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ENGINEERING, SURVEYING & PLANNING
LANDSCAPE ARCHITECTURE, GIS
NATURAL RESOURCE SERVICES

MIDDLE BIG HORN WATERSHED STUDY

LEVEL I STUDY – REPORT

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ACRONYMS

AC	Asbestos Cement
AMA	Agricultural Management Assistance Fund
AML	Appropriate Management Level
BLM	Bureau of Land Management
BMP	Best Management Practices
BOR	Bureau of Reclamation
CIR	Consumptive Irrigation Requirement
DEM	Digital Elevation Model
DMI	Domestic, Municipal, and Industrial
DMRP	Development, Management, and Rehabilitation Plan
DWSRF	Drinking Water State Revolving Fund
EDU	Equivalent Dwelling Units
EIS	Environmental Impact Statement
EQIP	Environmental Quality Incentives Program
ESA	Endangered Species Act
ESIS	Ecological Site Information System
EXIF	Exchangeable Image File Format
FEMA	Federal Emergency Management Agency
FWS	Fish and Wildlife Service
GDD	Growing Degree Days
GIS	Geographic Information System
GPM	Gallons per Minute
HMA	Herd Management Area
HUC	Hydrologic Unit Codes
IUP	Intended Use Plan
LHC	Lower Hanover Canal
MBH	Middle Big Horn
MRG	Mineral Royalty Grant
NADD	North Antelope Drainage District
NCA4	Fourth National Climate Assessment
NEPA	National Environmental Policy Act
NHD	National Hydrography Dataset
NRCS	Natural Resource Conservation Service
OMB	Office of Management and Budget
OSLI	Office of State Lands and Investments
PRISM	Parameter-elevation Regressions on Independent Slopes Model
REA	Rapid Ecoregional Assessment
RUS	Rural Utilities Service
SHPO	State Historic Preservation Office
SWAP	State Wildlife Action Plan
SWPP	Small Water Project Program
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
USACE	US Army Corps of Engineers
USBR	US Bureau of Reclamation
USDA	US Department of Agriculture
USDI	US Department of Interior
USFWS	US Fish and Wildlife Service
USGS	US Geologic Survey
WBD	Watershed Boundary Dataset
WBHCP	Wyoming Bird Habitat Conservation Partnership
WCCD	Washakie County Conservation District
WCFSP	Water Conservation and Field Services Program
WDA I	Water Development Account I
WDA II	Water Development Account II
WDEQ	Wyoming Department of Environmental Quality
WGFD	Wyoming Game and Fish Department
WSEO	Wyoming State Engineer's Office
WWDC	Wyoming Water Development Commission
WWDO	Wyoming Water Development Office
WYDOT	Wyoming Department of Transportation
WYPDES	Wyoming Pollutant Discharge Elimination System

INTRODUCTION

This report summarizes the findings of the Middle Big Horn (MBH) Level I Watershed Study[1] performed by Y2 Consultants, LLC (Y2), Eagle Engineering and Surveying (EES, formerly Donnell and Allred), and Dahlgren Consulting (Dahlgren). This team was contracted by the Wyoming Water Development Commission (WWDC) on behalf of the Washakie County Conservation District and South Big Horn Conservation District, the project Sponsors. Two supporting documents were also developed: the Map Book and the Project Summary Book. The Map Book consists of supplemental maps that are referenced within this report. The Project Summary Book provides single-page summaries of each potential project developed as part of the Development, Management, and Rehabilitation Plan.

The purpose of this project was to provide a comprehensive inventory of the watershed and bring forward potential watershed improvement and development projects across the study area. The study area includes approximately 1800 square miles. This project is located in north-central Wyoming and the study area includes parts of four counties: Washakie, Big Horn, Hot Springs, and Park. The primary centers of population for this study are the towns of Worland and Basin. These communities are predominantly agricultural mixed with some industrial operations.

A series of meetings were held to gather information about the watershed and potential projects, and to ensure the general public was engaged with and informed about the purpose and scope of this project. The information gathered included existing studies, fieldwork, and inventories conducted by Y2 and EES personnel. Stakeholders were also engaged one-on-one to bring forward potential projects. Coordination with stakeholders to visit and document their potential projects provided a large resource of information about the study area.

Figure 1 (inset) and Map 1 in the Map Book provide context for the location of the Middle Big Horn Level I Watershed, showing the study area boundary and the surrounding area. The irregularly shaped boundary that defines the watershed is made up of constituent sub-watersheds. Each of these sub-watersheds was found to have a unique impact and role on the behavior of the Middle Big Horn watershed. While a vast majority of the watershed is a dry, arid, and friable climate, the low-lying regions are predominantly agriculture land and river bottom. The low-lying regions provide the largest impact on the study area in terms of economic support and development. Some of the upland regions are used for livestock grazing but are limited to certain areas due to poor soils and limited water availability.

As part of this watershed study, Y2 was tasked with visiting and taking inventory across the watershed. Inventory, in this case, is defined as a collection of features as related to water resources and water use within the watershed. This was no small task due to the large area that is encompassed by the watershed. To fully understand this area, Y2 made several weeklong inventory efforts within the study area. During these visits, Y2 used the most crucial component in the watershed: the people. It became apparent from the onset of this study that to fully develop and understand the watershed, listening to and incorporating the local stakeholders' input was important. By reaching and engaging stakeholders, Y2 was able to gather a substantial amount of area-specific information. This also served another key function of this study: the gathering, researching, and compiling of projects for individual stakeholders.

[1] Use of the names "Bighorn" as one word and "Big Horn" as two words can be highly variable. For this document the Middle Big Horn Watershed, the Big Horn River, the Big Horn Conservation District, Big Horn County, the Big Horn Canal, and the contract with the Wyoming Water Development Office will use two-words. All other uses for the mountains, basin, geologic formation, sheep, and forest will use one word following the United States Board of Geographic Names and the United States Geological Society.

The projects that were gathered focus on the development and improvement of water conveyance and availability across the watershed. As mentioned previously, the low-lying regions of the watershed are primarily agriculturally driven. These regions use and require large volumes of water. By developing projects that supplement water availability, these regions' productivity and longevity will be enhanced.

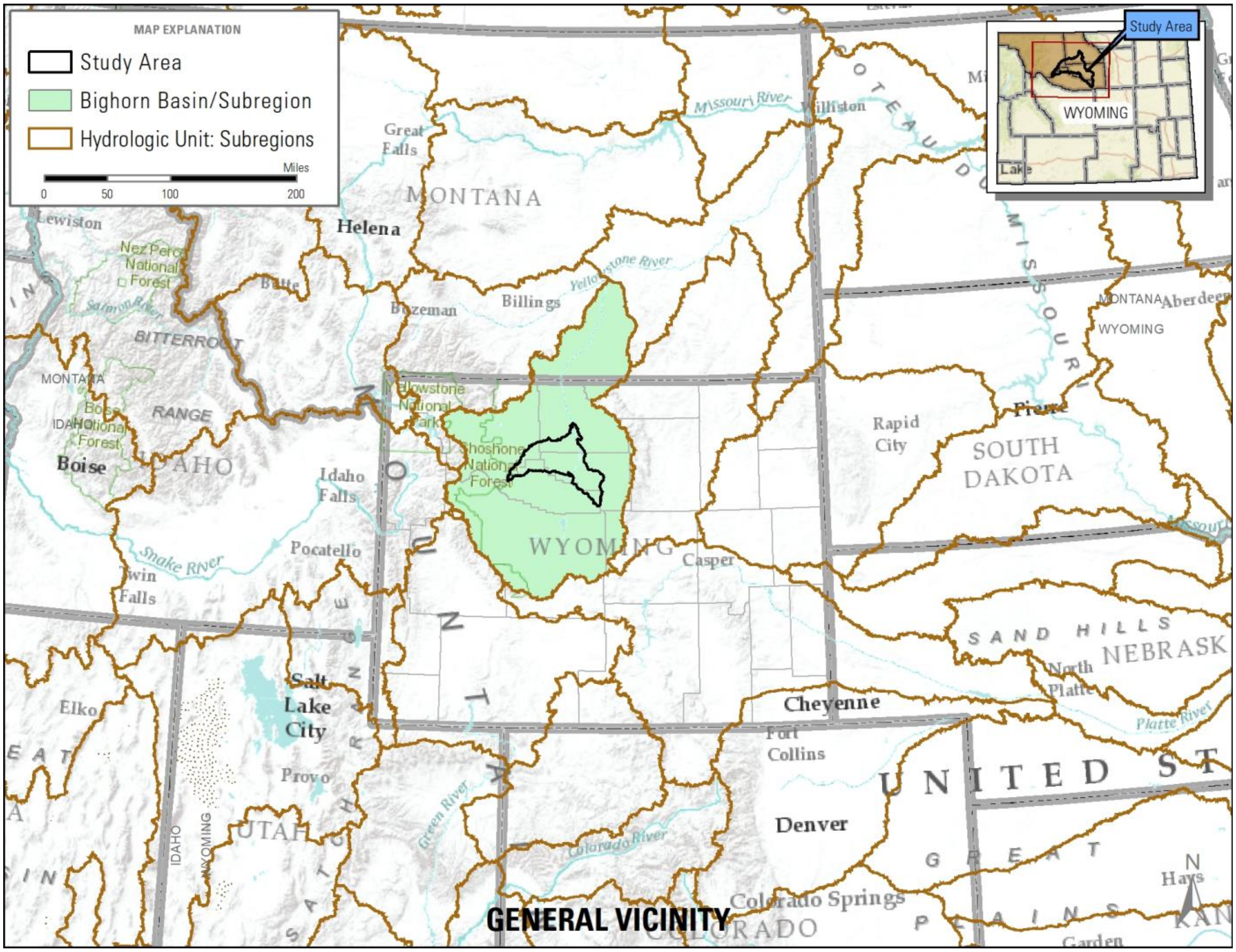


Figure 1: Middle Big Horn Level I study area vicinity map.

One of the largest issues that was noted in this study was the large-scale erosion and conveyance of sediment from several drainages that feed into the Big Horn River. In the past, there have been attempts to mitigate and stem the delivery of sediment to the river system. These attempts largely consisted of silt dams and spreader dikes. These structures were installed around the mid-1960s. Many of these structures have not been maintained. In many cases these structures have been completely silted in and no longer serve their functional purpose. As a result, there is substantial sediment loading into the Big Horn River. There were several conclusions developed about this issue that are discussed in the Development, Management, and Rehabilitation Plan (DMRP) in Chapter 5 of this study.

The DMRP serves to assist the study Sponsors and local stakeholders to understand and implement beneficial changes. The Sponsors for this study are the Washakie County Conservation District and the South Big Horn Conservation District. A map of the conservation districts across the study area is provided in Figure 2. The DMRP is intended to provide recommendations to improve the overall quality and health of the watershed. The recommendations made are intended to be practical and within the realm of feasibility. To facilitate these management activities, cost estimates and funding sources have been developed and identified for each project. These options are provided with the intent of being able to facilitate future progress on identified projects. Many potential projects identified within this study can be sponsored by the conservation districts through the WWDC Small Water Project Program (SWPP).

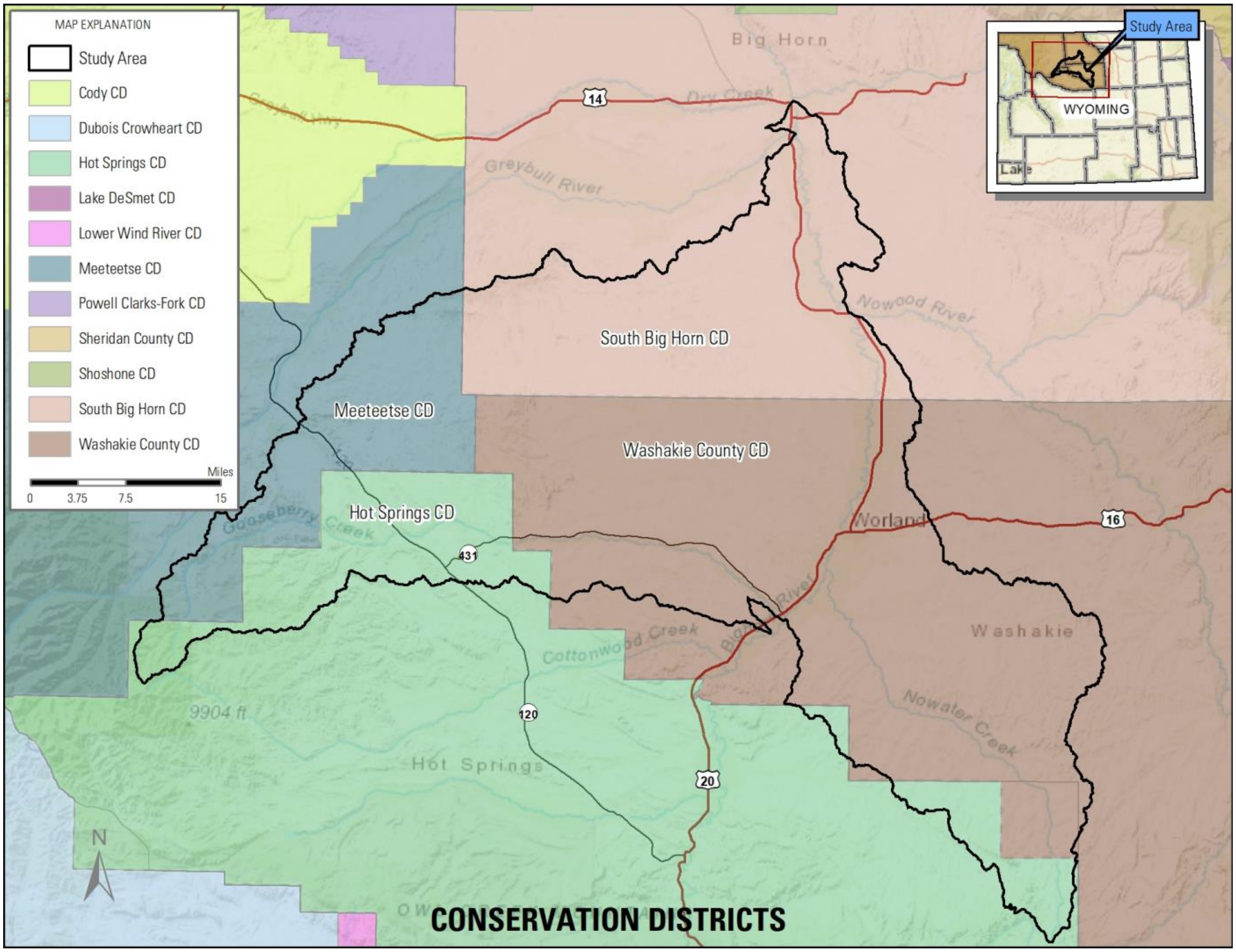


Figure 2: Conservation districts included within the study area.

The goal of the SWPP is to improve watershed condition and function by providing project grants to eligible public entities like conservation districts, irrigation districts, and municipalities. A variety of projects can be funded by the SWPP, and projects must prove they provide adequate public benefit and improve watershed health. Funding is also available through other entities including the US Department of Agriculture, the Office of Surface Mining Reclamation and Enforcement, the Natural Resources Conservation Service, and the US Bureau of Reclamation.

Also incorporated as an additional part of this study was an examination of a special project: the Lower Hanover Canal (LHC) Pathway Evaluation. This is a canal enclosure project in which Y2 was requested to recommend suggestions for improving the condition and function of the LHC that would benefit the public, enhance recreation opportunities, and decrease erosion and water loss. For the purposes of this study, the project was considered for feasibility and ease of implementation. Y2 worked with local stakeholders to determine if there was sufficient public interest in the project to move forward. Y2 held meetings with both public officials and the public to gauge interest.

CHAPTER 1: SCOPING AND PROJECT MEETINGS

Y2 hosted two initial public meetings to obtain input and provide information on this study, per the scope of services. Over the course of these meetings, information was gathered related to potential stakeholder projects (Figure 3). Two meetings were held to accommodate the two conservation districts that span the study area. This increased the ease of access for members of the public to attend.

The agenda for these meetings included a discussion of the goals and criteria defined by the WWDC. This discussion was led by the project manager, Dave Myer, PE. The main purpose of this project was to provide a comprehensive understanding and inventory of the Middle Big Horn River Watershed. This inventory is a composite of other existing studies and fieldwork conducted by Y2 and EES personnel. Additionally, during this study Y2 and EES collated projects and assessed these projects for Small Water Project Program funding and Level I study and funding. These projects were either brought to the study personnel's attention by members of the public or found during field inventory work. In the initial set of meetings, Y2's contact information was distributed to members of the public to ensure that engagement and interaction with the public continued for the duration of the project.

Figure 3: Meeting with Basin area stakeholders.

SEPTEMBER 25, 2018 MEETING IN BASIN

This meeting was held at the Big Horn County Fairgrounds and served as an opportunity for the public to learn about the study. Over the course of the meeting, discussions were held about concerns related to present issues in the Basin area, specifically the North Antelope Drainage District.

SEPTEMBER 27, 2018 MEETING IN WORLAND

Y2 conducted this meeting at the Worland Community Center. This meeting served as an opportunity for the public to learn about the project. Over the course of the meeting, discussions were held about concerns relating to present issues in the Worland area.

MARCH 19, 2019 MEETING IN WORLAND

Y2 conducted a public meeting to gather projects and as part of the Lower Hanover Canal Pathway Evaluation to gauge public interest in proceeding with further development of the Lower Hanover Canal.

Prior to the public meeting, the team met informally with City officials on the morning of March 19, 2019. The mayor expressed interest in seeing the canal entirely enclosed. The group also agreed that adding parking along Park Drive, especially at its southern end, would benefit Sanders Park and make some sense of the odd configuration of Park Drive between South 12th Street and Howell Avenue.

Later that day, the team held an open discussion with the public at the Washakie County Extension Office. Most attendees were present to discuss possible water improvement projects under Task 5: Development, Management, and Rehabilitation Plan; however, several individuals approached the design team to evaluate and comment on the "open" and "closed" canal concepts.

The most strident comment concerned the number of studies and the lack of actual progress on canal improvements. Overall the comments were strongly positive in favor of providing a solid core pathway project to launch the trail system, with emphasis on safety and access for all ages. Proffered amenities/furnishings were approved in concept, and one individual requested dog watering stations. There did not appear to be a significant determination by the public whether an enclosed or open channel was to be preferred, so long as safety and pedestrian and vehicular access were assured. John Hefenieder, Lower Hanover Canal Company (the "Canal Company") representative, joined the discussion and stated that the Company "would only go for it [canal improvements] *if it's all buried*." [emphasis added]

Following the public meeting, Y2 attended the regularly scheduled City Council meeting at the Town Hall. Y2 presented all concepts to the Council and the public in attendance

MARCH 20, 2019 MEETINGS IN BASIN AND MANDERSON

Y2 held "office hours" at the Basin Area Chamber of Commerce and the Manderson Town Hall to discuss potential projects and issues related to drainage with local landowners.

OCTOBER 30, 2019 MEETINGS IN WORLAND AND BASIN

Meetings were held on October 30th, 2019 to present the findings and conclusions of the Middle Big Horn Level I Watershed Study. Two separate meetings were held to ensure public engagement. The first meeting was held on the morning of the 30th in Worland at the Worland Community Center. The second meeting was held later that evening in Basin at the Big Horn County Fairgrounds.

CHAPTER 2: REVIEW OF EXISTING INFORMATION ON THE WATERSHED

Previously collected information from existing sources was gathered and organized by Y2 using a database system known as Zotero. The study area has had multiple studies performed on smaller sub-areas. These previous studies provided baseline information and datasets for this study.

Zotero is a reference management software used to manage research materials and bibliographic data into a searchable database while developing a report or document. For this report, Zotero was used to store and organize data sources for the literature review process as well as the location assignment for the spatial reference library. The Zotero database can be exported and imported across computers for additional access to reference material beyond the bibliography associated with this report. The Zotero library for this report is available in the Project Notebook.

For an additional source of information, Y2 made use of the Suitewater database. Suitewater, a publicly available web-based mapping application and water resource planning and analysis tool, was used to facilitate document development for this report. The application was developed by and for conservation districts in Wyoming and it is intended to provide useful landscape and watershed level information for planning purposes.

ENGINEERING LITERATURE REVIEW

An engineering literature review was performed on existing Level I studies performed throughout the study area. This review yielded insight into the various engineering work types that would be encountered throughout this project. Multiple Level I studies have been performed on various smaller project areas within the area. These studies provided valuable project and engineering specific information.

Level I studies that were reviewed as part of this study include the following:

- Gooseberry Creek Level I Study
- Hanover Irrigation District Master Plan Level I Study
- Manderson Water Master Plan Level I Study
- Owl Creek Watershed Level I Study
- South Worland Level I Master Plan Study
- Washakie Rural Water Supply Project Level I Study

A full list of resources that were used in the development of this study is available in the Zotero database and the compiled literature cited at the end of this report.

ECOLOGY LITERATURE REVIEW

For this Middle Big Horn Level I Watershed Study, a review of adjacent Level 1 watershed studies was completed. The Greybull River, Kirby Creek, Owl Creek, and Belle Fouche River reports were reviewed. Online resources such as US Department of Agriculture's Web Soil Survey and Ecological Site Information System (ESIS) provided baseline ecosystem information for the study area. US Fish and Wildlife Service's Information, Planning, and Consultation System and Wyoming's State Wildlife Management Plan provided targeted wildlife information. Information on the federal management of the watershed was also gathered from the Bureau of Land Management. Additionally, members of the project team have extensive knowledge of the study area and 100+ years of combined historic experience in the watershed. Many of the conclusions that were established over the course of this study were derived from common knowledge provided by select members of the project team. To provide confirmation of this knowledge citations have been added as appropriate.

A full list of the resources gathered and used for the development of this study are shown in the literature cited at the end of this report and are available in the Zotero database.

CHAPTER 3: WATERSHED INVENTORY AND DESCRIPTIONS

INVENTORY METHODOLOGY

An inventory was performed for each separate water use and control component as detailed below. Smaller-scale studies have been performed within the defined study area. The goal of the inventory for this project was to gather the information developed in these previous studies, along with that gathered during this study, into one complete watershed-wide inventory. In this case, the inventory is comprised of a variety of components. These components included such items as irrigation diversion points, acres of irrigable land, upland water sources, potential projects, etc. The individual components of this inventory are discussed in this section.

As part of the inventory, a comprehensive Geographic Information System (GIS) database was developed based on existing information and information gathered in the field. Field inventory information was gathered by Y2 personnel during the inventory period of this study. Y2 and EES were able to refine and target certain areas that had not been previously classified in the review of existing information. This work was conducted in coordination with Y2's GIS staff and personnel in the field. Previously existing GIS data was updated as appropriate based on field visits and new technology. New GIS data was developed as needed to support the analysis and inventory for this report.

The GIS data gathered and developed as part of the Level I watershed study is compiled in a GIS dataset. A list of the GIS features/layers developed and referenced for this study are provided in Appendix A – Table 18. As specified in the contract and WWDC's GIS Standards Technical Memorandum (V.2, 05/19), the GIS data is also provided and available in an electronic format developed using ESRI's ArcGIS latest desktop version (currently 10.7). GIS associated calculations were performed using EPSG: 3737 projected coordinate system (NAD83 / Wyoming East Central (ftUS)). The use of the GIS to develop a targeted approach to each respective area served as an integral component to the successful completion of this task. The development of the GIS framework for this project involved the acquisition of many databases from past studies completed within the spatial region of the Middle Big Horn Watershed. These databases were compiled to form the base data layer for the field inventory process.

Following the review of previous studies, focus areas for inventory efforts were defined. These focus areas were defined based on the absence of data and previous inventories. This was done in an effort to avoid duplicating services, as it was important to the WWDC project managers that existing information was not duplicated.

As part of the initial information review and GIS database development, Y2 accessed numerous resources for information. The Wyoming Water Development Office operates and maintains an online-based ArcGIS portal that contains multiple existing datasets applicable to the study area (http://waterplan.state.wy.us/gis/gis.html). This portal helped focus Y2's field inventory efforts on areas where work had not been previously performed, or where previous inventory work was minimal. Additionally, the Wyoming State Engineers Office information database, ePermit, was used to gather water rights information for points of diversion and points of use. This data was assessed to ensure the most up to date information was included.

The method of inventory was to break the overall study area into its constituent Hydrologic Unit Codes (HUC) HUC12 watersheds. The overall study area was a modified HUC8 which, by request of WWDO, was broken down into HUC12 sub-watersheds. Watersheds are displayed in a nested hierarchy represented by HUC levels. Levels contain two to twelve digits and are named regions (2-digit), sub-regions (4-digit), basins (6-digits), sub-basins (8-digits), watersheds (10-digits), and sub-watersheds (12-digits), respectively. These sub-watersheds provided a method to compartmentalize the planning process for inventory operations. The following pages detail a summary of the findings in each watershed. These summaries are intended to function in tandem with the developed GIS database provided as part of this project.

One of the primary functions of this study was to highlight potential water improvement projects in the study area. The primary issue faced in this effort was the age of the existing water infrastructure. For instance, many of the structures that were installed to mitigate silt loading from the uplands having long since exceeded their useful lifespan. Because of this exceedance of design life, one of the most common issues observed in the outlying sub-watershed was the degradation of silt dam integrity (Figure 4).

Figure 4: Silt dam in the Fifteenmile drainage.

STUDY AREA OVERVIEW

The study area is situated within the Wind/Big Horn River drainage, a major tributary to the Yellowstone River and the Missouri River (Figure 5). The Wind/Big Horn River drainage begins at the Continental Divide in the Wind River Range in west-central Wyoming and supplies the Big Horn River which flows into the Yellowstone River east of Billings, Montana. The drainage is comprised of the Wind River and the Big Horn River basins. The "Wedding of the Waters", south of Thermopolis, serves as the delineation between the two basins. This location is also where the name of the mainstem river changes from Wind to Big Horn. The study area is in the central part of the Bighorn Basin, just south of Worland to just south of Greybull.

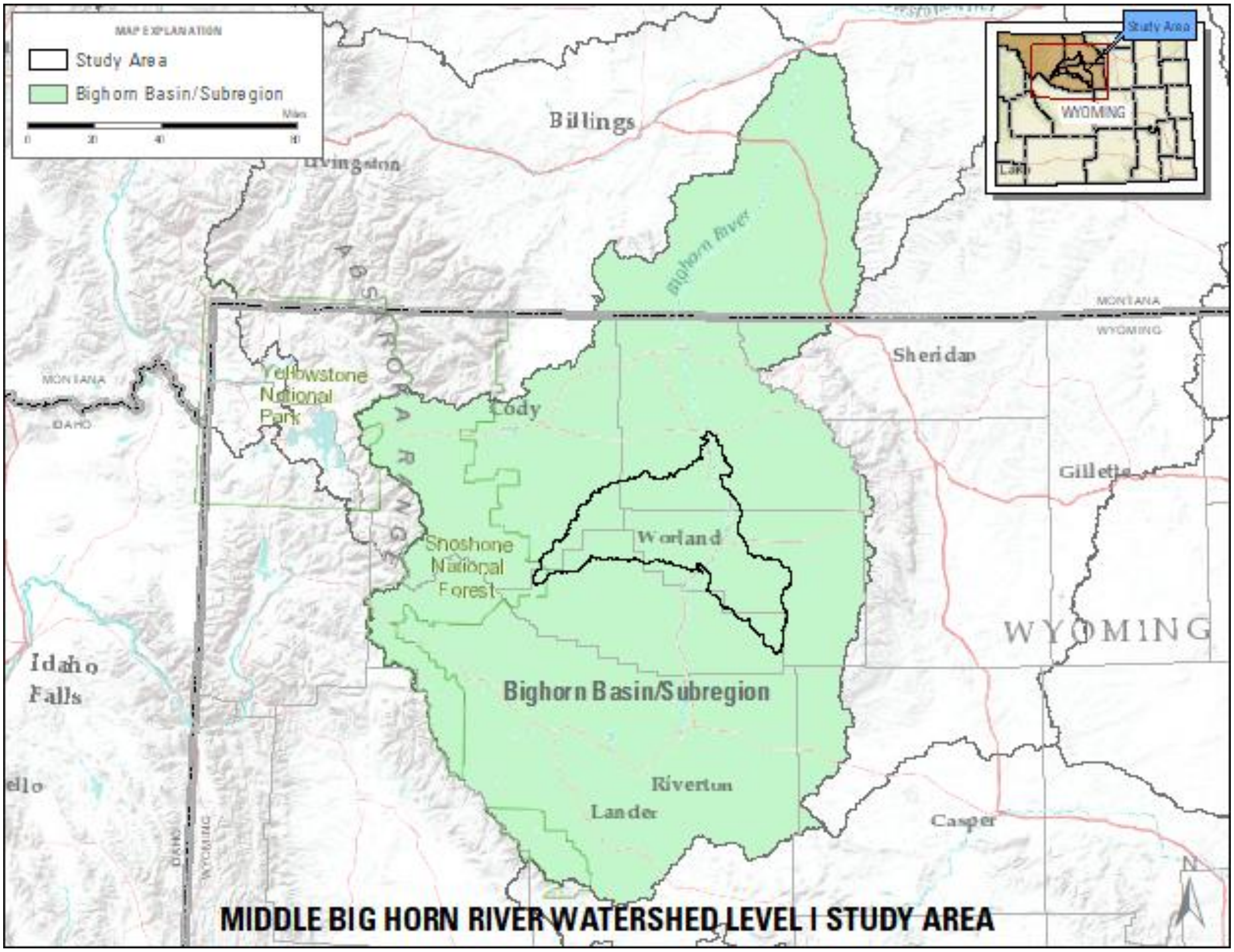


Figure 5: Middle Big Horn Watershed Study area boundary.

The Bighorn Basin is a roughly elliptical, northwest-trending area in north-central Wyoming. It covers an area of approximately 12,500 square miles and measures approximately 140 miles east-west and approximately 100 miles north-south to the Montana state line—and continues northward about 22 miles into Montana. It is bounded on the east by the Bighorn and Pryor Mountains; on the south by the Owl Creek and the Bridger Mountains; on the west by the Absaroka Mountains, and on the northwest by the Beartooth Mountains. The west side of the basin is covered by the volcanic Absaroka Range, but structurally the basin extends westward into the Yellowstone Plateau. The basin is topographically open at its north end, where it merges into the Crazy Mountain Basin of south-central Montana (Figure 6).

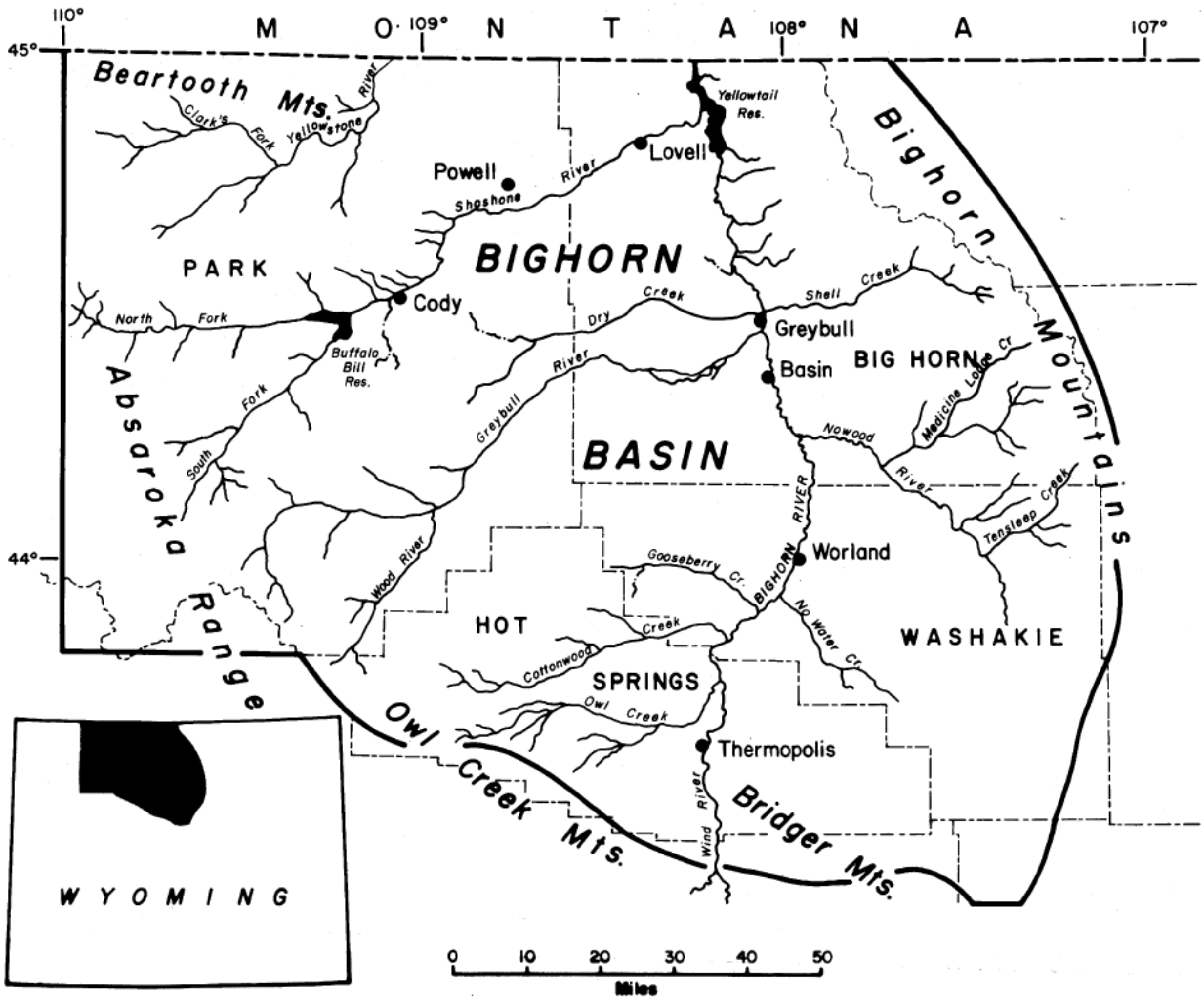


Figure 6: Bighorn Basin river systems.

PHYSICAL SYSTEMS

GEOLOGY

This section of the report references three key reports:

- Occurrence and Characteristics of Groundwater in the Bighorn Basin, Wyoming; Libra, Doremus, and Goodwin; 1981 (University of Wyoming, 1981).
- Wind/Bighorn River Basin Water Plan Update – Level 1 Groundwater Study (2008-2011) (*Wyoming State Water Plan - Wind/Bighorn River Basin Plan*, 2012)
- Tectonic Structures Responsible for Anisotropic Transmissivities in the Paleozoic Aquifers Southern Bighorn Basin, Wyoming; (Blackstone, Jr. & Huntoon, 1984).

STRATIGRAPHY AND DEPOSITIONAL HISTORY

Up to 33,000 feet of Cenozoic to Paleozoic sedimentary rocks have been deposited in the Bighorn Basin. A generalized stratigraphic column is presented in Libra et al. 1981. A detailed description of the geologic formations and their stratigraphy is contained in the Wind/Bighorn River Basin Water Plan Update – Level 1 Groundwater Study. Refer to the Map Book, Maps 2 and 3 for the surficial and bedrock geology of the study area.

The first Paleozoic Era sedimentary rocks were deposited in the middle of the Cambrian Period onto Precambrian basement rocks. In total, approximately 4,000 feet of Paleozoic Era rocks have been deposited in the Bighorn Basin. The Paleozoic aged rocks generally reflect a marine transgressive/regressive depositional environment. Marine limestones and dolomites are the dominant lithologies of the Paleozoic sequence. Much less extensive are sandstones and shales, which represent beach and nearshore conditions of deposition. Deposition in the Paleozoic Era was broken by long periods of erosion, which created several regional unconformities.

The early Mesozoic Era (i.e., the Triassic Period) was characterized by shallow seas that deposited the Dinwoody, Chugwater, Gypsum Springs, and Sundance formations. Sandstones, siltstone, shale carbonates, and evaporates were deposited during this time. A transition to a terrestrial environment occurred during the Jurassic Period and sandstones and shales of the Morrison Formation were deposited in shallow marine, marshy, eolian, fluvial, and deltaic conditions.

During the Cretaceous Period, thousands of feet of interbedded sandstones and thick shales were deposited under terrestrial, shallow marine, marshy, eolian, fluvial, and deltaic conditions. In ascending order (from oldest to youngest), the Cretaceous formations include the Cloverly, Mowry – Thermopolis, Frontier, Cody, Mesaverde, Meeteetse, and Lance Formations. The Lance Formation represents the retreat of the Cretaceous seas and the beginning of the terrestrial environments characterizing the Tertiary Period of the following Cenozoic Era.

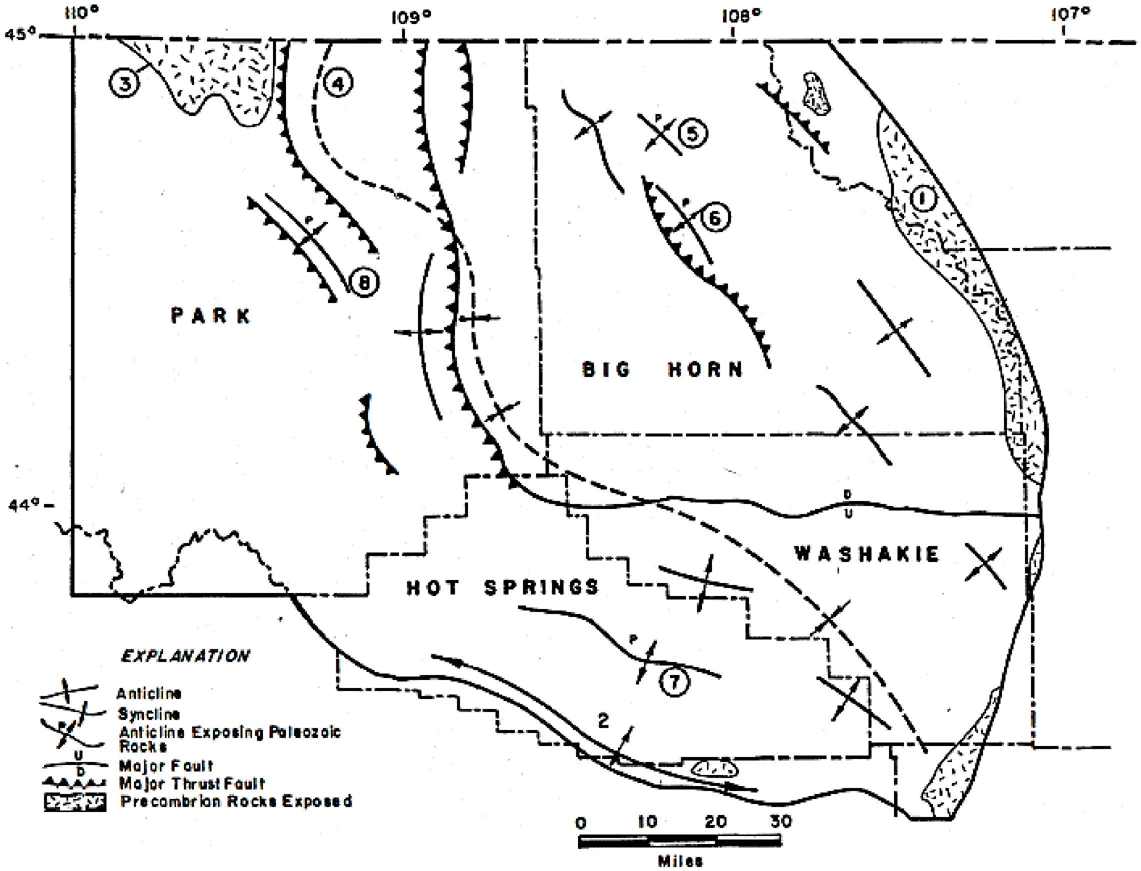
Late Cretaceous time marked the beginning of the Laramide orogeny. Mountains surrounding the Bighorn Basin, uplifted by compressional forces, provided a source for more than 10,000 feet of Tertiary sediments. These deposits are comprised of conglomerates, sandstones, and shales that were deposited in alluvial fans, streams, or lake environments. During the Eocene Epoch, several thousand feet of volcanic material was deposited in the western part of the basin. General uplift and warping of the basin during the late Tertiary Period caused the removal of many Tertiary deposits.

The youngest units within the basin are Pliocene and Quaternary terrace deposits and recent alluvial deposits. The age and occurrence of many of the Pliocene and Quaternary deposits have been correlated with glacial and interglacial conditions. These unconsolidated deposits may be up to several hundred feet thick at certain locations.

STRUCTURE

The Bighorn Basin is an asymmetric syncline between the Bighorn Mountains on the east and the Absaroka and Beartooth mountains on the west. The synclinal axis is offset west of the basin center and trends generally northwest (Figure 7). The maximum structural relief in the Bighorn Basin exceeds 38,000 feet. This is defined by the difference between the elevation of the Precambrian basement rocks in the deepest part of the basin, which is approximately 24,000 feet below sea level and the elevation of Cloud Peak, which is nearly 13,200 feet above sea level in the Bighorn Mountains to the east.

The basin is rimmed by mountains with Precambrian granite cores mantled by moderately to steeply dipping sedimentary beds. The western margin is covered by the Tertiary aged Absaroka volcanics. It is suspected that the basin structure continues under these deposits far into the Yellowstone Park region.



Major structural features of the Bighorn basin, Wyoming. 1 - Bighorn Mt. uplift; 2 - Owl Creek uplift; 3 - Beartooth uplift; 4 - Synclinal axis of the Bighorn basin; 5 - Little Sheep Mt. anticline; 6 - Sheep Mt. anticline; 7 - Thermopolis/Warm Springs anticline; 8 - Rattlesnake Mt. anticline.

Figure 7: Bighorn Basin structural features.

Several cross-sections across the Bighorn Basin are shown in the Level I Groundwater study (Wyoming State Geological Survey, 2012). Figure 8 shows the locations of these cross-sections. One of the cross-sections, Section I-I', is located in the Middle Big Horn Watershed and this cross-section is shown at the bottom of the figure.

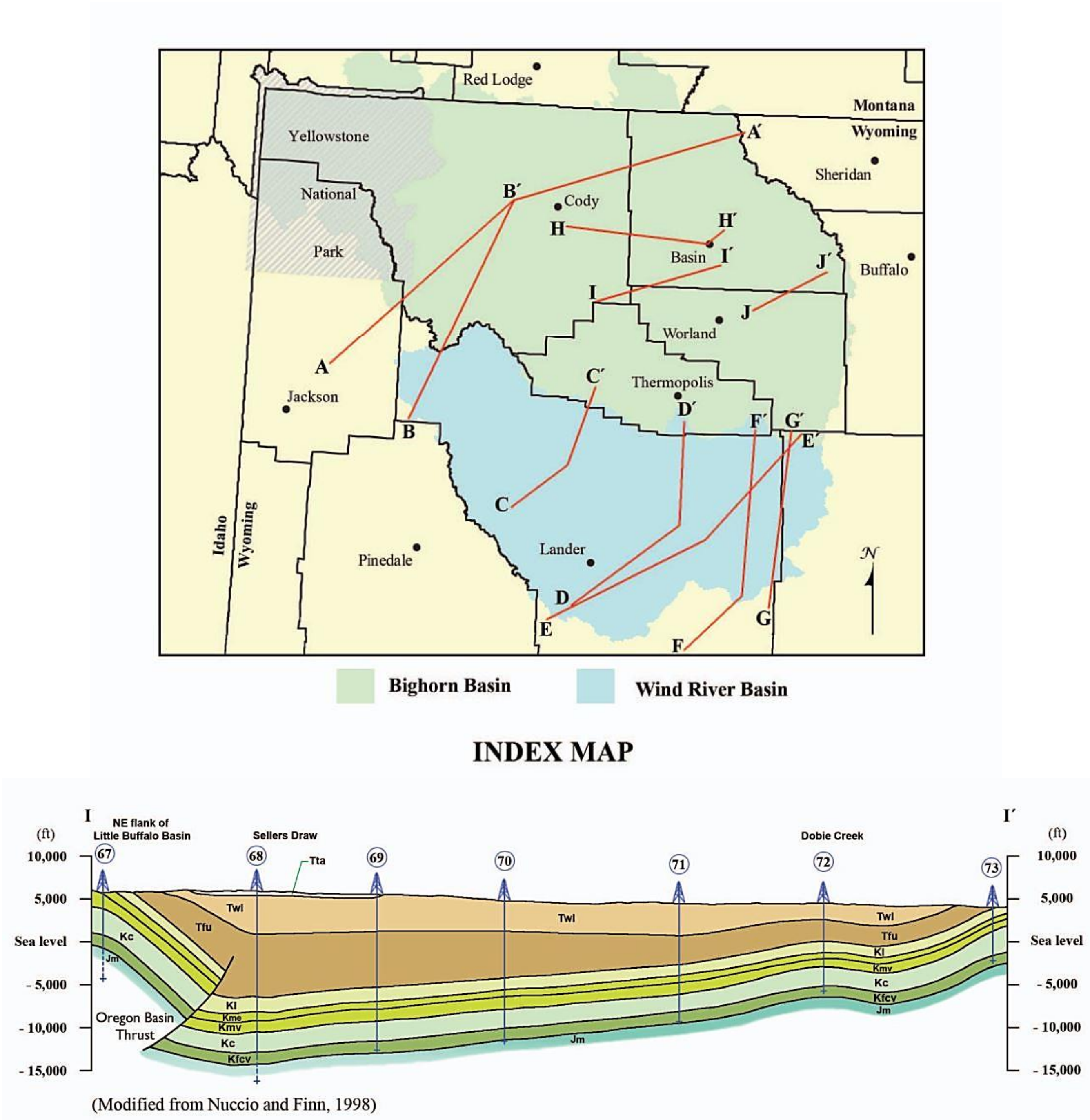


Figure 8: Geologic cross-section of Bighorn and Wind River Basins (Wyoming State Geological Survey, 2012). Section I-I′ and J-J′ run through the Middle Big Horn Watershed.

Along the margins of the basin numerous geologic structures are present (Figure 9). Some of the structures created zones of enhanced fracture permeability in areas, whereas in others the structures create barriers to fluid movement. These structures often exhibit associated faulting and fracturing, which increase the permeability of the deformed rocks and decrease the efficiency of confining beds to act as flow barriers, allowing for fluid movement across formations that might normally act as confining beds or aquitards. Where these structures are eroded and older strata are exposed, discharge may occur through fracture and solution zones from deeper aquifers within the basin.

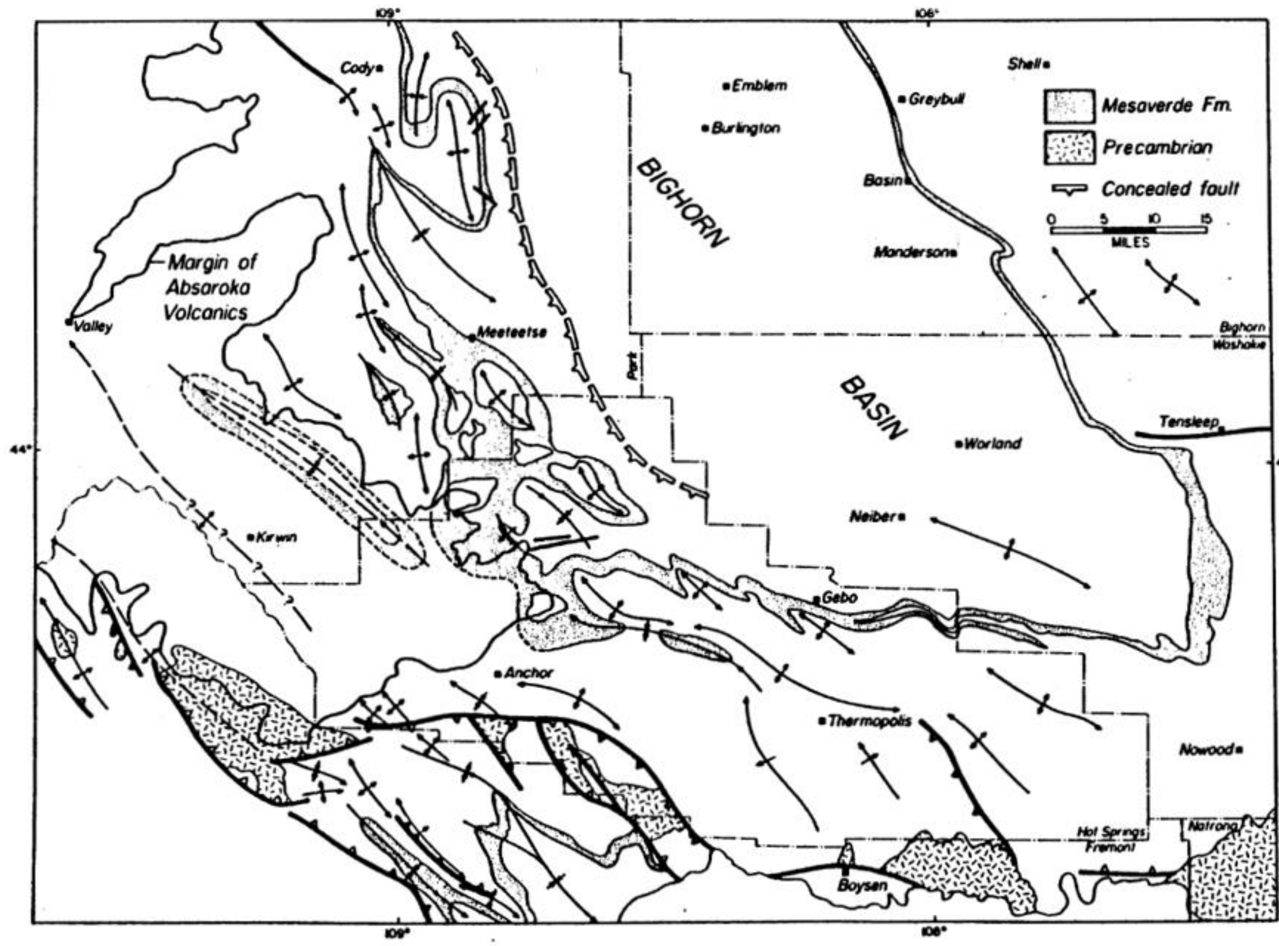


Figure 9: Southern Bighorn Basin tectonic map. The MBH study area is in the left central portion of this figure.

TOPOGRAPHY

The Bighorn Basin offers the typical contrast of landscapes and environments that identify Wyoming. The center of the basin is low, flat, and dry, characterized by rolling plains broken by broad river valleys, narrow terraces, and badlands; surrounding mountains contain thick forests and rise over 13,000 feet to perpetually snow-capped summits. The lowest elevation within the Bighorn Basin is approximately 3,500 feet, where the Big Horn River crosses the Wyoming/Montana state line. Elevations in the mountains commonly exceed 10,000 feet, reaching a maximum of 13,175 feet at Cloud Peak in the Bighorn Mountains. Total topographic relief in the Bighorn Basin is approximately 9,700 feet. Four major rivers flow across the Bighorn Basin: the Big Horn, Shoshoni, Greybull, and Clarks Fork; these rivers flow into the Yellowstone River in Montana.

The Wind River – Big Horn River is the primary drainage for the basin. The river cuts the Wind River Canyon and the Owl Creek Mountains at the southern end of the basin. The name of the river changes from the Wind River to the Big Horn River a few miles south of Thermopolis at the "Wedding of the Waters." Downstream of this location, the Big Horn River flows northward through the Bighorn Basin. Near the Montana – Wyoming state line, the Big Horn River cuts a deep, narrow canyon through the Bighorn Mountains.

GROUNDWATER

Integrated aquifer systems are defined as stratigraphically adjacent water-bearing units, which have reasonably consistent areal extent, hydrologic properties, and recharge/discharge mechanisms, and which are not separated regionally by thick confining beds.

Figure 10, which is plate III from the Wind/Bighorn River Basin Water Plan Update Level I Groundwater Study, shows the relationships between stratigraphic units and hydrogeologic units in the Bighorn Basin (Wyoming State Geological Survey, 2012).

The two most significant bedrock aquifer systems present in the Bighorn Basin are the Paleozoic and Upper Cretaceous-Tertiary aquifer systems, each comprised of several discrete member aquifers. This grouping of the stratigraphic units' aids in the regional analysis of groundwater movement, quality, and other hydrologic properties. The degree of hydrologic connection between member aquifers may vary due to the presence or absence of local confining beds and/or fracture zones.

As shown in Figure 10, the Paleozoic aquifer system consists of the Ordovician through Pennsylvanian aged sandstone and carbonate strata, represented principally by the Big Horn, Darby, Madison, and Tensleep Formations. This aquifer system is underlain by the thick, relatively impermeable shales of the Cambrian Gallatin and Gros Ventre formations, and is overlain by intertonguing siltstone, shale, and limestone facies of the Permian Phosphoria Formation, which act as local confining beds. Major water-bearing units are interbedded with less permeable strata that act as confining beds locally, restricting hydrologic connection between the major aquifers except in areas with extensive structural deformation.

The Pennsylvanian Epoch Tensleep Sandstone and Mississippian Epoch Madison Limestone are the most extensively exploited Paleozoic aged aquifers. Available data on the Tensleep Sandstone indicate it generally has the highest permeability within the Paleozoic aquifer system, although the permeability of the Tensleep likely decreases with depth (toward the center of the basin). The Madison Limestone has somewhat lower water production capabilities; however, in areas of secondary permeability, the Madison can produce high yields. Areas of intense fracturing produce the highest yields across all Paleozoic aquifers.

Recharge to the Paleozoic system likely occurs primarily in outcrop areas through direct infiltration of precipitation and seepage or recharge from surface water. Away from the basin margins, the Paleozoic aquifer can be under highly artesian conditions due to thick overlying shale and confining units.

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ERA	System	Series	Lithostratigraphic units of Love et al. (1993) in Bighorn Basin and Owl Creek and Bighorn Mountains	Hydrogeologic division of Lowry et al. (1976)	Hydrogeologic unit of Libra et al. (1981)		Hydrogeologic unit of Western Water Consultants, Inc. (1982a,b) and Doremus (1986)	Hydrogeologic unit of Western Water Consultants, Inc. (1983b)	Hydrogeologic unit of Cooley (1984, 1986)	Hydrogeologic unit of Jarvis (1986a) and Spencer (1986a)	Hydrogeologic unit of Wyoming Statewide Framework Plan (WWC Engineering et al., 2007, fig. 4-9)	Hydrogeologic unit used in this report	
CENOZOIC	Quaternary	Holocene and Pleistocene	Quaternary alluvium, terrace deposits, and glacial deposits	1	Major aquifer		Principal aquifers	Secondary aquifer			Major aquifer	Alluvial aquifers, terrace-deposit aquifers, and glacial-deposit aquifers	Quaternary unconsolidated-deposit aquifers
	Tertiary	Pliocene[1]					Units not present and (or) discussed in study						
		Miocene	Lower Miocene and Oligocene rocks[2]										
		Oligocene	White River Formation	2							Marginal aquifer	White River aquifer	
		Eocene	Wapiti Formation[2]; Aycross Formation[2]; Wagon Bed Formation								Wagon Bed Formation–marginal aquifer	Wagon Bed confining unit	
			Tatman Formation[2]										
			Willwood Formation	3	Aquifer/discontinuous aquifers and confining units	Upper Cretaceous/Tertiary aquifer system		Secondary aquifer			Minor aquifer	Willwood aquifer[7]	Lower Tertiary/Upper Cretaceous aquifer system
		Paleocene	Fort Union Formation		Aquifer/discontinuous aquifers and confining units			Secondary aquifer			Major aquifer–sandstone	Fort Union aquifer	
MESOZOIC	Cretaceous	Upper Cretaceous	Lance Formation		Aquifer/discontinuous aquifers and confining units		Principal aquifer (Lance–Meeteetse–Mesaverde aquifer)	Secondary aquifer	Not discussed	Not discussed	Major aquifer	Lance aquifer	
			Meeteetse Formation; Lewis Shale		Aquifer/discontinuous aquifers and confining units			Secondary aquifer			Major aquitard	Meeteetse aquifer and confining unit	
			Teapot Sandstone Member; Mesaverde Formation; Eagle Sandstone		Aquifer/discontinuous aquifers and confining units			Secondary aquifer			Major aquifer–sandstone	Mesaverde aquifer	
			Cody Shale	4	Regional aquitard		Major regional confining unit	Leaky confining unit			Major aquitard	Cody confining unit	
			Frontier Formation		Minor aquifer	Upper Paleozoic–Lower and middle Mesozoic aquifers/aquifer system	Principal aquifer (Frontier aquifer)	Alternating leaky confining units and secondary aquifers			Minor aquifer	Frontier aquifer[7]	Lower and middle Mesozoic aquifers and confining units
			Mowry Shale		Aquitard		Leaky confining unit (Regional confining unit)	Leaky confining unit			Major aquitard	Mowry confining unit (Mowry–Thermopolis c.u.)	
		Lower Cretaceous	Muddy Sandstone		Aquitard		Minor aquifer	Secondary aquifer			? Muddy Sandstone ?[4]	Muddy Ss aquifer	
			Thermopolis Shale				Leaky confining unit	Leaky confining unit			Major aquitard	Thermopolis confining unit	
			"Dakota Sandstone"; Cloverly Formation; "Lakota Sandstone"	5	Minor aquifer		Principal aquifer (Cloverly aquifer)	Secondary aquifer			Major aquifer–sandstone	Cloverly aquifer[7]	
	Jurassic	Upper Jurassic	Morrison Formation		Minor aquifer and (or) local confining unit		Major regional confining unit	Alternating leaky confining units and secondary aquifers			Minor aquifer	Morrison confining unit and aquifer[7]	
		Upper Jurassic / Middle Jurassic	Sundance Formation		Minor aquifer and (or) local confining unit			Alternating leaky confining units and secondary aquifers			Marginal aquifer	Sundance confining unit and aquifer	
		Middle Jurassic	Gypsum Spring Formation		Minor aquifer and (or) local confining unit		Major regional confining unit	Alternating leaky confining units and secondary aquifers			Marginal aquifer	Gypsum Spring confining unit and aquifer	
	Jurassic(?) and Triassic(?)		Nugget Sandstone		? Nugget[2] ?			Leaky confining unit			Major aquifer–sandstone	Nugget aquifer	
	Triassic	Upper Triassic	Chugwater Group or Formation: Popo Agie Formation or Member		Minor aquifer and (or) local confining unit				Confining unit	Leaky confining unit	Marginal aquifer	Chugwater aquifer[7]	Chugwater–Dinwoody aquifer and confining unit
			Chugwater Group or Formation: Crow Mountain Sandstone or Sandstone Member										
			Chugwater Group or Formation: Alcova Limestone or Limestone Member										
		Lower Triassic	Chugwater Group or Formation: Red Peak Formation or Member										
			Dinwoody Formation; Goose Egg Formation		Minor aquifer and (or) local confining unit		Dinwoody Formation–leaky confining unit	Dinwoody Formation–leaky confining unit	Minor aquifer and discontinuous confining unit	Dinwoody Formation–leaky confining unit	Dinwoody Formation–marginal aquifer; Marginal aquifer	Dinwoody confining unit	Goose Egg aquifer and confining unit; Goose Egg–Phosphoria aquifer and confining unit
PALEOZOIC	Permian		Phosphoria Formation and related rocks (Park City Fm); Goose Egg Formation				Principal aquifer (Phosphoria–Tensleep aquifer)	Secondary aquifer		Aquifer (Park City[3]–Tensleep aquifer)	Minor aquifer	Phosphoria aquifer and confining unit[7]	
			Possible uppermost Minnelusa Formation[2]										
	Pennsylvanian	Upper Pennsylvanian	Tensleep Sandstone	6	Major aquifer	Paleozoic aquifer system		Principal aquifer	Major aquifer	Paleozoic aquifer system	Major aquifer–limestone[5]	Tensleep aquifer[7]	Paleozoic aquifer system
		Middle Pennsylvanian	Amsden Formation: Ranchester Limestone Member		Minor aquifer		Major regional confining unit	Leaky confining unit	Upper Amsden Fm–confining unit	Ranchester Limestone Member of Amsden Formation	Marginal aquifer	Amsden confining unit[7]	
		Lower Pennsylvanian	Amsden Formation: Horseshoe Shale Member							Horseshoe Shale Member of Amsden Fm (Amsden confining unit)			
	Mississippian	Upper Mississippian	Amsden Formation: Darwin Ss Mbr		Darwin Ss Mbr–Minor aquifer				Darwin Sandstone Member of Amsden Formation	Darwin Ss Mbr of Amsden Fm		Madison aquifer[7]	Madison–Bighorn aquifer
		Lower Mississippian	Madison Limestone		Major aquifer		Principal aquifer (Madison aquifer)	Principal aquifer	Major aquifer (Madison–Bighorn aquifer)	Aquifer (Madison aquifer)	Major aquifer–limestone		
	Devonian	Upper Devonian	Darby Formation; Three Forks Formation; Jefferson Formation		Three Forks and Jefferson Formations–aquitard/local confining unit and (or) minor aquifer			Jefferson Formation–Leaky confining unit			Major aquifer–limestone	Darby aquifer	
		Lower Devonian	Beartooth Butte Formation[2]										
	Silurian[6]												
	Ordovician	Upper Ordovician / Lower Ordovician	Bighorn Dolomite; Harding Sandstone equivalent		Major aquifer			Principal aquifer			Major aquifer–limestone	Bighorn aquifer	
	Cambrian	Upper Cambrian	Gallatin Limestone and equivalent		Regional aquitard		Major regional confining unit	Leaky confining units	Confining unit	Confining unit (Gallatin–Gros Ventre confining unit)	Minor aquifer	Gallatin confining unit	Gallatin–Gros Ventre confining unit
		Middle Cambrian	Gros Ventre Formation and equivalent								Minor aquifer	Gros Ventre confining unit	
			Flathead Sandstone		Major aquifer (Flathead aquifer)		Principal aquifer (Flathead aquifer)	Principal aquifer	Major aquifer	Aquifer (Flathead aquifer)	Major aquifer–limestone[5]	Flathead aquifer	
	Precambrian		Precambrian rocks	7					Basal confining unit		Major aquitard	Precambrian basal confining unit	

[1]Pliocene rocks not present in Bighorn Basin.
[2]Function of lithostratigraphic unit as hydrogeologic unit not defined.
[3]Park City Formation considered equivalent to all or parts of Phosphoria and Goose Egg Formations.
[4]Function of Muddy Sandstone as hydrogeologic unit not defined in WWC Engineering et al. (2007, fig. 4-9).
[5]Predominant lithology of formation is sandstone, and it is unknown why formation is defined as "Major aquifer–limestone" in WWC Engineering et al. (2007, fig. 4-9).
[6]Silurian rocks not present in Bighorn Basin.
[7]Tertiary, Mesozoic, and Paleozoic sedimentary-rock hydrogeologic units identified as continuing under the Absaroka Range and Yellowstone Volcanic Area.

Abbreviations used in the columns:
c.u. Confining unit
Fm Formation
Ss Sandstone
Mbr Member

Modified from Lowry et al. (1976); Libra et al. (1981); Western Water Consultants, Inc. (1982a,b; 1983b); Cooley (1984, 1986); Doremus (1986); Jarvis (1986a); Spencer (1986a); Love et al. (1993); and WWC Engineering et al. (2007)

Plate III. Relation of lithostratigraphic units to hydrogeologic units, Bighorn Basin, Wyoming.

Figure 10: Comparison of stratigraphic and hydrogeologic units in the Bighorn Basin. (Wyoming State Geological Survey, 2012)

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The Upper Cretaceous-Tertiary aquifer system includes all bedrock units lying stratigraphically above the Cretaceous Cody Shale, a regional confining bed consisting of a thick series of relatively impermeable shales (Figure 10). The formations comprising the Upper Cretaceous–Tertiary system include the Mesaverde, Meeteetse, Lance, Fort Union, and Willwood Formations. Major water-bearing units are lenticular, discontinuous sandstone bodies that are hydrologically isolated to varying degrees by intervening siltstones and claystones. The intertonguing and discontinuous nature of major water-bearing units prevents the identification of regionally extensive productive horizons.

Recharge to the Upper Cretaceous-Tertiary aquifer system is through both infiltration at the outcrop and downward leakage from overlying strata.

In addition to the two major aquifer systems, other smaller hydrologically isolated bedrock aquifers exist within the basin. These include the basal Cambrian Flathead Sandstone, carbonate facies of the Permian Phosphoria Formation, and sandstone units of the Lower Cretaceous Cloverly and the Upper Cretaceous Frontier formations.

The Tertiary Absaroka volcanics also represent a potential, but currently undeveloped, ground-water source. Where present and where there is enough saturation, unconsolidated Quaternary terrace and flood plain deposits constitute important aquifers within the basin.

The Wind/Bighorn River Basin Water Plan Update – Groundwater Study Level 1 (2008-2011) has a summary of aquifers and development potential within the Bighorn Basin part of this study. Table 19 in Appendix A summarizes this information.

SOILS AND SOIL QUALITY

Soils throughout the study area are of poor quality. A majority of the soil in the study area is defined as Youngston-Rock outcrop-Persayo-Neiber. This soil is part of the Persayo and Neiber series of soils. These are typically seen in the Fifteenmile region and dominate as the largest soil type in the area. This is not a singular type of soil but a grouped classification for soils in this regime. Refer to Map Book, Map 4 for the soil types mapped within the study area.

The top layer of the Persayo-Neiber complex is classified as extremely friable and susceptible to breakdown. The soil is yellowish-brown with some intermixed pale brown coloring. It is a mix of silty loam and clay giving the soil unique properties. Typically soils in the Neiber series are granular, soft, friable, and non-plastic. This contrasts with the Persayo series, which is granular, soft, friable, and sticky/plastic. The combination of these two series results in a hybrid soil complex with varied properties.

Given the composition of the soils in the Fifteenmile area, it can reasonably be inferred from a literature review that the soil in this area is of poor quality and not suitable for development. Figure 11 shows the contrasted and extreme erosion that is present in most of this area. The soil in the area throughout the Fifteenmile region is friable and exhibits a variety of material characteristics that are not predictable.

Figure 11: Example of long-term erosion of poorly cohesive soil in the Fifteenmile drainage.

WATERSHED CLIMATE

CLIMATE

The climate of the watershed is often harsh with cold winters, hot summers, and low precipitation. The climate is strongly influenced by the watershed's location within the basin. The Bighorn Mountains to the East, the Bridger Mountains to the south, and the Owl Creek and Absaroka Mountains to the West form an open-ended basin with a gap in the mountains to the north that minimizes mixing winds but allows cold air masses from the north to spill into the basin and stagnate. Cold air draining off the mountains also contributes to the famously cold temperatures seen in the Bighorn Basin. In the summer, the stagnant air, dry conditions, and lack of rangeland vegetation exposing dark bare soils allow for high daytime temperatures due to solar radiation and low nighttime temperatures due to radiant cooling. The surrounding mountains also block moisture from entering the basin from all directions except the north. Most of the precipitation in the summer comes from thunderstorms originating from the northwest and in the winter as dry snows from the north (E. Carr, 2017).

Specific climate/weather recording stations within the watershed are few and are located along the Big Horn River. The stations are Worland FAA Station (489785), Worland (489770), Rairden 2 WSW (487473), and Basin Coop Station (480540); some with more consistently collected data than others. Two of the more consistent stations were chosen, Worland FAA Station (489785) and Basin Coop Station (480540), to highlight the last 50 years of climatic variation in the watershed (Western Regional Climate Center, 2020).

The Worland FAA Station (489785) reports an average maximum temperature of 60.6°F (range of 30.2°F in January to 90.5°F in July), and an average minimum temperature of 31.3°F (range of 3.7°F in January to 56.6°F in July) for an average temperature of 45.9°F. Record temperatures of -50°F and 107°F have been recorded. Growing Degree Days (GDD) are 2547 (using base 50°F). Growing Degree Days shown here are calculated by taking the sum of the individual growing degree days per each day of the growing season (see Equation 1). Precipitation averages 7.46” with the majority coming in April through September. February is the driest month averaging 0.19” and May is the wettest averaging 1.49”. The average annual snowfall for Worland is 30.1”, with the majority coming in December and January. (Western Regional Climate Center, 2020)

Equation 1: Growing Degree Days Equation (where *n* is growing season length in days)

$$Sum\ of\ GDD = \left(\left(\frac{T_{Max} - T_{Min}}{2}\right) - (T_{base})\right) * n$$

The Basin Coop Station (480540) reports an average maximum temperature of 61.2°F (range of 29.6°F in January to 91.6°F in July), and an average minimum temperature of 30.3°F (range of 2.2°F in January to 56.0°F in July) for an average temperature of 45.8°F. Record temperatures of -51°F and 115°F have been recorded. Average Growing Degree Days are 2580 (using base 50°F). Precipitation averages 6.48” with the majority coming in April through September. February is the driest month averaging 0.21” and May is the wettest averaging 1.17”. The average annual snowfall for Basin is 19.4”, with the majority coming in December, January, and March. (Western Regional Climate Center, 2020)

Over the last 50 years for the Worland FAA Station (489785), current averages seem to be similar to the ones 50 years ago (Table 1). However, precipitation has increased with the exception of the 2000s. The average maximum and minimum temperatures all increased in the 1980s, 1990s, and 2000s. (Western Regional Climate Center, 2020)

Table 1: Worland FAA station (489785) decade average data. (Western Regional Climate Center, 2020)

Years	Average Precipitation (in.)	Average Maximum (°F)	Average Minimums (°F)
1970s	7.04	59.9	30.3
1980s	7.54	60.5	32.3
1990s	9.12	61.0	31.7
2000s	6.18	60.5	31.0
2010s	8.14	60.1	30.6

Over the last 50 years, the Basin COOP Station (480540) shows an increase in average precipitation, maximum temperatures, and minimum temperatures. Most notable is the steadily increasing minimum temperatures (Table 2). (Western Regional Climate Center, 2020)

Table 2: Basin COOP station (480540) decade average data. (Western Regional Climate Center, 2020)

Years	Average Precipitation (in.)	Average Maximum (°F)	Average Minimums (°F)
1970s	6.24	60.9	29.3
1980s	6.36	61.8	30.9
1990s	7.60	60.0	31.6
2000s	6.18	61.0	31.7
2010s	7.85	61.7	32.9

While not a significant change over the decades, these trends could be leading towards long-term changes. The increase in precipitation and temperatures along with the increase in growing degree days may provide an opportunity for new crops and/or new varieties of current crops that may improve farm production and income.

CLIMATE SCIENCE

Information about current climate science is copious and comprehensive. This section of the Middle Big Horn Level I Watershed Study report summarizes pertinent climate literature so landowners can consider planning and preparing for long-term and short-term climate variability and associated extreme weather events.

The intent of this section is not to debate whether climate change is real, perceived, or human-caused. Rather, it is to summarize the scientific literature so landowners can develop workable response strategies and have them available for implementation over time if or as needed.

INFORMATION SOURCES

There is no one comprehensive suite of climate information available for use specific to the study area, but there is global, national, state, regional, and localized information that can be referenced. Much of this information is available online. Key websites include:

- National Center for Atmospheric Research
- Western Water Assessment
- USDA Natural Resources Conservation Service (NRCS)
- Western Regional Climate Center
- Wyoming State Climate Office

Use and application of information from these sources take three forms:

- Generalized broad-scale material
- Comprehensive watershed and study area scale material, such as that found in assessments for the Shoshone National Forest (USDA Forest Service) and Wyoming Basin (USDI Bureau of Land Management)
- Generalized and comprehensive “nearby” material that can potentially be extrapolated to the localized watershed and study area scales, such as that found in assessments for Montana and Colorado, which border Wyoming north and south, respectively

NATIONAL CLIMATE ASSESSMENT

The Global Change Research Act of 1990 mandates an authoritative assessment of the science of climate change, with a focus on the United States. Every four years, a report is prepared by the President and provided to Congress. The President is to report on the environmental, economic, health, and safety consequences of climate change.

The Fourth National Climate Assessment (NCA4) was released in late 2018 (USGCRP, 2018). Summary findings, while broad scale, include:

> *Climate change creates new short-term and long-term risks and exacerbates existing vulnerabilities in communities across the United States, presenting growing challenges to human health and safety, quality of life, and the rate of economic growth.*
>
> *Communities, governments, and businesses should be working to reduce risks from, and costs associated with climate change.*
>
> *The quality and quantity of water available for use by people and ecosystems across the country is being affected by climate change, increasing risks and costs to agriculture, energy production, industry, recreation, and the environment.*
>
> *Impacts from extreme weather and climate-related events increasingly threaten the health and well-being of the American people, particularly populations that are already vulnerable. Rising temperatures, extreme heat, drought, wildfire on rangelands, and heavy downpours are expected to increasingly disrupt agricultural productivity in the United States. Expected increases in challenges to livestock health, declines in crop yields and quality, increased invasive species, increased woody plants and drought on rangelands and changes in extreme events in the United States and abroad threaten rural livelihoods, sustainable food security, and price stability.*
>
> *Our Nation's aging and deteriorating infrastructure is further stressed by increases in heavy precipitation events, coastal flooding, heat, wildfires, and other extreme events, as well as changes to average precipitation and temperature. Without adaptation, climate change will continue to degrade infrastructure performance over the rest of the century.*
>
> *Outdoor recreation and tourist economies are reliant on benefits provided by our natural environment that will be degraded by climatic impacts in many ways. Increased wildfire will continue to change over forest and rangeland systems further impacting these industries.*

SHOSHONE NATIONAL FOREST

As discussed in other sections of this Level I report, the study area is reliant on precipitation and subsequent streamflow from two drainages. The study area is fed by the highest elevations of the Gooseberry Creek drainage, which is part of the study area, and also the Upper Wind River headwaters, a high-elevation, snowpack dominated hydrology supporting a large concentration of glaciers and large snowfields that provide considerable streamflow to the Wind/Big Horn River. These high-elevation water towers are predominately located on public lands managed by the Shoshone National Forest (other important high-elevation water towers are located within the Wind River Indian Reservation, which is bounded north and south by the Shoshone Forest).

The Rocky Mountain Research Station, in conjunction with the Shoshone National Forest, assessed past, current, and future climate in a comprehensive and exhaustive report. The objective of the report was to "synthesize the current understanding of paleo and historical climate of the Shoshone as a reference point, determine what future climates may look like, and what the effects of future climate may be on natural resources". With this information, the Forest Service and others can "identify vulnerabilities and information gaps and develop adaptation tools and strategies" (Rice et al., 2012).

Projections for the Shoshone National Forest of annual temperature increases of 3 °F (1.7 °C) by 2050, winter temperature increases of 4 °F (2.2 °C), and summer temperature increases of 5 °F (2.7 °C) compared to current averages were presented. Associated with this is a projected 10% increase in annual precipitation, with western higher elevations experiencing wetter winters.

These projected increases in temperatures and precipitation amounts will have potential impacts on water quantity and quality, the timing of annual flow conditions, and agricultural and ecological conditions. While consequences listed are difficult to mitigate, the increased temperatures and thus increased Growing Degree Days (GDD) along with increased moisture may provide the potential for diversification of crops or crop varieties. However, this may also create disadvantages such as the difficult sugar beet harvest experienced in the fall of 2019.

In their projections of increased temperatures and precipitation potentials, they looked at water quantity and quality, snowpack, timing of annual flow, and economics. The study follows currently observed extreme climatic events. The water quantity study projects that peak flow events will increase while annual, summer, and drought flow events will decrease. They project periodic flooding magnitudes will increase impacting surface water storage, impact on aquatic habitats, and water quality. Magnified impacts on water supply during drought may impact human, agricultural, and recreational uses, resulting in an increase in groundwater demand and increased costs of water treatment.

While the study projects a 10% increase in winter precipitation, the timing of the snowmelt and the conversion of snow to rain during the winter months is anticipated to have a significant impact on water availability (Rice et al., 2012). It is projected that snowmelt will begin 10-28 days earlier resulting in potentially less annual water supply stored as snow and earlier release of stream flows from storage and the loss of winter habitat for snow dependent wildlife. This earlier release of snowmelt will impact the filling of reservoirs and stock water dams and with the increase in temperatures, there can be an anticipated increase in evaporation from these storage areas. This can impact human and agricultural water availability, grazing seasons, salmonid spawning, and recreational opportunities.

Economically, the Rice et al. (2012) study points out the potential for loss in agricultural production and hydropower generation. If water supplies do decrease, there will be associated costs with tapping into groundwater and increased treatment costs of remaining surface waters. Hotter, drier seasons are associated with more frequent extreme fire events with fire seasons beginning earlier and lasting longer. An increase in invasives and pests is anticipated as well. On the positive side, there may be increased potential for recreation, though winter recreational timeframes may be shortened.

In addition to the hydrology and economic discussion above, the report also summarizes conditions for wetlands, vegetation, invasive species, fire, insects, pathogens, wildlife, fish, biochemical cycling, and land use. These additional summaries may or may not influence the study area.

WYOMING BASIN RAPID ECOREGIONAL ASSESSMENT

The Bureau of Land Management (BLM) prepares Rapid Ecoregional Assessments (REAs) to provide information that supports regional planning and analysis for the management of ecological resources. REAs provide an assessment of baseline ecological conditions, evaluation of current risks from drivers of ecosystem change, and a predictive capacity for evaluating future risks. Additionally, the REAs may be used for identifying priority areas for conservation or restoration and for assessing the cumulative effects of multiple land uses. One such REA has been prepared for the Wyoming Basin, which includes the Middle Big Horn Level I Watershed Study area. One aspect of this REA is climate. The REA "*describes the current climate of the Wyoming Basin, the range of potential climate change for the Wyoming Basin, and the reasonably foreseeable climate futures for ecosystems as they are understood now*" (E. N. B. Carr & Melcher, 2017).

The REA reached similar causalities and projections as Rice et al., (2012). It states that:

> *Based on climate projections, the Wyoming Basin could experience changes in snowpack that in turn could change water availability, including annual runoff and runoff seasonality. […] Climate can influence fire regimes, promote expansions of invasive plant species, and affect hydrological regimes. Warming temperatures may result in earlier snowmelt and runoff, with delayed start of the snow accumulation season in the fall, and a longer frost-free or growing season. These changes may result in a shift in individual seasons with winters being somewhat wetter and warmer and summers being somewhat warmer and drier. […] A longer growing season, with spring arriving earlier and fall somewhat later may expand the potentials for crop choices and calving season. This may also increase irrigation needs and increase costs. The drier years of the current climate may become the average years of the future for summer (June-August) soil moisture. Because of earlier snowmelt and runoff, soil moisture also increases earlier in the spring and dries out earlier in the late summer. Soil moisture drying out during the growing season will impact rangelands and may impact grazing seasons and wildlife habitat, potentially pushing wildlife onto private agricultural lands impacting economic returns to producers. […] Average minimum temperatures are likely to increase with fewer winter cold days to keep mountain pine beetle populations in check. […] Earlier timing of snowmelt and runoff […] may influence snow cover at lower elevations and habitat for some land species and streamflow thresholds for riparian species.*

MONTANA CLIMATE ASSESSMENT

The Montana Institute on Ecosystems, based at both Montana State University and the University of Montana, organized the Montana Climate Assessment and published its first assessment report in 2017 (Whitlock et al., 2017). Due to the proximity of the Middle Big Horn Level I study area to Montana, the information in the report may be applicable, if used with due caution.

The assessment focused on three areas: water, forests, and agriculture.

Major findings: Water

Based on historic records, rising temperatures will reduce snowpack, shift historical patterns of streamflow, and may result in additional stress on water supply, particularly during summer and early fall. Montana's snowpack has declined over the observational record, being the most pronounced since the 1980s. Historical observations show a shift toward earlier snowmelt and earlier peak spring runoff in the Mountain West. Projections suggest that these patterns are likely to continue as temperatures increase. Groundwater demand will likely increase as elevated temperatures and changing seasonal availability of surface water sources force water users to seek alternatives.

Rising temperatures will exacerbate persistent drought periods. Multi-year and decadal-scale droughts have been, and will continue to be, a natural feature. Rising temperatures will likely exacerbate drought. This coupled with changes in snowpack and runoff may increase irrigation demand.

Major findings: Forests

The effects of climate on forests include temperature changes and shifts in precipitation that together alter humidity, soil moisture, and water stress. An increase in fire risk (e.g., probability of occurrence)—including an increase in size and possible frequency and/or severity (e.g., tree mortality rate)—is expected in the coming century as a result of longer fire seasons due to increased temperatures and decreased summer precipitation and increased fuel loads from historic fire suppression. Rising temperatures are likely to increase bark beetle winter survival, which has been linked to increased fire impacts. Climate-induced changes to other insects and forest pathogens are more varied and less certain.

Major findings: Agriculture

The results of this analysis produced several key messages. Every component of agriculture—from prices to plant pollinators (seed alfalfa and dry beans) and crop pests—exhibits complex relationships to climate, depending on the location, weather variability, and agricultural and economic practices and policies. Social and economic resilience to withstand and adapt to variable conditions has always been a hallmark of farmers' and livestock producers' strategies for coping with weather/climate variability. Decreasing mountain snowpack will continue to lead to decreased streamflow and less reliable irrigation capacity during the late growing season. Reduced irrigation capacity will have the greatest impact on hay, sugar beet, malt barley, market garden, and potato production across the state. Increases in temperature will allow winter annual weeds, such as cheatgrass, to increase in distribution and frequency in winter wheat cropland and rangeland. Their spread will result in decreased crop yields and forage productivity as well as increased rangeland wildfire frequency. Diversified cropping systems, including rotation with pulse crops and innovations in tillage and cover-cropping, along with other measures to improve soil health, will continue to allow adaptation to climate change.

CLIMATE SUMMARY

The intent of summarizing relevant climate reports here is to summarize the scientific literature so decision-makers and managers can develop workable response strategies and have them available for implementation over time as they are needed.

There are common threads across all reports relative to potential direct, indirect, and cumulative effects of climate change. The most notable and pertinent thread are effects on the water, or hydrologic cycle, as water transcends all other resource uses in the study area and is a key driver behind local and regional economies. These reports present a warning of the potential results of the changes in the climate we are currently experiencing and what the future may hold for the study area as the climate continues to shift. These reports also provide alternative concepts to consider such as the potential for new crops and crop varieties and longer growing seasons. It is to the benefit of the public in the study area to consider what is happening in the area and develop a response.

GEOMORPHOLOGY

INTRODUCTION

Geomorphology is the study of landforms and their relationships to underlying geologic structure, along with the history of geologic change recorded by surficial features (Bates & Jackson, 1984). Congruently, river morphology is the study of the pattern and geometry of streams within catchment basins that have incised across landforms (Wilson & Moore, 1998).

Geomorphic characterization and stream classification provide a means to describe channel form and to better understand existing and expected channel processes within a watershed. This allows for further understanding of channel function and stability, and appropriate, sustainable management approaches for maintaining stable systems or rectifying unstable systems.

A Level I geomorphic characterization (Rosgen, 1996, 2014, 2019) was completed for the study area. This broad-level inventory provides users base-level, reconnaissance-scale delineation of fluvial landscapes. Completion of Level I geomorphic characterization can then lead to Level II morphological descriptions, Level III river stability prediction, and Level IV monitoring and validation efforts (Figure 12).

This is detailed further in Figure 13, and the associated stream types labeled A through G are shown in Figure 14 and Figure 15. This top-level delineation conveys generalized information about streams and rivers in the study area, useful for identifying priority areas for further examination.

The broad-level characterization presented here was developed through both office and fieldwork, following fluvial geomorphology and stream classification principles. As more detailed information is gained over time from Level II, III, and IV efforts, this Level I geomorphic characterization can be revised if necessary.

Streams and rivers that flow on land surfaces, and groundwater flowing beneath the surface, are the plumbing system of Earth's continents (Hauer & Lamberti, 2007). These pathways form in response to precipitation patterns and the dynamic form of catchment basins (i.e., watersheds) that ensue through long geologic and biologic timeframes.

The streams that develop within drainage basins (i.e., watersheds) are highly organized three-dimensional systems. They are self-formed in that any water in the channel and any debris that water carries, result in the channel. This self-formation occurs within a range of dynamic equilibrium, subject to the magnitude of the water's energy and the debris load. The result is a quasi-stable pattern, profile, and dimension that neither aggrades nor degrades under the present climate (Dunne & Leopold, 1978).

This quasi-stable form is a product of the adjustment of boundary conditions to the quantity of streamflow and erosional debris produced within the watershed, above a reach length along a stream (Rosgen, 1996). Unstable stream conditions can result when independent variables are altered naturally or otherwise anthropogenically. Such alteration can, whether slowly or rapidly, result in changes in channel morphology through aggradation or degradation. Adverse and undesirable consequences, such as stream bank instability and erosion, atypical flood events, or lowering and loss of water tables, can result.

The goal of this assessment is to understand the existing and expected channel processes within the study area. Methods and findings for the assessment are presented below.

STREAM CLASSIFICATION

Hierarchical assessment of stream channel morphology provides context for identifying driving forces and response variables at multiple scales of inquiry (Rosgen, 1996). Information required at each scale varies with the degree of resolution desired.

For this WWDC Level I watershed study, a Rosgen Level I geomorphic characterization (Rosgen, 1996, 2014, 2019) was completed. This broad-level inventory (Figure 12) provides reconnaissance-scale delineation of fluvial landscapes (Figure 13) and their corresponding stream types (Figure 14 and Figure 15) across the area of consideration. Such information provides for:

- Preliminary integration of watershed characteristics with stream system morphological response
- An initial framework for organizing and sharing watershed and fluvial geomorphology information
- Physical assessment and inventory data sets that can be correlated with similar general level biological and chemical data sets
- A mechanism for detailing more stream-reach specific assessment and inventory data needs

Completion of Level I geomorphic characterization can then lead to Level II morphological descriptions, Level III river stability prediction, and Level IV monitoring and validation efforts.

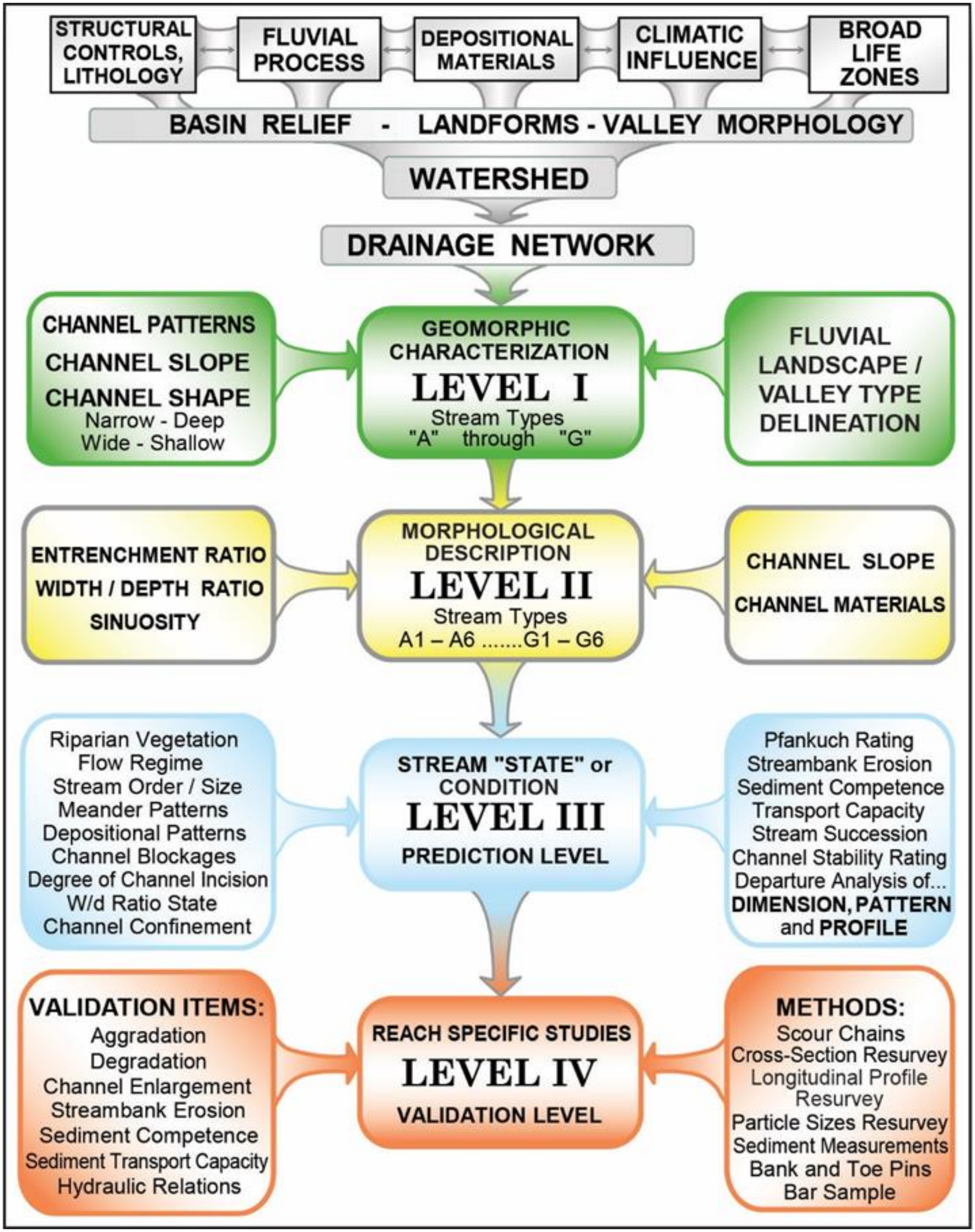

Figure 12: River inventory and assessment hierarchy. (Rosgen, 2014)

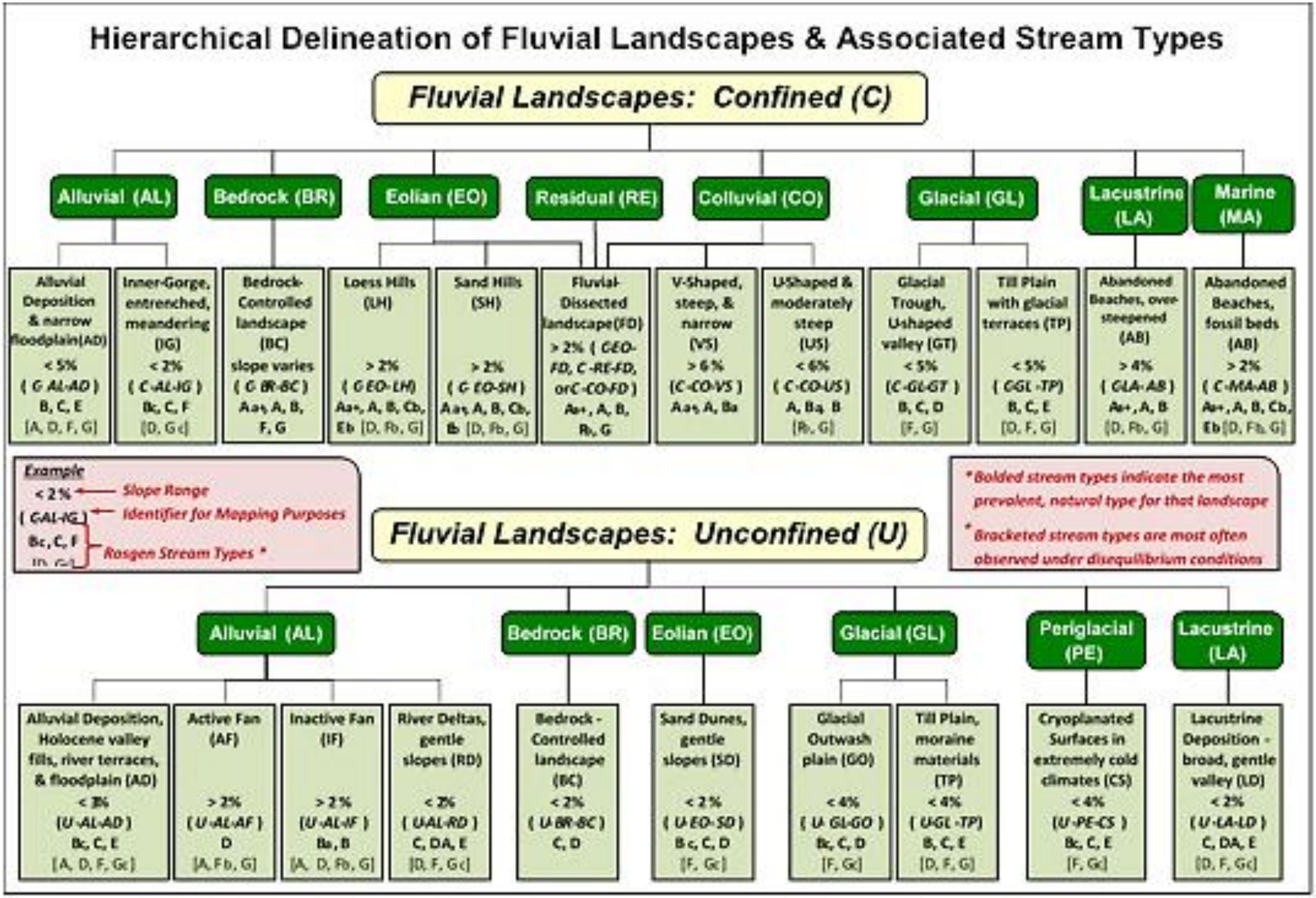

Figure 13: Fluvial landscapes and associated stream types. (Rosgen, 2014)

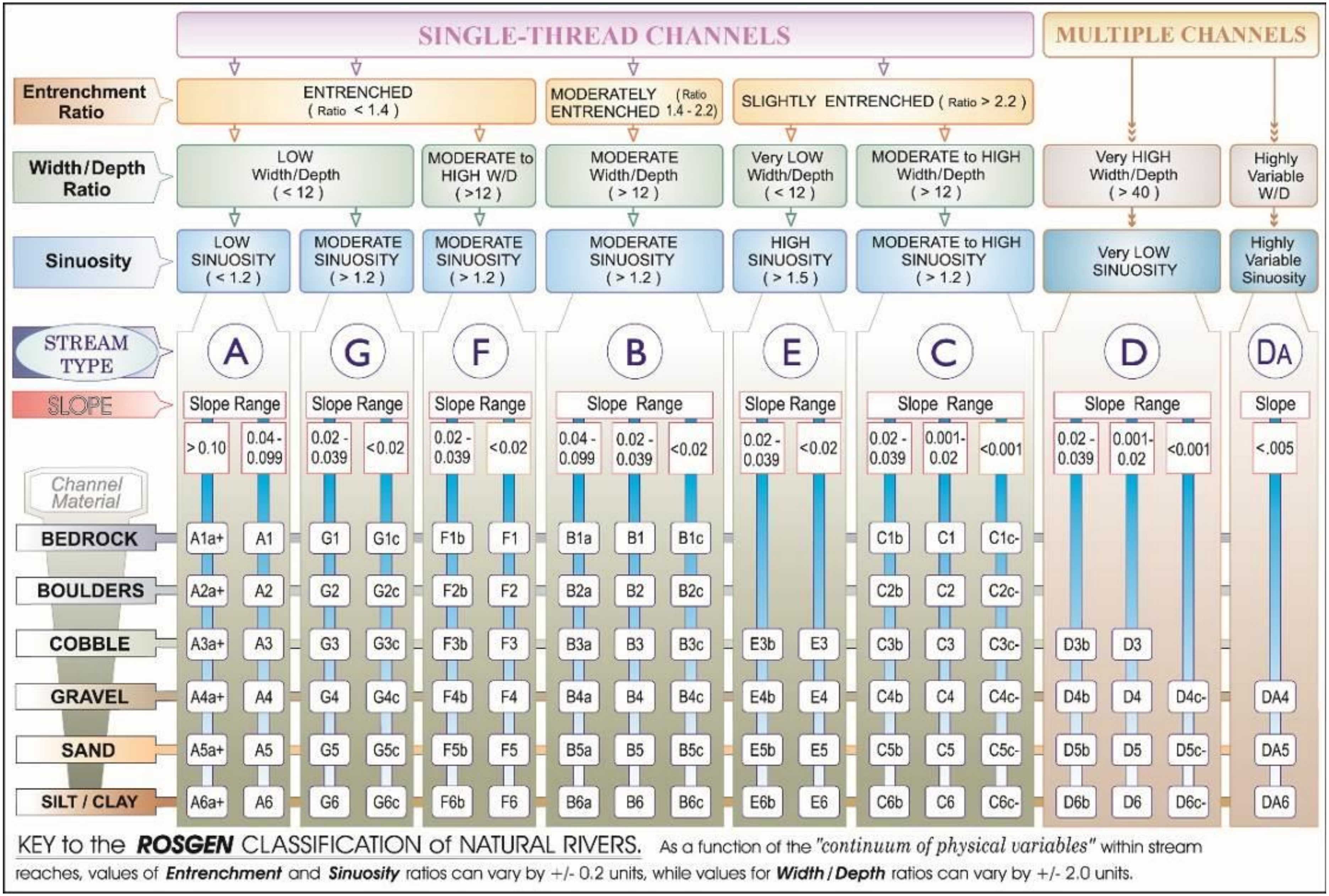

Figure 14: Rosgen Stream Type Classification Key. (Rosgen, 2014)

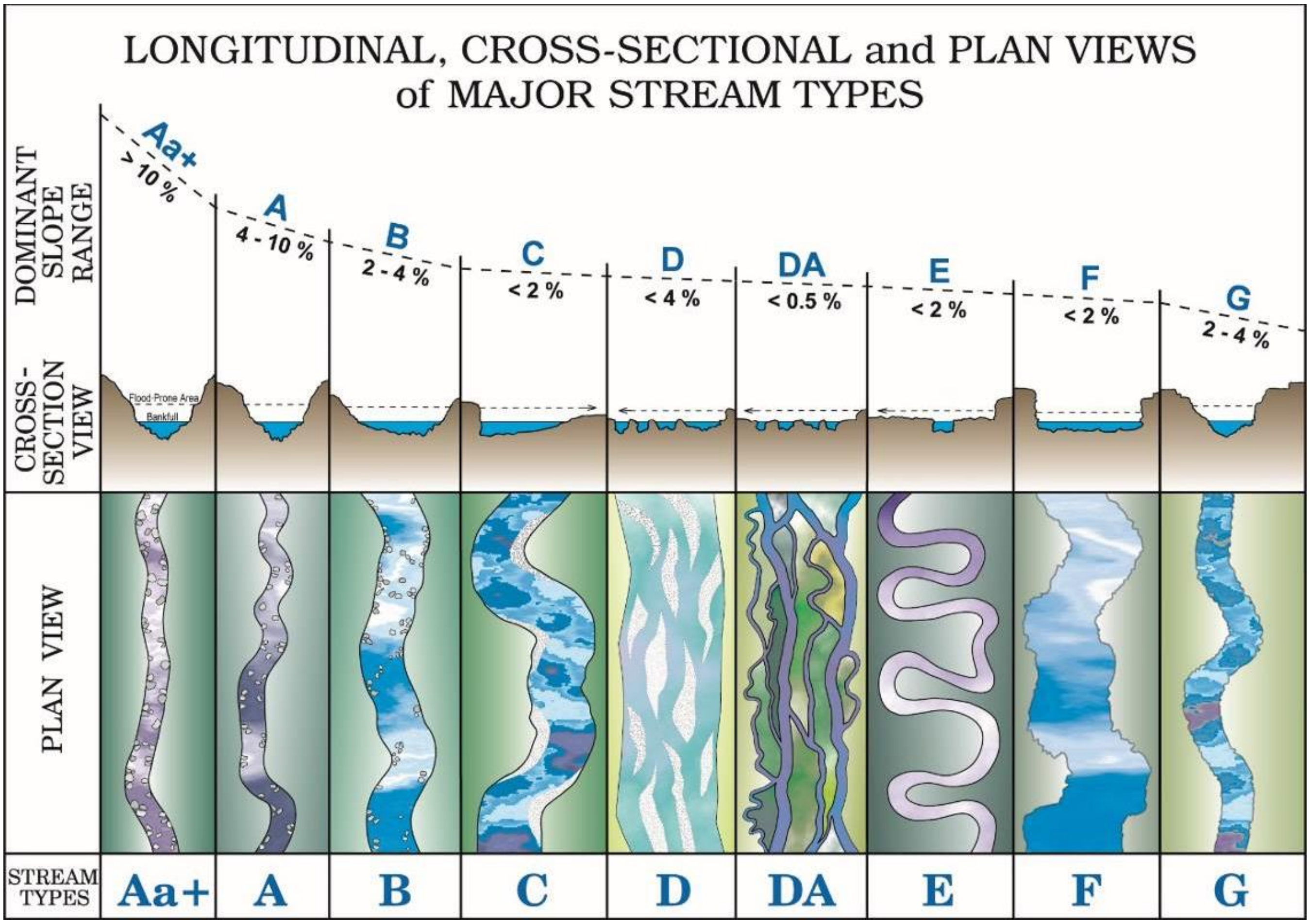

Figure 15: Rosgen stream types - typical patterns, profiles, and dimensions. (Rosgen, 2014).

LEVEL I CHARACTERIZATION APPROACH

Multiple types of GIS information were used for the Level I characterization. These included the National Hydrography Dataset (NHD), Watershed Boundary Dataset (WBD), topographic maps, a three-dimensional Digital Elevation Model (DEM), PRISM precipitation data, bedrock, and surficial geologic maps, and satellite imagery (infrared and standard color). Cross-evaluation of these data allowed for the identification of basin relief, landforms, and valley morphology, which led to an assessment of channel pattern, slope, and shape. From this, potential fluvial landscapes and associated stream types across the study area were selected.

The twenty-two fluvial landscapes in Figure 13 are second-generation representations (Rosgen, 2014). First-generation representation contains eleven valley types (Rosgen, 1996). Second generation representation was used in this assessment to better define fluvial geomorphology in the study area. The crosswalk between the two representations is available and shown in Figure 16.

Evaluation of available data indicates that, while there is geologic, geomorphic, and hydrologic variability across the study area, there is also much consistency, particularly when the study area is evaluated at a reconnaissance-level scale as done for this Level I watershed study. This scaled approach led to the identification and development of various fluvial landscape mapping units or associations (Figure 17 and Figure 18). Spatial representations of surface water flow, Rosgen classifications, and stream classifications for the study area are available in the Map Book, Maps 5 through 7.

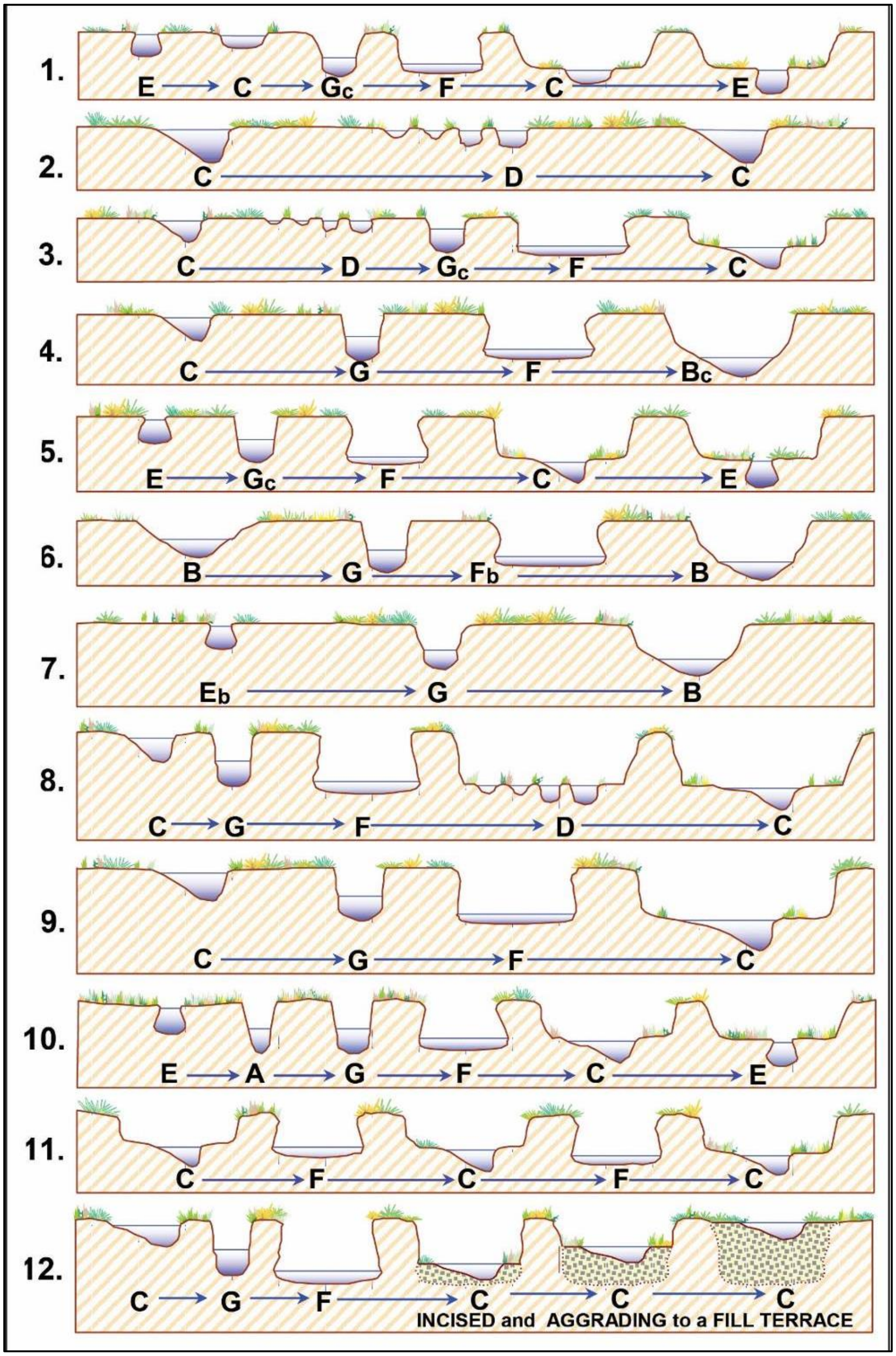

Figure 16: Crosswalk between fluvial landscapes (Rosgen 2014) and valley types (Rosgen 1996).

Valley Type in Rosgen (1996)	New Identifier for Mapping	Delineation of Fluvial Landscapes	Slope Range	Associated Stream Types*
I	*C-CO-VS*	***Confined Colluvial:*** V-Shaped, Steep, & Narrow	> 6%	Aa+, A, Ba
II	*C-CO-US*	***Confined Colluvial:*** U-Shaped & Moderately Steep	< 6%	A, Ba, B [Fb, G]
III	*U-AL-AF*	***Unconfined Alluvial:*** Active Fan	> 2%	D [A, Fb, G]
III	*U-AL-IF*	***Unconfined Alluvial:*** Inactive Fan	> 2%	Ba, B [A, D, Fb, G]
IV	*C-AL-IG*	***Confined Alluvial:*** Inner-Gorge – Entrenched & Meandering	< 2%	Bc, C, F [D, Gc]
V	*C-GL-GT*	***Confined Glacial:*** Glacial Trough, U-Shaped Valley	< 5%	B, C, D [F, G]
VI	*C-BR-BC*	***Confined Bedrock:*** Bedrock-Controlled Landscape	*varies*	Aa+, A, B, F, G
VI	*U-BR-BC*	***Unconfined Bedrock:*** Bedrock-Controlled Landscape	< 2%	C, D
VII	*C-EO-FD, C-RE-FD, C-CO-FD*	***Confined Eolian, Residual, or Colluvial:*** *Fluvial-* Dissected Landscape	> 2%	Aa+, A, B, Fb, G
VIII	*C-AL-AD*	***Confined Alluvial:*** Alluvial Deposition & Narrow Floodplain	< 5%	B, C, E [A, D, F, G]
VIII	*U-AL-AD*	***Unconfined Alluvial:*** Alluvial Deposition, Holocene Valley Fills, River Terraces, & Floodplain	< 3%	Bc, C, E [A, D, F, Gc]
IX	*U-GL-GO*	***Unconfined Glacial:*** Glacial Outwash Plain	< 4%	Bc, C, D [F, Gc]
X	*U-LA-LD*	***Unconfined Lacustrine:*** Lacustrine Deposition - Broad, Gentle Valley	< 2%	C, DA, E [D, F, Gc]
XI	*U-AL-RD*	***Unconfined Alluvial:*** River Deltas, Gentle Slopes	< 2%	C, DA, E [D, F, Gc]
	C-EO-LH	***Confined Eolian:*** Loess Hills	> 2%	Aa+, A, B, Cb, Eb [D, Fb, G]
	C-EO-SH	***Confined Eolian:*** Sand Hills	> 2%	Aa+, A, B, Cb, Eb [D, Fb, G]
	C-GL-TP	***Confined Glacial:*** Till Plain with Glacial Terraces	< 5%	B, C, E [D, F, G]
	C-LA-AB	***Confined Lacustrine:*** Abandoned Beaches, Over-Steepened	> 4%	Aa+, A, B [D, Fb, G]
	C-MA-AB	***Confined Marine:*** Abandoned Beaches, Fossil Beds	> 2%	Aa+, A, B, Cb, Eb [D, Fb, G]
	U-EO-SD	***Unconfined Eolian:*** Sand Dunes, Gentle Slopes	< 2%	Bc, C, D [F, Gc]
	U-GL-TP	***Unconfined Glacial:*** Till Plain, Moraine Materials	< 4%	B, C, E [D, F, G]
	U-PE-CS	***Unconfined Periglacial:*** Cryoplanated Surfaces in Extremely Cold Climates	< 4%	Bc, C, E [F, Gc]

**Bolded stream types indicate the most prevalent, natural type for that landscape; Bracketed stream types are most often observed under disequilibrium conditions*

Figure 17: Fluvial landscape associations.

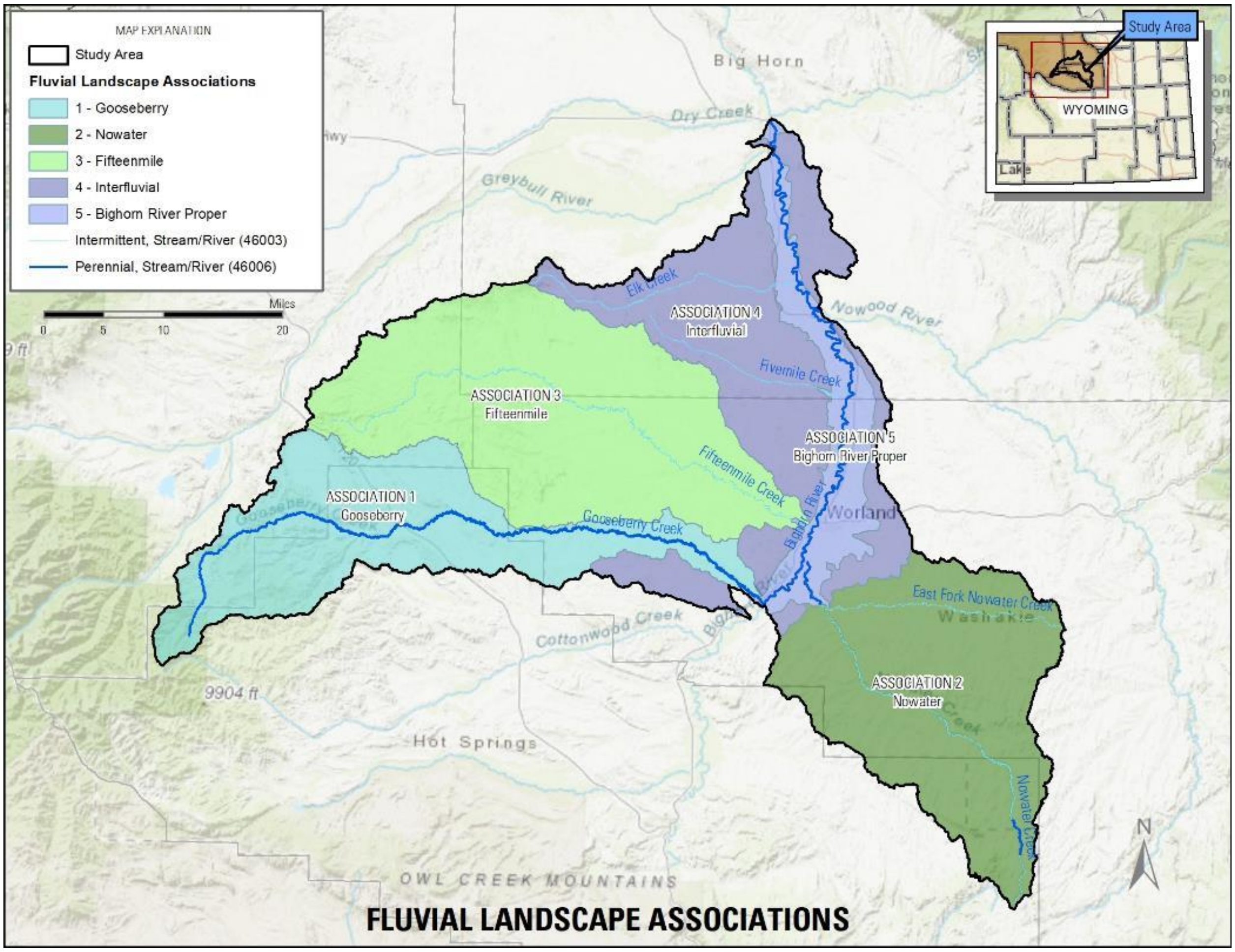

Figure 18: Fluvial Landscapes, mapping units or associations developed for the Middle Big Horn River Level 1 Watershed.

Table 3: Fluvial landscape associations within the study area.

Fluvial Landscape Association	Area (approximate acres within study area)	Dominant Fluvial Landscapes	Inclusions	Notes
1	229,937	C-AL-FD, U-AL-FD	U-AL-AF, U-AL-IF, C-BR-BC, C-CO-VS, C-CO-US, C-CO-FD	Gooseberry, including Little Buffalo, Middle, Left Hand, Enos tributaries
2	264,461	C-AL-FD, U-AL-FD, C-CO-FD	U-AL-AF, U-AL-IF, C-BR-BC, C-CO-VS, C-CO-US	Nowater, including East Fork tributary
3	333,226	C-AL-FD, U-AL-FD, C-CO-FD	U-AL-AF, U-AL-IF, C-BR-BC, C-CO-VS, C-CO-US	Fifteenmile, including Middle, Badger, Waterhole, Cottonwood tributaries
4	241,288	C-AL-FD, U-AL-FD, C-CO-FD	U-AL-AF, U-AL-IF,	Interfluve areas along Big Horn River proper, such as Antelope, Elk, Fivemile, Tenmile, Little Gooseberry
5	84,348	U-AL-FD	U-AL-AF, U-AL-IF, C-CO-US	Big Horn River proper (as represented by irrigated and sub-irrigated agricultural lands)

FLUVIAL LANDSCAPE ASSOCIATIONS AND EXPECTED/POSSIBLE STREAM TYPES

Association 1 – Gooseberry

This association covers most of the Gooseberry Creek watershed (Figure 19). This watershed is dominated by fluvial landscapes C-AL-FD and U-AL-FD. There are inclusions of U-AL-AF, U-AL-IF, C-BR-BC, C-CO-VS, C-CO-US, and C-CO-FD.

Much of the watershed is comprised of soft sedimentary geologic material. The Willwood Formation dominates in the lower elevations but does outcrop at mid- to high elevations in localized areas. Bands of the Fort Union, Lance, Mesa Verde, and Meeteetse formations occur at mid- to high elevations. Several pockets of the Cody Shale outcrop occur at mid-elevations, particularly in the Little Buffalo Basin. Absaroka volcanic supergroup material, consisting of the Aycross, Tepee Trail, and Wiggins formations, occur at the highest elevations of the watershed.

Precipitation varies from eight inches per year, near the Big Horn River confluence, to 24 inches at higher elevations. Elevations range from 4,200 to 10,600 feet. Vegetation is dominated by grasses, forbs, and sagebrush at low to mid-elevations. Limber pine (*Pinus flexilis*), juniper (*Juniperus spp*.), Douglas-fir (*Pseudotsuga menziesii*), and aspen (*Populus tremuloides*) occur in small, scattered stands at mid-elevations. High elevation areas are dominated by whitebark pine (*Pinus albicaulis*), Engelmann spruce (*Picea engelmannii*), sub-alpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*), Douglas-fir, and limber pine, with forb and grass understories. The highest elevations are dominated by alpine vegetation, such as sedges (*Carex* spp.), low growing willows (*Salix* spp.), hairgrass (*Deschampsia* spp.), narcissus-flowered anemone (*Anemone narcissiflora*), and lousewort (*Pedicularis parryi*).

The watershed consists of the main Gooseberry Creek channel as well as perennial flow, sub-watershed channels: Buffalo/Little Buffalo Creek (supported by water produced from oil/gas development), Middle Creek, Left Hand Fork, and Enos Creek. Gooseberry Creek is tributary to the Big Horn River.

Figure 19: Headwaters of Gooseberry Creek watershed.

The mouth of Gooseberry Creek is bisected by irrigation canals and has areas of irrigated cropland and pasture. Canal leakage and irrigation return flow contributes to natural perennial flow directly before the creek drains into the Big Horn River. Because of the man-made influence, the mouth of the watershed is included in the Big Horn River proper association rather than the Gooseberry association.

Lower to mid-elevations of the watershed are highly dissected by grassed waterways and ephemeral streams. These waterways and streams transition to intermittent streams of much flatter slopes. The intermittent channels coalesce at various junctures and drain to the main Gooseberry Creek channel. Grassed waterways are not a Rosgen stream type, for there is no definable channel incision. However, they are critically important drainage features on the landscape, facilitating watershed stability in small headwater areas of highly erosive material.

There are extensive lengths of V- and U-shaped colluvial valleys. These are most dominant in the headwaters, but also occur along the interfluve margins of Gooseberry Creek and its major tributaries. Aa+, A, and B stream types dominate.

C-AL-FD and U-AL-FD fluvial landscapes are the most dominant type in this watershed. C and E stream types are dominant in both landscapes. They alternate in a downstream direction due to three primary reasons. One reason is geologic control on belt width. The second reason is that water and sediment supply ratios form streams tending to width/depth ratios in and around 12, the only classification difference between the two types of any consequence. The third reason is that in areas where there is homogenous deposition of fine sediment (sands and finer), E stream types tend to form; while in areas where there is heterogeneous deposition of course sediment (gravels and larger), C stream types tend to form. The E stream types are sedge/rush dominated. The C stream types are willow dominated.

Some stream reaches have down cut to F and G stream types due to historic land use and management. Some of these reaches are going through the evolution of channel adjustment, naturally returning to their stable form (Figure 16).

Portions of the watershed are classic “badlands” landscapes. In these areas, C-CO-FD fluvial landscapes are found in areas of first- and second-order streams. They are dominated by Aa+, A, and G stream types. Flatter slopes are B and Fb types. These drain into C-AL-FD and U-AL-FD fluvial landscapes.

Active and inactive alluvial fans, generally small in areal coverage and extent, occur throughout the watershed. D and B stream types, respectively, dominate these landforms. Some reaches have down cut to Fb and G stream types due to historic land use and management. Some reaches are going through the evolution of channel adjustment, naturally returning to their stable form.

Short lengths of bedrock channel do occur, but mostly in the volcanic geology and the highly tilted sedimentary geologies. Aa+, A, and G stream types dominate these landforms.

Association 2 - Nowater

This association covers most of the Nowater Creek watershed. This watershed is dominated by fluvial landscapes C-CO-FD, C-AL-FD, and U-AL-FD. There are inclusions of U-AL-AF, U-AL-IF, C-BR-BC, C-CO-VS, and C-CO-US fluvial landscapes, either in isolated areas or scattered through the dominant fluvial landscapes.

The watershed is comprised of soft sedimentary geologic material. The Willwood Formation occurs in the lower elevations of East Nowater Creek and at the mouth of Nowater Creek proper. The Fort Union Formation occurs at mid-elevations. Bands of the Lance, Meeteetse, and Mesa Verde Formations occur at mid- to high elevations of Nowater Creek proper. The Cody Shale Formation occurs at high elevations of Nowater Creek proper, with pockets of the Frontier, Mowry, Thermopolis, and Wagon Bed Formations in the uppermost (highest) elevations.

Precipitation varies from eight inches per year near the Big Horn River confluence to 20 inches at higher elevations. Elevations range from 4,032 to 7,274 feet. Vegetation is dominated by grasses, forbs, saltbush (*Atriplex* spp.), and sagebrush (*Artemisia* spp.). Limber pine, juniper, Douglas-fir, and aspen do occur in small, scattered stands at the highest elevations.

The watershed is highly dissected by grassed waterways and ephemeral streams. These waterways and streams transition to intermittent streams of much flatter slope. The intermittent channels coalesce at various junctures and drain to form the main, but still intermittent East Nowater Creek and Nowater Creek channels. Nowater Creek is tributary to the Big Horn River.

The mouth of Nowater Creek is bisected by irrigation canals and has areas of irrigated cropland and pasture. Canal leakage and irrigation return flow does allow for perennial flow directly before the creek drains into the Big Horn River. This flow is entirely artificial, except for occasional flood flows from the upper watershed. Because of the man-made influence, the mouth of the watershed is included in the Big Horn River Proper association rather than the Nowater association.

Parts of the Nowater Creek watershed are a classic "badlands" landscape. As discussed above, grassed waterways are prevalent, but are not a Rosgen stream type, for there is no definable channel incision. However, they are critically important drainage features on the landscape, facilitating watershed stability in small headwater areas of highly erosive material.

C-CO-FD landscapes are found in areas of first- and second-order streams. They are dominated by Aa+, A, and G stream types. Flatter slopes are B and Fb types. This landscape drains into C-AL-FD and U-AL-FD valleys. These areas are either one or the other of these two fluvial landscapes, or they alternate in a downstream direction due to geologic control on belt widths. C and E stream types are dominant in both valley types. Some reaches have down cut to F and G stream types due to historic land use and management. Some reaches are going through the evolution of channel adjustment, naturally returning to their stable form.

Active and inactive alluvial fans, generally small in areal coverage and extent, occur throughout the watershed. D and B stream types, respectively, dominate. Some reaches have down cut to Fb and G stream types due to historic land use and management. Some reaches are going through the evolution of channel adjustment, naturally returning to their stable form.

Short lengths of bedrock channel do occur, but mostly in the highly tilted sedimentary geologies along the southern and eastern margins of the watershed. Aa+, A, and G stream types dominate these landforms.

There are also short lengths of V- and U-shaped colluvial valleys, again mostly in the highly tilted sedimentary geologies. Aa+, A, and B stream types dominate these landforms.

Association 3 – Fifteenmile

This association covers most of the Fifteenmile Creek watershed (Figure 20). This watershed is dominated by fluvial landscapes C-CO-FD, C-AL-FD, U-AL-FD. There are inclusions of U-AL-AF, U-AL-IF, C-BR-BC, C-CO-VS, C-CO-US fluvial landscapes, either in isolated areas or scattered through the dominant fluvial landscapes.

Figure 20: Fifteenmile creek watershed.

The watershed is comprised of soft sedimentary geologic material. The Willwood Formation dominates. The Tatman Formation occurs, in a relatively small areal extent, on the northern and southern margins of the Upper Fifteenmile Creek HUC. Highly tilted sedimentary beds of the Fort Union, Lance, and Meeteetse Formations occur on the extreme west end of the watershed. The areal extent of this material is also relatively small.

Precipitation varies from six inches per year, near the Big Horn River confluence, to 14 inches at higher elevations. Elevations range from 4,013 to 6,824 feet. Vegetation is dominated by grasses, forbs, saltbush, and sagebrush. Limber pine and juniper do occur in small, scattered stands at the highest elevations.

The watershed is highly dissected by grassed waterways and ephemeral streams. These waterways and streams transition to intermittent streams of much flatter slope. The intermittent channels coalesce at various junctures and drain to form the main, but still intermittent Fifteenmile Creek channel. Fifteenmile Creek is tributary to the Big Horn River.

The mouth of Fifteenmile Creek is bisected by irrigation canals and has areas of irrigated cropland and pasture. Canal leakage and irrigation return flow does allow for perennial flow directly before the creek drains into the Big Horn

River. This flow is entirely artificial, except for occasional flood flows from the upper watershed. Because of the man-made influence, the mouth of the watershed is included in the Big Horn River Proper association rather than the Fifteenmile association.

Much of the Fifteenmile Creek watershed is a classic "badlands" landscape. As discussed above, grassed waterways are prevalent, but they are not a Rosgen stream type, for there is no definable channel incision. However, they are critically important drainage features on the landscape, facilitating watershed stability in small headwater areas of highly erosive material.

C-CO-FD fluvial landscapes are found in areas of first- and second-order streams. They are dominated by Aa+, A, and G stream types. Flatter slopes are B and Fb types. This landscape drains into C-AL-FD and U-AL-FD valleys. These areas are either one or the other of these two fluvial landscapes, or they alternate in a downstream direction due to geologic control on belt width. C and E stream types are dominant in both landscapes. Some reaches have down cut to F and G stream types due to historic land use and management. Some reaches are going through the evolution of channel adjustment, naturally returning to their stable form.

Active and inactive alluvial fans, generally small in areal coverage and extent, occur throughout the watershed. D and B stream types, respectively, dominate. Some reaches have down cut to Fb and G stream types due to historic land use and management. Some reaches are going through the evolution of channel adjustment, naturally returning to their stable form.

Short lengths of bedrock channel do occur, but mostly in the highly tilted sedimentary geologies along the western margin of the watershed. Aa+, A, and G stream types dominate these landforms.

There are also short lengths of V- and U-shaped colluvial valleys, again mostly in the highly tilted sedimentary geologies along the western margin of the watershed. Aa+, A, and B stream types dominate these landforms.

Association 4 – Interfluvial

This association covers the interfluvial region of the study area, i.e., drainage areas lying between the three major watersheds (Gooseberry Creek, Nowater Creek, and Fifteenmile Creek). This area is dominated by fluvial landscapes C-CO-FD, C-AL-FD, and U-AL-FD. There are inclusions of U-AL-AF, and U-AL-IF fluvial landscapes, either in isolated areas or scattered through the dominant landscapes.

The association is comprised of soft sedimentary geologic material. The Willwood Formation dominates both east and west of the Big Horn River. Smaller areas of Fort Union, Lance, Meeteetse, Mesa Verde, Cody Shale, and Frontier Formations are present. Many of these smaller areas are highly tilted, particularly between the communities of Manderson and Greybull. Scattered pockets of alluvium/colluvium, gravel, pediments, and alluvial fan deposits occur throughout the association.

Precipitation varies from 6 to 12 inches per year. Elevations range from 3,911 to 5,961 feet. Vegetation is dominated by grasses, forbs, saltbush, and sagebrush.

The watershed is highly dissected by grassed waterways and ephemeral streams. Some of these waterways and streams transition to intermittent streams of much flatter slope. The intermittent channels coalesce at various junctures and drain into the Big Horn River.

The mouths of some of these intermittent channels are bisected by irrigation canals and have areas of irrigated cropland and pasture. Canal leakage and irrigation return flow does allow for perennial flow in these channels, which then drain into the Big Horn River. These flows are entirely artificial, except for occasional flood flows from the upper watershed. Because of the man-made influence, the mouths of these watersheds are included in the Big Horn River Proper association rather than the Interfluvial association.

Much of the Interfluvial Association is a classic "badlands" landscape. As discussed above, grassed waterways are prevalent, but they are not a Rosgen stream type, for there is no definable channel incision. However, they are critically important drainage features on the landscape, facilitating watershed stability in small headwater areas of highly erosive material.

C-CO-FD landscapes are found in areas of first- and second-order streams. They are dominated by Aa+, A, and G stream types. Flatter slopes are B and Fb types. This landscape drains into C-AL-FD and U-AL-FD landscapes. These areas are either one or the other of these two fluvial landscapes, or they alternate in a downstream direction due to geologic control on belt width. C and E stream types are dominant in both landscapes. Some reaches have down cut to F and G stream types due to historic land use and management. Some reaches are going through the evolution of channel adjustment, naturally returning to their stable form.

Active and inactive alluvial fans, generally small in areal coverage and extent, occur throughout the watershed. D and B stream types, respectively, dominate. Some reaches have down cut to Fb and G stream types due to historic land use and management. Some reaches are going through the evolution of channel adjustment, naturally returning to their stable form.

Association 5 – Big Horn River Proper

This association covers the Big Horn River valley as bounded by agricultural activity, i.e., irrigation. The communities of Greybull, Basin, Manderson, and Worland lie along a north-to-south axis through the association (Figure 21). This association is predominately fluvial landscape U-AL-FD. There are inclusions of U-AL-AF, U-AL-IF, and C-CO-US fluvial landscapes, either in isolated areas or scattered through the dominant landscape.

Figure 21: Big Horn River proper west of Worland.

The association is predominately Holocene alluvium and colluvium, gravel, pediment, and fan deposits. At various locations along the margins of the association, small outcrops of Mowry Shale, Thermopolis Shale, Frontier, Cody Shale, Mesa Verde, Meeteetse, Lance, Fort Union, and Willwood Formations occur.

Precipitation varies from six to ten inches per year. Elevations range from 3,767 to 4,400 feet. Except for irrigated lands, upland areas are dominated by grasses, forbs, saltbush, and sagebrush; while wetter areas are dominated by cottonwood (*Populus* spp.), Russian olive (*Elaeagnus angustifolia*), and salt cedar (*Tamarix* spp.).

The area is dominated by regulated perennial streamflow through releases from Boysen Reservoir, located approximately 35 miles upstream. The mouths of the other four associations lie within this association, as discussed in the narrative for those associations. Most of these watershed mouths are bisected by irrigation canals and have areas of irrigated cropland and pasture. Thus, canal leakage and irrigation return flow allows for perennial flow that drains into the Big Horn River. These flows are entirely artificial, except for occasional flood flows from the upper watersheds outside of this association.

The Big Horn River is predominately C stream type. There are reaches of F stream type resulting from encroachment by land use activity, e.g., irrigation, agriculture development, highways, and railroads.

Active and inactive alluvial fans, generally small in areal coverage and extent, occur along the margins of the association. D and B stream types, respectively, dominate. Some reaches have down cut to Fb and G stream types due to historic land use and management. Some reaches are going through the evolution of channel adjustment, naturally returning to their stable form.

STREAM CLASSIFICATION SUMMARY

The geomorphic characterization descriptions for the five fluvial landscape associations within the study area distinguish as natural or "expected" Rosgen stream types. The descriptions also distinguish types that may be present if streams within the associations are in disequilibrium relative to the water and sediment supply provided by the watershed area the streams are associated with.

As discussed in the Physical Systems: Surface Water: Hydrography section of this WWDC Level I study report, there are over 5,200 miles of stream in the study area (USGS, 2016). Roughly 95% of this mileage is intermittent and ephemeral. For this WWDC Level I study and its associated Rosgen Level I geomorphic characterization only perennial streams, or roughly 5% of the total stream miles, were reviewed and assigned an "expected" Rosgen Level I stream type (Figure 22 and Map Book, Map 6). An exception is for streams within the Shoshone National Forest in the Gooseberry Creek watershed. The Shoshone National Forest has Rosgen Level II, III, and IV data for streams within their administrative boundary. These data are included in Figure 22 and Table 4. Detailed information is in the project file and is also available at the Shoshone National Forest Supervisor's Office in Cody, WY.

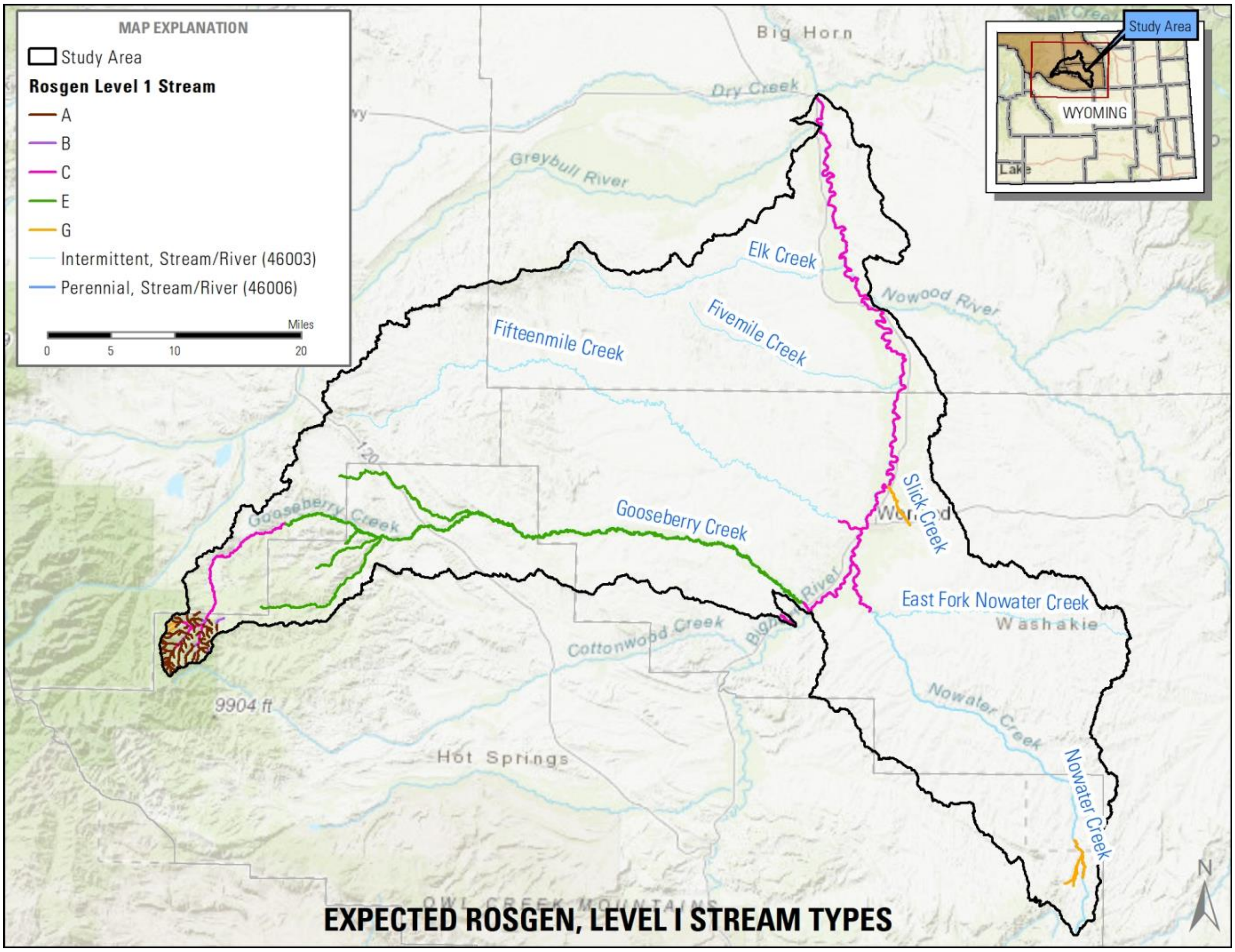

Figure 22: Expected Rosgen stream types for perennial streams in the study area. Stream types for ephemeral and intermittent channels are not mapped, except for lands managed by the USDA Forest Service.

The majority of the assigned "expected" stream types are in Associations 1 and 5. A minor amount occurs in Association 2. Since there is no perennial mileage in Associations 3 and 4, no stream typing was conducted (Table 4). As shown in the table, perennial streams in the study area are predominately Rosgen types C and E. Association 1 contains significant Rosgen type A stream mileage, which reflects the more detailed delineation work conducted by the Forest Service. Note that much of this mileage is likely intermittent flow rather than perennial flow.

Table 4: Expected miles of Rosgen Level I stream types for perennial streams by fluvial landscape association.

Fluvial Landscapes Association	Rosgen Type A	Rosgen Type B	Rosgen Type C	Rosgen Type D	Rosgen Type E	Rosgen Type F	Rosgen Type G
1	35	4	20	---	130	---	1
2	---	---	<1	---	---	---	10
3	---	---	<1	---	---	---	---
4	---	---	<1	---	---	---	---
5	---	---	77	---	<1	---	5
Total	35	4	98	---	130	---	16

CHANNEL STRUCTURE AND STREAM STABILITY

The core outcome of a Rosgen Level I assessment is the identification and quantification of "expected" channel structure and stream stability or stable form across the area of study. For example, and as discussed above, in Fluvial Landscape Association 1, Rosgen stream types C and E are the "expected" stable form along much of the Gooseberry Creek mainstem.

A secondary outcome is reconnaissance-level qualitative notation, or professional judgment, of stream state (Figure 23) or existing channel structure and stream stability across the area of study. This is accomplished during the examination and evaluation of available GIS imagery and field verification conducted during the "expected" stream typing effort.

Validation of the reconnaissance-level stream state determination can then occur on a stream reach by stream reach scale through Rosgen Level II, III, and IV inventory and assessment efforts (Figure 17) or through the use of other available tools such as *Proper Functioning Condition Assessment for Lotic Areas* or *Stream Visual Assessment Protocol* procedures (Dickard et al., 2015; National Water and Climate Center, 1998). Such reach by reach scale validation efforts provide qualitative and quantitative information on whether assessed stream reaches are in:

- An undisturbed naturally stable form or a recovered stable form,
- Complete disequilibrium due to natural events or land use activities, such as ungulate grazing, road crossings, recreational pursuits, or irrigation diversions,
- And an intermediate state of stream system recovery after a disequilibrium event or activity (Figure 23).

RECONNAISSANCE-LEVEL STREAM STATE ANALYSIS

The majority of the perennial stream mileage appears to be in either an undisturbed naturally stable form (State 1) or a recovered stable form operating at a new base level (State 6). Much of the remaining perennial stream mileage seems to be at an intermediate state of stream system recovery (either State 2 or 5) on either a static or upward trend. Some perennial stream mileage was observed to be in complete disequilibrium (States 3 or 4) but this situation tends to be localized rather than extensive (Figure 23).

A significant amount of the intermittent and ephemeral stream mileage appears to be dominated by historical downcutting. This suggests extensive mileage in States 2 through 6. This situation is particularly evident in fluvial landscape associations 2, 3, and 4.

Those downcut reaches at State 6 appear to be stable but operating at a new base level. Downcut reaches at States 2 and 5 are, by definition, at an intermediate state of stream system recovery, at various stages in the evolutionary sequence (Figure 23) and trend is unknown. Downcut reaches at States 3 and 4 are, by definition, at complete disequilibrium. Some of these reaches appear to have, or do have, active headcuts, which could negatively affect reaches in the upstream direction that are at States 1, 2, 5, and 6.

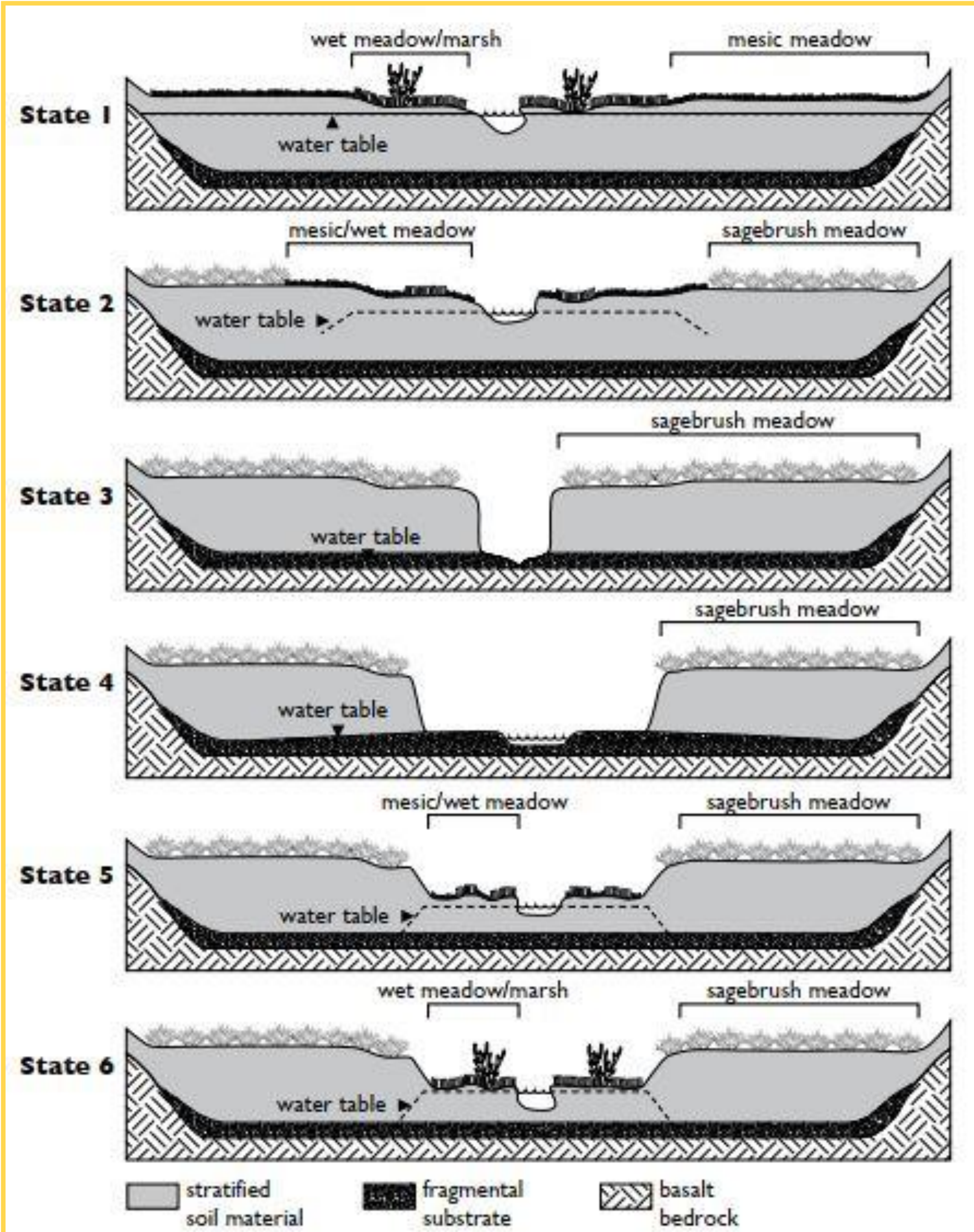

Figure 23: Various stream states that occur across a landscape or study area. (Dickard et al., 2015)

SEDIMENT TRANSPORT

Erosion and sedimentation in uplands and subsequent sediment delivery to streams and rivers is an issue in portions of the study area and has been for decades. The concerns occur mostly in the lower elevation, lower mean annual precipitation landscapes dominated by the Willwood Formation. In these areas, soils are highly erodible and vegetative cover is minimal as confirmed in soil surveys and research studies (see the Rangeland Management section below and the project file). The Fifteenmile Creek watershed is of most concern, followed by interfluve drainages of Elk Creek, Fivemile Creek, and Tenmile Creek. The East Fork Nowater Creek watershed is also an area of concern.

These concerns lead to issues from high sediment concentration and loading in the Big Horn River, and impacts on water use (municipal, industrial, and agricultural), infrastructure (bridges and diversions), and reservoir storage (Yellowtail Reservoir downstream of the study area).

Sediment control efforts have been implemented in the Fifteenmile Creek drainage in the past, but those efforts were short-term and of limited effectiveness (Marston & Dolan, 1999). While there may be opportunities to mitigate concerns in all areas of interest, the cost would be exceptionally high, commitment to long-term and frequent maintenance would be necessary, and the overall effectiveness, both short- and long-term, would be marginal. A comprehensive sediment study is being discussed and, if conducted, may lead to additional thoughts of mitigating sediment concerns. In the meantime, efforts should focus on the implementation of Best Management Practices (BMPs) for land use activities that have the potential to expose the landscape to erosion.

One site-specific area of concern is a large mid-channel bar in the Big Horn River downstream of the US Highway 20 bridge crossing at Worland. Some speculate this bar is a result of sediment from Fifteenmile Creek.

PHYSIOGRAPHIC AND ANTHROPOGENIC CONSIDERATIONS

Almost forty-five percent of the study area is comprised of the Willwood Formation, a sedimentary sequence deposited during the Late Paleocene to Early Eocene (Figure 10). The lithology is primarily sandstones, siltstones, mudstones, and shales that are up to 1200 feet thick in places. Soils are mainly Entisols and Aridisols. Entisols are soils that exhibit little to no soil development other than the presence of a thin topsoil horizon. Aridisols are dry soils where climate restricts soil weathering and plant growth. They often contain accumulations of salt, gypsum, or carbonates that reduce soil productivity and plant growth.

The Willwood Formation is one of the most erosive geologies known. Table 5 illustrates the areal extent of the Willwood Formation across the study area. Annual precipitation is 7 to 12 inches and mostly falls during short-duration, high-intensity thunderstorms. Storm response is mostly Horton overland flow, that quickly leads to either soil piping and/or rill formation, then gully formation, then flashy channel flood flows. This response is due to low soil productivity, minimal vegetative growth, slow to non-existent soil infiltration rates (due to high to very high K factors, or soil erodibility factors) and high runoff rates. These multiple factors result in a highly dissected, high-drainage density landscape that very effectively carries water and high to extreme sediment loads downstream to the Big Horn River.

Coupled with these physiographic considerations are anthropogenic effects. Heavy sheep and cattle grazing from the 1920s to 1960s resulted in a loss of cryptobiotic and vegetative soil cover, vegetative type conversion on southerly aspects (native grasses and forbs to cheatgrass), and loss in streambank stability. To mitigate these historical effects, erosion and sediment control projects (sediment and flood detention basins, stock ponds, and revegetation with non-native grasses) were implemented in the 1960s and 1970s. Those efforts were, at considerable cost, short-term and of limited effectiveness (Marston & Dolan, 1999). Additionally, these projects resulted in further alteration of the natural water and sediment balance and created breach hydrology scenarios producing atypical sediment pulses. Present-day grazing continues, but through revisions of grazing management plans livestock use has been reduced considerably, promoting recovery of watershed processes, through sustainable adaptive grazing management strategies.

Other historical and on-going anthropogenic considerations include wild horses, whose numbers were recently reduced to desired management levels, and roads, which are a minor consideration in the big picture as their areal extent is minimal.

Table 5: Willwood Formation areal extent across the study area by fluvial landscape association.

Fluvial Landscape Association	Area (approximate acres within study area)	Willwood Formation (Acres)	Willwood Formation (%)	Notes
1	229,937	60,183	26	Gooseberry, including Little Buffalo, Middle, Left Hand, Enos tributaries
2	264,461	35,391	13	Nowater, including East Fork tributary
3	333,226	230,263	69	Fifteenmile, including Middle, Badger, Waterhole, Cottonwood tributaries
4	241,288	168,620	70	Interfluve areas along Big Horn River proper, such as Antelope, Elk, Fivemile, Tenmile, Little Gooseberry
5	84,348	7,635	9	Big Horn River proper (as represented by irrigated and sub-irrigated agricultural lands)
Totals	1,153,261	502,092	44	

RESULTS AND SUMMARY

The 5,200 miles of streams and rivers in the study area, through a qualitative assessment conducted during the Rosgen Level I geomorphic characterization as described above, appear to be at various states of condition and stability (Figure 15 and Figure 22).

Most of the perennial stream mileage (roughly 5% of the total; approximately 283 miles) in the study area appears to be in either an undisturbed naturally stable form (State 1), or a recovered stable form operating at a new base level (State 6). Stream reaches at either of these states are most desirable as it implies there are no significant issues or concerns with channel structure and stream stability. Much of the remaining perennial stream mileage appears to be at an intermediate state of stream health (either State 2 or 5), on either a static or upward trend. These states are also desirable as it indicates existing land management and use is allowing for maintenance and/or recovery of channel structure and stream stability. Some perennial stream mileage appears to be in disequilibrium (States 3 or 4), but this situation tends to be localized rather than extensive. Reaches in this condition are generally undesirable and thus are potential candidates for changes in land use and management designed to promote recovery or stream restoration projects.

A significant amount of the intermittent and ephemeral stream mileage (roughly 95% of the total mileage) appears to be dominated by historical downcutting. This suggests extensive mileage in States 2 through 6. This situation is particularly evident in fluvial landscape associations 2, 3, and 4. Those intermittent and ephemeral downcut reaches at State 6 appear to be stable but operating at a new base level. This situation is desirable as it implies channel structure and stream stability have recovered to a stable form.

Downcut reaches at States 2 and 5 are, by definition, at an intermediate state of stream health. In other words, these reaches are at various stages in their evolutionary sequence of recovery (Figure 23). However, since trend is unknown, it is also unknown which reaches are recovering in a positive, desirable direction versus those that are not.

Downcut reaches at States 3 and 4 are, by definition, at complete or near complete disequilibrium. Some of these reaches appear to have, or do have, active headcuts. Continued upstream migration of these headcuts, if left unchecked, could negatively affect reaches in the upstream direction that are at States 1, 2, 5, and 6, which is undesirable.

Validation of the reconnaissance-level stream state determination discussed above can occur on a stream reach by stream reach scale through Rosgen Level II, III, and IV inventory and assessment efforts (Figure 17) or through the use of other available tools such as *Proper Functioning Condition Assessment for Lotic Areas* or *Stream Visual Assessment Protocol* procedures (Dickard et al., 2015; National Water and Climate Center, 1998). Such reach by reach scale validation efforts would provide qualitative and quantitative validation on whether assessed stream reaches are in:

- an undisturbed naturally stable form or a recovered stable form
- complete disequilibrium due to natural events or land use activities, such as road crossings, recreational pursuits, ungulate grazing, or irrigation diversions
- an intermediate state of stream system recovery after a disequilibrium event or activity

Once validation work is complete, site-specific projects designed to further aid and promote healthy channel condition and stream stability could be developed.

RECOMMENDATIONS

UPLANDS DRAINING TO THE BIG HORN RIVER

Much of the low elevation landscapes in the study area are naturally prone to extreme erosion and subsequent sediment delivery to streams, and ultimately the Big Horn River. This physiographic fact should be recognized as a base consideration for land management and use within and downstream of the study area.

Additionally, past efforts to control this erosion and sediment delivery are documented to be costly, short-term, and of limited effectiveness (Marston & Dolan, 1999). While there is a desire to implement additional mitigative activities to control erosion and sediment delivery, benefits versus costs should be considered and evaluated beforehand. Construction and maintenance of sediment control structures in remote areas are very costly, in both dollars and manpower, especially given the inherent physiographic factors described previously. Maintenance is a long-term commitment of money and manpower that will need to recur on a regular and consistent basis (every few to several years).

BIG HORN RIVER PROPER

As discussed above, sediment delivery to the Big Horn River from surrounding upland areas has created issues with impacts on water uses (municipal, industrial, and agricultural), infrastructure (bridges and irrigation diversions) and reservoir storage (Yellowtail Reservoir downstream of the study area).

One site-specific area of concern is a large mid-channel bar in the Big Horn River downstream of the US Highway 20 bridge crossing at Worland. Some speculate this bar is a result of sediment delivery from Fifteenmile Creek.

As previously discussed, control of sediment delivery to the river is problematic. Thus, rather than invest in that control, the best course of action to mitigate the effects of the mid-channel bar may be periodic dredging of the bar material. The same can be said relative to mitigating sediment delivery effects at Yellowtail Reservoir. A comprehensive sediment study for the area is being discussed, if the study occurs it may lead to additional information and options for sediment control.

SURFACE WATER

SURFACE WATER: HYDROGRAPHY

STUDY SETTING: WATERSHEDS AND STREAM NETWORK

Watersheds and drainage networks across the country are available as digital geospatial datasets that allow for mapping and modeling surface waters. The packages include the USGS National Hydrography Dataset (NHD) and Watershed Boundary Dataset (WBD) (United States Geological Survey, n.d.).

Watersheds are displayed in a nested hierarchy represented by Hydrologic Unit Code (HUC) levels. Levels contain two to twelve digits and are named regions (2-digit), sub-regions (4-digit), basins (6-digits), sub-basins (8-digits), watersheds (10-digits), and sub-watersheds (12-digits), respectively.

WWDC Level I watershed studies are typically performed at the watershed and sub-watershed scale. Watersheds generally range from 40,000 to 250,000 acres in size and sub-watersheds generally range from 10,000 to 40,000 acres. The study area, which is approximately 1,153,215 acres in size, lies within all or parts of eight watersheds and 39 sub-watersheds (Figure 24 and Map Book, Map 8).

The drainage network within the study area, as depicted in the NHD, is a complex combination of natural and man-made features. For this study, the NHD was carefully reviewed and edited to more accurately portray the on-the-ground situation (Figure 24). The review and edits are based on discussions in the Physical Systems: Geomorphology section of this report, various definitions of perennial, intermittent, and ephemeral streamflow (Table 6), stream gage records, stream classification data from the Shoshone National Forest, and field validation.

The NHD does not differentiate between ephemeral and intermittent streams in arid and semi-arid environments; rather they are combined and shown as intermittent. In actuality, for this study area, much of the intermittent mileage displayed in the tables is ephemeral.

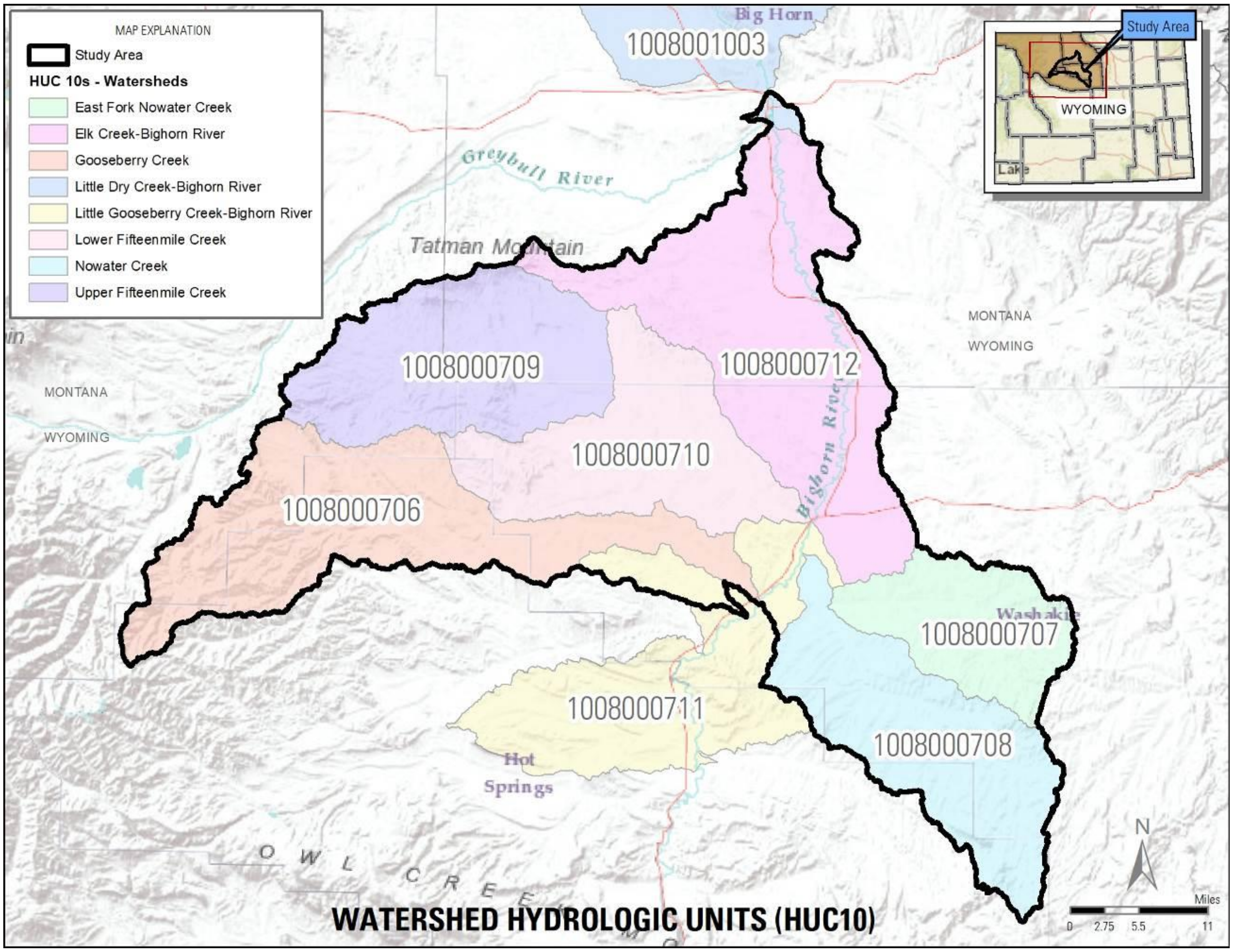

Figure 24: Watershed Hydrologic Units (HUC10s) wholly or partially within the study area.

Table 6: Various definitions for perennial, intermittent, and ephemeral streamflow considered in this study.

Definition Source	Perennial	Intermittent	Ephemeral
National Hydrography Dataset User Guide (https://nhd.usgs.gov/userguide.html)	Contains water throughout the year, except for infrequent periods of severe drought	Contains water for only part of the year, but more than just after rainstorms, and at snowmelt	Contains water only during or after a local rainstorm or heavy snowmelt
Proper Functioning Condition Assessment for Lotic Areas	Flows continuously in all or most years; Streambed is often below the water table for most of the year	Flows only at certain times, but continuously for at least one month; Streambed is below the water table part of the year and above the water table part of the year	Flows only in direct response to precipitation; streambed is always above the water table
Wyoming DEQ (http://sgirt.webfactional.com/wqd/)	A stream, or part of a stream, that flows continually during all the calendar year as the result of a groundwater discharge or surface runoff	A stream or part of a stream where the channel bottom is above the local water table for some part of the year, but is not a perennial stream	A stream which flows only in direct response to a single precipitation event in the immediate watershed or in response to a single snowmelt event, and which has a channel bottom that is always above the prevailing water table

The characterization of watersheds, drainage networks, and water resources in this assessment are not bound by the watershed and sub-watersheds listed in Table 20 and Table 21 in Appendix A. This is because water rights and uses along the Big Horn River portion of the study area are reliant on precipitation and subsequent streamflow that flows from the Upper Wind River headwaters: a high-elevation, snowpack dominated water supply supporting a large concentration of glaciers and snowfields that provide considerable streamflow to the Wind/Big Horn River. While this report focuses on conditions and trends within the study area, it stresses the importance of recognizing and understanding the hydrology of upstream watersheds.

IMPORTANT ATTRIBUTES, CHARACTERISTICS, AND PROCESSES OF THE STUDY AREA CLIMATE

Watershed hydrology is best explained through discussion of components of the water cycle, such as precipitation, evapotranspiration, infiltration, and collection (in the form of groundwater) (USGS, n.d.). To assess the water cycle within the study area, an understanding of the geology, soils, and vegetation present, and their interaction with the water cycle, is important. These three principles are discussed in other areas of the report.

Air temperatures, an important driver of the water cycle, vary considerably across the study area and with elevation (University of Wyoming, n.d.). On average, air temperature values decrease 5 to 6 degrees per 1,000 feet of elevation increase. One of the warmest areas in the State of Wyoming is the lower elevations of the Bighorn Basin, with the City of Basin having an average maximum temperature in July of 92°F (University of Wyoming, n.d.). The highest elevations of the study area—i.e. upper Gooseberry Creek—typically only see highs in the 70s and 80s.

Aside from being one of the warmest areas of the State, the Bighorn Basin can also be one of the coldest (University of Wyoming, n.d.). The mean minimum temperature in January is 0°F in Worland and Basin. Temperature inversions along the Big Horn River commonly result in extremely cold conditions for prolonged periods of time, i.e., days to weeks from November through February. In other parts of the study area during winter months, temperature fluctuation can be rapid and frequent, with alternating mild and cold spells driven by Chinook winds, an adiabatic warming wind, flowing off the Absaroka Mountains and cold fronts moving south from Canada.

Annual precipitation, a key element of watershed hydrology, varies across the study area as well. Generally, precipitation ranges vary from six to eight inches at lower elevations along the Big Horn River and 22 to 24 inches at the highest elevations of the Gooseberry Creek watershed. Precipitation amounts generally are a function of elevation. Land areas below roughly 7,500 feet receive less precipitation than land areas at higher elevations. The high elevation mountain ranges, like the Wind River Range, Absaroka Range, and Owl Creek Range, function as high mountain water storage for the study area (University of Wyoming, n.d.).

Annual precipitation, within the Bighorn Basin and across the Wind River Basin, upstream of the study area, varies from as little as six to eight inches at lower elevations to 60 inches or more at higher elevations. This variation in contributing precipitation illustrates that flows in the Big Horn River, through the study area, are reliant on the elevation and precipitation zones in the mountainous regions of the study area (University of Wyoming, n.d.).

The timing of precipitation influences how the water cycle interacts with soils and vegetation. The timing and form of precipitation determine its availability to vegetation, e.g., late-season snow will be made slowly available to deeper-rooted vegetation and groundwater recharge through gradual melting, while mid-season rain is available to surface and more shallow-rooted vegetation with higher rates of surface runoff. Precipitation timing varies with elevation. In June, low elevations receive a higher percentage of their annual average precipitation than higher elevations (University of Wyoming, n.d.). Lower elevations also receive most of their annual average precipitation during the April/May/June timeframe (University of Wyoming, n.d.). At higher elevations precipitation is more uniformly distributed, on a monthly basis, across the year (University of Wyoming, n.d.).

In the areas of the basin that receive 18 inches or less of annual precipitation (equivalent to semi-arid and arid environments), the majority of the annual precipitation returns to the atmosphere through evapotranspiration. Thus, minimal runoff is generated (Equation 2. from (MacDonald & Stednick, 2003)). An exception can occur when summer thunderstorm rainfall intensity exceeds soil infiltration rates, resulting in overland flow.

Equation 2: Equation for evapotranspiration.

$$ET = 18.1'' + 0.28(Annual\ Precipitation - 18.1'')$$

In the areas of the basin that receive 18 inches or more of annual precipitation, most of the annual precipitation falls as snow, while the remainder falls as rain during late spring through early fall. Summer thunderstorms can produce short-duration, high-intensity precipitation that can result in hydrograph spikes. The volume of flow in these spikes is small compared to the volume of flow from rainfall floods in the semi-arid and arid regions of the study area, i.e., areas below 18 inches of annual precipitation. This comparatively smaller flood flow volume correlates to the areal coverage of stream channels where rainfall was received (Troendle & Bevenger, 1996).

Precipitation in higher elevations typically falls as snow from October through May (University of Wyoming, n.d.). The snowpack depth builds through this time period, acting as a natural water storage reservoir that begins to melt in April, causing streams to rise accordingly and contribute flows to the Wind and Big Horn Rivers. By early to mid-June the majority of the snowpack has melted, but elevated streamflow continues into August due to soil moisture and groundwater influences (NWCC, 2019).

Minimal snow can accumulate at lower elevations in the study area and melting of that snow contributes little to annual average stream flows (University of Wyoming, n.d.). Rain-on-snow events can occur at the lower elevations, resulting in localized flooding. Rain-on-snow events are rare at higher elevations.

Streamflow across the study area is variable but correlated with temperature and precipitation. Natural, unregulated flow in the perennial streams, e.g., upper Gooseberry Creek, and regulated flow in the Big Horn River is predominately from annual snowmelt runoff. However, there can be small to large increases in flow for short periods of time due to summer thunderstorm activity.

Only a very small percentage, 12,734 acres or 1.1%, of the study area is snow-dominated hydrology, and thus capable of producing perennial streamflow. This limited areal extent is above 7,800 feet and only in the headwaters of Gooseberry Creek. The remainder of the study area is a rain-snow dominated hydrology (mid-elevations) or a rain dominated hydrology (low-elevations), producing intermittent and ephemeral flow.

Flow in the Big Horn River, as discussed previously, is predominately a result of hydrology upstream of the study area. This hydrology is a combination of snow dominated, rain-snow dominated, and rain dominated precipitation events. Additionally, these flows are regulated through large reservoir management (Boysen and Yellowtail, respectively), an interstate compact, and water rights seniority, both upstream and downstream of the study area. The Yellowstone River Compact was established in 1950 and regulates flows between Wyoming, Montana, and North Dakota.

In the snow zone, annual snowmelt flows typically start to increase in late March to early April, peak in late May to early June, and return to baseflow levels in August. There is considerable year-to-year variability in the shape of the annual hydrograph and the number of instantaneous peak flows during the snowmelt period. The magnitude of annual peaks also exhibits high variability. Flow duration for the unregulated perennial streams is typical of snowmelt dominated areas, where the high flow period is relatively short and gradual release of groundwater maintains a baseflow for the remainder of the water year.

In the non-snow zone, flows tributary to perennial streams range from ephemeral to intermittent. Any flow that occurs in the spring is for a short period of time, resulting from minor snowpack accumulation and low-intensity, long-duration spring rains. Many of these flows do not reach flood stage.

Flows that occur in the summer and early fall, also only for a short period of time, are from short-duration, high-intensity thunderstorms. These storms can produce extreme and damaging flood events that carry large volumes of sediment.

Regulated flows, e.g., Big Horn River flows, are by nature variable and are a function of water right designations and other requirements, such as river basin compacts.

Streams across the study area have a low-flow channel, a high-flow or bankfull channel, and a floodplain to handle above-bankfull flows. Flooding is a natural part of the water cycle and access to the floodplain is critical to maintaining stream pattern, profile, and dimension. The width of the flood-prone area varies by stream and valley type and can be relatively narrow to very wide, i.e., tens of feet to hundreds of feet. (Refer to the Physical Systems: Geomorphology section of this report for more information.)

Floodplains and associated riparian areas are important to the regulation of water quality and water distribution over time. Healthy stream and riparian systems dissipate flood energy and recharge alluvial aquifers. Water is then slowly released from the aquifers back to the channel during drier periods of the year.

SURFACE WATER: WATER QUALITY

Water quality across the study area is addressed through numerous venues, many of which are tied to federal law, most notably the Clean Water Act and Safe Drinking Water Act. The federal government is responsible for oversight pursuant to these acts, but implementation and compliance have been delegated to the states to varying degrees. In Wyoming, the Department of Environmental Quality (WDEQ) is the most notable state-level agency involved in water quality.

WDEQ has designated surface water uses to waterbodies across Wyoming through a hierarchical classification system. Surface water classes and designated uses, with definitions, within the study area are available through the Wyoming Surface Water Classification List and Recreation Designated Uses Web Map (WDEQ, n.d.-b, 2001). Because the information at these sites is regularly updated, users should directly access them when information is needed.

The state has four major classes of surface water with various subcategories for each class (WDEQ, 2001). Class 1 designations are based on value determinations rather than primary use and are protected for all uses. There are no Class I waters in the study area. Classes 2 through 4, and their sub-classes, are protected for specified uses and the uses contained in each lower classification. Use designations, in order of classification priority, are drinking water, game fish, non-game fish, fish consumption, other aquatic life, recreation, wildlife, agriculture, industry, and scenic value. Within the Big Horn River drainage there are surface waters classified under all classes within 2 through 4. The majority of the waters in the study area are designated as Class 2 or 3. Most Class 2 waters can be designated for fisheries, and therefore tend to be perennial within the study area. Class 3 waters can support other aquatic life and subsequent designations, but not fisheries. Class 4 cannot be designated for fisheries or other aquatic life. (WDEQ, 2001)

CONSERVATION DISTRICT REPORTS

General reporting on water quality is available at the South Big Horn and Washakie County Conservation District's websites (South Big Horn Conservation District, n.d.; Washakie County Conservation District, n.d.).

The links to the water quality reports for the respective conservation districts can be found on the conservation district websites:

- Washakie County Conservation District Publications (https://www.washakiecd.com/)
- South Big Horn Conservation District (http://www.sbhcd.org/)

WYOMING INTEGRATED 305B/303D REPORT

The State of Wyoming 2016-2018 Integrated Water Quality Monitoring and Assessment Report, commonly called the 303(d)/305(b) report, indicates there are bacteriological water quality concerns in six waterbodies within the study area (Table 7 and Map Book, Map 9) (WDEQ, n.d.-c). A Total Maximum Daily Load (TMDL), approved in 2014, has been prepared (WDEQ, 2014). The report contains recommended control measures to achieve required load reductions to attain bacteria targets for impaired stream segments. Best Management Practices (BMPs) are being implemented to improve conditions in these listed waterbodies.

Table 7: Waterbodies within the study area listed for water quality impairment. (WDEQ, 2014)

Waterbody	Identifier	Location	Class	Miles	Cause
Nowater Creek	WYBH100800070809_01	From the confluence with the Big Horn River to a point 6.6 miles upstream	3B	6.6	Fecal Coliform
Fifteenmile Creek	WYBH100800070909_01	From the confluence with the Big Horn River to a point 2.2 miles upstream	3B	2.2	Fecal Coliform
Big Horn River	WYBH100800071000_01	From the confluence with the Nowood River to a point 36.1 miles upstream	2AB	36.1	Fecal Coliform
Big Horn River	WYBH100800071000_02	From the confluence with the Greybull River upstream to the confluence with the Nowood River	2AB	22.1	Fecal Coliform
Sage Creek	WYBH100800071001_01	From the confluence with the Big Horn River to a point 7.4 miles upstream	3B	7.4	Fecal Coliform
Slick Creek	WYBH100800071001_02	From the confluence with the Big Horn River to a point 5.8 miles upstream	3B	5.8	Fecal Coliform
Big Horn River	WYBH100800100301_01	From the confluence with the Greybull River to a point 10.5 miles downstream	2AB	3.1*	Fecal Coliform

*This value is representative of the mileage of reach that falls within the watershed study area.

The integrated report also summarizes the state of perennial streams and rivers in the Bighorn and Yellowstone basins for biological condition, drinking water suitability, and human health condition. Relative to biological condition, the survey identified the most common stressors and their relative impact. Results are reported in 2014 Bighorn-Yellowstone Probabilistic Survey (Hargett & ZumBerge, 2014). Stressors, including riparian disturbance and channel instability, on biological condition were assessed.

WYPDES PERMITS

The Clean Water Act stipulates that the discharge of pollutants from a point source into surface waters within the study area can be regulated by permit under the Wyoming Pollutant Discharge Elimination System (WYPDES) Program. The permits contain limitations and conditions that will ensure that the state's surface water quality standards are protected. There are various types of permits depending upon the type of activities taking place or being implemented (WDEQ, n.d.-a). See Map Book, Map 9 for WPDES permitted discharge and classified waters.

SURFACE WATER: FLOODING

Flooding within the Middle Big Horn Watershed tends to occur in the lower regions of the watershed, primarily along the Big Horn River. Flooding along this corridor is largely driven by ice jams (Figure 25). In March of 2014 and February of 2017 two very similar and significant flood events occurred in Worland as a result of ice jamming in the vicinity of the U.S. 20/26 (Big Horn Avenue) bridge.

Ice floes, some over two feet thick, jammed in the area of an island that formed over many years immediately downstream of the bridge, backing up water over a large area near the river.

In September 2017, Washakie County, the City of Worland and the Washakie County Conservation District teamed up to remove the 16,000 cubic yards, or 1.3-acre island immediately downstream from the U.S. 20/26 (Big Horn Avenue) bridge (Figure 26 and Figure 27).

Figure 25: 2014 ice jam flooding Big Horn River - Riverside Park area in Worland. (Donnell & Allred, 2014)

Figure 26: 1.3 acre, 16,000 cubic yard island downstream of Big Horn Avenue Bridge. (Donnell & Allred, 2017)

Figure 27: Removal of deposited silt island near Worland, WY. (Donnell & Allred, 2017)

The Bureau of Reclamation agreed to lower the river flows during the project, which was completed in three weeks at a cost of about $110,000. There have been no ice jams at this location since the island was removed, but it is already beginning to slowly re-form in the same location.

In 2017, a flood also eroded a large portion of the east bank and engulfed about 400 feet of 24” outfall sewer pipe which carries more than half of the Worland area sewer volume, located between Worland and the wastewater treatment plant to the north. The sewer outfall pipe is composed of fragile clay tile installed in 1957; it was stabilized and the river bank was repaired to its original location through a long-term project involving the City of Worland, U.S. Army Corps of Engineers Omaha District, the Washakie County Conservation District, Y2, WDEQ, and NRCS (Figure 28). The City of Worland has performed remedial work in response to the effects of flooding. The armored and reconstructed bank is shown in Figure 29.

Figure 28: Exposed Worland sewer.

Figure 29: Revegetated and reconstructed riverbank in proximity to erosion that uncovered sewer main.

During the 2017 flood, the USGS stream gauge in Worland (which has been discontinued) indicated the river level rose over seven feet between February 10th and 11th leading to significant flooding of the mostly residential area west of the railroad. The gage height for this event is presented in Figure 30 (USGS, 2016).

After the 2017 floods (Figure 31), Washakie County Commission Chairman Terry Wolf met with U.S. Senator John Barrasso, Chairman of the Environment and Public Works Committee, in Washington, D.C. at the U.S. Army Corps of Engineers’ (USACE) request. That meeting eventually resulted in the USACE Omaha office approving ten Section 205 pilot projects in the northern U.S. on the Missouri River watershed, including a study of the Big Horn River at Worland. In May 2018, a USACE Silver Jackets seminar was conducted at the Washakie County Emergency Operations Center by USACE engineers to educate local leaders, engineers, and public works personnel on ice engineering and ice jam specifics. Funding for the Section 205 Study was granted on October 19, 2018. Two months later, in December, city and county officials met at the Washakie County Emergency Management office with engineers from the USACE, Omaha District to discuss the flooding, the 205 study, and other options for future mitigation.

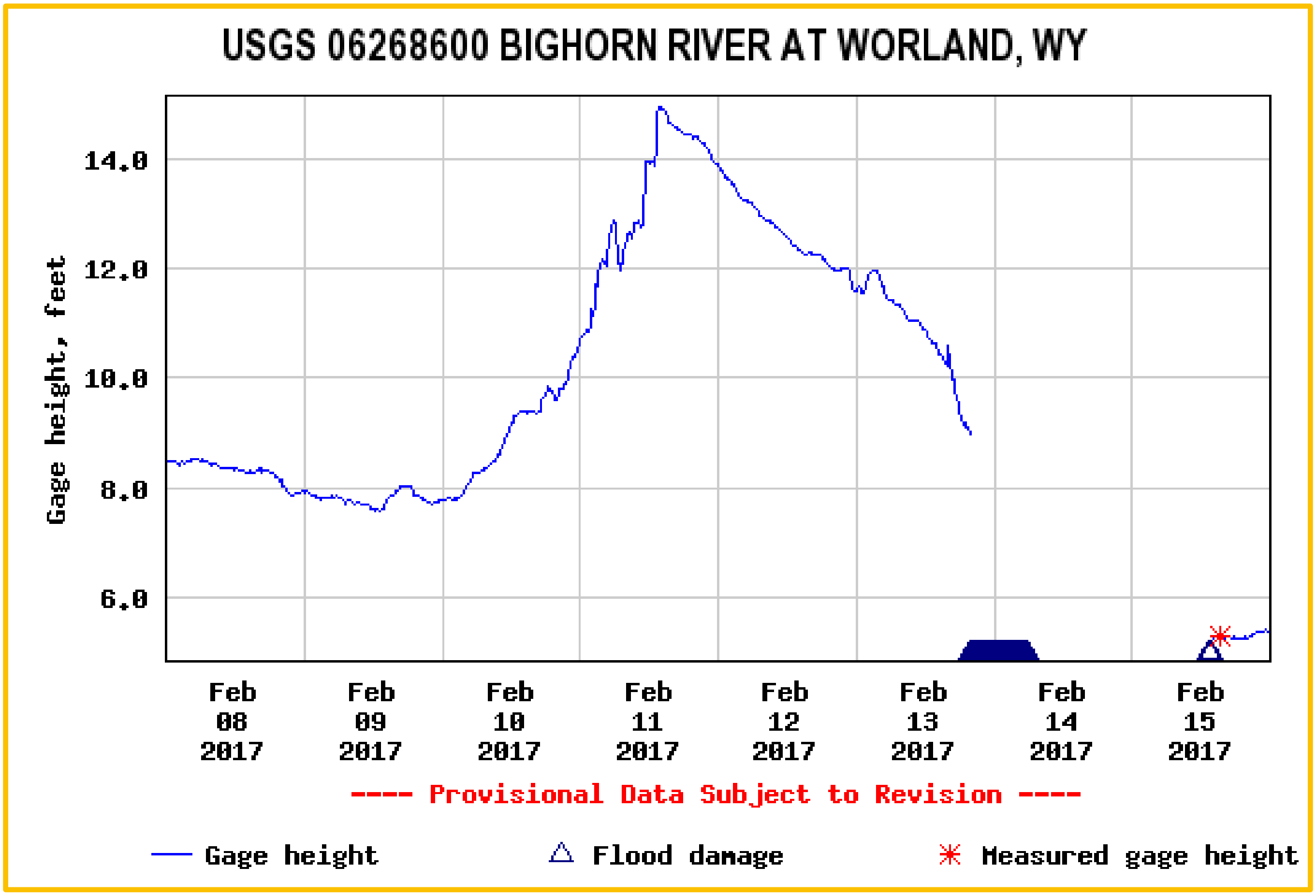

Figure 30: USGS flow gage at Worland showing flood event. (USGS, 2016)

Ice jams also occurred in January and February of 2018 at the confluence of Fifteenmile Creek and the Big Horn River. The week of February 11, 104 structures had to be evacuated in Worland due to flooding, including 24 businesses. Communications infrastructure was also damaged. In December 2018, an ice jam that lasted over a month occurred at the confluence of Gooseberry Creek and the Big Horn River.

More recently, flooding has been witnessed further downstream at several locations near Basin. The entire corridor along the Big Horn River is susceptible to flooding. The FEMA flood zones along the Big Horn River for the Worland and Basin area are shown in Figure 32 and Figure 33. Additional FEMA flood zones within the study area are depicted in the Map Book, Maps 10 through 17.

Several key points of flooding were identified and are listed in the bullets below in order of flow along the Big Horn River:

- Worland, North of Highway 20 Bridge crossing,
- Worland, North of Fivemile confluence with Big Horn River,
- Manderson, South of Highway 20 crossing, and
- Basin, North of County Lane 42 crossing.

Figure 31: Worland Fire Chief Chris Kocher showing ice thickness after the 2017 Ice Jam Flood.

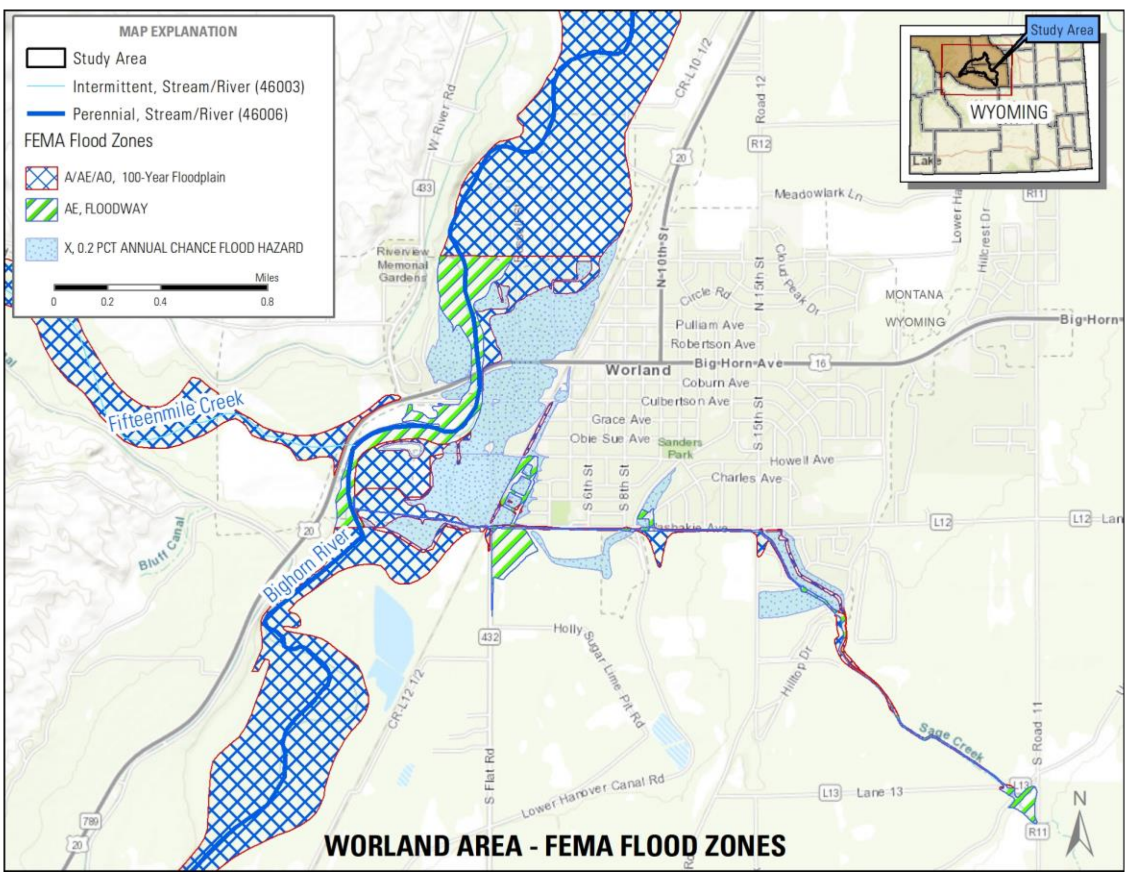

Figure 32: Worland area flood zones.

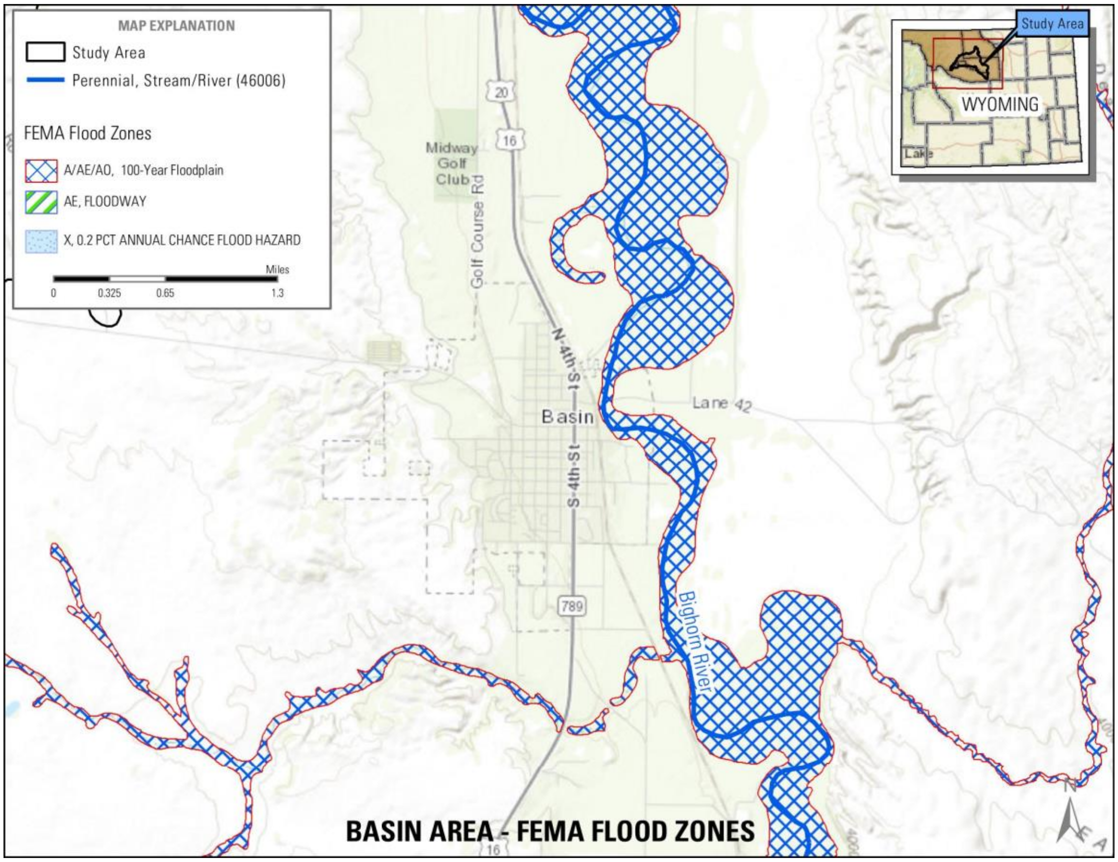

Figure 33: Basin area flood zones.

SURFACE WATER: RUNOFF

Several areas were identified with consistent runoff and drainage issues throughout the study area. These areas are primarily located within the lower regions of the area especially around Worland and Basin (Figure 34 and Figure 35). Within these areas the dominant issue is drainage of surface water from fields and irrigation. The instances that were highlighted as part of the inventory effort for this study are discussed below and shown in Figure 36 through Figure 42. This flow can potentially reach stream channels and produce small to very large sediment-laden flash floods (e.g., Fifteenmile Creek). Fifteenmile Creek is one of the largest contributors to sediment loading in the study area and has consistently been noted as a problem area during this study.

The Worland Montanez drainage project (number 38-1 in the Project Summary Book) is illustrative of one of the collected projects that highlights drainage issues in the study area. These projects were highlighted through stakeholder engagement and were examined in the field by Y2 personnel. Currently there is no installed drainage/catch ditch for this area. Installation of drainage infrastructure here could mitigate or prevent the existing flooding issues caused by irrigation upgradient of the subject area.

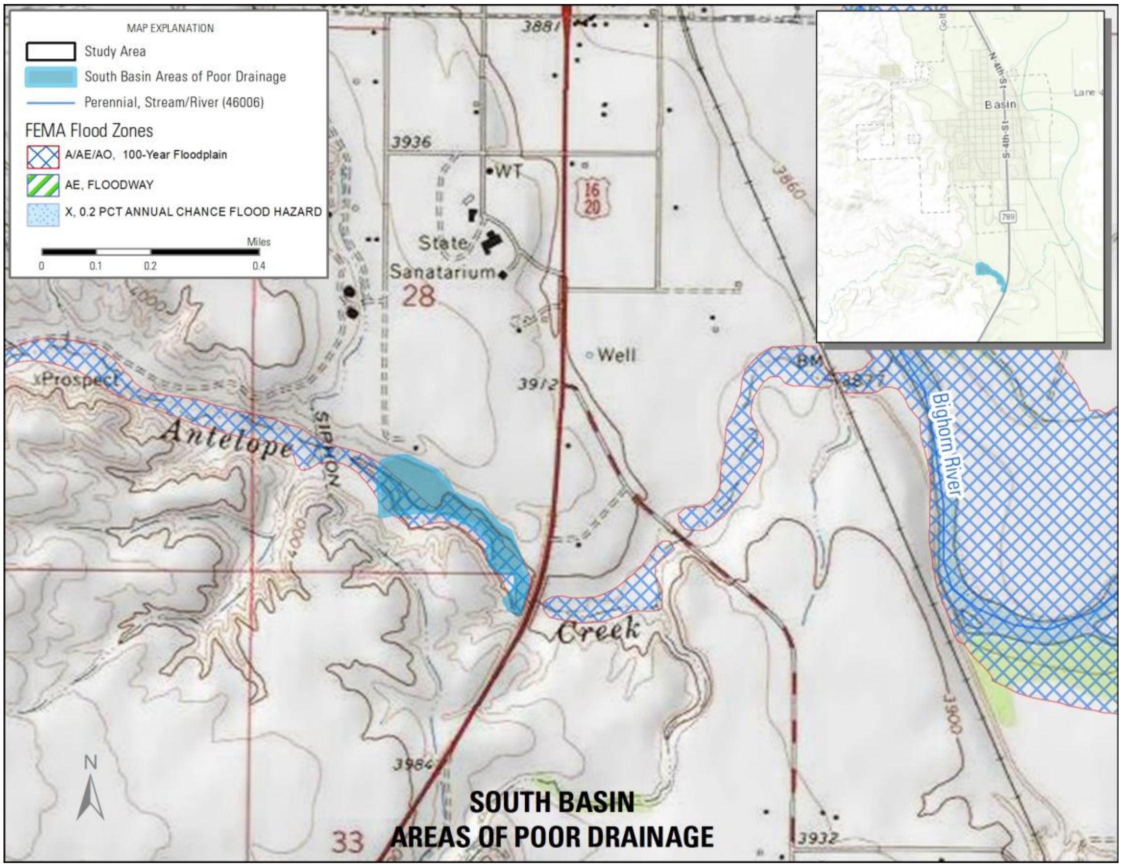

Figure 34: Areas of poor drainage south of Basin.

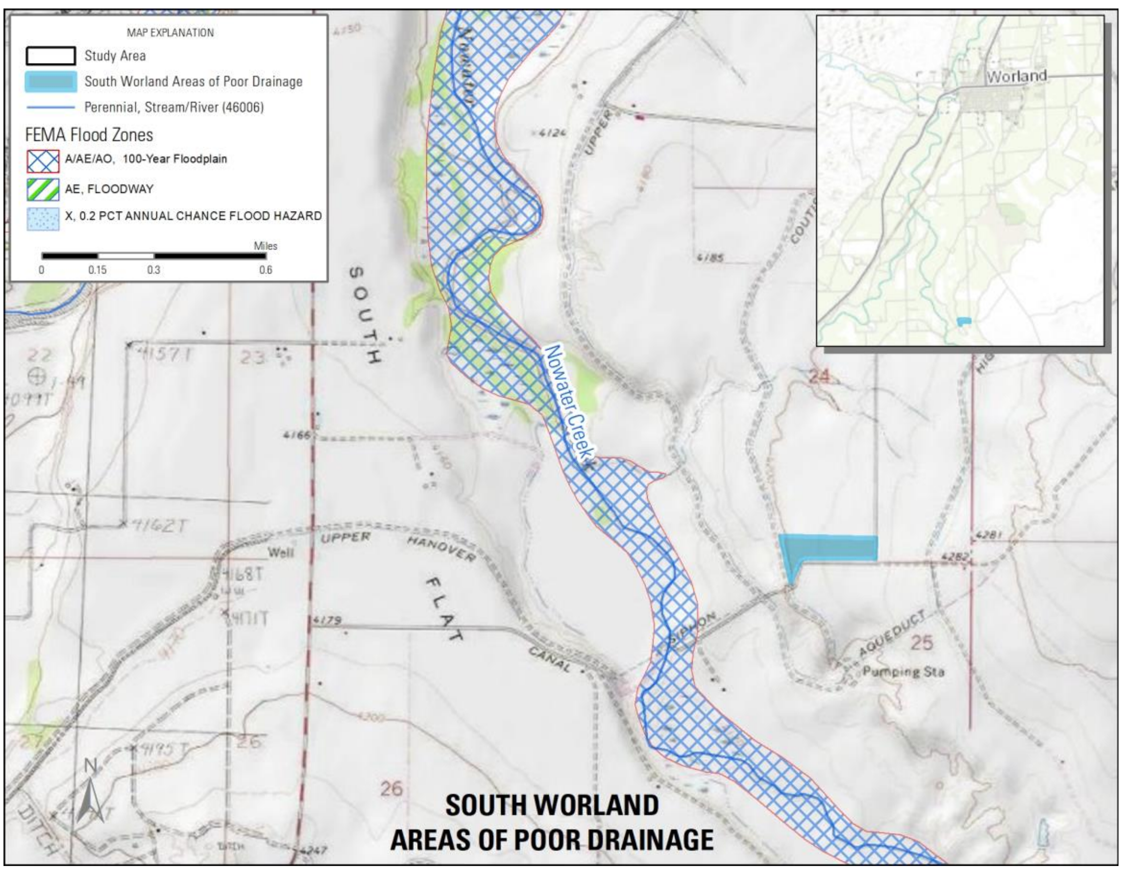

Figure 35: Areas of poor drainage south of Worland.

Moving north through the lower regions of the study area, the Y2 team observed drainage issues along West River Road (Figure 37). West River Road lies on top of a bench that overlooks the Big Horn River to the east. This bench is predominantly used for irrigation and over the past 50 years has seen several drainpipes installed underneath the road draining from west to east. Over the course of the inventory effort, Y2 personnel were contacted by a local stakeholder about a drainage issue that was occurring along this corridor. The drain had been installed some years ago and had recently failed. Y2 personnel observed excavation of the drain (Figure 36) and noted a substantial buildup of fines within the drainpipe. In conversations with the stakeholder, it was found that such drainage systems were a common feature installed in this region. Many of these drains have not been documented and location of these systems are typically relayed via common knowledge or locations based on observance of vegetation growth along the drain line. These drains are typically excavated and replaced as they fail. Since there are not recorded locations for these lines, it was impossible to document the exact locations of these drainage devices.

Figure 36: West River Road drainage project.

Additional drainage and runoff issues were encountered in Basin. These issues were encountered within the North Antelope Drainage District (NADD) which lies to the south of Basin (Figure 38). This is an existing drainage system that was originally installed in the early 1900s. The original installation consisted of clay-based drain tiles. These tiles have long since exceeded their useful lifespan. This issue has been caused by a variety of breakdowns including the collapse and growth of native vegetation and tree root structures. This, in turn, has led to the development of multiple instances of flooding that occur during peak irrigation drainage intervals. That is to say, the point where peak water usage is drained, or lack thereof, via the drainage network. This was a common issue that was detailed in both public and local stakeholder meetings.

This drainage area includes several agricultural properties to the south as well as multiple residential properties to the north. All these properties have in some way been impacted by the failed drainage network. Figure 39 and Figure 40 show pooling of water in areas that should be well drained. These areas rely on a proper functioning drainage network.

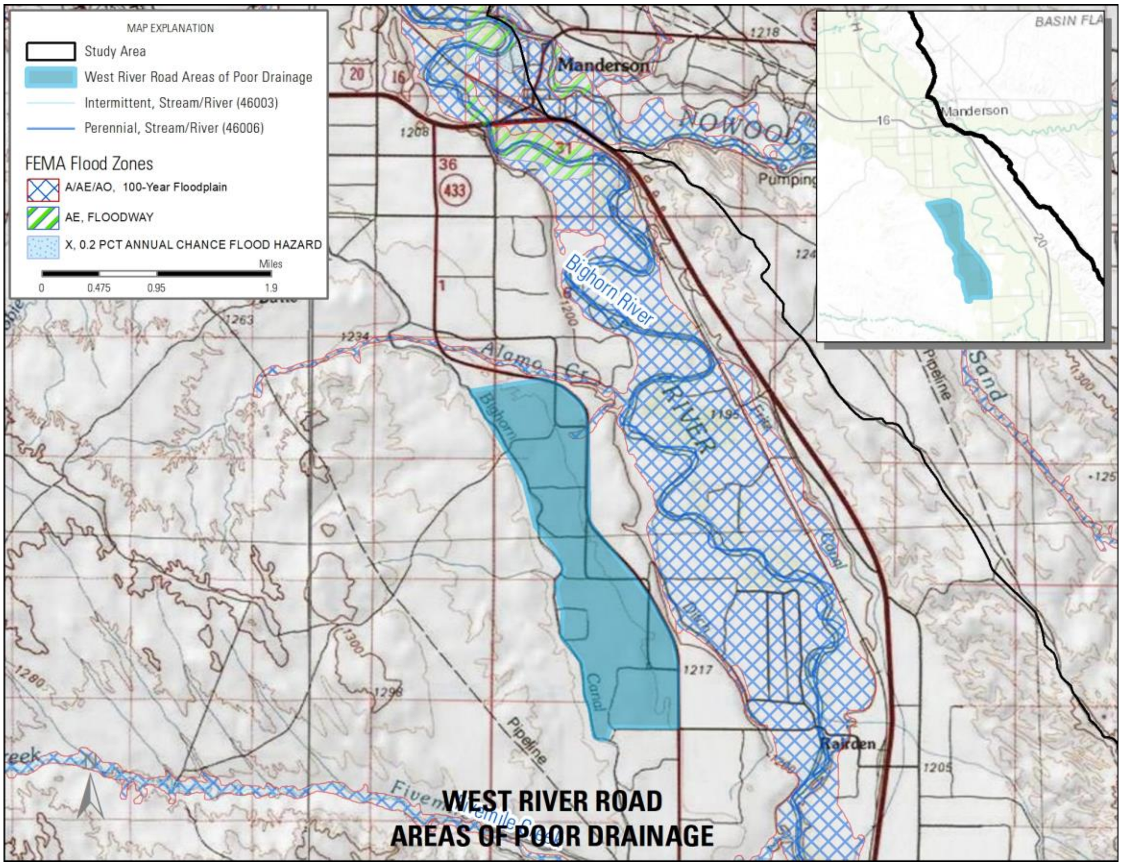

Figure 37: Areas of poor drainage along the West River Road.

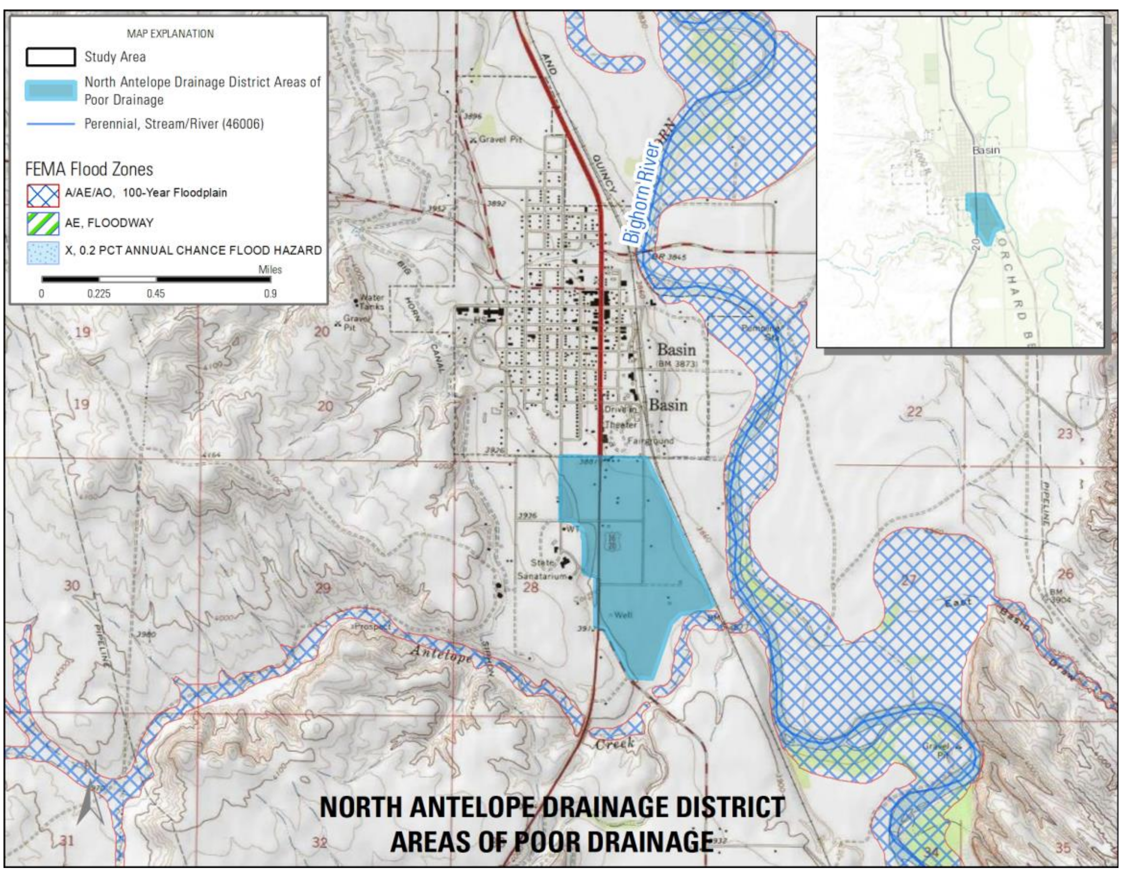

Figure 38: North Antelope Drainage District (NADD) poor drainage areas.

Figure 39: View of ponding in a pasture serviced by NADD.

Figure 40: Ponding in poorly drained area of NADD.

While the above figures demonstrate the issues that are the result of the failed drainage network, the following figures show the state of the infrastructure. Figure 41 and Figure 42 both show examples of access manholes for the North Antelope Drainage District. These manholes have been modified and re-installed over the lifetime of the drain system. These modifications have typically been made in response to new instances of water inundation in the area.

Figure 41: NADD drainage network access.

Figure 42: NADD ditch and access.

The infrastructure for drainage in the NADD has long since exceeded its design life and would greatly benefit the local residents if an effort was made to install a new drainage system. This would augment the overall quality of life and provide a more efficient method for the return of water to the Big Horn River from the Big Horn Canal.

BIOLOGICAL SYSTEMS

FISH AND WILDLIFE: FISHERIES

Fisheries within the watershed study area are essentially limited to the Big Horn River (refer to Figure 43 and Map Book, Map 18). This section of the river, while considered aquatic critical habitat, has the highest percentage of "most-disturbed" stream miles at 48% among all HUC 8 clusters in the Bighorn Basin (Hargett and ZumBerg, 2014) and has a low protection score based on Wyoming Game and Fish's stream fishery classification system (Wyoming

Game and Fish Department Fish Division, 2006). The river has several irrigation diversions along its length affecting flow. The river is fully allocated and the diversions into the extensive canal systems present in the area can significantly reduce flows.

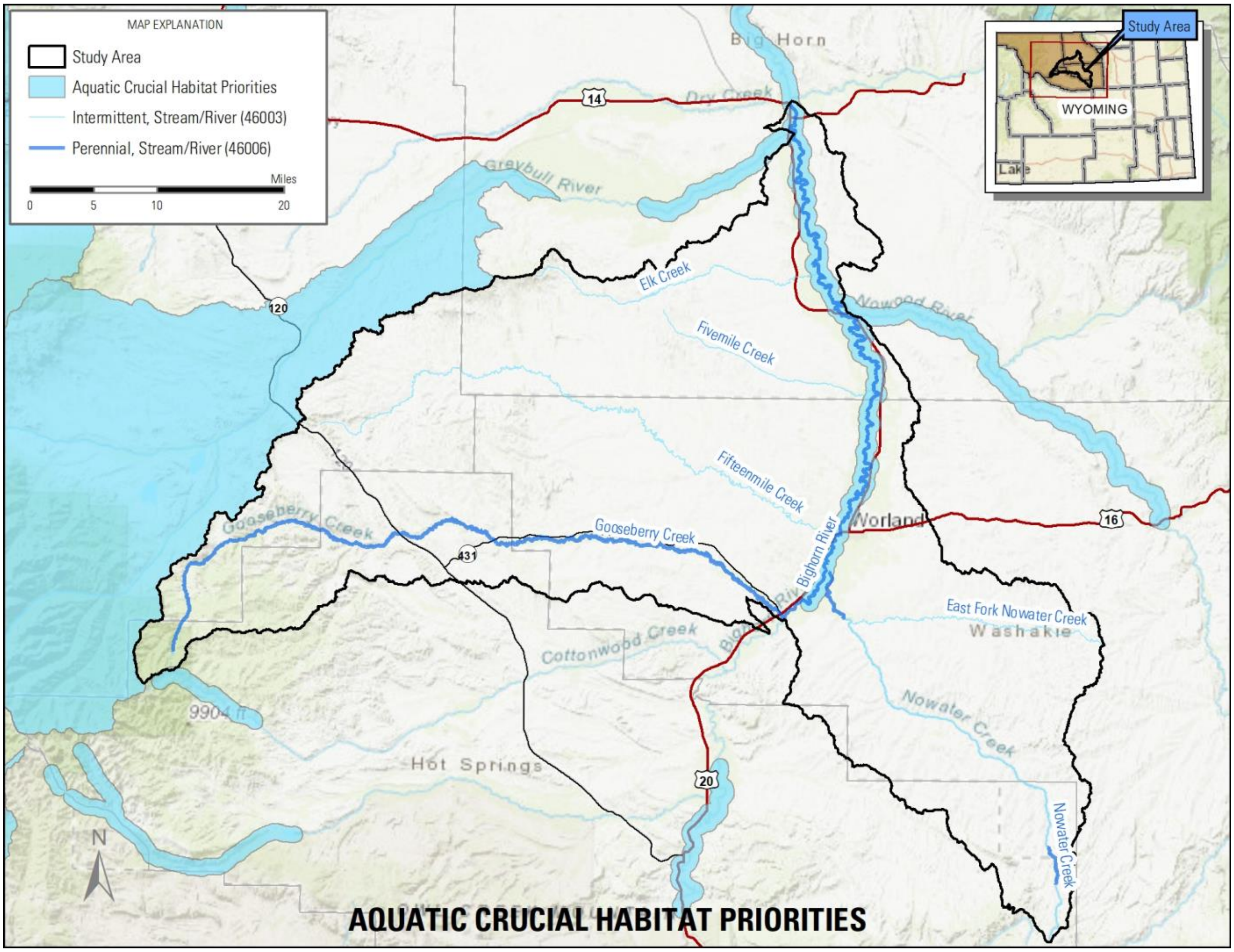

Figure 43: Aquatic crucial habitat priorities across the study area.

FISH AND WILDLIFE: WILDLIFE HABITAT, GAME, AND SENSITIVE SPECIES

The Middle Big Horn study area provides habitat to many upland and aquatic wildlife species. Wildlife in Wyoming are the property of the citizens of the state and managed by the Wyoming Game and Fish Department (WGFD). The Department's mission is "Conserving Wildlife, Serving People". The WGFD uses a State Wildlife Action Plan (SWAP), revised to provide a strategy for managing various wildlife groups including mammals, birds, reptiles, amphibians, fish, and mussels. (Wyoming Game and Fish Department, 2017)

The SWAP is habitat-based and thus links closely to the vegetative cover found across the study area. Habitat-based approaches such as this are designed to follow the idea of multiple species management. This habitat-based approach focuses on two primary components of Wyoming's landscape: terrestrial and aquatic areas. Terrestrial habitats include aspen/deciduous forests; cliffs, canyons, caves, and rock outcrops; desert shrublands; foothill shrublands; montane and subalpine forests; mountain grasslands and alpine tundra; prairie grasslands; riparian areas; sagebrush shrublands; wetlands; and xeric and lower montane forests. Aquatic habitats include the Bear River Basin, Green

River Basin, Northeastern Missouri River Basin, Platte River Basin, Snake/Salt River Basin, and Yellowstone River Basin. WGFD uses the habitat-based approach to ensure all species are given acknowledgment.

The Middle Big Horn study area, while mostly considered a cold desert, has a diversity of habitat that hosts several large wildlife species important to the recreational industry of the region. Virtually all the study area is habitat of some importance to one species or another. Looking at the combination of crucial big game habitat and sage grouse core habitat, it is obvious the watershed is of utmost importance to the wildlife in this part of the state (Figure 44, Map Book, Map 19).

With the encroachment of development, the degradation of habitat, and the potential spread of large predators absent from the watershed for decades, many of the wildlife species, especially big game, are moving into urban areas and impacting agricultural operations. Big game animals have increasingly moved onto agricultural operations and impacted agricultural production. Loss of haystacks and reduced hay and crop yields have been reported, primarily related to deer depredation. Mule deer historically avoided urban areas but are now increasingly present, impacting landscaping and increasing vehicle collisions and human confrontations. Pronghorn have become so habituated to agricultural areas that they have been observed remaining in fields during harvest and simply moving around harvesting equipment. WGFD has a depredation payment system in place to compensate landowners for damage to their products caused by wildlife. The WGFD Chapter 28 Regulation provides a process for a landowner that has property being damaged by big game, game birds, or wolves to be compensated. This program is often not fully used because some landowners are tolerant of the big game present, are less impacted, or they find that the compensation process is too complex to make it worth their efforts (Demaree, 1985; Van Tassell et al., 2000). A further compounding factor Van Tassell et al. (2000) points out is that one of the primary depredation management tools that WGFD has is the ability to control the number of hunting licenses in an area and the associated hunting season. Van Tassell et al. (2000) states that this tool is easily compromised by landowners not allowing hunting access, thus creating a safe haven for wildlife, thereby concentrating wildlife on their property. A further contributing factor are recreational ranchers that have a high tolerance of wildlife on their property because of their economic stability. These ranches create wildlife sanctuaries that force wildlife onto neighboring properties when forage becomes limited. These neighboring landowners may not have the financial stability to tolerate high numbers of big game animals moving on and off their properties.

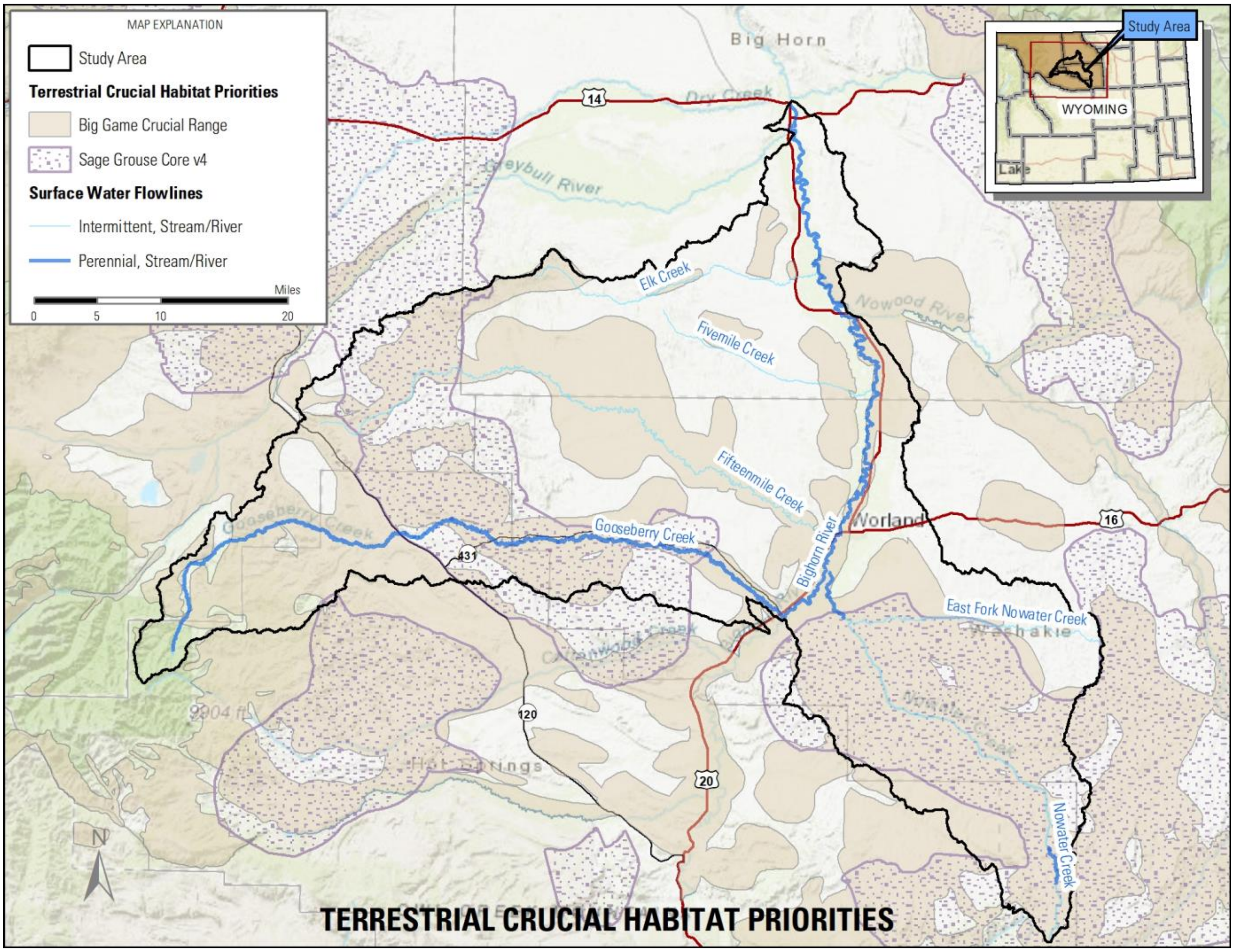

Figure 44: Terrestrial crucial habitat across study area.

Pronghorn (*Antilocapra americana*) are common throughout the study area. Pronghorn prefer the open shrublands that most of the watershed provides. They are intermediate foragers, eating grasses, forbs, and shrubs (Robbins, 1993; Krausman, 1996). Pronghorn use most of the watershed at some level except for the developed areas and the upper elevations in the southwest corner of the study area. Pronghorn are present in most all the range within the study area yearlong. Crucial winter/yearlong range occupies about 32% (368,350 acres) of the study area. Winter/yearlong range occupies about 45% (524,377 acres) of the study area, while general yearlong range is 13% (151,733 acres) of the study area. A small migration corridor, approximately 10,600 acres, links the upper portions of the Fifteenmile and Gooseberry drainages. Pronghorn habitat is stable in the study area and pronghorn encroachment onto agricultural lands seems to be increasing. The largest threat to the Pronghorn's habitat is cheatgrass (*Bromus tectorum*) invasion. See Map Book, Map 20 for details.

Elk (*Cervus canadensis*) are primarily found around the headwaters of Gooseberry and Nowater Creeks. Elk are primarily grazers, or bulk foragers, though elk will occasionally browse on willows and aspen (Robbins 1993, Krausman 1996). Most of the elk habitat within the study area, 63,290 acres or 5.5% of the area, is listed as critical winter habitat. The head of Gooseberry Creek is also surrounded by 28,576 acres of winter habitat. Yearlong habitat accounts for 1.5% of the study area, located primarily around the headwaters of Nowater Creek. Both sections of habitat have migration corridors. On Nowater, the migration corridor is connected to the crucial winter range, while the corridor at the Gooseberry Creek headwaters follows along the northwest boundary of the study area, feeding into the critical winter range there. Elk habitat faces potential degradation from invasive species and some forage competition with cattle grazing. Wildfire has the potential to increase foraging habitat while decreasing sheltering habitat. See Map Book, Map 21 for details.

Moose (*Alces alces*), while occasionally spotted along the Big Horn River, are primarily found in the upper reaches of Gooseberry Creek. Moose are browsers, or concentrate foragers, though they will occasionally forage on aquatic vegetation (Robbins, 1993; Krausman, 1996). Habitat in the watershed is yearlong in the upper reaches of the watershed and winter/yearlong along a small section of the creek. This yearlong habitat blends down to winter (21,267 acres) and crucial winter range (3,679 acres). Moose have a narrow diet range and wildfire and livestock grazing of riparian habitats hold the potential to reduce their habitat. Moose are more impacted by climate change than other large ungulates due to their specific diet. See Map Book, Map 22 for details.

Mule deer (*Odocoileus hemionus*) are ubiquitous in the watershed with over 99.3% of the watershed listed as some level of habitat. Urban areas typically account for the remaining 0.7% of habitat. However, mule deer have readily adapted to the urban environment and have begun to encroach into Worland and the surrounding developing areas, a common trend in the Bighorn Basin. Mule deer are considered primarily browsers but will use forbs as well (Robbins, 1993; Krausman, 1996). Mule Deer will consume grass early in the season while the nutritive value is high, but senescent grasses do not meet their dietary requirements. Just over 55% (638,067 acres) of the study area is considered yearlong mule deer habitat. Crucial winter/yearlong habitat comprises just over 33% (384,977 acres) of the study area. This habitat is located primarily along the waterways and upper elevations of the stream systems. These are the areas of primary overlap with agriculture and private and urban locations, making them the most vulnerable habitats. Conversely, many of these urban and agricultural areas provide additional forage and water resources. See Map Book, Map 23 for details.

White-tailed deer (*Odocoileus virginianus*) prefer thicker cover than mule deer, and thus, are essentially habitat-limited to the Big Horn River corridor and Gooseberry Creek. Small lower segments of Fifteenmile and Nowater Creeks provide marginal habitat. The linear aspect of the habitat provides approximately 138, 975 acres of yearlong habitat. Whitetails, like mule deer, are essentially browsers, supplementing their diet with forbs and occasionally grass (Robbins, 1993; Krausman, 1996). In agricultural areas they will feed more on field and hay crops. There is some habitat overlap with mule deer; however, white-tailed deer are becoming more prevalent in the study area with the increase in brush cover along the waterways. See Map Book, Map 24 for details.

Bighorn sheep (*Ovis canadensis*) are not documented as occurring in the study area. However, the upper Gooseberry Creek headwaters are less than one mile from winter/yearlong habitat and just 6 miles from yearlong habitat. Thus, there is potential for sheep to periodically occupy this small portion of the study area. See Map Book, Map 25 for details.

Threatened and Endangered Species listed by the US Fish and Wildlife Service's (USFWS) IPaC system for the study area lists the Canada lynx (*Lynx canadensis*), grizzly bear (*Ursus arctos horribilis*), and Ute ladies'-tresses (*Spiranthes diluvialis*) as threatened species in the study area, with whitebark pine listed as a candidate species. The USFWS is the agency within the Department of the Interior dedicated to the management of fish, wildlife, and their habitats, and charged with enforcing federal wildlife laws including, but not limited to, the Endangered Species Act. In addition to managing threatened and endangered species, they manage migratory birds, restore significant fisheries, conserve and restore wildlife habitat including wetlands, and distribute money to state fish and wildlife agencies.

Special Status Species are designated by the BLM and include federally listed, or proposed for listing, as threatened or endangered, candidate species, state protected and sensitive species, and other Special Status Species including federal and state "species of concern". The BLM designates Special Status Species where there is credible scientific evidence to document a threat to the continued viability of a species population. Moreover, Special Status Species are typically designated as sensitive by a BLM state director in cooperation with state agencies that are responsible for managing the species. State natural heritage programs are typically involved as well, where applicable. The Wyoming State BLM Office identifies 82 species as sensitive (available on the Wyoming BLM webpage). Primary to the study area is the greater sage-grouse. (Wyoming BLM, 2010)

The Greater Sage-Grouse (*Centrocercus urophasianus*) is a native gallinaceous bird endemic to the sagebrush region. In 2010, the USFWS issued a decision that the Greater Sage-Grouse was warranted for listing under the Endangered Species Act (ESA). However, at that time the listing was precluded by a higher priority species. Subsequently, in 2015 the USFWS concluded the sage-grouse did not meet the standards for protection under the ESA. As a sagebrush obligate the study area offers a large amount of habitat. Currently 99% of the watershed is considered occupied range, though many areas such as the agricultural and salt desert shrub areas are marginal habitat at best. The watershed does contain 386,937 acres, or 33.6%, of core habitat. The major threat to the Greater Sage-Grouse is loss of habitat, primarily due to juniper encroachment and the invasion of cheatgrass and the associated accelerated fire cycles that accompany cheatgrass invasion. See Map Book, Map 26 for detail.

Other upland wildlife species of importance in the study area include the Chukar Partridge (*Alectoris chukar*) and Pheasant (*Phasianus colchicus*), both introduced species for bird hunting. Some duck and geese hunting occur along the river and on the associated agricultural fields. Potential for grey wolf (*Canis lupus*) and North American wolverine (*Gulo gulo*) passing through the Gooseberry headwaters area exists. The Bald Eagle (*Haliaeetus leucocephalus*) has an increasing presence along the Big Horn River. Several other birds and a few amphibians, some with sensitive status, occur in scattered populations within the study area.

Overall, most of the upland habitat is stable within the study area. The increasing threat from invasive species, such as cheatgrass, and the associated fire risk pose the greatest threat to existing upland habitats. Oil and gas development are relatively limited and thus pose minimal risks to wildlife and their habitats. The primary limiting factor for wildlife in most of the study area is the availability of year-round water sources.

FIFTEENMILE HERD MANAGEMENT AREA

The Fifteenmile Herd Management Area (HMA) is located in the northwest portion of the watershed straddling Fifteenmile Creek (Map Book, Map 27). The HMA is about 30 miles northwest of Worland and covers over 81,000 acres. Though listed at that acreage, the horses roam well outside of the boundary, coming within 15 to 20 miles of Worland. The horses on the HMA are supported by a single well and seasonal precipitation; this stresses wildlife populations. While the HMA overlaps five winter sheep grazing allotments, there is minimal overlap with livestock as the allotments have only been grazed four times between 1984 and 2016. The HMA was the site of the first federal wild horse gather in 1938. Periodic gathers have been made between 1984 and 2009 removing 1,207 horses. On August 16, 2019 the BLM released two decision records approving two management actions on the HMA. The first is to update the 1985 Fifteenmile Wild Horse Herd Management Area Plan. The updated plan adjusts the Appropriate

Management Level (AML) from 30 to 100 horses; the previous AML was 70 to 160 horses. Recent population counts put the actual number of horses on the HMA and surrounding area at 700 horses. The decision also approves a gather of horses to return numbers to the lower end of the AML. Priority will first be given to removing horses outside the boundary of the HMA on private and state lands, then reducing numbers within the HMA.

LAND COVER

VEGETATION AND PLANT COMMUNITIES

Land cover is a coarse measure aggregating types of vegetation. Vegetation plays a significant role in the hydrology of a watershed. The precipitation, no matter what form it comes in, will interact with the vegetation in some way. Vegetation influences how much precipitation reaches the ground, the amount of precipitation that is intercepted and lost to evaporation, soil infiltration and runoff rates thus groundwater recharge, and soil erosion and sediment transport thus influencing water quality. Landcover also influences soil evapotranspiration rates by not only intercepting precipitation but also influencing soil temperatures and contributing greater or lesser amounts of soil organic matter that is better at holding water. Some vegetation, like xeric shrubs common in the watershed, are better adapted to hot windy conditions, and thus, transpire less soil water. The biological integrity of an area is inherently linked to certain land cover types. Ecosystem resistance and resilience are readily reflected in these data as well as land and wildlife productivity potential.

While several landcover datasets are available for the watershed, each with varying numbers of land cover categories, attributes, and resolutions, the information presented here (Figure 45; Appendix A, Table 22; Map Book, Map 28) is based on the National Land Cover Database.

PLANT COMMUNITIES

The dominant land cover class/plant community in the study area is categorized as a mix of Herbaceous (39.7% of the study area cover) and Shrub/Scrub (50.1% of the study area cover) cover classes. These classes are a mix of species from the sagebrush steppe and the salt desert shrub. Shrubs in the steppe are primarily Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and Douglas rabbitbrush (*Chrysothamnus viscidiflorus*) in the uplands and basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) and rubber rabbitbrush (*Ericameria nauseosa*) in the more mesic areas. The more saline areas support shrubs such as Gardner's saltbush (*Atriplex gardneri*), shadscale saltbush (*Atriplex confertifolia*), and spiny hopsage (*Grayia spinosa*). Often these species will create mosaics due to soil and topography characteristics.

Mixed in with these shrubs are perennial native grasses such as: needle and thread (*Hesperostipa comata*), Sandberg bluegrass (*Poa secunda*), blue grama (*Bouteloua gracilis*), alkali sacaton (*Sporobolus airoides*), bluebunch wheatgrass (*Pseudoroegneria spicata*), western wheatgrass (*Pascopyrum smithii*) and bottlebrush squirreltail (*Elymus elymoides*). Due to heavy grazing pressure prior to the late 1950's many of the steppe areas have been converted to stands of Wyoming big sagebrush and Sandberg bluegrass. The salt desert shrub system remains relatively intact. The largest change to these systems is the introduction of cheatgrass (*Bromus tectorum*), an exotic invasive species that alters soil water availability and increases fire frequency and intensity, eventually creating a near monoculture system of cheatgrass.

Barren lands comprise 1.7% of the study area and are intermixed with the Herbaceous and Shrub/Scrub cover classes. These are essentially badland and rock outcrop areas.

Evergreen, mixed, and deciduous forests are less than 2% of the cover classes. Evergreen forest consists of mixed spruce-fir forests dominantly composed of Engelman spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). Spruce-fir forests transition to lodgepole pine (*Pinus contorta*) forests as elevation decreases, containing Douglas fir (*Pseudotsuga menziesii*) and aspen (*Populus tremuloides*). Woodlands of limber pine (*Pinus flexilis*) and Rocky Mountain juniper (*Juniperus scopulorum*) are found along lower elevation cliffs and hillsides, transitioning to areas dominated by sagebrush steppe as elevation decreases. Deciduous forests, other than aspen, are found scattered along riparian corridors and around ponds and reservoirs. The primary species found here historically have been cottonwoods (*Populous* spp.) as well as green ash (*Fraxinus pennsylvanica*), boxelder (*Acer negundo*) and willows (*Salix* spp.). However, a large portion of these areas have been invaded by Russian olive (*Elaeagnus angustifolia*), salt cedar (*Tamarix* spp.), and elms (*Ulmus* spp.). Many of the understories have been converted to pastureland, especially along the Big Horn River, thus a number of herbaceous invasives are present.

Cultivated crops and hay/pastureland occupy approximately 5.5% of the watershed, primarily clustered along the Big Horn River and Nowater and Gooseberry Creeks. Crops are primarily sugar beets, malt barley, corn, dry beans, and wheat. Hay and pastureland are a mix of alfalfa (*Medicago sativa*) and grasses.

Wetlands, including open water, are very limited in the study area comprising only 1% of the study area. Virtually all of these are located along the river with a few located on the creeks. Some along the river are irrigation induced.

The remainder of the county, about 1.2% of the study area, is listed as being developed to some extent.

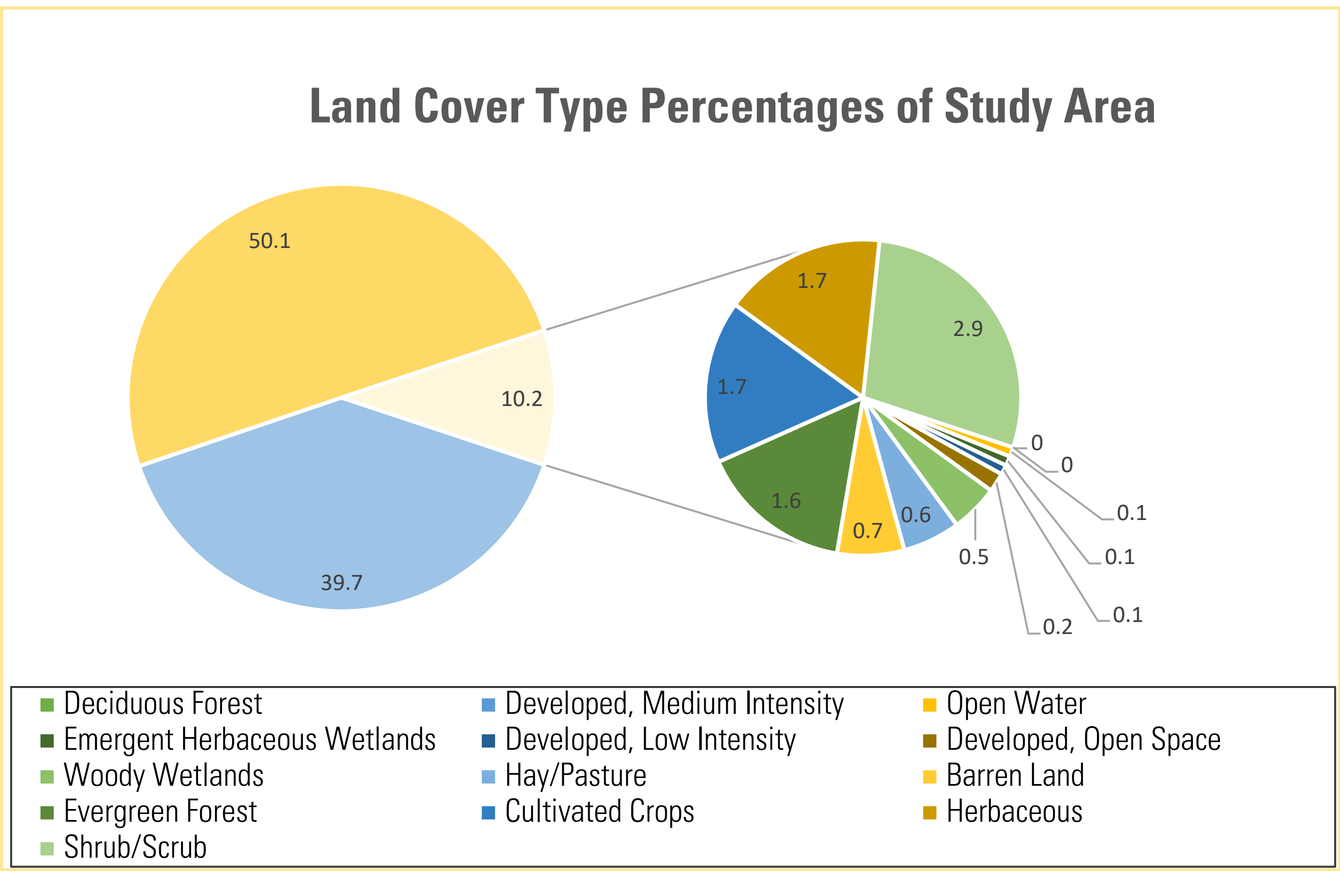

Figure 45: Land cover percentage breakdown for the Middle Big Horn Watershed Study Area.

RANGELAND MANAGEMENT AND POTENTIAL

Over 93 percent of the watershed could be considered rangeland, herbaceous, shrub/scrub, barren, or forest cover types. In addition to providing wildlife habitat, the watershed's rangeland has been historically grazed by both cattle and sheep for over 100 years. In the 1880s both cattle and sheep grazed in the watershed. Initially cattle dominated the livestock industry. In the mid-1890s sheep began to outnumber cattle in the watershed. This was due to a majority of the watershed being better suited for sheep than for cattle along with a preferential market for sheep. Grazing was uncontrolled during this time period, and with the increasing number of homesteaders, the grazing pressure on the rangeland resource began to overwhelm the forage available on the low production system. By the very early 1900s effects of the uncontrolled grazing were becoming evident and the bulk of the blame was placed on sheep, thus contributing to the early range wars of the sheepmen versus the cattlemen (King 1965). Despite the conflict, sheep remained a mainstay of grazed livestock as the numbers of cattle increased, all in an uncontrolled grazing situation. With the passage of the Taylor Grazing Act in 1934 some grazing control began to occur. Also, beginning in the late 1970s to early 1980s the numbers of sheep grazing public land began to decrease due to economics resulting from international imports, labor costs, and predation. While some smaller sheep operations remained, cattle became the primary livestock and the numbers of cattle have remained relatively constant since, increasing slightly with some conversions from sheep to cattle allotments. However, in recent decades the number of sheep have increased in the watershed, due to increased wool and lamb prices as well as the small niche market of using sheep for weed biocontrol.

A limitation to grazing the uplands in the study area is the lack of available stock water. Stock ponds were put in place across the study area historically. However, many of these have silted in or eroded, reducing their ability to retain water. There may be opportunity to repair and maintain existing stock ponds in targeted areas, but rangeland carrying capacity is minimal, meaning stocking levels are inherently low, resulting in great expenditure for a small number of livestock. Analysis of benefit versus cost is recommended before any work occurs.

Much of the area of concern is managed by the BLM, whose budgets for this type of work simply do not exist, plus they must demonstrate their expenditures are in the public interest through NEPA, which is problematic. The WWDC's SWPP can provide funding for stock water infrastructure and development, including small reservoirs, wells, solar platforms, and pipelines and conveyance facilities. There may be other funding sources but benefit versus cost is an element of consideration as money is allocated.

With the above, the best course of action is to manage these landscapes as extremely sensitive areas that can only provide minimal commodity outputs. A comprehensive sediment study is being discussed by various entities in the study area and if conducted, may lead to additional thoughts on mitigating sediment concerns. In the meantime, efforts should focus on the implementation of Best Management Practices (BMPs) for land use activities that have the potential to expose the landscape to erosion.

A further complicating factor in managing the rangelands of the watershed is that the ecological sites tend to be of low potential and have poor resilience. The USDA-NRCS defines an Ecological Site as:

> *"… a distinctive kind of land with specific soil and physical characteristics that differ from other kinds of land in its ability to produce a distinctive kind and amount of vegetation and its ability to respond similarly to management actions and natural disturbances."*

The watershed has numerous ecological sites within it, but five dominate, accounting for almost three-fourths of the watershed's ecological sites. These five ecological sites are:

- R032XY112WY-Gravelly (Gr) 5-9" Bighorn Basin Precipitation Zone,
- R032XA122WY-Loamy (Ly) 5-9" Bighorn Basin Precipitation Zone,
- R032XY144WY-Saline Upland (SU) 5-9" Bighorn Basin Precipitation Zone,
- R032XY150WY-Sandy (Sy) 5-9" Bighorn Basin Precipitation Zone, and
- R032XY154WY-Shale (Sh) 5-9" Bighorn Basin Precipitation Zone.

The majority of the study area are classified as Loamy 5-9" and Saline Upland 5-9".

These ecological sites are all recognized as being low potential sites, high in bare and erosive soils. Many are shrub dominated or have been converted to lower ecological states through historic grazing practices or by invasive species. Below are the average potentials expected for these ecological sites with ranges depending on the ecological state that the site is in.(Jornada, n.d.)

The Gravelly (Gr) ecological site should average 200 lbs/acre of total above ground production and can range from 350 lbs/acre down to as low as 25 lbs/acre. Of this 75% should be grasses/grasslikes, 10% forbs, and 15% shrubs. As ecological conditions decline it can be expected that the shrub component will increase at the expense of grasses/grasslikes, and the deep-rooted perennial grasses will be replaced by shallow rooted perennial grasses like Sandberg bluegrass, threadleaf sedge, and invasives. The site should average 10 to 20% bare soil with 20 to 50% of the soil surface covered by coarse rock fragments (Jornada, n.d.).

The Loamy (Ly) ecological site should average 320 lbs/acre of total above ground production and can range from 570 lbs/acre down to as low as 55 lbs/acre. Of this, 60 to 70% should be grasses/grasslikes, 10% forbs and 15 to 30% shrubs. As ecological conditions decline it can be expected that the shrub component will increase at the expense of grasses/grasslikes, and the deep-rooted perennial grasses will be replaced by shallow rooted perennial grasses like Sandberg bluegrass, blue grama, threadleaf sedge, and invasives. The site should average 15 to 35% bare soil, with this percentage increasing as shrubs increase and deep-rooted perennial grasses are lost from the system. Invasive species can cause increases or decreases in bare ground dependent on the species. (Jornada, n.d.)

The Saline Upland (SU) ecological site is dominated by salt tolerant plants and should average 300 lbs/acre of total above ground production and can range from 550 lbs/acre down to as low as 75 lbs/acre. Of this 50% should be grasses/grasslikes, 10% forbs, and 40% shrubs. As ecological conditions decline it can be expected that the shrub component will increase at the expense of grasses/grasslikes, and the deep-rooted perennial grasses will be replaced by shallow rooted perennial grasses like Sandberg bluegrass and invasives, in some places all cool-season perennial grasses have been eliminated and the area is only woodies and the invasive halogeton (*Halogeton glomeratus*). The site should average 30 to 40% bare soil, with this percentage increasing as shrubs increase and deep-rooted perennial grasses are lost from the system. Invasive species can cause increases or decreases in bare ground dependent on the species. (Jornada, n.d.)

The Sandy (Sy) ecological site should average 400 lbs/acre of total above ground production and can range from 600 lbs/acre to as low as 55 lbs/acre. Of this 70% should be grasses/grasslikes, 15% forbs, and 15% shrubs. As ecological conditions are reduced it can be expected that the shrub component will increase at the expense of grasses/grasslikes, and the deep-rooted perennial grasses will be replaced by shallow rooted perennial grasses like

Sandberg bluegrass, threadleaf sedge, blue grama and invasives. The site should average 25 to 35% bare soil, with this percentage increasing as shrubs increase and deep-rooted perennial grasses are lost. Invasive species can cause increases or decreases in bare ground dependent on the species. (Jornada, n.d.)

The Shale (Sh) ecological site is dominated by salt tolerant plants and should average 100 lbs/acre of total above ground production and can range from 250 lbs/acre to as low as 15 lbs/acre. Of this 60% should be grasses/grasslikes, 15% forbs, and 25% shrubs. As ecological conditions are reduced it can be expected that the shrub component will increase at the expense of grasses/grasslikes, and the deep-rooted perennial grasses will be replaced by shallow rooted perennial grasses like Sandberg bluegrass, blue grama, and invasives. The site should average 75 to 85% bare soil, with this percentage increasing as shrubs and invasives increase and deep-rooted perennial grasses are lost. (Jornada, n.d.)

Efforts have been made in the past to improve production on these ecological sites in the watershed. Between the 1950s and the 1970s range developments were put into place, such as silt dams, water spreaders, furrows, and crested wheatgrass plantings. With the highly erosive nature of the soils the water spreaders, furrows and silt dams were quickly rendered ineffective (Marston & Dolan, 1999). Some of the crested wheatgrass plantings are still productive but forming monocultures with a high degree of bare soil in the interplant space.

Adequate water is a documented limiting resource for livestock production in this watershed. Prior to the mid-1970s numerous stock dams were put in drainages in the uplands for livestock water. Most all of these dams have been silted in or the dams have been breached rendering them ineffective. The loss of the stock and silt dams has resulted in a high silt load coming off these rangelands and contributing to the silt loading in the Big Horn River. Potential exists to repair these dams through BLM maintenance agreements. However, the cost to benefit ratio of this action can quickly be lost by one thunderstorm or heavy runoff event that silts the structures back in or breaches the dams.

Establishment of stock wells have been discussed as an alternative. However, the Willwood formation that underlies most of the watershed is not a water bearing formation, thus making the successful establishment of stock wells highly unlikely and will likely be cost prohibitive. These efforts would trigger a need for a NEPA analysis on all federal lands, though efforts could be explored on State Trust lands.

It is critical that these areas remained grazed. However, the lack of water, the vastness of these landscapes, and the fact that over 70% of the landscape is under federal management increases the difficulty of employing successful range improvements. Efforts should be made to allow flexibility in grazing management. Changing types and classes of livestock as well as turnout dates and season of use are all tools that can be employed to enhance the potential for success. Seeding some of the higher potential sites may yield increased forage production and soil organic matter that may help stabilize the soils. Evaluation of existing stock dams should be performed, and those with maintenance agreements, and highest potential for success, should be repaired under a cooperative effort between federal agencies and permittees. One successful well has been installed in the HMA along Fifteenmile Creek; further efforts should be made to develop other wells in similar locations and distribute water over the landscape.

Though a large portion of this watershed has a low production potential, some efforts should be made to use it, reduce the presence of invasives, and minimize erosion. This will require a significant effort of collaboration between the conservation districts, the BLM, the state, and permittees.

ANTHROPOGENIC SYSTEMS

AGRICULTURAL WATER USE

IRRIGATED LANDS

A GIS exercise indicated that there are approximately 64,710 irrigated acres in the MBH study area, representing just 6% of the watershed. For a depiction of irrigated lands in the study area see Map Book, Map 29. Common irrigated crops in the watershed include sugar beets, corn, malt barley, wheat, dry edible beans, and a few alternative crops. With the construction of the canal systems in the 1920s, water became more available in the watershed. Virtually all the irrigated acres in the watershed are along the Big Horn River on the east and west banks, and along Gooseberry Creek. All irrigation was flood-type irrigation based on canals, ditches, and rows. In the late 1940s with the release of internees at the Heart Mountain Internment Camp, several of the internees settled within the watershed and brought with them irrigation practices learned in California. One such farmer, Kaz Uriu, brought the first side-roll irrigation systems to the watershed, allowing an expansion of farming into many of the sagebrush areas that could not be readily irrigated. Flood irrigation continued to be innovated into the 1980s when pivot systems began to be established in the watershed. While pivots have become increasingly common in the area, many areas are still flood irrigated. Many of these are also grazed such as pasturelands and post-harvest beet tops.

IRRIGATION SYSTEMS

Land-use in the study area is mostly agricultural therefore there are several types of irrigation systems in place. The most prominent types of irrigation systems in the study area include pivot systems, drip and flood irrigation, and straight-line pivot systems. Within the study area pivot-type irrigation systems are more common in the southern region, while to the north, systems trend toward more straight-line irrigation and drip or flood irrigation.

Pivot and straight-line irrigation systems use sprinklers and movement around the field to water crops. The main difference is that pivot systems rotate in a circle around a fixed center-point while straight-line systems move laterally across the field. Both flood and drip irrigation systems are performed by conveying water over the ground, saturating the field at different rates depending on the crop requirements. Conveyance methods vary and there are ways to improve conveyance and sprinkler technology to better conserve water and improve irrigation efficiency.

The communities affected by the Middle Big Horn Level I Watershed Study are interested and trending towards more efficient and sustainable irrigation methods and technologies. This includes drip irrigation, a precise method of watering crops, where water waste is transpired into the atmosphere. Other possibilities include streamlined conveyance methods, outlined as possible solutions to many of the projects listed in the study area, including but not limited to pipeline improvements, canal lining, and irrigation ditch or flooding improvements.

WESTSIDE IRRIGATION PROJECT SUMMARY

The Westside Irrigation Project has undergone few changes since its inception in the mid-1980s (Figure 46). This project has historically been divided into three potential alternatives of varying acreage and elevation. All proposed alternatives for this project propose to divert water from the Big Horn Canal and pump water to the identified improved areas. If this project were to be implemented it would provide a net positive impact on the local stakeholders and their ability to develop cultivatable land.

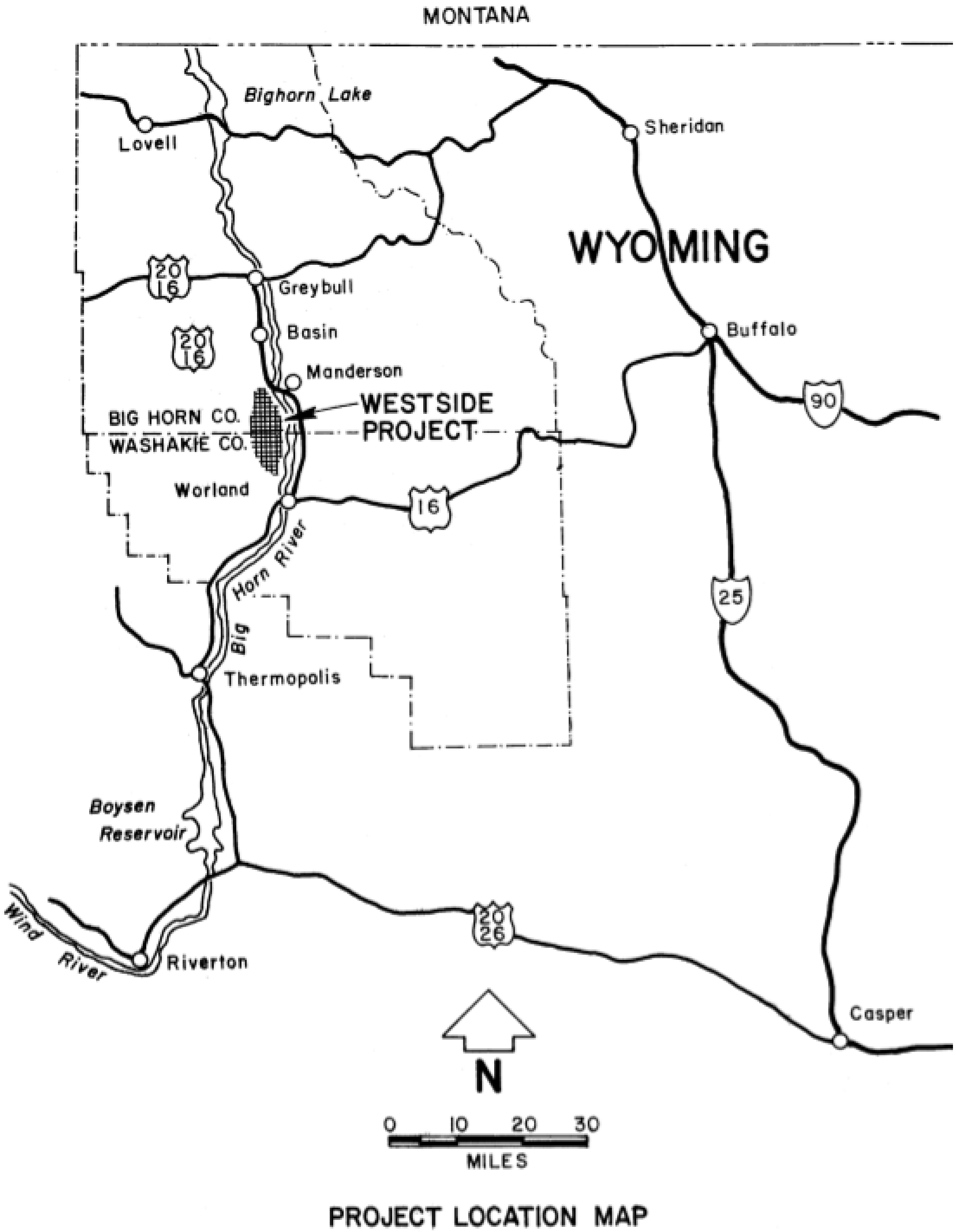

Figure 46: Proposed location of Westside Irrigation District (Bureau of Reclamation: Upper Mississippi Region, 1983)

Past studies have detailed the potential economic and water balance impacts that would be exerted on the study area and surrounding locales if this project were to be developed. Several studies have been performed by the Bureau of Reclamation (Bureau of Reclamation, 1988; Bureau of Reclamation: Upper Mississippi Region, 1983). Additional studies have been performed by multiple other engineering groups throughout the region. These studies were reviewed as part of this study to make informed recommendations.

Studies on this project have stated repeatedly that it is likely to proceed. However, there are conditions that could limit the development of this project. The land that this project is currently designated to occupy would need to be transferred from federal ownership, requiring congressional approval. The use of water rights would also require substantial examination to ensure that there are sufficient water rights available to provide water for this project. Current priority water rights may limit the availability of water needed for this project. Estimates for water demand indicate that to irrigate the full extent of proposed land it would require upwards of 18,000 to 20,000 acre-feet of water annually. If implemented this project would be the largest water user within the Upper Wind Basin. As part of this project's development requirements, the capacity of the Big Horn Canal conveyance would need to be increased. This would require augmentation to the Big Horn Canal itself to allow for the increase in flow. Improvements in the proposed study area, aside from water conveyance, would likely include the installation of pivot sprinkler systems in place of flood irrigation; this would increase water delivery area and efficiency. The installation of conveyance would need to overcome approximately 150 feet of elevation gain delivering water from the Big Horn Canal.

Implementing the Westside Irrigation Project would provide a net benefit to the basin, according to previous studies (Bureau of Reclamation, 1988; Bureau of Reclamation: Upper Mississippi Region, 1983; Nelson Engineering, 1985). These earlier studies mention the potential for improved economic impact on the farming community local to the project as well as that to the surrounding areas. The basin is largely irrigation driven and produces almost all its crops within those areas actively being irrigated. Adding irrigable acreage would provide a benefit to the area at large.

Local stakeholders have communicated interest in further development and improvement of available water resources and irrigable acres. The development of this project would occur mostly on federally owned lands, with some small tracts of privately-owned land included in the extent of the proposed improved area. While the overall benefit that would be yielded by this project is undeniable, there remain several key hurdles to its implementation. There is a clear and present benefit, but like so many projects of this magnitude there remains significant issues with permitting and project ownership.

Permitting will need to be performed under the Clean Water Act, Section 404, following the guidance of the Environmental Impact Statement (EIS) that was delivered for the Westside Irrigation Project. The primary delay of this project has historically been confirmation by congress to transfer ownership of this land for resale to interested and qualified parties. This coupled with the limited viability of the project, has and will continue to hinder this project's development.

DOMESTIC, MUNICIPAL, AND INDUSTRIAL (DMI) WATER USE

POTABLE WATER SYSTEMS

Prior to the mid-1980s, Bighorn Basin towns along the Big Horn River all sourced their drinking water from the river. Thermopolis, Worland, and Basin each had water treatment plants, which generally included coarse filtration, flocculation and settling, and rapid sand filters and chlorination, and each served areas outside of town. The Husky #1 well hit a major artesian water source with 5,180 gallons per minute (gpm) over a 24-hour period with nearly instantaneous recovery. The initial shut-in pressure was 193 psi with a drawdown of 11 psi during the 24-hour test. That well was released to Worland on March 30, 1979 for a municipal water source and plans were made to design a system to transport the water to Worland, 22 miles away. Black & Veatch of Kansas City and Donnell & Associates of Worland studied population trends in the 1980s and all indications were that the area would continue to grow at roughly the same rate, at least for the near future. The transmission line was sized to handle the predicted future growth with a design flow of 12 million gallons per day (mgd).

The Worland system operates now as it has since it began, using only the artesian wellhead pressure—no pumps—with the limiting factor being the high point over Rattlesnake Ridge northeast of Worland. Even with no pumps, the system can deliver just under 6 mgd, about 4,000 gpm, through the 24-inch diameter, asbestos cement (AC) pipeline. All public water systems require more than just one well, so two more well locations were chosen in the Paintrock anticline area. Worland #3 Well was the only well drilled for service due to its great capacity.

Along with the two artesian wells, Worland also installed two new 2.5 million gallon pre-stressed, post-tensioned, partially buried concrete reservoirs—one east of Worland immediately downstream from the new chlorination station, and the other about 91 feet lower, west of Worland. These tanks set the operating pressures for the two pressure zones that serve Worland plus five out-of-town water districts. The Husky #1 well was videoed to assess its condition in 2002. The video showed that the steel casing had split and dropped where the casing had been perforated years before, leaving a wide opening into the underground cavern accessing the water source.

An ongoing drought has lowered the shut-in pressure in Worland's wells by about 85 feet based on static wellhead pressures, but the system continues to deliver near-perfect quality water to around 6,875 equivalent dwelling units (EDU; one EDU is equivalent to one ¾-inch tap) from Lucerne to Greybull, including portions of Hot Springs, Washakie, and Big Horn counties. This is encompassing of the study area and shows adequate quality potable water.

INDUSTRIAL AND MINING

There are numerous industrial water users throughout the study area. These users range from industrial producers in the low-lying regions of the study area to oil and gas producers in the upland areas of the study area. There are two primary variations of water use in the basin for industrial and mining purposes. For the purposes of this consideration, industrial will encompass both the production of finished goods and the development of natural resources such as oil and gas. Refer to Map Book, Map 30 for a map of industrial and mining water use in the study area.

The primary use of water in the basin is for industrial usage with the majority of the water for this use being sourced from groundwater. This is largely driven by oil and gas production in the study area. The secondary usage of water is surface water. While surface water is a large component of water use in the study area it is largely transient and often does not get used in the volumes seen in groundwater usage.

There are multiple water rights in the area dedicated to industrial purposes. Some of these include oil and gas producers like Amoco, as well as domestic product manufacturers like the Holly Sugar Corporation (Wyoming Sugar Company, LLC) and Admiral Beverages (Pepsi Plant). In these cases, water is drawn from sources, either surface or groundwater, and used in industrial processes as part of the production process. Water is piped into the process, typically with some form of treatment being exerted on the water prior to use. Most industrial water is drawn from either a surface source or from a dedicated supply well. The more common uses of water in industrial purposes is typically for process water—water used within the process for operation or production. Process water can have multiple uses and definitions with common uses including heating or cooling of process components. Additionally, process water can be used on a component basis for production of a variety of products. For example, in processing of sugar beets, one of the largest industrial water use types in the area for produced goods, water plays a crucial role. Beets are delivered to the sugar processing plant via water flume from transport drop off. Once the beets are processed, they are soaked in high-temperature water; this extracts the raw sugars from the beet. This water syrup complex is then placed under a vacuum condition to evaporate the water from the water syrup complex. This evaporated water typically has a high sugar content and undergoes re-processing. This water can then be recycled back into the process multiple times to maximize the production of sugar and molasses. Once the water has been processed it is delivered to large evaporation and settling ponds.

For productions and management standards regarding mineral and energy development, roads, urban uses, croplands, or forestry reference Wyoming DEQ BMPs.

PRODUCED WATER

Throughout the study area there are numerous points where oil and gas are being produced. Along with the production of oil and gas, water is typically a by-product. For the purposes of this study, only wells located within the defined study area were examined for produced water quantities (Table 8).

Table 8: Produced water in counties included in study (WOGCC, 2019)

County	Produced Water (bbls.)
Big Horn County	12,975,245
Hot Springs County	17,007,658
Park County	16,699,735
Washakie County	1,452,461
Total Production	48,135,099

Production operations for oil and gas are widespread throughout the study area. Refer to Map Book, Map 31 for locations of produced water. Produced water is typically brackish in quality with high total dissolved solids. This water typically requires a substantial amount of processing to be made useable and dischargeable. Most produced water is either trucked off-site or left in evaporation ponds.There are some instances where the water is discharged into natural drainages. Instances of these methods were observed during the field visit portions of this project. These were most commonly observed in the immediate vicinity of well pads and production sites. Typically produced water is separated from produced fluids from the well by physical separation. Examples of oil and gas water separation and discharge can be seen in the following figures (Figure 47 and Figure 48). Common procedure is to treat the produced water following separation and either dispose of it via discharge or evaporation. In the instances that were observed in study area, it was most commonly discharged to the nearest drainage.

Figure 47: Discharge of produced water in Buffalo Basin.

Figure 48: View of oil and gas production pad in Fifteenmile drainage.

There are a total of 1,306 permitted wells within the study area. Figure 49 identifies the permitted use of the wells. The majority are permitted for domestic use, followed by stock use. Figure 50 through Figure 52 illustrate the number of wells permitted by decade, yield rate, and depths within the study area. All charts below are based on data from the Wyoming State Engineer's Office (WSEO) (WSEO, n.d.). See Table 23 through Table 26 in Appendix A for more information about number of wells by permitted use, priority date, yields, and depth.

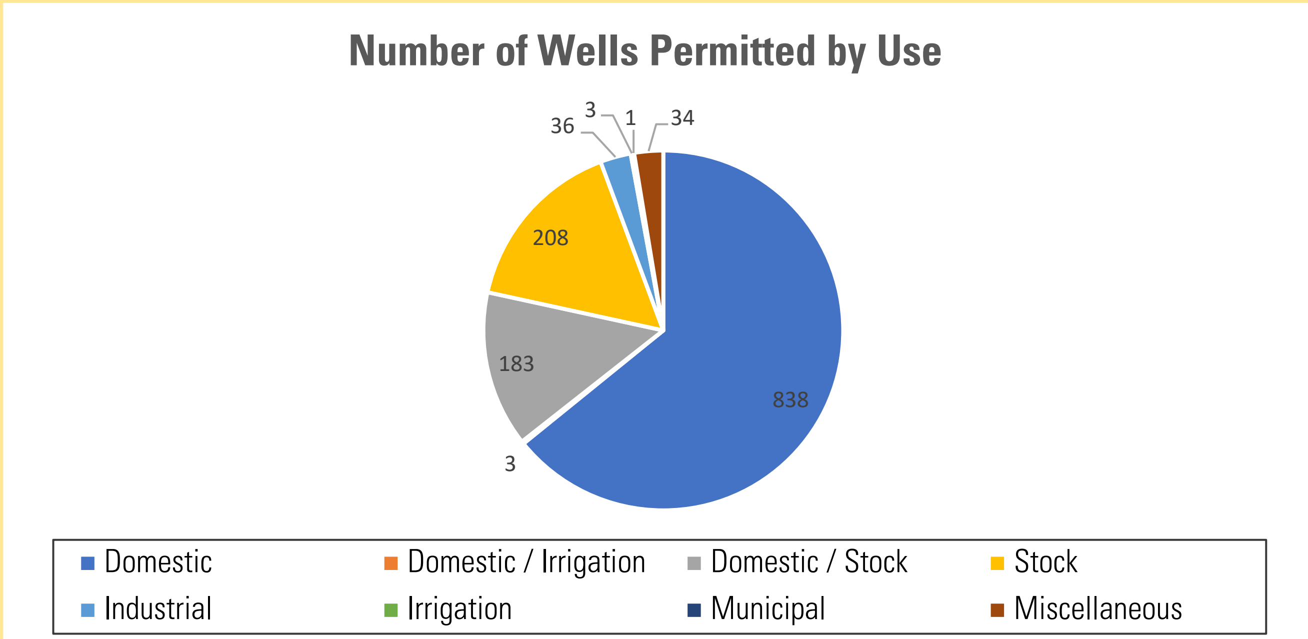

Figure 49: Permitted use and number of associated wells.

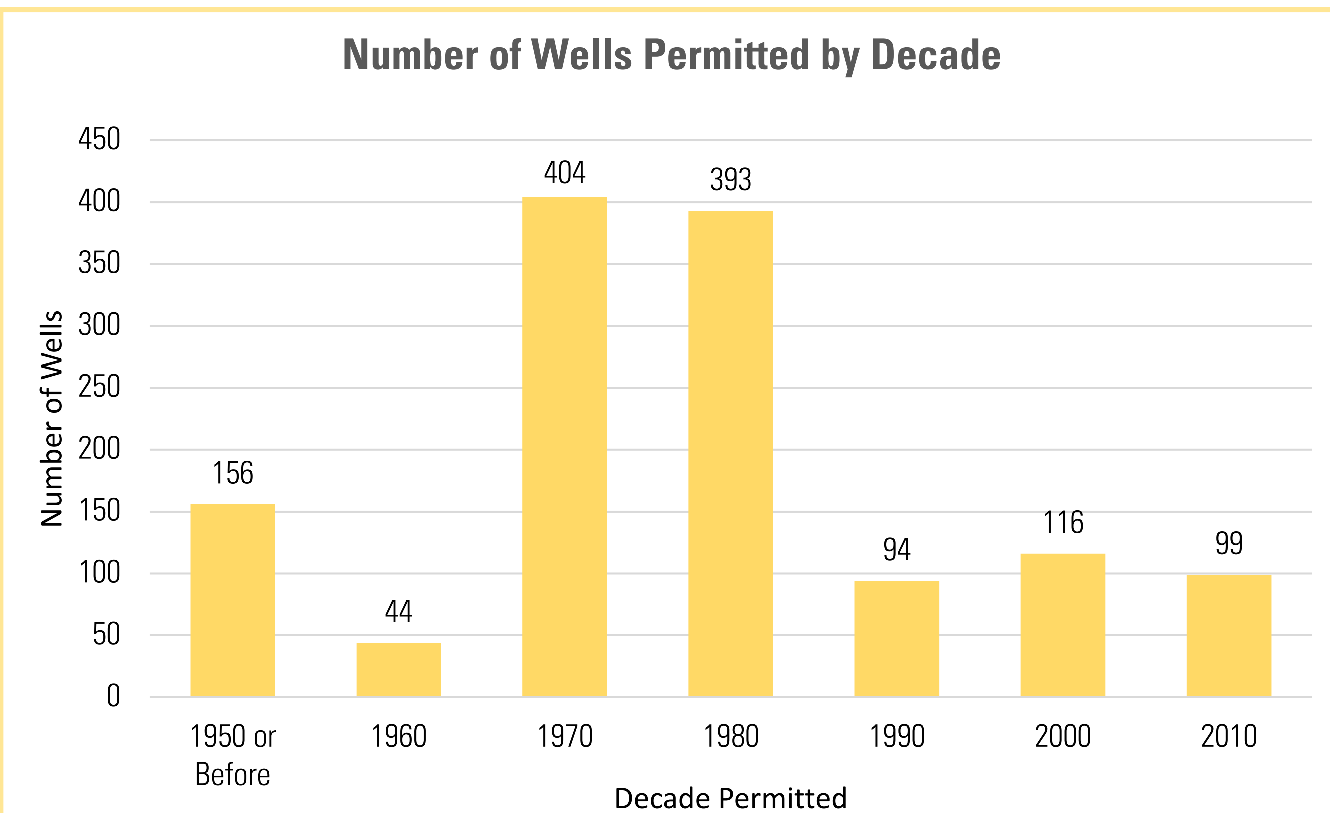

Figure 50: Shows the priority date for the wells. The majority of the wells were permitted between 1970 and 1990.

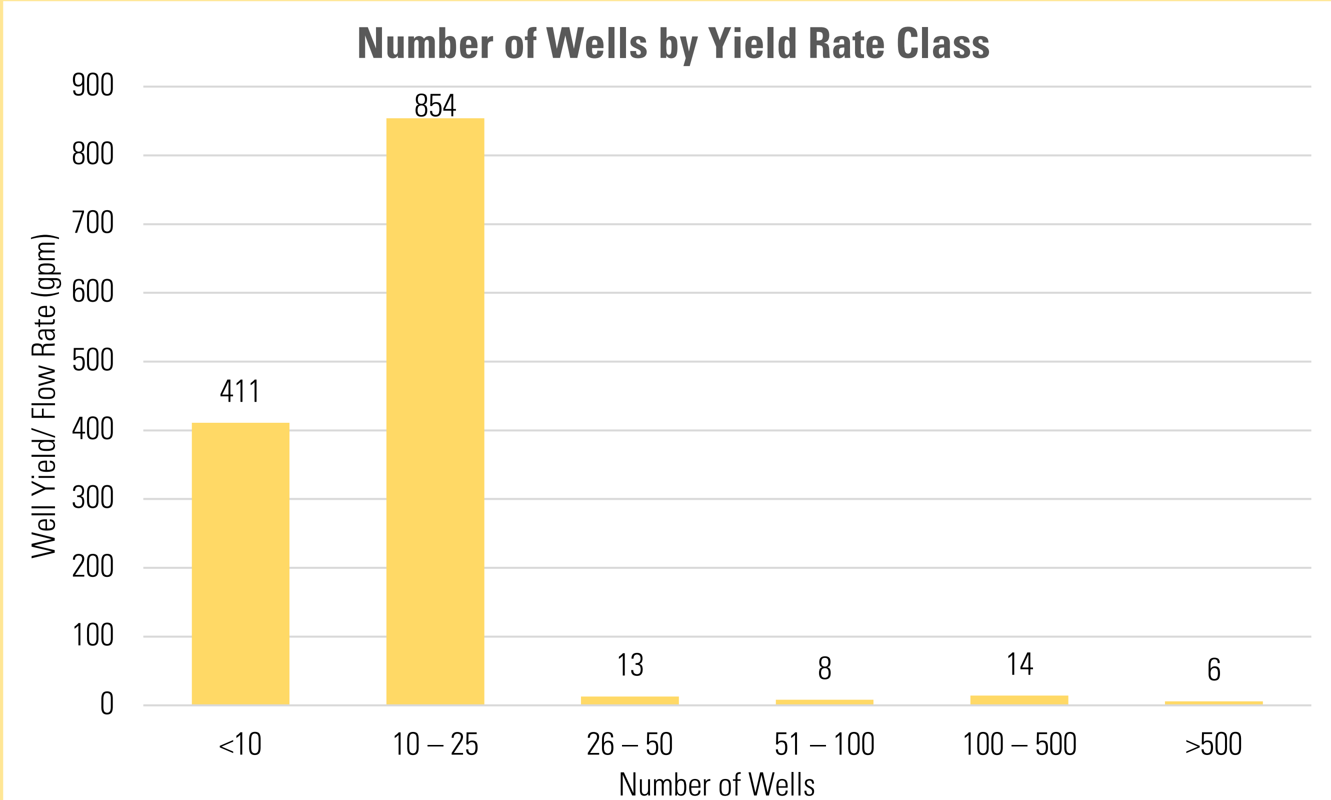

Figure 51: The permitted yield or flow rate of the wells within the watershed. The total yield is 29,383 gallons per minute (gpm), with the vast majority (65 %) of the wells permitted for between 10 and 25 gpm.

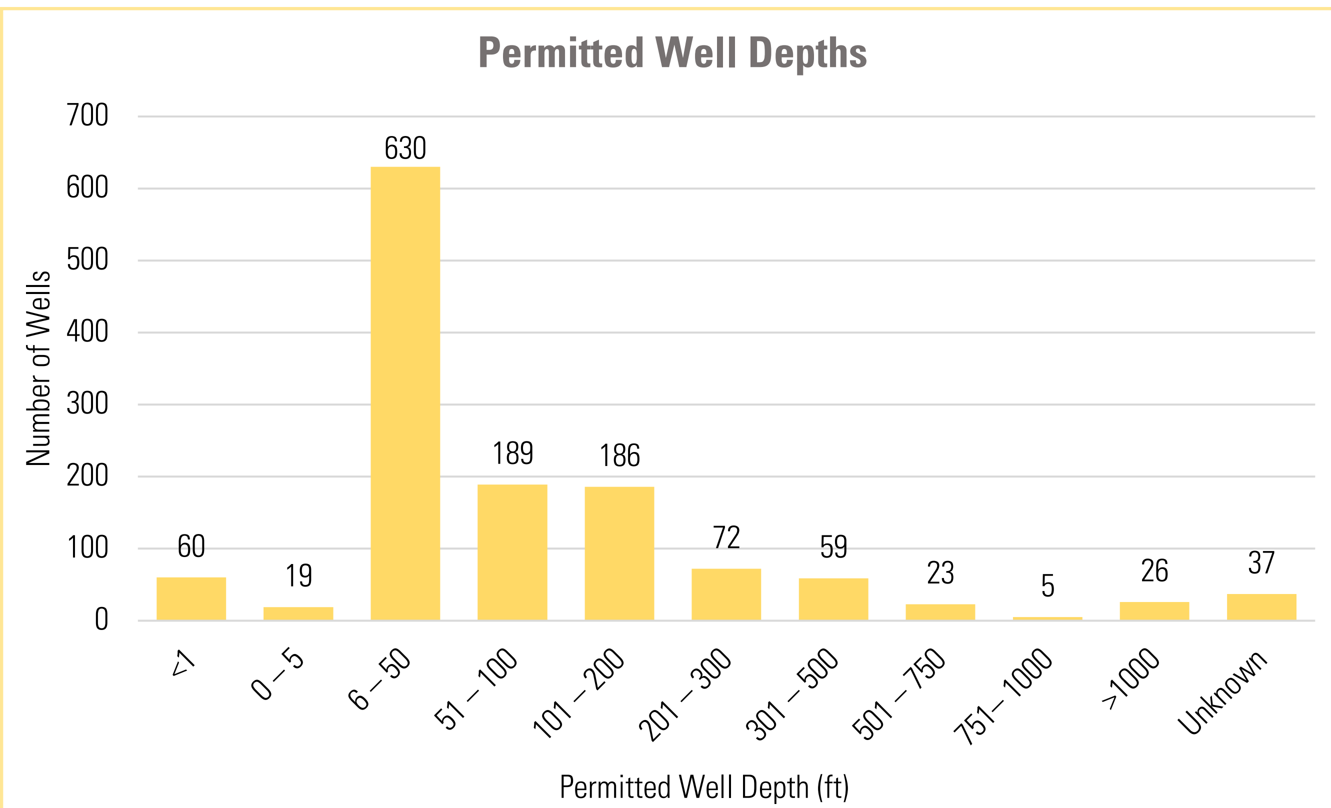

Figure 52: The depth of the wells in the watershed; 48% of the wells are between 6 and 50 feet deep and 29% are between 51 and 200 feet deep.

ESTIMATES OF GROUNDWATER USE WITHIN THE MIDDLE BIG HORN WATERSHED

Estimates of groundwater use within the Middle Big Horn Watershed are presented in this section of the report (Table 9). During this effort, procedures and values presented in the 2010 update to the Wind – Bighorn River Basin Plan were used, specifically information presented in Technical Memorandums 3A – Agriculture Use; 3B – Domestic and Municipal Use; and 3C – Industrial and Mining Use. The 2010 update to the Wind-Bighorn River Basin Plan is available at http://waterplan.state.wy.us/plan/bighorn/2010/report.html.

IRRIGATION GROUNDWATER USE

There are only three wells permitted for irrigation use within the study area and only two of these wells are adjudicated. There are only 27 acres adjudicated for irrigation use with groundwater as the source of the water. The one unadjudicated well permit allows groundwater to be used as additional supply for 162 acres that have original supply from surface water. In total there are approximately 190 acres of land that can be irrigated from groundwater.

The 2010 update estimates that the average or unit consumptive irrigation requirement (CIR) within the Bighorn Basin is approximately 1.94 acre-feet per acre. Therefore, on average approximately 370 acre-feet of water would be needed to meet the CIR need for the 190 acres irrigated from groundwater sources. Assuming an efficiency of 50% for the irrigation systems where wells are the source of water, means that approximately 740 acre-feet of water per year would need to be pumped.

STOCK GROUNDWATER USE

There are 207 wells permitted for stock use within the study area with a total permitted yield of 2,046 gpm. The permitted yield of the stock wells ranges from 0.5 to 900 gpm. The 2010 update estimates stock water use for the entire River Basin (reference the Task 3A – Agricultural Water Use technical memorandum). In Big Horn and Washakie Counties, the 2010 update estimates that approximately 1,540 acre-feet per year of water is required for stock use (Figure 53) (MWH Americas et al., 2010). The Basin plan does not specify or estimate the amount of water supplied by surface verses groundwater sources.

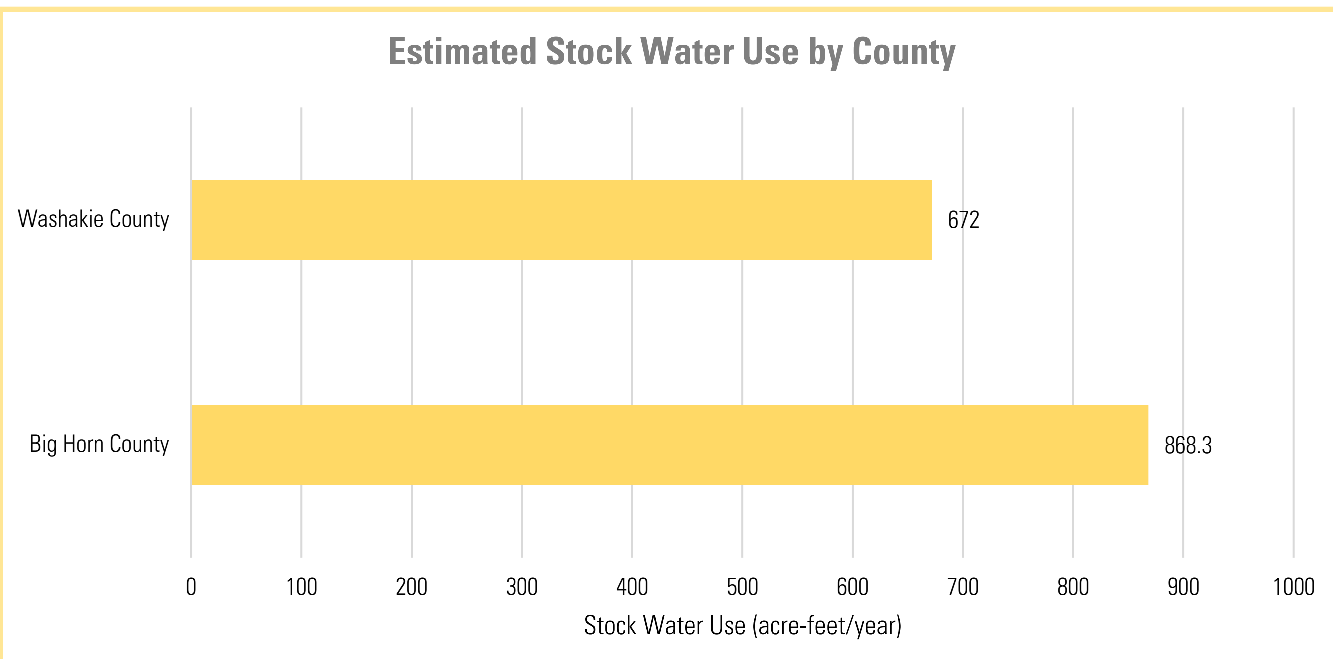

Figure 53: Estimated annual stock water use (acre-feet) by County per Technical Memorandum: Wind Bighorn Basin Plan Task 3A.

DOMESTIC GROUNDWATER USE

Within the study area there are 1,024 permitted domestic wells with 838 permitted for domestic use only and 186 permitted for both domestic and stock uses and/or permitted for domestic use and another use.

Most of the rural domestic water use in the study area is likely supplied by domestic wells. The 2010 update assumed that there are 2.5 persons using each of the domestic wells. This value is consistent with the 2010 census data, which shows that there are approximately 2.1 people living in each household in Big Horn and Washakie Counties. Based on the previous 2010 update, the rural domestic per capita water usage range is assumed to be between 150 and 300 gallons per day per person.

On average each domestic well pumps approximately 205,300 gallons per year or 0.63 acre-feet per year. Therefore, the total domestic use of groundwater within the study area is approximately 645 acre-feet per year. The domestic groundwater use could range from approximately 430 to 860 acre-feet per year, depending on the daily per capita water use. Since some of the groundwater pumped for domestic use is returned to the aquifers through percolation from leach fields and domestic irrigation, the actual consumptive use of domestic water likely is less than the estimate shown above.

MUNICIPAL GROUND WATER USE

There is only one permitted municipal well within the study area, servicing the Town of Manderson. Manderson has two wells, but one of the wells is not located within the study area.

The Town of Worland is located within the study area. However, the wells that serve Worland are not located within the study area and pumping of the Worland wells is not counted in the water use estimates for the study area.

The Town of Manderson has not reported water use in the 2018 WWDC Public Water System Survey Report or other recent reports. Therefore, estimates of the amount of municipal water use in Manderson were made using the same assumptions and estimates as outlined in the domestic water use section.

The municipal domestic per capita water usage range is assumed to be between 150 and 300 gallons per capita per day (gpcpd), which is the same range as the domestic use estimates. According to the 2010 US Census, Manderson's population is 114. Therefore, estimated municipal groundwater demand is between 19 or 38 acre-feet per year, with an average estimated municipal use of 29 acre-feet per year. A review of the Town of Manderson water rights indicates that the Town has adjudicated water rights of 40 acre/ft per year from both of their wells.

INDUSTRIAL

Industrial uses of water within the study area are associated with industrial facilities, mining operations, and oil and gas production. There are 36 wells permitted for industrial use within the study area and the total permitted yield for industrial use is 8,250 gpm. The permitted well yields range from 0.5 to 1,440 gpm. Permitted production rates or well yields correspond to the maximum sustainable pumping rate for a well and are not representative of the actual amount of water that is pumped in a yearly or annual period. Without actual records concerning the amount of water pumped, the industrial water use in the study area is difficult to quantify.

In addition, water is produced as a by-product of oil and gas production and the produced water often is not measured. The quality of the produced water often is poor and has high total dissolved solids (TDS; salinity) and other undesirable constituents often are present. Due to its poor quality, produced water often is not suitable for many uses.

Using the procedures described in the 2010 update, it is estimated that there is approximately 85 acre-feet per year of groundwater pumped for industrial use within the study area. This value does not include water produced by oil and gas activities.

MISCELLANEOUS

There are 34 wells permitted for miscellaneous use within the study area and the total permitted yield for industrial use is 2,130 gpm. The permitted well yields range from 5 to 1,000 gpm.

Table 9: Annual withdrawal (acre-feet/year) by usage. (WSEO, n.d.)

Usage	Number of Wells	Annual Withdrawal (Acre-Ft/Yr)	Estimation Method
Domestic	1024	430 – 860	Min Usage 150 gpcpd; Max Usage 300 gpcpd
Stock	207	1540	Technical Memo - Wind-Bighorn Basin Plan Task 3A
Industrial	36	85	Technical Memo - Wind-Bighorn Basin Plan Task 3C
Irrigation	3	740	Technical Memo - Wind-Bighorn Basin Plan Task 3A
Municipal	1	19 - 38	Min Usage 150 gpcpd; Max Usage 300 gpcpd

WATER STORAGE

RESERVOIRS

There are no natural lakes or reservoirs of significant size in the Middle Big Horn River Watershed Study Area.

UPLAND WATER STORAGE

Along with a few limited natural water sources, various upland livestock/wildlife water sources exist within the study area. Storage projects have been developed over time within the watershed in coordination with the BLM, Forest Service, NRCS, and private landowners.

Efforts to evaluate the general availability and locations of upland water sources within the study area began with GIS data acquisition from the Bureau of Land Management, the USDA Forest Service, the Wyoming State Engineer's Office (WSEO), the National Hydrography Dataset (NHD), and previously identified upland sources identified through other WWDC projects. GIS data were refined, attributed, or added to use the most current available remotely sensed aerial imagery and later verified in the field as possible. This qualitative assessment of natural and water development features yielded a minimum of 1,128 natural and man-made 'upland' water features. Approximately four hundred of these water features were linked to extant WYSEO permits (current to 2019) within the GIS database for the study. WYSEO permitted surface and groundwater diversions associated with identified upland water storage are depicted in Map Book, Map 32.

Not all upland water features identified in the GIS analysis are assumed to be reliable water sources for wildlife or stock, seasonally or year-round. Given the local geology, it is expected that an unknown number of the historic water development projects within the watershed have either failed or have filled with sediment and are no longer viable sources of livestock and wildlife water. For several reasons, but mostly due to the enormity of the study area, it was impossible to field verify or remotely parse out functional water features from the non-functional water development projects with any precision. A qualitative assessment was therefore not performed on the efficacy of existing water development projects within the watershed.

LAND

LAND OWNERSHIP

The Middle Big Horn River Level I Study Area is approximately 1,153,260.68 acres and includes lands from Big Horn, Hot Springs, Park, and Washakie Counties. The surface lands within the study area are majority managed by federal agencies. The Bureau of Land Management (BLM) owns the largest with about 74% of the study area. An additional 1% is federally managed by the United States Forest Service (USFS) in the westernmost portion of the study area and the Bureau of Reclamation (BOR) just south of Worland. The second largest land ownership is private with 19% of the study area. The State of Wyoming manages 5% of the land and local government ownership is <1%. Figure 54 and Figure 55 show the respective breakdowns of land management and ownership within the study area (see also Table 27 in Appendix A).

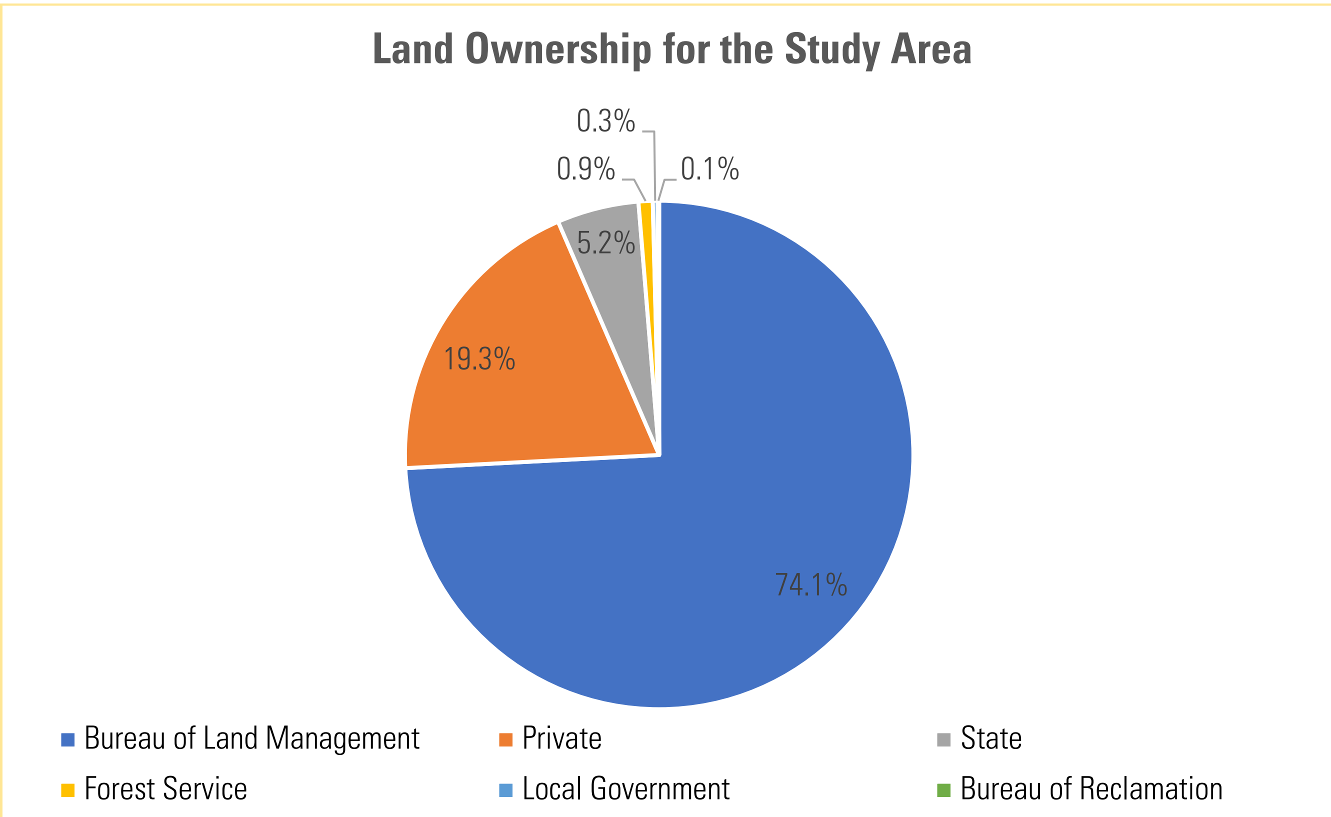

Figure 54: Land ownership breakdown for the study area.

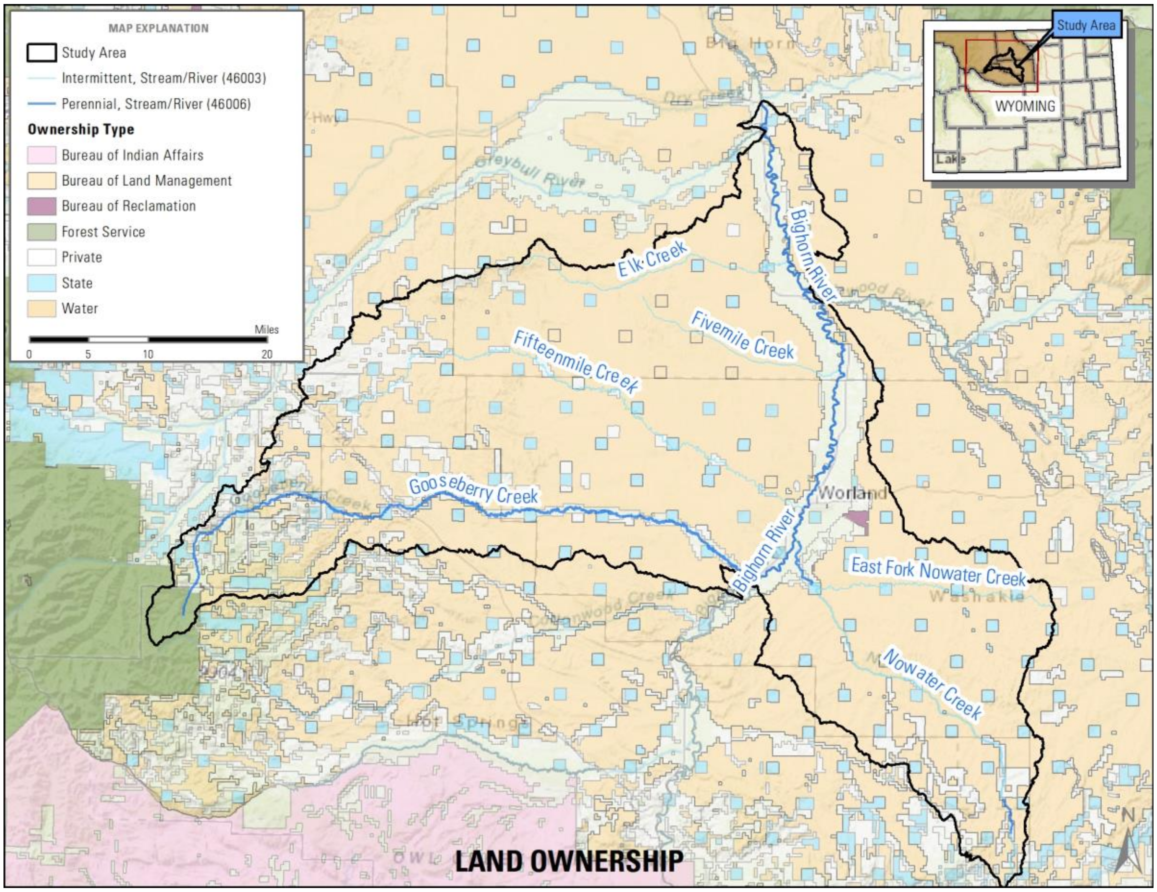

Figure 55: Land ownership designation within the study area.

LAND USE

The Middle Big Horn River Study area is centered between the Absaroka Mountains to the west and the Bighorn Mountains to the east. The majority of the study area is remote and unpopulated. The US Highway 20 corridor that runs north to south through the eastern portion of the study area includes most of the population of the area in the towns of Worland and Basin. This corridor is the main zone for crops and pastures due to its proximity to the Big Horn River. Outside of approximately 5 miles east and west of the Highway 20 corridor, the land is predominately scrub/shrub or herbaceous lands. The area is arid and classified as 50 percent Scrub/Shrub. Due to majority of BLM managed lands in the region, there are 128 BLM allotments that cover almost the entirety of the study area (Figure 55; Map Book, Map 33). Most of these lands are leased to private landowners for grazing. The western corner of the study area intersects the Shoshone National Forest, becoming more forested with evergreens as the terrain gains elevation to nearly 13,000 feet. The USFS has three allotments that cover the National Forest within the study area. Aside from grazing and agricultural uses the Bighorn Basin is known for its recreation. The vast amount of wildlife in the region makes this a popular area for big game hunting as well as fishing, boating, and hiking.

LAND MANAGEMENT AND UPLAND WATER RESOURCES

With the Taylor Grazing Act came the establishment of grazing districts and the Grazing Service to manage grazing on public lands. In 1946 the Grazing Service was merged with the General Land Office to form the BLM. The BLM is the major land manager within the watershed, managing over 74 percent of the land within the study area. Combined with the US Forest Service, other federal agencies, and state lands, over 80 percent of the watershed is managed by state and federal agencies, leaving just 20 percent of the watershed as private; the vast majority of that land is used for crop production, with only small pockets of privately held rangeland. Grazing on BLM lands in Wyoming must meet requirements specified in Standards for Healthy Rangelands and Guidelines for Livestock Grazing Management for the Public Lands.

CULTURAL RESOURCES

Cultural resources were considered as part of this study. It is recognized that cultural resources are within the study area. However, cultural locations are considered sensitive information. In an attempt to limit the replication of past work these resources were not included in this study. Cultural resources within the study area are inventoried and can be found in the Wyoming State Historic Preservation Office (SHPO) database.

ANTHROPOGENIC SYSTEMS SITE VISIT FINDINGS

Observations made across the study area related to irrigation both in terms of lands and systems were limited to the regions in the immediate vicinity of the Big Horn River and its associated canals. This region appears to be dominated by flood and sprinkler irrigation types with a common trend towards sprinkler irrigation (Figure 56 through Figure 59). In talks with landowners and stakeholders it was made apparent that there is a consistent desire for the installation of new pivot type sprinkler systems. These systems are commonly noted as having higher efficiency along with associated higher costs. Observing the difference in the areas around flood irrigation and sprinkler irrigation systems presented a clear benefit with those areas irrigated via sprinklers.

Figure 56: View of Lower Hanover Canal and associate agricultural production.

Figure 57: View of flood pipe irrigation to the west of Manderson.

Figure 58: View of existing supply ditch off the Big Horn Canal near Manderson, WY.

Figure 59: View of buried irrigation device.

Land use in the watershed areas was observed to be largely varied from grazing to oil and gas development (Figure 60 through Figure 63). In the low-lying regions of the watershed the primary use of land is agricultural with some intermixed industrial usage as well as domestic. The usage of the watershed land changes moving into the upland regions toward the west. Here the land use is primarily grazing of livestock, which does vary on a temporal basis. Additional use is seen in the development of oil and gas reserves.

Figure 60: View of upland water storage tank in the Fifteenmile drainage.

Figure 61: View of upland water storage trough in Nowater Drainage.

Figure 62: Vegetated silt dam and associated ephemeral wetland.

Figure 63: View of Fifteenmile drainage from Tatman Mountain.

FIELD VISIT SUMMARY AND FINDINGS

As part of the inventory portion of this study, Y2 and EES progressively performed field work in an attempt to gather as much information about the state of the watershed as possible. Field visits were performed throughout the later portion of 2018 and into early 2019. Given the immensity of the watershed it was not possible for the team to access every area or feature. However, the areas that were accessed were assumed to be representative of the entire watershed for those regions with shared features.

In the early phases of this study, site visits were performed along the corridor extending from Worland to Basin as part of the initial effort to assess the watershed. The two pictures, Figure 64 and Figure 65, were taken during the first site visits performed in August and September of 2018. Within these two figures the distinct erosion driven features (i.e., water flowlines, soil downcutting and sharp slopes) that define most of the western regions of the watershed can be seen.

Figure 64: View looking west into the study area.

Figure 65: View looking east from Fifteenmile drainage.

As part of the inventorying and verification process for the study area the Y2 team coordinated internally to develop a GIS of existing features and structures for field verification. While replication of services was not desired, Y2 did provide some spot checking throughout the study area. Figure 66 and Figure 67 both show instances where verification of features was performed. Figure 66 shows an existing silt dam that was verified in the field for functional status, location, and other attributes that were then incorporated into the developed GIS. This was one of the rare instances where the integrity of the silt dam had not been compromised. A large amount of vegetation was observed on the main dam structure. This is presumed to aid in the maintenance of the integrity of the structure. If the various silt dam remediation projects are developed across the rest of the watershed it appears that incorporation of vegetation would provide a beneficial effect for the silt dam. While this won't limit the deposition of silt it will limit washout of the dam structures. Figure 67 provides an example of field verification of a headgate located on the Big Horn Canal.

Figure 66: View of vegetated silt dam in Fifteenmile drainage.

Figure 67: Representative view of headgate along the Big Horn Canal.

Later visits by the Y2 team accessed further regions of the watershed with a primary focus on the western areas into Fifteenmile and the other sub-drainages located off US Highway 20. Figure 68 and Figure 69 were both taken during field visits in November 2018. These images show the contrast between the central northern regions of the watershed (Figure 68) and the central regions (Figure 69). The central northern regions are dominated by sagebrush and grassland

and are heavily used by local stockgrowers. There are many leases and land holdings in these areas that provide key rangeland for stock grazing. This is contrasted by the central regions of the watershed that consists of the Fifteenmile drainage. The Fifteenmile drainage, while not as heavily used for grazing, does see use from some stockgrowers. Within this range feral horses were observed. Noticeably in the central regions of the watershed, seen in Figure 69, there was a more common occurrence of erosion and erosional features. The occurrence of erosion in this region was commonly noted as the cause of many water quality issues in the lower regions of the watershed and along the Big Horn River. As part of this, the Y2 team observed multiple silt dams, spreader dikes, and stock reservoirs all in a dilapidated state. Most commonly these control devices were completely silted in and had either started to erode or had completely eroded along the primary structure body.

Figure 68: View looking south from Tatman Mountain.

Figure 69: View looking north from Five Mile drainage.

CHAPTER 4: WATERSHED STREAMFLOW HYDROLOGY

STREAM GAGING STATIONS

Over the years, numerous gaging stations have been installed across the study area to collect streamflow data. These gages are operated by the U.S. Geological Survey (USGS) and Wyoming State Engineer's Office (WSEO). Because new gages are added and existing gages are discontinued depending upon need and funding, users should directly access the gaging websites for the most current information. These websites are map-based and are illustrated in Map Book, Map 34.

PEAK FLOWS

MEASURED

Some gages provide peak flow data, which equates to the highest flow of the year for the station. Twelve gages within the study area were analyzed for peak flows (Table 10). The magnitude of the peaks and the time of year the peaks occur varied by station. In a general sense, these data illustrate peak flows are a direct function of either precipitation or flow regulation.

More specifically, data from four of the twelve stations suggest peaks are a result of both summer rainfall and/or spring snowmelt, with most peaks occurring from April through October. Four are related to regulated flows, with peaks occurring from February through December depending upon reservoir management. Three are related to spring snowmelt, with most peaks occurring from May through June.

Table 10: Monthly timing of annual peak flows at various USGS gages in the study area.

Number	Location	Hydrology	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
6274250	Elk Creek near Basin, WY	Rain&Snow				4	6	6	1	1	4	1			23
6268500	Fifteen Mile Creek near Worland, WY	Rain&Snow				3	5	11	4	6	5	2			36
6267400	East Fork Nowater Creek near Colter, WY	Rain&Snow		1	2	1	3	5	3	2	2	1			20
6266460	Murphy Draw near Grass Creek, WY	Rain&Snow				1	5	4	1	2	3				16
6274300	Bighorn River at Basin, WY	Regulated			1		9	18	2		1	3			34
6269500	Bighorn River at Manderson, WY	Regulated		1			1	7							9
6269000	Bighorn River near Manderson, WY	Regulated		1			1	3	1			1			7
6268600	Bighorn River at Worland, WY	Regulated					1	4	1	1				1	8
6267000	Gooseberry Creek at Neiber, WY	Snow			4	1	3	3	1						12
6266000	Gooseberry Creek near Grass Creek, WY	Snow				1	4	4	3						12
6265800	Gooseberry Creek at Dickie, WY	Snow				3	7	10		1					21

CALCULATED

Peak flows for various recurrence interval floods, e.g., 10-year and 100-year, can be estimated using measured streamflow data as a base. Such calculations were performed using regression equations in the Water Resources Investigations Report 03-4107 (Table 11) at the mouth of the three major watersheds in the study area that are tributary to the Big Horn River, i.e., Gooseberry, Nowater, and Fifteenmile (Miller, 2003).

Peak flows for the Big Horn River proper were not calculated using Miller 2003 because flows are heavily regulated. Rather, a log-Pearson type III analysis using PeakFQ was performed using peak flow data from USGS gages 06268600 and 06274300 (Figure 70 and Figure 71) (USGS, 2014).

Table 11: Peak flows for various recurrence interval (RI) floods at the mouths of Gooseberry, Nowater and Fifteenmile Creeks. (USGS, 2014)

	Peak Discharge (cfs)		
RI (year)	Gooseberry	Nowater	Fifteenmile
1.5	343	336	373
2	516	527	584
2.33	612	635	703
5	1160	1260	1390
10	1770	2000	2200
25	2740	3190	3510
50	3610	4280	4700
100	4630	5580	6120
200	5800	7080	7760
500	7670	9490	10400

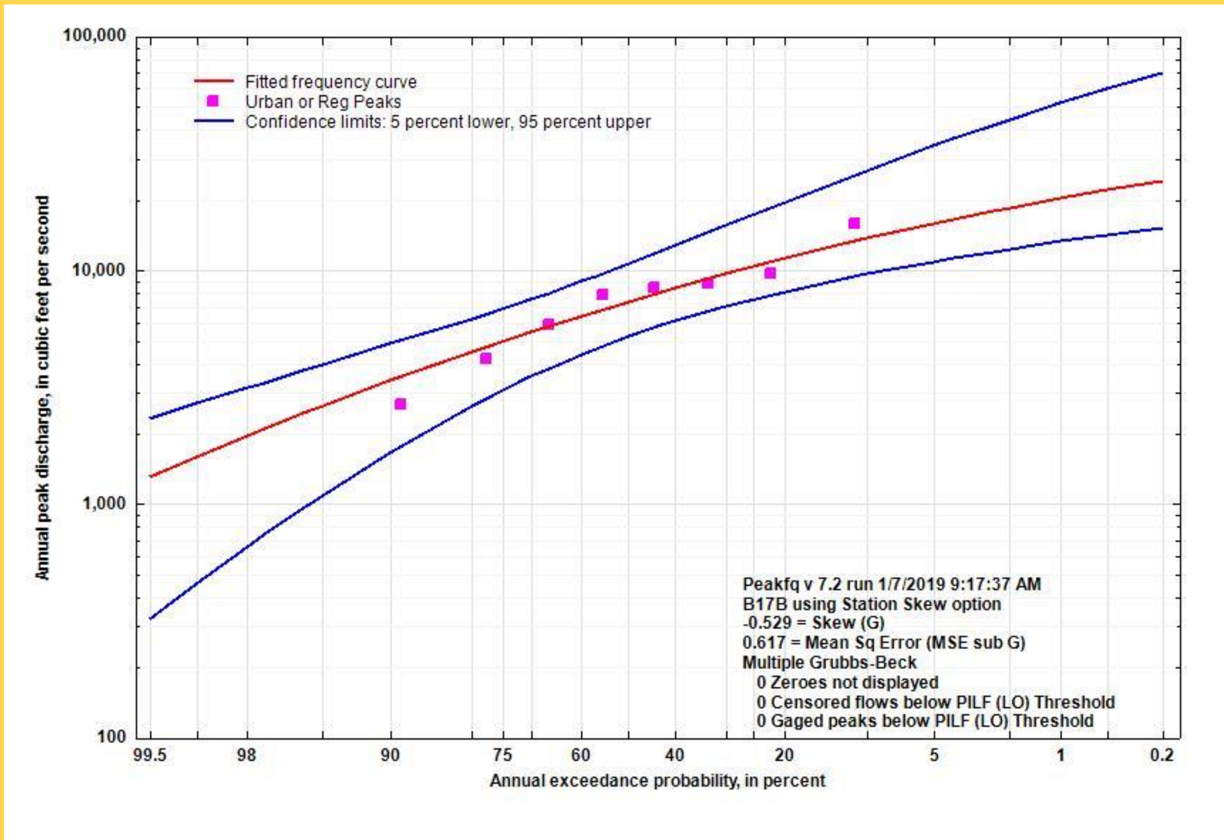

Figure 70: Annual peak flows for the Big Horn River at Worland for various return intervals. (USGS, 2014)

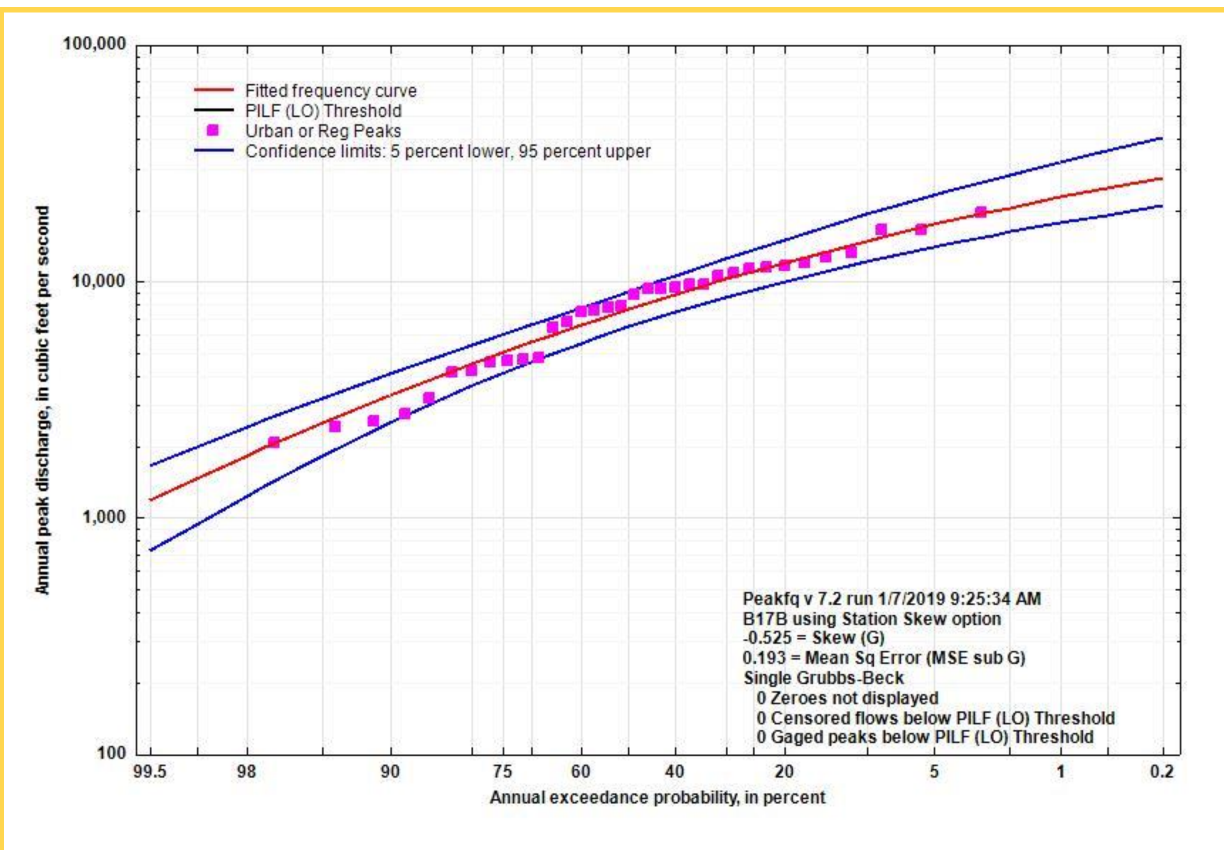

Figure 71: Annual peak flows for the Big Horn River at Basin for various return intervals. (USGS, 2014)

HYDROLOGIC MODELING

BACKGROUND

Various hydrologic modeling efforts have been conducted over the years that include part or all of the study area. Most notable are the 2003 Wind/Bighorn River Basin Plan and 2010 Wind/Bighorn River Basin Update. These two plans contain sub-basin surface water models that calculate water budgets at various nodes within each sub-basin. Water budgets are calculated for dry, normal, and wet year scenarios. There are ten sub-basin models within the Wind/Bighorn River Basin Plan (Table 12) (BRS, 2003; MWH Americas et al., 2010).

Table 12: Basins and sub-basins modeled in the 2003 and 2010 Wind/Bighorn River Basin Plan. (BRS, 2003; MWH Americas et al., 2010)

Basins	Sub-basins	Notes
Yellowstone	Madison/Gallatin	---
	Yellowstone	---
Clarks Fork	Clarks Fork	---
Wind	Upper Wind	---
	Little Wind	---
	Popo Agie	---
	Lower Wind	Changes to Big Horn River at "Wedding of the Waters"
Big Horn	Upper Big Horn	The entire study area is within this sub-basin
	Owl Creek	Enters Big Horn River upstream of the study area
	Nowood	Enters Big Horn River and study area near Manderson
	Lower Big Horn	---
	Greybull	---
	Shoshone	---

The study area is in the Upper Big Horn sub-basin model, but only comprises 52% of the area covered by the model (Table 13). The Upper Big Horn planning model has three sub-basin models that enter at various nodes (Figure 72). The Lower Wind sub-basin model outflow node enters at the upstream end of the Upper Big Horn sub-basin model south of Thermopolis. This node is commonly called "Wedding of the Waters", which is where the river changes names from Wind to Big Horn. The Owl Creek sub-basin model outflow node enters the Big Horn River upstream of the study area but downstream of the Lower Wind node. The Nowood sub-basin model outflow node enters the study area and Big Horn River near Manderson.

Table 13: Comparison of acreage between the study area, planning model, and basin plan.

Middle Big Horn Study Area	Upper Big Horn Sub-Basin Model	Wind/Big Horn River Basin Plan
1,153,261 acres	2,212,263 acres	20,658,583 acres

In addition to these three sub-basin model nodes, there are thirteen drainage basins lateral to the Big Horn River that enter as output nodes in the Upper Big Horn sub-basin model. Seven of these thirteen outflow nodes are within the study area. They are Enos Creek, Gooseberry Creek, Nowater Creek, Fifteen Mile Creek, Unnamed Creek, Adobe Creek South, and Adobe Creek North.

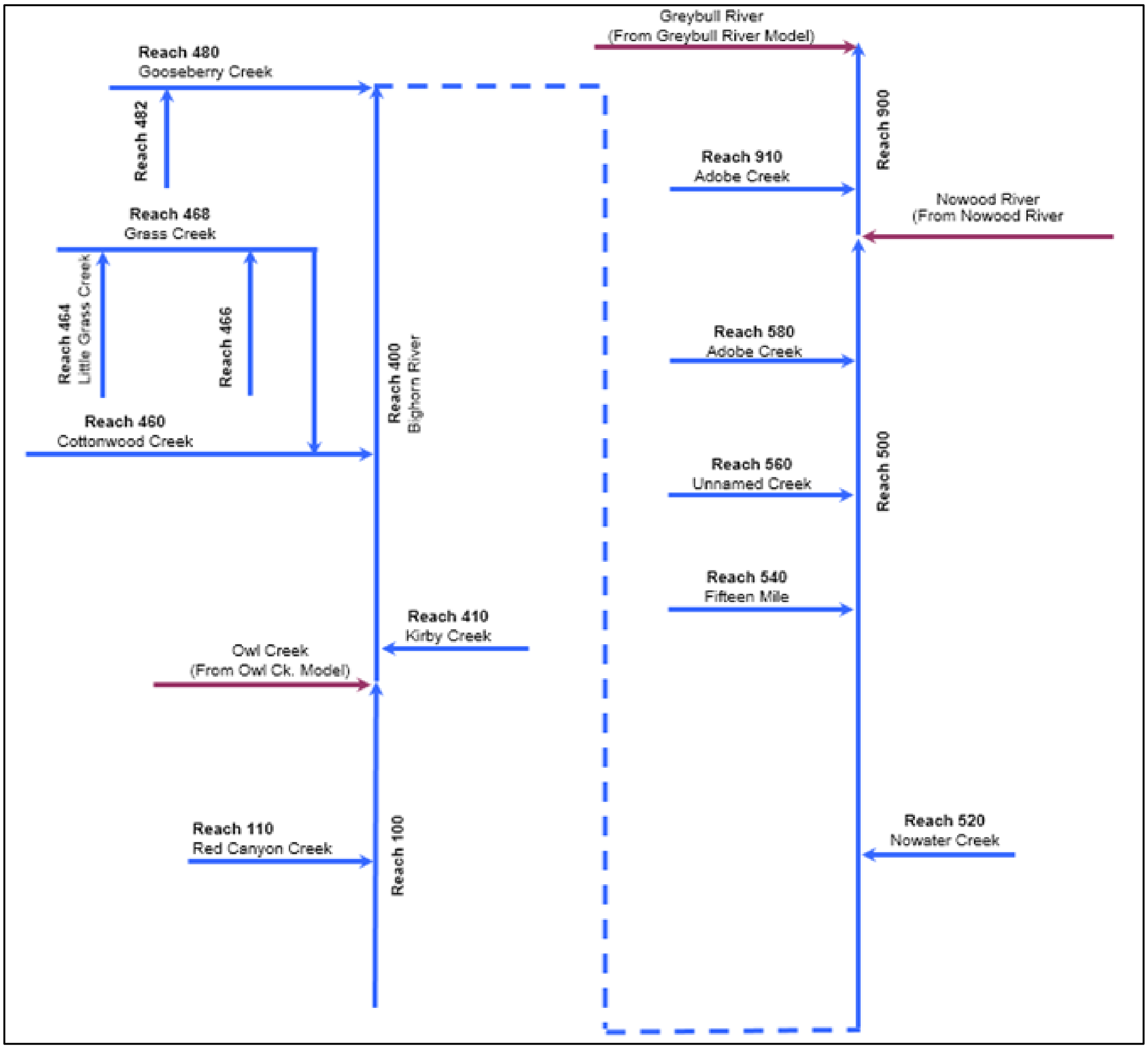

Figure 72: Schematic for Upper Big Horn Planning Model showing various input and output nodes. (BRS, 2003)

Through Water Year 2018, there were only four active gages in the study area. Three are on the Big Horn River. In the downstream direction, one is at Boys School (0303BH08[2]), one at Worland (06268600[3]) (discontinued July 1, 2018), and one at Basin (06274300[4]). These three gages record, predominantly, regulated flow released from Boysen Reservoir, which is in the Lower Wind sub-basin mode. These regulated flows are modified (additions/subtractions) by water inputs, diversions, and consumptive use between the two ends of the study area (start of reach 100 and end of reach 900). The fourth gage is on Gooseberry Creek (0313GC01)[5], roughly in the middle of the watershed. This gage is only operated seasonally from late March through early October. Refer to Map Book, Map 34 for a representation of stream gages in the study area.

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[2] Operated by the Wyoming State Engineer's Office
[3] Operated by the U.S. Geological Survey
[4] Operated by the U.S. Geological Survey
[5] Operated by Wyoming State Engineer's Office

The streamflow record since the 2010 Wind/Bighorn River Basin Plan update to the original 2003 plan, at all four gages, is incomplete to varying degrees. The gage record at Boy's School is mostly complete but has missing data during low flow seasons 2010–2012 (Figure 73 and Figure 74). The gage record at Worland has no data between 1970 and early January 2015, and then some missing and estimated data through 2018 (Figure 75 and Figure 76). The gage record at Basin has both missing and estimated data, but at least has some data for the years 2010 through 2018 (Figure 77 and Figure 78). The gage record for Gooseberry is missing data for 2013 through 2015 (Figure 79). (MWH Americas et al., 2010)

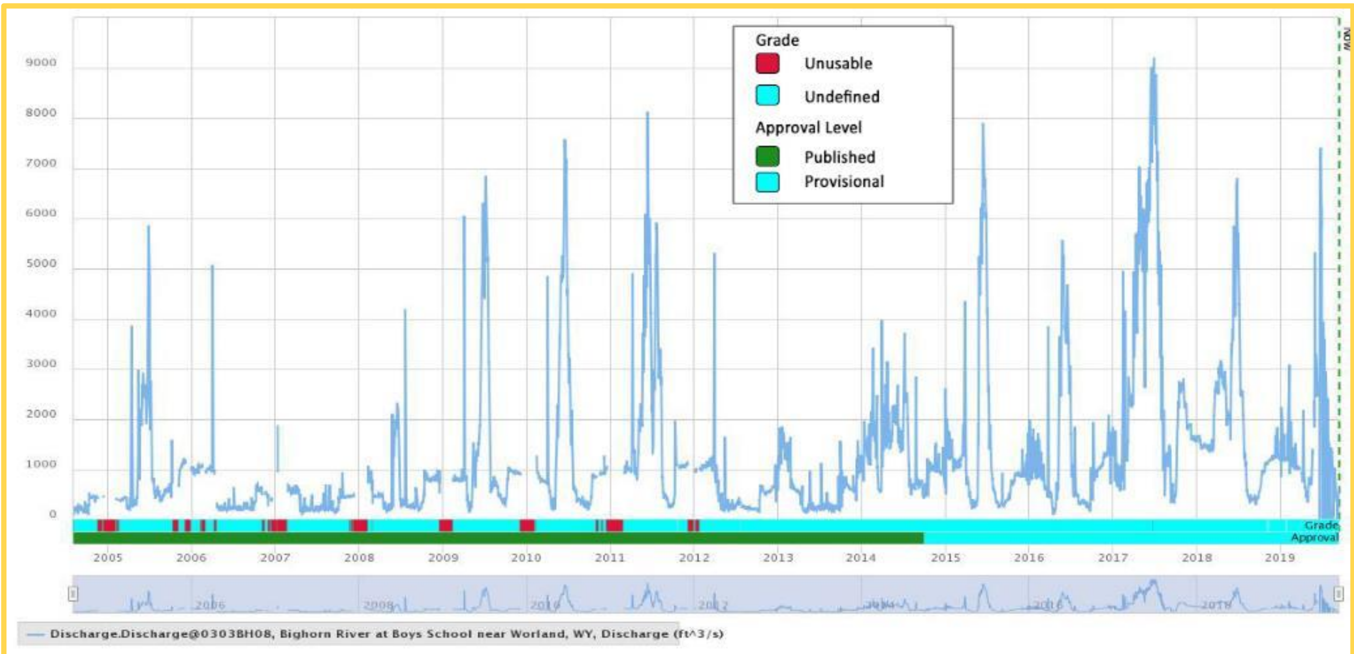

Figure 73: Streamflow record for Big Horn River at Boy's School (MWH Americas et al., 2010).

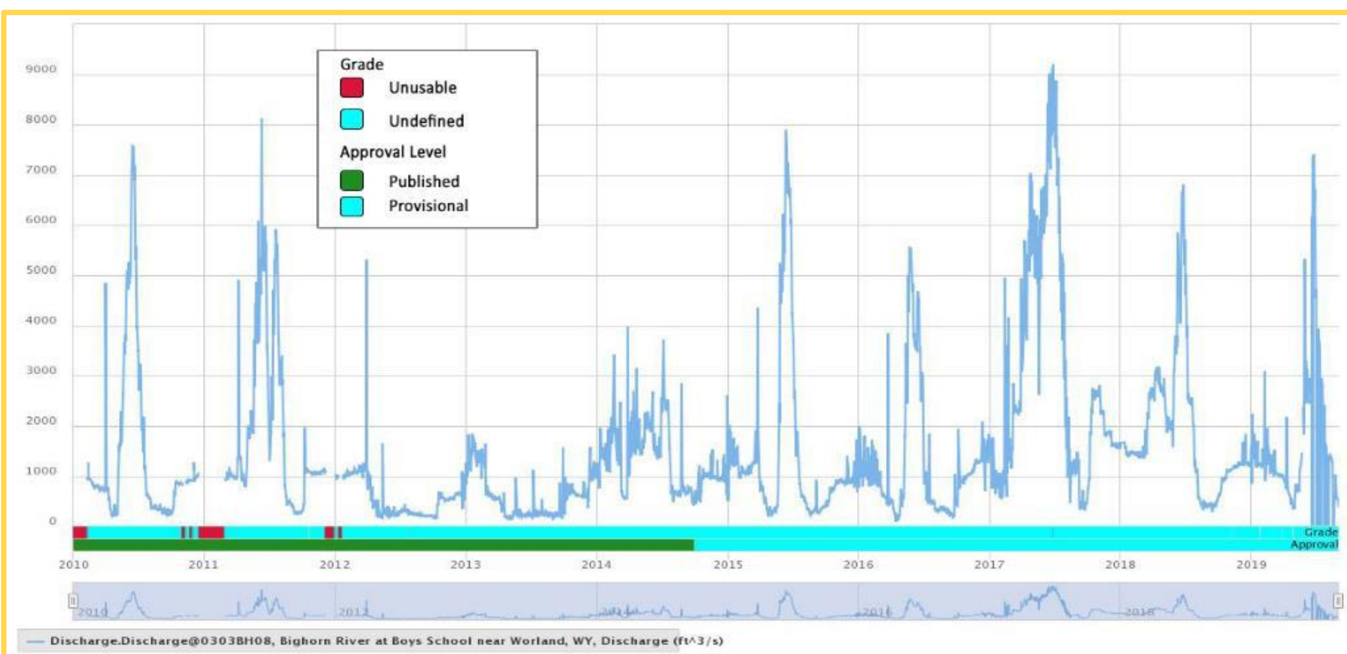

Figure 74: Streamflow record for Big Horn River at Boy's School since 2010 River Basin Plan update (MWH Americas et al., 2010).

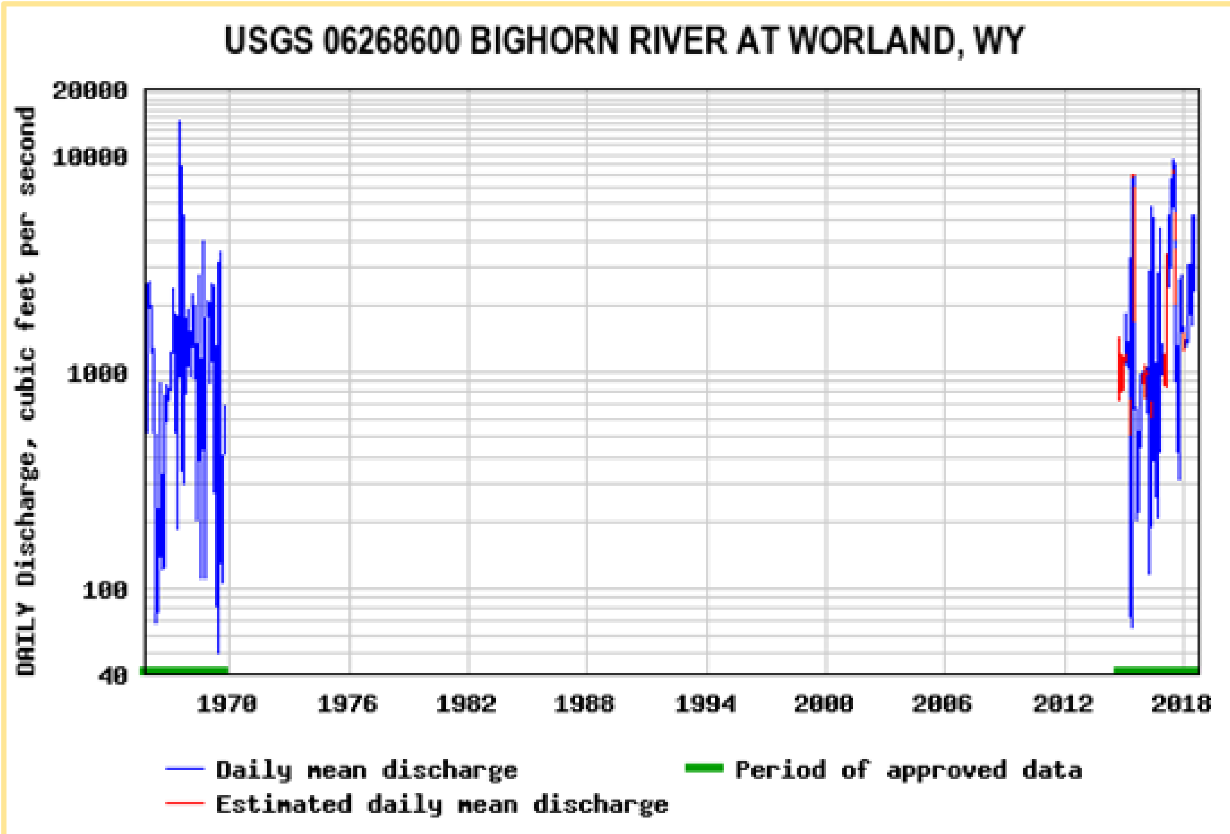

Figure 75: Streamflow record for Big Horn River at Worland (MWH Americas et al., 2010).

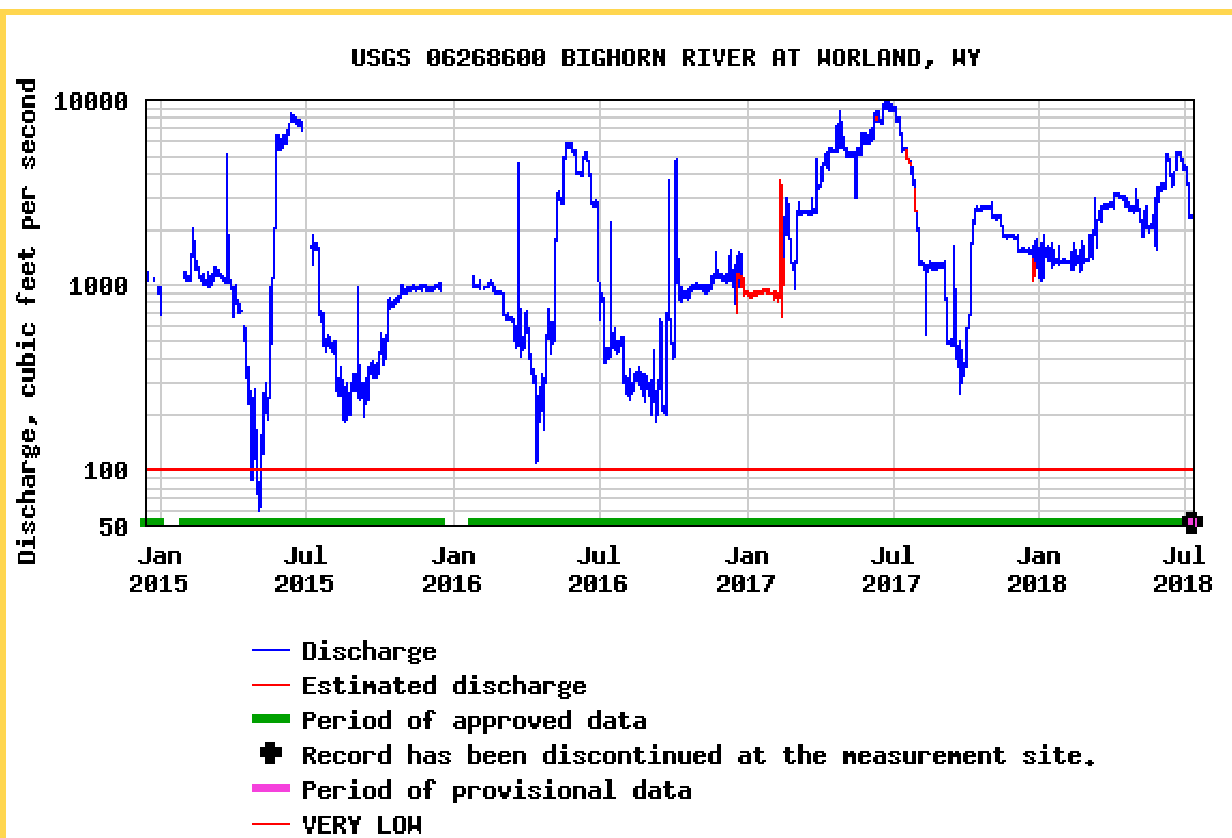

Figure 76: Streamflow record for Big Horn River at Worland since 2010 River Basin Plan update (MWH Americas et al., 2010).

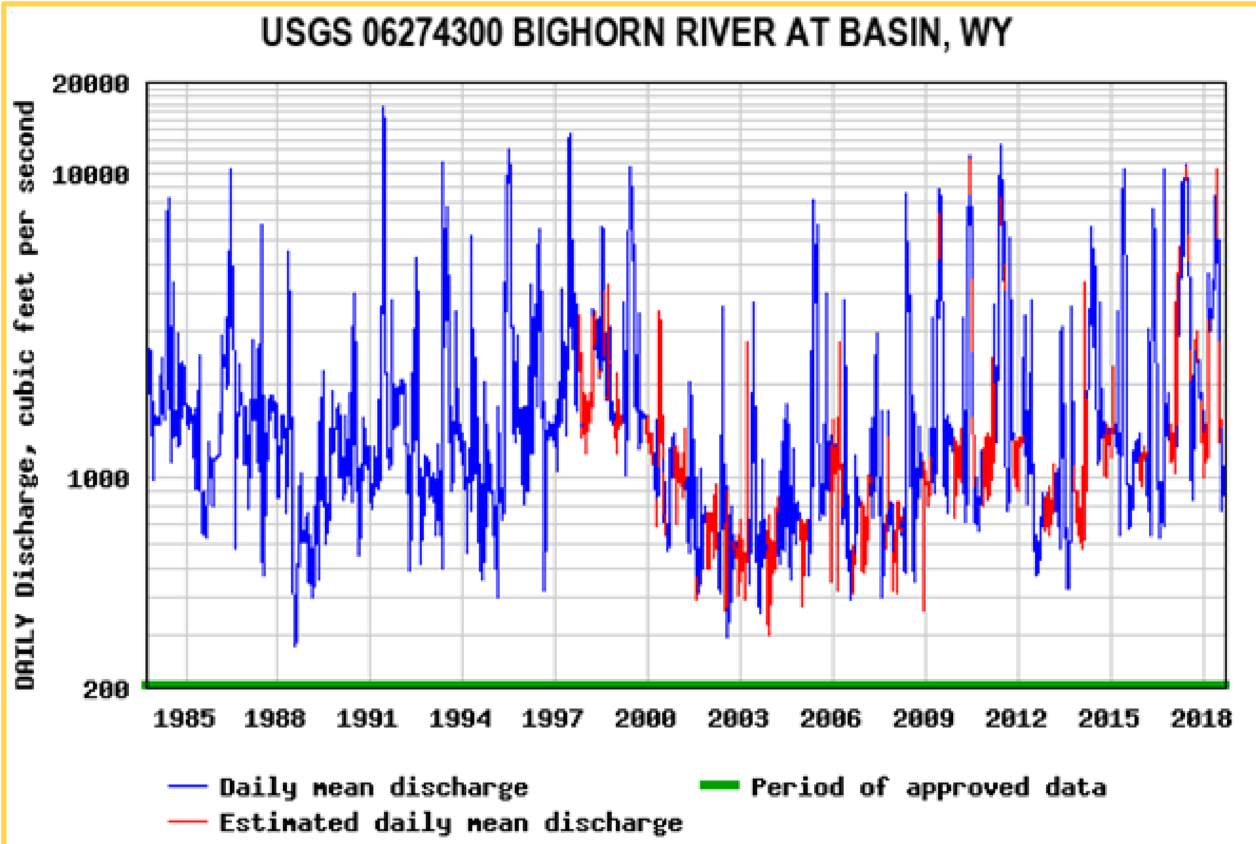

Figure 77: Streamflow record for Big Horn River at Basin (MWH Americas et al., 2010).

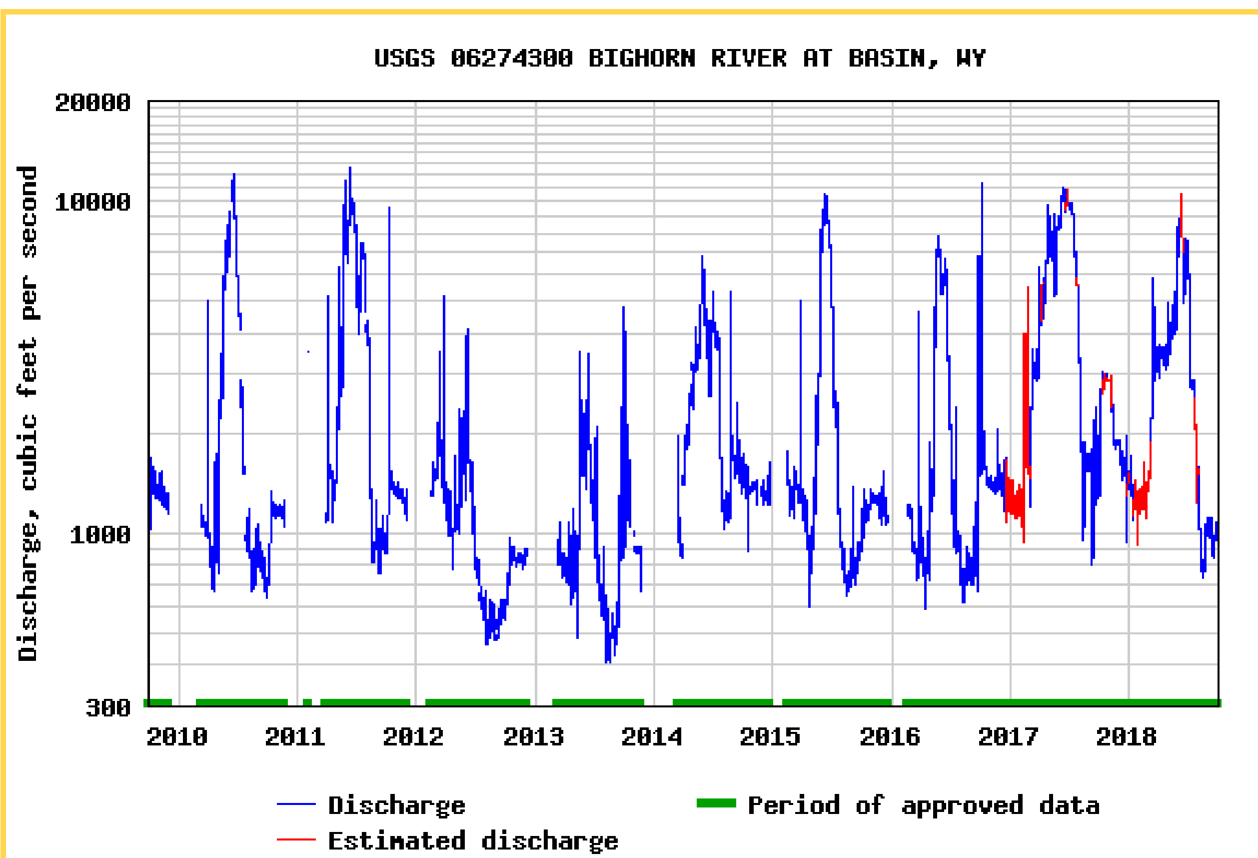

Figure 78: Streamflow record for Big Horn River at Basin since 2010 River Basin Plan update (MWH Americas et al., 2010).

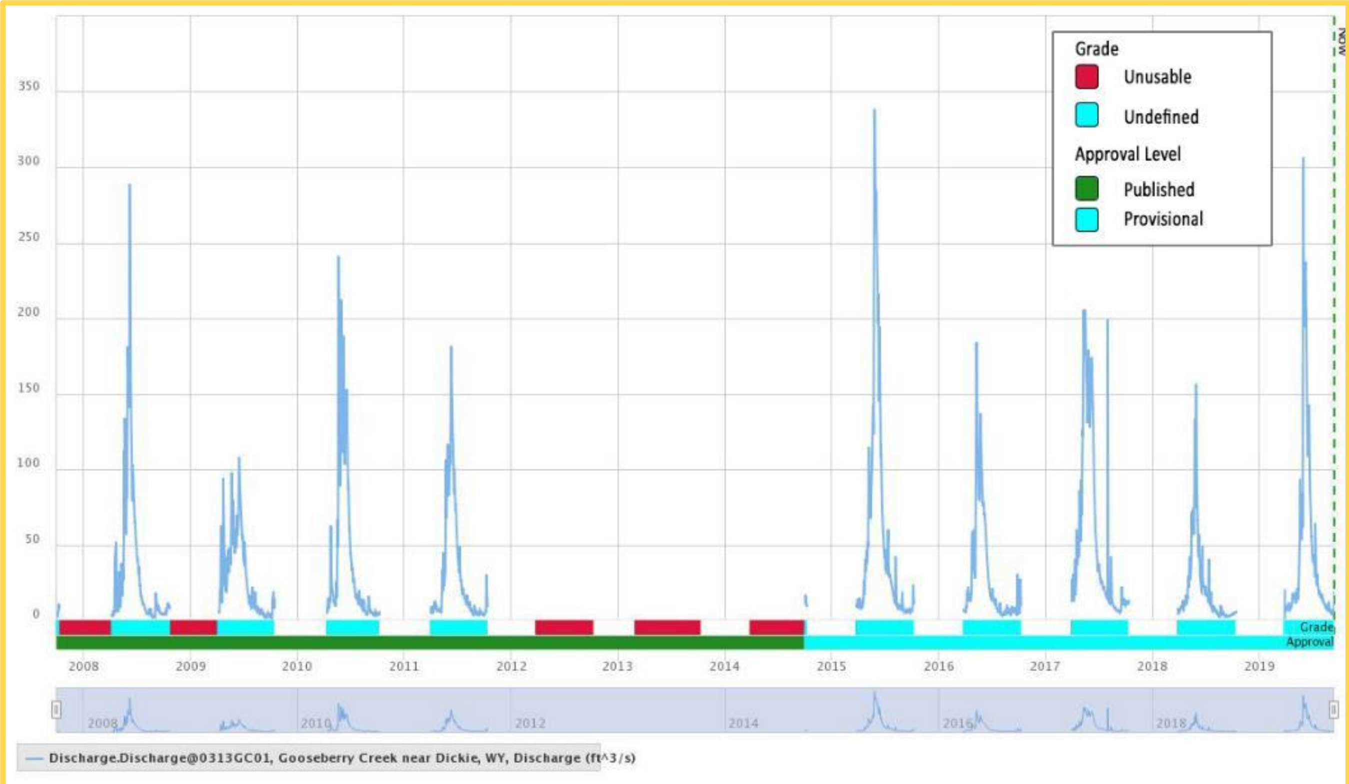

Figure 79: Streamflow record for Gooseberry Creek near Dickie since 2008 (MWH Americas et al., 2010).

There are techniques and procedures for filling missing streamflow data (see 2003 and 2010 Basin Plan reports and associated technical memorandums at the WWDC websites). Conducting such an exercise for these four gages is problematic given there are not only multiple years of missing data, but also extended periods of missing data within years.

In summary, updating the 2010 Upper Bighorn sub-basin model, wholly or partially, as part of this study is problematic. There are five core reasons:

- There are insufficient streamflow records for the years 2010 through 2018;
- There are three sub-basin models within the Upper Bighorn sub-basin model, each of which would need to be updated to accurately reflect their node inputs into the Upper Bighorn sub-basin model;
- There are thirteen lateral drainage nodes within the Upper Bighorn sub-basin model, each of which would need to be updated to accurately reflect node inputs;
- The majority of the water uses in the study area are reliant on flows generated in the Wind River portion of the Wind/Big Horn River Basin Plan area; which feed Boysen Reservoir; which acts as a buffer used to meet downstream demands; and
- The study area only comprises 52% of the area covered by the Upper Bighorn sub-basin model

Thus, in lieu of updating the model in whole or at nodes within the study area, hydrographs for dry, average, and wet years, as presented in output tables in the 2010 River Basin Plan, are presented for major nodes in the study area (Figure 80 through Figure 84). The major nodes are:

- From the Upper Bighorn sub-basin model
    - Big Horn River to Owl Creek (100) (Figure 80)
    - Gooseberry Creek (480) (Figure 81)
    - Big Horn River from Gooseberry Creek to Nowood River (500) (Figure 82)
    - Big Horn River from Nowood River to USGS Gage (900) (Figure 83)
    - From the Nowood sub-basin model (800) (Figure 84)

Remaining nodes within the Upper Bighorn sub-basin model and the output node from the Owl Creek sub-basin model are not presented because they contribute minor volumes of flow relative to the acre-foot volumes in the presented nodes.

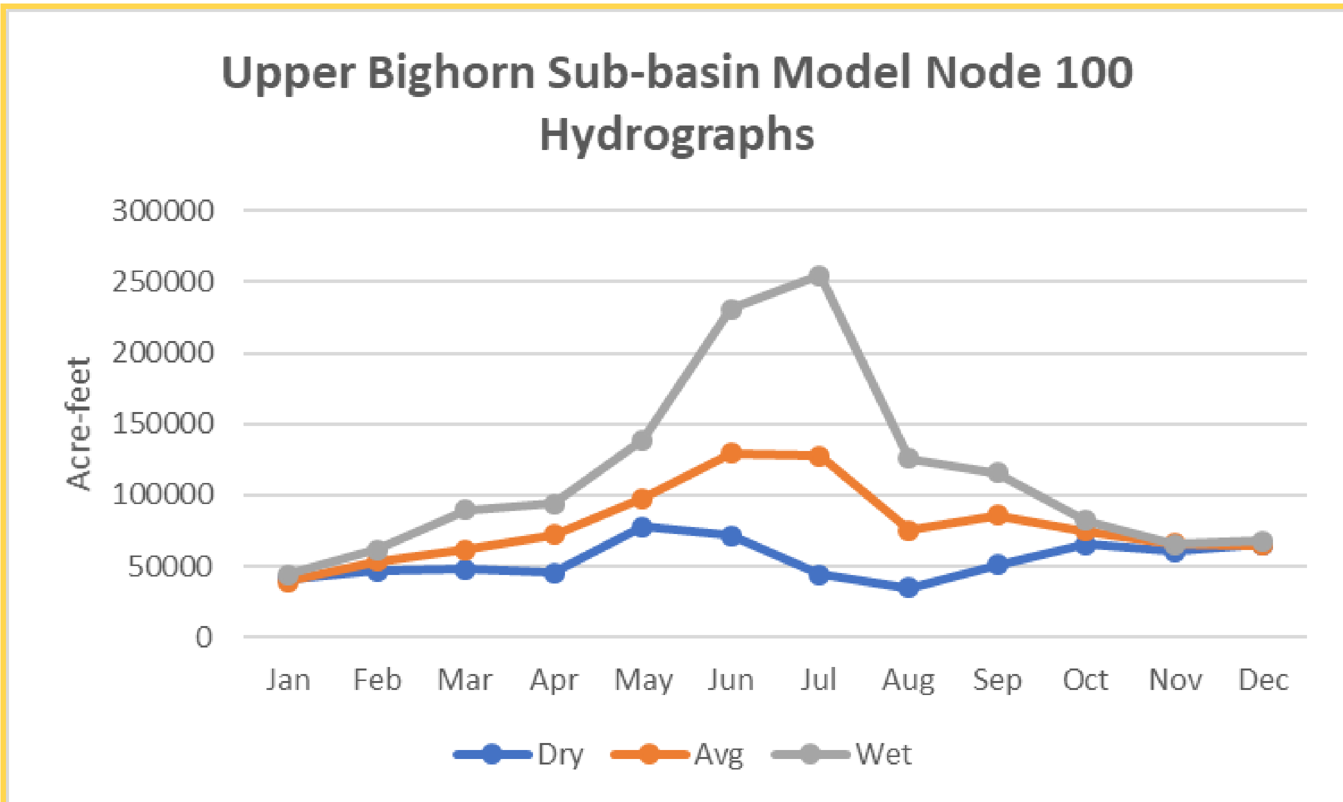

Figure 80: Dry, average, and wet year hydrographs at Upper Bighorn Sub-basin Model Node 100 (Big Horn River to Owl Creek).

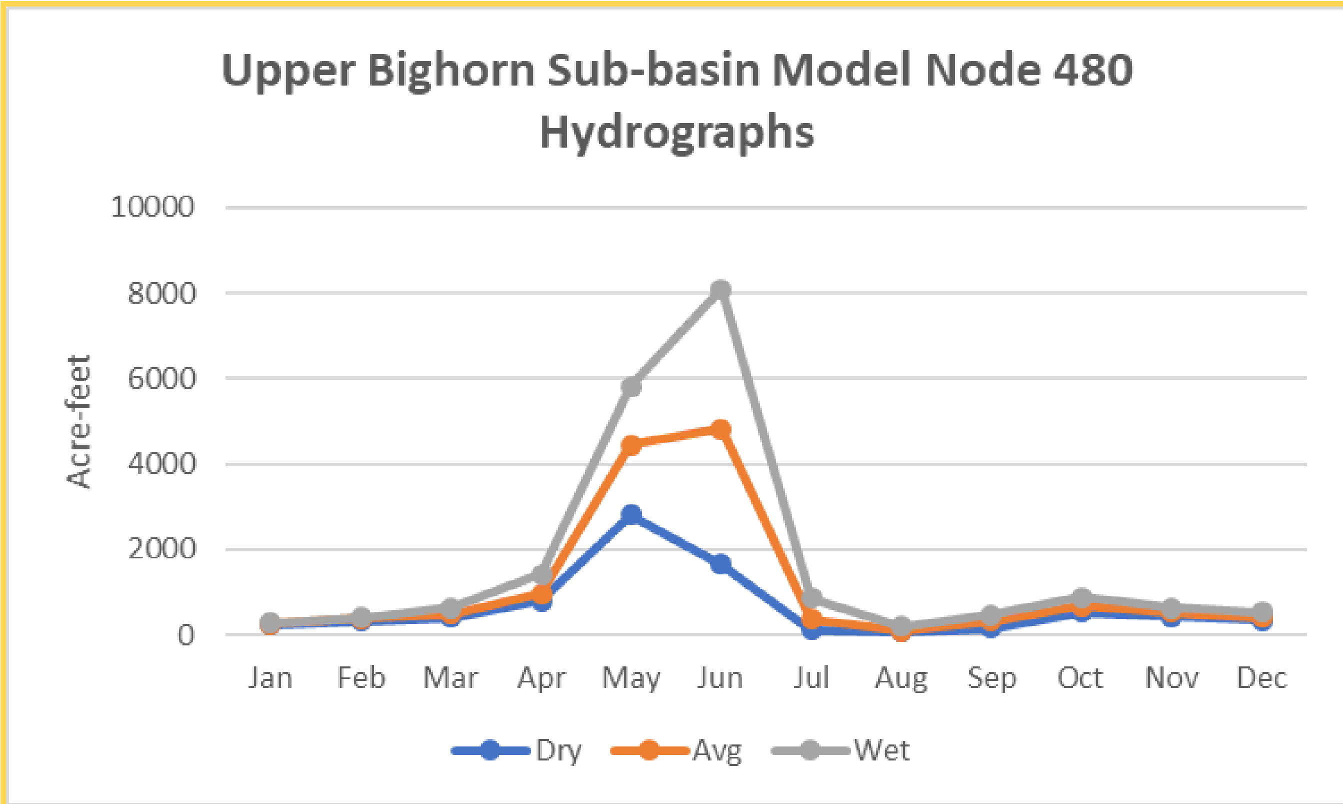

Figure 81: Dry, average, and wet year hydrographs at Upper Bighorn Sub-basin Basin Model Node 480 (Gooseberry Creek).

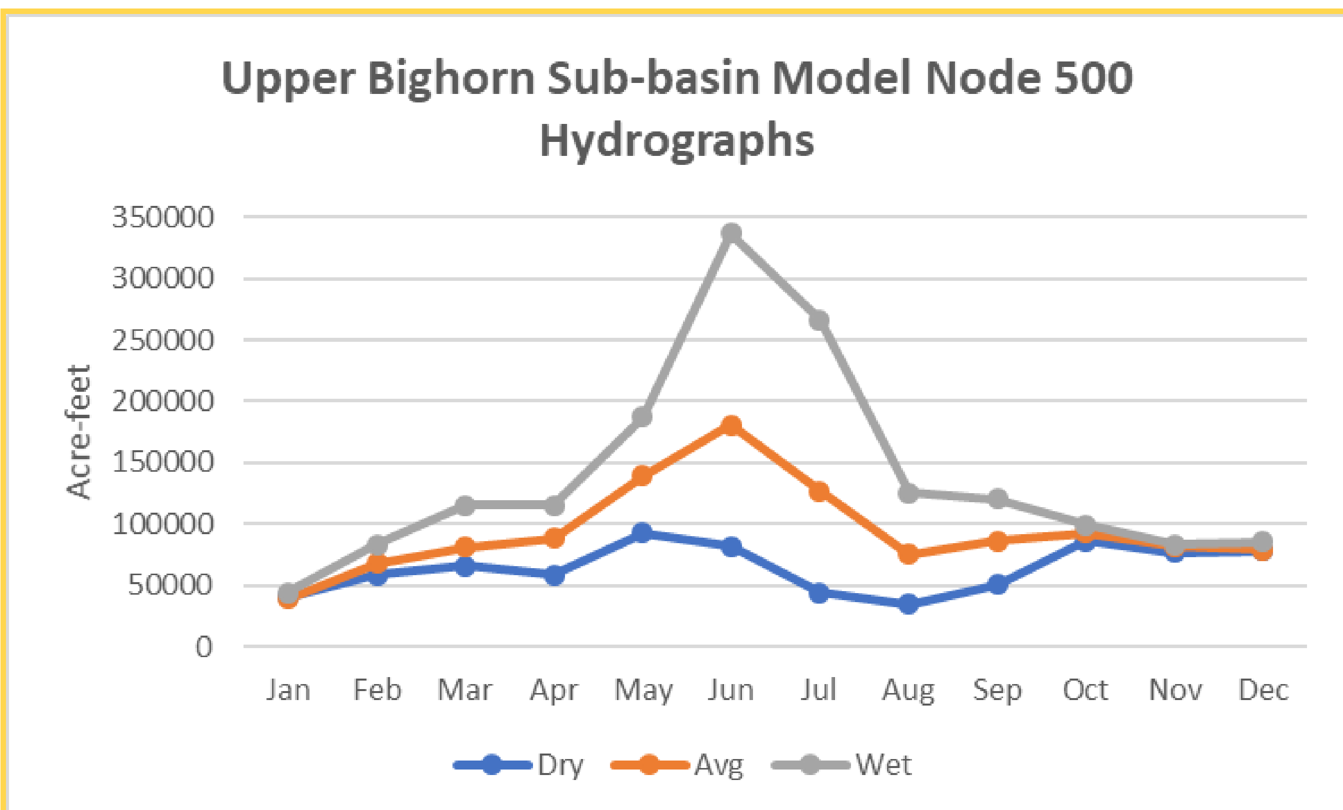

Figure 82: Dry, average, and wet year hydrographs at Upper Bighorn Sub-basin Basin Model Node 500 (Big Horn River from Gooseberry Creek to Nowood River).

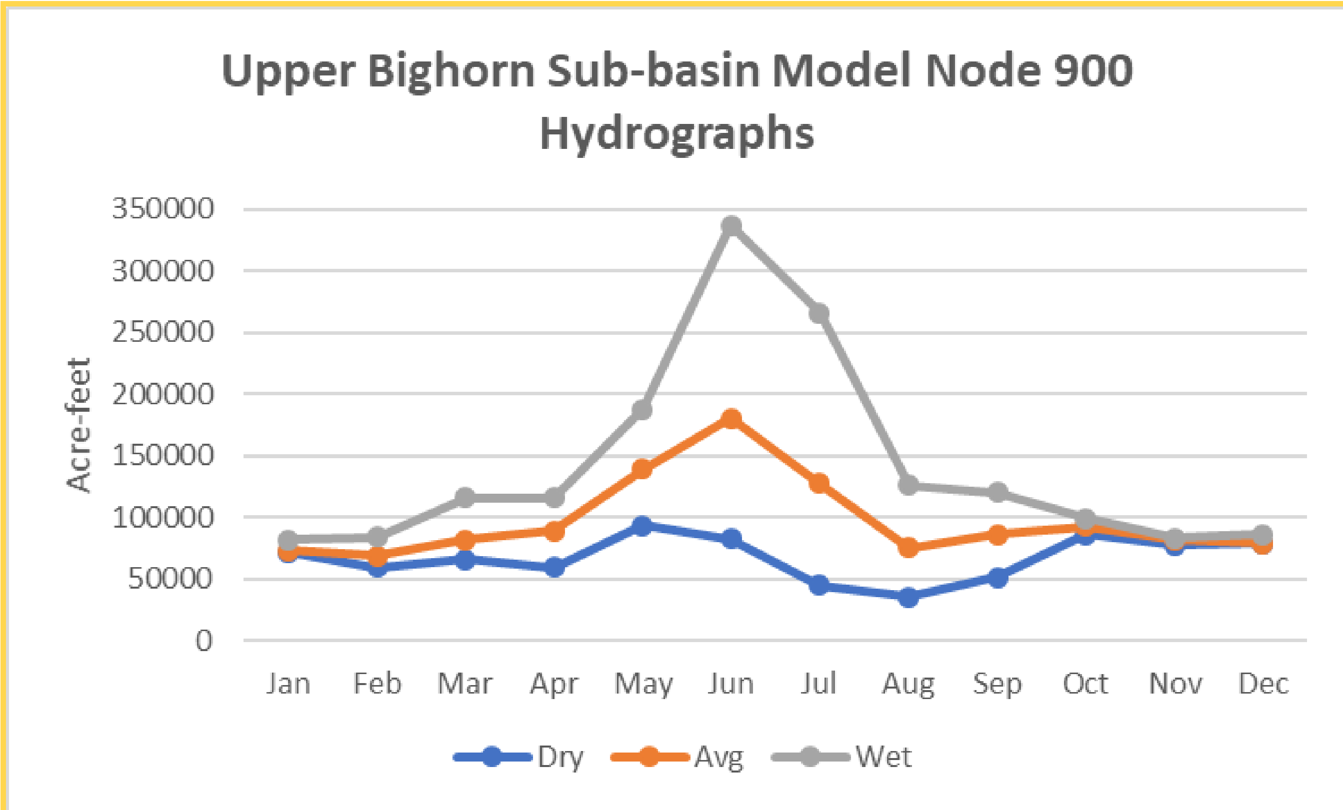

Figure 83: Dry, average, and wet year hydrographs at Upper Bighorn Sub-basin Basin Model Node 900 (Big Horn River from Nowood River to USGS gage).

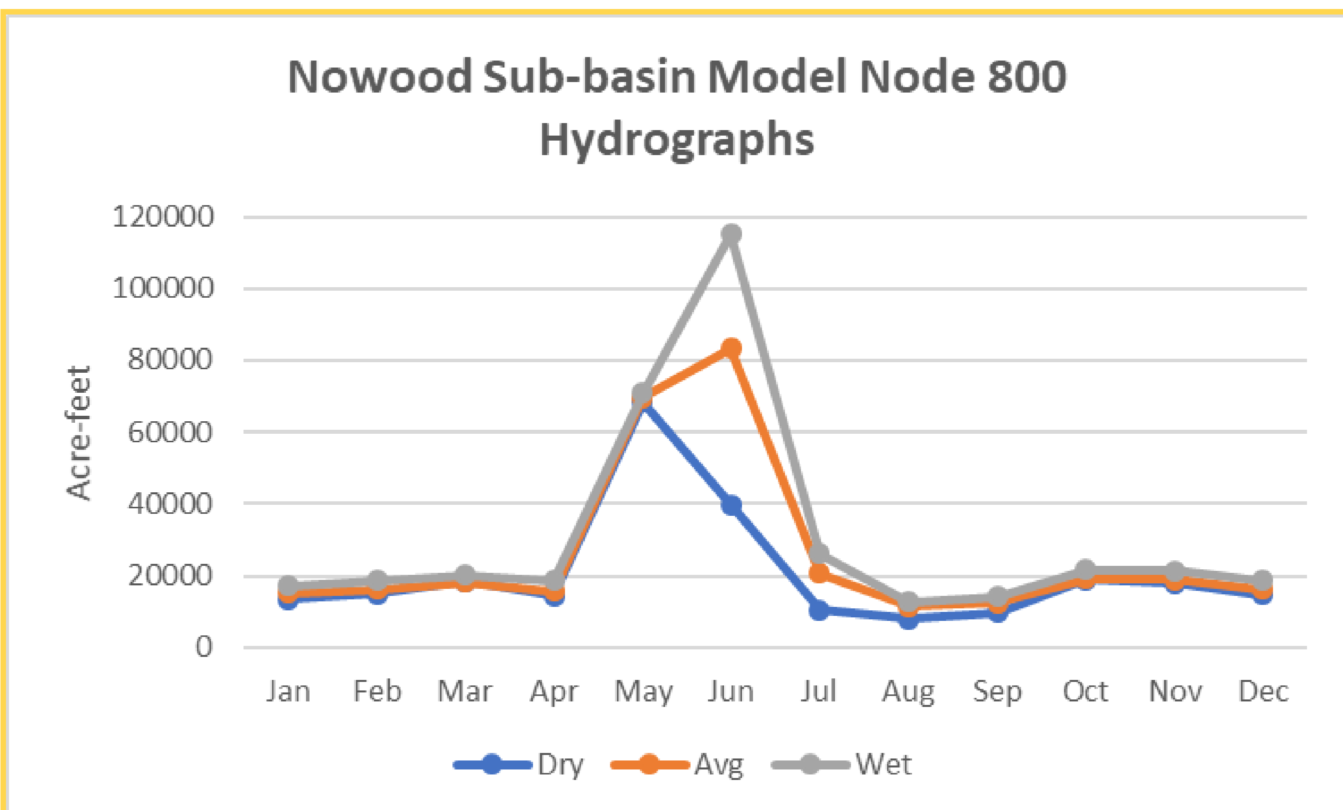

Figure 84: Dry, average, and wet year hydrographs at Nowood Sub-basin Model Node 800.

AVAILABLE FLOW AND SHORTAGES

The narrative in the 2010 Wind/Bighorn River Basin Plan Update summarizes available flow and shortages for the Upper Bighorn sub-basin, which includes the study area. A synopsis of this narrative is presented below.

Flows in the Big Horn River are highly regulated by Boysen Reservoir. The reservoir is operated to deliver sufficient water to canals and ditches along the mainstem of the river, thus through the study area, to minimize shortages.

One potential future water use is the proposed Westside Project, which would divert Big Horn River flow to irrigate new agricultural lands in the Worland area. Surface water availability calculations indicate this potential diversion is within the water supply availability estimates. (Bureau of Reclamation, 1988; Bureau of Reclamation: Upper Mississippi Region, 1983)

Shortages within the study area are exclusively on Gooseberry Creek. Flow is available to assist with the shortage, if adequate storage facilities are in place. A portion of the available flow in Gooseberry Creek is from oil and gas production discharges, which could potentially decrease over time if production decreases, exacerbating existing shortage issues and concerns. Numerous studies of the Gooseberry Creek shortages have been conducted. The most recent was prepared by and is titled Gooseberry Creek Level I Study (Lidstone and Associates, Inc., 2005). The report presents three alternatives for additional study. These options include:

- Construction of an 8,000-acre-foot reservoir,
- Acquiring water from the Grass Creek Oil Field, and
- Improving irrigation systems.

STREAMSTATS

StreamStats is a web-based USGS application that provides spatial analytical tools useful for water-resources planning and management. The application is also useful for engineering and design purposes. The application is in varying stages of completion as it is being built on a state-by-state basis through cooperative agreements. Information for Wyoming is presently under development and is expected to be released in 2024.

Once available, the map-based user interface can be used to delineate drainage areas, and then derive basin characteristics and estimates of streamflow statistics at site-specific locations along a stream channel. The interface can also be used to select locations of stream gages and obtain flow statistics and other information for said stations. The application will be very useful for watershed studies and river basin planning efforts, as well as development of local water resource use and distribution projects.

CHAPTER 5: DEVELOPMENT, MANAGEMENT, AND REHABILITATION PLAN

During the Middle Big Horn Level I Watershed Study, a Development, Management, and Rehabilitation Plan (DMRP) was developed to make recommendations for issues identified over the course of the study period. This plan was to be technically sound, achievable, practical in nature, and possible from an economic standpoint. The purpose of this DMRP is to provide a conceptual framework to assist the Sponsors in applying improvements to the watershed based on real cases that were observed. This plan is not a one-size-fits-all solution to problems that have been identified in this study. The development of the plan was performed in conjunction with a GIS inventory for the study area based on pre-existing and field gathered information. The Project Summary Book provides an inventory of the potential projects gathered. Refer to Table 28 and Map Book, Map 35 for an overview of potential projects.

OVERVIEW OF RECOMMENDED WATERSHED IMPROVEMENTS

Across the study area many opportunities have been identified for development, management, or rehabilitation. These issues have been organized into seven categories based on problems and solutions for the aspect of the watershed they relate to. The categories are:

- **Irrigation and Drainage System Improvements and Rehabilitation:** Improvements were identified through coordination with local stakeholders and study area inventory efforts. Improvements have been identified for numerous structures and locations to augment existing infrastructure.
- **Livestock/Wildlife Upland Water Source Developments:** Over the course of this project field visits into the outlying regions of the study area identified limited opportunities for existing water sources.
- **Surface Water Storage Opportunities:** Across the watershed study area there are numerous but often limited opportunities to sustainably enhance the existing condition of water storage. Additionally, these areas could be used, in certain cases, as silt management countermeasures.
- **Riverbank Stabilization:** There are consistent issues with existing channel stability and condition across the study area.
- **Wetland Development and Enhancement:** There may be opportunity for wetland improvements along the perennial reaches of Gooseberry Creek.
- **Grazing Management:** Throughout the uplands, range improvement projects such as fencing, water development, and mineral placement can improve the distribution of livestock and potentially improve rangeland health. Managing the season of use can also be used to improve bank stability and reduce erosion in the watershed.
- **Hydroelectric Power Generation:** One potential hydropower project was identified with the City of Worland's artesian well.

Some of the categories, like "Irrigation and Drainage System Improvements and Rehabilitation" include specific projects that can directly improve that aspect of the watershed. For some categories, like "Wetland Development and Enhancement", no specific projects were developed within this aspect of the watershed, but if projects from other categories are implemented it will have a positive effect on this category. In the following sections we will discuss potential watershed improvements in more detail prior to discussing the recommendations within the DMRP. Specific project recommendations, if applicable, within each category are listed further in this chapter in the Watershed Improvement Projects section.

IRRIGATION AND DRAINAGE SYSTEM IMPROVEMENTS AND REHABILITATION

Much of the existing infrastructure in the area for irrigation, water transmission, and drainage has exceeded its effective design life. Because of this, there is a large demand to rehabilitate existing water infrastructure. Whether in the more agricultural regions of the watershed in the outlying upland regions, or within town limits, improved access and conveyance of water provides an unquestionable benefit to the watershed. Replacement with parts in kind or complete re-design and evaluation of the existing irrigation and drainage infrastructure would benefit many agricultural producers in the region. Improvements made to these systems provide increased water transmission efficiency, limit losses associated with infiltration and seepage, and prevent surface ponding and below-grade water infiltration in homes. Improvements to water conveyance will drive improvements in overall water availability and water quality throughout the low-lying irrigated regions of the study area. Many producers in the area have started to take a proactive approach and have begun installing improved irrigation systems and methods.

Strategies for the improvement of water conveyance in the watershed include:

- Rehabilitation of existing diversion and delivery structures,
- Mitigation of seepage losses through the installation of low permeability conveyance structure materials,
- Installation of underground pipelines from existing diversion points to points of use, and
- Installation of a ditch liner for those cases where piping is impractical.

If the above strategies are followed there are several benefits that will be observed over time across the study area. However, the benefits observed are a direct function of the number and size of improvements made. Some of these benefits are:

- Improved water quality,
- Reduced erosion and seepage,
- Increased water availability and subsequent increases in plant growth, along with higher nutrient availability,
- Reduced sediment loading in source and return water flows,
- Improved economic output for the region, and
- Increased aquatic health for natural fauna, livestock, and humans.

During our interactions with governmental and local stakeholders across the study area, there was a clear desire to develop water conveyance enhancements. Any efforts to augment water conveyance across the study area will be beneficial. For more information on these projects see the section on Irrigation and Drinage Systems that begin later in this chapter on pg. 109. A complete list of projects related to irrigation can be found in the Project Summary Book.

LIVESTOCK/WILDLIFE UPLAND WATER SOURCE DEVELOPMENTS

Throughout the course of the inventory for this study, an assessment of outlying areas used for livestock grazing was completed. During this assessment wildlife was observed in conjunction with livestock. Water is a critical component for wildlife and livestock to thrive. Multiple upland water sources were observed by Y2 in a variety of conditions during the field inventory. There are multiple livestock growers that operate on either deeded or leased land. Water supply is a constant challenge for many of these operators. Water sources vary from seeps and springs to operators trucking water in for stock use.

There are a variety of upland water sources and structures dedicated to water storage for stock and wildlife use, such as tanks or other storage vessels and earthen dams or ponds. These dams and ponds also serve a function of providing sediment loading mitigation and controlled release of water. This combined function occurs the most in areas of the watershed that are prone to silt delivery with runoff. This case is typically observed in the Fifteenmile drainage, located centrally in the watershed.

The primary issue observed, as related to water storage in upland areas, is the buildup of silt and lack of maintenance of existing silt mitigation structures. Many of the silt mitigation structures installed in the study area were completed over 30 years ago and have seen no dedicated maintenance since. The dual role, water storage and silt mitigation, that these structures served in their ideal operational state is no longer occurring.

There were several instances observed throughout the watershed study where water was delivered for livestock use from a seep or spring. Many of these seeps and springs have not undergone improvement. This was noted in the northern region of the watershed, specifically in the Tatman Mountain area. In other regions, such as the Gooseberry and Nowater drainages, there has been more widespread development of seeps and springs for use (Map Book, Map 32). Over the course of the study it was noted that many of these springs run perennially with only limited interruption during dry years. For the seeps and springs observed over the inventory period of this project there was substantial potential for improved production. While many of these seeps and springs have undergone improvements, they could be further augmented to deliver water for upland use in the watershed. Springs play a crucial role in the development and continued use of range within the Middle Big Horn Watershed. In many cases, especially throughout the northern reaches of the watershed, water is scarce. This scarcity can be improved upon with better development of springs and seeps.

In this study, numerous upland water sources were identified through local stakeholders (Map Book, Map 32). If these potential projects can be either established or rehabilitated, it would improve water availability across the watershed for livestock and wildlife use. Improved water access will limit stress on livestock and wildlife, improve livestock yield and the health of wildlife in the area, and could expand grazing range for livestock. Water source development could disperse grazing pressure and reduce soil erosion, if coupled with proper grazing management. Increased water availability would augment the overall quality of the watershed. By improving water access in water-limited areas, the distribution of livestock can be increased and allow for more efficient and sustainable use of rangelands. This, in turn, can drive an improved economic benefit for the livestock industry for the long term.

Much of the area currently utilized for livestock grazing is remote. This increases the development cost of these projects. However, a targeted approach to those areas where there are proven wells or seeps will allow for development, like in the Nowater drainage, the Tatman Mountain area within the Fifteenmile drainage, and the upper Gooseberry. The application of controlled water delivery and access for stock and wildlife provides a value-added component to the watershed.

A more thorough summary of the individual projects as related to upland water sources are shown in the following sections. These are primarily related to wells, springs, and seep developments in the uplands of the watershed. Within each of the summaries is a baseline estimate for cost. However, for a more in-depth estimate, it is recommended that spring and well development experts be contacted. For more information on these projects see the section on Upland Water Source Development that begin later in this chapter on pg. 117. A complete list of projects related to upland water source development can be found in the Project Summary Book.

SURFACE WATER STORAGE OPPORTUNITIES

There are numerous opportunities to enhance the existing water storage infrastructure across the watershed. These opportunities include stock ponds and silt dams. The improvement of water storage in the uplands would provide additional water to wildlife and livestock. Additionally, some of these developments can be used as silt management countermeasures, improving water quality. Silt dams are a common method of surface water storage in the study area that commonly are in need of maintenance. For more information on these projects see the section on Surface Water Storage Opportunities that begin later in this chapter on pg. 122. A complete list of projects related to surface water storage can be found in the Project Summary Book.

RIVERBANK STABILIZATION

The conditions of the primary streams, associated channels and tributaries were assessed as part of the hydrologic examination of this study. This investigation included field visits by Y2. The results of this investigation are discussed in Chapter 3 – Channel Structure and Stream Stability. This examination details the general geomorphology and evolution of the stream systems in the watershed study area.

There are multiple projects that could enhance the stability of riverbanks in the watershed. Projects such as these are highly variable dependent on the form and condition of each reach of stream in question. For more information on these projects see the section on Riverbank Stabilization that begin later in this chapter on page 126. A complete list of projects related to riverbank stabilization can be found in the Project Summary Book. For more information on channel stabilization projects in general contact the Natural Resources Conservation Service (NRCS) and Wyoming Game and Fish Department (WGFD) and refer to the WDEQ Stream and Lakeshore Restoration BMPs.

WETLAND DEVELOPMENT AND ENHANCEMENT

The establishment or re-establishment of wetlands would serve to help mitigate the current silt loading issues that are seen in the study area. There is an opportunity to do so along the perennial reaches of Gooseberry Creek. Some examples of improvement projects could include mechanical restructuring of the stream channel, stream bank revegetation, mechanical dispersion of water to the floodplain, or introduction of beaver.

There are no specific projects for the development or rehabilitation of wetlands. Projects such as these are highly variable dependent on the historic or potential wetland in question. For more information on projects such as these contact the NRCS, WGFD, and/or USACE and refer to the WDEQ BMPs.

GRAZING MANAGEMENT

The implementation of sustainable grazing management practices, such as management in stock type, numbers, rotation, and season of use, in the future can improve and maintain upland ground stability, reducing erosion and stream sediment loads. The use of water placement, mineral placement, and fencing are practices that can increase the distribution of stock in the uplands and reduce grazing impact to riparian areas. Sustainable grazing management practices can also improve upland resilience to invasive annual grasses, fire, and juniper encroachment, and improve wildlife habitat quality. (Chambers et al., 2016)

There is are no specific projects regarding grazing management. Projects such as these are dependent on the site in questions history, use, and current management practice. Grazing management plans can be extensive dependent on the size of the operation. For more information on projects such as these contact the local NRCS and BLM or Forest Service offices (for public land projects) and refer to WDEQ BMPs.

HYDROELECTRIC POWER GENERATION

The City of Worland receives its water from an artesian aquifer, which provides sufficient pressure to develop a considerable amount of head pressure. This head pressure could be utilized to develop hydroelectric power for use by the City of Worland. More information is provided in the Hydroelectric Power Generation section on page 127.

WATERSHED IMPROVEMENT PROJECTS

Of categories that were discussed above, the Irrigation and Drainage System Improvements and Rehabilitation, Livestock/Wildlife Upland Water Source Developments, Surface Water Storage Opportunities, Riverbank

Stabilization, and Hydroelectric Power categories have potential projects. Refer to the following sections and the Project Summary Book for additional information on these projects. The Wetland Development and Enhancement and Grazing Management categories do not have specific projects but will benefit from many of the projects included in the other categories.

Project types were determined from the projects obtained from local stakeholders and multiple site visits performed across the study area. Refer to Map Book, Map 35 and Table 28 for a map and table of potential projects within the study area. Each project type overview includes case studies, typical details, funding options, and project considerations. Project types include:

- Irrigation and Drainage System Improvements and Rehabilitation
  - Drainage
  - Ditches and Pipelines
- Livestock/Wildlife Upland Water Source Developments
  - Wells
  - Springs
- Surface Water Storage Opportunities
  - Silt Dams
- Riverbank Stabilization
- Hydroelectric Power

Each category, as discussed above, is influenced by different project types. The Irrigation and Drainage System Improvements and Rehabilitation category includes drainage, ditch, and pipeline projects. The Livestock/Wildlife Upland Water Source Developments category includes well and spring projects. The Surface Water Storage Opportunities category includes silt dam projects.

Each project type section below details the project as well as case studies. Each of the following project types were gathered through either onsite inventory or from public engagement and subsequent site visits. Provided details for each project type are for typical construction and may not reflect final design.

The following development options have been assessed for each project type. These topics are included in each of the project reports for local stakeholders to be able to advance their projects. Criteria defined by the WWDC were used in the selection and definition of potential projects; these are shown below:

- Rehabilitation or replacement of existing structures
- Mitigation of seepage
- Enhanced water conveyance
- Cost reduction
- Improved water efficiency
- Economic practicality
- Feasibility
- Reduction of runoff resulting in sediment and contaminants

The summary of individual projects has been included in the Project Summary Book where project stakeholders can identify their respective projects and use the information developed to advance their projects. The project summaries also designate a public sponsor and project details for each project.

In the following sections project overview, case studies, cost estimates, and funding options are described. Y2 also provided basic quantities of materials and components along with typical details for each of the projects. While almost all of these projects provide distinct benefits there can be in some cases drawbacks to their development. As part of this study Y2 has endeavored to highlight drawbacks and other project considerations as applicable to certain projects. The intent here is not to highlight negative aspects of projects but to ensure that an all-encompassing perspective is provided.

PROJECT COSTS

Table 14 lists the cost and quantity of the projects by project type. There is significant variation in the costs of some project types due in part to the unique nature of each project and its associated parameters. Each project type includes new projects and rehabilitation of existing infrastructure in the minimum and maximum cost estimate.

Table 14: Cost and quantity of the projects by project type.

Project Type	Number of Projects	Percentage of Total Projects Gathered	Estimated Minimum Cost	Estimated Maximum Cost
Pipeline	22	31.4%	$11,955	$144,120
Silt Dam/Stock Reservoir	15	21.4%	$18,500	$645,500
Irrigation	9	12.9%	$5,395	$28,980
Spring Development	6	8.6%	$10,500	$12,000
Well Development	4	5.7%	$50,100	$50,100
Drainage	4	5.5%	$15,000	$1,144,000
Streamflow Monitoring	2	2.9%	$9,000	$9,000
Riverbank Stabilization	5	7.2%	$18,700	$53,700
Bridge Refurbishment	1	1.4%	$17,000	$25,000
Hydroelectric Power Generation	1	1.4%	$500,000	$500,000
Settling Pond	1	1.4%	$20,000	$30,000

The costs shown in Table 29 in Appendix A were used to develop rough cost estimates for the projects listed in Table 14. These costs were based on information gathered from previous experience and vendors in the area. Each of these costs are based on rough component estimates.

PROJECT FUNDING

The projects summarized in the following section have been highlighted for funding opportunities. There are some intricacies to the development of funding opportunities for this study. Some funding sources place specific criteria on the components of a project that are eligible for funding. For those projects that had ineligible components, efforts were made to maximize the funding opportunities by combining funding sources.

The use of combined funding sources is not uncommon and often results in a favorable outcome. While this does introduce another layer of complexity to the project application it is not insurmountable. The goal of this section was to minimize the out of pocket expense for each project stakeholder. This is not a guarantee that funding will be accessible or provided for any one project.

Additional information on specific funding sources mentioned under project types is available in the Funding Sources section further in the chapter. Funding sources were assigned to project types based on eligibility, potential financial award, and relevance to the project. Please see a breakdown of each generic project type and their respective funding sources below (Table 28 and Table 30 in Appendix A).

PROJECT ECOLOGICAL EFFECTS

Water development projects will have multiple ecological impacts. Increased irrigation efficiency will result in less water loss; therefore, less water drawn from the watershed. These projects could result in the protection of future streamflow and water availability for irrigation, grazing, and wildlife, as well as increased groundwater recharge. Projects increasing bank stability, both mechanically and through revegetation and grazing management, can benefit water quality through the reduction of erosion and sediment loading. Wetland development would maintain stream access to floodplains resulting in recharge of floodplain water storage and improved habitat. Increased wetland footprints would also increase natural water filtration, improving water quality. These are just some of the ecological effects of the gathered project types; it is important to consider all potential effects from an ecological standpoint for these projects prior to implementation.

IRRIGATION AND DRAINAGE SYSTEM IMPROVEMENTS AND REHABILITATION

DRAINAGE PROJECTS

Throughout the project multiple areas for improvement for drainage and runoff were identified. These areas were identified primarily through interaction with local stakeholders. Drainage is a crucial component in adequate development of agriculture in this area and it can negatively affect residences when drainage systems fail, causing the water table to rise. Across the watershed there are low-lying areas that are underlain by impermeable soils that restrict drainage. In many cases artificial drainage was installed to remove stagnant water from the area.

One of the challenges faced by many areas in the watershed is the limited drainage capacity of native soils. This places constraints on local producers in terms of crop production and ease of growth. Many of the existing drainage systems in the region have long since passed their useful lifetime. The effective design life of most systems in the area is around 30 to 50 years. In some areas, a drainage system has been in place for almost 100 years. The root of this issue lies for the most part in the makeup of the native soil.

Aging infrastructure represents the largest issue that is faced by drainage systems in the area. In many instances, drains were installed over 50 years ago and have long since failed or are in a non-functioning condition. Many of the installed drains are in unknown locations or are known only in approximation. Drains are commonly located by looking at the water delivery gradient to plants; water delivery gradients are observable in some cases by distinct lines through crop fields indicated by enhanced growth.

PROJECT CASE STUDIES

While drainage projects were not a major constituent of the projects that were gathered for this study, they are important. Y2 was able to speak with multiple people, often affected by the same drainage area, who stressed the impacts that poor drainage was having on them. The areas that were specifically highlighted were local to areas within and around Basin and the West River Road.

West River Road Drainage

The majority of drain locations were unknown along the northern stretch of the West River Road (Figure 37). Y2 was able to meet with Howard Wildman and observe the excavation of one such drain along the West River Road. This drain had failed and was being excavated for replacement. Mr. Wildman had prior knowledge of this drain's location and was able to successfully excavate and replace the drain. During conversations with Mr. Wildman it was determined that there were many such drains in the area that needed repair. It was also determined that the drain networks in this area were contributing to erosion at their points of discharge. In many cases the drains flow underneath the West River Road and discharge from the bluff below the West River Fields. This discharge is not controlled and thus exposes the soil beneath the discharge point to raw hydraulic impact. This impact erodes soil beneath the discharge point and contributes to the erosion of the bluff face.

This example represents one of the more severe cases present in the area both in terms of primary and secondary effects. The primary impact of these areas of poor drainage is increased stagnant water and poorly drained crops. The secondary impact is the soil erosion occurring where the drained water is conveyed and released into the Big Horn River. This limits overall growth potential for crops and limits producers' production capability for their available acreage.

North Antelope Drainage District (NADD) (Project ID: 1-1)

This project would either rehabilitate or re-design the existing drainage network in the North Antelope Drainage District (NADD) that was installed in the early 1900s. This drainage system has exceeded its productive lifespan and is in need of repair.

This project constitutes one of the largest and most needed improvement and rehabilitation projects that was examined during this study. This project is located south of Basin, WY (Figure 38). The project would either rehabilitate or re-design the existing drainage network that was installed in the early 1900s. Currently drainage is accomplished by the same drain tile installed when the original drainage network was built. Much of this system has been compromised by integrity collapse and vegetation infiltration. In many cases the overburden on the existing system has led to portions of the system collapsing. In other cases, the systems flow channels are assumed to have been occluded by root structures. Plainly put, the system no longer functions as was originally intended.

If this project does not proceed, the current flooding issues seen in the Town of Basin will continue. This has a negative effect on the livelihood and wellbeing of the affected citizens. The flooding has led to reduced property value and costs incurred as a result of water damage. If the drain system is reconstructed with a new and functional drain system these issues should be resolved.

The existing NADD is currently assessing its status as a public entity. The commonly known Drainage District has been in place since 1921 when bids were first called for construction of the drainage system that is still in place today. This call for bids can be seen in Figure 85.

The solution, as assessed by the project team, would be to install new drainpipe in a new layout. It is estimated that the cost to rehabilitate the existing system will exceed a complete redesign with new materials. There is an existing network of manholes that could be utilized to tie in the new drainage network and there is also sufficient fall across the NADD to allow for self-cleaning flow if properly designed.

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CALLS FOR BIDS

Copy received until Monday noon

Bids received until Feb. 18, 1921.

NOTICE TO DRAINAGE CONTRACTORS.

CALL FOR BIDS, ANTELOPE DRAINAGE DISTRICT, BASIN, BIG HORN COUNTY, WYOMING.

Sealed proposals will be received by the Antelope Drainage District, at the office of Clyde W. Atherly, District Engineer, Basin, Wyoming, until 10:00 o'clock a. m. February 18, 1921, for the construction of

Excavating and laying 8,794 feet closed tile drain and the backfilling 10,378 feet of trench. The average depth of the drains is nine feet.

Plans and specifications may be examined at the office of the Engineer, who will furnish proposal blanks.

Plans and specifications will be furnished by the Engineer for $13.00, upon request, which sum will not be returned.

The district is the owner of one Bay City Dry Land Dredge, and a one half owner in an Austin Backfiller. The above machinery will be leased or sold to the best responsible bidder.

Certified check in the sum of Two Hundred ($200.00) Dollars, made payable to J. C. Stewart, Treasurer of the said district, must accompany each proposal.

Right is reserved to reject any or all proposals.

Attention of bidders is called to the opening of bids by the North Bench Drainage District on same day.

ANTELOPE DRAINAGE DISTRICT,
CLYDE W. ATHERLY,
District Engineer.

Basin, Wyoming, Jan. 26, 1921.

Figure 85: Original call for bids for North Antelope Drainage District drain installation.

Given the current layout of the drainage system, it stands to reason that the removal of the existing drain infrastructure and re-installation of engineered drains is the best course of action. Using the existing layout would allow for simpler and more direct installation. Currently there is a system of manholes that could serve as cleanout nodes for the new system. Given some of the distances between the existing manholes, additional manholes would need to be installed to meet criteria of the design engineer.

Installation of new drains can be accomplished through a broad variety of methods. For the purposes of this recommendation and initial cost estimate, Y2 investigated the use of a continuously laid drain system. This system, the EZFlow 1001-FB-Mesh 4" Drain Pipe, allows for continuous installation by a small crew immediately following trenching. This particular system eliminates the need for bedding with pea gravel as it is sleeved in a permeable fabric. This may not be the exact drain that is installed but could serve as an option.

This system, once installed, should require minimal maintenance and upkeep thus limiting the required upkeep and maintenance fund. Regardless of this reduction in overall cost, the system itself will incur substantial cost and will require funding assistance. The WaterSMART grant program is specifically designed for water improvement in the western United States. The program aims to provide funding for water conservation efforts including, but not limited to:

- Conveyance projects,
- Hydropower projects, and
- Water supply reliability and preservation.

This program provides 50/50 cost share funding up to $300,000 through a “Small Project Fund” and the same up to $1,000,000 for projects that qualify financially as “Large Project Fund”. It is anticipated that this project will be designated a Large Project in terms of cost. This may serve as a potential source of funding for the NADD refurbishment.

Another funding option is the USDA Water & Waste Disposal Loan & Grant Program, which provides funding for stormwater drainage in addition to water and wastewater systems.

This project is anticipated to incur substantial cost and merits an enhanced design beyond the scope of this Level I study. The project provides a clear potential for improved water utility and quality of life for the residents of the NADD. Cost estimation for this project is developed in Table 15. Costs for this project were developed based on available materials and methods for field drainage.

Table 15: North Antelope Drainage District cost estimate.

Project	Name	Latitude	Longitude
1-1	**North Antelope Drainage District**	44.365892	-108.037
Component	**Unit Cost**	**Units**	**Total Cost**
Preparation of Final Design	$25,000	1	$25,000
Permitting and Mitigation	$25,000	1	$25,000
Legal Fees	$15,000	1	$15,000
Acquisition of Access and ROW	$5,000	1	$5,000
Pre-construction Costs	$70,000	1	$70,000
Project Components	**Unit Cost**	**Units**	**Total Cost**
Drain pipe - EZFlow 1001-FB-Mesh 4" Drain Pipe	$5	8000	$40,000
Manholes - Typical	$6,000	11	$66,000
Digging and Embedding - Operations	$35	8000	$280,000
4" PVC Connections	$500	11	$5,500
Project Mobilization	$28,000	1	$28,000
Material Delivery	$5,000	1	$5,000
Construction Engineering (10% of Components Cost)	$42,450	1	$42,450
Components and Engineering	$467000	1	$467,000
Contingency (15% of Components and Engineering)	$70,000	1	$70,000
Total Project Cost			**$1,143,950**

TYPICAL DETAILS

For each of the projects identified under this project type the following detail has been developed (Figure 86). This is intended to represent the typical installation of a drain setup for a typical field installation.

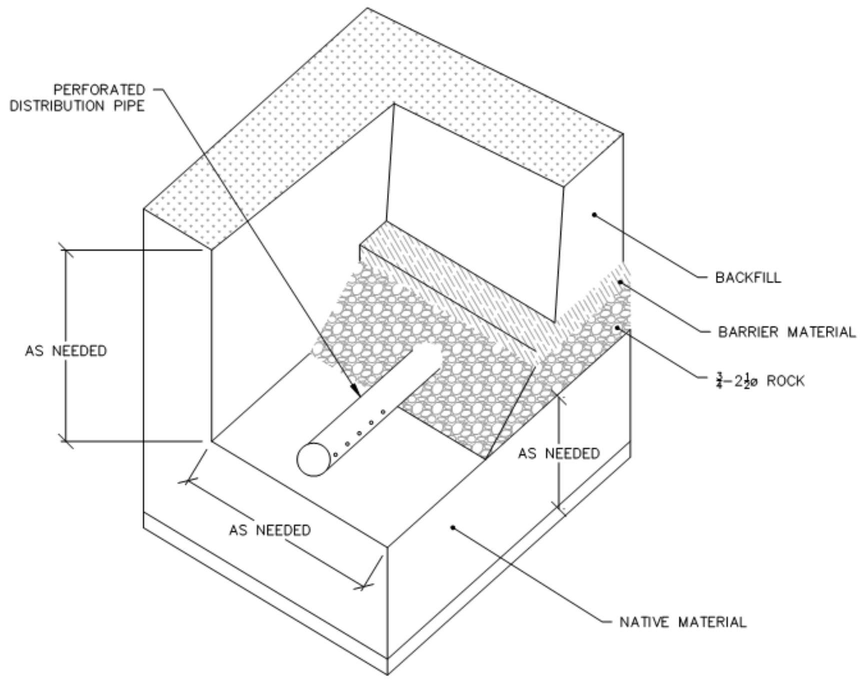

Figure 86: Typical detail for field drain installation.

DRAINAGE IMPROVEMENT COST ESTIMATION

This project type could include trenching cost and gravel cost, which is at an average of $5.00 per foot and $37.00 per ton, respectively. All cost estimates for drainage improvement for this project type are based on ideal installation conditions. There may be additional costs associated with installation in areas with varied terrain and conditions.

FUNDING OPTIONS

Projects of this type may be eligible for funding through the USDA Rural Development Program. All the drainage type projects listed in this study are eligible. This source offers long-term low interest loans that can be applied towards the total cost of the project. Additionally, there may be consideration for funding in the form of a grant if there are sufficient funds available. The loan for this program is a 40-year loan which is based on the useful life of the facilities to be installed. One funding criterion that may pose a challenge is that the project must be financially stable. It may become necessary for larger scale projects to pursue private loans to sufficiently finance these projects.

PROJECT CONSIDERATIONS

Excessive drainage may overly dewater fields if not properly installed, resulting in the opposite problem from what is currently being experienced. Additional consideration should be given to the anticipated discharge point for these systems such that erosion is minimized. This can be accomplished by flow energy dampening using rock armoring. For those projects that are located on federal lands, unless there is an up-to-date pre-existing maintenance agreement, prior to project advancement a full NEPA analysis may be required. This is the case for both independent and connected actions. It is advised that prior to commencing any project the stakeholder of the project contact the appropriate federal land management field office. Drainage design is highly site specific. Proper engineering design should be developed for each drainage project.

DITCH AND PIPELINE PROJECTS

The conversion of ditches from open ditch to either a lined or piped flow path was a commonly observed project type. The preferred method is piping the existing ditch. This project type entails the conversion of conventional flow paths through established ditches into lined or piped flow structures limiting exposure to raw soil and improving flow conveyance efficiency.

In meetings with stakeholders it was found that this was the most common project type and most prevalent grievance. Flow and flow efficiency are two of the largest challenges that most agricultural producers are presented with. Any improvement that can be made will provide a distinct benefit to the watershed and the producer. By improving the method of conveyance, minor improvements are made to the overall health of the watershed. This in turn has an impact on the relative wellbeing of the producer and their product, whatever that product may be. Over the course of this project Y2 was able to identify 22 projects related to ditches and flow conversion. Many of these projects were tied into other source supply projects. Others were related purely to the enhancement of existing flow conveyance.

Permitting for these conversions will be handled through the State Engineer's Office. Given that pipe and other lined conveyances have improved flow and hydraulic characteristics this may necessitate a modification to existing permits.

PROJECT CASE STUDY

Given that this was the most populated project type in the set of projects that were collected there are many that could serve as case studies. Most of the ditch and pipeline projects gathered were in established flow lines. There were only a handful of cases that were entirely new flow paths. These new paths are almost exclusively related to spring development projects.

Orchard Bench Road Ditch Conversion (Project IDs: 24-1, 24-2, 24-5, 24-6, 37-3, 37-4, 37-5, and 37-6)

One ranch located just north of Manderson, near Orchard Bench Road, contributed several conventional pipeline projects (24-1, 24-2, 24-5, 24-6, 37-3, 37-4, 37-5, and 37-6). These projects are primarily driven by the desire to move away from conventional ditch flow. In the case of the Orchard Bench projects, the ditches are rough earthen ditches which would greatly benefit in terms of flow conveyance and improved availability of land cover.

The installation of the converted ditch would provide increased flow, safety, and useable land for the stakeholder. This would allow for increased production with reduced operations and maintenance requirements. The installation for this project is anticipated to be typical with removal and grading of the rough ditch edges. Placement of the converted pipe would occur on proper bedding material with native fill being placed on top of the newly installed pipe.

TYPICAL DETAILS

For those projects that are related to pipeline development and improvement the following typical detail is intended to represent installation and may not be representative for every case (Figure 87).

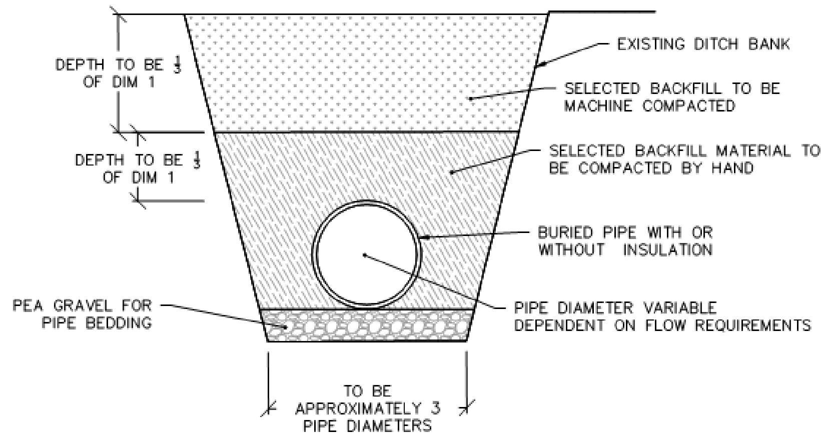

Figure 87: Typical detail for ditches with pipe installation.

COST ESTIMATES

There were two primary pipeline scenarios that were considered to estimate pipeline cost: small diameter and large diameter. The small diameter pipelines were defined as pipelines sized below 4" in diameter. Any pipeline larger than 4" was considered a large diameter pipeline with costs representative of such.

Some of the pipelines that were considered for this project, primarily the large diameter pipeline projects, may also be considered irrigation conversion. These pipelines are intended to enhance the delivery efficiency of water from diversion point to point(s) of use. All pipeline lengths were estimated based on Exchangeable Image File Format (EXIF) data from pictures taken during site reconnaissance. For rough estimation purposes it was assumed that recreational grade GPS accuracy (±25 feet) was sufficient.

A price of $6.88 per foot was assumed for pipelines below 4" in diameter. A price of $18.51 per foot was assumed for large diameter pipelines greater than 4". Trenching and gravel would also be components in pipeline installation in most cases and was estimated at $5.00 per foot and $37.00 per ton, respectively. All cost estimates for the development of canal lining for this project are based on ideal installation conditions. There may be additional costs associated with installation in areas with varied terrain and conditions. Component costs are listed in Table 29 in Appendix A.

Lining current ditches is also an option that is cheaper but less efficient than piping. However, while piping provides less overall water loss than lining, lining may still be a more effective option depending on location and budget.

FUNDING OPTIONS

Funding for projects related to the lining or placement of pipes in place of existing ditches can be derived from the Small Water Project Program (SWPP) grants. The purpose of this program is to provide funds for the refurbishment and rehabilitation of existing water supply systems.

The sources Small Water Project Program (SWPP) and WaterSMART were identified as the most opportune funding application for irrigation ditch, canal lining, and pipeline installation work. WaterSMART source funding is ideal because of the focus on conveyance improvement and water conservation improvement. This program is also focused on the western United States; therefore, it encompasses the agricultural land that is present in much of the Middle Big Horn Watershed. Other reliable sources of funding for irrigation sources include USDA grant programs such as

Agricultural Management Assistance fund (AMA), Environmental Quality Incentives Program (EQIP), and Rural Development grants and loans.

PROJECT CONSIDERATIONS

Care should be taken in the sizing of piping for ditch conversion projects. Most ditches and points of diversion have a permitted amount of water that can be drawn over a given period. In cases where piping is oversized it is possible to draw too much water and exceed the permitted amount. Additional concerns can arise during installation if proper design is not performed. Piping must be carefully installed to ensure that leaks do not develop and to ensure the longevity of the pipeline being installed. For those projects that are located on federal lands, unless there is an up-to-date pre-existing maintenance agreement, prior to project advancement a full NEPA analysis may be required. This is the case for both independent and connected actions. It is advised that prior to commencing any project the stakeholder of the project contact the appropriate federal land management field office. Cost estimates shown are rough approximations based on general design assumptions. When constructing, an in-depth flow analysis should be performed to ensure recommended and generally accepted good engineering practice is used.

LIVESTOCK/WILDLIFE UPLAND WATER SOURCE DEVELOPMENTS

WELL PROJECTS

Wells are a critical component to water availability in the study area, as they access water supplies beyond what is available from surface water sources (precipitation and transient streamflow). Wells are drilled into water-bearing formations and can either be pumped or can produce, in rare cases, under an artesian condition. Artesian wells don't require pumping as the water naturally flows to the surface because of the gradient in the water table present in the water bearing formation. The more common case is to produce water from the bearing formation via submersible pump. It is critical to recognize that the Willwood formation common in the study area is a poor water bearing formation.

There are numerous wells in the study area: 1,306 by the count of this inventory. These existing wells in the study area are used for a variety of uses: domestic, agriculture, and industrial. There were a limited number of well development projects that were gathered for this study. In many cases the water quality that is available for a typical shallow depth well is not desirable and can only be used in a limited capacity for stock and wildlife.

Permitting for these projects will need to occur through the State Engineers Office and filed under the UW 5 Permit. This is the permitting process for wells that flow less than 25 gallons per minute. This permit is for groundwater appropriation and allows the permittee to obtain water rights for the well.

The State Engineer's Office maintains certain construction standards for new wells. Those are listed below and will be applied to any new well construction:

- Annular space for upper seal is defined,
- Top 20 feet must have a 2-inch annulus,
- Casing must be certified ASTM, API, NSF, or AWWA,
- Casing must be one nominal size larger than pump assembly,
- No 4-inch pumps in a 4-inch well casing,
- Increased distance from contaminant sources,
- Must use potable water for drilling,

- Much more rigorous disinfection standards,
- Gravel packed wells should be sealed from above the gravel to the surface,
- Backflow prevention is required,
- 18-inch stickup (consistent with county health departments),
- Changed well type descriptions, and
- Commercially manufactured screen is required for gravel-packed and naturally developed wells.

Across the watershed there are many opportunities for well developments. This study was limited in terms of the number of well development projects presented by local stakeholders that came forward with projects. Despite this, Y2 was able to gather several other well development projects. Any improvements to overall water supply and distribution in the watershed will provide a distinct advantage to the entire area.

PROJECT CASE STUDY

There were two cases that were observed over the course of this study that represent typical well development for the study area. Wells, as mentioned before, do not constitute a large fraction of the projects gathered. However, it was observed that the well development projects in this study focus on either new development or re-development of existing wells.

Neves Well at Tatman Mountain (Project ID: 5-1)

For new development, one of the best case studies was the Neves well. This project was gathered by Y2 during a site visit with Dave Neves while visiting Tatman Mountain. Located in an upland region of Tatman Mountain, 35 miles northwest of Worland, this well could supply water to gravity fed water storage areas located down-gradient. There are several seeps located down-gradient from the proposed location of this well, indicating that there may be potential for development of a viable well. The water from this well could be produced using a solar powered submersible pump. It was mentioned by Mr. Neves that the water had been analyzed and contained a substantial amount of mineral and sulfate making it unsuitable for drinking water.

TYPICAL DETAILS

For those projects that are related to well development and improvement the following typical detail is intended to represent installation for wells and may not be representative for every case (Figure 88).

COST ESTIMATES

Well construction costs for this study were based on the recommendations of the NRCS for typical well development. Based on this, the cost for the improvement and development of a well was defined as $100 per vertical foot. This does not include material mobilization to the site of the well development. All cost estimates for well development

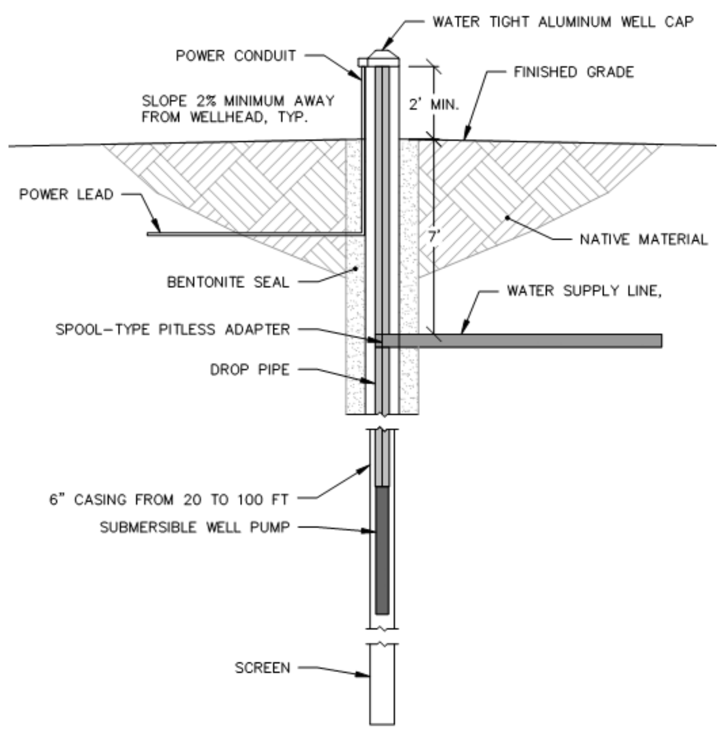

Figure 88: Typical detail for well installation.

for this project are based on ideal installation conditions. There may be additional costs associated with installation in areas with varied terrain and conditions. Well depths were assumed to be 250 feet; this may vary depending on individual well sites. Component costs are listed in Table 29 in Appendix A.

Given that most of the projects that were collected are in outlying regions of the study area, a substantial component of the project cost is for mobilization. In some cases, projects are over 30 miles from paved roads and often take several hours to reach travelling at safe speeds.

One common project type that was observed and identified through coordination with local stakeholders was the installation of solar power supplied pumps. These were estimated at a cost of $9,000 per solar system based on the best available information for similar systems. There was no local cost modification applied to this cost. The costs for these systems were assumed to include the pump, solar arrays, and associated controllers. This price will vary depending on the depth to water in the well. All cost estimates for well development and improvement for this project are based on ideal installation conditions. There may be additional costs associated with installation in areas with varied terrain and conditions. There may be variation in the actual cost for well development due to site conditions and total depth drilled to access water.

FUNDING OPTIONS

For wells the primary funding option is Small Water Project Program (SWPP) grants. Funding will come from the WDA I for new development and WDA II for refurbishment of existing wells. The maximum financial contribution from the WWDC is $35,000. The individual project proponent will need to elect to pursue a given project.

FUNDING ELIGIBILITY

The sources SWPP and MRG were identified as the most opportune funding application for well development. SWPP is recommended for well development funding. MRG is also recommended because wells provide an essential service. If there is still leftover funding required for these projects, a reliable option would be application for USDA Rural Development funds in the form of loans.

PROJECT CONSIDERATIONS

Well development, if not performed correctly, can lead to challenges that make the well inefficient and potentially detrimental to the well owner. If wells are not properly completed there can be potential for contamination and a compromised nature of the producing formation. This can limit the ability to produce usable water and become financially infeasible to correct.

Additional concerns can develop over the amount of power that is required to produce water from each well. In the cases that were considered for this project it was assumed that solar power could be sufficient to produce water from each well. This may not be the case and additional power may be required to produce usable quantities of water. For those projects that are located on federal lands, unless there is an up-to-date pre-existing maintenance agreement, prior to project advancement a full NEPA analysis may be required. This is the case for both independent and connected actions. It is advised that prior to commencing any project the stakeholder of the project contact the appropriate federal land management field office. Well development will be dependent on terrain and existing geologic conditions at the well site. Well depths will vary, thus changing the costs shown in the project summaries.

SPRING PROJECTS

Springs are naturally occurring surface water supplies that exist where a water bearing formation is exposed to the ground surface. If there is a significant gradient these springs can supply a large amount of water. Y2 was able to observe multiple springs in the study area and identified several projects related to the development and improvement of these sources. There are varying degrees of water quality available from these springs. This quality varies spatially and is dependent on the surrounding areas. Springs observed in highland areas, more prevalent in the peripheral regions of the watershed, were observed to have better water quality than those in the lower upland regions, located more centrally in the watershed.

Springs play a key role in water supply to the watershed. In many cases Y2 observed springs with substantial output. Most of these springs have undergone some form of improvement effort and are currently producing flows that could be augmented. Y2 observed several instances of spring improvements in various stages of development, from minor improvements to raw outflows with no improvement. Most of the springs that have undergone improvement are located on ranches and other livestock operation areas. This tracks with conventional logic in that springs are typically located in highland areas that are commonly grazed or used as grazing corridors.

Permitting for these spring development projects will need to occur through the State Engineer's Office and will be filed under the UW 5 Permit. This is the permitting process for springs that flow less than 25 gallons per minute. This is a permit for groundwater appropriation and allows the permittee to obtain water rights to the spring in question.

PROJECT CASE STUDIES

The case study that will be considered for this type of project consists of two separate springs that were observed in the western region of the watershed.

LU Sheep Ranch Spring (Project ID: 34-1)

The first case is the LU Sheep Ranch involving a previously improved spring located near one of their summer ranch cabins approximately 15 miles south of Meeteetse. This spring is capable of producing large volumes of water and was noted to produce water on a perennial basis. This spring was last improved over 10 years ago. Additional improvements to this spring would provide considerable amounts of water to be used in lower reaches of the watershed as stock water or potential irrigation source. Currently the spring has had some rudimentary improvements, stock exclusion fence, and some flow enhancement. The existing improvements could benefit from redevelopment. This location is ideally situated in a highland region of the watershed; water produced from this spring could be easily piped to lower elevations. This increases the utility for this spring by removing the need for artificial pressurization to move produced water.

Gallovich Spring (Project IDs: 33-1, 33-2, and 33-3)

An alternative spring development case was observed in the western region of the study area in a similar location to that of the LU Sheep Ranch. This case involves a system of raw springs that have undergone no development. This is a unique case proposing to install a drain pickup field. This field would be installed in a manner that would intercept most of the water being produced from the springs. The collected water from this spring system would then be delivered to a holding tank several hundred feet down gradient of the spring. It was observed at the time of Y2's site visit that the volume of water being produced from this spring system was substantial. This volume of water, if developed, would contribute significantly to the overall volume of water production that occurs in this area as a result of springs.

TYPICAL DETAILS

Typical details for this project type have been modeled from the NRCS Spring Development Detail (Figure 89). There are a wide variety of spring development options and this may not apply exactly to every situation.

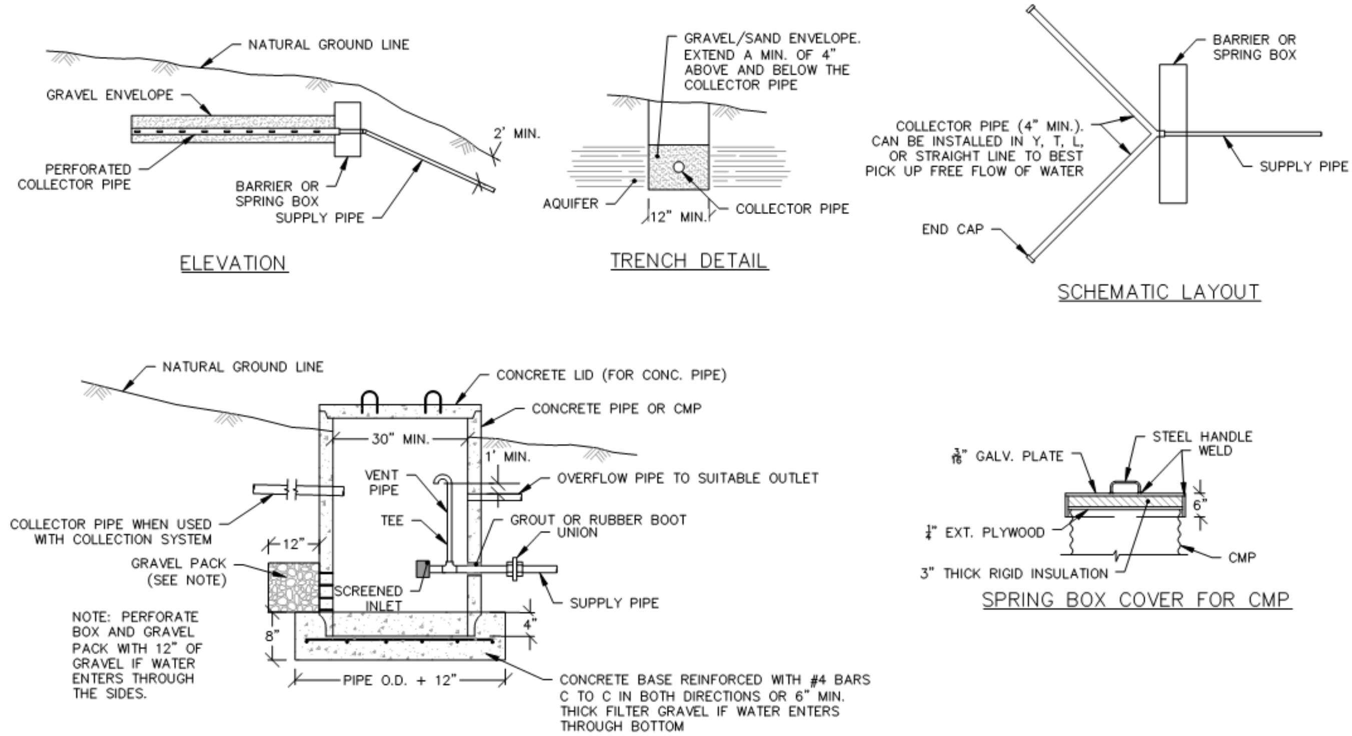

Figure 89: NRCS Typical detail for spring development sourced from NRCS.

COST ESTIMATES

Multiple spring development and improvement projects were identified within the study area. Spring development components include pipe material, at a comparable cost to the data listed in the pipeline section above, and a spring box, estimated at $1,000 per box for the purpose of this study area. Basic labor time and assembly are required to install or repair these springs. The overall cost for the development of a spring was estimated to be within $10,000 to $12,000 within the study area. All cost estimates for spring development and improvement for this project are based on ideal installation conditions. There may be additional costs associated with installation in areas with varied terrain and conditions. Component costs are listed in Table 29 in Appendix A.

FUNDING OPTIONS

Funding for projects as related to development of existing springs can be derived from the Small Water Project Program (SWPP) grants. The purpose of this program is to provide funds for development of new water sources. For spring development this will be classified as "groundwater development".

Funding Eligibility

The sources EQIP, SWPP, and WaterSMART were identified as most opportune funding applications for spring development because spring development improves water use and typically does not require large cost to construct. Between the three programs, each spring project should be able to apply for enough funding. Each of the spring projects fell around $10,000, therefore the initial funding source was assigned SWPP because it is considered a

"Small" level project. SWPP funds 50% of a project up to $35,000, therefore additional funding applications would need to be secured from the other two sources, or local-level sources.

PROJECT CONSIDERATIONS

Careful consideration and planning should be taken in the development of springs. For naturally high producing spring sites the development of the spring site could detrimentally affect the riparian, wetland, and/or stream areas down slope being fed by the spring site. This could be especially true if large amounts of water are piped or transferred to tanks away from the site. For those projects that are located on federal lands, unless there is an up-to-date pre-existing maintenance agreement, prior to project advancement a full NEPA analysis may be required. This is the case for both independent and connected actions. It is advised that prior to commencing any project the stakeholder of the project contact the appropriate federal land management field office. Spring development can vary largely from the provided detail. The detail provided is only one example of a possible spring development plan. Most spring development designs are highly site specific and may vary in cost.

SURFACE WATER STORAGE OPPORTUNITIES

SILT DAM PROJECTS

Silt dams are a common project type that was observed. The challenge faced by these projects is that they are, for the most part, unlikely to proceed due to ownership and permitting constraints. Another limiting factor is in part, the remote location of many of these projects and the high cost of maintaining and repairing the dams once they are functional. The high costs associated here, along with poor access conditions, prevents the timely upkeep needed to ensure that these structures function as intended.

For those silt dams on federal land without a maintenance agreement a NEPA process may need to be performed for any modification or improvement. Additional consideration should be given for the performance of an environmental analysis for each respective project based on the complexity of it. Silt dam projects that are eroded or exceed routine maintenance may require and EA.

Y2 observed this class of projects more commonly than any other project class aside from flow conversion projects. These projects are mostly located within the central region of the watershed. In interaction with local stakeholders, Y2 learned that these structures had been installed with the intent of controlling flow from regions with friable soil that contribute large loads of silt to the watershed. Many of these structures were observed to be completely silted in and had long ago ceased to function. This can be remedied but may not serve as the most viable or cost-effective solution.

For the remediation of silt dams to be fully effective a dedicated maintenance effort would need to be in place. This would be extremely cost prohibitive as there are over 1,300 separate silt dams present in the study area.

PROJECT CASE STUDIES

There are two case studies that will be considered here.

Silted-In Dam

The silted-in dam was possibly the most common case that was seen in the study area. To provide a visual illustration of this, Figure 90 shows a dam in this condition. This condition appeared to occur in areas with a more ready ability to grow vegetation than in other portions of the watershed where erosion was prevalent. In the image below it can be seen that this particular silt dam was heavily vegetated. This vegetation allows for the slowing of water flow through the silt dam which in turn allows sediment to fall out of solution from inflows. This leads to the gradual aggradation of the silt dam floor, eventually leading to a non-functional condition. Technically this condition does limit overall silt delivery, but it also limits the amount of viable water storage capability that would normally be seen for a silt dam of this size.

In other cases, silt dams were observed to have been completely silted in without vegetation. In these cases, preferential flow paths were observed developing through the silted in dam. This represents a systemic problem wherein accumulated silt is being discharged further down into the watershed. This bypasses the normal sediment delivery process and provides direct sediment flow into the watershed. It was observed that in those dams with preferential flow paths developing that many had developed cuts through the primary dam structure. This presents another challenge in the rehabilitation and management of these structures. The entire primary dam structure, the prism that defines the water confining portion of the dam, will need to be reconstructed following excavation of the deposited material.

Eroded Dam

In the cases of an eroded dam, the silt dam does not experience deposition. In these cases, the dam is simply eroded, causing failures in the dam structure. In these cases, there is a flaw in the material of which or on which the dam was constructed. This flaw results in a point or area of failure of the dam when subjected to water and/or flow conditions. In some materials, particularly poorly structured soils, the introduction of water modifies the material properties of the matrix. This modification can result in material failure. These failures can then propagate through the dam structure resulting in the condition shown in Figure 91.

Figure 90: Silted in and vegetated silt dam.

In this particular case the silt dam had eroded and resulted in a “tunnel” through the dam that was approximately 15 feet in diameter. This erosion has completely compromised the dam’s ability to hold water thus limiting its ability to supply stock with water and retain sediment. Fortunately, this particular dam was located in a relatively water rich area of the watershed. In other areas throughout the watershed this was not the case. In most cases where erosion has compromised a silt dam the erosion cuts through the extent of the dam structure. These cuts typically extend below the lowest point in the silt dam completely stopping the dam’s ability to maintain water and allowing silt to remain suspended in the watershed.

Figure 91: Eroded silt dam.

TYPICAL DETAILS

It should be noted that in almost every real-world case for silt dams, the dam crest geometry and layout will be variable to suit the native terrain in which it is to be installed. A typical silt dam detail is shown in Figure 92.

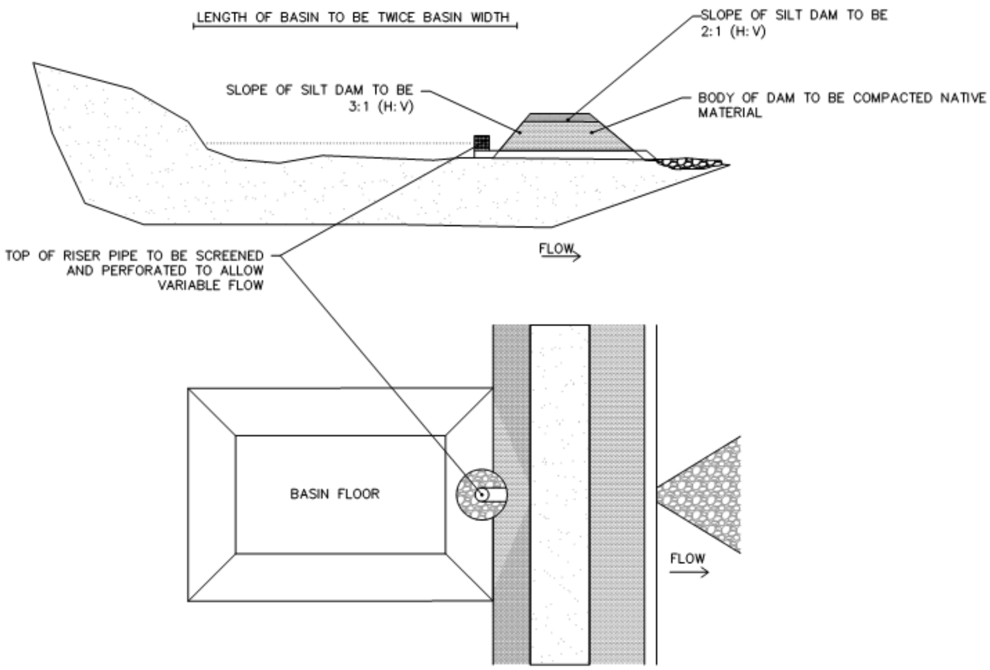

Figure 92: Typical detail for silt dam.

COST ESTIMATES

Stock ponds and silt dams were assumed to be similar structures and were both estimated based on the same assumptions. For these water storage impoundments, a cost of $18,000 to $30,000 was assumed for cleaning of deposited sediment. The assumption used for most storage ponds in the area was a cost of $28,000 per pond. This cost includes excavation, installation of standpipe and outflow control, dam and pond lining, as well as equipment mobilization costs. These projects are complicated by the highly erosive nature of the watershed. Targeted development locations and detailed cost-benefit analysis will need to be performed. For any silt dam that is either refurbished or constructed, a thorough consideration of the design life of the structure needs to be considered.

As listed in Table 29 in Appendix A, the component costs are estimated to be approximately $5.00 per cubic yard for excavation, $4,500.00 per standpipe, $10,000.00 per acre for pond lining, and $3,500.00 per mobilization. All cost estimates for silt dam development and improvement for this project are based on ideal installation conditions. There may be additional costs associated with installation in areas with varied terrain and conditions.

FUNDING OPTIONS

Funding for projects as related to development of surface water storage can be derived from Small Water Project Program (SWPP) grants. The purpose of this program is to provide funds for refurbishment and rehabilitation of existing surface water storage. Rehabilitation of stock ponds and silt dams may qualify for a SWPP grant, however, funding for silt dam rehabilitation may be difficult to acquire considering the variable longevity of these systems.

The sources EQIP, SWPP, and WaterSMART were identified as the most opportune funding application for stock pond development and silt dam refurbishment or redevelopment. EQIP is recommended as the initial funding source because these projects are typically large and expensive, and EQIP provides funding up to $450,000 depending on project need and result. All three funding sources provide for water resource development and improvements, which dam, and stock pond projects fall under. Most projects will not require funding beyond EQIP, but the options are listed regardless.

PROJECT CONSIDERATIONS

Due to the unrealistic nature and cost of repairing and maintaining all stock and silt dams in the study area it may be necessary to look into alternative solutions for silt control at the primary points of discharge to the Big Horn River. There is potential for these projects to be compromised soon after completion if a large precipitation event occurs. For those projects that are located on federal lands it is advised that prior to commencing any project the stakeholder of the project contact the appropriate federal land management field office. There is no guarantee that stock or silt dams that have been reconstructed will operate for a given span of time due to potential for rapid silt deposition during large runoff events.

RIVERBANK STABILIZATION

The stabilization of riverbanks is critical in this watershed. Riverbanks that are not stable can erode, causing an increased sediment load downstream and can compromise adjacent land. Streams can be stabilized in a variety of different ways, from adding rip rap to increasing vegetation. The method of stabilization should be assessed for each project.

PROJECT CASE STUDY

Big Horn Land & Livestock Stream Restoration #1 (Project ID: 16-1)

This is a re-current flooding location along the Big Horn River. This is a potential point for riverbank restoration and enhancement. The installation of functional engineered flooding countermeasures could have a marked benefit for this location.

TYPICAL DETAILS

For each of the projects identified under this project type the following detail has been developed (Figure 93). This is intended to represent the typical riverbank stabilization method.

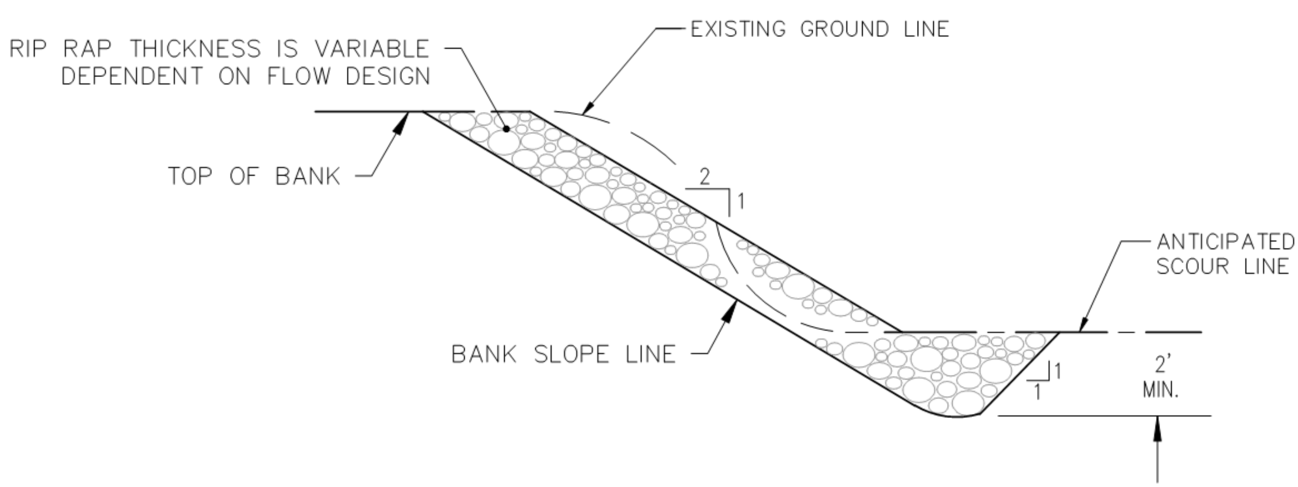

Figure 93: Typical streambank restoration detail.

COST ESTIMATES

Riverbank stabilization projects include the cost of design, permitting, mobilization, and riverbank restoration. The largest cost is the construction, which was estimated at $61 per foot. Component costs are listed in Table 29 in Appendix A.

FUNDING OPTIONS

Funding for riverbank stabilization projects can be applied for through WDEQ 319 funds and USDA Environmental Quality Incentives Program (EQIP). WDEQ 319 funds are available to public and private entities to reduce nonpoint sources of pollution. EQUIP incentivizes parties to improve natural resources on their property including water resources, water quality, and erosion control and provides funding up to $450,000 depending on project need and result.

HYDROELECTRIC POWER GENERATION

PROJECT CASE STUDY

City of Worland – High Head Hydropower Project

This project was obtained in coordination with the City of Worland. Currently, Worland receives its water from an artesian aquifer. This aquifer supplies water to the intake and staging tanks at a pressure sufficient to develop a considerable amount of head pressure. This head pressure could be utilized to develop hydroelectric power for use by the City of Worland. The engineering and development of this project would provide an added electric input for the City of Worland and could potentially be delivered to the City's grid. Additionally, the installation of power cogeneration equipment in line with the artesian supply line would provide a pressure reduction, reducing strain on current pressure reducing equipment.

By taking advantage of the natural pressure head that is available from the City of Worland supply wells, the installation of a micro-hydroelectric system would eliminate the need for a pressure reducing valve and allow for the City of Worland to supply power to the existing inlet works facility. If surplus energy is produced by the system it could conceivably be sent into the grid, thus generating revenue to pay for operations and maintenance or debt service.

One of the challenges that is faced by the implementation and use of a micro-hydroelectric system is the start stop flow that occurs. To counter this Y2 has found a micro-hydroelectric system provider that specializes in the design and installation of these systems. The prospective company highlighted for this project is SOAR Hydroelectric. Based on information provided from the City of Worland, it was found that during periods of flow the potential power generation from a system installed would be around 65 kW-hr. This number assumes a 70% operational efficiency for the installed turbine. Permitting would be required through the Federal Energy Regulatory Commission and the Wyoming State Engineer's Office.

A Level II study with the WWDC is recommended for this hydroelectric project. This study would determine the available head and water supply, review water rights, refine the estimate for amount of power, develop conceptual designs, inventory and recommend upgrades to the existing power lines and systems, provide estimates of costs and revenue, and identify permitting requirements.

COST ESTIMATES

A cost estimate for this project is shown in Table 16.

Table 16: City of Worland high head hydropower project cost estimate.

Project	Name	Latitude	Longitude
2-1	**City of Worland High Head Hydropower**	44.025201	-107.874813
Component	**Unit Cost**	**Units**	**Total Cost**
Preparation of Final Design	$37,500	1	$37,500
Permitting and Mitigation	$25,000	1	$25,000
Legal Fees	$25,000	1	$25,000
Acquisition of Access and ROW	--	1	--
Pre-construction Costs	$87,500	1	$87,500
Project Components	**Unit Cost**	**Units**	**Total Cost**
10" Iron Pipe	$350	25	$8,750
Valving - High Pressure Gate Valve 300# Flange	$4,000	4	$16,000
350 KW Inline Generator (~450hp)	$15,000	1	$15,000
Check Valves, 300# Flange	$4,000	2	$8,000
Gages	$1,500	4	$6,000
Control System - SCADA	$8,500	1	$8,500
Power Bank	$25,000	2	$50,000
Pressure Relief Valve 10" 300# Flange	$10,000	2	$20,000
Construction Engineering (10% of Components Cost)	$13,225	1	$13,225
Components and Engineering	$145,475	1	$145,475
Contingency (15% of Components and Engineering)	$22,000	1	$22,000
Total Project Cost			**$487,950**

FUNDING OPTIONS

The WaterSMART Water and Energy Efficiency Grants program through the Bureau of Reclamation was identified as a funding source for this project because it is a large undertaking to provide water-based power to people in the community. This program provides 50% funding up to $1,000,000.

FUNDING SOURCES

Funding source eligibility for each project type is listed in Table 30 in Appendix A.

WASHAKIE COUNTY CONSERVATION DISTRICT (WCCD)

RURAL COST SHARE PROGRAM

The Washakie County Conservation District (WCCD) created the Rural Cost Share program to fund projects that benefit the public, improve water quality, protect soils, and enhance habitat. This cost share program is only available to Washakie County residents. The WCCD will fund a maximum of 50% and $10,000 of the project, the exact cost share and amount being determined by the WCCD Board of Supervisors. The landowner must match at least 25% of the cost of each project.

COMMUNITY AND RESOURCE ENHANCEMENT COST SHARE PROGRAM

The Community and Resource Enhancement Cost Share Program provides funds to implement natural resource conservation practices that prevent soil erosion, improve water quality and quantity, promote energy conservation, and enhance wildlife habitat. This program is also available for landowners who can’t typically qualify for federal farm bill programs. This program reimburses a maximum of $2,500 up to 50% of the project cost. The applicant must match at least 25% of the cost of each project. Projects supported by this program include streambank stabilization, irrigation water management, livestock water gaps, reservoir rehabilitation, solar pumps, and spring development. This cost share program is only available to Washakie County businesses and residents.

WYOMING OFFICE OF STATE LANDS AND INVESTMENTS (OSLI)

FARM LOANS

Regular farm loans are commonly issued loans for most agricultural purposes. The OSLI states that these loans are intended to: “Purchase livestock, fertilizers, and equipment calculated to maintain or increase the earning capacity of the borrower's agricultural operation”. This can be applied to most projects that are agricultural in nature, including but not limited to:

- Irrigation ditch development and conveyance modification,
- Canal lining materials, and
- Pipeline materials.

More information can be found here: https://lands.wyo.gov/grants-loans/loans/farm-loans

MINERAL ROYALTY GRANT (MRG)

The main purpose of the Mineral Royalty Grant program, which is specific to the State of Wyoming, is to alleviate an emergency, comply with state or federal rules or regulations, or provide an essential public service. Therefore, for our purposes, two project types fall under this grant funding: well development and bridge refurbishment. An argument could be made for funding hydropower projects and general public service projects as well, such as pipeline improvements, silt dam improvements, or other water resource improvements that impact the communities studied in the Middle Big Horn Watershed Study.

More information can be found here: https://lands.wyo.gov/grants-loans/grants/mineral-royalty-grants

WYOMING WATER DEVELOPMENT PROGRAM (WWDP)

The Wyoming Water Development Program uses tax revenues from state derived non-renewable resources to develop water projects across the state. This program arranges the planning, selection, financing, construction, acquisition, and operation of projects providing the conservation, storage, transmission, supply, and use of water.

SMALL WATER PROJECT PROGRAM (SWPP)

The small water project program is a funding program for the development of water improvement projects. This can include water storage tanks, pipelines, and reservoirs. This funding source applies to almost every project listed under the Middle Big Horn Watershed Study. Within this project the potential project types can include small reservoirs, pipelines, wells, and springs.

More information can be found here: http://wwdc.state.wy.us/small_water_projects/small_water_project.html

PLANNING PROGRAM

The WWDP conducts two types of planning studies: Level I and Level II. Project planning is completed within Levels I and II, which are 100% grant funded. Project construction is completed within Level III. Within the DRMP developed during this Level I study, the City of Worland hydroelectric power project is recommended for Level II funding to complete a more thorough feasibility study, but it is not eligible for Level III funding.

More information can be found here: http://wwdc.state.wy.us/planning_program/planning_program.html

WYOMING GAME AND FISH DEPARTMENT (WGFD)

WATER DEVELOPMENT/MAINTENANCE HABITAT PROJECT GRANT

The water development/maintenance program can be used to fund the development and maintenance of springs, windmills, guzzlers, water protection, and pumping. The grantee of the fund is responsible for all permits and NEPA processes. This program has a maximum funding limit of $7,500 per project along with a 50% cash or in-kind contribution from the grantee.

BUREAU OF LAND MANAGEMENT (BLM)

COOPERATIVE AGREEMENT FOR RANGE IMPROVEMENTS

This program derives funding from the BLM range improvement fund. There is a limited amount of funding available from this program which can be applied to reservoirs, pits, springs, and wells. This does include any necessary pipelines for distribution.

More information can be found here: https://www.blm.gov/services/electronic-forms

BUREAU OF RECLAMATION (BOR)

WATER CONSERVATION FIELD SERVICES PROGRAM (WCFSP) – CHALLENGE GRANT PROGRAM

The Water Conservation and Field Services Program (WCFSP) Challenge Grant Program offers up to $300,000 of federal funding per project. This program focuses on projects that will enhance water use efficiency or demonstrate the implementation and use of advanced treatment technologies. There is a focus placed on the prevention of decline for "candidate species" within this program.

More information can be found here: https://www.usbr.gov/pn/programs/wat/fieldservices.html

WATER CONSERVATION FIELD SERVICES PROGRAM (WCFSP)

The Water Conservation Field Services Program (WCFSP) is a smaller level of funding than the Challenge Grant Program. Up to $100,00 is offered per project. This is assigned through local competitions within the region and as such is not a guaranteed funding source.

A combined funding program can occur between the Challenge Grant Program and the conventional WCFSP. If this occurs, then the cost share must be done on a 50/50 basis between the recipient and the BOR.

More information can be found here: https://www.usbr.gov/pn/programs/wat/fieldservices.html

WATERSMART WATER AND ENERGY EFFICIENCY GRANT

The WaterSMART grant program is specifically designed for water improvement in the western United States. The program aims to provide funding for water conservation efforts including, but not limited to:

- Hydropower projects,
- Water supply reliability and preservation, and
- Conveyance projects.

This program provides 50/50 cost share funding up to $300,000 through a "Small Project Fund" and the same up to $1,000,000 for projects that qualify financially as "Large Project Fund".

More information can be found here: https://www.usbr.gov/watersmart/weeg/

WYOMING DRINKING WATER STATE REVOLVING FUND (DWSRF)

DWSRF is overseen by the WDEQ, the WWDO, and the Office of State Lands and Investments (OSLI). Funding is limited to drinking water source, treatment, transmission, storage, and distribution projects. Funding is allocated only after costs have been incurred during the project. Additionally, to be reimbursed for construction costs, an environmental review must be performed prior to any work.

Loans provided by the DWSRF do require a 0.5% loan origination fee but carry a 2.5% interest rate. Special cases may allow for lower interest rates or partial principal forgiveness. Loans are typically up to 20 years but may be allowed up to 30 years under certain circumstances. To obtain a loan, the Sponsor must demonstrate that they can repay the loan, show capacity for development, and adhere to federal environmental, social, and economic costcutting requirements and state procurement requirements. Additionally, the project must be listed on the current year's DWSRF Intended Use Plan (IUP).

More information can be found here: https://lands.wyo.gov/grants-loans/loans/drinking-water-state-revolving-funds

US DEPARTMENT OF AGRICULTURE (USDA)

RURAL UTILITIES SERVICE (USDA RUS)

US Department of Agriculture Rural Utilities Service (USDA RUS) can provide funding assistance through its Water & Waste Disposal Loan & Grant Program. Funds from this program can be allocated to drinking water sourcing, treatment, storage, and distribution projects. In some cases, funding can be used for legal and engineering fees, land acquisition, water and land rights, permits and equipment, interest incurred during construction, purchase of facilities to improve service or prevent loss of service, and other costs incurred for the completion of the project.

Loans provided through RUS can be up to 40 years but are dictated by the useful life of the facility in question. Interest rates are determined by project need and median household income of the area being serviced.

The Rural Development Loan program also falls under this category of the USDA.

More information can be found here: https://www.rd.usda.gov/about-rd/agencies/rural-utilities-service

AGRICULTURAL MANAGEMENT ASSISTANCE (AMA)

The Natural Resources Conservation Service (NRCS) through the USDA includes different grant programs such as the Agricultural Management Assistance fund (AMA). AMA provides financial assistance up to 75% of the cost of installation of certain water conservation practices, up to $50,000 in a fiscal year. Projects that fall under this funding type include relevant agricultural, farming, or irrigation related water resource development and improvement.

AMA is available in 16 states including Wyoming. Its main purpose is to help agricultural producers manage financial risk through best practices with land and water.

More information can be found here:
https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/ama/

ENVIRONMENTAL QUALITY INCENTIVES PROGRAM (EQIP)

This program, the Environmental Quality Incentives Program (EQIP), is also funded independently under the NRCS. The purpose of this funding program is to incentivize parties to improve natural resources on their property including water resources, wastewater conveyance, water and air quality, and erosion control.

A one-on-one conservation plan is developed alongside this program funding, which caps out at around $450,000 per project (maximum) with an application and need assessment. Y2 is a Technical Service Provider for NRCS and is able to assist with EQIP projects for both the engineering and natural resources.

More information can be found here:
https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY (WDEQ)

WDEQ 319 FUNDS

The Wyoming Department of Environmental Quality (WDEQ) website details these funds as follows:

> *Clean Water Act Section 319 funds to reduce nonpoint source pollution are available to public and private entities, including local governments, cities, counties, school systems, colleges and universities, nonprofit organizations, state agencies, federal agencies, watershed groups, for-profit groups, and individuals. Awards to individuals are limited to demonstration projects. Nonpoint source pollution is pollution which results from runoff of contaminants into surface waters or infiltration of contaminants into groundwater. It is generally associated with human land use activities such as agriculture, construction, mineral exploration, recreation, timber harvesting, and urban development. Section 319 grant funds are primarily directed towards "on-the-ground" watershed restoration or protection projects, but please be sure to read through all guidance to understand eligible project types and program priorities.*

More information can be found here:
http://deq.wyoming.gov/wqd/non-point-source/resources/grant-resources/?no_redirect=true

PERMITTING

For the construction of any new infrastructure or activity involving rehabilitation, there are a variety of permits that will apply based on specific project criteria. The following is a comprehensive list of the permits and regulatory steps that will need to be taken for rehabilitation projects in the study area.

- **NEPA**
- **Army Corp of Engineers**
  - Section 404 Permit
- **Wyoming Department of Environmental Quality**
  - NPDES and Section 401 Certification
- **Endangered Species Act**
  - Section 7 Consultation
- **Fish and Wildlife Coordinating Act**
- **Wyoming Board of Land Commissioners**
- **Wyoming State Engineer's Office**
  - Water storage permit
  - Permit to construct dam review
  - Ditch Enlargement Program
  - Well drilling
- **Mining Permit**
- **Special Use Permits/Rights of Way/Easements**
- **Environmental Considerations**
- **County Permits**

DEVELOPMENT, MANAGEMENT, AND REHABILITATION SUMMARY

The study area is a diverse system comprised of many opportunities to contribute to improving the function of the watershed. The proposed efforts to rehabilitate this watershed are plentiful and would require substantial coordination and cooperation across multiple agencies. The study area for this project is immense in scale; therefore, the projects identified in the above section comprise most of the available opportunities but may not include all of the potential project types or opportunities for improvement.

The number of development, management, and rehabilitation projects and areas within the study area is substantial. These developments and the items detailed in this chapter could have a marked effect on the watershed if fully implemented. These projects are not a guaranteed solution to any one of the issues that are faced by the watershed but collectively some benefit and improvement could be derived from them.

Improvements made to irrigation and water conveyance would allow for more responsible and efficient use and development of the watershed's water resources. It was a commonly noted theme amongst stakeholders that there is a clear desire and need for more efficient irrigation. Given that there is a finite supply of water available to most producers, any improvement in the effective use of that water provides clear benefits to the producers in the region. Unfortunately, many of these improvements are expensive and difficult for many producers to obtain and implement.

There are multiple opportunities to improve the number and quality of water supply points in the watershed. These can be responsibly developed to improve water access throughout. In visits to the watershed, multiple water supply augmentation points and new developments were noted and gathered as part of this study. These developments include existing wells, springs, and new supply developments; all of which if implemented properly, could provide project stakeholders with improved access and supply to water. By increasing water availability in the watershed, even on a small scale, there will be a net positive effect on watershed management. Water availability and access will be one of the challenges that defines the next century. Any efforts that can be made now to improve use and availability of water will pay dividends to future users and citizens of the watershed.

To provide the Sponsors and local stakeholders with the means to develop their water infrastructure and capability, Y2 has assembled a collection of project assessments for those projects gathered over the course of this study. These projects, if implemented, should allow for improved conditions in their immediate areas of effect. The collection of these projects can be found in the supplemental attachment to this study report, Project Summary Book. These summaries are intended to provide conceptual level details and sketches to allow stakeholders and Sponsors the opportunity to pursue watershed improvements (refer to Table 28 for a list of the projects).

CHAPTER 6: LOWER HANOVER CANAL PATHWAY EVALUATION

INTRODUCTION

The Y2 Team proposed a scope alteration to the Middle Big Horn Level I Watershed Study to "recommend suggestions to improve watershed condition and function and provide ***benefit for the public and the environment*****,** which includes ***enhancing recreational opportunities*** while ***decreasing erosion and water loss***."

Y2 and EES were instructed to focus this task on a portion of the Lower Hanover Canal. The Lower Hanover Canal departs the Big Horn River near the Riverview Subdivision; it flows north nearly 20 miles through the Bighorn Basin, finally rejoining the river near Rairden Lane. The canal itself inhabits a fascinating place in local lore, as its construction predates the incorporation of the City of Worland.

Y2 and EES studied the run of the Lower Hanover Canal within the Worland city limits, specifically its run from the Washakie Avenue bridge at Newell Sargent Park, north-northeasterly to its crossing beneath Big Horn Avenue (US16) to South 15th Street–a run of approximately 4,570 lineal feet, or just under a mile. The canal is literally and figuratively central to the city and many of its residential neighborhoods; the subject portion of the Lower Hanover Canal (hereinafter referred to as the "urban" section) is anticipated to serve as the key element of the primary loop of an interconnected trails system (see below), long advocated by local activists.

Improvements to the Canal will provide immediate benefit for the public and the environment. The canal easement, improved to serve as a community asset, will provide enhanced recreation opportunities, while the canal itself would be routed through an improved channel in order to decrease erosion and water loss.

ENHANCING RECREATIONAL OPPORTUNITIES

The *2015 Grow Worland Community Comprehensive Plan* (hereinafter the "Comp Plan") includes "Worland goals 2015", the organizing framework for the Comprehensive Master Plan (Comp Plan pg. 42) (Community Builders, Inc, 2015), namely:

1. Community Pride & Character
2. Healthy Intergenerational Community
3. An Active Downtown
4. Residential Neighborhoods
5. Quality Utility and Transportation Structure
6. Unique Natural Resources with Great Recreation Choices
7. Vibrant Economy & Tourism Industry
8. A Well-Planned City

These goals are interrelated and speak to the values of the community. The case can be made that enhancing the Lower Hanover Canal as part of the trail system through the city's heart will address each one of the eight overarching goals.

To begin, Sidewalks and Trails are introduced in the Community Snapshot chapter, under the Transportation section (Comp Plan pg. 34):

> "In 2003, the Worland Area Trails Master Plan was completed calling for an area-wide public trails network. If ultimately constructed as planned, the plan will include six primary trail loops, three future trail loops and secondary trail connections within the proposed trail network."

According to the referenced Worland Area Trails Master Plan, Nelson Engineering et al, October 1, 2003 (hereinafter "Trails Plan") the system would be launched with Trail Loop Number One which features the urban section of the Lower Hanover Canal (Nelson Engineering, 2003).

Trails are also referenced—along with the aquatics center, golf course, shooting complex, community center, and county fairgrounds—as providing options for many interests and abilities (Comp Plan pg. 63) because "Worland residents and visitors enjoy City parks and recreational opportunities as well as the natural environment" (Comp Plan pg. 43). Theme 6's Guiding Principles include "Conservation and protection of parks and open spaces" and its goals include "Enhance park and recreational opportunities and facilities" (Comp Plan pg. 63).

As called for by the Comp Plan's Theme 6 "Unique Natural Environment with Great Recreation Choices", a clearly defined and enhanced trail system through the community will "Minimize Impacts on the Natural Environment" (Comp Plan pg. 63) by enhancing protection of the floodplain and water quality, and "Enhance Park and Recreational Opportunities and Facilities" (Comp Plan pg. 64) by connecting existing city parks, schools, and recreation sites via pedestrian-safe pathways. As a draw for visitors and residents, the enhanced Trail is expected to strengthen a "Healthy Intergenerational Community" by providing "opportunities for residents to lead active and healthy lifestyles (Comp Plan pg. 48).

Finally, under the desire for a "Unique Natural Environment with Great Recreation Choices" (Comp Plan pg. 63), the plan reiterates:

> "To enhance park and recreational facilities, the [Comp] Plan focuses on accommodating people of all abilities, ensuring the availability of adequate amenities, designs that require minimal maintenance, and integration of interpretive messages and historic and cultural resources into community parks and open spaces. For expansion of recreational opportunities, the [Comp] Plan addresses *extension of the trail system to connect key community destinations and enhancing the offerings of recreational activities and facilities for youth and older adults."* [emphasis added]

DECREASING EROSION AND WATER LOSS

Flow data from above and below the urban section of the Canal are unavailable; however, it is the accepted wisdom that significant loss of water occurs through this section by way of seepage through failures in the canal lining. Descriptions of excessive groundwater and damp basements and subgrade flooding in adjoining neighborhoods, particularly west of the canal, was provided as evidence.

During Y2's site visit in August 2018, no immediate visible evidence of water overflowing its banks was observed, even though the available freeboard appeared to be no more than a foot or two in many locations. Therefore, the presumed water loss may be attributed to seepage through collective failure of the canal lining.

The consultant also did not observe with the naked eye evidence of erosion. As noted above, water was within a foot or two of the tops of the banks, therefore any scouring of banks would not be visible. However, hearsay describes the canal as growing shallower over time, which suggests scouring and deposition of silt.

The consultant was directed to consider means of limiting water loss due to seepage. Two options were explored:

> (1) to maintain free-flowing canal waters through a new concrete-lined channel, or
>
> (2) to enclose the canal waters completely in a box culvert or pipe. The second option would also serve to decrease losses due to evaporation; however, at 0.8 miles the urban canal is a fraction of the total run,

therefore direct losses from the urban run may be negligible overall. As mentioned above, flow data above and below the urban run of the canal are unavailable.

TRAILS MASTER PLAN – 2003

INTRODUCTION

The "Trails Plan" presages the city's Comp Plan by proffering community trails to serve basic community needs, such as public safety (children traveling to school), health, recreation, alternative transportation, enhanced property values and economic stimulus (Trails Plan pg. I-1). The public workshops which contributed to the Trails Plan revealed the "amazing" potential for an areas-wide public trails network and verified that it wasn't a new idea in the community, having been proposed in 1992 (Trails Plan I-3).

The ten proposed Master Plan Trail Loops total over 73 miles of mapped trails, varying from paved neighborhood trails suitable for tricycles, wheelchairs, and strollers, to rugged outlying trails following existing canal maintenance tracks.

TRAIL LOOP NUMBER ONE

Proposed Trail Loop Number One is designed to serve the greatest community need with a small-to-moderately sized project, looping the Lower Hanover Canal, Washakie Avenue, and Road 11.

> "The key to Loop No. 1 (and to the entire system) is the Lower Hanover Canal segment, which bisects Worland from northeast to southwest. Once installed, the segment will link parks, schools, neighborhoods, the downtown area, and other public/semi-public properties." (Trails Plan, Trail Loop Number One).

Dialing in further, the "urban" portion of this primary loop serves the densest neighborhoods and connects the most important community nodes (two elementary schools, two city parks, a church, the community center, Medical center and Senior center) with residential neighborhoods and downtown businesses. This 4,500 lineal foot segment is the subject of the LHC project.

The Trails Plan describes alternating treatments to sections of the Trail Loop Number One pathway, where certain runs of the canal are proposed to be placed in box culverts to allow more surface area for multi-purpose paths and driving lanes, alternating with open stretches of water featuring adjacent multi-purpose walkways. For example, the Howell Avenue to Washakie Avenue run was proposed to be placed in box culverts with the pathway placed on the top of the culverts. It was labeled the "Promenade" segment, as it was considered an important link between Newell Sargent and Sanders Parks. The stretch north from Howell Avenue was proposed to be an "open canal employing the adjacent access road." (Trails Plan, Trail Loop Number One)

LOWER HANOVER CANAL PATHWAY CONCEPTS – 2019

Y2 made numerous attempts to contact the Lower Hanover Canal Company representative to discuss the project in the early phases of the study but was not successful.

City officials and team co-members were extremely helpful, notably Brian Burky, Steve Hunt, and Mike Donnell. During several conversations, theories were posed and discussed, ideas reviewed, and comments received. Suggestions that the open canal options were less preferred for safety reasons were tempered with the reality that numerous municipalities successfully provide open water (San Antonio, St. Paul, Venice). Other outside-the-box ideas included gaining pathway width by abandoning Park Drive, because it is not an official city street and because it interrupts the connectivity between a proposed pathway alignment and the Community Center and Sanders Park grounds.

Following these conversations, with the guidance of the community workshop-driven citizen-approved Trails Plan, and in accordance with the contract for the Lower Hanover Canal Pathway Evaluation, Y2 generated two schematic sketches illustrating open segments and closed (covered) segments of canal pathway (refer to Maps 36-43 in the Map Book). However, rather than mixing and matching half-open and half-closed schemes, each concept illustrates a single methodology. The team emphasized during presentations that the open vs. closed segments may be mixed-and-matched, as described below.

OPEN CANAL CONCEPT PLANS

For convenience sake, the set of open canal concept plans illustrate a solution where nearly all of the urban waterway is open to the air, in which case the canal water would be directed through a lined channel. Existing east-west alley access would be maintained, but existing bridge crossings could be replaced with extended closed-channel (box culvert) sections to reduce installation and maintenance costs, and to create pedestrian-focused plazas at intersections. Refer to Map Book, Maps 36 through 39 for maps of the open canal concept plans.

These pedestrian plazas would punctuate the trail at nodes containing street furnishings, plantings, and safe crossings. An additional, critical, pedestrian crossing would bridge the canal to connect South Side School directly with the Community Center grounds; the realignment of Park Drive to the “outside” of the canal alignment would also provide students an escape route along the roadway. A second mid-block pedestrian bridge crossing would occur at Grace Avenue, a third would link Saint Mary Magdalen School and South 8th Street in line with the existing alley, and a fourth would link the alley between Coburn and Big Horn Avenue with the pathway, proposed plaza, and North 14th Street.

An enlarged plaza was proposed just north of Coburn Avenue, where the canal “easement” narrows but property ownership may allow the Town to install a trail access point with designated parking, signage, and amenities.

The advantage of the open canal solution is that it enables the community to enjoy the cooling effects of the sounds and sights of flowing water, and to acknowledge the critical importance of irrigation projects such as the canal in making life in the arid west— and in Worland in particular—even possible.

Disadvantages to an open waterway are primarily about public safety. The canal company reportedly has maintained the position that, because the canal was there first, adjacent landowners are responsible for providing and maintaining safety fencing along the canal. This presumption has proven untenable, as community members remain wary of the danger of the canal, despite the wire fencing bordering the canal.

CLOSED CANAL CONCEPT PLANS

The second option focused on an all enclosed canal, wherein the public access pathway would happen atop or adjacent to the canal cover, depending upon practical alignments. Refer to Map Book, Maps 40 through 43 for maps of the closed canal concept plans.

With the current emphasis on escape-from-school routes in active shooter scenarios, Y2 determined that, under any scenario, the “promenade” (closed) section should be shifted to the north between Culbertson Avenue and Howell

Avenue, so that no open channel would impede South Side School students' immediate access to the public right of way and the Community Center grounds. A formal crosswalk is proposed from the School gate across Park Drive, but multi-directional egress would not be limited by any adjacent waterway.

In addition, the closed channel between Culbertson and Howell would create additional surface area for expanded events (farmers' markets, art fairs, concerts and gatherings) as part of the Community Center and Sanders Park activities.

The team also suggests reversing the street/canal configuration currently existing and as proposed in the Trails Plan; two-way vehicular traffic on Park Drive would be shifted to abut the south-east private property boundary, and the multi-use pathway, constructed atop the enclosed canal waterway, would become integral to the Community Center grounds, northwest of the road. Park Drive would be narrowed to encourage slow speeds, accommodate student crosswalks and local-only traffic, yet would adequately accommodate emergency vehicles.

MIXED OPEN-CLOSED CANAL CONCEPT

Under any scenario, the open channel section may be shifted to the south between Howell and Washakie, in the area where less intensive public events may transpire. Improved access for local traffic to alleys and for emergency vehicles would be provided. Cost savings may be realized in this section by running the canal through an open lined trough rather than a box culvert. However, safety issues remain paramount, and any improvement in this area should include strategic and sturdy fencing.

PUBLIC FEEDBACK

A public meeting was held on March 19, 2019 in Worland to gauge public interest in proceeding with further development of the Lower Hanover Canal. The most strident comment concerned the number of studies and the lack of actual progress on canal improvements. Overall, the comments were strongly positive in favor of providing a solid core pathway project to launch the trail system, with emphasis on safety and access for all ages. Proffered amenities/furnishings were approved in concept, and one individual requested dog watering stations. There did not appear to be a significant determination by the public whether an enclosed or open channel was to be preferred, so long as safety and pedestrian and vehicular access were assured. John Hefenieder, Lower Hanover Canal Company (the "Canal Company") representative, joined the discussion and stated that the Company "would only go for it [canal improvements] *if it's all buried*." [emphasis added]

FIXED COSTS

Table 17 was developed to outline costs gathered from local vendors and common knowledge based on type of project and common components. These costs have been applied to the Lower Hanover Canal Pathway Evaluation to obtain a reasonable estimate for the cost of this project.

This is not intended to serve as a complete estimate for the total cost of the canal and the applied pathway system. For example, potential additional costs may arise as a result of procuring necessary easements. The 60-foot right-of-way for the urban section of the Lower Hanover Canal is assumed, and may be inferred from neighborhood plats which appear to have left room for it (Park Addition, Park Addition Block 3, Healy Addition, Court Place Addition, Second Addition to Court Place Addition, Evans Addition), no recorded easements nor rights-of-way were uncovered during this study.

In addition, the proposed pathway access plaza north of Coburn Avenue includes a privately-owned triangular parcel in addition to the undefined roadway (North 14th Street) width.

The estimate assumes that a reinforced concrete box culvert will be the most cost-efficient solution; such a structure could be accessed via manholes for maintenance purposes. Should the City choose to install a cast-in-place trench profile with pre-stressed concrete cover, additional expense will be incurred.

Finally, the proposed pathway underpass beneath Big Horn Avenue—necessary for safety, particularly of students going to and from Eastside and Southside schools—is assumed to require significant excavation and possibly additional shoring. Whereas the existing canal is assumed to be approximately 6 feet deep and will become narrower when consolidated into a 5-foot to 10-foot box culvert, the design would require an additional 9-feet tall by 10-feet wide "channel" adjacent to the buried pipe to accommodate the multi-use pathway. It is impossible to estimate a cost for this item without considerable study of the existing Big Horn Avenue bridge construction, structure, and condition. Finally, there will be some cost associated with sidewalls framing the tunnel down to the underpass floor elevation and back up to grade, and consideration to piping/pumping of any runoff which may accumulate inside the tunnel.

CONSTRUCTION COST ESTIMATES

LHC project cost estimates were developed based on individual components (Table 17). Cost estimates were performed for 2020. Financing for each component and for the project was examined to try to develop the most economically feasible cost option. This project will take full advantage of pre-cast materials for the conveyance structure. This will allow for increased availability of materials and provide a consistent solution for the installation of the pathway-pipeline system. Additional construction costs will be incurred in a manner typical of such a large-scale project. The following estimate has been provided to give the Sponsor a rough estimate of the projected cost for this project. The estimates for the amount and types of materials have been provided in Table 17 below. Price estimates are based on the component prices listed in Table 29 in Appendix A.

POTENTIAL FUNDING SOURCES

- Mineral Royalties Grant
- Drinking Water State Revolving Fund
- Community Development Block Grant
- USDA Rural Development Water and Environmental Programs
- Business Ready Communities Grant and Loan Program

SUMMARY

The design and implementation of the 'urban' run of the Lower Hanover Combined Canal Pathway system would augment the aesthetic and practicality of the Worland pathways network. Additionally, if implemented, this system would greatly enhance the efficiency of water delivery in the area and mitigate seepage caused damages. This is a highly detailed and public project that, if developed correctly, would yield benefit for everyone in the area.

Table 17: Estimated 2020 fixed costs and quantities for Hanover Canal options.

LOWER HANOVER CANAL PATHWAY PHASE 1 (Howell Ave. - Culbertson Ave.) Work Item / Material	Estimated Quantity	Unit of Meas.	Estimated Unit Cost	Estimated Extended Total
Mobilization	1	Lump Sum	$70,000	$70,000
Demolition				
Demolition, existing asphalt roadway, Culbertson-Howell (20'w x 1,707' l x 18" d)	1900	Cu.yd.	$18	$34,200
Canal				
Inlet Grate (Howell/Park Dr)	3	Lump Sum	$6,500	$19,500
Culvert (10' dia. concrete) 5'x10' RC Box Installed	1,707	Lineal Ft.	$850	$1,450,950
Manhole (maint. access)	3	Each	$5,500	$16,500
Asphalt Paving				
Sidewalk (10'w x 1,707'L x 2"layer)	1900	Sq.Yd..	$15	$28,500
Bike Pathway (10'w x 1,707'L x 2"layer)	1900	Sq.Yd.	$15	$28,500
Roadway, Howell-Culbertson (20'w x 1,707'L, 3" thick)	3795	Sq.Yd,	$22	$83,490
Parking + So 12th St extension @ Sanders Park – 3" thick	2435	Sq.Yd.	$22	$53,570
Concrete Paving				
Pedestrian Plaza (1,720 sq.ft., 4" thick)	1,720	Sq.Ft.	$8	$13,760
Concrete curb-and-gutter, Park Drive and driveways	3,670	Linear Ft.	$38	$139,460
3/4 Base Course and Pit Run Subbase				
3/4 crush Base Course: Park Drive (34,140 sf), curb/gutter (7,340 sf), parking (21,900), sidewalk+pathway (34,140), plazas (1,720) = 99,240 sf @ 4" deep	1,225	Cu.yd.	$45	$55,125
Pit Run Subbase: Park Dr (34,140 sf), parking (21,900) = 56,040 sf @ 18" deep	3,113	Cu.yd.	$32	$99,616
Landscape and Reclamation				
Trees	100	Each	$350	$35,000
Shrubs	600	Each	$45	$27,000
Topsoil (40'w x 1,707'L) = 68,280 sf @ 4" d	850	Cu.yd.	$80	$68,000
Sod	68,280	Sq.Ft.	$0.75	$51,210
Irrigation System	1	Lump Sum	$75,000	$75,000
Furnishings				
Bench	30	Each	$650	$19,500
Water Fountain	2	Each	$3,000	$6,000
Picnic Table	5	Each	$750	$3,750
Bike Rack (4 "U" racks@ $100 each + $100 concrete slab)	4	Each	$600	$2,400
Signage Kiosk	2	Each	$600	$1,200
Bollard	14	Each	$150	$2,100
SUBTOTAL WITHOUT MOBILIZATION:				$2,314,331
TOTAL				**$2,384,331**

CHAPTER 7: CONCLUSION

This report is intended to provide a summary of the Level I study that was performed on the Middle Big Horn River Watershed. This study was performed in partnership with Eagle Engineering and Surveying (formerly Donnell & Allred) and Dahlgren Consulting. An examination was performed on the study area to determine the overall state of the watershed and the various appurtenances therein. This involved the collection of potential water development related projects. These projects have been gathered and are detailed in the Project Summary Book.

To gather projects and ensure that the general public was informed on the purpose and scope of this project, the project team held a series of meetings to highlight the project and engage the public. Within these meetings it was detailed that the main purpose of this project was to provide a comprehensive understanding and inventory of the Middle Big Horn River Watershed. This inventory is a composite of other existing studies and fieldwork conducted by Y2, EES, and Dahlgren Consulting personnel. At each meeting, concerned local stakeholders were engaged one-on-one. From these meetings multiple potential projects were gathered. Coordination was performed with stakeholders to visit and document their potential projects. From these visits, Y2 was able to observe a large portion of the study area and examine the watershed. These site visits were perhaps the single largest source of information for this report.

Throughout the study area it was found that land ownership and use are varied. The Middle Big Horn River Level I Study Area is approximately 1,153,261 acres and includes lands from Big Horn, Hot Springs, Park, and Washakie Counties. The majority of the study area is remote and unpopulated. The US Highway 20 corridor that runs north to south through the eastern portion of the study area includes most of the population of the area in the towns of Worland, Basin, and Greybull. This corridor is the main zone for crops and pastures due to its proximity to the Big Horn River. Outside of approximately 5 miles of either direction of the Highway 20 corridor the land is predominately scrub/shrub or herbaceous lands. Land use in the watershed areas was observed to be largely varied. In the low-lying regions of the watershed the use of land is primarily agricultural with some intermixed industrial usage and domestic use. The usage of the watershed land changes moving into the upland regions toward the west. Here the land use is primarily livestock grazing, which varies seasonally. Additional use is seen in the development of oil and gas reserves.

Insight into the study area was garnered through the review of existing information from past reports on the study area. A large effort was made to gather as much previously developed information as possible. These references were gathered and cited in Zotero as part of the digital resource library. This library was then georeferenced within the GIS spatial database that was developed for this study.

An inventory for each separate water use and control component and review of previous studies within the study area were conducted. As part of the inventory task, a comprehensive GIS database was developed based on this gathered information. This GIS was updated following each site visit with new information. GIS played a key role in the development of this project by allowing the team to focus on those sections and areas that lacked previous study.

The field team observed erosion being a consistent problem stemming from multiple factors in the central regions of the watershed. It was commonly observed that many of the erosion control structures—silt dams—had long exceeded their effective lifespan. Consequently, the lack of sediment and erosion control has led to the degradation of many stream structures in the central areas of the watershed.

Additional consideration was given to the examination of the study area's surface water and geomorphology characteristics. Throughout the study area, several areas were identified with consistent runoff and drainage issues. These areas are primarily located within the lower regions of the area especially in the corridor between South Worland and Basin. The study team worked to develop stream classification within the study area. An evaluation of available data indicated that, while there is geologic, geomorphic, and hydrologic variability across the study area, there is also much consistency, particularly when the study area is evaluated at a reconnaissance-level scale, as done for this MBH Level I Watershed Study. Within this study a series of fluvial landscape associations were developed. Each one describes the morphology of common regions in the study area. The majority of the perennial stream mileage appears to be in either an undisturbed naturally stable form (State 1) or a recovered stable form operating at a new base level (State 6). Erosion and sedimentation in uplands and subsequent sediment delivery to streams and rivers is an issue in portions of the study area and has been for decades. The concerns occur mostly in the lower elevation, lower mean annual precipitation landscapes dominated by the Willwood Formation. From observations in the field, the study area offers a broad and dynamic range of stream types at various points of geomorphic evolution. As noted in the report, there are multiple associations of stream types. These stream types vary from one region of the watershed to the next.

An examination was performed on the geology of the study area. Over the course of the fieldwork that was performed for this study it was found that the geology, in surficial terms, was relatively uniform with variation at different elevations consistent with the stratigraphic layout. The Bighorn Basin offers the typical contrast of landscapes and environments that identifies Wyoming. The center of the basin is low, flat, and dry, characterized by rolling plains broken by broad river valleys, narrow terraces, and badlands; surrounding mountains contain thick forests and rise over 13,000 feet to perpetually snow-capped summits. The Bighorn Basin is an asymmetric syncline between the Bighorn Mountains on the east and the Absaroka and Beartooth mountains on the west. Additional examination was performed on the hydrogeology of the region. There are two major bedrock aquifer systems present in the Bighorn Basin; the Paleozoic and Upper Cretaceous-Tertiary aquifer systems, each comprised of several discrete member aquifers.

Given that a watershed is a living system, the associated biological systems present in the watershed were examined. The Middle Big Horn study area provides habitat to many upland and aquatic wildlife species. The study area, while mostly considered a cold desert, has a diversity of habitat that hosts several large wildlife species that are important to the recreational industry of the region. Virtually all the study area is habitat of some importance. Within the examination of biological systems, vegetation cover was considered. Vegetation plays a significant role in the hydrology of a watershed. The precipitation will interact with the vegetation variably dependent on the form and season of the precipitation. Vegetation influences how much precipitation reaches the ground, the amount of precipitation that is intercepted and lost to evaporation, soil infiltration and runoff rates, groundwater recharge, soil erosion and sediment transport. All of these interactions influence water quality.

Many of the anthropogenic systems that were examined are directly dependent on the biological systems health and function. These two systems are directly related and are dependent on the good stewardship of the operators of the anthropogenic systems. During the irrigation inventory it was found that while pivot irrigation has become increasingly common in the area, many areas are still flood irrigated. Many of these areas are also grazed as pasturelands and post-harvest beet tops. The communities affected by the Middle Big Horn Level I Watershed Study are interested and trending towards more efficient and sustainable irrigation methods and technologies. This includes drip irrigation, a precise method of watering crops, where water waste is transpired into the atmosphere. Other possibilities include streamlined conveyance methods, outlined as possible solutions to many of the projects listed in the study area, including but not limited to pipeline improvements, canal lining, and irrigation ditch or flooding improvements.

Water supply plays a crucial role in the operability and longevity of the anthropogenic component of the watershed. Whether this is for domestic drinking water, supplied primarily via the artesian Worland well system, or for dedicated process water for industrial uses. There are numerous industrial water users throughout the study area. These users range from industrial producers in the low-lying regions of the study area to oil and gas producers in the upland areas of the study area. As a component of industrial and natural resource production in the area there are large volumes of produced water. Produced water is typically brackish in quality with high total dissolved solids. This water typically requires a substantial amount of processing to be made useable and dischargeable. Most produced water is either trucked off-site or left in evaporation ponds. There are some instances where the water is discharged into natural drainages.

The Middle Big Horn Level I Watershed Study developed a Development, Management, and Rehabilitation Plan (DMRP) for issues identified over the course of the study period. This plan was to be technically sound, achievable, practical in nature, and possible from an economic standpoint. The development of the plan was performed in conjunction with GIS inventory for the study area based on pre-existing and field gathered information. There were over seventy projects identified, including a bridge refurbishment, drainage infrastructure, irrigation infrastructure, hydroelectric power installation, pipelines, riverbank stabilization, silt dams / stock reservoirs, and spring and well developments. One project was recommended for Level II advancement: The City of Worland – High Head Hydropower project.

An additional discretionary task was included for the development. This task was to evaluate two separate conceptual options for the development of the Lower Hanover Canal Pathway. These concepts are intended to provide direction towards the development and improvement of the existing pathway infrastructure. Two base concepts were designed, an open concept and a closed concept. However, these concepts were designed to be used concurrently to create a customized combination of open and closed canal concepts if desired.

The study area is a diverse system comprised of many opportunities to contribute to improving the function of the watershed. The proposed efforts to rehabilitate this watershed are plentiful and require substantial coordination and cooperation across multiple agencies. The projects identified comprise most of the available opportunities, though many other similar projects likely exist throughout the watershed.

Appendix A: TABLES

Appendix A Table of Contents	

Table 18: GIS sources for Middle Big Horn Level I Watershed Study Report.

Section	Map #	Page Referenced in Report	Official Map Title on Map	Data Source Cited on Map
INTRODUCTION	1	1	Study Area Location	Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
CHAPTER 3: WATERSHED INVENTORY AND DESCRIPTIONS	2	11	Bedrock Geology	USGS Bedrock Geology, 2014; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	3	11	Surface Geology	USGS Surface Geology, 2018; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	4	19	Soils	NRCS SSURGO General Soils Map, 2013; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	5	32	Surface Water Flowlines	Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	6	32, 42	Rosgen Geomorphic Characterization	Y2 Rosgen Classification, 2020; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	7	33	Stream Classifications and Crucial Stream Corridors	WGFD Crucial Stream Corridors, 2007; WGFD Classification, 2016; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	8	49	Watershed Hydrologic Units (HUC10) within the Study Area	Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	9	54	Wyoming Integrated 305b/303d Report Classified Waters and 2018 WYPDES Permitted Discharges	WDEQ WYPDES, 2019; WDEQ Classified Waters, 2018; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	10	58	HUC 10 Watershed - East Fork Nowater Creek / FEMA Flood Zones	FEMA Flood Data 2014; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019, ESRI Counties, Towns, World Topographic Background, 2019
	11	58	HUC 10 Watershed - Elk Creek - Big Horn River / FEMA Flood Zones	FEMA Flood Data 2014; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019, ESRI Counties, Towns, World Topographic Background, 2019
	12	58	HUC 10 Watershed - Gooseberry Creek / FEMA Flood Zones	FEMA Flood Data 2014; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019, ESRI Counties, Towns, World Topographic Background, 2019

Table 18: GIS sources for Middle Big Horn Level I Watershed Study Report. (continued)

Section	Map #	Page Referenced in Report	Official Map Title on Map	Data Source Cited on Map
CHAPTER 3: WATERSHED INVENTORY AND DESCRIPTIONS	13	58	HUC 10 Watershed - Little Dry Creek-Big Horn River (portion within Study Area) / FEMA Flood Zones	FEMA Flood Data 2014; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019, ESRI Counties, Towns, World Topographic Background, 2019
	14	58	HUC 10 Watershed - Little Gooseberry Creek-Big Horn River (portion within Study Area) / FEMA Flood Zones	FEMA Flood Data 2014; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019, ESRI Counties, Towns, World Topographic Background, 2019
	15	58	HUC 10 Watershed - Lower Fifteenmile Creek / FEMA Flood Zones	FEMA Flood Data 2014; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019, ESRI Counties, Towns, World Topographic Background, 2019
	16	58	HUC 10 Watershed - Nowater Creek / FEMA Flood Zones	FEMA Flood Data 2014; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019, ESRI Counties, Towns, World Topographic Background, 2019
	17	58	HUC 10 Watershed - Upper Fifteenmile Creek / FEMA Flood Zones	FEMA Flood Data 2014; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019, ESRI Counties, Towns, World Topographic Background, 2019
	18	64	Aquatic Crucial Habitat Priorities	WGFD Habitat Priority, 2015; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	19	66	Terrestrial Crucial Habitat Priorities	WGFD Habitat Priorities, 2015; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	20	67	Proghorn Seasonal Habitat	WGFD Habitat, 2012; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	21	68	Elk Seasonal Habitat	WGFD Habitat, 2012; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	22	68	Moose Seasonal Habitat	WGFD Habitat, 2012; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	23	68	Mule Deer Seasonal Habitat	WGFD Habitat, 2012; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	24	68	White Tail Deer Seasonal Habitat	WGFD Habitat, 2012; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	25	68	Big Horn Sheep Seasonal Habitat	WGFD Habitat, 2012; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019

Table 18: GIS sources for Middle Big Horn Level I Watershed Study Report. (continued)

Section	Map #	Page Referenced in Report	Official Map Title on Map	Data Source Cited on Map
CHAPTER 3: WATERSHED INVENTORY AND DESCRIPTIONS	26	69	Greater Sage-Grouse Seasonal Habitat	WGFD Sage-grouse Range, 2015; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	27	69	Herd Management Area	BLM HMA, 2019; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	28	70	National Land Cover Database	USDA Land Cover, 2013; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	29	74	Irrigated Lands and State Engineers Office Permitted Points of Use	Y2 Irrigated Lands, 2020; SEO Points of Use, 2019; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	30	78	Industrial and Mining Water Permits	SEO, 2019; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	31	79	Produced Water Locations and SEO Groundwater PODs	WOGCC Produced Water Locations, 2018; SEO, 2019; Y2 Groundwater PODs, 2019; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	32	84, 104, 105	Identified Upland Water Storage Features and Associated WYSEO POD Permit	Y2 Upland Water Sources, 2020; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
	33	86	BLM and USFS Allotments	USFS Allotments, 2010; BLM Allotments, 2016; Y2 Adjusted Flowlines, 2020; WYDOT Major Roads 2011; ESRI Counties, Towns, World Topographic Background, 2019
CHAPTER 4: WATERSHED STREAMFLOW HYDROLOGY	34	90, 94	Stream Gage Coverage & Hydrology Modeling Reaches/Nodes	Y2 Stream Flow Gages, 2020; USGS Hydrology Modeling Reaches/Nodes 2010; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019
CHAPTER 5: DEVELOPMENT, MANAGEMENT, AND REHABILITATION	35	102, 106	Overview of Identified Potential Projects within the Study Area	Y2 Potential Projects, 2020; Y2 Adjusted Flowlines, 2020; WYDOT Roads, 2019; ESRI Counties, Towns, World Topographic Background, 2019

Table 18: GIS sources for Middle Big Horn Level I Watershed Study Report. (continued)

Section	Map #	Page Referenced in Report	Official Map Title on Map
CHAPTER 6: LOWER HANOVER CANAL PATHWAY EVALUATION	36	137	Worland Trails- Lower Hanover Canal Pathway- Open Canal Concept Plan 1 of 4
	37	137	Worland Trails- Lower Hanover Canal Pathway- Open Canal Concept Plan 2 of 4
	38	137	Worland Trails- Lower Hanover Canal Pathway- Open Canal Concept Plan 3 of 4
	39	137	Worland Trails- Lower Hanover Canal Pathway- Open Canal Concept Plan 4 of 4
	40	137	Worland Trails- Lower Hanover Canal Pathway- Buried Canal Concept Plan 1 of 4
	41	137	Worland Trails- Lower Hanover Canal Pathway- Buried Canal Concept Plan 2 of 4
	42	137	Worland Trails- Lower Hanover Canal Pathway- Buried Canal Concept Plan 3 of 4
	43	137	Worland Trails- Lower Hanover Canal Pathway- Buried Canal Concept Plan 4 of 4

Table 19: Summary of hydrogeology and aquifers within the Middle Big Horn study area (Wyoming State Geological Survey, 2012).

	Section/Hydrogeologic Unit	Component geologic units	Aquifer class	Current uses	Development potential	Groundwater resources factor
Cenozoic						
	7.2.1 Quaternary unconsolidated deposit aquifers	alluvium, colluvium, terrace landslide, and glacial deposits	Major Aquifer - Alluvial	domestic, stock, irrigation, public supply from shallow wells	variable - can be high in areas - mostly same as current uses - maybe complicated by interconnection to surface water	As much as 100 but generally less than 30 feet of sand and gravel interbedded with silt and clay with some coarser cobble and boulder deposits (near mountainous source areas) - small areal extent and limited continuity - Can be highly productive locally where saturated thickness is large and coarse grained deposits predominate - significant source of water primarily in alluvium near larger streams and rivers where recharge from surface water and irrigation predominates - Water quality is variable and commonly reflects source of recharge - Highly vulnerable to surface/near surface sources of contamination.
7.2.3 cont.	7.2.3.1 Willwood Aquifer	Willwood Formation	Minor Aquifer	stock and domestic	same as current uses - stock and domestic	Aerially extensive and exposed throughout the central part of the BHB - 800-5,000 feet of fine-to-coarse grained sheet or channel sandstones interbedded with shale and other fine grained strata, with some local lenses of conglomerate and coal - Sandstones vary widely in geometry and thickness - Channel (shoestring) sandstones are very narrow and generally less than 10 feet thick - The proportion of sandstone to fine grained strata varies substantially by location from 3 to 88 percent and averaging approximately 25 percent - Water table conditions may exist in the shallowest sandstones - Well productivity dependent on the number of beds and total thickness of sandstone penetrated - Median spring and well yields are less than 10 gal/min - Water quality varies widely and is susceptible to contamination from surface sources - Nearly indistinguishable from the Fort Union on physical characteristics.
7.2.3.1 Lower Tertiary/Upper Cretaceous aquifer system	7.2.3.1 Fort Union aquifer	Fort Union Formation	Major Aquifer - Sandstone	stock and domestic	same as current uses - stock and domestic	Aerially extensive primarily along the margins of the BHB - 1,000 to 11,500 feet of fine to coarse grained sheet or channel sandstones interbedded with shale and other fine-grained strata, with some local lenses of conglomerate and coal - Sandstones vary widely in geometry and thickness - Channel (shoestring) sandstones are very narrow and generally less than 10 feet thick - The proportion of sandstone to fine-grained strata varies substantially by location from 3 to 88 percent and averaging approximately 25 percent - Water table conditions may exist in the shallowest sandstones - Well productivity dependent on the number of beds and total thickness of sandstone penetrated - Median spring and well yields are less than 10 gal/min - Water quality varies widely and is susceptible to contamination from surface sources - Nearly indistinguishable from the Fort Union on physical characteristics.
	Mesozoic					
	7.2.3.4 Lance Aquifer	Lance Formation	Major Aquifer	stock, domestic, and limited public supply	marginal - same as current uses - mostly stock and domestic wells located in outcrop areas	Exposed at the surface around the perimeter of the basin, mostly deeply buried in the subsurface - 800 to 1,800 feet of sandstone interbedded with shale, claystone, siltstone, and thin coal - Lenticular sandstones are often confined by fine-grained lithologies resulting in a sequence of subaquifers - Primarily intergranular permeability can be enhanced by fractures in deformed areas - Relatively low yield, variable hydrogeologic characteristics, variable water quality, and limited access to the aquifer preclude any substantial aquifer development - Water quality variable; unusable without treatment to marginally suitable for most uses including domestic.
	7.2.3.5 Meeteetse aquifer and confining unit	Meeteetse Formation and Lewis Shale	Major Confining Unit and Minor Aquifer	stock and domestic	Marginal - stock and domestic	650 to 1,200 feet of lenticular clayey to silty fine-grained poorly indurated sandstone interbedded with shale, claystone, siltstone, bentonite, and occasionally thin coal - Lenticular sandstones are commonly confined by fine-grained lithologies resulting in a sequence of subaquifers - Where present, the Lewis Shale is interbedded with the Meeteetse Formation and functions as a confining unit - Considered both and aquifer and confining unit - Poor water quality precludes most uses without treatment

Table 19: Summary of hydrogeology and aquifers within the Middle Big Horn study area (Wyoming State Geological Survey, 2012).

	Section/Hydrogeologic Unit	Component geologic units	Aquifer class	Current uses	Development potential	Groundwater resources factor
	7.2.3.6 Mesaverde aquifer	Mesaverde Formation	Major Aquifer - Sandstone	few water wells - mostly oil and gas	moderate - stock, domestic, and limited public water supply - Teapot Sandstone likely best potential	900 to 1,800 feet of variable sequence of massive lenticular fine to coarse grained sandstone, carbonaceous shale and coal - Lenticular sandstones range from 50 to 40 feet thick are often confined by fine grained lithologies resulting in a sequence of subaquifers - The lowermost part of the formation, the Eagle Sandstone, consists of fine-grained sandstone, and shaley sandstone - Variable, generally poor water quality precludes most uses without treatment.
7.2.4 Cody Confining Unit		Cody Shale	Major Confining Unit`	possible stock and domestic	not significant	2,100 to 3,000 feet of upper gray sandy shale interbedded with shaley sandstone, and a lower dark gray marine shale with some glauconitic sandstone and thin beds of bentonite - Sandstones and fractured zones can yield small quantities of water locally - Poor water quality limits most uses without treatment
7.2.5.1 Lower and middle Mesozoic aquifers and confining units	7.2.5.1 Frontier Aquifer	Frontier Formation	Minor Aquifer	stock and domestic where exposed in outcrop areas	marginal - same as current uses - mostly stock and domestic wells located in outcrop areas	450 to 700 feet of lenticular fine to medium grained argillaceous sandstone and conglomeritic sandstone beds, interbedded with shale and lesser amounts of lignite and bentonite. - Alternating lenticular sandstone interbedded with shale strata creates a series of subaquifers - Contains less than 50 percent sandstone - Highly variable, generally poor water quality precludes many uses without treatment.
	7.2.5.2 Mowry-Thermopolis confining unit and Muddy Sandstone aquifer	Mowry Shale, Muddy Sandstone, Thermopolis Shale	Major Confining Unit and Minor Aquifer	very few (probably stock and domestic) water wells limited to basin margins - mostly oil and gas	minor - stock and domestic limited to low yield wells along the basin margin outcrop areas	Combined thickness over 700 feet - Mowry Shale thin-bedded resistant/brittle shale with thing sandstone and bentonite beds in the upper part - Thermopolis Shale, soft black shale with sandy silty, and bentonite zones - Muddy aquifer (10 to 50 feet thick): includes massive sandstone interbedded with mudstone, siltstone, shale, bentonite, and stone conglomerate - Water quality precludes most uses without treatment but based on few samples (mostly produced water)
	7.2.5.6 Cloverly aquifer	Cloverly Formation	Major Aquifer - Sandstone	domestic and stock in outcrop areas	mostly marginal - same as current uses - domestic and stock wells located in outcrop areas better along Wind River Range	85 to 470 feet thick includes three units, upper Dakota Sandstone interbedded with silty sandstone and shale, a middle shale unit with uncommon sandstone lenses, and a lower lenticular Lakota Sandstone with conglomeratic sandstone with some siltstone and shale - Both sandstone units are permeable and 70 to 90 feet thick - Evaluated as a potential source of public water supply in the northeastern BHB - Water quality is variable, generally fresh in outcrop areas and declining with depth.
	7.2.5.7 Morrison confining unit and aquifer	Morrison Formation	Confining Unit and Minor Aquifer	possibly stock and domestic in outcrop areas	limited by outcrop area and small yields - adequate only for stock and domestic use	75 to 300 feet of interbedded shale and sandstone, with minor silty fine-grained sandstone, limestone and conglomerate lenses - The fine grained strata are confining units, and the sandstones are commonly local aquifers or subaquifers - Water quality is variable (based on few samples) generally better in outcrop areas and declining with depth.
	7.2.5.8 Sundance confining unit and aquifer	Sundance Formation	Marginal Aquifer	possibly stock and domestic in outcrop areas	limited by outcrop area and small yields - adequate only for stock and domestic use	200 to 370 feet thick - Shale interbedded with glauconitic sandstone, siltstone, and limestone - Fine grained strata are confining units, and the interbedded sandstones are commonly local aquifers or subaquifers - Water quality variable and generally poor precluding most uses without treatment except in outcrop areas based on few samples.
	7.2.5.9 Gypsum Spring confining unit and aquifer	Gypsum Spring Formation	Marginal Aquifer	very few wells - possibly stock and domestic	very limited by small outcrop area and poor water quality	200 to 370 feet of siltstone, claystone, and shale with thin limestone and massive gypsum beds - Fine-grained strata are considered confining units and solution zones in gypsum beds are commonly local aquifers or subaquifers - Very limited outcrop area and accessibility - Likely poor water quality
7.2.6 Chugwater-Dinwoody aquifer and confining unit		Chugwater Group or Formation and Dinwoody Formation	Marginal Aquifer and Confining Unit	although overall confining, can yield small quantities of water in outcrop areas	marginal -insignificant	450 to 1,200 feet thick of: Chugwater composed of fine-grained sandstone, siltstone, and shale with some thin lenticular beds of limestone and gypsum - Dinwoody includes silty shale and siltstone, with limestone, dolomite, and gypsum in the upper part - Water quality variable and generally poor based on few (mostly produced water) samples better in outcrop areas and declining with depth to generally unusable without treatment

Table 19: Summary of hydrogeology and aquifers within the Middle Big Horn study area (Wyoming State Geological Survey, 2012).

	Section/Hydrogeologic Unit	Component geologic units	Aquifer class	Current uses	Development potential	Groundwater resources factor
Paleozoic						
7.2.7 Paleozoic system	7.2.7.1 Goose Egg - Phosphoria aquifer and confining unit	Phosphoria/Park City Formations and Goose Egg Formation	Minor Aquifer	limited to few low-yield wells along in and near outcrop areas	minor - stock and domestic wells located in outcrop areas	The Park City is 25 to 325 feet of cherry dolomitic carbonates - The Goose Egg (Phosphoria equivalent) is 100 to 300 feet of evaporites including gypsiferous siltstone, mudstone, and silty shale - Overall low permeability but complex intertounging between facies creates small permeable zones that can function as both a confining unit and an aquifer - Subaquifers can be hydraulically interconnected and hydraulically connected with the underlying Tensleep aquifer by faults and fractures - Intergranular permeability is generally small, but locally enhanced by fractures especially near the basin margins - Water quality is variable (based on few samples) generally fresh in outcrop areas and declining with depth (based on produced water samples) to generally unusable without treatment
	7.2.7.4 Tensleep aquifer	Tensleep Sandstone and Ranchester Limestone Member of the Amsden Formation	Major Aquifer - Limestone	domestic, public, industrial, and irrigation (rare) primarily along the eastern margin outcrops or at shallow depths	high - for many users - primarily around the basin perimeter where fractures enhance permeability and not too deeply buried	The Tensleep is cross-bedded, well sorted, fine to medium grained sandstone cemented with carbonate and silica with cherry dolomite in the upper part and discontinuous limestone and dolomite in the lower part - The Ranchester is primarily limestone generally not permeable except where dolomitized - One of the most productive aquifers in the basin - Porosity and permeability is primarily intergranular dependent on the amount of secondary cementation and re-crystallization, both increasing with depth - Fractures and solution processes (in carbonate rich zones) significantly enhances intergranular permeability in deformed areas where the most productive wells are located - Water quality is generally good to excellent in and near (downdip of) outcrop areas, especially where groundwater circulation is vigorous, and declines downdip into the basin becoming unusable without treatment
	7.2.7.5 Amsden confining unit	Amsden Formation	Marginal Aquifer and Confining Unit	no development per better potential in other, often shallower Pz aquifers	insignificant - except where integrated with adjacent aquifers	120 to 300 feet of Ranchester Limestone, Horseshoe Shale, and Darwin Sandstone - Water quality variable and generally poor based only on produced water samples.
	7.2.7.6 Madison - Big Horn aquifer	Darwin Sandstone (Member of the Amsden Fm.), Madison Limeston, Darby, Three Forks, and Jefferson Formations, and Big Horn Dolomite	Major Aquifer - Limestone	domestic , commercial, stock, public supply fornumerous communities and irrigation along the eastern margin outcrops or at shallow depths	high - for many uses - primarily around the basin perimeter where shallow and solution enhanced fracture permeability dominates	The most important aquifer system in the BHB - Predominantly thick-bedded limestone and dolomite with minor interbedded siltstone and some chert - Hydrogeologic units of the aquifer system are hydraulically connected by solution enlarged joints and fractures - Thickness is highly variable and depends on ths thickness and extent of hydraulic connection - Faulting and fracturing also provide hydraulic connection with overlysing and underlying hydrogeologic units at some locations - Primary permeability is insignificant in the dense, finely crystalline carbonates - Permeability is mostly secondary fractures, joints, and caverns attributed folding and faulting of brittle carbonates solution enhanced by groundwater flow - Permeability decreases basinward due to less deformation, decreasing solution enhancement of fractures (lower hydraulic gradient & less flow), re-precipitation of cements, and decreasing carbonate solubility as temperature increase - Most productive hydrogeologic unit in the basin where solution enhanced fracture permeability dominates - Most wells are located along the basin margin where structurally deformed and exposed or present at relatively shallow depths - Some wells yield large and dependable supplies of potable water - Water quality is generally good to excellent in and rear (downdip of) outcrop areas, especially where groundwater circulation is vigorous within hgihliy permeable solution-enhanced fractures and declines downdip into the basin eventually becoming unusable without treatment - Water quality also reflects mixing between different hydrogeologic units

Table 19: Summary of hydrogeology and aquifers within the Middle Big Horn study area (Wyoming State Geological Survey, 2012).

Section/Hydrogeologic Unit	Component geologic units	Aquifer class	Current uses	Development potential	Groundwater resources factor
7.2.8 Gallatin - Gros Ventre confining unit	Gallatin Limestone and Gros Ventre Formation	Minor Aquifer and Confining Unit	few if any wells - very limited quantitative hydrogeologic or water quality information available	probably not significant	800 to 1,200 feet of Gallatin: glauconitic gray-green shale and pebbly limestone with minor interbedded sandstone, and Gros Ventre: glaconitic and sandy limestone with interbedded shale, sandy limestone, and minor interbedded limey sandstone - Althrough generally considered confining units both may yield small quantities of water to wells and springs especially from interbedded limestones and sandstones - Very little quantitative hydrogeoloic or water quality information is available for the BHB
7.2.9 Flathead aquifer	Flathead Sandstone	Major Aquifer - Limestone	stock and irrigation along the east margin of the BHB, where outcropping or at shallow depths	Same as current - potentially very good source of groundwater for development but limited by accessibility to outcrop areas and very deep burial in most of the BHB	absent in the northeastern BHB - 100 to 200 feet of fine to medium grained arkosic and quartzitic sandstone with some interbedded shale in the upper part - primary permeability is intergranular but secondary permeability is present as a result of fracturing near folds and faults - where confined commonly under high artesianpressure and will flow at ground surface - flowing wells located along the mountain basin margin can yield large and dependable supplies of potable water - water from limited environmental samples was generally fresh
7.2.10 Precambrian basal confining unit	Precambrian Crystalline Basement Complex	Major Confining Unit and Minor Surficial Aquifer in outcrop areas	local domestic, possible stock	same as current - domestic and stock	Nonporous igneous and metamorphic rocks function as the basal confinement for the WRB groundwater basin - In outcrop areas shallow wells are developed locally for domestic use - Permeability is from weathered regolith, and jointed and fractured crystalline bedrock - Little quantitative hydrogeologic and water quality information is available - Water quality from spring samples is very fresh and based on shallow depth of circulation, high rate of circulation, high rate of recharge, lack of soluble mineral and low surface area of the aquifer matrix (fractures), good to excellent water quality is probably common.

Table 20: Watersheds in the study area (USGS, 2016).

HUC10 Name	HUC10 Number	Acres
Gooseberry Creek	1008000706	230,249
East Fork Nowater Creek	1008000707	98,778
Nowater Creek	1008000708	170,944
Upper Fifteenmile Creek	1008000709	175,711
Lower Fifteenmile Creek	1008000710	157,954
Little Gooseberry Creek-Big Horn River	1008000711	47,259
Elk Creek-Big Horn River	1008000712	267,565
Little Dry Creek-Big Horn River	1008001003	4,799
	Total:	**1,153,261**

Table 21: Sub-watersheds in the study area (USGS, 2016).

HUC12 Name	HUC12 Number	Acres
Deer Creek-Gooseberry Creek	100800070601	24,762
Middle Creek	100800070602	13,996
Mormon Creek-Gooseberry Creek	100800070603	21,228
Upper Buffalo Creek	100800070604	21,957
Lower Buffalo Creek	100800070605	22,163
Enos Creek-Gooseberry Creek	100800070606	36,922
Gillies Draw-Gooseberry Creek	100800070607	34,375
Hillberry Reservoir-Gooseberry Creek	100800070608	28,902
Blake-Denton Number 1 Reservoir-Gooseberry Creek	100800070609	25,945
Joe Henry Fork	100800070701	20,011
Upper East Fork Nowater Creek	100800070702	31,213
Denver Jake Draw	100800070703	14,969
Lower East Fork Nowater Creek	100800070704	32,586
Headwaters Nowater Creek	100800070801	41,799
Mud Creek	100800070802	33,890
Upper Nowater Creek	100800070803	33,246
Middle Nowater Creek	100800070804	49,446
Lower Nowater Creek	100800070805	12,563
Enright Reservoir-Fifteenmile Creek	100800070901	40,598
Badger Creek-Fifteenmile Creek	100800070902	36,707
Big Draw-Fifteenmile Creek	100800070903	34,835

Table 21: Sub-watersheds in the study area (USGS, 2016). (continued)

HUC12 Name	HUC12 Number	Acres
Dry Cottonwood Creek	100800070904	20,165
Timber Creek-Fifteenmile Creek	100800070905	43,406
Upper Middle Fork Fifteenmile Creek	100800071001	27,238
Lower Middle Fork Fifteenmile Creek	100800071002	37,405
Reservoir Creek-Fifteenmile Creek	100800071003	26,466
North Fork Fifteenmile Creek	100800071004	16,914
Schuster Draw-Fifteenmile Creek	100800071005	49,932
Little Gooseberry Creek	100800071104	20,823
Horse Gulch-Big Horn River	100800071106	26,436
Tenmile Creek	100800071201	20,296
Slick Creek-Big Horn River	100800071202	40,707
Fivemile Creek	100800071203	27,466
Sixmile Creek-Big Horn River	100800071204	36,120
South Fork Elk Creek	100800071205	17,721
Elk Creek	100800071206	44,732
Alamo Creek-Big Horn River	100800071207	30,962
Antelope Creek-Big Horn River	100800071208	49,562
Lovell Draw - Big Horn River	100800100309	4,799
Total		**1,153,261**

Table 22: Land cover percentage breakdown.

Land Cover Type	Acres	Percentage of Study Area
Developed, High Intensity	172.1	0.0
Mixed Forest	211.5	0.0
Deciduous Forest	1006.0	0.1
Developed, Medium Intensity	1023.5	0.1
Open Water	1418.8	0.1
Emergent Herbaceous Wetlands	2294.0	0.2
Developed, Low Intensity	5851.5	0.5
Developed, Open Space	6632.0	0.6
Woody Wetlands	8410.8	0.7
Hay/Pasture	18407.8	1.6
Barren Land	19621.3	1.7
Evergreen Forest	20188.6	1.7
Cultivated Crops	33290.9	2.9
Herbaceous	457885.9	39.7
Shrub/Scrub	577733.7	50.1

Table 23: Permitted use and number of wells (WSEO, n.d.).

Usage	Number of Wells
Domestic	838
Domestic / Irrigation	3
Domestic / Stock	183
Stock	208
Industrial	36
Irrigation	3
Municipal	1
Miscellaneous	34

Table 24: Number of wells by priority date (WSEO, n.d.).

Decade	Number of Wells
1950 or Before	156
1960	44
1970	404
1980	393
1990	94
2000	116
2010	99

Table 25: Permitted well yields (WSEO, n.d.).

Yield (gpm)	Number of Wells
<10	411
10 – 25	854
26 – 50	13
51 – 100	8
100 – 500	14
>500	6

Table 26: Permitted well depth (WSEO, n.d.).

Depth (Feet)	Number of Wells
<1	60
0 – 5	19
6 – 50	630
51 – 100	189
101 – 200	186
201 – 300	72
301 – 500	59
501 – 750	23
751– 1000	5
>1000	26
Unknown	37

Table 27: Land ownership across the study area.

Land Ownership	Acres	Percent of Study Area
Bureau of Land Management	854,702.5	74.1
Private	222,415.5	19.3
State	60,003.1	5.2
Forest Service	10,056.4	0.9
Local Government	2,911.5	0.3
Bureau of Reclamation	1,547.9	0.1

Table 28: Potential projects overview and summary table.

Project ID	Project Name	Latitude	Longitude	Project Type	Potential CFS	Potential acre-ft	Practicality	Funding Source	Sponsor	New or Rehabilitation
1-1	North Antelope Drainage District	44.365892	-108.037	Drainage	--	--	Medium	USBR WaterSMART, USDA Water & Waste Disposal Loan & Grant Program	Qualified Public Entity	Rehabilitation
2-1	City of Worland High Head Hydropower	44.025201	-107.874813	Power Generation	--	--	Low	WWDC Level II Planning Study, USBR WaterSMART	City of Worland	Rehabilitation
2-3	Newell Sargent Park Irrigation	44.005539	-107.958926	Irrigation	--	--	High	SWPP	City of Worland	Rehabilitation
2-4	Sanders Park Irrigation	44.01225	-107.954619	Irrigation	--	--	High	SWPP	City of Worland	Rehabilitation
2-5	Kiwanis Park Irrigation	44.0142	-107.943285	Irrigation	--	--	High	SWPP	City of Worland	Rehabilitation
2-6	Veterans Park Irrigation	44.022312	-107.940963	Irrigation	--	--	High	SWPP	City of Worland	Rehabilitation
2-7	Riverside Park Irrigation	44.017656	-107.968677	Irrigation	--	--	High	SWPP	City of Worland	Rehabilitation

Table 28: Potential projects overview and summary table. (continued)

Project ID	Project Name	Latitude	Longitude	Project Type	Potential CFS	Potential acre-ft	Practicality	Funding Source	Sponsor	New or Rehabilitation
3-1	Rattlesnake Ridge Stock Reservoir	44.071999	-107.871322	Silt Dam/Stock Reservoir	--	0.05	Low	SWPP, USDA Environmental Quality Incentives Program, OSLI Farm Loan, WCCD Community and Resource Enhancement Cost Share Program	Washakie County Conservation District	Rehabilitation
5-1	Neves Well	44.297881	-108.4891152	Well Development	--	--	Low	SWPP, OSLI Mineral Royalty Grant	South Big Horn Conservation District	Rehabilitation
5-2	Neves Spring Development for Stock Use	44.302662	-108.461456	Spring Development	1	--	Medium	SWPP	South Big Horn Conservation District	New Water Supply
6-1	Fifteenmile Spreader Dike Refurbishment	44.2681592	-108.4607147	Silt Dam/Stock Reservoir	--	3.16	Low	SWPP, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
7-1	Highway 20 Drainpipe	44.3561501	-108.0400975	Drainage	--	--	Low	SWPP, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
8-1	Bridge Refurbishment	44.3239394	-108.041411	Bridge Refurbishment	--	--	High	OSLI Mineral Royalty Grant	South Big Horn Conservation District	Rehabilitation
9-1	McKim Weir Reconstruction	44.269334	-108.0332479	Monitoring	--	--	High	OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
10-1	Fivemile Silt Dam Refurbishment #1	44.2388085	-108.2000015	Silt Dam/Stock Reservoir	--	0.00	Low	SWPP, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
11-1	Burlington Pass Road Silt Dam Washout	44.2320167	-108.4321381	Silt Dam/Stock Reservoir	--	2.94	Low	SWPP, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
12-1	Lungren Spring Development	43.6016007	-107.6772604	Spring Development	1.1	--	Medium	SWPP, OSLI Farm Loan	Hot Springs Conservation District	New Water Supply

Table 28: Potential projects overview and summary table. (continued)

Project ID	Project Name	Latitude	Longitude	Project Type	Potential CFS	Potential acre-ft	Practicality	Funding Source	Sponsor	New or Rehabilitation
12-2	Lungren Cattle Co. Silt Dam Erosion	43.6739121	-107.6477875	Silt Dam/Stock Reservoir	--	0.75	Low	SWPP, USDA Environmental Quality Incentives Program	Hot Springs Conservation District	Rehabilitation
12-3	Lungren Pipeline	43.6016007	-107.6772604	Pipeline	1.11	--	Medium	SWPP, USBR WaterSMART, OSLI Farm Loan	Hot Springs Conservation District	Rehabilitation
13-1	Big Horn Canal Erosion Feature	44.2346872	-107.9745444	Irrigation	--	--	High	SWPP	South Big Horn Conservation District	Rehabilitation
14-1	Kienlen Reservoir Rehabilitation	43.9707437	-108.1446808	Silt Dam/Stock Reservoir	--	0.00	Low	SWPP, USDA Environmental Quality Incentives Program, WCCD Community and Resource Enhancement Cost Share Program	Washakie County Conservation District	Rehabilitation
15-1	Fifteenmile Silt Dam Development	44.1658888	-108.477198	Silt Dam/Stock Reservoir	--	0.00	Low	SWPP, USDA Environmental Quality Incentives Program, WCCD Community and Resource Enhancement Cost Share Program	Washakie County Conservation District	Rehabilitation
16-1	Big Horn Land & Livestock Stream Restoration 1	44.2077661	-107.9150071	Riverbank Stabilizatio n	--	--	Low	WDEQ 319 Funds, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
17-1	Euler Stream Restoration	44.2211154	-107.942473	Riverbank Stabilizatio n	--	--	Low	WDEQ 319 Funds, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
18-1	Big Horn Land & Livestock Stream Restoration 2	44.2157022	-107.9322591	Riverbank Stabilizatio n	--	--	Low	WDEQ 319 Funds, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
19-1	Banjo Road Pipeline Conversion	43.99997	-107.9042086	Pipeline	4.53	--	High	SWPP, OSLI Farm Loan, USBR WaterSMART	Washakie County Conservation District	Rehabilitation

Table 28: Potential projects overview and summary table. (continued)

Project ID	Project Name	Latitude	Longitude	Project Type	Potential CFS	Potential acre-ft	Practicality	Funding Source	Sponsor	New or Rehabilitation
20-1	Stulc Irrigation Supply	44.4290324	-108.0237304	Irrigation	--	--	High	SWPP, OSLI Farm Loan, USBR WaterSMART	South Big Horn Conservation District	Rehabilitation
20-2	Stulc Riverbank Stabilization #1	44.4374864	-108.0330699	Riverbank Stabilization	--	--	Medium	WDEQ 319 Funds, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
20-3	Stulc Riverbank Restoration #2	44.4356517	-108.0388795	Riverbank Stabilization	--	--	Medium	WDEQ 319 Funds, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
21-1	Scheurman Settling Pond	44.1101685	-107.8880516	Settling Pond	--	--	Medium	SWPP, USDA Environmental Quality Incentives Program, OSLI Farm Loan	Washakie County Conservation District	New Water Suply
21-2	Scheurman Pipeline	44.161038	-107.879784	Pipeline	6.41	--	Medium	SWPP, USBR WaterSMART, OSLI Farm Loan WCCD Community and Resource Enhancement Cost Share Program	Washakie County Conservation District	New Water Supply
23-1	Hamilton Ditch Conversion	44.1392566	-107.8801042	Pipeline	5.55	--	Medium	SWPP, USBR WaterSMART, OSLI Farm Loan, WCCD Community and Resource Enhancement Cost Share Program	Washakie County Conservation District	Rehabilitation
23-2	Hamilton Spillway Refurbishment	44.1392481	-107.8863231	Irrigation	--	--	High	SWPP, OSLI Farm Loan, WCCD Community and Resource Enhancement Cost Share Program	Washakie County Conservation District	Rehabilitation
24-1	Foss Ditch Conversion #1	44.2753843	-108.0304154	Pipeline	5.55	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
24-2	Foss Ditch Conversion #2	44.2768496	-108.0303806	Pipeline	5.55	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation

Table 28: Potential projects overview and summary table. (continued)

Project ID	Project Name	Latitude	Longitude	Project Type	Potential CFS	Potential acre-ft	Practicality	Funding Source	Sponsor	New or Rehabilitation
24-3	Foss Ditch Conversion #3	44.2779961	-108.0279049	Pipeline	5.55	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
24-4	Foss Ditch Conversion #4	44.2390514	-107.9594129	Pipeline	5.55	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
24-5	Foss Ditch Conversion #5	44.2707118	-108.0208881	Pipeline	5.55	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
25-6	Ditch 11 Buried Pipeline	44.3275144	-108.0348137	Pipeline	5.55	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
26-1	Fivemile Silt Dam Refurbishment #2	44.19297	-108.040405	Silt Dam/Stock Reservoir	--	0.00	Low	SWPP, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
27-1	Fivemile Silt Dam Refurbishment #3	44.283566	-108.199158	Silt Dam/Stock Reservoir	--	0.64	Low	SWPP, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
28-1	Fivemile Silt Dam Refurbishment #4	44.285854	-108.163719	Silt Dam/Stock Reservoir	--	1.08	Low	SWPP, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
29-1	Fivemile Silt Dam Refurbishment #5	44.285168	-108.16066	Silt Dam/Stock Reservoir	--	0.29	Low	SWPP, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
30-1	Fivemile Silt Dam Refurbishment #6	44.242771	-108.162209	Silt Dam/Stock Reservoir	--	0.05	Low	SWPP, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
31-1	Elk Creek Silt Dam Refurbishment	44.296078	-108.322578	Silt Dam/Stock Reservoir	--	0.28	Low	SWPP, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
32-1	Tatman Silt Dam Refurbishment	44.288914	-108.485023	Silt Dam/Stock Reservoir	--	1.08	Low	SWPP, USDA Environmental Quality Incentives Program	South Big Horn Conservation District	Rehabilitation
33-1	Gallovich Spring Development for Stock Use #1	43.942966	-108.898453	Spring Development	1	--	Medium	SWPP, OSLI Farm Loan	Hot Springs Conservation District	New Water Supply

Table 28: Potential projects overview and summary table. (continued)

Project ID	Project Name	Latitude	Longitude	Project Type	Potential CFS	Potential acre-ft	Practicality	Funding Source	Sponsor	New or Rehabilitation
33-2	Gallovich Spring Development for Stock Use #2	43.9384	-108.902229	Spring Development	1	--	Medium	SWPP, OSLI Farm Loan	Hot Springs Conservation District	New Water Supply
33-3	Gallovich Spring Development for Stock Use #3	43.937687	-108.902191	Spring Development	1	--	Medium	SWPP, OSLI Farm Loan	Hot Springs Conservation District	New Supply
33-4	Gallovich Pipeline	43.937687	-108.902191	Pipeline	1.04	--	Medium	SWPP, USBR WaterSMART, OSLI Farm Loan	Hot Springs Conservation District	Rehabilitation
34-1	LU Sheep Ranch Spring Development for Stock Use	43.932133	-108.932671	Spring Development	1	--	Medium	SWPP, OSLI Farm Loan	Meeteetse Conservation District	New Water Supply
35-1	Feraud Drainage	44.004482	-108.28302	Drainage	--	--	High	SWPP, USBR WaterSMART WCCD Community and Resource, Enhancement Cost Share Program	Washakie County Conservation District	Rehabilitation
35-2	Feraud West Reservoir	44.004604	-108.297821	Silt Dam/Stock Reservoir	--	1.18	Medium	SWPP, USDA Environmental Quality Incentives Program, WCCD Community and Resource Enhancement Cost Share Program	Washakie County Conservation District	New Water Supply
36-1	Harrison Pipeline #1	44.367184	-108.035683	Pipeline	6.41	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
36-2	Harrison Pipeline #2	44.364746	-108.045845	Pipeline	7.85	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
37-1	McKim Ditch Conversion #1	44.284061	-108.036362	Pipeline	6.41	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
37-2	McKim Ditch Conversion #2	44.280651	-108.012909	Pipeline	4.53	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation

Table 28: Potential projects overview and summary table. (continued)

Project ID	Project Name	Latitude	Longitude	Project Type	Potential CFS	Potential acre-ft	Practicality	Funding Source	Sponsor	New or Rehabilitation
37-3	McKim Ditch Conversion #3	44.284153	-108.009247	Pipeline	4.53	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
37-4	McKim Ditch Conversion #4	44.290916	-108.007599	Pipeline	5.55	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
37-5	McKim Ditch Conversion #5	44.287766	-108.003288	Pipeline	5.55	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
37-6	McKim Ditch Conversion #6	44.291584	-108.039902	Pipeline	4.53	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
37-7	McKim Well Development #1			Well Development	--	--	Medium	SWPP, OSLI Mineral Royalty Grant	South Big Horn Conservation District	New Water Supply
37-8	McKim Well Development #2			Well Development	--	--	Medium	SWPP, OSLI Mineral Royalty Grant	South Big Horn Conservation District	New Water Supply
38-1	Montanez Drainage	43.935337	-107.968056	Drainage	--	--	High	USBR WaterSMART, WCCD Community and Resource Enhancement Cost Share Program	Washakie County Conservation District	Rehabilitation
39-1	Rayburn Siphon	43.981773	-107.988342	Pipeline	6.41	--	Medium	SWPP, USBR WaterSMART, OSLI Farm Loan, WCCD Community and Resource Enhancement Cost Share Program	Washakie County Conservation District	Rehabilitation
39-2	Rayburn Vega Ditch	43.977165	-107.989777	Pipeline	6.41	--	Medium	SWPP, USBR WaterSMART, OSLI Farm Loan, WCCD Community and Resource Enhancement Cost Share Program	Washakie County Conservation District	Rehabilitation
40-1	Zadra Irrigation System	44.39204	-108.028404	Irrigation	--	--	High	SWPP, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation
41-1	Asment Pipeline	44.3275	-108.041	Pipeline	6.41	--	High	SWPP, USBR WaterSMART, OSLI Farm Loan	South Big Horn Conservation District	Rehabilitation

Table 29: Estimated unit and supply cost for projects gathered.

Component	Unit Cost	Cost Basis
Excavation	$10.00	per cubic yard
Gravel	$37.00	per ton
Spring Box	$1,000.00	per box
Valve	$50.00	per valve
Trenching	$5.00	per foot
Mobilization	$3,500.00	per mob
Standpipe	$4,500.00	per standpipe
Pond Lining	$10,000.00	per acre
Solar Pump System	$9,000.00	per system
Fencing	$5.00	per foot
Unit Cost - Springs ($/EA)	$4,550.00	per spring
Livestock/Wildlife Water Tanks	$3,000.00	per tank
Permitting	$500.00	per spring
Guzzler Installation	$5,000.00	per installation
Guzzler	$10,000.00	per guzzler
Drilling cost	$100.00	per foot
Final Plans and Specs – Pond	$1,500.00	per pond
Final Plans and Specs – Spring	$1,500.00	per spring
Final Plans and Specs – Irrigation	$2,500.00	per irrigation system
Final Plans and Specs – Riverbank Stabilization	$3,500.00	per project
Permitting	$1,000.00	per project
Low Pressure 1.5" DIA	$3.34	per foot
Low Pressure 1.5" DIA (below frost line)	$5.00	per foot
2" PVC Pipe-Schedule 40	$2.55	per foot
4" PVC Pipe-Schedule 40	$7.37	per foot
6" PVC Pipe-Schedule 40	$12.95	per foot
8" PVC Pipe-Schedule 40	$17.82	per foot
10" PVC Pipe-Schedule 40	$24.70	per foot

Table 29: Estimated unit and supply cost for projects gathered. (continued)

Component	Unit Cost	Cost Basis
12" PVC Pipe-Schedule 40	$32.61	per foot
14" PVC Pipe-Schedule 40	$50.66	per foot
16" PVC Pipe-Schedule 40	$61.67	per foot
18" PVC Pipe-Schedule 40	$92.55	per foot
20" PVC Pipe-Schedule 40	$108.33	per foot
24" PVC Pipe-Schedule 40	$155.73	per foot
Riverbank Restoration	$61.00	per foot

Table 30: Funding eligibility by project breakdown.

	Washakie County Conservation District (WCCD)		Wyoming Office of State Lands and Investments		Wyoming Water Development Commission		Wyoming Game and Fish Department	Bureau of Land Management	State Agencies (Misc.)		Department of Agriculture				Bureau of Reclamation	Federal Agencies (Misc.)
Project Type	Rural Cost Share Program	Community and Resource Enhancement Cost Share Program	Regular Farms Loans	Mineral Royalty Grant	Wyoming Water Development Program	SWPP	Water Development Program	Agreement for Range Improvements	Water Conservation FSP	Drinking Water State RF	RUS	RDWE	AMA	EQIP	WaterSMART	Mineral Royalty Grant
Spring dev.	x	x			x	x	x	x	x		x	x	x	x	x	x
Well dev.	x	x		x	x	x		x	x	x	x	x		x	x	x
Bridge Refirb.				x												
Stock pond	x	x	x			x	x	x	x				x	x	x	
Silt dam						x	x	x	x					x	x	
Irrigation	x	x	x		x	x			x				x	x	x	
Canal lining	x	x	x		x	x			x				x	x	x	
Pipelines	x	x	x		x	x		x			x	x	x	x	x	x
Hydropower		x									x	x		x	x	x
Storage						x			x		x	x	x	x	x	x

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