TETON WATERSHED

Water Supply and Water Use Study Report: 2008-2012




Montana Department of Natural Resources and Conservation
DNRC Report: WR 2.D.7b Teton Watershed
Helena, MT
August, 2016

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

Conversion Factors

1 cubic foot (Cfs) = 7.48 Gallons
1 cubic foot per second = 40 miner's inches
1 cubic foot per second = 448 gallons per minute
1 acre foot = a volume of one acre surface area to a depth 1 foot
1 acre foot= 325,851 gallons
1 cubic foot per second x 24 hrs = 1.83 acre feet

Acronyms

AF	Acre Foot
CFS	Cubic Foot per Second
DNRC	Department of Natural Resources and Conservation
ET	Evapotranspiration
FLU	Final Lands Unit GIS data set
FWP	Fish Wildlife and Parks
HWY	Highway
MBMG	Montana Bureau of Mines and Geology
NRCS	Natural Resources and Conservation Service
POR	Period of Record
SCS	Soil Conservation Service
SNOTEL	Snow Telemetry
SWE	Snow Water Equivalent
USGS	United States Geological Survey
WRS	Water Resource Survey completed by State Engineers Office

Acknowledgments

This report was prepared by Aaron Fiaschetti of the Department of Natural Resources and Conservation (DNRC). Gratitude is extended to everyone that participated in the study, landowners who granted permission to install stream gages, and the Teton Conservation District and Teton Watershed Group who provided additional support for the study.

This report would not have been possible without the support from Dave Yerk with Montana Fish Wildlife and Parks, DNRC staff, and reviewers. This report benefited greatly from the previous work done to understand the geology and hydrogeology of the Teton Watershed. Gratitude is owed to the authors whose work was used in this report.

Introduction

This report characterizes the surface water hydrology and to a lesser extent the hydrogeology of the Teton River watershed. Beneficial water use within the watershed includes: agriculture, stock, fish and wildlife, and domestic and municipal use. Most years, flows are not sufficient to meet all of these demands. Montana Fish, Wildlife and Parks (FWP) identified the Teton River and some of its major tributaries as chronically dewatered (MFWP, 1991). In addition, reaches of the Teton River are listed as not fully supporting agriculture, aquatic life and recreational uses (MDEQ, 2014) resulting in inclusion on the Total Maximum Daily Load (TMDL) 303(d) list.

Surface water flow in the Teton River watershed varies by reach in response to natural inflow, year-round diversions, return flow, and general losses and gains from groundwater. Several miles of the river are dry year-round above the City of Choteau during most years as a result of irrigation diversions and losses to groundwater. Downstream the Teton River begins to flow again near Choteau as it gains from groundwater; the river typically flows year round between the municipalities of Choteau and Dutton. Below Dutton, irrigation demands and losses to groundwater regularly dry up the river near its mouth during the late summer and fall months. During the study water flowed for the entire length of Teton on two occasions in 2008 and 2011 under well above average water supply conditions.

Water rights in the Teton watershed date back to 1874 and the most reliable rights on the river have a priority date older than 1900. Water right conflicts date back to the early 1900's resulting in the 1905 Perry v Beattie decree and a water commissioner for 25 water users upstream from Choteau. The over appropriation of water in the Teton Watershed prompted the Montana Legislature to close the watershed to additional appropriation of surface water and groundwater (with exceptions) in 1993.

The Teton Watershed study was completed by the Department of Natural Resources and Conservation (DNRC) at the request of the Teton Watershed group. Funding for the study was supplied in part by a grant from the Teton County Conservation District. The study spanned five years (2008-2012) in an effort to capture normal, above average, and below average water years. Gaging of select streams in the Choteau area continues by request to support water management. Data from these additional efforts are also presented in this report.

This report is available online through the DNRC Water Management Bureau web page http://dnrc.mt.gov/divisions/water/management. All streamflow data associated with the report and active gaging is available via the Montana Bureau of Mines and Geology/DNRC Surface Water Assessment and Monitoring Program web page http://www.mbmg.mtech.edu/.

Goals & Objectives

The goal of this study is to improve the knowledge and understanding of the water supply and demands in the watershed as well as the effects of dewatering the river. The information gathered could provide a first step toward developing local solutions to water related problems.

The specific objectives of this project are to: 1) characterize the surface water hydrology of the Teton River and its tributaries, and 2) investigate impacts of dewatering the shallow groundwater aquifers.

Project Area

Physiography

The study focused on the Teton River and major tributaries from its confluence with the Marias River upstream to the confluence of the North and South Forks of the Teton, a reach of about 183 miles.

The headwaters of the Teton River originate in the Sawtooth Range of the Rocky Mountains along the east side of the Continental Divide. The river flows generally to the east where it joins the Marias River at the Town of Loma, Montana. Major Tributaries to the Teton River include the South Fork and North Fork of the Teton River, Deep Creek, Spring Creek, McDonald Creek, Willow Creek, and Muddy Creek.

The Teton River is predominantly fed by snowmelt and rain during the spring and early summer months. River flows during the rest of the year are sustained by groundwater inflow and periodic runoff following rainfall events.

The Teton River watershed spans approximately 2,047-square miles in Teton, Chouteau and Pondera Counties (Figure 1). Elevations range from the 9,352 foot Rocky Mountain in the headwaters, to a low of 2,600 feet at the confluence of the Marias River. Approximately 89 percent of the watershed is located in the prairie with the remaining 11 percent in the mountainous headwaters

With the exception of the forested headwaters, the watershed is primarily private land used for hay production, irrigated pasture, and livestock grazing. Irrigation (primarily flood) occurs throughout the watershed on approximately 76,800 acres of land.

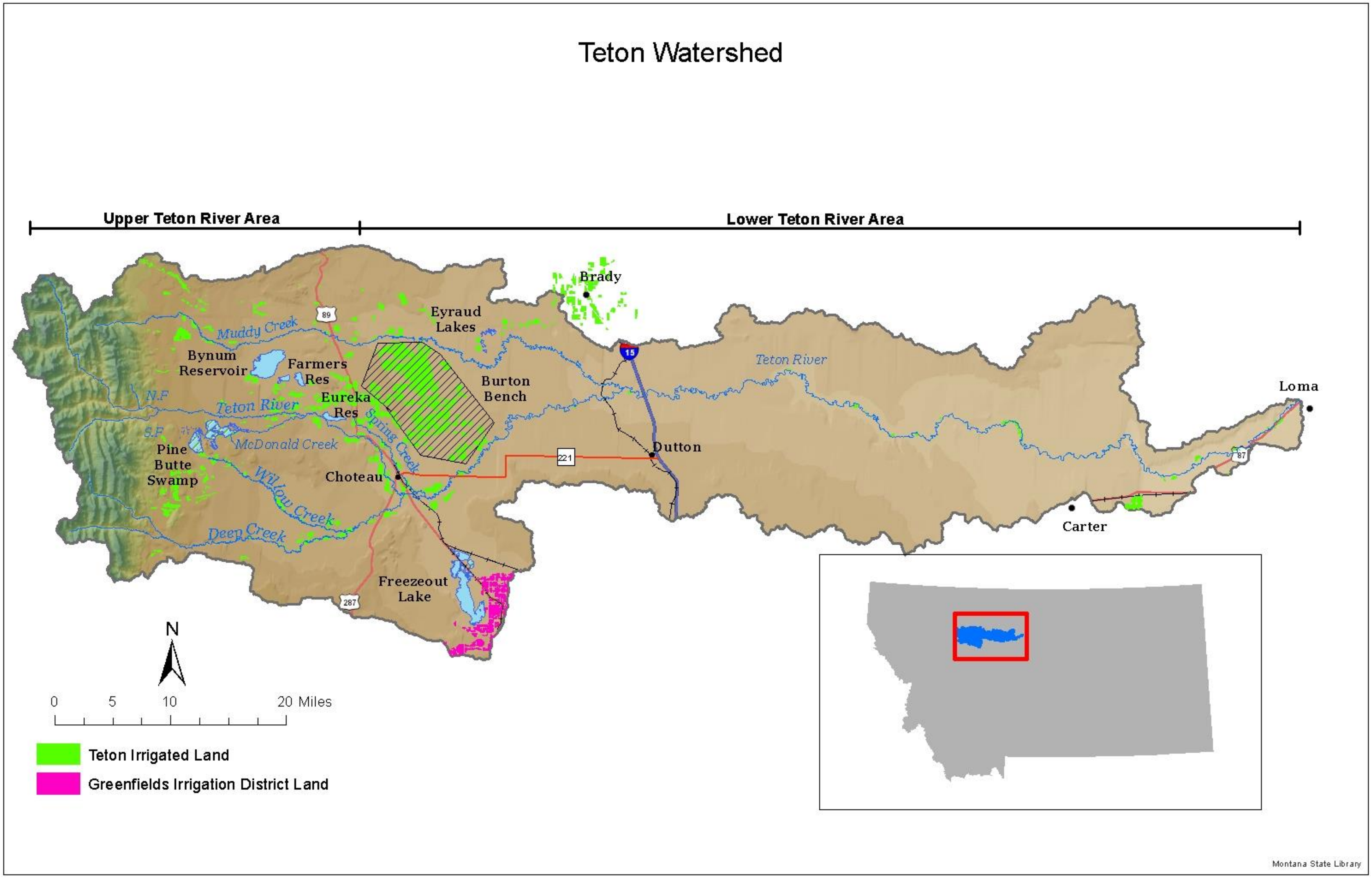


Figure 1: Teton Watershed location map.

Climate

Average annual precipitation (including snow) ranges from 11 inches in the lower elevations of the watershed to over 46 inches at the highest elevations (Figure 2; Daly and Taylor, 1998). Approximately 89 percent of the watershed (prairie) receives on average 12 inches of precipitation annually, while the mountainous areas receive an average of 17.6 inches. Less than 10 percent of the watershed (the mountainous areas that receive 20 inches or more of precipitation) is responsible for the majority of water production. The average annual temperature for the watershed is 43 degrees Fahrenheit, with 128 growing days.

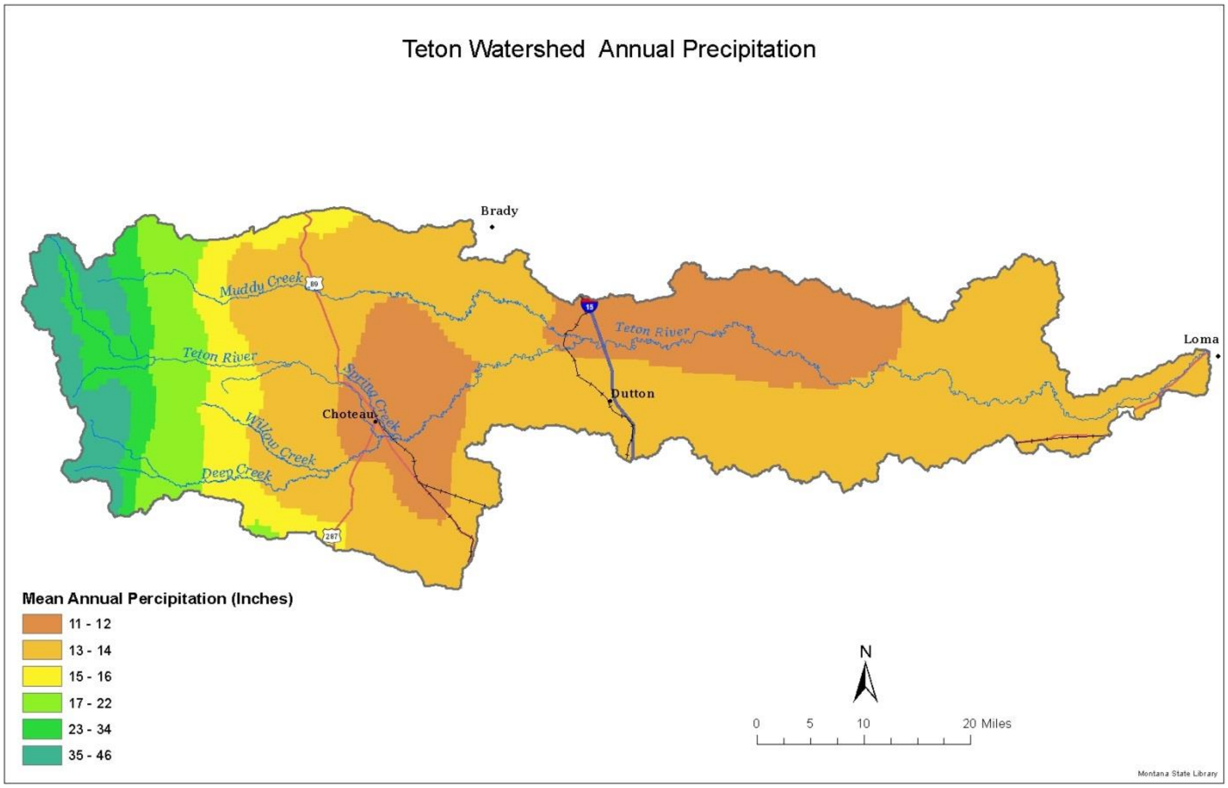


Figure 2: Precipitation map of the Teton Watershed.

Average monthly precipitation in the prairie portion of the watershed is represented by data from the Choteau and Carter, National Weather Service (NWS) Cooperative observer weather stations, (Figure 3) (Western Regional Climate Center) http://www.wrcc.dri.edu/). The wettest months in the prairie are May and June. Thunderstorms in July and August can add significant moisture. Because of the semi-arid nature of the prairie, irrigation is used to supplement the natural precipitation and increase crop production.

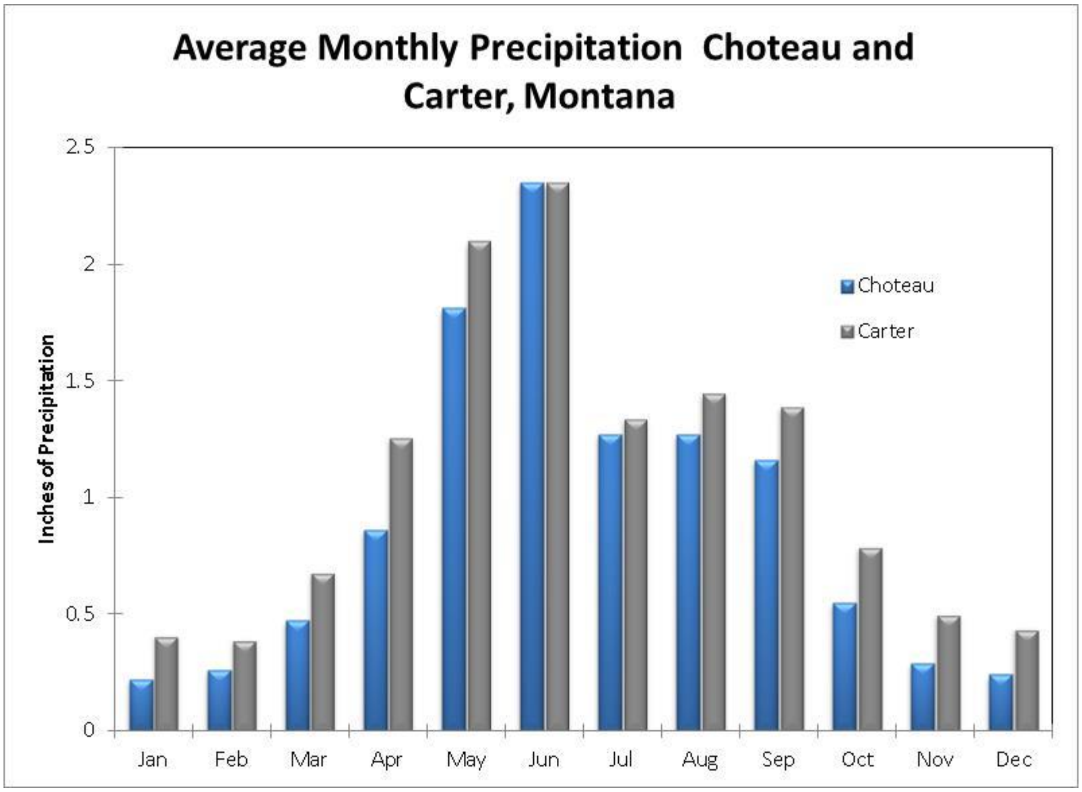


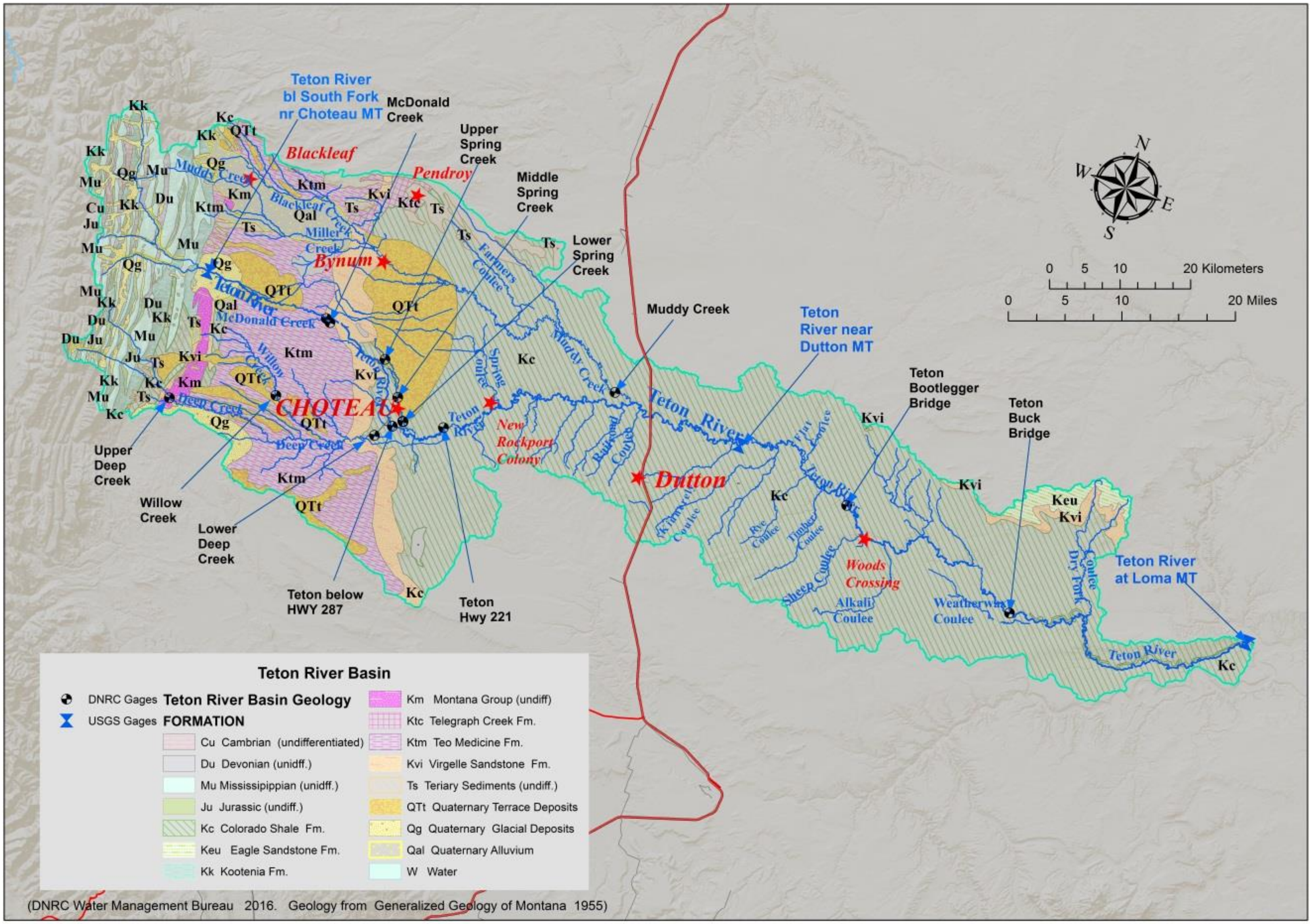
Figure 3: Precipitation recorded at Choteau and Carter, Montana.

Geology

The Teton River originates in the complexly faulted and folded sedimentary rocks of the Rocky Mountain Front. In contrast, the eastern two-thirds of the Teton drainage is underlain by relatively flat-lying Cretaceous-age mudstones and sandstones that are deformed by the Sweetgrass Arch, a broad arch extending from the Little Belt Mountains into southern Alberta (Figure 4).

The bedrock geology of the mountainous headwaters of the Teton River are Mississippian-age (345 million years before present), marine limestone, and dolomite of the Madison Group and Cretaceous-age (64 million years before present), mudstone and sandstone rocks including the Two Medicine through Kootenai formations. These rocks were deposited in shallow marine and non-marine environments along the margin of a foreland basin.

These rocks are highly disturbed and are commonly referred to as the Lewis Overthrust or Disturbed Belt. Tectonic activity caused mountain building and resulted in the present day rugged Sawtooth range of the Rocky Mountains.



(DNRC Water Management Bureau 2016. Geology from Generalized Geology of Montana 1955)

Figure 4: Geology of the Teton Watershed.

The geology of the plains between the Rocky Mountain Front and the Teton confluence is primarily composed of Cretaceous sedimentary rocks of the Two Medicine, Virgelle, and Telegraph Creek Formations and the Kevin Member of the Marias River Formation. These flat laying Cretaceous-aged sedimentary rocks are primarily sandstones and shales visible on buttes and incised areas near streams and rivers Berg (2008) and Vuke and Others (2002).

The surficial geology of the plains reflects Quaternary glacial activity. Glacial till, glacial lake, and outwash deposits are present near Choteau Patton (1990). A piedmont glacial moraine can be seen along the Teton River near the Rocky Mountain Front Nimick and Others (1983). Glacial till deposits are present throughout plains of the Lower Teton River below Choteau. Berg (2008) and Vuke and others (2002). Glacial geology of the Pine Butte area near the Rocky Mountain Front has been discussed by Riechmuth (1981), Nimick and Others (1983), and Wylie (1991). Glacial geology of the Burton Bench and Choteau areas has been discussed by Patton (1990).

The floodplain areas of the Teton River, Deep Creek, Muddy Creek, and Spring Creek are composed of Holocene and Pleistocene-aged valley deposits Berg (2008) and Vuke and others (2002).

Hydrogeology

Alluvium and glacial deposits are generally unconfined and are recharged by direct infiltration of precipitation, seepage[1] from streams/rivers, leakage from irrigation ditches, irrigated fields, and irrigation return flow. Aquifer discharge includes diversion to wells, baseflow discharge to surface water, seepage to springs, evapotranspiration, and subsurface underflow to other aquifers or basins. Recharge to bedrock aquifers is primarily derived from seepage from streams, infiltration of precipitation, snowmelt in topographically high outcrop areas, and leakage through confining units. On a regional scale, potentiometric surface mapping shows that groundwater in the bedrock often has a hydraulic connection with valley aquifers and discharge in topographically lower areas by upward leakage to shallower aquifers and streams Smith and Others (2000).

The disturbed belt and headwaters of the Teton River watershed is what Huntoon (1985) refers to as a fault-severed basin boundary. Steeply-dipping thrust faults sever the hydraulic continuity of bedrock aquifers thereby limiting groundwater recharge and groundwater flow

---

[1] Seepage is defined as the slow loss of a liquid through a porous medium, for this report seepage is the loss of surface water through the river bed or ditch to ground water.

eastward from the mountains. Bedrock aquifers are considered to be in dynamic equilibrium with recharge equal to underflow out of the bedrock.

Previous Investigations

At the outset of the study all available data, literature and maps related to the hydrology of the basin were compiled and reviewed. All existing and historic streamflow data were retrieved from the United State Geological Survey (USGS) NWIS database. The USGS currently maintains three streamflow gages in the watershed:

- 06102500 Teton River below the South Fork Confluence
- 06108000 Teton River near Dutton
- 06108800 Teton River at Loma

Historical but discontinued USGS gages in the watershed are:

- 06103000 Teton River at Strabane
- 06104500 Teton River near Choteau
- 06108500 Teton River near Fort Benton
- 06103500 McDonald (Spring) Creek near Strabane
- 06104000 McDonald (Spring) Creek near Choteau
- 06105000 Deep Creek at Frazer Ranch near Choteau
- 06106000 Deep Creek near Choteau
- 06105500 Willow Creek near Choteau
- 06106500 Muddy Creek near Bynum
- 06107000 North Forth Muddy Creek near Bynum
- 06107500 Muddy Creek near Agawam

The State Engineers Office, a predecessor of the DNRC Water Resources Division, inventoried land and water use of Teton, Chouteau, and Pondera Counties in the respectively published 1962 and 1964 Water Resource Surveys. The history of land and water use is detailed in these documents. This information is taken from county courthouse records including land ownership, water right decrees and appropriation, articles of incorporation of ditch companies, and other documents regarding the distribution and use of water.

The USGS has estimated water use in Montana, Canon and Johnson (2004) on a county and watershed basis. The estimated uses include irrigation, domestic, municipal, and reservoir evaporation.

The Teton Watershed has been the focus of regulatory studies by multiple state and federal government entities, these studies and listings include:

- Montana Fish, Wildlife and Parks (FWP) identified the Teton River and its major tributaries as chronically dewatered in 1991 MFWP (1991).
- The Montana Department of Environmental Quality (DEQ) listed the Teton River and tributaries as impaired for low flow alterations, water quality, and temperature in the 2014 303(d) list MDEQ (2014). The major cause of impairment was identified as flow alteration.
- The United States Environmental Protection Agency (EPA) completed a Water Quality Management Plan and Total Maximum Daily Loads (TMDLs) for the Teton River Watershed US EPA (2003).
- The State of Montana classified the Teton River into three different standards: B-1, B-2 and B-3. All three standards intend for the waters to be “maintained suitable for drinking, culinary, and food processing purposes after conventional treatment; bathing, swimming, and recreation, waterfowl, furbearers, agricultural, and industrial water supply”. Fisheries and associated aquatic life classifications vary from: “growth and propagation of salmonid” (B-1), “marginal growth and propagation of salmonid” (B-2), and “growth and propagation of non-salmonid” (B-3) (Montana Code ARM 17.30.623-625).

Several research reports were found about the hydrogeology of the Pine Butte Swamp Preserve and the Burton Bench areas. Reichmuth (1981) and Nimick and Others (1983) investigated the glacial and structural geology and hydrogeology of the Pine Butte and McDonald Swamp areas for The Nature Conservancy. Wylie (1991) further investigated the hydrogeology of the Durr (Pine Butte) and McDonald Swamps. The Nature Conservancy (TNC) conducted surface water and groundwater monitoring in the area around the Pine Butte and McDonald Swamps from 1991-1996.

Patton (1990) and Madison (2004) of the Montana Bureau of Mines and Geology (MBMG) completed two investigations of the geology and hydrogeology of the Burton Bench and Teton Valley Aquifers near Choteau. Geologic mapping efforts in the area have been completed both by the Montana Bureau of Mines and Geology and the USGS, Berg (2008), Berg and Vuke (2002), Mudge and Others (1983) and Vuke and Others (2002).

This is the first detailed investigation of the hydrology and water use characteristics of the Teton River watershed.

Watershed Overview

Hydrology

The Hydrology of the Teton River is complex due to irrigation diversions, off-stream storage, and natural hydrological phenomena. For most discussions in this report the river is bisected into two major geographical areas, the Upper and Lower Teton River, (Figure 1). The river is further divided into a series of sub-watersheds and reaches (Figure 5) to systematically explain the characteristics of the river and tributary contributions.

Headwaters Reach

The Headwaters Reach of the Teton River includes the higher elevation and water producing area upstream of the confluence of North and South Forks of the Teton River. The North and South Forks of the Teton River are straight to meandering, gravel-channels in narrow floodplains bounded by bedrock mountains. No major diversions of water are present in this reach.

Upper Teton Reach

The Teton River from the confluence of the North and South Forks downstream to Springhill (near Eureka Reservoir) is described as the Upper Teton Reach. The river in this reach is a meandering channel with a broad floodplain that has numerous historic side channels and some braided sections. The largest tributary of the Teton in this stretch is McDonald Creek.

All of the largest diversions on the river are located in this reach including: Teton Co-Operative Reservoir Company (Bynum), Farmers Co-Operative Canal Company, Eldorado Co-Operative Canal Company, Teton Co-Operative Canal Company (Eureka), and numerous other private diversions. Diversions in this reach are distributed by a water commissioner according to the 1905 Perry v. Beattie Decree.

Significant volumes of water diverted from the Teton River in this reach are stored in Farmers Reservoir, Eureka Reservoir, and Bynum Reservoir. In general, most water diverted from this reach is ultimately distributed to crops on the Burton Bench located northeast of Choteau.

The Teton River flows year round from the headwaters to the Bynum diversion. The presence and amount of water in the river below Bynum diversion to the confluence of McDonald Creek varies throughout the year depending on water supply, diversion priority, and demands.

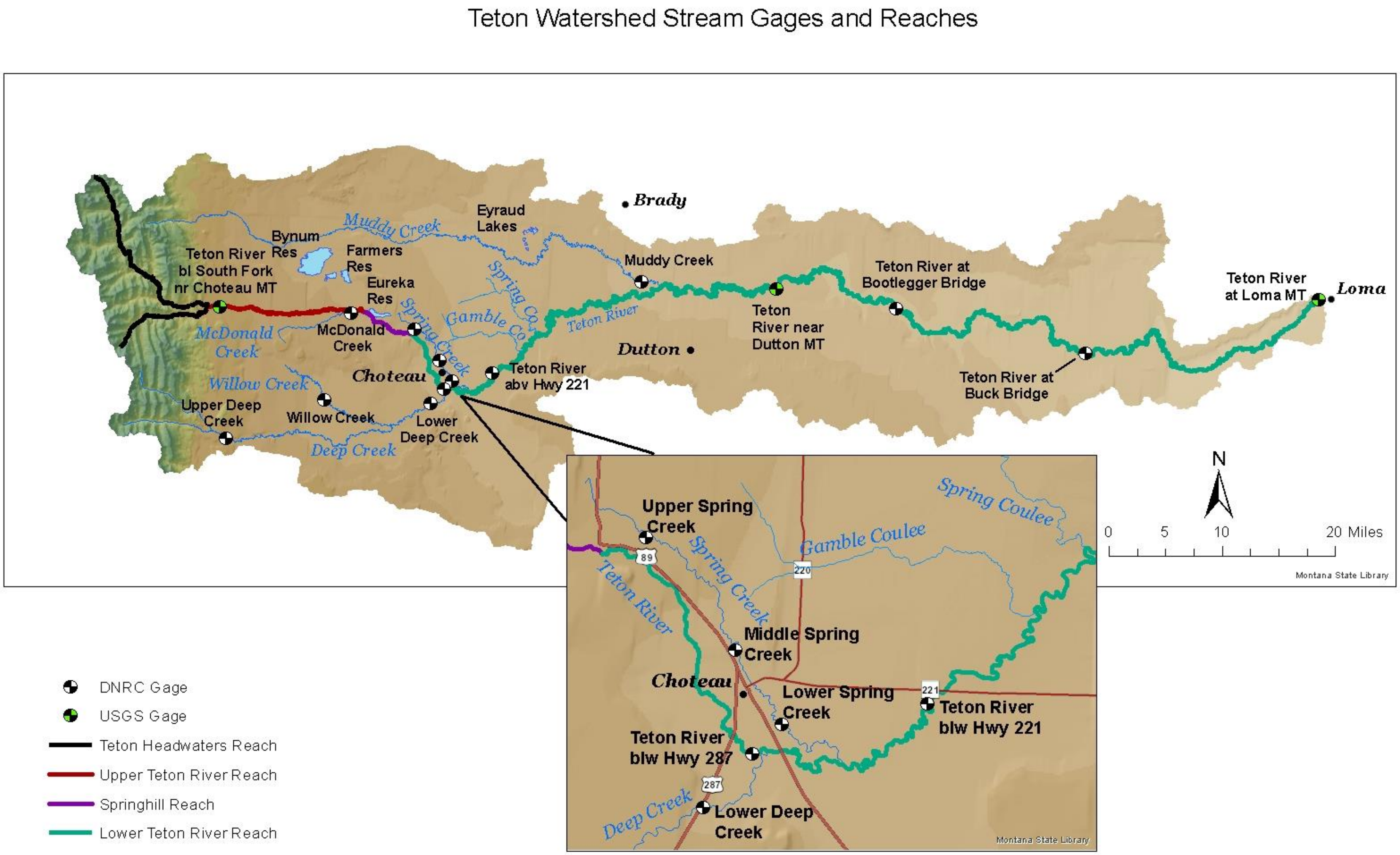


Figure 5: Reaches and stream gages of the Teton River and Tributaries.

The Teton River from the confluence of the North and South Forks to the Bynum Diversion has been documented to lose significant volumes of its flow to the shallow aquifer TNC (1991-1995), Nimick (1983) and Wylie (1991). This seepage from the Teton River recharges Teton River alluvium and glacial outwash gravels. In turn, groundwater discharges to local wetlands and to surface water of the Teton River, McDonald Creek, and to Willow Creek. Throughout the Upper Teton Reach, the river receives contributions from historical channels, springs and groundwater.

Springhill Reach

The Teton River from Springhill (near Eureka Reservoir) to the junction of Highway 89 and the Teton Canyon Road is described as the Springhill Reach. The Teton River is known to lose considerable amounts of water through the Springhill Reach. The river is commonly dry (through a five mile stretch) with flows present in the upstream and downstream ends of the reach. The river channel through the Springhill Reach is commonly braided and riparian vegetation is sparse.

Gravels of the Teton Valley Aquifer have been documented to thicken and the depth to groundwater increase in this area Patton (1990). Seepage of surface water has been documented to occur where the water table farther below the land surface Patton (1990). Since flows are commonly diverted or routed away from this area, the water table is artificially low, likely exacerbating losses along this stretch of the river. Riparian vegetation is sparse in the Springhill Reach due to dewatering and the increased depth to groundwater.

The Springhill Reach is also known as the “recharge reach” which describes how losses from the Teton River “recharges” the Teton Valley Aquifer. Groundwater from the Teton Valley Aquifer returns to the Teton River and Spring Creek down-gradient.

Groundwater in this area also receives recharge from leaky irrigation ditches and return flow from irrigated fields. Nicklin (2009) provided observations and a groundwater model to demonstrate that diversions to off-stream reservoirs reduce flows in the Teton River directly as well as indirectly by reducing recharge, storage, and return flows from the valley aquifer.

Lower Teton River Reach

The Teton River from the junction of Highway 89 and the Teton Canyon Road to Loma (the mouth of the river) is described as the Lower Teton River Reach (162 miles of river).

Downstream of the Springhill Reach, surface water lost to the aquifer reappears in the river channel along with riparian vegetation. The Teton River from, the junction of Hwy 89 and Teton Canyon Road to the Hwy 287 Bridge south of Choteau is a gaining stream Patton (1990). DNRC stream-gaging efforts and observations further support Patton's documentation. Downstream of Hwy 287, the river continues to gain groundwater from the thinning alluvium; this ceases near the Hwy 221 Bridge where the Colorado shale bedrock is exposed and the alluvium ends.

The channel form of the river changes from a broad valley floodplain above Hwy 221 to a fine grained, prairie channel that has down-cut into sedimentary rocks. The presence of shale bedrock at the Hwy 221 Bridge marks this transition.

Tributaries to this Reach include Spring, Deep, and Muddy Creeks and Gamble and Spring Coulees (Figure 5). Spring and Deep Creeks enter the Teton River below the City of Choteau. Deep Creek is an important tributary to the Lower River because it can contribute significant flows during runoff and springtime precipitation events and thereby connects the Lower River to the mountains. However, during the summer, water demands in the Deep Creek drainage exceed supply during most years.

Infiltration of precipitation and excess irrigation water on the Burton Bench recharges groundwater, and ultimately feeds tributaries of the Lower Teton River including Muddy Creek, and Gamble and Spring Coulees. Muddy Creek enters the Teton River near the Town of Dutton. Contributions from Muddy Creek are minimal due to upstream irrigation demands.

The Teton River flows year round from Choteau to Bootlegger Bridge. Demands during the irrigation season can dry up the Lower River in August and September from its mouth upstream as far as the area above Buck Bridge.

Water Management

Water management and water use on the Teton River has been contentious for over a century. A divisive feature of the Teton River is the losing Springhill Reach located above Choteau (where surface water seeps through the streambed to the shallow aquifer). Water users have long known about this losing reach and to stretch limited resources. The Springhill Reach is bypassed by a series of ditches (Bateman/Burd) to deliver water to the most senior water user in the Perry v. Beattie decree (located near Choteau). The losing Springhill Reach has become a dividing point where the river is managed as two separate systems the "Upper River" and the "Lower River" (Figure 1).

Upper River

Demands on the Upper Teton River are year-round (Figure 6). Typically water is diverted to meet irrigation demands from April to October and for storage during the rest of the year. Junior decreed users are typically shut off from direct flow by early July with only the most senior right holders diverting water from the river into August and September. Demands above the Springhill Reach use all of the water resources in most water years from March to November.

Flows in the Teton River below the Bynum diversion are minimal during winter months as the majority of water is diverted to off-stream storage. The presence of water between the Bynum diversion and McDonald Creek during the irrigation season is dependent on water supply and diversionary needs. The Teton River channel below the Eldorado Canal diversion is commonly dry for most of the summer months.

Flows from McDonald Creek enter the Teton River below most major diversions (Bynum, Farmers, Eldorado, and numerous private). Depending on the time of year, the Teton River channel is typically dry between the Bynum or Eldorado diversions and McDonald Creek. However inflows from the creek only sustain surface flow in the river channel to the Springhill Reach.

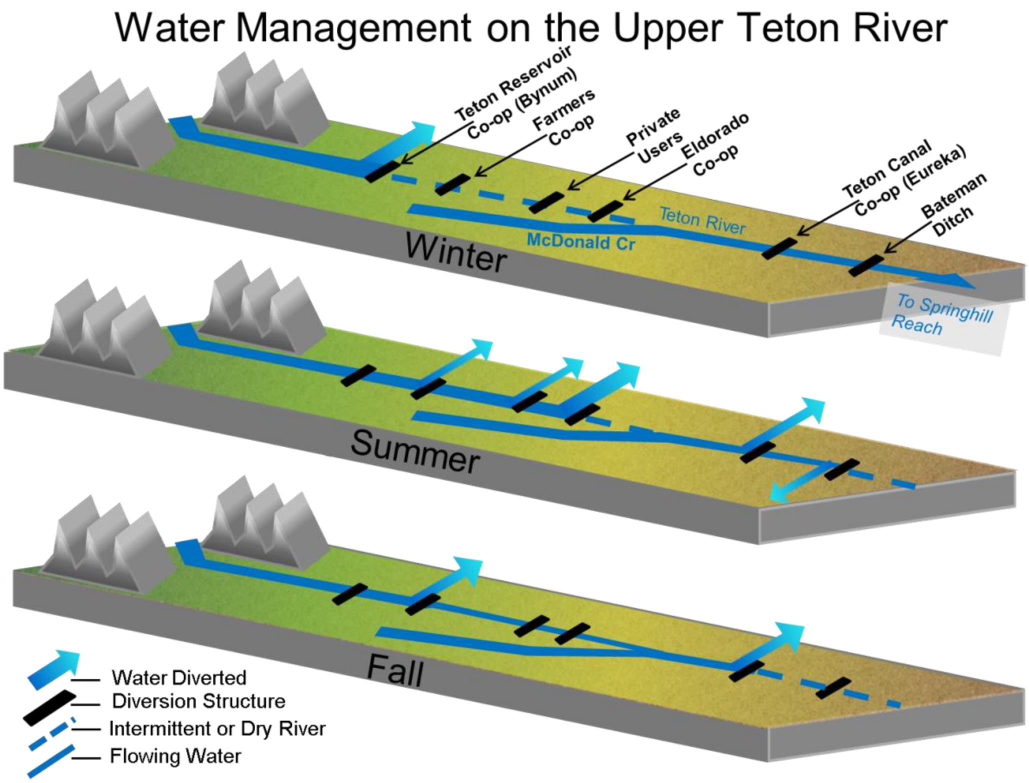


Figure 6: Conceptual model of water management in the Upper Teton River.

During the irrigation season and in early spring and late fall, McDonald Creek contributions to the Teton River are either captured by the Eureka diversion (storage and irrigation water) or the Bateman diversion (irrigation only). Water passing the Eureka and Bateman diversions enters the Springhill Reach.

Water typically enters the Springhill Reach from November until April, primarily from McDonald Creek and groundwater gains. The Springhill Reach rarely receives flow volumes equivalent to the volumes produced above the diversions.

Lower River

Water management on the Lower Teton River is less complicated as water supplies are more limited and there are no large storage reservoirs. Water demands on the Lower River typically exceed the already diminished water supply and the river is usually dried near the mouth in August and September.

Water Storage

Off-stream, water storage is an integral part of the hydrology and water management in the Teton Watershed. Farmers Co-operative Canal, Teton Co-operative Canal (Eureka Reservoir), Brady Irrigation Company, and Teton Co-operative Reservoir (Bynum Reservoir) all have off-stream storage facilities that capture water from the Upper Teton River. Flows are also utilized from Muddy and McDonald Creeks by Brady Irrigation Co. and Teton Co-operative Canal for their respective reservoirs. The largest reservoir in the watershed is Bynum Reservoir (Teton Co-operative Reservoir) with 90,000 acre-feet of storage. Storage projects above Choteau can store approximately 104,552 acre-feet of water (Table 1).

Farmers Co-operative Canal and Teton Co-operative Canal have the most senior storage rights and typically fill during times of lower irrigation demand in the spring and fall. Flows from McDonald Creek are heavily utilized to fill Eureka reservoir. Teton Co-operative Reservoir (Bynum) has the most junior right and is the largest storage project[2]. Teton Co-operative Reservoir typically captures winter baseflow from November to March and any available high spring flows above senior demands.

---

[2] At the time of and prior to this report the typical hierarchy of water storage follows the described order. The seniority of water rights is expected to change based on a Dec 15, 2015, Montana Supreme Court Decision. Teton CO-OP v. Teton COOP Reservoir Co., (DA 15-0136). Further litigation and adjudication is also in process and may affect water distribution on the river.

Reservoir	Irrigation Company	Water Source	Storage (acre-feet)
Bynum	Teton Co-Op Reservoir Co	Teton River	90,000
Eureka	Teton Co-Op Canal Co	Teton River	5,500
Farmers and Harvey Lakes	Farmers Co-Op Canal Co	Teton River	5,752
Brady, Round and Eyraud Lakes	Brady Irrigation Co	Muddy Creek and Teton River	3,300
Total			**104,552**

Table 1: Water storage in the Teton Watershed[3].

The storage reservoirs listed above are able to store 135% of the period of record average seasonal flow (April 1 -Oct 31) or (an estimated 111% of annual flow) produced by the headwaters of the Teton River (USGS Gage Teton River below South Fork). Historical USGS data (1948-1954) indicate winter baseflow on the Teton River increases the flow volume by 16% or 15,742 acre-feet. The mean volume of flow for November to March 2009 to 2014 is estimated to be 7,700 acre-feet (Dalby 2016). Suggesting that under more recent hydrological conditions winter baseflow is less substantial.

The Teton River produced enough water to fill all reservoirs only during the two highest water years of the study: 2008 and 2011. Data from the USGS gage below the South Fork confluence indicates that the headwaters of the Teton River produce enough flow (seasonal Apr 1 to Nov 1) to fill all storage projects about every three years on average.

Approximately 262 small storage reservoirs exist primarily in perennial and ephemeral coulee tributaries throughout the watershed. These smaller storage reservoirs are used for irrigation, stock water, and recreation. They have a collective storage volume of 13,841 acre-feet[4].Cannon and Johnson (2004) estimated average-annual, reservoir evaporation of 4,400 acre-feet for Bynum Reservoir due to its relatively large size (about 2,800 acres at full pool).

Inter-basin Water Transfers and Freezout Lake

Water is transferred out of the watershed to irrigated land near Brady in the Pondera Coulee (Marias River) drainage. The Brady irrigation district irrigates approximately 10,800 acres primarily with Muddy Creek water and supplemental Teton Co-operative Reservoir (Bynum) water.

Water is transferred into the Teton basin by the Greenfields Irrigation District (GID), which irrigates approximately 83,000 acres of land directly to the south of the Teton watershed. GID water supplies are derived from the Sun River and multiple storage reservoirs in the Sun River

---

[3] Storage volumes were obtained from the U.S Army Corps of Engineers National Dam Inventory database, DNRC Dam Safety records and personal communication with dam owners.

[4] Small reservoir storage volumes were obtained from DNRC water right records.

watershed. A small portion of GID-irrigated lands (6,972 acres) are located in the Teton watershed (Freezout Lake basin). Return flow from these primarily center pivot irrigated lands are minimal and enter Freezout Lake.

Freezout Lake Wildlife Management Area (WMA) is a series of ponds and adjacent uplands that provide habitat for waterfowl and upland game birds. The ponds total surface area is 5,000 acres, storing a total volume of 18,800 acre-feet. Originally, Freezout Lake was located in a closed basin with no drainage outlet. In order to manage water levels and water quality for wildlife, FWP created a drainage system to the Priest Butte Lake and ultimately to the Teton River.

Freezout WMA has water contracts with GID to support the function of the WMA. Each year approximately 3,500 acre-feet of water from the Sun River watershed is delivered to Freezout Lake. The majority of this water evaporates from the ponds. WMA managers release approximately 160 acre-feet of Sun River water into the Teton River. Releases occur throughout the open water season depending upon precipitation events, water quality, and management goals.

Role of Groundwater

Groundwater in the bedrock and valley aquifers of the mountainous headwaters of the Teton River is only briefly mentioned by Nimick and Others (1983). DNRC (2015) estimates infiltration of snowpack and precipitation into the soil, gravel, and bedrock of the mountainous headwaters sustains baseflow accounting for 62% of the flow in the Upper Teton River.

Surface waters in the Teton watershed are influenced by natural exchange between surface water and groundwater as well as irrigation diversions and return flow. Groundwater recharge by surface water or irrigation effectively stores water that is released later as surface-water baseflow. These shallow aquifers function similarly to constructed reservoirs.

Recharge to and storage in aquifers and the baseflow of streams they feed depend on the amount and temporal pattern of streamflows, diversions, and irrigation practices. Two general examples of the complexities of irrigation/diversion/groundwater processes are:

1. Irrigation of land near the Teton River and Spring Creek above Choteau recharges groundwater that contributes to baseflow. In turn, reduction in flows (diversion) in the Teton River reduces groundwater recharge and decreases baseflow to areas downstream.
2. Large quantities of Teton River water are used to irrigate land on the Burton Bench (which is outside of the river corridor). Irrigation recharges the Burton Bench Aquifer

> and this water eventually contributes to baseflow of the Teton River and tributaries downstream. In turn, since water is exported out of the river corridor (to terrace or bench areas outside the floodplain), the benefits of recharge are routed away from many miles of Teton River. These diversions in the Teton River decrease groundwater recharge and decrease baseflow contributions to areas downstream.

Diversion for irrigation and surface storage disrupt the natural exchange processes by reducing surface water flow and recharge to groundwater downstream of diversions. Reduced recharge to groundwater decreases the amount of water in aquifer storage and the amount of water that sustains baseflow under pre-existing conditions. Diversions for irrigation also influence surface water flow through conveyance losses and return flow.

Spring Creeks

The occurrence of spring creeks near the Teton River has been discussed by Nimick and others (1983), Patton (1990), and Wylie (1991). The common theme among these researchers is that seepage from the Teton River re-appears as springs down-gradient. The occurrence of the Pine Butte (Durr) and McDonald swamps are from Teton River water seepage. The Nature Conservancy conducted eight synoptic streamflow runs (1991-1996) documenting that the Teton River loses an average of 23% of its volume from the confluence of the North and South Fork to the Bynum diversion. Synoptic runs made by Nimick and 0thers (1983) and Wylie (1991) yielded similar results.

Wylie (1991) has shown a direct relationship between surface water flows and groundwater levels in the unconsolidated aquifers of the Teton River near the swamps. Research has shown that the magnitude of streamflow in spring creeks is directly related to groundwater levels in the underlying unconsolidated aquifers along the Teton River.

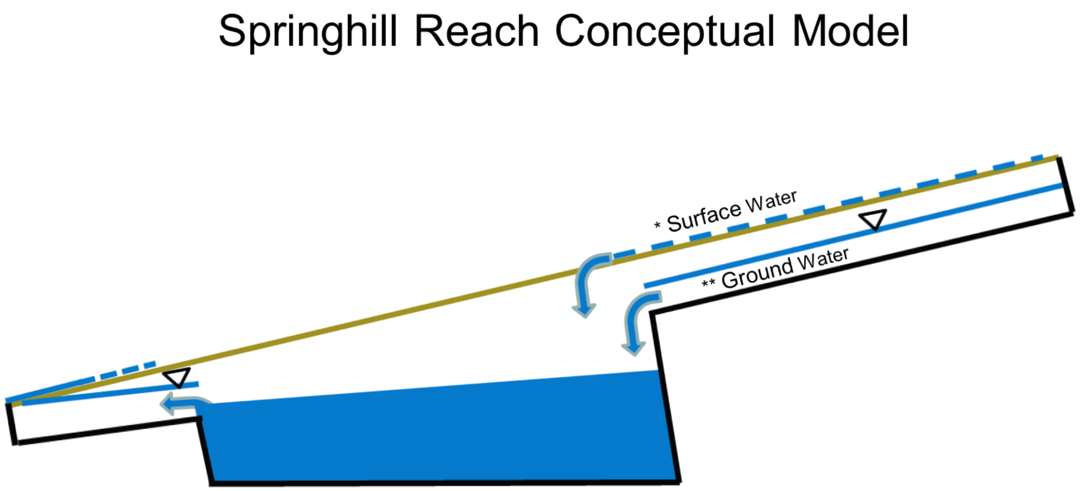
Patton (1990) discussed the occurrence of water in Spring Creek and the Teton River near Choteau as discharge from the Teton Valley Aquifer to topographically low areas. Patton identified the source of recharge for the Teton Valley Aquifer in order of importance:

- the Teton River above Eureka Reservoir
- surface water (Teton River) flowing below the Springhill Reach (when present)
- irrigation losses (ditch and field) within the Teton Valley
- precipitation
- surrounding bedrock aquifers.

Two spring creeks were gaged during this study Spring Creek and McDonald Creek. The Teton River below Choteau is essentially a spring creek under current water management. Meaning, the majority of the water supply of the Teton River at this location is primarily from groundwater discharge rather than surface flow from upstream.

Springhill Reach

Think of the Springhill Reach like a bathtub that is tilted on one end (Figure 7). As water moves downgradient (down river) it spills into the tub, and as the tub fills, water eventually spills out the lower end. Since the Spinghill Reach is underlain by shale (bottom of the tub), the volume entering the tub is approximately equal to the volume leaving the tub (little water is lost to the bedrock below)[5].



* Surface water flowing into the Springhill reach provides a secondary source of water. The occurrence of surface water into this reach is primarily limited to when no other uses (storage/irrigation) for the water are needed (November to March).

** Ground water flowing downgradient is the primary source of water to the Springhill reach as ground water enters the reach year round.

Figure 7: Conceptual model of the Springhill Reach

Groundwater enters the reach year-round. The volume of groundwater entering the Reach is related to the volume of water present in the Teton River upstream[6] (higher river flows = increased groundwater levels). Typically, surface water enters the reach from November till March. River water seeps through the river bed and percolates down to the water table. This secondary source of water raises the water table and increases the amount of water leaving the Reach (spilling out of the tub).

---

[5] Based on the hydrogeology and geology of the Teton Valley aquifer and observed streamflows.

[6] See discussion of losses on the Upper River in Spring Creeks section on p.18

As the tub fills water travels farther down the Springhill Reach because gravels beneath the river bed become saturated. On the lower end, surface water creeps upstream as the water table rises and intersects the river bed at a higher elevation.

Methods

Streamflow Monitoring

Streamflow monitoring locations for this study were identified through a combination of review of existing research, field reconnaissance, and discussions with local residents. GPS locations of DNRC gages are presented in Appendix A.

Each gaging site consisted of a stilling well, staff gage and a water level logger. Stilling wells were constructed using a perforated, 10 foot long, 2 inch diameter galvanized steel pipe with a welded drive point and a locking cap. A staff gage was mounted on the outside of the stilling well. A capacitance-type water level logger (Tru Track WT-HR or AquaRod Water Level Logger) was installed inside the stilling well and set to record stage at 30 minute intervals. The elevation of the stilling well was surveyed using a laser level. This step enabled field staff to check for casing movement between visits.

Field visits were conducted about once a month. During each visit, the staff gage was read manually, data were downloaded from the water level recorder and stream discharge was measured. Other field observations included the gaging pool control, flow conditions, and weather.

Discharge measurements followed standard USGS methodology Nolan and Others (2000) and DNRC Standard Operating Procedures using either a Marsh-McBirney FlowMate® Model 2000 Flow Meter or a Sontek FlowTracker®. High flow measurements were made at some of the gages using bridge equipment or an acoustic-Doppler measuring device.

Stream stage and discharge relationships were developed using the Aquatic Informatics Aquarius® Rating Curve program. Rating equations were used to convert the 30-minute water stage data into discharge and then these were summarized as daily average streamflow. Streamflows were measured throughout the winter on several gages. Winter data should be considered with caution as icing tends to affect the developed stage/discharge relationship. DNRC personnel corrected winter flow data following established protocols McDonald (1954).

Within the Teton Basin, only the USGS stations near Dutton and Loma have continuous mean-daily, discharge records for the study period (2009 to 2014); other stations are discontinuous with winter records frequently missing. To aid in development of a generalized-annual, Teton-Basin water budget, missing values for key stations were estimated using regression and time-series methods.

Groundwater

DNRC staff monitored several existing wells in the Lower Teton River (Dent Bridge to the Loma area) during the study. Wells were located through research and public outreach to Lower River landowners. Depth to groundwater measurements were made using an EnviroTech Waterline® electronic sounder. GPS locations are presented in Appendix A. See Appendix D for well locations Figure and data.

Local Fish Wildlife and Parks (FWP) staff provided groundwater data in the Choteau area. FWP monitored one well located north of Choteau near Spring Creek. Continuous depth to groundwater data was measured using a Solnist Leveolgger® pressure transducer. Data was obtained from the Groundwater Information Center for two wells monitored by the Montana Bureau of Mines and Geology in Choteau and Loma

Irrigated Lands, Irrigation Diversions and Evapotranspiration

Irrigation water use was split into two categories, water diverted and water consumed. Diverted refers to the volume of water diverted from the source (river, stream, or well) to the field. Consumed is the volume of water used by crops during growth (evapotranspiration).

Irrigation in the watershed was quantified and characterized in the Geographic Information System (GIS). This included identifying (1) irrigated lands, (2) the types of irrigation systems used and (3) the ditches and water sources that supplied the irrigated lands. Additional information on the DNRC irrigated land estimation process can be found in Appendix B.

Multiple sources of irrigated land data were used to estimate the location and quantity of irrigated land in the watershed. A composite of the following three data sets was created in GIS to evaluate all potential irrigated land.

1. Water Resource Survey, State Engineers Office
2. Department of Revenue, Final Lands Unit
3. DNRC Water Rights Mapper

Irrigated land was mapped in detail by the State Engineers Office (Teton, Choteau and Pondera Counties) Water Resources Surveys (WRS 1962-64). This information was later digitized in GIS by DNRC. The WRS identified irrigated land and ditches were found to be relatively accurate, however land use has changed in the more than five decades since the WRS have been completed.

Irrigated land has been mapped by the Montana Department of Revenue Final Lands Unit (FLU) every two years since 2005 for the purposes of taxation. The 2012 FLU dataset is a GIS data layer identifying irrigated land by application type, such as flood, sprinkler, and pivot. The FLU dataset does not include irrigated pasture.

The DNRC Water-Rights Mappers GIS program is used by claims examiners to evaluate filed claims in the Montana water-rights adjudication process. Irrigated land is mapped based on claimed water right places of use based on 1980 imagery.

Once compiled in the GIS, irrigated acres were reduced to an estimate of “what is actually being irrigated” based on the volume of water found to be consumed on a field using remote sensing techniques. Acres that fell below one standard deviation of the watershed average consumption (ET) were assumed to not be irrigated.

Irrigation diversions were estimated using water commissioner records for the 25 water users adjudicated in the 1905 Perry v. Beattie Decree, with some adjustments made. Water commissioner records were obtained from the Teton County Courthouse. Decreed users are required to have measurement devices on all diversions, the majority of which are Parshall Flumes.

Diversion records were summed according to irrigation company and private water users were lumped into one group. Water diversions outside of the Perry V Beattie Decree were estimated using a diversion rate (diversion per irrigated acre), calculated from decreed diversions (water commissioner records) [Non-decreed diversions = irrigated acres x diversion rate].

Consumptive use of irrigation water (evapotranspiration (ET)) was estimated using remote sensing data and mapped irrigated acres in the GIS for the year 2007. DNRC had estimated ET state-wide for the Montana Water Supply Initiative in 2015 using 2007 LandSat Imagery (USGS and NASA, 2007). Although 2007 is outside the study period, it was the most complete, current, and accurate estimate of consumptive use available and represented water use during a “typical” year. Additional information about the DNRC remote sensing ET process can be found in Appendix C.

Error in Water Measurement

Streamflow data collected by DNRC and USGS is controlled for quality. It should be noted that the measurement of water comes with uncertainty and under the best conditions the error is assumed to be at a minimum five percent. Flows during winter periods or very low flow conditions are assumed to have a greater uncertainty. Measurements of diversions from water commissioner records are also assumed to have at a minimum five percent error or greater based on the condition of the measurement device. Human error and record keeping may add additional error associated with diversion measurements.

Water Supply Hydrology

Precipitation and Snowpack

Streamflow in the Teton Watershed is dependent upon precipitation and the accumulation of snowpack. The relationship between precipitation and streamflow is complex and further complicated by conditions such as: the previous year's precipitation, large rain events, diversions, and groundwater storage.

Mountain snowpack and precipitation most heavily influences flow on the Teton River (above the Springhill Reach) and Deep Creek. Flow on the Teton River below Choteau is mainly influenced by the accumulation of prairie snowpack, precipitation, groundwater inflow, and irrigation practices near Choteau.

Snowpack

Mountain snowpack is measured by the National Resource Conservation Service (NRCS) to forecast water supply. NRCS currently maintains two SNOTEL (Snowpack Telemetry) stations, Mt. Lockhart (6,400 ft) and Waldron (5,600 ft) and one snow course site Freight Creek (6,000 ft) in the North Fork of the Teton drainage. The bulk of the snowpack accumulating area (approximately 7% of the Teton watershed's land mass) is located at or above the elevation of the NRCS sites. The highest elevations of the watershed are over 3,000 feet higher than the snow measurements sites.

The period of record for the SNOTEL sites is 1979 to present. Prior to 1979, both SNOTEL sites were operated as snow courses from 1968. The Freight Creek snow course has been operated since 1948.

Snow water equivalent (SWE) data over the study period are compared to the "Normals", which is the median SWE value for the last 30 years (1981-2010). The accumulation and melt of the snowpack and 30 year Normals at the SNOTEL sites (inset graph) are plotted in (Figure 8) for the study period.

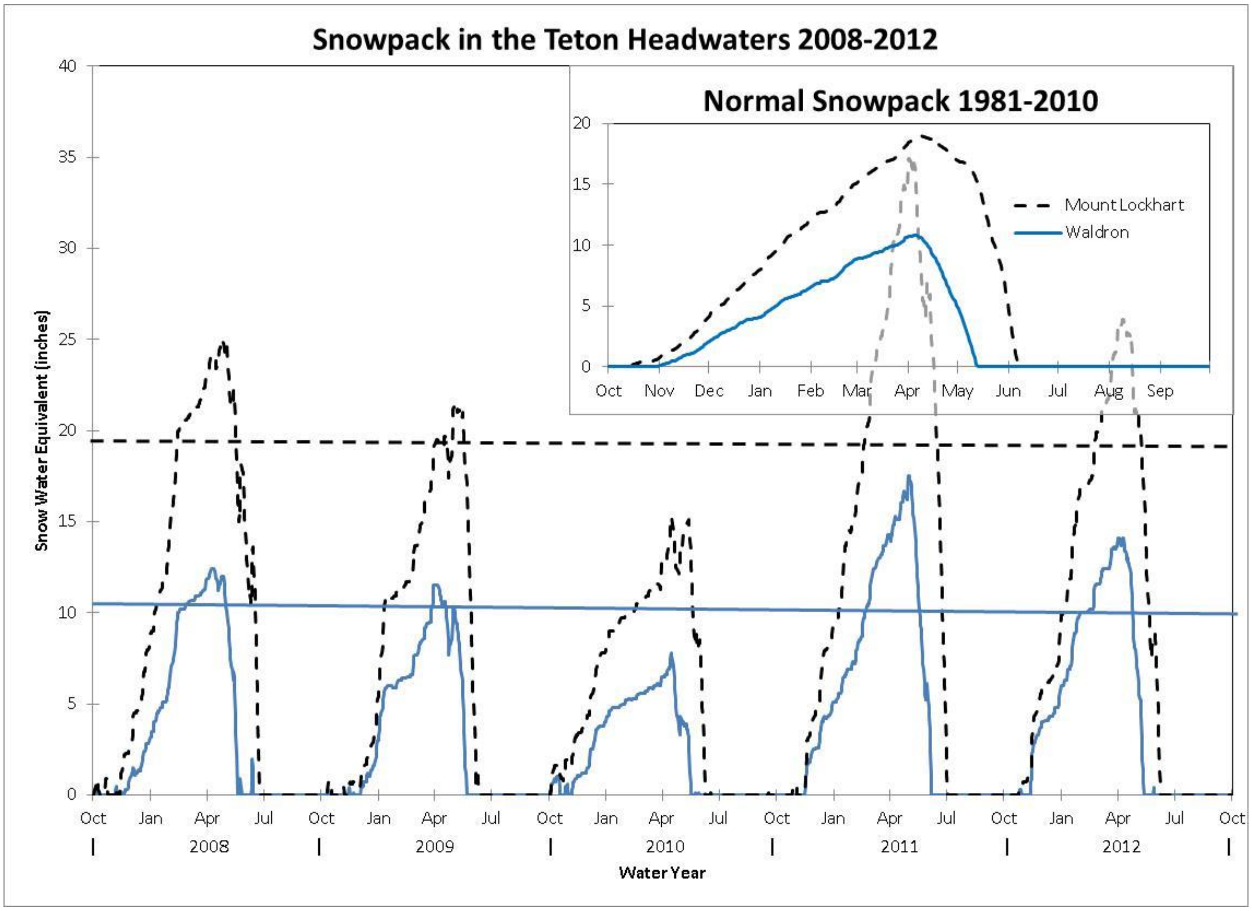


Figure 8: NRCS SNOTEL SWE data Mount Lockhart and Waldron stations 2008-2012 by water year with inset graph depicting 30 year average. Horizontal lines denote Normal maximum SWE accumulation.

Monthly SWE accumulation at the Freight Creek snow course is presented in Table 2. Data at Freight Creek generally mimics data found at the SNOTEL sites. Above average to average snowpack conditions were present in four out the five study years, with 2010 being the only below average year. The snowpack in 2011 was the second highest snowpack on record.

Freight Creek
Snow Water Equivalent (SWE) Inches

Year	March	April	May
2008	14.5	14.2	12.8
2009	6.4	11.6	8.4
2010	6.6	5.4	2.6
2011	11.4	16.1	19.4
2012	14	16.3	13.1
Normals	**10.4**	**11.9**	**9**

Table 2: Snow Water Equivalent at Freight Creek snow course.

The normal peak snowpack occurs in mid-April and the snowpack is normally depleted at or below the elevations of the snow monitoring sites by the first of June. Over the study period the snowpack at both SNOTEL sites tended to melt faster than the normal melt-out date (Early June Mt. Lockhart, Mid-May Waldron). Melt-out dates in 2011 were the closest to normal.

Precipitation

Precipitation recorded at the Mt. Lockhart and Waldron sites is presented as departures from normal and accumulated precipitation 30 year "Normals", which are average values (Figure 9). Precipitation, including both snow and rain, was average or above average for each year of the study except 2010.

Precipitation gives insight into conditions outside of the snow accumulating months where rains can drive snowmelt swollen rivers to flood levels or boost flows during critical low flow periods. In general, rain is most likely to add to water supplies in May and June and then again in October. The large rain event in May of 2008, markedly boosted the 2008 water supply conditions.

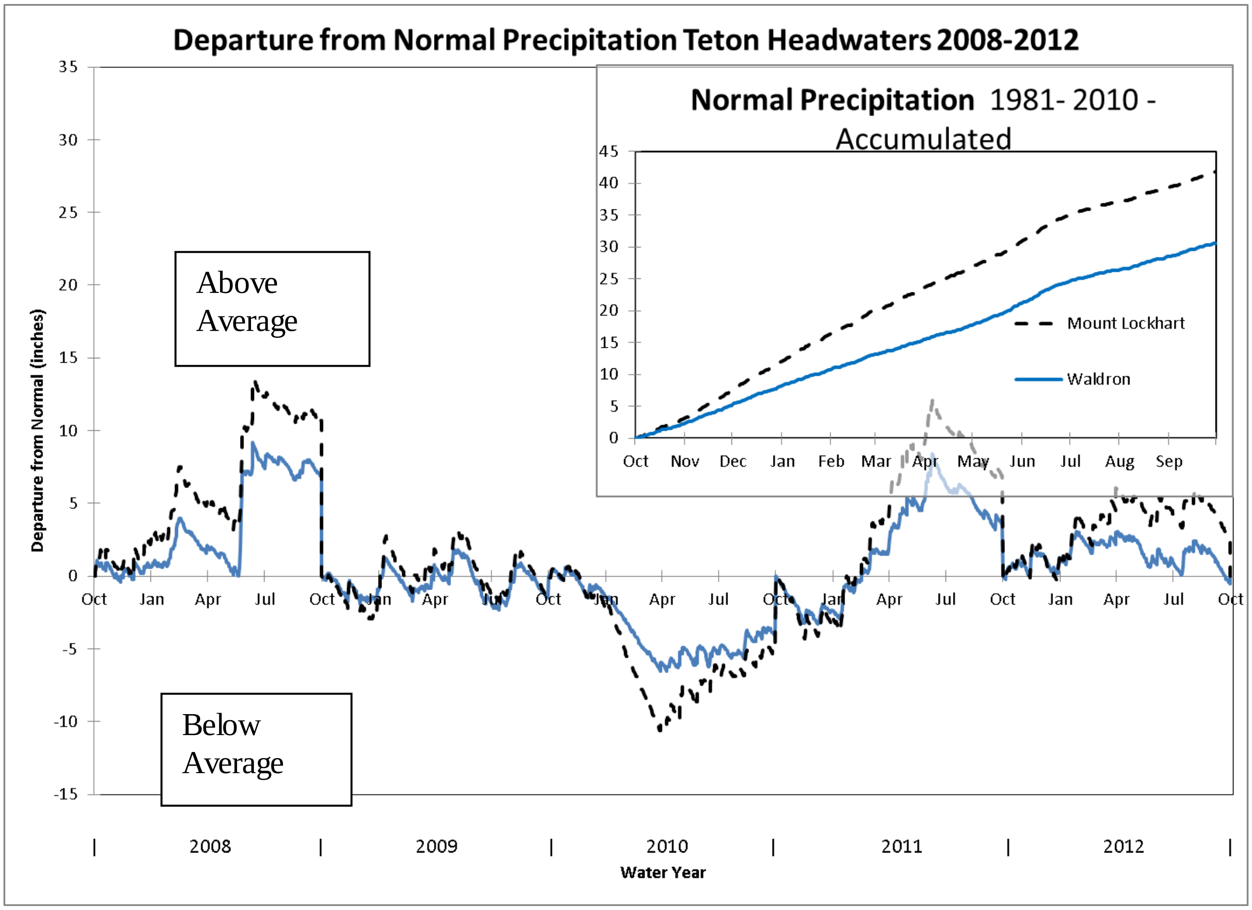


Figure 9: NRCS SNOTEL precipitation departure from average Mt. Lockhart and Waldron sites.

Precipitation over the prairie portion (89% of the watershed landmass) during the study is presented as monthly departures from average for the Choteau and Carter weather stations (Figure 10), NWS Cooperative Observer Program.

In general, precipitation conditions over the prairie mimic those found in the mountains albeit on a reduced scale reflecting the much drier prairie environment. The exception is that precipitation in 2010 was above average at both stations and below average conditions were found at Carter in 2009.The frequent occurrence of above average and below average months shows the dynamic nature of precipitation in the watershed.

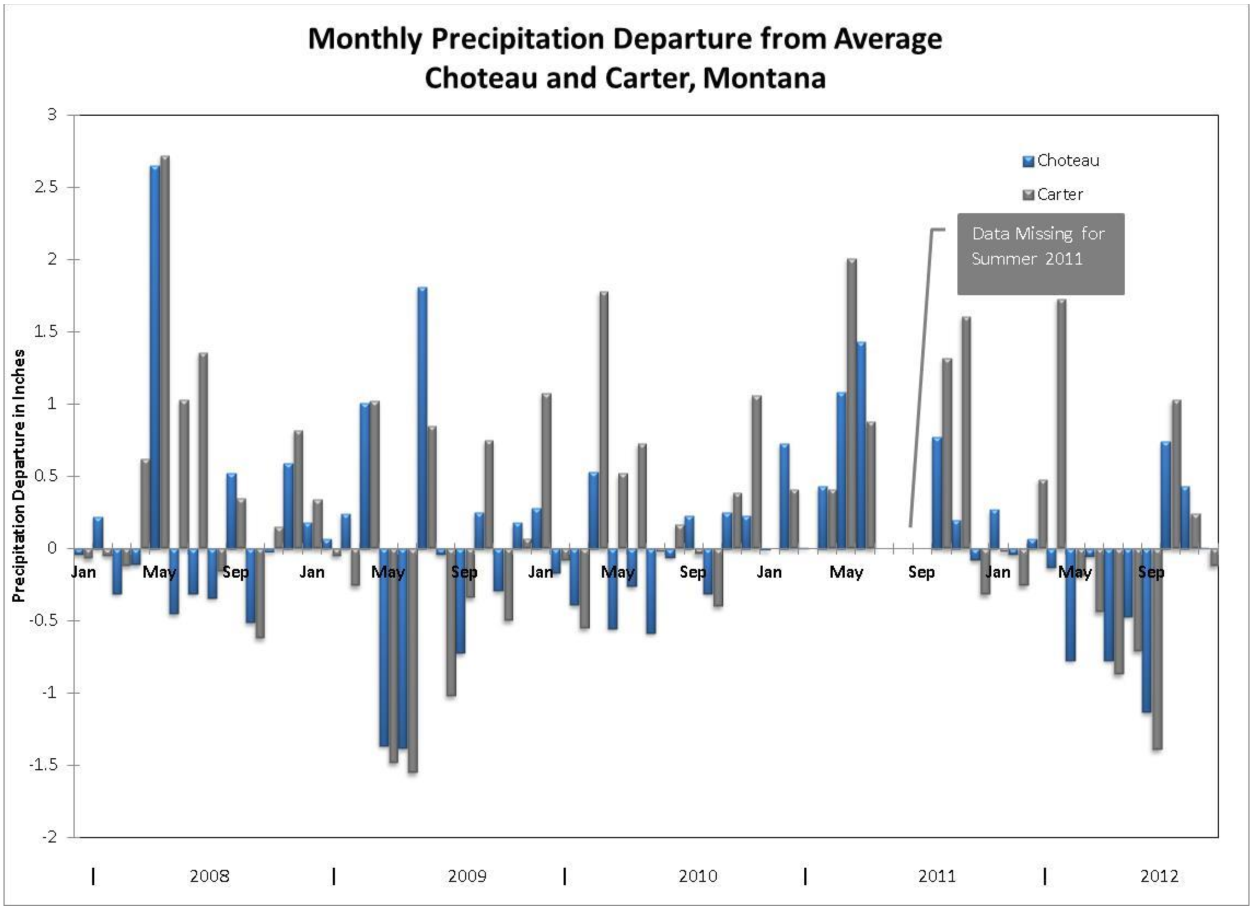


Figure 10: Monthly precipitation departure from average at Carter and Choteau, Montana.

Surface Water Resources

The 183 mile Teton River and its tributaries traverse the rugged Rocky Mountains and rolling prairie environment throughout its course to the Marias River. The amount and occurrence of water in this dynamic river system depends on snowmelt and rainfall, and water use and management. In order to further describe the hydrology of the watershed, DNRC installed 12 stream gages in 2008 and 2009 (Figure 5) and (Appendix D). DNRC gaging efforts supplemented the three active USGS streamflow gaging sites on the Teton River. Historically the USGS had operated eleven gages at one time or another from 1906 to 1932 (Appendix D)

DNRC stream gages were operated year round in areas where winter baseflow were deemed important to the study. All other DNRC gages were operated seasonally (May through October) to characterize flow conditions during the irrigation season. The complex hydrology of the Teton River and its tributaries required gage locations to be changed, added and removed during the study period. Two gages on the Teton River (above the Bynum Diversion and at Crawford Bridge) proved to be poor locations to gage due to channel alterations and diversions. Data from these gages are of limited value and are not presented in this report.

The sheer number of gages required to characterize the complexities of the Teton watershed is overwhelming for this report. Thus, stream gaging information is summarized in the following section. Additional information (including hydrographs and descriptive text) on all DNRC and USGS stream gages in the watershed can be found in Appendix D.

Stream Gages of the Teton Watershed: A Brief Introduction

The following is an overview of the seven gages along the Teton River and eight tributary gages. Stream gages are listed in order from upstream to downstream.

Teton River Gages

1) **Teton River below the South Fork Confluence (USGS)**
    - This is the only gage on the Teton River representing natural inflow and full connection with mountain precipitation/snow melt.
    - Operates seasonally (April 1 to Oct 31). This gage is operated annually as of 2016.
2) **Teton River below Highway 287 near Choteau**
    - This is the first gage below all of the major diversions on the Upper River. The Teton River is typically dry for several miles above this gage.
    - Inflows are derived mostly from groundwater discharge, local precipitation, and irrigation return flow.
    - Rarely connects to the Upper Teton River via surface flow.
3) **Teton River above Hwy 221**
    - This real-time gage was installed in 2012 by the Teton watershed group as a tool to measure water supplies leaving the Choteau area.
    - Captures tributary inflows from Deep and Spring Creek.

- Located at the contact between gravels and the Colorado Shale. All Teton Valley groundwater is expected to re-appear as surface water at this gage.

4) **Teton River near Dutton (USGS)**
    - Represents flow in the middle reaches of the river.
    - Inflows are derived mostly from: groundwater discharge in the Choteau area, tributary inflows, local precipitation, and irrigation return flow.
    - In general the Teton River does not gain any additional flows from tributaries or groundwater below this point. Local precipitation events add flows periodically.
5) **Teton River at Bootlegger Bridge**
    - Represents flow in the middle/lower reaches of the river.
    - Inflows are similar to the Dutton Gage.
    - Irrigation withdrawals are evident at this location.
6) **Teton River at Buck Bridge**
    - Represents flow in the lower reaches of the river.
    - Inflows are similar to the Dutton Gage.
    - Irrigation withdrawals are evident at this location. Flows less than 10 cfs are common during the irrigation season and no-flow conditions were present in 2012.
7) **Teton River at Loma (USGS)**
    - Represents flow leaving the Teton River watershed.
    - Inflows are similar to the Dutton Gage.
    - Irrigation withdrawals are evident at this location.
    - No-flow conditions are frequent at this location. During the study, no-flow periods were observed in 2008, 2009, and 2012.

Tributaries

1) **Deep Creek (2-Gages)**
    - Deep Creek originates in the Rocky Mountains west of Choteau and flows 37 miles through the prairie to the Teton River near Choteau. Deep Creek has the highest median elevation of all tributaries.
    - Two stream gages reflect depleted inflows (Upper Deep Creek) and contributions to the Teton River (Lower Deep Creek).
    - High flows are common during spring runoff and during summer rain storms.
    - Water demands on the creek commonly exceed supply in the lower reaches during the irrigation season.
2) **Willow Creek**
    - This small tributary of Deep Creek starts in the Pine Butte Swamp and Rocky Mountain Front.
    - The Willow Creek drainage area has limited access to the Rocky Mountains.
    - Water demands on the creek commonly exceed or nearly exceed supply during the irrigation season.
    - The Willow Creek stream gage represents conditions in the middle reaches of the creek.

3) **McDonald Creek**
    - McDonald Creek originates in the McDonald Creek Swamp west of Choteau and is fed primarily by groundwater discharge from the Teton Valley Aquifer.
    - McDonald Creek is the only tributary that flows into the Teton River above the losing Springhill Reach.
    - The McDonald Creek gage is located near the mouth and represents water leaving the creek.
    - Consistent year round flow to the Teton River play a key role in satisfying senior water users below the Eldorado diversion.

4) **Muddy Creek**
   - Muddy Creek originates along the Rocky Mountain front and flows 80 miles through the prairie to the Teton River near Collins, Montana.
   - The Muddy Creek gage is located near the confluence and reflects flow leaving the creek.
   - Muddy Creek drainage has limited access to the Rocky Mountains.
   - Muddy Creek is used to convey stored irrigation water and water is exported outside of the watershed.
   - Upstream water demands on the creek nearly exceed or exceed supply during the irrigation season.
5) **Spring Creek (3-Gages)**
   - Spring Creek originates in the Teton River Valley north of Choteau and flows to the Teton River below Choteau.
   - This small tributary is fed by groundwater discharge from the Teton Valley Aquifer.
   - Three gages were installed on the creek (Upper, Middle, and Lower) to characterize flow.

Water Supply During the Study: Where the Present Meets the Past

A first step to understanding the hydrology of the watershed is to compare historic streamflows with those observed in this study (Figure 11). USGS gages provide the best reference in the watershed for long-term comparison.

The use of seasonal or annual volumes simplifies the assessment of supply conditions. However, dry or wet periods within a particular year can be lost in the numbers as spring rains can make up for a dry winter or a dry spring offsets a large snowpack.

Period of record data should be considered with caution because two out of the three long-term gages have a short period of record (i.e. a few large water supply years could sway the average away from many dry years). It is important to keep in mind that prior to the study annual flows were below average for five years. Meaning, water supplies and demand were likely stressed by low water supplies.

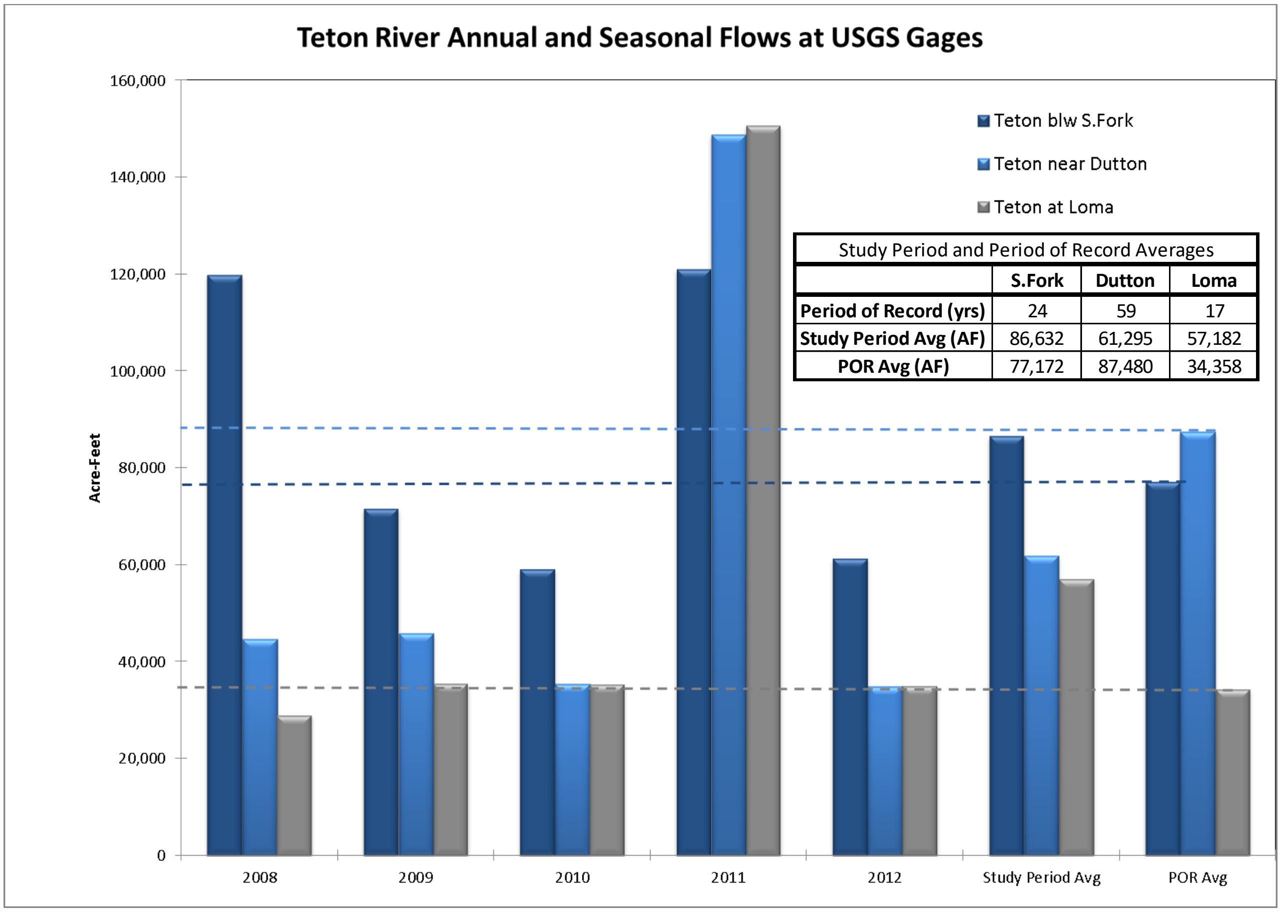
USGS streamflow period of records in the Teton watershed are:

- Teton River below S. Fork Confluence (1947 to 1955 and again from 1998 to present)
- Teton River near Dutton - since 1955
- Teton River at Loma - since 2000

The big story during the study was the strong water supply years (2008 and 2011) for the Upper Teton River (measured at the Teton River below the South Fork gage). The causes of these strong showings are very different spring rains in 2008 and the second largest snowpack ever recorded in 2011. Regardless, the results were flows nearly double the seasonal average. The difference between the period of record and study period average (on the Upper River) shows how 2008 and 2011 significantly boosted study period averages.

The implications of having two large water years close to each other also affects diversion volumes as more water was available to divert. One must keep in mind that 2008 and 2011 will skew the study period average in favor of a water supply that may not be typically available.

The Teton River below the South Fork confluence gage provides the best reference between precipitation and realized water supply, because diversions are not present above the gage. Only seasonal (April to October) data are available for the Teton River below the South Fork. Water use and management effect the volume of water measured at the Dutton and Loma gages, complicating the relationship between actual water supply and measured water supply.



Study Period and Period of Record Averages			
	S.Fork	**Dutton**	**Loma**
Period of Record (yrs)	24	59	17
Study Period Avg (AF)	86,632	61,295	57,182
POR Avg (AF)	77,172	87,480	34,358

Figure 11: Annual flow volume and Period of Record (POR) averages in acre-feet for Teton River USGS gages. Note that only seasonal April to Oct data are available for the Teton below the South Fork. Historical data (1947-1955) indicates that winter baseflow typically add another 15,742 acre-feet to the seasonal volume of the Teton below S.Fork Gage. Dalby (2016) estimated the study period mean winter flow to be 7,700 acre-feet.

The 2009, 2010 and 2012 water years were below average at the Teton River below the South Fork gage. Below-average conditions were found at the Dutton gage each year except 2011 and average or near-average conditions were found all years except for 2011 at the Loma gage.

It is not surprising that annual and seasonal data do not correlate well between all three gages. Period of record and water management are key factors. The Dutton gage does not correlate with the South Fork due to the long period of record. The Dutton gage captures times where water supply conditions were wetter (the 1970's) and likely times where water was managed differently on the Upper River. Near average conditions appear at the Loma gage in part due to the short period of record that reflects conditions under recent years and water management. The data suggest that flow passing the Loma gage are independent of water supply and precipitation conditions during most years (except 2011) and are more dependent on Upper River water use.

The Big Picture: Seasonal and Annual Hydrology

Looking at streamflows on an annual basis helps put the hydrology of the watershed in perspective (Figure 12). Typically rivers tend to increase in volume as they near the mouth due to increased drainage area and access to precipitation, tributaries, and groundwater inflows. However, the Teton does not follow this pattern (Figure 13).

Over the study period the headwaters of the Teton River produced 86,000 acre-feet of water from April 1 to October 31. Annually, that volume is estimated (based on adding estimated/historical winter flows) to climb to 94,000 and 102,000 acre-feet respectively. The flow of the Teton River from the headwaters is reduced (diversions and natural loss) to nearly 0 acre-feet in the Springhill Reach. Below this point, groundwater gains near Choteau (8,000 acre-feet) are present in the River. A little farther downstream more groundwater gains and surface water inflows from Spring Creek and Deep Creek boost flows to 27,000 acre-feet. As the Teton progresses downstream to Dutton, flows on the river increase to 61,000 acre-feet[7] from tributary inflows (Spring and Gamble Coulees and Muddy Creeks) and groundwater gains. Between Dutton and the mouth (Loma), the river again decreases in flows with 57,000 acre-feet leaving the watershed.

---

[7] However, the majority of this gain was realized during the month of June during runoff likely influenced by the wet years in 2008 and 2011.

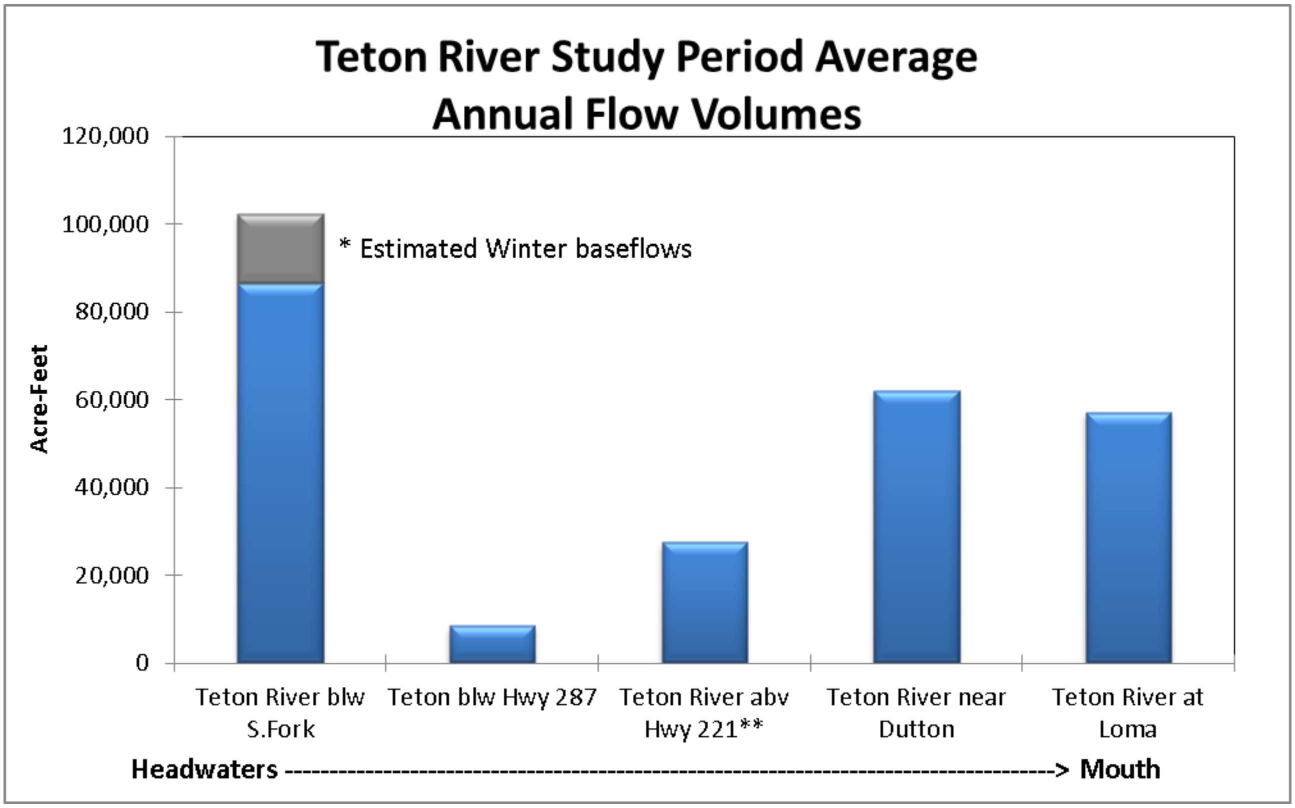


*Figure 12: Study period annual flow for select Teton River Gages. *Note seasonal data are only available for Teton River below the South Fork (April 1 to Oct 31). Historically, winter baseflow average 15,742 acre-feet, study period average estimates are 7,700 acre-feet. **Teton River above Highway 221 was installed by the Teton watershed group and maintained by DNRC starting in 2012. The period of record for this gage (2012-2014) does not match the others and is shown purely as an added reference point.*

Teton Tributaries

Seasonal (April 1 to October 31) and annual Tributary streamflows (Figure 13) show tributary productivity and contributions to the river. In general, each tributary and its interaction with the river are unique. In some cases contributions to the Teton River are directly measured with gaging locations (Muddy and McDonald Creeks). However, estimation of the direct contribution of other tributaries is limited by the presence of diversions and natural losses/gains below gages. Like the Teton River the most productive tributary, Deep Creek, loses volume from upstream to downstream, and unlike the Teton River, Spring Creek gains water from upstream to downstream. Gaging efforts in Willow, McDonald and Muddy Creeks were not sufficiently detailed to quantify gains and losses.

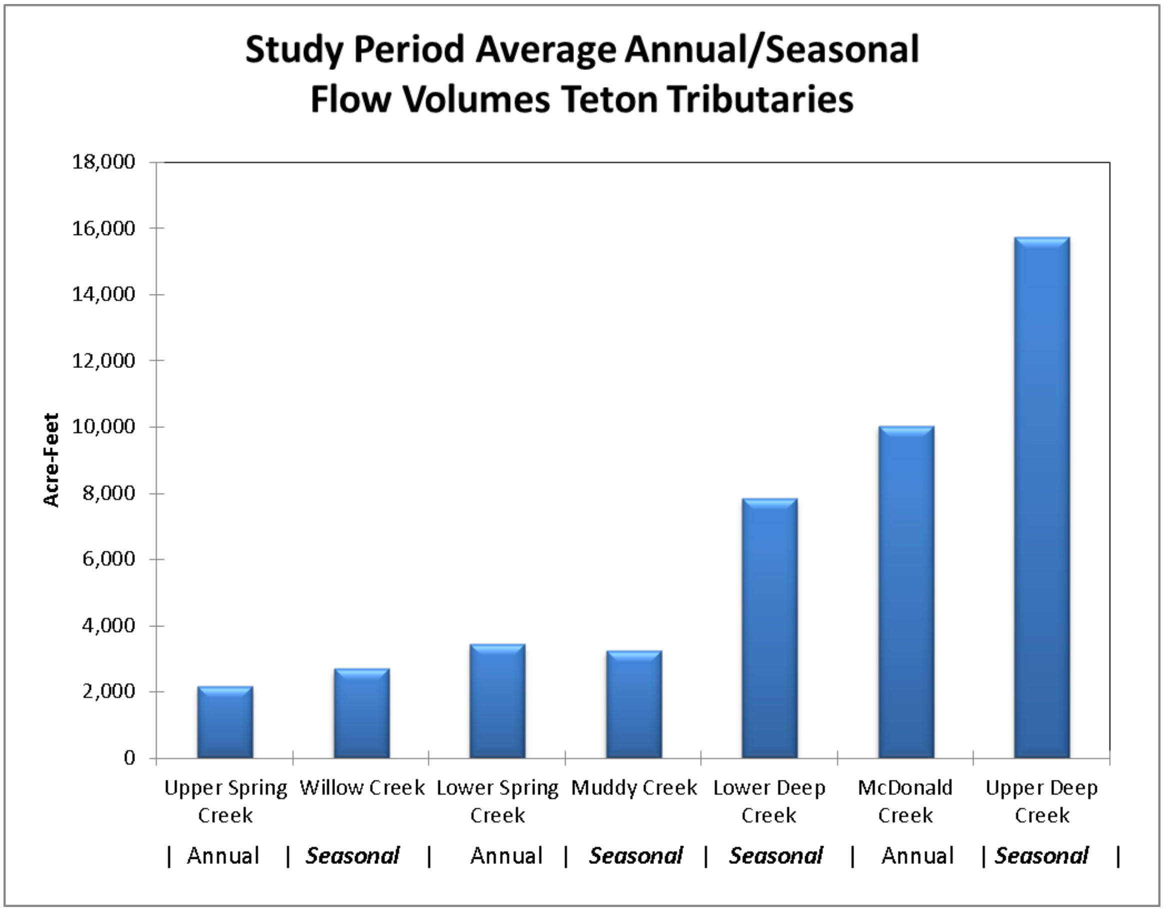


Figure 13: Study period annual and season flow for select Teton tributary gages. Note: Both seasonal and annual flow data is presented.

Inflow v. Outflow

A watershed inflow vs. outflow diagram (Figure 14) further supports the conclusion that the Teton watershed is not typical. Since, annual data was unavailable for all gages, the comparison was made on a seasonal basis from April 1 to October 31. Winter baseflow is not expected to change the picture.

The following information was used to evaluate gains and losses:

Inflows

- (Teton River below the South Fork + Upper Deep Creek +Willow Creek + Muddy Creek)

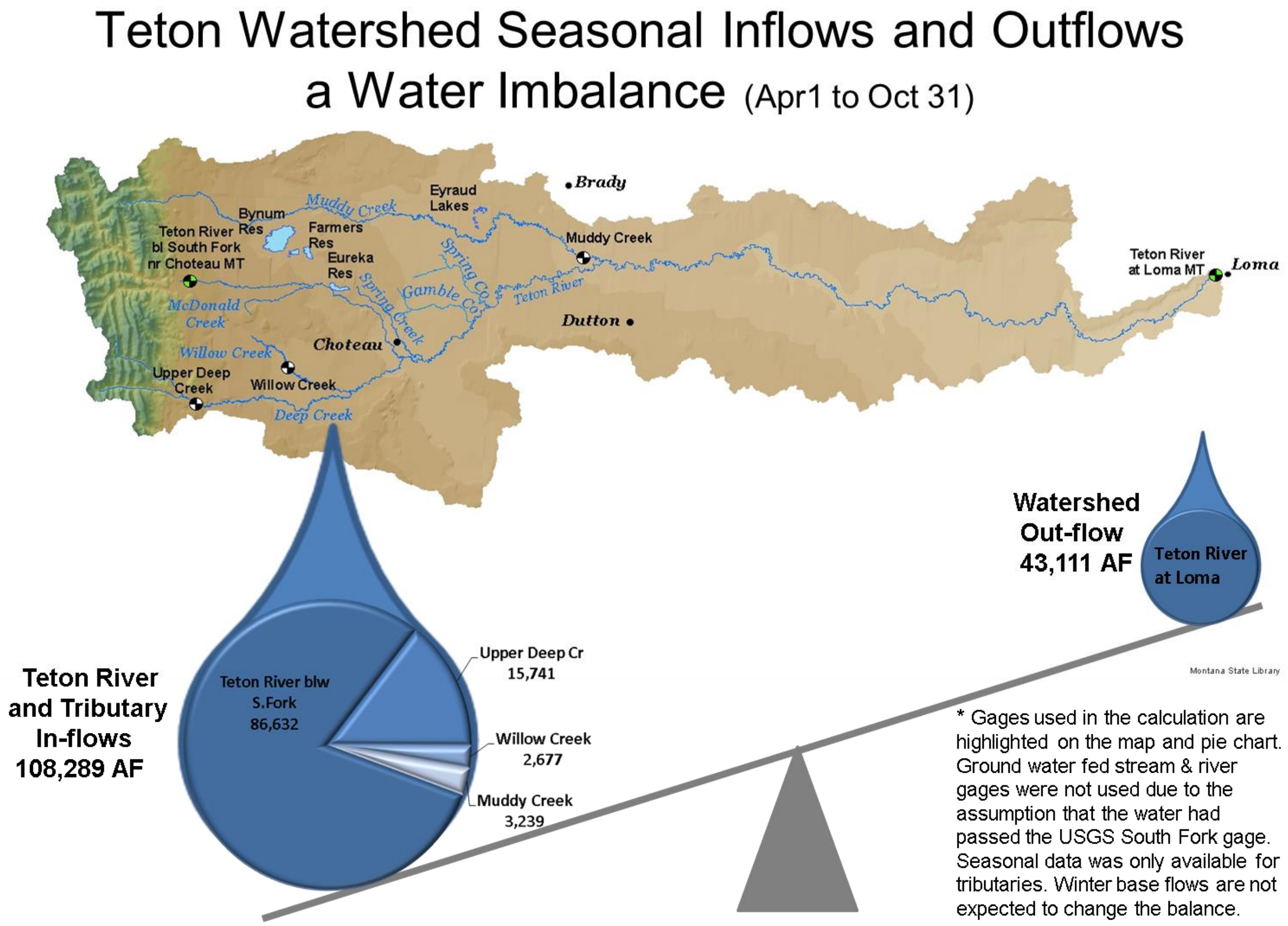
Outflows

- Teton River at Loma.

Gages Not Used

- Groundwater fed tributaries (McDonald and Spring Creeks) were not included due to the assumption that water was counted by the USGS Teton below S. Fork gage (see Spring Creek Discussion above).
- The same applies to groundwater gains to the Teton River near Choteau.

An imbalance in flows is apparent since the mountainous headwaters produce significantly more runoff (65,178 acre-feet) than reaches the mouth of the watershed. The majority of water loss is attributed to irrigation consumption. Water diversion and consumption above Choteau is the most obvious player in this water imbalance. However, water consumption below Choteau contributes as well.



* Gages used in the calculation are highlighted on the map and pie chart. Ground water fed stream & river gages were not used due to the assumption that the water had passed the USGS South Fork gage. Seasonal data was only available for tributaries. Winter base flows are not expected to change the balance.

Figure 14: Seasonal Teton watershed in-flows vs. out-flows.

A Closer Look at watershed variability: Daily Streamflows

Teton River Stream Gages

The hydrographs of the Teton River range from snowmelt-derived systems where baseflow is increased by abundant water supplies in May and June to spring creeks where subtle changes in flows differentiate peaks from baseflow. Select hydrographs from the watershed are presented below. Complete stream gaging records appear in Appendix D.

USGS Gage Teton River below South Fork Confluence

The USGS gage 06102500 Teton River below South Fork Confluence is located west/upstream of the City of Choteau. The gage is located above all major irrigation withdrawals and is representative of natural inflow to the Teton River.

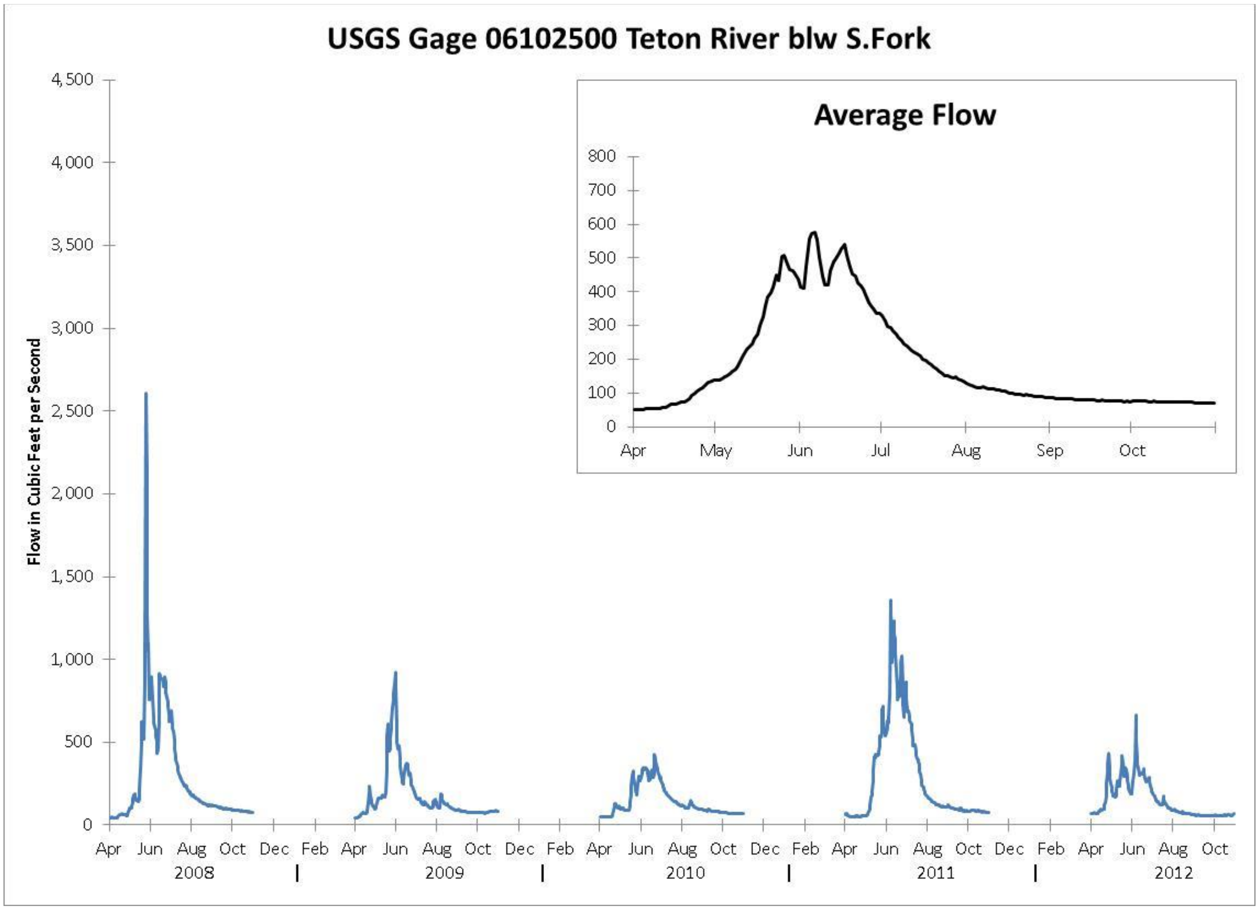


Figure 15: Hydrograph of USGS Gage 06102500 Teton River below the confluence of the South Fork and period of record average flow (1947-1954 & 1998-2012).

The hydrograph (Figure 15) of the Teton River above diversions is one of ample water supplies during snow melt and spring rains (May and June) with the highest flow observed during the study period at 2,600 cfs (May 25, 2008). However, water supplies are typically limited to baseflow (75 to 115 cfs) from July to November. Historical, winter baseflow for 1948-1954 averaged 57 cfs, estimated baseflow for 2009-2014 is about 26 cfs.

DNRC Gage Teton River Below Highway 287

The DNRC gage Teton River below Highway 287 is located approximately 30 miles downstream from the USGS Gage 06102500 Teton River below S.Fork gage and is south/downstream of Choteau. The Teton River is typically completely dewatered for several miles between the Highway 287 gage and the upstream USGS gage. Water in the river at this location is primarily derived from groundwater discharge from the Teton Valley Aquifer, to a lesser extent from irrigation return flow (Burd ditch tail water), and precipitation in the Choteau area.

The hydrograph (Figure 16) reflects variable inflows from multiple sources of water, and this makes it difficult to separate their relative contributions. The Watershed Overview and Groundwater Surface Water Exchange sections discuss the connection between groundwater levels in the Teton Valley Aquifer and the occurrence of water in Teton River. In years of substantial snowpack and runoff such as 2008 and 2011, the river near Choteau will briefly benefit from some high flows from the Upper River (note peak flows in 2011).

The hydrograph contains a double peak that result from natural and man-made causes. The average primary peak appears to occur in May and June because high flows in 2011 have skewed the average. However, in most years the primary peak occurs in March and April. Peak flows are subtle at this location with an average peak of 36 cfs and low flows typically less than 5 cfs.

Flows rise from January through March resulting in a primary peak flow in March. Winter increases in groundwater levels are the result of a mixture of Upper Teton River and McDonald Creek water entering Springhill Reach and seeping into the shallow aquifer. Typically, this occurs from November until March. Upstream demands increase in April and May, diverting water away from the Springhill Reach leading to a decline in groundwater levels in the Teton Valley Aquifer.

The second peak typically begins in early June coinciding with high flows on the Upper River. Increased seepage in the Upper Teton River above the Springhill Reach[8], precipitation and irrigation return flow provide the water for the second peak. The secondary peak typically

---

[8] See discussion of seepage losses on the Upper River page in the Spring Creek section p 18.

begins to recede in mid-June with low-flow (baseflow) conditions being observed from August to January.

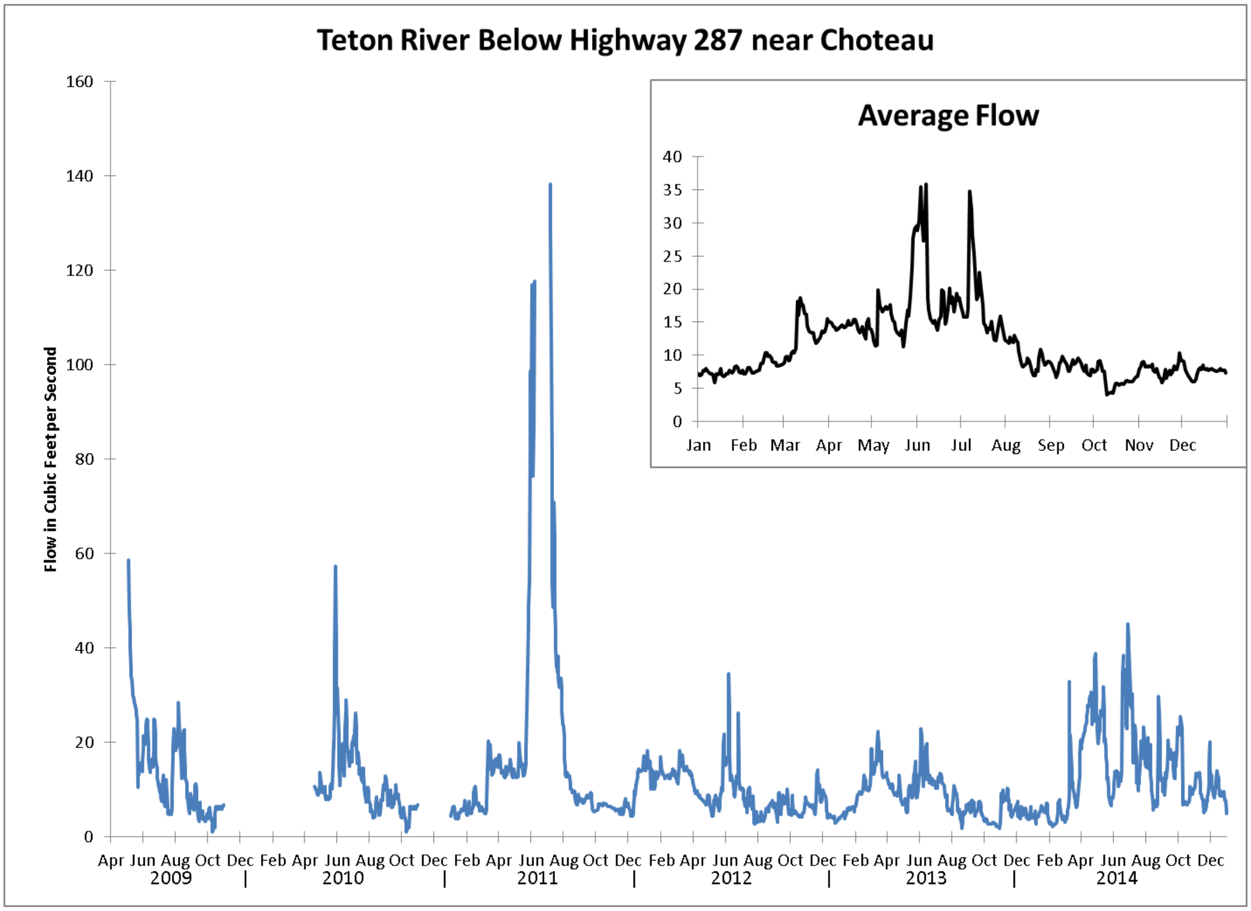


Figure 16: Hydrograph of the Teton River below Choteau site (2008-2014).

USGS Gage Teton River near Dutton

USGS gage 06108000 Teton River near Dutton is located approximately 64 miles downstream of DNRC Gage Teton River below Highway 287. The Dutton Gage represents the maximum water supply measured in the Lower Teton River. This is due to precipitation, tributary inflows (Deep, Spring, and Muddy Creeks), and groundwater inflows. Downstream of Dutton, the Teton River does not gain additional water. Streamflow data below Dutton includes two DNRC gages and one USGS gage (See Appendix D).

The hydrograph (Figure 17) of the Teton River at Dutton is characterized by two peaks: one related to melting prairie snowpack and another primary peak resulting from springtime precipitation and to a limited extent mountain precipitation/snowpack. There was not a discernible peak during 2012.

In general, the Lower Teton River does not benefit from snowpack accumulated in the Rocky Mountains with the exception of contributions from Deep Creek. In years of substantial snowpack and runoff such as 2008 and 2011, the river benefits briefly from some high flows from the Upper River (note peak flows in 2011).

Flow increases in March as runoff from prairie snowpack and precipitation generally increases flow. Precipitation events in May and June further increase flow and create flashy peaks. From the June peak, the hydrograph declines through July into August at which point the river returns to baseflow conditions. Although the Teton River flows year round at the Dutton Gage no-flow conditions were observed during the study downstream at the Buck Bridge and Loma Gages.

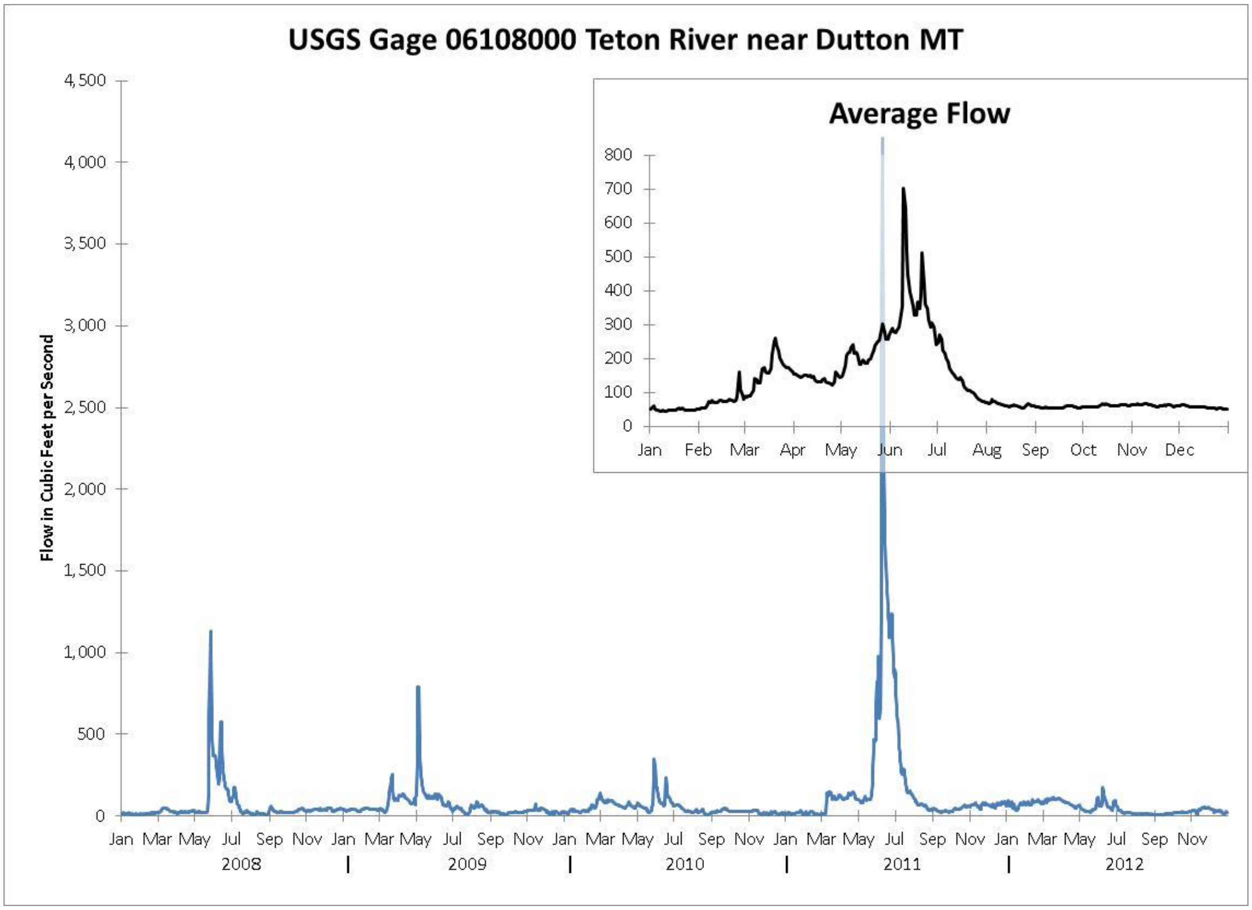


Figure 17: Hydrograph of USGS gage 06108000 Teton River near Dutton and period of record average flow (1954 -2012).

Teton River Tributary Stream Gages

Tributaries to the Teton River include McDonald Creek, Spring Creek, Willow Creek, Deep Creek, and Muddy Creek. The hydrology and contributions of each tributary are unique. Tributaries fed by groundwater discharge (Spring Creek and McDonald Creek) are discussed separately due to their unique relationship to water management in the Teton River. The following overview describes the general characteristics of select tributaries. See Appendix D for additional information on all tributary gages.

Deep Creek Drainage

Deep Creek produces the most water of any tributary of the Teton River. This occurs as a result of the creek's trellis drainage that extends deep into the Rocky Mountains. Gaging efforts in the Deep Creek drainage include two gages on Deep Creek (Upper and Lower) and one gage on Willow Creek. Abundant irrigated agriculture exists within the drainage. Much like conditions found along the Teton River, water supply produced near the headwaters of Deep Creek exceeds that found near the bottom of the drainage (Figure 13).

Upper Deep Creek

The Upper Deep Creek gage is located 20 miles west of Choteau near the Rocky Mountain Front. This gage is representative of depleted inflows into the creek; a major diversion above the gage on the North Fork of Deep Creek exports water into the Willow Creek drainage. A hydrograph of daily average flows and study period averages illustrates seasonal peaks and baseflow periods (Figure 18).

The hydrograph of Upper Deep Creek is one of ample water supplies during snow melt and spring rains (average peak flow of 138 cfs). However, water supplies are typically limited to baseflow from July to November. Typically baseflow ranges from 12 to 30 cfs. The drainage responds quickly to rain events as several flashy peaks are present in the hydrograph.

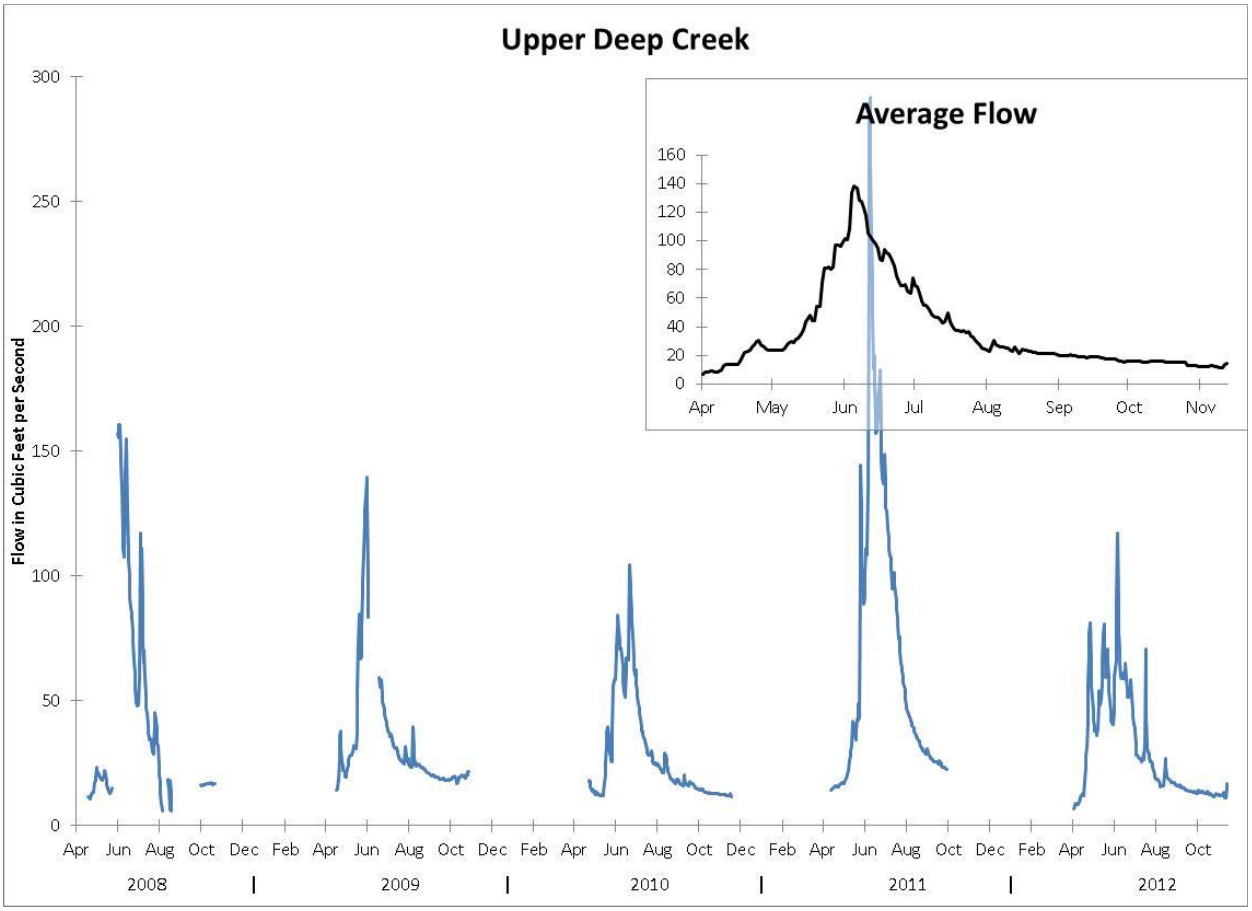


Figure 18: Hydrograph of Upper Deep Creek and period of record average flow (2009 -2012).

Lower Deep Creek and Willow Creek

The hydrographs of Lower Deep Creek and Willow Creek (See Appendix D) differ from conditions found near the mountains. Irrigation demands, runoff, and precipitation events shape the erratic hydrographs. Demands on both creeks resulted in very low (1cfs or less) to no-flow conditions frequently during low water supply months (July and August).

Muddy Creek

The Muddy Creek drainage area is the largest of Teton River tributaries at 426 square miles. However, water supply conditions found near the mouth of the creek are comparable to that of a much smaller drainage (Figure 13) (see also Appendix D). Unlike Deep Creek and the Teton River, the drainage area of Muddy Creek does not extend deep into the Rocky Mountains, limiting water supplies. The Muddy Creek drainage has abundant irrigated agriculture and the creek is also used to distribute stored irrigation (Teton River) water from Bynum Reservoir. In addition, Muddy Creek and to a lesser extent Teton River water is stored and exported out of the basin by the Brady Irrigation Company.

Flow in Muddy Creek was highest in (May) during precipitation driven runoff events and/or times of reduced irrigation demand. Flow at other times was lower as a result of irrigation diversions and lower water supply conditions. The data suggest that the majority of water generated by the watershed, released from storage, and discharged from Burton Bench aquifer (irrigation return flow) does not make it to the gage near the mouth of creek.

Groundwater Fed Tributaries

Spring Creek

Spring Creek is a small, yet highly visible tributary of the Teton River. Spring Creek is fed primarily by groundwater discharging from the Teton Valley Aquifer and to a lesser extent local precipitation and irrigation return flow. Spring Creek is located below the losing Springhill Reach and much like the adjacent Teton River (below the Springhill Reach) is affected by management of the Upper Teton River and natural processes.

The hydrograph (Figure 19) of Upper Spring Creek is closely related to that of the Teton River below Highway 287. The hydrograph reflects variable inflows from multiple sources of water this makes it difficult to identify their relative contributions.

Spring Creek tends to gain water from its uppermost reaches to the confluence. The three gages (Upper, Middle and Lower Spring Creek) characterize gains and losses on the creek. Irrigation diversions do occur on the creek and are reflected in the hydrographs of Middle and Lower Spring Creek sites (Appendix D). Hydrographs of daily average flows and study period averages illustrate seasonal peaks and baseflow periods at the Upper Spring Creek Gage (Figure 20).

The average primary peak appears to occur in May and June because high flows in 2011 have skewed the average. However, in most years the primary peak occurs in March and April. Peak flows are subtle at this location with an average peak of 6 cfs and low flows typically less than 2 cfs.

The source of water for Spring Creek is the same as the Teton River below Hwy 287, therefore the causes and patterns of peak flows are the same. Spring Creek’s flow rises from January until March resulting in a primary peak flow in March. Observed wintertime increases are a result of increases in groundwater levels due to flows entering the losing Teton River Springhill Reach (November to March). As upstream demands increase in April water is diverted away from the Springhill Reach and flow recedes in Spring Creek.

The second peak typically begins in early June coinciding with high flows on the Upper River. The source of water for the second peak results from increased seepage in the upper Teton River above the Springhill Reach, precipitation, groundwater discharge and irrigation return flow. The secondary peak typically begins to recede in mid-June with low flow (baseflow) conditions observed from August to January.

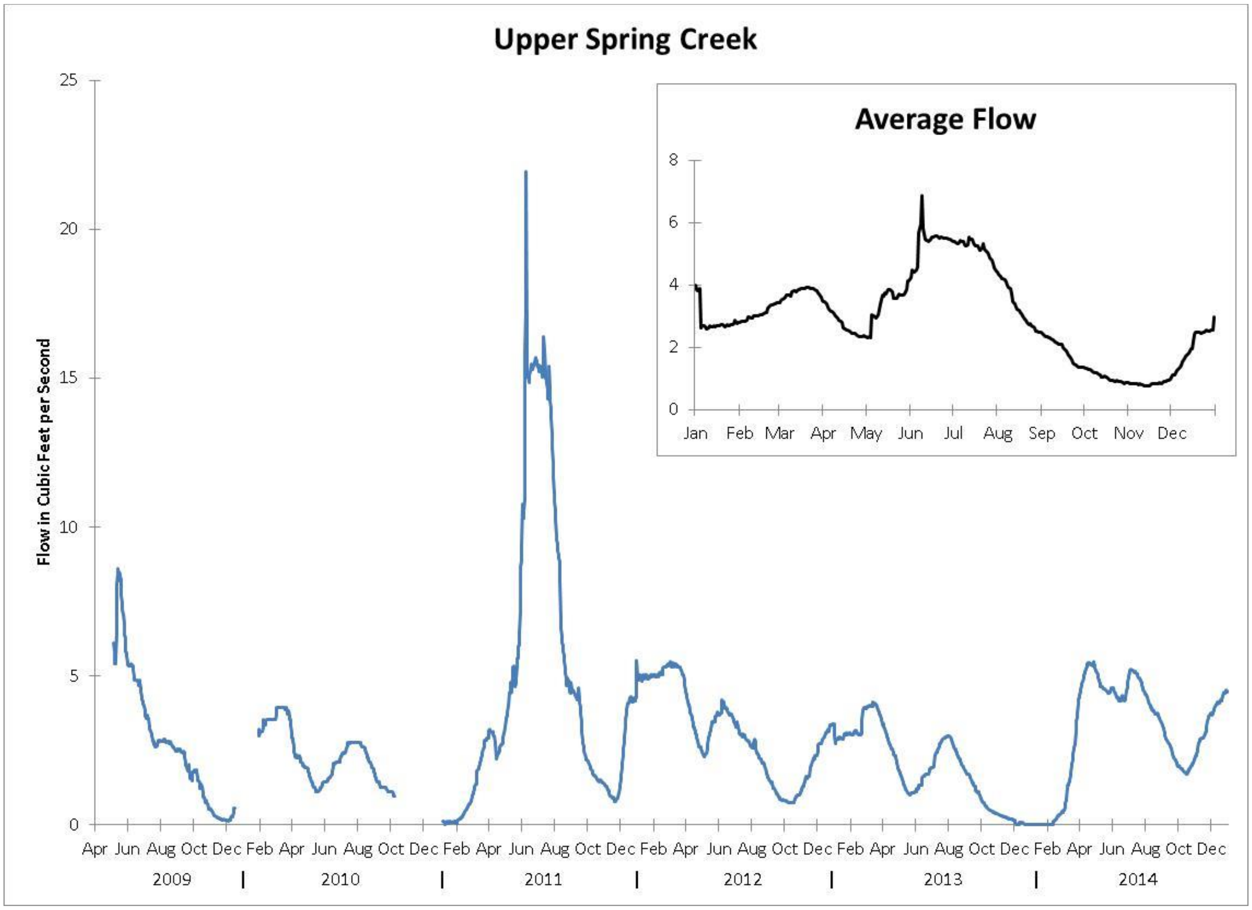


Figure 19: Hydrograph of Upper Spring Creek and period of record average flow (2009-2014).

McDonald Creek

McDonald Creek is a groundwater fed stream that plays an important role in the water supply of the Teton River. During the majority of the irrigation season, McDonald Creek contributes nearly 100% of the Teton River's flow below their confluence. A hydrograph of daily average flow and study period averages at this site illustrate seasonal peaks and baseflow periods (Figure 20).

McDonald Creek originates in the McDonald Swamp approximately nine miles above the gage. The hydrograph of McDonald Creek contains two peaks, a common theme among groundwater fed tributaries in the watershed. The primary peak occurs in March, and secondary peak in May and June. The connection between surface water losses from the Teton River and flows from McDonald Creek have been documented by Wylie (1991) and have been discussed in the Previous Investigations and Water Management sections of the report.

A connection between the management of flow in the Teton River and flow in McDonald Creek has not been established. The hydrograph appears to mimic the Teton River below South Fork during high flows of May/June. However, the reason for increasing flow in February and March is unclear. Prairie snowmelt (Chinook winds), precipitation, and water management are potential contributors as well as unknown groundwater relationships. McDonald Creek is up-gradient of the Springhill Reach and is not affected by the occurrence of water in that reach.

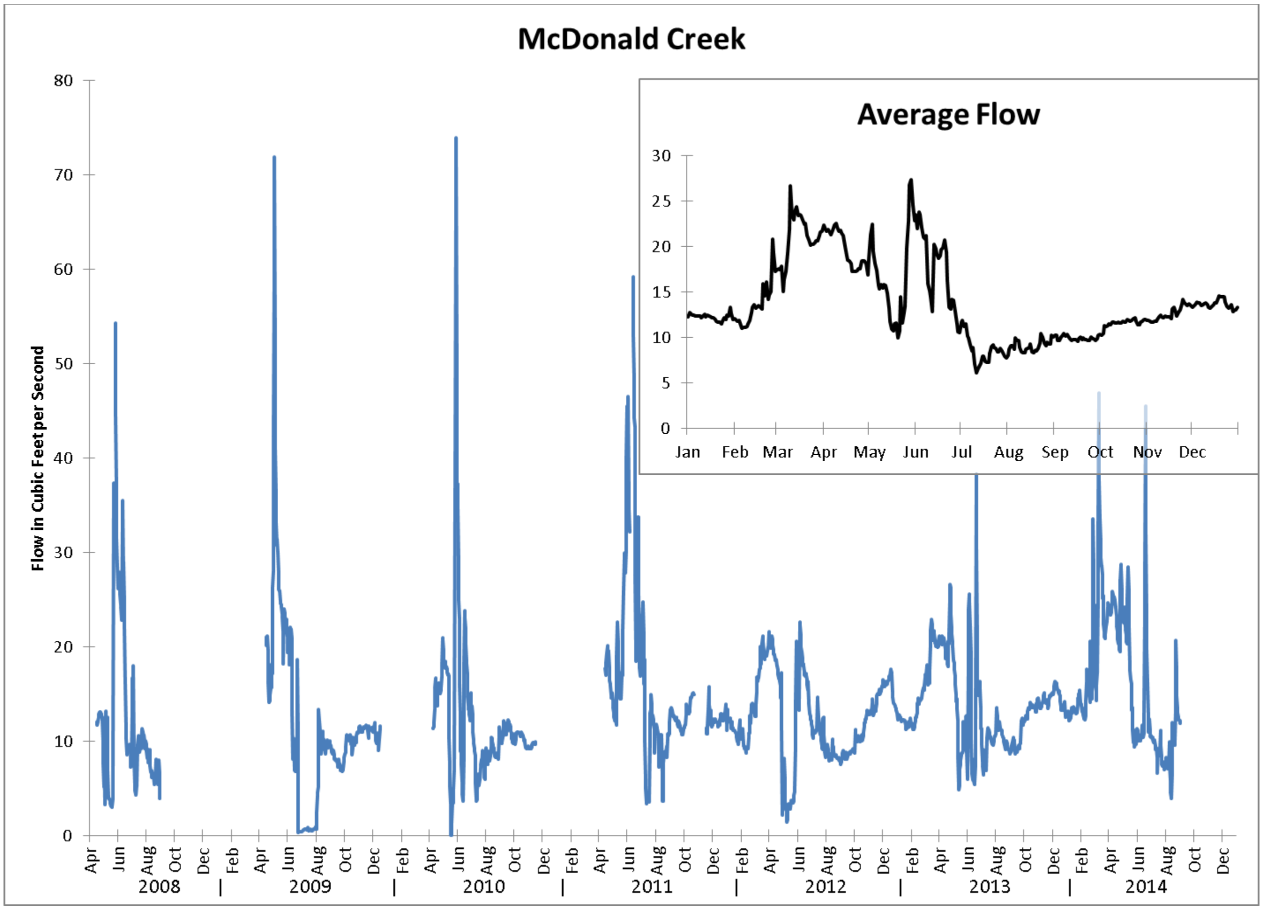


Figure 20: Hydrograph of McDonald Creek and period of record average flow (2008-2014).

Groundwater and Surface Water Exchange: What goes down (underground) must come up (downstream)

Exchanges between surface water and groundwater in the Teton watershed are dynamic and range from natural processes of exchange (e.g. surface water seepage to the subsurface or groundwater discharge to a stream) to human-influenced processes (e.g. seepage from an irrigation ditch, field, and/or irrigation return flow). Groundwater interacts with river systems on multiple scales from small interactions within the streambed to large regional areas of discharge. These interactions can change with time (e.g. during spring runoff) or can be affected by prolonged drought or diversions.

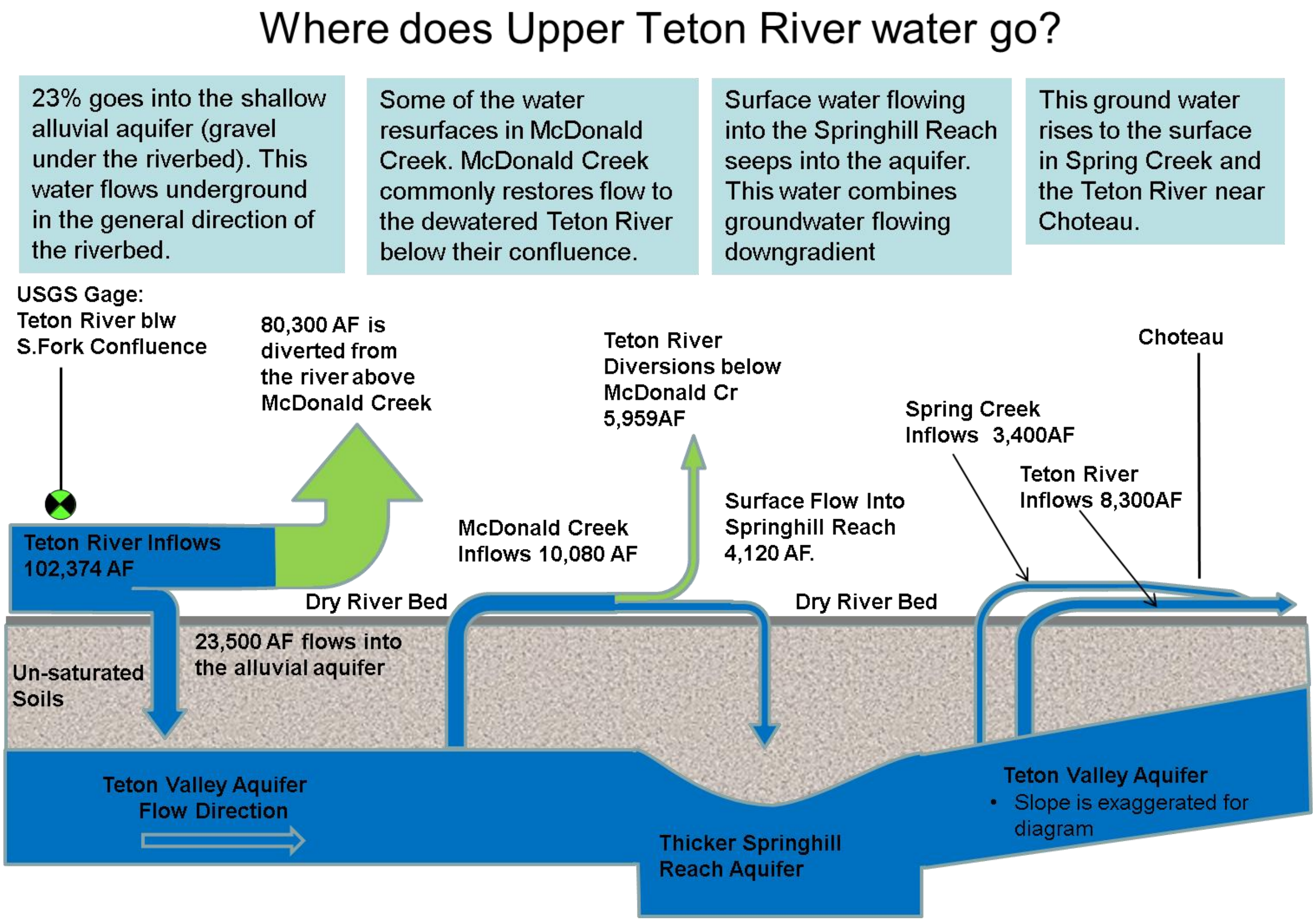
Natural exchanges between the Teton River and the shallow aquifer have been documented (near the mountains to the Bynum diversion) by Nimick and Others (1983), Wylie (1990), and TNC (1991-1995). In general, these studies show that the Teton River loses significant quantities of water to the shallow aquifer over this stretch. The "lost" water sustains local swamps, shallow groundwater levels, springs and spring creeks, and the municipal water supply of Choteau. Patton (1990) discussed the loss of Teton River water in the Springhill Reach as well as groundwater discharge to the Spring Creek and the Teton River in the Choteau area.

Patton (1990) and Madison (2004) discuss human influences on exchange on the Burton Bench. The influences include irrigation seepage, groundwater recharge, and groundwater discharge. The overarching theme of both investigations is that groundwater is artificially high on the Burton Bench due to irrigation, resulting in increased groundwater storage and ultimately discharge from the Burton Bench Aquifer. Nicklin (2009) discussed the effects of irrigation diversions on the shallow aquifer of the Teton River in the Springhill Reach.

Upper Teton River (Choteau to the Mountains)

A conceptual model of surface water and groundwater exchange on the Upper Teton River is presented in Figure 21. The Teton Valley Aquifer is relatively thin (approximately 20 ft) and composed of permeable sands and gravels that are underlain and laterally constrained by low-permeability bedrock. Groundwater within the Teton Valley Aquifer generally flows down gradient (downstream), parallel to the Teton River.

Exchange between surface water and groundwater depends on the potential head difference (i.e. elevation) between surface water and groundwater and the conductivity of the streambed material. In the Upper Teton River exchange is primarily dependent on the thickness of gravels and the elevation of the land surface. Generally, thicker gravels equate to a deeper water table which causes surface water loss to groundwater. Thinning gravels and depressions in the land surface are areas of groundwater discharge.


Where does Upper Teton River water go?

23% goes into the shallow alluvial aquifer (gravel under the riverbed). This water flows underground in the general direction of the riverbed.

Some of the water resurfaces in McDonald Creek. McDonald Creek commonly restores flow to the dewatered Teton River below their confluence.

Surface water flowing into the Springhill Reach seeps into the aquifer. This water combines groundwater flowing downgradient

This ground water rises to the surface in Spring Creek and the Teton River near Choteau.

Figure 21: Conceptual model of surface water and groundwater exchange on the Upper Teton River[9].

As the Teton River exits the mountains, significant volumes (23%) of water seep into the shallow aquifer above the major Upper Teton River diversions. Comparison of recorded flows at the upstream USGS gage (Teton River below the S. Fork) and summation of diversions indicate that the volume of water diverted is less [10] (21%) than the volume of water measured at the

---

[9] Streamflows and diversions were calculated from USGS and DNRC gages and water commissioner records respectively. Seepage was calculated in the upper reach using Nature Conservancy data and in the Springhill reach by subtracting summed water commissioner records from observed streamflows. All flow into the Springhill reach is assumed to seep to the aquifer.

[10] Note USGS stream gage data and diversion data suggest a loss of 21% or 22,000 acre-feet. This provides a secondary estimate of seepage to compare to the volume of water measured by The Nature Conservancy.

USGS gage. This indicates that the unaccounted for water seeps into the shallow aquifer prior to reaching the diversions. Diversions typically dry the Teton River above McDonald Creek.

Discharge of groundwater has been documented to sustain the swamps of the Upper River and flows in McDonald Creek. McDonald Creek's consistent flows restart the normally dry Teton River, providing an important water source to downstream water users. Surface water flowing in the Teton River (below the McDonald Creek confluence) is either diverted (April – November) or it enters the Springhill Reach (November to March). Water entering the Springhill Reach ultimately seeps into the local aquifer which is thicker in this area than other reaches of the river.

Groundwater in the Springhill Reach is derived from multiple sources (Patton 1990). The first source is groundwater flowing downgradient though the Teton Valley Aquifer, the second is intermittent surface water flow in the Springhill Reach. Recharge into the Springhill Reach and the Teton Valley Aquifer is dependent on water supply and water demands.

Downstream the aquifer thins again and groundwater begins to discharge to depressions in the land surface forming Spring Creek and restarting the Teton River. The Teton Valley Aquifer ultimately pinches out near the Highway 221 Bridge, at this point all water within the aquifer is assumed to discharge to the Teton River.

Hydraulic Connection

Surface water and groundwater are connected throughout the Teton Watershed. Groundwater in the Teton Valley Aquifer is recharged by the Teton River seepage, precipitation and up-gradient groundwater inflows. Surface water flows in the Choteau area (Teton River near Choteau and Spring Creek) depend on groundwater discharging from the Teton Valley Aquifer. The connection between flows in the Choteau area and the Upper River is not always easily recognized since the Teton River is commonly dry in the Springhill Reach and water management on the Upper River is complex.

Hydrographs of smaller groundwater-dependent streams and the Upper Teton River vary greatly in magnitude and this makes comparison difficult. Hydrographs were "normalized" and plotted as weekly Z-scores (standard deviations above and below the mean) to illustrate connections between: the Upper River, spring creeks, groundwater levels and precipitation (Figure 22). See Appendix F for more information about Z-scores.

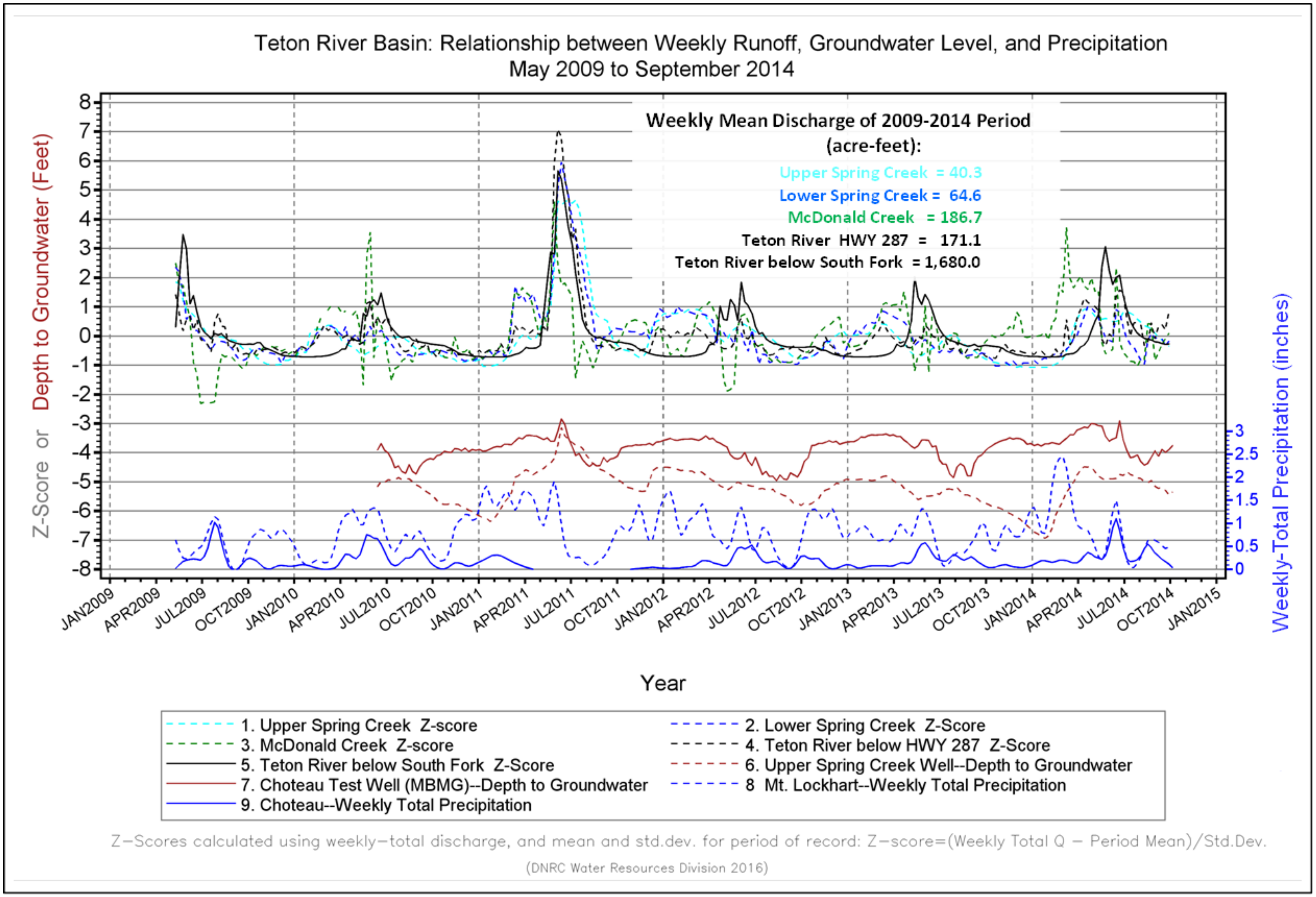


Figure 22: Hydrographs (Z-scores) of Upper Teton River, Tributaries and groundwater measurements. Note: winter data was estimated for 2008 and 2009 for Teton River below Hwy 287, Upper Spring Creek, Lower Spring Creek, and McDonald Creek. Winter data was estimated for Teton River below the S. Fork for all years.

The messages illustrated by the figure are:

1. Even though the Upper Teton River is not connected via surface water to Spring Creek, McDonald Creek, and Teton River near Choteau, a pattern of elevated flows occurring at the same time (May and June) is evident between the water bodies. This suggests that downstream groundwater fed streams are dependent on the Upper Teton River seeping more water to the shallow aquifer during high flow periods (spring snowmelt).
2. Flows increase on Upper Spring Creek, Lower Spring Creek, and Teton River below Hwy 287 from December to March. This increase is independent from flows on the Teton River at the USGS gage (below South Fork) and is related to water flowing into Springhill Reach.
3. Other confounding factors, (diversions, precipitation (plotted), prairie snowmelt, and irrigation return flows) partially obscure these relationships. However, looking at the five years of data presented, a repetitive pattern is evident.

A Closer Look at Surface Water/Groundwater Connections

Upper Teton River Exchange

The Teton River has been shown to lose significant quantities of water to the shallow aquifer near the mountains. The hydrograph (Figure 23) of the Teton River and nearby well (NCW 9) shows that the elevation of groundwater is related to the amount of water in the Teton River.

The data implies that when more water is in the river, more water is lost to alluvium, thus groundwater levels rise. The presence of ice jam during the winter of 1989 and the corresponding rise in groundwater further suggest the connection between the river and shallow aquifer.

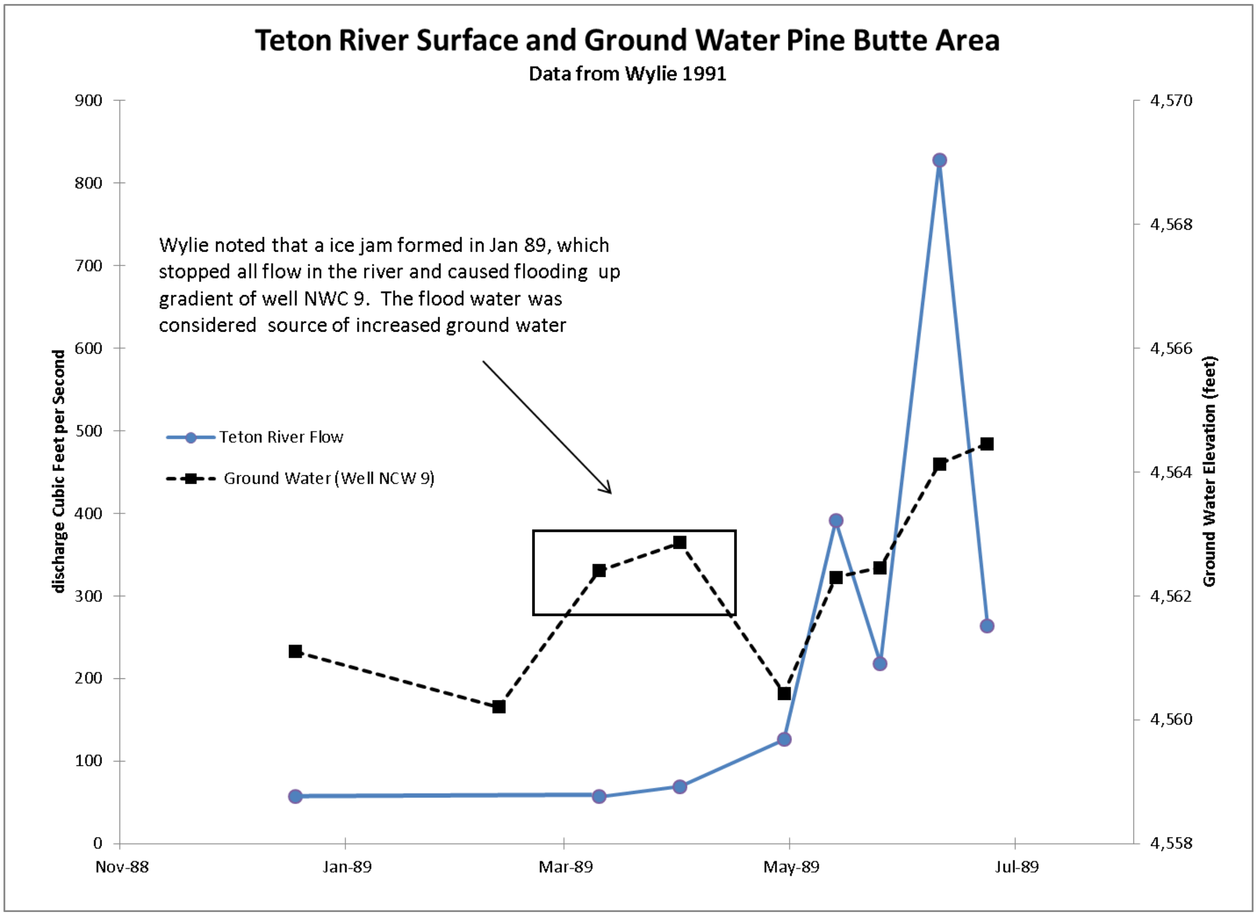


Figure 23: Upper Teton groundwater and surface water measurements Groundwater levels are related to the volume of water in the Teton River. Note: The data is derived from Wylie(1991).

Choteau Area Groundwater Exchange

Hydrographs of the Upper Spring Creek site and a nearby (100 yards) shallow well indicated a strong correlation between groundwater elevation and flow in Spring Creek (Figure 24). Increases and decreases in groundwater correspond to changes in flows with changes in groundwater preceding changes in streamflows by approximately 2 to 5 days. This lag is expected since flows in Spring Creek are dependent on groundwater discharge.

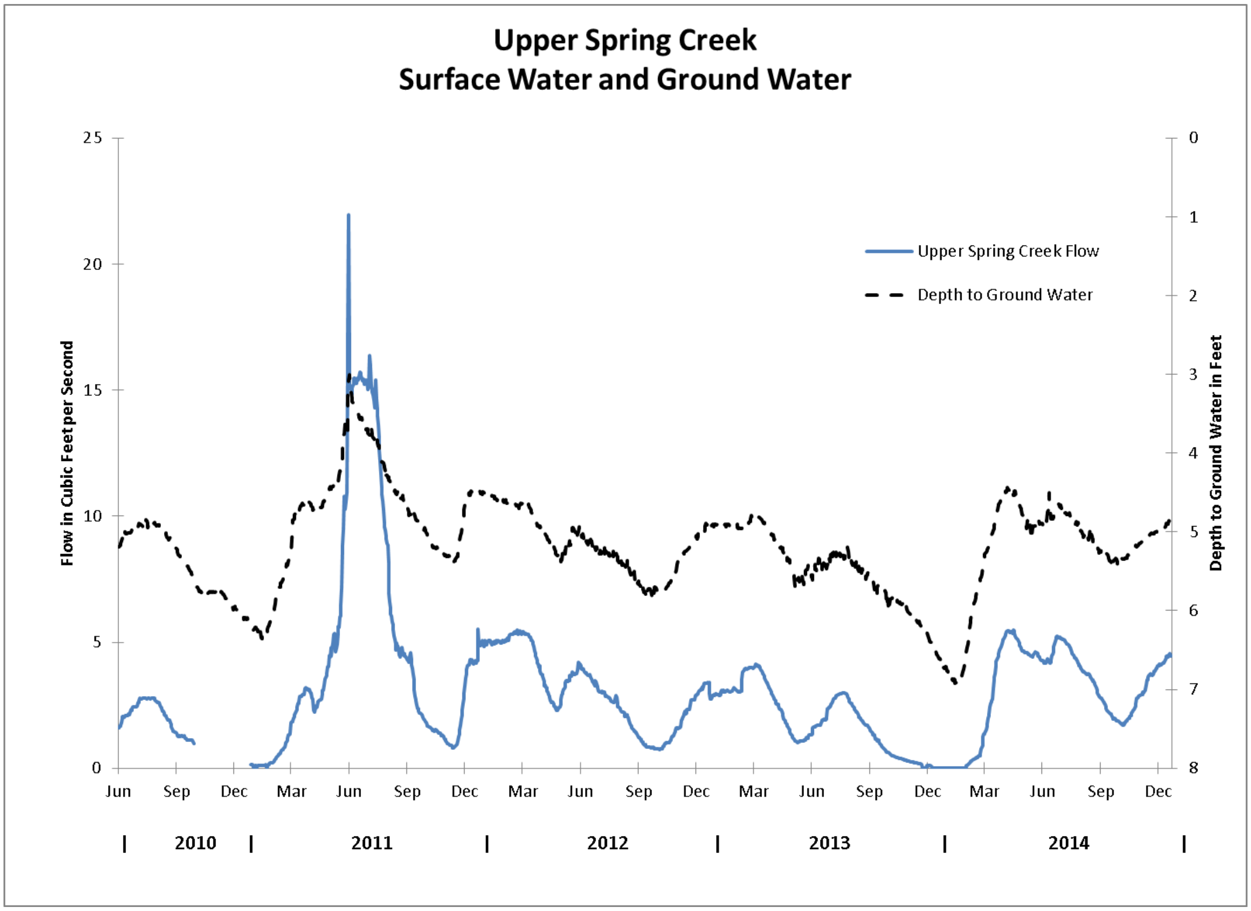


Figure 24: Upper Spring Creek groundwater and surface water measurements. In general groundwater levels start to increase 2-5 days before flow in Spring Creek starts to increase.

The relationship between groundwater elevation, in the City of Choteau test well (MBMG Statewide Monitoring Network, GWIC ID 78294) and flow downgradient on the Teton River (below Hwy 287) (Figure 25) is not as clear as it is on Upper Spring Creek. Because flow on the Teton River are influenced by irrigation returns and local precipitation, weekly average values that are less erratic are presented to assist with comparison of trends.

Groundwater in the City of Choteau test well increases from September to March and decreases through the summer months. Streamflow fluctuations in the Teton River follow the same general pattern as groundwater with some exceptions. Increases in groundwater precede increases in streamflows by more than a month in some instances. The lag time may occur in part due to the distance (1.5 miles) between the well and gage. The surface water and groundwater relationship on the Teton River is similar to Spring Creek because the source of water is the same.

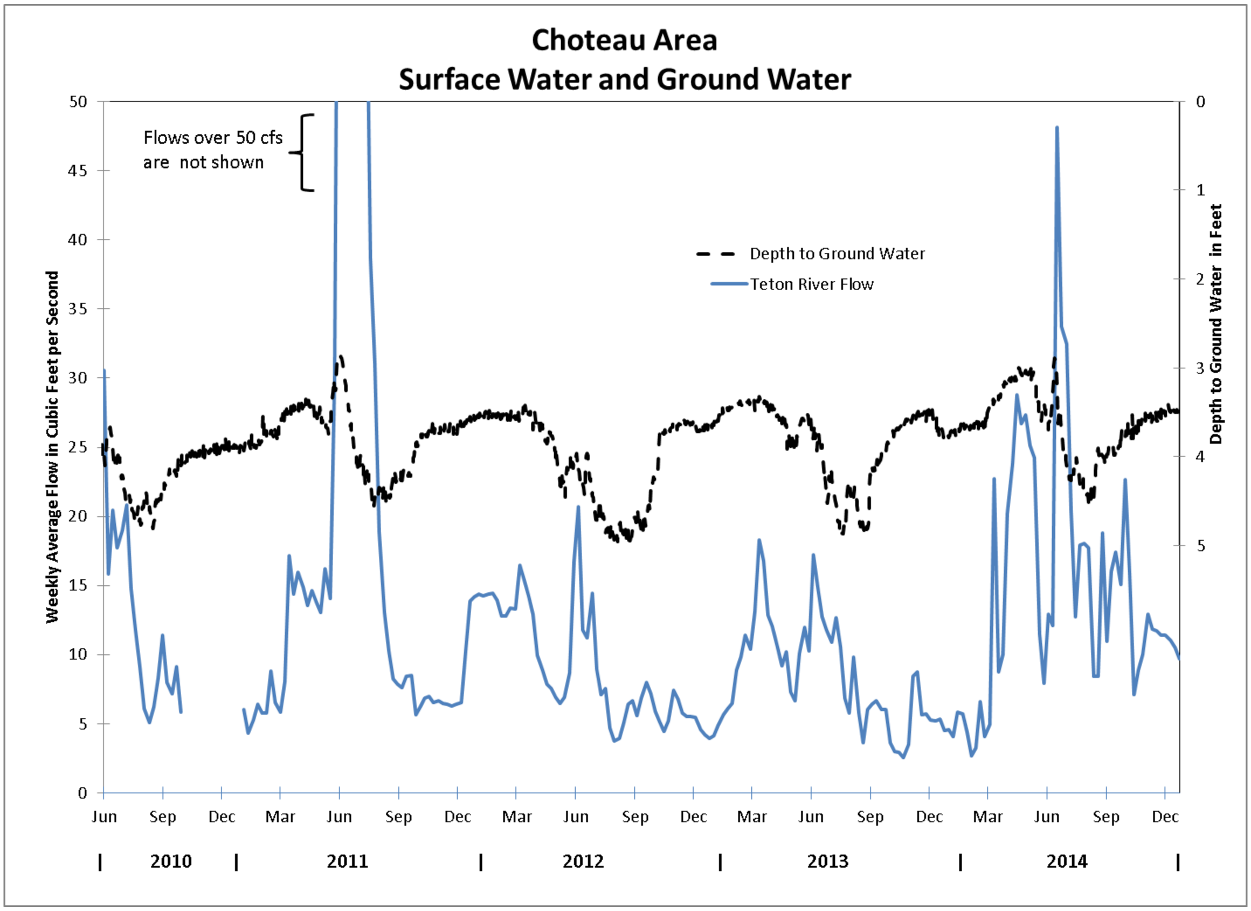


Figure 25: Choteau area groundwater and surface water measurements. Note: streamflow values area presented as weekly averages to make trend analysis easier.

Lower Teton River Groundwater Exchange

Examination of exchange on the Lower Teton River below Highway 221 to Loma is limited to the Dent Bridge to Loma area. DNRC staff measured eight groundwater wells during 2008 and 2009 in the Dent Bridge to Buck Bridge area and MBMG data is used for a monitoring well located near Loma. DNRC monitoring included a continuous recorder in Teton Well 2. Groundwater measurements made by DNRC staff and a map of well locations can be found in Appendix D.

The geology of the Lower Teton River consists of a thin unconsolidated aquifer bounded by low permeability bedrock and is similar to that found upstream. The primary source of groundwater in the Lower River Aquifer is assumed to be seepage from the Teton River. Hydrographs of groundwater wells completed in the alluvium of Buck Bridge area (Figure 26) indicate that groundwater levels respond to the changing flows in the Teton River (higher flows equal higher groundwater and vice-versa).

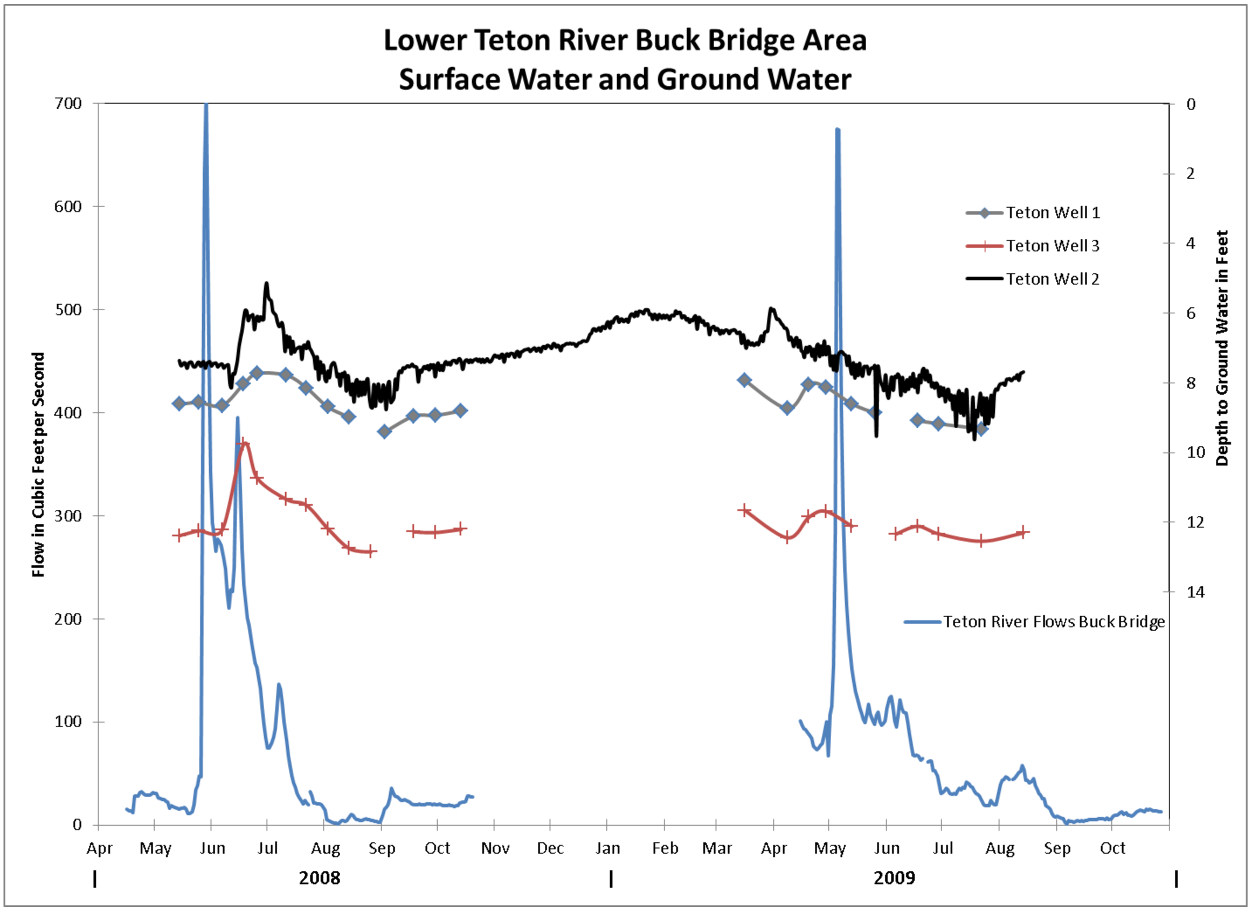


Figure 26: Lower Teton River, Buck Bridge area groundwater and surface water measurements

Downstream near Loma, very similar relationship exists (Figure 27) between flow measured at the USGS gage and groundwater level at a nearby well (GWIC ID 155439). Groundwater levels rise during elevated flow conditions and fall under low flow conditions.

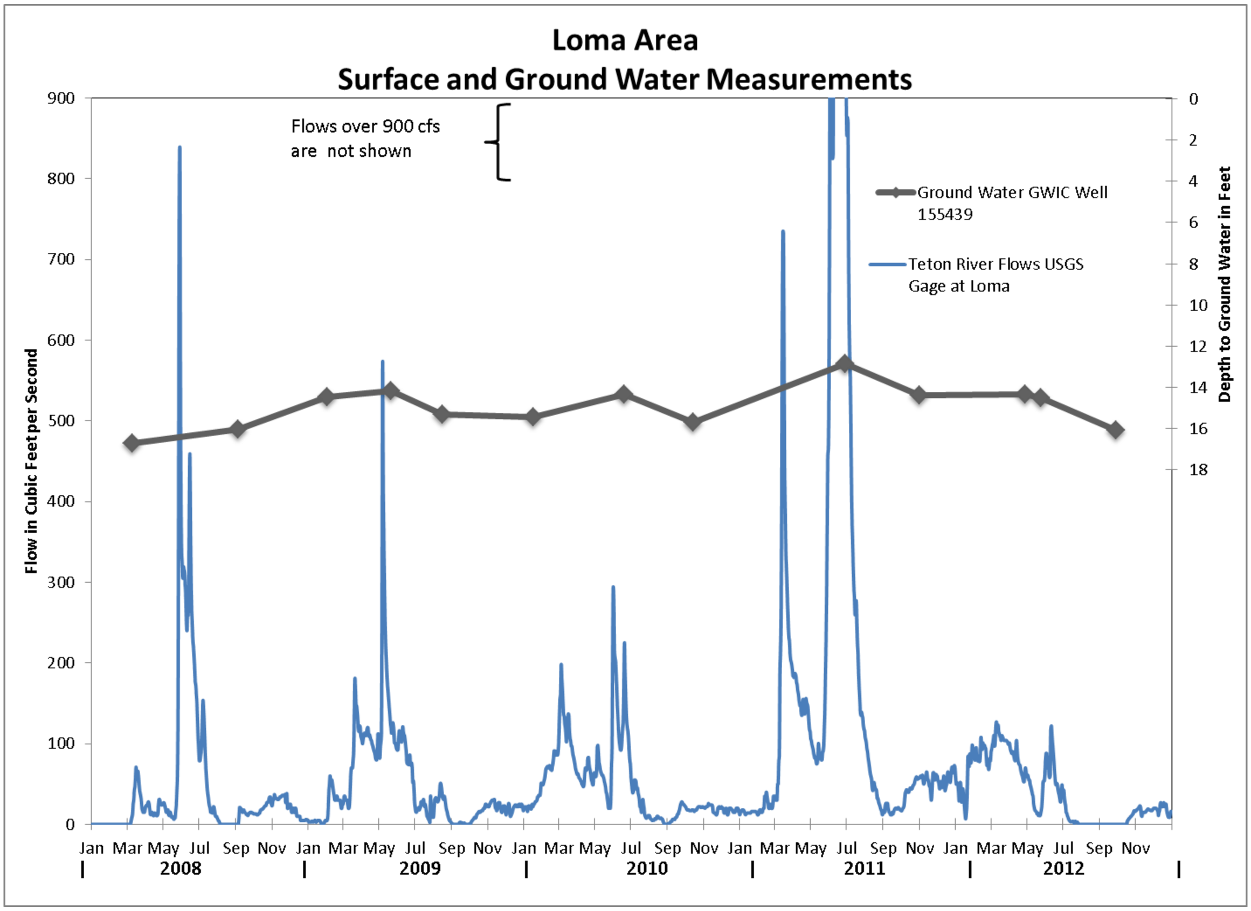


Figure 27: Lower Teton River, Loma area groundwater and surface water measurements.

Water Use Hydrology

The beneficial use of water in the Teton Watershed includes irrigated agriculture, stock, domestic, municipal, and fish and wildlife. DNRC inventory of water use (DNRC 2015) has shown that irrigated agriculture is the largest consumptive use of water in Montana. This report will only inventory irrigated agriculture due to the minor volume of water estimated to be consumed by other uses. DNRC (2015) estimated that combined, public water supply and domestic consume 355 acre feet and stock consume 784 acre feet in the Teton Watershed per year.

Withdrawals and storage of water for irrigation as well as associated consumption and return flow play a significant role in the hydrology of the Teton watershed. Flood, sprinkler, and center pivot irrigation of small grains (barley and wheat) and hay (alfalfa and grass) (U.S Department of Agriculture 2012) dominate consumptive water use in the Teton watershed. The most common method of irrigation in the watershed is flood irrigation (68%), followed by center pivot irrigation (27%) and the remainder is other forms of sprinkler irrigation.

Irrigated Acres

The purpose of identifying irrigated land was to get a representative, recent estimate that could be used with other information to quantify the volume of water consumed during the study period. Estimates of irrigated acres in the watershed range from 48,000 acres [11] (Montana Department of Revenue FLU 2012), 61,610 acres (USGS 2000), and 73,916 acres (WRS 1962-64). DNRC estimated irrigated acreage using a method based on historic and current information, aerial photos, and Landsat imagery, (the methodology is described in Appendix B &C). Irrigated acres were estimated for the year 2007, which was drier than average, and are summarized by sub-watershed in Table 3.

Location	Irrigated Acres
Upper Teton River (All users above Choteau including McDonald Creek)	51,523
Teton River below Choteau (Including Spring	3,286
Muddy Cr (Private and Brady Irr Co)	12,648
Deep Creek	9,393
Total	76,850

Table 3: DNRC identified irrigated acres in the Teton watershed by location.

Of the 76,850 acres of irrigated land identified (Figure 1), the bulk (67% or 51,523 acres) is located on the Burton Bench, Muddy Creek drainage, or along the Teton River above Choteau. These acres are supplied with water from the Upper Teton River. Irrigation along the Teton River below Choteau totals 4% or 3,286 acres and are supplied with water from the Teton River or Spring Creek. The remaining acres are located in the Deep Creek drainage (12% or 9,393 acres) or are located in the Muddy Creek/Pondera drainage (17% or 12,648 acres) and are irrigated with Muddy Creek water.

The Brady Irrigation Company exports Muddy Creek and Teton River water into the Pondera Coulee (Marias River) drainage for irrigation in the Brady area. Muddy Creek supplies the bulk of irrigation water (~75%)[12] for the Brady area, with Teton Co-Operative Reservoir Company water supplementing supplies. Storage of water in Brady, Round, and Eyraud lakes (3,300 acre-feet combined) play an important role in the Brady Irrigation Company's operations. Brady irrigation acres and consumption are split according to the water supply source (Upper Teton or Muddy Creek).

The Greenfield Irrigation District (GID) imports Sun River water into the Teton Watershed to irrigate approximately 6,972 acres of land in the Freezout Lake area. GID acres are excluded

---

[11] FLU data does not include irrigated pasture.

[12] Personal communication with Brady Irrigation District personnel.

from analysis because the source of water is imported and most return flow evaporates from Freezout Lake.

Estimation of Irrigation Diversions

Water commissioner[13] irrigation diversion measurements were tallied over the study period for the 25 Upper Teton water users adjudicated in the 1905 Perry v. Beattie Decree. Irrigation within the decree accounts for 67% of irrigated land in the watershed.

Using these measured diversions, a diversion rate was calculated by dividing irrigated acres by the diversion volume. Diversions outside of the Perry v. Beattie Decree were estimated using the calculated decreed diversion rate (irrigated acres * diversion rate (acre-feet)). The use of measured diversion rates (to estimate non-decreed diversions) was deemed to be more accurate than using literature reported values from the Soil Conservation Service.

The alternative to estimating non-decreed diversions (apart from measuring each one) is using estimation techniques from the Soil Conservation Service (SCS, now known as Natural Resource Conservation Service). SCS provides a method for estimating irrigation diversions based on irrigation and conveyance system efficiency. See Appendix E for SCS diversion estimations for Teton and Chouteau counties.

Decreed Diversions

The amounts of water available to divert in 2008 and 2011 were nearly double that of an average year. With two years of strong water supplies, the average diversions over the study period may not reflect the typical diversion year. However, the fact remains that irrigation diverts most of the water supply every year regardless of the available supply.

Irrigation diversions also include storage diversions which occur during the non-irrigation and irrigation seasons. In the larger storage projects (Bynum) water diverted one year when it is available may be used another year when water supplies are lower.

Annual Diversions

Over the study period, decreed water users diverted an average of 86,275 acre-feet of water annually with 76,754 acre-feet during the irrigation season (Figure 28 & Table 4). Study period diversion averages are skewed by large diversions in 2008 to Bynum Reservoir. Water commissioner data for the high flow period (May 23 -June 23, 2008) was found to exceed flows

---

[13] Monthly water commissioner records (60) were obtained from the Teton County Court house for the years 2008-2012. Records were entered into Microsoft Excel for analysis.

measured at the USGS gage and reported ditch capacities. The data were adjusted by DNRC staff to conform to these limitations using ditch capacities (BOR Bynum Diversion Study 2007), tallied diversions (excluding Bynum) during that time period, and USGS records.

The range of observed diverted volumes shows that irrigation water use is limited by the supply, and when excess water is available it is readily used. On average, 1.67 acre-feet of water was diverted to each acre of irrigated land within the decreed area of the Upper Teton River. The estimated Upper Teton diversion rate is lower than estimates for the Sun River (which has approximately four times the Upper Teton water supply, but only irrigates approximately 112,000 acres) to the south at 3.2 acre-feet per acre (DNRC 2012) further reinforcing that irrigation diversions are limited by supplies in the Teton Watershed.

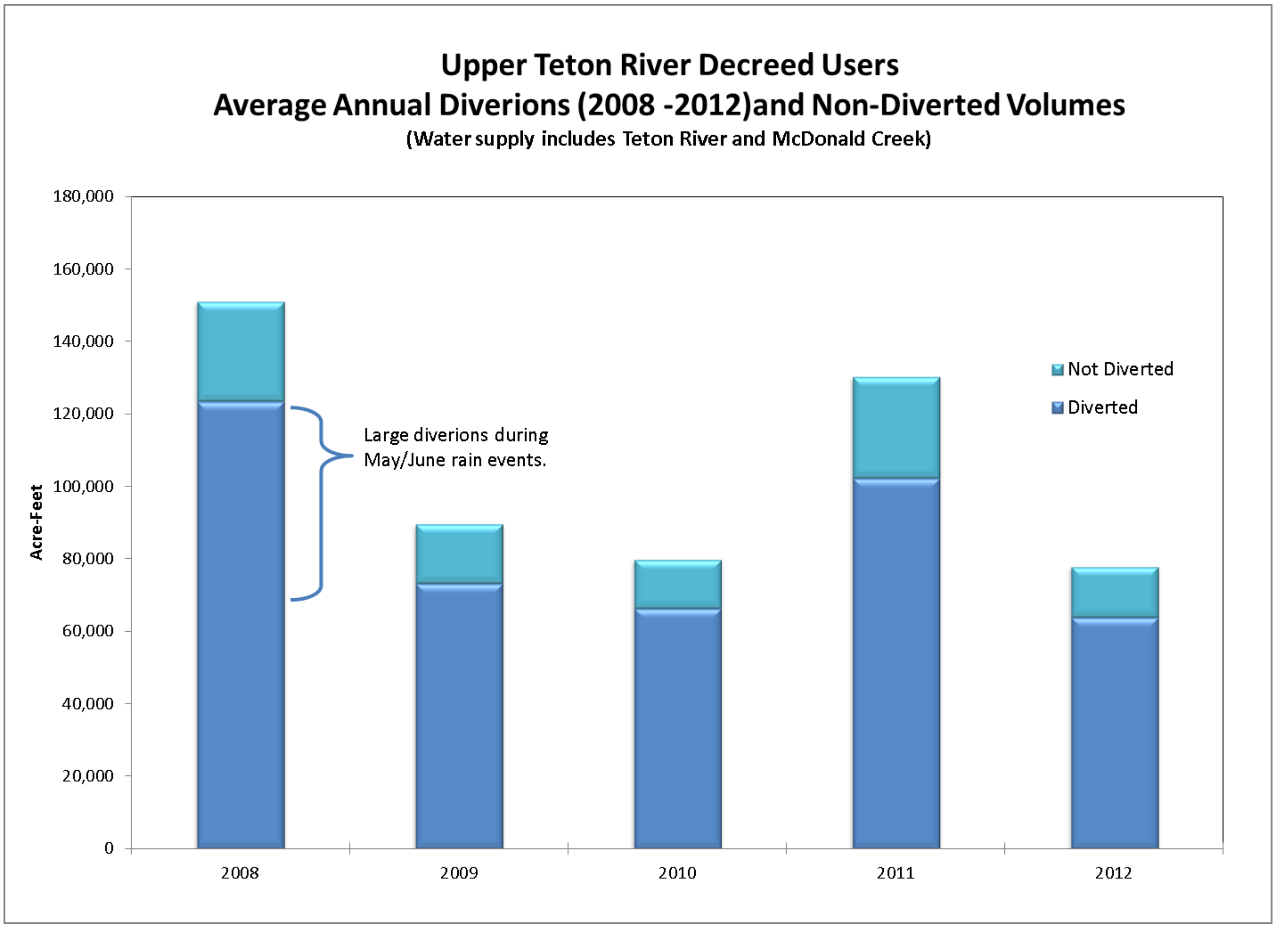


Figure 28: Average annual Upper Teton diversions over the study period.

When compared to inflows (Teton River below South Fork gage and McDonald Creek), water diversions are 24% less than the annual water supply[14]. The average annual volume of water not diverted during the study was 26,823 acre-feet. The un-diverted volume nearly doubled (43,300 acre-feet) over the average during the highest water supply year of 2011.

The Teton River has been documented to lose significant volumes of water to the aquifer Nimick (1983), Wylie (1991), and TNC (1991-1995). It is likely that Upper River irrigators do not have access to the full volume of water that passes by the South Fork Gage and the majority of the non-diverted volume is actually lost to the groundwater and not available for diversion in the upper river.

During the late fall and early winter, some Teton River water is not diverted and flows into the losing Springhill Reach. However, this water is primarily derived from McDonald Creek inflows.

Monthly Diversions

Looking at study period average monthly diversions (Figure 29) the pattern of use and priority becomes evident[15]. During the winter months when water supplies/demands are low, water is diverted for storage primarily to Bynum Reservoir. When water supplies become more abundant and the irrigation season starts, water is diverted to all the irrigation companies and to private users, primarily for irrigation.

As the irrigation season progresses irrigation/crop demands increase and water supplies dwindle. The bulk of the water goes to senior irrigation companies (Eldorado & Teton Canal) and senior private users. In the fall as crop/irrigation demands decrease, the water flows again to junior irrigators and back into reservoirs for building winter storage levels. As previously mentioned high flows in 2008 have skewed the May and June volumes diverted to Teton Co-Operative Reservoir Co. (Bynum).

---

[14] Annual Flow is estimated for the USGS gage Teton River below South Fork, using historical flows. Winter baseflows are estimated at 15,742 AF.

[15] See Figure 6 for reference.

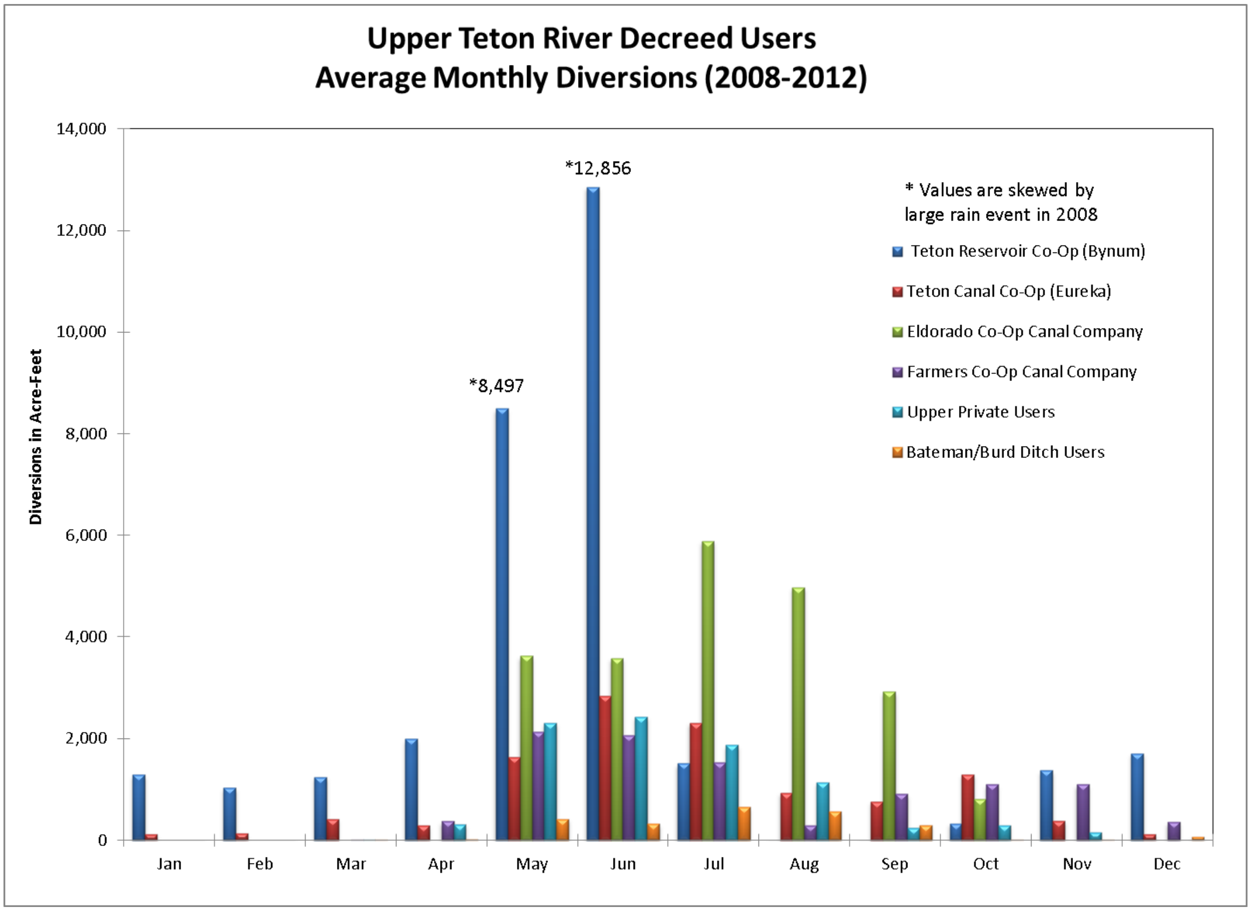


Figure 29: Average monthly Upper Teton Diversions over the study period.

Non-Decreed Diversions

Water diversions outside of the decree were estimated using the average diversion rate of 1.67 acre-feet per acre. Diversion estimates appear in Table 4. Diversions outside of the decree are estimated to be 42,297 acre-feet of water. The Muddy Creek drainage (including Brady Irr Co lands, located near Brady) contains the largest amount of irrigated acres and therefore, has the largest diverted volume outside of the decree.

Location	Irrigated Acres	Diverted Volume (Acre-Feet)
Upper Teton River (All users above Choteau including McDonald Creek)	51,523	86,275
Teton River below Choteau (Including Spring Creek)	3,286	5,488
Muddy Cr (Private and Brady Irr Co)	12,648	21,123
Deep Creek	9,393	15,686
Total	76,850	128,572

Table 4: Diversion estimates for areas of the Teton watershed and watershed totals.

Estimation of Irrigation Water Consumption

Water consumption or (ET) evapotranspiration was estimated for irrigated lands using a remote sensing data set that was available for the 2007 irrigation season[16]. The 2007 data set gives a reasonable approximation of the typical amount of water that might be consumed by irrigated crops and the overall level of irrigation service for the watershed (Table 5). In the Teton, the 2007 water year was slightly drier than the driest water year (2010) within the study period. It is expected that ET (much like diversions) is dependent on water supply and would increase during years of greater water supplies. Appendix C describes the remote sensing method in more detail.

Irrigated crops are estimated to consume 55,952 acre feet of water in the Teton watershed (including Teton water consumed by irrigation in the Brady area). This is roughly half of the water supply entering the watershed. Irrigated lands in the watershed were estimated to consume on average 0.70 acre-feet of irrigation water per acre. Irrigation water consumption in the Teton watershed had previously been estimated at 63,900 acre-feet by the Cannon and Johnson (2004).

Location	Irrigated Acres	Diverted Volume (Acre-Feet)	Consumption (ET) (Acre-Feet)
Upper Teton River (All users above Choteau including McDonald Creek)	51,523	86,275	39,164
Teton River below Choteau (Including Spring Creek)	3,286	5,488	2,272
Muddy Cr (Private and Brady Irr Co)	12,648	21,123	7,733
Deep Creek	9,393	15,686	6,783
Total	76,850	128,572	55,952

Table 5: Estimated irrigation consumption and diversions by drainage.

Irrigation consumption was highest in Upper Teton River decreed land with 39,164 acre feet of water consumed. Outside the decree, the largest consumption occurred in Muddy Creek (6,783 acre-feet) and the lowest on the Teton River below Choteau (2,272 acre-feet).

Irrigation Efficiencies

Irrigation efficiency was calculated by dividing the consumed volume by the diverted volume. On average, approximately 45% of the diverted water is consumed by crops. The remaining 55% is not consumed or “lost” during conveyance in ditches and in the field during irrigation. Much of this “lost” water will eventually return to the system as return flow. Return flow is

---

[16] The Montana Water Supply Initiative completed by DNRC in 2015 used the 2007 Irrigated Land ET data set to estimate water use for the State of Montana. In much of Montana, 2007 benefited from good spring and early summer moisture but the remainder of the summer and fall was dry.

commonly utilized by irrigators (especially surface returns); this reuse of water allows irrigators to stretch water resources, improving overall system efficiency.

Conveyance efficiency (ditch loss) on the Burton Bench was reported by Patton (1990) to be 72% for Farmers Co-op and 78% for the Eldorado Co-op; Madison (2004) estimated a 93% conveyance efficiency based on measurements made on the Eldorado canal. Alternatively SCS (USDA 1978) estimates much lower conveyance efficiencies of 35% for Teton County. Local water users estimated 50% conveyance efficiency for their operations.

For this study, field efficiency is estimated using:
- SCS Teton County flood irrigation efficiency estimate (55%) (USDA 1978)
- Wheel line sprinkler irrigation is considered by DNRC to be the same efficiency as flood (55%) (MCA 36.12.1902)
- Center Pivot irrigation field efficiency of 80% (Ashley and Others).

Using the average of these conveyance efficiencies of 66%, and a weighed watershed average field efficiency of 62% results in an average total irrigation efficiency for the watershed of 41% (0.66*0.62*100). It is likely that surface water and groundwater return flow from ditch and field losses are re-used (sometimes more than twice) by other irrigators. This re-use improves the overall irrigation efficiency of the watershed. Generally, one can imply that, total ditch losses in the watershed are similar to total field application losses.

Changes in Irrigation Efficiencies

Since the WRS was published in the early 1960's, irrigation technology has improved with the appearance of the center pivot sprinkler irrigation in the watershed. Typically, with flood and hand/wheel line sprinklers, the strategy is to irrigate the field in "sets" where water is applied to a portion of the field to saturate the entire soil profile. This method gives crops access to a larger volume of stored soil water, thus allowing crops to grow for a longer period of time between irrigations depending on how much water the soil can hold.

Two byproducts of saturating the soil profile are that excess water seeps down below the root zone into the shallow groundwater aquifer, and because large volumes of water are applied to cover the entire irrigation area excess water frequently runs off the field as surface flow. These two byproducts are the primary reasons why crops irrigated by flood/non-center pivot sprinkler consume about half the water applied to them.

Advantages of center pivot irrigation are automation, mobility, lower diversion requirement, and adjustable and uniform application. These advantages allow producers to change their irrigation strategy to meet the irrigation demand of the crop and typically water is applied at a rate to only fill the soil profile in the upper crop root zone. This method minimizes deep percolation and surface runoff leading to more efficient water use, consuming approximately 80 percent of the water applied to the field. Therefore, crops under center pivot irrigation are usually more productive and consume more water than flood irrigated fields.

The WRS survey (1962, 1964) maps of irrigated land show that no center pivots existed in the watershed at that time. As of 2012, FLU data indicates that 27% or 20,750 acres are irrigated with center pivots and the trend is that center pivot irrigation is increasing in Montana (USDA FRIS).

This change within the watershed is significant, and one can assume that 20,750 acres of land are now about 25% more efficient at the field scale than in the past. This is a positive shift for producers as productivity improves and labor is reduced. However, increased productivity can result in increased water consumption, and reductions to both surface water and groundwater return flow which can alter the hydrology of the watershed.

Level of Service

Full service irrigation is defined as supplying water to meet the full crop demand for the entire growing season. On a per acre basis, DNRC estimated water consumption values ranged from 1.46 to 0.27 acre-feet/acre in the watershed. The average consumption per acre in the watershed is 0.70 acre-feet/acre (about 8.4 inches).

The highest consumption/acre values are found with senior irrigation companies within the Upper Teton River Area who have the most reliable access to water and the lowest rates are found on the Lower Teton River below Choteau where water is scarcer.

Based on Irrigation Water Requirements (IWR) (USDA, 2003) and DNRC consumptive use rules, optimal crop growth in the Teton is not met at 0.70 acre feet/acre. The 2007 water year was drier than average, however the data suggests that a significant percentage of irrigated land in the Teton does not meet optimal crop growth likely because of lack of water supply.

Generalized Irrigation Water Use

Generalized Teton watershed irrigation water budget over the study period is illustrated in Figure 30 using the following data:

1) Estimate of water consumed by evapotranspiration (ET).
2) Study period average seasonal (Apr1 to Oct 31) gaged flows to show the occurrence/use of water.

3) Estimate of average diversions. Annual diversion numbers were used with the assumption that water diverted during the non-irrigation season to storage was used ultimately during the irrigation season. Averaging of diversion numbers is assumed to account for carryover storage.
4) Reservoir evaporation.
5) MBMG estimates of Burton Bench irrigation return flow.

The generalized seasonal irrigation water budget indicates that inflow is greater than outflow. The general story is that the vast majority of water from the Upper Teton River and McDonald Creek is diverted to service approximately 51,500 acres of irrigation. Irrigation consumes 45% of the diverted water, 5% evaporates, and yet only 11% of the unused water is estimated to return to the system. Groundwater storage, reservoir carryover storage, underestimation of ET, seepage in the Lower Teton River, and sub-irrigated land are all potential explanations for the unaccounted for non-consumed water.

Irrigation in the Deep Creek drainage consumes roughly 37% of the volume generated. However, measured flows out of the drainage were only 42% of the water generated. This indicates that other less understood losses or underestimation of irrigation consumption account for the 21% difference.

Over the study period, the Teton River from Dutton to Loma either lost large volumes of water (up to 15, 000 acre-feet), outflow was equal to inflow, or the reach gained modest volumes (1,700 acre-feet) depending on the year. The consumption of 2,272 acre-feet from irrigated agriculture does not correlate well with the observed large losses during some years. The losses and gains identified above suggest that the hydrology of Lower River is not fully understood. Likely sources of the losses could be a combination of underestimation of irrigation ET, riparian ET, other withdrawals or losses to the groundwater.

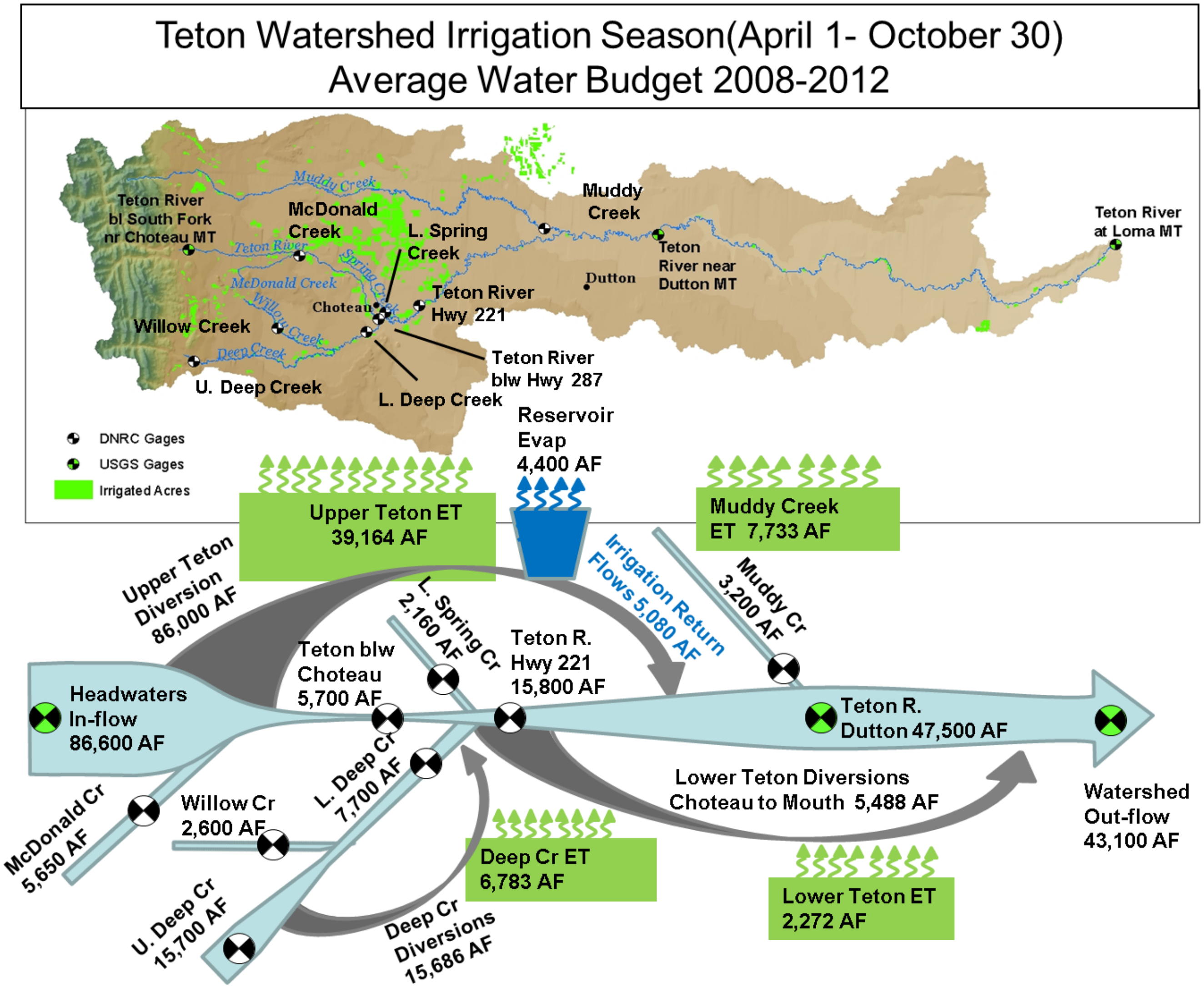


Figure 30: Generalized irrigation season water budget in the Teton watershed. Most water is diverted from the Upper Teton and Deep Creek drainages for irrigation. Diversion, consumption and return flow volumes are shown by sub-watershed.

Water Use and Supply During the Late Summer

The scarcity of water becomes most prevalent during July and August when temperatures and daylight hours peak. Crops are growing at the highest rates of the year and keeping up with crop irrigation demands becomes crucial to production. At this time of peak water demand, water supplies are diminished by a depleted snowpack and precipitation becomes infrequent. When water demands exceed the supply the result is very low to no-flow conditions, causing impacts to agriculture, fish, and wildlife.

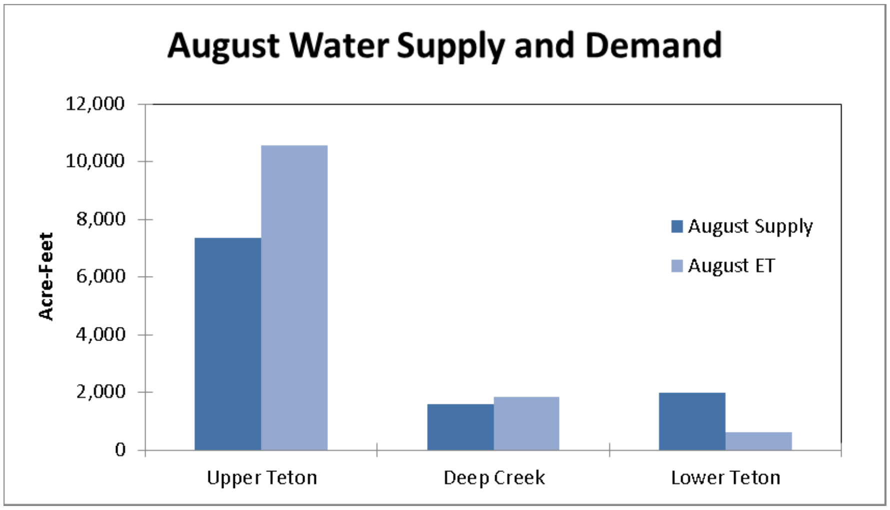


Figure 31: Estimated August water supply and demand for select locations.

Typically, seasonal/annual water budgets do not capture this imbalance of supply and demand. A monthly water budget during the late summer better captures the essence of this late-season supply and demand story. However, irrigation water consumption data for the Teton Watershed is only available as seasonal sums. Monthly water consumption for August was estimated using Irrigation Water Requirements (IWR) (USDA, 2003) program[17]. Crops are estimated to consume 27% of the total seasonal demand in August.

Water supply and demand in August (Figure 31), indicates that demand in both the Upper Teton River and Deep Creek areas exceeds the supply. In the Lower Teton, an already reduced supply into the reach is estimated to exceed the irrigation demand. However, during the study dry/nearly-dry streambeds were frequently observed (suggesting that demands exceed supply)

---

[17] IWR calculates monthly and seasonal irrigation requirements based on local climate conditions and engineering equations for ET. IWR monthly values were converted to a percent of total ET. The percent values were then multiplied by the remote sensing ET value to estimate monthly consumption.

at the Loma gage on the Lower Teton River, this indicates that other losses are occurring such as loss of surface water to the shallow aquifer or significant ET by riparian vegetation.

Other locations in the watershed where dry/nearly dry stream beds were frequently observed include:

- Willow Creek
- Lower Deep Creek Gage
- Muddy Creek Gage

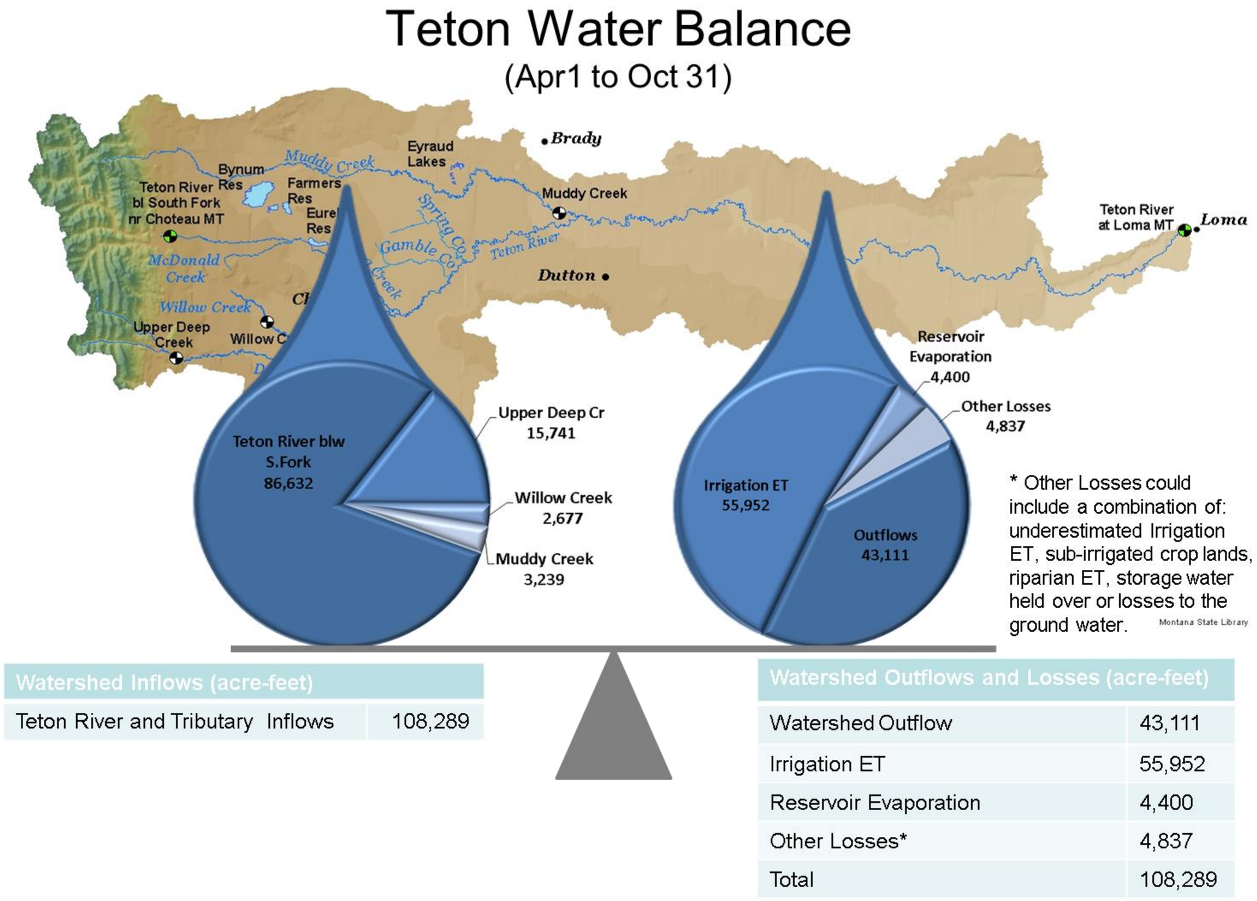
Based on the lack of water supply in these locations, it is assumed that demand exceeded the supply during the late summer.

Conversion to center pivot irrigation adds to the story since center pivots typically increase consumptive water use, reduce return flow, and in some instances allow for later-season irrigation that historically did not occur. The replacement of flood irrigation and ditch diversions with pivot irrigation and pumping systems enables irrigators (depending on seniority of a water right) to pump water and irrigate during times of low streamflows. Historically when flood irrigated, water may not have been used under low flow conditions because there was insufficient supply to meet the diversionary demands to physically get water to the field via a ditch and then to spread water in the field. This is one of the challenging aspects of shifting to higher efficient irrigation systems. This increase in consumption, and in some cases expansion of the period of diversion, further reduces water supplies.

Water Balance

A complete watershed balance that accounts for all losses and gains was difficult to achieve due to the complexity of water management in the Teton Watershed. The most striking part of this water balance is that 61% of the water generated by the headwaters had to be accounted for through losses from the system. There are certainly unaccounted for water gains and losses that are not presented in this water balance.

The study period average water balance (Figure 32) was developed using: measured inflow and outflow (DNRC and USGS gages), estimated irrigation water consumption (ET), reservoir evaporation and other losses. Mass balance is nearly achieved; a volume of water 4,837 acre-feet “other losses” could not be accounted for with the irrigated ET estimation. Gaged losses from Dutton to Loma exceed the estimated ET for that reach and account for one-half of the volume of the “other losses” category.



* Other Losses could include a combination of: underestimated Irrigation ET, sub-irrigated crop lands, riparian ET, storage water held over or losses to the ground water.

Watershed Inflows (acre-feet)	
Teton River and Tributary Inflows	108,289

Watershed Outflows and Losses (acre-feet)	
Watershed Outflow	43,111
Irrigation ET	55,952
Reservoir Evaporation	4,400
Other Losses*	4,837
Total	108,289

Figure 32: Seasonal water balance for the Teton River.

Lower Teton River Water Supplies

The occurrence of water in the 155 miles of river from Choteau to Loma is a story of water gains and losses. The complexity of all gains and losses are not fully understood. However, an attempt was made to quantify the sources that make up the Lower River (Figure 33). Sources are presented upstream to downstream and are percentages of the averaged seasonal study period (April 1 to Oct 31) volume observed at the mouth of the Teton River (USGS gage Teton River near Loma).

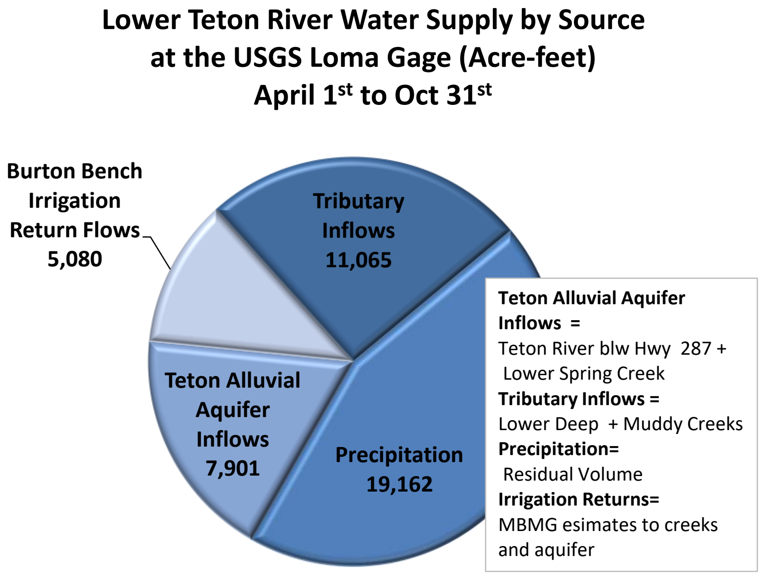


Figure 33: Lower Teton River water supply by source, April 1st to Oct 31st

The water supply of the Lower Teton River starts in the Choteau area, groundwater inflows from the Teton Valley Aquifer restart the dewatered Teton River and form Spring Creek. Groundwater inflows from the Teton Valley Aquifer make up 16% of the seasonal water supply found at Loma. The next source of water to the Lower River is tributary inflows from Deep and Muddy creeks. Their combined flow make up 23% of the volume found at Loma. Surface water (springs & coulees) and groundwater irrigation return flow make up 10% of the Lower River's volume. Precipitation falling over the 1,800 square miles of the lower watershed is estimated to make up the remaining 40% of the total volume.

During wet years of 2008 and 2011, rains and mountain runoff boosted Lower River flows in June where approximately 50% of the annual water supply passed the Loma gage. During normal or dry years the percentage of water supply generated by precipitation over the Lower River is expected to be significantly less.

During the five year study period, the Teton River was observed to gain and lose flow between the USGS gages at Dutton and Loma in different years of the study. The Teton River from Dutton to Loma is a segement where tributaries are ephemeral (only flow during snowmelt and heavy rain events). Irrigation consumption is estimated to be 2,273 acre feet over that reach. Based on this conceptual model, the following relationship between Dutton and Loma are expected:

- Flows are greater at Loma during spring runoff (March to May)
- Flows are less at Loma during the irrigation season (May to October)
- Flows should be equal during the non-irrigation base flow period (November to March)

Annual losses to the Teton River were observed between Dutton and Loma during in 2008, 2009, 2010 and 2012 whereas a gain was observed over that reach in 2011. Contributions from ephemeral tributaries could explain the gain that occurred during the wet year of 2011.

However, the losses of 11,150 (2008), 11,650 (2009), 941(2010), and 5,430 (2012)acre feet exceed the estimated Lower River irrigation consumption of 2,273 acre feet for all years except 2010, and suggests a loss mechanism other than irrigation diversions.

Observed streamflow losses during the non-irrigation season demonstrate that water from the Teton River downstream of Dutton is lost through seepage to the subsurface in addition to irrigation diversions.

Advancement and recession of continental glaciers (Illinoian 191,000-130,000 and Wisconsin 85,000 to 21,000 years ago) have moved the channels of the Teton and Missouri Rivers over time (Alden 1932, Patton 1990). In this process, some remnants of ancestral channels were left intact while others were buried. Saturated ancestral channels serve as alluvial aquifers and can be locally more productive (contain more water) and transmissive than the surrounding glacial sediments and bedrock.

Observations by local residents, geologic maps, and well logs suggest that the alluvial aquifers of the Teton and Missouri Rivers may be connected and interact in an area northeast of Fort Benton called “Crocon du Nez”. Under this premise, the topographically higher Teton River may leak water to the Missouri which is located approximately half a mile to the south.

Glaciation in Lower Teton River presents some possible explanations for river losses including:

- Locally thicker deposits of coarse-grained materials along the Lower Teton River which mark the historic channel locations of the Teton and Missouri Rivers
- The connection of the Teton and Missouri River aquifers in the “Crocon du Nez” area

Further investigation would be needed to support these interpretations.

Effects of Dewatering on the Shallow Aquifer

Dewatering of the Teton River by irrigation diversions occurs in two primary locations. The first location extends from the Springhill area upstream towards to the Bynum Diversion (ranging from 5 to 12 miles) on the Upper River. The second location is from the Teton’s mouth at Loma to a point above Buck Bridge (a reach up to 40 miles) on the Lower River.

Teton Valley Aquifer near Choteau

The Teton River near Choteau and Spring Creek are connected to the shallow Valley Aquifer Nimick (1983), Patton (1990), and Wylie (1991) and receive discharge from the Teton Valley Aquifer when groundwater intersects their streambeds.

Hydrographs of Spring Creek/Teton River near Choteau and nearby wells show that during times of dewatering, a reduction in groundwater levels occurs. This occurrence is followed by a reduction in flows in Spring Creek and the Teton River near Choteau. These data indicate that dewatering of the river, in particular the Spring Hill Reach reduces the amount of groundwater available to discharge to the Teton River (near Choteau) and Spring Creek. In recent years, this has led to the complete dewatering of Spring Creek in Choteau's city park.

Lower Teton River Aquifer

The Lower Teton River is connected to the shallow valley aquifer in much the same way it is on the Upper River. Hydrographs of surface and groundwater in the Buck Bridge and Loma areas indicate that groundwater levels are dependent on the Teton River. Dewatering of the Lower River reduces groundwater levels in the nearby valley aquifer. The effect of reduced groundwater levels on the Lower River is not well documented. However, basic hydrolgeologic principles suggest that reducing groundwater levels adjacent to the river will reduce discharge to gaining reaches or increase seepage from losing reaches of the river.

Summary

Teton Watershed Streamflow Characteristics

The Teton River and its tributaries do not conform to that of a text book watershed. The Teton captures nearly all of the stream and runoff conditions found in Montana from alpine streams to prairie coulees. In addition, the geologic history of the area has left a complex mosaic of bedrock and glacial deposits that comprise aquifers and underlie streams, canals, and irrigated acres. Hydrographs reflect the diversity of conditions with the added complexity of water management in the basin.

Flows near the mountains reflect the pattern of a snowpack runoff with an abundance of water in May and June and baseflow for the rest of the year. As water moves farther from the mountains significant diversions occur depleting water supplies. Dry conditions are found year round in the Teton River above Choteau. A combination of natural losses, diversions, and routing of flow around the Springhill Reach are responsible for no-flow conditions. However, diversions and routing of flow play a more significant role in dewatering of the Springhill Reach than natural losses. During the study, the Teton River was only connected (water flowed from the mountains to the mouth) briefly during above average water supply conditions in 2008 and 2011.

Groundwater inflow in the Choteau area restarts the Teton River and form Spring Creek. Hydrographs in this area indicate that water supplies are from multiple source areas. Surface water lost from the Teton River above the Bynum diversion and water flowing in the Springhill Reach both contribute significantly to the occurrence of water in the Choteau area. Hydrographs in this area show a double peak. A primary winter peak related to flow entering the Springhill Reach and a secondary peak (May) related to increased seepage in the Upper Teton River (above the Springhill Reach) and precipitation.

Tributary inflow and irrigation return flow (Burton Bench) add volume to the Teton River as it flows from Choteau to Loma. However, precipitation (especially during wet years) over the lower watershed is estimated to be the largest single source of water supply for the Lower River. In some ways, the complete dewatering of the Upper River, causes the Lower River to function as a separate, disconnected system. Hydrographs in the Lower River also contained a double peak. A lesser peak occurs in March/April when the prairie snowpack melts and the primary peak occurs in May/June from spring rains and to a limited extent mountain precipitation and snow melt. Baseflow occurs for the rest of the year.

In general, as the distance increases from the headwaters, flow decreases due to irrigation diversions and storage. The Teton River below Choteau has very limited access (Deep Cr) to flows derived from the Rocky Mountains, because irrigation diversions capture flow year round. Dry (no-flow) conditions are commonly found during the late summer on the Lower River at Loma. No-flow conditions on the Lower River have been documented as far upstream as the Buck Bridge area.

Streamflow and Water Supply Conditions

The largest source of water in the Teton Watershed is the accumulation of snowpack and precipitation over the Rocky Mountains (~ 11 % of the watershed area). Contributions of flows from the mountains are not always realized in downstream hydrographs as the majority of the available water is diverted in the Upper River.

Mountain precipitation was above average or at average conditions four out the five years of the study period; only 2010 was below average. The snowpack in 2011 was the second highest on record.

The USGS gage Teton River below the South Fork provides the most direct relationship between mountain precipitation and "natural" streamflows. Above average streamflow conditions were found at the USGS gage in 2008 and 2011. Flow conditions in 2009 were just below average. Data suggests that precipitation in the mountains is not always realized as equivalents in streamflow (e.g. average snowpack ≠ average streamflows).

Over the study period, two very large water supply years occurred in 2008 (large spring rains) and 2011 (large snowpack and precipitation). These two strong water years have skewed study period flow statistics of most gages in the watershed. It should also be noted that prior to the study water supplies were below average for five years.

During the study, precipitation over the prairie portion (89% of the watershed) generally mimicked conditions found in the mountains, on a reduced scale reflecting the much drier prairie environment. Exceptions are precipitation in 2010 that was above average at Choteau and Carter, and below average conditions at Carter in 2009.

The relationship between precipitation and streamflow is blurred for most of the watershed as diversions and groundwater inflows mask water supply conditions found in the headwaters. Two exceptions are the realization of streamflows during spring rains and the melting of snow over the prairie.

Surface Water and Groundwater Interactions

Interactions between the Teton River and the shallow valley aquifer are dynamic and have been documented by several authors. In general, the amount of groundwater found in the nearby valley aquifer is related to the amount of water in the river. Thus, the amount of groundwater discharged to local spring creeks and the Teton River is ultimately governed by how much water comes out of the mountains and how much water is left after diversions.

The occurrence of water in the Teton River near Choteau and Spring Creek is related to the amount of water in the Teton Valley Aquifer. The Teton Valley Aquifer receives water from multiple sources, however the most important are:

- Seepage of Teton River water between the confluence of the North and South Forks of the Teton down to the Bynum diversion dam.
- Seepage of Teton River water in the Springhill Reach.

Downstream on the Lower River, interactions between the Teton River and Valley Aquifer are less understood. However, in general the river and aquifer share the same relationship: more river water = more groundwater and vice versa.

Irrigation practices recharge groundwater and a portion of this water eventually makes its way back to the river. The majority of irrigation occurs on the Burton bench outside of the river corridor, thus discharge of irrigation recharged groundwater does not make its way back to the area of river from which it was taken. Groundwater discharge from irrigation practices are expected to benefit the Teton River anywhere from the Highway 221 Bridge crossing to Dutton.

Irrigation Water Use

DNRC estimated irrigated acres and water consumption using existing GIS data sets and remote sensing technology. Irrigation diversion rates were estimated using water commissioner records. The Teton Watershed is estimated to contain 76,800 acres of irrigation. These acres are estimated to require 128,500 acre-feet of water diversions and consume 55,900 acre-feet.

Demands in the Teton Watershed nearly exceed the water supply. Irrigation diversion records have shown that Upper River irrigators capture available water supplies by diverting nearly all water under ranging water supply conditions. Diversion rates were skewed by two strong water supply years (2008 and 2011) during the study. Study period average diversion rates may not reflect typical conditions.

Water uses in the Lower River caused no-flow conditions near the mouth of the river three out of the five study years, indicating that irrigation demands exceed the reduced water supply that enters the Lower River. In the Teton above Choteau, water demands on the Upper River resulted in nearly year round no-flow conditions during all years of the study.

The majority of irrigated land (approximately 51,000 acres or 67%) were adjudicated in the 1905 Perry v. Beattie Decree (Upper Teton River) or are located near the mountains in the Deep and Muddy Creek drainages (22,041 acres or 28% combined). It is no surprise that Irrigated acres and water consumption are the highest where water supplies are most reliable.

Irrigation in the Muddy and Deep Creek drainages consumes significant volumes of water. In Deep Creek nearly 50% of the supply is consumed. The percent of the water supply that is consumed in Muddy Creek is unknown (inflows were not gaged). It is expected that the majority of water produced by Muddy Creek is consumed; based upon the size of the drainage, MBMG estimates of Burton Bench discharge, and DNRC gage data.

Irrigation along the Teton River from Choteau to Loma is limited by topography. However, 3,286 acres of irrigation were identified, consuming 2,272 acre-feet of water. Water used below Dutton stresses the water supply significantly as indicated by no-flow conditions observed at the USGS Loma Gage in three out of the five study years. Much like the Upper Teton River, water use and consumption is limited by available supplies.

Watershed wide irrigation is estimated to be 45% efficient, meaning that crops consume 45% of the water diverted from the source. Conveyance and farm efficiency data suggest that the non-consumed water losses (55% of the diverted volume) are split about equally between ditches and at the field. It is expected that diverted water is used multiple times for flood irrigation (e.g. water runs off one field and is captured to irrigate another field), thus improving overall efficiency and stretching limited resources. Water diverted for center pivot irrigation is diverted once and consumed.

DNRC estimates of irrigated acres and water consumption represent typical conditions in the watershed under average/ slightly dry water supply conditions. The following indicators suggest that water use in the Upper River is limited by supply:

1. Irrigation diversion records show that Upper River diversions capture nearly all the water supply no matter the water year (well above average or below average).
2. Estimates of irrigation service indicate that a significant amount of irrigated land could use additional water to meet crop demands.

DNRC expects that irrigation consumption will increase under better water supply conditions, and consumption will increase as more flood irrigated land is converted to center pivot irrigation.

Irrigation return flow was estimated by MBMG during investigations of the hydrogeology of the Burton Bench. The artificially high Burton Bench Aquifer is estimated to discharge 9,600 acre-feet of water annually as a result of irrigation recharge occurring in the area.

This volume is split between surface water discharge (2,900 acre-feet to the coulees draining the Burton Bench and 4,600 acre-feet to Muddy Creek) and groundwater discharge (2,100 acre feet leaves the aquifer underground via aquifer to aquifer transfer). It is likely that surface water return flow is utilized during the irrigation season.

Return flow was not inventoried by DNRC staff. It is expected that most of the diverted water not consumed by crops, or what appear to be irrecoverable losses eventually return to the Teton River.

Since irrigated land was first inventoried in the watershed in the early 1960s, approximately 27% or 20,000 acres of land are now irrigated using a center pivot. The popularity of irrigation by center pivot continues to increase in Montana. The effects of conversions or future changes are outside of the scope of this study, however increasing irrigation efficiency on a significant volume of irrigated land will increase consumption and affect the hydrology of the watershed.

Water Balance

The water balance in the Teton River is unique as inflow to the watershed is larger than outflow. The watershed balance is assumed to be incomplete as mid-watershed gains/inflows were not fully captured by the gage network (Deep and Muddy Creeks). Therefore it is expected that additional volumes of water should be included as inflows and losses to get a more accurate balance.

A study period average water balance was nearly achieved; a volume of water 4,837 acre-feet "other losses" could not be accounted for. Gaged losses from Dutton to Loma in excess of the estimated ET account for one-half of the other losses. The use of water for irrigation (storage, diversion and consumption) results in a watershed where inflow is greater than outflow.

Effects of Dewatering on the Shallow Aquifer

From the mountains to the mouth, the Teton River is connected to its adjacent valley aquifer. Seepage from the Teton River is a major source of recharge for the valley aquifer. Dewatering of the river reduces recharge and causes groundwater levels to decrease.

Decreased groundwater levels affect the river differently depending on location. In general, decreased groundwater levels reduce groundwater discharge to the river and in some instances increases river seepage to the shallow aquifer.

Recommendations

Disputes over water rights and adjudication proceedings in the Teton frequently end up in court, suggesting that water distribution is not seen as fair by all parties. This report provides key information about water resources that can be used to develop local solutions to water management and distribution on the Teton. The DNRC Water Management Bureau and Havre

Regional Office offer assistance to interested parties to move beyond the knowledge gained in the report and work towards cooperative management of the Teton River.

As a first step, two water management alternatives are presented for consideration:

1. Water users and interested parties in the Teton Watershed could develop a cooperative management plan for the Teton River and its tributaries. Key elements of cooperative management plan are:
    - Development of target surface water inflows into the Springhill Reach to satisfy downstream water rights based on priority.
    - Establishment of a network of internet accessible real-time stream gages in key locations. Stream gages would help water users and managers meet management goals and improve transparency.
    - Development of a working group or building the Teton watershed group's capacity to develop a watershed-specific water supply and growing season forecast through consultation with water supply forecast experts, agricultural experts and water users. This information could be used by producers and resource managers to:
        1. Hedge the potential agricultural losses from low water supplies
        2. Develop water distribution/drought plans to lessen the effects of low water supplies on uses throughout the watershed
2. Distribution of water according to the Temporary Preliminary Decree is a tool that is available for water users to ensure that water is distributed equitably following the Prior Appropriation Doctrine. The Musselshell River Distribution Project offers an example of how water management through the enforcement of water rights based on priority is successfully (and cost effectively) achieved through a Temporary Preliminary Decree, over a 342 mile long river. The Musselshell River Distribution Project success relies on the following:
    - An enforceable decree from the Water Court
    - Employment of multiple water commissioners as well as a chief water commissioner to distribute water according the Montana Water Use Act
    - Cooperative and understood distribution of both decreed and stored water
    - A network of Internet accessible real-time USGS and DNRC stream and reservoir volume gages.
    - Access to data, which allows for transparency and accountability so that water commissioners, dam operators and water users can effectively distribute water.

References Cited:

Alden, W.C., 1932 Physiography and Glacial Geology of Eastern Montana and Adjacent Areas: U.S Geological Survey Professional Paper 174.

Allen R.G., Masahiro, T., and Trezza, R., 2007, Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC)—Model, Journal of Irrigation and Drainage Engineering, July/Aug 2007

Ashley R.O., Neibling W.H., Bradley A.K., Irrigation Scheduling, Using Water-use Table, University of Idaho, College of Agriculture

Berg, R.B., 2008, Geologic Map of the Choteau 30' x 60' Quadrangle, North Central Montana: Montana Bureau of Mines and Geology, MGMG 571, Scale 1:1,000,000.

Berg, R.B and Vuke S.M., 2002, Geologic Map of the Fort Benton 30' x 60' Quadrangle, North Central Montana: Montana Bureau of Mines and Geology, MGMG 571, Scale 1:1,000,000.

Bureau of Reclamation., (BOR) 2007, AgriMet, The Great Plains Cooperative Agricultural Weather Network. http://www.usbr.gov/gp/agrimet/

Bureau of Reclamation., 2007, Bynum Diversion Study. Teton Co-operative Reservoir Company, Montana.

Cannon, M.R and Johnson D.R., 2004, Estimated Water Use in Montana in 2000. Scientific Investigations Report 2004-5223

Dalby, C. 2016, Estimation of Missing Streamflow Records for Selected Teton River Stream Gages. Montana Department of Natural Resources and Conservation, Water Resources Division, Helena, Montana.

Daly, C., and Taylor, G., 1998, Montana Average Annual Precipitation, 1961-1990: Parameter-Elevation Regression on Independent Slopes Model (PRISM), Oregon Climate Service. http://nris.mt.gov/

DNRC., 2015, Montana State Water Plan. Montana Department of Natural Resources and Conservation, Water Resources Division, Helena, Montana

Huntoon, P.W., 1985, Fault Severed Aquifers along the Perimeters of Wyoming Artesian Basin, Vol 23, No 2, P176-181

Madison, J.P., 2004, Hydrogeology of the Burton Bench Aquifer, North-Central Montana. Montana Bureau of Mines and Geology Open-File Report MBMG 512

McDonald, C.C 1954, Determination of Streamflows for Periods of Ice Effect, USGS Boston District

Montana Climate Office, University of Montana, Weather data
www.climate.umt.edu

Montana Code, Water-Use Classifications—Missouri River Drainage except Yellowstone, Belle Fourche and Little Missouri River Drainages. Montana Code ARM 17.30.623 B-1 Classification standards and ARM17.30.610

Montana Department of Environmental Quality, 2014, Clean Water Act Information Center, 303 (d) List. http://cwaic.mt.gov/

Montana Dept. of Fish, Wildlife and Parks, 1991, Dewatered Streams List.
http://fwp.mt.gov/gisData/metadata/dewateredStreams.htm#Metadata_Reference_Information

Montana Department of Natural Resources and Conservation (DNRC)., 2012, Sun River Watershed Group Special Study Report.

Montana Department of Revenue, Final Lands Unit (FLU) GIS data set 2012. Montana State Library, Geographic Information Clearinghouse.

Mudge, M.R., and Others., 1983, Geologic and Structure Map of the Choteau 1^0 x2^0 Quadrangle, Western Montana: A Digital Database: U.S. Geological Survey, Miscellaneous Investigations Series Map I-1300.

National Weather Service (NWS) Co-operative Observer Program
http://www.nws.noaa.gov/om/coop/

Nicklin, M.E., 2009, Opinions, Affects of Rerouting Teton River Flows Using Bateman Ditch Choteau Cattle Company Water Right 187182, Nicklin Earth & Water, INC.

Nimick, D.A, Rasumssen, R.S, Woessner, W.W, Schmidt J.C., 1983, Geologic and Hydrologic Investigations at Pine Butte and McDonald Swamps, Teton County, Montana

Nolan K.M., Shields R.R., and Rehmel M.S., 2000, Methods of Stream Discharge by Wading: U.S. Geological Survey, Water Resources Investigation Report 00-4036, USGS Training Class SW1271.

Patton, T.W., 1990, Geology and Hydrogeology of the Teton and Burton Bench Aquifers, Montana Bureau of Mines and Geology Water Development Project Completion Report

Reichmuth, D.R., 1981, Glacial & Groundwater Geology of the Crab Butte – Pine Butte Vicinity, Teton County , Montana. Prepared for the Nature Conservancy.

Smith, L.N., LaFave, J.I., Patton, T.W., Rose, J.C., McKenna, D.P., 2000. Ground-water resources of the Lower Yellowstone River Area: Dawson, Fallon, Prairie, Richland, and Wibaux Counties, Montana. Part A- Descriptive overview and basic data, Montana Bureau of Mines and Geology: Ground-Water Assessment Atlas 1A, 43 p. http://www.mbmg.mtech.edu/pdf/groundwateratlas1.pdf.

State Engineer's Office, 1962.1964, Water Resources Survey (WRS), Teton, Pondera and Chouteau Counties, Montana.

The Nature Conservancy (TNC),1991-1996, Monitoring of Surface Water in the Pine Butte and McDonald Creek Swamps.

U.S. Department of Agriculture (USDA), 1977-2008 Farm and Ranch Irrigation Survey (FRIS)

U.S. Department of Agriculture.,2003, Irrigation Water Requirement Program. http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull//?cid=stelprdb1044890

U.S. Department of Agriculture, National Agricultural Statistics Service, 2012, Census of Agriculture, County Level Data

U.S. Department of Agriculture, Soil Conservation Service, 1978, Water Conservation and Salvage Report Montana:

U.S Environmental Protection Agency, 2003, Water Quality Management Plan and TMDLs for the Teton River Watershed Final:

U.S Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA), 2007, Landsat: A Global Land-Imaging Mission. http://landsat.usgs.gov/index.php

Wylie, A., 1991, Hydrologic Investigation of Durr and McDonald Swamps, Teton County, Montana. Masters of Science Thesis, University of Montana.

Vuke, S.M, Colton, R.B, and Fullerton, D.S., 2002, Geologic Map of the Great Falls, North 30' x 60' Quadrangle, Central Montana: Montana Bureau of Mines and Geology, MGMG 459, Scale 1:1,000,000.