YELLOWSTONE RIVER HYDROGRAPH TRENDS, WATER RIGHTS AND USAGE

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ABSTRACT

The Yellowstone River and its tributaries are an important case study for water struggles in the highly arid western landscape. In the following chapters I: 1) evaluated seven variables used to characterize the volume and timing of discharge in the Yellowstone River and tributaries for long term (1898-2007) and more recent trends (1970-2007) using 18 USGS stream gauge stations, 2) quantified all current (2008) water rights in the greater Yellowstone River Basin, evaluated trends in water use, and conducted a physical inventory of all surface water withdrawals from the Yellowstone River and tributaries, and 3) assessed, in a general way, water management needs in the Yellowstone River Basin as discerned from the results in the previous chapters and in relation to the needs of native fishes and other biota in the river and provided recommendations for improved Montana water management to benefit water users and native fish species. Declines in volume and magnitude of annual and seasonal discharges are present in the basin, more so in areas where there are no water storage facilities. Timing of flows are occurring earlier in the year throughout the basin, leaving less water in the later summer and fall when water demands are the greatest. Rights to water greatly over allocate the water resources in the basin, though some rights can be considered duplicate and non-consumptive. The estimate of water use and the physical inventory reveal issues of potential resource misuse. There are numerous changes in water policy Montana water managers should consider if water is to remain available in the Yellowstone River Basin.

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DEDICATION

This thesis is dedicated to my best friends, Eric Blind, Grandpa Coutts, and my wife Jenny.

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INTRODUCTION

In the twenty-first century, increasing demand for the limited supplies of water is expected to play an important role in the economic development and quality of life in the Western United States (Baron et al. 2002, Poff et al. 2003). Since 1950, demand for water for municipal, industrial, irrigation, hydropower and other uses in the United States increased by as much as 100% through 1970 and another 127% through 2000 (Kenny et al. 2009). It is projected that over the period 2000-2050 water demand will continue to increase in the arid West, where only 2% of the global freshwater runoff occurs, and development and human population continue to increase (Postel 1996; Vorosmarty et al. 2000; Baron 2002; IPCC 2007; Bates et al. 2008; Standish-Lee et al. 2008). In addition, projected changes in climate in the western United States are expected to result in increased air temperatures and longer growing seasons, placing further demands on water supplies (Bates et al. 2008). Average temperatures in the West have reportedly risen by 1-3ºC (2-5ºF) in the twentieth century, with some models projecting increases from 2-7ºC (4-13º F) by 2100 (IPCC 2007). Shortage of water in the west is projected to be especially acute in the more arid regions (IPCC 2007; Bates et al. 2008), including portions of Montana and western North Dakota. This region of the upper Great Plains is also the location of major energy development activities for oil, natural gas, and coal.

Most of the important western rivers where water demands are projected to increase contain ecologically distinct native fish communities (Mac et al. 1998; Kenney 2003). Fish species in such rivers often have local or restricted distributions. They have also evolved specialized adaptations to the highly variable discharges, high suspended sediment, high conductivities, and other common aspects of such habitats. For example, distinct fish faunas have been described from arid regions of the Colorado River (Mac et al. 1998), Rio Grande (Levings et al. 1998), and Missouri River basins

(Galat 1999). In all of these locations, water development has negatively impacted water quantity and water quality available to native faunas, imperiling the native fishes far more than what is occurring in the eastern United States (Mac et al. 1998).

Increasing water withdrawals for expanding irrigated agriculture, industries and municipalities have the potential to affect both the quantity and quality of available habitat for the native faunas. For example, declines of numerous native fishes of the arid west such as the Colorado pikeminnow *Ptychocheilus lucius,* humpback chub *Gila cypha,* and the bonytail chub *Gila elegans* have been attributed in part to declines in water quantity and associated habitat degradation caused by anthropogenic factors (Mac et al. 1998; Desert Fish Habitat Partnership Workgroup 2008; USFWS 2009). Numerous studies have shown that these water withdrawals may create especially acute problems during the low water periods of summer, which is also often the peak period for water demands for irrigation and other uses (Mote et al. 2005; Schindler and Donahue 2006; Rood 2008).

In assessing the extent and impacts of water use on native fishes of Montana, one serious limitation is the lack of adequate documentation of the quantities of water withdrawn seasonally and annually. In Montana, monitoring water rights rests almost solely with the water users as the issue of overuse or misuse only becomes evident during low flow years and water rights not being fulfilled. It is the water users that report and sometimes prove misuse, it is Montana's Department of Natural Resources and Conservation (DNRC) that imposes penalties or orders corrective actions if misuse can be proven. Lack of accurate data on withdrawals makes it difficult or in many cases impossible to link withdrawals with hydrographic changes and then to fish community changes. Long term accurate water use and withdrawal data are needed to assess all aspects of surface and ground water supplies to evaluate changes in the availability over time, to forecast trends, and to assess the effectiveness of water resource management models (Taylor and Alley 2001).

The Yellowstone River, one of the least regulated large rivers in the arid west with no storage dams on the mainstem, provides an important source of water for irrigation, industrial, energy, and municipal purposes to Wyoming, Montana, and North Dakota. The basin contains nearly 505,857 hectares (1.25 million acres) of irrigated agriculture (Stermitz et al. 1963), overlying approximately 45.4 billion tonnes (50 billion tons) of strippable coal (Boris and Krutilla 1980). The river provides municipal water for the Montana municipalities of Billings, Laurel, Miles City and Glendive (Sobashinski and Lozovoy 1982).

The river also provides important recreational and ecological benefits. The upper Yellowstone River and tributaries are recognized for their world-renowned blue ribbon trout fisheries, while farther downriver, warmer waters provide other highly valued sport fishing opportunities (Haddix and Estes 1976; Figure 1.1). The Yellowstone is also an important ecological repository for several fish species listed as endangered (i.e., the pallid sturgeon *Scaphirhynchus albus*) or of special concern (i.e., paddlefish *Polyodon spathula*, blue sucker *Cycleptus elongates*, sturgeon chub *Macrhybopsis gelida*, northern redbelly dace *Phonixus eos,* finescale dace *Phonixus neogaeus,* and the pearl dace *Margariscus margarita*). It is therefore important to balance water related development in the Yellowstone with instream flow requirements for sustaining fish populations and other aquatic life.

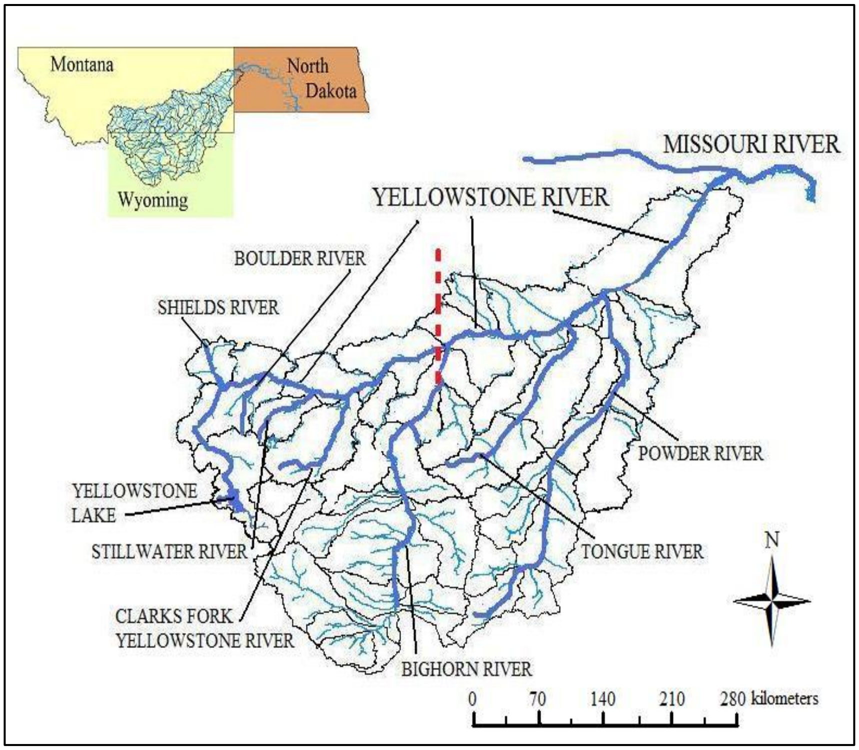

Figure 1.1 Yellowstone River Basin and major tributaries, including the division (hatched red vertical line) between the designated upper basin and lower basin.

Major concerns exist for the future of the river and its biota. The State of Montana and the landowners along the watercourse are in the best position to ensure that sufficient water is reserved for appropriate and essential stream-flow, including for native fishes. Little research, however, has been done to document the direct effect consumptive use practices have on the hydrograph of the Yellowstone River, the way in which water is withdrawn, how accurately a water withdrawal is measured by each user, or the users' compliance with water law. The United States Geological Survey estimated surface water withdrawals in the Yellowstone River Basin (YRB) in 1990 at approximately 26 million m^3/day (300 m^3/s (10,633 ft^3/s) including municipal, self supplied domestic, commercial, industrial, thermoelectric power, mining, and agriculture (Miller and Quinn 1997). Most but not all of these withdrawals were consumptive.

Accurate information on irrigation water withdrawal is especially crucial because irrigation is the largest off-river use of water in the YRB. In 1981, approximately 90% of all water withdrawal in the basin was for irrigation, amounting to 1.85 billion m^3 (1.5 maf), which is approximately a 116.4 m^3/s (4,112 ft^3/s) reduction in flow, assuming the irrigation withdrawals occurred in the typical irrigation season between May 1st and October 31st (Department of Natural Resources and Conservation 1981).

The objectives of this study are to: 1) assess the long term trends and recent changes in the hydrograph of the Yellowstone River and its tributaries, including trends in magnitude and timing of peak flows, seasonal flows, and base flows; 2) inventory and quantify all current water rights for the Yellowstone River and its tributaries, including all state permitted water rights, all federal reserved and appropriated water rights, and all other water reservations held on the rivers; 3) inventory and quantify all withdrawals from the Yellowstone River and its tributaries; 4) update the physical inventory and compare actual use with permitted use of water in the basin; 5) identify water management needs in the YRB as discerned from the results of my research from the previous objectives and in relation to the needs of native fishes and other biota in the river. Findings of this work can inform future research to more thoroughly assess effects of present and future water demand and withdrawals on the native fish fauna.

STUDY SITE

The study area is the YRB of Wyoming, Montana, and North Dakota (Figure 1.1). The basin encompasses approximately 180,000 km² (71,000 square miles), of which 92,000 km² are in Montana (The Water Resource Division 1977). Average annual precipitation in the Montana portion of the basin is 38 cm (15 in.; Stermitz et al. 1963). The river originates in the Absaroka Mountains in Wyoming, flows north into Montana through Yellowstone National Park, and then northeast through the plains of eastern Montana where it joins with the Missouri River in extreme western North Dakota (Figure 1.1). The main channel contains several irrigation diversion dams, but is unregulated by large dams and reservoirs for its entire 1,080 kilometers, making it the longest free-flowing river in the lower 48 states (Watershed Profiles, no date). Major tributaries to the Yellowstone in upstream to downstream order include the Lamar, Gardiner, Shields, Boulder, Stillwater, Clarks Fork of the Yellowstone, Bighorn, Tongue, and Powder rivers (Figure 1.1).

The Yellowstone River mainstem and tributary discharges fluctuate greatly from year to year depending on snow accumulation and snowmelt runoff patterns. Mountain snowpack is the primary source of water; mainstem mean discharges are 5 to 10 times greater during spring runoff than during the fall and winter months. The mean annual discharge of the Yellowstone River near the mouth is 362 m³/sec (12,800 ft³/s; White and Bramblett 1993).

The river can be divided into three ecological zones based on fish fauna (White and Bramblett 1993). The upper coldwater or salmonid zone, inhabited by 16 fish species, extends from the headwaters to Big Timber, Montana near the confluence with the Boulder River. The transition zone, inhabited by both coldwater and warmwater fish species (38 species in all), extends from Big Timber to the confluence with the Bighorn River. The lower warmwater zone, inhabited by 51 fish species, extends from the Bighorn River mouth to the confluence with the Missouri River (Haddix and Estes

1976). In all, 56 fish species in 16 families inhabit the river, with 20 of the species being non-native. Though the pallid sturgeon is the only federally-listed endangered fish species, several others are listed by Montana as species of special concern, including, paddlefish, blue sucker, northern redbelly dace, finescale dace, pearl dace, and sturgeon chub (Galat 1999; Zelt et al. 1999).

Background on Yellowstone River water issues

The YRB and its water have a long history of usage by humans. Indigenous cultures have lived in the basin for more than 11,000 years (National Park Service, 2008). In 1805, Captain William Clark of the Lewis and Clark Expedition was the first to report on the Yellowstone River to European civilizations. By 1874 commercial river boats had begun to use the Yellowstone River, and by 1882 the Northern Pacific Railroad line was extended to Billings, Montana (Zelt et al. 1999). Human settlement increased in the basin in ensuing decades, resulting in increasing demands on the basin's water for mining and energy industries, irrigation, municipal uses, and more recently, recreation.

During the last century, development and manipulation of water resources within the basin for mining and energy industries, irrigation, municipal and other consumptive uses has altered the hydrograph of the river and its major tributaries. Over the period 1911-1960, the Yellowstone's annual discharge averaged 11.5 billion m^3/year (9.3 maf) whereas over the more recent period 1967-2006 it has averaged only 10.6 billion m^3/year (8.6 maf) (U.S. Geological Survey 2006). In the coming decades, increasing demand for extraction of the limited water will likely occur against a background of reduced water inputs (Mote et al. 2005; Rood et al. 2005; Rood et al. 2008), earlier runoff (Cayan et al. 2001; Stewart et al. 2004; Gibson et al. 2005; Stewart et al. 2005) and greater temperatures caused by climate change (Gibson et al. 2005; IPCC 2007). As a quasi-natural river, the Yellowstone in particular, with no large means of storage, may be strongly impacted. Water is received as it melts off and moves down the basin. There is little control to dampen the magnitude or delay the timing of flows in a system without dams and reservoirs.

Mining, oil and energy industries

The YRB is an area with immeasurable amounts of natural resources, many of them very valuable to energy development and with that require water in multiple areas of the extraction, transportation, and refinement processes. As of 2008, the majority of energy production and mining uses for water in the basin came from the Fort Union coal formation in eastern Montana, strategic metal production from the Stillwater Mining Complex of the Beartooth Mountains, and three oil refineries located along the Yellowstone River.

Commercial coal mining in the basin originated near Red Lodge in the 1880's (Zelt et al. 1999). Production and demand grew rapidly as the mining moved into the Powder River Basin by 1890, and increased greatly between 1915 and 1920 as other locations were developed (Zelt et al. 1999). Two tributary basins, the Tongue and Powder, are located over the Fort Union coal formation, which is the largest coal deposit in the United States with an estimated 45.4 billion tonnes (50 billion tons) of strippable subbituminous coal and lignite (Boris and Krutilla 1980). Water is often times used to extract, wash, sometimes transport, and to cool the steam used to produce electricity in coal fired power plants.

Metal mining in the basin historically produced gold, silver, arsenic, tungsten, copper, lead, zinc, and chromium (Hammarstrom 1993). The basin currently contains just a few of the most productive metal mines historically in either Montana or Wyoming (Zelt et al. 1999). Since the 1950's iron, chromium, uranium, and platinum have become the most important metal mining outputs (Zelt et al. 1999). For example, the Stillwater Mining Company extracts precious metals like palladium, platinum, rhodium, gold and silver. It is the only primary producer of palladium in the United States (2007 revenue: 619 million dollars; Stillwater Mining Company, 2008). Mining operations may use water for mineral processing and metal recovery, and sometimes to control dust.

Hydrocarbon production in the basin is a lucrative industry with three of the largest oil fields of the Rocky Mountain region located within its boundaries (Zelt et al. 1999). Commercial oil production began in the basin in 1884 with the Dallas oil field located in the Wind River Basin, Wyoming, with approximately ten other major fields being discovered within the Bighorn, Powder River, and Wind River Basins by 1928 (Zelt et al. 1999). The most common extraction method in the basin is hydraulic fracturing, or “fracking,” which involves injecting water, sand, and synthetic chemicals deep underground at high pressure, to break up shale rock and release oil and gas trapped inside and has the potential to damage aquatic systems. Fresh water is needed for modern fracking technologies in oil and gas production. Large volumes of more saline water created when extracting oil are in turn commonly discharged into streams, or forced back underground where they can leak into nearby groundwater (Zelt et al. 1999). To process the oil there are currently three oil refineries in Montana’s portion of the basin, two in Billings and one in Laurel with the capacity of refining 27,400 m^3/day; these also require freshwater to operate (Zelt et al. 1999).

Shortly before the end of the 20th century, another form of energy emerged in the vast oil fields and coal reserves in the basin. Coal-bed methane development represents another hydrocarbon-related environmental concern for Montana’s fish and wildlife, agriculture, and water quality (NRC 1996). The process of extracting this gas results in large quantities of highly saline water that is either discharged to the surface or injected underground, which can be detrimental to the receiving water body if flows are too low to buffer the effects (NRC 1996). This process is of major concern to Montana as Wyoming, which is upriver, has an estimated 20,000 wells pumping in the Powder River Basin with an estimated 8 to 80 liters of product water per minute depending on the well and with a projected increase to nearly 30,000 wells in total (Reddy and Jackson, 2009).

Agricultural uses

Agricultural activities in the YRB consists primarily of livestock production and irrigated and dryland crop production (Zelt et al. 1999). Most irrigated agriculture is located in the principal stream valleys along the Yellowstone River and its tributaries in Wyoming, Montana, and North Dakota. Typical irrigated crops in the basin are wheat, alfalfa, barley, hay other than alfalfa, corn, oats, and sugar beets listed in descending order of their average annual area in production (Zelt et al. 1999).

The YRB contains more than 505,900 irrigated hectares (1.25 million acres), 7,900 hectares (19,500 acres) in the Shields River basin, 9,700 hectares (24,000 acres) in the Stillwater River basin, 16,800 hectares (41,500 acres) in the Clarks Fork of the Yellowstone River basin, 188,200 hectares (465,000 acres) in the Bighorn River basin, 36,400 hectares (90,000 acres) in the Tongue River basin, 21,000 hectares (52,000 acres) in the Powder River basin, and 225,800 hectares (558,000 acres) along the mainstem of the Yellowstone River (Stermitz et al. 1963).

In 1997, nearly 26,000,000 m^3/day of surface water and 350,000 m^3/ day of groundwater were used for agriculture alone (Miller and Quinn, 1997). With all the other water uses in the basin (public supply, domestic, commercial, industrial, thermoelectric power, and mining) adding to less than 1 percent of the total withdrawn, agricultural water use needs to be frequently evaluated and monitored (Miller and Quinn, 1997).

Municipal uses

Municipal and domestic water use in the basin is largely from groundwater sources, and accounts for approximately 27 percent of the total groundwater use in the basin. Larger, surface water, municipal water works are present on the mainstem of the Yellowstone River and provide water to the Montana cities of Laurel, Billings, Miles City, and Glendive. Billings' municipal water plant is the largest of all; capable of supplying 246 million liters of water a day (65 million gallons per day) to nearly one hundred thousand people (City of Billings 2010). Municipalities in the basin have reserved water rights for future development that supersede both agricultural and fish and wildlife needs in times of low water throughout the basin. Development of future municipal water uses will depend on changes in water use efficiencies and population growth.

Fisheries and other recreational uses

There are also strong economic and ecological incentives for retaining water in the Yellowstone River for fisheries and other recreational uses. The upper and portions of the middle Yellowstone and its tributaries, including the Shields, Boulder, Stillwater and Bighorn Rivers, support world-renowned trout fishing. Trout fishing in Montana has been managed under a wild trout management policy since the 1970's, whereby all trout populations in the state's rivers are to be self-sustaining (MTFWP 2007). These fisheries were estimated in 2005 by Montana Fish, Wildlife and Parks (MTFWP) to generate about 196 million dollars in direct, day trip-related expenditures annually within Montana's economy, excluding various multiplier effects (MTFWP 2007). About 16 percent of all Montana angling in 2005, or 477,804 angler days, occurred in the rivers and reservoirs of the Upper Yellowstone River basin upstream of and including the Bighorn River, making it one of the state's most heavily fished waters (MTFWP 2007).

The lower Yellowstone River also supports popular recreational fishing for paddlefish, shovelnose sturgeon *Scaphirhynchus platorynchus*, sauger *Sander canadensis*, walleye *Sander vitreus*, channel catfish *Ictalurus punctatus*, northern pike *Esox lucius,* and burbot *Lota lota* (Haddix and Estes 1976). Paddlefish harvest alone has produced over 2.3 million dollars in direct (caviar) revenue since the 1990s (Montana Magazine 2006), which is a small fraction of the overall indirect economic value of the paddlefish fishery and other recreational fisheries in the basin. In 2005, MTFWP estimated that anglers spent 251.7 million dollars statewide on transportation, lodging, food, and other direct purchases, excluding license fees, in Montana (MTFWP 2007). It is estimated that with every dollar spent by the MTFWP Fisheries Program, anglers spend approximately eleven dollars benefiting local communities and the state's economy (MTFWP 2007).

The quasi-natural lower Yellowstone River is also a key ecological repository for numerous native species that have suffered declines throughout the Missouri River Basin due to habitat loss and declining flows (Bramblett and White 2001; USGS 2006b). These imperiled species include, but are not limited to, pallid sturgeon, sauger, sicklefin and sturgeon chubs, and blue sucker. Concern for three of these species is exemplified by the status of the federally listed pallid sturgeon; the sicklefin chub, sturgeon chub, and the blue sucker are classified as candidates for federal listing (Bramblett and White 2001; Welker and Scarnecchia 2004; USGS 2006b).

Historical water law and policy decisions

Yellowstone River water issues pertaining to usage and allocation in Montana date back more than a century, before statehood in 1889 (Water Resources Survey 1970). Although some believe that the Territorial Legislature adopted the Doctrine of Riparian rights, it was the state Supreme Court that held that riparian rights never prevailed in Montana and declared Prior Appropriation to be the valid Montana Water Right Law. The Riparian doctrine, a version of the common law of England, gave the owners of land bordering a stream the right to have that stream flow past their land undiminished in quantity and unaltered in quality and to use it for household and livestock purposes (Water Resources Survey 1970, page 2). The Doctrine of Riparian Rights had evolved in England and later in the eastern United States where annual rainfall is generally more than fifty centimeters (20 in.; Water Resources Survey 1970). Riparian law, however, only permitted a usufructuary right (i.e., the legal right to use and enjoy the benefits and profits of something belonging to another) to the landowners bordering a stream, restricting them from detaining or diverting the water, and also forbidding anyone from appreciably reducing the stream flow (Bureau of Land Management 2008; Water Resources Survey 1970).

In Montana, however, where mean annual precipitation is only about 38 cm (15 in.; Stermitz et al. 1963) miners and ranchers favored the Doctrine of Prior Appropriation, which allowed property rights to the water and permitted diversion and diminution of the streams (Water Resources Survey 1970). In 1921, the Montana Supreme Court declared the doctrine of Prior Appropriation to be the valid Montana water right law in *Mettler v. Ames Realty*, stating, “Our conclusion is that the common law doctrine of riparian rights has never prevailed in Montana since the enactment of Bannack Statutes in 1865 and that it is unsuited to the conditions here…”(Water Resources Survey 1970, page 2). Prior Appropriation, stating first in time is first in right, originated in California by the gold miners (forty-niners), and was used to divert water from the streams to mine gold. It permitted the early miners, as well as ranchers, to divert and diminish the stream flow.

Under the Doctrine of Prior Appropriation in Montana, water rights may be acquired by both riparian and non-riparian landowners. The doctrine allows the withdrawal of water regardless of the diminution of the instream flow. The seniority of the right is determined by the date the water was put to beneficial use; i.e., first in time is first in right. The right is strictly limited to the use (as opposed to the ownership) of the water. Stream waters are the property of the State of Montana and the appropriator acquires only a right to use the public resource, which must be beneficial, i.e., usefully employed by the activities of humans. Ownership of the water right acquired is considered a property right, in which the owner of the right may therefore not be deprived of it, except by due process of the law, and it requires just compensation if taken by the government (Water Resources Survey 1970), however there is considerable uncertainty in the law concerning what it means to “take.” These latter provisions served strongly to benefit those promulgating the initial Prior Appropriation Doctrine in the state, many of whom had individual interests in acquiring and maintaining control over water usage. In terms of how river water may benefit fisheries or aquatic life for all of Montana’s citizens, a historical water right thus confers some specific preferential benefits to the individual owner of the historical right over and above those of a typical Montana citizen without such a right, yet concerned with maintaining river flow for aquatic life.

In 1950, the Yellowstone River Compact was ratified by Montana, North Dakota, and Wyoming as a mechanism for allocating the water of the Clarks Fork of the Yellowstone, Bighorn, Tongue, and Powder Rivers among the states. Under the Compact, to all tributaries the following rules applied: 1) all rights existing before January 1, 1950 in each state were not affected by this compact and were allowed to maintain their status quo, with no future allocation of water diverted from the YRB without consent from all three signatory states, and 2) existing and future domestic and stock water uses, including reservoirs, with a capacity less than twenty-five hundred cubic meters (20 acre-feet) were exempted from the Compact (YSR Compact 1950). The compact allocated the unused and unappropriated flows of interstate tributaries as of January 1, 1950 to Wyoming and Montana as follows: Clarks Fork of the Yellowstone River: 60% to Wyoming, 40% to Montana; Bighorn River:

80% to Wyoming, 20% to Montana; Tongue River: 40% to Wyoming, 60% to Montana, and Powder River: 42% to Wyoming, 58% to Montana. North Dakota was a signatory to the Compact but did not receive any specific water allocation, even though the lowermost 24-km of the river, a key ecological zone and spawning area for several native fish species such as shovelnose sturgeon and paddlefish (Firehammer et al. 2006), is in North Dakota.

In the years following ratification of the Compact, the Yellowstone River has been confronted by the same factors associated with human economic development that were threatening nearly all other large rivers in the arid west. A site upstream of Livingston, Montana, in Paradise Valley had been identified by the United States Bureau of Reclamation (USBR) as a suitable location for a dam, and a dam was nearly built there in the 1970s (Schneider 1985). Several factors kept the Yellowstone River from being dammed. First, there was already considerable irrigation in the valley without the dam. Second, flood control could not be justified with most of the damaging floods impacting the basin farther down the Missouri River. Third, the river had a national reputation as being one of the best trout fishing rivers in the United States (Reisner 1993). The proposed dam on the Yellowstone River mainstem was not built, although two tributary dams, Yellowtail Dam on the Bighorn and Tongue River Dam on the Tongue River, were built. The Tongue River Dam near Decker was built by the State of Montana in 1940 to provide irrigation and flood control for the surrounding area. Yellowtail Dam near Hardin was built by the USBR in 1966 to provide irrigation, flood control, and hydroelectric power (Pick-Sloan Missouri Basin Program Yellowtail Unit 2008). Thirty-one percent of the entire Yellowstone Basin (mostly above Yellowtail Dam) is upstream of storage reservoirs (Koch et al. 1977). The Yellowstone River currently does not have any storage reservoirs on its mainstem, but six run-of-the-river diversions (structures built to increase the hydraulic head but with little to no storage capacity) were constructed on the mainstem during the period 1905 to 1940: Huntley Dam (rkm 566; completed 1934), Waco-Custer Dam (rkm 498; completed 1907), Ranchers Ditch Dam (rkm 469; completed 1904), Yellowstone Dam (rkm 445; completed 1909), Cartersville

Dam (rkm 380; completed 1934) and Intake Dam (rkm 114; completed 1911; Mefford 1999, Boyd and Thatcher 2008).

In the 1970s, the U.S. government, motivated by an oil crisis and a foreseeable decline in available hydroelectric power, sought different avenues to obtain needed energy. Proposals were developed to mine and export Montana's large coal reserves, and to construct coal-fired power plants. In 1971, the North Central Power Study identified 42 potential sites to build power plants in Montana, North and South Dakota, Colorado, and Wyoming. Twenty-one of these coal-fired generating plants were proposed in Montana, necessitating the use of cooling water drawn from the Yellowstone River and its tributaries. These plants would have consumed an estimated 4.19 billion m^3 of water (2.6 maf, approximately 1/3 of the rivers annual discharge) a year to generate energy using coal extracted from the Fort Union coal fields necessitating the development of Montana's undeveloped water rights (Posewitz 1979; Schneider 1985; Montana Water Resource Division 1977; White and Bramblett 1993). In 1974, the Montana Legislature implemented a 3-year moratorium on all water filings over 0.6 cubic meters per second (21cfs) in the Yellowstone Basin in response to the plans for large water withdrawals (White and Bramblett 1993).

In 1973, the Montana Water Use Act went into effect. The Act largely made the procedure for acquiring and changing water rights an administrative process overseen by the Montana Department of Natural Resources and Conservation (DNRC; Doney 1990). The Act changed the water rights administration significantly in several ways. First, all water rights existing prior to July 1, 1973 would have to be finalized through a statewide adjudication process in state courts. Second, a permit system was established for obtaining water rights for new or additional water developments, where before no permits had to be acquired. Third, an authorization system was established for changing water rights. Fourth, a centralized records system was established. Prior to 1973, water rights had been recorded, though not consistently, in county courthouses throughout the state. The Act also provided provisions to reserve water for future consumptive uses and to maintain minimum instream flows for water quality and fish and wildlife, though all the reservations would be junior to all water rights in existence at the time (Doney 1990). Most importantly, the Act authorized state and federal agencies to apply to the DNRC to acquire a state water reservation for existing or future beneficial uses (Doney 1990). As stated by White and Bramblett, “This legislation replaced a water use system that virtually guaranteed depletion of rivers with one that allowed instream flow advocates to compete with consumptive users for unreserved water (White and Bramblett 1993, pg. 411).” The plan to reserve water rights for future beneficial uses, including instream uses, was unprecedented in traditional western water law at the time (Peterman 1979; Schneider 1985), although instream flows for fisheries and aquatic life were still not specifically guaranteed.

Adjudication is a very important step for any state to validate and quantify their water demands and historic use. The process of adjudication is to examine the water claim, to issue decrees, and last to resolve any claim issues (MTDNRC 2008b). The first order of an official adjudication in the state was in the Powder River basin, a tributary to the Yellowstone River, in 1974. The statewide adjudication was not ordered until 1979 and has yet to be completed.

A general statewide adjudication is a slow process involving several steps. First, there is a public notice of the “Water Rights Order,” which requires all existing water users to claim their water rights. Failure to do so will result in abandonment and loss of the right. Next, DNRC examines all water rights and provides a summary report of all the rights to the water judge, who uses it to compose the basin decree. Next, if federal reservations are present, as they are in many of Montana’s basins, the court issues a temporary preliminary decree where they omit the federal reserved rights until they have been quantified. Once all claims have been examined and federal reserved rights quantified, a preliminary decree will be issued based on statements of claim, DNRC’s report, and the quantification on reserved water rights. The preliminary decree is then sent to all parties that may be affected by its outcome. At this time, any claims where objections were filed will go through a hearing process where they are settled or litigated. The last step is the final decree, which states the flow rate, priority date, beneficial use, time and place of use, source of water, and place and means of diversion for the decreed amount for each water right holder (MCA 85-2-2).

Statewide adjudication of water rights in Montana was ordered in 1979. As of 2007, more than 24,000 claims have been examined resulting in 59 of 89 basins having been given initial decrees (MTDNRC 2008b). Presently, in the Yellowstone River basin, there is currently only one final decree and it is on the Powder River which was actually started in 1974, five years before the general adjudication was ordered. There are temporary decrees on the Shields, Boulder, Stillwater, Clarks Fork, various small tributary creeks, and parts of the mainstem Yellowstone River (above Bridger Creek and between the Clarks Fork and Tongue Rivers). Preliminary decrees issued in the Yellowstone River basin are as follows: Tongue River, Little Bighorn River, Prior Creek, and the Yellowstone River between Bridger Creek and Clarks Fork Yellowstone River and Tongue River to the Powder River. Current examinations are still being conducted on Rosebud Creek, Bighorn River below Greybull, and the Yellowstone River below the Powder River (Figure 1.2).

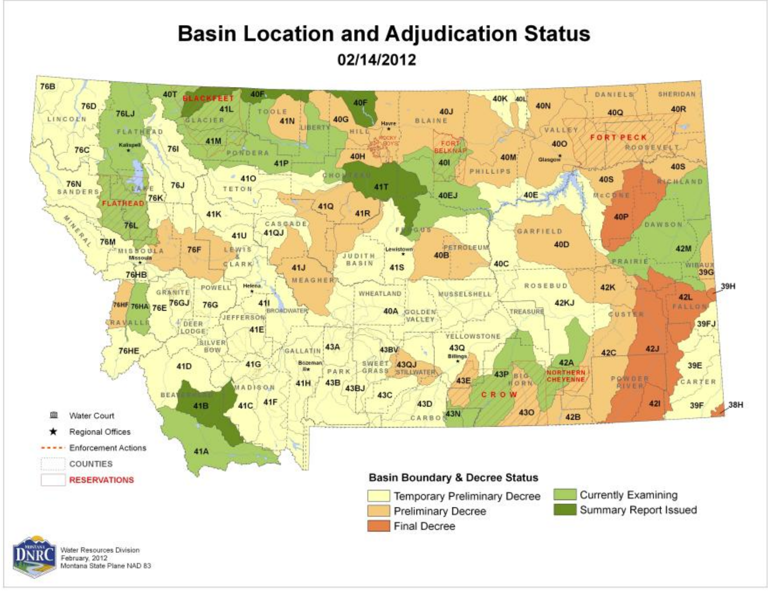

Figure 1.2 Adjudication statuses in Montana as of February 2012. Extracted from MT DNRC website.

Though the statewide adjudication has been ongoing since the late 1970's, the Water Adjudication Bureau, part of MT DNRC, must complete the examination of the remaining 57,000 claims (as of 2005) by June 30, 2015.

Much of the initial fisheries and aquatic research completed on the Lower Yellowstone River was done from the mid-1970's until the early 1980's, and was associated with the energy development and potential threats to the water resources. In December of 1978, after several studies of the aquatic resources were completed (Haddix and Estes 1976, Penkal 1981, Nelson and Peterman 1979, and Peterman 1979) MTFWP applied to the Montana Board of Natural Resources and Conservation (MBNRC) for 10.1 billion m^3 at Sidney to ensure water quality and preserve fish and wildlife for future years (8.2 maf; White and Bramblett 1993). After evaluating many competing applications, MBNRC granted 6.78 billion m^3 (5.5 maf) of the application to be the minimum instream flow requirements for fish and wildlife (Boris and Krutilla 1980). Neither the request nor the water granted to MTFWP for fish and aquatic life in 1978 considered future issues such as various types of energy production, global climate change, and the newly pending settlements with Indian reservations that may lead to development of water rights senior to those granted for instream flows.

Although this instream flow allocation was seen in some quarters as a major accomplishment for the conservation of fish and aquatic life, many factors prevent this allocation from guaranteeing protection. Threats to the instream flow of the Yellowstone River come from several sources. One factor is the differential prioritization of usage for reserved water rights according to region within the basin. In the upper basin, i.e. above the confluence with the Bighorn River, municipal use has first priority, instream use has second priority, and agriculture has third priority (Figure 1.1). In the lower basin, i.e. below the confluence with the Bighorn River to the North Dakota border, municipal use has first priority, agriculture has second priority, and instream flow has third priority (Sobashinski and Lozovoy 1982). Therefore on the Yellowstone above the confluence with the Bighorn River, during a low water year when the flow falls to the level of the instream flow reservation, a municipality using its preferential water reservation can draw the river below the level of the instream flow right. Below the Bighorn River, both municipalities and irrigation operations can withdraw from the river preferentially over the allocation for fish and aquatic life, rendering the instream fish and wildlife reservation irrelevant. It can be effectively argued that although the trout fisheries of the upper basin are more economically important, the diverse and ecologically specialized native fish community of the lower basin, where agriculture is more dominant, is more imperiled yet of lower priority in water allocation decisions. This hierarchal system is only for the 1973 water reservations and does not apply to any water rights senior to them which are still able withdraw water preferentially over all other junior water uses, including instream flow reservations.

A second caveat is that any water rights held before the establishment of the instream reservations in 1973 are senior, and many of them have not yet been adjudicated, meaning that the rights are subject to change. Once the river and its tributaries are fully adjudicated, it could potentially affect the water available for all reservations made in 1973.

Third, federal and Indian reserved water rights exist that are yet to be developed. These reserved water rights are of most concern due to their seniority and potential size. Presently, all compacts have been ratified for all federally withdrawn lands in the basin (MTDNRC 2011). Despite the efforts to provide instream flow for fish and other aquatic life, instream water rights are junior to nearly all of the federal and Indian water rights such as the Indian Reservations' rights, and until those rights are settled and developed, future water availability will be uncertain. Other future depletions that may reduce instream flows and aquatic habitat of the river come from consumptive use reservations that were also granted to the states by the MBNRC in 1978, giving them the same appropriation date as the instream reservations. Many of these reservations have yet to be developed by Montana and Wyoming. Periodic concerns with drought and the new settlements of tribal water rights strengthen the idea that the 1978 instream flow reservations in the Yellowstone River need to be scientifically reevaluated and critically re-appraised for their adequacy with regard to sustaining native fish and other aquatic life.

In 1989, the Montana Legislature passed House Bill 707 permitting a program for private water leasing for instream flow (White and Bramblett 1993). The bill, amended in 1991 and again in 2007, established a program that allows the MTFWP to convert water rights owned by them or leased by them from private appropriators to instream flow including water rights leased from tribes such as the Northern Cheyenne (White and Bramblett 1993). This approach allows MTFWP to better provide instream flows to restore and enhance flows on streams previously dewatered by senior water rights.

In 2008, Montana sued the state of Wyoming for failing to meet provisions set by the Yellowstone River Compact during recent years of drought. Montana contended that Wyoming allowed their first, second and third tier water users to use their water, leaving insufficient amounts in the river to meet Montana's first and second tier water users' demands. Montana also contended that Wyoming's water users were using their water more efficiently and this increased efficiency caused greater consumption than in 1950, resulting in less water returning to the river creating shortages downstream. The lawsuit was reviewed and a water master appointed by the Supreme Court concluded that Montana was right when it came to newly developed claims in Wyoming, but that Montana had no claim against Wyoming water users improving their efficiencies leaving less in the stream for downstream users (O'Regan and Shertzer 2011). The Supreme Court also pointed out that Montana should look for better instate remedies next time before trying to hold Wyoming liable (O'Regan and Shertzer 2011). Thus, one of Wyoming's most effective argument was that Montana has never quantified their water rights, nor does Montana know where extravagant wastes may be present.

In the coming decades, water use demands are expected to increase as additional lands adjacent to the river are brought under irrigation, coal-bed methane and other energy resources are increasingly developed, municipal use increases, coal production continues to increase (USGS 1997), and projected global climate change increases the persistence of droughts in the upper Great Plains region (Thompson 2008). It is the responsibility of the owners of the water course, the state of

Montana, to meet these challenges by ensuring that sufficient water is allocated for appropriate and essential stream flow for a range of uses, including the needs of fish and other aquatic life.

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CHAPTER 2 – TRENDS IN YELLOWSTONE RIVER BASIN WATER SUPPLY AS INTERPRETED THROUGH HYDROLOGIC ANALYSIS

ABSTRACT

The Yellowstone River and its tributaries comprise an important case study in the changes in magnitude and timing of discharge brought about by a changing human landscape, increased water demand, and climate change. In this chapter, I assessed long term trends (1898-2007) and recent changes (1970-2007) in the hydrographs of the Yellowstone River and its tributaries using data from 18 USGS Hydro-Climatic Data Network Stations. I evaluated seven variables used to characterize the discharge: 1) annual discharge, 2) magnitude of discharge, 3) absolute annual minimum discharge, 4) monthly discharge, 5) date when half of annual volume passed station, 6) date when maximum daily mean occurred, and 7) date when discharge returned to baseflow. Declines in volume and magnitude of annual and seasonal discharges are present in the basin, more so in areas where there are no water storage facilities. Timing of flow events are occurring earlier in the year throughout the basin, leaving less water in the later summer and fall when water demands are the greatest. The appearances of significant trends have increased since the 1970's, and it is expected that they will continue without serious changes in the basin. Lessened flows and altered timing stands to greatly affect all users of water in the basin, as is occurring in the rest of western North America.

INTRODUCTION

In the past century there have been substantial declines in annual discharges documented throughout many of the rivers and streams of the western United States. Many of the declines have been attributed to human development and increasing consumptive water use within various river basins (Baron et al. 2002; Mote et al. 2005; Rood et al. 2005, 2008). Climate change has also played a role in the declines (Vorosmarty et al. 2000; Schindler and Donahue 2006).

These changes in water supply and consumption have resulted in large changes in magnitude and timing of runoff (Cayan et al. 2001; Stewart et al. 2004, 2005; Gibson et al. 2005) and ultimately the quantity and duration of base flows. The magnitude of peak discharge can be affected by anthropogenic activities such as irrigation withdrawals, land use practices increasing runoff, damming of rivers, as well as changes in climate (Zelt et al. 1999; Gibson et al. 2005).

Observed changes in the timing of discharge have been most commonly characterized as an earlier peak and an earlier runoff pattern (Cayan et al. 2001; Regonda et al. 2004; Stewart et al. 2004, 2005; Gibson et al. 2005). In interior river basins with temperate climates, most annual discharge (often 50 to 80% of the total; Stewart et al. 2004) originates from snowmelt in spring and early summer. Despite high spring flows, discharge by late summer can be low, water withdrawals for human uses high as a percentage of total daily discharge, and instream water shortages severe. Earlier runoff and declining annual discharge can result in less water available for late summer demands for municipal, industrial, and irrigation uses. Earlier runoff can also result in a protracted period of baseflow conditions and in severe cases can result in decreases in average baseflow because of diminished groundwater recharge (Arnell 1999).

Ecological processes can be regulated by the timing of peak discharge (Poff et al. 1997) and by the timing and magnitude of baseflow. Decreased volume, earlier discharge, and lower and longer periods of base flow can have negative impacts on the local fauna and a river’s ecological functioning during the dry season. Many fish species in different areas have evolved specialized adaptations effective under the historic timing of runoff (Cayan et al. 2001; Stewart et al. 2004, 2005; Gibson et al. 2005). Low water conditions reduce a river’s ability to buffer against high temperatures and pollution, and can potentially disconnect riverine habitats causing isolation and mortality of native fauna (Gido et. al 2010). Late summer is a time when habitat for native fish and aquatic life can be minimal and potentially limiting due to decreased discharge and warmer water temperatures (Arismendi et al. 2012).

The Yellowstone River and its tributaries provide an important case study in the changes in magnitude and timing of discharge brought about by a changing human landscape, increased water demand, and climate change. The Yellowstone River mainstem, which is unregulated, and its tributaries experience a dominant bi-modal natural hydrograph because of snow melt dominated flows. The first rise is a response to early melting of snow in lower elevation areas in the basin, usually occurring in the early spring (March or April). The second and more significant rise happens later in the summer when the majority of snowpack in the higher elevations is being depleted (late May or June; Vorosmarty et al. 2000).

Irrigation withdrawals are the largest of all water withdrawals in the Yellowstone River Basin (YRB; approximately 96.5%; Miller and Quinn 1997). Irrigation withdrawals persist through late summer into the fall with many water permits expiring as late as the 31st of October (MTDNRC 2008). Determining the effects of this dominant water use on the natural hydrograph in the basin is crucial to understanding potential effects on fish and other aquatic life.

The magnitude of absolute minimum flows for rivers varies widely throughout the basin. Some of the rivers frequently or periodically experience near zero flow conditions (e.g., the Powder River; Hubert 1993), whereas others continue to flow at levels that may or may not provide sustainable conditions for the aquatic life dependent upon it. Absolute minimum flow is a direct reflection of the ground water table along a river, and can be used to determine the amount of use or overuse throughout time (Smakhtin et al. 2001). The eventual reduction in surface water supply as a result of groundwater development greatly complicates the administration of water rights and the overall effects may not be fully realized for many years.

A first step in understanding water supply, use, and demands in the YRB is a thorough analysis of the trends in monthly flows at its gauging stations. Trends in discharge would help explain where and when future water shortages are likely to occur. The monthly analyses would also provide information seasonally, whereas annual trends may not be effective at detecting seasonal changes. For example, an analysis based on total annual discharge may show no change, whereas a monthly analysis may detect long-term increases in the winter and spring months but long-term decreases in the summer months. Future instream flows will be needed to provide not just adequate volume, but also an adequate distribution of the runoff through time (Poff and Zimmerman 2010).

In this chapter, the objective is to assess long term trends and recent changes in the hydrographs of the Yellowstone River and its tributaries based on timing and magnitude of peak flows, seasonal flows, and base flows. Detailed time series analyses were used to test statistical validity of any apparent trends (Parrett 2006).

METHODS

To evaluate the hydrographs within the YRB, I used data downloaded online from 18 United States Geological Survey (USGS) Hydro-Climatic Data Network stations on the Yellowstone River and its seven major tributaries: Shields River, Boulder River, Stillwater River, Clarks Fork of the Yellowstone, Bighorn River, Tongue River, and Powder River (Table 2.1; Figure 2.1). I chose sites that were near the origin, the confluence, and state borders of the rivers to better detect any changes. On all but three of the tributaries (Shields, Boulder, and Stillwater), I chose at least two sites for analysis. The following USGS stations were used: The Yellowstone River near Livingston, MT (USGS 06192500), at Billings, MT (USGS 06214500), at Miles City, MT (USGS 06309000), and near Sidney, MT (USGS 06329500); Shields River near Livingston, MT (USGS 06195600); the Boulder River at Big Timber, MT (USGS 06200000); the Stillwater River near Absarokee, MT (USGS 06205000); the Clarks Fork Yellowstone River near Belfry, MT (USGS 06207500), and near Edgar, MT (USGS 06208500); the Bighorn River at Kane, WY (USGS 06279500), near St. Xavier, MT (USGS 06287000), and Bighorn River at Tullock Creek near Bighorn, MT (USGS 06294500); the Tongue River near Dayton, WY (USGS 06298000), at the State Line near Decker, MT (USGS 06306300), and at Miles City, MT (USGS 06308500); and the Powder River at Sussex, WY (USGS 06313500), at Moorhead, MT (USGS 06324500), and near Locate, MT (USGS 06326500). The

Sidney station (USGS 06329500) was used to represent the basin output and overall trend because the station dates back to 1910, and the flow at this site represents nearly all of the total annual discharge leaving the basin as runoff. All calculations were made using the data available during the chosen periods. In general, data were complete for these stations over the period of 1898 to 2007 (Table 2.1).

Table 2.1 USGS Hydro-Climatic Data Network sites.

Code	Site Number	River	Location	Period of Data
1	06192500	Yellowstone	Livingston, MT	1898 - 1905, 1929 – 2007
2	06195600	Shields	Livingston, MT	1979 – 2007
3	06200000	Boulder	Big Timber, MT	1948 - 1953, 1956 – 2007
4	06205000	Stillwater	Absarokee, MT	1911 - 1914, 1936 – 2007
5	06207500	Clarks Fork Yellowstone	Belfry, MT	1922 – 2007
6	06208500	Clarks Fork Yellowstone	Edgar, MT	1922 - 1969, 1987 – 2007
7	06214500	Yellowstone	Billings, MT	1905, 1928 – 2007
8	06279500	Bighorn	Kane, WY	1929 – 2007
9	06287000	Bighorn	St. Xavier, MT	1935 – 2007
10	06294500	Bighorn	Bighorn, MT	1946 – 2007
11	06298000	Tongue	Dayton, WY	1919 – 2007
12	06306300	Tongue	Decker, MT	1961 – 2007
13	06308500	Tongue	Miles City, MT	1939 - 1941, 1946 – 2007
14	06309000	Yellowstone	Miles City, MT	1923, 1929 – 2007
15	062313500	Powder	Sussex, WY	1939, 1940, 1950 - 1957, 1979 - 2007
16	06324500	Powder	Moorhead, MT	1930 – 2007
17	06326500	Powder	Locate, MT	1939 – 2007
18	06329500	Yellowstone	Sidney, MT	1911 – 2007

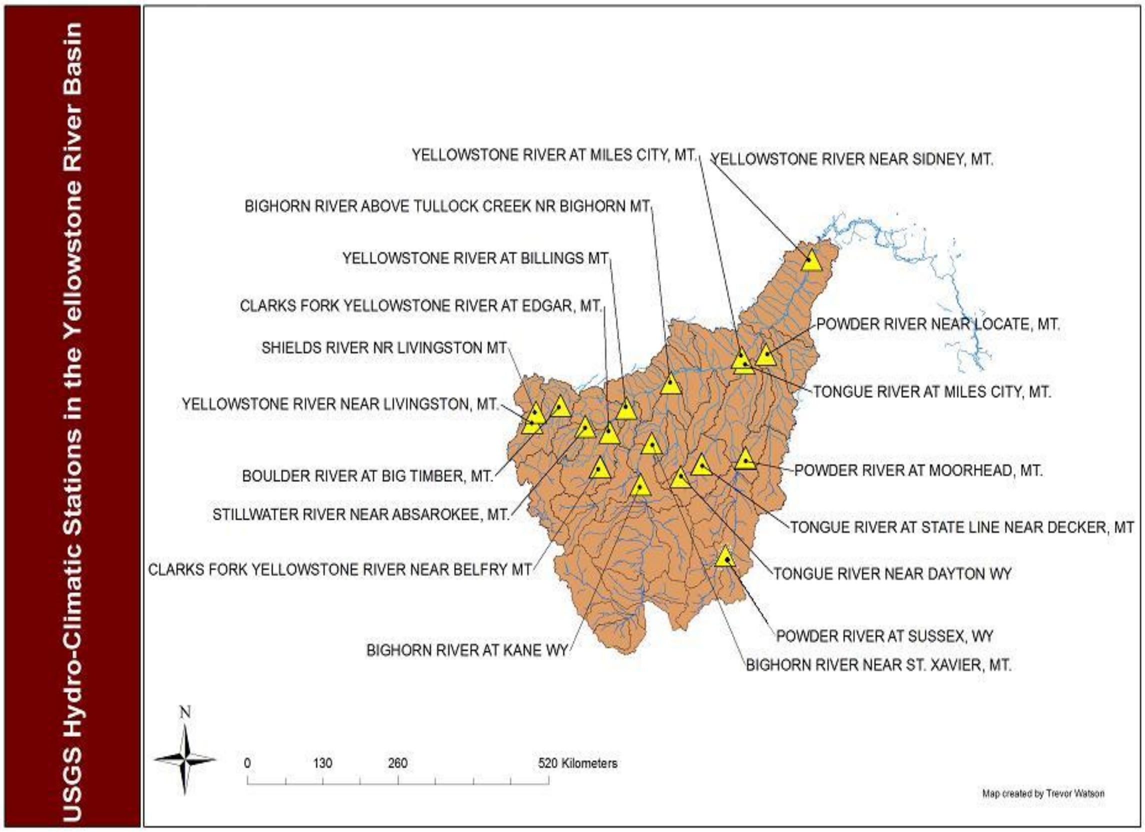

Figure 2.1 United State Geological Survey (USGS) Hydro-Climatic Data Network sites on the Yellowstone River and its seven major tributaries: Shields River, Boulder River, Stillwater River, Clarks Fork of the Yellowstone River, Bighorn River, Tongue River, and Powder River.

Seven variables used to characterize the discharge, four for aspects of volume and three for aspects of timing, were obtained or computed from the USGS records (Stewart et al. 2004; Smakhtin et al. 2001). The four variables chosen to depict discharge volume were: 1) annual discharge, i.e., the total volume of discharge past a station during an individual water year (October 1 to September 30), 2) magnitude of peak discharge, i.e., the largest magnitude of daily averaged discharge past a station within an individual water year, 3) absolute annual minimum discharge, i.e., smallest annual magnitude of daily averaged water flowing past a station within an individual water year, and 4) monthly discharge – i.e., average discharge during each month at a station. Three of the four variables have one value per year per station and the fourth variable (mean monthly discharge) had 12 values per year per station. The three variables chosen to depict timing of discharge were: 5) date during the water year when half of the annual volume of flow has passed a station, 6) date during the water year when the maximum daily mean was achieved, 7) date of return to baseflow (discharges below the 50th percentile flows) after spring rise.

The four volume variables: annual discharge, peak discharge, annual minimum discharge, and average monthly discharge (in m^3/s), were calculated based on daily statistics from the USGS gauging records for the entire period of record at all 18 stations (Table 2.1).

The first timing variable (the date of the water year when half of the flow has passed the gauging station) was calculated using historic daily averages from the USGS gauging records for the entire period of record at 9 of the 18 stations (1-5, 8, 11, 15, and 18) to detect for trends in timing of center mass of discharges in the basin. For this variable, the temporal centroid of streamflow (CT) measurement, a measurement of runoff timing (Stewart et al. 2004), was used to determine whether the snowmelt runoff in the basin is trending earlier or later in the water year. The CT used was the flow-weighted timing, or 'center of mass' of streamflow calculated as

$$CT = \Sigma(t_i q_i) / \Sigma q_i,$$

where t_i is the time in days from the beginning of the water year and q_i is the corresponding streamflow for water year day i. Therefore CT is a date given in days (Stewart et al. 2004). The CT measurement was chosen because it is easily and reliably determined, insensitive to spurious variations in flow, and it can be used to compare basins in different climatic regimes (Stewart et al. 2004). It has also been used effectively to detect a shift in timing of snowmelt runoff in many rivers in the Northwest (Roos 1987, 1991; Wahl 1992; Dettinger and Cayan 1995; Cayan et al. 2001; Stewart et al. 2004, 2005). The average CT was calculated from daily flow volumes for each of the eight snowmelt-dominated tributaries in the basin. The CT measurement was used only for the stations near the headwaters of the rivers, except on the Shields, Boulder, and Stillwater where there was only one station available, and the Yellowstone River where CT was also calculated at Sidney, site of the lowermost gauging station on the mainstem.

For the second timing variable (annual peak discharge), I obtained peak discharge values and dates of occurrence for each water year from the USGS gauging records for the entire period of record at all 18 stations. I then fit the Julian date with the water year calendar and found the water year day that the peak discharges occurred.

For the third timing variable (baseflow), I obtained daily mean discharges from the USGS gauging records for the entire period of record for 17 of the 18 stations and computed the date discharges returned to baseflow. Baseflow was identified as when the discharge was equaled or exceeded 50% of the time, also known as Q50, as outlined by Smakhtin et al. (2001). I determined the water day when discharge, after the ‘spring rise’ fell below the Q50 designation. In years when the base flow was not met before the end of the water year, I used the last day of the water year (365; September 30) as its measurement. One of the 18 gauging stations, the site near St. Xavier on the Bighorn (site 9), was excluded because of its unnatural flows owing to its location directly downstream of Yellowtail Dam on the Bighorn River.

Prior to trend analyses, for each variable I used Loess (local polynomial regression fitting) smoothing to serve as a visualization tool to better evaluate the data. The Loess smoothing approach to linear and non-linear regression (NIST/SEMATECH 2006) is best described as fixing a low-degree polynomial to small subsets of the data surrounding each point in the data set. Using weighted least squares, the polynomial fit was given more weight to data points near the response data being estimated and less to the ones further away (Appendix 1).

Seven null hypotheses were evaluated:

1.) There were no changes or trends in annual discharges in the YRB.
2.) There were no changes or trends in magnitude of peak discharges in the YRB.
3.) There were no changes or trends in magnitude of absolute annual minimum discharge in the YRB.
4.) There were no changes or trends in average monthly discharges in the YRB.
5.) There were no changes or trends in date of the CT measurements in the YRB.

6.) There were no changes or trends in the date of maximum daily means in the YRB.
7.) There were no changes or trends in the date when flows return to baseflow conditions in the YRB.

I used a non-parametric approach to test for trends for all seven variables. The four volume variables were tested for association between time and discharge; the three timing variables were tested for association between time and day, based on counts of concordant and discordant pairs. Tests were made using the Mann-Kendall Trend Analysis (Kendall Tau (KT)) test (Higgins 2004). Two analyses were run for each site, one using the entire time series of data present (Appendices 2-8) and the other from 1970 to 2007 based on observations of the Loess plots. I separated the results as positive or negative and assessed their significance at $P = 0.1$. Anything with a $P>0.10$ was determined to have no statistical trend, $0.05<P<0.1$ to have a trend detected but not significant, $P<0.05$ to be significant, and $P<0.01$ to be highly significant (Appendices 2-8; Higgins 2004)).

I used Pearson's correlation coefficient (parametric), and the Spearman's rank correlation coefficient test (non-parametric) to measure the correlation between the two variables time and discharge for the four volume measurements and time and water day for the three timing measurements. The correlation coefficients ranged from -1 to 1 (Appendices 2-8).

Last, to illustrate the general characteristics of the seven hydrologic variables (four volume, three timing) throughout the YRB, two long-term averages were computed for the available records, one the average from 1895 to 1969, and the other the average from 1970 to 2007 (Appendix 9). The mean annual discharge clearly depicts the differences in the sizes of the tributaries, while also providing a measure of their importance as contributors to the Yellowstone River system.

RESULTS

Overall, annual discharges, magnitudes of peak discharge, and baseflow tended to decline on the tributaries free of upstream reservoirs. Runoff also tended to occur earlier in more recent years.

Magnitude of Discharge

1. Annual Average Discharge

Although I observed variability in the average annual discharge for all of the rivers when considering the entire period of record, there was far less variability at individual sites over the more recent period (1970-2007). There were highly significant declining trends at sites 3, 11, 12, and 18 (P <0.01), significant declining trends at sites 2, 8, 9, 10, and 17 (P <0.05), and no sites with negative but insignificant trends (0.05≤P≤0.10) when evaluated over the entire periods of record (Appendix 2; Figure 2.2). All sites but 7 and 15 had negative slopes (Kendall Tau; KT) over their entire periods of record.

There was more consistent evidence of declines in the average annual discharge for all of the rivers over the period 1970-2007 with highly significant declining trends at sites 3, 4, 7-14, and 18 (P<0.01), significantly declining trends at sites 1, 5, 16, and 17 (P<0.05), and no sites with negative but insignificant trends (P<0.10). All sites had negative slopes (KT) over the period 1970-2007 (Appendix 2, Figure 2.3).

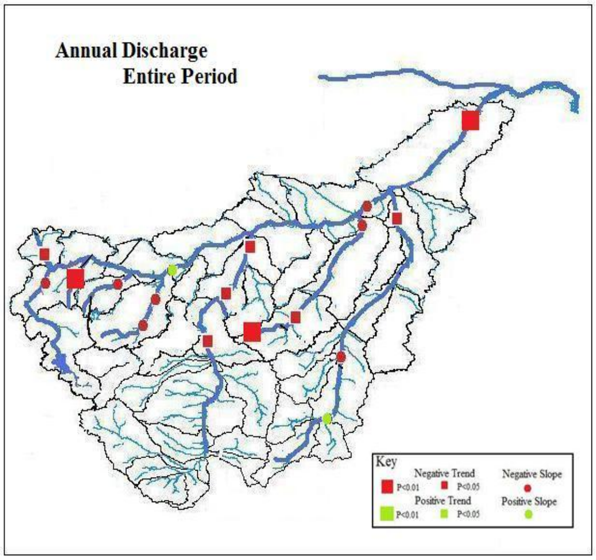

Figure 2.2 Trend analyses for annual discharge in the YRB for entire data periods.

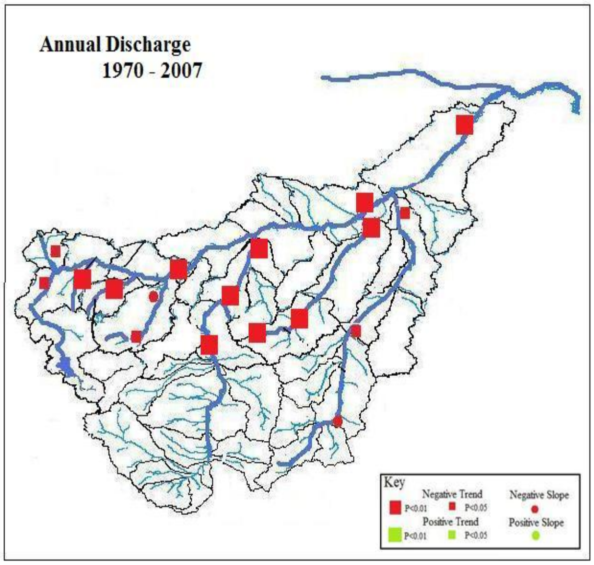

Figure 2.3 Trend analyses for annual discharge in the YRB from 1970 to 2007.

2. Magnitude of Annual Peak Discharge

Similar variability in the magnitude of annual peak discharge was observed for all of the rivers and their individual sites studied when considering their entire periods of record and over the more recent period 1970-2007. There were highly significant declining trends at sites 3, 8, 9, 14, 16, 17 and 18 ($P<.01$), significant declining trends at sites 12 and 13 ($P<.05$), and one site (2) with a negative but insignificant trend ($P<.10$) when evaluating the entire period of record (Appendix 3; Figure 2.4). All sites but 1, 5, and 7 had negative slopes (KT) for the entire period of record.

For annual peak discharge over the period 1970-2007, I found highly significant declining trends at sites 3, 9, and 16 ($P<0.01$), significantly declining trends at sites 4 and 11 ($P<0.05$), and negative but insignificant trends at sites 5, 7, and 18 ($0.05\leq P\leq 0.10$). All sites but site 6 had negative slopes (KT) for the period 1970-2007 (Appendix 3, Figure 2.5).

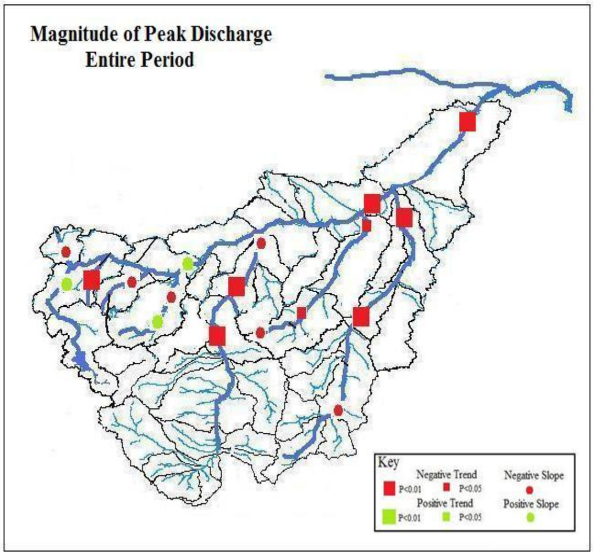

Figure 2.4 Trend analyses for magnitude of peak discharge in the YRB for the entire period.

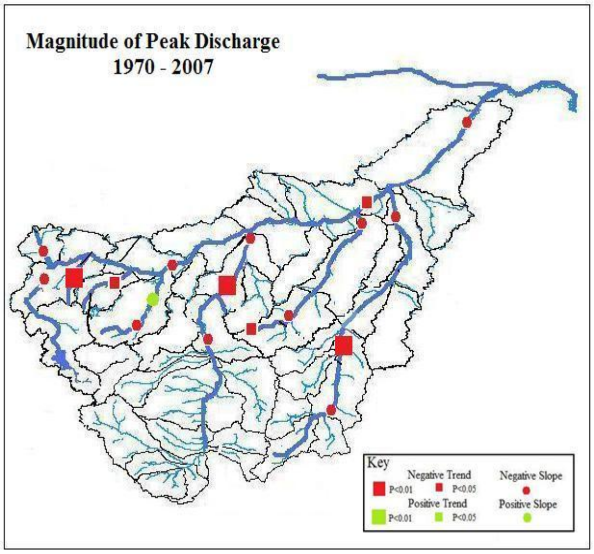

Figure 2.5 Trend analyses for magnitude of peak discharge in the YRB from 1970 to 2007.

3. Absolute Annual Minimum Discharge

Absolute annual minimum discharge showed highly significant (P<0.01) declining trends at sites 2, 5, and 6, highly significant (P<0.01) increasing trends at sites 8, 9, 10, and 14, significantly, declining trends at sites 3, 11, and 12 (P<0.05), and significantly increasing trends at site 16 (P <.05). No sites showed insignificant but declining or increasing trends (0.05≤P≤0.10), resulting in 8 decreasing and 10 increasing slopes (P<0.05) in the basin for their entire periods of record (Appendix 4; Figure 2.6).

Over the period 1970-2007, six sites (1, 8, 13-17) changed from increasing to decreasing slopes. Over that period sites 3, 5, 8, 11, 12, 13, 15, and 18 exhibited highly significant declining trends (P<0.01), and significantly declining trends at site 17 (P<0.05), and no positive or negative but insignificant trends detected (0.05≤P≤0.10; Appendix 4; Figure 2.7). No significant positive trends (P<0.05) were found in the basin for the period 1970-2007.

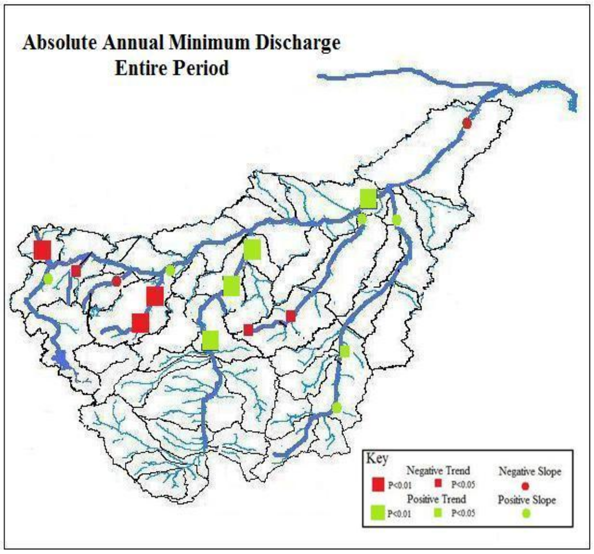

Figure 2.6 Trend analyses for absolute minimum annual discharge in the YRB for the entire period.

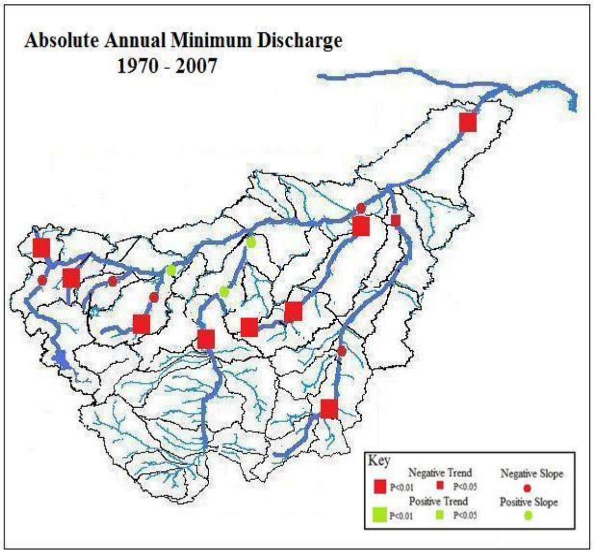

Figure 2.7 Trend analyses for absolute minimum annual discharge in the YRB from 1970 to 2007.

4. Average Monthly Discharges

Monthly discharges changed similarly throughout the basin by season regardless of river, with only a few deviations. The majority of the 18 sites on the eight rivers experienced declines late spring, summer, and early fall months (May-October), while showing increases in monthly discharges during the other months (Appendix 5; Figures 2.8 a-m). The lowest station in the basin, Site 18 Yellowstone River near Sidney, Montana was a clear depiction of this pattern, showing the most summer and fall months with significant declines, while the other months are experiencing increasing flows (Appendix 5). Overall there was little difference in decreasing versus increasing trends, but there were more sites with significantly and very significant decreasing trends than there were with increasing trends (Table 2.2).

Table 2.2 Significant trend results for Annual Monthly discharges.

Months	VS Dec.	Sig. Dec.	Dec. Trend	VS Inc.	Sig. Inc.	Inc. Trend
January	2	1	3	3	5	4
February	3	1	3	3	2	6
March	1	3	8	1	0	5
April	0	2	9	1	0	6
May	2	2	8	0	2	4
June	6	2	10	0	0	0
July	1	5	11	0	0	1
August	3	1	8	0	0	6
September	4	1	7	0	0	6
October	1	2	5	0	0	10
November	1	4	3	0	1	9
December	3	2	2	2	1	8
Totals	27	26	77	10	11	65

Dec. = Decreasing
Inc. = Increasing
VS = Very significant trend(p-value <0.01)
Sig.= Significant trend (p-value <0.05)
Trend = trend observed but not significant (p-value <0.10)

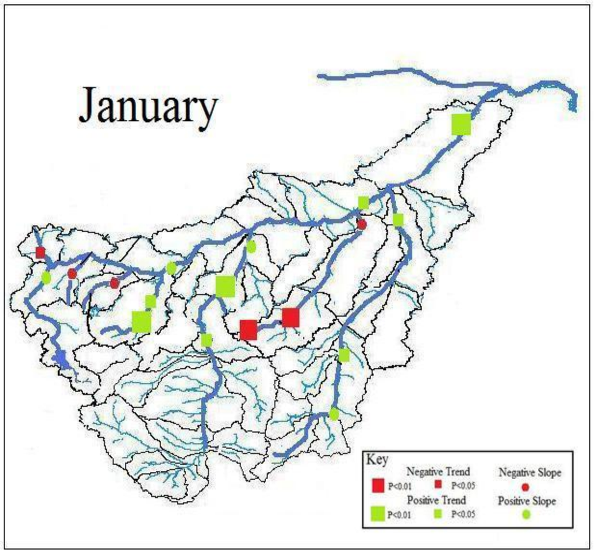

Figure 2.8a Trend analyses of average monthly discharges for January in the YRB.

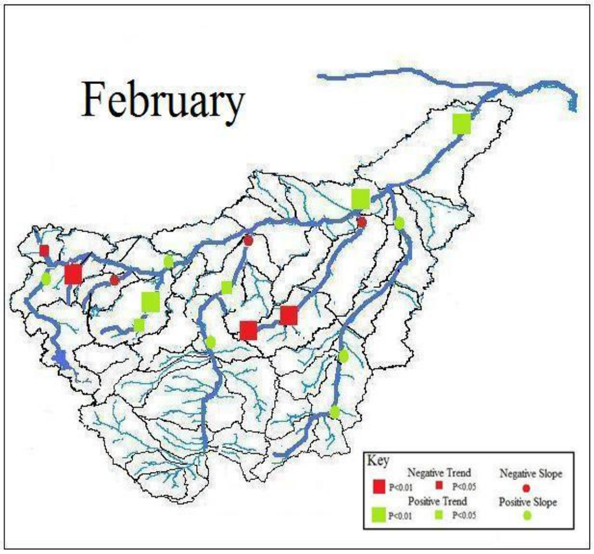

Figure 2.8b Trend analyses of average monthly discharges for February in the YRB.

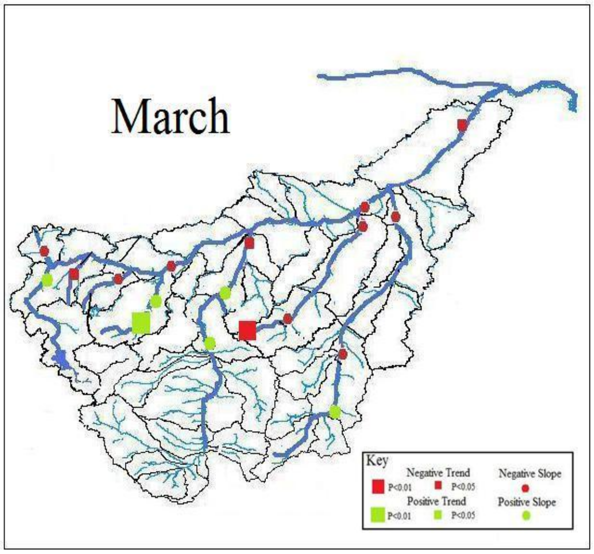

Figure 2.8c Trend analyses of average monthly discharges for March in the YRB.

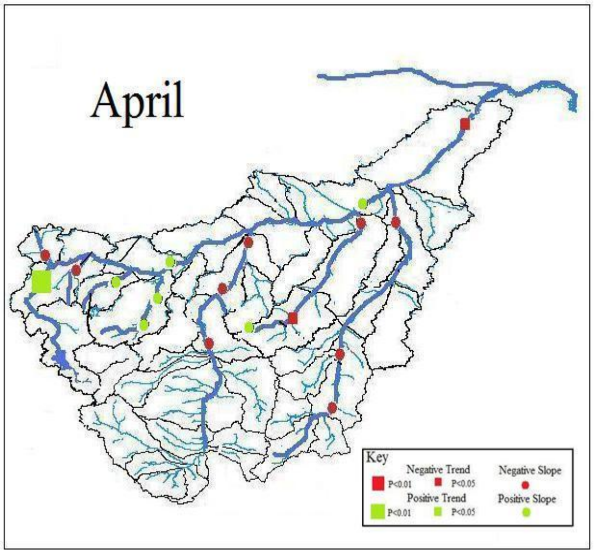

Figure 2.8d Trend analyses of average monthly discharges for April in the YRB.

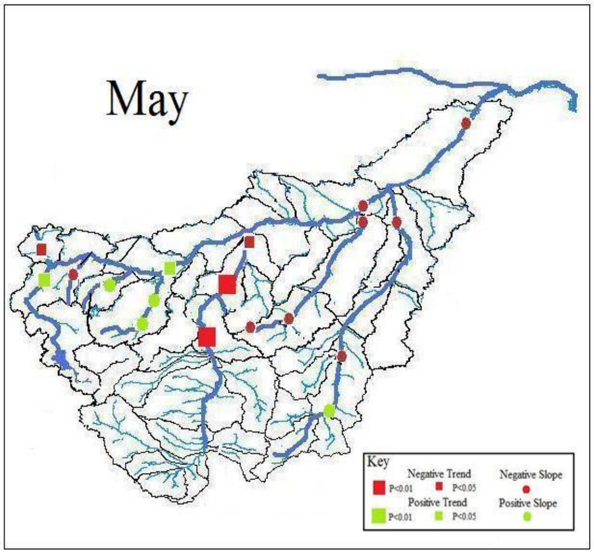

Figure 2.8e Trend analyses of average monthly discharges for May in the YRB.

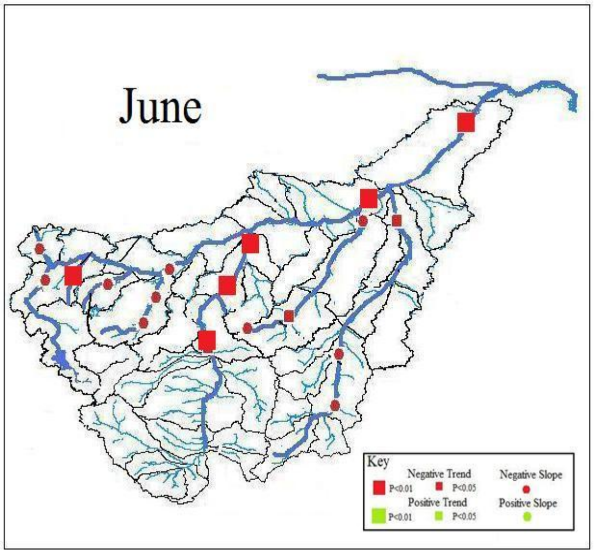

Figure 2.8f Trend analyses of average monthly discharges for June in the YRB.

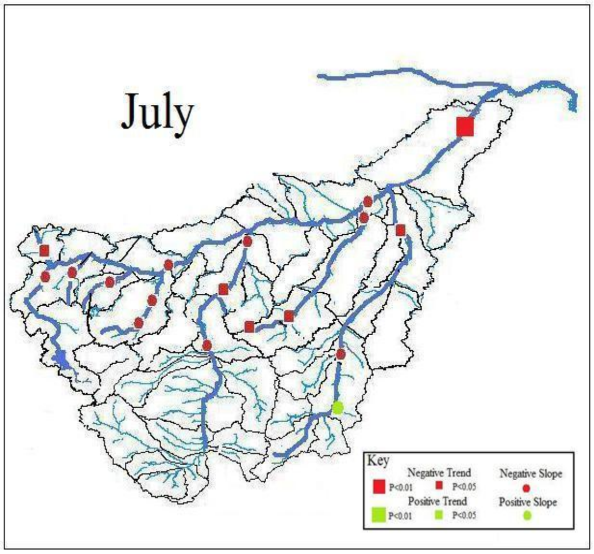

Figure 2.8g Trend analyses of average monthly discharges for July in the YRB.

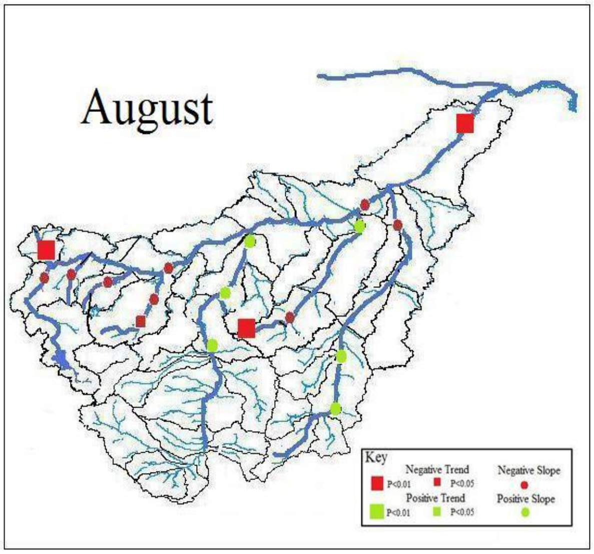

Figure 2.8h Trend analyses of average monthly discharges for August in the YRB.

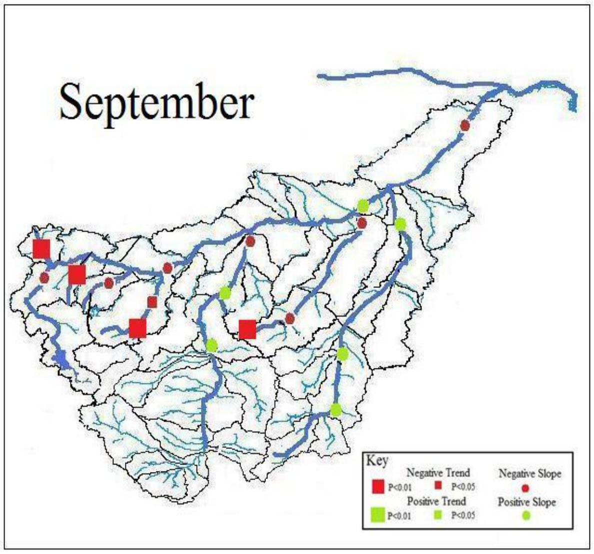

Figure 2.8i Trend analyses of average monthly discharges for September in the YRB.

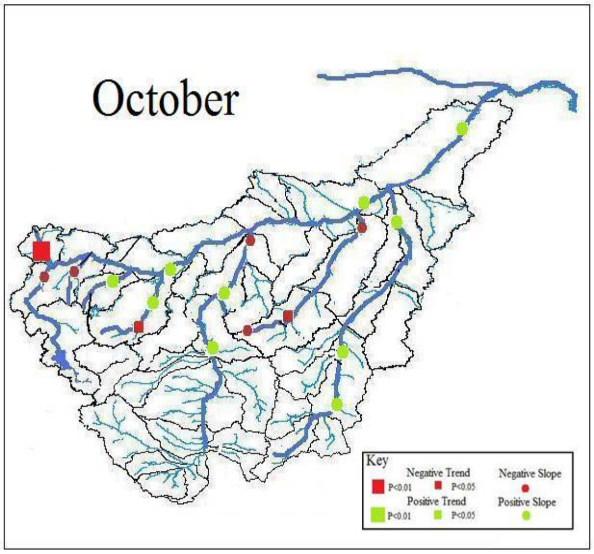

Figure 2.8j Trend analyses of average monthly discharges for October in the YRB.

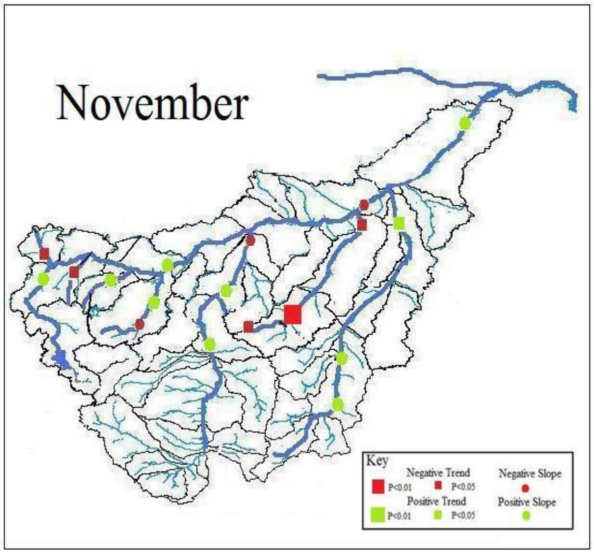

Figure 2.8k Trend analyses of average monthly discharges for November in the YRB.

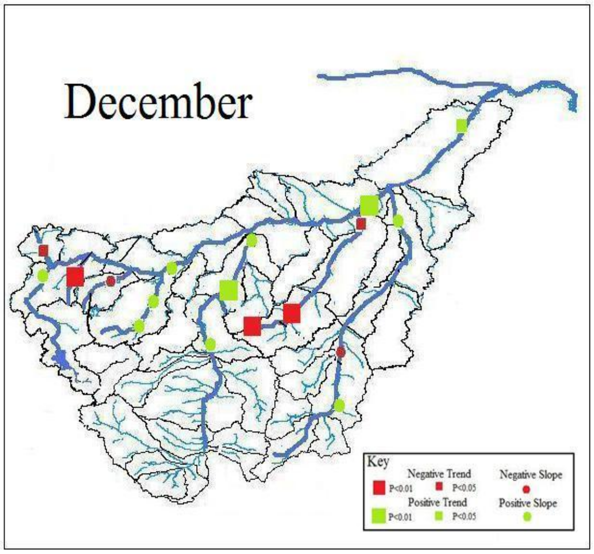

Figure 2.8m Trend analyses of average monthly discharge for December in the YRB.

Timing of Discharge

Overall, both the date of the CT measurement and the return date of baseflow measurements tended to occur earlier in more recent years within the YRB.

5. Centroid of Discharge

The center-time discharge results showed highly significant trends toward earlier runoff events at sites 8 and 18 (P<0.01), no sites with significant trends towards earlier runoff (P<0.05), and two sites (5 and 11) with insignificant trends but trending towards earlier runoff (0.05≤P≤0.10). All nine sites showed negative trending slopes however when evaluating the entire period of record for each site (Appendix 6, Figure 2.9).

Over the period 1970-2007, there were no sites with highly significant trends towards earlier runoff (P<0.01), significant trends towards earlier runoff at sites 4, 5, and 7 (P<0.05) and zero no insignificant trends (0.05≤P≤0.10). All but 8 sites exhibited negative slopes indicating earlier runoff events for the period 1970 to 2007 (Appendix 6, Figure 2.10).

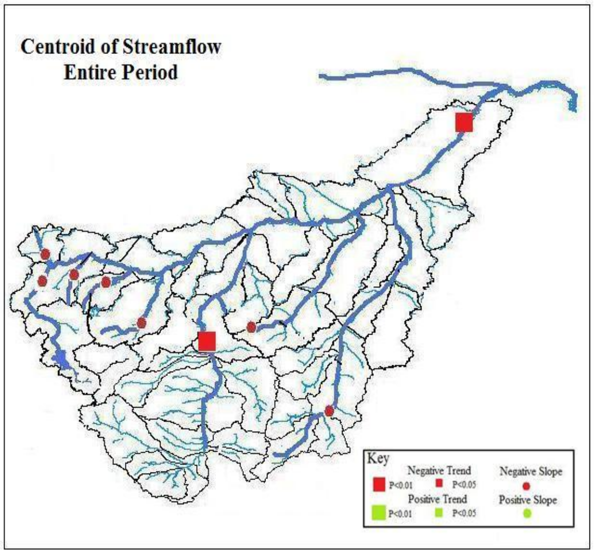

Figure 2.9 Trend analyses for centertime measurement for the entire period in the YRB.

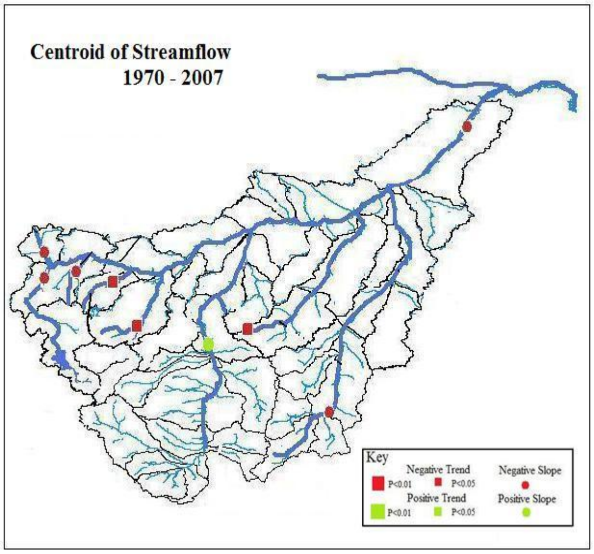

Figure 2.10 Trend analyses for centertime measurement from 1970 to 2007 in the YRB.

6. Annual Peak Discharge

Annual peak discharge showed the least significance in changes or trends of all of the variables evaluated. No sites showed highly significant trends (P<0.01). I found a significant trend (P<0.05) toward earlier annual peak discharge at site 1, and found eleven sites (2, 3, 5-9, 11, 12, 14, and 16) with insignificant but negative trends (0.05≤P≤0.10) in the basin for their entire periods of record (Appendix 7, Figure 2.11).

Similar results were found when evaluating the date of annual peak discharge for the more recent period1970-2007. Sites1 and 5 had highly significant trends ($P<0.01$) towards earlier in the year, no sites showed significant trends ($P<0.05$), and eleven sites (3-7,9, 11, 12, 14, 16, 18) showed insignificant trends but a negative slope towards earlier in the year in the basin for the period 1970-2007 (Appendix 7, Figure 2.12).

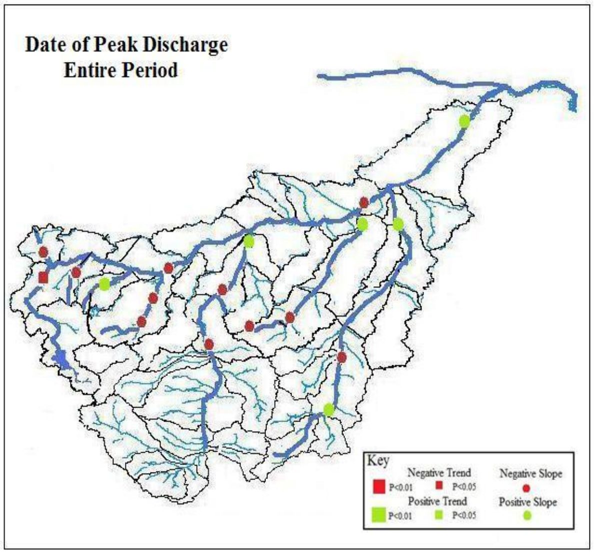

Figure 2.11 Trend analyses for peak discharge date for the entire period in the YRB.

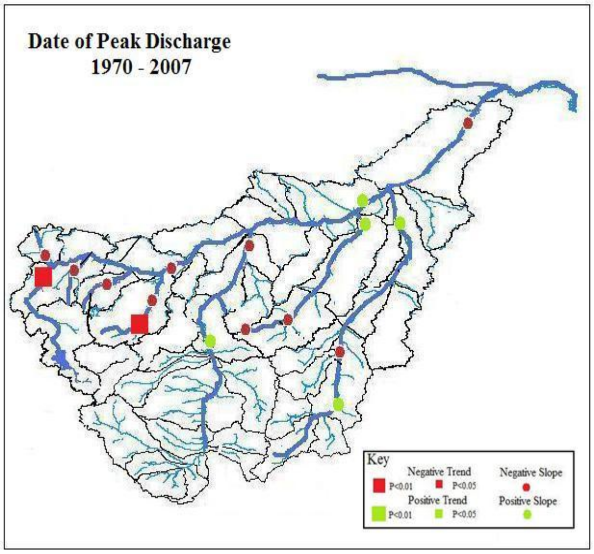

Figure 2.12 Trend analyses for peak discharge date from 1970 to 2007 in the YRB.

7. Annual Baseflow Conditions

Baseflow conditions showed highly significant ($P<0.01$) trends towards earlier in the year at sites 5, 10 and 17, significant trends ($P<0.05$) toward earlier in the year at sites 3 and 4, and all sites but 7 and 14 had negative slopes (9 insignificant ($P<0.10$) but with negative slopes) toward earlier in the year over their entire periods of record (Appendix 8, Figure 2.13).

Over the period 1970-2007, sites 1, 4, 7, and 13 exhibited highly significant trends ($P<0.01$) towards an earlier onset of baseflow conditions, significant trends ($P<0.05$) towards an earlier onset of baseflow conditions at sites 3, 5, 8, 10, and 17, and sites 7 and 14 changed to negative trends. (Appendix 8, Figure 2.14).

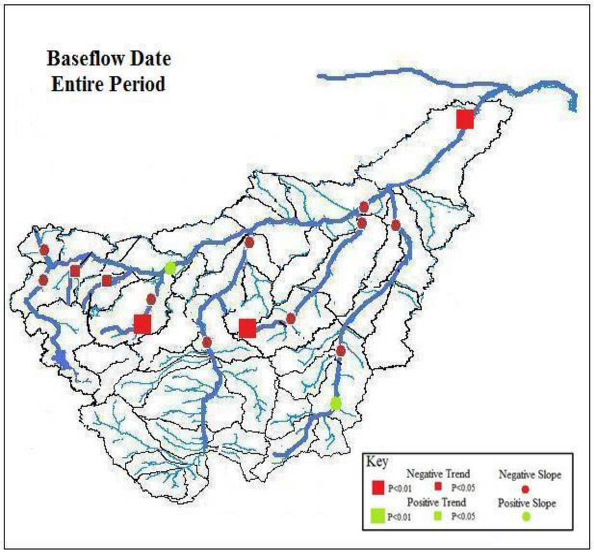

Figure 2.13 Trend analyses for date of return baseflow for the entire period in the YRB.

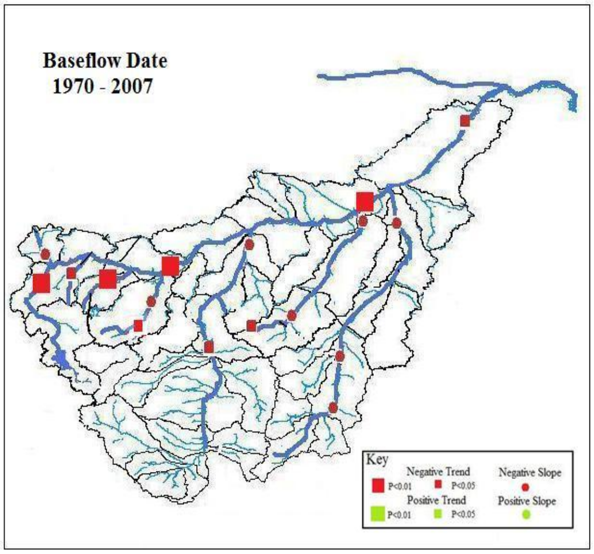

Figure 2.14 Trend analyses for date of return baseflow from 1970 to 2007 in the YRB.

I rejected all of the null hypotheses evaluated. There were many significant (P<0.05) and highly significant (P<0.01) trends identified for all of the variables throughout the basin. Other sites were not found significant (P<0.10) but trends were observed. The significant results were scattered throughout and are summarized in Appendices 2-8.

DISCUSSION

Records of the total volume from the tributaries and the mainstem Yellowstone River provide consistent indications that the historic magnitude and volume of discharge is declining in the YRB. Similar results have been documented in similar snow melt dominated systems along the Rocky Mountains in North America and the Pacific Northwest (Rood et. al 2005; Schindler and Donahue 2006; Luce and Holden 2009). For example, Rood et al. (2005) found that there were significant declines in total annual flow for many Rocky Mountain watersheds near the hydrographic apex of North America, and Luce and Holden (2009) found that the Pacific Northwest was experiencing the same declines.

Although several studies of various river systems in the West show that there are quantified changes occurring in the observable hydrograph (Lapp et al 2005; Rood et al. 2005; Mote et al. 2005; Barnett et al 2005; Cayan et al 2001), most focus on how it affects the timing of water and less so on the amount of water (Luce and Holden 2009). Part of this bias is due to the science of climate modeling, where there is greater confidence in temperature increases regionally (and thus changes in timing of runoff) than what will occur with magnitude of discharge resulting from precipitation at smaller scales in the Western region (Lapp et al. 2005; Rood et al. 2005; Mote et al. 2005).

The analyses also indicate that the declines in the YRB are prevalent basin wide from headwaters to mouth (Appendices 2-4; Figures 2.2-2.7). In contrast, some other studies, noting declines in discharge, saw within basin differences, e.g., greater changes in higher elevation areas than in areas lower in the basin (Rood et al. 2005). Much of this difference may be the result of the Yellowstone River mainstem and its tributaries having few large storage reservoirs that can unnaturally alter runoff patterns differentially between the tributaries and mainstem. The regulated portions the YRB (e.g., Bighorn and Tongue Rivers) were more likely to differ from the declining trends observed in most other variables and rivers (e.g., the absolute minimum discharge in the Bighorn River basin below Yellowtail Reservoir Figure 2.6 and 2.7).

In addition to magnitude of discharge, the significantly altered timing of runoff found in this study in the YRB is consistent with that reported in numerous studies in the West (Cayan et al. 2001; Baron et al. 2002; Regonda et al. 2004; Stewart et al. 2004, 2005; Gibson et al. 2005; Mote et al. 2005; Rood et al. 2008). For example, Cayan et al. (2001) found that not just hydrological fluctuations in spring-snowmelt, but also phenological fluctuations as well with earlier onset of bloom timing dates for lilacs (*Syringa volgaris)* and honeysuckles (*Lonicera tatarica* and *Lonicera korolkowii stopf)*, both strongly related to the springtime temperature variations observed mainly since the 1970’s. Mote et al. (2005) also found that the rising temperatures in the west, no matter the cause were resulting in declines in snow water equivalent (SWE) for snow packs in the west, primarily in the Cascades of Oregon. It has been argued that the most important changes occurring in the hydrological cycle in the

West is the declining snowpack accumulation and earlier runoff timing caused by temperature changes (Barnett et al. 2008).

Although occasional significance in trends was found when looking at the three timing variables basinwide, the most prevalent statistically significant trends were those indicating an earlier return of baseflow conditions (Figure 2.13, 2.14). Other studies have reported similar results for return to baseflow (Baron et al. 2002; Regonda et al. 2004; Stewart et al. 2004, 2005; Gibson et al. 2005; Rood et al. 2008). For example, Rood (2008) found the greatest changes in late summer flows, when demands are the greatest, were observed in the rivers draining the east slope of the Rocky Mountains, some at a rate of 0.2% per year. The substantial onset of earlier runoff and earlier return to baseflows in the basin reported here suggest that the free flowing Yellowstone River and the majority of its tributaries are going to be largely affected by these changes if observed trends remain the same.

Most other studies do not, however, investigate the causes of the observed magnitude and timing changes. Although the contributing causes of these changes in this study may be many, these confirmations in changes in stream flow magnitude and in volume are consistent with current perspectives on declining snowpack, climate change, and anthropogenic forcing (e.g., water withdrawals; Barnett et al., 2005; Mote et al., 2005; Lapp et al., 2005; Vorosmarty et al., 2000; Meehl et al., 2004; See Chapter 4). The cause of the recent changes in magnitude and timing appear to coincide well with estimates of warming and prolonged droughts studied during the same period (IPCC 2007; Vorosmarty et al., 2000; Schindler and Donahue, 2006). Of major concern is how it will affect each region specifically, and more importantly are the prolonged droughts and warming going to become the norm and need to be viewed as such (IPCC 2007; Luce and Holden, 2009).

There are major potential implications for water users and agricultural development of declining discharges and earlier returns to baseflow. With lower discharges, especially during low flow periods, future water allocation decisions can be expected to become increasingly difficult, especially in over allocated systems, such as the Powder River. With earlier base flow, and demand for water in the basin persisting into the fall with irrigation water users withdrawing water until they harvest crops, an earlier return to baseflow will result in more users being affected on a more frequent basis. This change toward earlier baseflows may require modified water allocation strategies, such as establishing a water use hierarchy based on beneficial use or policy changes on salvage water allocations.

These lower discharges values and earlier return to baseflow have major implications for the YRB's rivers (Schindler 2001; Schindler and Donahue 2006; Arismendi et al. 2012). As the flows decline, the ability of rivers to tolerate pollutant loads and thermal thresholds is reduced (Schindler 2001). As the rivers are affected by an earlier onset of snowmelt and decreased discharges due to climatic and anthropogenic factors such as withdrawals (Poff et al. 1997), there will be fewer cold days and nights (IPCC 2007), warmer and more frequent hot days (IPCC 2007), and duration and frequency of droughts will increase in most land areas (Gibson et al. 2005). The natural flow reductions and reductions from withdrawals will provide little protection against rising stream temperatures (Schindler 2001; IPCC 2007). Also, it is predicted that the trend of lessening snow packs and more rising temperatures will continue (IPCC 2007). Declining trends in the magnitude and earlier return to baseflow in the highly turbid, low gradient lower mainstem will result in the water temperature increasing substantially (Arismendi et al. 2012). Site 18, representing the end of the YRB watershed, near Sidney, Montana, had very noticeable declines in all of the variables, especially since 1970. For the native fishes and important fisheries of the lower Yellowstone river, the result from the Sidney Site (18), the most downriver, most cumulative site is of major concern because it provides the most accurate indication of how much water can be expected in that portion of the river.

Alterations in the magnitude and timing of flows identified in this study can be expected to affect the ecology of the river in many ways, including ways: altered timing of seasonal flows, increases in temperature, and in low water situations less dilution abilities can make unacceptable water chemistry (Schindler 2001). Lower magnitude peak discharges and earlier timing of peak discharge could pose potential threats to species keying into them as spawning cues. Quantity and quality of in-river habitat for aquatic fauna will also be affected by the amount and timing of discharge and resulting temperature changes (Schindler 2001; Sabo and Post 2008). Declines in magnitude of discharge and earlier timing of runoff can thus be expected to have cascading effects through not only the ecosystem for fishes and aquatic organisms but to impact water allocation decisions. Efforts to stabilize hydrographs in the face of anthropogenic factors such as irrigation withdrawals, the adjudication process, and human-induced climate change will be necessary to if the historical habitat and fauna of the Yellowstone river is to be maintained.

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CHAPTER 3 – AN INVENTORY AND PHYSICAL OBSERVATION OF WATER USE, HISTORIC AND CURRENT, IN THE YELLOWSTONE RIVER BASIN.

ABSTRACT

An understanding of and a system for quantification of existing water withdrawals and uses within the Yellowstone River Basin are necessary for effective water management. In this chapter I quantified all current (2008) water rights for the Yellowstone River and its tributaries, including all state permitted water rights, all federal reserved and appropriated water rights, and all other water reservations held on the rivers, 2) evaluated trends in irrigated agriculture development in the basin over the time period 1946 to 2008, 3) inventoried and quantified all known consumptive withdrawals from the Yellowstone River and its tributaries in 2006 using information from municipal, industrial, irrigation agriculture and livestock sources, and 4) conducted a physical inventory of surface withdrawals to estimate the number of mainstem surface water users. Rights to water greatly over allocate the water resources in the basin, although some rights can be considered duplicate and non-consumptive. There are large differences in the two accepted methods Montana uses to establish allowable water use for crops, creating room for large inefficiencies and waste. The physical inventory illustrates screening issues and provides evidence of misuse. In a system that is very heavily dependent on water it is unacceptable for these issues to persist. Not only will this mismanagement fail for the resource, but it cripples Montana's ability to litigate against unfair distribution of water by other states, when their own proves to be wasteful and unchecked.

INTRODUCTION

As water demands have increased throughout the arid west in the past century, allocation and over-allocation of the limited supply have become contentious and potential sources of conflict. A few of the numerous and widespread examples include water allotment disagreements among states in the Colorado River Basin (Gelt 1997), out of basin water transfers to California that have dewatered the

Owens River Valley (ICWD 2008), Klamath River disputes in southern Oregon and California over dams, declining fish populations, and failing water quality (Klamath 2009), and litigation between the State of Wyoming and Montana over provisions of the Yellowstone River Compact (Dengler 2007).

Water demand often is measured by amounts of withdrawal, i.e., water removal from ground- or surface water sources and considered to be self supplied (Vickers 2001). Nearly all water withdrawals in the west are used for human economic activity. In aggregate, agricultural, industrial, municipal, and thermoelectric power water uses account for about 95% of all water withdrawals in the United States, although not all of these withdrawals are considered consumptive, i.e. not immediately available for reuse (Kenny et al. 2009).

With the increasing demand for scarce water, and recent and current basin-wide adjudications across the West, many western states are working to develop more accurate and precise requirements of users for reporting water withdrawals to help in their ongoing adjudications (Perramond 2012). In most localities, the limited or complete lack of actual measurement of withdrawals has led to inaccurate estimates of historic and current usage prolonging efforts to reach final adjudications, for example in Washington and New Mexico (Bonkowski 2012; Perramond 2012). The poor databases on quantified withdrawals has crippled some states' ability to validate water demands in litigation. This problem was well illustrated in New Mexico v. Colorado (467 U.S. 310 (1984)) and further reinforced in the 2008 case between Montana and Wyoming (O'Regan and Shertzer 2011), when the Court required that the states have clear and convincing evidence standards to prove their case when seeking to enjoin the activities in one state that may negatively affect activities in another state. Some states that have experienced this problem have consequently enacted measures to more accurately quantify water usage (Perramond 2012).

In Montana, about 96.5% of all water withdrawals are for agriculture (Hutson et al. 2005). Despite the importance of agriculture in accounting for withdrawals, however, discussions with the overseeing agency (the Montana Department of Natural Resources and Conservation (DNRC)) indicate that there is no uniform, formal, comprehensive approach for accurately and precisely documenting total withdrawals. There is thus no overall system for accurately holding Montana's water users accountable for their withdrawals in Montana's river basins, nor a reliable system of enforcement.

In Montana's portion of the YRB, recent increases in water use demands and the need for providing instream flows for the endangered pallid sturgeon (*Scaphirhynchus albus*), other sensitive fish species, and other aquatic life (Haddix et al. 1976; Penkal 1981; Proboszcz et al. 2003), has made it clear that the increasingly scarce water must be accounted for. Water shortages are anticipated to increase because of factors such as climate change, increased evapotranspiration (ET) due to increased temperatures, land use changes, and increasingly common legal disputes. In areas with little to no monitoring, supervision, or enforcement, over use conditions tend to worsen beyond that expected with naturally increasing demand and long term landscape changes (Russell 1997). In the Yellowstone Basin, an important first step is to inventory water withdrawals from the basin.

In this chapter, my objectives were to: 1) inventory and quantify all current (2008) water rights for the Yellowstone River and its tributaries, including all state permitted water rights, all federal reserved and appropriated water rights, and all other water reservations held on the rivers, 2) evaluate trends in irrigated agriculture development in the basin over the time period 1946 to 2008, 3) inventory and quantify all known consumptive withdrawals from the Yellowstone River and its tributaries in 2006 using information from municipal, industrial, irrigation agriculture and livestock sources, and 4) conduct a physical inventory of surface withdrawals to estimate the number of mainstem surface water users and the estimated amount of potentially illegal use.

METHODS

Water Rights Inventory

Under the state of Montana's prior appropriation doctrine ("first in time first in right"), an understanding of the five types of water rights in the state (and their seniority) is essential. The first and earliest dated rights in the basin are federally reserved and Indian reserved rights, second are the existing rights (pre July 1, 1973), third the exempt rights, fourth are new appropriation rights (post July 1, 1973), and fifth are water reservations (Montana DNRC 2008). There is, however, one category of water rights that will be mentioned numerous times in this study, *viz.*, supplemental water rights; these rights will be considered separately.

Federal rights went with any federal non-Indian reservations (National Forest, National Park, etc.) and Indian water reservations were made after or at the same time as establishment of the Indian Reservation. The water rights carry with them the priority date of the reservations creation, some of these dating before statehood. For some of the Indian reservations where the water wasn't determined at the time, it was later determined that they had an attached right to water when the Reservation was created, although it wasn't quantified until the late 20th century. In 1979, the Reserved Water Rights Compact Commission (RWRCC) was created by the legislature to negotiate, on the behalf of the Governor's office, the quantification of these water rights.

Existing Rights are water rights that originated prior to July 1, 1973, that were filed on a Statement of Claim between 1979 and 1982 to document the historic water right (Montana DNRC 2008). These rights are subject to adjudication, but since they pre-date the new laws established in 1973, they are defined under the old laws that were present before the changed laws.

Exempt Rights are certain domestic groundwater wells below a certain size and livestock uses that are exempt from the permit system and the adjudications, but still are subject to priority. Any exempt rights on file with the DNRC were filed voluntarily and were most likely done to provide proof of use in case future appropriations impinge on their rights (Montana DNRC 2008).

New Appropriations are water uses originating after July 1, 1973. New Appropriations are differentiated by size and source of water right. Any groundwater use over 132.5 liters per minute (lpm; 35 gallons per minute (gpm)) or 12,335 cubic meters per year (m^3/yr; 10 acre-feet/year (ac-ft/yr)) or any surface water appropriation requires a permit issued by the Montana DNRC. Any groundwater use under 132.5 lpm, which is not to exceed 12,335 m^3/yr (10 ac-ft/yr) is considered exempt from filing but still requires a Groundwater Certificate, also issued by the DNRC.

The Administrative Rules of Montana defines supplemental irrigation as "additional water provided to lands which are already irrigated or to lands which will receive water through another right (ARM 36.12.1010). In other words, supplemental water rights are rights that were used to further develop, move, or alter original water rights (ARM 36.12.1010), and although not all of them are direct duplicates of the original permit, for the purpose of this study they will be viewed as duplicates. For example, there is a water permit for the same location on the lower Yellowstone River that has four different water rights attached to it, all giving claim to a flow rate of 11,355 lpm (3,000 gpm), with a max volume of 132,300 m^3 (107.25 ac-ft) on 12 hectares (30 acres), two for irrigation and two for stock water. There are numerous permits in the basin that are identical to the permit in the above example, and when the multiple water rights are added up they overestimate the amount of water allocated in the basin by several times even though the actual amount of water is not exceeding the original water permit for each site. Many of these supplemental rights were filed because a change was made to the specific place of use or water use needs, therefore a supplemental right was filed when either changed.

State (post-1973) water reservations are reservations that were granted to local, state, and federal agencies in 1978 by the Montana Board of Natural Resources and Conservation (MBNRC) to assure that future development by industry or other uses would not harm future agricultural, municipal, and instream water uses in the basin (Montana DNRC 2008). By November 1976, 30 applications had been received by the MBNRC by conservation districts, irrigation districts, federal and state agencies, and eight municipalities (Montana DNRC 2008). In 1978, the MBNRC granted water reservations for numerous uses in the YRB which have been appropriated in various amounts throughout the basin.

For this study, water rights data (number and water volume of permits) were extracted from the Montana DNRC website. The website has a water rights query system that allows anyone to search for all existing water rights held within the state. I used the site to produce an exhaustive list of all ‘paper’ water rights held within the YRB for groundwater and surface water permits. I divided the permits into two categories, adjudicated and non-adjudicated water rights, based on the date of acquisition. Adjudicated water rights are rights acquired before July 1, 1973 and must go through a statewide adjudication before given a final decree, whereas non-adjudicated rights are permits acquired since July 1, 1973, are considered new appropriations that have gone through claims examination, and are not required to be adjudicated.

I gathered all of the water rights and estimated the total number and volume of appropriated water based on the final cumulative list of rights present in the basin. To evaluate the total number of water rights in the basin, I separated them into 4 categories: 1) total number of water rights, 2) adjudicated and non-adjudicated, 3) surface versus groundwater sources, and 4) water rights with supplemental permits included versus rights without supplemental permits included.

I then quantified the water rights based on volume and separated the completed list into the following 6 categories for the entire basin and for each individual sub-basin: 1) total annual volume, 2) volume of adjudicated and non-adjudicated, 3) volume of consumptive and non-consumptive, 4) volume by type of use, 5) volume of groundwater versus surface water, and 6) volume of appropriated and non-appropriated reserved water rights.

Estimating the water volumes presented challenges. Many of the water rights present in the database lacked distinct volumes and/or flow restrictions based on varying circumstances. To estimate allocated water for rights that had a maximum flow present but not a volume I multiplied the permitted flow by the total water days the permit allowed the user per water year, also known as the period of use, to obtain an absolute maximum volume that could be used. This is not to say it will be used, and if it were there would be no other limitations, but when looking at DNRC’s query system it is the allotted amount. The majority of the rights without maximum flow and volume designated are stock water users with varying amounts of use based on maximum animal units allowed. Stock water use from ground or direct from the surface prior to 1962 and some during the period of 1962 to 1973 were not obligated to file, whereas newer users rights are based on animal units allowed on the property using a standard of 56.5 liters per day per animal unit (15 gallons per day per animal unit). Because of this difference, I concluded that the volume of water used for watering stock would be better assessed using agricultural census data and this approach is evaluated in the next section with irrigation use. I then compiled data on water reservations and instream flow rights from multiple sources to completely quantify all permitted water rights.

Trends in Irrigation Water Demands

Trends in irrigation water demands were based on agriculture census information for Montana and Wyoming by county within the YRB. Although county political boundaries do not exactly match the hydrologic units, they are close and serve as the best source of historic information available to track irrigated agriculture through time (Figure 3.1). I gathered crop information for the period of 1946 to 2008 for the following Montana counties: Big Horn, Carbon, Custer, Dawson, Park, Powder River, Prairie, Richland, Rosebud, Stillwater, Sweet Grass, Treasure, and Yellowstone; and Wyoming Counties: Big Horn, Fremont, Hot Springs, Natrona, Park, Sheridan, and Washakie. Using the county data, I estimated total area of irrigated crops and analyzed how much irrigated agriculture has increased in the basin by state and crop type from 1946 to 2009.

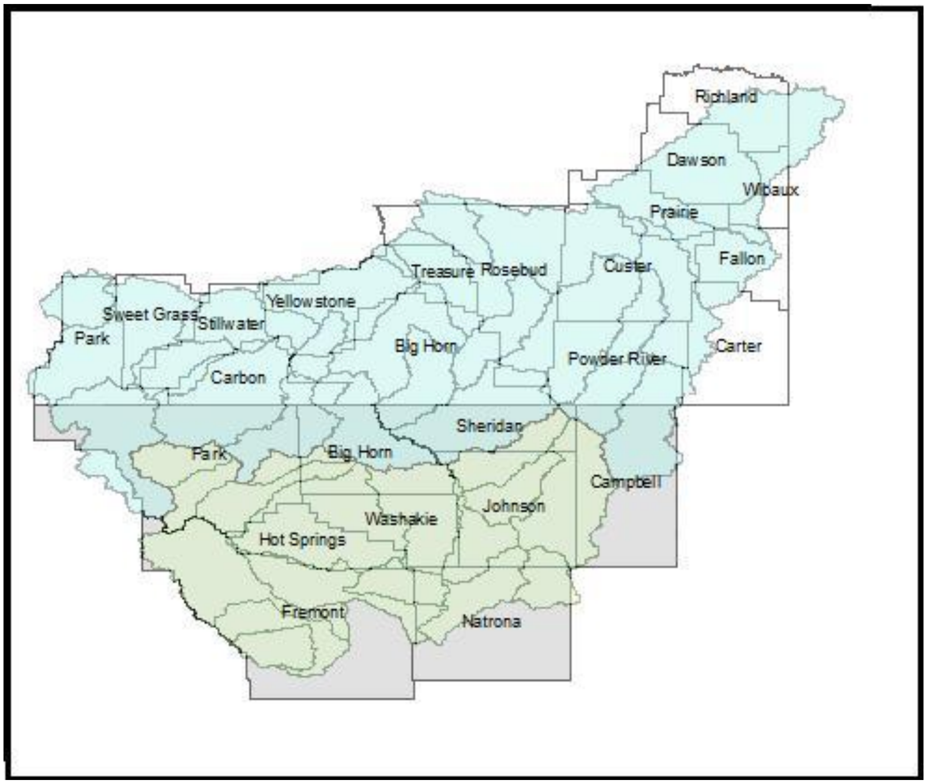

Figure 3.1 Wyoming (grey background) and Montana (white background) county boundaries map with hydrologic watersheds overlain.

Inventory of Annual Water Use

I estimated the amount of annual water use in the basin from agricultural census data for irrigated crops and livestock, and water use data from industrial and municipalities in 2006. I used 2006 for this comparison because it was the last complete year for all sets of data acquired that had been quality checked and accepted by provided sources. I then used the final results of both estimates to compare the percent of estimated volume of water rights actually withdrawn annually in the basin to the amount permitted (paper water) for allocation.

The 2006 irrigated agriculture census data for the Montana and Wyoming counties (Figure 3.1) were used to estimate water use in the basin. Two estimates were developed based on different use models, and different assumptions, of the relation between the agricultural census data and actual use: 1) the Irrigation Water Requirements program and 2) Montana DNRC’s allowed water use per irrigated hectare. Using the two methods, I was able to estimate the amount of water needed by the major crops that were grown in the basin based on crop needs and state allowance for the 2006 growing season.

The first method, the Irrigation Water Requirements (IWR) program, was originally created by Natural Resources Conservation Service (NRCS) Field Office Engineering Software (FOES) development team for use in the Cody, Wyoming Conservation District and in the NRCS (Irrigation Guide 1997). The program estimates the amount of monthly and seasonal net water requirements based on crop needs, effective precipitation, and length of the growing season (Irrigation Guide 1997). The program only estimates the amount of water needed for evapotranspiration (ET) by the crop and not the amount needed to effectively irrigate it considering irrigation efficiencies (Overcast 2008; Irrigation Guide 1997). IWR estimates ET crop requirements using the Blaney-Criddle method using local weather station estimates to determine average monthly air temperatures and monthly percentage of annual daytime hours to determine crops annual water needs (Overcast 2008; Irrigation Guide 1997; Ward and Trimble 2004). The program then subtracts the average effective precipitation for each area by the total water requirements for the crop provided by the process above (Overcast 2008; Irrigation Guide 1997). To evaluate water use using the IWR Program, I needed to evaluate the states irrigated agriculture by crop type and region, as both affect how much water is required. Based on a consumptive use methodology report done by Montana's DNRC, Montana can be divided into 5 different climate regions. The YRB is almost entirely in the high to moderately high consumptive water use regions (Montana DNRC Consumptive Use Methodology 2010). Using the IWR program, I chose two areas, one in Montana and one in Wyoming, to represent an average for each state's climate conditions that are taken into account within the program. I chose to use the climate database site near Billings, MT in Yellowstone County and the site near Thermopolis, WY in Hot Springs County for their central position in the watershed for both states (Figure 3.2).

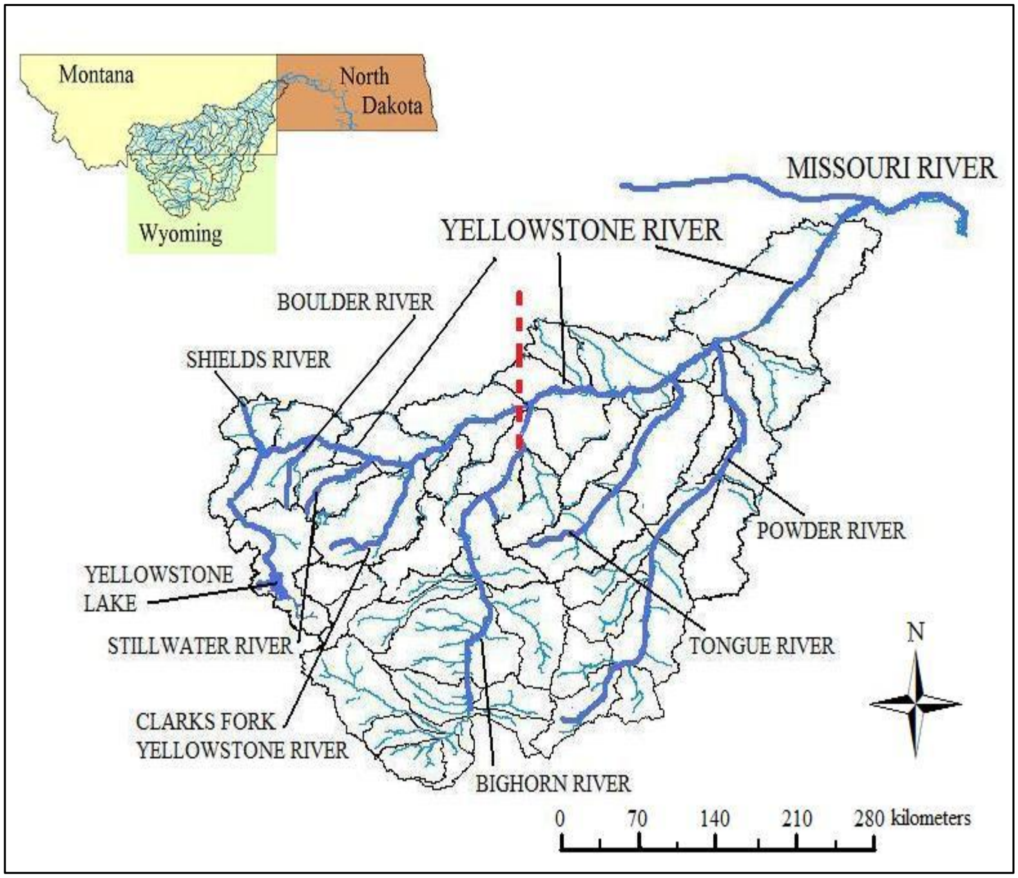

Figure 3.2 Montana, North Dakota, and Wyoming Map with Yellowstone River Basin Overlain.

Second, I measured water demands for 2006 in the Yellowstone river Basin using DNRC's adjudication standard for pre-1973 water use of 160 liters per minute per hectare (lpm/ha; 17 gallons/minute/acre (gpm/acre)) to estimate allowed water use in the basin. This standard was developed by the DNRC but only applies as a limiting factor to the new appropriation water rights. I chose this approach because of the way in which Montana decides its water allowance in the basin, by local efficiency standards and climatic zone, makes it difficult to estimate water demands basin-wide using any other method. With DNRC's designation of the 160 lpm/ha as being an acceptable amount, it provides a standard and best available option to use throughout the basin. For the final analysis (in volume), I used 214 days as the acceptable growing season, from April 1st to October 31st, making DNRC's designated acceptable volume 49,305.6 m^3/ha for a growing season.

I computed 2006 annual water demands for the entire basin by multiplying the standard water use by the total amount of irrigated acreage to estimate the maximum potential water use. I am assuming it to be the upper end of water demand because this method does not take into account the amount of effective precipitation that supplements crop needs. It is also assumed that the users are not applying more water than the crop needs, as that would be considered waste and against Montana water laws.

I estimated water demands for stock animals within the basin using county livestock census data for the period of 2003 to 2008 and DNRC's estimate of daily requirements for animal units in the basin. Livestock data were gathered from all Wyoming and Montana counties located within the basin to assess how much use is present in both states. The following counties were evaluated in Montana: Big Horn, Carbon, Custer, Dawson, Park, Powder River, Prairie, Richland, Rosebud, Stillwater, Sweet Grass, Treasure, and Yellowstone County; and Wyoming: Big Horn, Fremont, Hot Springs, Natrona, Park, Sheridan, and Washakie (Figure 3.1). DNRC established standards of 113 liters per day per animal unit (lpd/AU; 30 gallons per day per animal unit (gpd/AU) for pre-1973 stock permits and 56.5 lpd/AU (15 gpd/AU) for post-1973 permits for livestock watering needs. These standards only apply in Montana but serve as a reasonable estimating tool for livestock watering demands throughout the study area. I computed the annual water demands for the basin by multiplying those standards by the total AU's present to estimate upper and lower boundaries of water demand for livestock.

I obtained the 2006 water use data from each municipality and industrial water user in the basin. These estimates of annual water use were derived from their measurements and recordings taken at their established intervals for 2006 (Table 3.1).

Table 3.1 Annual Industrial and Municipal water withdrawals for 2006.

Industrial	**Withdrawn (m^3)**	**Reserved (m^3)**	**Percent Withdrawn**
YRB	525,898,955		
City			
Laurel	2,744,957	8,820,629	31%
Billings	34,414,276	65,991,278	52%
Miles City	1,889,261	3,563,529	53%
Glendive	1,121,614	4,047,054	28%
Total	40,170,108	82,422,490	49%

Physical inventory

To estimate the number of annual surface water withdrawal sites from the Yellowstone River and its major tributaries, and to estimate the number of undocumented (thus possibly illegal) water appropriators, I boated the Montana sections of the river and the seven major tributaries described in the study area from source to mouth and for any evidence of surface water use and recorded all potential water withdrawals (e.g., any development and equipment to aid in water withdrawals). I scheduled the individual river inventories balancing their estimated peak irrigation season and safe water levels for boating in 2009 (Table 3.2). Potential water withdrawal sites were recorded if there was an active withdrawal or any of the following: reasonable access to the river, fuel or electrical means within sight from the shore, evidence of stream alteration for stilling pool to withdrawal from, any manmade division of water from the channel, or if there was irrigation equipment (pumps, piping, fuel tanks, electrical hubs) present. For each potential withdrawal site photographs were taken, coordinates were logged, onsite data collection was conducted on withdrawal type (diversion or pump), size of headgate or mainline, energy source (electric or fuel) and pump type (centrifugal or turbine), and observations were made to determine any evidence of recent use, and whether there was any screening device present. All field activities were conducted while staying below the visible high water mark in accordance with Montana laws.

Table 3.2 Priority of rivers based on safe flows and irrigation demand.

River	**Priority**	**Date**
Clarks Fork Yellowstone	4	June 24 – 26
Shields	1	June 30 – July 4
Powder	3	July 6 – 9
Tongue	5	July 10 – 14
Boulder	2	July 17 – 20
Yellowstone	7,8,10	July 22 – 31
Stillwater	6	August 5 – 10
Bighorn	9	August 29 – September 3

Data collected and photos taken were then mapped using ArcGIS, and can be used to assist Montana DNRC in updating and monitoring pump sites within Montana's portion of the basin.

RESULTS

Water Rights Inventory

In total, there were 125,000 water rights in Montana's portion of the YRB as of 2007, adding up these rights gives claimants the rights to water in access of 1.25 trillion m³ of water annually (Table 3.3). Supplemental water rights, "duplicate rights", were found to account for nearly half the 125,000 permits. The supplemental permits, though half in total number, over-represented the amount of potential water appropriation by approximately 15 times with 94% of the total 1.25 trillion m³ being supplemental rights. With the supplemental rights removed the overall permitted use in the YRB in Montana was 77.1 billion m³ (Figure 3.3). The mainstem Yellowstone River was first in surface water withdrawals with 382.65 billion m³ (310,217,381 ac-ft) with supplemental rights and 35.84 billion m³ (29,053,416 ac-ft) without, followed by the Bighorn River with 573.54 billion m³ (464,979,941 ac-ft) with supplemental rights and 29.6 billion m^3 (23,998,992 ac-ft) without. The same order was present with groundwater withdrawals at 846,050,745 m^3 (685,905 ac-ft) with supplemental and 324,883,451 m^3 (263,387 ac-ft) without for the Yellowstone River mainstem and 580,900,581 m^3 (470,944 ac-ft) with supplemental and 55,371,370 m^3 (44,890 ac-ft) without in the Bighorn River Basin.

Table 3.3 Total quantified water rights in the Yellowstone River basin.

Rivers	**Supplemental included**	**Surface Water**		**Groundwater**	
		acre-feet	m^3	acre-feet	m^3
Yellowstone	*Yes*	310,217,382	382,647,506,163	685,905	846,050,745
	No	29,053,416	35,836,861,396	263,387	324,883,451
Shields	*Yes*	16,763,218	20,677,125,353	50,866	62,742,867
	No	1,519,192	1,873,895,497	35,324	43,571,266
Boulder	*Yes*	17,316,434	21,359,506,265	14,301	17,640,183
	No	836,669	1,032,015,894	11,000	13,568,794
Stillwater	*Yes*	28,080,892	34,637,269,963	22,576	27,846,889
	No	1,496,247	1,845,593,749	13,227	16,315,227
Clarks Fork Yellowstone	*Yes*	99,109,863	122,250,216,433	104,764	129,224,368
	No	4,166,587	5,139,409,227	56,530	69,728,864
Bighorn	*Yes*	464,979,941	573,544,312,605	470,944	580,900,581
	No	23,998,992	29,602,321,057	44,890	55,371,370
Tongue	*Yes*	51,639,290	63,696,126,569	53,140	65,547,015
	No	878,176	1,083,213,778	32,797	40,453,887
Powder	*Yes*	20,974,941	25,872,208,634	8,417	10,382,463
	No	143,263	176,712,556	4,997	6,163,462
Total	**Yes**	**1,009,081,959**	**1,244,684,271,984**	**1,410,913**	**1,740,335,111**
	No	**62,092,542**	**84,995,215,896**	**462,152**	**570,056,321**

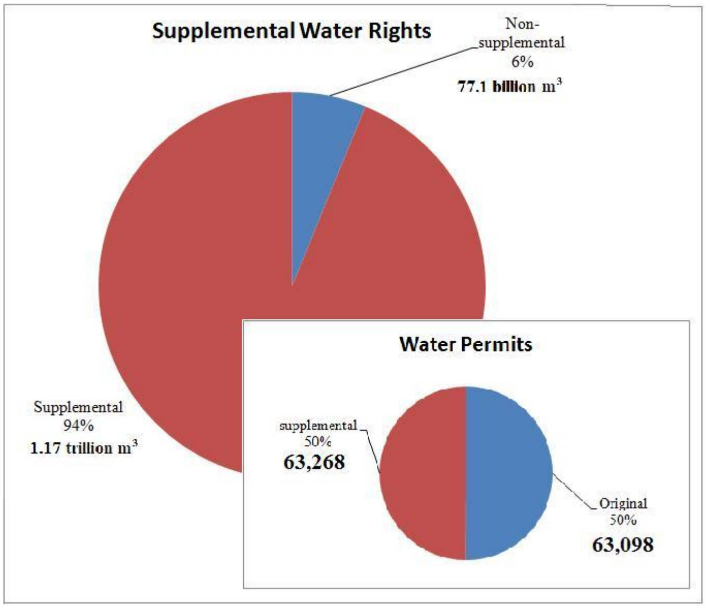

Figure 3.3 Summary of supplemental water permits and quantities.

Quantified existing rights, with exempt rights included, represented approximately 1.7 billion m³ of water in the basin with supplemental rights included and only 89 million m³ without supplemental rights. The mainstem Yellowstone River had the most quantified existing and exempt rights for surface water withdrawals with 797,079,260 m³ (646,203 ac-ft) with supplemental and 31,341,039 m³ (25,409 ac-ft) without, followed by the Bighorn River with 240,081,353 m³ (194,637 ac-ft) with supplemental and 39,996,863 m³ (32,426 ac-ft) without. The Bighorn River had the largest amount of quantified existing and exempt permitted groundwater withdrawals at 1,214,476 m³ (985 ac-ft) with supplemental and 61,244 m³ (50 ac-ft) without, followed by the Yellowstone River mainstem at 1,010,549 m³ (819 ac-ft) with supplemental rights and 472,244 m³ (383 ac-ft) without (Table 3.4).

Table 3.4 Quantified existing and exempt water rights.

Rivers	**Supplemental included**	**Surface Water**		**Groundwater**	
		thousand acre-feet	thousand m^3	thousand acre-feet	thousand m^3
Yellowstone	*Yes*	646,203	797,079,260	819	1,010,549
	No	25,409	31,341,039	383	472,244
Shields	*Yes*	7,592	9,365,130	104	127,802
	No	2,816	3,473,174	76	93,521
Boulder	*Yes*	1,391	1,715,242	15	18,019
	No	920	1,134,546	18	21,680
Stillwater	*Yes*	4,391	5,416,022	19	23,342
	No	1,841	2,270,850	15	18,449
Clarks Fork Yellowstone	*Yes*	10,348	12,763,651	150	185,501
	No	6,596	8,135,789	70	86,746
Bighorn	*Yes*	194,637	240,081,353	985	1,214,476
	No	32,426	39,996,863	50	61,244
Tongue	*Yes*	4,830	5,958,162	64	78,512
	No	1,411	1,740,404	53	64,871
Powder	*Yes*	17	20,517	0	491
	No	12	14,790	0	437
Total	**Yes**	**869,408**	**1,072,399,337**	**2,155**	**2,658,692**
	No	**71,430**	**88,107,455**	**664**	**819,191**

Quantified new appropriations in the basin accounted for nearly 19.7 million m^3 (16,000 ac-ft) of water, and had little (less than 5%) surface water duplication because of supplemental water rights. Groundwater use in the basin had more duplication (more than 64.5%) because of supplemental water rights. The Bighorn basin in particular stood out when looking at the amount of water permitted since 1973; the volume of permitted water use accounted for almost 85 percent of the new appropriations with 16,631,252 m^3 (13,483 ac-ft) with supplemental rights and 16,514,066 m^3 (13,388 ac-ft) without (Table 3.5).

Table 3.5 Quantified new appropriation water rights.

Rivers	**Supplemental included**	**Surface Water**		**Groundwater**	
		thousand acre-feet	thousand m³	thousand acre-feet	thousand m³
Yellowstone	*Yes*	693	854,511	749	924,431
	No	498	614,884	218	269,487
Shields	*Yes*	85	105,139	13	16,251
	No	18	21,658	5	6,516
Boulder	*Yes*	24	29,615	18	22,482
	No	13	16,341	8	9,473
Stillwater	*Yes*	34	41,470	33	40,593
	No	19	23,187	15	19,010
Clarks Fork Yellowstone	*Yes*	366	451,304	90	111,017
	No	194	239,424	59	73,174
Bighorn	*Yes*	13,401	16,530,154	82	101,098
	No	13,350	16,466,381	39	47,685
Tongue	*Yes*	21	25,879	58	71,449
	No	17	20,979	22	27,479
Powder	*Yes*	272	336,094	18	21,633
	No	98	121,322	10	12,000
Total	**Yes**	**14,896**	**18,374,164**	**1,061**	**1,308,955**
	No	**14,207**	**17,524,176**	**377**	**464,825**

Although federally reserved water rights in the basin had all been completed (ratified) in the YRB as of 2009 and the reservations are quantified, it was not possible to enumerate the amount of total water currently appropriated using the current records system. The rights are not listed as reserved or withdrawn from a set cumulative amount. The federal reservations located in the basin can be found in Table 3.6.

Table 3.6 Yellowstone River Basin Federal and Indian Reservation Compacts.

Yellowstone River Basin Compacts	Date Finalized
Northern Cheyenne Tribe MCA 85-20-301	April 1991
U.S. Department of the Interior, National Park Service -Yellowstone National Park MCA 85-20-401	January 1994
U.S. Department of the Interior, National Park Service -Little Bighorn Battlefield National Monument Bighorn -Canyon National Recreation Area MCA 85-20-401	May 1995
Crow Tribe MCA 85-20-901	June 1999
U.S. Department of Agriculture -Forest Service MCA 85-20-1401	April 2007
U.S. Department of Agriculture -Agricultural Research Service, Livestock, Range and Research Laboratory, Fort Keogh MCA 85-20-1101	March 2007

*(more information on these compacts can be found at the website: http://data.opi.mt.gov/bills/mca_toc/85.htm).

As for 1973 reservations there was more than 1.76 billion m³ (1.42 million ac-ft) of water throughout the entire basin, the majority of it surface water. Many of these reserved water rights were largely non-consumptive held for the purpose of instream flows. These appeared as supplemental because they were listed and repeated at numerous points down the watershed. Once these supplemental water rights were removed however, there was only 70 million m³ of water to be appropriated (Table 3.7). As of 2007, nearly 14.5 percent (224,000 m³) of the 1.5 million m³ of water reservations granted to Conservation Districts had been allocated and were being used annually (Figure 3.4). Municipalities were also granted water for future use in 1978 and though they were further along in their development then the conservation districts; there was still a considerable amount of water to be appropriated. Approximately 82 million m³ of water was granted to four municipalities in the YRB, and as of 2007 only 46% of this total volume had been appropriated

(Figure 3.4). Billings, Montana was the largest municipal reservation and had appropriated the largest percentage (Figure 3.5).

Table 3.7 Quantified reserved claims.

Rivers	**Supplemental included**	**Surface Water**		**Groundwater**	
		acre-feet	m^3	acre-feet	m^3
Yellowstone	*Yes*	65,345	80,601,853	6	7,501
	No	40,798	50,323,352	3	4,182
Shields	*Yes*	30,810	38,003,166	0	0
	No	655	807,519	0	0
Boulder	*Yes*	38,343	47,295,284	0	0
	No	988	1,218,559	0	0
Stillwater	*Yes*	60,048	74,067,593	0	0
	No	1,575	1,943,335	0	0
Clarks Fork Yellowstone	*Yes*	216,837	267,464,178	0	173
	No	2,776	3,424,561	0	173
Bighorn	*Yes*	859,528	1,060,211,684	15	18,139
	No	9,325	11,501,902	15	18,200
Tongue	*Yes*	113,709	140,258,429	0	530
	No	588	725,611	0	530
Powder	*Yes*	47,868	59,044,422	1	1,713
	No	219	269,609	1	1,713
Total	**Yes**	**1,432,487**	**1,766,946,607**	**23**	**28,057**
	No	**56,924**	**70,214,449**	**20**	**24,799**

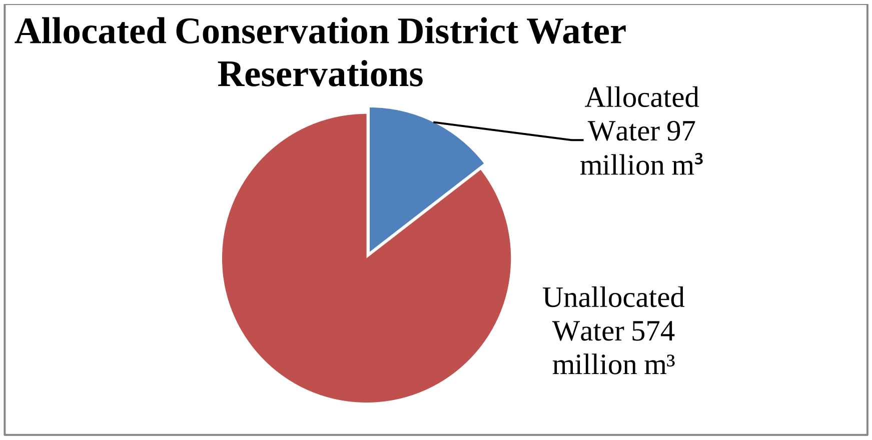

Figure 3.4 Total allocated amounts of conservation district water reservations.

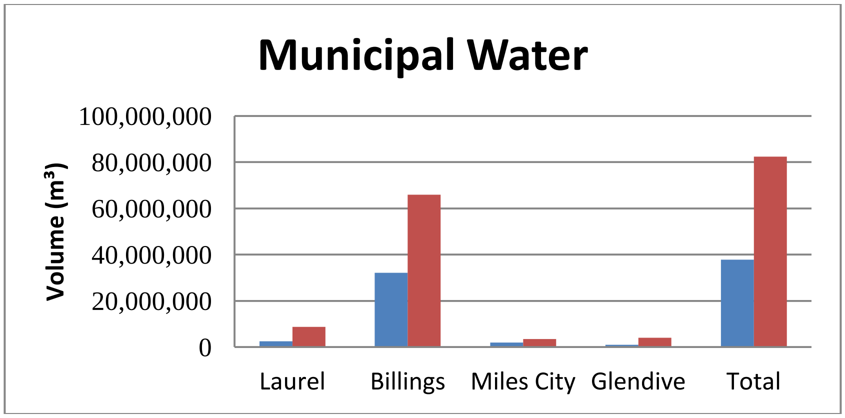

Figure 3.5 Percent (Blue) of total (Red) municipal reservations appropriated in the YRB.

As for adjudicated or non-adjudicated water rights, there were more than 73,000 pre-1973 water rights in adjudication holding claim to nearly 41 billion m³ (33.2 million ac-ft), compared to the 53,000 rights (44.2 billion m³ (35.8 million ac-ft)) that did not have to be adjudicated because they were post-1973 water rights (Figure 3.6).

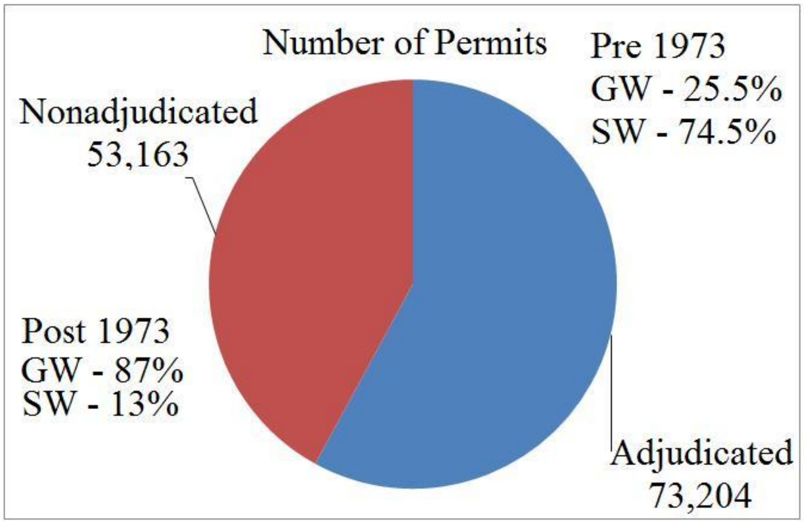

Figure 3.6 Adjudicated water rights versus non-adjudicated from surface and groundwater sources.

Of the two main recognized sources of water withdrawal in the basin, surface water and groundwater, surface water right permits outnumbered ground water permits in the pre-adjudication era, (pre-1973), whereas groundwater source permits outnumbered surface in the more recent permits (Figure 3.6). In total, they split fairly evenly with 61,500 surface water permits and 67,700 groundwater permits, though surface water was 99 to 1 over groundwater in total volume permitted (Figure 3.7).

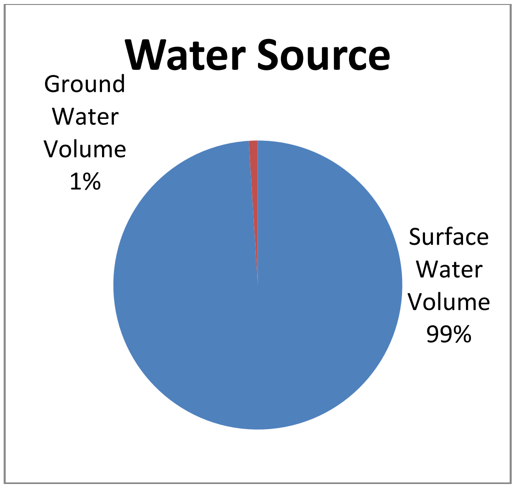

Figure 3.7 Water permit sources by volume in the Yellowstone River Basin.

The major water users in the basin in order from greatest to least were fisheries 37.6%, irrigation 23.1% (15.3 billion m³), power generation 17.2%, and fish and wildlife with 11% (Table 3.8). Consumptive water uses in the basin such as irrigation, stock, industrial, and municipal accounted for nearly 25% of the allocated water permits in the basin, approximately 21.5 billion m³ (17.4 million ac-ft) of water in 2007 not including supplemental water rights (Figure 3.8, Table 3.8).

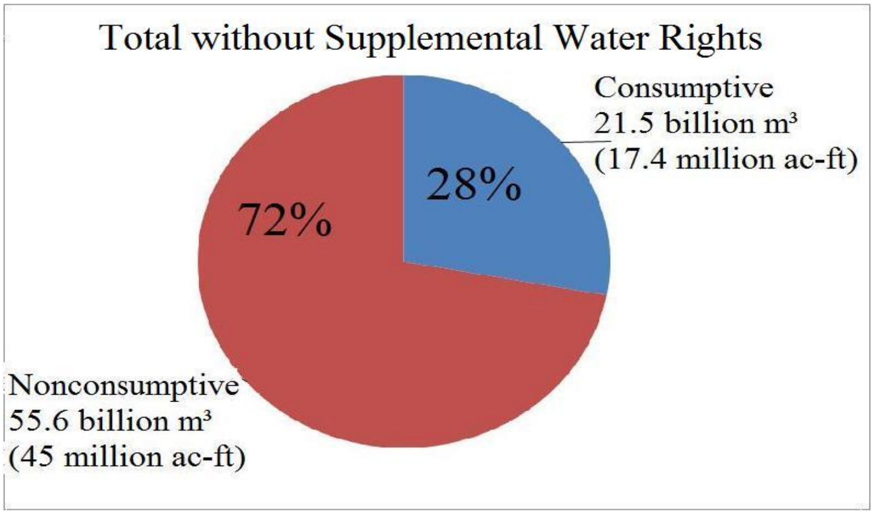

Figure 3.8 Consumptive versus non-consumptive water rights in the YRB.

Table 3.8 Percent of permitted water use by type in the YRB.

Permitted Water Use Percentages in the Yellowstone River Basin		
Use	**Percent**	**Type**
Fish and Wildlife	11	Nonconsumptive
Fisheries	37.6	Nonconsumptive
Flood Control	2.6	Nonconsumptive
Irrigation	**23.1**	**Consumptive**
Municipal	**0.2**	**Consumptive**
Industrial	**0.6**	**Consumptive**
Power Generation	17.2	Partially Consumptive
Recreation	2.2	Nonconsumptive
Stock	**1.4**	**Consumptive**
Total	**96**	

Trends in Irrigation Water Demands

Montana's population increased by 313% from 1890 to 1950, from 143,000 to 591,000, and then increased another 53% by the year 2000 with 902,195 residents (U.S. Census 2010). Montana's livestock were first introduced in the late 1850's and by 2010 they outnumbered people by nearly 3 to 1 with an estimated total of 3 million (U.S. Census 2010).

Developments of water uses in the basin increased greatly over time. More water permits with a priority date of 1972 to 1975 were filed than there was for the first hundred years of water rights on record (Figure 3.9). Since the official start of the centralization of water rights in the state and adjudication of the Yellowstone River Basin in 1973 there was a steady amount of water permits allocated every year with three extremely high years (1978, 1981 and 1982).

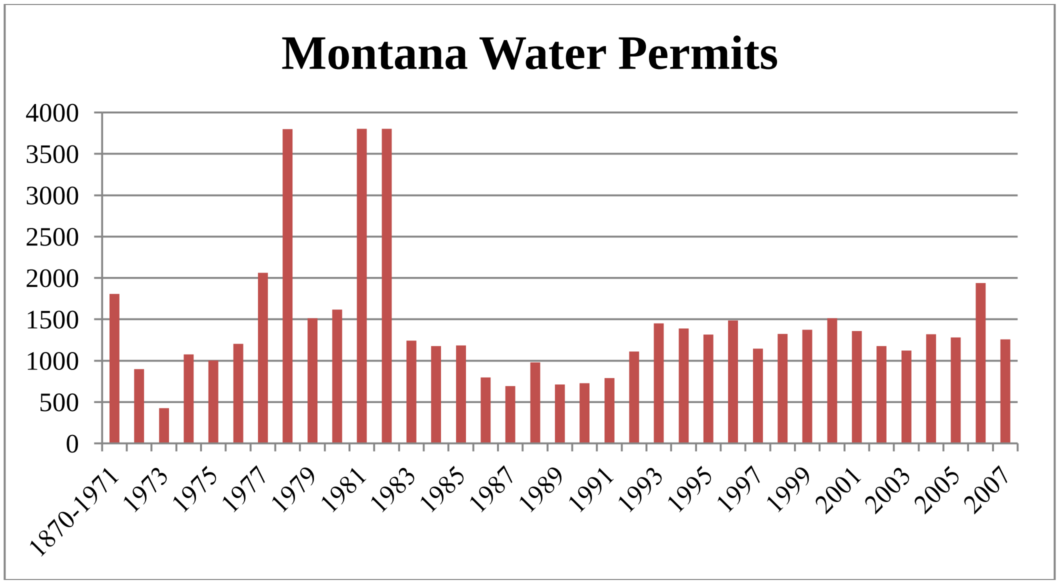

Figure 3.9 Number of Montana Water Permit Applications through time.

Irrigated agriculture increased at a similar pace in both Wyoming and Montana's portions of the basin since the 1940's (Figure 3.10). The greatest increase in irrigated agriculture took place from 1956 to 1966, continued increasing into the 1980's where it peaked, diminished slightly in the early 2000, and remained fairly constant as of 2008 (Figure 3.10).

Irrigated land area in the Yellowstone River Basin in both Wyoming and Montana increased from 100,000 Ha (243,000 acres) in 1946 to more than 314,000 Ha (776,000 acres) in 2006. Total irrigated land area which increased greatly from the 1940's to 2008, peaking in the 1980's at more than 450,000 Ha. As of 2008, Montana had 168,000 Ha (412,000 acres) and Wyoming had 148,000 hectares (365,000 acres) of irrigated crops in the perspective basins.

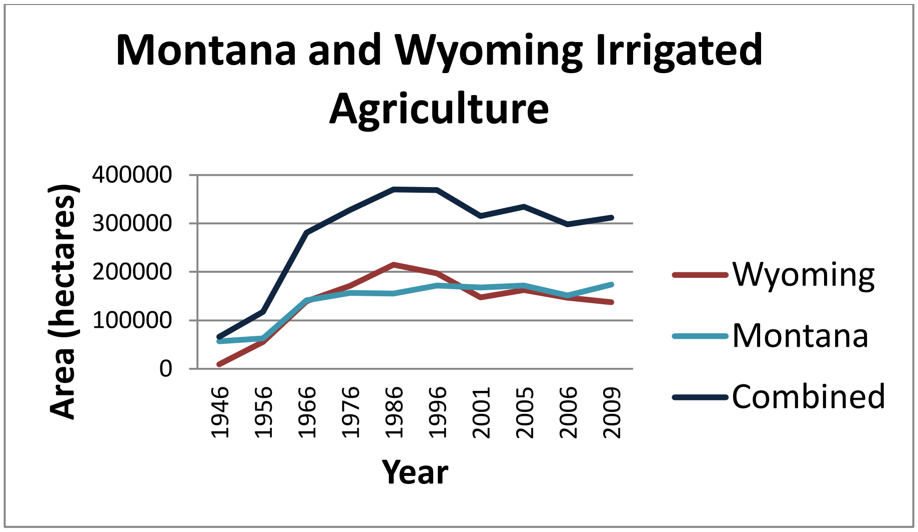

Figure 3.10 Montana and Wyoming irrigated agriculture since the 1940's.

The major crops in the basin were alfalfa, barley, corn, grass, mixed hay, sugar beets, and wheat. In the upper basin region of Montana, corn was the most commonly grown crop, whereas in the lower basin it was sugar beets (Figure 3.11).

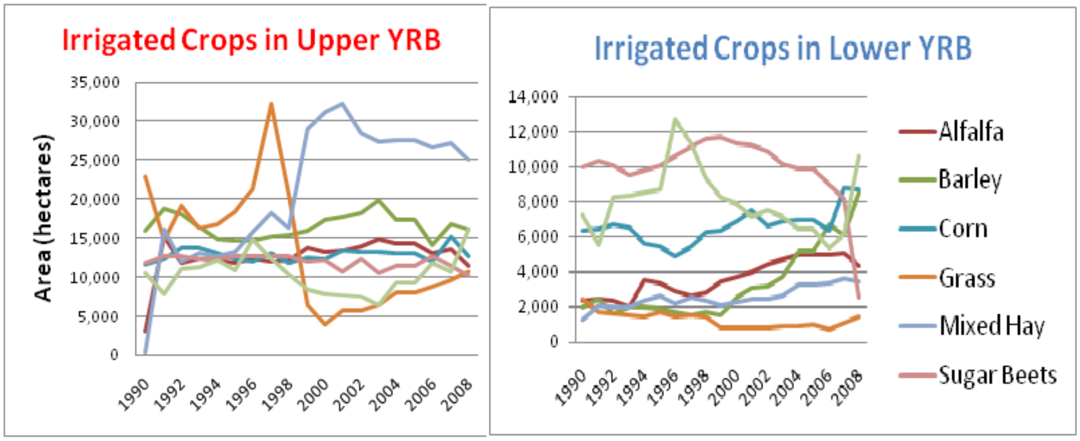

Figure 3.11 Crop comparisons for Montana's upper and lower portions of the Yellowstone River Basin.

Inventory of Annual Water Use

Wyoming's YRB livestock population in 2006 was greater than Montana's by 24 percent with 1,009,436 and 814,000 livestock animals respectively. Using DNRC's water allowance for livestock (56.5Lpd/AU (15gpd/AU) for pre-1973, 113Lpd/AU (30gpd/AU) for post-1973) in the basin, the annual water use by livestock amounted to approximately 37.5 to 75 million m³ of water.

As a base value for water needs that year, the IWR program provided that the entire basin used at least 1.3 billion cubic meters of water in 2006, where DNRC allowed up to 15.5 billion cubic meters of water to be used. Montana's portion of water use according to the IWR was approximately 671 million m³, at the same time DNRC allowed up to 8.2 billion m³; Montana's lower portion of the basin accounted for 184 million m³ of IWR's estimate and 2.25 billion m³ of the DNRC's allowance (Figure 3.12).

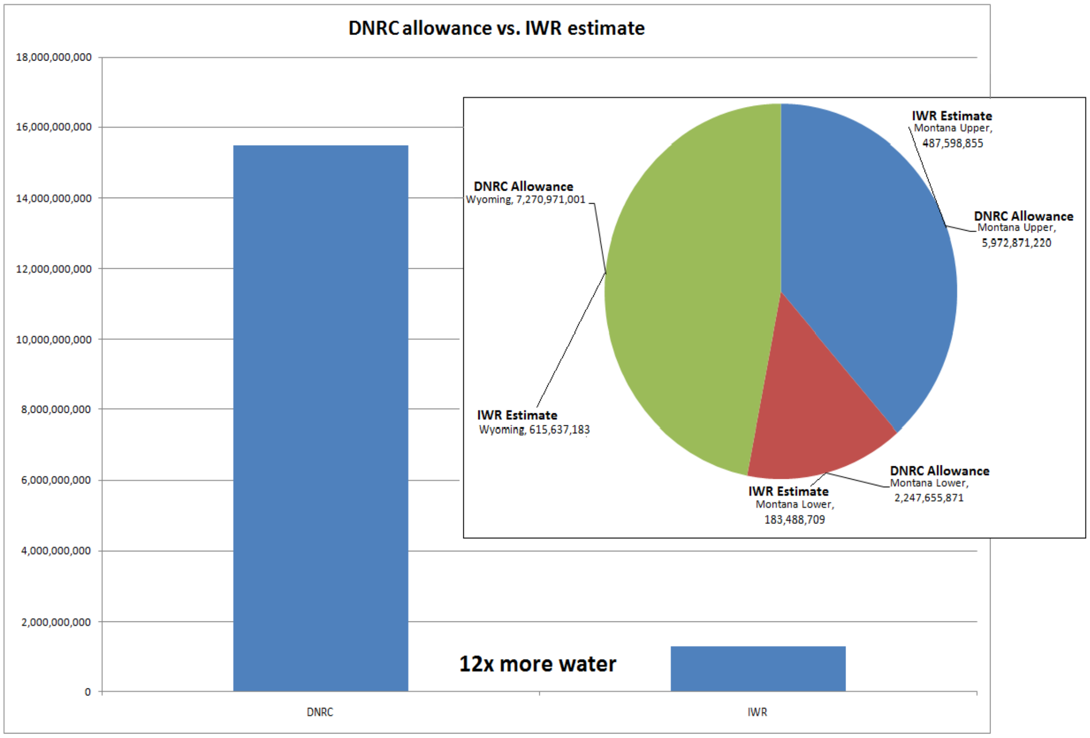

Figure 3.12 2006 irrigation water demand estimates for DNRC allowance and IWR program results.

Municipal water use on the mainstem Yellowstone River was in four cities: Laurel, Billings, Miles City, and Glendive. The 2006 water withdrawals was the highest from 2003 to 2007, with all sites cumulatively withdrawing more than 40 million cubic meters of water (Figure 3.13). In 2006, Billings, with the largest population, consumed 34.5 million m³, followed by Laurel at (2.7 million m³), Miles City (1.9 million m³) and Glendive (1.1 million m³; Figure 3.14).

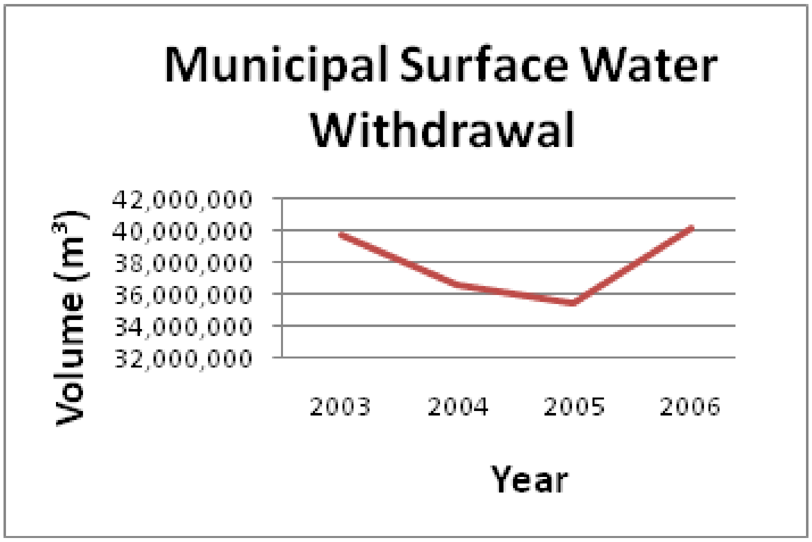

Figure 3.13 Municipal surface water use in the basin from 2003 to 2006.

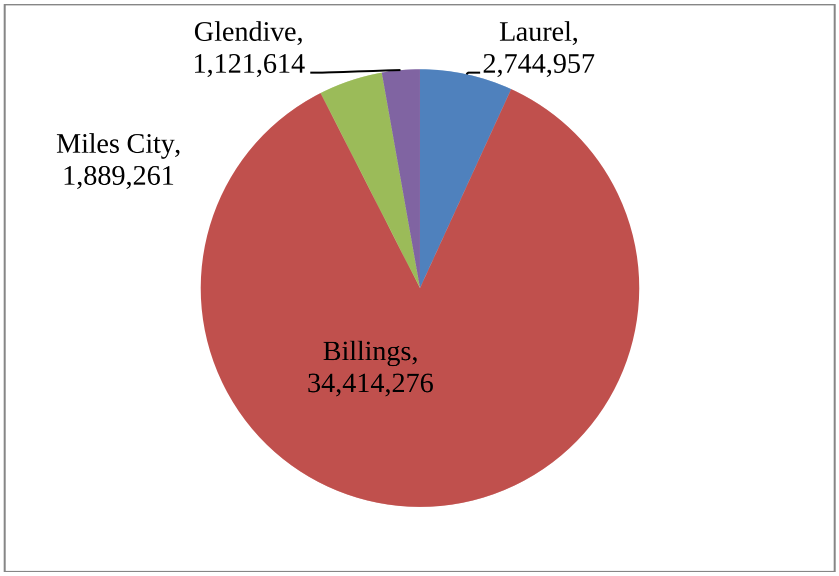

Figure 3.14 2006 municipal surface water use in cubic meters.

Industrial water use in the basin has occurred almost strictly on the Yellowstone River mainstem rather than tributaries. In 2006, 98.6% of the water used was withdrawn from the Yellowstone River (Figure 3.15). In all in 2006, industries reported using 526 million m^3 of water, though not all was consumptive use.

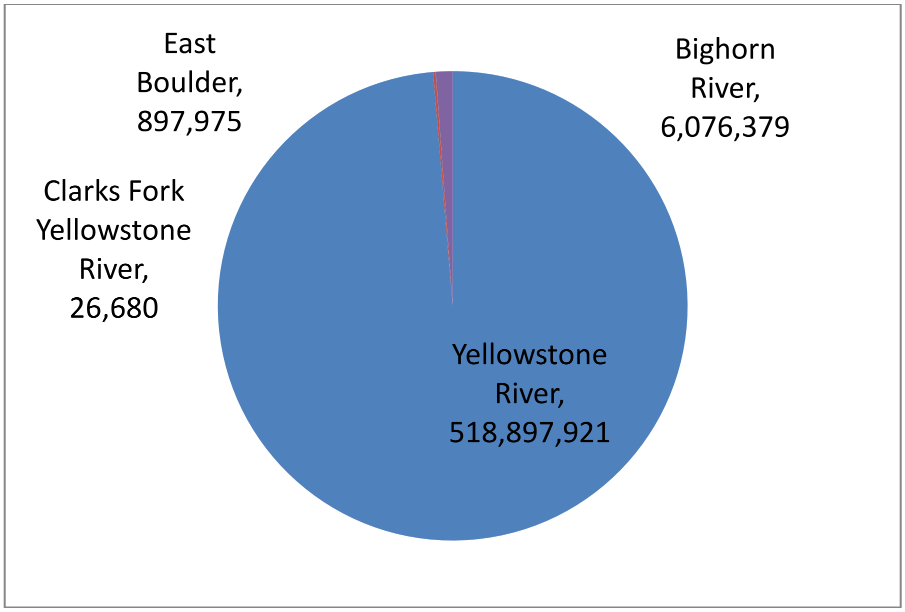

Figure 3.15 Industrial water use in the YRB in cubic meters.

Physical Inventory

During the physical inventory, 687 water withdrawal sites were documented and locations recorded. The Yellowstone River mainstem had the most withdrawal sites (317), followed by the Tongue River (144; Table 3.9). The 687 sites were either being used at that time for water withdrawal or had evidence of recent past water withdrawal such as water pumping equipment, access to the water, and/or recent tracks from pump to river. For each site, there were from zero to five pumps present or large irrigation canals, indicating that many sites served more than one and sometimes numerous water users.

Table 3.9 Withdrawal sites in the YRB 2009.

River	Number of Sites	Out of State Sites
Shields	20	NA
Boulder	20	NA
Stillwater	80	NA
Clarks Fork Yellowstone	35	NA
Bighorn	27	NA
Tongue	144	NA
Powder	44	NA
Yellowstone	317	23 ND
Total	**687**	**23**

The main types of water withdrawal methods used were centrifugal pumps, turbine pumps, domestic pumps (Figure 3.16), irrigation canals without diversions, irrigation canals with partial river diversions, and irrigation canals with full river low-head diversions (Figure 3.17).

Figure 3.16 Examples of domestic, centrifugal, and turbine pumps.

Sizes of intake pipes and headgate entrances ranged from less than 3 centimeters (approx.1 in) to 60cm (24 in) diameter mainlines to multiple 200 cm (78 in) headgates.

Figure 3.17 Examples of diversion types in the Yellowstone River Basin (A. Headgate without diversion; B. Side channel diversion; C. Multiple headgate partial channel diversion; D. Entire channel diversion with multiple headgates).

Of the 687 documented water withdrawal sites, 113 were found to have screening devices present, but there were also numerous withdrawal sites clearly identified without any type of screening devices present. Identifying presence of screening devices could only be done for shallow water withdrawals, unused pumps on the banks, and the open canal irrigation methods.

Ninety-two of the 687 documented water withdrawal sites discovered during the physical inventory were not found to match with locations on the DNRC's points of use or diversion. Of these undocumented water rights there were many documented to have no evidence of that year's use, only partially established pump sites without all components to withdrawal water and numerous small domestic water pumps with less than 10 centimeter (4 inch) diameter mainlines. There were, however, some significant pumping sites that could not be referenced to a specific right that not only were complete, but consisted of one to three pumping stations and showed evidence of recent use.

DISCUSSION

Water Rights Inventory

With all water rights considered, including supplemental rights, the 1.25 trillion m³ of water, calculated using total water permit allowances, for use in the entire YRB (Table 3.3) is nearly 118 times greater than the historic average annual discharge of 10.6 billion m³ from 1967-2006 (USGS 2006). Although this quantity is greatly reduced to approximately 85 billion m³ when all the supplemental water rights are removed, the amount is still nearly 8 times the estimated 10.6 billion m³ of average annual discharge historically. The water rights in the basin and in sub-basins were found to be overwhelmingly high in relation to actual supply no matter how it is calculated. Such over allocation is a common problem throughout the western states. For example, the Colorado River which serves approximately 20 million people in two countries has been over-allocated for years. That river's water has been a major source of political contentiousness since the 1920's. Even when the first compact was formed, it was compiled using overly optimistic assumptions regarding the amount of annual flow and thus allocated far more water than the river's actual annual average flow. This resulted in an immediate over allocation situation (TFDD, 2007), which has become ever more acute as water usage has steadily risen towards full utilization of the allocations. The result has been major distrust from the upper to the lower states because of the historic overuse and illegal water use by all of the states (TFDD, 2007). The approach since the 1970's has shifted from emphasis on structural solutions, to wise use and conservation in an attempt to better deal with and manage the shortages of water in the basin (TFDD, 2007).

In the YRB, major over-allocation of water rights is also a problem, with the major difference that much of the allocated water allocated has not yet been put to use, making it difficult to visualize exactly how soon development will occur and how soon the ensuing severe problems will develop. The distinctions among types of water rights proved to be very important to this study in terms of interpreting the results of the inventory, similarly, in the future, how the different types of rights are actually exercised and stand to affect the future amount of water remaining in the river. For example, the Federal and Indian compacts were formed and ratified on assumptions that the basins were not at that time over appropriated and that their agreed upon water right priority dates (date of ratification by Congress) will provide water. However, if the basin turns out to have been over-appropriated at the time of ratification, pending the results of the adjudication or the basin experiences reduction in water supply which raises the prospect that compacts were entered into without contemplation of climate change and potential over-appropriation, calling into question whether issues of subordination for some compacts will need to be revisited at some point in the future. The smaller, but equally important 1978 water reservations are still being developed, many of them still remain to be appropriated. The original statute of these water rights state they should be evaluated every 10 years to determine if they are adequate and being utilized as originally planned (MCA 85-2-605). These unused reserved rights may be an avenue in the future for acquiring and securing water rights for instream flow and other uses, but again have seniority issues with 1978 water right dates being junior to more senior appropriations.

Existing and exempt water rights, pre-1973 water rights, still in active adjudication account for nearly 1,072 billion m^3 of the total 1.25 trillion m^3 total rights (85.7%), and 41 billion m^3 of the 85 billion m^3 (48%) of permitted water minus supplemental rights (Table 3.4). These rights, which are still subject to change stand to greatly alter how much water is actually appropriated and used. Only a final decree can determine the future of these rights.

In Montana in particular, supplemental rights make for very confusing estimates of total appropriation. With the same amount of water divided up by multiple uses in different locations, it is difficult to determine the exact water amount that goes to which use, thus providing opportunities for overuse, waste, and complications selling or transferring water (Russell, 1997). Thus, when evaluating water needs in the basin, the type of water rights are just as important as the date and place of use.

The hierarchy of water rights and the large number of rights to water already appropriated reinforces the need for proper management and a clear, unambiguous reporting strategy to be adhered to by water users. Water measurement and recording are the most fundamental tools in water management and should be the first step needed to gain necessary information for better management. In the future, it may be increasingly necessary for such accurate reporting to insure supply to those demanding their actual water they have a right to appropriate, not just in basins that are already highly dewatered. Accuracy of results from my inventory was also less than optimal because recording and reporting of use is minimal and not required by the state of Montana. For example, in Montana, water use can be reported in several different, approximate ways, including estimates of time water was withdrawn, estimates and calculations built with estimates on pump and canal capacities, and daily averages. The state of Montana has the legal authority to make water users measure and report water use (MCA 85-2-113(2)(a)-(c)). The problem is one of ineffective use of that authority to request accurate and precise reporting. During my exploration of water rights and quantifying use in the basin, numerous water rights proved to be lacking in pertinent information when it came to amount of withdrawals, time of withdrawals, and total amount of water used by the permitted water user. On many of these rights, there were no dates of use specified, only maximum rates of withdrawal rather than total withdrawals, meaning that water could be withdrawn at the rate for the entirety of the year. Also, some rights had time of use but did not list restrictions on rate or quantity of water used. Overall, I found that many rights simply did not provide the pertinent information to properly manage any restrictions on the water use. It is very difficult to monitor any kind of misuse, or to rationally deal with increasing demands and water shortages, if there is no standardized and mandatory measuring and reporting. This inaccurate and imprecise approach is unacceptable, unnecessary, and ultimately counterproductive in a river system where water is under increasing demand in relation to a limited supply. Measuring and accurately reporting water use would help eliminate waste as well as illegal use in areas with water shortages. For the vast majority of users, like municipalities which had accurate and mandatory records of use, certainly those concerned with adherence to the law, accurate measurement would be an ultimately desirable and necessary improvement. An identified challenge had been to find a way to minimize upfront costs of meters to those with water rights. Montana addressed this in 1991 with their Water Measurement Program awarding grants to offset the costs, so metering should have been required for all these years ago. If Montana is not going to make accurate reporting mandatory for everyone, which would clearly seem the most rational, meaningful and egalitarian step, it would at least make sense to require it for the newly quantified water rights going through adjudication, as well as for all new water appropriations.

There are benefits to improved reporting. In litigation, courts have favored states that have claims that are quantified and recorded, and have made efforts to minimize wastes. Accurate reporting not only serves to assure the courts that the water is well monitored in the state, but it also demonstrates that a state recognizes the importance and value of the water, a finite resource, to its people. This rationale is well illustrated in New Mexico v. Colorado (467 U.S. 310 (1984)), where the court required that the states have clear and convincing evidence standards to prove their side of the case when seeking to enjoin the activities in one state that may negatively affect activities in another. Looking at this in a situation where a downstream state tries to enjoin the activities of an upstream state because they are being harmed, or that the downstream state believes they are not receiving their fair share of water, for either of the states to present a strong case they would have to have their rights well quantified and precisely accounted for. It is nearly impossible for a state to prove by clear and convincing evidence that they have the right to the water and they are not short on supply due to their own inefficiencies without accurate and defendable water data.

Inventory of Annual Water Use

The large differences in the overall allowable use using the IWR program and DNRC's acceptable amounts for water quantification for irrigation use in the basin (Figure 3.12) is of concern when comparing the differences in allocation the two methods produce. Although the IWR program and the DNRC's designation of water use are both considered acceptable water quantification measures in Montana, the discrepancy is not acceptable in a state where water is to be used beneficially and not wasted. The problem with defining waste and acceptable amount of use statewide and basin wide is seen in numerous western states (Russell, 1997). This problem is actually considered one of the more significant problems that hinder a state's ability to litigate or enjoin another water user or state when problems exist. Optimally, one reliable method needs to be chosen, validated for accuracy, and administered statewide. If that method is DNRC's approach it should surely be validated for accuracy, as it is more water than 12 times the IWR programs estimated amount is considered acceptable (Figure 3.12)

Physical Inventory

The results of the physical inventory highlighted some significant issues that deserve prompt attention. One major issue was lack of screening at most diversions. Of the more than 687 irrigation withdrawal locations identified in the study area (Table 3.7) only 16 percent (110 sites) were clearly screened. It was found that numerous larger irrigation canals, as well as smaller irrigation pumps were without screening devices. Lack of screening devices is of major concern in areas inhabited by species listed as endangered, threatened or of concern (Hiebert et al. 2000), e.g., the Federally endangered pallid sturgeon (*Scaphirhynchus albus)* in the lower Yellowstone River. Fish losses due to entrainment into irrigation devices can be very large, numbering into the hundreds of thousands, as estimated at Intake Diversion Canal, one of the larger irrigation canals, on the Yellowstone River (Hiebert et al. 2000). Screening of all diversions from the river should be a high priority. Even small pumps intakes can and should be effectively screened.

A second major issue arising from the field survey was the inability to link an actual water withdrawal use with a specific water right. About 14 percent of observed withdrawals were unable to be matched with a water right based on the withdrawal location. As of 2008, water right locations in the basin are logged and recorded by the DNRC in two different ways, the point of diversion and the point of use, but both of them may have the coordinates for the proprietor's headquarters and not the actual location of diversion or use. Under these conditions, it is not difficult to illegally withdraw water, especially when there is minimal enforcement other than other stakeholders. Even then, the permit system is confusing when anyone tries to validate a claim by querying it on a map, water rights permits are ambiguous in how much is available for use, and the standard for appropriation set by the state of Montana is grossly over allocating water to specific uses. A simpler approach must be found to address this issue. One approach might be to make water appropriators clearly mark their withdrawal site with a water right identification linking back to the specific water right on any diversion structure or pump, along with water meters, at the point of withdrawal. That approach will permit easier enforcement of existing water laws and be a large step toward preventing illegal use and insuring water use for those with rights, not just those withdrawing water but instream users as well (Poff et al. 1997).

Historically in the western U. S and elsewhere, it has been a long standing procedure to solve water shortage issues by looking elsewhere to obtain more water, when more effort should instead be made to conserve and efficiently use the available water. Agricultural practices utilize the largest of all water withdrawals in the West (96.5%) and have been designated the most inefficient users of the water (Hutson et al., 2005), thus providing massive potential to gain water by conservation measures. With water shortages becoming more common everywhere, it is ultimately in all water right users best interests to make sure it is being accurately monitored and recorded for their continued use and the use of others.

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CHAPTER 4: MANAGEMENT NEEDS FOR WATER AND NATIVE FISHES IN THE YELLOWSTONE RIVER BASIN: RECOMMENDATIONS FOR MOVING FORWARD

ABSTRACT

Among the many western rivers dealing with water management issues, the relation between water issues and native fishes is particularly important for the Yellowstone. In this chapter, I assess, in a general way, water management needs in the Yellowstone River Basin as discerned from the results in the previous chapters and in relation to the needs of native fishes and other biota in the river and provide recommendations for improved Montana water management to benefit water users and native fish species. These recommendations are not necessarily new. Although many of them have been identified and discussed in legal journals by water law experts over the past quarter century or longer, actual progress has been slow. Some obvious, important issues remain unresolved. The key improvements recommended in the water management system are to: 1) finalize the statewide general adjudication, 2) re-evaluate the water reservation hierarchy in the Yellowstone River Basin 3) review water policies and clarify ambiguities, 4) develop comprehensive, effective monitoring of water use statewide, and 5) consideration of these recommendations, along with an adequate consideration for instream flows for native fishes, in Montana's new State Water Plan. As the Department of Natural Resource Conservation (DNRC) seeks to wisely managing Montana's water for all Montanans, present and future, Montana Fish, Wildlife and Parks, as the lead state fish and wildlife management agency whose mission and expertise are in line with native fish needs, is well positioned to assist the DNRC and the Basin Advisory Committee in this role. Their effective input into any new State Water Plan is vital for a balanced water plan insuring the economic needs of the present and future, as well as the future of the Yellowstone River and its native fauna.

INTRODUCTION

> “Today, not only irrigable lands cry for water, but also rivers, streams, and the fish that inhabit them. New demands to serve the Northwest's growing population compete with instream needs for what little unallocated water remains.” (Russell 1997, page 152)

In this chapter, I identify, in a general way, water management needs in the Yellowstone River Basin (YRB) as discerned from the results of my research in the previous chapters and in relation to the needs of native fishes and other biota in the river. I also provide recommendations for improved Montana water management to benefit water users and native fish species. The recommendations are not necessarily new. Although many of the recommendations have been identified and discussed in legal journals by water law experts over the past quarter century or longer (e.g., adjudication, MacIntyre 1988; the issues of salvaged water and beneficial use; Stone 1993, MacIntyre 1994; irrigation efficiency, Norris 2011), actual progress has been slow in many areas of water management. Some obvious, important issues remain unresolved. Emphasis here is not from the general legal perspective *per se* but from the perspective of water’s role in maintaining native fishes and aquatic habitats in the YRB.

Among the many western river basins dealing with water management issues, the relation between water issues and native fishes is particularly important for the Yellowstone. As the longest river in the United States that still retains a hydrograph close to natural (White and Bramblett 1993), it remains a repository for many native species badly depleted or extirpated elsewhere in the broader Missouri River Basin (e.g. flathead chubs *(Platygobio gracilis),* sturgeon chubs (*Macrhybopsis gelida),* sicklefin chub (*Macrhybopsis meeki),* western silvery minnow (*Hybognathus argyritis),* Welker and Scarnecchia 2004, Scarnecchia et. al 2000; shovelnose sturgeon *(Scaphirhynchus platorynchus),* Everett et al. 2003; pallid sturgeon (*Scaphirhynchus albus),* Bramblett and White 2001). The pallid sturgeon has been listed as a federally endangered species since 1990 (U. S. Fish and Wildlife Service 2014). With so many human activities dependent upon the limited water resources (Chapter 2), and a wide array of demands on the water (Chapter 3), increasing effort must be directed toward reconciling and planning the needs of various stakeholders and the needs for water withdrawal in relation to its retention in the river for the native biota. Compared to a century ago, there is today a wider array of demands recognized for water. As MacIntyre (1994) put it two decades ago: “Today, the west is settled… The challenge faced today in states such as Montana is to administer a limited resource for the benefit of all of the people of the state through more efficient water resource management” (p. 309).

The natural flow regime

One need barely envisioned a century ago, when water was more abundant in relation to demands, is the need to leave adequate water in the river for the benefit of native fishes and other aquatic life. Native river fishes, adapted through natural selection to rivers such as the Yellowstone, evolved under conditions of their historical flow regimes (Poff et al. 1997). Alterations to the historical flow regimes of rivers, the main focus in Chapter 1, is commonly implicated in the declines of stream and river-dwelling native fish populations (Baxter 1977, Marchetti and Moyle 2001, Lytle and Poff 2004, Propst and Gido 2004, Gido et al. 2010). Changes to the timing and magnitude of the hydrograph, as seen in Chapter 2, are believed to have contributed to the imperiled status of about 40% of North American freshwater and diadromous fishes (Jelks et al. 2008; Poff and Zimmerman 2010). Declines in these species are associated with altered geomorphic processes that create and maintain instream habitat (Poff et al. 1997), altered autecological processes (e.g. spawning and reproductive cues, Taylor and Miller 1990), and reduced summer rearing and overwintering habitat (Schlosser 1991). Xenopoulos and Lodge (2006) concluded that species that are specifically sensitive to certain aspects of the hydrograph (e.g., high discharge) would be most vulnerable to changes in those aspects. How much change and what impact specific hydrograph changes will have on specific species in particular river basins is difficult to predict because of multiple variables and drivers at play, but it is readily understood that when other systems have encountered the same types of alterations as seen in the Yellowstone, and documented in Chapters 2 and 3, the native fish communities and fisheries have suffered (Marchetti and Moyle 2001; Xenopoulos and Lodge 2006). It is generally accepted, as a result, that the natural flow regime (Poff et al. 1997) is a desirable goal for recovery and restoration of impacted river systems. Marchetti and Moyle (2001) found that natural flow regimes and higher flows not only benefitted the native species adapted to these conditions, but these natural characteristics can halt, delay, and sometime prevent invasive species introduction and expansion, an increasing problem for native fishes in rivers globally.

Looking forward in this century, several factors affecting, affected by, or associated with, hydrograph changes (magnitude and timing) away from the historical flow regime may be important for native Yellowstone River fish fauna and fisheries, as has been documented elsewhere in the United States (Marchetti and Moyle 2001; Perkins et al. 2010) and worldwide (Parmesian and Yohe 2003; Foley et al. 2005; Parmesan 2006). Climate change in this century is projected to increase global surface temperatures 1-3°C, with significant regional variability (IPCC 2007), thereby increasing the probability of warm days, hot and/or dry spells, and many types of extreme weather events (Bell et al. 2004; Leung et al. 2004; Diffenbaugh et al. 2005). Concurrent anthropogenic water development may also prove detrimental in the future to the YRB fisheries. High demands for agricultural and municipal water withdrawals may reduce streamflow by increasing zero flow days and stream desiccations, resulting in fish extirpations (Gido et al. 2010). In the YRB, as elsewhere, even though the natural flow regime may be desirable from a long-term ecosystem health standpoint, its attainment will be difficult to achieve when multiple stakeholders are involved (Cardwell et al. 1996). Today, there are relatively few river systems in the West that have any water available for new uses. The reality of river management is that solutions that satisfy multiple objectives are neither straightforward nor easily agreed upon, but in the end decisions improving or at least stabilizing the declining water situation must be made, preferably sooner rather than later (Cardwell et al. 1996).

There is a critical need for further research to understand flow requirements for native fish species and to make species-specific recommendations for instream flows in the YRB. The present study was not designed to investigate the instream flow needs for native biota; instead, it emphasizes water resources abundance, timing, and uses by economic sector. Evidence from past studies habitat suggests that several of the native species are obligatory large river fishes; although they may ascend smaller tributaries to spawn, during low flow periods in summer they require main channel habitat for rearing. These species include the blue sucker, sicklefin chub (U. S. Fish and Wildlife Service 1993; Everett et al. 2004), shovelnose sturgeon, pallid sturgeon, and to a lesser extent, sturgeon chubs (Holton 1990). Werdon (1992) reported that sturgeon chubs were found in the Yellowstone and Powder rivers, but that abundance in the Powder River, a highly dewatered prairie river, had declined in recent years. To more accurately define habitat requirements during the low-flow periods of summer, studies are needed of instream flow needs for native fishes using simulations and field data (Bowen et al. 2003) and resulting in specific, science-based recommendations. Such an effort would be a natural successor to this study. Despite inevitable uncertainties in climate modeling and in species-specific water requirements, the clearly projected increases in water demands, regardless of minor differences in scenarios, indicate there is a great need at this time for matching water management not only to the increasing needs of human water users but to the needs of the YRB's native fishes and other aquatic fauna. In this chapter, I list recommendations based on results of Chapters 2 and 3 and on remediable difficulties and challenges encountered in those investigations. These recommendations are intended to improve water management in the basin, not only for native fishes but also for the long-term well-being of those with water rights dependent upon consistent annual and seasonal withdrawals.

RECOMMENDATIONS

The key improvements recommended in the water management system are to: 1) finalize the statewide general adjudication, 2) reevaluate the water reservation hierarchy in the Yellowstone River Basin 3) review water policies and clarify ambiguities, 4) develop comprehensive, effective monitoring of water use statewide, and 5) consideration of these recommendations, along with an adequate consideration for instream flows for native fishes, in Montana's new State Water Plan.

1. Finalize the statewide general adjudication

The importance of adjudication, i.e., the legal process to determine who has a valid water right, how much water can be used, and who has priority during shortages, has long been recognized as important to Montana water management (MacIntyre 1988). Without Montana's water adjudication finalized, providing maximum volumes and rates per right, there is not an accurate estimate of the total water used and available for use. This inadequacy can have negative implications for native fishes and Montana's irrigators and other water users. For example, in 2008, the state of Montana filed a Bill of Complaint against the state of Wyoming, claiming Wyoming had breached the Yellowstone River Compact by consuming Yellowstone River water in excess of the amount allotted to it by Congress in 1951 (O'Regan and Shertzer 2011). In the end, the Court agreed with the Water Master's claim that, before Montana tries to hold Wyoming liable for breach of the Compact, Montana must attempt to address its own water shortages with intrastate solutions (O'Regan and Shertzer 2011), which cannot be done until an estimate of use (accurate or not) is available. To do this, Montana must complete their adjudication process; it would provide a measure of water use and potential availability within each basin of the state. Lacking adjudication, Montana, failed to validate their claim of harm against Wyoming and may face a future with inadequate water supplies on short years in the Tongue and Powder River Basins, and possibly other shared basins, as they have in the past.

An additional part of the adjudication that directly relates to the water inventory in Chapter 3 is Montana's maximum water use designation. Montana currently allows two processes (Irrigation Water Requirements (IWR) and DNRC's allowed amount) to establish maximum water use for undefined water withdrawals. Other states, such as Oregon and Wyoming have moved to a maximum water per hectare of 28.3 liters per minute (lpm; 3 acre-feet (acft) per acre), which is far less than Montana's 160 lpm per hectare (17 acft per acre), but much more in line and even still more generous than the IWR programs recommendations of 13.5 lpm per hectare. Because Montana has not designated one set protocol, it allows large differences of volumes to be withdrawn (Figure 3.12, Chapter 3), more than can be beneficially used and therefore allowing wasting of water. Wastage is inconsistent with the policy of DNRC, the water management agency. Montana would benefit by establishment of one, modern, scientifically justifiable and verifiable approach for establishing a standard maximum allowed water usage per applicable uses.

Completed adjudication will, in theory, place DNRC in a stronger position to enforce provisions against wasting. Although The Water Use Act empowered the DNRC to enforce water laws in Montana, the actual task is often complicated for a variety of economic and political reasons. The DNRC is obligated to file suit against any user who they believe is wasting water. Their first step is typically to try and obtain voluntary compliance by the water users to lessen their amount of waste; however, they also have the power to decide when someone is wasting water and enter the user's property without permission to monitor the operations. Currently, determination of waste presents challenges because Montana defines waste by a list of considerations rather than by clearly defined efficiency standards. Once a final decree is ordered, the users must then be monitored to make sure they are using water within the allotted amount. If users are found noncompliant, DNRC may have the records they need to enjoin the users and have their decision upheld if taken to court.

2. Re-evaluate the water use hierarchy in the Yellowstone River Basin.

The differential prioritization of reservation usage between the upper and lower portions of the basin is a clear manifestation that instream values for native fishes have historically not been of primary concern. In the upper basin, i.e. above the confluence with the Bighorn River, municipal reservations has first priority, instream has second priority, and agriculture has third priority (Figure 1.1, Chapter 1). In contrast, in the lower basin, i.e. below the confluence with the Bighorn River to the North Dakota border, municipal has first priority, agriculture has second priority, and instream flow has third priority (Sobashinski and Lozovoy 1982). During a low water year when the instream flow reservation is all that is available in the river, a municipality with the same water right date (1978) could use some of the instream flow reservation water to fulfill its entitlement above the Bighorn River. Below the Bighorn River, however, both reserved municipalities and irrigation operations can withdrawal from the river preferentially over the allocation for fish and aquatic life, potentially rendering the instream fish and wildlife allocation irrelevant and draining the river. Although it might be argued by some that the blue ribbon trout fisheries of the upper basin (Kerkvliet et al. 2002) are more economically important than the cool and warmwater species of the lower basin, the more diverse and more ecologically specialized native fish community of the lower basin, where more private lands exist and agriculture is more dominant, is more imperiled yet of lower priority in water allocation decisions. Ecologically speaking, however, the river is an equally valuable resource from source to mouth.

This inconsistent policy within the basin makes the instream flow reservations of limited usefulness when the lower basin is in need of water. Irrigation reservations are the largest of the reservations, and if they are available to be further developed and appropriated, even when there is not enough for sustaining fish and wildlife needs, then all other options to preserve adequate flows are irrelevant. This issue is of major concern since the 1978 reservations as of 2008 were only 15% developed (Figure 3.4) and the calculated consumptive water use in the basin was already greater than two times that of the 1970 to 2007 recorded annual mean discharge. Without change, further appropriation of reserved rights that are senior to instream flows will occur and further diminish flows in the Yellowstone River and tributaries, with no consideration for any fish, let alone native’s.

3. Review water policies and clarify ambiguities in terms.

Ambiguous or imprecisely defined terms continue to be in need of clarification and refinement, as has been pointed out in past decades (Stone 1993; MacIntyre 1994). Terms such as salvaged water, beneficial use, duty of water, and waste would benefit from additional consideration and specifications in any new water management plans.

One primary water policy that is in need of review and revision is Montana's policy for salvaged water. MCA 85-2-419 gives holders of appropriation rights to salvaged water to be used for other beneficial uses. Salvaged water, as defined in MCA 85-2-102 means to make "water available for beneficial use from an existing valid appropriation through application of water saving methods." The idea is to provide incentives for the appropriator to partake in conserving water by making the water available to the appropriator. MacIntyre (1994) noted that "In 1991, Montana made a substantial positive change in its water law to provide a necessary incentive [MCA 85-2-419]. Although the appropriator must still prove that the new uses will not adversely affect other water users, an appropriator who salvages water retains the right to the water for beneficial uses" (p. 316). However, an argument could be made that the water was not being used efficiently to begin with, thereby constituting waste, and by law is should no longer be theirs. The salvaged water statute goes against Montana court's other prior rulings, such as Whitcomb v. Helena Water Works Company in 1968. In that ruling, holders of junior water rights gained access to water theretofore held by the city water works company diverting water from streams to keep storage reservoirs full when others were being deprived of the water. MCA 85-2-412 states that water no longer needed or put to a beneficial use is to be left instream for use by other uses and users. The statute on salvaged waters (MCA 85-2-419) subsequently gave the water right holders the control of this water whether or not they needed or could put it to beneficial use (Russell 1997). This statute seriously limits the access of other members of the public to the water.

Another issue with the current salvaged water policy is with the premise that it is functioning to conserve water. Water is most commonly salvaged by updating water delivery standards or application techniques. Before the water was salvaged, it percolated back into the ground, supplementing the groundwater and return flows to the water source. When the water is "salvaged" and put to use elsewhere, the excess that used to be termed nonconsumptive and may have been appropriated by another user is no longer available, causing water shortages without actually appropriating any additional water. This outcome is pertinent to native fishes because simple water saving practices such as more efficient use may actually result in less water for future or current appropriations, and ultimately less water in the river or stream. Salvaged water, without at least some of it being returned to the state, will thus exacerbate water shortages in already water-short basins. Dispensation of salvaged water either to the appropriator, to other members of the public, to instream flows, or in some proportions to each, is a topic that deserves to be revisited.

In addition, ambiguously defined or imprecise terms in water policy such as beneficial use, duty of water, and waste continue to create a large avenue for resource overuse and enforcement difficulties. Beneficial use, unless otherwise provided, means: "a use of water for the benefit of the appropriator, other persons, or the public, including but not limited to agricultural (including stock water), domestic, fish and wildlife, industrial, irrigation, mining, municipal, power, and recreational uses" (85-2-102 (2)(a), MCA). First, the term is not clearly defined; the definition states what water can be used for but does not clearly state what efficiencies must be met. Second, the determination of a beneficial use is often based on local customs. As a result, in areas where inefficient uses are common, the concept affords considerable wastage of water. With beneficial use beings defined this loosely, with no clear determination of what exactly was meant by the legislature when the wording was drafted, courts may become weary of deciding specific limitations (Russell 1997).

Another term needing clarification is "Duty of Water," which is a smaller part of the concept of beneficial use. The duty of water is best defined as the criteria to be followed in allocating water to agricultural uses (MacIntyre 1994), based on the amount of water needed and used to irrigate a fixed amount of land. For example, if the amount of water to be used is small and the irrigated area is large then the duty of the water is described as high. The Montana legislature determined the standard for duty of water to be 160 liter per minute per hectare (17 gpm per acre), which was based on commonly accepted methods of irrigation to meet the peak consumptive use values of alfalfa during a drought year, and the reasonable efficiency for the method of irrigating the field. While this concept was originally drafted to promote efficient use, it actually sets an available maximum amount to a water right in which courts will usually grant without sound scientific determination, even if new advances in crops or technologies will allow less water to be necessary. This discrepancy can lead to excessive usage in states like Montana where the duty of water limit allows nearly 7,000 m^3 per hectare (14 acre-feet per acre), even though estimates by the Bureau of Reclamation state that farming needs can be met with as little as 1,500 m^3 per hectare (3 acre-feet per acre; MacIntyre 1994). This problem was readily apparent in Chapter 3, where the difference of water used for irrigation is alarmingly higher using the DNRC's accepted amount compared to the estimated individual crop requirements.

Another definition that's in need or review and refinement is the term "waste". Montana's definition of waste is, "the unreasonable loss of water through the design or negligent operation of an appropriation or water distribution facility or the application of water to anything but a beneficial use." Therefore, waste is not a set determination relative to scientifically based criteria (e.g., verified water needs for particular crops, climates, and soil types), which makes the process of proving waste a difficult task. As currently applied, the term waste also does not consider when a water use would be better for the environment or economy to leave the water in the stream as opposed to irrigating. When evaluating waste the state only looks at the duty of the water and that it is a beneficial use; it is up to the user to determine if it is economically beneficial for their use, leaving no consideration for public needs and the preservation for other public resources such the native fish and wildlife.

4. Develop comprehensive, effective monitoring of water use statewide

Water measurement and recording are the most fundamental tools in water management and need to be the first action Montana takes to achieve better water management. Without accurate monitoring and recording of water use, in the YRB as well as throughout Montana, any determination of water use may only yield a crude estimate. Considering the large differences that can occur, for example, when evaluating maximum water use criteria for irrigation (Figure 3.12, Chapter 3), it may yield a very poor estimate. Not all water right users in Montana are required to measure or report their annual use, it is only during times of extreme low water and in areas that are highly prone to dewatering that there are policies that require water measurement devices and accurate reporting of water use. Although Montana will reach adjudication statewide, it may not be any closer to knowing actual use because of the lack of an effective program for measuring and recording water usage.

My field component mirrored my inventory results when evaluating withdrawal sites physically in the basin. The first observation was that it was difficult to match the withdrawal in the field with a specific water right. As far as I could determine while remaining off of private property, for few or no sites was the water right identified. Requiring the water right to be identified by water right number on the pump or other withdrawal infrastructure would allow relative ease of enforcement and identification of improper withdrawals.

The second observation was that the basin was largely devoid of any measuring devices at withdrawal sites. During my inventory of water use in the basin, the only water users that provided good defendable measurements of use were the industries and the municipalities. However they are some of the smaller users (Chapter 3). Although industries and municipalities may take a larger share of water in the future with the expanding energy development and population growth, for the foreseeable future it is irrigation that will remain by far the largest water user. A recommended approach would be to require metering of all withdrawals. In 1991 Montana implemented a Water Measurement Program to provide assistance to help minimize upfront costs to install metering devices for private water development activities. These grants are to be used to pay up to 25% or $2500 (whichever is less) of the costs of water measurement devices or headgates (DNRC 2013).

5. Consideration of these recommendations, along with an adequate consideration for instream flows for native fishes, in Montana's new State Water Plan.

At the direction of the Montana State Legislature, the Water Resources Division of the DNRC is in the midst of an effort to update the Montana State Water Plan. As part of that effort, the 2015 Montana Water Supply Initiative (MSWI) "engages citizens in the planning process to develop strategies and recommendations for meeting Montana's future water needs" (http://www.dnrc.mt.gov/wrd/water_mgmt/state_water_plan/yellowstone/default.asp).

Under the MSWI, a basin advisory council (BAC) has been established in the YRB, one of four such basins statewide, "to provide a forum for public involvement and to assist DNRC in important water planning tasks" (J. Robinson, DNRC, Letter to Water interests, Feb 1, 2013). If representatively constituted, this BAC will provide a useful forum for not only insuring continued water supplies for irrigation, industrial, and municipal use, but also for vital water needs for native fishes, a key example of what MacIntyre (1994) referred to 20 years ago as the "expansive array of purposes" that are important to the broader public-at-large. With the current composition of the BAC heavily dominated by irrigation interests (i.e., Conservation Districts), in nearly the same percentage that irrigation consumes Yellowstone River water (Chapter 3), it is imperative that instream flow needs for native fishes be given its proper consideration and its water. As DNRC seeks to wisely managing Montana's water for all Montanans, present and future, Montana Fish, Wildlife and Parks, as the lead state fish and wildlife management agency whose mission and expertise are in line with native fish needs, is well positioned to assist the DNRC and the BAC in this role. Their effective input into the new State Water Plan is vital for a balanced, representative water plan insuring the economic needs of the present and future, as well as the future of the Yellowstone River and its native fauna.

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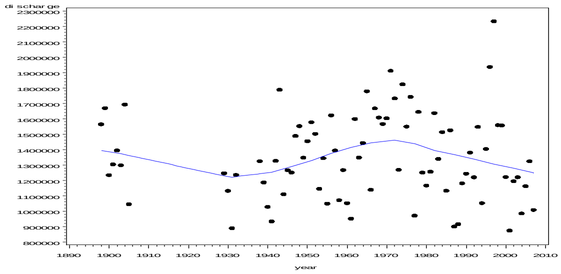
APPENDICES

APPENDIX 1

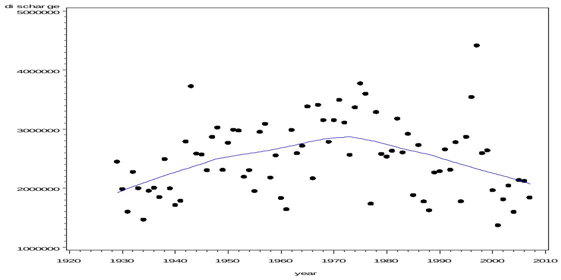
Loess Smoothing Results Figures 1-95.

Figures 1-18: Annual Average Discharge

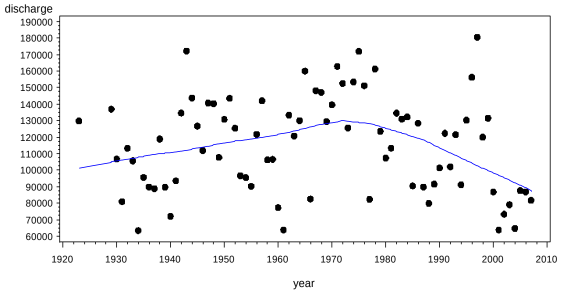
1. Yellowstone River near Livingston, MT:



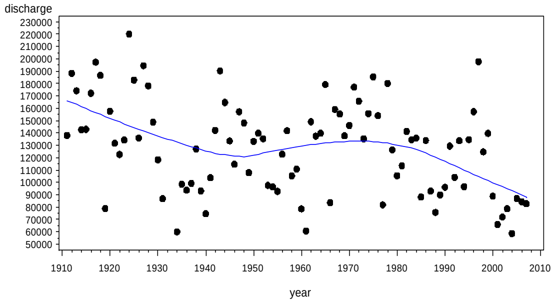
2. Yellowstone River at Billings, MT:



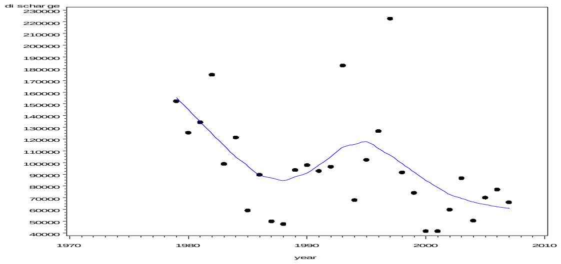
3. Yellowstone River at Miles City, MT:



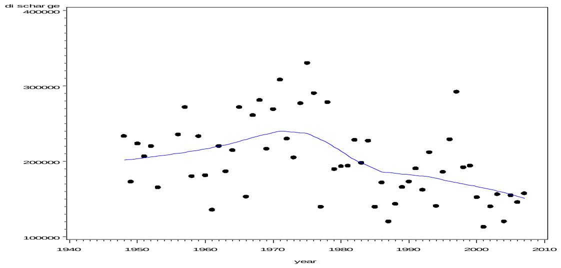
4. Yellowstone River at Sidney, MT:



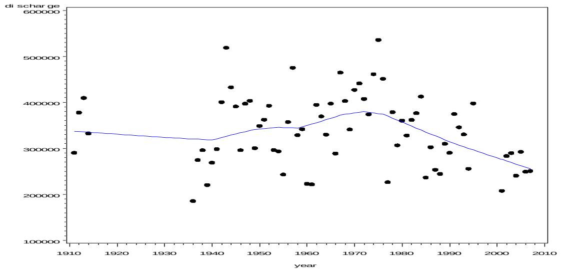
5. Shields River:



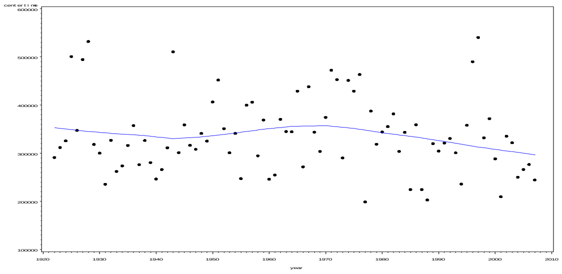
6. Boulder River:



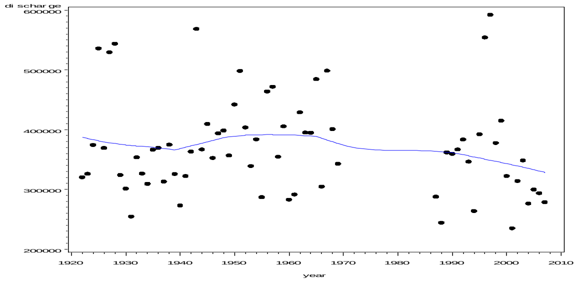
7. Stillwater River:



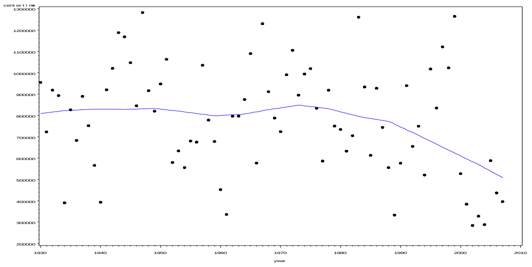
8. Clarks Fork River near Belfry, MT:



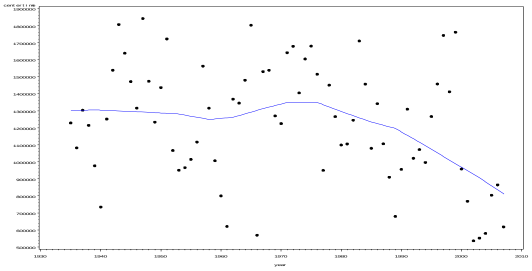
9. Clarks Fork River near Edgar, MT:



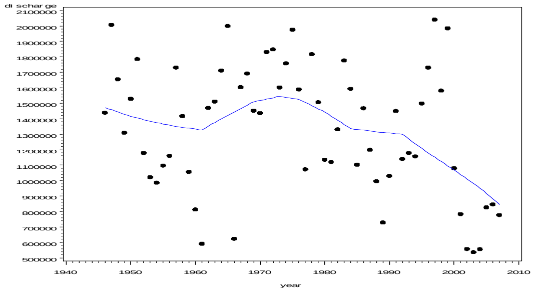
10. Bighorn River at Kane, WY:



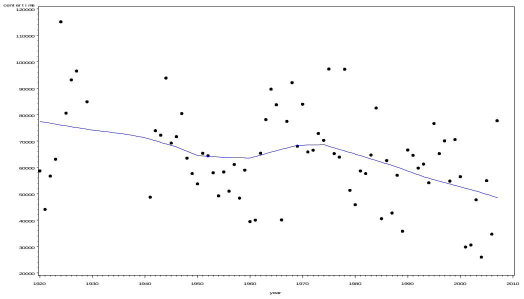
11. Bighorn River near St. Xavier, MT:



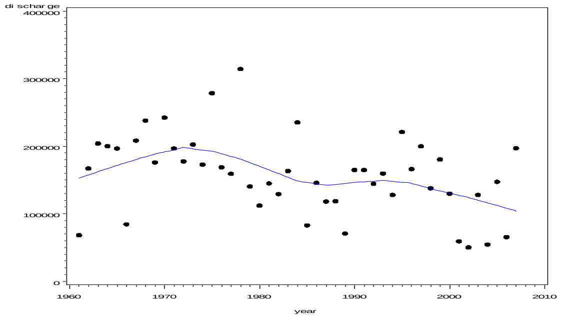
12. Bighorn River near Bighorn, MT:



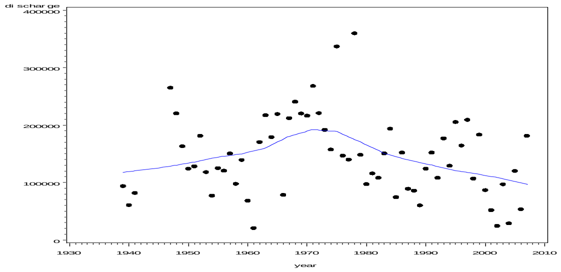
13. Tongue River near Dayton, WY:



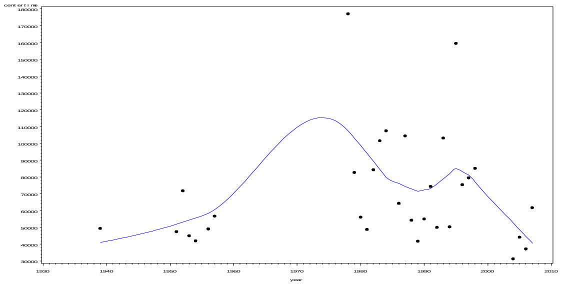
14. Tongue River at State Line near Decker, MT:



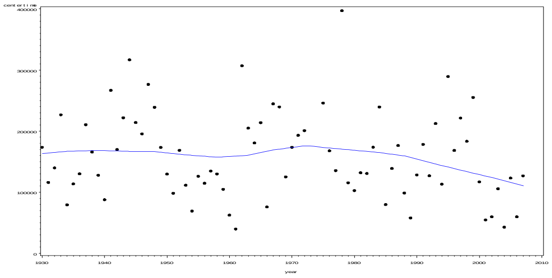
15. Tongue River at Miles City, MT:



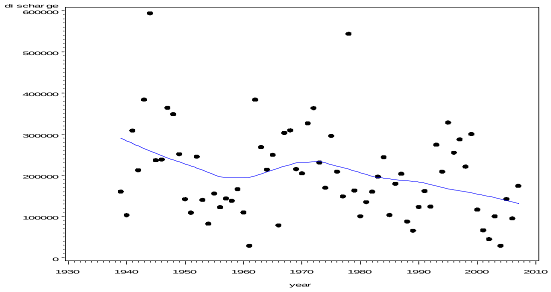
16. Powder River near Sussex, WY:



17. Powder River at Moorhead, MT:

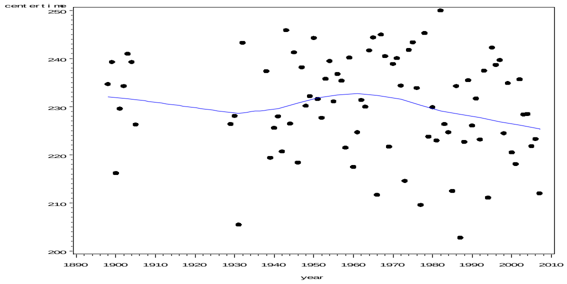


18. Powder River near Locate, MT:

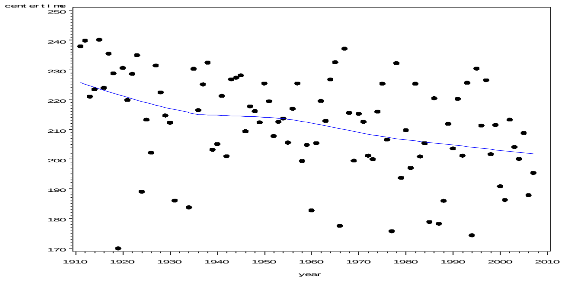


Figures 19-27: Magnitude of Annual Peak Discharge

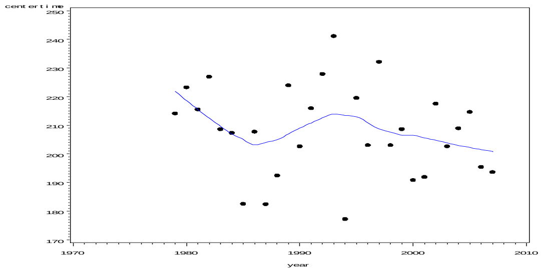
19. Yellowstone River at Livingston, MT:



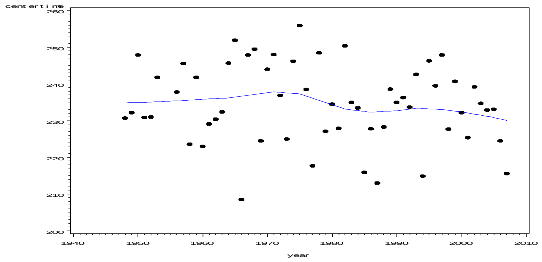
20. Yellowstone River at Sidney, MT:



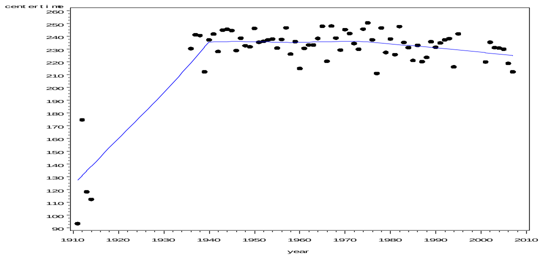
21. Shields River:



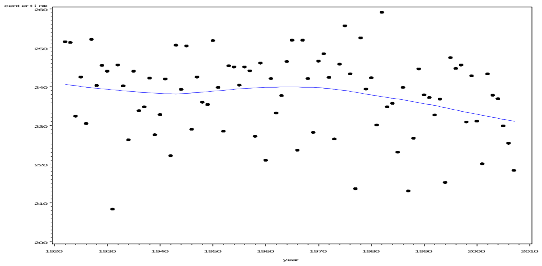
22. Boulder River:



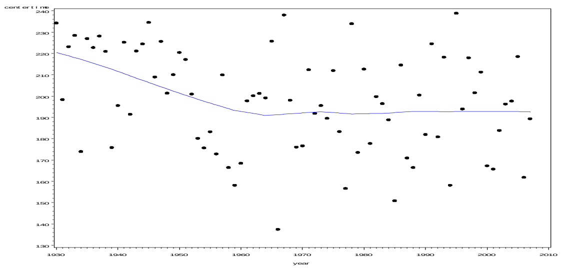
23. Stillwater River:



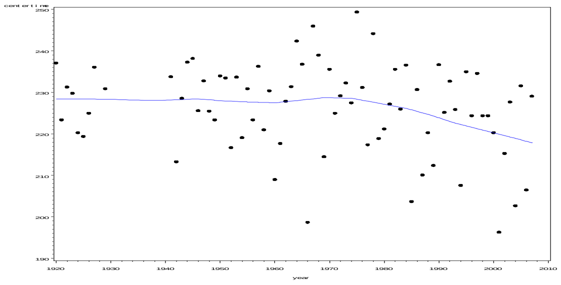
24. Clarks Fork River near Belfry, MT:



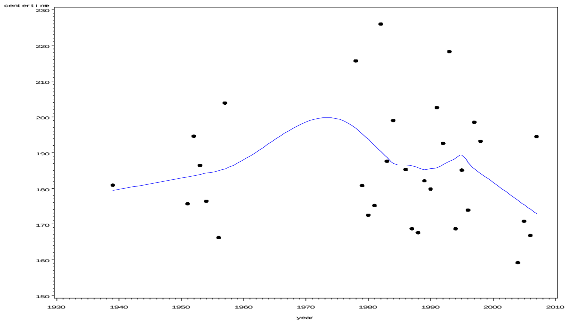
25. Bighorn River at Kane, WY:



26. Tongue River at Dayton, WY:

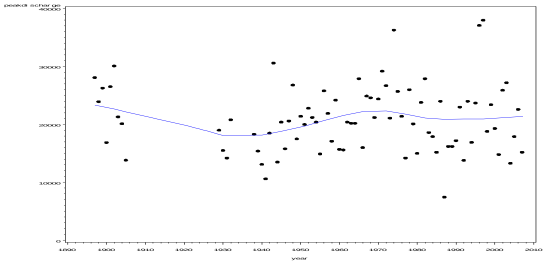


27. Powder River at Sussex, WY:

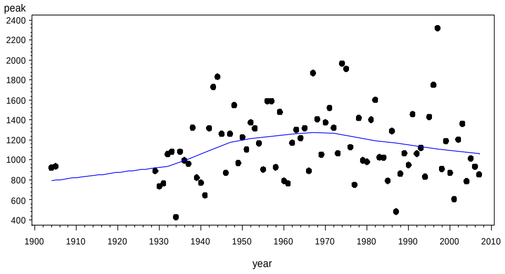


Figures 28-45: Absolute Annual Minimum Discharge

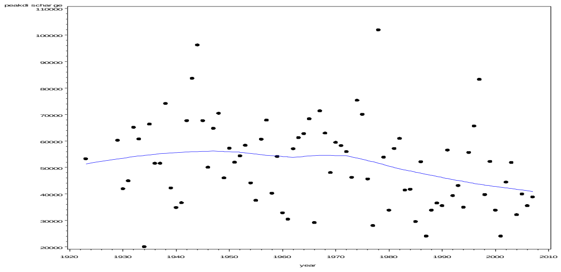
28. Yellowstone River at Livingston, MT:



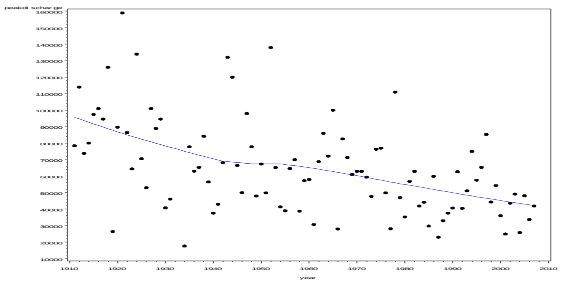
29. Yellowstone River at Billings, MT:



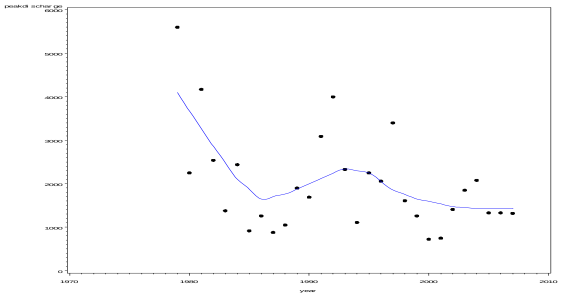
30. Yellowstone River near Miles City, MT:



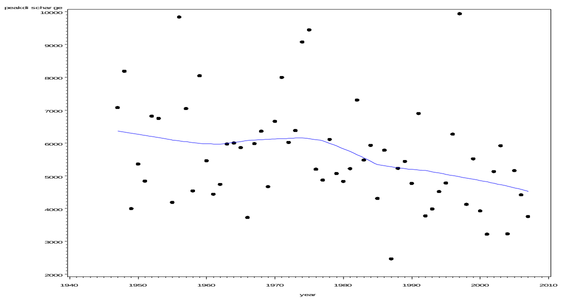
31. Yellowstone River at Sidney, MT:



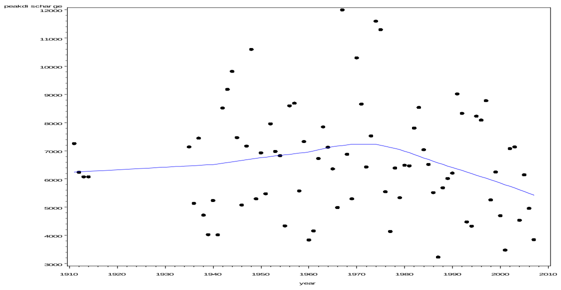
32. Shields River:



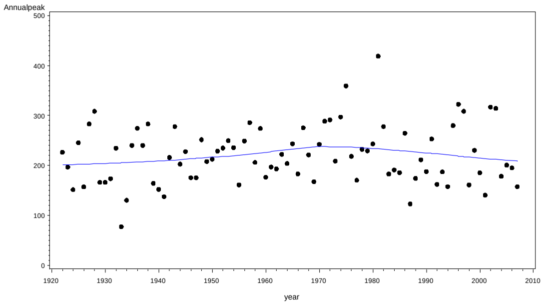
33. Boulder River:



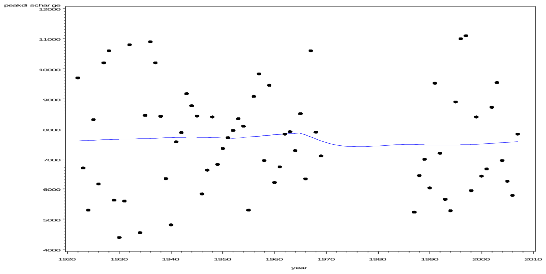
34. Stillwater River:



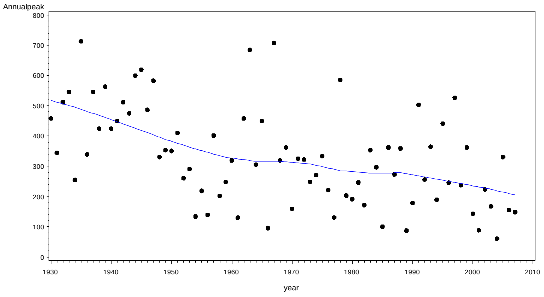
35. Clarks Fork River near Belfry, MT:



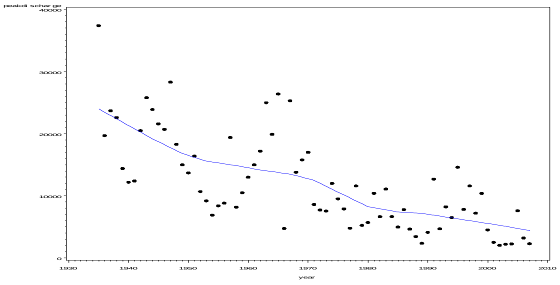
36. Clark Fork River at Edgar, MT:



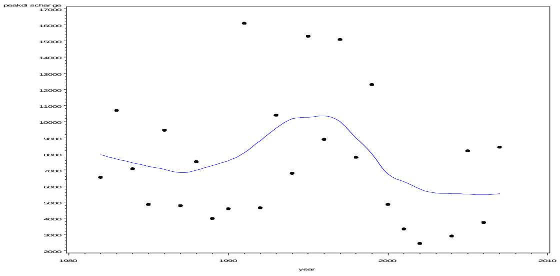
37. Bighorn River near Kane, WY:



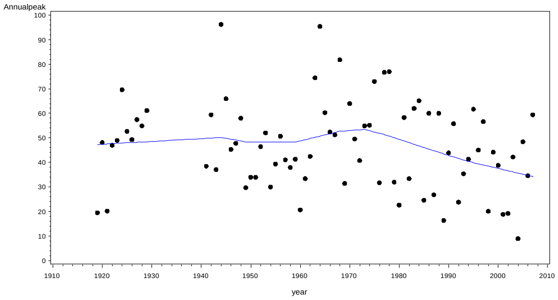
38. Bighorn River at St. Xavier, MT:



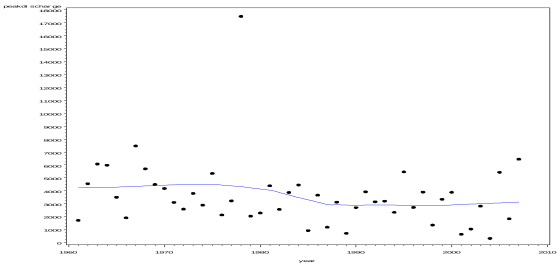
39. Bighorn River near Bighorn, MT:



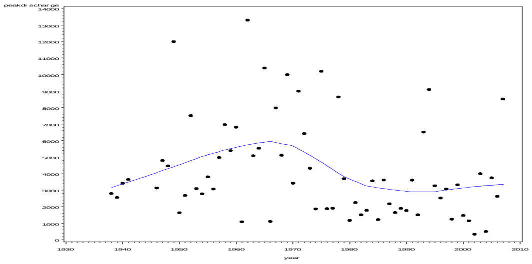
40. Tongue River near Dayton, WY:



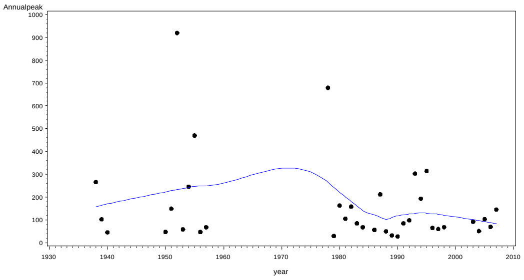
41. Tongue River at State Line near Decker, MT:



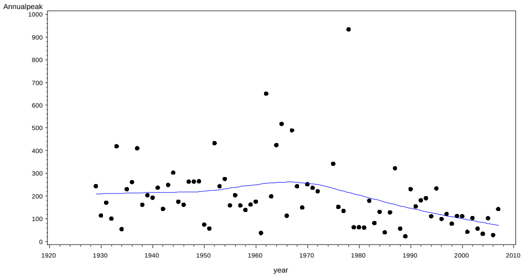
42. Tongue River at Miles City, MT:



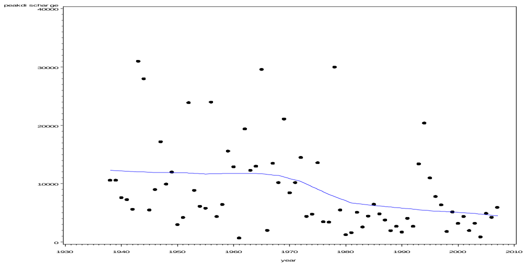
43. Powder River near Sussex, WY:



44. Powder River near Moorhead, MT:

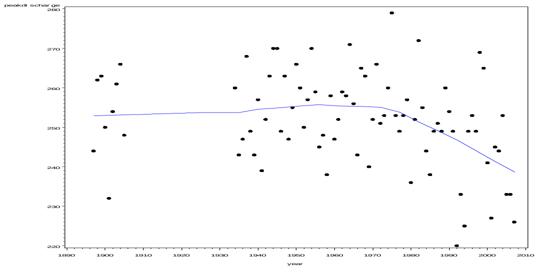


45. Powder River at Locate, MT:

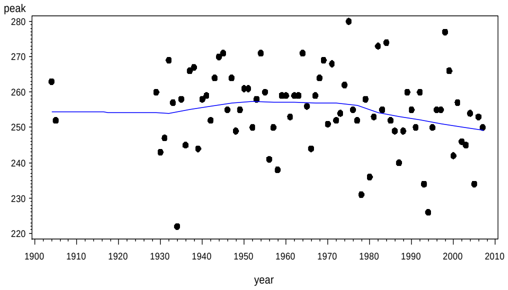


Figures 46-63: Timing of Discharge

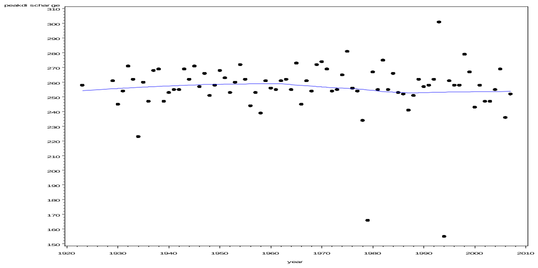
46. Yellowstone River at Livingston, MT:



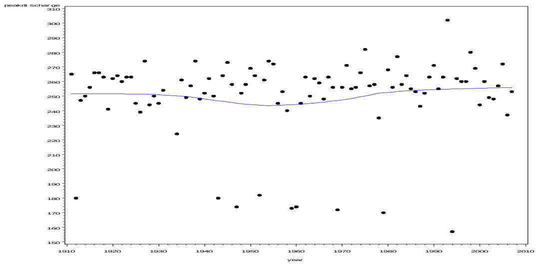
47. Yellowstone River at Billings, MT:



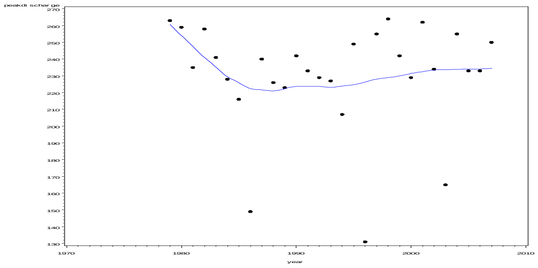
48. Yellowstone River at Miles City, MT:



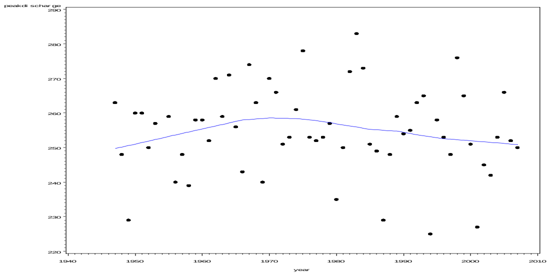
49. Yellowstone River near Sidney, MT:



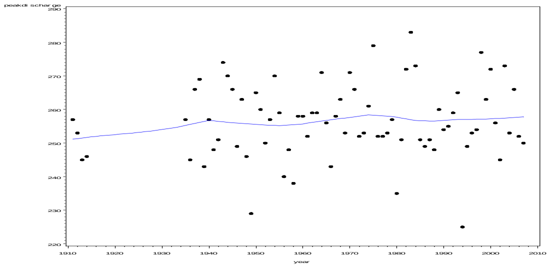
50. Shields River:



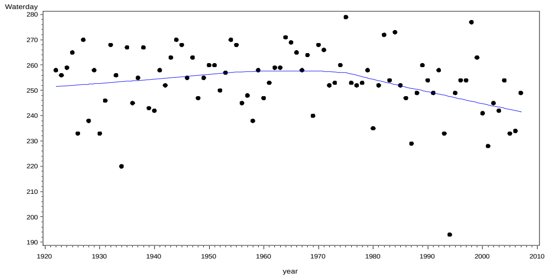
51. Boulder River:



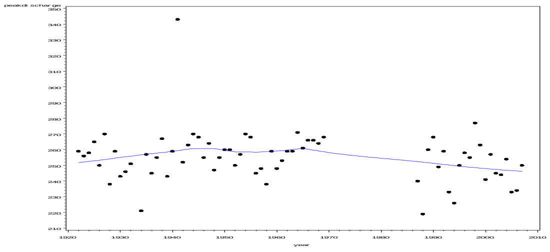
52. Stillwater River:



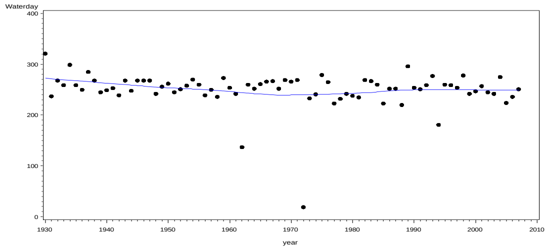
53. Clarks Fork River near Belfry, MT:



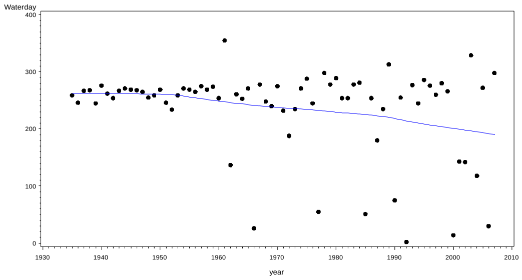
54. Clarks Fork River near Edgar, MT:



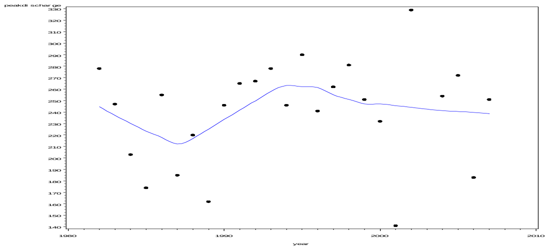
55. Bighorn River near Kane, WY:



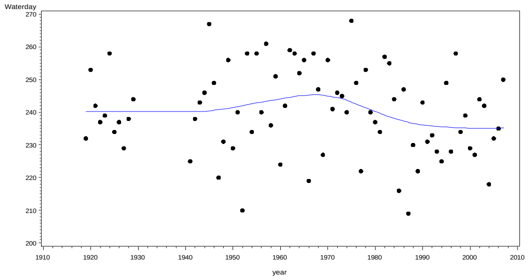
56. Bighorn River near St. Xavier, MT:



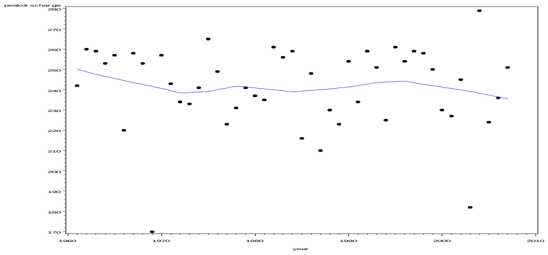
57. Bighorn River near Bighorn, MT:



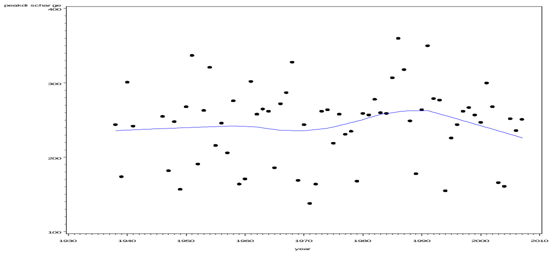
58. Tongue River near Dayton WY:



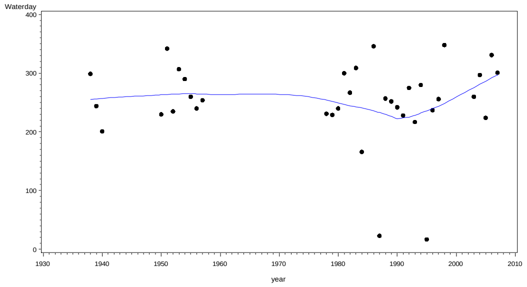
59. Tongue River at State Line near Decker, MT:



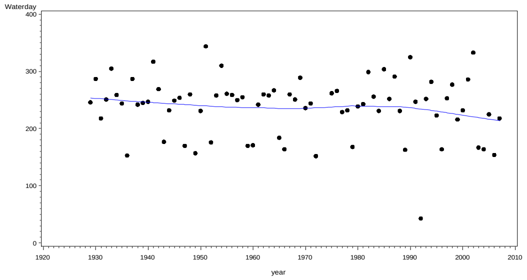
60. Tongue River at Miles City, MT:



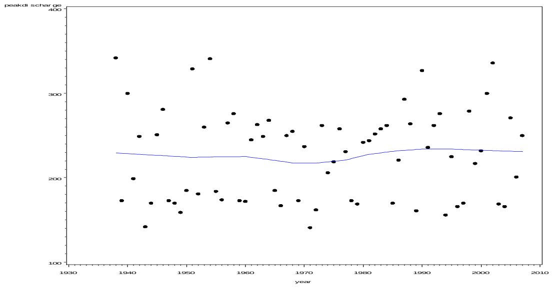
61. Powder River near Sussex, WY:



62. Powder River near Moorhead, MT:

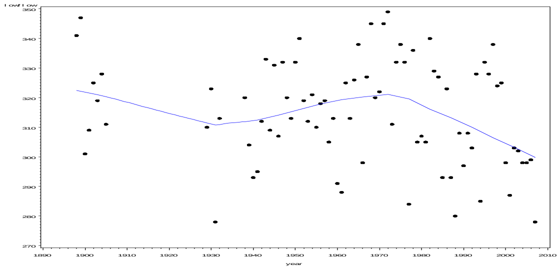


63. Powder River at Locate, MT:

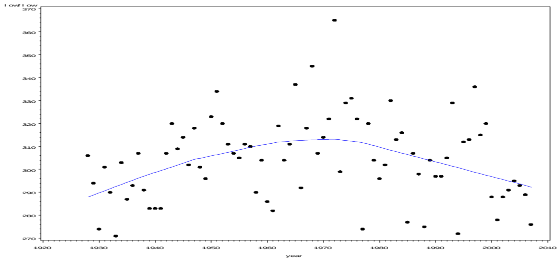


Figures 64-80: Annual Peak Discharge

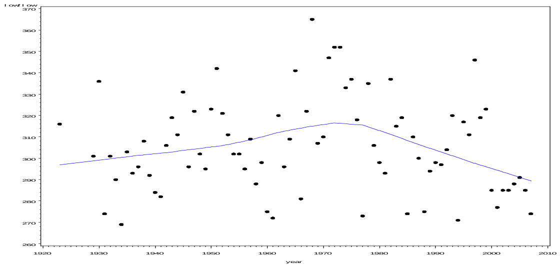
64. Yellowstone River at Livingston, MT:



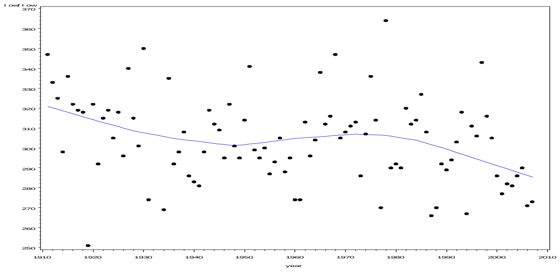
65. Yellowstone River at Billings, MT:



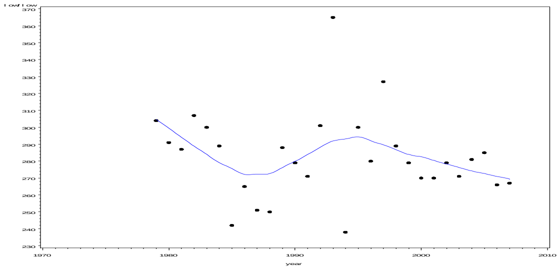
66. Yellowstone River at Miles City, MT:



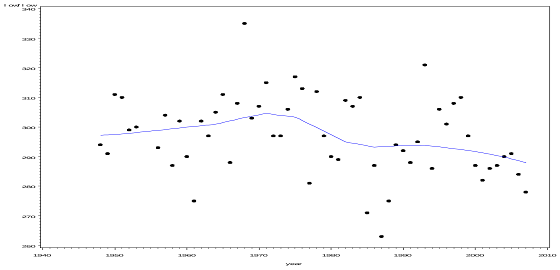
67. Yellowstone River at Sidney, MT:



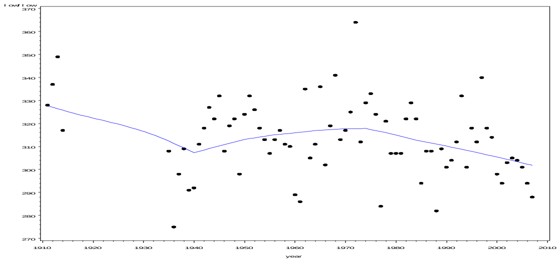
68. Shields River:



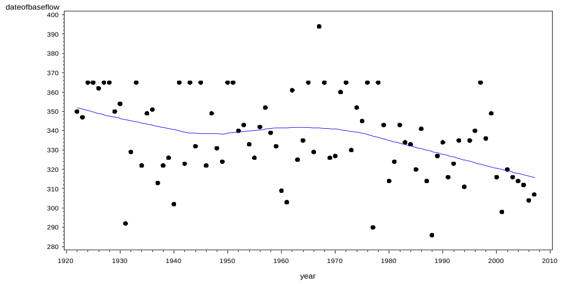
69. Boulder River:



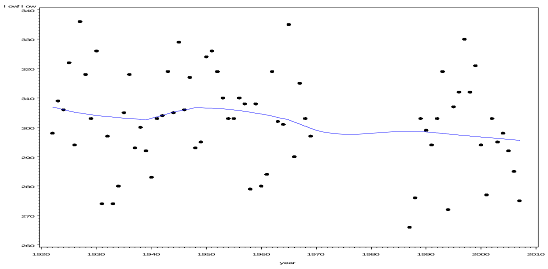
70. Stillwater River:



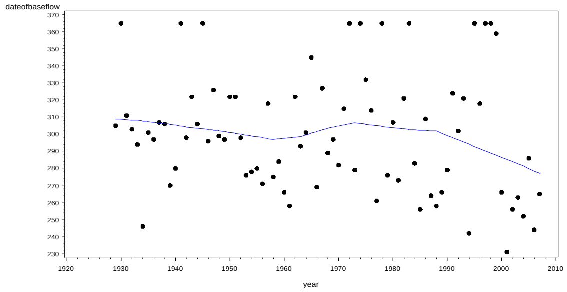
71. Clarks Fork near Belfry, MT:



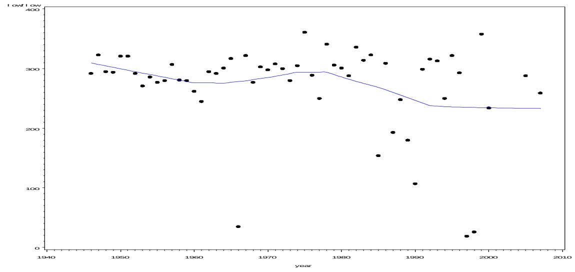
72. Clarks Fork near Edgar, MT:



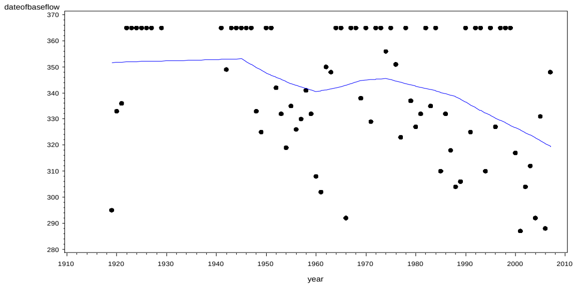
73. Bighorn River near Kane, WY:



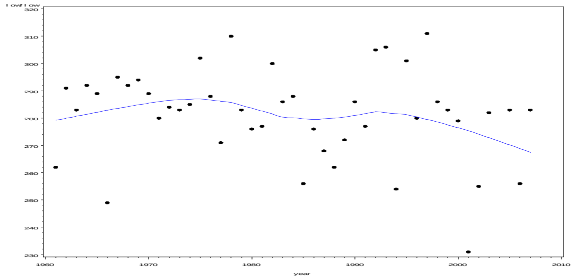
74. Bighorn River near Bighorn, MT:



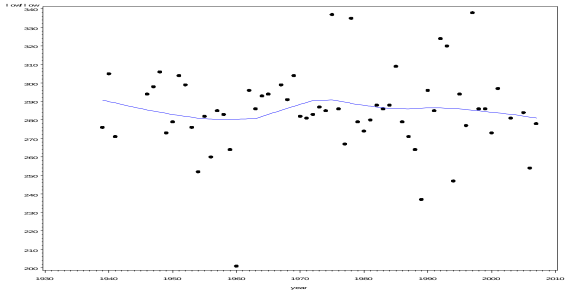
75. Tongue River at Dayton, WY:



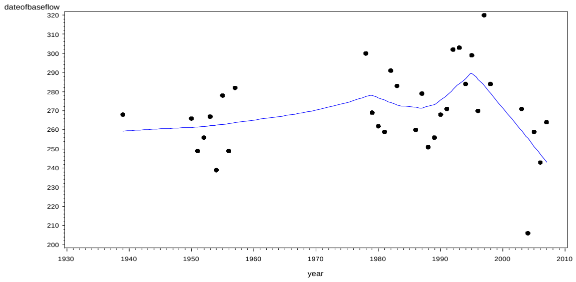
76. Tongue River at Stateline near Decker, MT:



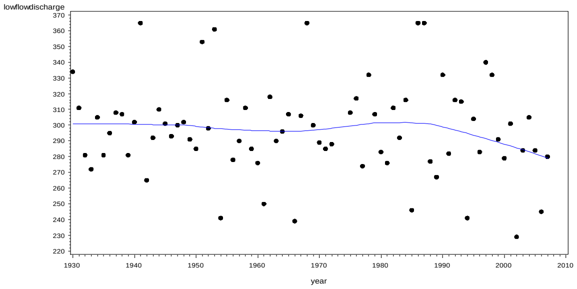
77. Tongue River at Miles City, MT:



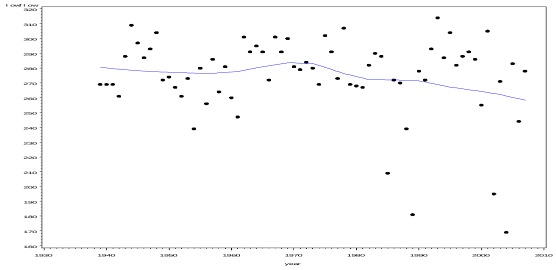
78. Powder River near Sussex, WY:



79. Powder River near Moorhead, MT:

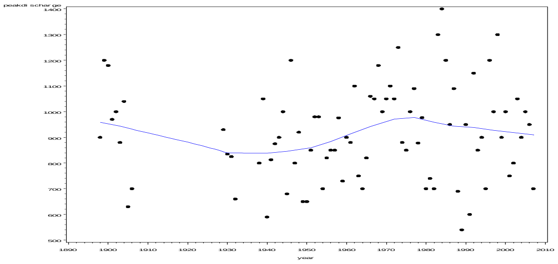


80. Powder River near Locate, MT:

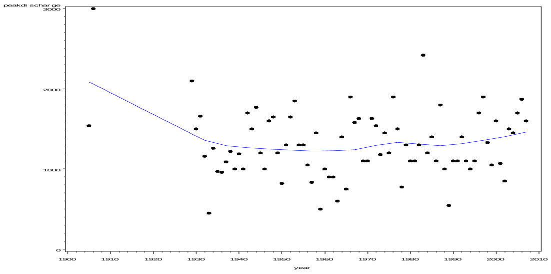


Figures 81-97: Timing of Annual Baseflow

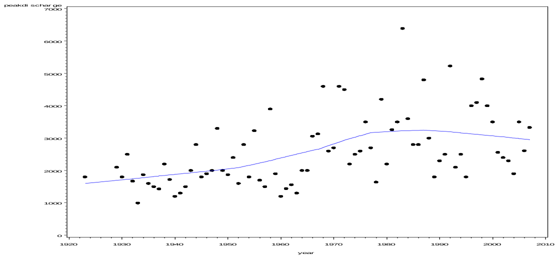
81. Yellowstone River at Livingston, MT:



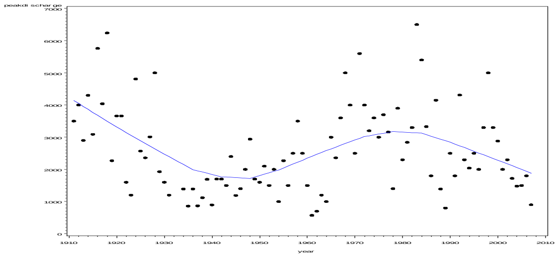
82. Yellowstone river at Billings, MT:



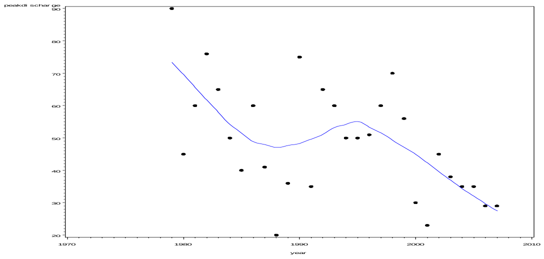
83. Yellowstone River at Miles City, MT:



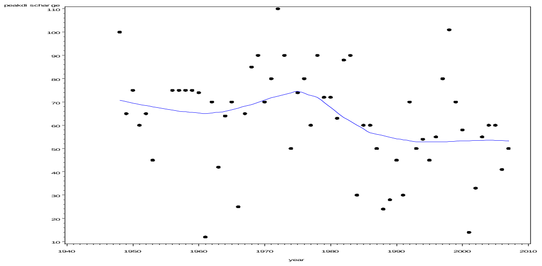
84. Yellowstone River at Sidney, MT:



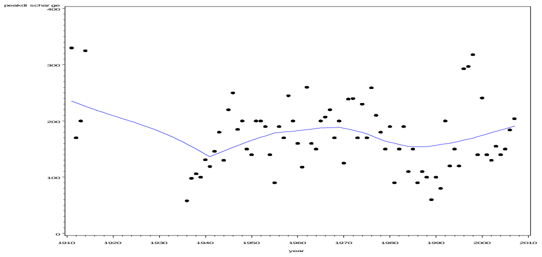
85. Shields River:



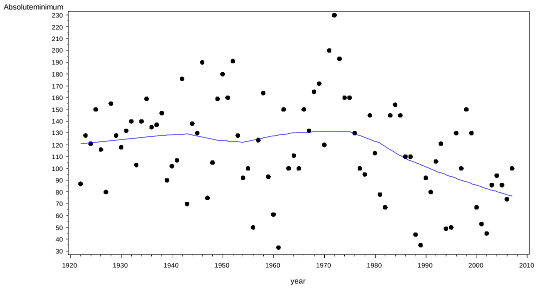
86. Boulder River:



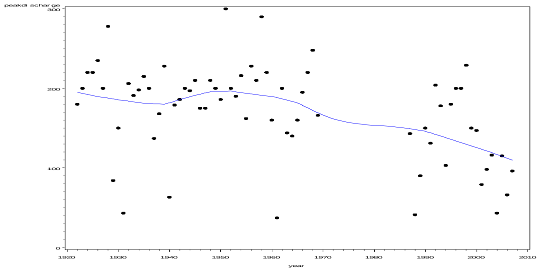
87. Stillwater River:



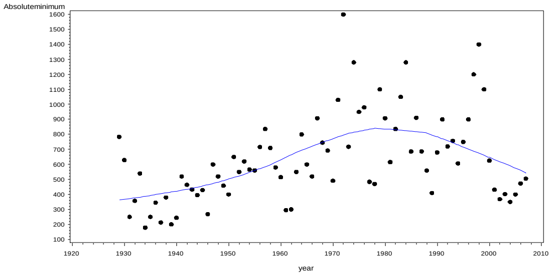
88. Clarks Fork River at Belfry, MT:



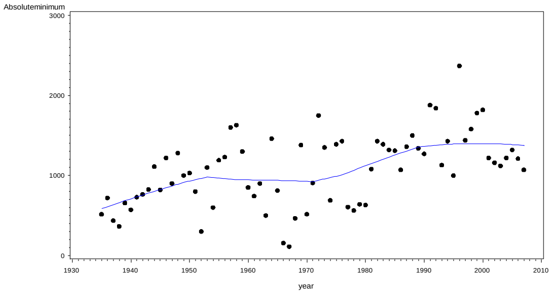
89. Clarks Fork River near Edgar, MT:



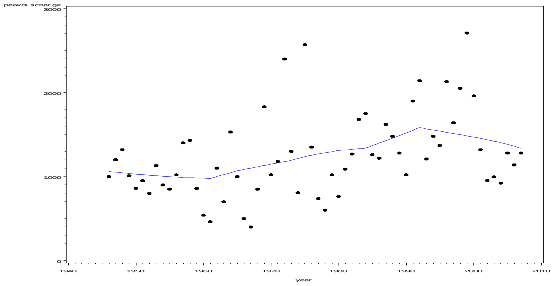
90. Bighorn River near Kane, WY:



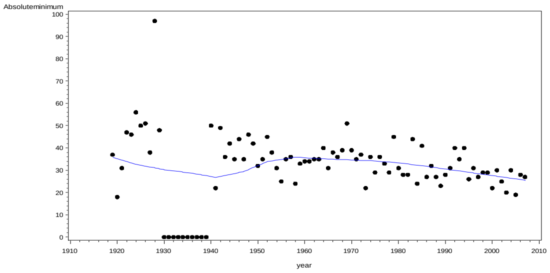
91. Bighorn River at St. Xavier, MT:



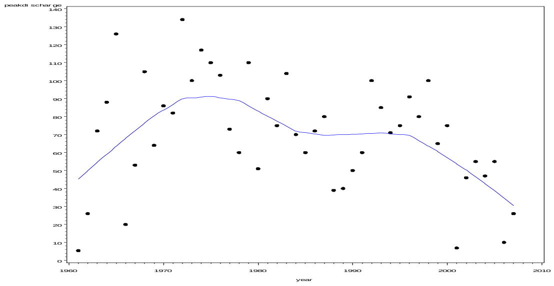
92. Bighorn River near Bighorn, MT:



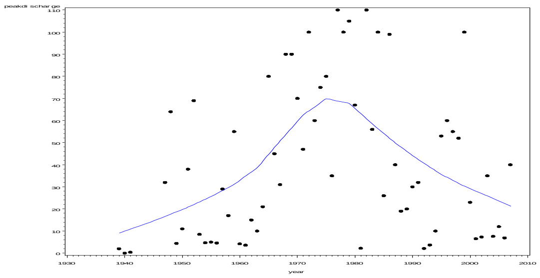
93. Tongue River at Dayton, WY:



94. Tongue River at State Line near Decker:

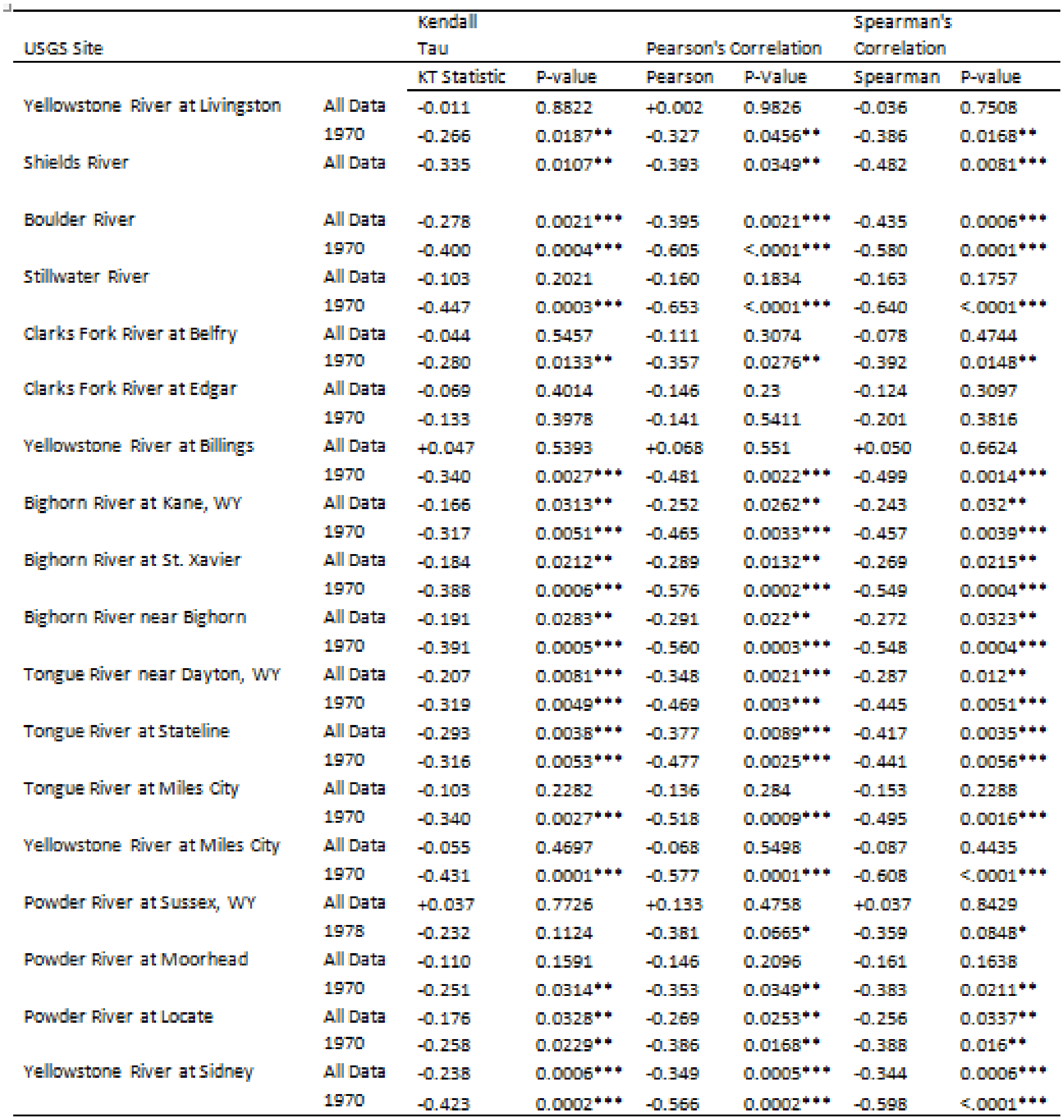


95. Tongue River at Miles City, MT:



APPENDIX 2

Trend analysis results for magnitude of annual discharge in the Yellowstone River Basin.



USGS Site		Kendall Tau		Pearson's Correlation		Spearman's Correlation	
		KT Statistic	P-value	Pearson	P-Value	Spearman	P-value
Yellowstone River at Livingston	All Data	-0.011	0.8822	+0.002	0.9826	-0.036	0.7508
	1970	-0.266	0.0187**	-0.327	0.0456**	-0.386	0.0168**
Shields River	All Data	-0.335	0.0107**	-0.393	0.0349**	-0.482	0.0081***
Boulder River	All Data	-0.278	0.0021***	-0.395	0.0021***	-0.435	0.0006***
	1970	-0.400	0.0004***	-0.605	<.0001***	-0.580	0.0001***
Stillwater River	All Data	-0.103	0.2021	-0.160	0.1834	-0.163	0.1757
	1970	-0.447	0.0003***	-0.653	<.0001***	-0.640	<.0001***
Clarks Fork River at Belfry	All Data	-0.044	0.5457	-0.111	0.3074	-0.078	0.4744
	1970	-0.280	0.0133**	-0.357	0.0276**	-0.392	0.0148**
Clarks Fork River at Edgar	All Data	-0.069	0.4014	-0.146	0.23	-0.124	0.3097
	1970	-0.133	0.3978	-0.141	0.5411	-0.201	0.3816
Yellowstone River at Billings	All Data	+0.047	0.5393	+0.068	0.551	+0.050	0.6624
	1970	-0.340	0.0027***	-0.481	0.0022***	-0.499	0.0014***
Bighorn River at Kane, WY	All Data	-0.166	0.0313**	-0.252	0.0262**	-0.243	0.032**
	1970	-0.317	0.0051***	-0.465	0.0033***	-0.457	0.0039***
Bighorn River at St. Xavier	All Data	-0.184	0.0212**	-0.289	0.0132**	-0.269	0.0215**
	1970	-0.388	0.0006***	-0.576	0.0002***	-0.549	0.0004***
Bighorn River near Bighorn	All Data	-0.191	0.0283**	-0.291	0.022**	-0.272	0.0323**
	1970	-0.391	0.0005***	-0.560	0.0003***	-0.548	0.0004***
Tongue River near Dayton, WY	All Data	-0.207	0.0081***	-0.348	0.0021***	-0.287	0.012**
	1970	-0.319	0.0049***	-0.469	0.003***	-0.445	0.0051***
Tongue River at Stateline	All Data	-0.293	0.0038***	-0.377	0.0089***	-0.417	0.0035***
	1970	-0.316	0.0053***	-0.477	0.0025***	-0.441	0.0056***
Tongue River at Miles City	All Data	-0.103	0.2282	-0.136	0.284	-0.153	0.2288
	1970	-0.340	0.0027***	-0.518	0.0009***	-0.495	0.0016***
Yellowstone River at Miles City	All Data	-0.055	0.4697	-0.068	0.5498	-0.087	0.4435
	1970	-0.431	0.0001***	-0.577	0.0001***	-0.608	<.0001***
Powder River at Sussex, WY	All Data	+0.037	0.7726	+0.133	0.4758	+0.037	0.8429
	1978	-0.232	0.1124	-0.381	0.0665*	-0.359	0.0848*
Powder River at Moorhead	All Data	-0.110	0.1591	-0.146	0.2096	-0.161	0.1638
	1970	-0.251	0.0314**	-0.353	0.0349**	-0.383	0.0211**
Powder River at Locate	All Data	-0.176	0.0328**	-0.269	0.0253**	-0.256	0.0337**
	1970	-0.258	0.0229**	-0.386	0.0168**	-0.388	0.016**
Yellowstone River at Sidney	All Data	-0.238	0.0006***	-0.349	0.0005***	-0.344	0.0006***
	1970	-0.423	0.0002***	-0.566	0.0002***	-0.598	<.0001***

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

APPENDIX 3

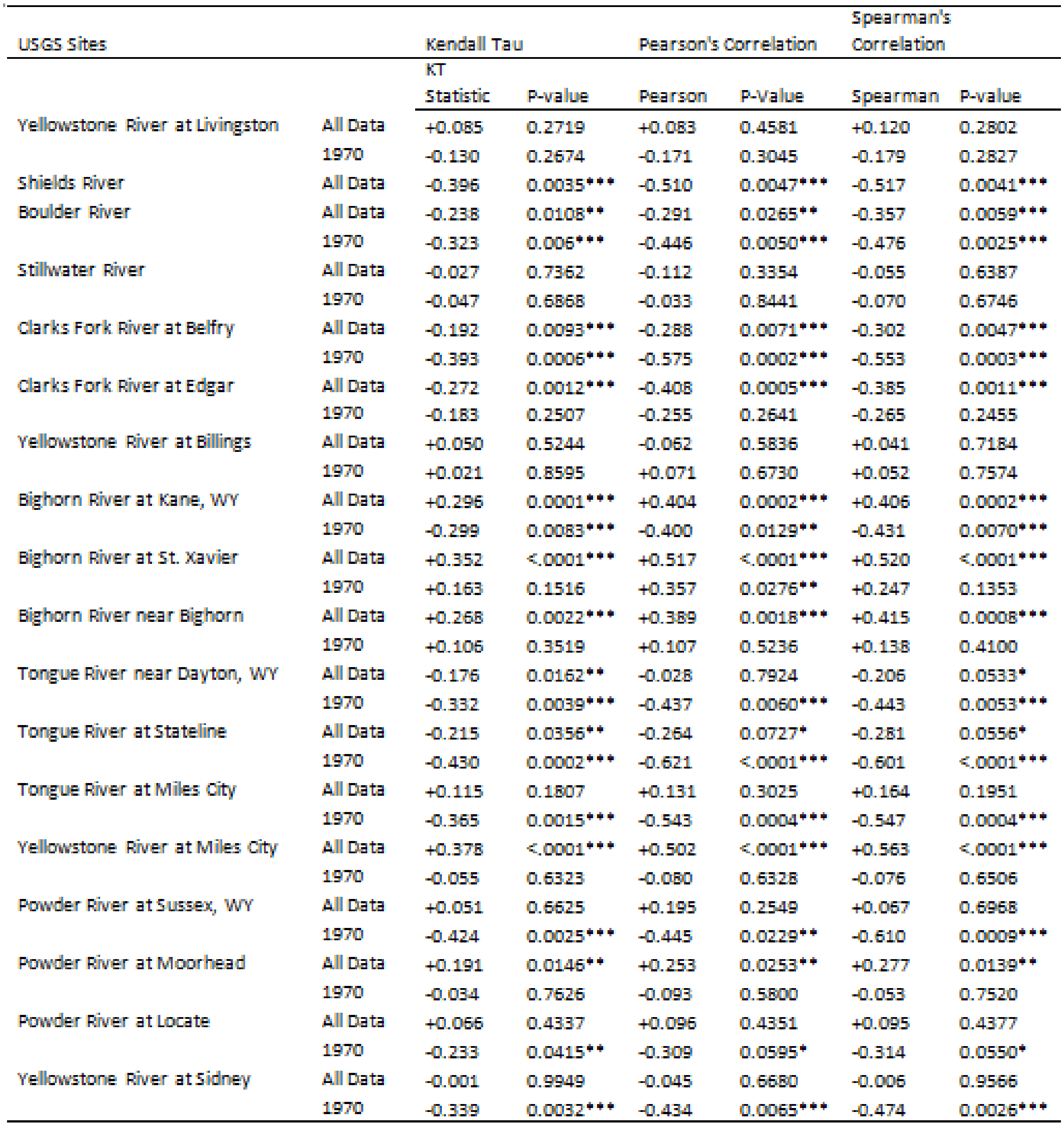
Trend analysis results for magnitude of annual peak discharge in the Yellowstone River Basin.

USGS Sites		Kendall Tau		Pearson's Correlation		Spearman's Correlation	
		KT Statistic	P-value	Pearson	P-Value	Spearman	P-value
Yellowstone River at Livingston	All Data	+0.016	0.8287	+0.009	0.9338	+0.014	0.8969
	1970	-0.156	0.1704	-0.163	0.3282	-0.228	0.1688
Shields River	All Data	-0.251	0.058*	-0.416	0.0246**	-0.345	0.0671*
Boulder River	All Data	-0.245	0.0056***	-0.323	0.0119**	-0.362	0.0044***
	1970	-0.366	0.0012***	-0.453	0.0043***	-0.526	0.0007***
Stillwater River	All Data	-0.074	0.3399	-0.088	0.4487	-0.107	0.3559
	1970	-0.266	0.0187**	-0.430	0.0071***	-0.394	0.0145**
Clarks Fork River at Belfry	All Data	+0.052	0.4808	+0.111	0.3096	+0.069	0.527
	1970	-0.197	0.0827*	-0.266	0.106	-0.288	0.079*
Clarks Fork River at Edgar	All Data	-0.034	0.6874	-0.047	0.7042	-0.032	0.7926
	1970	+0.114	0.4686	+0.135	0.5611	+0.166	0.4714
Yellowstone River at Billings	All Data	+0.046	0.5461	+0.098	0.3857	+0.066	0.5561
	1970	-0.219	0.0528*	-0.261	0.1131	-0.330	0.0428**
Bighorn River at Kane, WY	All Data	-0.349	<.0001***	-0.499	<.0001***	-0.501	<.0001***
	1970	-0.128	0.2578	-0.154	0.3554	-0.185	0.2652
Bighorn River at St. Xavier	All Data	-0.551	<.0001***	-0.711	<.0001***	-0.747	<.0001***
	1970	-0.348	0.0022***	-0.448	0.0048***	-0.487	0.002***
Bighorn River near Bighorn	All Data	-0.124	0.3874	-0.119	0.5706	-0.167	0.424
Tongue River near Dayton, WY	All Data	-0.100	0.197	-0.162	0.1567	-0.152	0.1843
	1970	-0.231	0.0417**	-0.376	0.0198**	-0.347	0.0328**
Tongue River at Stateline	All Data	-0.203	0.0446**	-0.235	0.1111	-0.282	0.0544*
	1970	-0.093	0.4138	-0.174	0.2953	-0.133	0.4247
Tongue River at Miles City	All Data	-0.184	0.0288**	-0.232	0.0604*	-0.295	0.016**
	1970	-0.160	0.1591	-0.216	0.193	-0.220	0.1839
Yellowstone River at Miles City	All Data	-0.208	0.0065***	-0.270	0.0153**	-0.312	0.0048***
	1970	-0.252	0.0269**	-0.340	0.0369**	-0.379	0.0189**
Powder River at Sussex, WY	All Data	-0.052	0.653	-0.236	0.1662	-0.083	0.6313
	1970	-0.033	0.8153	-0.252	0.2238	-0.058	0.7813
Powder River at Moorhead	All Data	-0.293	0.0002***	-0.267	0.019**	-0.429	<.0001***
	1970	-0.330	0.0046***	-0.377	0.0234**	-0.447	0.0062***
Powder River at Locate	All Data	-0.296	0.0003***	-0.383	0.0011***	-0.451	<.0001***
	1970	-0.154	0.1745	-0.244	0.1399	-0.228	0.1689
Yellowstone River at Sidney	All Data	-0.357	<.0001***	-0.495	<.0001***	-0.509	<.0001***
	1970	-0.213	0.0609*	-0.313	0.0558*	-0.325	0.0468**

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

APPENDIX 4

Trend analysis results for the absolute annual minimum discharges within the Yellowstone River Basin.



USGS Sites		Kendall Tau		Pearson's Correlation		Spearman's Correlation	
		KT Statistic	P-value	Pearson	P-Value	Spearman	P-value
Yellowstone River at Livingston	All Data	+0.085	0.2719	+0.083	0.4581	+0.120	0.2802
	1970	-0.130	0.2674	-0.171	0.3045	-0.179	0.2827
Shields River	All Data	-0.396	0.0035***	-0.510	0.0047***	-0.517	0.0041***
Boulder River	All Data	-0.238	0.0108**	-0.291	0.0265**	-0.357	0.0059***
	1970	-0.323	0.006***	-0.446	0.0050***	-0.476	0.0025***
Stillwater River	All Data	-0.027	0.7362	-0.112	0.3354	-0.055	0.6387
	1970	-0.047	0.6868	-0.033	0.8441	-0.070	0.6746
Clarks Fork River at Belfry	All Data	-0.192	0.0093***	-0.288	0.0071***	-0.302	0.0047***
	1970	-0.393	0.0006***	-0.575	0.0002***	-0.553	0.0003***
Clarks Fork River at Edgar	All Data	-0.272	0.0012***	-0.408	0.0005***	-0.385	0.0011***
	1970	-0.183	0.2507	-0.255	0.2641	-0.265	0.2455
Yellowstone River at Billings	All Data	+0.050	0.5244	-0.062	0.5836	+0.041	0.7184
	1970	+0.021	0.8595	+0.071	0.6730	+0.052	0.7574
Bighorn River at Kane, WY	All Data	+0.296	0.0001***	+0.404	0.0002***	+0.406	0.0002***
	1970	-0.299	0.0083***	-0.400	0.0129**	-0.431	0.0070***
Bighorn River at St. Xavier	All Data	+0.352	<.0001***	+0.517	<.0001***	+0.520	<.0001***
	1970	+0.163	0.1516	+0.357	0.0276**	+0.247	0.1353
Bighorn River near Bighorn	All Data	+0.268	0.0022***	+0.389	0.0018***	+0.415	0.0008***
	1970	+0.106	0.3519	+0.107	0.5236	+0.138	0.4100
Tongue River near Dayton, WY	All Data	-0.176	0.0162**	-0.028	0.7924	-0.206	0.0533*
	1970	-0.332	0.0039***	-0.437	0.0060***	-0.443	0.0053***
Tongue River at Stateline	All Data	-0.215	0.0356**	-0.264	0.0727*	-0.281	0.0556*
	1970	-0.430	0.0002***	-0.621	<.0001***	-0.601	<.0001***
Tongue River at Miles City	All Data	+0.115	0.1807	+0.131	0.3025	+0.164	0.1951
	1970	-0.365	0.0015***	-0.543	0.0004***	-0.547	0.0004***
Yellowstone River at Miles City	All Data	+0.378	<.0001***	+0.502	<.0001***	+0.563	<.0001***
	1970	-0.055	0.6323	-0.080	0.6328	-0.076	0.6506
Powder River at Sussex, WY	All Data	+0.051	0.6625	+0.195	0.2549	+0.067	0.6968
	1970	-0.424	0.0025***	-0.445	0.0229**	-0.610	0.0009***
Powder River at Moorhead	All Data	+0.191	0.0146**	+0.253	0.0253**	+0.277	0.0139**
	1970	-0.034	0.7626	-0.093	0.5800	-0.053	0.7520
Powder River at Locate	All Data	+0.066	0.4337	+0.096	0.4351	+0.095	0.4377
	1970	-0.233	0.0415**	-0.309	0.0595*	-0.314	0.0550*
Yellowstone River at Sidney	All Data	-0.001	0.9949	-0.045	0.6680	-0.006	0.9566
	1970	-0.339	0.0032***	-0.434	0.0065***	-0.474	0.0026***

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.0

APPENDIX 5

Trend analysis results for average monthly discharges within the Yellowstone River Basin.

Yellowstone River at Livingston, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.063	0.4026	0.115	0.3142	0.082	0.4713
February	0.037	0.6223	0.041	0.7211	0.033	0.7743
March	0.050	0.5037	-0.117	0.3043	-0.132	0.2456
April	0.202	0.0071***	0.042	0.7144	0.108	0.3417
May	0.187	0.0129**	0.270	0.0161**	0.273	0.1051
June	-0.029	0.6977	0.013	0.9119	-0.031	0.7854
July	-0.088	0.2423	-0.001	0.9964	-0.015	0.8928
August	-0.133	0.0761*	-0.036	0.7526	-0.073	0.5219
September	-0.096	0.2012	-0.029	0.8003	-0.051	0.6543
October	-0.032	0.6653	0.099	0.3866	0.134	0.2404
November	0.033	0.6596	0.106	0.3536	0.117	0.3033
December	0.030	0.6883	0.190	0.0927*	0.176	0.1208

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Shields River

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	-0.271	0.0391**	-0.315	0.0957*	-0.408	0.0279**
February	-0.300	0.0221**	-0.303	0.1102	-0.469	0.0102**
March	-0.103	0.4308	-0.033	0.8647	-0.144	0.4551
April	-0.251	0.0557*	-0.329	0.0815	-0.333	0.078*
May	-0.276	0.0356**	-0.373	0.0465**	-0.416	0.0249**
June	-0.182	0.1651	-0.282	0.1385	-0.314	0.0968*
July	-0.315	0.0163**	-0.281	0.1405	-0.428	0.0207**
August	-0.463	0.0004***	-0.225	0.2405	-0.618	0.0004***
September	-0.462	0.0012***	-0.424	0.022**	-0.564	0.0015***
October	-0.340	0.0096***	-0.531	0.0031***	-0.513	0.0044***
November	-0.338	0.0102**	-0.500	0.0058***	-0.494	0.0065***
December	-0.330	0.012**	-0.504	0.0053***	-0.479	0.0085***

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Boulder River

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	-0.175	0.0525*	-0.251	0.0578*	-0.288	0.0284**
February	-0.277	0.0022***	-0.355	0.0062***	-0.402	0.0018***
March	-0.221	0.0143**	-0.308	0.0188**	-0.339	0.0092***
April	-0.047	0.5963	-0.078	0.5554	-0.077	0.5608
May	-0.045	0.6146	-0.156	0.2395	-0.091	0.4951
June	-0.258	0.0038***	-0.335	0.0095***	-0.374	0.0035***
July	-0.174	0.0521*	-0.213	0.1057	-0.269	0.0393**
August	-0.138	0.1227	-0.141	0.2881	-0.193	0.1420
September	-0.244	0.0064***	-0.265	0.0423**	-0.334	0.0096***
October	-0.171	0.0554*	-0.217	0.0989*	-0.226	0.0851*
November	-0.189	0.0341**	-0.253	0.0474**	-0.266	0.0417**
December	-0.266	0.003***	-0.391	0.0022***	-0.391	0.0022***

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Stillwater River near Absarokee

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	-0.023	0.7825	0.025	0.8405	-0.044	0.7227
February	-0.002	0.9827	0.003	0.9809	-0.021	0.8631
March	-0.094	0.2626	-0.100	0.4221	-0.133	0.2822
April	0.034	0.6759	-0.056	0.6385	0.052	0.6654
May	0.010	0.8994	0.004	0.9735	-0.006	0.9622
June	-0.113	0.1586	-0.135	0.2586	-0.167	0.1612
July	-0.111	0.1674	-0.141	0.2366	-0.159	0.1818
August	-0.104	0.1943	-0.115	0.3354	-0.142	0.2347
September	-0.075	0.3506	-0.102	0.3954	-0.101	0.3972
October	0.104	0.2003	0.138	0.2500	0.160	0.1833
November	0.054	0.5196	0.147	0.2351	0.090	0.4683
December	-0.048	0.5626	0.014	0.9107	-0.053	0.6699

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Clarks Fork near Belfry, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.170	0.0203**	0.289	0.007***	0.243	0.0239**
February	0.170	0.0209**	0.310	0.0037***	0.275	0.0104**
March	0.291	<.0001***	0.469	<.0001***	0.428	<.0001***
April	0.057	0.4357	-0.022	0.8408	0.084	0.4411
May	0.060	0.4098	-0.016	0.8817	0.076	0.4844
June	-0.027	0.7147	-0.022	0.8386	-0.056	0.6090
July	-0.093	0.2047	-0.121	0.2683	-0.143	0.1899
August	-0.147	0.0444**	-0.213	0.049**	-0.220	0.0421**
September	-0.247	0.0007***	-0.315	0.0032***	-0.362	0.0006***
October	-0.169	0.0214**	-0.291	0.0066***	-0.257	0.017**
November	-0.012	0.8696	-0.074	0.5001	-0.016	0.8829
December	0.132	0.0716*	0.272	0.0114**	0.190	0.0798*

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Clarks Fork River near Edgar, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.222	0.0071***	0.295	0.0137**	0.339	0.0043***
February	0.314	0.0001***	0.309	0.0098***	0.441	0.0001***
March	0.098	0.2335	0.128	0.2943	0.154	0.2061
April	0.041	0.6190	0.012	0.9213	0.067	0.5825
May	0.011	0.8929	-0.032	0.7957	0.010	0.9323
June	-0.061	0.4558	-0.101	0.4098	-0.108	0.3767
July	-0.109	0.1849	-0.190	0.1187	-0.164	0.1794
August	-0.161	0.0502*	-0.225	0.0632*	-0.225	0.0426**
September	-0.179	0.03**	-0.247	0.0404**	-0.260	0.031**
October	0.055	0.5040	0.014	0.9089	0.084	0.4944
November	0.117	0.1558	0.110	0.3683	0.163	0.1815
December	0.157	0.056*	0.229	0.0588*	0.224	0.0647*

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Yellowstone River near Billings, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.056	0.4691	0.438	<.0001***	0.456	<.0001***
February	0.019	0.8093	0.283	0.0111**	0.308	0.0054***
March	-0.087	0.2548	-0.113	0.3170	-0.116	0.3074
April	0.079	0.3056	0.055	0.6288	0.042	0.7088
May	0.182	0.0178**	-0.009	0.9364	-0.024	0.8349
June	-0.015	0.8456	-0.295	0.0079***	-0.316	0.0043***
July	-0.006	0.9359	-0.119	0.2913	-0.119	0.2942
August	-0.046	0.5506	-0.008	0.9446	-0.029	0.8001
September	-0.033	0.6690	0.038	0.7331	0.047	0.6767
October	0.094	0.2212	0.101	0.3726	0.121	0.2840
November	0.880	0.2513	0.197	0.0804*	0.201	0.0732
December	0.127	0.0979*	0.435	<.0001***	0.427	<.0001***

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Bighorn River near Kane, WY

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.181	0.0189**	0.223	0.0498**	0.256	0.0237**
February	0.132	0.0875*	0.165	0.1487	0.194	0.0881*
March	0.005	0.9484	0.004	0.9724	-0.014	0.9031
April	-0.146	0.0582*	-0.178	0.1198	-0.225	0.0477**
May	-0.249	0.0013***	-0.354	0.0015***	-0.369	0.0009***
June	-0.298	0.0001***	-0.409	0.0002***	-0.415	0.0001***
July	-0.146	0.0594*	-0.171	0.1348	-0.216	0.0579*
August	0.016	0.8393	-0.089	0.4362	0.022	0.8509
September	0.069	0.3695	0.105	0.3598	0.093	0.4163
October	0.020	0.7924	0.025	0.8296	0.022	0.8500
November	0.069	0.3695	0.058	0.6166	0.077	0.5020
December	0.144	0.0629*	0.202	0.0757*	0.195	0.0878*

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Bighorn River near St. Xavier, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.273	0.0006***	0.364	0.0015***	0.385	0.0008***
February	0.197	0.0136**	0.297	0.0107**	0.300	0.0099***
March	0.005	0.9544	0.021	0.8596	0.003	0.9771
April	-0.049	0.5421	0.028	0.8126	-0.058	0.6264
May	-0.340	<.0001***	-0.473	<.0001***	-0.494	<.0001***
June	-0.468	<.0001***	-0.647	<.0001***	-0.641	<.0001***
July	-0.183	0.0223**	-0.258	0.0278**	-0.268	0.0218**
August	0.117	0.1424	0.166	0.1610	0.180	0.1277
September	0.005	0.9506	0.031	0.7957	-0.007	0.9517
October	0.010	0.9015	-0.026	0.8271	-0.038	0.7513
November	0.088	0.2713	0.075	0.5308	0.090	0.4498
December	0.217	0.0065***	0.281	0.0161**	0.301	0.0097***

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Bighorn River near Bighorn, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.072	0.4088	0.101	0.4340	0.114	0.3787
February	-0.056	0.5197	-0.033	0.7978	-0.036	0.7835
March	-0.221	0.0113**	-0.258	0.0428**	-0.297	0.0189**
April	-0.119	0.1717	-0.066	0.6084	-0.158	0.2198
May	-0.208	0.017**	-0.289	0.0229**	-0.312	0.0135**
June	-0.342	<.0001***	-0.493	<.0001***	-0.481	<.0001***
July	-0.131	0.1320	-0.206	0.1090	-0.194	0.1306
August	0.033	0.7065	0.079	0.5439	0.064	0.6200
September	-0.105	0.2268	-0.118	0.3626	-0.168	0.1931
October	-0.118	0.1756	-0.216	0.0912*	-0.182	0.1564
November	-0.047	0.5888	-0.120	0.3511	-0.085	0.5113
December	0.064	0.4624	0.032	0.8064	0.073	0.5744

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Tongue River at Dayton, WY

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	-0.274	0.0004***	-0.442	<.0001***	-0.385	0.0005***
February	-0.318	<.0001***	-0.506	<.0001***	-0.436	<.0001***
March	-0.220	0.0048***	-0.400	0.0003***	-0.312	0.0058***
April	0.059	0.4467	-0.139	0.2285	0.089	0.4412
May	-0.101	0.1930	-0.180	0.1180	-0.143	0.2146
June	-0.133	0.0863*	-0.188	0.1024	-0.203	0.0759*
July	-0.190	0.0143**	-0.211	0.0649*	-0.272	0.0169**
August	-0.221	0.0045***	-0.343	0.0022***	-0.316	0.0051***
September	-0.203	0.0089***	-0.328	0.0036***	-0.293	0.0096***
October	-0.050	0.5271	-0.258	0.0246**	-0.080	0.4917
November	-0.187	0.0161**	-0.355	0.0015***	-0.268	0.0186**
December	-0.253	0.0011***	-0.373	0.0008***	-0.344	0.0022***

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Tongue River at Stateline near Decker, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	-0.282	0.0052***	-0.375	0.0095***	-0.419	0.0034***
February	-0.338	0.0008***	-0.431	0.0025***	-0.464	0.001***
March	-0.166	0.1007	-0.251	0.0887*	-0.219	0.1393
April	-0.247	0.0143**	-0.341	0.0192**	-0.341	0.0191**
May	-0.095	0.3449	-0.131	0.3802	-0.132	0.3763
June	-0.232	0.0213**	-0.349	0.0162**	-0.333	0.0223**
July	-0.225	0.0259**	-0.258	0.0801*	-0.317	0.0297**
August	-0.121	0.2296	-0.145	0.3316	-0.177	0.2348
September	-0.154	0.1257	-0.250	0.0897*	-0.205	0.1659
October	-0.204	0.0436**	-0.267	0.0691*	-0.278	0.0588*
November	-0.265	0.0087***	-0.380	0.0085***	-0.387	0.0072***
December	-0.282	0.0053***	-0.417	0.0035***	-0.413	0.0039***

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Tongue River at Miles City, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	-0.051	0.5446	-0.024	0.8467	-0.082	0.5138
February	-0.003	0.9729	0.018	0.8855	-0.002	0.9887
March	-0.127	0.1350	-0.177	0.1576	-0.181	0.1491
April	-0.130	0.1226	-0.196	0.1145	-0.181	0.1459
May	-0.072	0.3958	-0.048	0.7049	-0.106	0.4009
June	-0.090	0.2872	-0.102	0.4190	-0.123	0.3303
July	-0.075	0.3771	-0.052	0.6786	-0.099	0.4335
August	0.119	0.1603	0.142	0.2579	0.150	0.2343
September	-0.011	0.9009	0.000	0.9987	-0.011	0.9312
October	-0.124	0.1457	-0.191	0.1277	-0.172	0.1714
November	-0.200	0.0188**	-0.345	0.0048***	-0.256	0.0395**
December	-0.189	0.0261**	-0.268	0.0306**	-0.256	0.04**

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Yellowstone River at Miles City, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.60000	0.0392**	0.08813	0.4311	0.084	0.4508
February	0.209	0.006***	0.013	0.9092	0.047	0.6743
March	-0.078	0.3028	0.021	0.8514	0.077	0.4921
April	0.025	0.7427	0.200	0.0717*	0.280	0.0107**
May	-0.015	0.8484	0.244	0.0271**	0.277	0.0118**
June	-0.216	0.0046***	-0.011	0.9205	-0.055	0.6211
July	-0.084	0.2691	-0.111	0.3191	-0.134	0.2311
August	-0.013	0.8615	-0.172	0.1193	-0.199	0.0706*
September	0.033	0.6655	-0.157	0.1565	-0.162	0.1441
October	0.091	0.2331	-0.035	0.7532	-0.059	0.5990
November	0.145	0.0576*	-0.063	0.5717	0.035	0.7530
December	0.308	<.0001***	0.047	0.6742	0.029	0.7943

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Powder River near Sussex, WY

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.198	0.0999*	0.331	0.0557*	0.277	0.1132
February	0.071	0.5508	0.224	0.1951	0.104	0.5535
March	0.005	0.9660	0.017	0.9226	0.020	0.9084
April	-0.012	0.9208	0.025	0.8851	-0.018	0.9173
May	0.029	0.8092	0.023	0.8976	0.011	0.9478
June	-0.022	0.8535	0.086	0.6250	-0.024	0.8907
July	0.012	0.9174	0.190	0.2811	0.005	0.9761
August	0.043	0.7220	0.189	0.2850	0.078	0.6626
September	0.064	0.5935	0.075	0.6733	0.105	0.5564
October	0.029	0.8125	0.213	0.2258	0.115	0.5176
November	0.181	0.1444	0.400	0.0233**	0.247	0.1735
December	0.061	0.6142	0.171	0.3342	0.099	0.5774

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Powder River near Moorhead, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.163	0.037**	0.220	0.0559*	0.241	0.0362**
February	0.074	0.3463	0.029	0.8024	0.116	0.3181
March	-0.133	0.0883*	-0.232	0.0436**	-0.200	0.0838*
April	-0.135	0.0834*	-0.244	0.0338**	-0.206	0.0745*
May	-0.055	0.4814	-0.064	0.5826	-0.077	0.5080
June	-0.098	0.2092	-0.111	0.3381	-0.143	0.2179
July	-0.106	0.1756	-0.178	0.1250	-0.139	0.2328
August	0.009	0.9107	-0.057	0.6230	0.006	0.9592
September	0.067	0.3941	0.031	0.7908	0.099	0.3964
October	0.126	0.1084	0.170	0.1427	0.185	0.1089
November	0.126	0.1064	0.164	0.1557	0.193	0.0943*
December	-0.055	0.4813	-0.077	0.5084	-0.066	0.5727

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

Powder River near Locate, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.193	0.019**	0.220	0.069*	0.264	0.0283**
February	0.055	0.5007	-0.135	0.2697	0.088	0.4707
March	-0.154	0.0608*	-0.275	0.0224**	-0.228	0.0591*
April	-0.147	0.0748*	-0.272	0.0238**	-0.241	0.046**
May	-0.073	0.3730	-0.080	0.5135	-0.110	0.3695
June	-0.172	0.0364**	-0.244	0.0435**	-0.240	0.0468**
July	-0.172	0.0364**	-0.187	0.1237	-0.248	0.0401**
August	-0.114	0.1651	-0.131	0.2837	-0.174	0.1534
September	0.042	0.6117	-0.051	0.6794	0.064	0.6034
October	0.130	0.1130	0.085	0.4861	0.197	0.1052
November	0.162	0.0484**	0.257	0.0332**	0.236	0.0508
December	0.003	0.9752	-0.048	0.6929	-0.023	0.8490

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

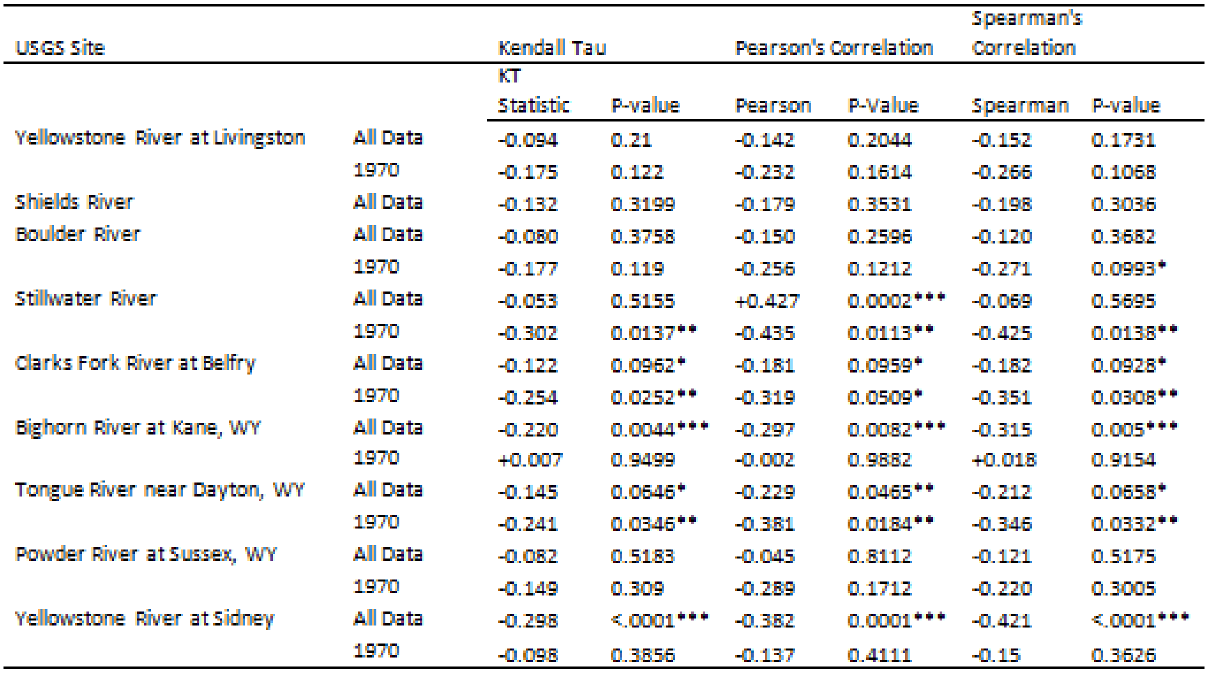
Yellowstone River near Sidney, MT

Months	Kendall Tau	P-value	Pearson's Correlation	P-value	Spearman's Correlation	P-value
January	0.197	0.0047***	0.211	0.0404**	0.300	0.0031***
February	0.194	0.0054***	0.162	0.1164	0.275	0.0071***
March	-0.149	0.032**	-0.190	0.0659	-0.217	0.0347**
April	-0.141	0.0425**	-0.259	0.0112**	-0.208	0.043**
May	-0.127	0.0688*	-0.227	0.0267**	-0.194	0.0592*
June	-0.313	<.0001***	-0.441	<.0001***	-0.444	<.0001***
July	-0.218	0.0017***	-0.324	0.0014***	-0.316	0.0018***
August	-0.240	0.0006***	-0.365	0.0003***	-0.339	0.0008***
September	-0.103	0.1400	-0.153	0.1391	-0.151	0.1442
October	0.020	0.7748	-0.067	0.5186	0.016	0.8786
November	0.074	0.2858	0.089	0.3930	0.095	0.3580
December	0.600	0.0392**	0.214	0.037**	0.224	0.0294**

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

APPENDIX 6

Trend analysis results for CT measurements in the Yellowstone River Basin.

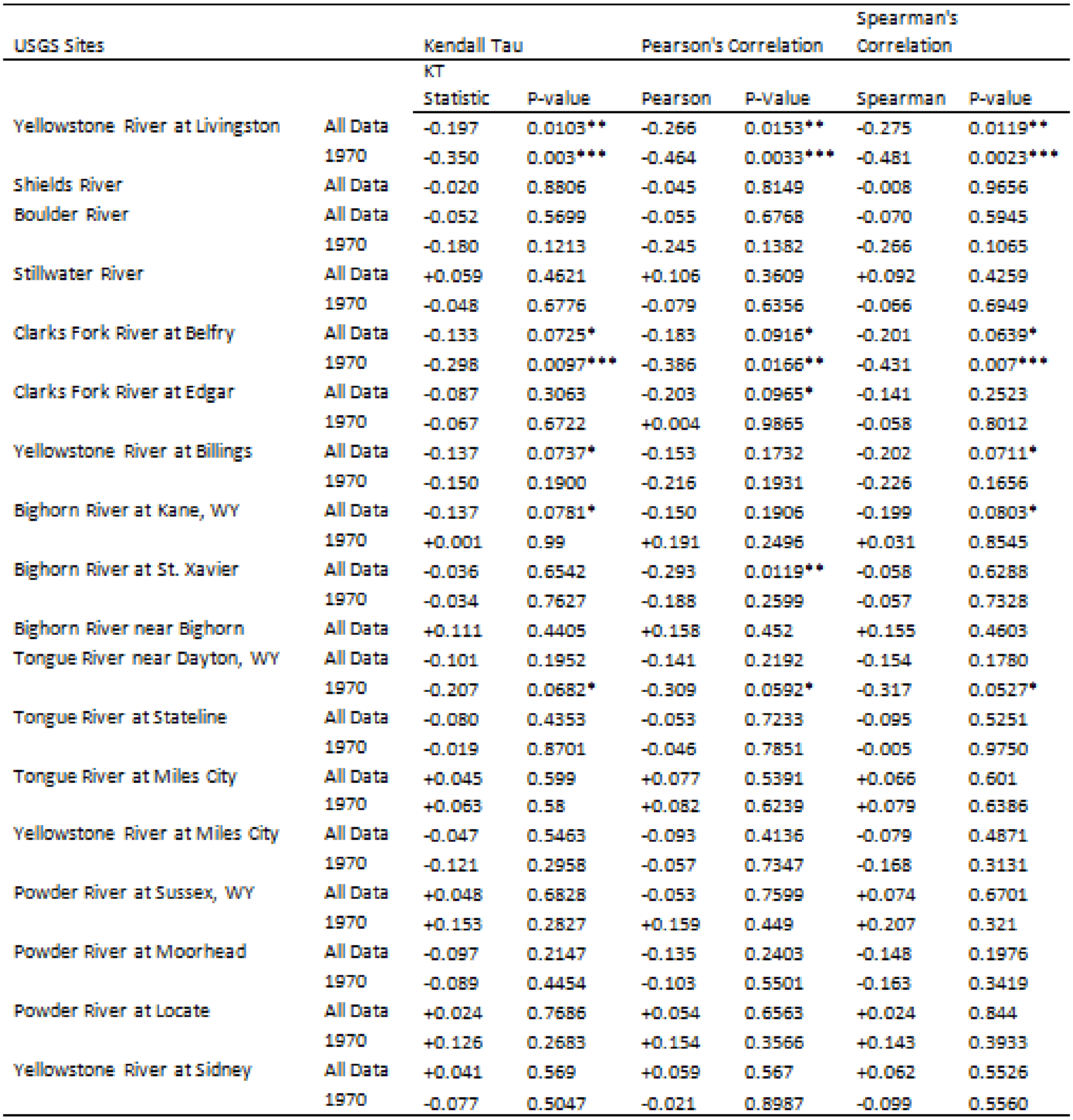


USGS Site		Kendall Tau		Pearson's Correlation		Spearman's Correlation	
		KT Statistic	P-value	Pearson	P-Value	Spearman	P-value
Yellowstone River at Livingston	All Data	-0.094	0.21	-0.142	0.2044	-0.152	0.1731
	1970	-0.175	0.122	-0.232	0.1614	-0.266	0.1068
Shields River	All Data	-0.132	0.3199	-0.179	0.3531	-0.198	0.3036
Boulder River	All Data	-0.080	0.3758	-0.150	0.2596	-0.120	0.3682
	1970	-0.177	0.119	-0.256	0.1212	-0.271	0.0993*
Stillwater River	All Data	-0.053	0.5155	+0.427	0.0002***	-0.069	0.5695
	1970	-0.302	0.0137**	-0.435	0.0113**	-0.425	0.0138**
Clarks Fork River at Belfry	All Data	-0.122	0.0962*	-0.181	0.0959*	-0.182	0.0928*
	1970	-0.254	0.0252**	-0.319	0.0509*	-0.351	0.0308**
Bighorn River at Kane, WY	All Data	-0.220	0.0044***	-0.297	0.0082***	-0.315	0.005***
	1970	+0.007	0.9499	-0.002	0.9882	+0.018	0.9154
Tongue River near Dayton, WY	All Data	-0.145	0.0646*	-0.229	0.0465**	-0.212	0.0658*
	1970	-0.241	0.0346**	-0.381	0.0184**	-0.346	0.0332**
Powder River at Sussex, WY	All Data	-0.082	0.5183	-0.045	0.8112	-0.121	0.5175
	1970	-0.149	0.309	-0.289	0.1712	-0.220	0.3005
Yellowstone River at Sidney	All Data	-0.298	<.0001***	-0.382	0.0001***	-0.421	<.0001***
	1970	-0.098	0.3856	-0.137	0.4111	-0.15	0.3626

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

APPENDIX 7

Trend analysis results for timing of annual peak discharge dates in the Yellowstone River Basin.



USGS Sites		Kendall Tau		Pearson's Correlation		Spearman's Correlation	
		KT Statistic	P-value	Pearson	P-Value	Spearman	P-value
Yellowstone River at Livingston	All Data	-0.197	0.0103**	-0.266	0.0153**	-0.275	0.0119**
	1970	-0.350	0.003***	-0.464	0.0033***	-0.481	0.0023***
Shields River	All Data	-0.020	0.8806	-0.045	0.8149	-0.008	0.9656
Boulder River	All Data	-0.052	0.5699	-0.055	0.6768	-0.070	0.5945
	1970	-0.180	0.1213	-0.245	0.1382	-0.266	0.1065
Stillwater River	All Data	+0.059	0.4621	+0.106	0.3609	+0.092	0.4259
	1970	-0.048	0.6776	-0.079	0.6356	-0.066	0.6949
Clarks Fork River at Belfry	All Data	-0.133	0.0725*	-0.183	0.0916*	-0.201	0.0639*
	1970	-0.298	0.0097***	-0.386	0.0166**	-0.431	0.007***
Clarks Fork River at Edgar	All Data	-0.087	0.3063	-0.203	0.0965*	-0.141	0.2523
	1970	-0.067	0.6722	+0.004	0.9865	-0.058	0.8012
Yellowstone River at Billings	All Data	-0.137	0.0737*	-0.153	0.1732	-0.202	0.0711*
	1970	-0.150	0.1900	-0.216	0.1931	-0.226	0.1656
Bighorn River at Kane, WY	All Data	-0.137	0.0781*	-0.150	0.1906	-0.199	0.0803*
	1970	+0.001	0.99	+0.191	0.2496	+0.031	0.8545
Bighorn River at St. Xavier	All Data	-0.036	0.6542	-0.293	0.0119**	-0.058	0.6288
	1970	-0.034	0.7627	-0.188	0.2599	-0.057	0.7328
Bighorn River near Bighorn	All Data	+0.111	0.4405	+0.158	0.452	+0.155	0.4603
Tongue River near Dayton, WY	All Data	-0.101	0.1952	-0.141	0.2192	-0.154	0.1780
	1970	-0.207	0.0682*	-0.309	0.0592*	-0.317	0.0527*
Tongue River at Stateline	All Data	-0.080	0.4353	-0.053	0.7233	-0.095	0.5251
	1970	-0.019	0.8701	-0.046	0.7851	-0.005	0.9750
Tongue River at Miles City	All Data	+0.045	0.599	+0.077	0.5391	+0.066	0.601
	1970	+0.063	0.58	+0.082	0.6239	+0.079	0.6386
Yellowstone River at Miles City	All Data	-0.047	0.5463	-0.093	0.4136	-0.079	0.4871
	1970	-0.121	0.2958	-0.057	0.7347	-0.168	0.3131
Powder River at Sussex, WY	All Data	+0.048	0.6828	-0.053	0.7599	+0.074	0.6701
	1970	+0.153	0.2827	+0.159	0.449	+0.207	0.321
Powder River at Moorhead	All Data	-0.097	0.2147	-0.135	0.2403	-0.148	0.1976
	1970	-0.089	0.4454	-0.103	0.5501	-0.163	0.3419
Powder River at Locate	All Data	+0.024	0.7686	+0.054	0.6563	+0.024	0.844
	1970	+0.126	0.2683	+0.154	0.3566	+0.143	0.3933
Yellowstone River at Sidney	All Data	+0.041	0.569	+0.059	0.567	+0.062	0.5526
	1970	-0.077	0.5047	-0.021	0.8987	-0.099	0.5560

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

APPENDIX 8

Trend analysis results for return date of baseflow conditions after spring pulse in the Yellowstone River Basin.

USGS Sites		Kendall Tau		Pearson's Correlation		Spearman's Correlation	
		KT Statistic	P-value	Pearson	P-Value	Spearman	P-value
Yellowstone River at Livingston	All Data	-0.123	0.1072	-0.199	0.0732*	-0.194	0.0807*
	1970	-0.340	0.0031***	-0.462	0.0035***	-0.472	0.0027***
Shields River	All Data	-0.193	0.1481	-0.125	0.5189	-0.268	0.1606
Boulder River	All Data	-0.198	0.0311**	-0.272	0.0388**	-0.309	0.0184**
	1970	-0.292	0.0114**	-0.364	0.0247**	-0.415	0.0095***
Stillwater River	All Data	-0.168	0.0339**	-0.223	0.0516*	-0.232	0.0422**
	1970	-0.344	0.003***	-0.440	0.0057***	-0.482	0.0022***
Clarks Fork River at Belfry	All Data	-0.260	0.0005***	-0.362	0.0006***	-0.375	0.0004***
	1970	-0.232	0.0435**	-0.440	0.0057***	-0.471	0.0029***
Clarks Fork River at Edgar	All Data	-0.118	0.1599	-0.196	0.1064	-0.173	0.1561
	1970	-0.044	0.7853	+0.004	0.9871	-0.058	0.8031
Yellowstone River at Billings	All Data	+0.031	0.6868	+0.038	0.7355	+0.039	0.7338
	1970	-0.316	0.0057***	-0.444	0.0053***	-0.464	0.0033***
Bighorn River at Kane, WY	All Data	-0.142	0.0664*	-0.146	0.1988	-0.199	0.0792*
	1970	-0.232	0.0435**	-0.296	0.0715*	-0.343	0.0349**
Bighorn River near Bighorn	All Data	-0.080	0.3856	-0.263	0.0485**	-0.131	0.3308
	1970	-0.186	0.1288	-0.335	0.0568*	-0.283	0.1101
Tongue River near Dayton, WY	All Data	-0.239	0.0037***	-0.312	0.0058***	-0.316	0.0051***
	1970	-0.294	0.013**	-0.409	0.0108**	-0.389	0.0156**
Tongue River at Stateline	All Data	-0.162	0.1221	-0.190	0.2058	-0.241	0.1072
	1970	-0.154	0.1889	-0.253	0.1306	-0.245	0.1435
Tongue River at Miles City	All Data	-0.029	0.7461	+0.033	0.7993	-0.035	0.7915
	1970	-0.058	0.6235	-0.109	0.5267	-0.090	0.6025
Yellowstone River at Miles City	All Data	-0.033	0.6686	-0.048	0.6996	-0.057	0.6180
	1970	-0.360	0.0017***	-0.535	0.0005***	-0.512	0.0010***
Powder River at Sussex, WY	All Data	+0.130	0.2917	+0.125	0.489	+0.169	0.348
	1970	-0.077	0.6021	-0.256	0.2280	-0.112	0.6015
Powder River at Moorhead	All Data	-0.074	0.3461	-0.105	0.3644	-0.103	0.3738
	1970	-0.126	0.2816	-0.184	0.2832	-0.197	0.2485
Powder River at Locate	All Data	-0.032	0.7013	-0.189	0.1194	-0.037	0.7615
	1970	-0.079	0.4891	-0.226	0.1723	-0.100	0.5488
Yellowstone River at Sidney	All Data	-0.213	0.0026***	-0.262	0.0103**	-0.307	0.0025***
	1970	-0.254	0.0268**	-0.362	0.0257**	-0.385	0.0169**

*Insignificant trend detected with P-value < 0.10
** Significant trend detected with P-value < 0.05
***Very Significant trend detected with P-value < 0.01

APPENDIX 9

Calculated averages for all variables and sites in the Yellowstone River Basin.

Rivers	Annual Discharge	CT	Peak Discharge Date	Peak Discharge	Return to Baseflow	Minimum Flow
	million m³/year	waterday	waterday	m³/s	waterday	m³/s
Yellowstone at Livingston						
1898-1969	3,275	231	255	575	317	25.1
1970-2007	3,361	228	249	611	313	26.9
Shields R.						
1979-2007	236	208	230	57	282	1.4
Boulder						
1948-1969	522	235	254	167	300	1.9
1970-2007	478	234	255	155	295	1.7
Stillwater						
1911-1969	835	224	255	189	315	5
1970-2007	816	232	258	187	312	4.8
Clarksfork at Belfry						
1922-1969	830	239	255	212	342	3.5
1970-2007	817	236	251	230	329	3.1
Clarksfork at Edgar						
1922-1969	933	227	258	219	304	5.3
1987-2007	853	218	248	210	297	3.7
Yellowstone at Billings						
1905-1969	5,995	225	257	1134	304	36.6

Rivers	Annual Discharge	CT	Peak Discharge Date	Peak Discharge	Return to Baseflow	Minimum Flow
1970-2007	6,287	222	253	1176	305	38
Bighorn at Kane, WY						
1929-1969	1,999	203	256	401	301	14
1970-2007	1,815	192	244	260	299	22
Bighorn at St. Xavier						
1935-1969	3,117		254	489		24
1970-2007	2,886		219	201		36
Bighorn near Bighorn						
1946-1969	3,350	194			282	28
1970-2007	3,199	187	241	216	264	40
Tongue near Dayton, WY						
1919-1969	165	228	242	49	346	0.9
1970-2007	147	225	238	44	337	0.87
Tongue at Stateline						
1961-1969	420	213	241	130	283	1.8
1970-2007	379	209	241	96	281	2.1
Tongue at Miles City						
1939-1969	356	198	243	147	283	0.8
1970-2007	356	199	247	97	287	1.4
Yellowstone at Miles City						

Rivers	Annual Discharge	CT	Peak Discharge Date	Peak Discharge	Return to Baseflow	Minimum Flow
1923-1969	9,908	216	258	1553	305	58.4
1970-2007	10,017	208	254	1352	307	90
Powder at Sussex, WY						
1939-1957	127	183	264	220	262	0.16
1979-2007	187	186	245	133	273	0.64
Powder at Moorehead						
1930-1969	399	206	242	233	299	0.45
1970-2007	376	198	232	154	296	0.83
Powder at Locate						
1939-1969	537	211	225	346	279	0.42
1970-2007	463	197	228	176	271	0.69
Yellowstone at Sidney						
1911-1969	11,527	216	247	2094	307	68
1970-2007	10,359	205	255	1436	300	81.6