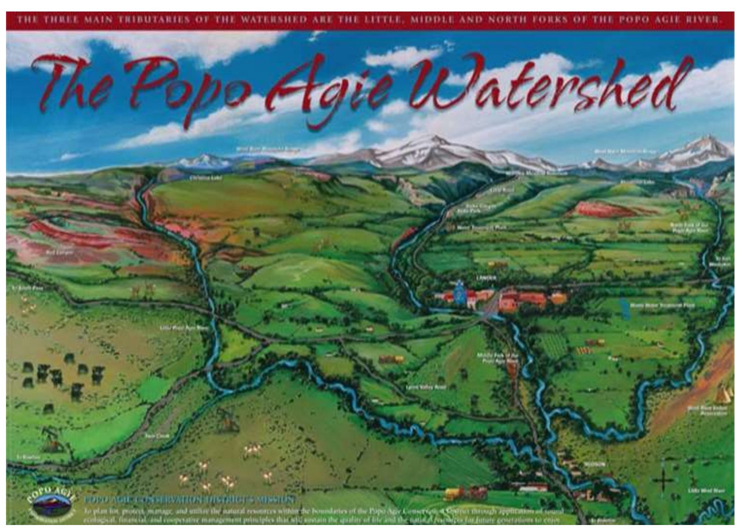


1

WELCOME!

Meeting Topics

1. Watershed Study Methods and Results
    - Water Budget
    - Irrigation Infrastructure
    - Micro-storage
    - Aquifer Storage and Recovery
2. Watershed Study Recommendations
3. What's next?



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Water Budget

Methods and Results

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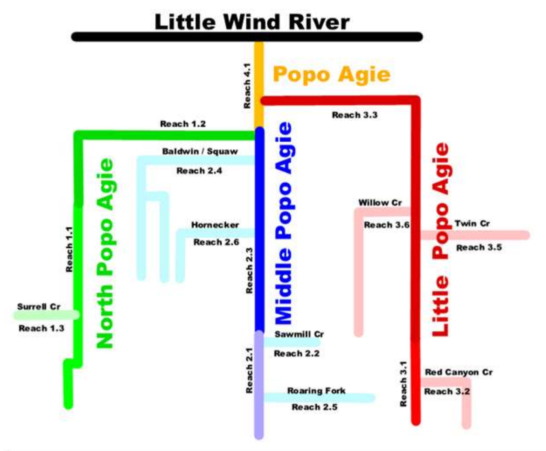
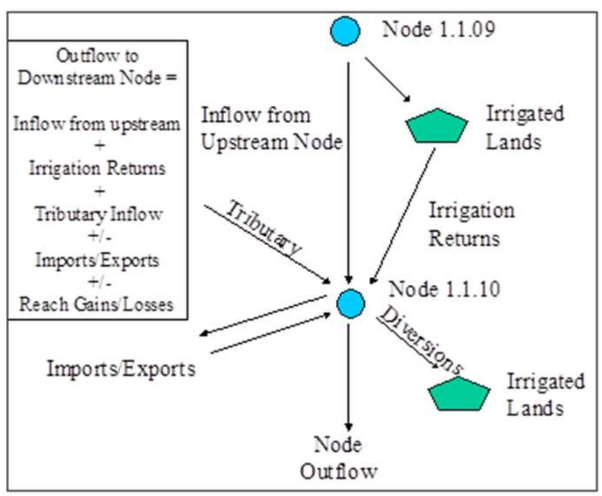


Figure 6.2 Popo Agie River Model Reach Diagrams.



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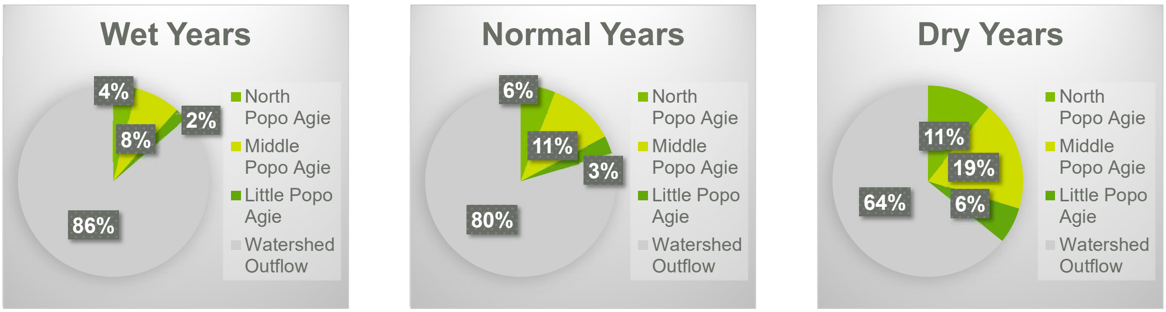
Total Annual Diversions vs Watershed Outflow



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Model Outflows Summarized by Reach

Normal				(Average Daily cfs)											
	Reach	Node	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North	Reach 1.1	1.1.26	USGS 06232500	23	26	36	46	203	405	163	35	28	46	38	24
	Reach 1.2	1.2.16	North Popo Agie Outflow	23	26	36	44	201	406	168	46	41	54	41	24
Middle	Reach 2.1	2.1.12	USGS 06231600	36	38	49	58	269	530	239	73	55	65	55	40
	Reach 2.3	2.3.38	Cemetery	60	62	81	69	289	567	183	7	25	72	89	67
	Reach 2.3	2.3.44	Conf Middle and North Popo Agie	90	95	127	128	538	1,067	414	95	98	145	141	100
Little	Reach 3.1	3.1.10	Little Popo Agie North Fork	28	27	37	37	164	247	105	43	39	42	37	31
	Reach 3.3	3.3.30	USGS Gage 06233500	45	44	59	66	179	345	157	53	54	68	58	51
Big	Reach 4.1	4.1.18	USGS Gage 06233900 - End	98	101	135	243	704	1,260	572	173	137	141	139	108

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Losses due to Inefficiencies in Conveyance and Application

Diversion Ditch	Total Diversion Volume (acre-feet)	Total Conveyance Losses (acre-feet)	Total Application Losses (acre-feet)	Total Combined Losses (acre-feet)	Combined Average Daily Losses (cfs)
Enterprise – Sawmill	8,182	3,682	2,743	6,425	26.6
Gaylor and Warnock	3,332	1,333	1,117	2,450	10.1
Scott	191	77	64	141	0.6
Hornecker, Swamp and Melon	1,763	705	591	1,296	5.4
Meyer	724	290	243	533	2.2
Nicol and Table Mountain	9,553	3,821	3,068	6,889	28.5
Meadow, Cottonwood, and Island	1,511	604	507	1,111	4.6
Baldwin	2,567	1,027	861	1,888	7.8
Dutch Flat / Taylor	7,804	1,561	2,617	4,178	17.3
Cemetery	3,311	728	1,110	1,838	7.6
Last and Forrest	319	128	107	235	1
AggDev BC-1	4,799	1,919	1,609	3,528	14.6
Enterprise - Roaring Fork	8,346	3,339	2,799	6,138	25.4
Sandstone et al.	3,882	1,553	1,302	2,855	11.8

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Losses are over a 4-month irrigation season (Normal Years)

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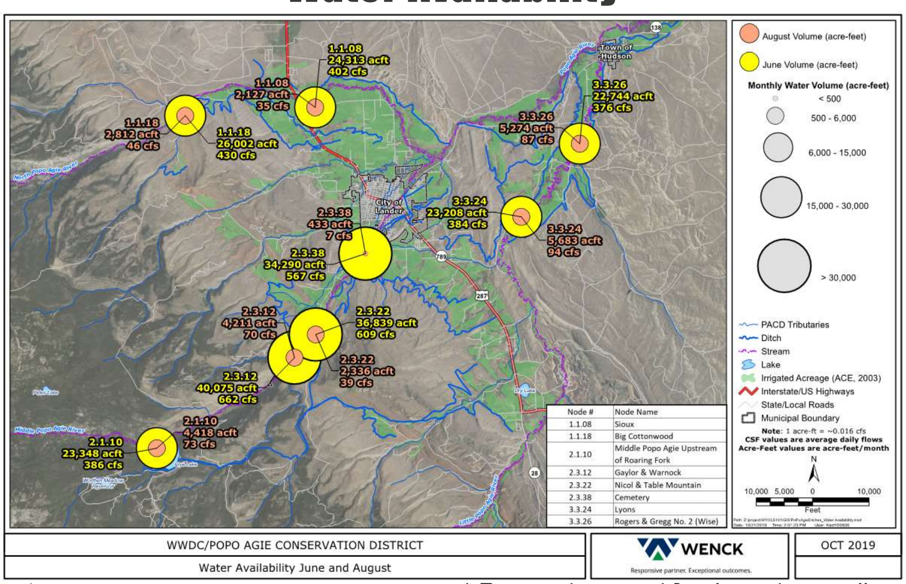
Water Availability



* Does not account for downstream allocations

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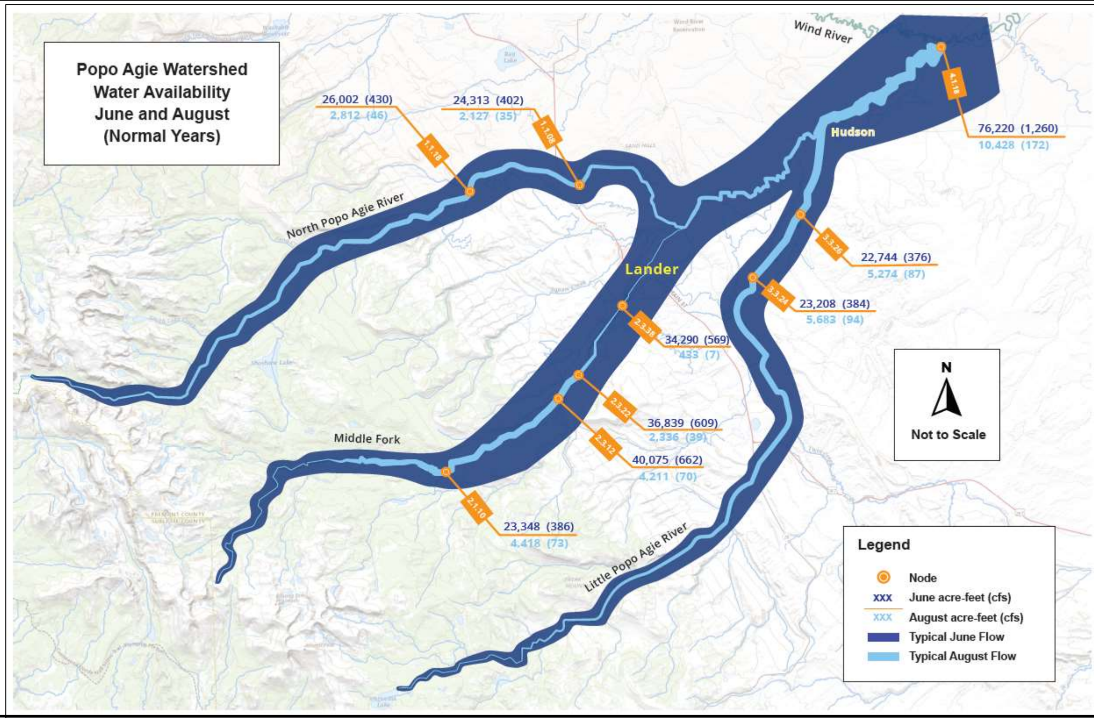

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Irrigation Infrastructure

Methods and Results

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General Approach

Challenges

- High Conveyance Loss
- Inefficient Delivery
- Poor Condition

Primary Objective: Conservation Potential

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Site Investigation

Site Tours

- Review irrigation ditches and infrastructure

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Irrigation System Improvements

Ditch	Project	Benefit
Cemetery & Dutch Flat / Taylor	Ditch Consolidation	Maintenance/access in residential area Seepage loss reduction Hillslope Stability
Nicol and Table Mountain & Baldwin/ Paralta	Ditch Consolidation	Seepage loss reduction Maintenance reduction
Enterprise	Ditch Lining: Sawmill Creek Reach	Seepage loss reduction
Enterprise	Cascade Reach: Pipe Drop	Seepage loss reduction Erosion and sedimentation reduction
Enterprise	Beason Creek: Thompson Headgate & Drop	Improved flow regulation
Lyons	Ditch Capacity upgrade and Wasteway	Seepage loss reduction Conveyance improvement

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Irrigation System Improvements

Ditch	Project	Ranking
Enterprise	Ditch Lining: Sawmill Creek Reach	11
Cemetery - Dutch Flat / Taylor	Ditch Consolidation: Cemetery and Dutch Flat / Taylor	10
Enterprise	Beason Creek: Thompson Headgate & Drop	9
Lyons	Ditch Capacity upgrade and Wasteway	9
Nicol and Table Mountain - Paralda	Ditch Consolidation: Nicol Table Mountain and Baldwin Paralta	8
Enterprise	Cascade Reach: Pipe Drop	7

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MICRO-STORAGE ASSESSMENT

Methods and Results

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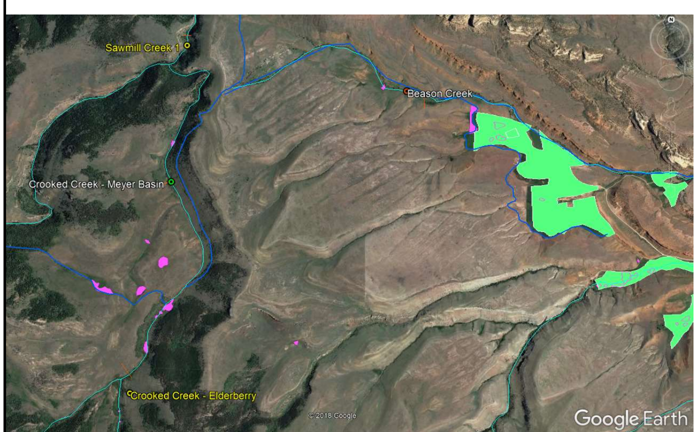
Microstorage



Water availability

- Water is available in May and June on all three branches
- For 100-acre hay field, need approximately 150 acre-feet plus additional for transmission loss to satisfy August irrigation need
- Overall watershed examined

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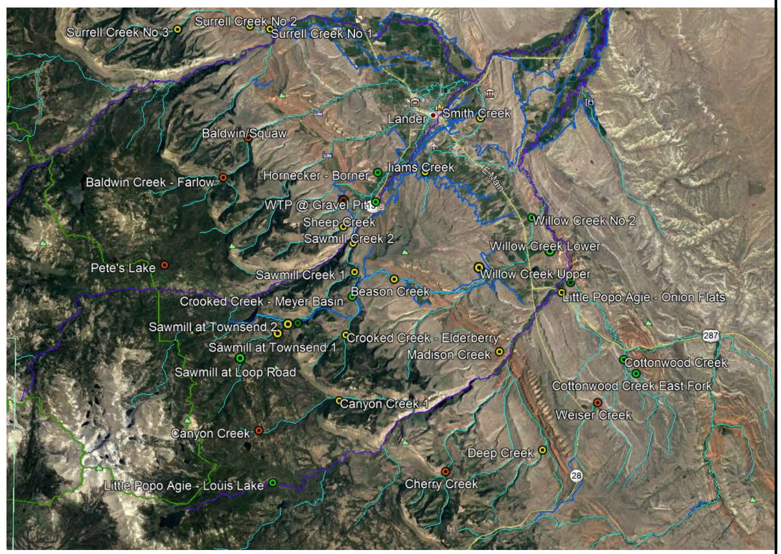
Microstorage

Exclusions (general)

- Wilderness area
- Mainstem storage
- Existing reservoirs
  - (Worthen included)
- Oxbows in lower Popo Agie



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Microstorage

Assumptions

- Achieved 300 acre-feet of storage for flexibility
- 5 feet of freeboard required per SEO Safety of Dams law
- Embankment volume based on 300 acre-feet plus 5 feet of freeboard, also estimated for 150 acre-feet of storage – relative comparison for rankings
- Cost = $15/cubic yard, consistent with Anderson and previous studies
- Overall costs for 300 acre-feet: $50,000 - $14M; most $2M or less

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Microstorage

- Worthen Meadows Reservoir not evaluated in this manner but recommended for advancement and evaluation with other ongoing studies
- Water Treatment Plant
  - Not microstorage but evaluated for cost
  - Minimum size to accommodate 400,000 gallons/day (1.2 acre-feet)
  - Maximum size on site (up to 440 acre-feet)

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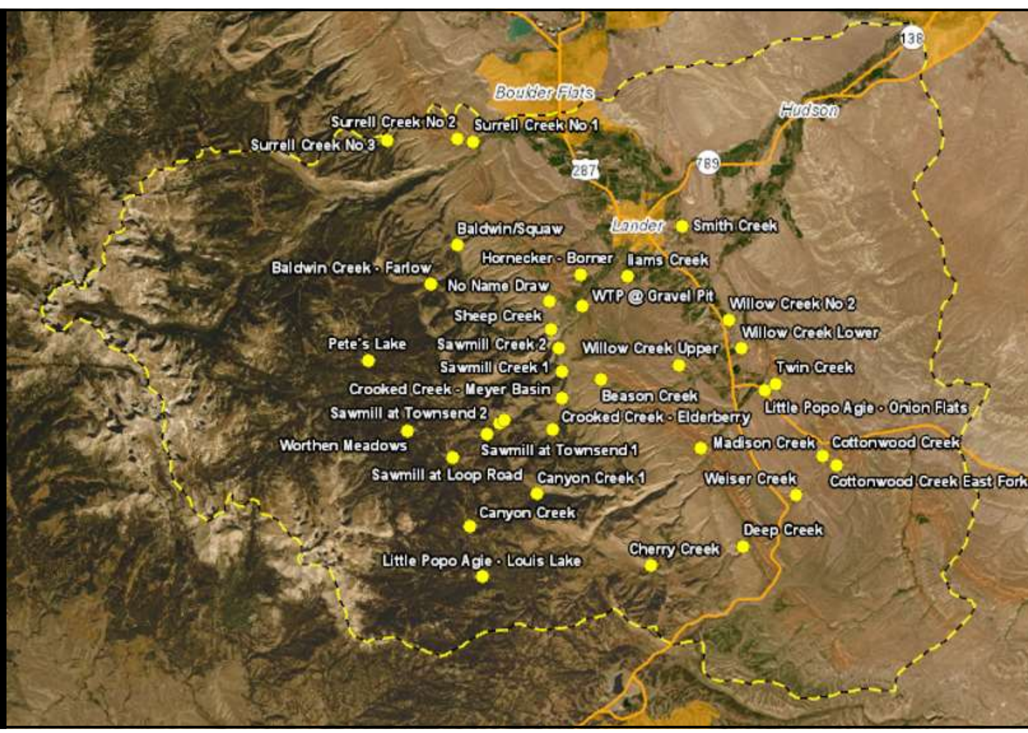

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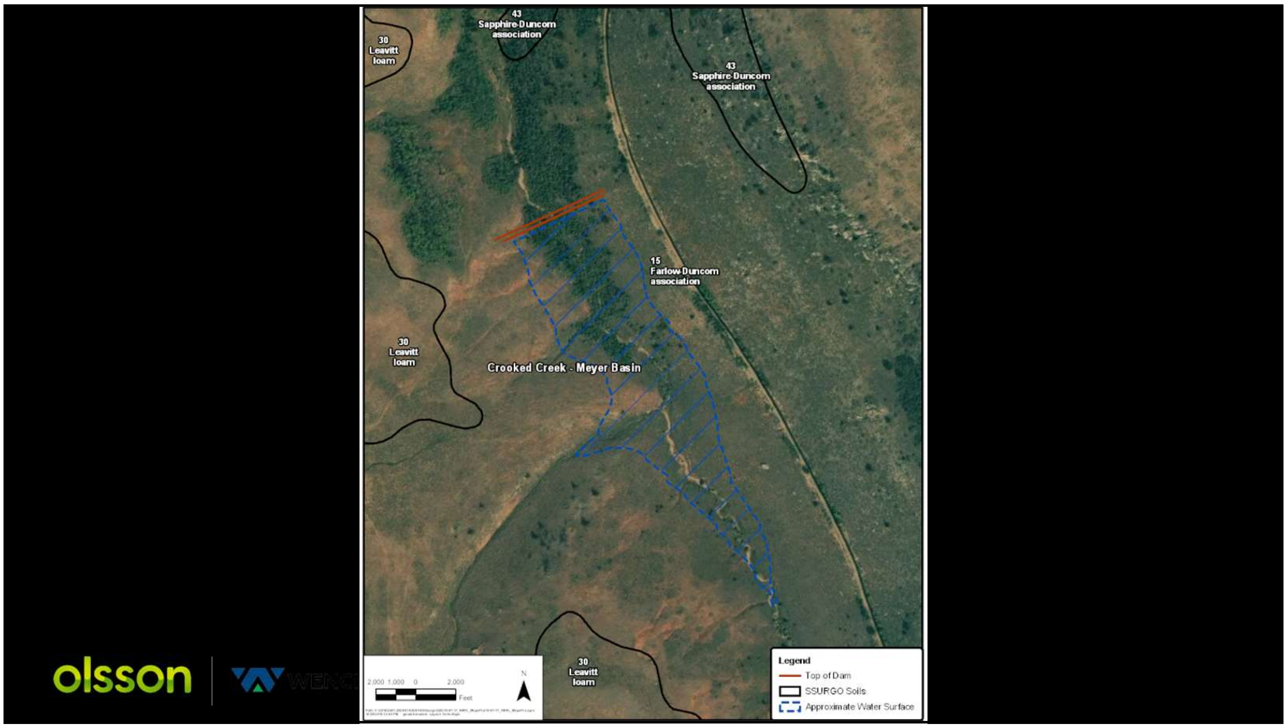
43
Sapphire-Duncom
association
30
Leavitt
loam
43
Sapphire-Duncom
association
15
Farlow-Duncom
association
30
Leavitt
loam
Crooked Creek - Meyer Basin
30
Leavitt
loam
2,000 1,000 0 2,000
Feet
N
Legend
Top of Dam
SSURGO Soils
Approximate Water Surface
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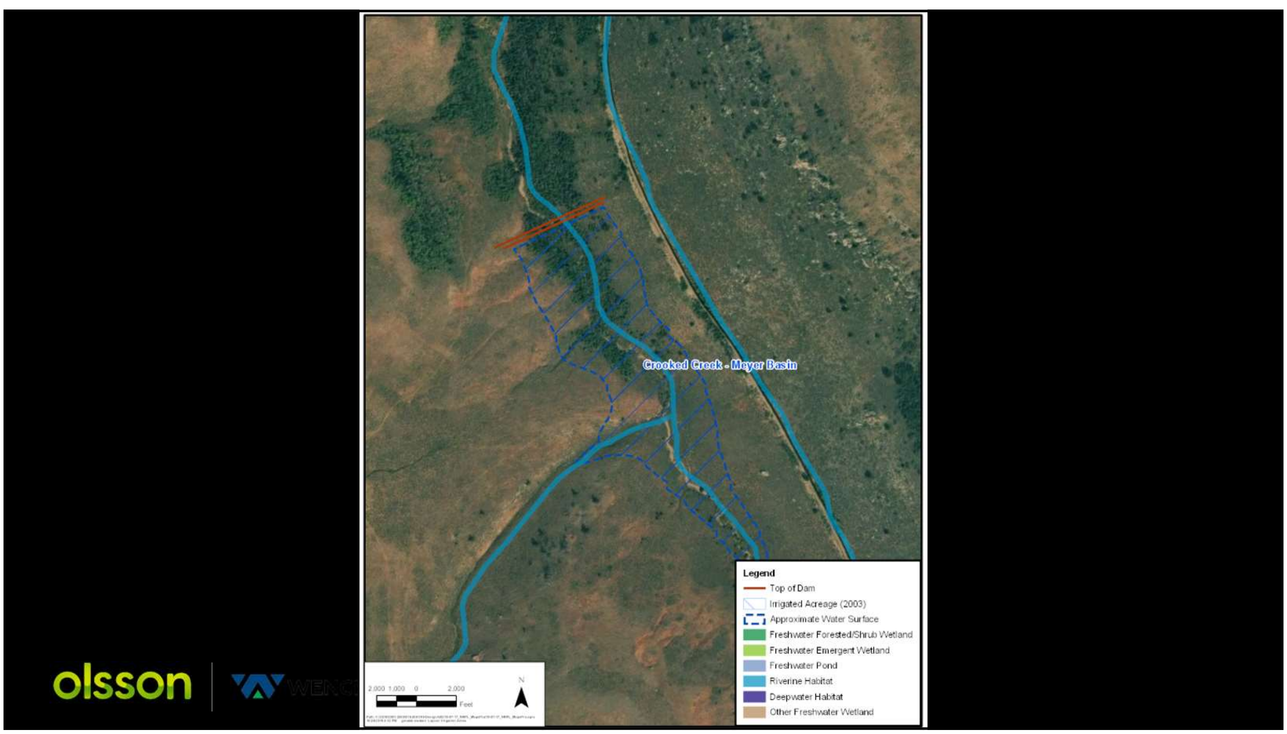
Crooked Creek - Meyer Basin
Legend
Top of Dam
Irrigated Acreage (2003)
Approximate Water Surface
Freshwater Forested/Shrub Wetland
Freshwater Emergent Wetland
Freshwater Pond
Riverine Habitat
Deepwater Habitat
Other Freshwater Wetland
2,000 1,000 0 2,000
Feet
N
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Table 5.4. Short List of Potential Micro-Storage Sites Dam Volumes and Costs

		Dam and Reservoir Information											
		300 acre-feet of storage						150 acre-feet of storage (approximate values)					
	Site Name	Dam height, feet	Dam height plus 5 feet of freeboard, feet	Surface area, acres	Dam volume, cubic yards	Cost @ $15/cubic yard	Cost, $/acre-foot of water	Dam height plus 5 feet of freeboard, feet	Height difference	Approx. area (volume) difference	Approx. dam volume, cubic yards	Cost @ $15/cubic yard	Cost, $/acre-foot of water
North	Surrel Creek No. 1	54	59	13	117,976	$1,769,641	$5,899	42	71%	54%	63,199	$947,984	$6,320
	Surrel Creek No. 2	44	49	23	112,463	$1,686,943	$5,623	40	81%	68%	76,269	$1,144,042	$7,627
	Surrel Creek No 3	81	86	8.4	357,176	$5,357,644	$17,859	62	72%	55%	195,001	$2,925,010	$19,500
Middle	Baldwin - Farlow	50	55	12	101,668	$1,525,022	$5,083	39	72%	54%	55,169	$827,537	$5,517
	Baldwin/Squaw	82	87	9.1	234,687	$3,520,305	$11,734	67	77%	62%	145,010	$2,175,145	$14,501
	Crooked Creek - Elderberry	54	54	12	131,444	$1,971,660	$10,269	49	90%	82%	107,260	$1,608,906	$10,726
	Crooked Creek - Meyer Basin	52	57	14	91,148	$1,367,220	$4,557	39	68%	49%	44,572	$668,573	$4,457
	Hornecker - Borner (MPA diversion)	21	26	25	117,928	$1,768,923	$5,896	18	69%	50%	58,999	$884,992	$5,900
	Hornecker - Borner (tributaries)	21	26	25	117,928	$1,768,923	$5,896	18	69%	50%	58,999	$884,992	$5,900
	No Name Draw	43	48	16	261,429	$3,921,441	$13,071	34	71%	53%	138,246	$2,073,691	$13,825
	Pete's Lake	6	11	58	8,251	$123,758	$413	8	74%	58%	4,801	$72,012	$480
	Sawmill Creek 1	90	95	9.5	105,987	$1,589,808	$5,299	75	79%	65%	68,793	$1,031,901	$6,879
	Sawmill Creek 2	87	92	8.8	963,521	$14,452,813	$48,176	71	77%	63%	605,846	$9,087,695	$60,585
	Sawmill Creek - Fossil Hill	52	57	18	62,940	$944,101	$3,147	69	120%	126%	79,238	$1,188,573	$7,924
	Sawmill at Loop Road	24	29	32	58,246	$873,689	$2,912	21	74%	58%	33,644	$504,656	$3,364
	Sawmill at Townsend 1	41	46	17	108,355	$1,625,320	$5,418	34	73%	57%	61,695	$925,432	$6,170
	Sawmill at Townsend 2	66	71	14	256,459	$3,846,879	$12,823	54	77%	62%	158,254	$2,373,809	$15,825
	Sheep Creek	90	95	9.4	745,791	$11,186,858	$37,290	74	78%	64%	479,995	$7,199,931	$48,000
	Smith Creek	15	20	40	35,566	$533,485	$1,778	12	63%	41%	14,719	$220,779	$1,472
	WTP @ Gravel Pit (Minimum Size)	4	6	0.8	3,217	$48,252	$161	---	---	---	---	---	---
	WTP @ Gravel Pit (Maximum Size)	37	42	22	424,900	$6,373,500	$21,245	---	---	---	---	---	---
	Worthen Meadows Reservoir	---	---	---	---	---	---	---	---	---	---	---	---
Little	Beason Creek	33	38	21	133,517	$2,002,758	$6,676	26	68%	49%	65,402	$981,028	$6,540
	Canyon Creek	34	39	19	68,561	$1,028,413	$3,428	29	75%	59%	40,221	$603,312	$4,022
	Canyon Creek 1	38	43	15	116,628	$1,749,415	$5,831	24	56%	31%	36,475	$547,126	$3,648
	Cherry Creek	32	37	25	95,636	$1,434,543	$4,782	28	77%	62%	58,828	$882,414	$5,883
	Cottonwood Creek	26	31	28	55,165	$827,469	$2,758	26	84%	72%	39,608	$594,121	$3,961
	Cottonwood Creek East Fork	38	43	24	41,337	$620,056	$2,067	35	81%	68%	28,209	$423,129	$2,821
	Deep Creek	94	99	9.1	325,367	$4,880,505	$16,268	78	78%	64%	209,359	$3,140,384	$20,936
	Iiams Creek	38	38	15	279,329	$4,189,928	$22,648	37	98%	94%	261,872	$3,928,078	$21,233
	Little Popo Agie - Louis Lake	13	18	37	44,887	$673,306	$2,244	13	74%	58%	25,813	$387,190	$2,581
	Little Popo Agie - Onion Flats	29	34	42	29,019	$435,281	$1,451	27	81%	68%	19,833	$297,490	$1,983
	Madison Creek	N/A	N/A	9.8	N/A	N/A	N/A	26	0%	0%	16,481	$247,217	$1,648
	Onion Flats - from Devils Creek	29	34	42	29,019	$435,281	$1,451	27	81%	68%	19,833	$297,490	$1,983
	Twin Creek	20	25	31	22,570	$338,555	$1,129	19	77%	62%	13,969	$209,536	$1,397
	Weiser Creek	40	45	20	87,441	$1,311,617	$4,372	34	75%	59%	51,889	$778,333	$5,189
	Willow Creek No. 2	18	23	42	22,381	$335,708	$1,119	18	78%	64%	14,365	$215,480	$1,437
	Willow Creek Lower	15	20	50	70,232	$1,053,478	$3,512	14	70%	52%	36,321	$544,812	$3,632
	Willow Creek Upper	43	48	16	98,816	$1,482,239	$4,941	35	74%	58%	57,250	$858,747	$5,725

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Table 5.5. Potentially Available Water at the End of the Season

	Site Name	Surface area, acres	Starting storage June, acre-feet	Net Evaporation, June through August, acre-feet	Seepage, acre-feet	Remaining Volume, acre-feet	Cost, $/acre-foot of remaining water
North	Surrel Creek No. 1	13	300	19	3	277	$6,381
	Surrel Creek No. 2	23	300	34	6	260	$6,477
	Surrel Creek No 3	8.4	300	13	2	285	$18,782
Middle	Baldwin - Farlow	12	300	19	3	278	$5,485
	Baldwin/Squaw	9.1	300	14	2	284	$12,396
	Crooked Creek - Elderberry	12	192	18	3	171	$11,550
	Crooked Creek - Meyer Basin	14	300	21	3	276	$4,952
	Hornecker - Borner (MPA diversion)	25	300	38	6	256	$6,916
	Hornecker - Borner (tributaries)	25	300	38	6	256	$6,916
	No Name Draw	16.2	300	24	4	272	$14,443
	Pete's Lake	58	300	88	15	197	$627
	Sawmill Creek 1	9.5	300	14	2	283	$5,613
	Sawmill Creek 2	8.8	300	13	2	285	$50,796
	Sawmill Creek - Fossil Hill	18	300	27	4	268	$3,517
	Sawmill at Loop Road	32	300	48	8	245	$3,573
	Sawmill at Townsend 1	17	300	26	4	270	$6,020
	Sawmill at Townsend 2	14	300	21	4	275	$13,979
	Sheep Creek	9.4	300	14	2	283	$39,469
	Smith Creek	40	300	60	10	230	$2,317
	WTP @ Gravel Pit (Minimum Size)	0.8	---	---	---	---	---
	WTP @ Gravel Pit (Maximum Size)	22.2	---	---	---	---	---
	Worthen Meadows Reservoir	---	---	---	---	---	---
Little	Beason Creek	20.6	300	31	5	264	$7,591
	Canyon Creek	19.2	300	29	5	266	$3,863
	Canyon Creek 1	15	300	22	4	274	$6,381
	Cherry Creek	24.8	300	37	6	256	$5,594
	Cottonwood Creek	28.1	300	42	7	251	$3,302
	Cottonwood Creek East Fork	23.8	300	36	6	258	$2,402
	Deep Creek	9.1	300	14	2	284	$17,189
	Iiams Creek	15.4	185	23	4	158	$26,540
	Little Popo Agie - Louis Lake	36.9	300	56	9	235	$2,863
	Little Popo Agie - Onion Flats	42	300	64	11	226	$1,927
	Madison Creek	9.8	77	15	2	60	$4,132
	Onion Flats - from Devils Creek	42	300	64	11	226	$1,927
	Twin Creek	31	300	47	8	245	$1,381
	Weiser Creek	20.2	300	30	5	264	$4,960
	Willow Creek No. 2	42	300	63	10	227	$1,480
	Willow Creek Lower	50.4	300	76	13	211	$4,984
	Willow Creek Upper	16.2	300	24	4	271	$5,460

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Microstorage

Ranking

- Property ownership considered two ways, state and private scores
- Divided into three groups for visual ranking

Criteria	Weight
Water availability	2
Versatility of benefit	2
Cost	2
Bedrock geology and soils	1
Proximity to irrigation	1
Proximity to structures	1
Wetlands	1
Property ownership	1

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Table 5.9. Micro-Storage Sites Scoring and Ranking with Original Propery Ownership

Site Name	Branch	Water Availability*	Beneficial Uses*	Cost*	Bedrock Geology and Soils	Proximity to Irrigation	Proximity to Structures	Wetlands	Property Ownership (Original)	Total
Willow Creek No. 2	L	3	2	3	3	3	2	3	3	22
Willow Creek Lower	L	3	3	2	2	3	3	1	3	20
Crooked Creek - Meyer Basin	M	3	3	2	3	1	3	3	1	19
Hornecker - Borner (MPA diversion)	M	3	3	2	1	3	1	3	3	19
Sawmill Creek - Fossil Hill	M	3	3	3	3	1	3	2	1	19
Twin Creek	L	3	2	3	1	3	1	3	3	19
Cottonwood Creek	L	2	1	3	2	3	1	3	3	18
Cottonwood Creek East Fork	L	3	1	3	2	3	2	2	2	18
Hornecker - Borner (tributaries)	M	2	3	2	1	3	1	3	3	18
Little Popo Agie - Louis Lake	L	3	3	3	3	1	3	1	1	18
Sawmill at Loop Road	M	3	2	3	3	1	3	2	1	18
Deep Creek	L	2	1	1	3	3	2	3	2	17
Madison Creek	L	2	2	3	1	2	1	3	3	17
Onion Flats - from Devils Creek	L	1	2	3	3	3	1	3	1	17
Sawmill at Townsend 1	M	3	2	2	3	1	3	2	1	17
Sawmill at Townsend 2	M	3	2	1	3	1	3	3	1	17
Sawmill Creek 1	M	3	3	2	1	1	3	3	1	17
Sawmill Creek 2	M	3	3	1	2	2	1	3	2	17
Smith Creek	M	1	2	3	3	3	2	1	2	17
Surrel Creek No. 1	N	3	3	2	1	3	1	3	1	17
Beason Creek	L	1	3	1	1	3	2	3	2	16
Canyon Creek 1	L	2	1	2	3	1	3	3	1	16
Crooked Creek - Elderberry	M	2	3	2	1	1	3	3	1	16
Iiams Creek	L	1	3	1	3	3	1	2	2	16
Sheep Creek	M	1	3	1	3	2	1	3	2	16
Surrel Creek No 3	N	1	3	1	3	1	3	3	1	16
Surrel Creek No. 2	N	3	3	2	1	2	1	3	1	16
Willow Creek Upper	L	1	2	2	3	3	1	3	1	16
Baldwin - Farlow	M	2	2	2	3	1	1	3	1	15
Cherry Creek	L	2	1	2	3	1	3	1	2	15
Little Popo Agie - Onion Flats	L	1	2	3	1	3	1	3	1	15
No Name Draw	M	1	2	1	1	3	1	3	3	15
Pete's Lake	M	1	1	3	3	1	3	1	1	14
Canyon Creek	L	1	1	2	3	1	3	1	1	13
Baldwin/Squaw	M	2	2	1	1	1	1	3	1	12
Weiser Creek	L	1	1	2	1	3	1	2	1	12

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AQUIFER STORAGE AND RECOVERY

Methods and Results

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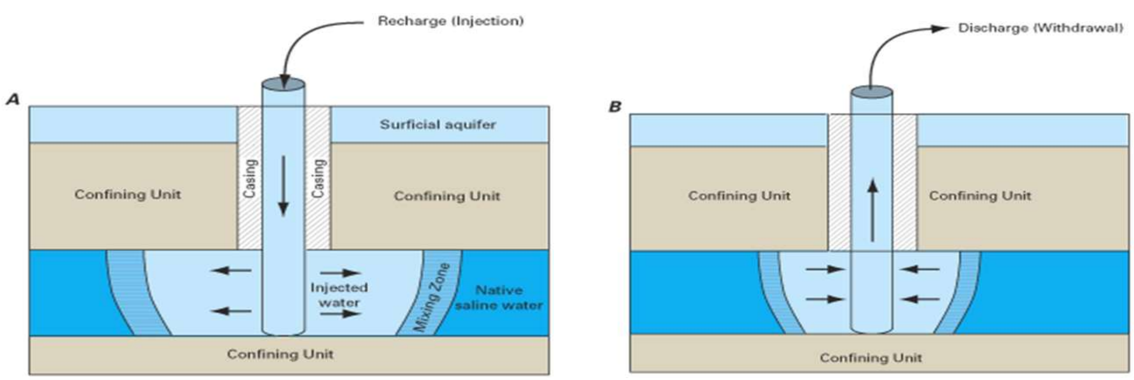
Aquifer Storage and Recovery



Injection and Withdrawal from a Typical Aquifer Storage and Recovery Well (USGS 2003).

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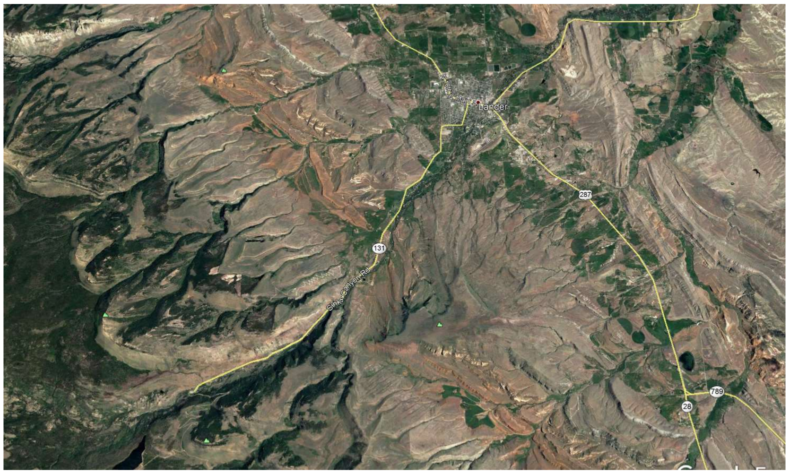
General Approach



Selection Criteria

- Location
- Aquifers
- Regulatory
- Operational
- Hydrogeologic
- Cost

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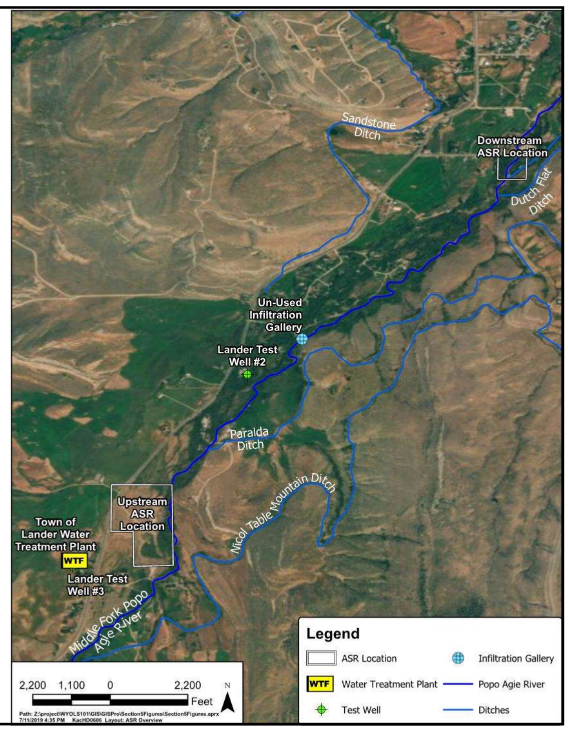
Primary Considerations

- Transmissivity
- Distance to River
- Storage Zone Thickness
- Injection Capacity
- Well Installation
- Water Collection and Discharge
- Operation and Maintenance



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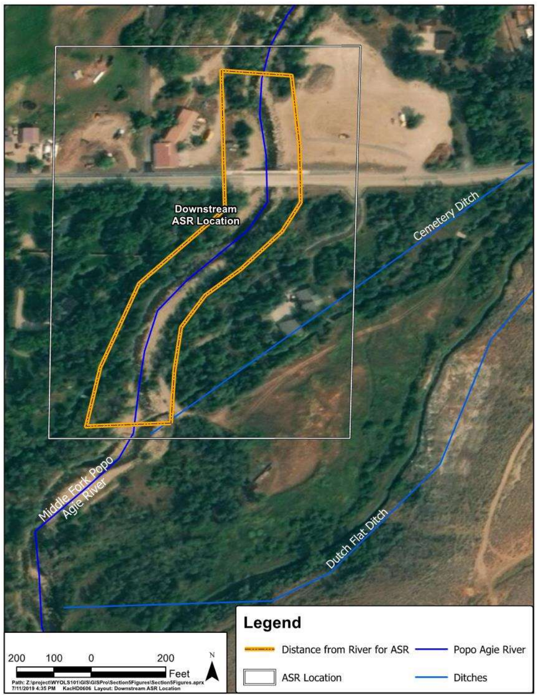
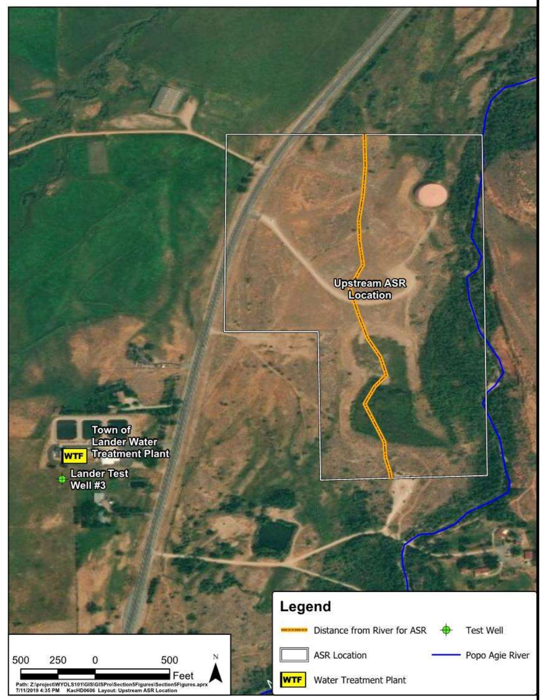
Two Sites Evaluated





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Watershed Study Recommendations

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Proposed Project Summary/Recommendations

1. Irrigation system conveyance improvements with estimated water savings

Enterprise: Ditch lining Sawmill Creek Reach	3.5 cfs
Cemetery & Dutch Flat / Taylor Ditch Consolidation	2.0 cfs
Enterprise: Beason Creek: Thompson Headgate	0.3 cfs
Lyons: Ditch Capacity upgrade and Wasteway	0.3 cfs
Nicol and Table Mountain / Baldwin & Paralta: Ditch Consolidation	0.5 cfs
Enterprise: Cascade Reach-Pipe Drop	1.5 cfs

- Estimated cost range: $44,000 - $900,000

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Proposed Project Summary/Recommendations

2. Microstorage

- 60 - 285 acre-feet available in August
- Estimated costs: $50,000 to $14 million, most less than $2 million ($630-$50,800/acre-foot for first year)

3. ASR

- Estimated flow = 1.1 cfs back to the river
- Estimated costs: $25,000 to $500,000

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Worthen Meadows Reservoir

"Water Supply Evaluation and Groundwater Development Alternatives" Draft Technical Memorandum (April 2019, Version 2.0, by Wyoming Groundwater, Hinckley Consulting and WWC Engineering)

- Operational changes to Worthen Meadows Reservoir
  - Capacity is 1503.6 acre-feet
  - Typically drawn down to 750 acre-feet for winter for dam safety
  - Dead pool is 30 acre-feet
- General conclusions based on reservoir modeling:
  - WMR could meet increased demands and be able to re-fill in the spring
- Estimated cost = not quantified but minor

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Questions?

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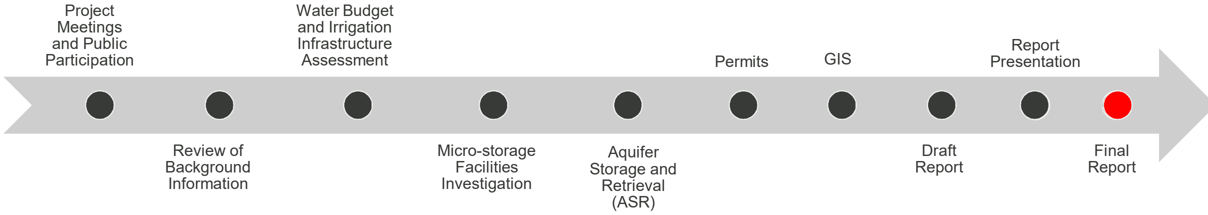
Next Steps



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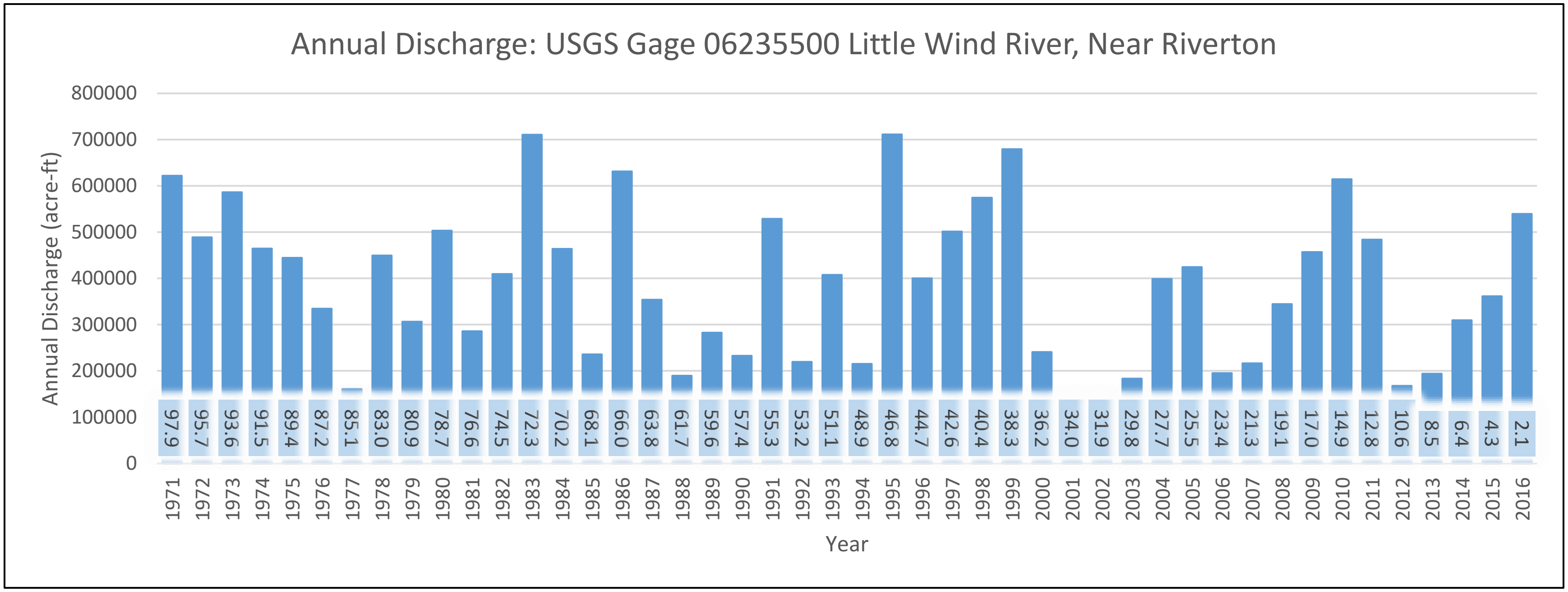
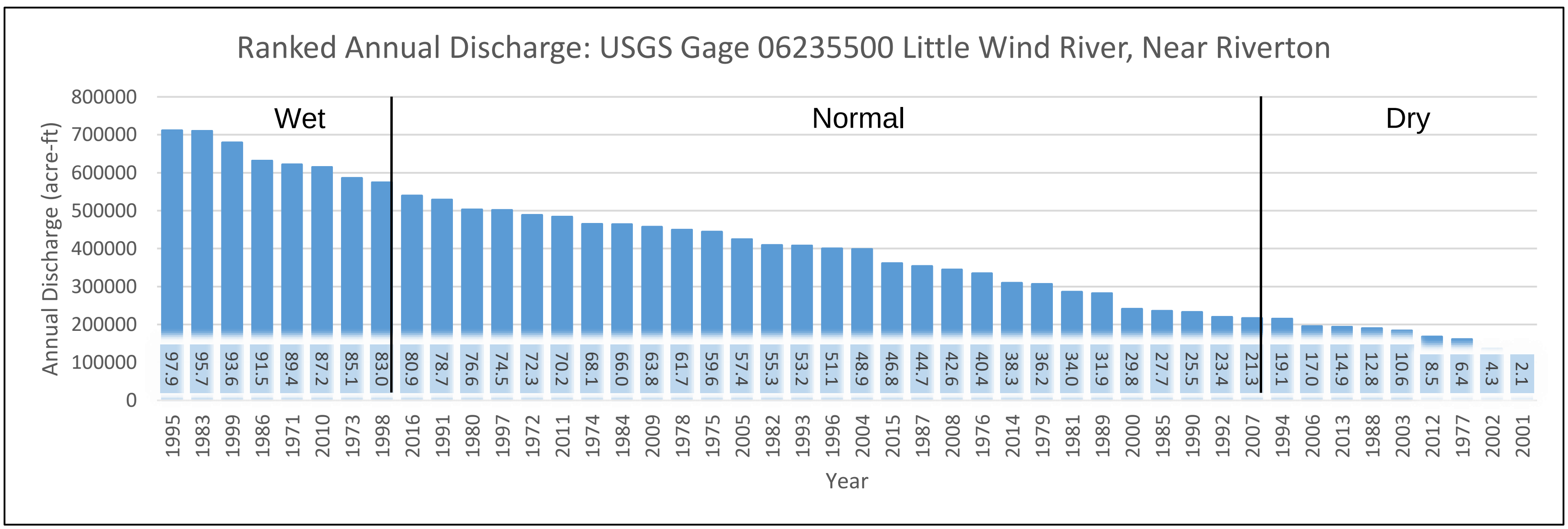
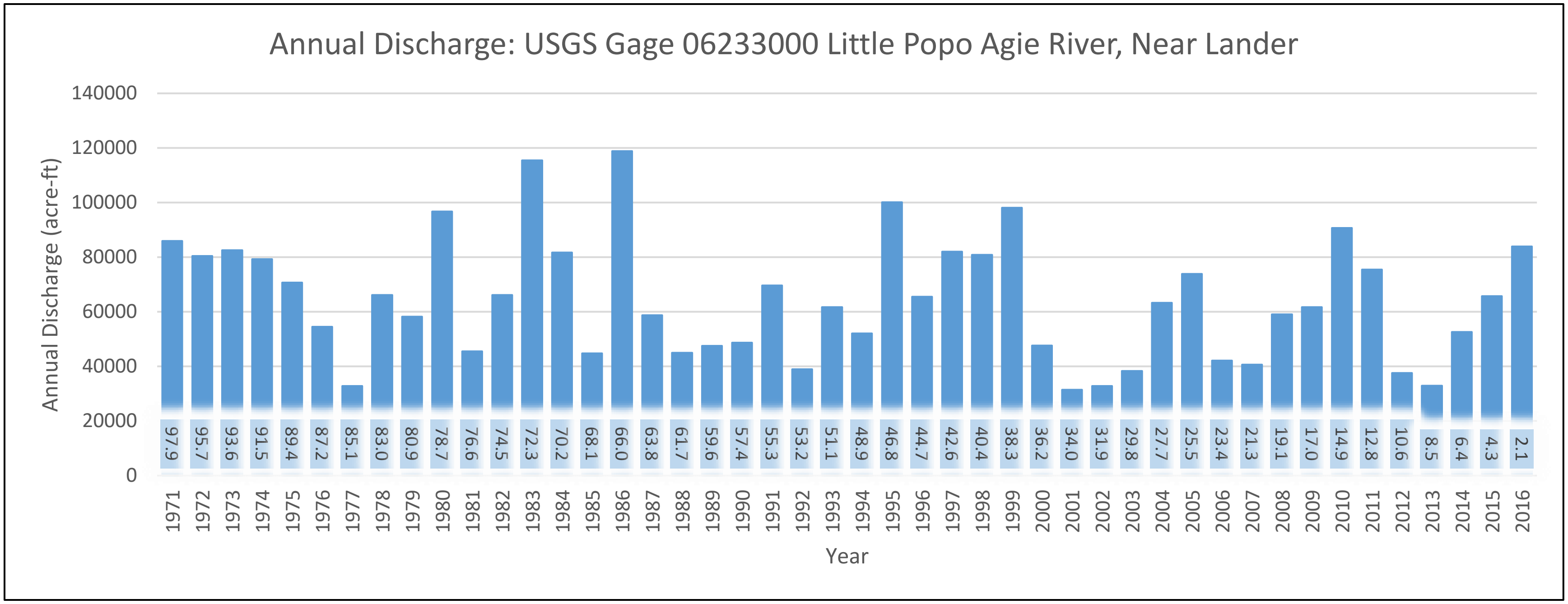
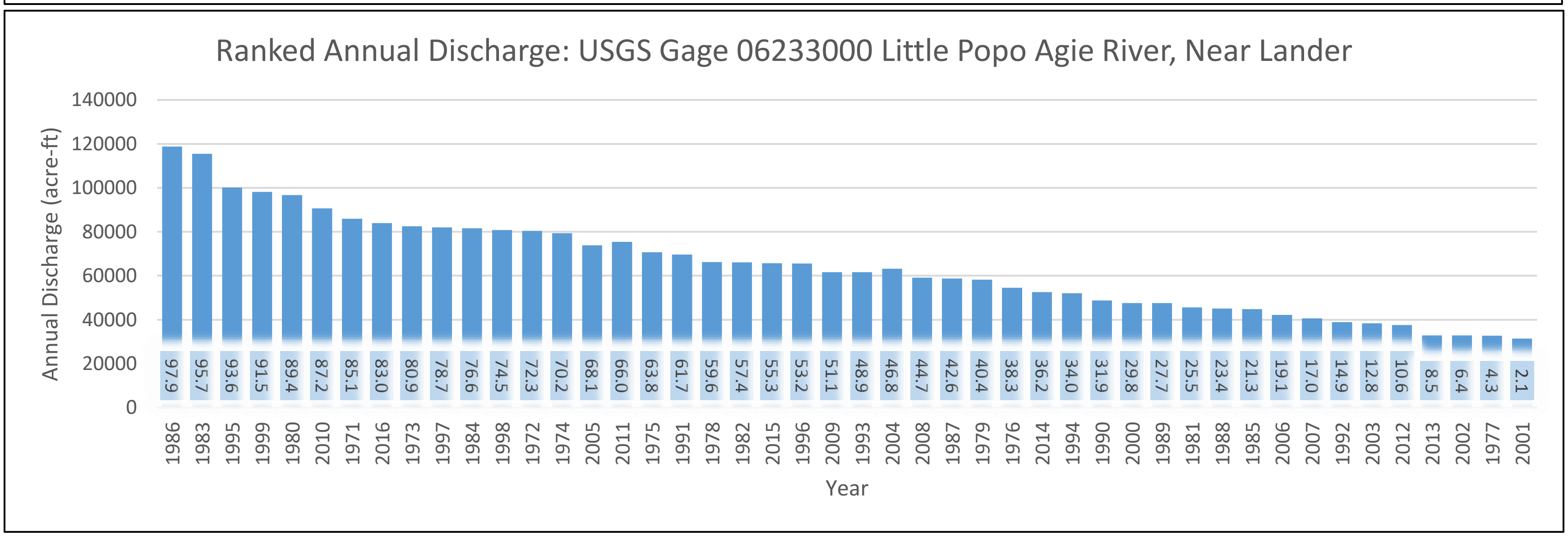
APPENDIX B
WATER BUDGET INFORMATION



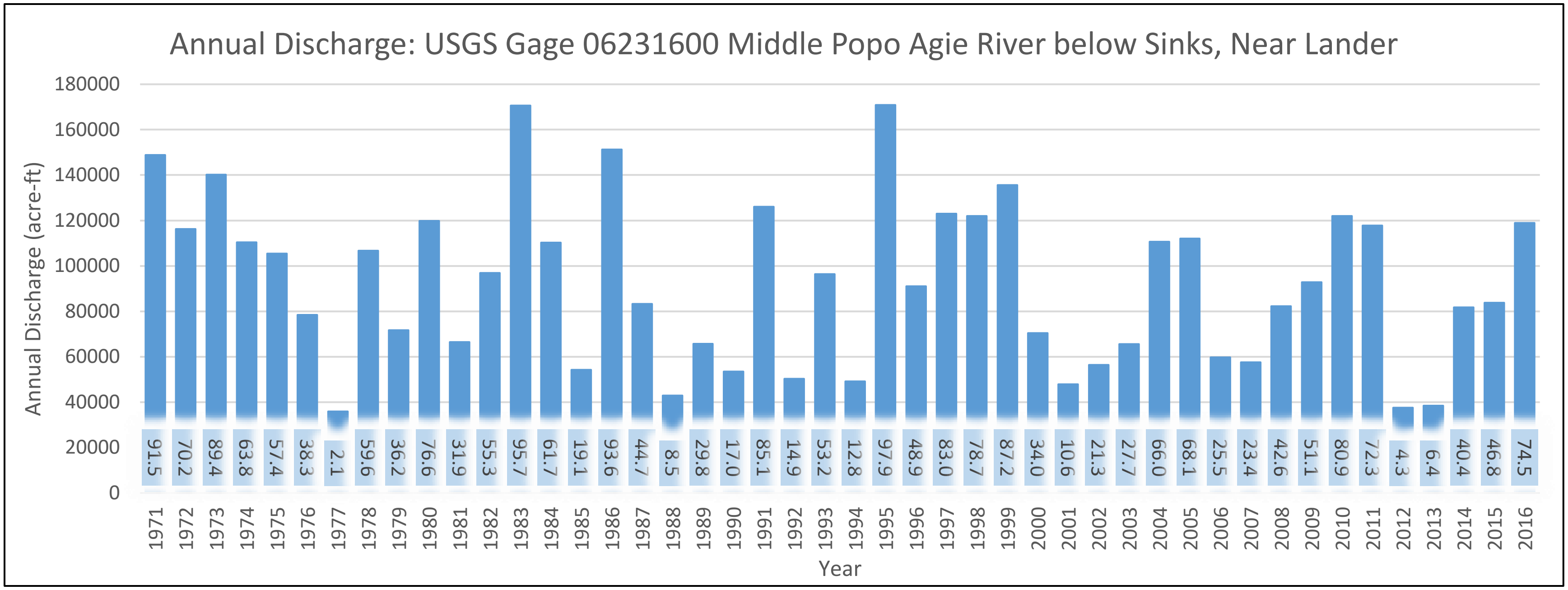


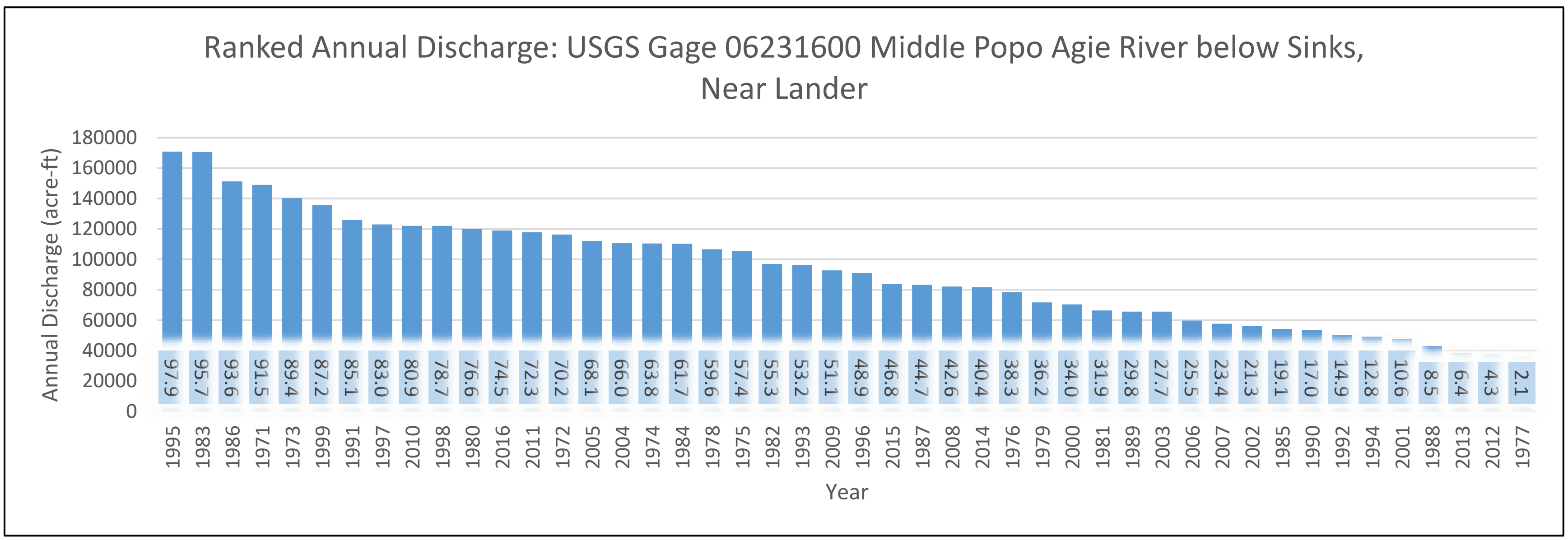
Note: Values below each bar represent the percentage of years in study period exceeded.



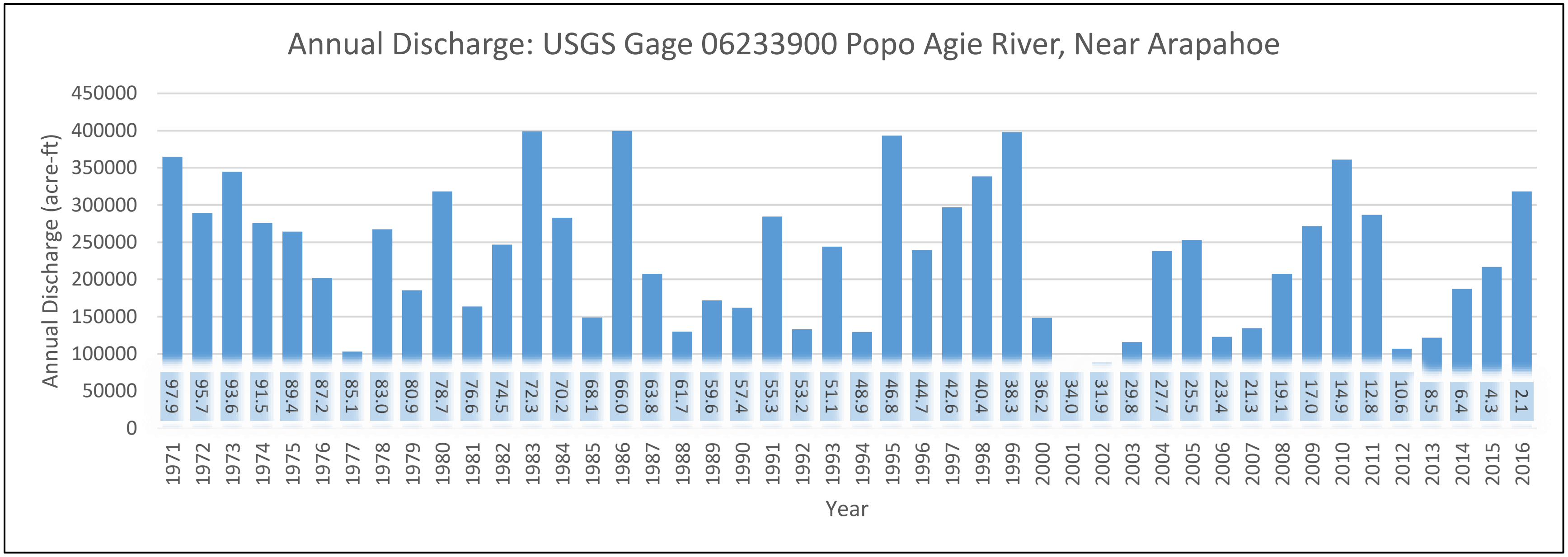


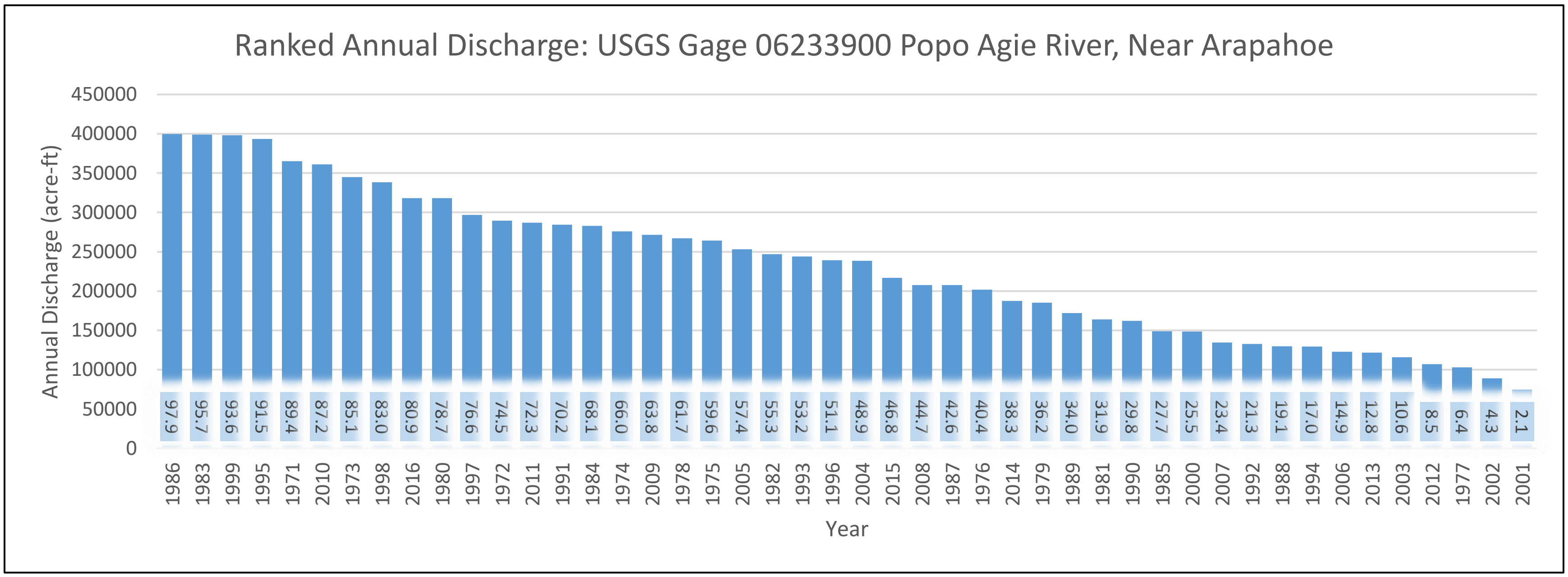
Note: Values below each bar represent the percentage of years in study period exceeded



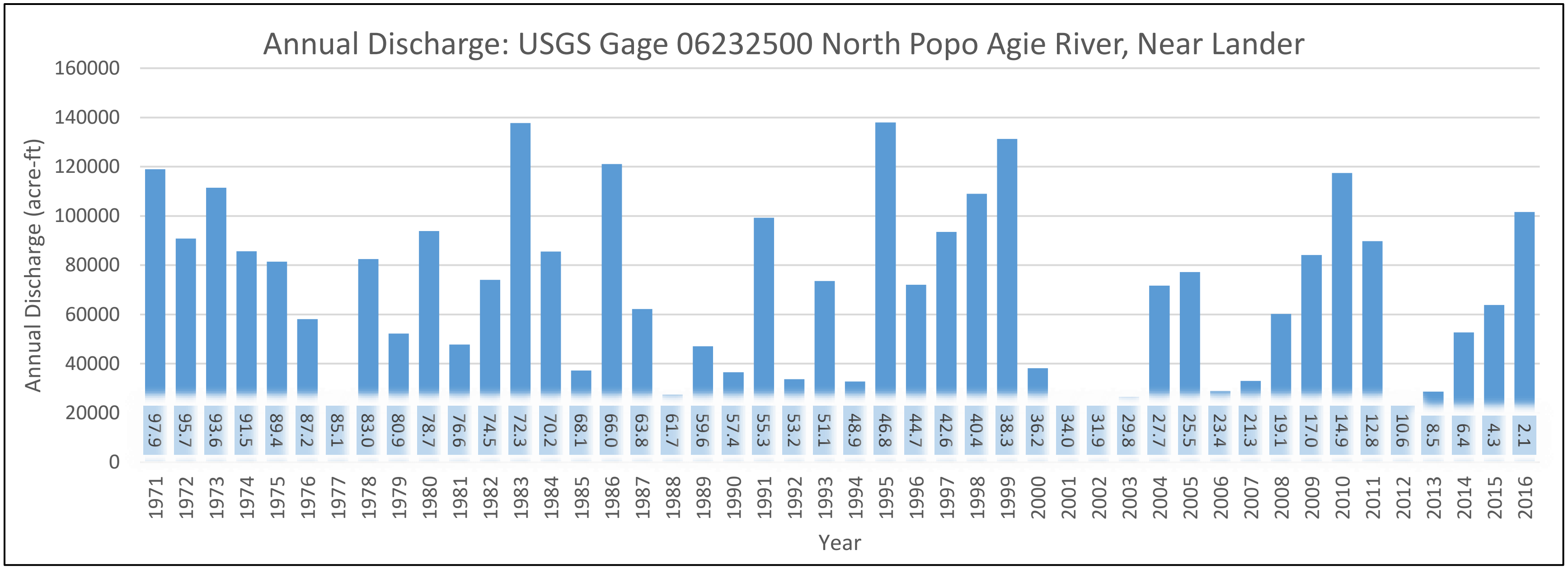


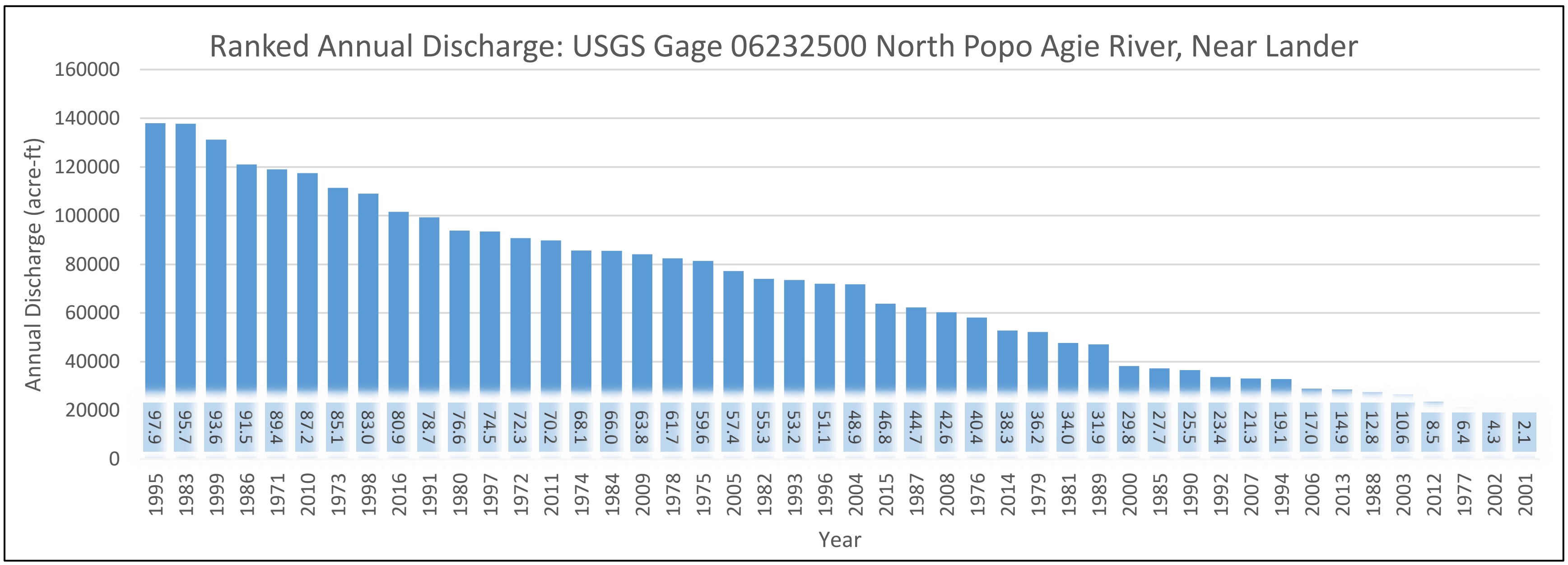
Note: Values below each bar represent the percentage of years in study period exceeded



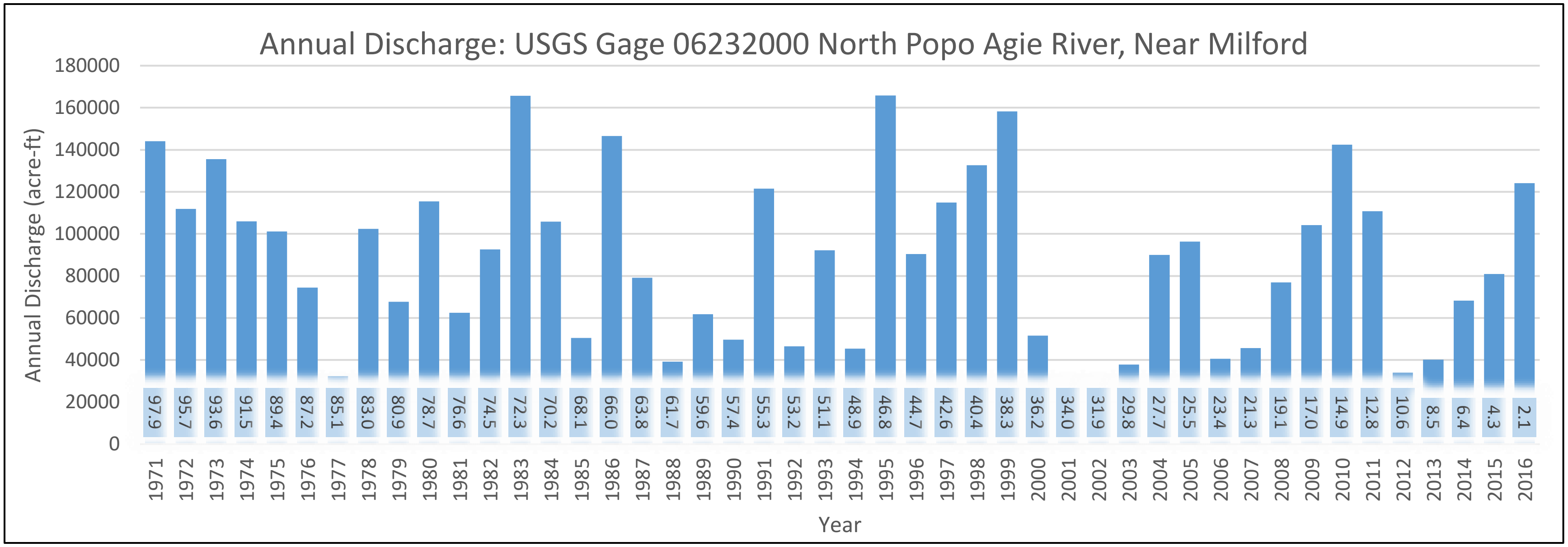


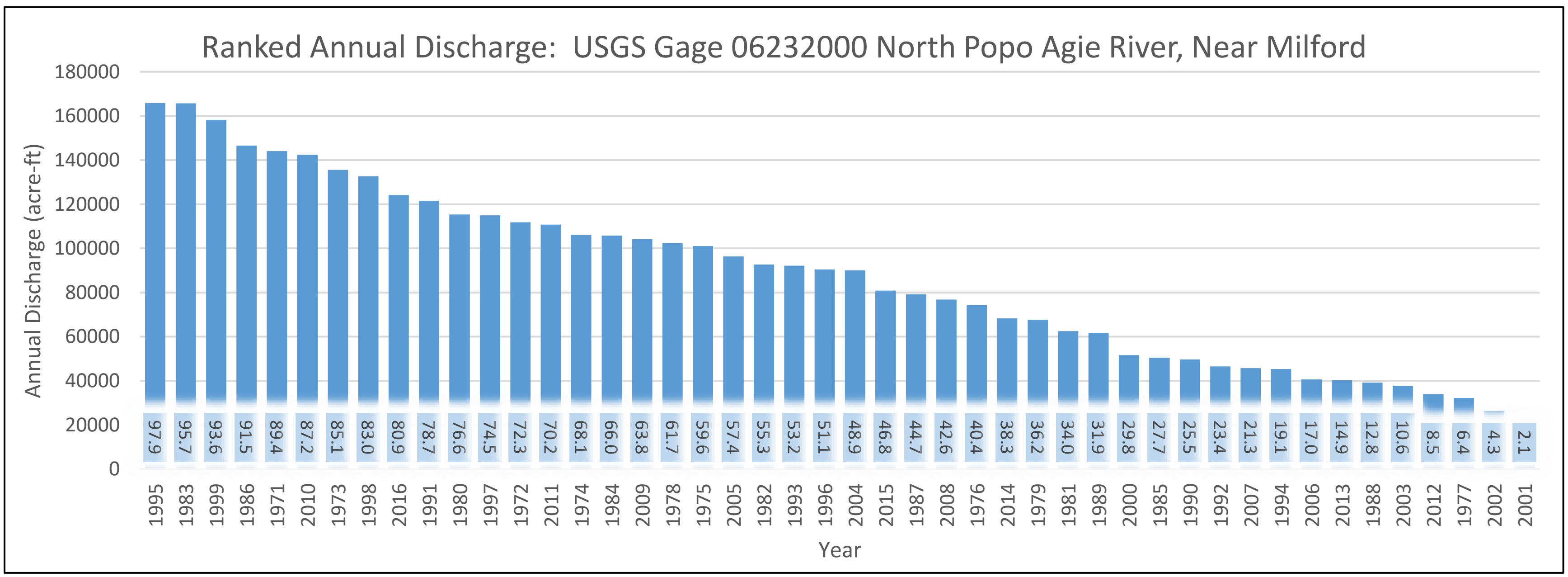
Note: Values below each bar represent the percentage of years in study period exceeded





Note: Values below each bar represent the percentage of years in study period exceeded





Note: Values below each bar represent the percentage of years in study period exceeded

DRY YEARS

Reach 1 NET Flow (In - Out) Summary Table

OUTFLOW (ACRE-FT)

NODE	Name	Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Node 1.1.10 NET Flow (In - Out)	USGS 06232000	1.1	1,746	1,938	2,752	3,468	8,886	9,211	5,724	3,840	1,689	2,495	2,390	2,070
Node 1.1.12 NET Flow (In - Out)	Red Butte	1.1	1,746	1,938	2,752	3,272	8,355	8,408	4,781	3,116	1,357	2,436	2,390	2,070
Node 1.1.13 NET Flow (In - Out)	Surrell Creek Confluence	1.1	1,929	2,112	3,020	2,846	7,108	6,467	1,720	625	389	2,585	2,704	2,302
Node 1.1.14 NET Flow (In - Out)	AggDiv NPA-1	1.1	1,746	1,938	2,752	3,150	8,027	7,914	4,199	2,670	1,153	2,399	2,390	2,070
Node 1.1.16 NET Flow (In - Out)	Mountain Range	1.1	1,749	1,938	2,752	3,051	7,779	7,575	3,846	2,472	1,150	2,485	2,446	2,088
Node 1.1.18 NET Flow (In - Out)	Big Cottonwood	1.1	1,749	1,938	2,752	2,510	6,318	5,368	1,251	482	239	2,321	2,446	2,088
Node 1.1.20 NET Flow (In - Out)	North Fork and Shady Grove	1.1	1,929	2,112	3,020	2,689	6,706	5,898	1,089	201	261	2,616	2,730	2,305
Node 1.1.24 NET Flow (In - Out)	AggDiv NPA-2	1.1	1,929	2,112	3,020	2,519	6,246	5,204	273	0	0	2,565	2,730	2,305
Node 1.1.26 NET Flow (In - Out)	USGS 06232500	1.1	905	1,157	1,785	2,422	6,246	5,204	273	0	0	1,534	1,455	1,180
Node 1.2.08 NET Flow (In - Out)	Sioux	1.2	905	1,157	1,785	2,331	6,055	5,004	125	27	167	1,692	1,515	1,188
Node 1.2.10 NET Flow (In - Out)	Milford	1.2	905	1,157	1,785	2,214	5,743	4,539	0	0	0	1,670	1,519	1,188
Node 1.2.12 NET Flow (In - Out)	Harrison	1.2	905	1,157	1,785	2,147	5,568	4,288	0	0	0	1,675	1,528	1,190
Node 1.2.14 NET Flow (In - Out)	AggDiv NPA-3	1.2	905	1,157	1,785	2,218	5,826	4,791	704	720	528	1,933	1,605	1,200
Node 1.2.16 NET Flow (In - Out)	North Popo Agie Outflow	1.2	905	1,157	1,785	2,319	6,130	5,299	1,350	1,293	876	2,067	1,638	1,204
Node 1.3.10 NET Flow (In - Out)	Surrell NF	1.3	180	174	268	337	790	1,098	469	143	150	263	258	214
Node 1.3.12 NET Flow (In - Out)	AggDev SC-1	1.3	180	174	268	337	790	1,098	469	143	150	263	258	214
Node 1.3.14 NET Flow (In - Out)	Surrell Outflow	1.3	180	174	268	337	790	1,098	469	143	150	263	258	214

Reach 2 NET Flow (In - Out) Summary Table

NODE	Name	Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Node 2.1.10 NET Flow (In - Out)	Middle Popo Agie Upstream of Roaring Fork	2.1	1,612	1,799	2,313	4,088	8,494	8,417	3,994	1,524	1,798	2,319	1,997	1,569
Node 2.1.11 NET Flow (In - Out)	Confluence Roaring Fork	2.1	2,237	2,386	3,086	4,100	9,354	9,138	3,994	1,524	1,798	2,913	2,742	2,252
Node 2.1.12 NET Flow (In - Out)	USGS 06231600	2.1	2,237	2,386	3,086	4,100	9,354	9,138	3,994	1,524	1,798	2,913	2,742	2,252
Node 2.2.10 NET Flow (In - Out)	Sawmill NF	2.2	1,190	1,117	1,469	1,093	4,527	5,734	4,760	1,204	815	1,454	1,418	1,298
Node 2.2.12 NET Flow (In - Out)	Enterprise - Sawmill	2.2	1,190	1,117	1,469	585	3,155	3,662	2,324	0	0	1,300	1,418	1,298
Node 2.2.14 NET Flow (In - Out)	Sawmill Outflow	2.2	1,190	1,117	1,469	585	3,155	3,662	2,324	0	0	1,300	1,418	1,298
Node 2.3.10 NET Flow (In - Out)	Conf Sawmill	2.3	3,428	3,503	4,554	4,686	12,509	12,800	6,319	1,524	1,798	4,214	4,160	3,550
Node 2.3.12 NET Flow (In - Out)	Gaylor & Warnock	2.3	3,428	3,503	4,554	4,673	12,022	11,480	5,455	1,342	1,685	4,120	4,160	3,550
Node 2.3.14 NET Flow (In - Out)	Lander City Pipeline	2.3	3,428	3,503	4,554	4,673	12,022	11,480	5,455	1,342	1,685	4,120	4,160	3,550
Node 2.3.16 NET Flow (In - Out)	Scott	2.3	3,428	3,503	4,554	4,673	11,972	11,349	5,391	1,335	1,673	4,110	4,160	3,550
Node 2.3.18 NET Flow (In - Out)	Hornecker, Swamp and Melon	2.3	3,428	3,503	4,554	4,673	11,479	10,792	5,001	1,060	1,454	3,891	4,160	3,550
Node 2.3.20 NET Flow (In - Out)	Nicol and Nicol Meyer	2.3	3,428	3,503	4,554	4,656	11,351	10,536	4,844	924	1,353	3,806	4,160	3,550
Node 2.3.22 NET Flow (In - Out)	Nicol & Table Mountain	2.3	3,428	3,503	4,554	4,655	9,764	7,364	2,874	450	801	3,157	4,180	3,556
Node 2.3.24 NET Flow (In - Out)	Meadow, Cottonwood, and Island	2.3	3,428	3,503	4,554	4,567	9,587	7,198	2,622	203	689	3,151	4,186	3,558
Node 2.3.26 NET Flow (In - Out)	Baldwin	2.3	3,428	3,503	4,554	4,567	9,083	6,199	2,023	0	320	2,959	4,186	3,558
Node 2.3.28 NET Flow (In - Out)	Conf. Hornecker	2.3	3,467	3,539	4,625	4,567	9,469	7,058	2,547	316	696	3,364	4,381	3,646
Node 2.3.30 NET Flow (In - Out)	Chalmers & Fogg	2.3	3,467	3,539	4,625	4,567	9,340	6,802	2,388	204	586	3,262	4,381	3,646
Node 2.3.32 NET Flow (In - Out)	Olson and Barnaby	2.3	3,467	3,539	4,625	4,567	9,340	6,802	2,388	204	586	3,262	4,381	3,646
Node 2.3.34 NET Flow (In - Out)	Lander City	2.3	3,467	3,539	4,625	4,567	9,340	6,802	2,388	204	586	3,262	4,381	3,646
Node 2.3.36 NET Flow (In - Out)	Dutch Flat / Taylor	2.3	3,467	3,539	4,625	4,567	8,034	4,438	1,240	0	185	2,746	4,381	3,646
Node 2.3.38 NET Flow (In - Out)	Cemetery	2.3	3,467	3,539	4,625	4,567	7,423	3,496	708	0	0	2,716	4,381	3,646
Node 2.3.40 NET Flow (In - Out)	Baldwin Creek Confluence	2.3	3,846	3,924	5,161	5,401	9,858	7,284	3,842	2,442	1,700	3,708	4,971	4,081
Node 2.3.42 NET Flow (In - Out)	Last and Forrest	2.3	3,846	3,924	5,161	5,381	9,806	7,206	3,750	2,372	1,668	3,702	4,971	4,081
Node 2.3.44 NET Flow (In - Out)	Conf Middle and North Popo Agie	2.3	4,751	5,081	6,946	7,701	15,936	12,505	5,100	3,664	2,544	5,769	6,610	5,285
Node 2.4.10 NET Flow (In - Out)	Baldwin/Squaw NF	2.4	378	385	536	851	2,398	3,590	2,754	1,913	1,190	669	470	412
Node 2.4.12 NET Flow (In - Out)	AggDev BC-1	2.4	378	385	536	564	1,622	2,417	1,375	856	706	582	470	412
Node 2.4.14 NET Flow (In - Out)	Baldwin/Squaw Outflow	2.4	378	385	536	804	2,339	3,617	2,900	2,208	1,527	896	549	422
Node 2.5.10 NET Flow (In - Out)	Roaring Fork NF	2.5	626	587	772	575	2,380	3,014	2,502	633	428	764	745	682
Node 2.5.12 NET Flow (In - Out)	Enterprise - Roaring Fork	2.5	626	587	772	12	861	721	0	0	0	594	745	682
Node 2.5.14 NET Flow (In - Out)	Roaring Fork Div	2.5	626	587	772	12	861	721	0	0	0	594	745	682
Node 2.5.16 NET Flow (In - Out)	Roaring Fork Outflow	2.5	626	587	772	12	861	721	0	0	0	594	745	682
Node 2.6.10 NET Flow (In - Out)	Hornecker Creek NF	2.6	39	37	71	187	787	1,486	1,353	955	605	327	152	74
Node 2.6.12 NET Flow (In - Out)	AggDev HC-1	2.6	39	37	71	0	159	538	238	100	213	256	152	74
Node 2.6.14 NET Flow (In - Out)	Hornecker Creek Outflow	2.6	39	37	71	0	159	538	238	100	213	256	152	74

Reach 3 NET Flow (In - Out) Summary Table

OUTFLOW (ACRE-FT)

NODE	Name	Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Node 3.1.10 NET Flow (In - Out)	Little Popo Agie NF	3.1	1,449	1,404	1,917	2,439	6,853	6,329	2,791	1,848	1,408	1,770	1,796	1,650
Node 3.1.12 NET Flow (In - Out)	Conf. Red Canyon	3.1	1,944	1,885	2,583	3,241	9,211	8,539	3,712	2,436	1,912	2,404	2,427	2,218
Node 3.1.14 NET Flow (In - Out)	AggDev LPA-1	3.2	1,944	1,885	2,583	3,198	9,095	8,363	3,505	2,277	1,839	2,391	2,427	2,218
Node 3.1.16 NET Flow (In - Out)	USGS Gage 06233000	3.3	1,945	1,885	2,583	3,261	9,285	8,687	3,925	2,554	2,078	2,500	2,463	2,226
Node 3.2.10 NET Flow (In - Out)	Red Canyon NF	3.2	496	481	666	853	2,495	2,416	1,164	774	589	649	631	568
Node 3.2.12 NET Flow (In - Out)	AggDev RC-1	3.2	496	481	666	802	2,359	2,210	921	588	504	634	631	568
Node 3.2.14 NET Flow (In - Out)	Red Canyon Outflow	3.3	496	481	666	802	2,359	2,210	921	588	504	634	631	568
Node 3.3.12 NET Flow (In - Out)	AggDev LPA-2	3.3	2,243	2,104	2,753	3,183	9,075	8,370	3,553	2,269	1,947	2,477	2,463	2,341
Node 3.3.14 NET Flow (In - Out)	Conf. Twin Creek	3.3	2,303	2,173	2,843	3,469	9,314	8,996	4,366	2,706	2,249	2,593	2,500	2,386
Node 3.3.16 NET Flow (In - Out)	Bryant and Ocenas	3.3	2,303	2,173	2,843	3,432	9,213	8,844	4,188	2,570	2,186	2,582	2,500	2,386
Node 3.3.18 NET Flow (In - Out)	Conf. Willow Creek	3.3	2,454	2,304	3,024	3,828	10,039	10,543	6,113	4,386	3,597	3,455	2,966	2,628
Node 3.3.20 NET Flow (In - Out)	AggDev LPA-3	3.3	2,454	2,304	3,024	3,801	9,972	10,453	6,018	4,332	3,592	3,470	2,974	2,629
Node 3.3.22 NET Flow (In - Out)	Millard and Shedd	3.3	2,454	2,304	3,024	3,536	9,943	10,896	5,990	4,040	3,584	3,791	3,093	2,670
Node 3.3.24 NET Flow (In - Out)	Lyons	3.3	2,454	2,304	3,024	3,494	9,867	10,844	5,990	4,137	3,737	3,907	3,135	2,675
Node 3.3.26 NET Flow (In - Out)	Rogers & Gregg No. 2 (Wise)	3.3	2,454	2,304	3,024	3,346	9,490	10,313	5,403	3,747	3,625	3,942	3,161	2,679
Node 3.3.28 NET Flow (In - Out)	Hudson	3.3	2,454	2,304	3,024	3,346	9,490	10,313	5,403	3,747	3,625	3,942	3,161	2,679
Node 3.3.30 NET Flow (In - Out)	USGS Gage 06233500	3.3	2,454	2,304	3,024	3,228	6,431	8,608	3,818	1,149	1,403	2,781	2,844	2,683
Node 3.5.10 NET Flow (In - Out)	Twin Creek NF	3.5	60	69	90	325	325	724	898	453	254	63	16	43
Node 3.5.12 NET Flow (In - Out)	AggDev TC-1	3.5	60	69	90	221	43	300	399	70	79	31	16	43
Node 3.5.14 NET Flow (In - Out)	Twin Creek Outflow	3.6	60	69	90	269	187	540	704	341	243	94	31	45
Node 3.6.10 NET Flow (In - Out)	Willow Creek NF	3.6	138	131	180	218	490	720	447	262	181	166	158	148
Node 3.6.12 NET Flow (In - Out)	AggDev WC-1	3.6	138	131	180	152	312	451	131	20	70	146	158	148
Node 3.6.14 NET Flow (In - Out)	Willow Creek Outflow	3.6	138	131	180	182	403	603	324	191	174	186	168	150

Reach 4 NET Flow (In - Out) Summary Table

NODE	Name	Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Node 4.1.10 NET Flow (In - Out)	Inflow From Reach 3	4.1	4,751	5,081	6,946	10,410	15,936	12,505	5,100	3,664	2,544	5,769	6,610	5,285
Node 4.1.12 NET Flow (In - Out)	Snavely and Grant Young	4.1	4,751	5,081	6,946	10,088	15,763	12,745	4,845	3,219	2,489	6,100	6,738	5,327
Node 4.1.14 NET Flow (In - Out)	Mid-Reach 4.1	4.1	4,751	5,081	6,946	9,939	15,359	12,136	4,129	2,670	2,238	6,055	6,738	5,327
Node 4.1.16 NET Flow (In - Out)	Conf. Little Popo Agie	4.1	7,205	7,385	9,970	13,333	22,288	21,576	9,005	4,759	4,211	9,054	9,636	8,018
Node 4.1.18 NET Flow (In - Out)	USGS Gage 06233900 - End	4.1	4,545	5,020	7,066	13,133	22,201	19,272	4,311	1,818	3,061	5,161	5,760	5,090

NORMAL YEARS

OUTFLOW (ACRE-FT)

Reach 1 NET Flow (In - Out) Summary Table

NODE	Name	Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Node 1.1.10 NET Flow (In - Out)	USGS 06232000	1.1	2,281	2,456	3,261	3,968	14,985	29,344	14,376	6,244	2,909	3,981	3,397	2,436
Node 1.1.12 NET Flow (In - Out)	Red Butte	1.1	2,281	2,456	3,261	3,827	14,527	28,647	13,459	5,508	2,616	3,940	3,397	2,436
Node 1.1.13 NET Flow (In - Out)	Surrell Creek Confluence	1.1	2,505	2,679	3,615	3,728	14,257	29,000	11,310	3,207	2,035	4,342	3,805	2,721
Node 1.1.14 NET Flow (In - Out)	AggDiv NPA-1	1.1	2,281	2,456	3,261	3,739	14,245	28,217	12,892	5,054	2,435	3,916	3,397	2,436
Node 1.1.16 NET Flow (In - Out)	Mountain Range	1.1	2,282	2,456	3,261	3,668	14,028	27,920	12,534	4,837	2,446	4,007	3,449	2,450
Node 1.1.18 NET Flow (In - Out)	Big Cottonwood	1.1	2,282	2,456	3,261	3,279	12,770	26,002	10,010	2,812	1,639	3,897	3,449	2,450
Node 1.1.20 NET Flow (In - Out)	North Fork and Shady Grove	1.1	2,505	2,679	3,615	3,615	13,908	28,503	10,682	2,763	1,937	4,385	3,826	2,724
Node 1.1.24 NET Flow (In - Out)	AggDiv NPA-2	1.1	2,505	2,679	3,615	3,492	13,512	27,900	9,888	2,126	1,683	4,350	3,826	2,724
Node 1.1.26 NET Flow (In - Out)	USGS 06232500	1.1	1,377	1,599	2,172	2,761	12,272	24,492	9,888	2,126	1,683	2,760	2,321	1,464
Node 1.2.08 NET Flow (In - Out)	Sioux	1.2	1,377	1,599	2,172	2,696	12,100	24,313	9,715	2,127	1,868	2,918	2,371	1,469
Node 1.2.10 NET Flow (In - Out)	Milford	1.2	1,377	1,599	2,172	2,612	11,831	23,909	9,186	1,713	1,716	2,906	2,374	1,469
Node 1.2.12 NET Flow (In - Out)	Harrison	1.2	1,377	1,599	2,172	2,564	11,680	23,690	8,906	1,508	1,659	2,917	2,381	1,470
Node 1.2.14 NET Flow (In - Out)	AggDiv NPA-3	1.2	1,377	1,599	2,172	2,615	11,892	24,121	9,553	2,206	2,174	3,158	2,445	1,477
Node 1.2.16 NET Flow (In - Out)	North Popo Agie Outflow	1.2	1,377	1,599	2,172	2,688	12,150	24,559	10,164	2,773	2,502	3,277	2,473	1,480
Node 1.3.10 NET Flow (In - Out)	Surrell NF	1.3	223	223	353	448	1,488	2,997	1,300	394	396	445	357	271
Node 1.3.12 NET Flow (In - Out)	AggDev SC-1	1.3	223	223	353	448	1,488	2,997	1,300	394	396	445	357	271
Node 1.3.14 NET Flow (In - Out)	Surrell Outflow	1.3	223	223	353	448	1,488	2,997	1,300	394	396	445	357	271

Reach 2 NET Flow (In - Out) Summary Table

NODE	Name	Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Node 2.1.10 NET Flow (In - Out)	Middle Popo Agie Upstream of Roaring Fork	2.1	1,454	1,647	2,046	3,415	14,766	28,348	14,221	4,418	3,316	2,977	2,391	1,609
Node 2.1.11 NET Flow (In - Out)	Confluence Roaring Fork	2.1	2,158	2,326	2,970	3,530	16,278	32,079	14,480	4,418	3,316	3,940	3,309	2,394
Node 2.1.12 NET Flow (In - Out)	USGS 06231600	2.1	2,158	2,326	2,970	3,530	16,278	32,079	14,480	4,418	3,316	3,940	3,309	2,394
Node 2.2.10 NET Flow (In - Out)	Sawmill NF	2.2	1,326	1,278	1,740	977	5,311	10,780	5,428	2,112	1,470	2,030	1,729	1,479
Node 2.2.12 NET Flow (In - Out)	Enterprise - Sawmill	2.2	1,326	1,278	1,740	625	4,171	9,043	3,141	278	739	1,930	1,729	1,479
Node 2.2.14 NET Flow (In - Out)	Sawmill Outflow	2.2	1,326	1,278	1,740	625	4,171	9,043	3,141	278	739	1,930	1,729	1,479
Node 2.3.10 NET Flow (In - Out)	Conf Sawmill	2.3	3,484	3,604	4,710	4,155	20,449	41,121	17,621	4,696	4,055	5,870	5,039	3,873
Node 2.3.12 NET Flow (In - Out)	Gaylor & Warnock	2.3	3,484	3,604	4,710	4,147	19,980	40,075	16,729	4,211	3,840	5,654	5,039	3,873
Node 2.3.14 NET Flow (In - Out)	Lander City Pipeline	2.3	3,484	3,604	4,710	4,147	19,980	40,075	16,729	4,211	3,840	5,654	5,039	3,873
Node 2.3.16 NET Flow (In - Out)	Scott	2.3	3,484	3,604	4,710	4,147	19,975	40,005	16,650	4,183	3,833	5,651	5,039	3,873
Node 2.3.18 NET Flow (In - Out)	Hornecker, Swamp and Melon	2.3	3,484	3,604	4,710	4,141	19,665	39,534	16,284	3,891	3,619	5,545	5,039	3,873
Node 2.3.20 NET Flow (In - Out)	Nicol and Nicol Meyer	2.3	3,484	3,604	4,710	4,137	19,598	39,413	16,126	3,731	3,482	5,468	5,039	3,873
Node 2.3.22 NET Flow (In - Out)	Nicol & Table Mountain	2.3	3,484	3,604	4,710	4,097	18,480	36,839	13,760	2,336	2,722	4,749	5,059	3,878
Node 2.3.24 NET Flow (In - Out)	Meadow, Cottonwood, and Island	2.3	3,484	3,604	4,710	4,033	18,334	36,682	13,512	2,120	2,654	4,779	5,072	3,882
Node 2.3.26 NET Flow (In - Out)	Baldwin	2.3	3,484	3,604	4,710	4,033	18,192	35,938	12,868	1,623	2,274	4,619	5,072	3,882
Node 2.3.28 NET Flow (In - Out)	Conf. Hornecker	2.3	3,630	3,747	4,912	4,192	19,011	37,783	13,906	2,265	2,961	5,215	5,396	4,079
Node 2.3.30 NET Flow (In - Out)	Chalmers & Fogg	2.3	3,630	3,747	4,912	4,172	18,882	37,575	13,726	2,114	2,815	5,133	5,396	4,079
Node 2.3.32 NET Flow (In - Out)	Olson and Barnaby	2.3	3,630	3,747	4,912	4,172	18,882	37,575	13,726	2,114	2,815	5,133	5,396	4,079
Node 2.3.34 NET Flow (In - Out)	Lander City	2.3	3,630	3,747	4,912	4,172	18,882	37,575	13,726	2,114	2,815	5,133	5,396	4,079
Node 2.3.36 NET Flow (In - Out)	Dutch Flat / Taylor	2.3	3,630	3,747	4,912	4,170	17,900	35,044	11,756	1,065	2,058	4,621	5,396	4,079
Node 2.3.38 NET Flow (In - Out)	Cemetery	2.3	3,630	3,747	4,912	4,170	17,476	34,290	11,054	433	1,504	4,376	5,396	4,079
Node 2.3.40 NET Flow (In - Out)	Baldwin Creek Confluence	2.3	4,061	4,176	5,517	5,056	20,433	40,038	14,989	3,067	3,438	5,529	6,073	4,571
Node 2.3.42 NET Flow (In - Out)	Last and Forrest	2.3	4,061	4,176	5,517	5,043	20,389	39,970	14,899	2,996	3,409	5,526	6,073	4,571
Node 2.3.44 NET Flow (In - Out)	Conf Middle and North Popo Agie	2.3	5,439	5,775	7,689	7,731	32,538	64,529	25,064	5,769	5,912	8,802	8,546	6,051
Node 2.4.10 NET Flow (In - Out)	Baldwin/Squaw NF	2.4	430	429	606	899	2,938	5,584	3,614	2,142	1,424	843	574	474
Node 2.4.12 NET Flow (In - Out)	AggDev BC-1	2.4	430	429	606	693	2,269	4,565	2,273	1,067	996	784	574	474
Node 2.4.14 NET Flow (In - Out)	Baldwin/Squaw Outflow	2.4	430	429	606	865	2,877	5,601	3,717	2,407	1,771	1,064	639	481
Node 2.5.10 NET Flow (In - Out)	Roaring Fork NF	2.5	704	679	924	519	2,820	5,724	2,882	1,122	781	1,078	918	785
Node 2.5.12 NET Flow (In - Out)	Enterprise - Roaring Fork	2.5	704	679	924	115	1,512	3,731	258	0	0	963	918	785
Node 2.5.14 NET Flow (In - Out)	Roaring Fork Div	2.5	704	679	924	115	1,512	3,731	258	0	0	963	918	785
Node 2.5.16 NET Flow (In - Out)	Roaring Fork Outflow	2.5	704	679	924	115	1,512	3,731	258	0	0	963	918	785
Node 2.6.10 NET Flow (In - Out)	Hornecker Creek NF	2.6	146	143	202	323	1,217	2,411	1,872	1,298	872	547	296	190
Node 2.6.12 NET Flow (In - Out)	AggDev HC-1	2.6	146	143	202	156	676	1,586	787	428	525	499	296	190
Node 2.6.14 NET Flow (In - Out)	Hornecker Creek Outflow	2.6	146	143	202	156	676	1,586	787	428	525	499	296	190

OUTFLOW (ACRE-FT)

Reach 3 NET Flow (In - Out) Summary Table

NODE	Name	Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Node 3.1.10 NET Flow (In - Out)	Little Popo Agie NF	3.1	1,675	1,606	2,266	2,223	9,895	14,922	6,325	2,622	2,330	2,537	2,245	1,897
Node 3.1.12 NET Flow (In - Out)	Conf. Red Canyon	3.1	2,251	2,159	3,056	2,966	13,359	20,224	8,507	3,515	3,177	3,448	3,033	2,553
Node 3.1.14 NET Flow (In - Out)	AggDev LPA-1	3.2	2,251	2,159	3,056	2,935	13,258	20,071	8,305	3,353	3,112	3,440	3,033	2,553
Node 3.1.16 NET Flow (In - Out)	USGS Gage 06233000	3.3	2,252	2,159	3,056	2,980	13,419	20,350	8,700	3,732	3,347	3,539	3,065	2,559
Node 3.2.10 NET Flow (In - Out)	Red Canyon NF	3.2	576	553	791	779	3,581	5,481	2,417	1,082	922	922	789	655
Node 3.2.12 NET Flow (In - Out)	AggDev RC-1	3.2	576	553	791	743	3,464	5,302	2,181	893	847	911	789	655
Node 3.2.14 NET Flow (In - Out)	Red Canyon Outflow	3.3	576	553	791	743	3,464	5,302	2,181	893	847	911	789	655
Node 3.3.12 NET Flow (In - Out)	AggDev LPA-2	3.3	2,507	2,411	3,270	3,614	13,239	20,075	8,338	3,442	3,231	3,523	3,065	2,715
Node 3.3.14 NET Flow (In - Out)	Conf. Twin Creek	3.3	2,567	2,480	3,360	3,911	13,487	20,712	9,143	3,869	3,540	3,641	3,098	2,760
Node 3.3.16 NET Flow (In - Out)	Bryant and Ocenas	3.3	2,567	2,480	3,360	3,884	13,400	20,580	8,970	3,730	3,485	3,633	3,098	2,760
Node 3.3.18 NET Flow (In - Out)	Conf. Willow Creek	3.3	2,732	2,633	3,576	4,275	14,459	22,929	11,111	5,579	4,922	4,531	3,580	3,009
Node 3.3.20 NET Flow (In - Out)	AggDev LPA-3	3.3	2,732	2,633	3,576	4,255	14,400	22,851	11,016	5,520	4,922	4,548	3,586	3,010
Node 3.3.22 NET Flow (In - Out)	Millard and Shedd	3.3	2,732	2,633	3,576	4,074	14,277	23,257	11,232	5,603	5,235	4,996	3,728	3,053
Node 3.3.24 NET Flow (In - Out)	Lyons	3.3	2,732	2,633	3,576	4,044	14,206	23,208	11,211	5,683	5,396	5,111	3,763	3,057
Node 3.3.26 NET Flow (In - Out)	Rogers & Gregg No. 2 (Wise)	3.3	2,732	2,633	3,576	3,937	13,879	22,744	10,627	5,274	5,311	5,156	3,785	3,059
Node 3.3.28 NET Flow (In - Out)	Hudson	3.3	2,732	2,633	3,576	3,937	13,879	22,744	10,627	5,274	5,311	5,156	3,785	3,059
Node 3.3.30 NET Flow (In - Out)	USGS Gage 06233500	3.3	2,732	2,633	3,576	4,013	10,858	20,869	9,505	3,190	3,284	4,090	3,526	3,062
Node 3.5.10 NET Flow (In - Out)	Twin Creek NF	3.5	60	69	90	325	325	724	898	453	254	63	16	43
Node 3.5.12 NET Flow (In - Out)	AggDev TC-1	3.5	60	69	90	250	82	355	412	63	99	41	16	43
Node 3.5.14 NET Flow (In - Out)	Twin Creek Outflow	3.6	60	69	90	284	204	563	702	332	254	98	29	44
Node 3.6.10 NET Flow (In - Out)	Willow Creek NF	3.6	157	153	217	265	785	1,524	799	369	285	243	200	173
Node 3.6.12 NET Flow (In - Out)	AggDev WC-1	3.6	157	153	217	218	632	1,290	491	122	187	230	200	173
Node 3.6.14 NET Flow (In - Out)	Willow Creek Outflow	3.6	157	153	217	240	709	1,421	674	292	285	265	208	173

Reach 4 NET Flow (In - Out) Summary Table

NODE	Name	Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Node 4.1.10 NET Flow (In - Out)	Inflow From Reach 3	4.1	5,439	5,775	7,689	10,969	32,538	64,529	25,064	5,769	5,912	8,802	8,546	6,051
Node 4.1.12 NET Flow (In - Out)	Snavely and Grant Young	4.1	5,439	5,775	7,689	10,765	32,354	64,866	25,207	5,833	6,270	9,294	8,703	6,096
Node 4.1.14 NET Flow (In - Out)	Mid-Reach 4.1	4.1	5,439	5,775	7,689	10,658	32,007	64,337	24,510	5,274	6,047	9,264	8,703	6,096
Node 4.1.16 NET Flow (In - Out)	Conf. Little Popo Agie	4.1	8,170	8,408	11,265	14,790	43,287	85,925	35,019	9,395	9,870	13,548	12,274	9,162
Node 4.1.18 NET Flow (In - Out)	USGS Gage 06233900 - End	4.1	5,900	6,084	8,147	14,722	42,575	76,220	34,587	10,428	8,226	8,460	8,404	6,497

WET YEARS

OUTFLOW (ACRE-FT)

Reach 1 NET Flow (In - Out) Summary Table

NODE	Name	Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Node 1.1.10 NET Flow (In - Out)	USGS 06232000	1.1	2,320	2,552	4,007	7,638	23,254	58,671	23,540	7,557	5,676	5,876	4,966	3,474
Node 1.1.12 NET Flow (In - Out)	Red Butte	1.1	2,320	2,552	4,007	7,513	22,849	57,967	22,618	6,772	5,367	5,832	4,966	3,474
Node 1.1.13 NET Flow (In - Out)	Surrell Creek Confluence	1.1	2,555	2,789	4,332	7,614	23,327	60,858	21,782	4,321	4,680	6,258	5,387	3,767
Node 1.1.14 NET Flow (In - Out)	AggDiv NPA-1	1.1	2,320	2,552	4,007	7,435	22,599	57,532	22,049	6,288	5,176	5,805	4,966	3,474
Node 1.1.16 NET Flow (In - Out)	Mountain Range	1.1	2,322	2,552	4,007	7,372	22,408	57,225	21,686	6,045	5,185	5,900	5,022	3,490
Node 1.1.18 NET Flow (In - Out)	Big Cottonwood	1.1	2,322	2,552	4,007	7,027	21,294	55,287	19,150	3,886	4,335	5,779	5,022	3,490
Node 1.1.20 NET Flow (In - Out)	North Fork and Shady Grove	1.1	2,555	2,789	4,332	7,514	23,018	60,349	21,149	3,839	4,575	6,302	5,410	3,769
Node 1.1.24 NET Flow (In - Out)	AggDiv NPA-2	1.1	2,555	2,789	4,332	7,405	22,668	59,739	20,351	3,160	4,308	6,264	5,410	3,769
Node 1.1.26 NET Flow (In - Out)	USGS 06232500	1.1	1,402	1,682	2,958	6,233	19,762	50,138	19,192	3,160	4,308	4,608	3,877	2,493
Node 1.2.08 NET Flow (In - Out)	Sioux	1.2	1,402	1,682	2,958	6,175	19,610	49,940	19,011	3,141	4,499	4,775	3,930	2,499
Node 1.2.10 NET Flow (In - Out)	Milford	1.2	1,402	1,682	2,958	6,101	19,371	49,530	18,480	2,698	4,338	4,762	3,934	2,500
Node 1.2.12 NET Flow (In - Out)	Harrison	1.2	1,402	1,682	2,958	6,058	19,237	49,306	18,198	2,476	4,279	4,772	3,941	2,500
Node 1.2.14 NET Flow (In - Out)	AggDiv NPA-3	1.2	1,402	1,682	2,958	6,103	19,426	49,719	18,840	3,194	4,816	5,028	4,009	2,508
Node 1.2.16 NET Flow (In - Out)	North Popo Agie Outflow	1.2	1,402	1,682	2,958	6,168	19,654	50,153	19,451	3,789	5,160	5,155	4,039	2,511
Node 1.3.10 NET Flow (In - Out)	Surrell NF	1.3	233	237	325	587	2,033	5,572	2,632	435	345	479	366	277
Node 1.3.12 NET Flow (In - Out)	AggDev SC-1	1.3	233	237	325	587	2,033	5,572	2,632	435	345	479	366	277
Node 1.3.14 NET Flow (In - Out)	Surrell Outflow	1.3	233	237	325	587	2,033	5,572	2,632	435	345	479	366	277

Reach 2 NET Flow (In - Out) Summary Table

NODE	Name	Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Node 2.1.10 NET Flow (In - Out)	Middle Popo Agie Upstream of Roaring Fork	2.1	1,866	2,073	2,662	5,188	17,520	54,561	20,152	5,247	5,752	4,226	3,661	2,455
Node 2.1.11 NET Flow (In - Out)	Confluence Roaring Fork	2.1	2,580	2,765	3,529	5,703	19,428	62,117	22,606	5,247	5,752	5,223	4,586	3,242
Node 2.1.12 NET Flow (In - Out)	USGS 06231600	2.1	2,580	2,765	3,529	5,703	19,428	62,117	22,606	5,247	5,752	5,223	4,586	3,242
Node 2.2.10 NET Flow (In - Out)	Sawmill NF	2.2	1,359	1,315	1,649	1,661	5,832	18,206	9,681	2,634	1,283	2,137	1,759	1,498
Node 2.2.12 NET Flow (In - Out)	Enterprise - Sawmill	2.2	1,359	1,315	1,649	1,337	4,786	16,385	7,301	607	485	2,023	1,759	1,498
Node 2.2.14 NET Flow (In - Out)	Sawmill Outflow	2.2	1,359	1,315	1,649	1,337	4,786	16,385	7,301	607	485	2,023	1,759	1,498
Node 2.3.10 NET Flow (In - Out)	Conf Sawmill	2.3	3,938	4,080	5,178	7,040	24,214	78,502	29,906	5,854	6,237	7,246	6,345	4,741
Node 2.3.12 NET Flow (In - Out)	Gaylor & Warnock	2.3	3,938	4,080	5,178	7,040	24,202	77,844	29,023	5,385	6,006	7,034	6,345	4,741
Node 2.3.14 NET Flow (In - Out)	Lander City Pipeline	2.3	3,938	4,080	5,178	7,040	24,202	77,844	29,023	5,385	6,006	7,034	6,345	4,741
Node 2.3.16 NET Flow (In - Out)	Scott	2.3	3,938	4,080	5,178	7,040	24,202	77,830	28,785	5,362	6,004	7,034	6,345	4,741
Node 2.3.18 NET Flow (In - Out)	Hornecker, Swamp and Melon	2.3	3,938	4,080	5,178	6,980	23,982	77,435	28,486	5,033	5,707	6,758	6,345	4,741
Node 2.3.20 NET Flow (In - Out)	Nicol and Nicol Meyer	2.3	3,938	4,080	5,178	6,939	23,902	77,313	28,333	4,917	5,636	6,706	6,345	4,741
Node 2.3.22 NET Flow (In - Out)	Nicol & Table Mountain	2.3	3,938	4,080	5,178	6,936	23,914	75,762	25,817	3,427	4,968	5,760	6,357	4,744
Node 2.3.24 NET Flow (In - Out)	Meadow, Cottonwood, and Island	2.3	3,938	4,080	5,178	6,878	23,730	75,529	25,541	3,179	4,894	5,787	6,370	4,748
Node 2.3.26 NET Flow (In - Out)	Baldwin	2.3	3,938	4,080	5,178	6,878	23,730	75,042	25,133	2,981	4,680	5,572	6,370	4,748
Node 2.3.28 NET Flow (In - Out)	Conf. Hornecker	2.3	3,989	4,127	5,255	6,991	24,347	77,027	26,131	3,403	5,259	6,165	6,638	4,871
Node 2.3.30 NET Flow (In - Out)	Chalmers & Fogg	2.3	3,989	4,127	5,255	6,991	24,347	76,805	25,949	3,245	5,166	6,097	6,638	4,871
Node 2.3.32 NET Flow (In - Out)	Olson and Barnaby	2.3	3,989	4,127	5,255	6,991	24,347	76,805	25,949	3,245	5,166	6,097	6,638	4,871
Node 2.3.34 NET Flow (In - Out)	Lander City	2.3	3,989	4,127	5,255	6,991	24,347	76,805	25,949	3,245	5,166	6,097	6,638	4,871
Node 2.3.36 NET Flow (In - Out)	Dutch Flat / Taylor	2.3	3,989	4,127	5,255	6,991	24,347	76,152	23,795	2,275	4,511	5,175	6,638	4,871
Node 2.3.38 NET Flow (In - Out)	Cemetery	2.3	3,989	4,127	5,255	6,991	24,290	75,803	23,246	1,890	4,201	4,630	6,638	4,871
Node 2.3.40 NET Flow (In - Out)	Baldwin Creek Confluence	2.3	4,385	4,518	5,769	8,023	28,068	84,912	28,671	4,648	6,154	5,857	7,353	5,378
Node 2.3.42 NET Flow (In - Out)	Last and Forrest	2.3	4,385	4,518	5,769	8,010	28,028	84,844	28,582	4,571	6,124	5,853	7,353	5,378
Node 2.3.44 NET Flow (In - Out)	Conf Middle and North Popo Agie	2.3	5,787	6,200	8,727	14,178	47,682	134,996	48,032	8,360	11,284	11,008	11,392	7,889
Node 2.4.10 NET Flow (In - Out)	Baldwin/Squaw NF	2.4	395	391	513	1,042	3,760	8,972	5,115	2,268	1,422	899	604	487
Node 2.4.12 NET Flow (In - Out)	AggDev BC-1	2.4	395	391	513	859	3,168	7,942	3,767	1,121	970	835	604	487
Node 2.4.14 NET Flow (In - Out)	Baldwin/Squaw Outflow	2.4	395	391	513	1,012	3,707	8,966	5,210	2,524	1,782	1,134	673	495
Node 2.5.10 NET Flow (In - Out)	Roaring Fork NF	2.5	714	691	867	873	3,066	9,570	5,089	1,385	674	1,123	925	788
Node 2.5.12 NET Flow (In - Out)	Enterprise - Roaring Fork	2.5	714	691	867	515	1,908	7,555	2,453	0	0	997	925	788
Node 2.5.14 NET Flow (In - Out)	Roaring Fork Div	2.5	714	691	867	515	1,908	7,555	2,453	0	0	997	925	788
Node 2.5.16 NET Flow (In - Out)	Roaring Fork Outflow	2.5	714	691	867	515	1,908	7,555	2,453	0	0	997	925	788
Node 2.6.10 NET Flow (In - Out)	Hornecker Creek NF	2.6	51	47	77	234	987	2,602	1,883	1,132	743	457	212	105
Node 2.6.12 NET Flow (In - Out)	AggDev HC-1	2.6	51	47	77	86	508	1,769	793	204	378	405	212	105
Node 2.6.14 NET Flow (In - Out)	Hornecker Creek Outflow	2.6	51	47	77	86	508	1,769	793	204	378	405	212	105

OUTFLOW (ACRE-FT)

Reach 3 NET Flow (In - Out) Summary Table

NODE		Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Node 3.1.10 NET Flow (In - Out)	Little Popo Agie NF	3.1	1,752	1,713	2,183	2,731	14,115	30,731	11,787	3,432	2,518	2,782	2,306
Node 3.1.12 NET Flow (In - Out)	Conf. Red Canyon	3.1	2,356	2,305	2,944	3,660	19,098	41,666	15,913	4,599	3,430	3,782	3,118
Node 3.1.14 NET Flow (In - Out)	AggDev LPA-1	3.2	2,356	2,305	2,944	3,633	19,009	41,511	15,710	4,426	3,362	3,772	3,118
Node 3.1.16 NET Flow (In - Out)	USGS Gage 06233000	3.3	2,357	2,305	2,944	3,673	19,152	41,786	16,104	4,821	3,607	3,877	3,151
Node 3.2.10 NET Flow (In - Out)	Red Canyon NF	3.2	604	592	761	961	5,088	11,115	4,363	1,368	991	1,011	812
Node 3.2.12 NET Flow (In - Out)	AggDev RC-1	3.2	604	592	761	929	4,984	10,934	4,126	1,166	912	1,000	812
Node 3.2.14 NET Flow (In - Out)	Red Canyon Outflow	3.3	604	592	761	929	4,984	10,934	4,126	1,166	912	1,000	812
Node 3.3.12 NET Flow (In - Out)	AggDev LPA-2	3.3	2,568	2,482	3,097	4,446	18,992	41,508	15,741	4,511	3,485	3,860	3,151
Node 3.3.14 NET Flow (In - Out)	Conf. Twin Creek	3.3	2,628	2,551	3,187	4,746	19,249	42,137	16,543	4,930	3,796	3,980	3,186
Node 3.3.16 NET Flow (In - Out)	Bryant and Ocenas	3.3	2,628	2,551	3,187	4,722	19,172	42,004	16,369	4,781	3,737	3,972	3,186
Node 3.3.18 NET Flow (In - Out)	Conf. Willow Creek	3.3	2,798	2,709	3,392	5,160	20,433	45,440	19,092	6,717	5,218	4,926	3,694
Node 3.3.20 NET Flow (In - Out)	AggDev LPA-3	3.3	2,798	2,709	3,392	5,143	20,381	45,359	18,995	6,651	5,218	4,943	3,701
Node 3.3.22 NET Flow (In - Out)	Millard and Shedd	3.3	2,798	2,709	3,392	4,978	19,842	44,939	19,035	6,600	5,473	5,514	3,877
Node 3.3.24 NET Flow (In - Out)	Lyons	3.3	2,798	2,709	3,392	4,951	19,779	44,877	19,009	6,671	5,639	5,635	3,914
Node 3.3.26 NET Flow (In - Out)	Rogers & Gregg No. 2 (Wise)	3.3	2,798	2,709	3,392	4,857	19,489	44,400	18,420	6,227	5,549	5,682	3,936
Node 3.3.28 NET Flow (In - Out)	Hudson	3.3	2,798	2,709	3,392	4,857	19,489	44,400	18,420	6,227	5,549	5,682	3,936
Node 3.3.30 NET Flow (In - Out)	USGS Gage 06233500	3.3	2,798	2,709	3,392	4,924	13,959	36,740	17,978	3,354	2,883	4,412	3,614
Node 3.5.10 NET Flow (In - Out)	Twin Creek NF	3.5	60	69	90	325	325	724	898	453	254	63	16
Node 3.5.12 NET Flow (In - Out)	AggDev TC-1	3.5	60	69	90	258	110	351	410	37	90	39	16
Node 3.5.14 NET Flow (In - Out)	Twin Creek Outflow	3.6	60	69	90	289	218	556	699	318	253	99	30
Node 3.6.10 NET Flow (In - Out)	Willow Creek NF	3.6	161	158	205	324	1,016	2,613	1,363	386	264	257	204
Node 3.6.12 NET Flow (In - Out)	AggDev WC-1	3.6	161	158	205	282	880	2,377	1,053	122	160	243	204
Node 3.6.14 NET Flow (In - Out)	Willow Creek Outflow	3.6	161	158	205	301	949	2,506	1,236	301	263	281	213

Reach 4 NET Flow (In - Out) Summary Table

NODE		Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Node 4.1.10 NET Flow (In - Out)	Inflow From Reach 3	4.1	5,787	6,200	8,727	15,264	52,007	134,996	48,032	8,360	11,284	11,008	11,392
Node 4.1.12 NET Flow (In - Out)	Snavely and Grant Young	4.1	5,787	6,200	8,727	15,080	51,414	134,502	47,997	8,283	11,586	11,625	11,582
Node 4.1.14 NET Flow (In - Out)	Mid-Reach 4.1	4.1	5,787	6,200	8,727	14,984	51,107	133,967	47,297	7,687	11,351	11,592	11,582
Node 4.1.16 NET Flow (In - Out)	Conf. Little Popo Agie	4.1	8,585	8,909	12,119	20,014	65,440	171,418	66,278	12,016	14,798	16,211	15,245
Node 4.1.18 NET Flow (In - Out)	USGS Gage 06233900 - End	4.1	5,421	5,563	8,129	19,950	65,269	156,212	56,608	12,934	14,488	11,228	11,739

Dry Years (4 Month Irrigation Season)

North Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Conveyance Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Red Butte	3,588	40%	1,435	5.9
AggDiv NPA-1	2,213	40%	885	3.7
Mountain Range	2,540	40%	1,016	4.2
Big Cottonwood	9,868	40%	3,947	16.3
North Fork and Shady Grove	4,298	40%	1,719	7.1
AggDiv NPA-2	2,654	35%	929	3.8
Sioux	5,001	30%	1,500	6.2
Milford	1,562	40%	625	2.6
Harrison	1,139	40%	456	1.9
AggDiv NPA-3	3,015	40%	1,206	5.0

Middle Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Conveyance Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Enterprise - Sawmill	8,560	45%	3,852	15.9
Gaylor & Warnock	3,072	40%	1,229	5.1
Scott	275	40%	110	0.5
Hornecker, Swamp and Melon	2,152	40%	861	3.6
Nicol and Nicol Meyer	879	40%	351	1.5
Nicol & Table Mountain	9,140	40%	3,656	15.1
Meadow, Cottonwood, and Island	1,651	40%	660	2.7
Baldwin	2,866	40%	1,146	4.7
Dutch Flat / Taylor	5,939	20%	1,188	4.9
Cemetery	2,301	22%	506	2.1
Last and Forrest	349	40%	140	0.6
AggDev BC-1	5,243	40%	2,097	8.7
Enterprise - Roaring Fork	8,108	40%	3,243	13.4
AggDev HC-1	4,196	40%	1,678	6.9

Little Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Conveyance Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
AggDev LPA-1	788	40%	315	1.3
AggDev RC-1	922	40%	369	1.5
AggDev LPA-2	1,415	40%	566	2.3
Bryant and Ocenas	678	40%	271	1.1
AggDev LPA-3	922	40%	369	1.5
Millard and Shedd	5,067	30%	1,520	6.3
Lyons	3,100	30%	930	3.8
Rogers & Gregg No. 2 (Wise)	4,128	38%	1,569	6.5
AggDev TC-1	1,900	40%	760	3.1
AggDev WC-1	1,204	38%	457	1.9

Normal Years (4 Month Irrigation Season)

North Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Conveyance Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Red Butte	3,284	40%	1,314	5.4
AggDiv NPA-1	2,025	40%	810	3.3
Mountain Range	2,325	40%	930	3.8
Big Cottonwood	9,032	40%	3,613	14.9
North Fork and Shady Grove	3,934	40%	1,574	6.5
AggDiv NPA-2	2,841	35%	995	4.1
Sioux	4,577	30%	1,373	5.7
Milford	2,162	40%	865	3.6
Harrison	1,546	40%	619	2.6
AggDiv NPA-3	2,760	40%	1,104	4.6

Middle Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Conveyance Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Enterprise - Sawmill	8,182	45%	3,682	15.2
Gaylor & Warnock	3,332	40%	1,333	5.5
Scott	191	40%	77	0.3
Hornecker, Swamp and Melon	1,763	40%	705	2.9
Nicol and Nicol Meyer	724	40%	290	1.2
Nicol & Table Mountain	9,553	40%	3,821	15.8
Meadow, Cottonwood, and Island	1,511	40%	604	2.5
Baldwin	2,567	40%	1,027	4.2
Dutch Flat / Taylor	7,804	20%	1,561	6.4
Cemetery	3,311	22%	728	3.0
Last and Forrest	319	40%	128	0.5
AggDev BC-1	4,799	40%	1,919	7.9
Enterprise - Roaring Fork	8,346	40%	3,339	13.8
AggDev HC-1	3,882	40%	1,553	6.4

Little Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Conveyance Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
AggDev LPA-1	721	40%	288	1.2
AggDev RC-1	844	40%	338	1.4
AggDev LPA-2	1,295	40%	518	2.1
Bryant and Ocenas	620	40%	248	1.0
AggDev LPA-3	844	40%	338	1.4
Millard and Shedd	4,637	30%	1,391	5.7
Lyons	2,838	30%	851	3.5
Rogers & Gregg No. 2 (Wise)	3,779	38%	1,436	5.9
AggDev TC-1	1,739	40%	696	2.9
AggDev WC-1	1,102	38%	419	1.7

Wet Years (4 Month Irrigation Season)

North Popo Agie

Diversion Ditch	Total Diversion Volume (acre-ft)	Percent Loss to Conveyance Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Red Butte	3,296	40%	1,318	5.4
AggDiv NPA-1	2,032	40%	813	3.4
Mountain Range	2,333	40%	933	3.9
Big Cottonwood	9,064	40%	3,625	15.0
North Fork and Shady Grove	3,948	40%	1,579	6.5
AggDiv NPA-2	2,851	35%	998	4.1
Sioux	4,593	30%	1,378	5.7
Milford	2,170	40%	868	3.6
Harrison	1,552	40%	621	2.6
AggDiv NPA-3	2,769	40%	1,108	4.6

Middle Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Conveyance Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Enterprise - Sawmill	8,509	45%	3,829	15.8
Gaylor & Warnock	2,466	40%	986	4.1
Scott	276	40%	110	0.5
Hornecker, Swamp and Melon	1,876	40%	750	3.1
Nicol and Nicol Meyer	636	40%	254	1.1
Nicol & Table Mountain	7,750	40%	3,100	12.8
Meadow, Cottonwood, and Island	1,516	40%	606	2.5
Baldwin	1,521	40%	609	2.5
Dutch Flat / Taylor	5,356	20%	1,071	4.4
Cemetery	2,195	22%	483	2.0
Last and Forrest	320	40%	128	0.5
AggDev BC-1	4,815	40%	1,926	8.0
Enterprise - Roaring Fork	8,352	40%	3,341	13.8
AggDev HC-1	3,895	40%	1,558	6.4

Little Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Conveyance Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
AggDev LPA-1	724	40%	289	1.2
AggDev RC-1	847	40%	339	1.4
AggDev LPA-2	1,300	40%	520	2.1
Bryant and Ocenas	623	40%	249	1.0
AggDev LPA-3	847	40%	339	1.4
Millard and Shedd	4,654	30%	1,396	5.8
Lyons	2,847	30%	854	3.5
Rogers & Gregg No. 2 (Wise)	3,792	38%	1,441	6.0
AggDev TC-1	1,745	40%	698	2.9
AggDev WC-1	1,105	38%	420	1.7

Dry Years (4 Month Irrigation Season)

North Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Application Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Red Butte	3,588	34%	1,203	5.0
AggDiv NPA-1	2,213	34%	742	3.1
Mountain Range	2,540	34%	852	3.5
Big Cottonwood	9,868	34%	3,309	13.7
North Fork and Shady Grove	4,298	34%	1,441	6.0
AggDiv NPA-2	2,654	34%	890	3.7
Sioux	5,001	18%	883	3.6
Milford	1,562	34%	524	2.2
Harrison	1,139	34%	382	1.6
AggDiv NPA-3	3,015	34%	1,011	4.2

Middle Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Application Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Enterprise - Sawmill	8,560	34%	2,870	11.9
Gaylor & Warnock	3,072	34%	1,030	4.3
Scott	275	34%	92	0.4
Hornecker, Swamp and Melon	2,152	34%	722	3.0
Nicol and Nicol Meyer	879	34%	295	1.2
Nicol & Table Mountain	9,140	32%	2,936	12.1
Meadow, Cottonwood, and Island	1,651	34%	553	2.3
Baldwin	2,866	34%	961	4.0
Dutch Flat / Taylor	5,939	34%	1,991	8.2
Cemetery	2,301	34%	771	3.2
Last and Forrest	349	34%	117	0.5
AggDev BC-1	5,243	34%	1,758	7.3
Enterprise - Roaring Fork	8,108	34%	2,719	11.2
AggDev HC-1	4,196	34%	1,407	5.8

Little Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Application Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
AggDev LPA-1	788	34%	264	1.1
AggDev RC-1	922	34%	309	1.3
AggDev LPA-2	1,415	34%	475	2.0
Bryant and Ocenas	678	34%	227	0.9
AggDev LPA-3	922	34%	309	1.3
Millard and Shedd	5,067	30%	1,511	6.2
Lyons	3,100	17%	536	2.2
Rogers & Gregg No. 2 (Wise)	4,128	25%	1,020	4.2
AggDev TC-1	1,900	34%	637	2.6
AggDev WC-1	1,204	33%	395	1.6

Normal Years (4 Month Irrigation Season)

North Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Application Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Red Butte	3,284	34%	1,101	4.6
AggDiv NPA-1	2,025	34%	679	2.8
Mountain Range	2,325	34%	779	3.2
Big Cottonwood	9,032	34%	3,028	12.5
North Fork and Shady Grove	3,934	34%	1,319	5.5
AggDiv NPA-2	2,841	34%	953	3.9
Sioux	4,577	18%	808	3.3
Milford	2,162	34%	725	3.0
Harrison	1,546	34%	518	2.1
AggDiv NPA-3	2,760	34%	925	3.8

Middle Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Application Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Enterprise - Sawmill	8,182	34%	2,743	11.3
Gaylor & Warnock	3,332	34%	1,117	4.6
Scott	191	34%	64	0.3
Hornecker, Swamp and Melon	1,763	34%	591	2.4
Nicol and Nicol Meyer	724	34%	243	1.0
Nicol & Table Mountain	9,553	32%	3,068	12.7
Meadow, Cottonwood, and Island	1,511	34%	507	2.1
Baldwin	2,567	34%	861	3.6
Dutch Flat / Taylor	7,804	34%	2,617	10.8
Cemetery	3,311	34%	1,110	4.6
Last and Forrest	319	34%	107	0.4
AggDev BC-1	4,799	34%	1,609	6.6
Enterprise - Roaring Fork	8,346	34%	2,799	11.6
AggDev HC-1	3,882	34%	1,302	5.4

Little Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Application Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
AggDev LPA-1	721	34%	242	1.0
AggDev RC-1	844	34%	283	1.2
AggDev LPA-2	1,295	34%	434	1.8
Bryant and Ocenas	620	34%	208	0.9
AggDev LPA-3	844	34%	283	1.2
Millard and Shedd	4,637	30%	1,383	5.7
Lyons	2,838	17%	491	2.0
Rogers & Gregg No. 2 (Wise)	3,779	25%	934	3.9
AggDev TC-1	1,739	34%	583	2.4
AggDev WC-1	1,102	33%	362	1.5

Wet Years (4 Month Irrigation Season)

North Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Application Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Red Butte	3,296	34%	1,105	4.6
AggDiv NPA-1	2,032	34%	681	2.8
Mountain Range	2,333	34%	782	3.2
Big Cottonwood	9,064	34%	3,039	12.6
North Fork and Shady Grove	3,948	34%	1,324	5.5
AggDiv NPA-2	2,851	34%	956	4.0
Sioux	4,593	18%	811	3.3
Milford	2,170	34%	727	3.0
Harrison	1,552	34%	520	2.2
AggDiv NPA-3	2,769	34%	929	3.8

Middle Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Application Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
Enterprise - Sawmill	8,509	34%	2,853	11.8
Gaylor & Warnock	2,466	34%	827	3.4
Scott	276	34%	93	0.4
Hornecker, Swamp and Melon	1,876	34%	629	2.6
Nicol and Nicol Meyer	636	34%	213	0.9
Nicol & Table Mountain	7,750	32%	2,489	10.3
Meadow, Cottonwood, and Island	1,516	34%	508	2.1
Baldwin	1,521	34%	510	2.1
Dutch Flat / Taylor	5,356	34%	1,796	7.4
Cemetery	2,195	34%	736	3.0
Last and Forrest	320	34%	107	0.4
AggDev BC-1	4,815	34%	1,615	6.7
Enterprise - Roaring Fork	8,352	34%	2,800	11.6
AggDev HC-1	3,895	34%	1,306	5.4
			34%	

Little Popo Agie

Diversion Ditch	Total Annual Diversion Volume (acre-ft)	Percent Loss to Application Inefficiencies	Total Losses (acre-ft)	Avergae Daily Losses (cfs)
AggDev LPA-1	724	34%	243	1.0
AggDev RC-1	847	34%	284	1.2
AggDev LPA-2	1,300	34%	436	1.8
Bryant and Ocenas	623	34%	209	0.9
AggDev LPA-3	847	34%	284	1.2
Millard and Shedd	4,654	30%	1,388	5.7
Lyons	2,847	17%	492	2.0
Rogers & Gregg No. 2 (Wise)	3,792	25%	937	3.9
AggDev TC-1	1,745	34%	585	2.4
AggDev WC-1	1,105	33%	363	1.5

Dry Years (4 Month Irrigation Season)

North Popo Agie

Diversion Ditch	Total Diversion Volume (acre-ft)	Total Combined Losses (acre-ft)	Combined Average Daily Losses (cfs)
Red Butte	3,588	2638	10.9
AggDiv NPA-1	2,213	1627	6.7
Mountain Range	2,540	1867	7.7
Big Cottonwood	9,868	7256	30.0
North Fork and Shady Grove	4,298	3161	13.1
AggDiv NPA-2	2,654	1819	7.5
Sioux	5,001	2383	9.8
Milford	1,562	1148	4.7
Harrison	1,139	837	3.5
AggDiv NPA-3	3,015	2217	9.2

Middle Popo Agie

Diversion Ditch			
Enterprise - Sawmill	8,560	6722	27.8
Gaylor & Warnock	3,072	2259	9.3
Scott	275	203	0.8
Hornecker, Swamp and Melon	2,152	1582	6.5
Nicol and Nicol Meyer	879	646	2.7
Nicol & Table Mountain	9,140	6592	27.2
Meadow, Cottonwood, and Island	1,651	1214	5.0
Baldwin	2,866	2107	8.7
Dutch Flat / Taylor	5,939	3179	13.1
Cemetery	2,301	1278	5.3
Last and Forrest	349	257	1.1
AggDev BC-1	5,243	3855	15.9
Enterprise - Roaring Fork	8,108	5962	24.6
AggDev HC-1	4,196	3085	12.7

Little Popo Agie

Diversion Ditch			
AggDev LPA-1	788	579	2.4
AggDev RC-1	922	678	2.8
AggDev LPA-2	1,415	1041	4.3
Bryant and Ocenas	678	498	2.1
AggDev LPA-3	922	678	2.8
Millard and Shedd	5,067	3031	12.5
Lyons	3,100	1466	6.1
Rogers & Gregg No. 2 (Wise)	4,128	2589	10.7
AggDev TC-1	1,900	1397	5.8
AggDev WC-1	1,204	852	3.5

Normal Years (4 Month Irrigation Season)

North Popo Agie

Diversion Ditch	Total Diversion Volume (acre-ft)	Total Combined Losses (acre-ft)	Combined Average Daily Losses (cfs)
Red Butte	3,284	2415	10.0
AggDiv NPA-1	2,025	1489	6.2
Mountain Range	2,325	1709	7.1
Big Cottonwood	9,032	6641	27.4
North Fork and Shady Grove	3,934	2893	12.0
AggDiv NPA-2	2,841	1947	8.0
Sioux	4,577	2181	9.0
Milford	2,162	1590	6.6
Harrison	1,546	1137	4.7
AggDiv NPA-3	2,760	2029	8.4

Middle Popo Agie

Diversion Ditch			
Enterprise - Sawmill	8,182	6425	26.6
Gaylor & Warnock	3,332	2450	10.1
Scott	191	141	0.6
Hornecker, Swamp and Melon	1,763	1296	5.4
Nicol and Nicol Meyer	724	532	2.2
Nicol & Table Mountain	9,553	6889	28.5
Meadow, Cottonwood, and Island	1,511	1111	4.6
Baldwin	2,567	1888	7.8
Dutch Flat / Taylor	7,804	4177	17.3
Cemetery	3,311	1839	7.6
Last and Forrest	319	235	1.0
AggDev BC-1	4,799	3528	14.6
Enterprise - Roaring Fork	8,346	6137	25.4
AggDev HC-1	3,882	2854	11.8

Little Popo Agie

Diversion Ditch			
AggDev LPA-1	721	530	2.2
AggDev RC-1	844	620	2.6
AggDev LPA-2	1,295	953	3.9
Bryant and Ocenas	620	456	1.9
AggDev LPA-3	844	620	2.6
Millard and Shedd	4,637	2774	11.5
Lyons	2,838	1342	5.5
Rogers & Gregg No. 2 (Wise)	3,779	2369	9.8
AggDev TC-1	1,739	1279	5.3
AggDev WC-1	1,102	780	3.2

Wet Years (4 Month Irrigation Season)

North Popo Agie

Diversion Ditch	Total Diversion Volume (acre-ft)	Total Combined Losses (acre-ft)	Combined Average Daily Losses (cfs)
Red Butte	3,296	2423	10.0
AggDiv NPA-1	2,032	1494	6.2
Mountain Range	2,333	1715	7.1
Big Cottonwood	9,064	6664	27.5
North Fork and Shady Grove	3,948	2903	12.0
AggDiv NPA-2	2,851	1954	8.1
Sioux	4,593	2189	9.0
Milford	2,170	1595	6.6
Harrison	1,552	1141	4.7
AggDiv NPA-3	2,769	2036	8.4

Middle Popo Agie

Diversion Ditch			
Enterprise - Sawmill	8,509	6682	27.6
Gaylor & Warnock	2,466	1813	7.5
Scott	276	203	0.8
Hornecker, Swamp and Melon	1,876	1379	5.7
Nicol and Nicol Meyer	636	467	1.9
Nicol & Table Mountain	7,750	5589	23.1
Meadow, Cottonwood, and Island	1,516	1115	4.6
Baldwin	1,521	1119	4.6
Dutch Flat / Taylor	5,356	2867	11.8
Cemetery	2,195	1219	5.0
Last and Forrest	320	236	1.0
AggDev BC-1	4,815	3541	14.6
Enterprise - Roaring Fork	8,352	6141	25.4
AggDev HC-1	3,895	2864	11.8

Little Popo Agie

Diversion Ditch			
AggDev LPA-1	724	532	2.2
AggDev RC-1	847	623	2.6
AggDev LPA-2	1,300	956	4.0
Bryant and Ocenas	623	458	1.9
AggDev LPA-3	847	623	2.6
Millard and Shedd	4,654	2784	11.5
Lyons	2,847	1347	5.6
Rogers & Gregg No. 2 (Wise)	3,792	2378	9.8
AggDev TC-1	1,745	1283	5.3
AggDev WC-1	1,105	783	3.2

APPENDIX C
ADDITIONAL FIGURES AND TABLES ON MICROSTORAGE

INDEX TO APPENDIX C FIGURES

Site Name	Figure Number for Potential Microstorage Site Layout and Soils	Figure Number for Irrigated Acres (from ACE 2003) and National Wetlands Inventory
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Surrell Creek No 1	C-3a	C-3b
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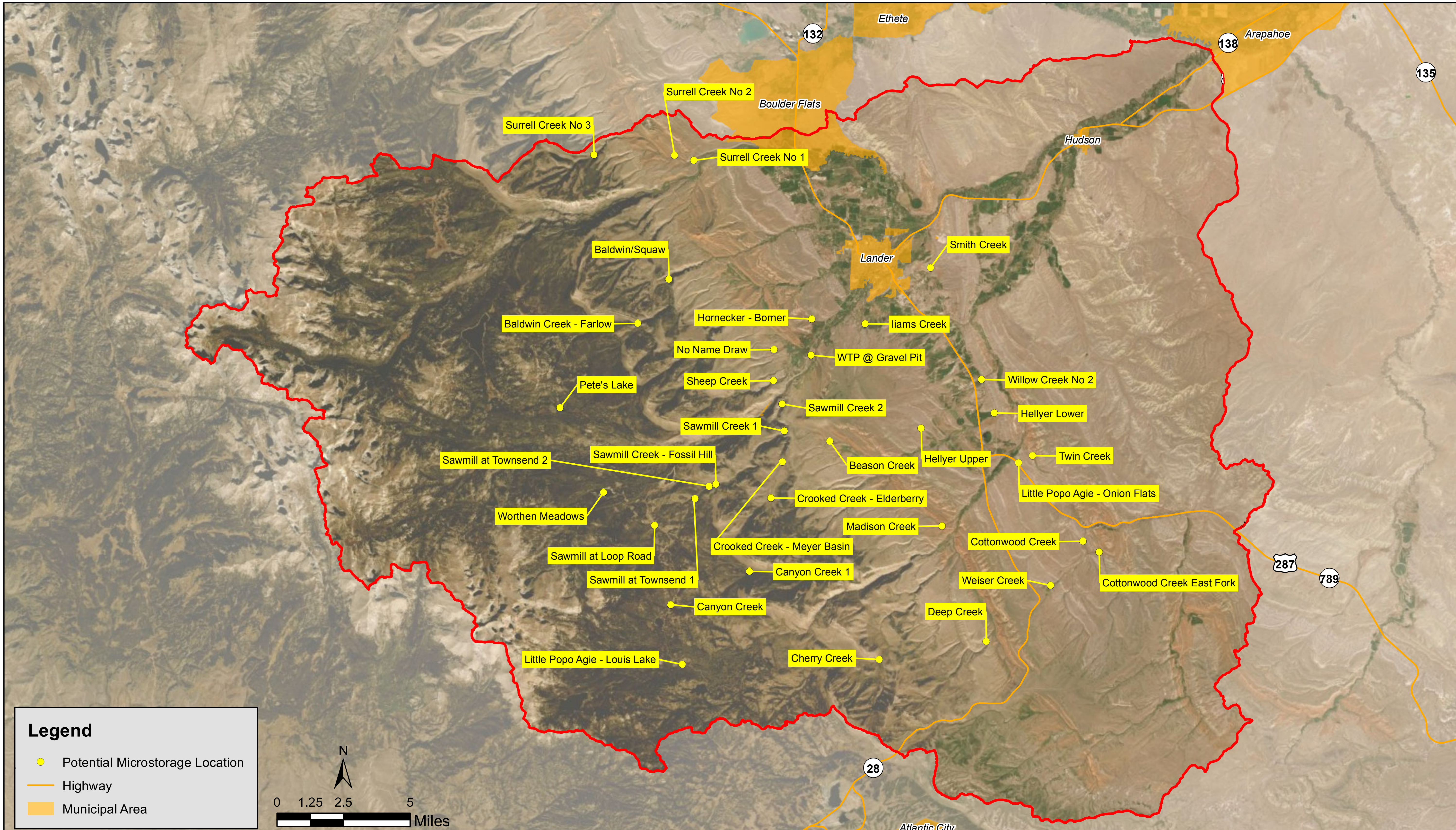
Deep Creek	C-35a	C-35b
Weiser Creek	C-36a	C-36b



POPO AGIE WATERSHED STUDY

Potential Microstorage Location Overview

olsson
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APPENDIX C

INDEX MAP

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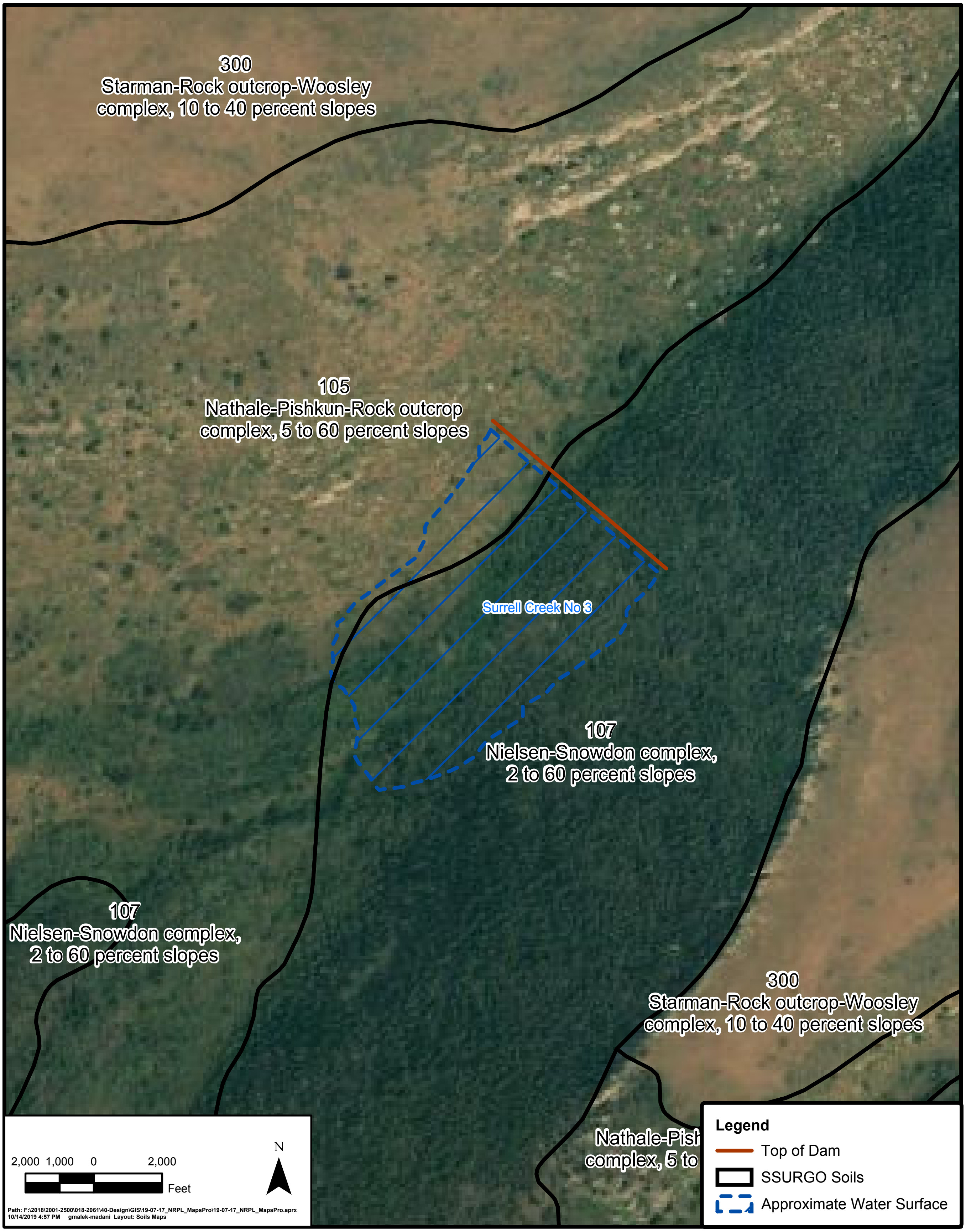

POPO AGIE WATERSHED STUDY

Surrell Creek No 3
Potential Microstorage Layout and Soils

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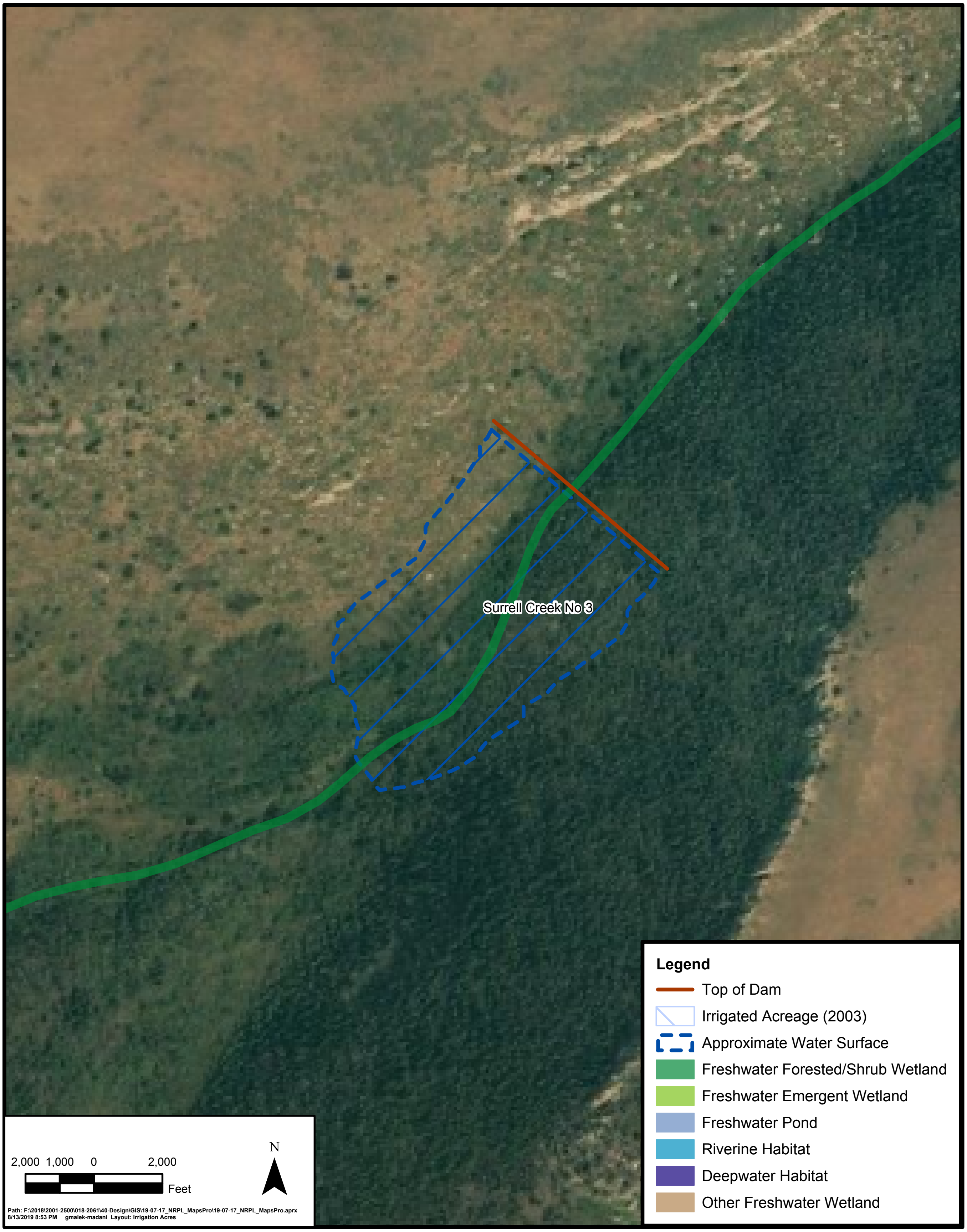
FIGURE
C-1a



POPO AGIE WATERSHED STUDY

Surrell Creek No 3
Potential Microstorage Irrigation & NWI

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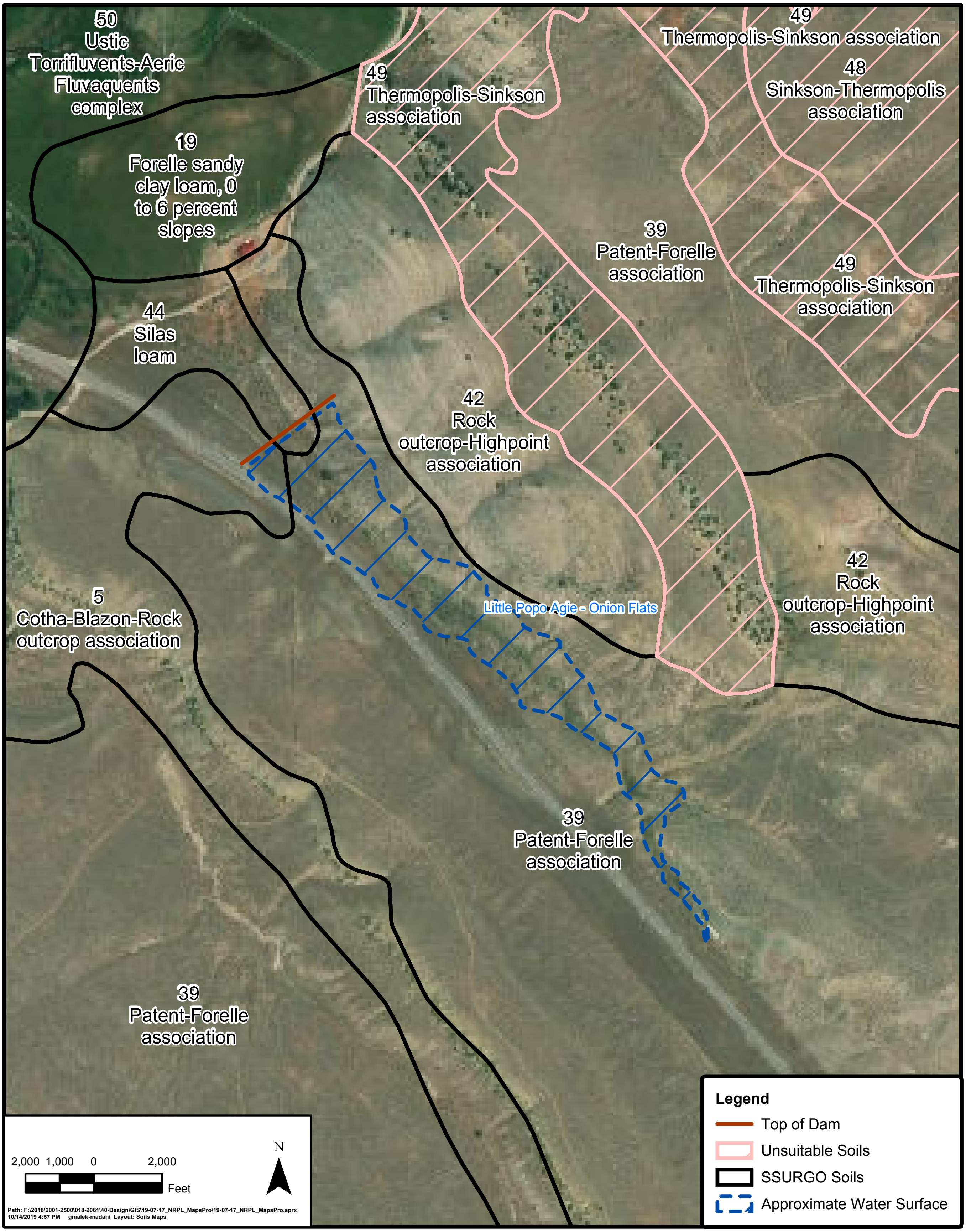
FIGURE

C-1b



POPO AGIE WATERSHED STUDY

Little Popo Agie - Onion Flats
Potential Microstorage Layout and Soils

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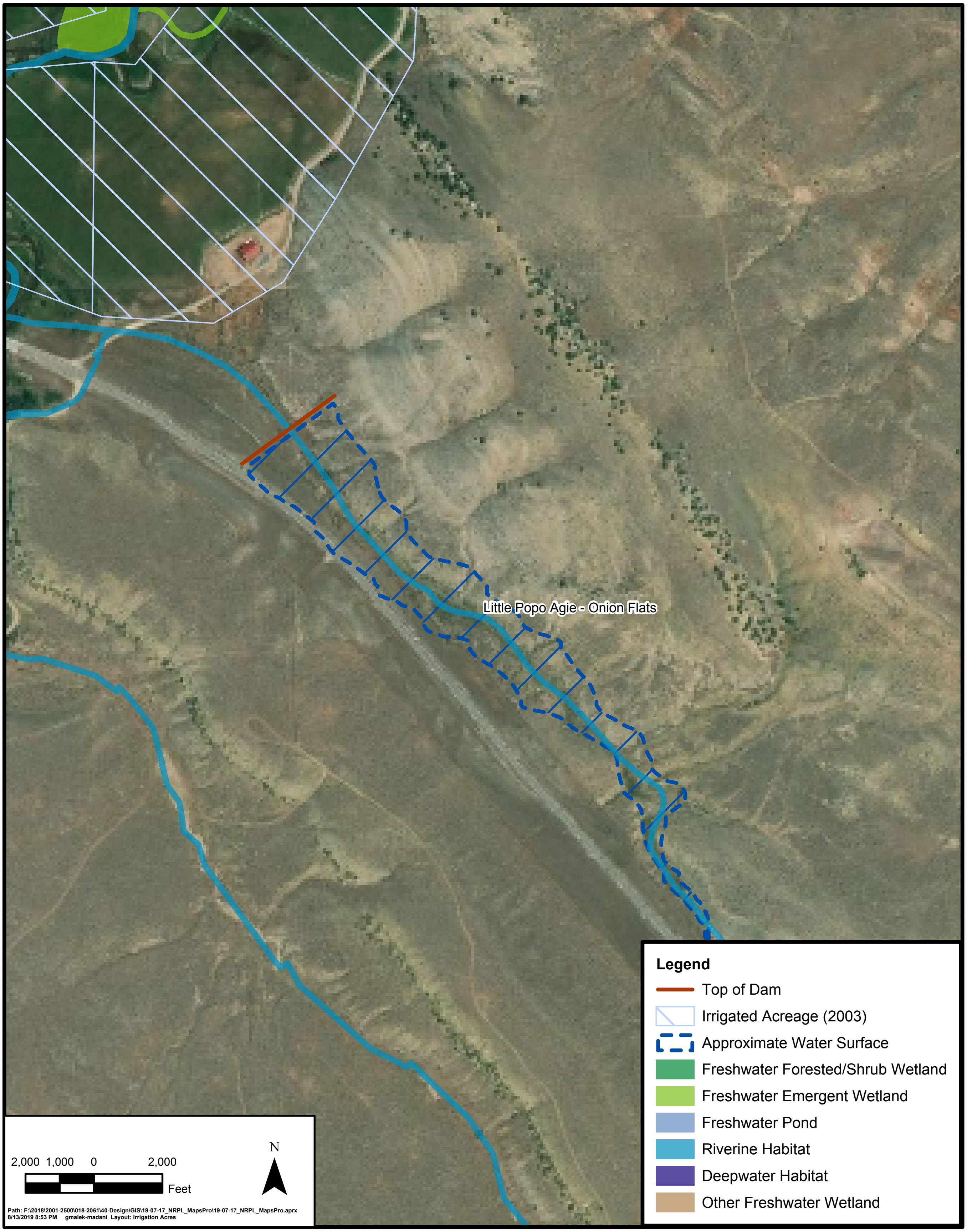
FIGURE
C-2a



POPO AGIE WATERSHED STUDY

Little Popo Agie - Onion Flats
Potential Microstorage Irrigation & NWI

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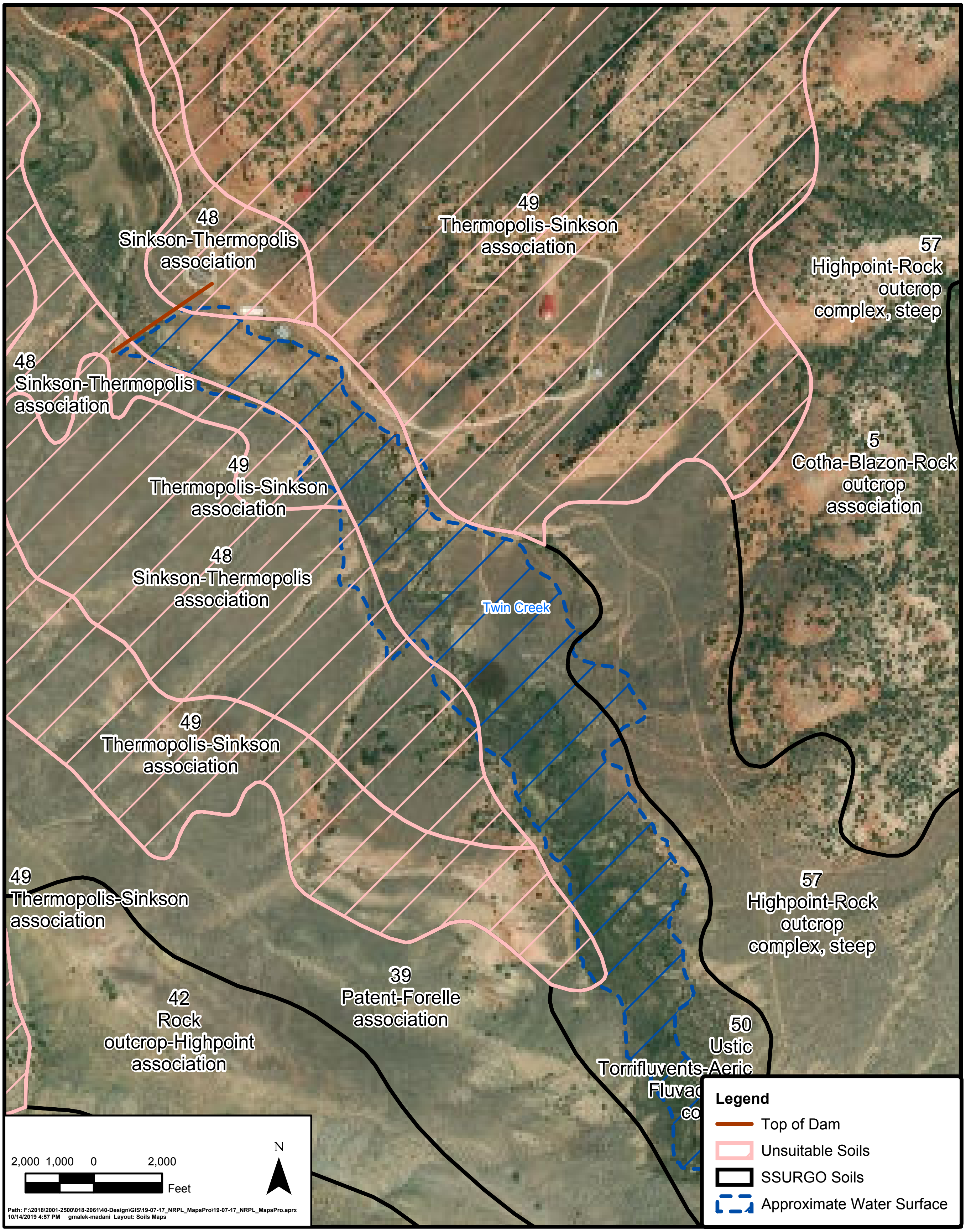
FIGURE

C-2b



POPO AGIE WATERSHED STUDY

Twin Creek
Potential Microstorage Layout and Soils

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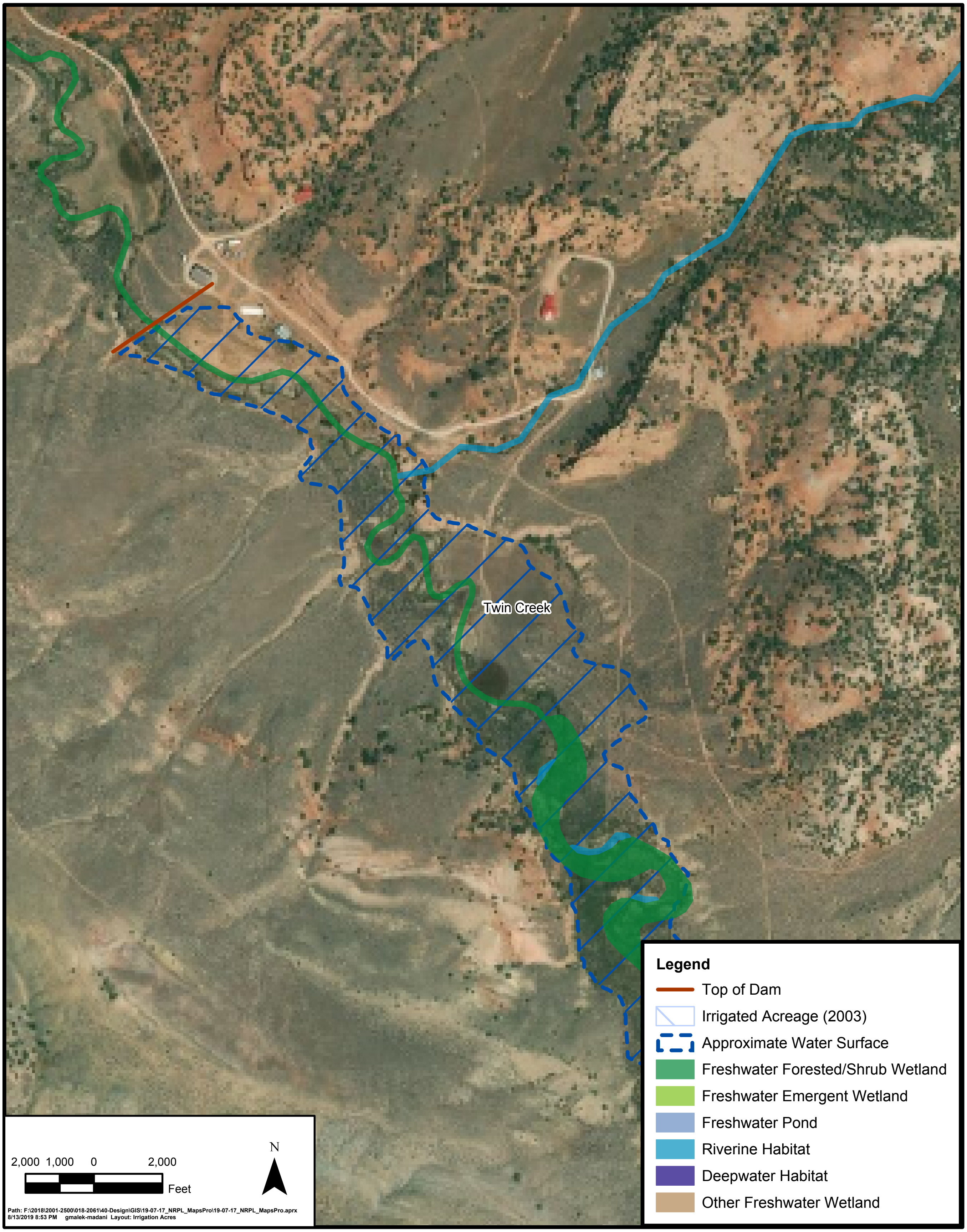
FIGURE

C-3a



POPO AGIE WATERSHED STUDY

Twin Creek
Potential Microstorage Irrigation & NWI

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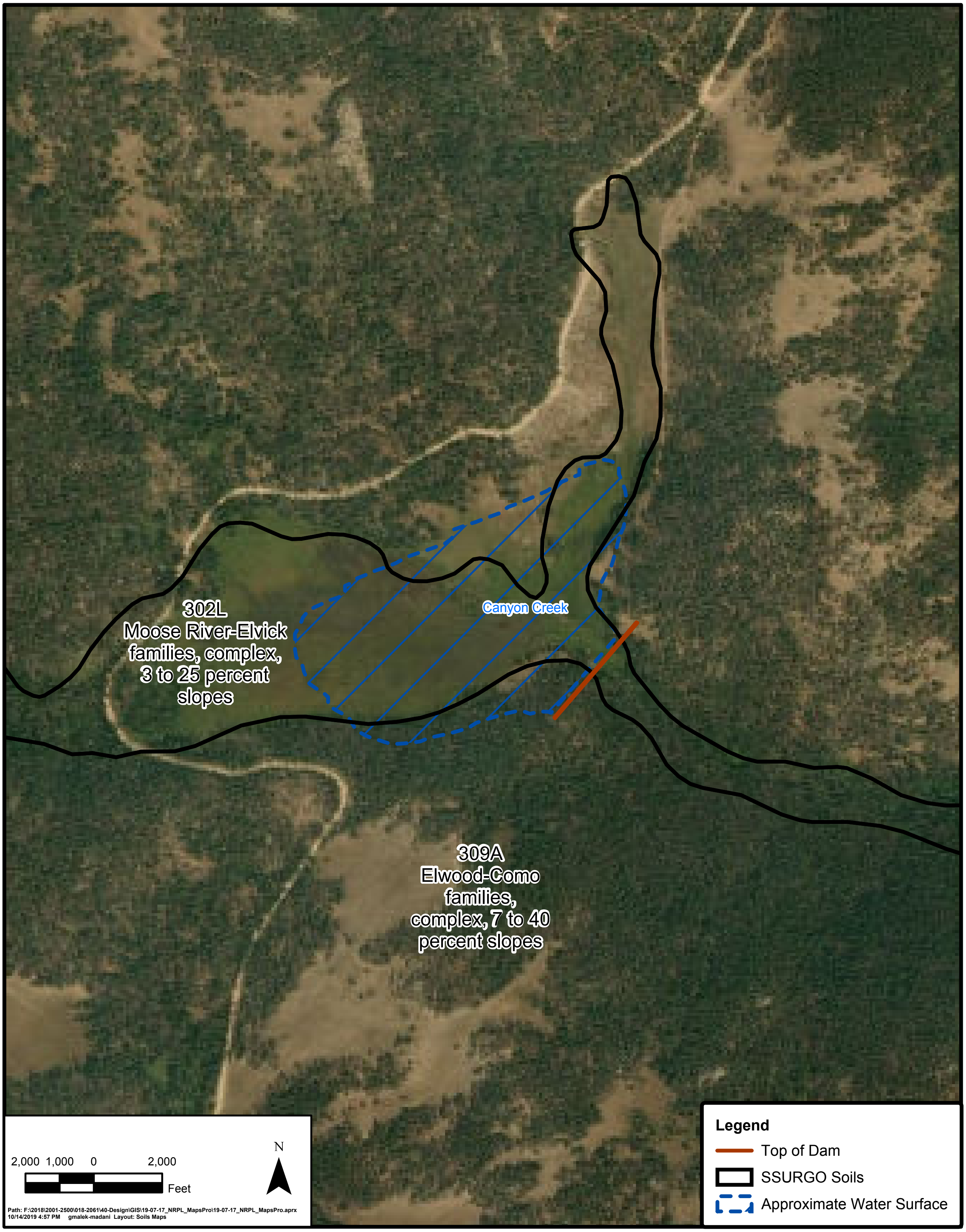
FIGURE

C-3b



POPO AGIE WATERSHED STUDY

Canyon Creek
Potential Microstorage Layout and Soils

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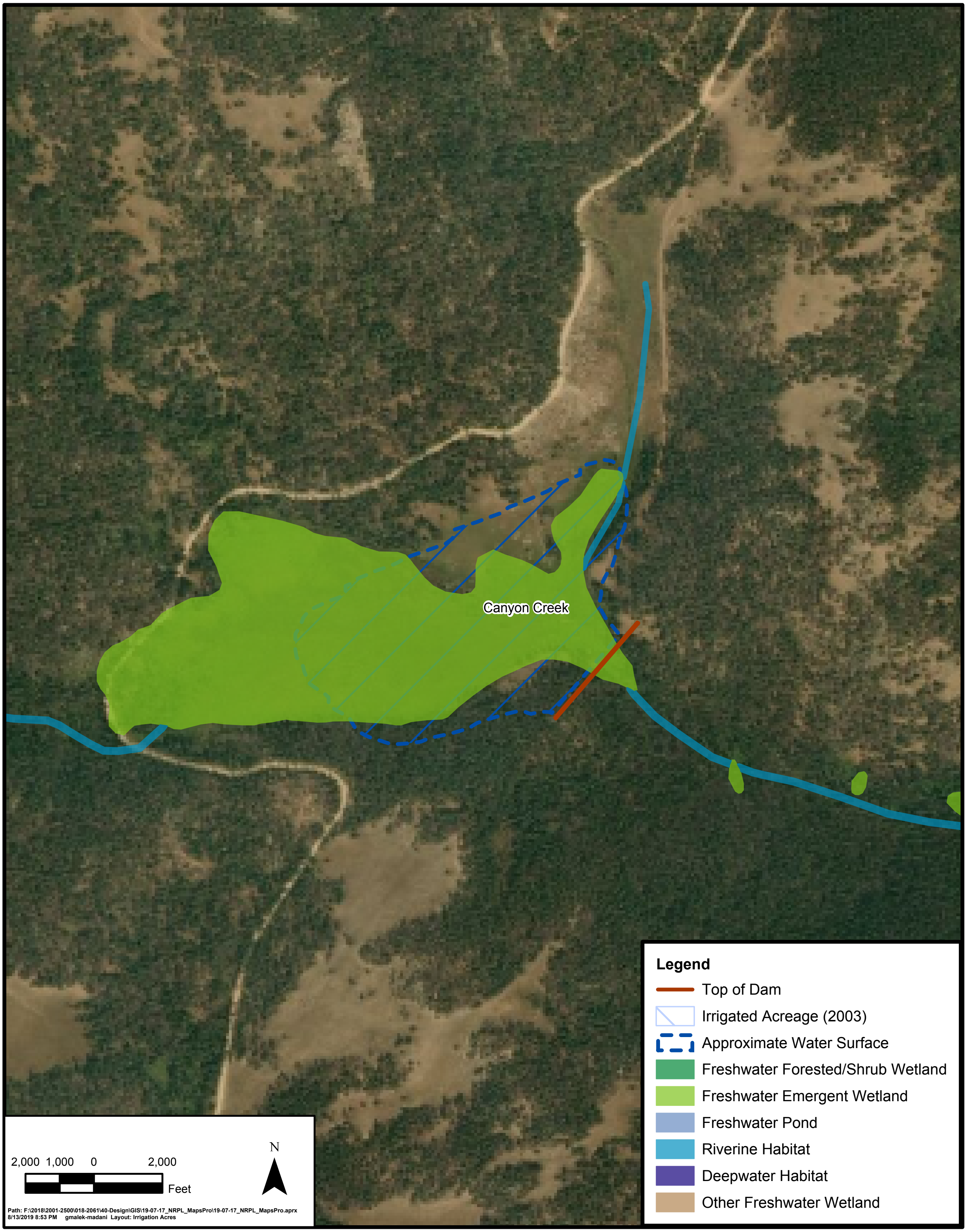
FIGURE

C-4a



POPO AGIE WATERSHED STUDY

Canyon Creek
Potential Microstorage Irrigation & NWI

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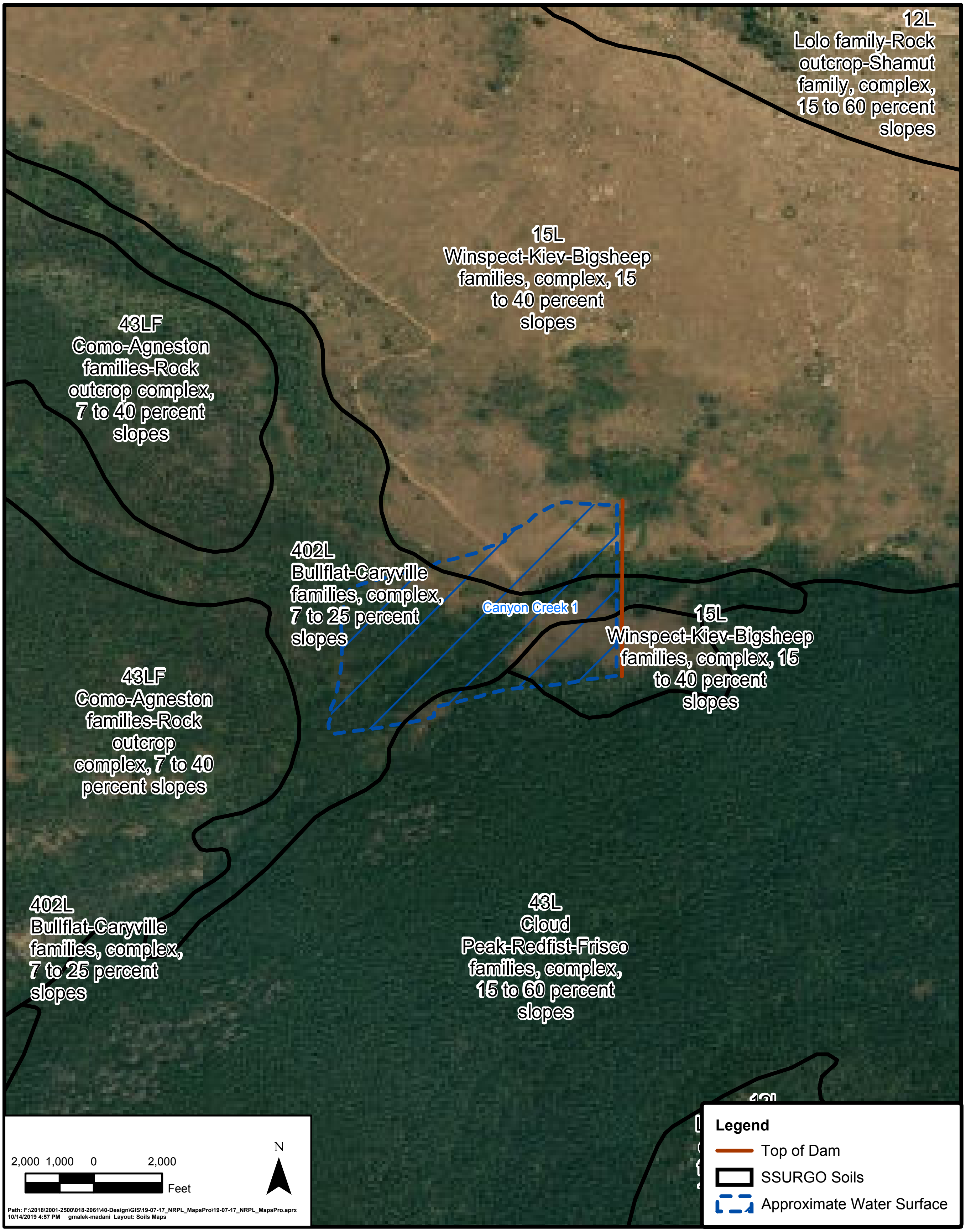
FIGURE C-4b



POPO AGIE WATERSHED STUDY

Canyon Creek 1
Potential Microstorage Layout and Soils

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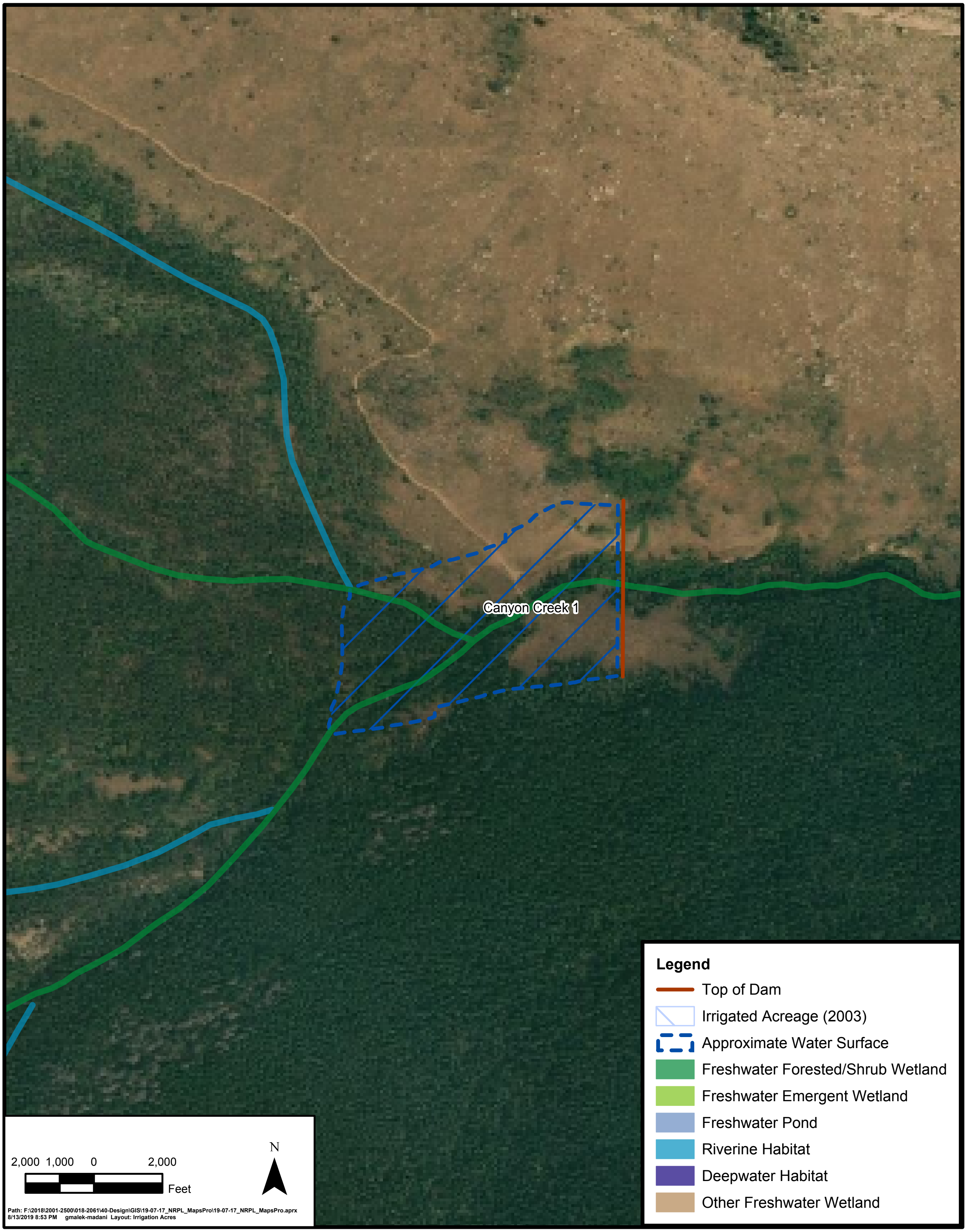
FIGURE

C-5a



POPO AGIE WATERSHED STUDY

Canyon Creek 1
Potential Microstorage Irrigation & NWI

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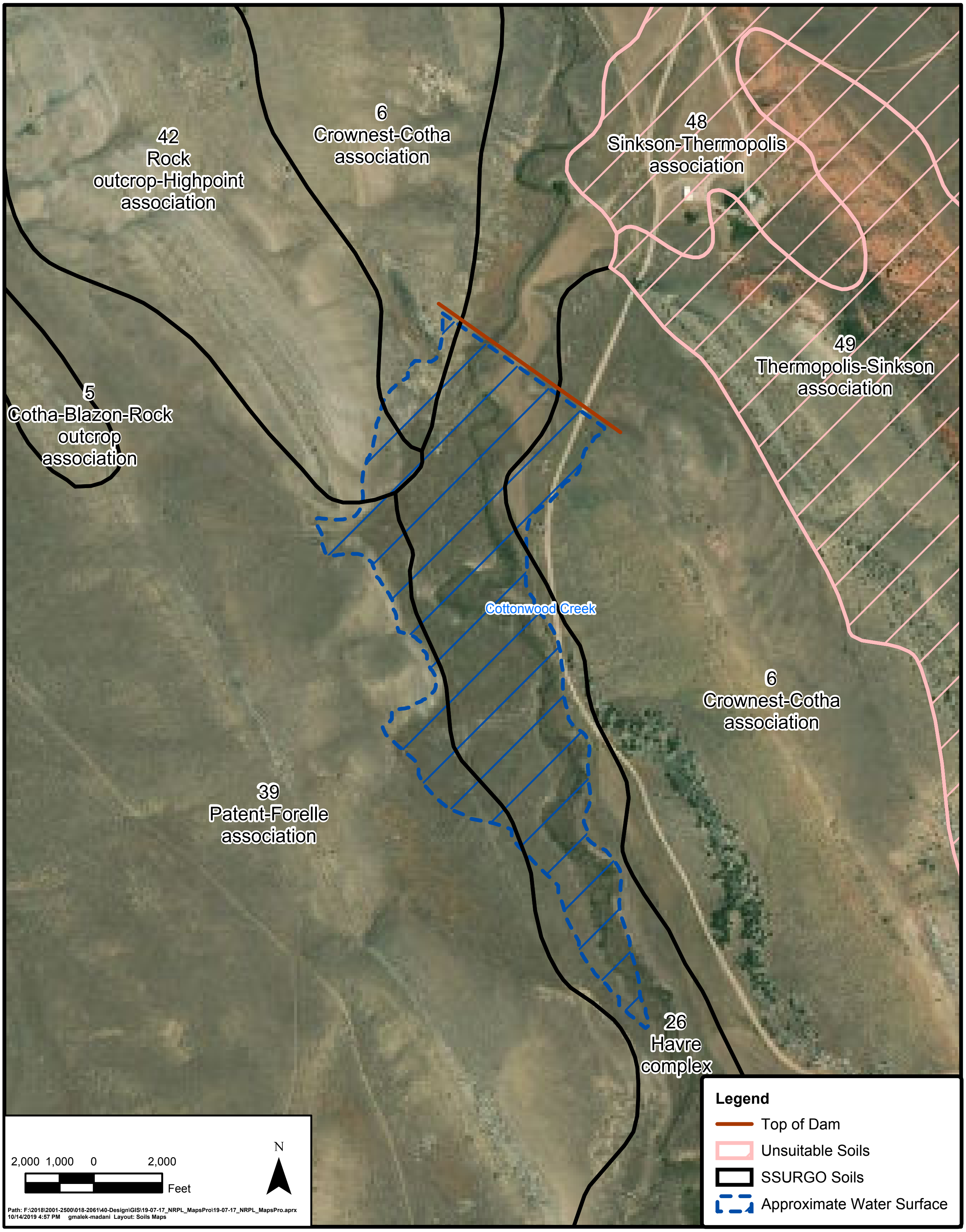
FIGURE

C-5b



POPO AGIE WATERSHED STUDY

Cottonwood Creek
Potential Microstorage Layout and Soils

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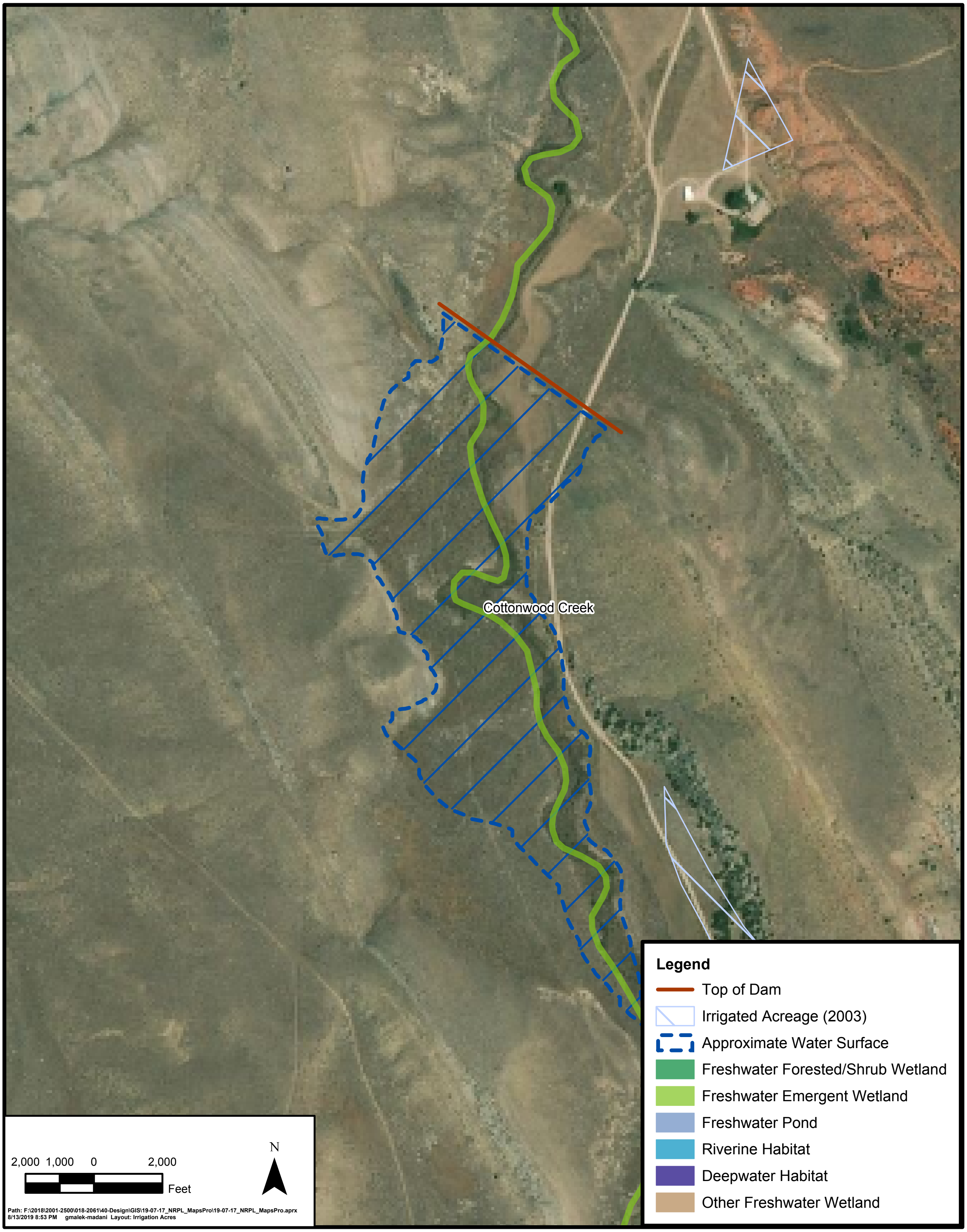
FIGURE

C-6a



POPO AGIE WATERSHED STUDY

Cottonwood Creek
Potential Microstorage Irrigation & NWI

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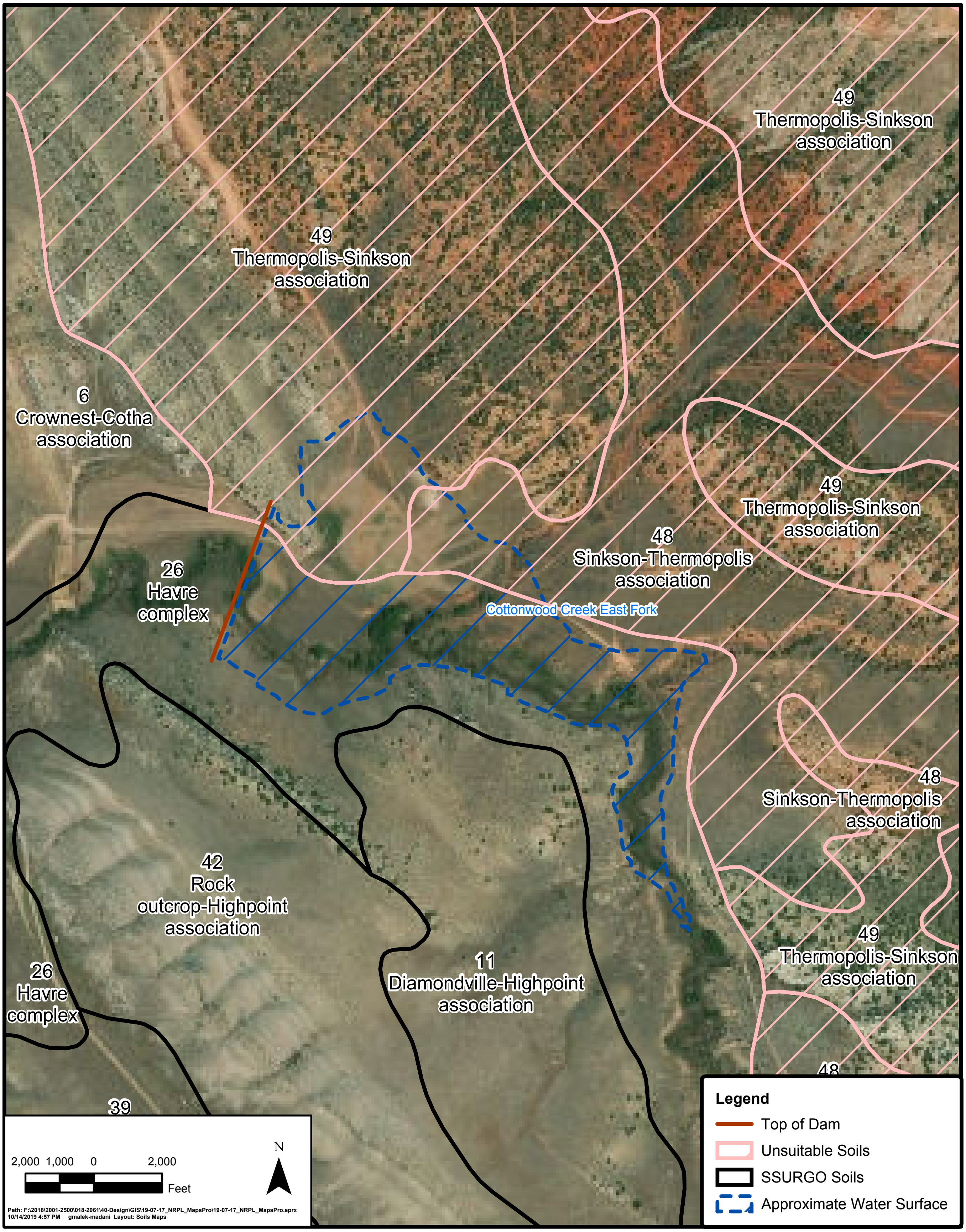
FIGURE
C-6b



POPO AGIE WATERSHED STUDY

Cottonwood Creek East Fork
Potential Microstorage Layout and Soils

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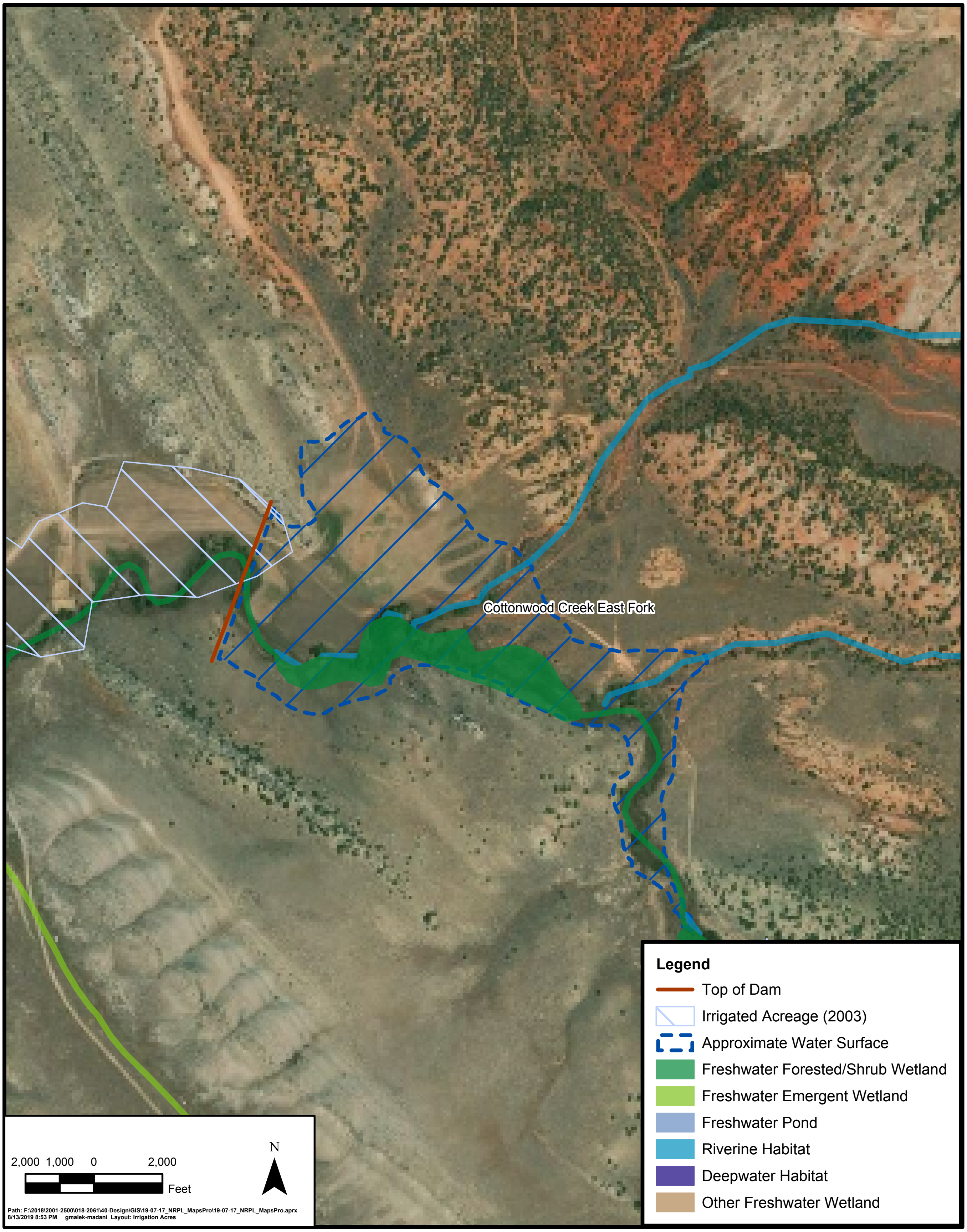
FIGURE
C-7a



POPO AGIE WATERSHED STUDY

Cottonwood Creek East Fork
Potential Microstorage Irrigation & NWI

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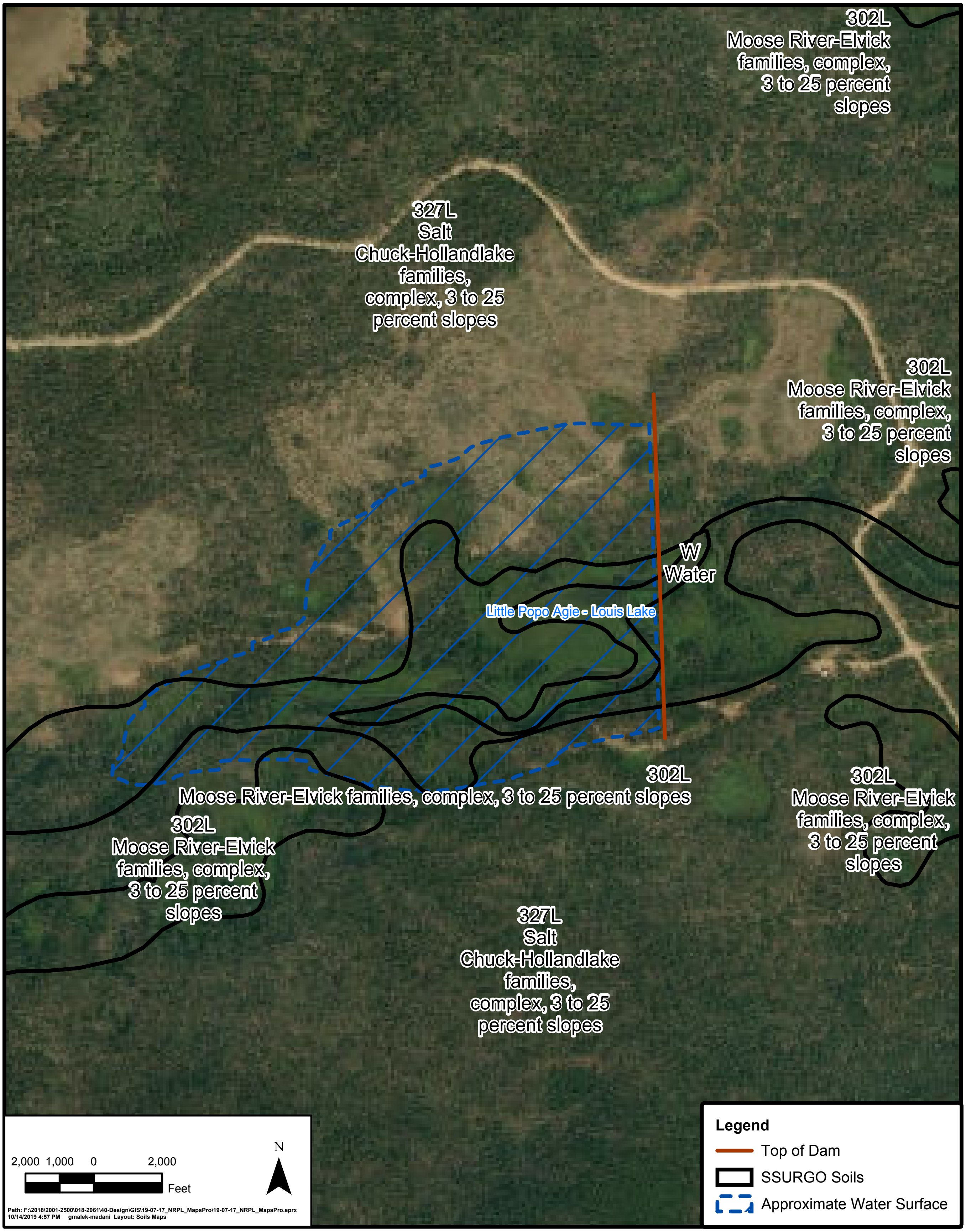
FIGURE

C-7b



POPO AGIE WATERSHED STUDY

Little Popo Agie - Louis Lake
Potential Microstorage Layout and Soils

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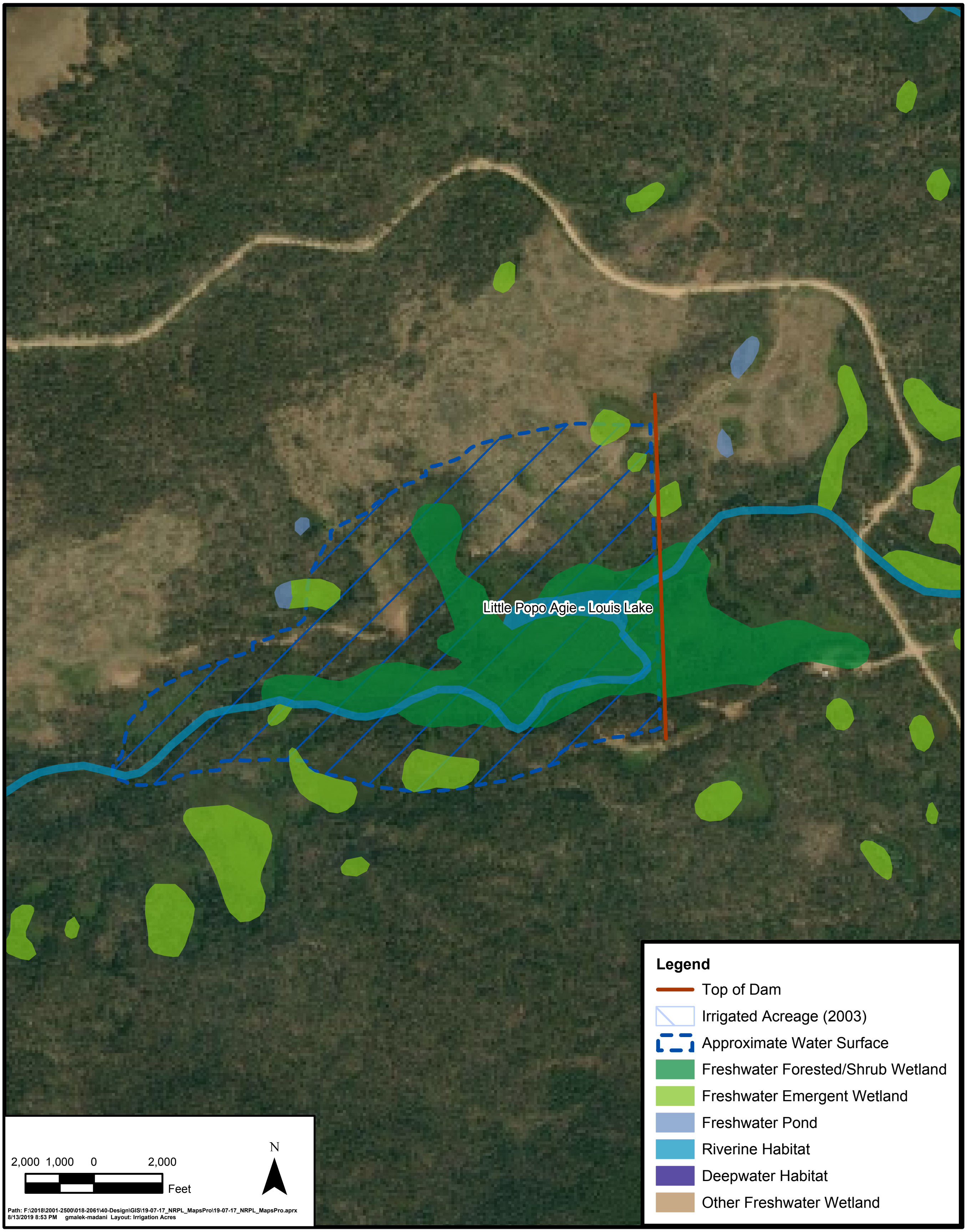
FIGURE
C-8a



POPO AGIE WATERSHED STUDY

Little Popo Agie - Louis Lake
Potential Microstorage Irrigation & NWI

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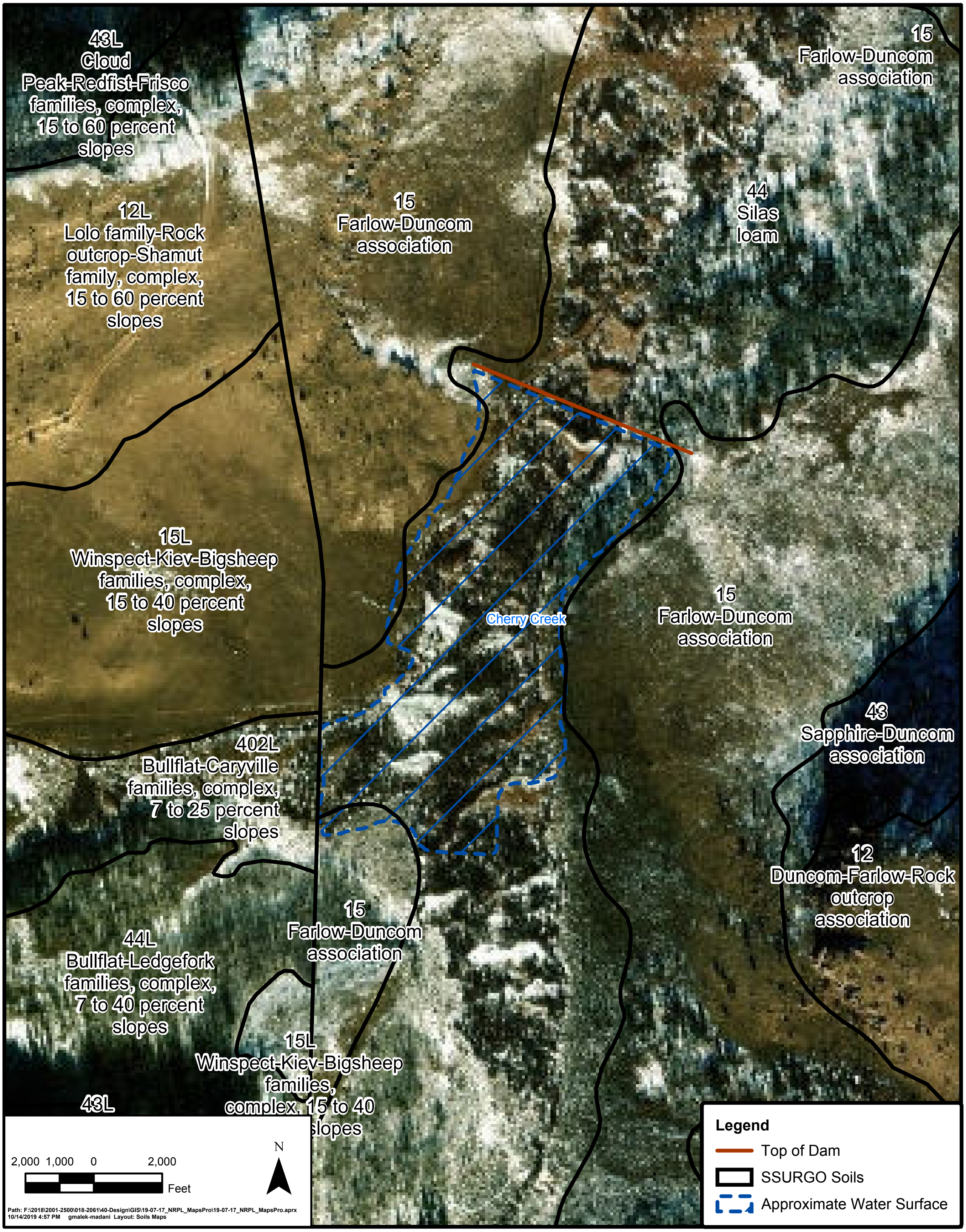
FIGURE

C-8b



POPO AGIE WATERSHED STUDY

Cherry Creek
Potential Microstorage Layout and Soils

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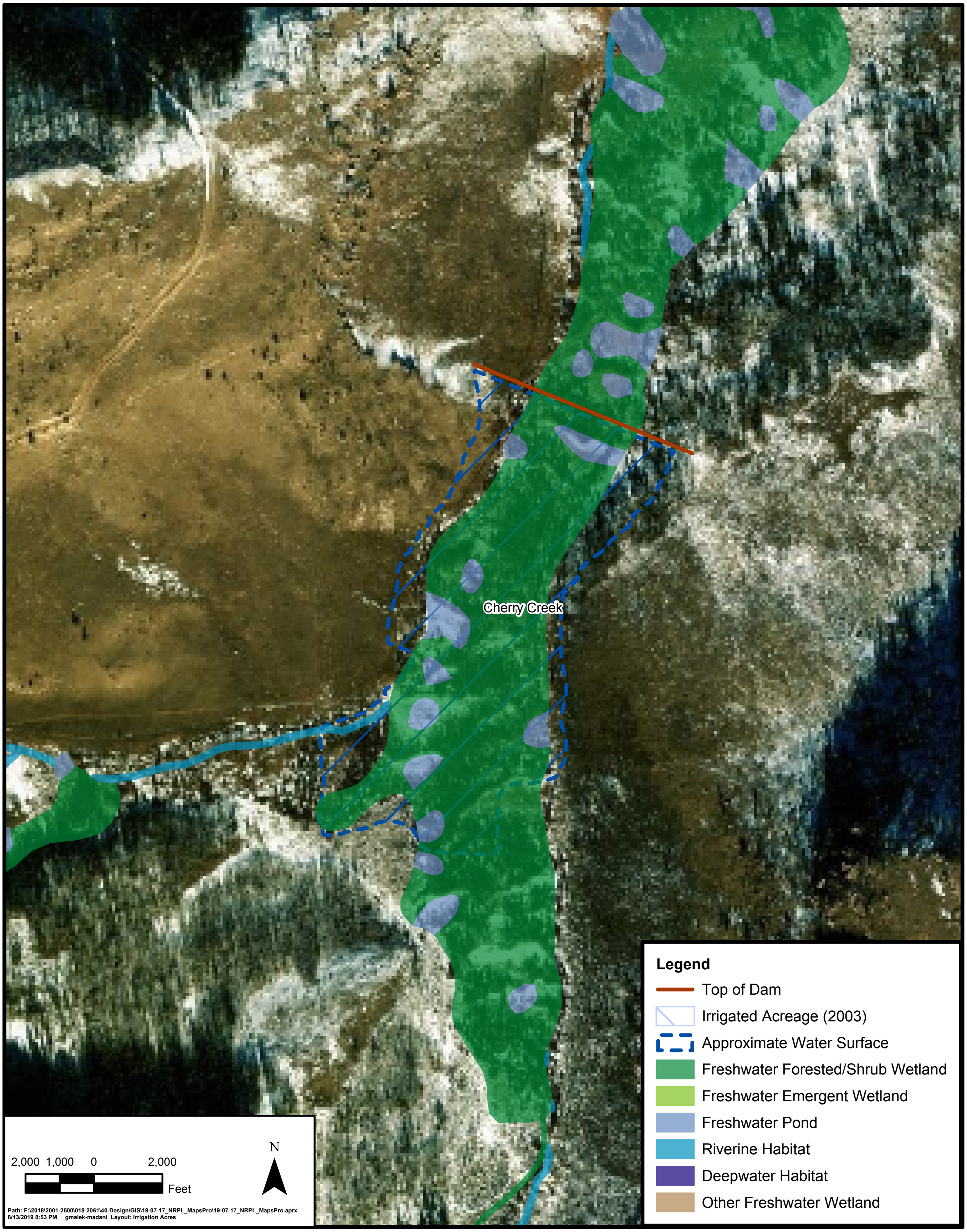
FIGURE

C-9a



POPO AGIE WATERSHED STUDY

Cherry Creek
Potential Microstorage Irrigation & NWI

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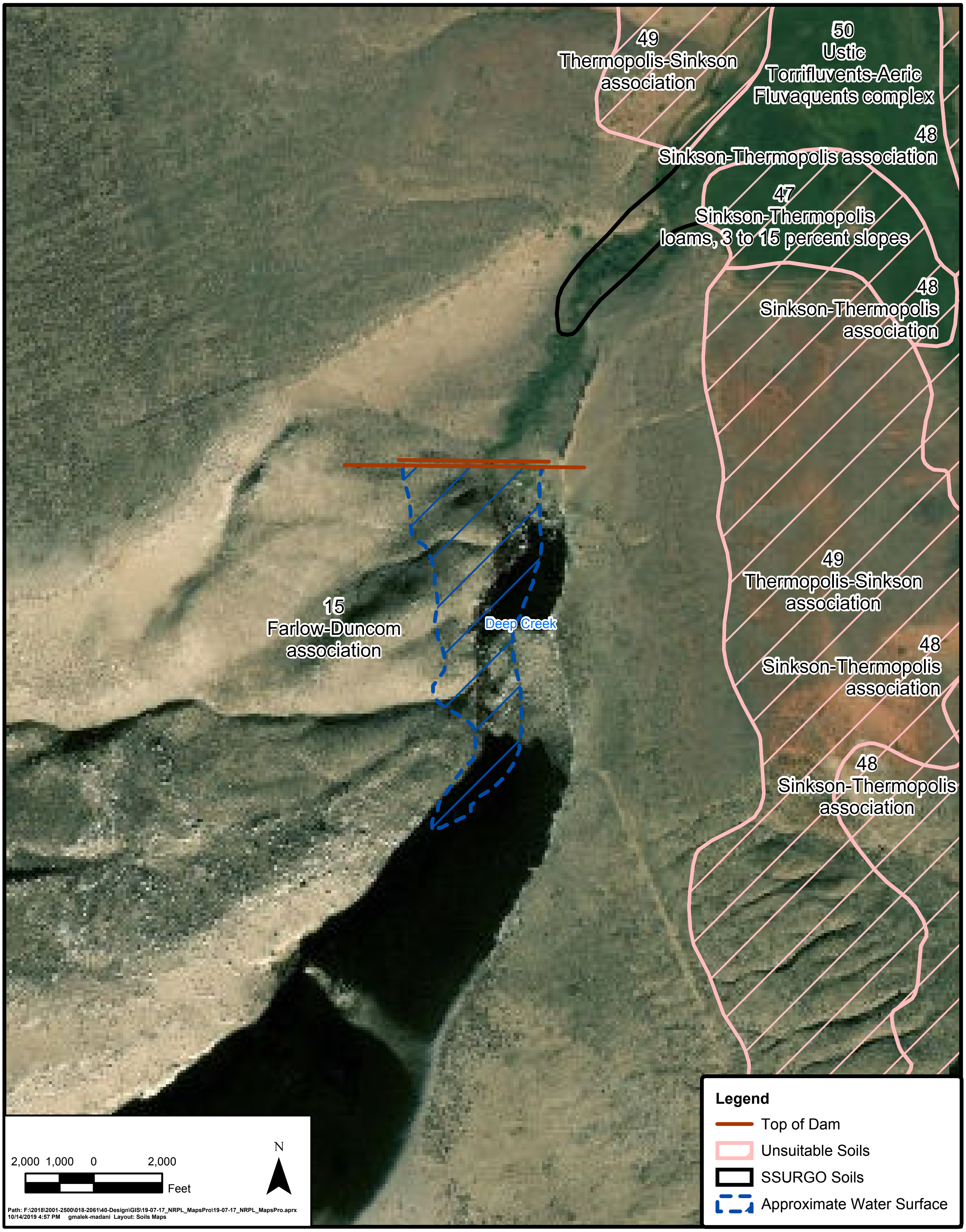
FIGURE

C-9b



POPO AGIE WATERSHED STUDY

Deep Creek
Potential Microstorage Layout and Soils

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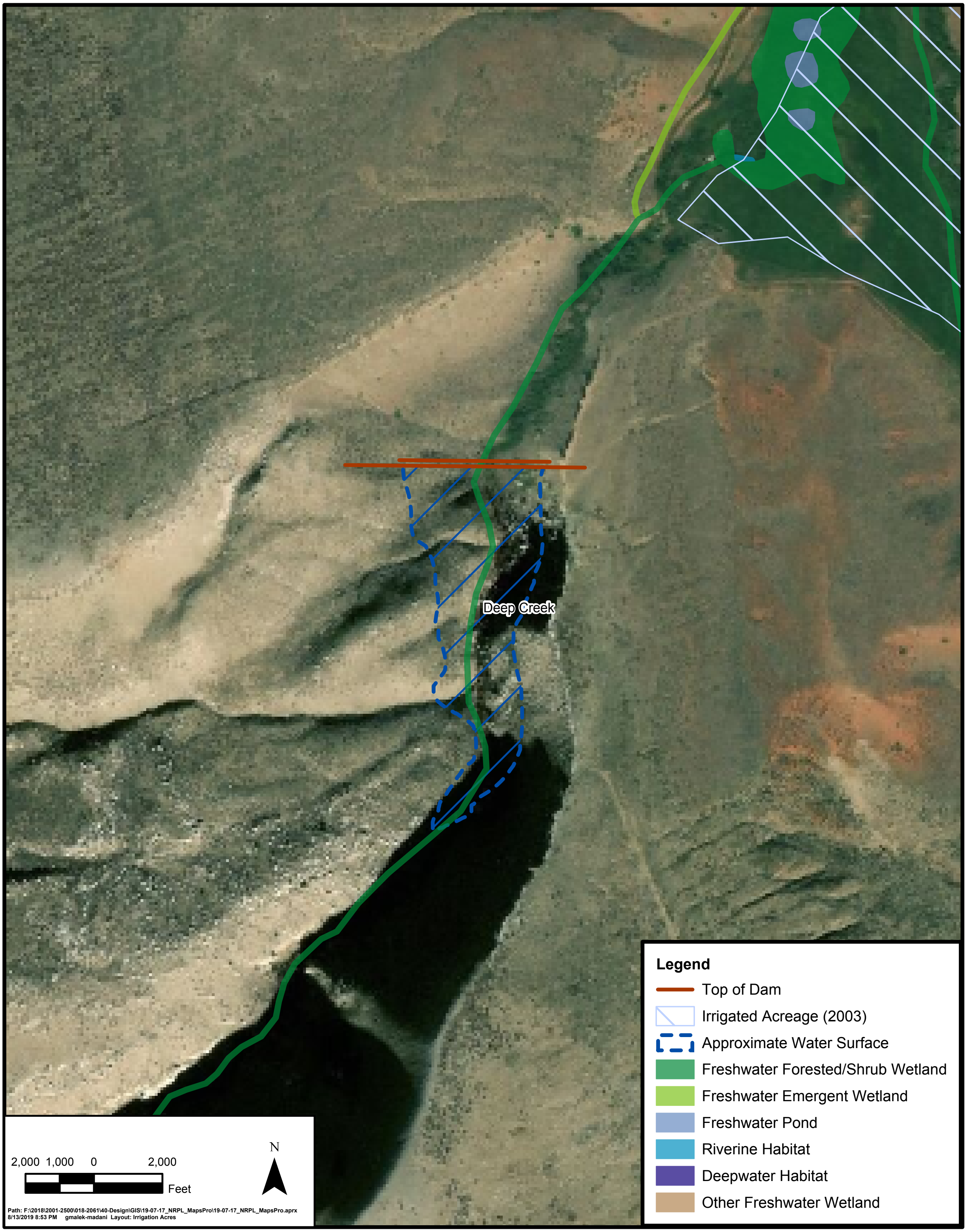
FIGURE

C-10a



POPO AGIE WATERSHED STUDY

Deep Creek
Potential Microstorage Irrigation & NWI

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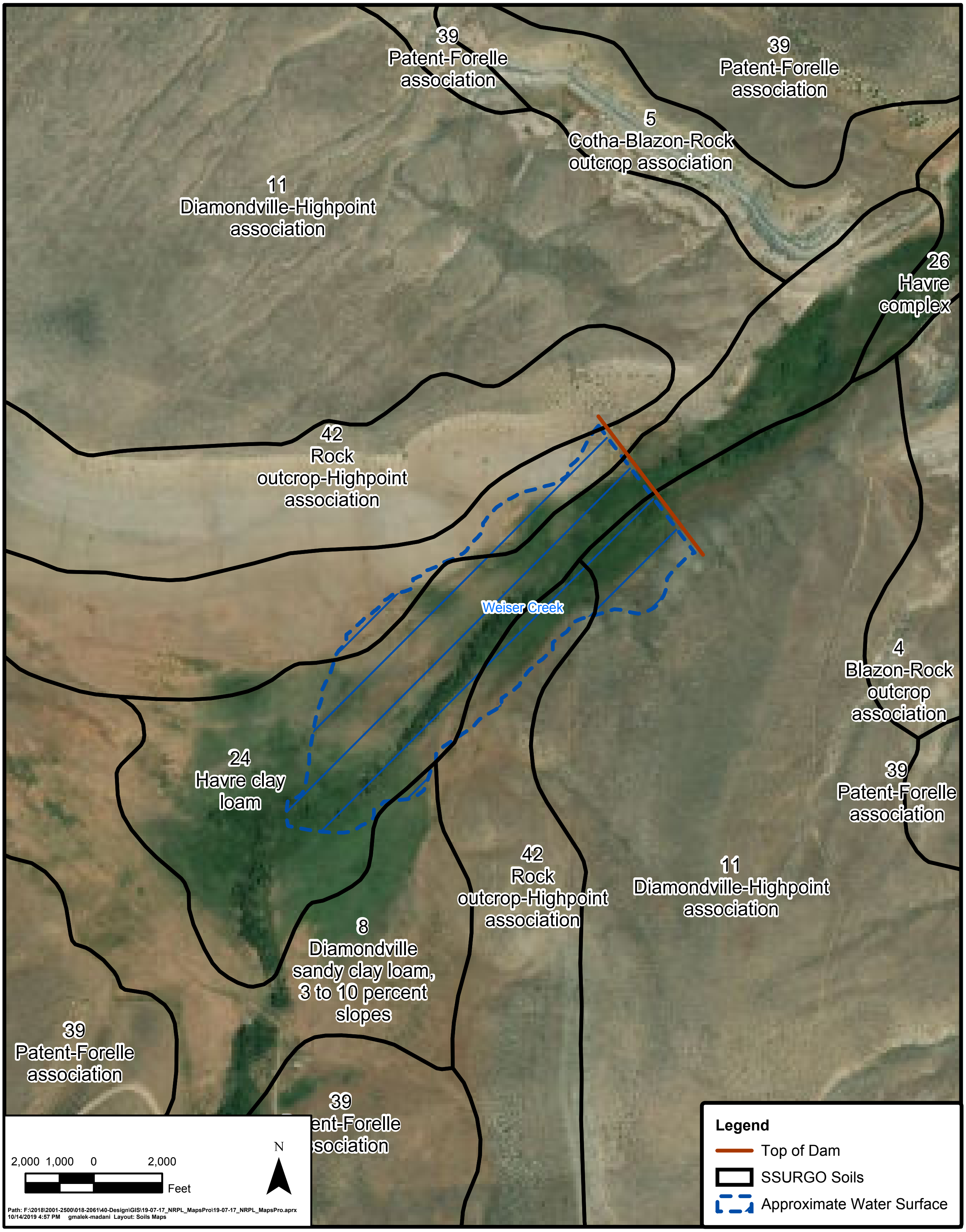
FIGURE

C-10b



POPO AGIE WATERSHED STUDY

Weiser Creek
Potential Microstorage Layout and Soils

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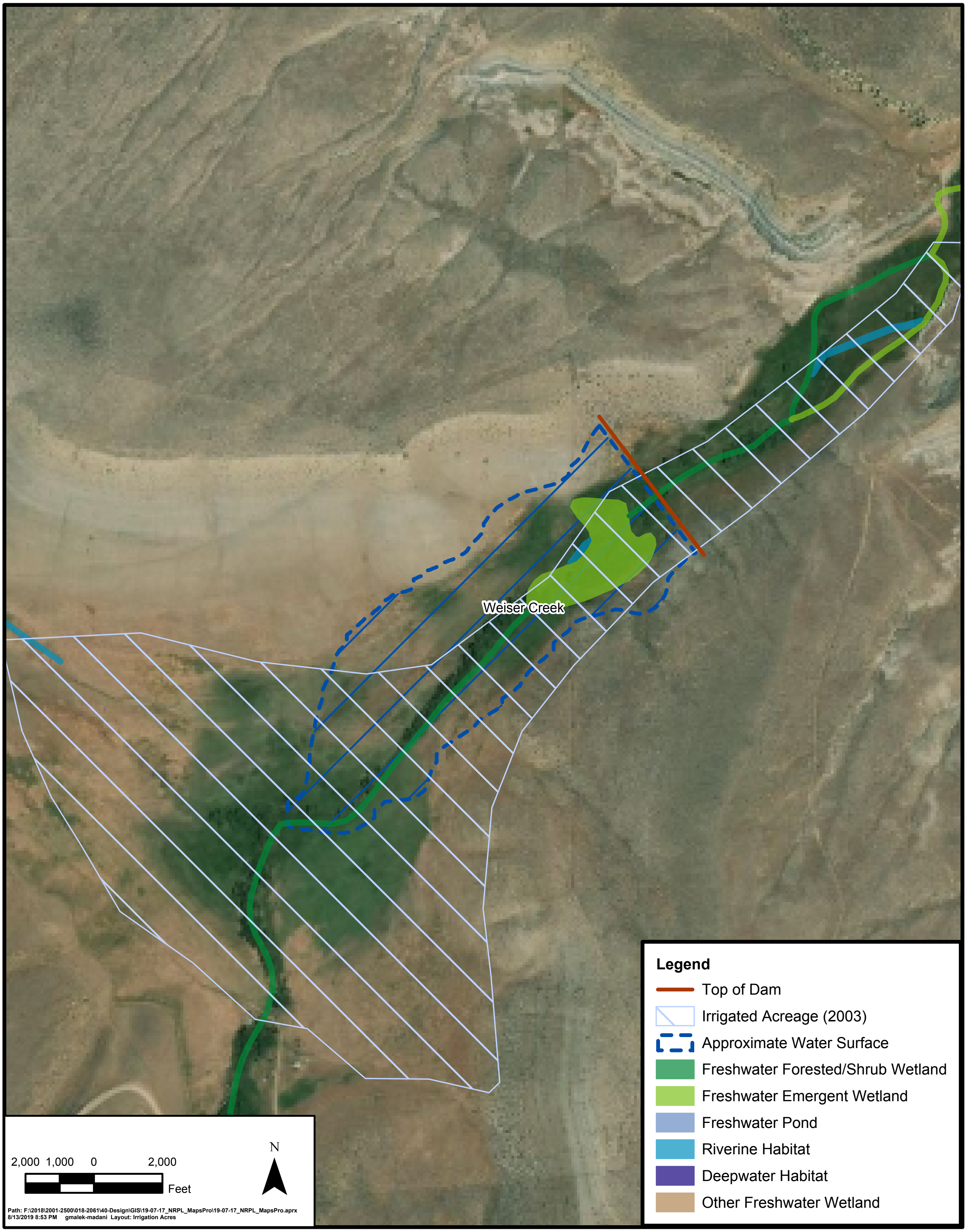
FIGURE
C-11a



POPO AGIE WATERSHED STUDY

Weiser Creek
Potential Microstorage Irrigation & NWI

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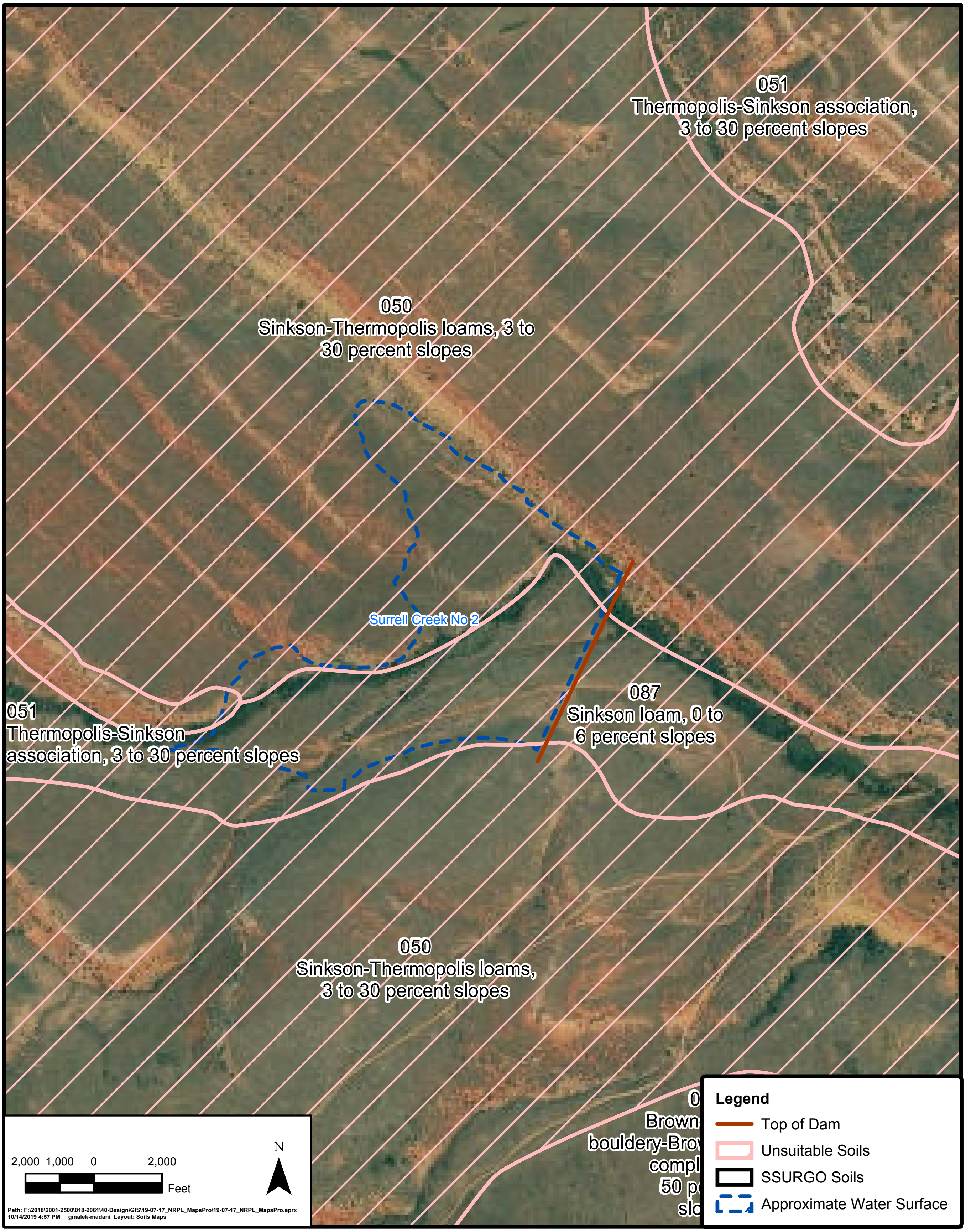
FIGURE

C-11b



POPO AGIE WATERSHED STUDY

Surrell Creek No 2
Potential Microstorage Layout and Soils

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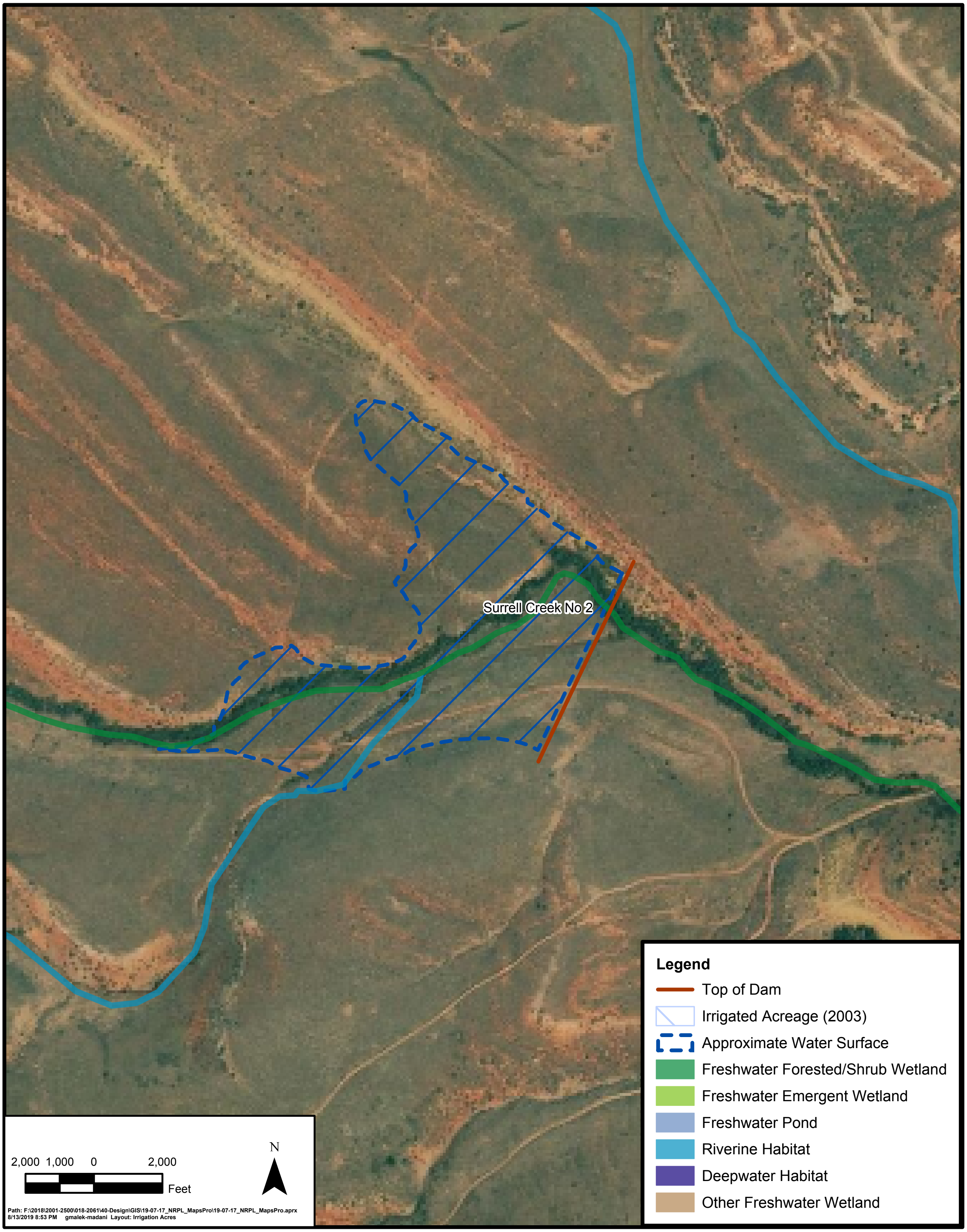
FIGURE
C-12a



POPO AGIE WATERSHED STUDY

Surrell Creek No 2
Potential Microstorage Irrigation & NWI

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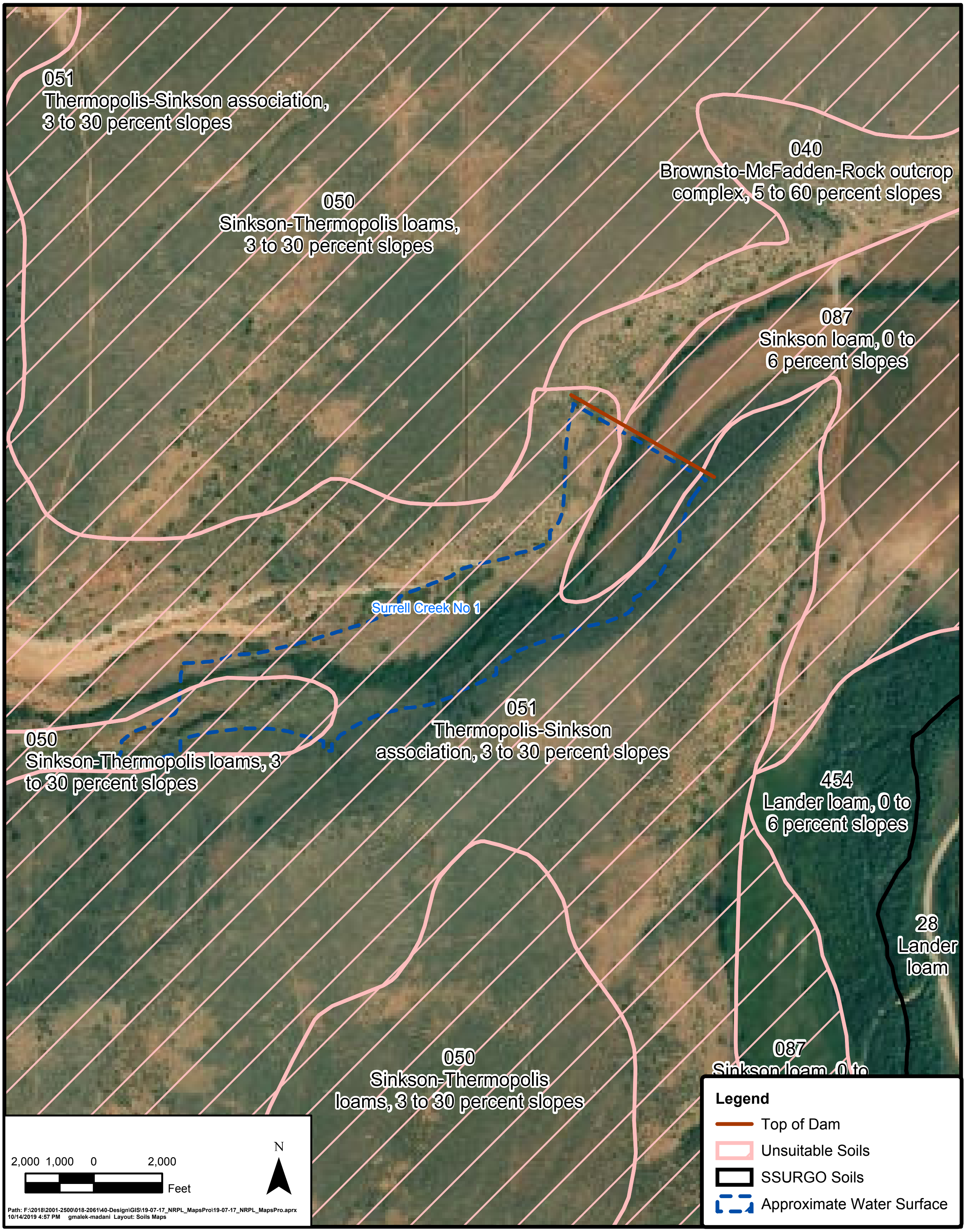
WENCK

FIGURE

C-12b



POPO AGIE WATERSHED STUDY

Surrell Creek No 1
Potential Microstorage Layout and Soils

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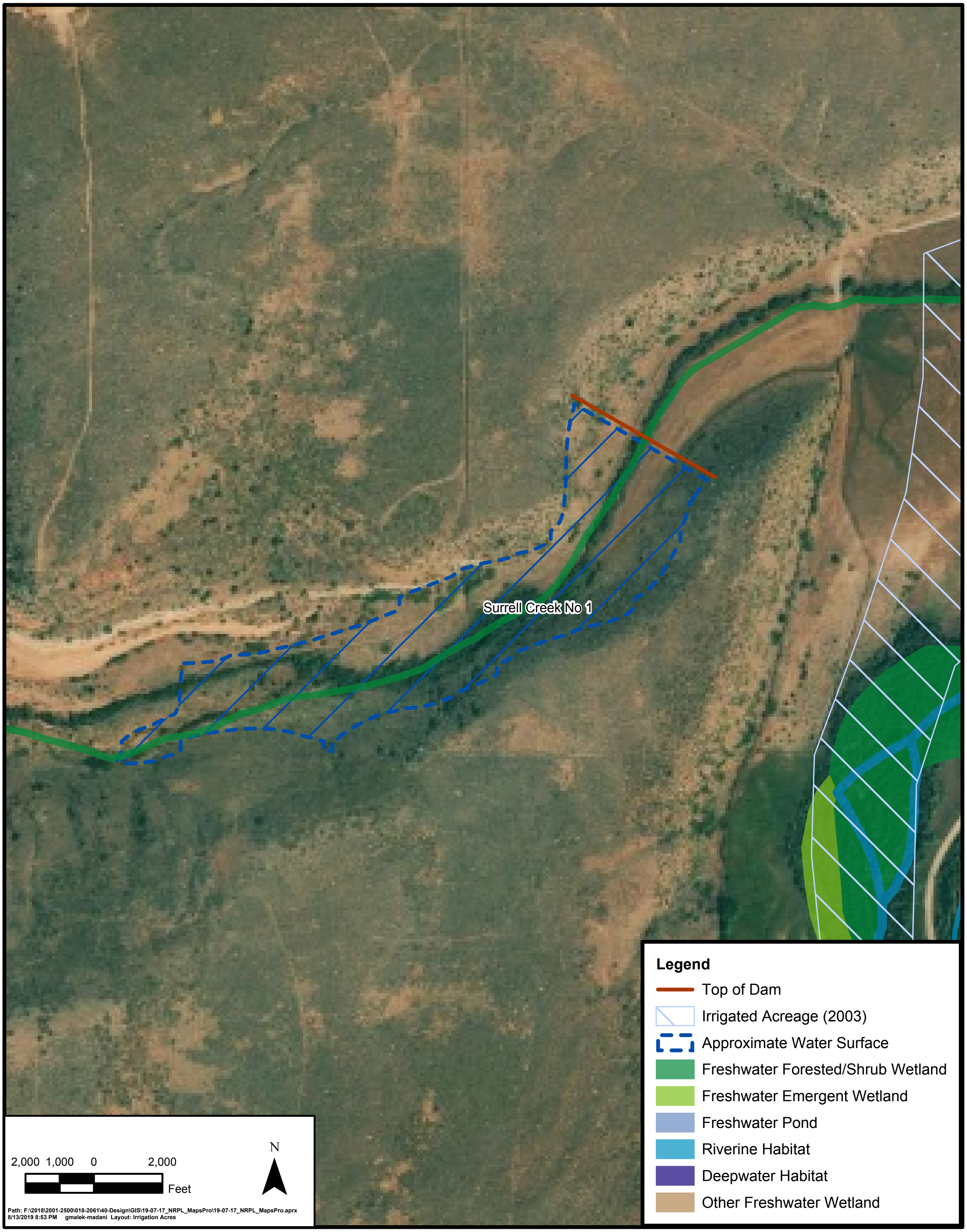
WENCK

FIGURE

C-13a



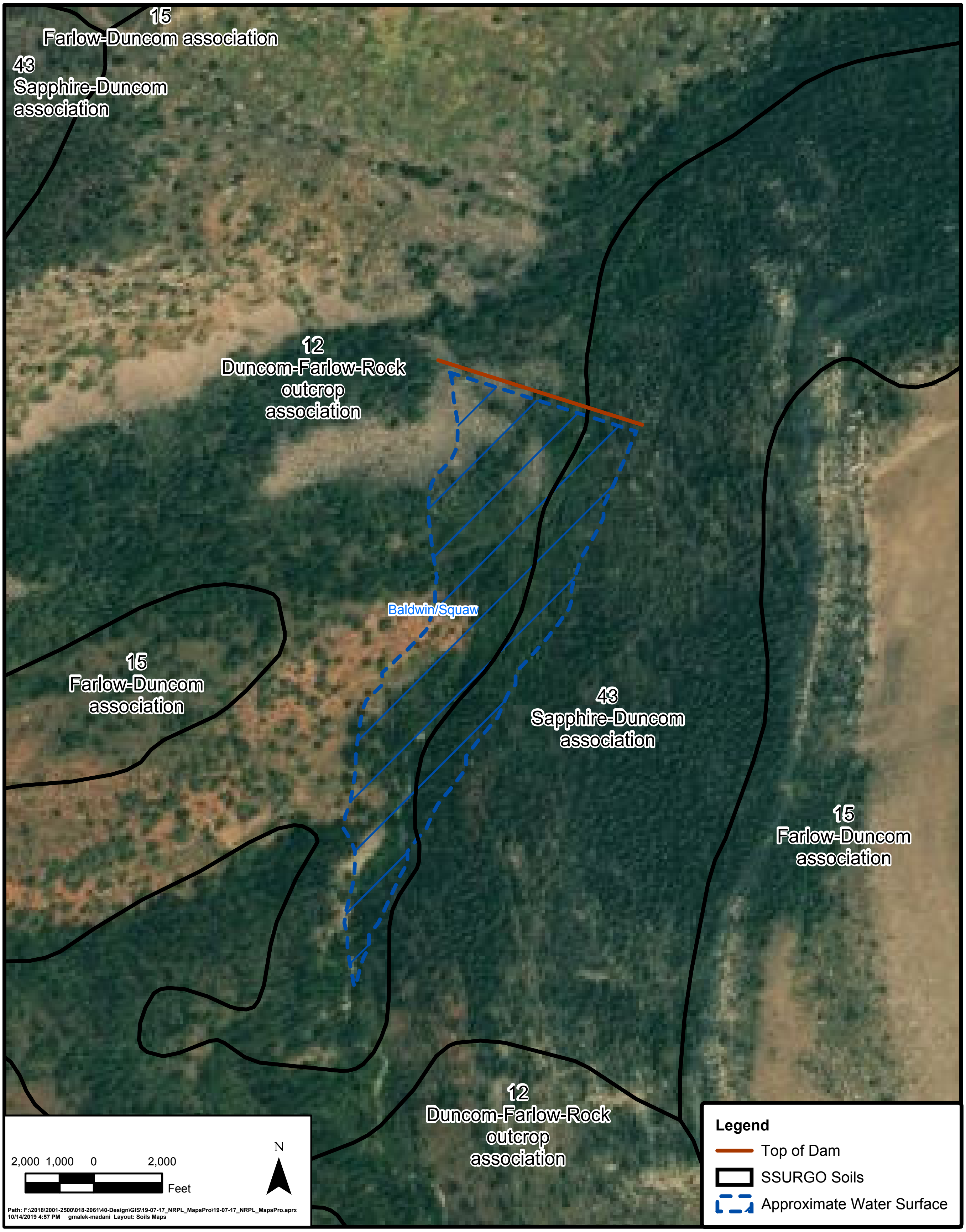
POPO AGIE WATERSHED STUDY

Surrell Creek No 1
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-13b



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POPO AGIE WATERSHED STUDY

Baldwin/Squaw
Potential Microstorage Layout and Soils

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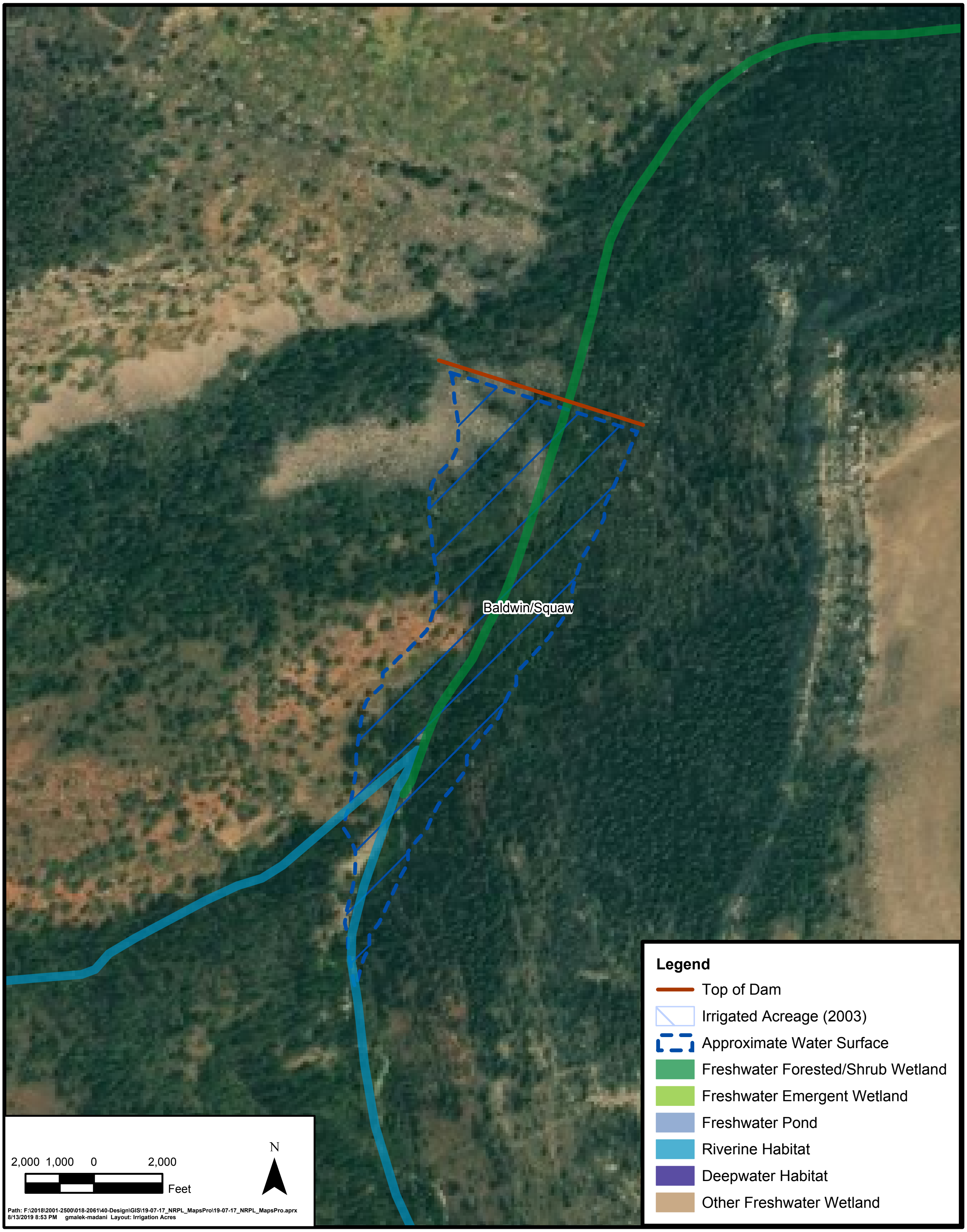
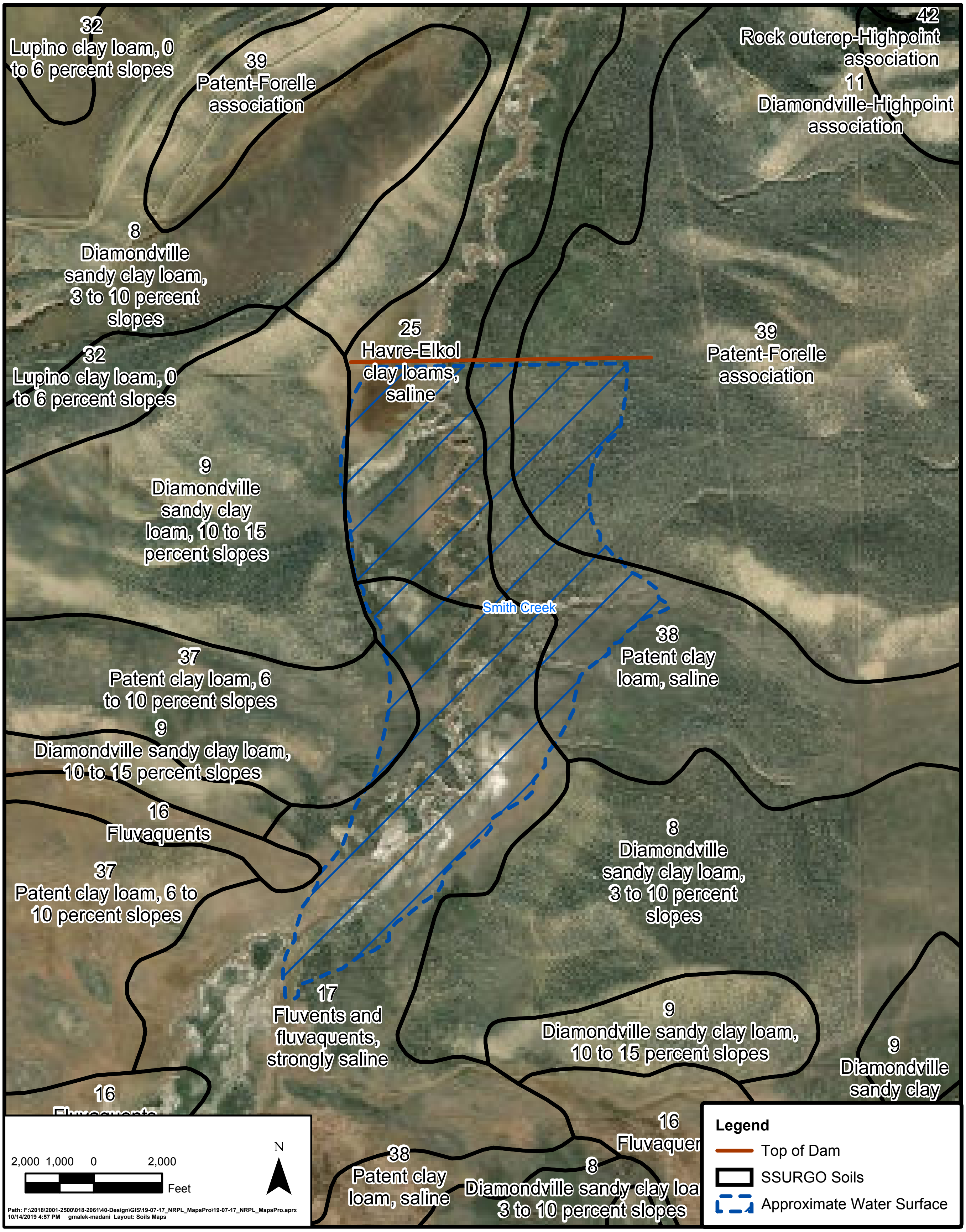
WENCK

FIGURE

C-14a



POPO AGIE WATERSHED STUDY	olsson WENCK	FIGURE
Baldwin/Squaw Potential Microstorage Irrigation & NWI		C-14b



POPO AGIE WATERSHED STUDY

Smith Creek
Potential Microstorage Layout and Soils

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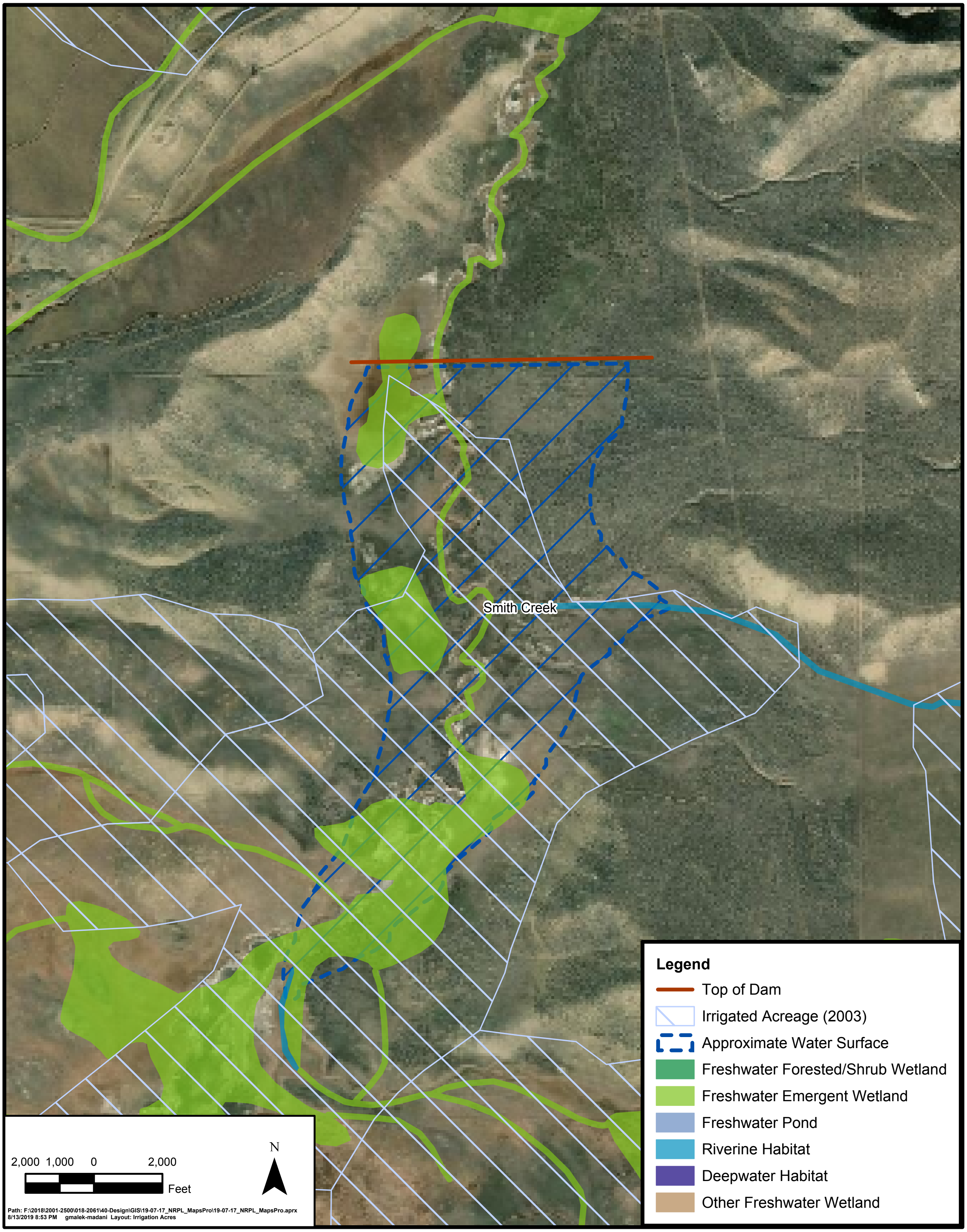
FIGURE

C-15a



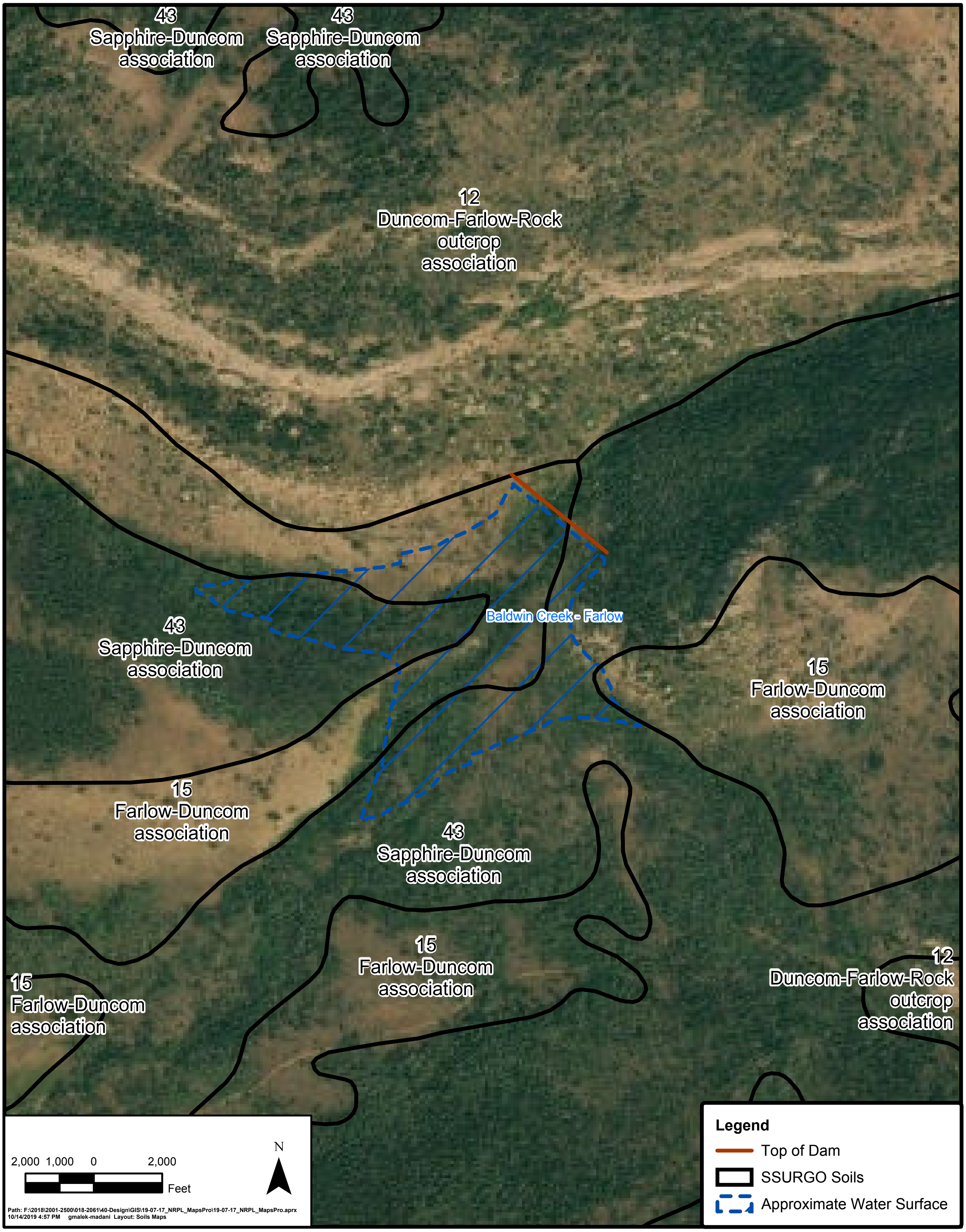
POPO AGIE WATERSHED STUDY

Smith Creek
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-15b



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10/14/2019 4:57 PM gmalek-madani Layout: Soils Maps

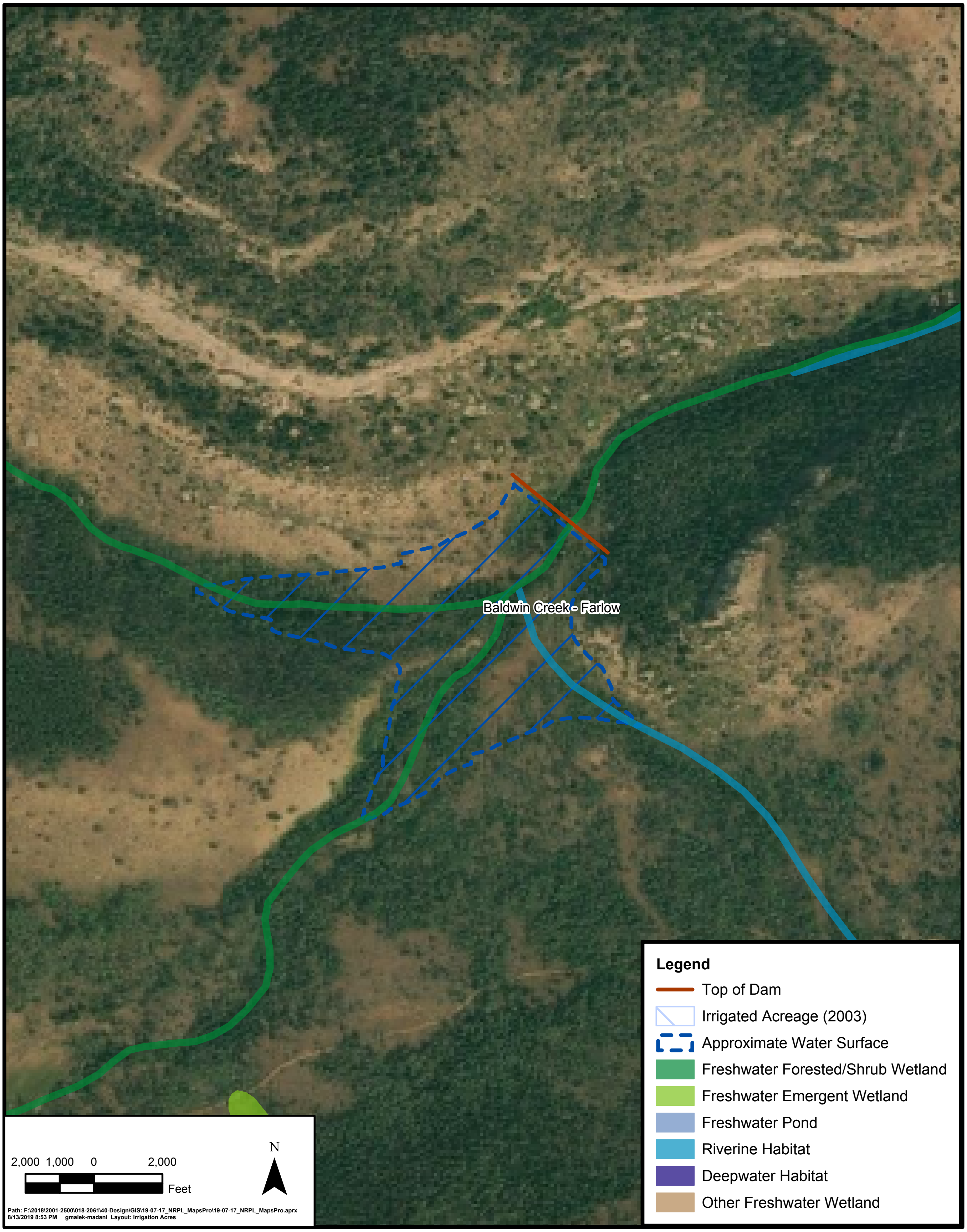
POPO AGIE WATERSHED STUDY

Baldwin Creek - Farlow
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE

C-16a



POPO AGIE WATERSHED STUDY

Baldwin Creek - Farlow
Potential Microstorage Irrigation & NWI

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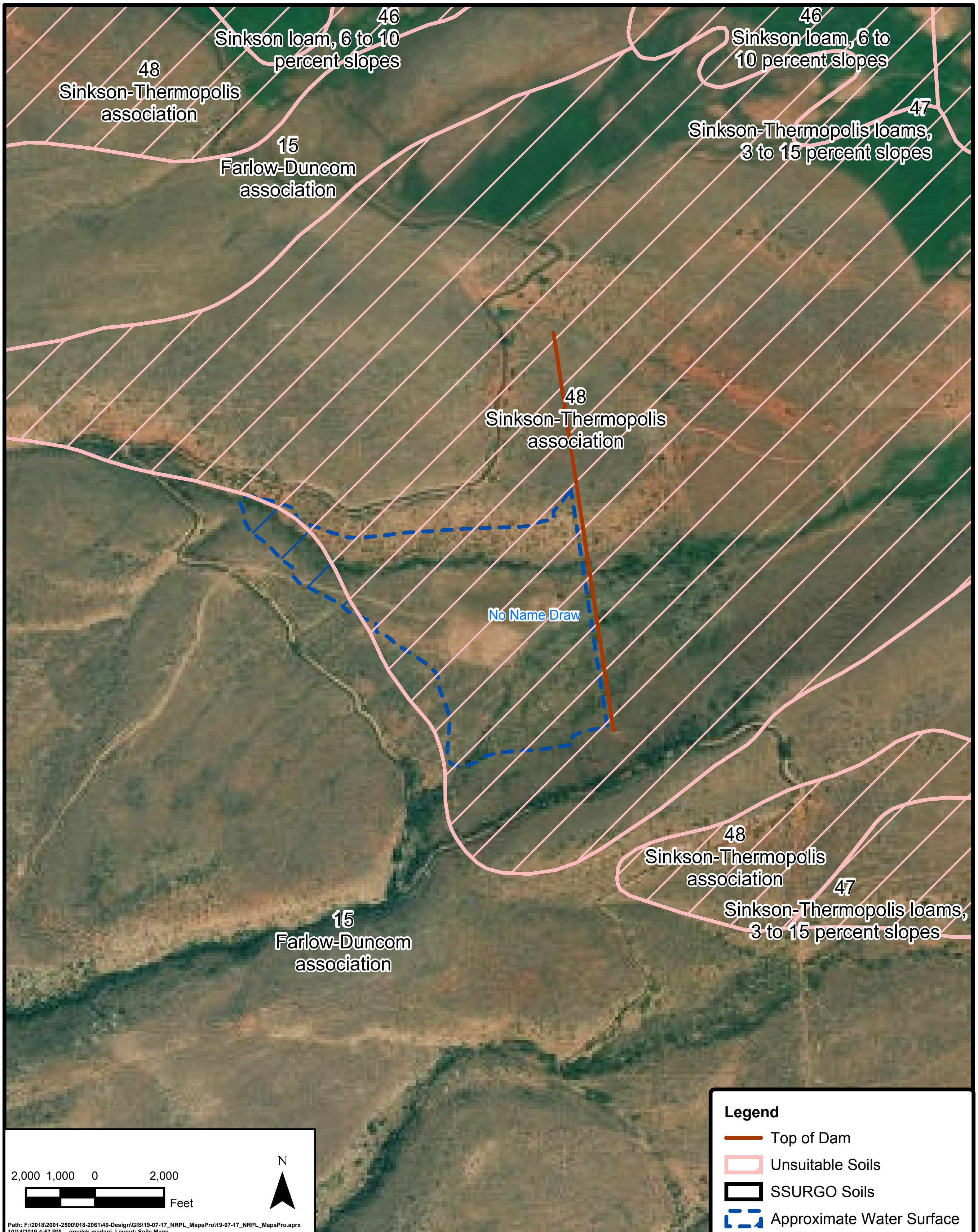
WENCK

FIGURE

C-16b

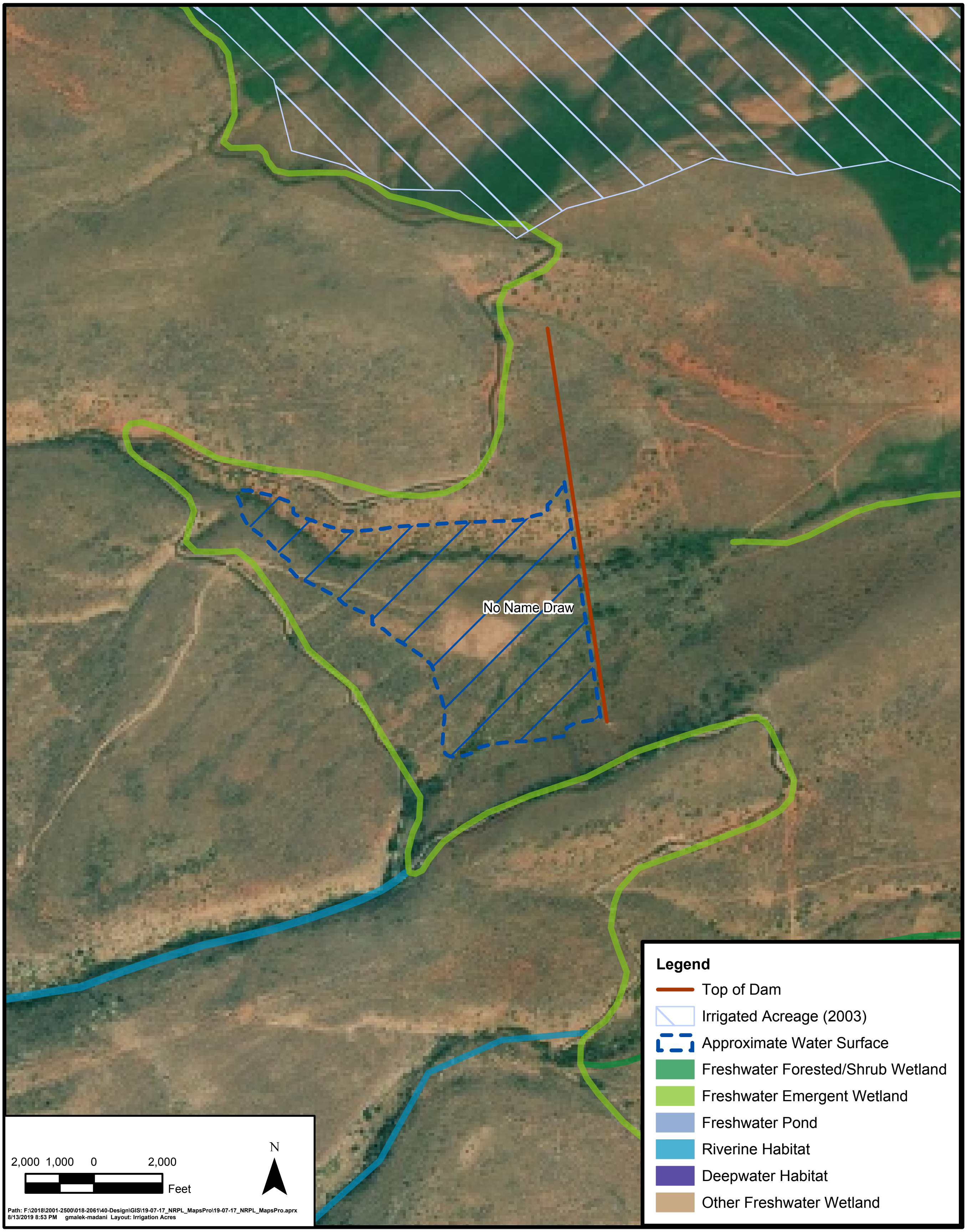


POPO AGIE WATERSHED STUDY

No Name Draw
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE
C-17a



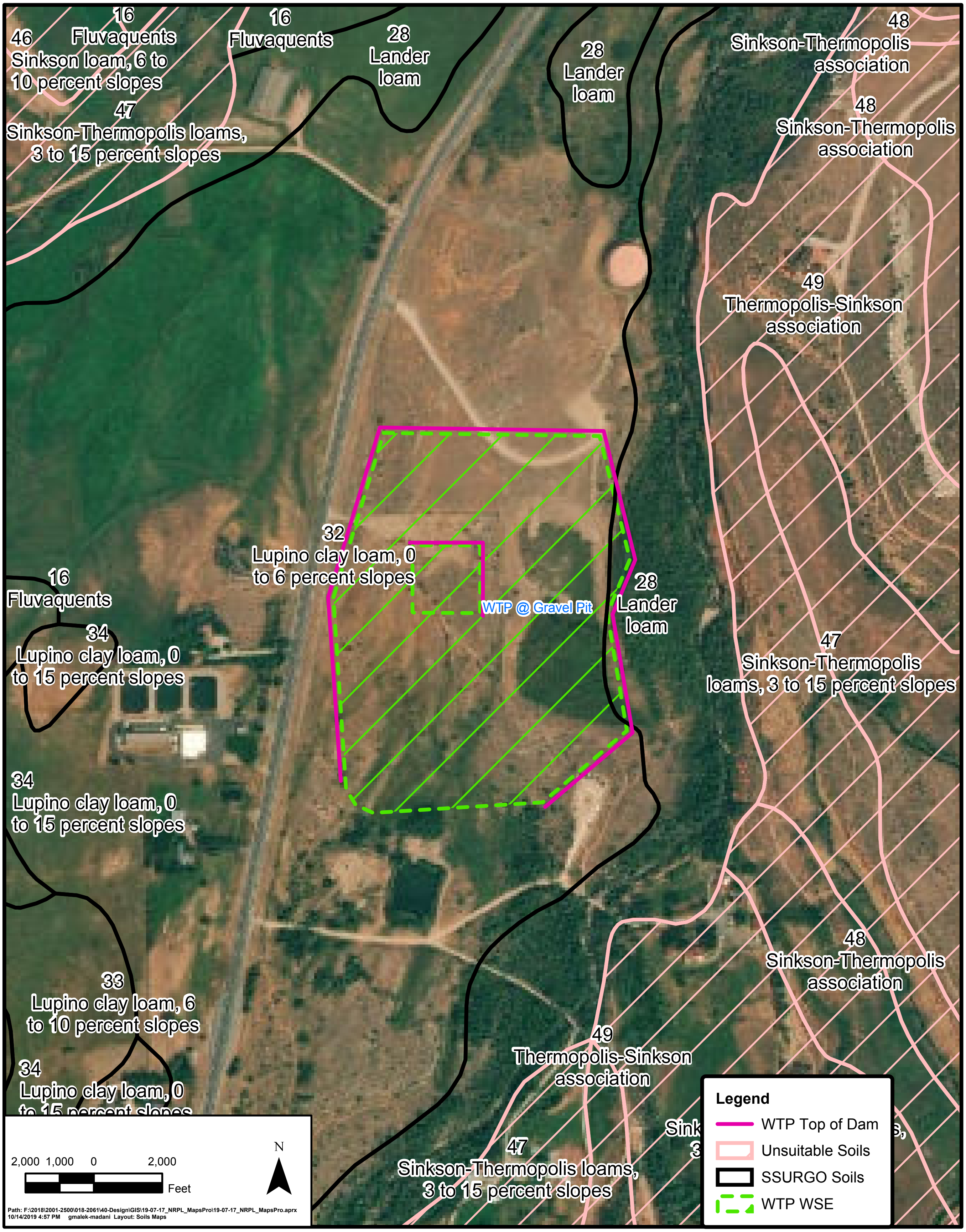
POPO AGIE WATERSHED STUDY

No Name Draw
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-17b

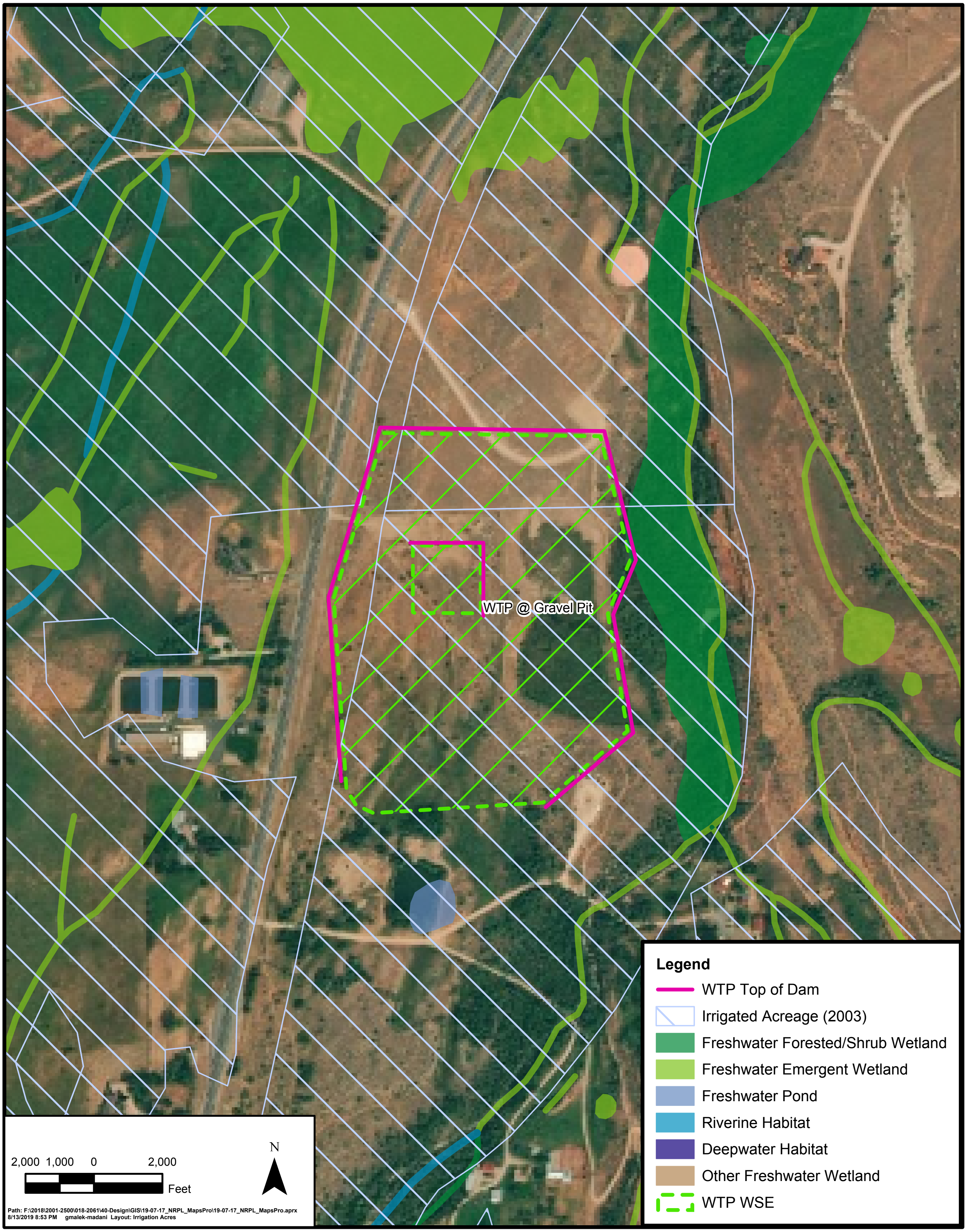


POPO AGIE WATERSHED STUDY

WTP @ Gravel Pit
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE
C-18a



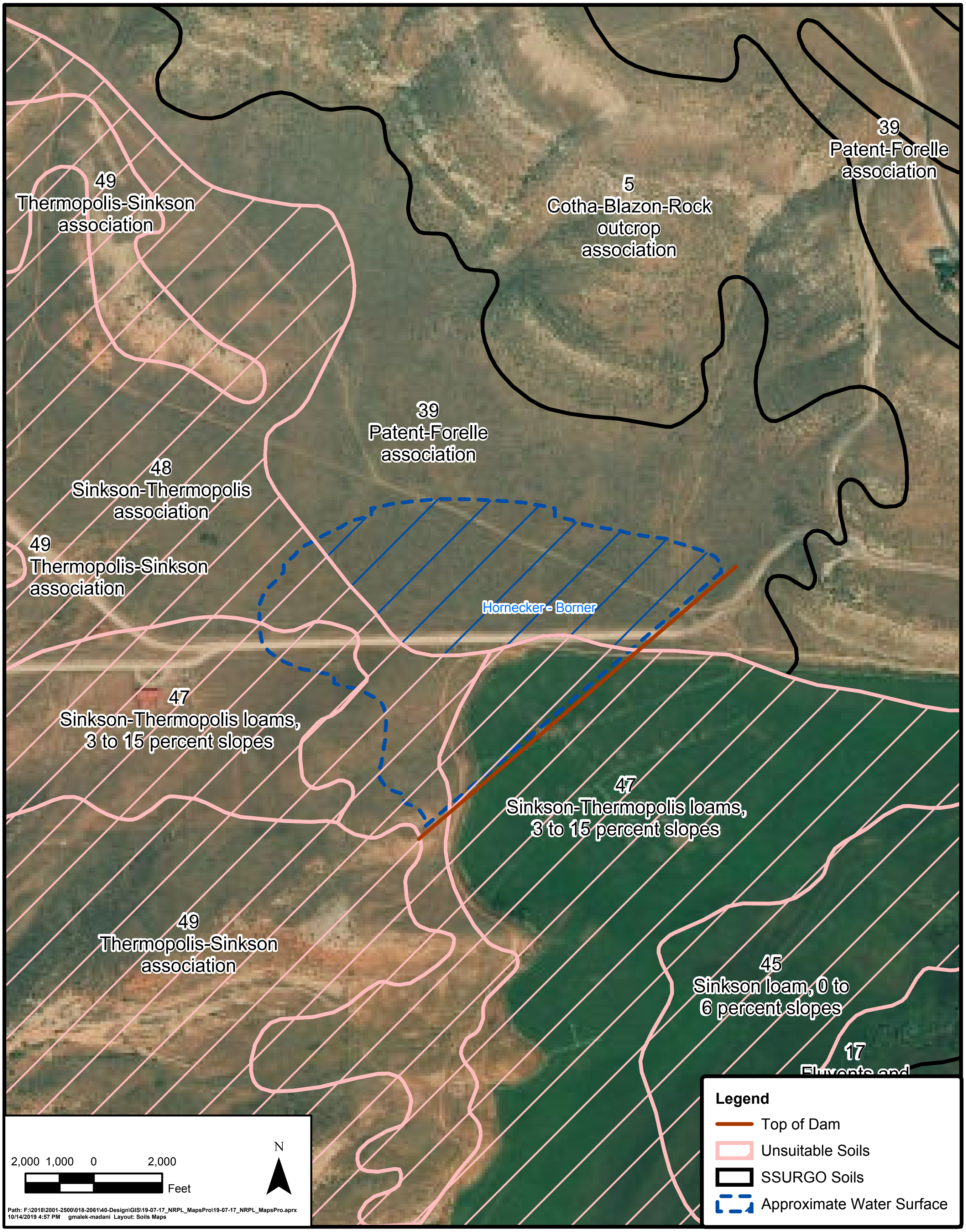
POPO AGIE WATERSHED STUDY

WTP @ Gravel Pit
Potential Microstorage Irrigation & NWI

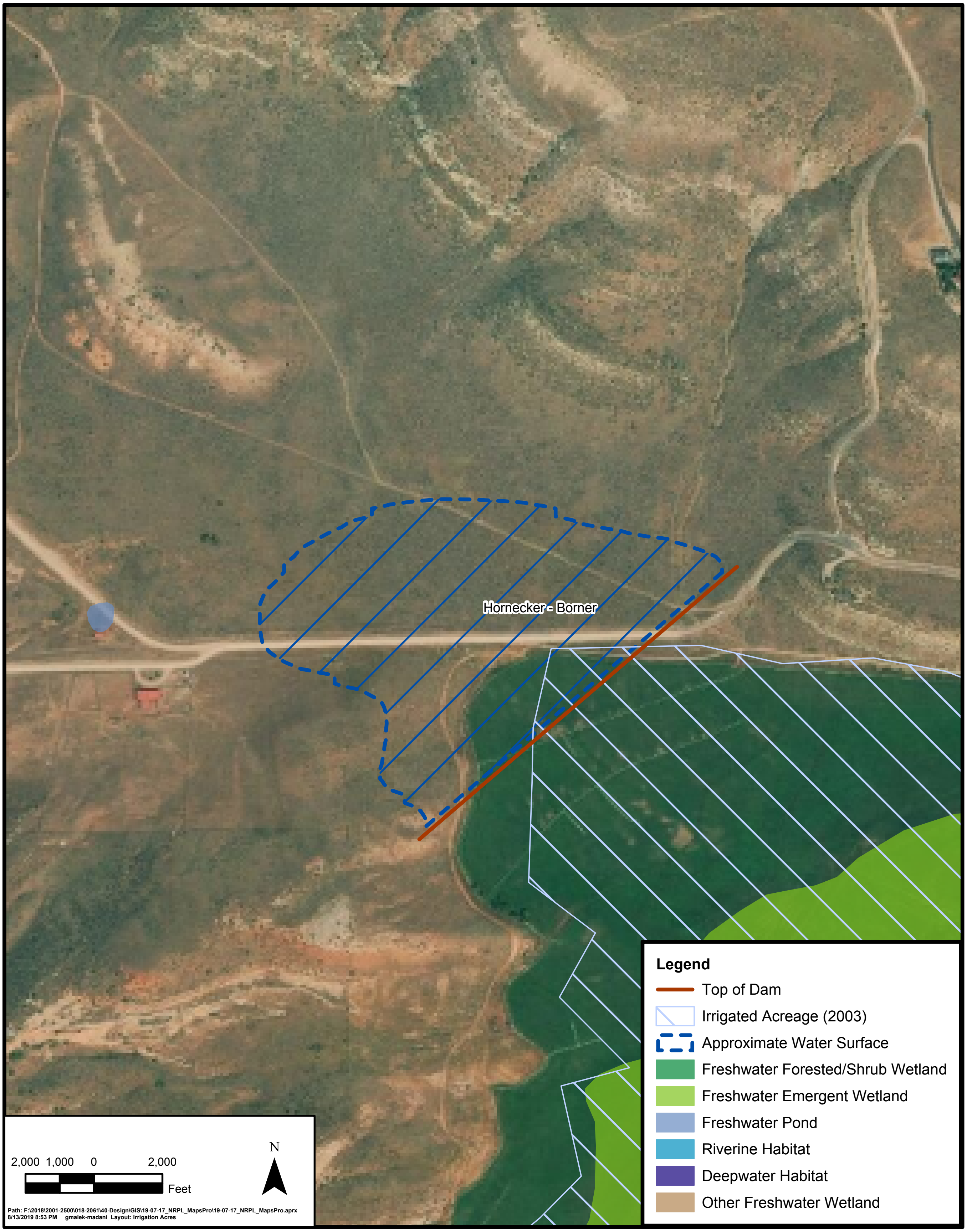
olsson
WENCK

FIGURE

C-18b



POPO AGIE WATERSHED STUDY	olsson WENCK	FIGURE
Hornecker - Borner Potential Microstorage Layout and Soils		C-19a

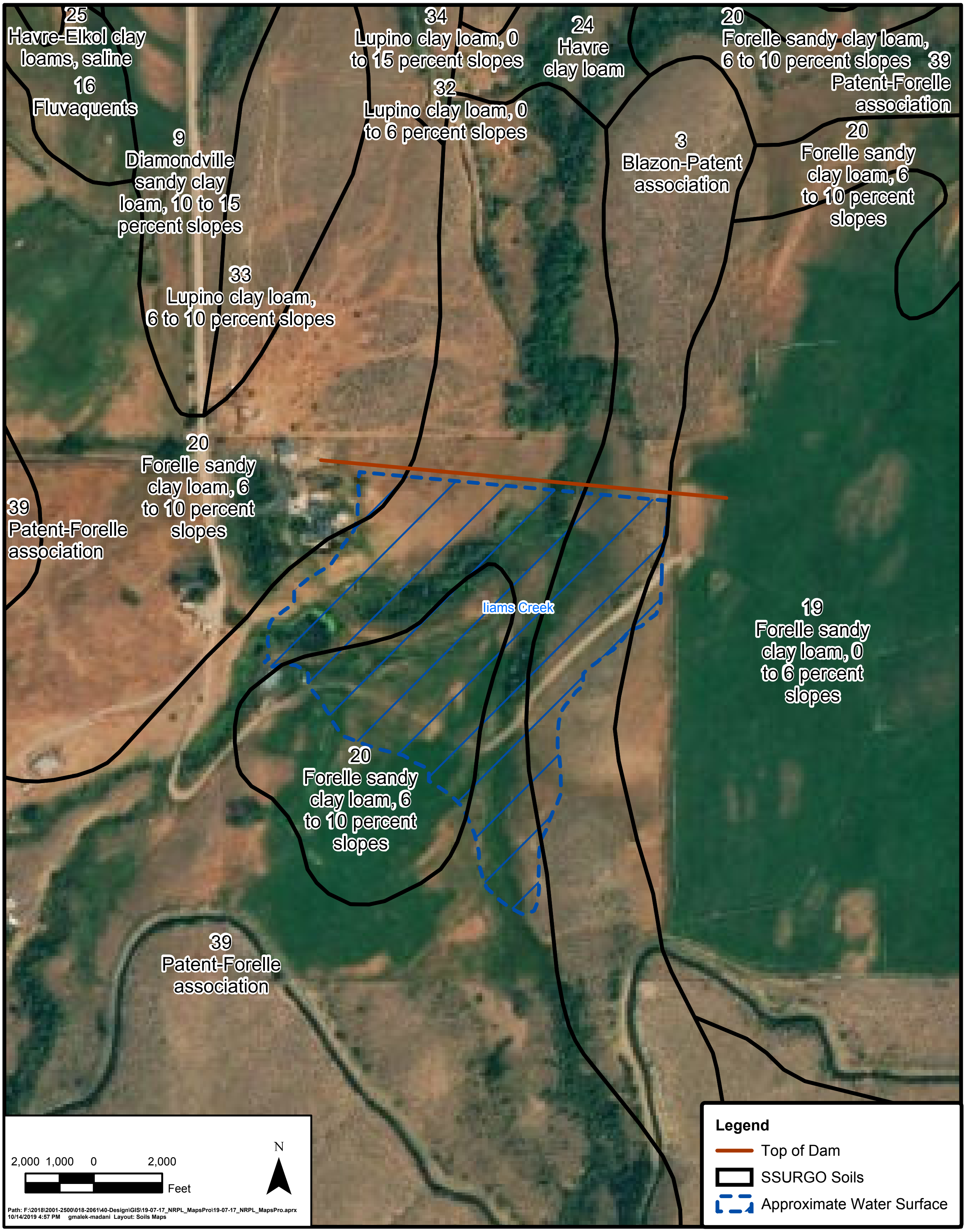


POPO AGIE WATERSHED STUDY

Hornecker - Borner
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE
C-19b

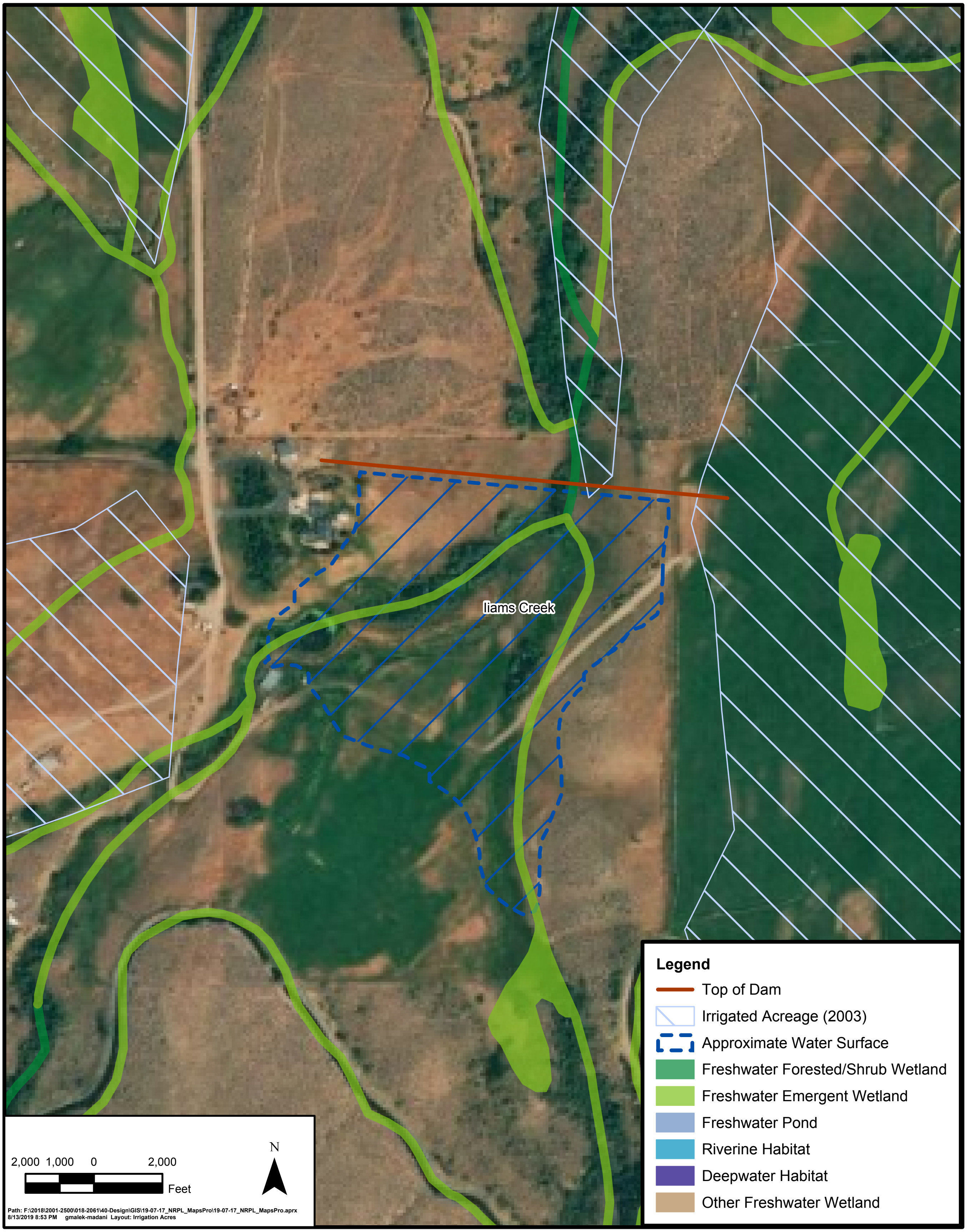


POPO AGIE WATERSHED STUDY

Iiams Creek
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE
C-20a



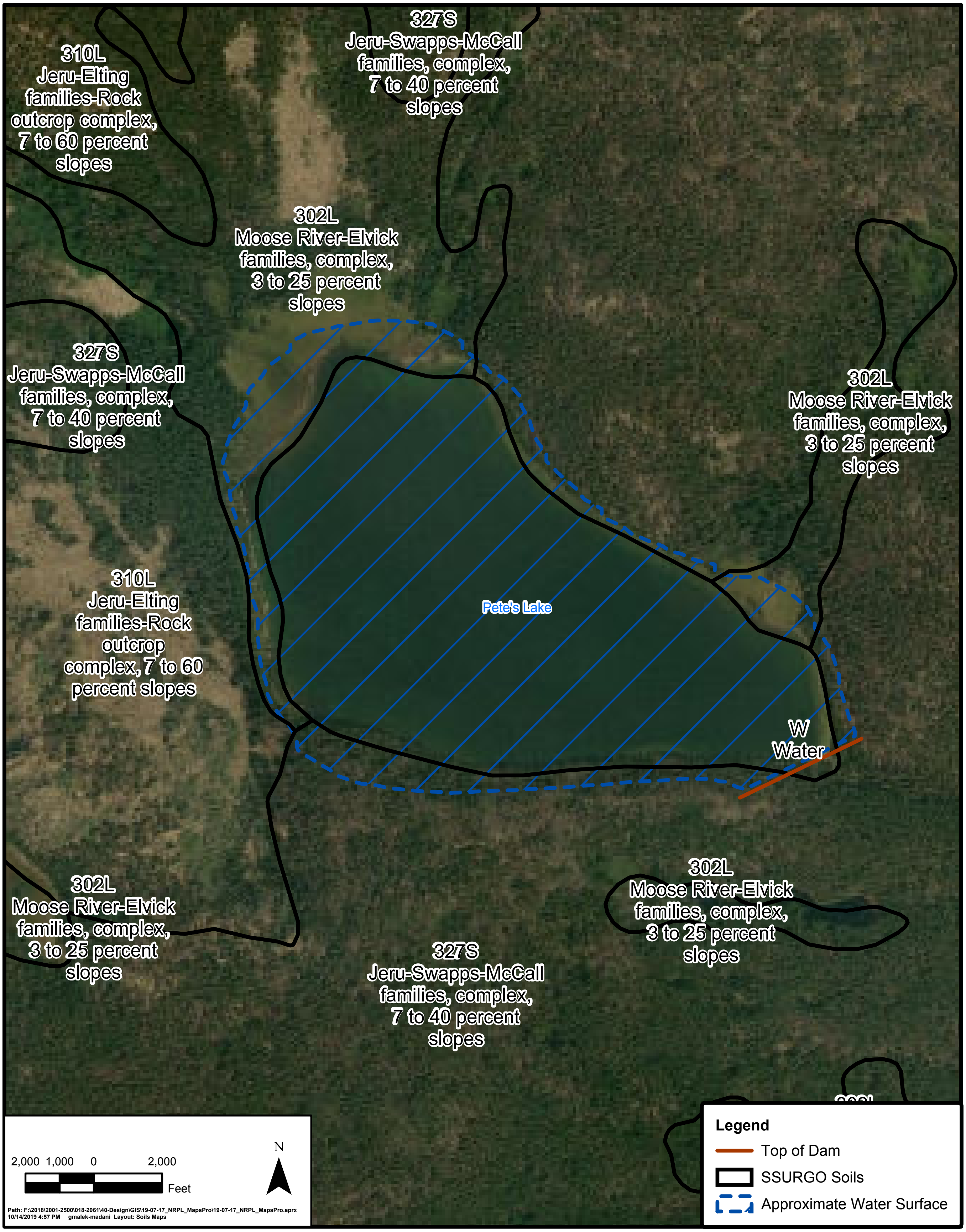
POPO AGIE WATERSHED STUDY

Iiams Creek
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-20b



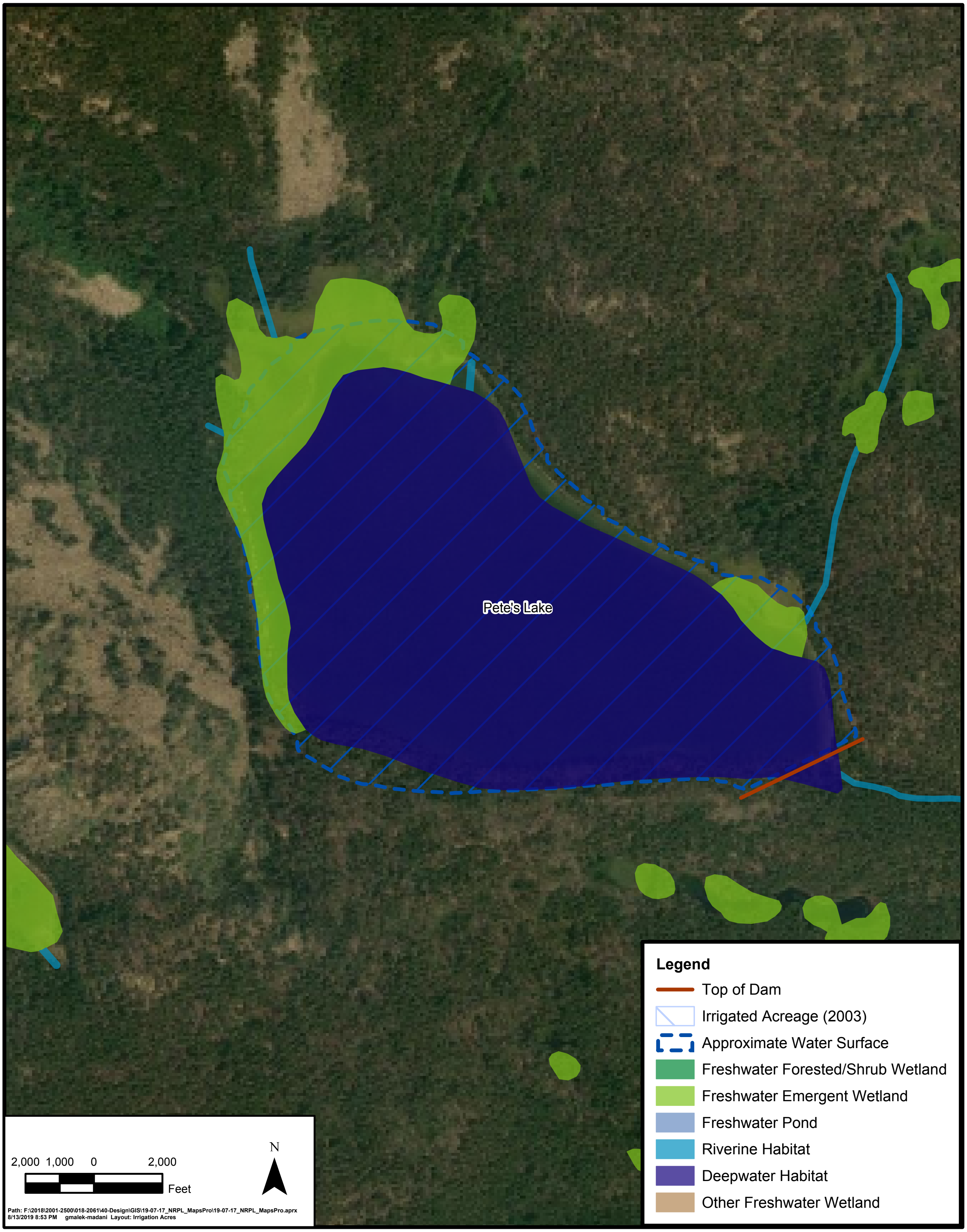
POPO AGIE WATERSHED STUDY

Pete's Lake
Potential Microstorage Layout and Soils

olsson WENCK

FIGURE

C-21a



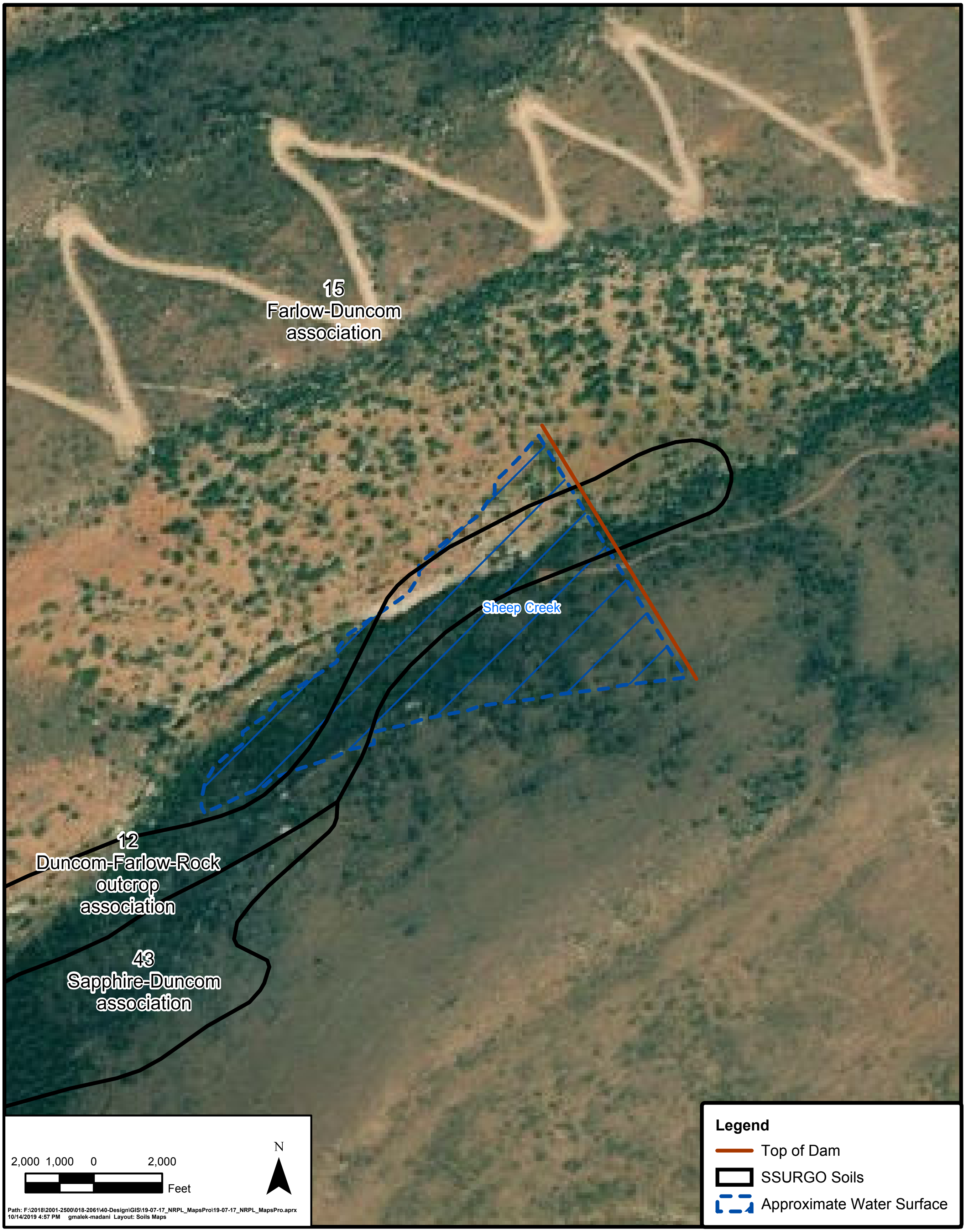
POPO AGIE WATERSHED STUDY

Pete's Lake
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-21b



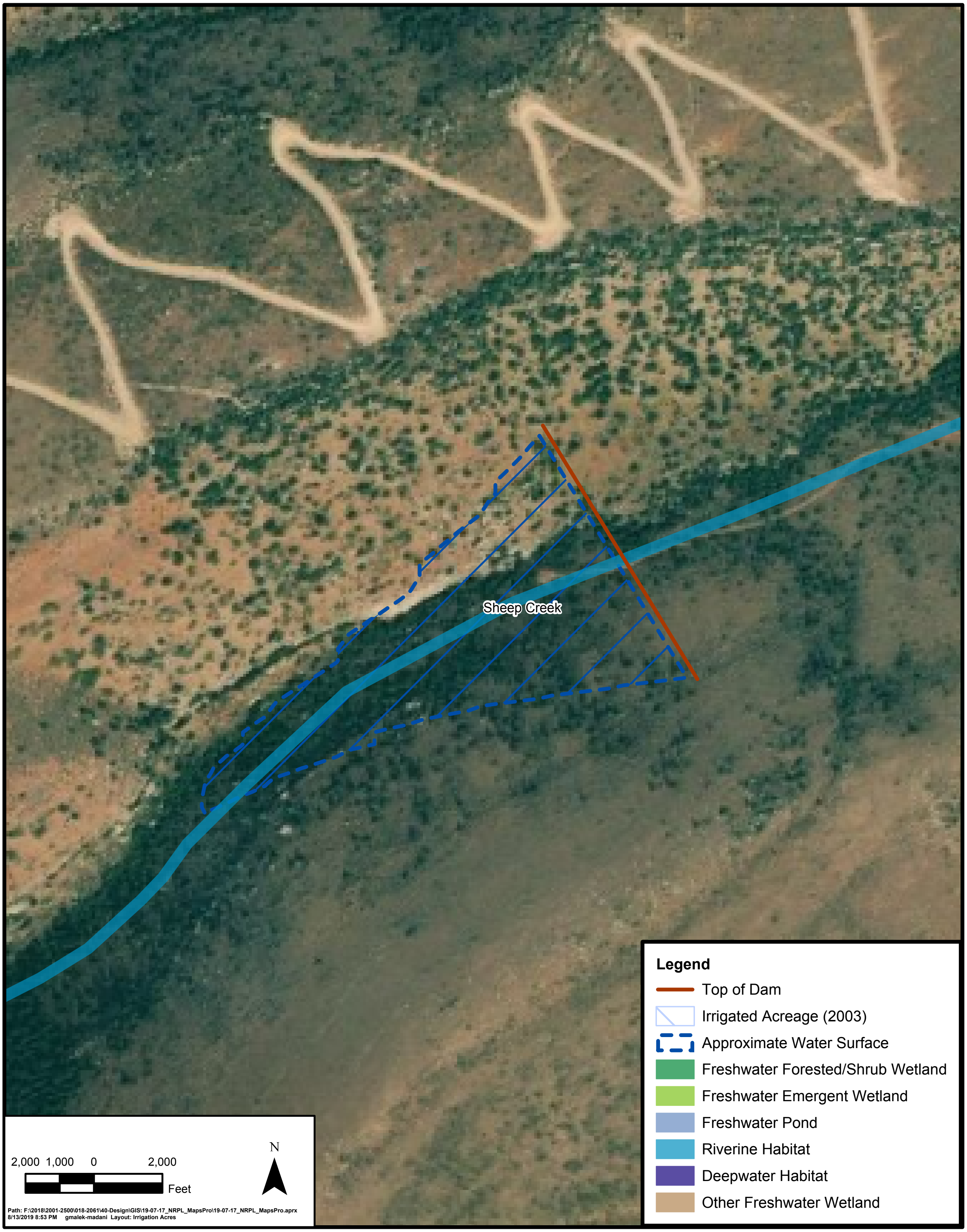
POPO AGIE WATERSHED STUDY

Sheep Creek
Potential Microstorage Layout and Soils

olsson WENCK

FIGURE

C-22a



POPO AGIE WATERSHED STUDY

Sheep Creek
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE
C-22b

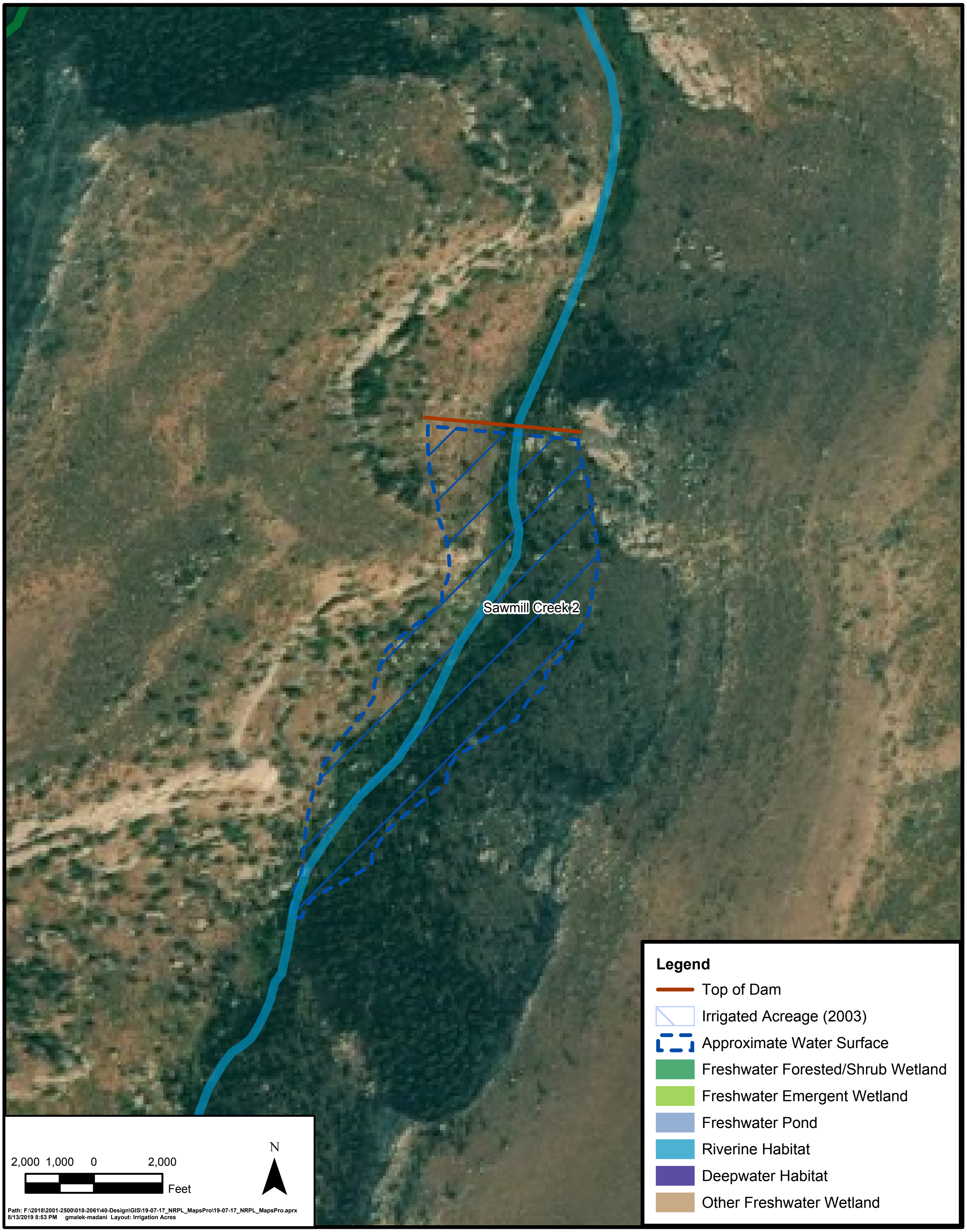
POPO AGIE WATERSHED STUDY

Sawmill Creek 2
Potential Microstorage Layout and Soils

olsson WENCK

FIGURE

C-23a



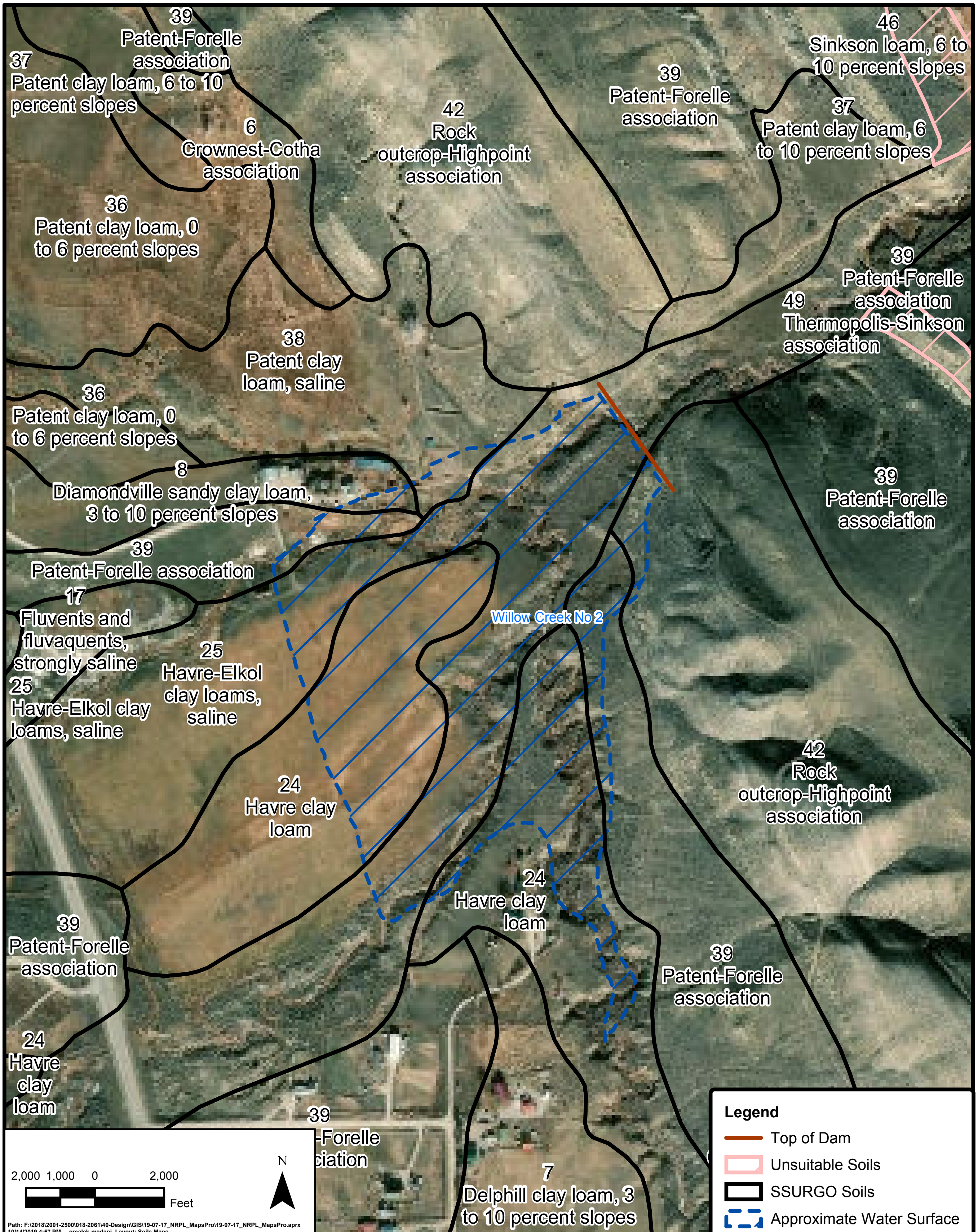
POPO AGIE WATERSHED STUDY

Sawmill Creek 2
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-23b



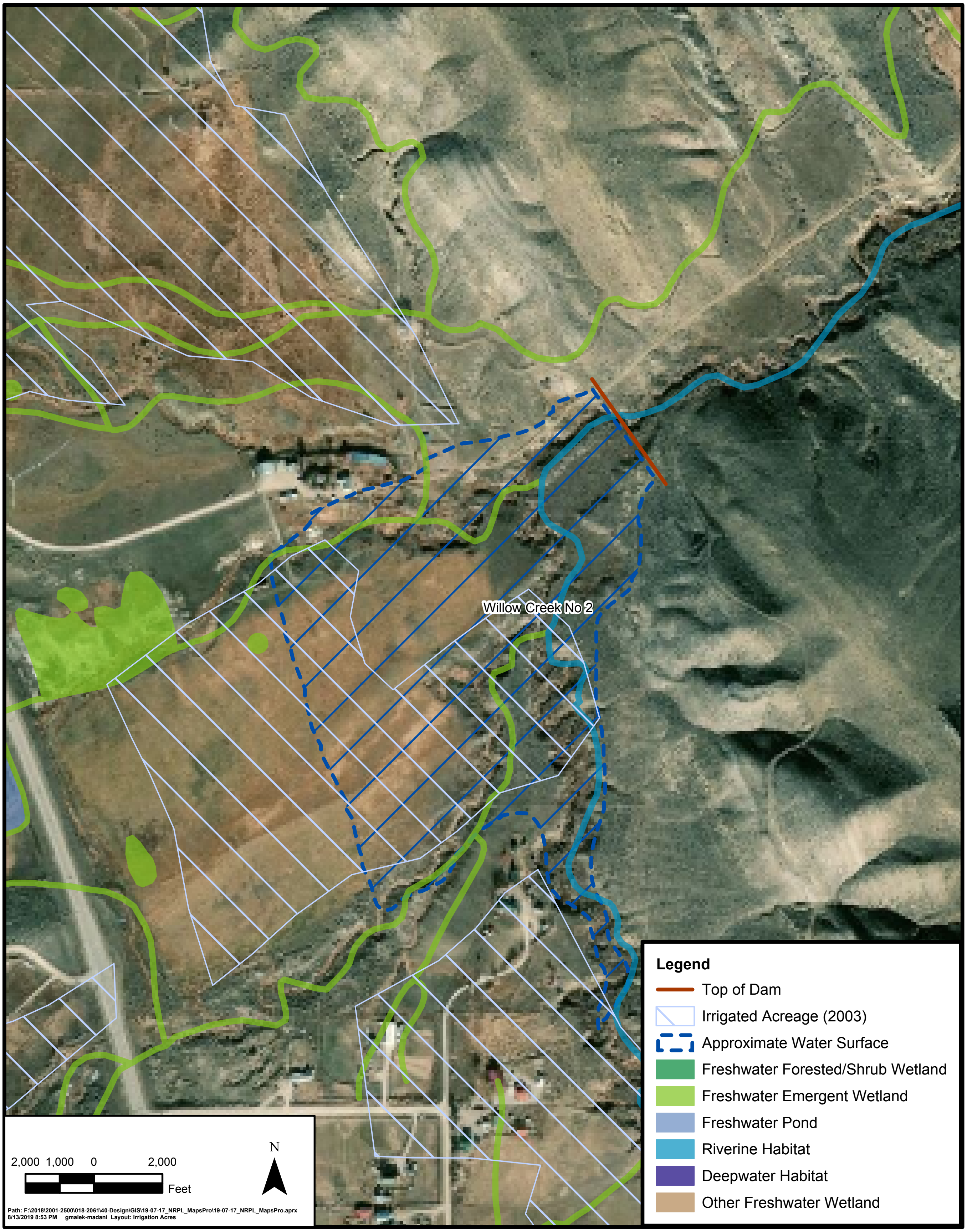
POPO AGIE WATERSHED STUDY

Willow Creek No 2
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE

C-24a



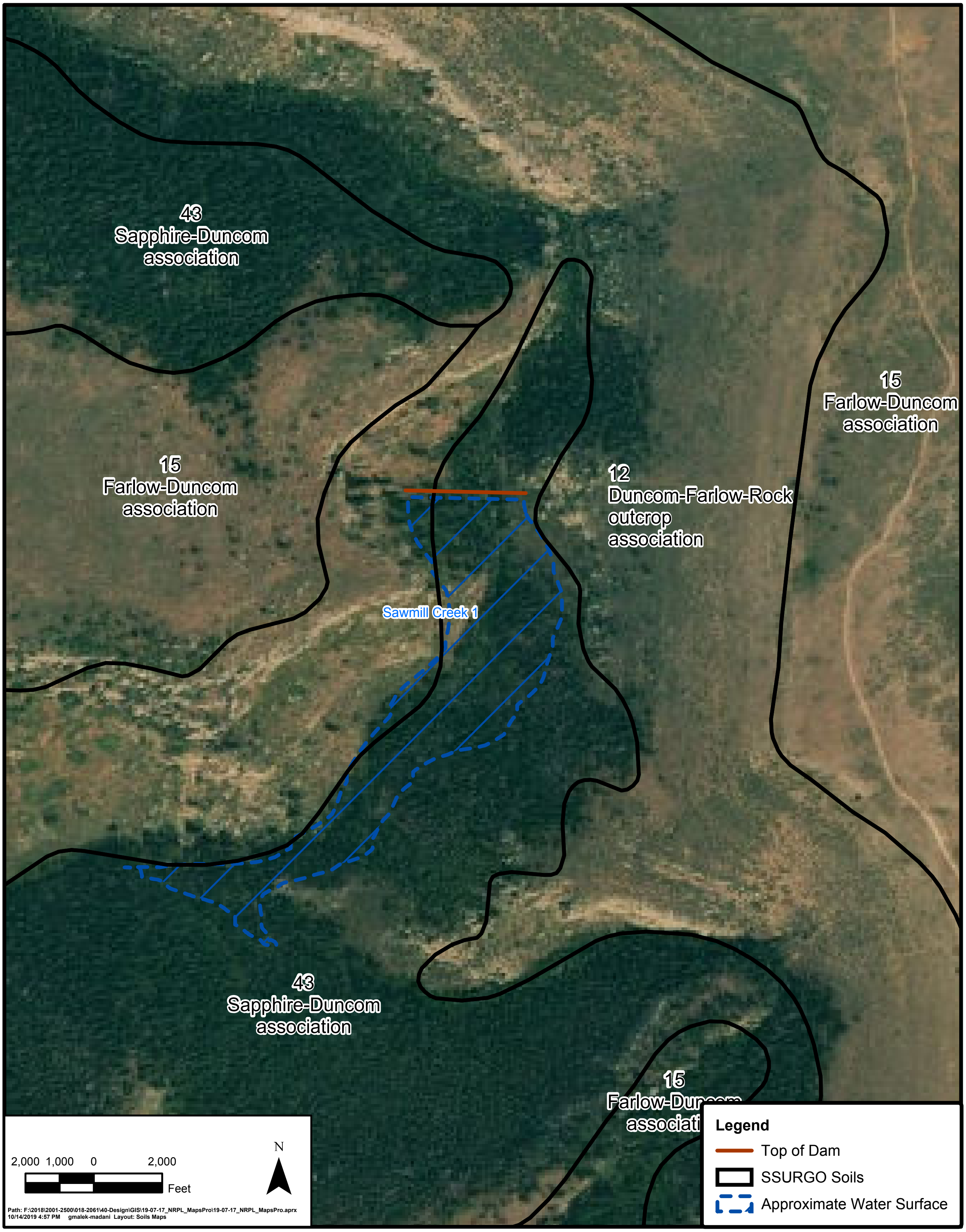
POPO AGIE WATERSHED STUDY

Willow Creek No 2
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-24b

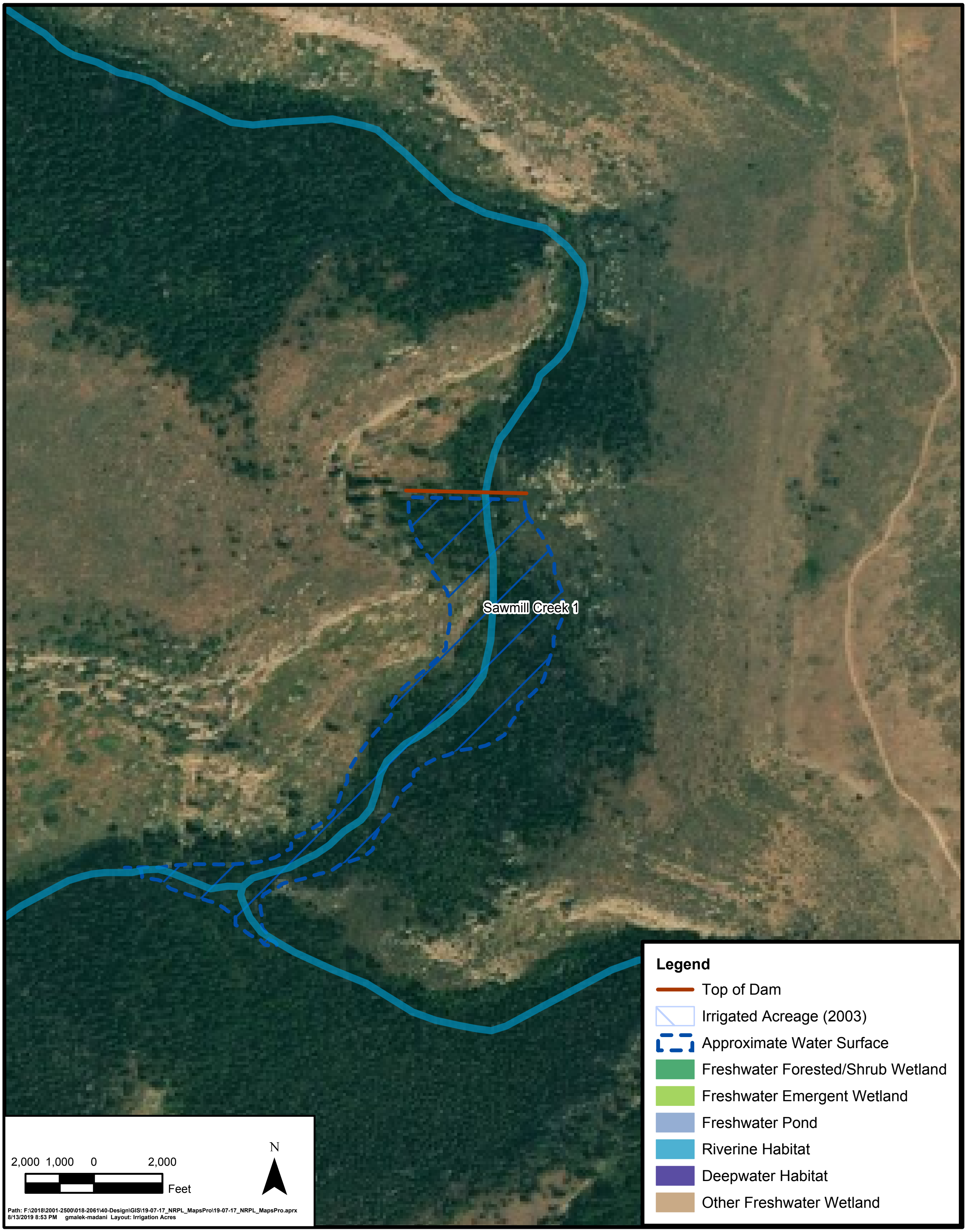


POPO AGIE WATERSHED STUDY

Sawmill Creek 1
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE
C-25a

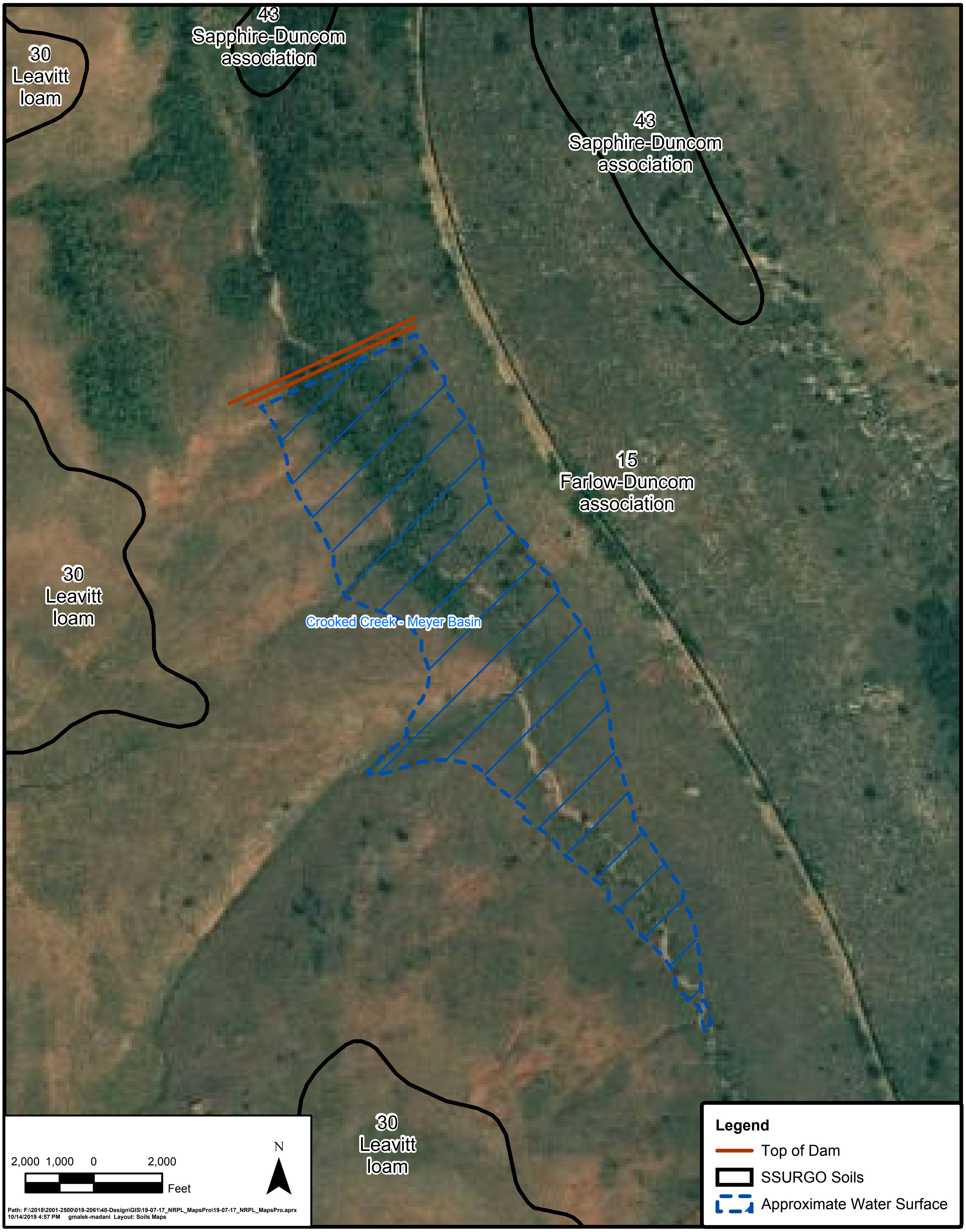


POPO AGIE WATERSHED STUDY

Sawmill Creek 1
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE
C-25b



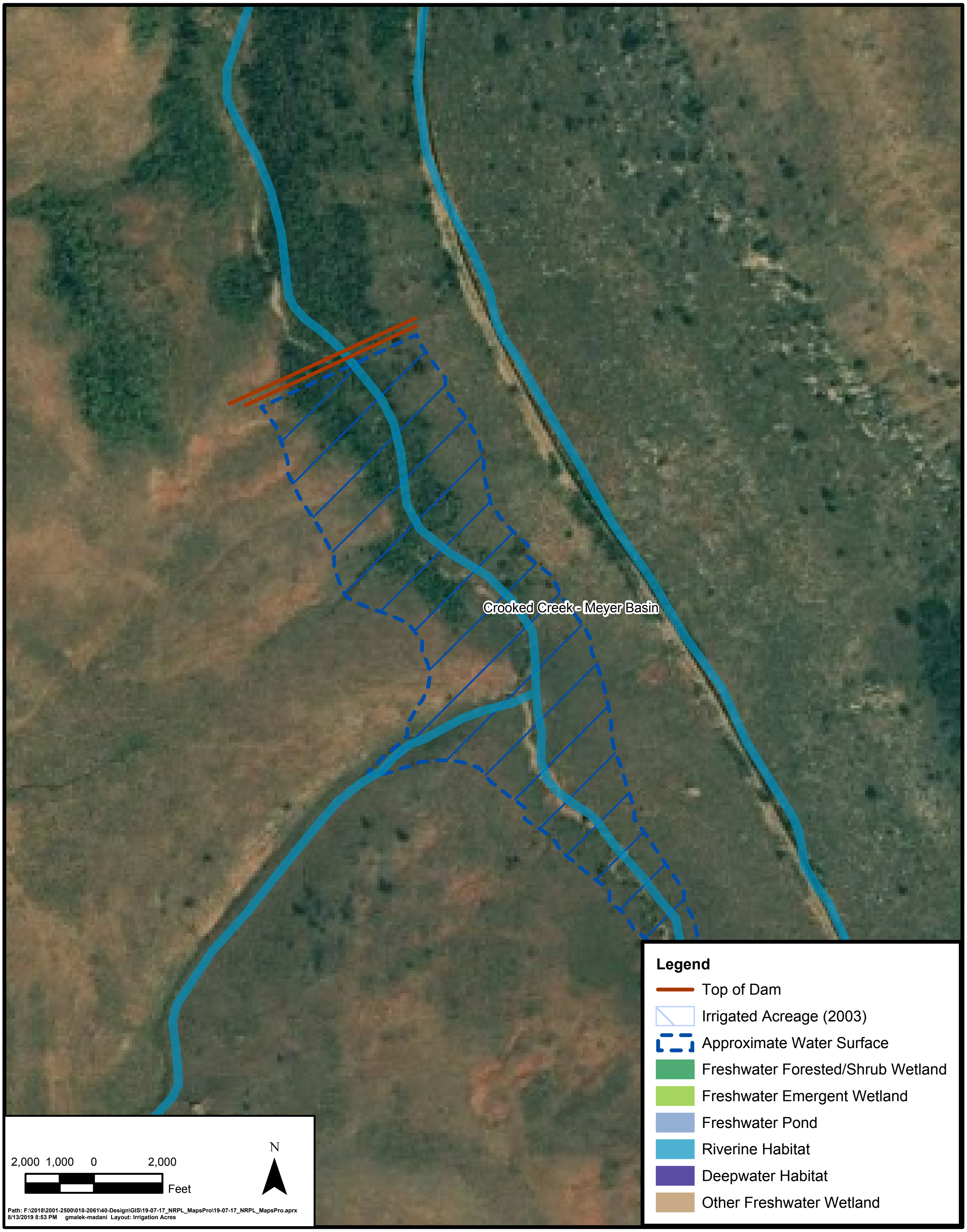
POPO AGIE WATERSHED STUDY

Crooked Creek - Meyer Basin
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE

C-26a



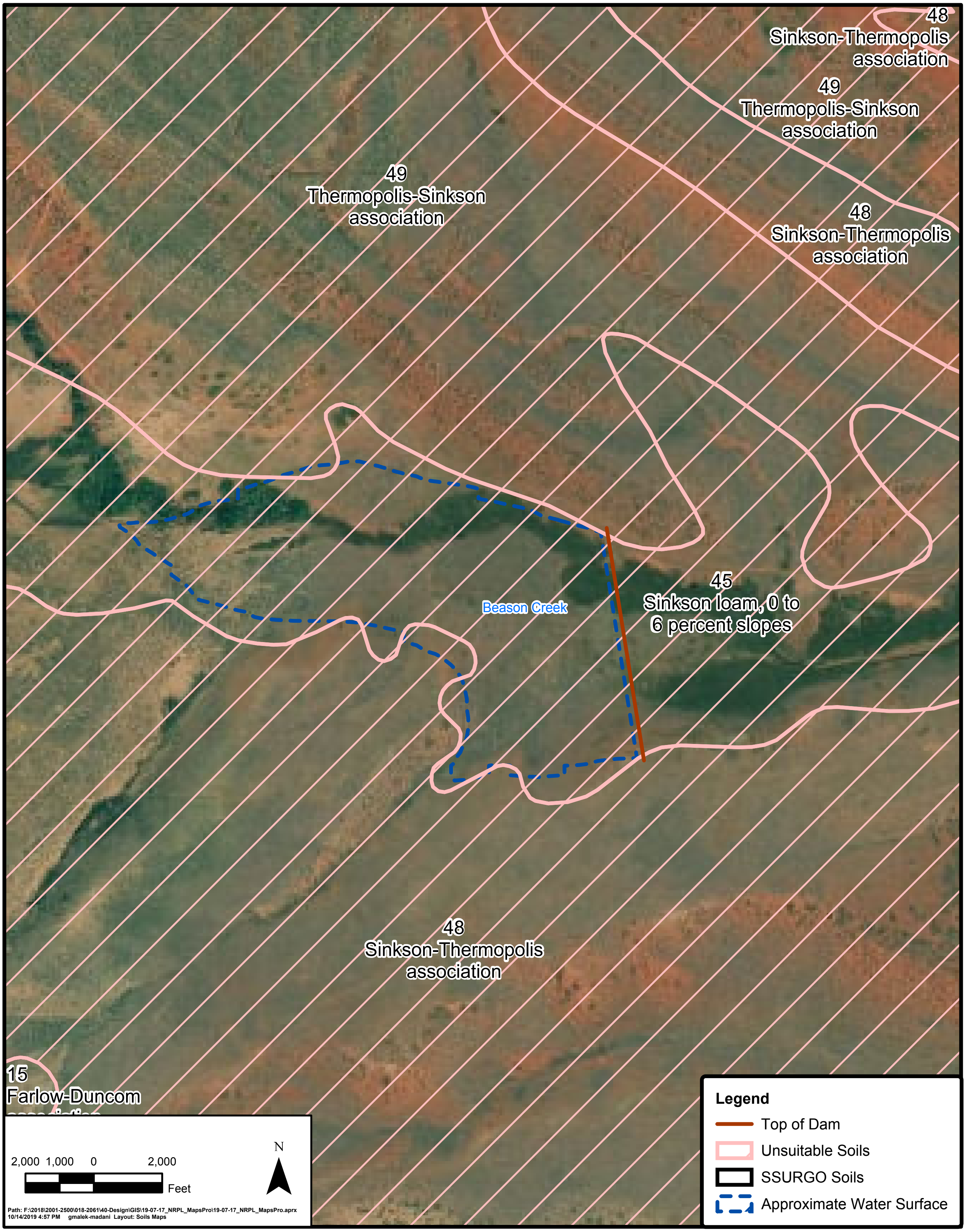
POPO AGIE WATERSHED STUDY

Crooked Creek - Meyer Basin
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-26b



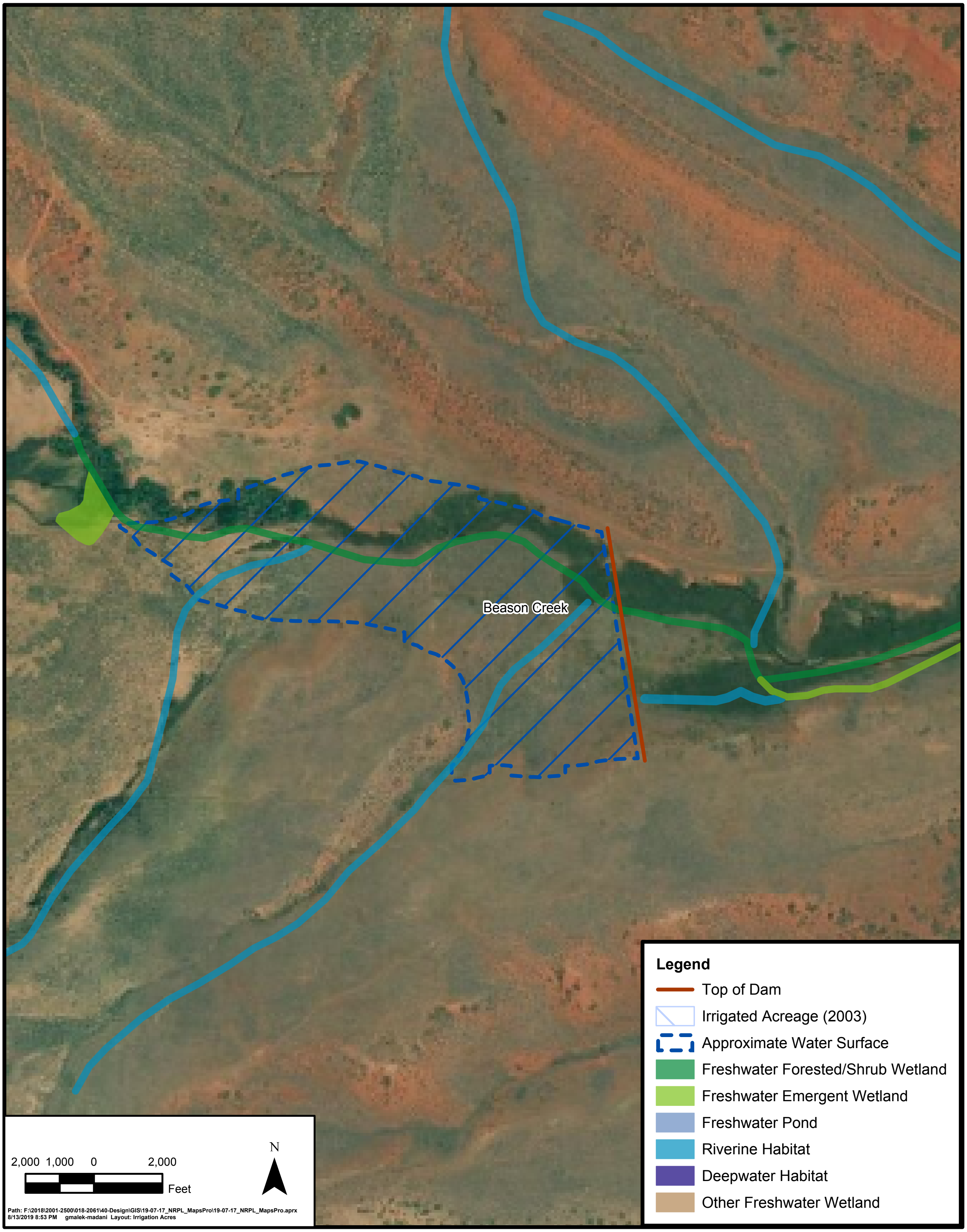
POPO AGIE WATERSHED STUDY

Beason Creek
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE

C-27a



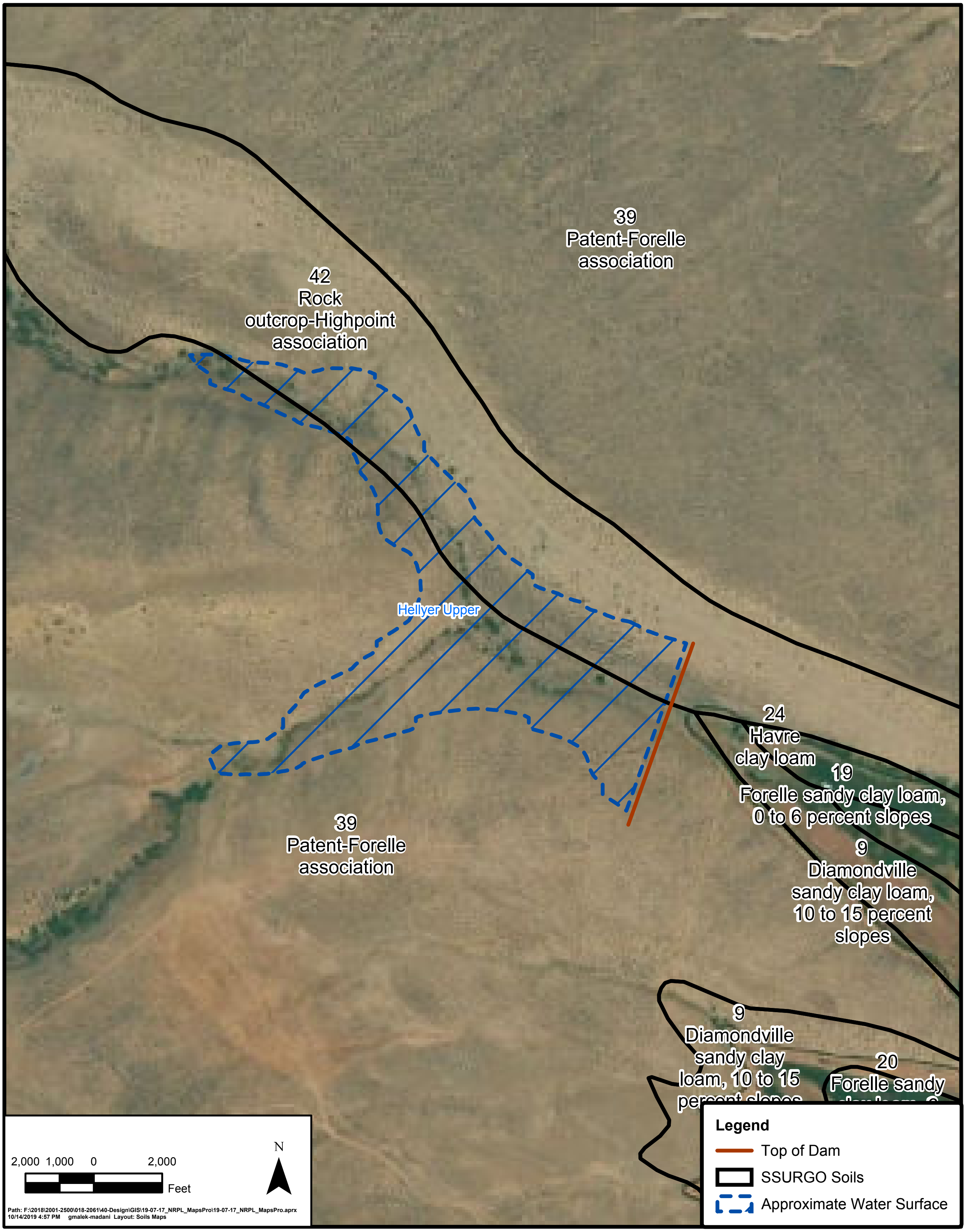
POPO AGIE WATERSHED STUDY

Beason Creek
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-27b

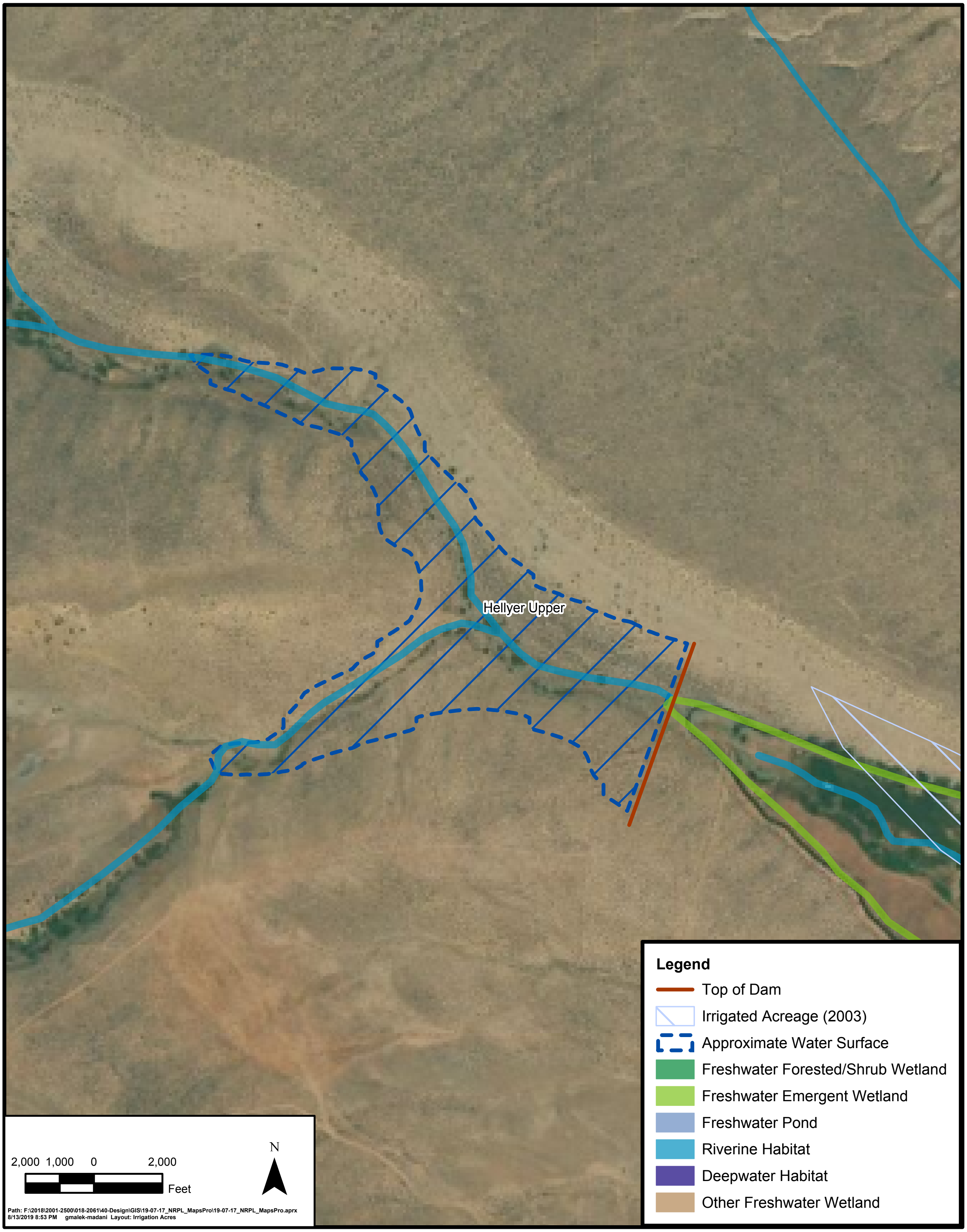


POPO AGIE WATERSHED STUDY

Hellyer Upper
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE
C-28a



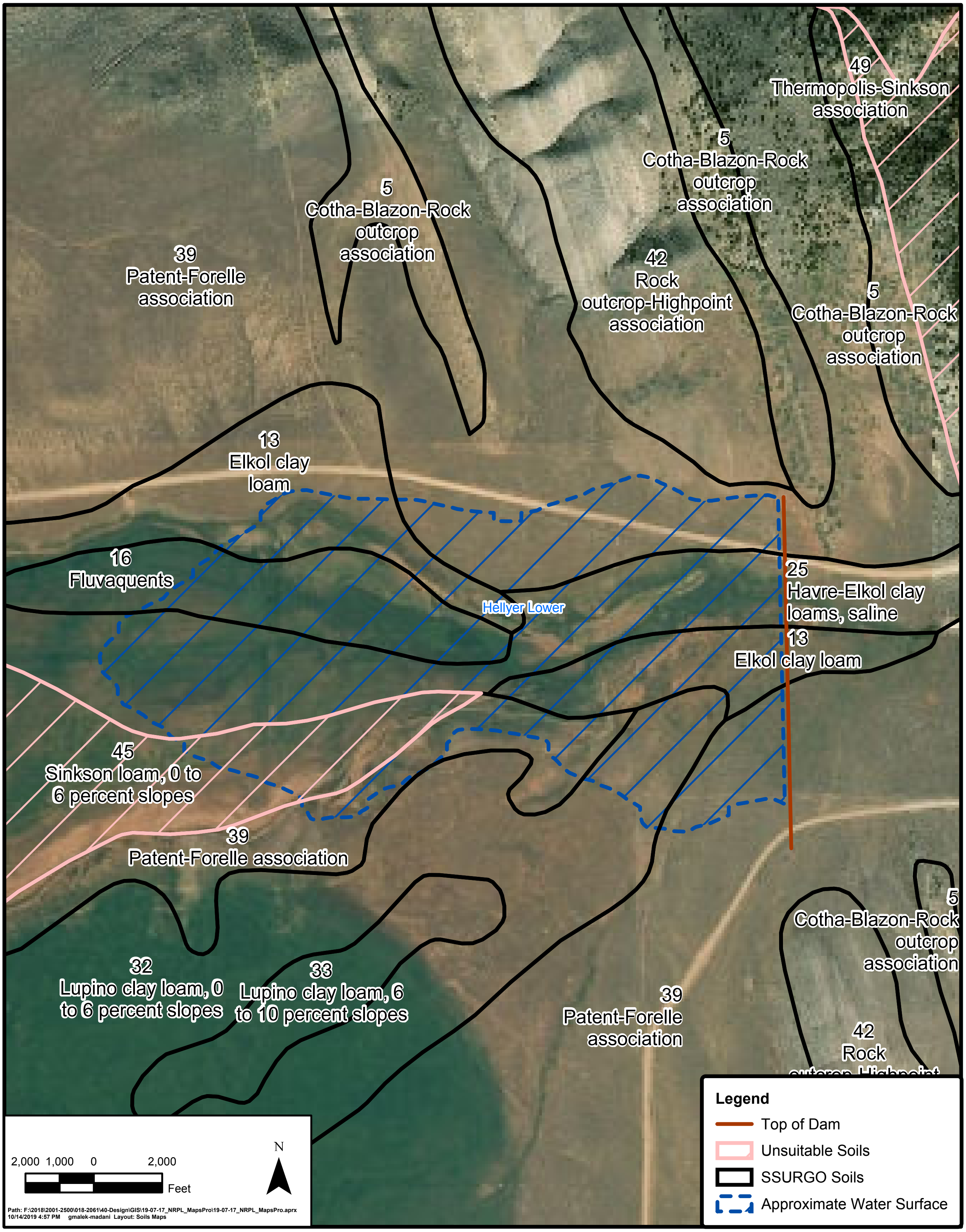
POPO AGIE WATERSHED STUDY

Hellyer Upper
Potential Microstorage Irrigation & NWI

olsson WENCK

FIGURE

C-28b

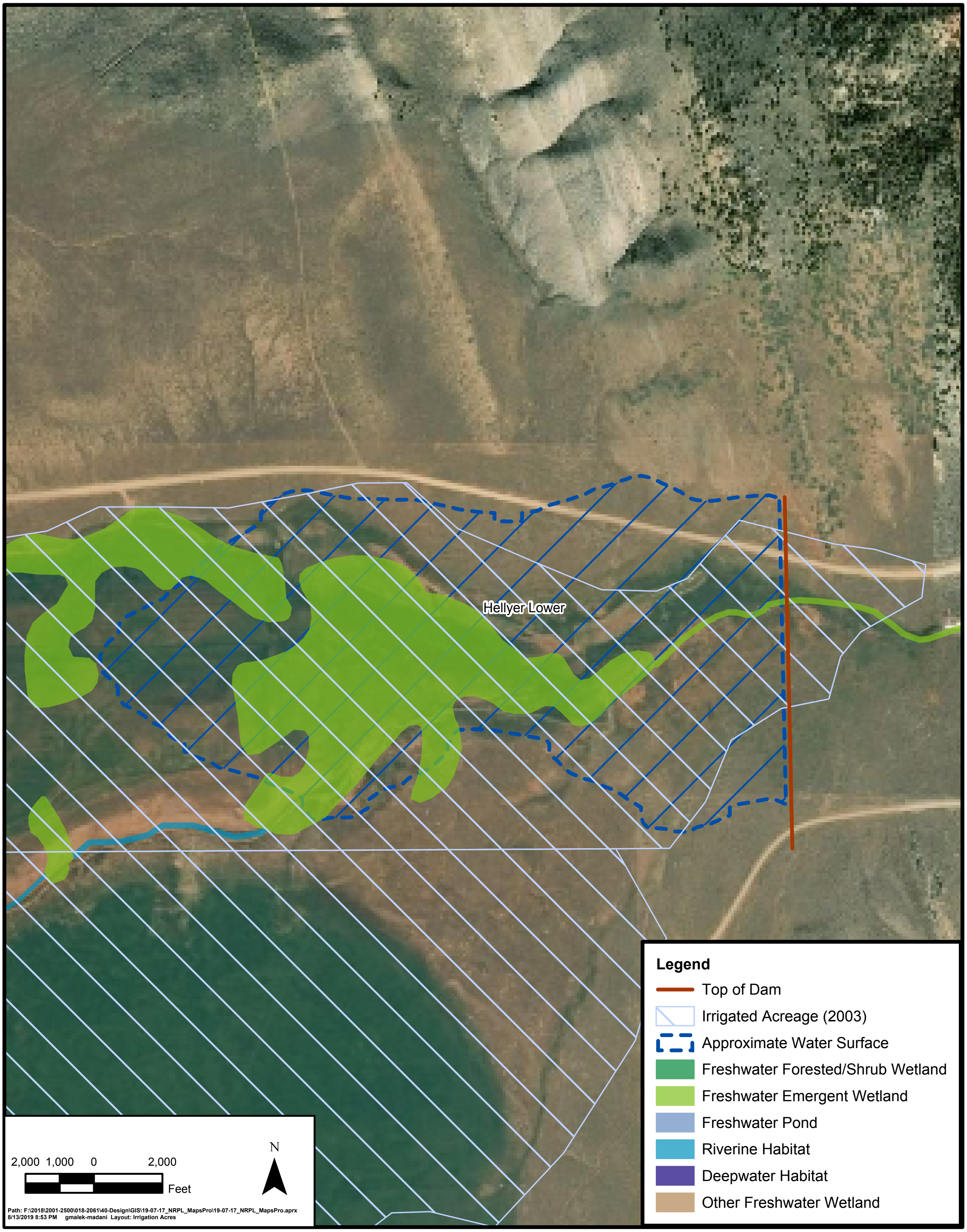


POPO AGIE WATERSHED STUDY

Hellyer Lower
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE
C-29a



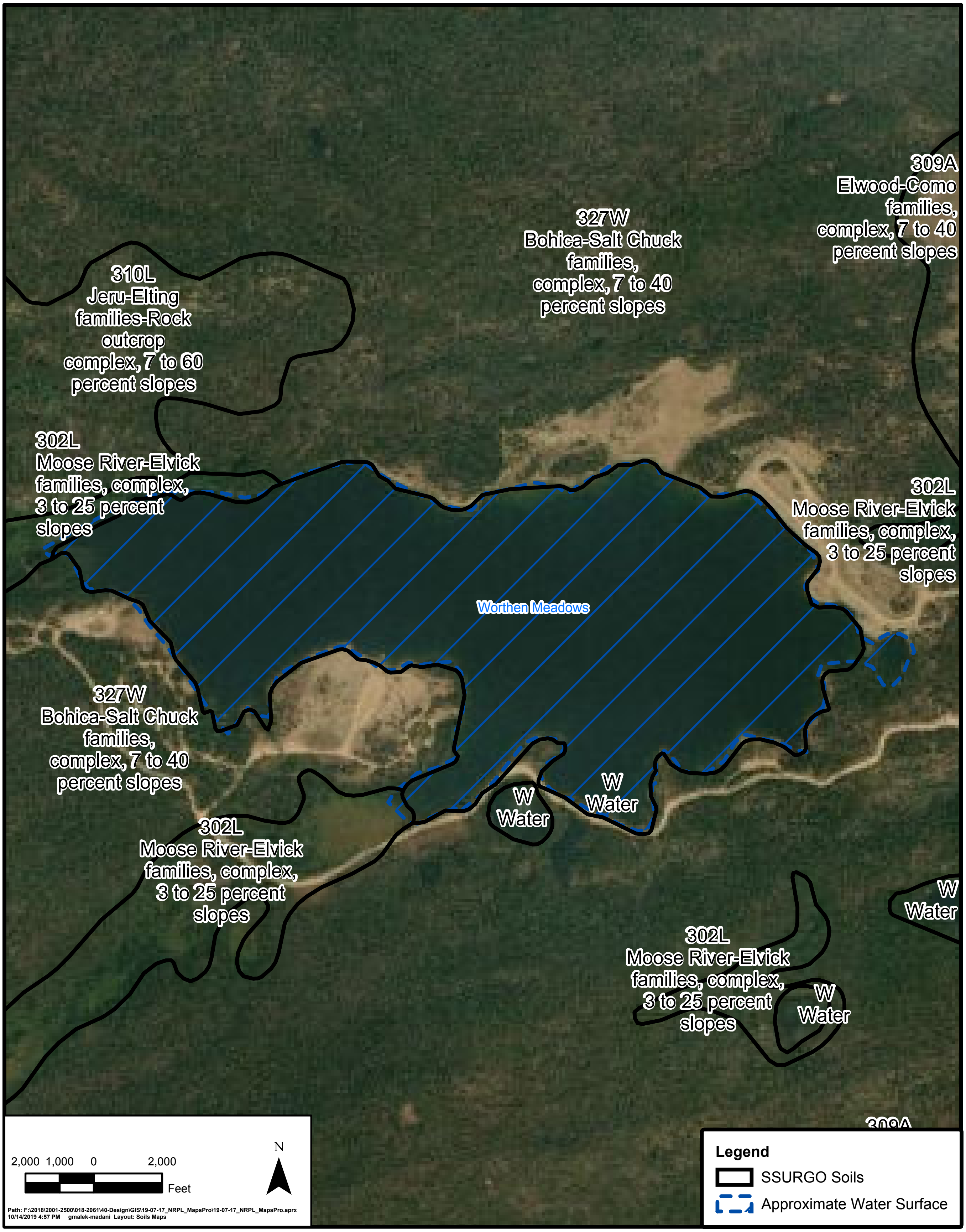
POPO AGIE WATERSHED STUDY

Hellyer Lower
Potential Microstorage Irrigation & NWI

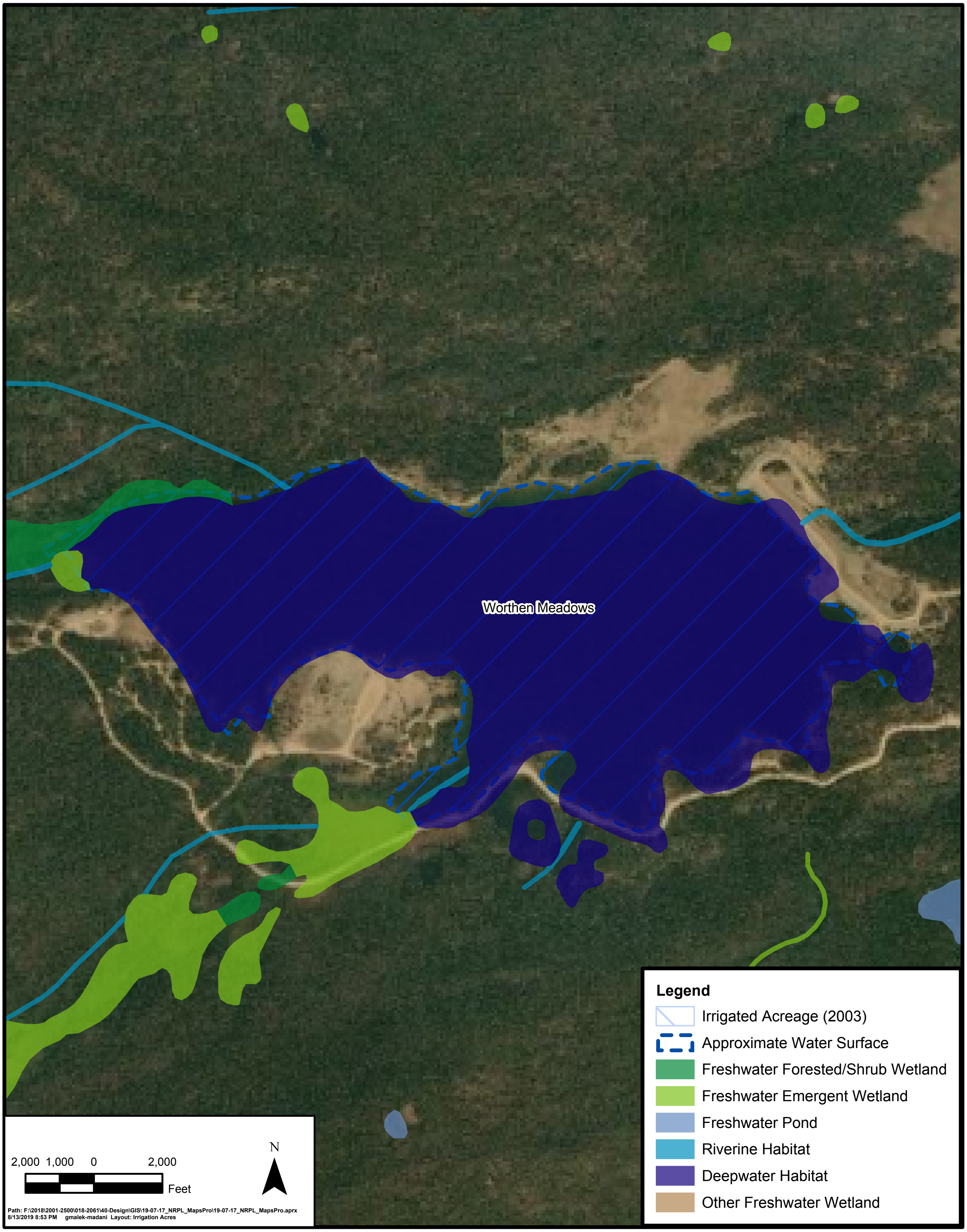
olsson
WENCK

FIGURE

C-29b



POPO AGIE WATERSHED STUDY	olsson WENCK	FIGURE
Worthen Meadows Potential Microstorage Layout and Soils		C-30a



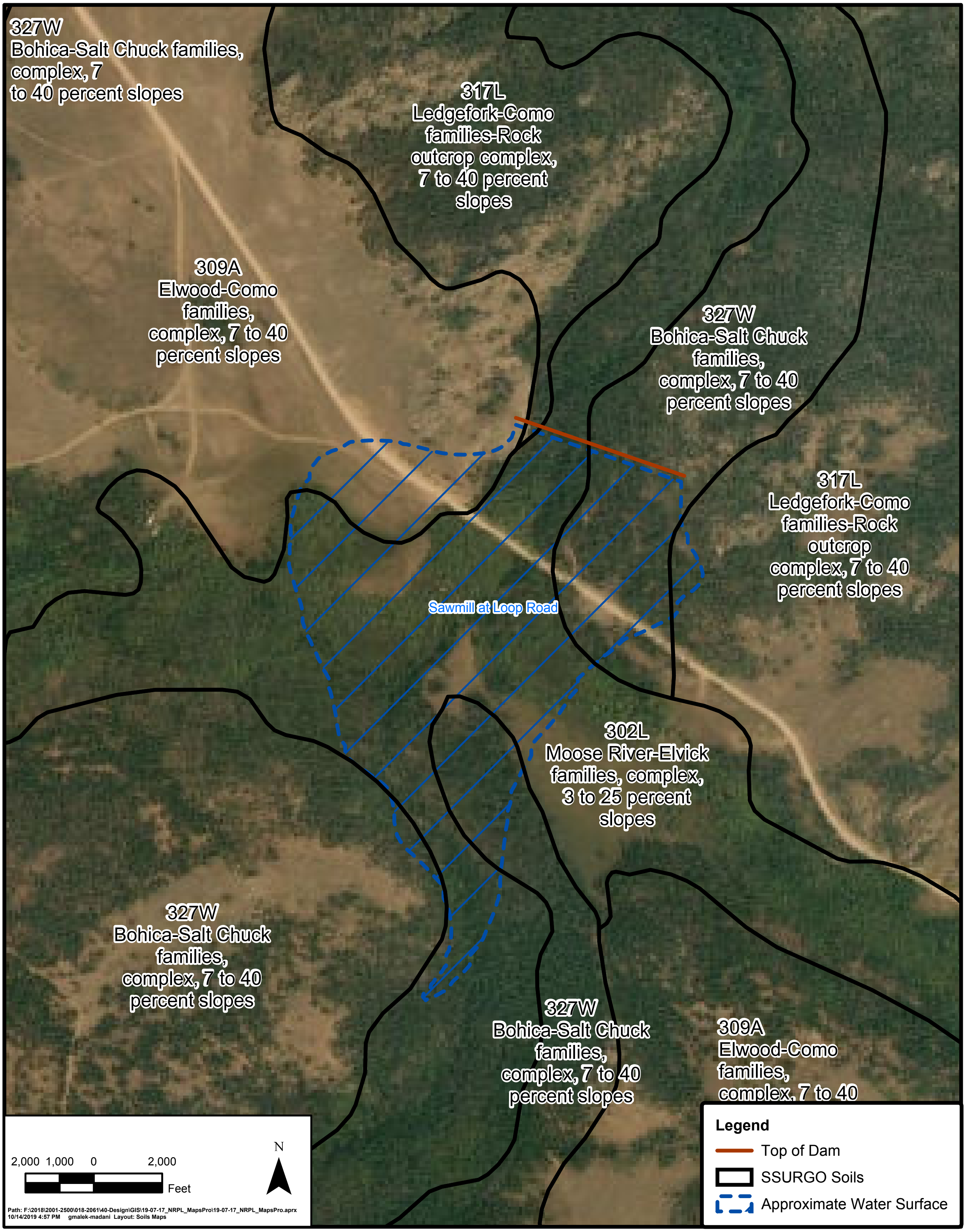
POPO AGIE WATERSHED STUDY

Worthen Meadows
Potential Microstorage Irrigation & NWI

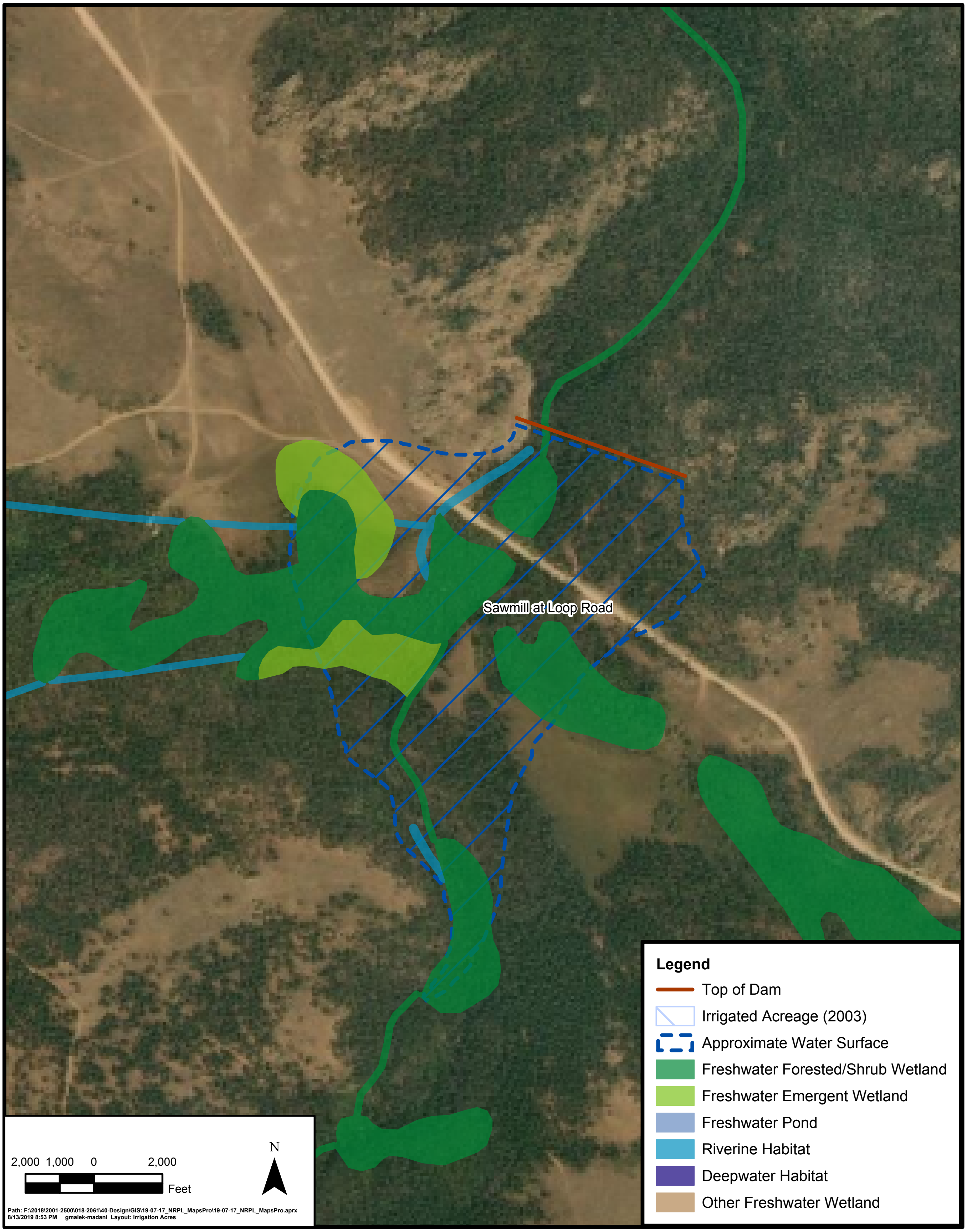
olsson
WENCK

FIGURE

C-30b



POPO AGIE WATERSHED STUDY	olsson WENCK	FIGURE
Sawmill at Loop Road Potential Microstorage Layout and Soils		C-31a

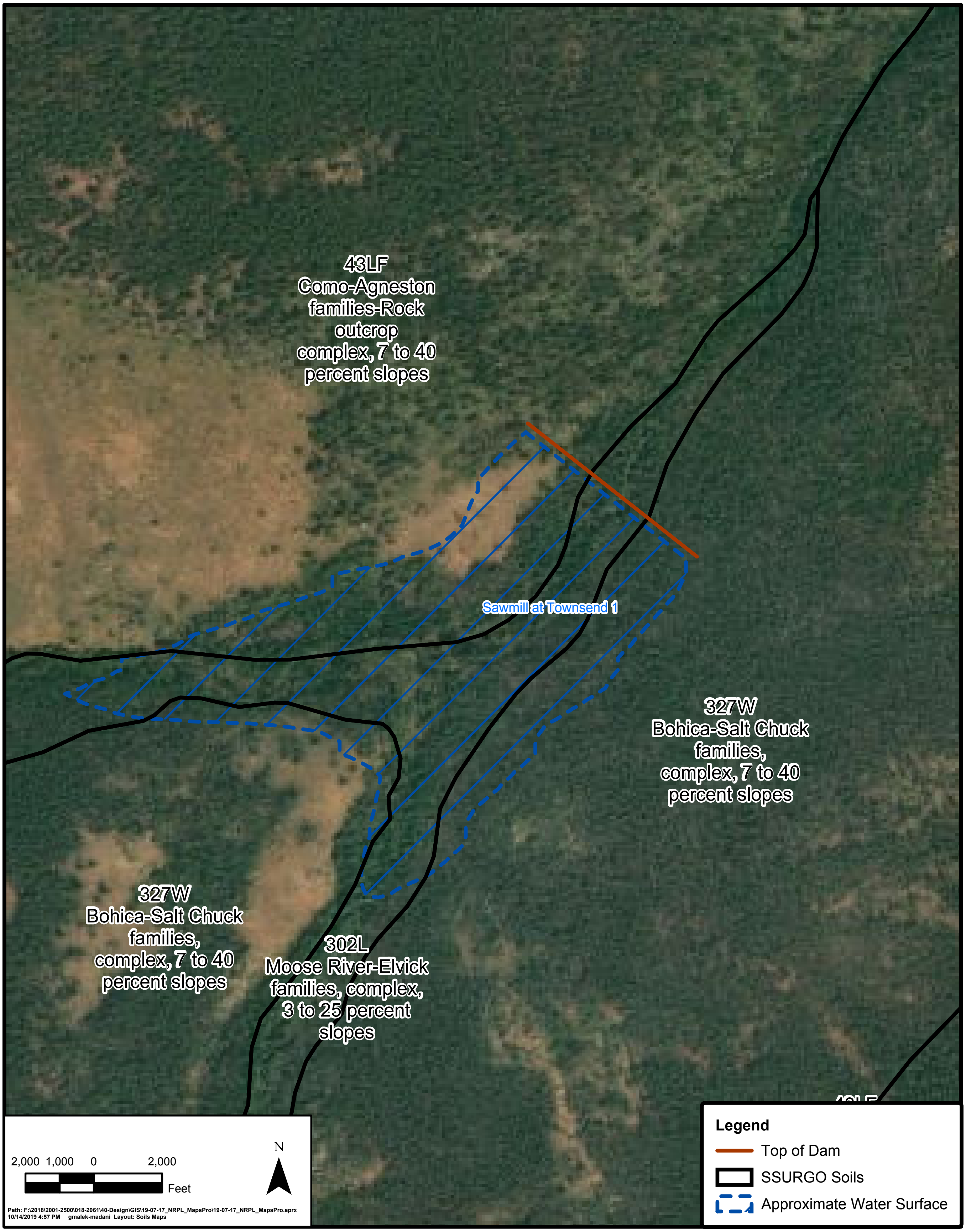


POPO AGIE WATERSHED STUDY

Sawmill at Loop Road
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE
C-31b



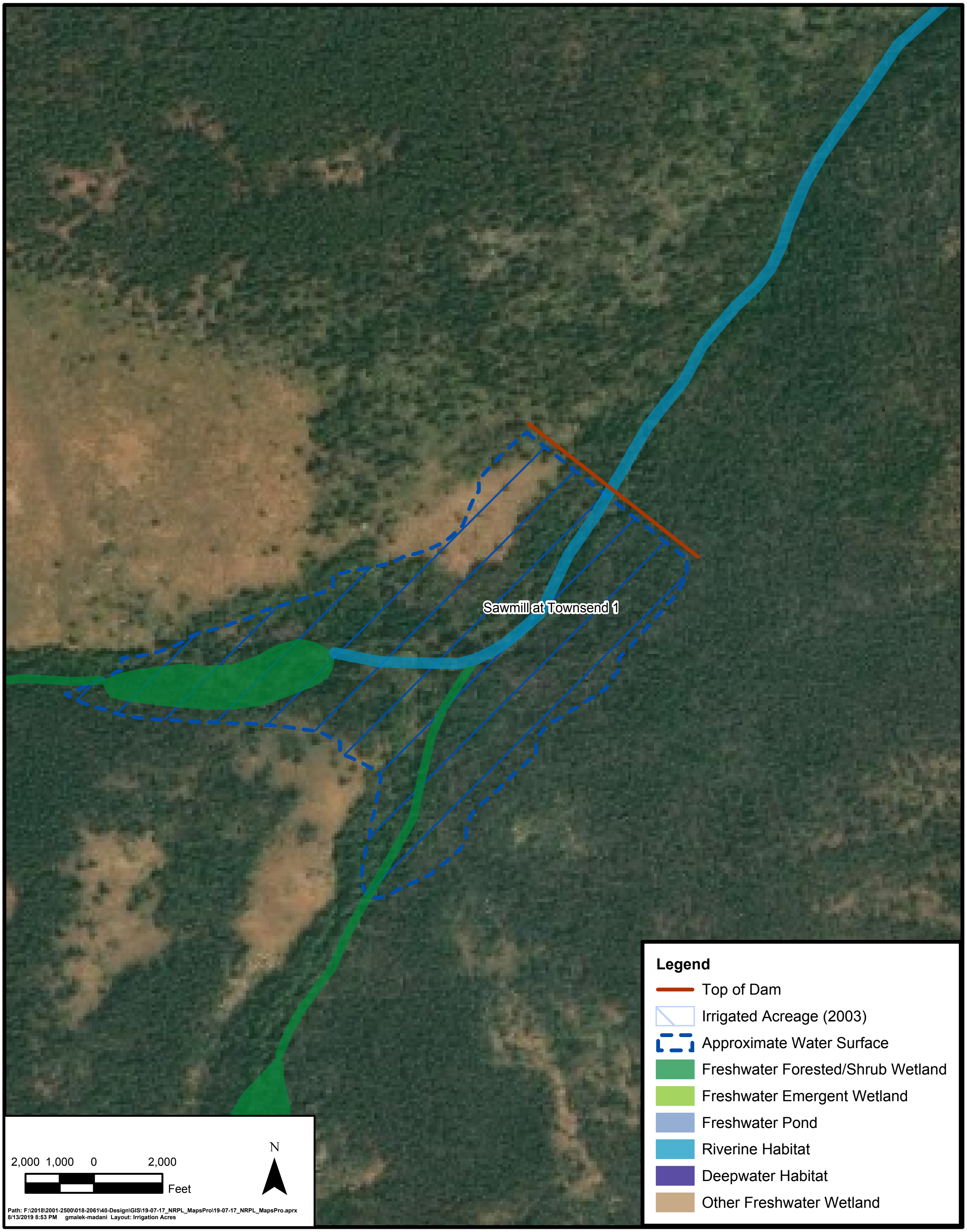
POPO AGIE WATERSHED STUDY

Sawmill at Townsend 1
Potential Microstorage Layout and Soils

olsson WENCK

FIGURE

C-32a



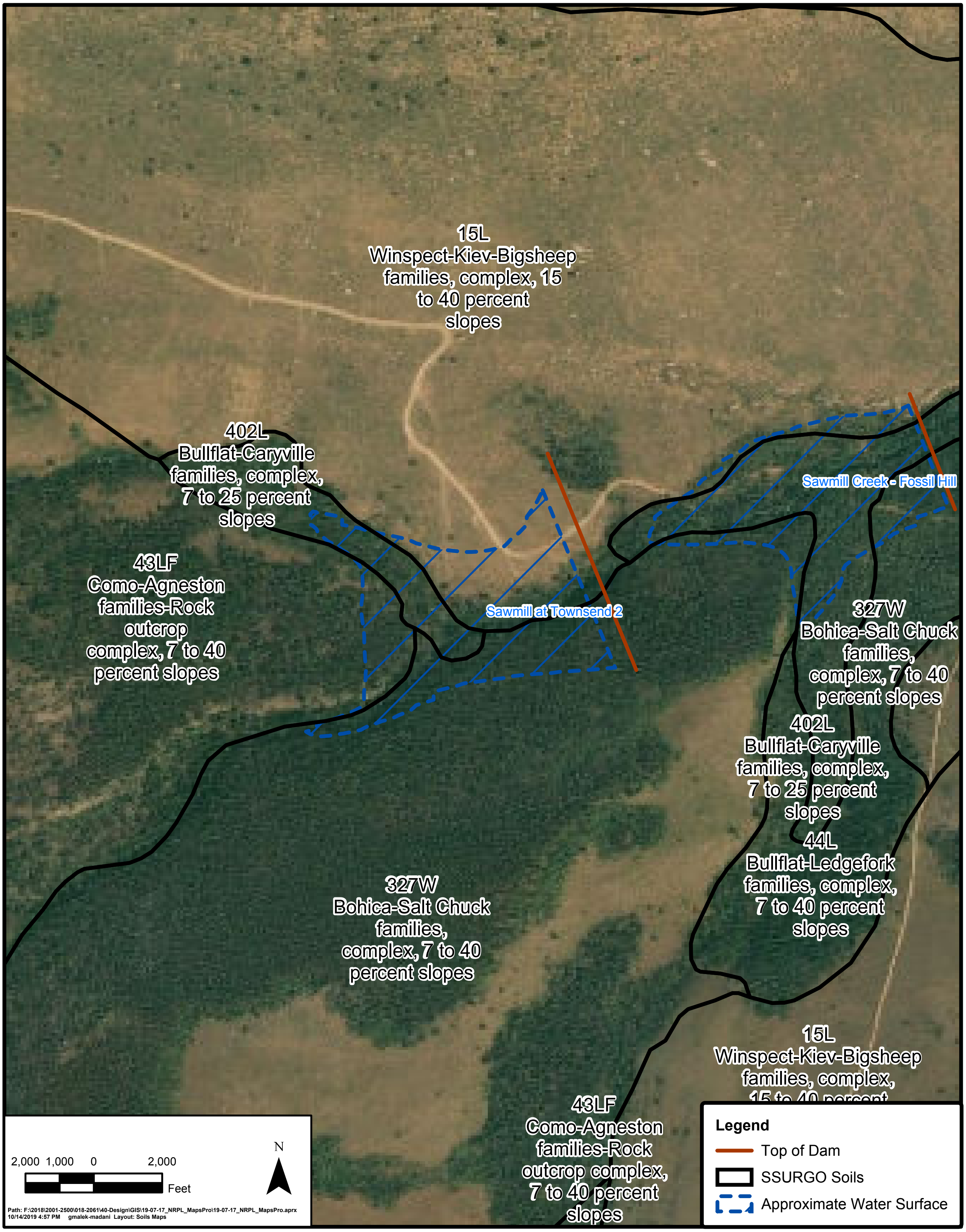
POPO AGIE WATERSHED STUDY

Sawmill at Townsend 1
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-32b



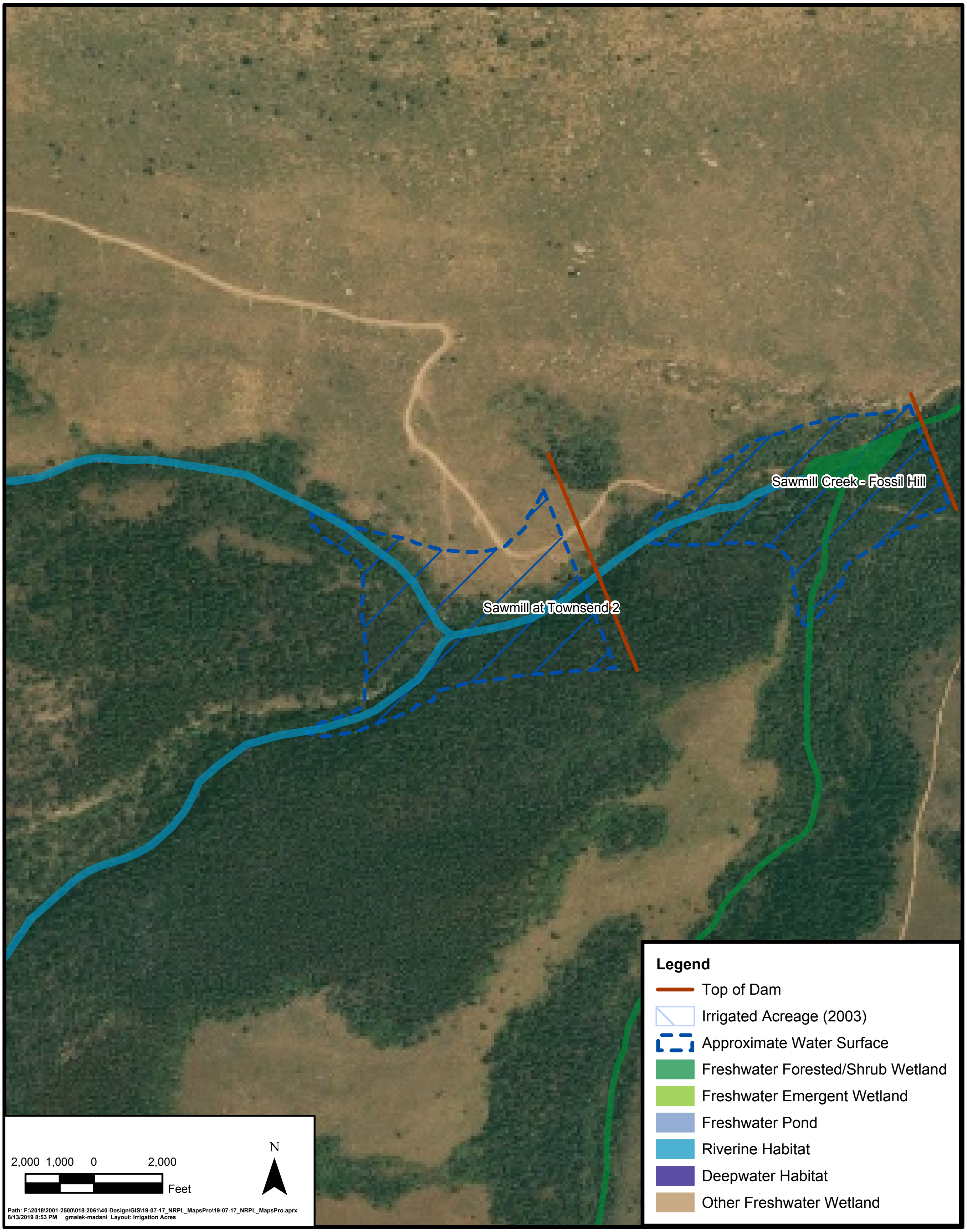
POPO AGIE WATERSHED STUDY

Sawmill at Townsend 2
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE

C-33a



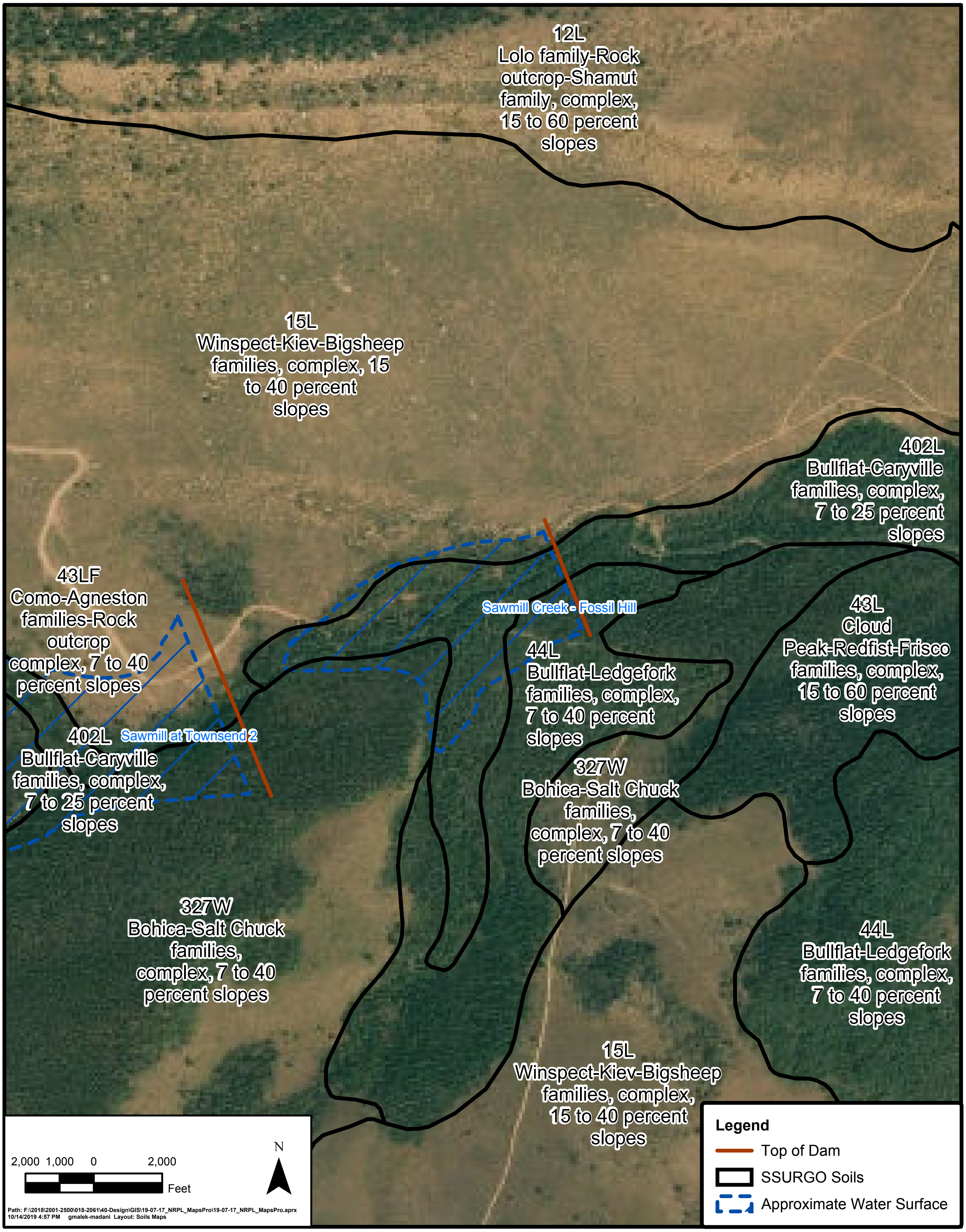
POPO AGIE WATERSHED STUDY

Sawmill at Townsend 2
Potential Microstorage Irrigation & NWI

olsson WENCK

FIGURE

C-33b



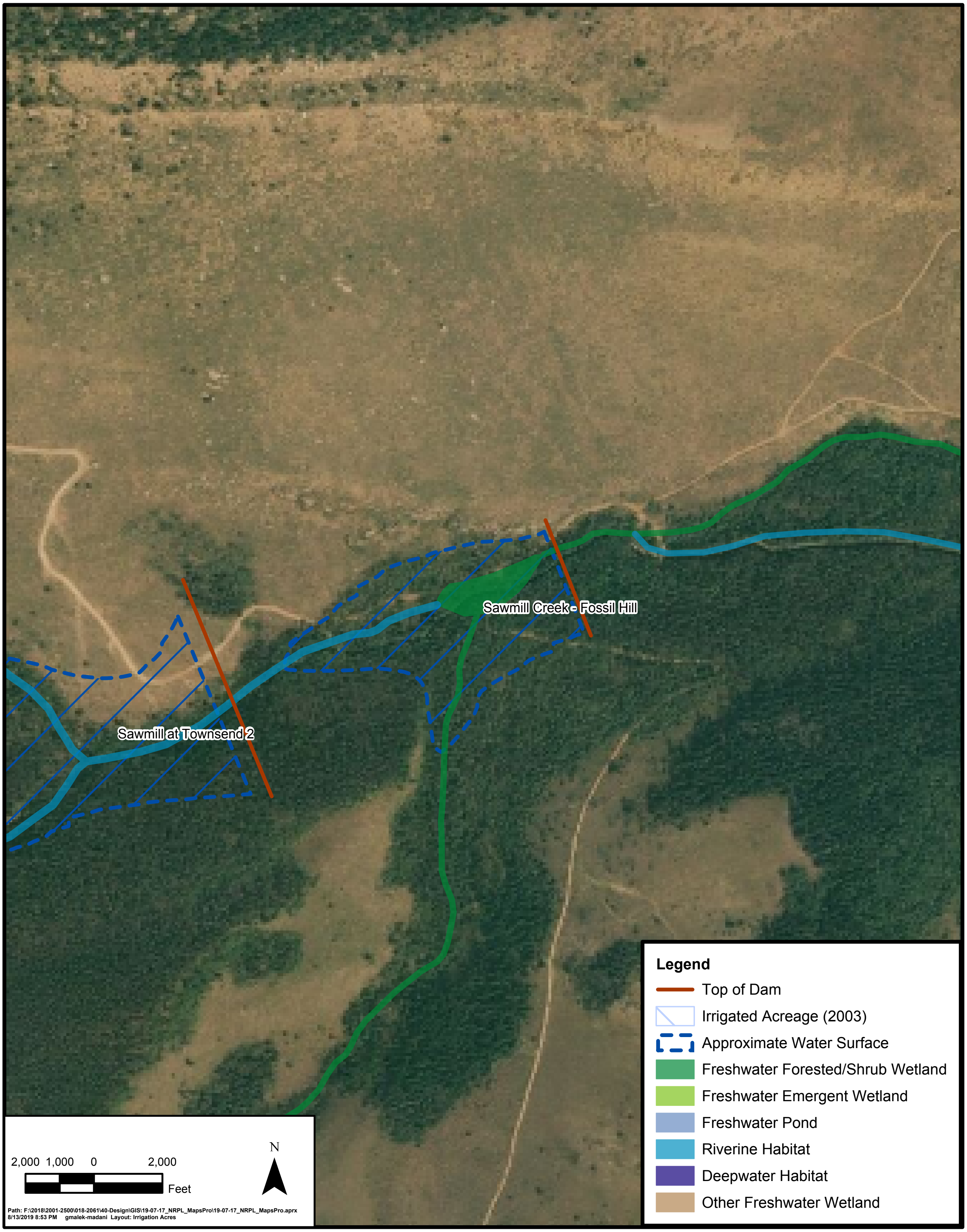
POPO AGIE WATERSHED STUDY

Sawmill Creek - Fossil Hill
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE

C-34a



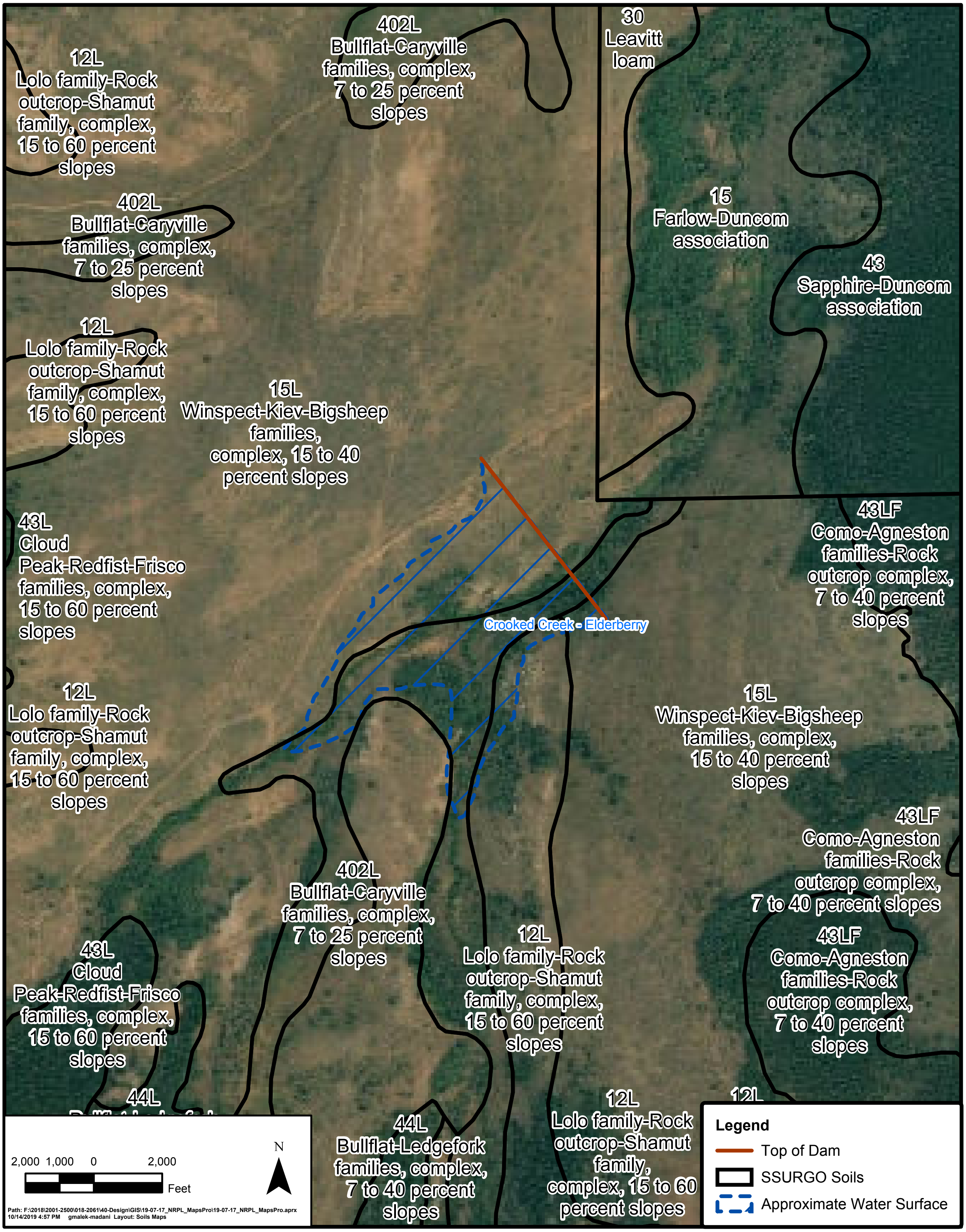
POPO AGIE WATERSHED STUDY

Sawmill Creek - Fossil Hill
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-34b



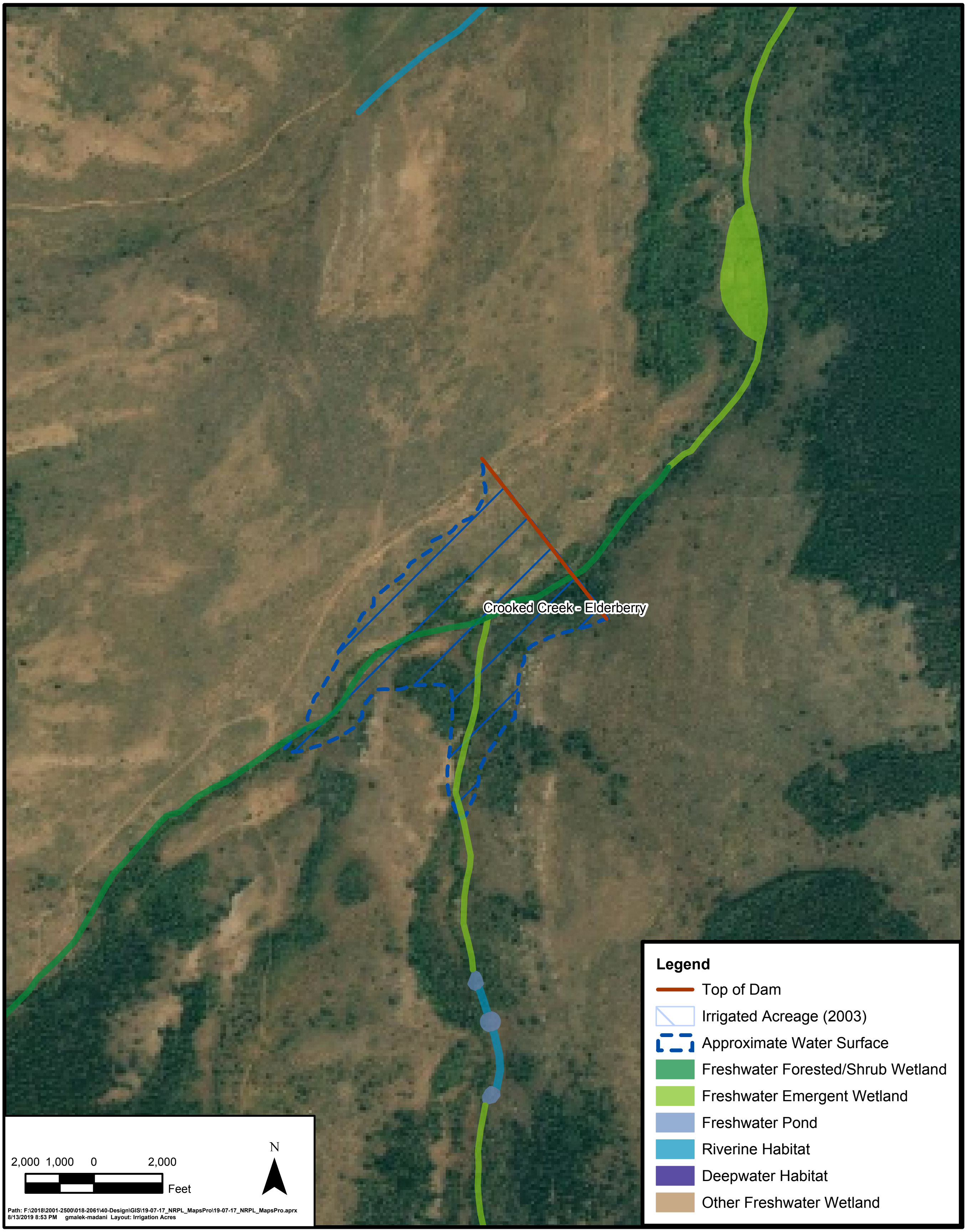
POPO AGIE WATERSHED STUDY

Crooked Creek - Elderberry
Potential Microstorage Layout and Soils

olsson
WENCK

FIGURE

C-35a



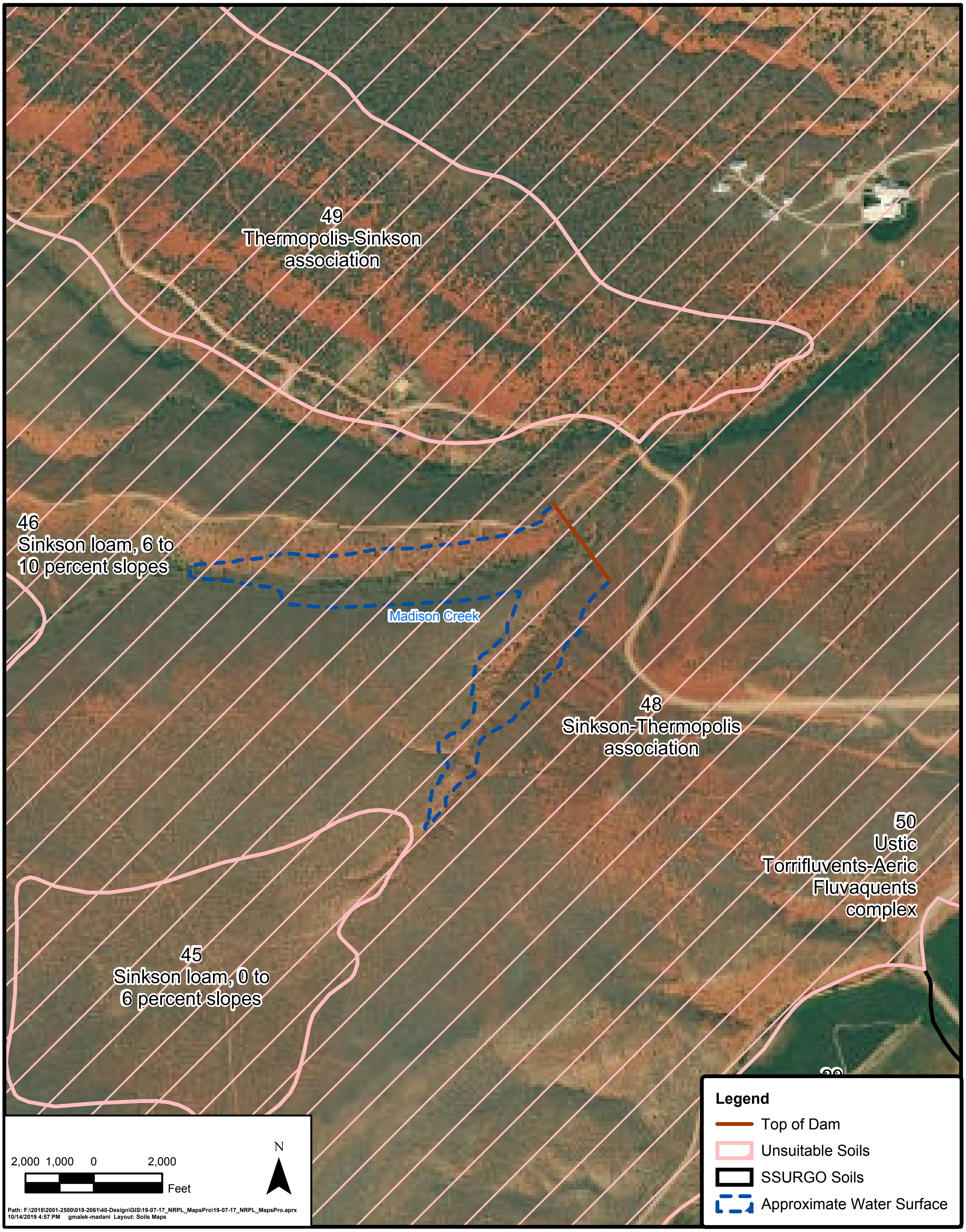
POPO AGIE WATERSHED STUDY

Crooked Creek - Elderberry
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-35b



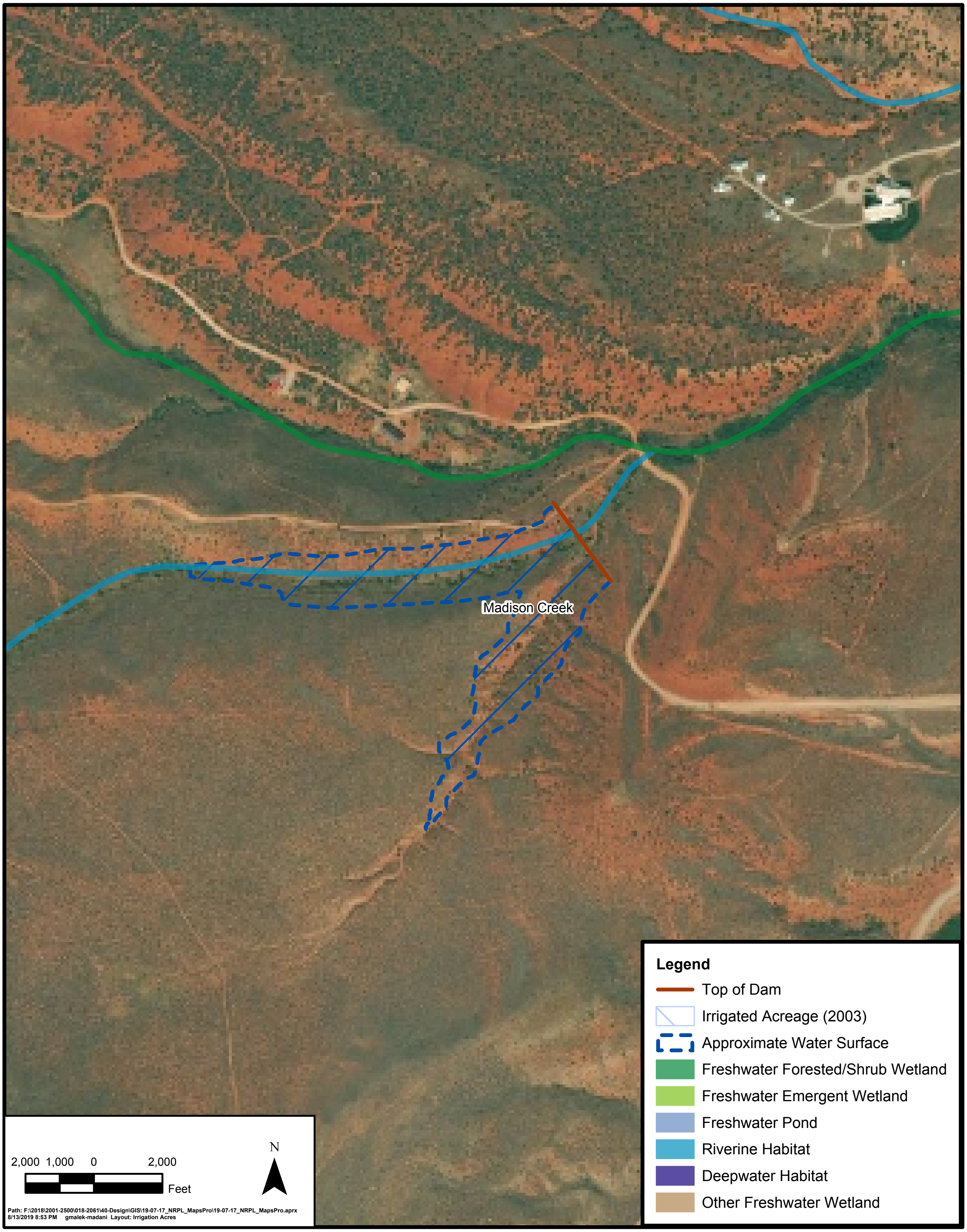
POPO AGIE WATERSHED STUDY

Madison Creek
Potential Microstorage Layout and Soils

olsson WENCK

FIGURE

C-36a



POPO AGIE WATERSHED STUDY

Madison Creek
Potential Microstorage Irrigation & NWI

olsson
WENCK

FIGURE

C-36b

Table C-1 Popo Agie River Watershed Microstorage potential sites - Review and Considerations (6/19/2019)

Site Name	Pros	Cons	Other comments
Willow Creek #2	Landowner interest - pumping and sprinkler system, provide late season water, and utility value for stock-water.	Farm road close or in pool area, Possible electrical line permissions needed.	Soils need further investigation SA – 22 Ac Elev 5360' Dam bottom of 5320'
Hellyer (lower) – **new site** (-108.632, 42.752 Decimal Degrees)	Pumping and sprinkler system, provide late season water, and utility value for stock-water.	Pool area may impact pivot swing Need permission from adjacent landowner	Soils need further investigation, dam already on site for reference to this and Willow Creek #2 SA – 51 Ac Elev 5420' Dam bottom of 5390'
No Name Draw (between Wood Hill and Narrow Hill) – **new site** (-108.803, 42.781 Decimal Degrees)	Fill with Gaylor-Warnock Ditch, Structure/flume combination, Storage volume possibly satisfactory for microstorage, Single owner	Possible soils concern; Chugwater/red soil is close.	
Beason Creek – **from Table 2**	Larger AF storage, in-line with Enterprise Ditch, directly benefit adjacent and downstream landowners	Location – SG, Big Game possible concerns. Soils.	30-35 SA @ 40' depth
Smith Creek	Larger volume reservoir, multiple benefits, Cemetery Ditch relief, mainly state lands	Reservoir lower than adjacent irrigated lands, need to pump. Some private lands to consider.	
Hellyer (upper) - **new site** (-108.69, 42.742 Decimal Degrees)	Utility value for stock water, pumping and sprinkle system, and provide late season water. Could fill or release to Enterprise Ditch depending on location.	High dam wall above Enterprise Ditch, pasture would be flooded below ditch.	7-8 SA sites
Iams Creek	Fill with Table Mtn Ditch, late season storage	Soil slump seen on Table Mtn Ditch, Storage size	

Site Name	**Pros**	**Cons**	**Other comments**
WTP Gravel Pit Min	Close to middle fork, multiple purpose incl. ARS	Cost of moving material to gain storage, possibly sell as usable material to recover costs. Ability to hold water above static ground water level. How to configure dam or dike was a question.	
Cottonwood Creek 1 and 2 East Fork	Site One has greatest storage and water availability, capture low elevation water	Similar to Twin Creek site lacking local user and is it enough storage to make a difference on main stem lil popo? Sediment loading may be a question.	20' dam 21 SA 40' dam 40 SA
Sawmill Creek Fossil Hill	Lends itself to assist directly to Enterprise Ditch	Storage is small, steep canyon location, FS lands, karst geology	
Sawmill Creek, confluence of Townsend creek	Lends itself to assist directly to Enterprise Ditch	Storage is a little greater that Fossil, steeper drainage, FS lands, geology issues possibly	
Sawmill Creek, at loop road crossing	Lends itself to assist directly to Enterprise Ditch, greatest storage site of the three on sawmill, possible other recreation opportunities.	FS Land	Union existing road with a dam. Increase road height, 40' dam approx. 60 ac pool.
Twin Creek	Captures early spring melt of lower watershed	Flashy and high volume sediment transport system, lacks local user, small storage not really impact lil Po	
Surrel Creek 1&2	Good water availability	Steep topography, mixed private and tribal ownership, North Fork function well late season, does it make sense to trans-basin flow to middle?	
Crooked Creek	Pool area could be large	Need to pump to use, private property deed restrictions, difficult to access	

Site Name	**Pros**	**Cons**	**Other comments**
Crooked Creek - Elderberry		FS land, difficult to access	
Middle Popo Mid Valley	Close to middle fork, multiple purpose pond	Pinch point already, houses routinely flood. Easement	
Onion Flats #2 (not on list)	Larger storage potential	Lack direct user, require a diversion from twin creek and ditch to supply water	
Onion Flats #1	Capture low elevation/early water	Limited storage and direct user, sediment concerns	
Lil Popo Louis Lake	Larger storage site	FS, a lot of changes to existing infrastructure to accommodate.	
Hornecker - Borner	Capture low elevation/early water	Area topography uniformly sloping, difficult to find dam location to get any storage size, overlay existing irrigated lands. Lack local user	
Madison Creek		Lack local users, complex landownership pattern with homes, questionable watershed production,	
Sheep creek		Steep, lacks minimum storage	
Blue Hill		Lacks size	