<u>Teton Watershed Study Appendices</u>

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Appendix A: Gage and Well Locations

GPS locations of DNRC Gages

Site	Elevation (feet)	Drainage Area (Sq Miles)	Latitude	Longitude
Teton River at Crawford Bridge	4,200	127	47.8843839°	-112.3714972°
Teton River abv Bynum Divirson	4,500	121	47.878065°	-112.493809°
Teton River blw Choteau	3,778	192	47.7887882°	-112.1791640°
Teton River abv Hwy 221	3,684	501	47.8113944°	-112.0884719°
Teton River at Bootlegger Bridge	3,113	1467	47.9087697°	-111.3234672°
Teton River at Buck Bridge	2,903	1657	47.8560519°	-110.9619375°
Upper Spring Creek	3,942	1	47.8641647°	-112.2392270°
MIddleSpring Creek	3,845	5	47.8254391°	-112.1900407°
Lower Spring Creek	3,783	11	47.7996250°	-112.1642997°
Upper Deep Creek	4,633	38	47.7151978°	-112.5901233°
Lower Deep Creek abe Hwy 287	3,860	277	47.7693853°	-112.2040111°
McDonald Creek near Mouth	4,183	16	47.8812564°	-112.3621247°
Willow Creek	4,159	76	47.7693858°	-112.4053894°
Muddy Creek near Collins	3,417	426	47.934281°	-111.811118°

GPS Location of Measured Wells

Well Number	Longitude	Latitude
Teton Well 1	-111.112	47.889
Teton Well 2	-110.95015	47.856872
Teton Well 3	-110.827263	47.883573
Teton Well 4	-111.030022	47.889816
Teton Well 5	-111.029	47.889
Teton Well 6	-110.815569	47.873388
Teton Well 7	-110.632	47.867
Teton Well 8	-110.613376	47.871881
MBMG 155439	-110.411129	47.919063
MBMG 78294	-112.196193	47.819569
Upper Spring Creek	-112.239349	47.865604

Appendix B: DNRC Irrigated Land Delineation Method

Introduction

There are a number of sources of information on irrigated acreage in Montana. The DNRC Water Rights Database contains a variety of information on water rights claims and permits with irrigation as the use and each of these is associated with an irrigated acreage. This database is based on information established to provide the water-right holder with a legal entitlement to a maximum rate of water diversion associated with a particular amount and location of irrigated acreage.

While this information serves the intended purpose well, it is not adequate for an inventory of consumptive use for several reasons. First, the data provides information on the maximum amount of use that would occur (for example, full-service irrigation on all acres) in a year that is not constrained by physical water availability in other words no water shortages would occur throughout the irrigation season; second, not all drainages in Montana have been adjudicated and the final amounts of diversion rate and acreage determined; third, a variety of logistical and economic factors influence how much irrigation occurs in any given year.

To account for these potential limitations, a process was developed to map irrigated acreage across the state for the purpose of providing an estimate of consumptive use for a typical year. The year 2007 was selected because of water-supply conditions and the availability of supporting information, including the number of cloud-free Landsat scenes.

Several sources of data were used to map existing irrigation in a Geographic Information System.

DOR FLU data

The Montana Department of Revenue has GIS coverage of land use that evaluates irrigated lands for property taxes. This data (FLU) is state wide and includes data from the RWRCC and DNRC's evaluation of existing uses. The FLU data has large parcel data that has limited value for individual field evaluation. Because it is important to have unique irrigated parcels for the evaluation of consumptive water use, the FLU coverage was intersected with the BLM's GCDB (legal land description) coverage to obtain a FLU coverage that has a maximum parcel size of the GCDB data. This GIS file was then used to select those parcels that do not include the other DNRC data (described below).

DNRC Water-Rights Mapper Data

The DNRC has a GIS program that is used by its claims examiners to evaluate SB76 filed claims in the Montana water-rights adjudication process. This evaluation is based on 1980 imagery and includes areas that are not included in the previous data. The data that is not included is added to the data set.

Montana Water Resource Survey (WRS)

The Montana Water Resources Surveys are a comprehensive county by county assessment of Montana's historical water use. This data was collected and published from 1943 thru 1965 by the State Engineers Office and from 1966 thru 1971 by the Water Conservation Board (both predecessors of the current DNRC). Most published surveys consist primarily of two parts: Part I; a known historical account of water use in the county, and Part II; survey maps of current water use at the time of publishing. The survey data was derived from courthouse records in conjunction with individual contacts with landowners, field investigations and aerial photography. Data collected from various other agencies and resources were also used. This information, while dated, is an excellent and detailed source of information on irrigated acreage at one point in time and was integrated with the DOR FLU, and DNRC Water Rights Mapper.

Final Irrigation GIS Data

All of the data sets were filtered to eliminate polygons less than 5.0 acres in size and an ESRI shapefile was produced with the following attribute:

Irr_id: unique numbers for each polygon in the coverage. This id number can be used to link to the original data sets.
Proj: this attribute describes which data set was used for the polygon.
Class: HKM's irrigation evaluation.
Unit: RWRCC unit that was used.
Crop: crop type if available in the base data.
Sys: type of irrigation system if available in base data.
Acres: polygon size in acres.
Basin: Water Court basin id.
Irrcode: WRS code (this code can be used to identify irrigation district lands vs. private lands).

Appendix C: DNRC ET Remote Sensing Estimation Method

Estimating evapotranspiration (ET) using remote sensing requires the processing Landsat 7 (USGS and NASA, 2007) over the 2007 irrigation season. The resolution of Landsat 7 pixels are 30 square meters. Landsat scenes are unusable if the cloud cover is greater than 30%. Cloud cover in usable Landsat scenes is masked using products and protocols developed by the USGS. The processed Landsat scene is then downloaded into GIS for processing. In 2007 usable Landsat scenes for the Teton watershed were available for June 23, July 09, July 25, August 26 and September 11.

The DRNC remote sensing method requires the creation of a shortwave composite image using three of the Landsat Satellite Enhanced Thematic Mapper Plus band designations. Red (Band 3) is used to determine plant growth as low reflectance of this band indicates high plant growth. Near Infrared (Band 4) is used to determine plant growth as high reflectance of this band indicates high plant growth. The thermal Shortwave Infrared (Band 7) is used to identify hot and cool areas. Evaporation of water causes cooling, cool shortwave infrared values indicate high evaporation (high water use) and hot values indicate low water use and low evaporation.

A transpiration grid is created by subtracting the Red (band 3) from Near Infrared (Band 4). An evaporation grid is created using Shortwave Infrared (Band 7). The ranges of values for both grids are bounded to remove anomalous high and low values.

The values of the transpiration and evaporation grids are further bounded to reflect actual water use by selecting the hottest and coldest pixels within known irrigated lands. Hot and cold pixel selection is subjective and the decision is based color imagery and local agricultural knowledge.

The coldest pixel in the transpiration grid represents the area of highest plant growth. The transpiration reference is created by selecting coldest transpiration pixel value. The hottest pixel of the transpiration grid represents no growth and this value is identified. The hottest pixel in the evaporation grid represents the area with the least evaporation and lowest water use. The evaporation reference value is created by selecting the hottest evaporation pixel value. The coldest pixel in the evaporation grid indicates the most evaporation and highest water use.

The transpiration and evaporation grids and reference values are combined and averaged to create an evapotranspiration (ET) grid and (ET) reference value for each pixel.

The Great Falls AgriMet weather station was used to compute ET values. This is the closest AgriMet stations to the Teton watershed and most closely represent conditions found in the Teton. Over the growing season the AgriMet stations compute theoretical reference ET values for Alfalfa Mix based on local weather conditions. AgriMet theoretical values were averaged for several days preceding and proceeding the date of the Landsat scene.   Averaging the ET values helps mitigate anomalous values that could occur due to crop cutting or cloud cover.

The DNRC irrigated lands polygons were overlaid on each of the five abovementioned Landsat scenes. The pixel values within the identified field polygons were averaged for each scene. The field pixel value was then compared to the highest ET value and the pixel value was converted to a reference percent. The field reference percent was then multiplied by the averaged AgriMet theoretical ET that date to determine actual ET.

The gaps between the Landsat scene dates were filled by multiplying the most recent field reference ET percent (determined by each Landsat scene) by the daily AgriMet theoretical alfalfa mix value.

Precipitation measured at the AgriMet station from January 1st to April 1st was used to estimated soil moisture (carry over) conditions and mimic plant use of existing soil moisture in the spring. Precipitation over the irrigation season was considered to be effective if the 24 hour precipitation was less than 0.5 inches. If the 24 hour precipitation was greater than 0.5 inches than only 0.5 inches was used. Precipitation (effective precipitation) was subtracted from the calculated ET for that day as: plant growth likely utilized natural precipitation, irrigation did not occur due to precipitation or precipitation added additional moisture to the soil.

ET over the irrigation season was summed up and aggregated at the sub-watershed and drainage scale.

Appendix D: Hydrographs and Streamflow and Ground Water Data

Streamflow hydrographs and descriptive text for all streamflow gages operated during the study period is presented in this appendix. The data includes both DNRC and USGS operated gages. In addition data collected by DNRC from 2013 to 2015 on select gages are also presented including the Teton River above Highway 221 gage. This real-time gage was installed by the watershed group in 2012 to provide water users information on the quantity of flow leaving the Choteau area.

Stream gage information for all active and inactive gages in the watershed is presented in Table D-1.

Site	Site ID	Elevation (feet)	Drainage Area (Sq Miles)	POR
DRNC Gages				
Teton River at Crawford Bridge	NA	4,200	127	2008-2009
Teton River abv Bynum Divirson	NA	4,500	121	2010
Teton River blw Choteau	TR-02	3,778	192	2009- Present
Teton River abv Hwy 221	TR-03	3,684	501	2012-Present
Teton River at Bootlegger Bridge	TR-05	3,113	1,467	2008-2012
Teton River at Buck Bridge	TR-06	2,903	1,657	2008-2012
Tributaries				
Upper Spring Creek	TR-12	3,942	1	2009- Present
MIddleSpring Creek	TR-13	3,845	5	2009- Present
Lower Spring Creek	TR-14	3,783	11	2009- Present
Upper Deep Creek	TR-08	4,633	38	2008-2012
Lower Deep Creek abe Hwy 287	TR-10	3,860	277	2009-2012
McDonald Creek near Mouth	TR-11	4,183	16	2008-Present
Willow Creek	TR-09	4,159	76	2008-2012
Muddy Creek near Collins	TR-15	3,417	426	2009-2012
USGS Active Gages				
Teton River below S.F Teton near Choteau	TR-01	4,770	110	Jun 1947 - Present
Teton River near Dutton	TR-04	3,235	1,238	Aug 1954- Present
Teton River at Loma	TR-07	2,560	2,010	June 1998 - Present
USGS Historical Gages				
Teton River at Strabane	NA	4,440	124	June 1908 - Sep 1925
Teton River near Choteau	NA	3,740	221	Apr 1906 - June 1919
Teton River near Fort Benton	NA	2,650	1,989	Mar 1929 - Sept 1932
McDonald Creek near Strabane	NA		5	June 1913- Sep 1920
McDonald Creek near Choteau	NA		10	Apr 1917 - Dec 1924
Deep Creek at Frazier Ranch near Choteau	NA		38	May 1912 - Nov 1912
Deep Creek near Choteau	NA	3,860	268	Apr 1911- Dec 1924
Willow Creek near Choteau	NA	3,780	88	Apr 1912 - Sept 1917
Muddy Creek near Bynum	NA	4,020	71	Mar 1912 - Dec 1924
Muddy Creek near Agawam	NA	3,800	274	Jun 1917 - Spet 1917
N.F Muddy Creek near Bynum	NA	4,020	55	May 1912 - Dec 1924

Table D-1: Stream gage information for the Teton Watershed

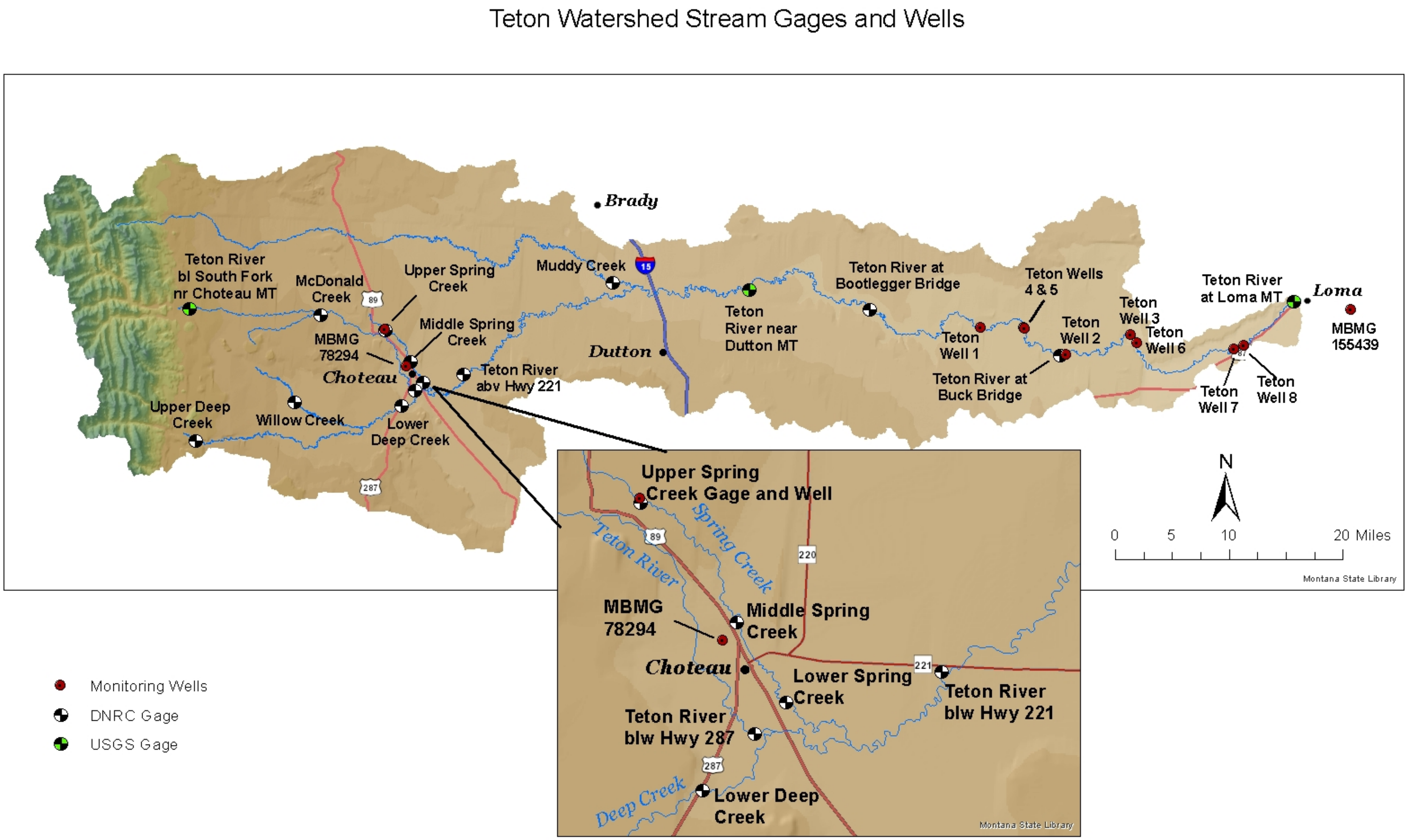


Figure D-1: Map of Stream Gages and Wells in the Teton Watershed

Teton River Gaging Stations

Teton River below South Fork Confluence USGS Gage 06102500

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 inflows of the Teton River. The drainage area is 110 square miles and the mean elevation of land above the site is 6,550 feet. The period of record is 1948 to 1954 and 1999 until present. The gage has been operated seasonally (April 1st to October 31st) since it was re-established in 1999. A seasonal hydrograph of daily average flows and historical averages at this site illustrate seasonal peaks and baseflow periods (Figure D-2).

The hydrograph of the Teton River at this location is dominated by the melting of snow in the mountainous headwaters. The river is relieved from its period of winter baseflows in April as rising temperatures melt low elevation mountain and foothill snowpacks. The bulk of the snowpack resides above 6,000 feet in elevation and the melting of this snow in May and June leads to the peak of the hydrograph in June. Following the peak, flows steadily decline and reach typical low conditions by mid-July.

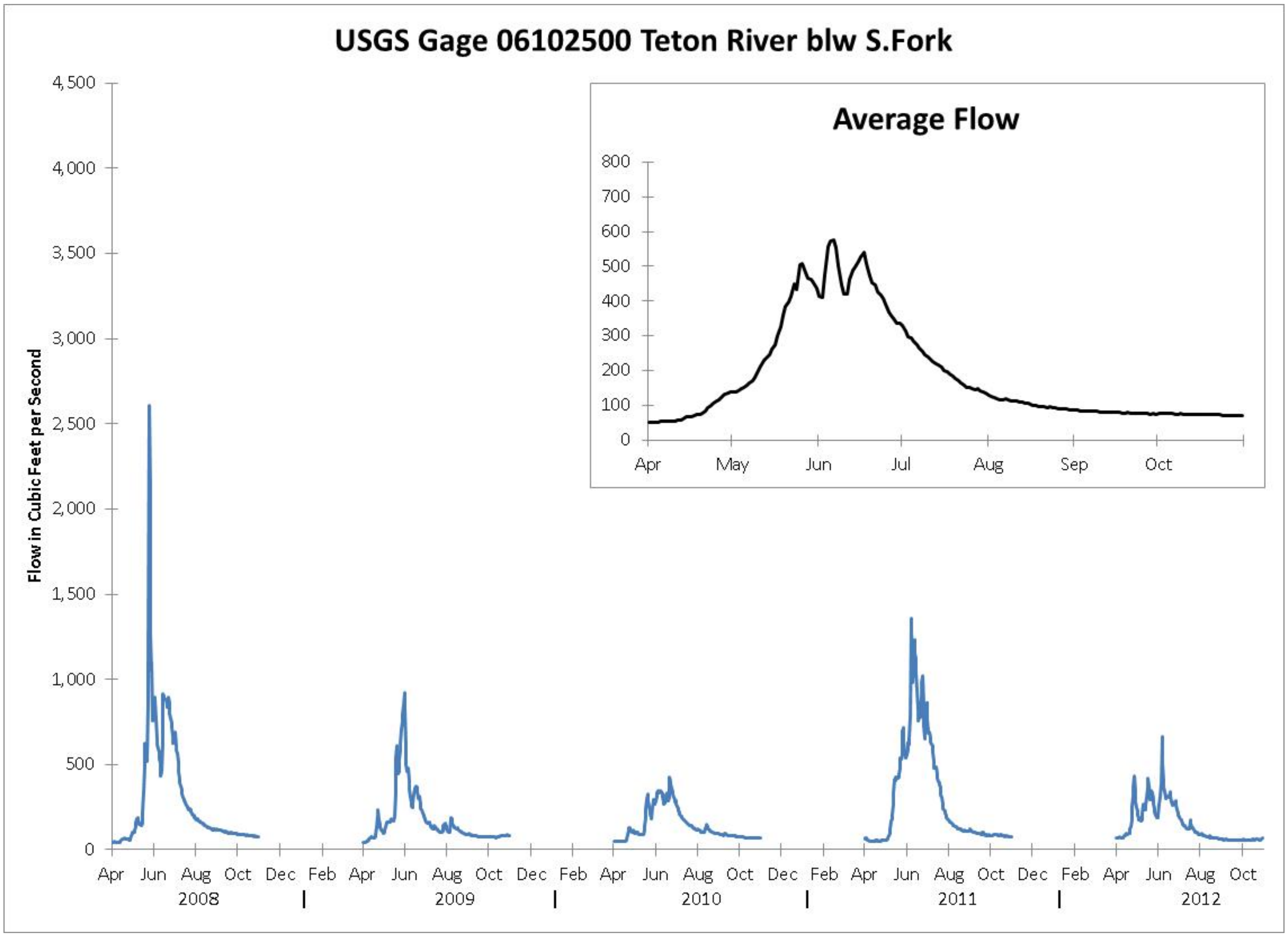


Figure D-2: Hydrograph of USGS gage 0610880 Teton River below the confluence of the South Fork and period of record average flow (1947-1954, &1999-2012).

The largest peak flow of 2,600 cfs occurred in 2008, when a spring rain event caused a significant peak flow. The average peak is 557 cfs and the period of record (POR) average flow is 187 cfs. The period of record average seasonal volume passing the gage is 77,172 acre-feet. Spring runoff in May and June make up 57% of the seasonal volume.

Teton River below Highway 287 near Choteau

The Teton River gage below Highway 287 near Choteau is located south/downstream of the City of Choteau. This gage is located below all major irrigation withdrawals on the Upper River. The Teton River is typically dewatered for several miles between the USGS gage below the South Fork and the DNRC gage below Hwy 287.

Water in the river at this location is primarily derived from: ground water discharge from the Teton Valley Aquifer, irrigation return flows (Burd Ditch tailwater), and precipitation in the Choteau area. The drainage area is 192 square miles and the mean elevation of land above the gage is 5,600 feet.

Seasonal data was collected in 2009 and 2010. Year round data has been collected at the site since April 2011. A hydrograph of daily average flows and study period averages at this site illustrates seasonal peaks and baseflow periods (Figure D-3)

The hydrograph of the Teton River at this location is dominated by two peaks. Natural and man-made causes create the observed double peaks. The magnitude of flows in 2011 has skewed the average peak flow to favor the later May and June peak.

Flows in the Teton River rise from January until March. The observed wintertime increases, result from increased in groundwater levels in the Teton Valley Aquifer upstream of the gage. Increases in groundwater levels are due to flows from the Upper Teton River and McDonald Creek entering the losing Springhill Reach, typically from November until March. Flows decrease in April and May due to upstream water demands diverting Teton River and McDonald Creek Water away from the Springhill Reach.

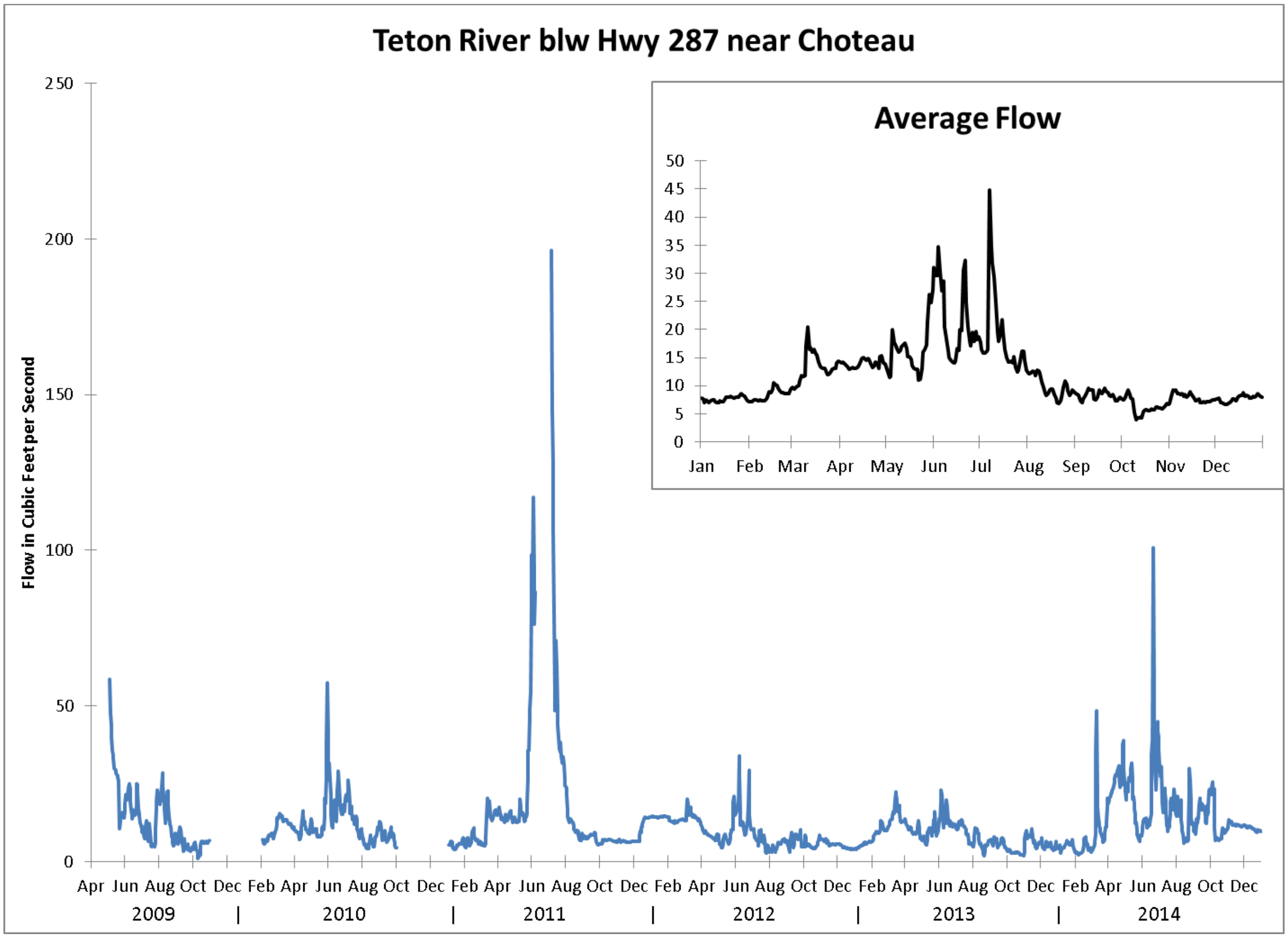


Figure D-3: Hydrograph of the Teton River below Choteau site 2008 -2014.

The second peak typically begins in early June coinciding with high flows on the Upper River. The source of water for the second peak is during times of elevated stream flows. Surface water losses to the ground water increase in the upper Teton River above and below the Springhill Reach. Flows are also supplemented by tailwater from the irrigation ditches (Burd ditch system), irrigation ground water return flow and precipitation. The secondary peak typically begins to recede in mid-June with low flow (baseflow) conditions being observed from August until January.

The largest peak flow occurred in 2011, when flows in exceeded the rating, flows over 200 cfs were estimated at this site. The average peak flow is 35 cfs and the POR average flow is 12 cfs. The average annual volume passing the gage is 8,433 acre-feet. Spring runoff in May and June make up 26% of the annual volume.

Teton River above Hwy 221 Near Choteau

The Teton River above Highway 221 gage as installed by the Teton Watershed group in June of 2012 to help facilitate management of the Teton River. This gage is a Sutron Bubbler pressure transducer system that is equipped with satellite communications. Data from the gage has been internet accessible via the Bureau of Reclamations (BOR) Great Plains Hydromet system (station code TFOM) or via the DNRC and MBMG Streamflow Website http://www.mbmg.mtech.edu/swamp/ . DNRC staff has maintained the gage since it was installed.

Year round data has been collected since 2012. A hydrograph of daily average flows and study period averages at this site illustrate seasonal peaks and baseflow periods (Figure D-4). Flows passing by the Teton River abv Hwy 221 gage are a good representation of: all ground water inflows to the river from the Choteau area (Teton Valley Aquifer), Deep Creek inflows, and Spring Creek inflows. The drainage area is 501 square miles and the mean elevation of land above the site is 5,100 feet.

Much like the upstream gages (Spring Creek and Teton River blw Hwy 287) the Hwy 221 gage has a double peaked hydrograph for the same reasons as mentioned above. The one major difference is the contributions of Deep Creek which add significant flows during runoff from the melting of snow in the Rocky Mountains and to a lesser extent the prairie. Deep Creek contributes significantly the to the May/June peak.

The largest peak flow occurred in 2014, when flows in exceeded the rating, flows over 230 cfs were measured at this site. The average peak flow is 140 cfs and the POR average flow is 40 cfs.

On average a volume of 27,421 acre feet pass by the Teton Hwy 221 gage annually. Spring runoff in May and June make up 23% of the annual volume.

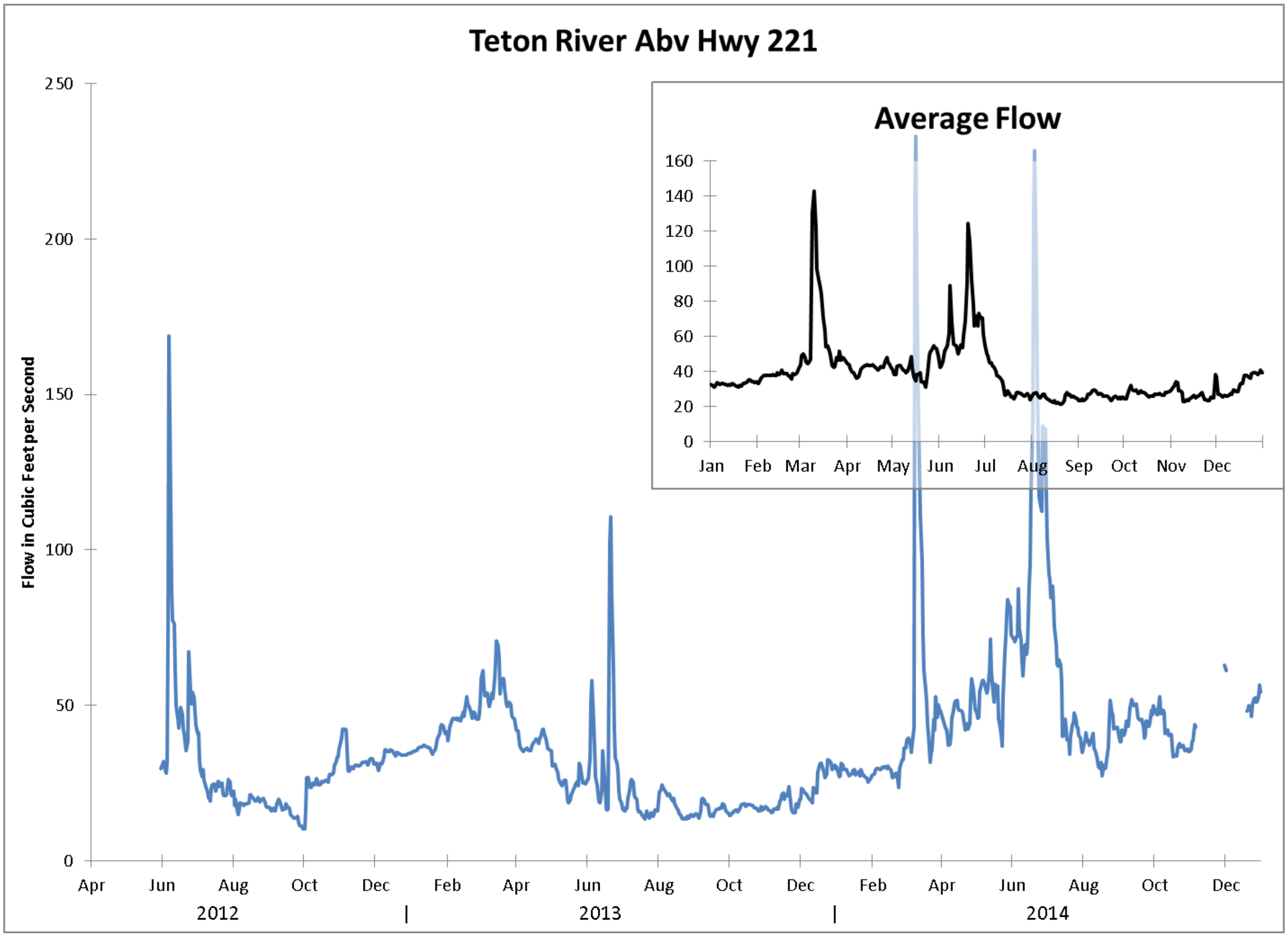


Figure D-4: Hydrograph of the Teton River above Highway 221.

Teton River near Dutton USGS Gage 06108000

The USGS gage 06108000 near Dutton represents mid-watershed conditions on the Teton River. The gage located east and downstream of the Town of Dutton, is representative of mid-river conditions. Water supply at this location includes inflows observed at the Teton River gage blw Hwy 287, Deep, Spring, and Muddy Creeks. The Dutton gage has operated year-round since 1954. The drainage area is a 1,238 square miles and the mean elevation of land above the gage is 4,470 feet. A hydrograph of daily average flows and historical averages illustrates seasonal peaks and baseflow periods (Figure D-5).

The hydrograph of the Teton River at this location is characterized by two peaks one related to melting prairie snowpack and precipitation and primary peak from springtime precipitation and to a limited extent mountain precipitation.

Winter baseflow conditions are observed from January to March. Runoff from prairie snowpack and precipitation generally increase flows in March and April. Precipitation events in May and June cause further increases flows and flashy peaks. In general the Teton River at this location 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 2011, the lower river will benefit from some high flows from the Upper River. From the June peak the hydrograph declines through July into August at which point the river returns to base-flow conditions.

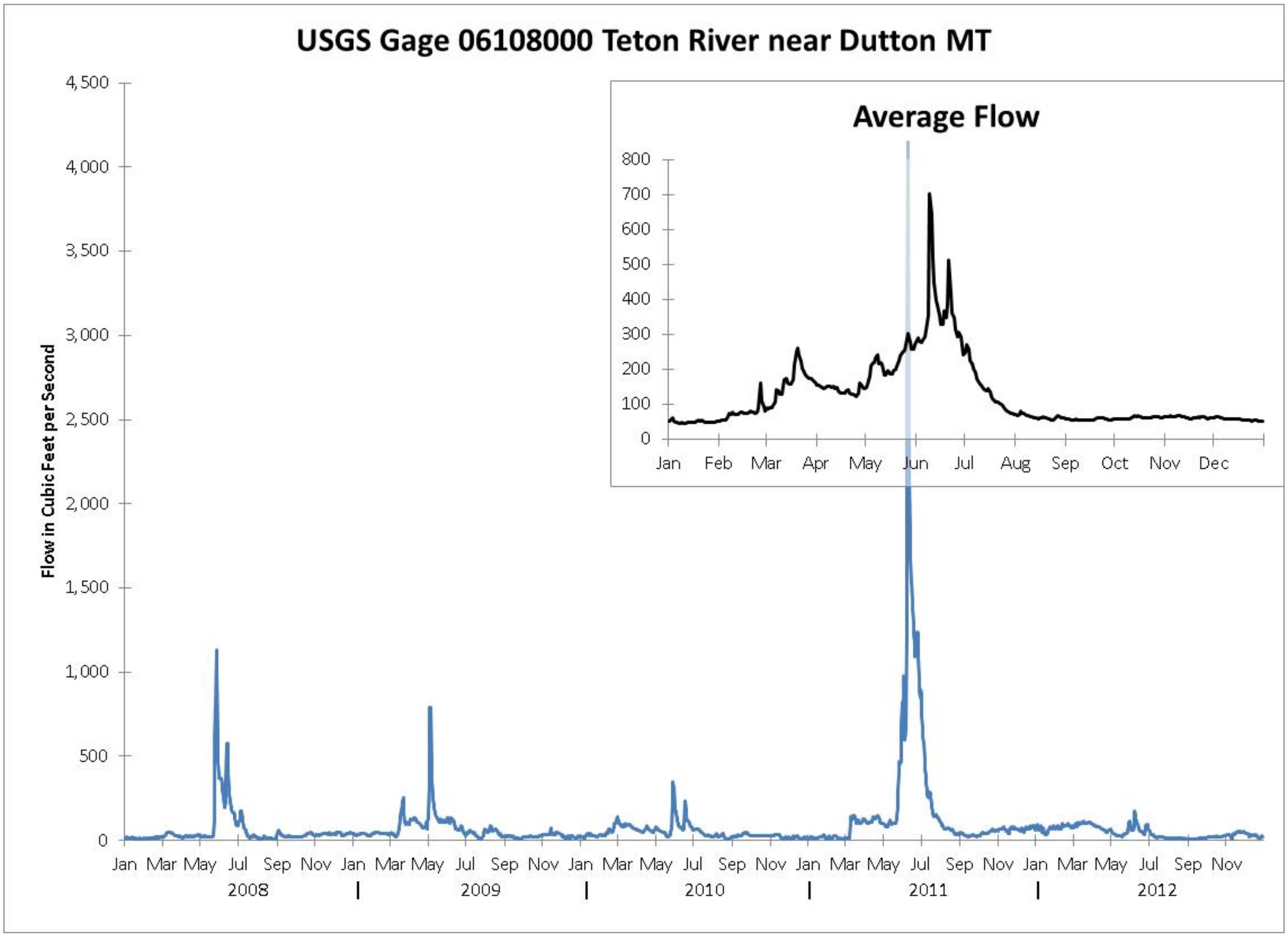


Figure D-5: Hydrograph of USGS gage Teton River near Dutton and period of record average flow1954 -2012.

The highest observed peak during the study period resulted from a rain event during runoff in June 2011, which caused a peak flow of 4,150 cfs.

The average peak flow is 702 cfs and the POR average flow is 122 cfs. The average period of record annual volume passing the gage is 87,480 acre-feet. Spring runoff in May and June make up 30% of the annual volume.

Teton River Bootlegger Bridge

The Bootlegger Bridge gage is located east and downstream of the Town of Dutton. The recorded flows at the Bootlegger Bridge station is representative of conditions in the middle reach of the lower river. The drainage area is 1,467 square miles and the mean elevation of lands above the gage is 4,320 feet. Flow conditions found at Bootlegger Bridge generally mimic those found at Dutton.

A hydrograph of daily average flows and historical averages illustrate seasonal peaks and baseflow periods (Figure D-6). Flows (April-June) were estimated in 2008 and 2009 due to logger malfunction and high water damage respectively, a linear regression was developed between the Bootlegger Bridge gage and the USGS gage at Dutton to estimate missing data.

The seasonal hydrograph of the Teton River at this location is characterized by a primary peak from springtime precipitation and to a limited extent mountain precipitation. A secondary peak is noticeable in April, however, due to seasonal gage operation the early spring peak was not fully captured. The Bootlegger Bridge gage was lost during high flow in 2011 and was not re-established. Low flows are typically reached by early July and persist into October. Flows tend to increase as irrigation demand decreased and precipitation increased in September and October.

Maximum peak flows were not measured to the Bootlegger Bridge due to gage damage during high water and the POR average flow is 60 cfs. High flows are expected to be similar to conditions observed at the USGS gage near Dutton.

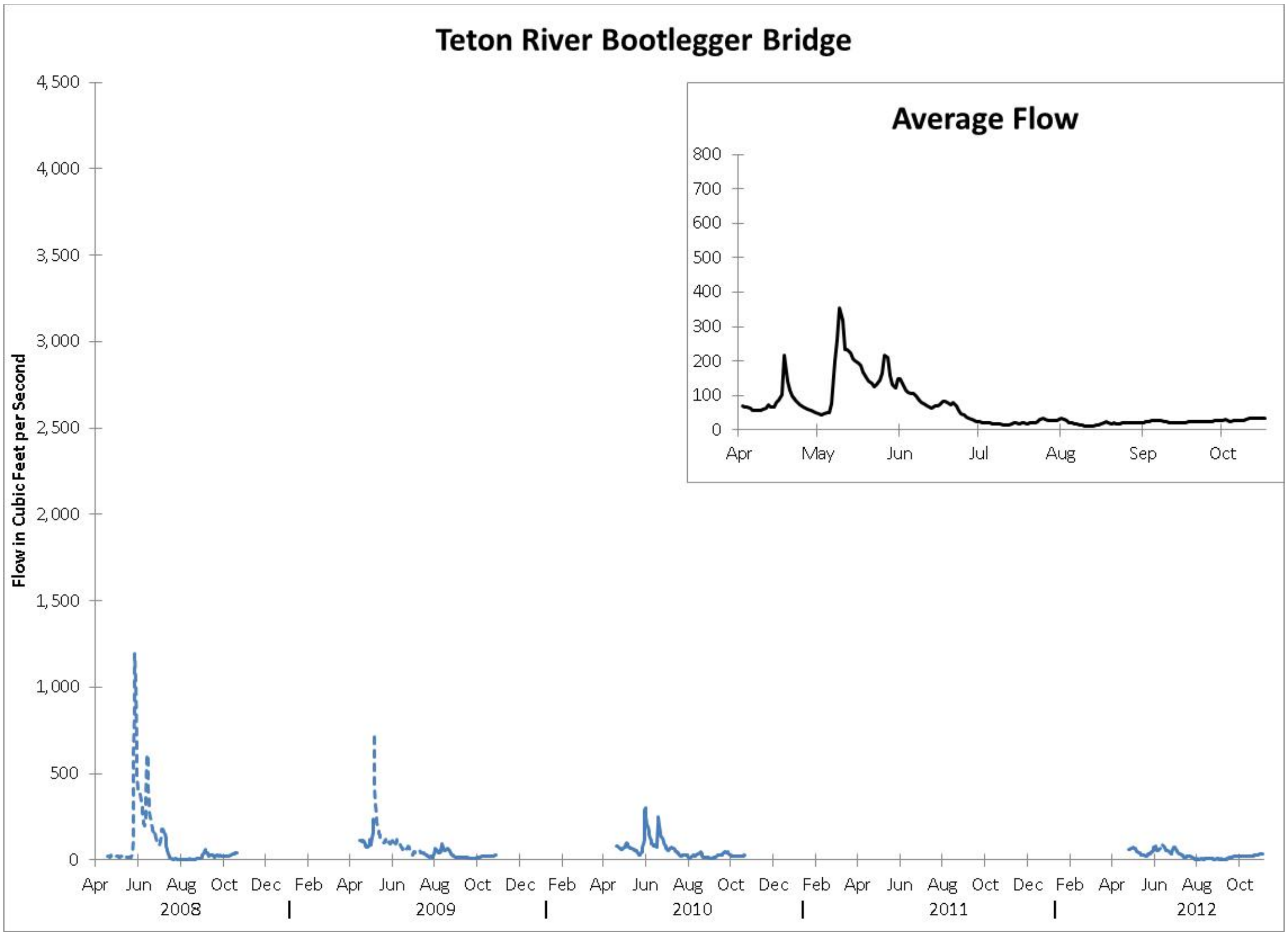


Figure D-6: Hydrograph at the Teton River at Bootlegger Bridge site 2008-2012.

The average seasonal volume passing the gage is 20,422 acre-feet. Spring runoff in May and June make up 65% of the seasonal volume

Teton River Buck Bridge

The Buck Bridge gage is located north of the Town of Carter. The recorded flow at the Buck Bridge station is representative of conditions in the lower reach of the lower river. Water supply conditions at this location mimic conditions found at the Bootlegger site with additional depletions. The drainage area at is 1,657 square miles and the mean elevation of lands above the gage is 4,200 feet.

Flows were estimated in 2008 and 2009 due to logger malfunction and high water damage respectively, a linear regression was developed between the Buck Bridge gage and the USGS gage at Loma to estimate missing data.

A hydrograph of daily average flows and historical averages illustrates seasonal peaks and baseflow periods (Figure D-7). The seasonal hydrograph of the Teton River at Buck Bridge mimics those conditions found upstream at Bootlegger Bridge and Dutton. The Buck Bridge gage was lost during high flow in 2011 and was not re-established until 2012. Very low (less than 10 cfs) were commonly observed at the Buck Bridge site in August and September. A period of no-flow conditions was observed in 2012. Flows tend to increase as irrigation demand decreased and precipitation increased in September and October.

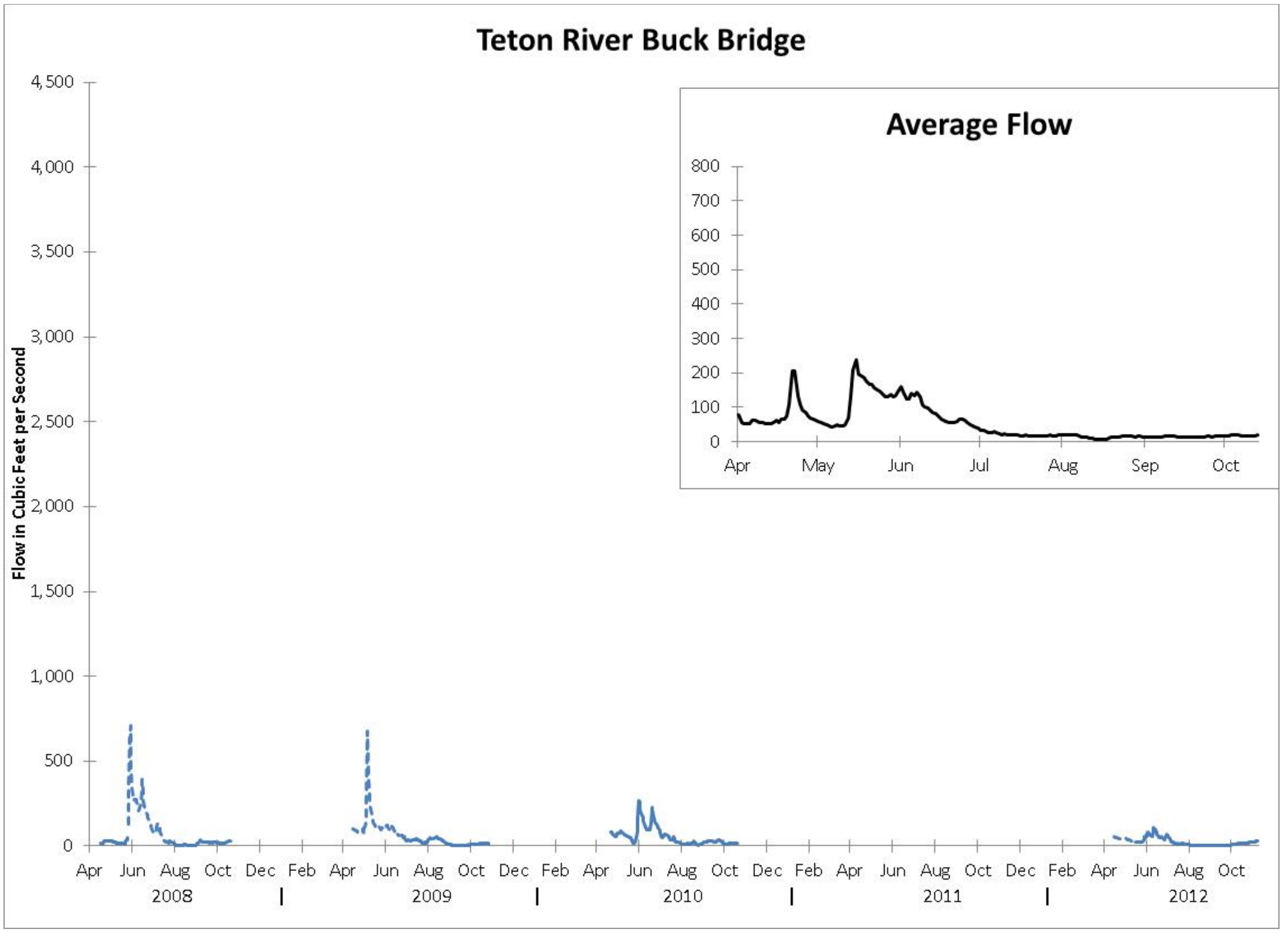


Figure D-7: Hydrograph of the Teton River at Buck Bridge site 2008-2012.

Maximum peak flows were not measured at the Buck Bridge due to gage damage during high water and the POR average flow is 51 cfs. The average seasonal volume passing the gage is 22,969 acre-feet. Spring runoff in May and June make up 69% of the seasonal volume

USGS Gage 06108800 Teton River at Loma

The USGS gage 06108800 Teton River at Loma is located above the confluence of Marias River. The gage is at the Town of Loma and has operated year-round since 1998. The drainage area is approximately 2,010 square miles and the mean elevation of land above the gage is 4,060 feet. A hydrograph of daily average flows and historical averages illustrate seasonal peaks and baseflow periods (Figure D-8). Water supply conditions and hydrogaph at Loma are similar to those found at Buck Bridge with additional depletions.

It is common for the river to be dry during the (low flow and high irrigation demand) months of August and September. No flow conditions were observed in 2008, 2009, and 2012. Flows tend to increase as irrigation demand lessens and precipitation increase in September and October.

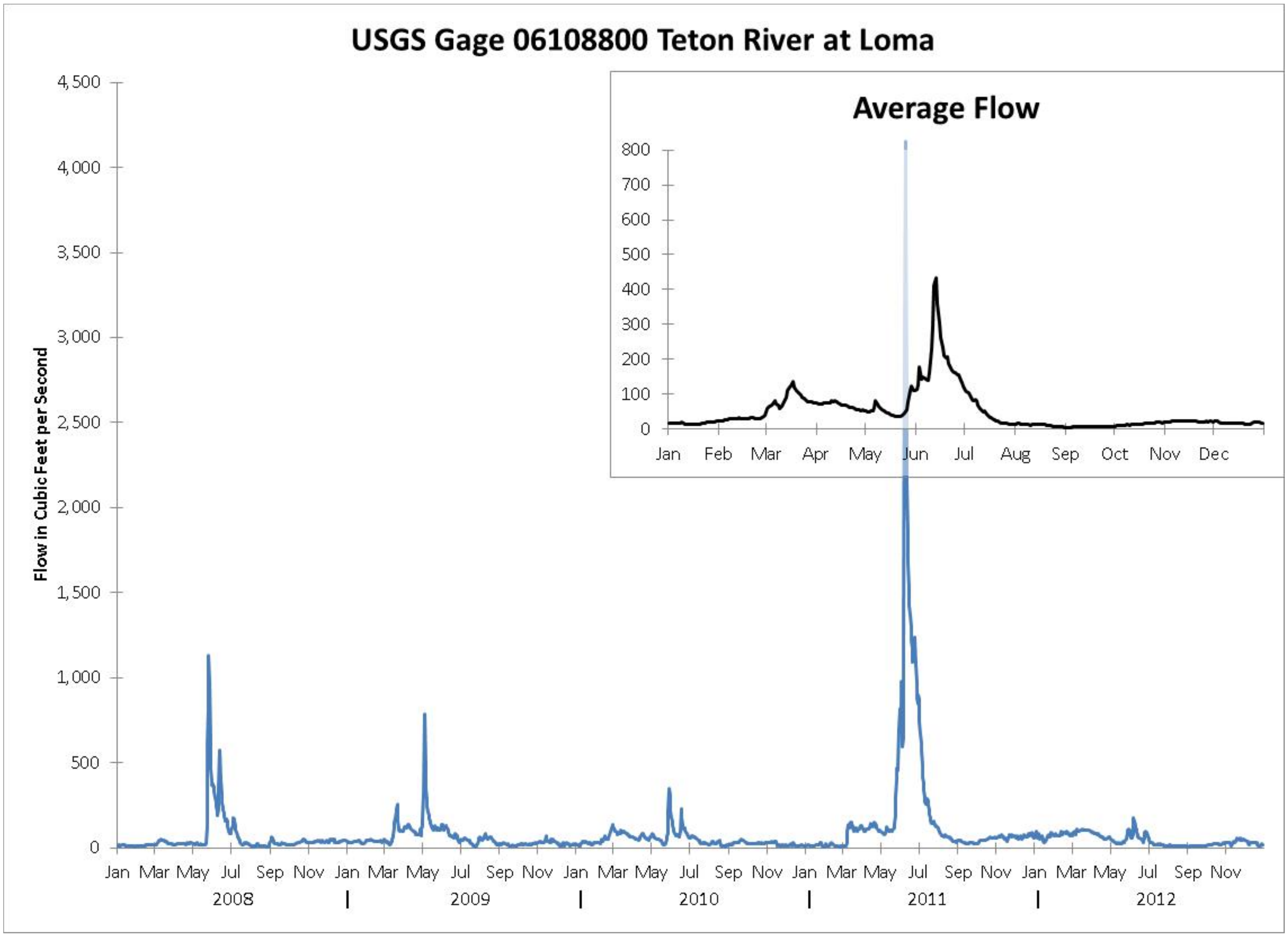


Figure D-8: Hydrograph of USGS gage Teton River at Loma and period of record average flow (1998 -2012).

The highest observed peak during the study period resulted from a rain event during runoff in June 2011, which caused a peak flow of 3,790 cfs. The average peak flow is 435 cfs and the POR average flow is 48 cfs. The period of record annual volume passing the gage is 34,358 acre-feet. Spring runoff in May and June make up 42% of the annual volume.

Teton River Tributary Stream Gages

Upper Spring Creek

The Upper Spring Creek gage is located north of Choteau. This gage is located above major irrigation withdrawals near the head of Spring Creek. The drainage area is 1 square mile and the median elevation of land above the gage is 4,050 feet.

Seasonal data was collected in 2009 and 2010. Year round data has been collected at the site since February 2011. A hydrograph of daily average flows and study period averages illustrate seasonal peaks and baseflow periods (Figure D-9). The hydrograph of Upper Spring contains two peaks. The magnitude of flows in 2011 has skewed the average in favor of peak flows in June. The primary peak occurs in March and the secondary peak occurs in May and June.

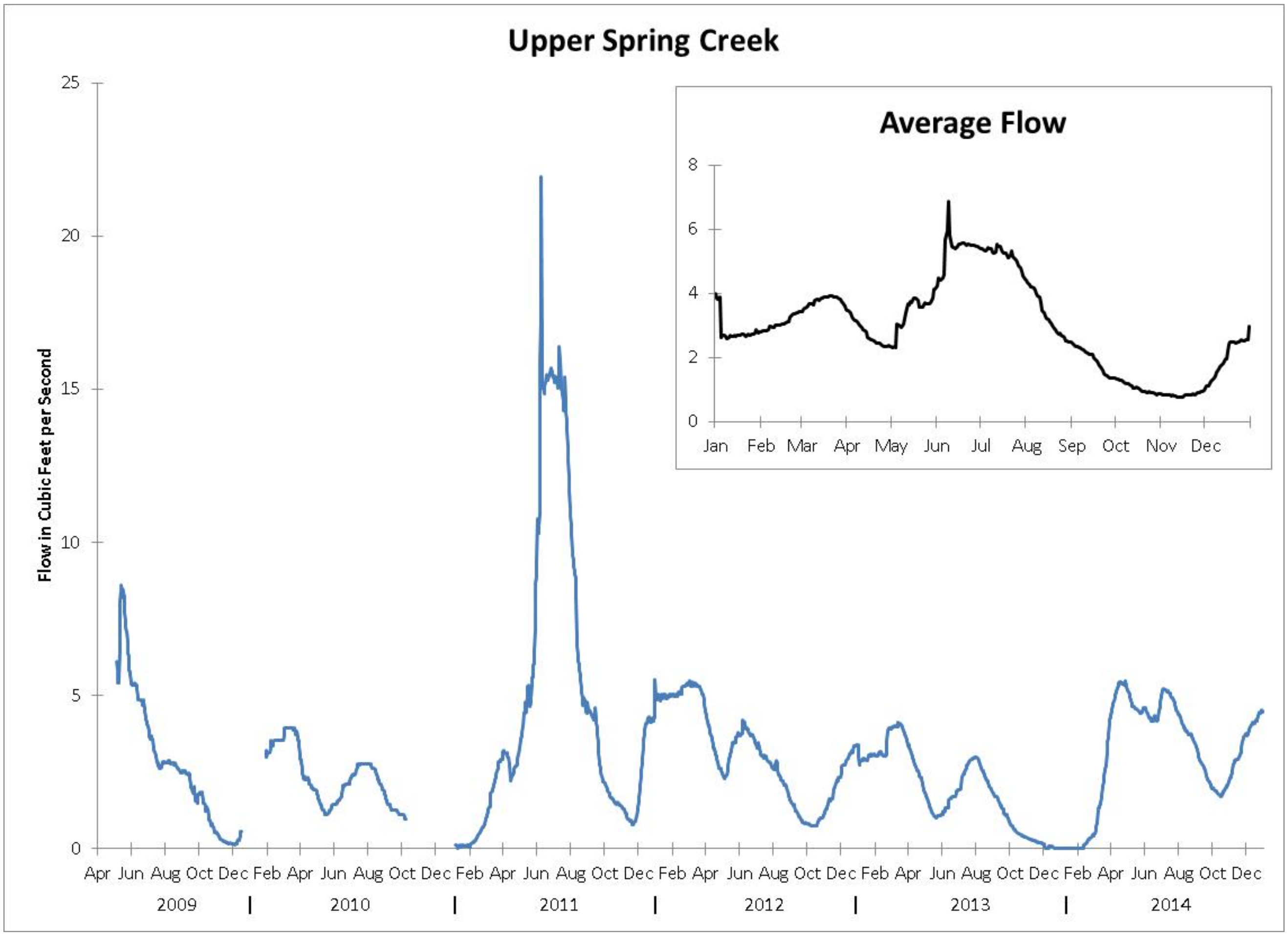


Figure D-9: Hydrograph of Upper Spring Creek and period of record average flow (2009 -2014).

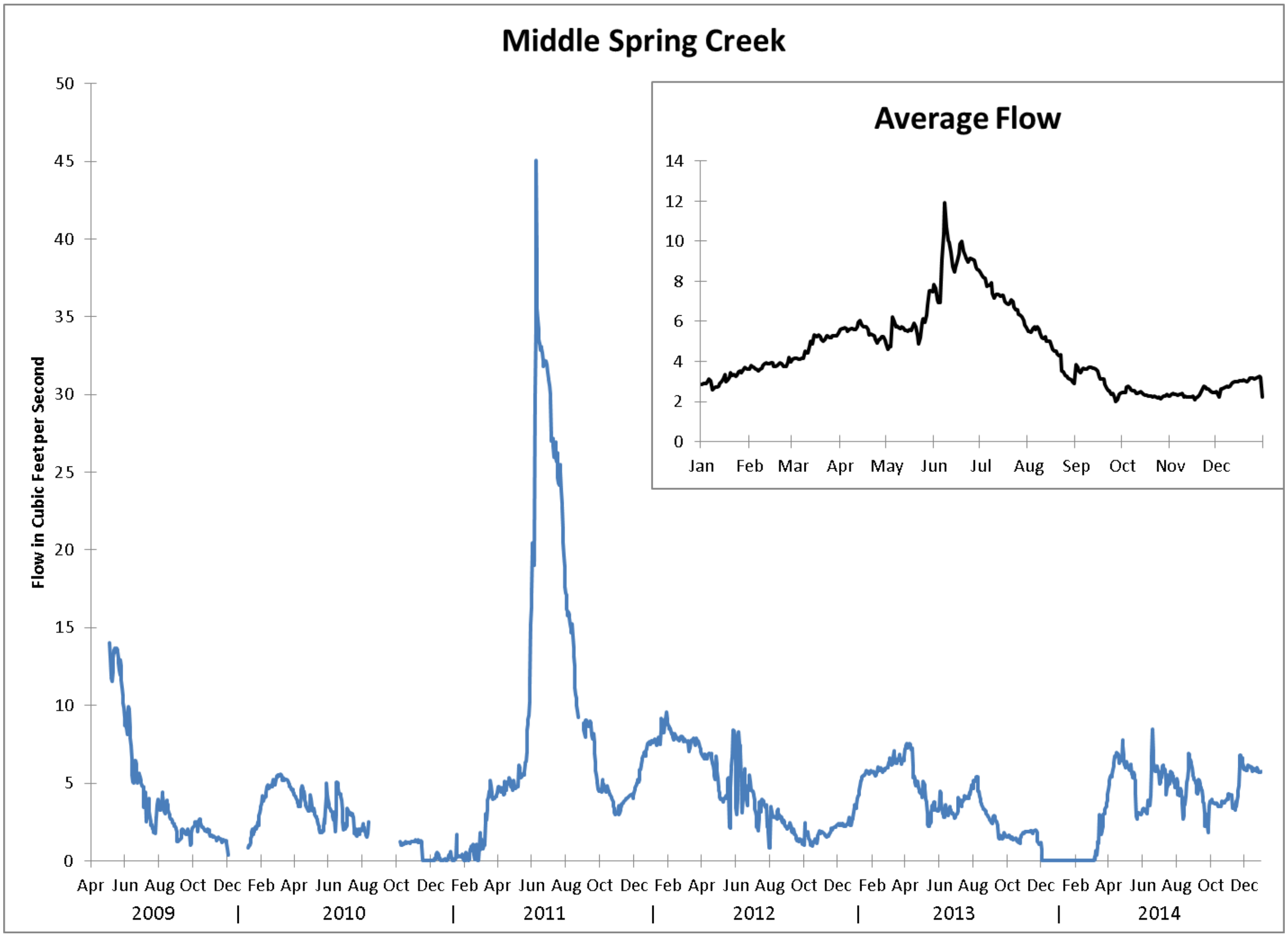
The largest peak flow of 22 cfs occurred in 2011. The average peak flow was 5 cfs and POR average flow is 3 cfs. The average annual volume passing the gage is 2,155 acre-feet. Spring runoff in May and June make up 24% of the annual volume.

Middle Spring Creek

The Middle Spring Creek gage is located above Choteau. This gage is located below irrigation withdrawals on the Spring Creek. The drainage area is 5 square miles and the median elevation of land above the gage is 3,980 feet.

Seasonal data was collected in 2009 and 2010. Year round data has been collected at the site since March 2011. A hydrograph of daily average flows and study period averages at this site illustrate seasonal peaks and baseflow periods (Figure D-10)

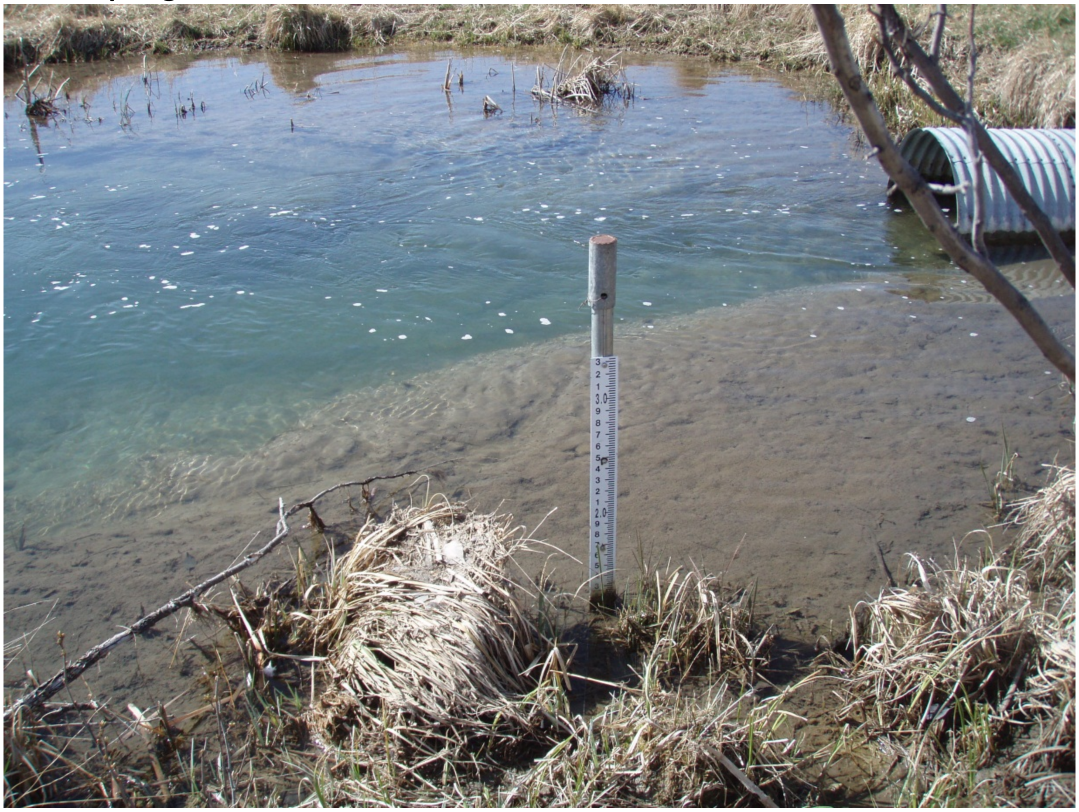
The hydrograph of Middle Spring Creek differs slightly from the Upper Spring Creek location. The two peaked hydrograph is not present in most years and the magnitude of flows in 2011 has skewed the average in favor of peak flows in June. The primary peak occurs in March, however the secondary peak in May and June is likely muted by local irrigation withdrawals.



FigureD-10: Hydrograph of Middle Spring Creek and period of record average flow (2009 - 2014).

The largest peak flow of 45 occurred in 2011. The average peak flow was 12 cfs and the POR average flow is 4.5 cfs. The average annual volume passing the gage is 3,291 acre-feet. Spring runoff in May and June make up 26% of the seasonal volume

Lower Spring Creek



The Lower Spring Creek gage is located east of Choteau. This gage is located below irrigation withdrawals on the Spring Creek. The drainage area is 10 square miles and the median elevation of land above the gage is 3,940 feet. Flows measured at the Lower Spring Creek gage likely, represent contributions to the Teton River. However, below the gage irrigation diversions are present and the creek is assumed to receive additional gains from ground water before reaching the Teton River.

Seasonal data was collected in 2009 and 2010. Year round data has been collected at the site since March 2011. A hydrograph of daily average flows and study period averages at this site illustrate seasonal peaks and baseflow periods (Figure D-11)

The hydrograph of Lower Spring Creek differs slightly from the Upper Spring Creek location. The two peaked hydrograph is not always prominent and the magnitude of flows in 2011 has skewed the average in favor of peak flows in June. The primary peak occurs in March, and the secondary peak in May and June is likely muted by local irrigation withdrawals during most years.

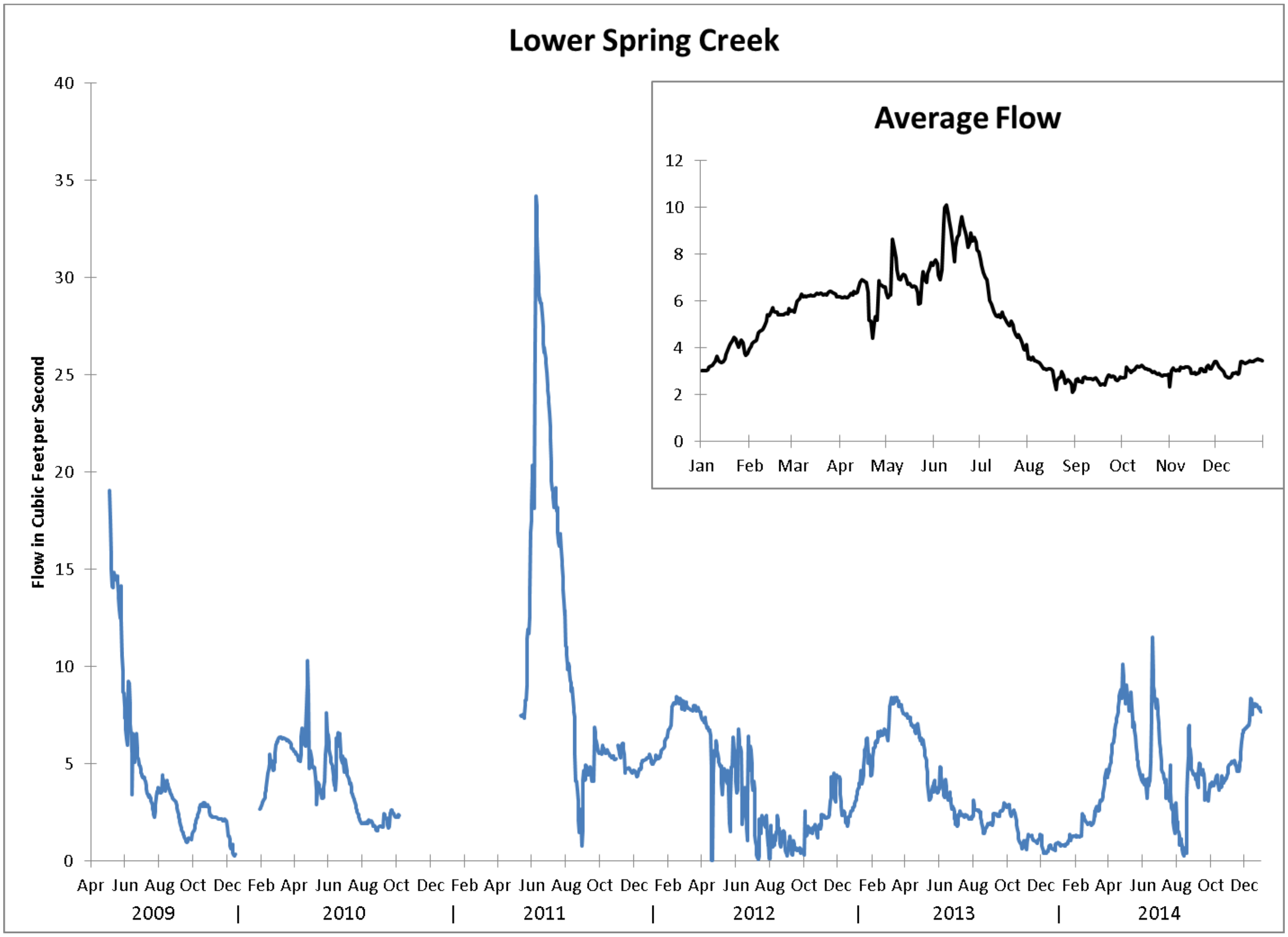


Figure D-11: Hydrograph of Middle Spring Creek and period of record average flow (2009 - 2014).

The largest peak flow of 34 cfs occurred in 2011. The average peak flow was 10 cfs and the average flow is 4.7 cfs. The average annual volume passing the gage is 3,425 acre-feet. Spring runoff in May and June make up 26% of the seasonal volume

McDonald Creek

The McDonald Creek gage is located west of Choteau. This gage is located 100 yards above the confluence of McDonald Creek and the Teton River. The drainage area is 16 square miles and the mean elevation of land above the gage is 4,470 feet.

Seasonal data was collected from 2008 until 2011. Year round data has been collected at the site since February 2012. A hydrograph of daily average flows and study period averages at this site illustrate seasonal peaks and baseflow periods (Figure D-12). McDonald creek originates in the McDonald swamp approximately 6 miles above the gage. The hydrograph of McDonald contains two peaks. The primary peak occurs in March, and secondary peak in May and June. The connection between surface water losses from the Teton River and McDonald Creek have been document by Wylie (1991) and have been discussed in the Previous Investigations and Water Management sections of the report. Periodic low flow conditions occur during the summer due to upstream irrigation withdrawals.

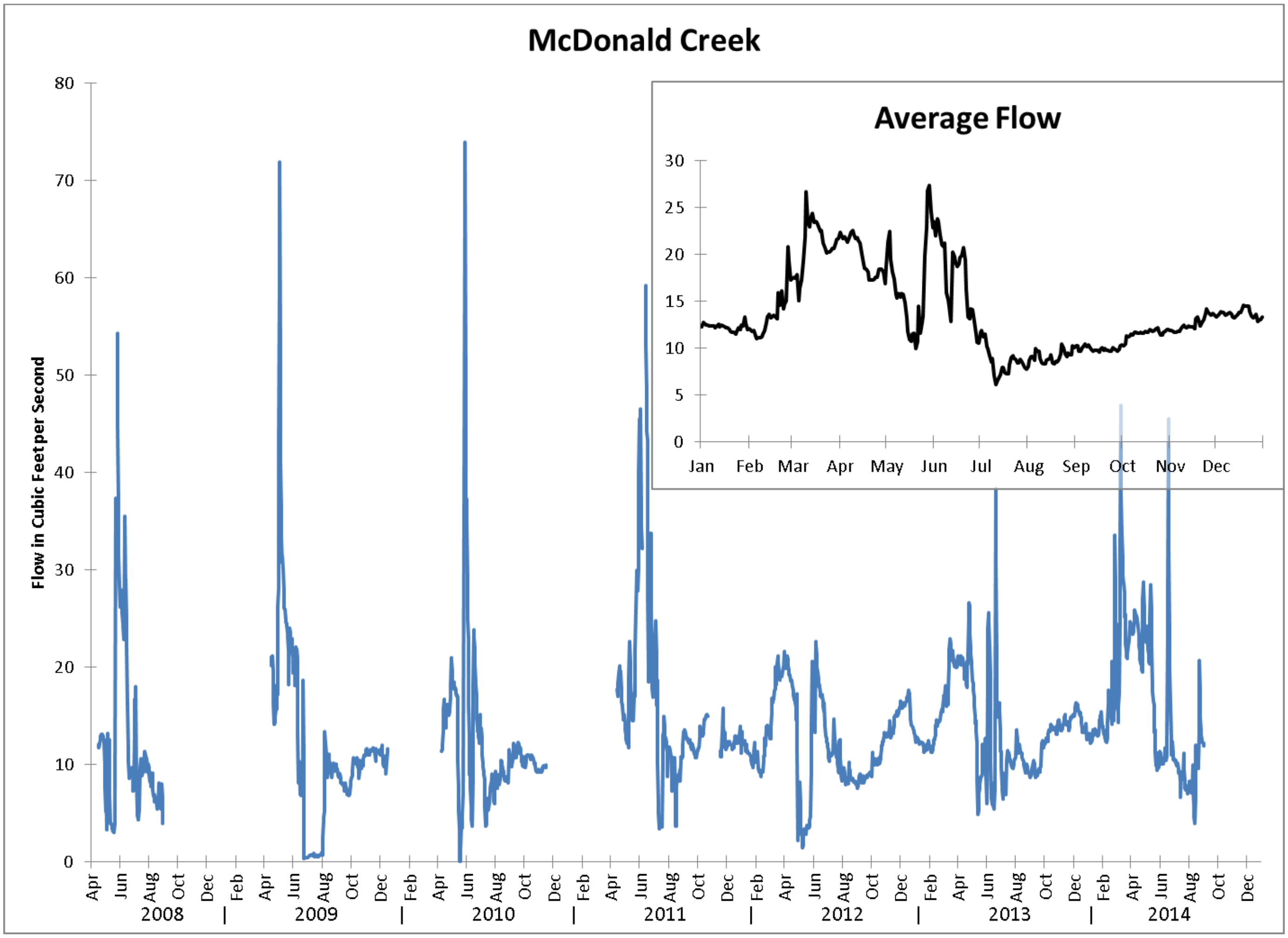


Figure D-12: Hydrograph of McDonald Creek and period of record average flow (2008 -2014).

The largest peak flow of 73 cfs occurred in 2010. The average peak flow was 31 cfs and the POR average flow is 14 cfs. The average annual volume passing the gage is 10,025 acre-feet. Spring runoff in May and June make up 20% of the seasonal volume

Upper Deep Creek

The Upper Deep Creek gage is located west of Choteau. This gage is representative of depleted inflows into the creek. A major diversion on the North Fork of Deep Creek diverts significant volumes of water for irrigation. The drainage area is 38 square miles and the mean elevation of land above the gage is 6,570 feet.

Seasonal data was collected from 2009 to 2012. A hydrograph of daily average flows and study period averages illustrate seasonal peaks and baseflow periods (Figure D-13).

The hydrograph of Deep Creek at this location is dominated by the melting of snow in the mountainous headwaters. Deep Creek is relieved from its period of winter baseflows in April as rising temperatures melt low elevation mountain and foothill snowpack. The bulk of the snowpack resides above 6,000 feet in elevation and the melting of this snow in May and June leads to the peak of the hydrograph in June. Following the peak in late May, flows steadily decline and reach typical low conditions by mid-July.

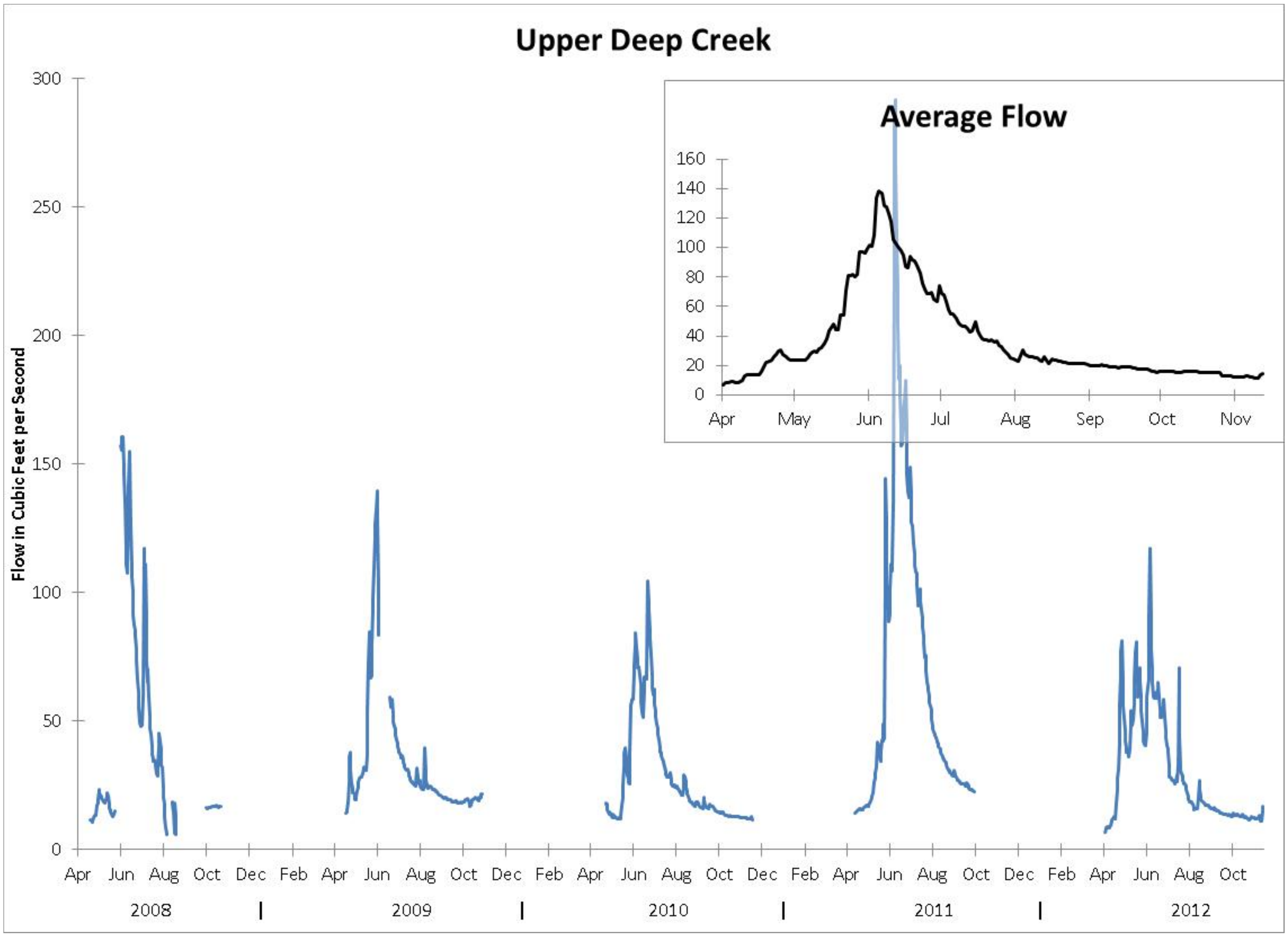


Figure D-13: Hydrograph of Upper Spring Creek and period of record average flow (2009 - 2012).

The largest peak flow of 291 cfs occurred in 2011. The average peak flow was 138 cfs and the POR average flow is 36 cfs. The average annual volume passing the gage is 15,741 acre-feet. Spring runoff in May and June make up 54% of the seasonal volume

Lower Deep Creek

The Lower Deep Creek gage is located near Choteau above the Highway 287 Bridge. The drainage area is 277 square miles and the mean elevation of land above the gage is 4,900 feet. Flows passing the Lower Deep Creek gage are representative of flows in the lower reaches of the creek. The majority of irrigation withdrawals on Deep Creek are located above the gage. Contributions from Deep Creek to the Teton River cannot necessarily be determined from the Lower Deep Creek gages because of the occurrence of downstream irrigation and the role of losses and gains from the ground water are unknown.

Seasonal data was collected from 2009 to 2012. The erratic hydrograph of daily average flows and study period averages illustrate seasonal peaks, irrigation diversions and baseflow periods (Figure D-14).

The hydrograph of Deep Creek at this location differs from conditions found upstream. Prairie snowmelt and precipitation creates an early peak in April. Irrigation demands, mountain runoff, and precipitation events shape the hydrograph from May until October. Demands on the system cause very low (1cfs or less) to no-flow conditions which were observed in 2009, 2012 and 2013 at this location.

The gage was frequently damaged during runoff and precipitation events. The gage was installed in 2012 and 2013 after runoff to prevent damage. Missing data was not able to be estimated due to the complexity of irrigation withdrawals from the system.

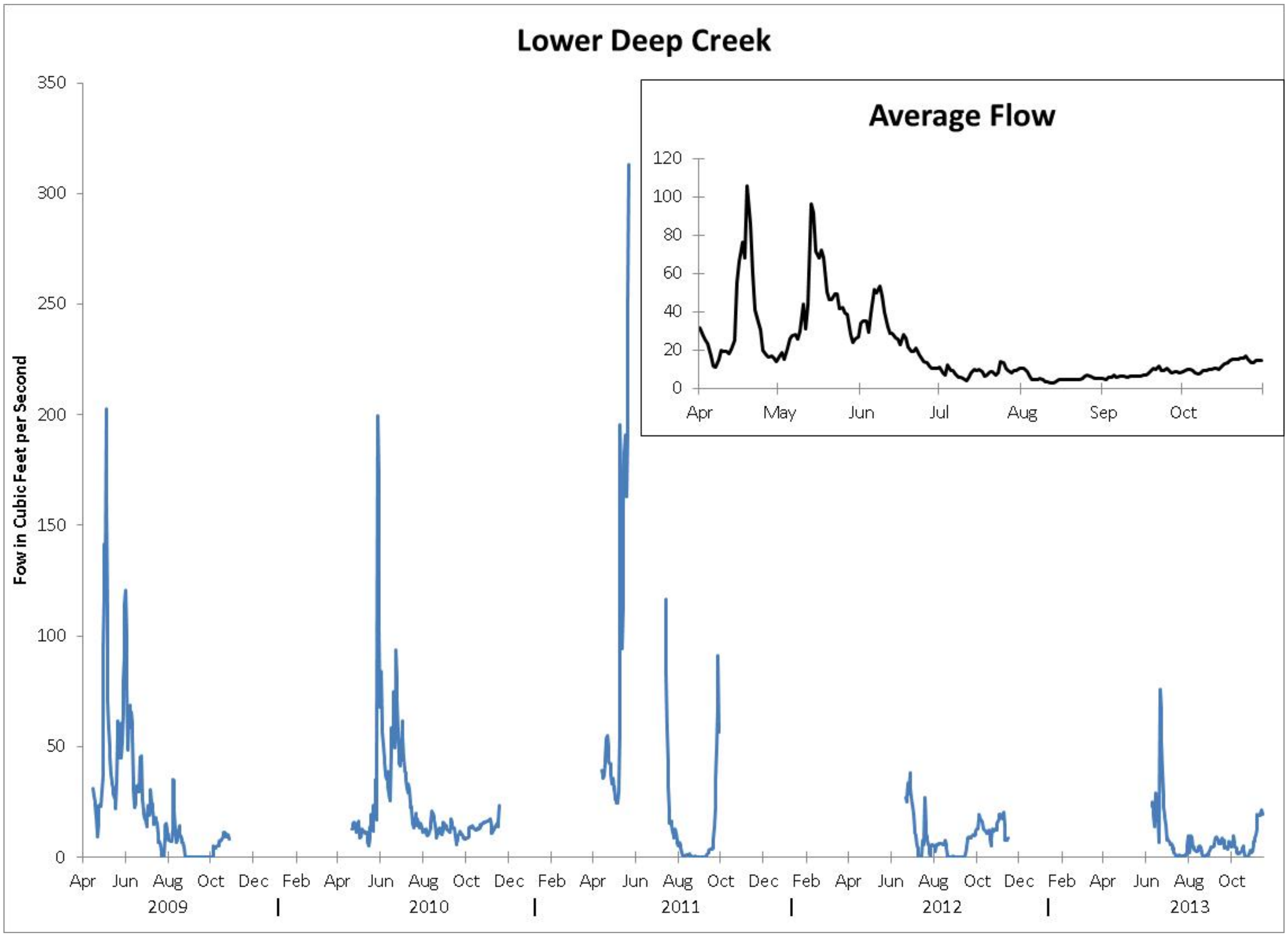


Figure D-14: Hydrograph of Lower Deep Creek and period of record average flow (2009-2013).

The recorded largest peak flow of 313 cfs occurred in 2011, the gage was lost due to high flows, flows are estimated to exceed the highest recorded flow. The average peak flow was 105 cfs and the POR average flow is 19 cfs. The average annual volume passing the gage is 7,826 acre-feet. Spring runoff in May and June make up 62% of the seasonal volume.

Willow Creek

The Willow Creek gage is located west of Choteau. The drainage area is 76 square miles and the mean elevation of land above the gage is 5,070. This gage is representative of conditions found in the middle section of the creek. Irrigation diversions are located both above the gage. Contributions from Willow Creek to Deep Creek cannot necessarily be determined from the Willow Creek gage because of the occurrence of downstream irrigation diversions and the role of losses and gains from the ground water are unknown.

Seasonal data was collected from 2008 to 2012. The hydrograph of daily average flows and study period averages at this site illustrates erratic peaks, irrigation diversions and low flow periods (Figure D-15).

Willow creek flows are derived from the Pine Butte Swamp and are supplemented by precipitation and snowmelt from the Rock Mountain front and nearby foothills. Flows at this location are elevated flows during: runoff (April & May), precipitation events (May-October) and times of reduced irrigation demand (periodic). Demands during the irrigation season reduce flows dramatically, very low (1cfs or less) to no-flow conditions were observed each year.

The gage was damaged during runoff in 2011; missing data was not able to be estimated due to the complexity of irrigation withdrawals from the system.

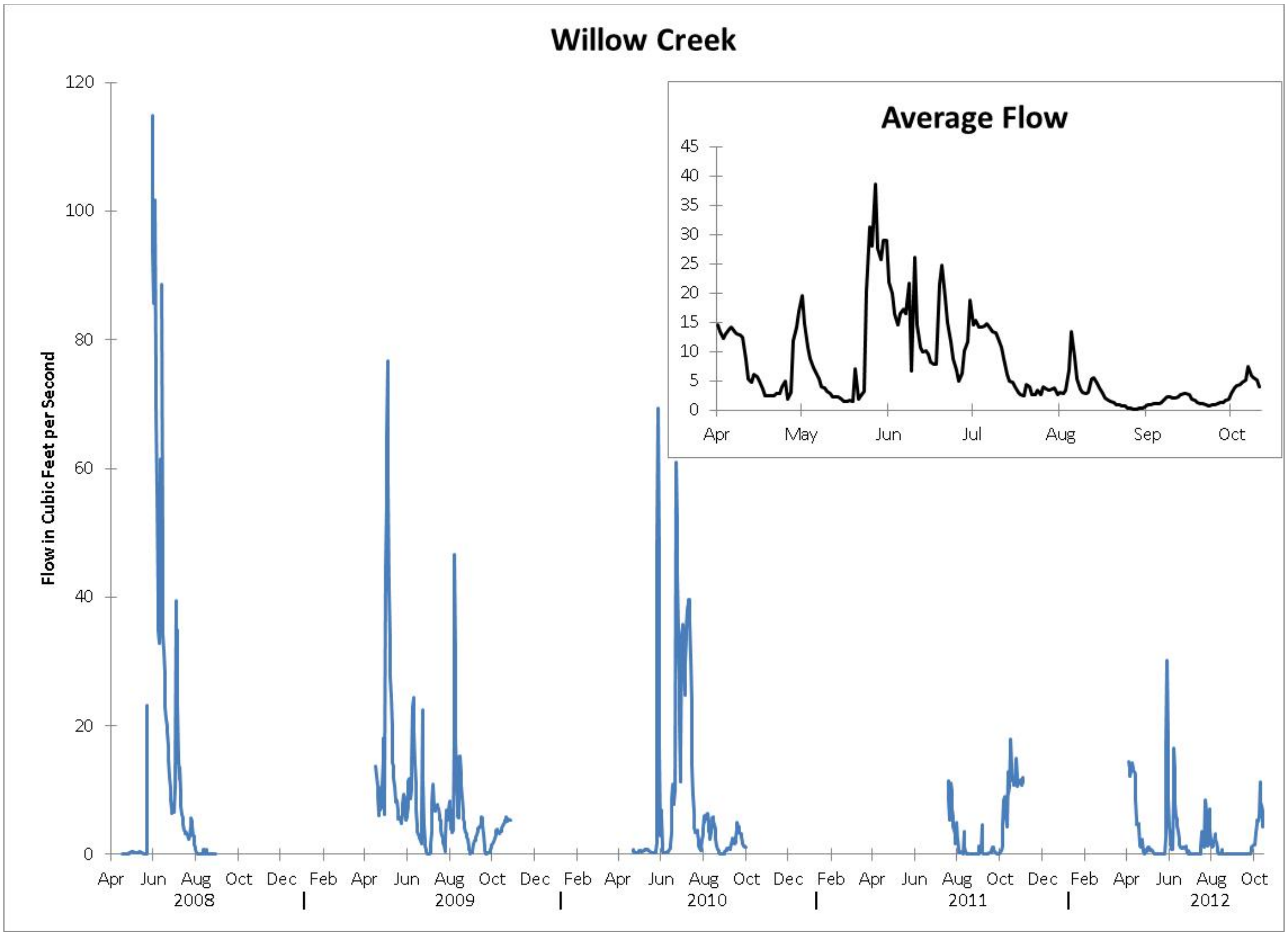


Figure D-15: Hydrograph of Willow Creek and period of record average flow (2009-2012).

The recorded largest peak flow of 114 cfs occurred in 2008, the gage was lost due to high flows following the recorded peek. The average peak flow was 38 cfs and the POR average flow is 7 cfs. The average annual volume passing the gage is 2,677 acre-feet. Spring runoff in May and June make up 55% of the seasonal volume

Muddy Creek

The Muddy Creek gage is located south of the Town of Collins. The drainage area is 426 square miles and the mean elevation of land above the gage is 4,280 feet. This gage is representative of conditions found in the lower reaches of the creek and contributions to the Teton River. Irrigation diversions are located above the gage. Muddy Creek is used to distribute stored irrigation Teton River water from Bynum Reservoir and water (Muddy Creek and Teton River) is exported out of the watershed by the Brady Irrigation Company.

Seasonal data was collected from 2009 to 2012. A hydrograph of daily average flows and study period averages illustrate erratic peaks and low flow periods (Figure D-16). Muddy Creek flows are derived from precipitation, snowmelt from the Rock Mountain Front and surrounding prairie, and irrigation storage. Flows at this location are elevated during: runoff (May), precipitation events or times of reduced irrigation demand. Muddy Creek flows are reduced by irrigation diversions and lower water supply conditions during the summer. The relationship between flows at the Muddy Creek gage and the use of the creek to distribute stored water is unclear. The data suggests the majority of storage water does not make it to the gage.

The gage was damaged during runoff in 2011; missing data was not able to be estimated due to the complexity of irrigation withdrawals from the system.

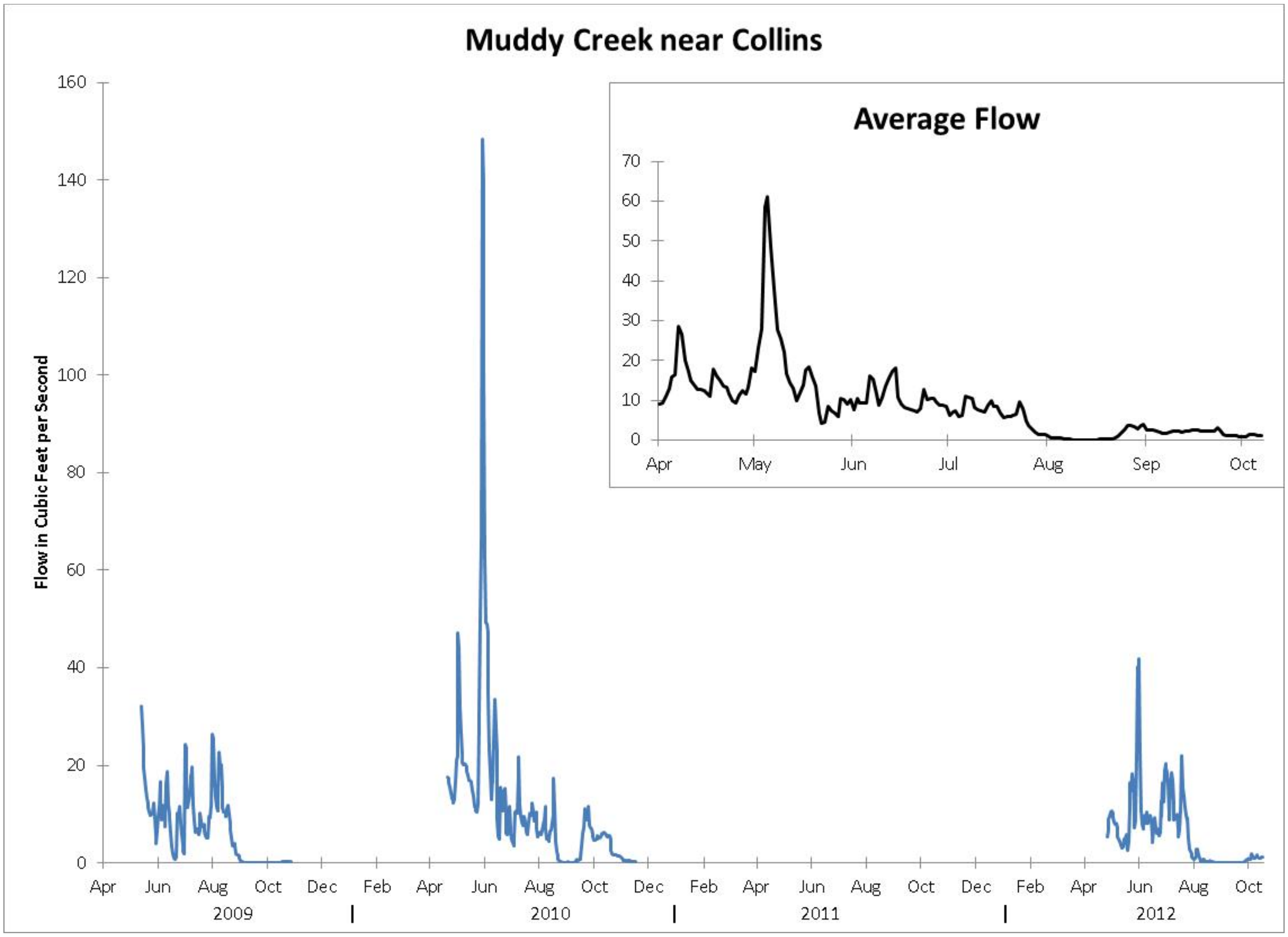


Figure D-16: Hydrograph of Muddy Creek and period of record average flow (2009 -2012).

The recorded largest peak flow of 148 cfs occurred in 2010. The gage was lost in 2011, it is estimated that flows exceeded 148 cfs in 2011. The average peak flow was 61 cfs and the POR average flow is 8 cfs. The average annual volume passing the gage is 3,239 acre-feet. Spring runoff in May and June make up 60% of the seasonal volume

Ground Water Data

Manual ground water measurements made on the Lower Teton River by DNRC Staff

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	Depth to Ground Water from Top of Casing in Feet							
Date	**Teton Well 1**	**Teton Well 2**	**Teton Well 3**	**Teton Well 4**	**Teton Well 5**	**Teton Well 6**	**Teton Well 7**	**Teton Well 8**
6/6/2008	7.73	6.03	10.74	3.25			30.13	
6/25/2008	7.78	6.50	11.34	4.78			30.21	
5/28/2008	8.03	6.10	9.76	1.80			30.28	
7/8/2008	8.14	7.22	11.51	1.86			31.80	
4/29/2008	8.56	7.40	12.24	3.81		11.35	30.24	
4/16/2008	8.61	7.50	12.38	3.93		11.37	30.58	
5/14/2008	8.65	7.46	12.21	6.02		11.56	30.55	
7/22/2008	8.69	8.28	12.18	3.60		11.54	31.84	
10/17/2008	8.80	7.49	12.20	7.94		11.57	29.82	
9/30/2008	8.93	8.18	12.29	6.00		11.62	31.30	
9/16/2008	8.95	7.32	12.27	5.45		11.58	30.86	
8/5/2008	8.98	8.71	12.75	0.13		11.92	31.98	
8/28/2008	9.41	8.82		5.15		12.50	30.32	
8/19/2008		8.46	12.85	5.71		12.02	32.04	
4/20/2009	7.92	6.57	11.65	6.76			29.61	11.93
5/18/2009	8.73	7.26	12.44	8.11			29.54	12.08
6/1/2009	8.04	6.68	11.85	6.00	4.93	11.07	31.20	11.99
6/12/2009	8.12	6.95	11.68	3.18	3.74	11.07	29.97	12.18
6/29/2009	8.60	7.28	12.11	4.65	7.93	11.38	31.30	12.35
7/14/2009	8.86	7.58		2.48	4.73		29.86	12.43
7/28/2009		8.47	12.33	4.22	8.00		33.13	12.44
8/11/2009	9.08	7.97	12.11	5.15	9.12	11.61	31.37	12.52
8/25/2009	9.17	7.95	12.33	0.00	9.06	11.85	31.37	12.75
9/22/2009	9.32	8.58	12.54	6.40	8.13	12.05	31.53	
10/19/2009		7.51	12.30				29.80	

Table D-2: Manual depth to ground water measurements made by DNRC staff.

Appendix E: Soil Conservations Service Diversion Estimates

The alternative to estimating non-decreed diversions is using data from the Soil Conservation Service (SCS, now known as Natural Resource Conservation Service) provides a method for estimating irrigation diversions based on irrigation and conveyance system efficiency.

The SCS 1978 “Water Conservation and Salvage Report for Montana” indicates that in Teton County: the ditch conveyance efficiency was 35% (65% of the diverted water was lost in irrigation ditches) and the farm efficiency was 55% for flood irrigation (45% of water applied to a field was not consumed). Farm efficiency of center pivots was estimated as 80% percent (Ashley and Others). Chouteau County numbers are 50% ditch conveyance efficiency and 45% farm efficiency.

Using this methodology a diversion rate of 8 acre-feet per acre is estimated and this value would exceed the available water supply. The SCS data-based diversion estimates are for the summation of all diversions in the specified drainage or area. This number cannot be used as an estimate of the total diversion diverted volume because the method does not take return flows into account. Irrigation water is typically reused and recycled as it flows downstream, especially with flood irrigation. Much of this “lost” irrigation conveyance and farm delivery water will eventually come back to the system as return flow.

Appendix F: Z-Scores Comparing Surface Runoff, Groundwater Levels, and Precipitation

Teton River Basin Runoff

Runoff from Teton Basin, upstream from the Teton River at Highway 287, is dominated (Figure F-1 and F-2) by spring snowmelt/precipitation events with the normal, peak-runoff season extending from April through July. Annual discharge of the Teton River below the South Fork is significantly larger than that of the spring creeks; in a typical year, runoff to the Teton River as it leaves the Rocky Mountain Front, is five to 40 times larger than that of the spring creeks and roughly five times larger than streamflow measured near Dutton and Loma (Figure F-1). Since much of the discharge of the Teton River below South Fork is diverted near the mountain front, the Teton River downstream is fed by precipitation, groundwater discharge and irrigation drainage for much of the year.

An early spring rise occurs in February on the lower-Teton, mainstem stations (Dutton and Loma) and on the spring creeks (Figure F-1); this rise is due to an early period of "spring thaw" and precipitation. From January through June, mean-daily discharge of the Upper Spring Creek gage varies from about 2.5 cfs to 4 cfs Figure F-2). Discharge at the Lower Spring Creek gage varies from about 3 cfs to 7 cfs and follows the general pattern of the Upper Spring Creek station. Starting approximately the second week in July, discharge at the Lower Spring Creek station drops below that of the Upper Site; this reflects diversions and depletions of streamflow by irrigation between the two stations, with the largest diversion/depletion in August of about 2 cfs. Within the period, 5-15-2009 to 10-14-2014, 2011 stands out as a very wet year (Figure F-1) with a larger spring rise, and longer duration peak-runoff period for mainstem and spring creek stations.

The spring creeks receive inflow from low-elevation snowmelt, precipitation and shallow groundwater recharge. The channel between the Upper and Lower Spring Creek stations lies along the contact between Quaternary-Tertiary terrace deposits to the east, composed of gravel, sand and silt, and Cretaceous shale and siltstone deposits to the west (Figure 4—main report) . The Teton River, which lies immediately east of the spring creek channel, contributes significant recharge through shallow groundwater flow.

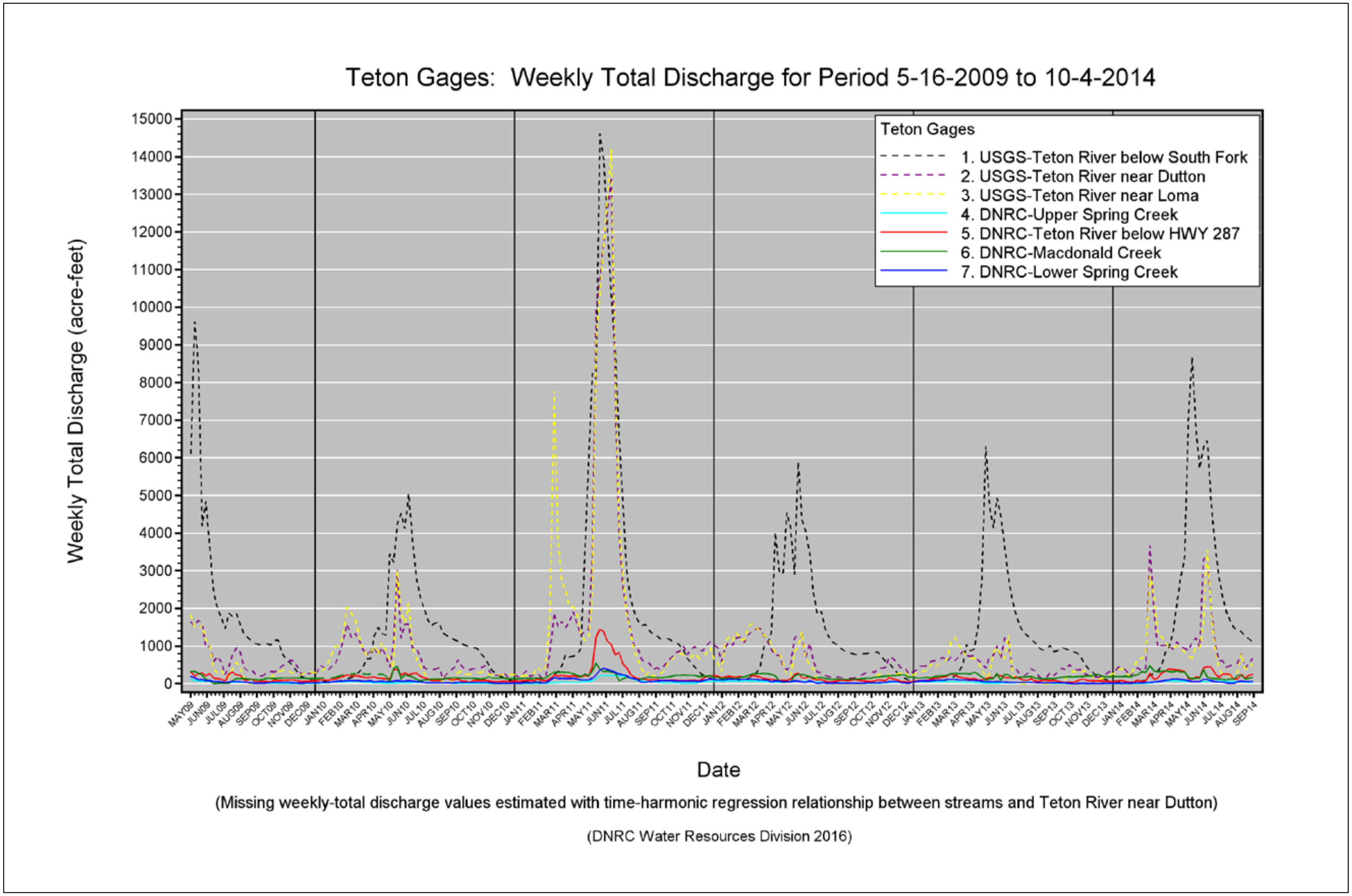

Figure F-1. Weekly total discharge (acre-feet) of Teton River Basin stream gaging stations (5-16-2009 to 10-4-2014)

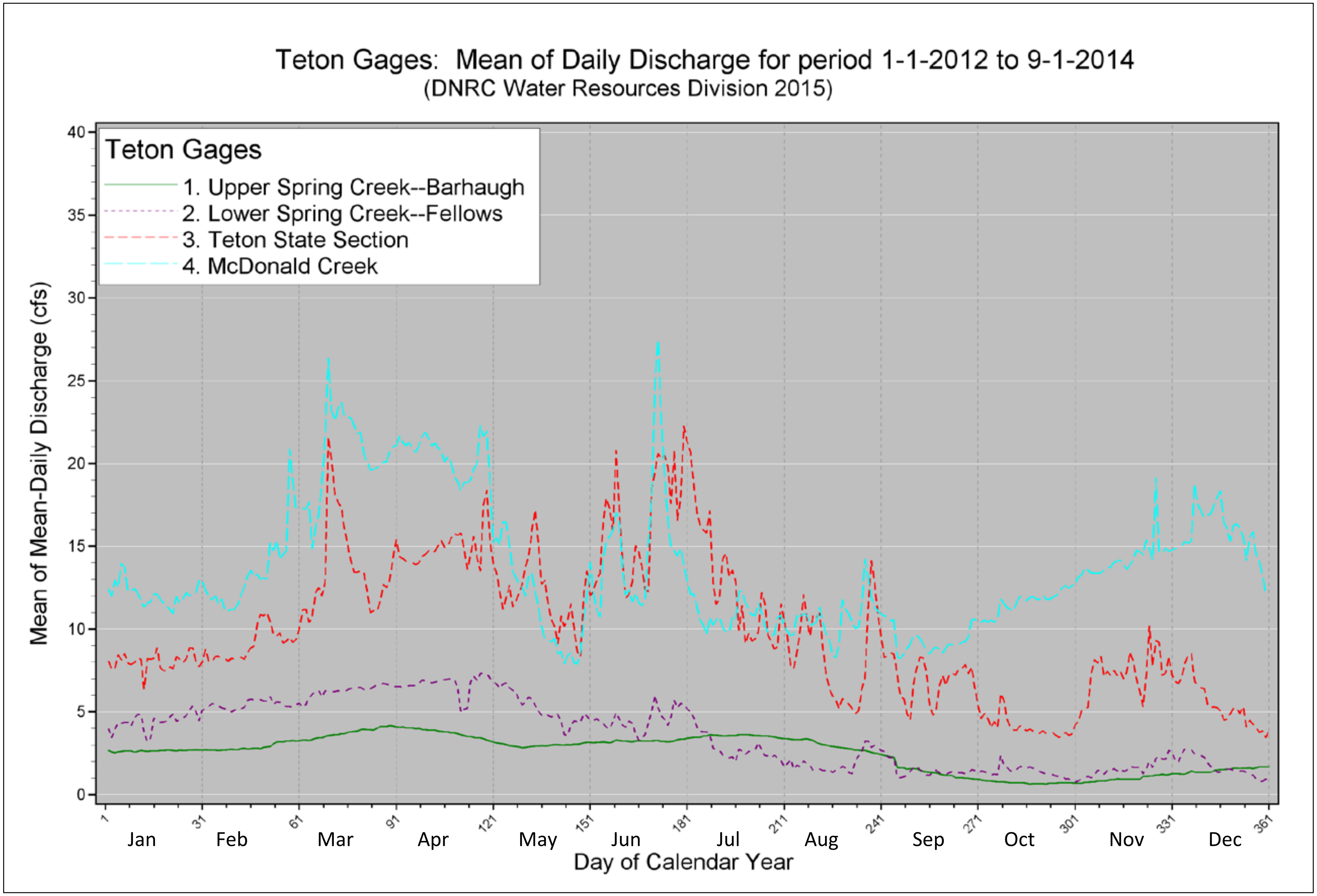

Figure F-2. Variation in mean-daily discharge at selected locations in the Upper Teton River Basin (2012-2014)

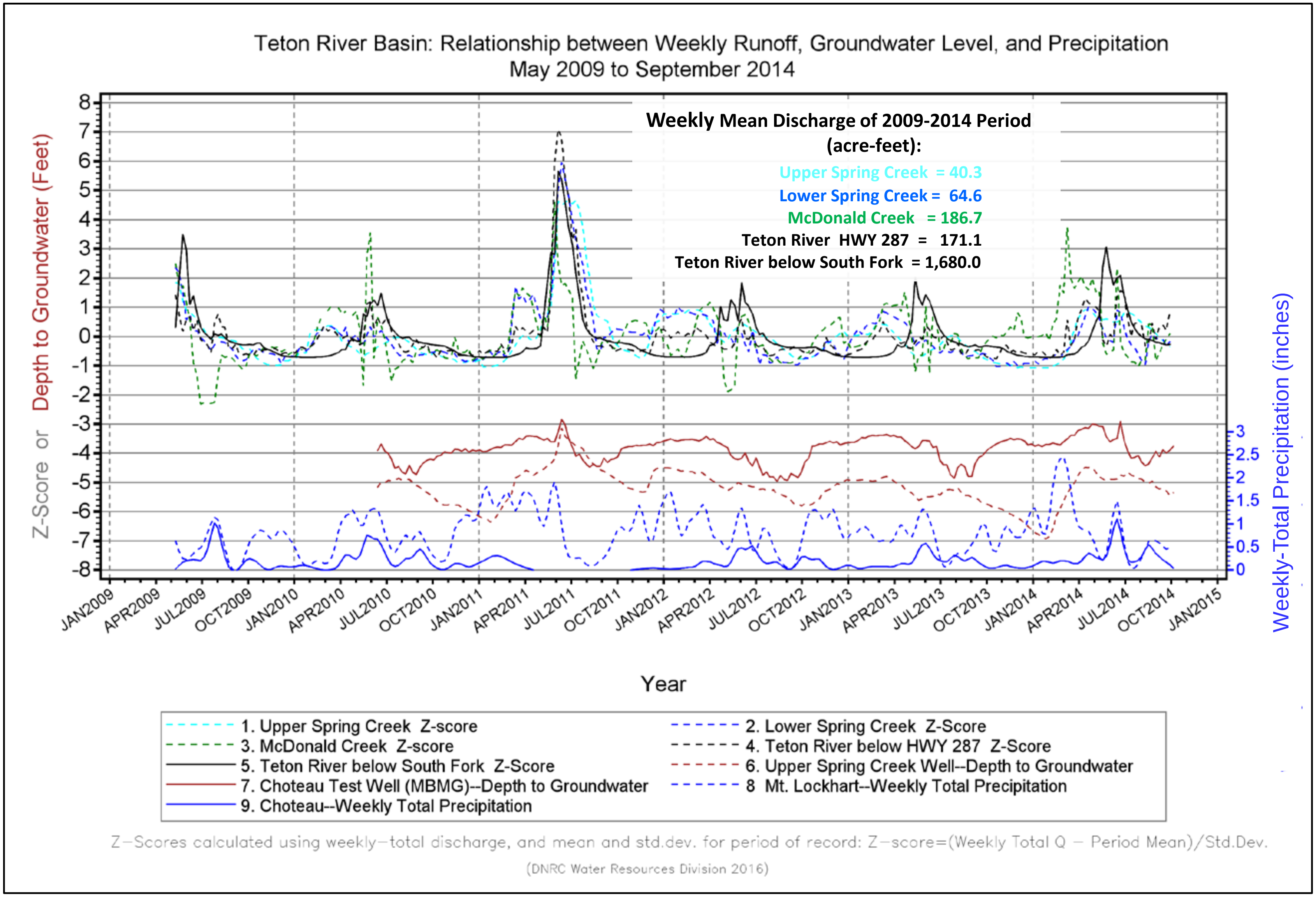

Figure F-3. Relationship between weekly, surface runoff, groundwater levels, and precipitation in the Teton River Basin.

Z-Scores

To better understand the temporal relationship between elements of mainstem and spring creek runoff, graphs were plotted that show fluctuations in weekly precipitation, shallow groundwater levels (at weekly increments), and spring-creek, surface flow. Because of the scale difference (Figure F-1) between discharge of the spring creeks, surface flow of Teton River below South Fork (upstream of the spring creeks), and Teton River below Highway 287 (downstream from the spring creeks), the data were re-scaled (i.e. normalized) by calculating standard scores (z-scores):

$$z = \frac{X - \mu}{\sigma}$$

$$where\ z = z - score$$
$$X = weekly\ discharge,$$
$$\mu = mean\ of\ period\ total$$
$$\sigma = standard\ deviation\ of\ period\ total$$

Z-scores measure how many standard deviations above or below the population mean an individual discharge observation is. Since standard deviation is a measure of how far individual observations vary from the mean, plotting z-scores over time gives a measure of how variable streamflow is over time; a z-score plot also re-scales the data so that temporal comparison of variation between station, with very small discharges and stations with very large discharges, is possible.

Figure F-3 shows z-scores for the mainstem Teton River stations and the spring creeks (May 2009 to September 2104); in addition the depth to shallow groundwater (near Choteau and near the Upper Spring Creek station) is shown on the left vertical axis, and precipitation at upper elevation (Mt Lockhart) and lower elevation (Choteau) is given on the right vertical axis. Normally z-score observations vary between -3 and +3; year 2011 stands out as unusual with z-scores ranging from 5 to 7 for several locations.

Several patterns in runoff are apparent in Figure F-3:

1. Annual runoff at all stations is dominated by snowmelt runoff that occurs between May and July; streamflow then declines in late July to October; in November flow begins to increase and steadily increases until the next spring rise;
2. The spring creek's peak runoff period is preceded by a period of elevated flow that occurs in March and May in response to precipitation, lower-elevation snowmelt, and ground water discharge;
3. The depth to shallow groundwater is relatively stable near Choteau -4.0 (±0.5) feet and the Upper Spring Creek -5.0 (±0.5) station ; water levels at both stations follow a similar pattern of increasing and decreasing elevation and seasonal variation. Increasing or stable elevations occur in November-May and begin declining to a seasonal low in September and October. Upper elevation precipitation contributes to this overall pattern, but it is not clear if precipitation occurring as rain is a direct influence through shallow groundwater recharge/discharge, or a more watershed scale process that increases Teton River mainstem flow, which in turn recharge the spring creeks surface flow.

Even though the Upper Teton River is not connected via surface water to Spring Creek, McDonald Creek, and the Teton River near Choteau, the 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 into the shallow aquifer during high-flow periods (spring snowmelt). Flows increase on Upper Spring Creek, Lower Spring Creek, and the Teton River below Hwy 287, from December to March; this increase is independent from flows on the Teton River at the USGS gage below the South Fork, and is related to water flowing into Springhill Reach. Other confounding factors, (diversions, precipitation, prairie snowmelt, and irrigation return flows) partially obscure these relationships. However, looking at the five years of data presented, a repetitive pattern is evident.

Because 2011 was a large runoff year and has the potential to skew results for other years, z-scores for individual calendar years were calculated and are plotted in Figures F-4 to F-9. Figure F-4 shows the period May 10, 2009 to December 31, 2009. All the stations (mainstem and spring creeks) have the largest positive deviation from the mean in May and June and then decline until the middle of July. The Upper and Lower Spring Creeks decline steadily throughout the remainder of the year (August-January), with McDonald Creek showing a slight positive increase in October through December. The Teton River below Highway 287 has a strong positive Z-score from mid-July through mid-August that is probably related to upper and lower-level precipitation over the same period.

The graph for 2010 (Figure F-5) shows the early spring rise on the spring creeks and Teton River Highway 287 station, but not for the Teton River below South Fork; it is possible that this is an artifact of the missing record estimation procedure[1]. The spring rise begins in February and extends through April, and does not appear to be related to precipitation during that period. Peak runoff is subdued (May-July) and beginning in August all stations begin a gradual decline to baseflow in November-December.
Patterns of variation are similar in 2011, 2012, 2013 and 2014; however in 2011 (FigureF-6) the early spring rise occurs over a narrower period (March-April) and is less pronounced. Weekly-total precipitation (Mt. Lockhart NRCS) was significant and contributed to the large flows of 2011 (Figure F-6).

Variation in shallow groundwater levels occurs due to recharge from the Teton River, irrigation recharge and return flow, and local precipitation. Examination of groundwater-levels from July 2010 to October 2014 shows general correlation in increasing and decreasing levels between the two sites, with the Upper Spring Creek well showing the greatest range of fluctuation and a stronger association with precipitation events. Ground-water levels are generally highest in March to June, decline over the recession part of the surface hydrographs to a low point in August-November, and then gradually climb back to previous March levels. Visual inspection of the ground-water level hydrographs indicates seasonality but no obvious trend in elevations over the 2009 to 2014 period. The Upper Spring Creek well trace suggests a decline of about 2 feet between January 2012 and January 2014, but water levels had fully recovered by April 2014.

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[1] The Teton River near Dutton was the only station with a continuous record that could be used to estimate missing discharge records for the Teton River below South Fork (Dalby 2016). The estimated pattern of runoff at Dutton is somewhat replicated in the estimated missing records of the Teton below South Fork station; consequently there may be a spring rise, but the estimation method does not capture it.

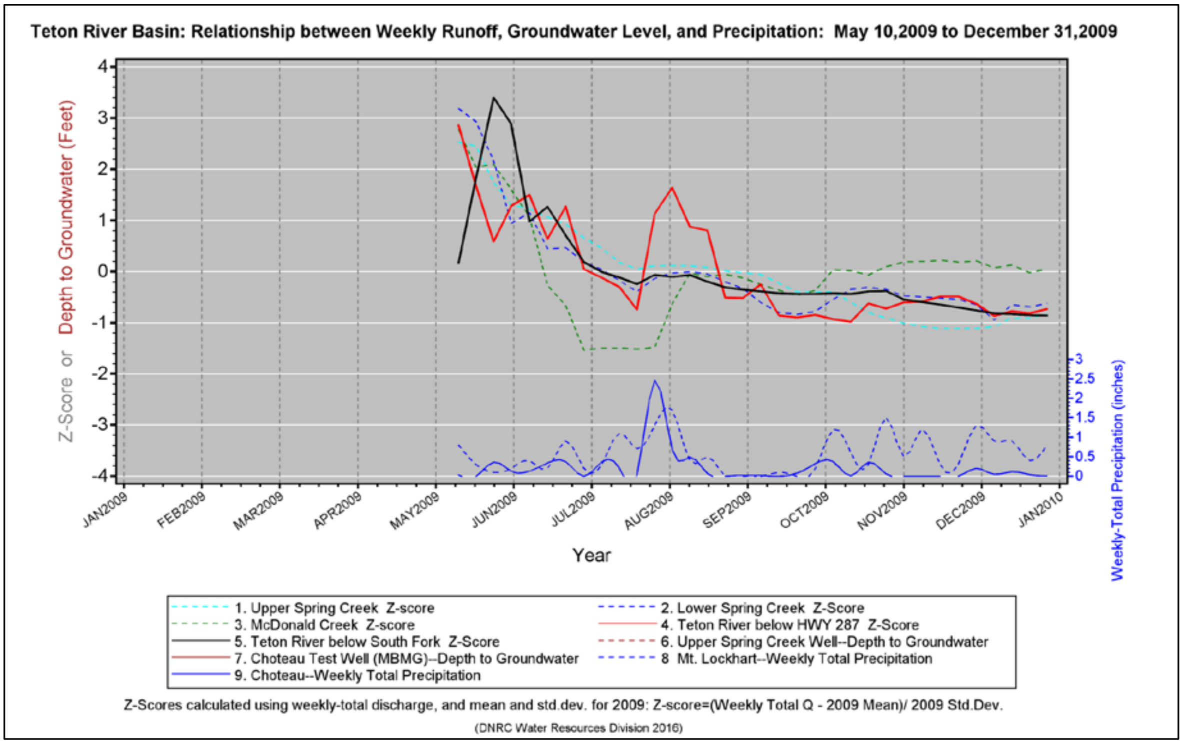

Figure F-4.

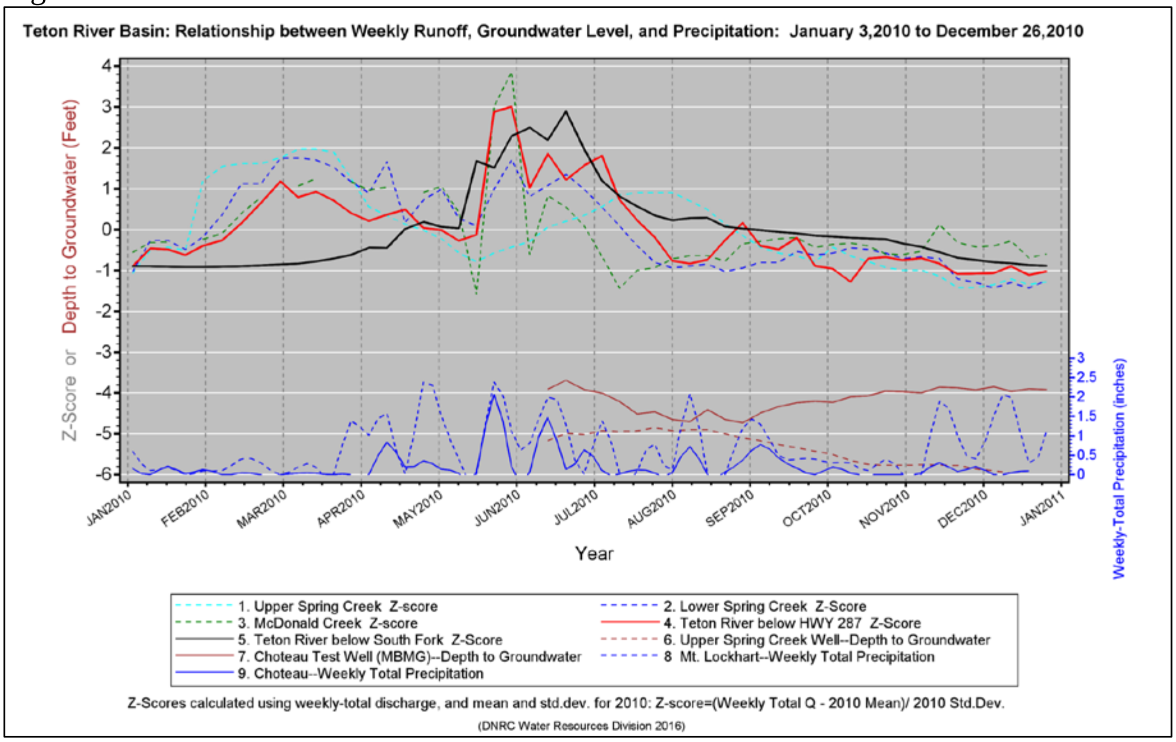

Figure F-5.

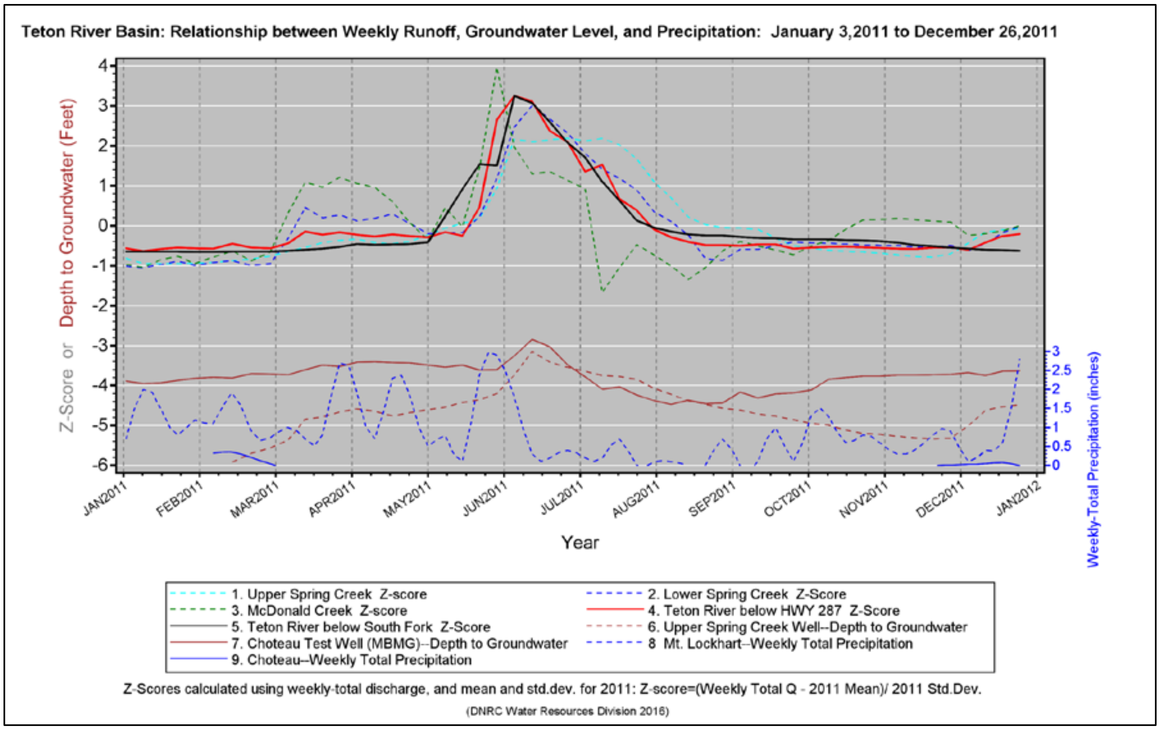

Figure F-6.

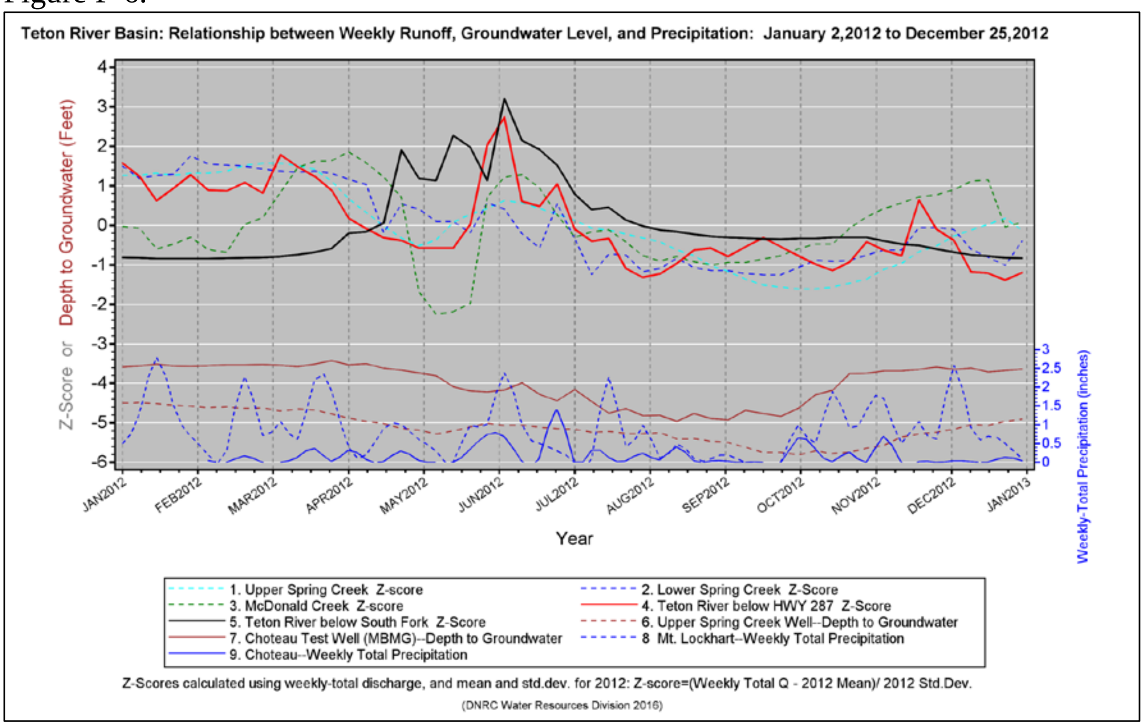

Figure F-7.

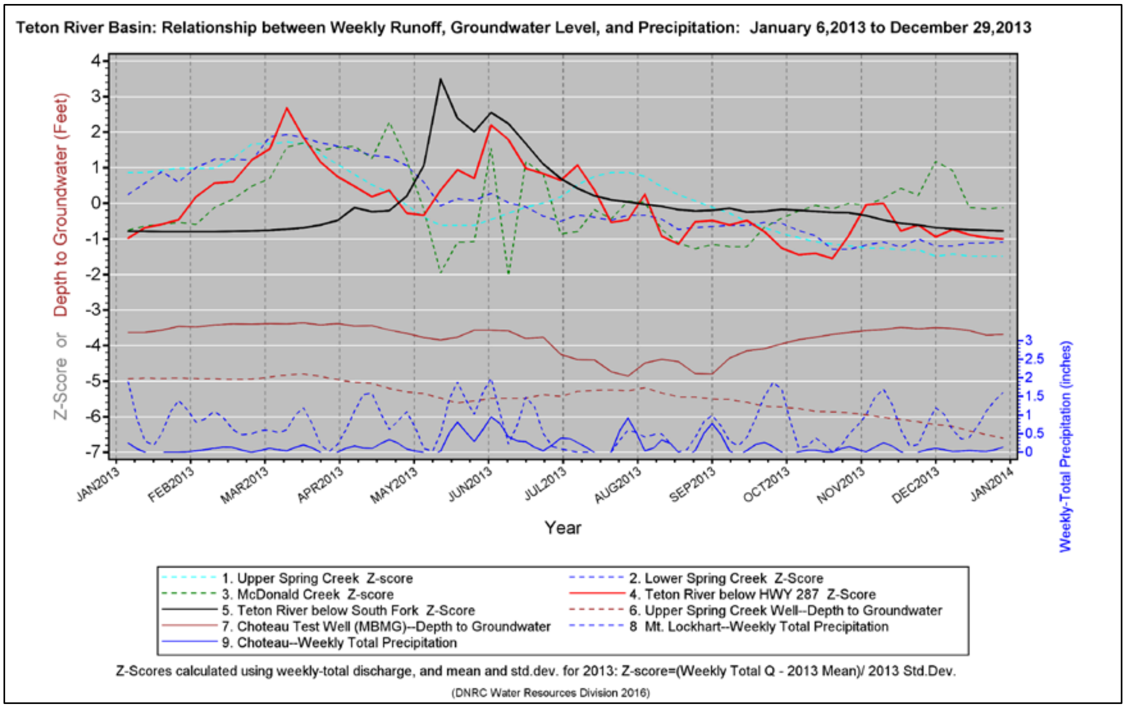

Figure F-8.

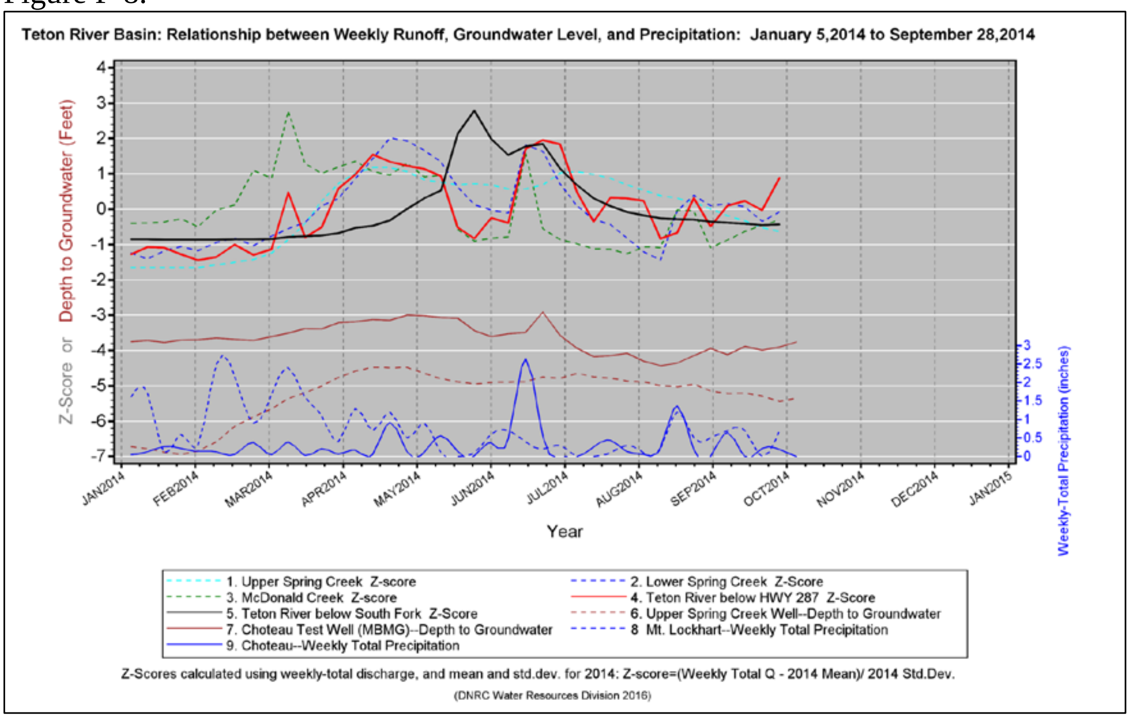

Figure F-9.