WATER SUPPLY REPORT SERIES II
INFORMATION FOR ENHANCING INSTREAM FLOWS TO BENEFIT SALMONIDS IN THE UPPER CLARK FORK RIVER

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Report Overview

The fishes of the Clark Fork River above the Blackfoot River confluence (i.e. the Upper Clark Fork River, UCFR) have been severely impacted by historic mining operations largely focused on copper, particularly in the vicinities of Butte and Anaconda. The major impact of these operations on the UCFR was through the uncontrolled disposal of mining wastes, much of which was either intentionally delivered or washed into the UCFR tributaries (especially Silver Bow Creek and Warm Springs Creek). Subsequent dispersal of these wastes spread metals throughout the UCFR and its floodplain. The contamination in the UCFR watershed is severe and widespread enough to cause the EPA to designate the nation's largest Superfund complex. This complex includes the UCFR and its nearby terrestrial areas, Silver Bow Creek, lower Warm Springs Creek, and for the later two, large terrestrial areas surrounding the creeks. Although copper is the primary metal of concern for fisheries, levels of arsenic, cadmium, lead, and zinc are also of concern (EPA 2004).

The obvious historic effect of metal contamination was to decimate much of the aquatic life in the UCFR. The less obvious effect is that the contamination seems to have allowed other degradations to go less addressed than in many other western Montana watersheds. Examples include nutrient pollution, excess sediments, dewatering, and numerous physical degradations (particularly from the interstate and railroad construction) including floodplain constriction, channelization, and creation of barriers on tributaries. As clean up efforts and natural dilution are allowing the UCFR to recover from metals pollution, it increasingly is evident that other issues potentially limiting the salmonid fishery need to be considered.

A major contemporary consideration in the UCFR is the impact of water withdrawals. In particular, summer water withdrawals (primarily for crop irrigation) and concomitant discharge that is naturally low conspire to produce low flows of concern. Issues for salmonids related to these low flows include elevated temperature, degraded physical habitat conditions, reduced dilution of pollutants including excess nutrients, and lower dissolved oxygen levels. As a result of these types of issues restoration efforts to benefit salmonids increasingly are focusing on summer flow enhancement in the UCFR (Workman et al. 1999, UCFRBSC 2006, CFC 2011, NRDP 2012, WRC 2012, Berg 2013). The major goal of this report is to provide information for ongoing and future flow augmentation efforts in the UCFR.

This report is broken in seven chapters, most of which focus on topics that are directly or indirectly related to low flow issues in the UCFR. Chapter 1 sets the historical stage by providing a brief overview of mining impacts on UCFR salmonids. Chapter 2 describes interactions between flow and other environmental conditions, both in general and in the UCFR setting. Chapter 3 evaluates the major methods used to determine instream flow needs for fish based on habitat consideration. Patterns of discharge and temperature in the UCFR are analyzed in Chapters 4 and 5, respectively. These analyses are used to guide Chapter 6 which focuses on strategies for flow augmentation. Chapter 7 describes methods for acquiring water for instream flow as well as approaches for reducing the impacts of irrigation, grazing, and domestic water use on UCFR salmonid fisheries.

References

Berg, C.B. 2013. Prioritizing the Upper Clark Fork River Tributaries for Instream Flow Restoration. M.S. thesis, University of Montana.

CFC. 2011. Aquatic Restoration Strategy for the Upper Clark Fork Basin. Report by the Clark Fork Coalition.

EPA. 2004. Clark Fork River Operable Unit of the Milltown Reservoir/Clark Fork River Superfund Site, Record of Decision, Part 2: Decision Summary. Report by US EPA.

NRDP. 2012. Final Upper Clark Fork River Basin Aquatic and Terrestrial Resources Restoration Plans. Report by Montana DOJ Natural Resources Damage Program.

UCFRBSC. 2006. Upper Clark Fork River Flow Study. Report by the Upper Clark Fork River Basin Steering Committee.

Workman, D., J. Kuipers, B. Farling, and P. Callahan. 1999. Restoring the Upper Clark Fork: Guidelines for Action. Report for Trout Unlimited.

WRC. 2012. Watershed Restoration Plan for the Upper Clark Fork River Tributaries. Report by the Watershed Restoration Coalition for the Upper Clark Fork River.

CHAPTER 1:

Metals Limitation to Salmonids of the Upper Clark Fork River

Introduction

The fishes of the Upper Clark Fork River have been severely impacted by historic mining operations largely focused on copper, particularly in the vicinities of Butte and Anaconda. The major impact of these operations on the UCFR was through the uncontrolled disposal of mining wastes, much of which was either intentionally delivered or washed into the UCFR tributaries (especially Silver Bow Creek and Warm Springs Creek). Subsequent dispersal of these wastes spread metals throughout the UCFR and its floodplain. Although copper is the primary metal of concern for fisheries, levels of arsenic, cadmium, lead, and zinc also are of concern (EPA 2004). Given that mining wastes continue to impact UCFR salmonids, an overview of metals pollution and its effects salmonid fisheries was conducted to provide a relevant context to help guide summer flow enhancement efforts.

Historic Pollution

Historically, there is no doubt that mining wastes were the primary limitation for fishes in the Upper Clark Fork River (UCFR). Copper mining in the Butte area became a major enterprise in the 1880s (Phillips and Lipton 1995), and the consequent effects on the UCFR were documented by Evermann in 1891 (Evermann 1893). Most of Evermann's observations were made on the Deer Lodge River (i.e. the Clark Fork River down to Garrison, see the first two quotes below) but also included some UCFR tributaries and the Hellgate River (i.e. the Clark Fork from Garrison to Missoula).

> *In some portions where the current is less swift the bed is made up of a constantly shifting mass of fine silt-like material, probably from the concentrators and reduction works at Anaconda and Butte. Throughout the entire length of this river the water is full of this solid matter in suspension. The amount of solid matter carried down by the Deer Lodge River from this source must be very considerable, and of course proves fatal to all kinds of fish life. We seined the river very thoroughly in the vicinity of Deer Lodge and did not find any fish whatever.*
>
> *This stream is said to have been well supplied with trout and other fish, but none have been seen since the concentrators began operations. Other life was also scarce; no living mollusks or crustaceans and but few insect larvae were seen.*

Silver Bow Creek is simply the name applied to the upper portion of Deer Lodge River. This comes down from the vicinity of Butte City, and its water has the consistency of thick soup, made so by the tailings which it receives from the mills at that city. No fish could live in such a mixture, and the fish in Browns Gulch are for the time being practically confined to that short stream.

Warm Spring and Silver Bow creeks are ruined by mining operations, and perhaps others are somewhat contaminated.

Hell Gate River (and its continuation, the Missoula) being composed largely of the muddy water of the Deer Lodge and the lower Little Blackfoot, is, of course, a rather muddy stream. By the time Missoula is reached the amount of solid matter in suspension is probably not enough to prove wholly destructive to fish, though there is no doubt that the number of fish in the river even here is very greatly reduced on account of this contamination.

Nearly two decades after Evermann's visit a major flood event had large effects on the distribution of mining wastes in the UCFR. The 1908 flood is the largest flood of record in the UCFR and affected both the lateral and longitudinal distributions of mining wastes. Specifically, this flood deposited mining wastes throughout most of the floodplain and also downstream where a large amount settled in Milltown Reservoir (Luoma et al. 2008). Early efforts to limit this pollution were made in 1911 and 1916 when the first two of the Warm Springs Ponds were built to capture contaminated sediments from Silver Bow Creek (Phillips and Lipton 1995), however these early efforts proved inadequate to restore fish to the UCFR.

Several sources provide evidence that mining wastes in the UCFR continued to be toxic to fish through the 1950's. A 1950 Fish, Wildlife, and Parks (FWP) survey near Garrison captured no fish (Phillips and Lipton 1995). This finding was supported by a 1957 assessment from the Columbia Basin Interagency Steering Committee that concluded that from the headwaters to the Rock Creek confluence that the river supported no fishery due to mining wastes (Phillips and Lipton 1995).

Initial Recovery of Fishery

Fish began to return to the UCFR after the advent of more effective clean up efforts in the late 1950's. A third pond was completed at the Warm Springs Ponds complex in the 1958, and fish began to re-establish after the 1959 initiation of liming operations at this site (Phillips and Lipton 1995). However, pollution remained problematic. In the 1960's and 1970's various issues involving the function and operation of Warm Springs ponds allowed for elevated releases of metals. Fish kills occurred periodically between 1959 and 1975 and populations remained low (Phillips and Lipton 1995). A new wastewater treatment plant in Butte became operational between 1972 and 1975, resulting in substantially reduced inputs of metals into

Silver Bow Creek. The ensuing improvements in water quality allowed for the establishment of brown trout downstream of Warm Springs Ponds, however fish kills continued to occur (Phillips and Lipton 1995). Periodic kills were documented from 1983 to 1991 in association with thunderstorms that washed metal salts off the floodplain and concomitantly reduced pH (Phillips and Lipton 1995). Since 1998, when the Superfund clean up efforts began, a wide variety of efforts have been underway to reduce metals contamination in the UCFR. These efforts, together with natural dilution, are allowing the river to recover yet the salmonid fishery remains depressed.

Recent Status of Fishery

Studies beginning in the 1990's show that trout densities in the UCFR remain depressed but are spatially variable. Based on data collected in 1991 and 1994, Lipton et al. (1995) found trout densities (fish per hectacre) were highest just below Warm Springs Ponds (apparently due to favorable feeding conditions and lower metal concentrations just below the ponds) then diminished greatly at 14 downstream sites ending just above (the former) Milltown Reservoir. Compared to reference sites on southwest Montana rivers, trout densities in the UCFR were much lower. More recent studies by FWP in 2011 and 2012 also show much higher trout abundance (fish per mile) below Warm Springs Ponds relative to downstream sites. Within each year trout abundance was relatively steady from below Sager Lane to Tavenner to Phosphate, then dropped near the Flint Creek confluence in 2012 only. Just downstream, the lowest trout abundance in both years was observed at Bearmouth and then at Milltown trout abundance increased, particularly in 2012 (Clark and Schmetterling 2013, Leon et al. 2014, Naughton 2015). Finer scale abundance estimates of brown trout and rainbow trout abundance (fish per mile) were made in 2009 on five reaches from Jens to Rock Creek. Trout densities were highest from Jens to Drummond, dropped by >50% in the reach from Drummond to Bear Gulch, continued to diminish slightly in the reaches from Bear Gulch to Bearmouth and Bearmouth to Beavertail, and then rebounded modestly from Beavertail to Rock Creek. When these 2009 data are compared to the corresponding data from 1987, it is evident that fish densities have increased slightly in four of the five reaches (Brad Liermann, FWP, unpublished data presented in Naughton 2015). Collectively, the FWP work shows that the area from Drummond to Beavertail has particularly depressed trout abundance (fish per mile), but may be weakly increasing in recent years. Given that the river gets bigger moving downstream, had the FWP results been expressed at fish density (fish per unit area) the depressed trout abundance from Beavertail to Drummond relative to upstream sites would be even more striking.

Recent studies provide information on the changing composition of the trout community in the UCFR. Lipton et al. (1995) reported that in 1991 rainbow trout were largely absent and brown trout predominated in the UCFR from below Warm Springs Ponds to a site in the vicinity the

Bateman Creek confluence (about two thirds of the way from Drummond to Rock Creek). Downstream of this site but a short distance above the Rock Creek confluence, rainbow trout were present. At the three sites below the Rock Creek confluence rainbow trout were more abundant than brown trout. FWP studies from 2011 and 2012 also found that brown trout dominate the upper UCFR. However, moving downstream a transition occurred at Bearmouth where rainbow trout and to a lesser extent cutthroat trout began to comprise an appreciable portion of the catch, and downstream at Milltown rainbow trout dominated the catch (Clark and Schmetterling 2013, Leon et al. 2014). A comparison of the distributions between 1991 and 2011/2012 suggests that rainbow trout have expanded their area of common occurrence from a short distance above the Rock Creek confluence to Bearmouth. This observation is supported by FWP studies from 2009 to 2013 in the Bear Gulch to Bearmouth reach that show no rainbow trout were captured in 2009 and 2010, but were increasingly present each year from 2011 to 2013. Cutthroat trout were also evident in this reach and generally showed increasing abundance from 2009 to 2013, and in all of these years were more abundant that rainbow trout (Leon et al. 2014).

The longitudinal patterns of trout species composition and abundance in the UCFR provide some insights the limiting factors for the salmonid fishery. Metals concentrations generally decrease moving downstream in the UCFR (Axtmann et al. 1997, Cain et al. 2004, Helgen and Moore 1996, Davis and Atkins 2001, Mayfield 2013). Brown trout are better able to tolerate high metals concentrations due to better acclimatization abilities than rainbow trout that also are more avoidant of metals laden water (Marr et al. 1995; Hansen et al. 1999). Further, trout mortality rates are higher in the upper UCFR relative to the downstream reaches, and this pattern is more evident for rainbow trout than brown trout (Mayfield 2013, Richards et al. 2013, Leon et al. 2014). Thus this mortality information and the dominance of brown trout suggest metals contamination remains a major limitation in the upper UCFR, although this contamination may interact with flow related consideration such as water quality issues and temperature. Downstream, the lower mortality rates and increasing presence of rainbow trout suggests that metals issues are less problematic, and thus the role of habitat conditions, elevated temperatures, and possibly non-metal water quality issues may play an increased role in depressing trout abundance. These observations of trout species composition together with their low abundance, particularly in the middle UCFR where metals pollution is less severe than upstream, point to the value of examining habitat, water quality, and temperature limitations to UCFR salmonids in the context of low summer flows. These topics are addressed in Chapter 2.

References

Axtmann, E.V., D.J. Cain, and S.N. Luoma. 1997. Effect of tributary inflows on the distribution of trace metals in fine-grained bed sediments and benthic insects of the Clark Fork River, Montana. Environmental Science and Technology 31: 750-758.

Cain, D.J., S.N. Luoma, and W.G. Wallace. 2004. Linking metal bioaccumulation of aquatic insects to their distribution patterns in a mining-impacted river. Environmental Toxicology and Chemistry 23:1463-1473.

Clark, R. and D.A. Schmetterling. 2013. Milltown Dam Removal Monitoring Fisheries Investigations in 2012. Report by Montana FWP for Montana DEQ and United States EPA.

Davis, A. and D. Aktins. 2001. Metal distribution in Clark Fork River sediments. Environmental Science and Technology 35: 3501-3506.

EPA. 2004. Clark Fork River Operable Unit of the Milltown Reservoir/Clark Fork River Superfund Site, Record of Decision, Part 2: Decision Summary. Report by US EPA.

Evermann, B.W. 1893. A reconnaissance of the streams and lakes of western Montana and northwest Wyoming. Bulletin of the United States Fish Commission XI: 3-60.

Hansen, J.A., D.F. Woodward, E.E. Little, A.J. DeLonay, and H.L. Bergman. 1999. Behavioral avoidance: possible explanation for explaining abundance and distribution of trout species in a metal-impacted river. Environmental Toxicology and Chemistry 18: 313-317.

Helgen, S.O. and J.N. Moore. 1996. Natural background determination and impact quantification in trace metal-contaminated river sediments. Environmental Science and Technology 30: 129-135.

Leon, J., P. Saffel, B. Liermann, J.Lindstrom, and T. Selch. 2014. Upper Clark Fork River Fisheries Monitoring Study: 2013 Annual Report. Report by Montana FWP for Montana DEQ.

Lipton, J. and 16 coauthors. 1995. Aquatic Resources Injury Assessment Report: Upper Clark Fork River Basin. Report by Montana DOJ, Natural Resource Damage Litigation Program.

Louma S.L., J.N. Moore, A. Farag, T.H. Hillman, D.J. Cain, and M. Hornberger. 2008. Mining Impacts on Fish in the Clark Fork River, Montana: A Field Ecotoxicology Case Study. Pages 779-804 in The Toxicology of Fishes, R. T. Giulio and D. E. Hinton, editors. CRC Press, Boca Raton, Florida.

Marr, J.C.A., H.L. Bergman, J. Lipton, and C. Hogstrand. 1995. Differences in relative sensitivity of naïve and metals-acclimated brown and rainbow trout exposed to metals representative of the Clark Fork River, Montana. Canadian Journal of Fisheries and Aquatic Sciences 52: 2016-2030.

Mayfield, M.P. 2013. Limiting Factors for Trout Populations in the Upper Clark Fork River Superfund Site, Montana. M.S. thesis, Montana State Univeristy.

Naughton, J. 2015. Clark Fork River Fishery Assessment: Flint Creek to Rock Creek Reach. Draft Report by RESPEC for Montana DOJ.

Phillips, G. and J. Lipton. 1995. Injury to aquatic resources caused by metals in Montana's Clark Fork River basin: historic perspective and overview. Canadian Journal of Fisheries and Aquatic Sciences 52: 1990-1993.

Richards, R., W. Schreck, P. Saffel, B. Liermann, J. Lindstrom, and T. Selch. 2013. Upper Clark Fork River Caged Fish Study: The Distribution and Timing of Trout Mortality Final report 2011-2012. Report by Montana FWP for Montana DEQ.

CHAPTER 2:

Flow and Salmonid Habitat Conditions in Gravel Bed Rivers: In General and in the Upper Clark Fork River Setting

Introduction

Flow regime is a critical aspect of a river's ecological function and as such greatly affects riverine habitats and ultimately their value for salmonids. Flow and habitat conditions are particularly linked in floodplain reaches such as those that characterize much of the Clark Fork River above the Blackfoot River confluence (Upper Clark Fork River, UCFR). In these lower gradient, unconfined reaches the river channel is reshaped by seasonal high flows and in the process interacts with the surrounding riparian zone to generate a dynamic patchwork of riverine habitats that provided the varied needs for salmonids. Further, in unconfined reaches the channels generally are shallower than those found in confined river reaches, rending them particularly prone to reduction in area with diminishing discharge. The purpose of this chapter is to review flow dynamics relative to the creation and function of salmonid habitats, particularly in gravel bed rivers, and then apply this fundamental understanding to the specific conditions present in the UCFR to evaluate potential limitations to the salmonid fishery.

Flow and Salmonid Habitat Conditions in Gravel Bed Rivers

Spring

Major floods are particularly important for creating habitat conditions because they have sufficient power and water depth to re-shape the riverine landscape, particularly in floodplain reaches. In the northern Rockies high discharge generally occurs in the late spring in association with peak snow melt from higher elevations, and these flows often are augmented by rain during this wet part of the year. When the resulting flows are particularly high in a given year (~50-100 year floods and greater), a large effect on the overall floodplain landscape is apparent. These major floods are especially important for setting the width, sinuosity, and sometimes even the location of the floodplain. Within the floodplain, major floods cause channel migration and can create new channels including those that are perched at lower discharge. Major floods also affect smaller scale habitat conditions, but a key point is that they are rare events. As such, smaller but much more frequent floods tend to be particularly important for re-working the large scale channel configurations set by the major floods. Accordingly, the familiar array of riffles, runs, and pools within a floodplain channels tend to be primarily shaped by smaller floods. Damming of rivers reduces peak flows, riparian vegetation, and sediments which cause floodplain reaches to become less dynamic, ultimately simplifying habitats and reducing their quality for salmonids as well as creating migration barriers. However, high trout densities are often observed immediately below reservoirs when favorable thermal and feeding conditions are created.

Floods are important sources of logs to the river channel, and these logs interact with the water to affect habitat conditions. Floods and the associated bank erosion fell riparian trees like cottonwoods, often bringing them into the river's channels. These new logs and those that have accumulated or fallen previously frequently will be mobilized by major floods, particularly in larger rivers, and during peak flows often end up perched high on the floodplain or exported downstream. As flows recede or in more modest floods, logs are more likely to deposit at lower elevation locations, particularly in floodplain reaches where they affect channel dynamics. Deposited logs can promote closure or partial closure of side channels, re-routing water to interact with the landscape in other areas and thus furthering the development of riverine habitats. Logs also tend to deposit on the heads of islands, partially armoring islands from future high flows and thus promoting their longevity and consequently habitat variation. In smaller channels and creeks logs are more likely to remain at or near their site of felling and thus have a more localized influence, particularly through creating small scale scour zones and the associated deeper water.

Although floods can destroy riparian vegetation, it is important to recognize this is a reciprocal cycle. Many riparian plants, such as willows and cottonwoods, germinate on the bare wet substrates that are left as flows recede in the late spring and early summer. Thus without spring floods many important riparian plants would decline for lack of sufficient recruitment, as is commonly observed on dammed rivers. Cottonwoods provide both a major source of logs to the river and also reach sufficient height to provide shade to larger channels where smaller plants like willows are less effective, helping reduce summer water temperatures. Willows are more important for shade on smaller channels, particularly as they often form thickets.

Willows, cottonwoods, and other riparian plants contribute to aquatic invertebrate production both directly and indirectly. Directly, riparian plants provide food and habitat for terrestrial insects that fall into the river particularly in smaller channels where the riparian vegetation is closer to the water. Indirectly, riparian plants deliver leafs and other plant materials to the water (aided greatly by high flows) that provide a major food source for aquatic invertebrates. Further, riparian vegetation slows the flow of water across the floodplain, promoting fine sediment deposition and removal from the active channel.

In contrast to riparian plants, aquatic primary producers are greatly diminished by spring flooding. Larger plants can be torn from their attachment site, and primary producers of all size are greatly reduced as substrates are mobilized. These effects help prevent aquatic primary producers from reaching nuisance levels. However, smaller species and sometime even larger ones (such as the algae Cladophora) can still become abundant later in the summer particularly when the water is warm, nutrient rich, and shallow.

Spring flooding plays many important roles in creating the varied habitats that are beneficial for salmonids, particularly in floodplain reaches. High flows, often aided by log deposition, help create habitats that vary in their morphology both within and between channels. Logs also create desirable and varied habitat conditions for salmonids both by providing cover and creating scour zones that make patches of deep water that is often adjacent to faster, shallower water. Varied habitats help meet their seasonally and ontogenetic (i.e. over the course of a life cycle) changing needs of salmonids. Young salmonids often prefer the slower, relatively shallow sections due to their lower swimming speeds and the lower risk of predation by larger fishes. In contrast, older salmonids gravitate towards deeper water, particularly the transition between fast and slow water where they can efficiently hold position in the slow water while feeding on invertebrate drift carried by the faster current. Salmonids of all sizes can benefit from perched high water channels that often contain no surface water during the late summer. These channels contain hyporheic flows (i.e. river associated groundwater), particularly when substrates are coarse, that often erupt towards the end of the channels as “spring brooks”. If these flows are appreciable they can provide an important cold water refuge during summer. Further, in the lower reaches of perched channels a backwater is frequently formed that creates suitable habitat for smaller salmonids.

Spring floods play an important role in maintaining suitable spawning conditions for salmonids that build redds (“nests”) in relatively coarse substrates such as gravel. High water velocities transport fine sediments and subsequently coarsen the remaining substrate, improving the survival of the larval salmonids by enhancing the flow of water through the redd. Further, the removal of fine substrates improves habitat conditions for aquatic invertebrates that tend to benefit from the cover and attachment sites provided by coarse, unembedded substrates. When riparian vegetation is reduced the deposition of fine sediments on the floodplain diminishes and erosion increases, ultimately increasing fine sediments in the active channel and posing risks to salmonid spawning success.

Summer

Spring high flows largely set the habitat template for the crucial summer season, particularly in floodplain reaches. As flows recede during the summer the varied habitats sculpted by spring flooding become increasing evident. The relatively homogenous, quick flowing waters of late spring largely mask the array of habitats such as runs, riffles, and pools that emerge during summer.

A diversity of habitats helps provide the varied needs of salmonids during the biologically productive summer season. Riffles and runs are particularly important for the aquatic invertebrate production that nourishes salmonids. These shallow water habitats, particularly riffles, diminish in area quickly as flows decline. This loss of wetted habitat reduces production by aquatic primary producers and ultimately that of aquatic invertebrates. Although shallow water habitats like riffles, and to a lesser extent runs, are important for salmonid food production they lack depth and often offer little reprieve from the current. These conditions render salmonids vulnerable to predation and energy expenditure. Accordingly, pools become key features as they provide the deep, slower moving water to reduce predation risk and energy expenditure. The overall result is that a mixture of riffle/run and pool habitats tends to benefit salmonid production.

Temperature conditions in rivers vary substantially with the geographic setting and channel conditions. In rivers with extensive floodplain reaches the relatively wide, shallow channels are very exposed to sun. In smaller channels riparian vegetation, particularly when tall, dense, and extensive, reduces this exposure but less so in larger channels. As the summer progresses, air temperatures increase and solar radiation diminishes slightly. These thermal aspects conspire with diminishing flows to create peak water temperatures, generally from mid July to mid August. Low flows contribute to higher water temperatures by increasing the time for heating from the water's emergence as cool groundwater, and also by providing a shallower mass of water to absorb the sun's energy. The result is that when flows are low, high temperatures arrive earlier in the season and also reach higher maximum temperatures.

Water temperatures can become high enough to become stressful or lethal for salmonids, particularly for bull trout and cutthroat trout. Bull trout growth is maximized at 13 C and temperatures above 21 C are lethal (Selong et al. 2001), similar to cutthroat trout who maximize growth at 14 C and reach lethality at 20 C (Bear et al. 2007). Rainbow trout, brook trout, and brown trout can tolerate higher water temperatures (Bear et al. 2007, Selong et al. 2001) and thus can survive in warmer river reaches where cutthroat trout and bull trout are at least seasonally excluded. Further, even when temperatures are below lethality for cutthroat and bull trout, they are vulnerable to competitive displacement as water temperatures increasingly exceed their growth optima. Accordingly, several studies have linked the competitive displacement of bull trout and cutthroat by introduced salmonids to warm yet sublethal temperatures (for example, Bear et al. 2007, McMahon et al. 2007).

High temperatures can conspire with low flows to create challenging conditions for salmonids relative to their movement patterns. Salmonids will move to find cooler water, often migrating upstream or into cold water tributaries. For bull trout, upstream migration over the summer also provides access to their spawning tributaries. However, as flows reach their minima in late summer low water conditions, particularly in riffles, can impede salmonid movement or make migrations risky from a predation perspective.

Low discharge can exacerbate water quality problems. In rivers with high levels of organic materials (typically from nutrient enrichment and associated increases in aquatic primary producers) respiration (particularly decay) can cause oxygen levels to fall. This is especially true at night when photosynthesis is not producing oxygen, and cold water fishes like salmonids are particularly vulnerable to this oxygen diminishment. High temperatures exacerbate this situation by increasing the oxygen needs of fish, reducing the amount of oxygen the water can hold, and increasing decay rates. Further, low discharge both promotes high summer water temperatures and also can reduce turbulence and the associated introduction of atmospheric oxygen into the water, rendering the oxygen conditions even more marginal. Low discharge is also problematic when toxic materials are present because a lower volume of water is available for dilution. This interaction can become even more of an issue for salmonids when water temperatures are elevated due to the combined effects of thermal and pollutant stressors.

Fall

In rivers where warm summer conditions and low discharge create stressful conditions for salmonids, fall brings a period of relief. As fall progresses water temperatures diminish and discharge increases, yet flows typically are insufficient to alter the habitat template set during spring flooding. Leaf fall brings provides a major source of food for aquatic invertebrates, helping promote food conditions for salmonids.

Winter

The three notable winter conditions from the perspective of salmonid are cold water, ice, and the potential for low flows. Cold water reduces the energy expenditure by salmonids and concurrently their ability to swim at high speeds. During winter habitats that are deep and slow, such as pools and scour areas around logs, provide an important energetic relief for salmonids. These refuges become increasingly important if ice constricts the river, particularly in shallow areas, spreading the water up the banks and reducing depth. Depth may diminish further when extended cold weather diminishes flow. A rare but potentially catastrophic situation can develop if thick ice is suddenly broken up by rapid warming, creating a moving ice jam that can “bulldoze” the channel and kill fish. This bulldozing also mobilizes large amounts sediments, creating an additional challenge particularly when the river bed contains pollutants.

Flow and Salmonid Habitat Conditions in the Upper Clark Fork River Setting

General UCFR Flow Considerations

Interactions between physical habitat conditions and low summer flows are potentially limitation to the UCFR salmonid fishery, particularly looking forward in time as metal concentrations presumably continue to decrease due to clean up efforts and natural dilution. Low flows diminish the habitat area, particularly shallow water habitats such as riffles, reducing the available habitat area for fish and also constraining aquatic primary production and the associated invertebrate production. Further, low flows diminish the distance from the water to the riparian vegetation, particularly in floodplain reaches, reducing the input of terrestrial insects. Fish migration can be impeded when flows are low as natural and human barriers typically are more challenging to cross when the water is shallow. Given the large number of partial barriers in the UCFR system and the need to move to avoid high water temperatures or reach spawning areas, this is a particularly relevant consideration. Further, low discharge presents a larger predation risk to salmonids, particularly as they move across shallow areas such as the abundant riffles of the UCFR. The large number of complete barriers in the UCFR tributaries (Workman 2009, CFC 2011) magnifies these movement concerns as salmonids may need to move greater distances in the river to reach cold water or spawning areas provided by the tributaries. These migration considerations are particularly relevant for bull trout and cutthroat trout that have been shown to migrate extensively in the UCFR and connected Blackfoot River for cool water and spawning (Schmetterling 2003, Mayfield 2013). Accordingly, Mayfield (2013) found that that post spawn mortality from avian predation was high for cutthroat in the UCFR.

In many area of the UCFR low flows contribute to the marginal summer thermal conditions for salmonids that likely are a limitation on the salmonid fishery (particularly bull trout and cutthroat trout), however degraded riparian habitats also play a role in elevating water temperatures. In smaller channels, such as the upper reaches of UCFR and its tributaries, reduced riparian vegetation can play an important role in elevating summer water temperatures. The diminishment of riparian vegetation is caused by numerous factors such as metals contamination of the floodplain, heavy grazing, direct removal, and confinement/degradation of the floodplain by the highway, railroad, and rip rapping. The loss of riparian vegetation is also of concern relative to habitat conditions, particularly in smaller channels and tributaries of the UCFR. These concerns include the loss of: plant materials for invertebrate forage, logs for creating desirable habitat conditions for salmonids, and in some places undercut banks for salmonid habitat - particularly in smaller channels with low gradient. In channels of all sizes, degraded riparian conditions contributes to increased erosion and the associated sediment issues that are problematic throughout much of the UCFR (EPA 2004, MT DEQ 2014).

UCFR Flow Considerations

The salmonid population in the UCFR is strongly depressed (Lipton et al. 1995) and this impairment likely results from numerous interacting factors including flow. Metal pollution (particularly copper) is the obvious source of reduced salmonid abundance, particularly in the upper reaches where pollution generally is most severe in the sediments, water, and aquatic invertebrates (Cain et al. 1992, Helgen and Moore 1996, Axtmann et al. 1997, Davis and Atkins 2001, Cain et al. 2004, EPA 2004, Mayfield 2013). However, salmonid populations are particularly depressed in the Bearmouth vicinity (fish per mile), despite the generally lower metal contamination relative to upstream reaches (Clark and Schmetterling 2013, Mayfield

2013, Leon et al. 2014, Naughton 2015), suggesting factors other than metal pollution alone may be limiting the fishery, particularly downstream of the Deer Lodge Valley.

Dissolved copper concentrations increase with discharge in the UCFR and this relationship becomes increasingly steep moving upstream (Mayfield 2013), thus examining patterns of fish mortality and abundance longitudinally can provide insights into the relative impacts of mining wastes. In general fish are exposed to the highest copper concentrations at high discharge in the upper UCFR, while less variability exists longitudinally at low discharge. [However, smaller spatial scales considerable differences exist in dissolved metal concentrations (including copper) providing some variance in the overall longitudinal pattern (for examples, see Mayfield 2013)]. In light of the general longitudinal and discharge patterns in metals, it would be expected that if metal toxicity (particularly copper) is the only limitation to the salmonid fishery of the UCFR that mortality should be highest in the upper river, particularly during spring. Further, the upper river should have the lowest salmonid populations. However, these expectations are only partly met based on several investigations.

Support for metals limitation in the upper UCFR is strong for salmonids, but interactions with temperature and water quality also seem to be part of the issue. Caged fish studies generally show higher brown trout mortality rates in the upper UCFR main stem relative to downstream sites (Richards et al. 2013, Leon et al. 2014). Mayfield (2013) also found that mortality rates (based on radio tagged fish) were highest for brown trout in the upper UCFR, and this pattern was even more evident for cutthroat trout. Brown trout are relatively resistant to metals relative to rainbow trout (and, by inference, this likely applies to cutthroat trout given that are very closely related to rainbow trout) owing to their greater ability to acclimatize to metals (Marr et al. 1995). Accordingly, the lower mortality rates of brown trout relative to cutthroat trout are particularly suggestive of metals limitation to the fishery. Collectively, the mortality investigations and the higher metal concentrations in the upper UCFR point to metal contamination as a major limitation in this stretch of river, but other water quality aspects and temperature seem to contribute to the problem.

Data collected for FWP's caged brown trout studies provide some insights into causes of mortality. Mortality of caged fish was relatively low during peak flows but then increased in the summer as temperatures climbed (Richards et al. 2013, Leon et al. 2014). Richards et al. (2013) observed that mortality was not elevated when high water temperatures were observed without elevated metals or pH. Elevated pH is largely due to liming and primary producer removal of carbon dioxide in Warm Springs Ponds, and diminishingly is evident in the river moving downstream. High pH and temperatures are of particular concern when $NH_{3/4}$ levels are high (largely due to decay of primary producers) as these conditions cause NH_4 to convert to highly toxic NH_3 form. Accordingly, the EPA's aquatic life water quality criteria (EPA 2013) incorporate pH and temperature. For example, at 20 C and pH 7.0 the chronic exposure maximum concentration is 1.9 mg/L $NH_{3/4}$-N, at 20 C and pH 9.0 is 0.16 mg/L, and at 25 C and pH 9.0 is 0.11 mg/L. Based on temperature, pH, and $NH_{3/4}$ graphs from Galen in 2011 and 2012

(Richards et al. 2013), $NH_{3/4}$-N levels seem to be near the EPA's criteria but not high enough to cause mortality to salmonids (see EPA 2013 for overview of salmonid references). Dissolved oxygen concentrations at Galen fell below the Montana DEQ's 4.0 mg/L standard in mid July of 2011 but remained above 6.0 mg/L in 2012. Both low dissolved oxygen and high $NH_{3/4}$ levels are linked to nutrient enrichment that causes high primary producer biomass in the upper UCFR (Suplee et al. 2012), and additionally of these abiotic stressors are exacerbated by high temperatures. The emergent picture is that although metals are the main limitation to salmonids in the upper UCFR, water quality issues and high temperatures provide additional stressors that may further diminish the fishery. Accordingly, even in the upper river flow augmentation could benefit the fishery by reducing temperatures, diminishing nutrient concentrations (including $NH_{3/4}$) and the associated primary producer biomass, increasing oxygen concentration, and lowering pH/reducing $NH_{3/4}$ toxicity (particularly provided flows are added below Warm Springs Ponds).

An additional flow linked consideration for the upper river is the dilution of metals washed into the river from thunderstorms. Thunderstorms with heavy rainfall wash metal salts and acidic materials on the surface of the floodplain into the river, providing a toxic pulse of high metals and low pH than can cause fish kills (Phillips and Lipton 1995, EPA 2004). Low summer flows exacerbate the risk from these rain events by providing a smaller volume of river water to dilute metal rich, acidic runoff. On going remediation efforts directed by the Montana Department of Justice and the EPA have been removing these metal sources from the floodplain, presumably reducing their impact and which may explain why no recent accounts of fish kills related to thunderstorms were located. However, some diminishing concerns still remain regarding thunderstorm events, and in this context low summer flows are still a potential concern.

In the UCFR from Flint Creek to Rock Creek metal contamination is less severe than upstream reaches (Cain et al. 1992; Axtmann et al. 1997, Cain et al. 2004, Helgen and Moore 1996, Davis and Atkins 2001, Mayfield 2013), yet fish densities per mile are low relative to areas both upstream and downstream (Clark and Schmetterling 2013, Mayfield 2013, Leon et al. 2014, Naughton 2015). Further, trout mortality rates are higher in the upper UCFR relative to the downstream reaches (Mayfield 2013, Richards et al. 2013, Leon et al. 2014). The implication is that factors other than metals alone are contributing to the low fish abundance from Flint Creek to Rock Creek. Naughton (2015) recently investigated possible causes of these low fish densities and concluded several factors may be responsible including high temperatures, limited number of tributaries (for thermal refuge, spawning, and rearing of young), barriers on tributaries, and poor physical habitat conditions. Highway construction, railroad construction, and rip rap have constrained the channel, reducing off channel habitats, pools, and, together with heavy grazing, promote riparian vegetation degradation in many UCFR locations from Flint Creek to Rock Creek. As a result of this degradation vegetative shading and log inputs are reduced, and additionally logs would seem to be more prone to export in the confined and straightened channels. In turn, low log densities further limit the creation of deeper habitats and also limit opportunities for cover. Naughton also suggested that high Cladophora abundance in the Flint Creek to Rock Creek stretch may be a fishery concern, as insects that live in Cladophora may be less available to trout and/or Cladophora may inhibit drift feeding. Some support for these ideas is provided by the caged fish studies that show that brown trout growth rates generally were low at the Flint Creek and Bearmouth sites (Richards et al. 2013, Leon 2014). Cladophora is most evident in shallow areas with relatively fast moving water (Flynn 2014) and benefits from nutrient enrichment (Suplee et al. 2012). Nutrient control efforts have seemed to reduce Cladophora biomass in recent years, however nutrient and Cladophora levels remain problematic (Suplee et al. 2012).

Although flow augmentation efforts in the UCFR have focused mostly on the Deer Lodge Valley, increased summer flows could benefit the salmonid fishery downstream that is of particularly diminished from Flint Creek to Rock Creek. This stretch has recently been identified as priority area by the Montana Department of Justice based on the low trout abundance (NRDP 2012). Increased flows would help reduce temperatures in this stretch, although probably not as much as in the upper UCFR where flows are particularly diminished and the distance to major cold water sources is smaller. Perhaps the biggest thermal benefit would come by enhancing late summer flows on tributaries in the middle UCFR, particularly those lacking barriers in their lower reaches, by providing cold water refugia. Increased summer flows would also help dilute nutrient levels and increase water depth which could help diminish Cladophora and also possibly enhance salmonid drift feeding by increasing water velocity. Increased water depth would seem to provide a particular habitat benefit in the middle UCFR reaches given the scarcity of deep water habitats, particularly pools (Mayfield 2013, Naughton 2015).

References

Axtmann, E.V., D.J. Cain, and S.N. Luoma. 1997. Effect of tributary inflows on the distribution of trace metals in fine-grained bed sediments and benthic insects of the Clark Fork River, Montana. Environmental Science and Technology 31: 750-758.

Bear, E.A., T.E. McMahon, and A.V. Zale. 2007. Comparative thermal requirements of westslope cutthroat trout and rainbow trout: implications for species interactions and development of thermal protective standards. Transactions of the American Fisheries Society 136: 1113-1121.

Cain, D.J., S.N. Luoma, J.L. Carter, and S.V. Fend. 1992. Aquatic insects as bioindicators of trace element contamination in cobble-bottom rivers and streams. Canadian Journal of Fisheries and Aquatic Sciences 49: 2141-2154.

Cain, D.J., S.N. Luoma, and W.G. Wallace. 2004. Linking metal bioaccumulation of aquatic insects to their distribution patterns in a mining-impacted river. Environmental Toxicology and Chemistry 23:1463-1473.

CFC. 2011. Aquatic Restoration Strategy for the Upper Clark Fork Basin. Report by the Clark Fork Coalition.

Clark, R. and D.A. Schmetterling. 2013. Milltown Dam Removal Monitoring Fisheries Investigations in 2012. Report by Montana FWP for Montana DEQ and Unite States EPA.

Davis, A. and D. Aktins. 2001. Metal distribution in Clark Fork River sediments. Environmental Science and Technology 35: 3501-3506.

Emerson, K., R.C. Russo, R.E. Lund, and R.V. Thurston. 1975. Aqueous ammonia equilibrium calculations: effect of pH and temperature. Journal of the Fisheries Research Board of Canada 32: 2379-2383.

EPA. 2004. Clark Fork River Operable Unit of the Milltown Reservoir/Clark Fork River Superfund Site Record of Decision Part 2: Decision Summary. Report by US EPA Region 8.

EPA. 2013. Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater 2013. Report prepared by U.S. EPA.

Flynn, K.F. 2014. Methods and Mathematical Approaches for Modeling Cladophora Glomerata and River Periphyton. Ph.D. Dissertation, Tufts University.

Hansen, J.A., D.F. Woodward, E.E. Little, A.J. DeLonay, and H.L. Bergman. 1999. Behavioral avoidance: possible mechanism for explaining abundance and distribution of trout species in a metal-impacted river. Environmental Toxicology and Chemistry 18: 313-317.

Helgen, S.O. and J.N. Moore. 1996. Natural background determination and impact quantification in trace metal-contaminated river sediments. Environmental Science and Technology 30: 129-135.

Leon, J., P. Saffel, B. Liermann, J.Lindstrom, and T. Selch. 2014. Upper Clark Fork River Fisheries Monitoring Study: 2013 Annual Report. Report by Montana FWP for Montana DEQ.

Lipton, J. and 16 coauthors. 1995. Aquatic Resources Injury Assessment Report: Upper Clark Fork River Basin. Report by Montana DOJ, Natural Resource Damage Litigation Program.

Marr, J.C.A., H.L. Bergman, J. Lipton, and C. Hogstrand. 1995. Differences in relative sensitivity of naïve and metals-acclimated brown and rainbow trout exposed to metals representative of the Clark Fork River, Montana. Canadian Journal of Fisheries and Aquatic Sciences 52: 2016-2030.

Mayfield, M.P. 2013. Limiting Factors for Trout Populations in the Upper Clark Fork River Superfund Site, Montana. M.S. thesis, Montana State University.

McMahon, T.E., A.V. Zale, F.T. Barrows, J.H. Selong, and R.J. Danehy. 2007. Temperature and competition between bull trout and brook trout: a test of the elevation refuge hypothesis. Transactions of the American Fisheries Society 136: 1313-1326.

MT DEQ. 2014. Final – Upper Clark Fork Phase 2 Sediment and Nutrients TMDLs and Framework Water Quality Improvement Plan. Report by Montana DEQ.

Naughton, J. 2015. Clark Fork River Fishery Assessment: Flint Creek to Rock Creek Reach. Draft Report by RESPEC for Montana DOJ.

NRDP. 2012. Final Upper Clark Fork River Basin Aquatic and Terrestrial Resources Restoration Plans. Report by Montana DOJ Natural Resources Damage Program.

Phillips, G. and J. Lipton. 1995. Injury to aquatic resources caused by metals in Montana's Clark Fork River basin: historic perspective and overview. Canadian Journal of Fisheries and Aquatic Sciences 52: 1990-1993.

Richards, R., W. Schreck, P. Saffel, B. Liermann, J. Lindstrom, and T. Selch. 2013. Upper Clark Fork River Caged Fish Study: The Distribution and Timing of Trout Mortality Final report 2011-2012. Report by Montana FWP for Montana DEQ.

Schmetterling, D.A. 2003. Reconnecting a fragmented river: movements of westslope cutthroat trout and bull trout after transport upstream of Milltown Dam, Montana. North American Journal of Fisheries Management 23: 721-731.

Selong, J.H., T.E. McMahon, A.V. Zale, and F.T. Barrows. 2001. Effect of temperature and growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. Transactions of the American Fisheries Society 130:1026-1037.

Suplee, M.W., V. Watson, W.K. Dodds, and C. Shirley. 2012. Response of algal biomass to large-scale nutrient controls in the Clark Fork River, Montana, United States. Journal of the American Water Resources Association 48: 1008-1021.

Workman, D. 2009. Qualitative Assessment of Habitat in Eight Tributaries to Upper Clark Fork River. Report to Montana FWP and NRDP.

CHAPTER 3:

Methods for Determining Instream Flow Needs of Salmonids

Introduction

A variety of methods are in use for assessing the relationship between flow modification and the associated ecological impact. The choice of method to assess instream flow needs varies with many considerations including flow regime, channel morphology, seasonality of impact, species of concern, data availability, cost, and complexity. Instream flow methods can be broken up into four major categories. Hydrological methods use discharge data alone to quantify instream flow needs. Hydraulic rating methods assess habitat conditions relative to discharge, typically in flow sensitive habitats such as riffles, using hydraulic variables that are related to flow (such as the wetted perimeter of a channel). Habitat rating (or simulation) methods relate discharge to habitat conditions so that the amount of each habitat can be predicted relative to flow which is then related to the needs of aquatic species of concern. Holistic methods integrate features of the entire river ecosystem (including the riparian zone) to assess flow alteration impacts relative to changes in the natural flow regime, and are mostly in use in dry areas (such as Australia and Africa) with widely varying flow regimes (Tharme 2003). For detailed comparisons of the conceptual basis for each method (excluding holistic), a reading of Jowett (1997) is recommended.

Worldwide, hydrological and habitat rating methods are used most often followed by hydraulic and then holistic methods (Tharme 2003). In the U.S. habitat simulation is the most widely used instream flow method (38%) followed by hydrological methods (26%), hydraulic methods (25%), combinations of these previous three methods (9%), and other methods (1%) (Tharme 2003). Holistic methods are not routinely used in the U.S. (Tharme 2003) and are thus not further considered. The goal of this chapter is to describe and evaluate the major instream flow techniques within each category with a particular emphasis on the potential of each method for determining minimum flow needs in summer that are protective of that habitats that support salmonids in the Upper Clark Fork River (UCFR).

Hydrological Methods

Tenet's Montana Method

Tenet (1976) developed the most widely used hydrological method, often referred to as the "Tenet" or Montana Method", and his approach remains in widespread use worldwide but ironically not in Montana (Pyrce 2004). Tenet used chemical, physical, and biological data from rivers (with a focus on those from Montana and Wyoming) to describe the impacts of flow reduction. Tenet quantified percent deviations from mean annual flow (relative to the undisturbed hydrograph) to quantify “impacts on fish, wildlife, recreation, and related environmental resources” in two six month blocks (October to March and April to September). Tenet’s major findings are presented in Table 1. Tenet recommended 30% of the mean annual flow to “sustain good survival habitat for most aquatic life forms” and 10% as “a minimum instantaneous flow recommended to sustain short-term survival habitat for most aquatic life forms”. For an overview of various modifications of Tenet’s method see Tharme (2003). Based on a study of southwest Montana River, Nelson (1980) found that mean annual flows of 31% to 51% were required as “absolute minimum recommendations” to sustain trout abundance, suggesting Tenet’s 30% guideline is a bit low in Nelson’s study rivers. Tenet’s method has the advantage of being inexpensive and easy to calculate (provided undisturbed mean annual flow can be calculated or estimated), particularly in lotic locations with existing gage data. An advantage of Tenet’s method in the UCFR is that his technique is largely based on Montana and Wyoming Rivers. However, the main issue with the Tenet’s method is that it makes no consideration of the site specific relationships between habitat conditions and flow. For example, Nelson (1980) found that a higher mean annual flow was required to sustain trout abundance in wider, shallower rivers of southwest Montana. Additionally, Jowett (1997) points out that as rivers decrease in size a larger portion of the annual flow is needed to prevent habitat degradation. Further, the Montana method cannot be used to determine flow tradeoffs relative to target species and/or amongst target species (although it should be noted this criticism applies to all the methods reviewed herein except habitat simulation). Accordingly, it seems the most appropriate use of Tenet’s methodology in the UCFR is as a cross reference for other instream flow methods, or on tributaries where no site specific information has been gathered. In the later case, hydrological models could be employed to estimate natural discharge and then actual flows would need to be determined during the period of low flows.

Flow Indices

Flow indices are the other major category of hydrological methods and are based on flow duration (exceedance) percentiles. For example, a common metric to maintain flows for pollution dilution is 7Q10 flow which is the seven day low flow with a return interval of 10 years. Many other metrics based on varying time frames and return intervals are used for diverse purposes including setting instream flow recommendations (Pyrce 2004). The main advantage of flow indices is that they are readily calculated from daily discharge data. However, flow indices alone do not seem to be well suited for setting minimum flows for salmonid protection in the UCFR as they make no accounting habitat conditions relative to flow. Perhaps the most suitable use of flow indices in the UCFR would be to quantify the exceedance frequency of low flows in light of minimum flows set by other methods.

Flow Duration Curves

Flow duration curves are sometimes used for low flow considerations (Pyrce 2004), and use cumulative frequency distributions to reveal the amount of time that a certain discharge occurs or, more commonly, is exceeded over a selected time frame. For example, a Q95 would be the flow that is equaled or exceeded 95% of the time. Like the previously described hydrological methods, flow duration curves are readily calculated from discharge data but make no consideration of habitat considerations. Again, perhaps the best use of flow duration curves in the UCFR setting would be to quantify flow patterns relative to minimum flows set by other methods.

Hydraulic Rating Methods

Wetted Perimeter

The wetted perimeter method is the most widely used of the hydraulic rating methods (Tharme 2003). As the name implies, the wetted perimeter of a cross section is determined along the bottom over a wide range of flows. Riffles typically are used because they decrease more rapidly in area as discharge falls than other major habitat types. Typically one or two break points are evident in the discharge versus wetted perimeter relationship that are referred to as the lower and upper inflection points. Mathematically these are not actual inflection points, but instead simply where the change in the slope of the relationship (i.e. curvature) is maximized. The logic behind using inflection points for setting minimum instream flows is that when flows fall below a breakpoint, the rate of habitat loss decreases more rapidly with diminishing flows. A critique of the wetted perimeter method is that when the break points are determined visually the scaling of the axes can influence the inflection point determination (see Gippel and Stewardson 1998, Figure 1). To overcome this issue, Gippel and Stewardson (1998) provide a mathematical basis for determining inflection points based on determination of maximum curvature of the wetted perimeter versus discharge relationship. These authors also discuss an alternative slope method where varying discharges are calculated as a percentage relative to a flow index such as the mean annual discharge. The inflection point is then determined based on a slope prescribed by the investigator (typically 1). Gippel and Stewardson (1998) found that in their study both the curvature and slope methods yielded similar break points (based on a slope of one for the slope method). However, Liu et al. (2006) found that curvature method yielded lower flow recommendations relative to the slope method, and suggested the curvature technique was preferable. Inflection points are more likely to be evident in channels that are more rectangular in shape relative to those that are more triangular (Gippel and Stewardson 1998). If no inflection point is evident, a specified length of wetted perimeter can be set to determine the associated minimum flow. Nelson (1980) found that single transects provided a more clear inflection point than averaged multiple transects in southwestern Montana rivers. Averaged multiple transects were more likely to provide two inflection points, and the lower of these corresponded to the “absolute minimum recommendation” for sustaining trout abundance based on field data (Nelson, 1980). Assumptions of wetted perimeter method include that by maintaining sufficient flows in riffles other deeper habitats will be adequately protected, and that dewatered riffles are problematic.

As flows decease so does riffle area and depth (as indexed by the wetted perimeter), and these are relevant considerations as they create several concerns for salmonids. Reduced riffle area limits macroinvertebrate production, and within the remaining area macroinvertebrates are further constrained by reduced feeding, particularly filter feeders. The result is less food production for salmonids, and this issue is compounded by reduced feeding opportunities on the diminished forage. Specifically, lower flows limit macroinvertebrate drift to downstream pools where salmonids tend to congregate (Rosenfeld and Ptolemy 2012 and references therein), especially at low discharge. Further, as riffles become shallow they can become partial migration barriers and/or predation risks which are of concern because salmonids often move in the summer to reach cooler upstream areas. In the case of fall spawners (such as bull trout, brown trout, and brook trout) summer and early fall migrations are often also undertaken to reach spawning areas.

The wetted perimeter method has several strengths, particularly in the UCFR setting, but also some limitations. This method generally is used for protecting fish forage and flow sensitive habitats, especially in western states, and thus seems appropriate in the UCFR where water augmentation is primarily directed towards enhancing salmonid populations. Further, the wetted perimeter method is based on site specific habitat conditions in riffles rather than generic rules of thumb common to hydrologic rating methods. This is particularly relevant in the UCFR as riffles are a major habitat type, and dewatering thus creates substantial concerns for forage conditions and fish migrations. Further, the large number of partial and complete barriers in the UCFR tributaries likely necessitates longer migration distances in the main stem to reach accessible tributaries for cooler water or spawning, and native salmonids of particular concern in the UCFR (bull trout and cutthroat trout) migrate widely (Schmetterling 2003, Mayfield 2013). Another concern with shallow riffle conditions are that they leave salmonids vulnerable to predation, particularly during periods of movement, which especially is relevant in the UCFR with its abundant riffle habitat. For example, Mayfield (2013) reported that cutthroat mortality was particularly high during their highly mobile period after spawning. Several logistical considerations are also advantageous for the wetted perimeter methodology. The requisite data can be collected using basic methodologies and analysis of the data is relatively straight forward. Further, a substantial amount of wetted perimeter data has already been collected in the UCFR and its tributaries (FWP 1986, Brummond 2011), some of which has been used to make minimum flow recommendations for the main stem (FWP 1986). The wetted perimeter method has several limitations. Wetted perimeters need to be quantified over a wide range of flows, requiring either numerous site visits or one visit to quantify channel shape and subsequent modeling based on the Manning equation and discharge (Annear and Conder 1984). In riffles with relatively evenly sloping banks (i.e. relatively triangular shape) inflection points may not be well defined, and this is relatively common in alluviated settings (Jowett 1997) such as much of the UCFR. Lastly, the wetted perimeter method makes no specific accounting of the availability of varied habitats or the target species habitat preferences. Overall, although the wetter perimeter method has some limitations, they seem to be outweighed by the numerous advantages in the UCFR setting.

Habitat Simulation

PHABSIM

Physical habitat simulation (PHABSIM and several variants) is the most widely used of the habitat simulation methods in the U.S. and worldwide (Tharme 2003). PHABSIM uses models to link habitat preferences of target species to hydraulic features (such as water depth, velocity, substrate) over varying discharge at multiple sites within a study reach. The results are then used to determine optimal flows for the target species based on weighted useable area, or at least the acceptable deviation. When PHABSIM alone is used to set flow targets, the underlying assumption is that the target species will diminish if their preferred physical habitats are not sustained in sufficient quantity.

PHABSIM may provide a useful tool in the quantifying habitat conditions relative to flow, but does not seem well suited alone for making instream flow recommendation in the UCFR. The primary advantage of PHABSIM is that it does consider both the local riverine conditions and the habitat needs of the local target species relative to flow. Further, PHABSIM can be used to determine flow versus habitat tradeoffs relative to target species and/or amongst target species. However, PHABSIM has been widely criticized based on numerous criteria, particularly on issues related to habitat preference determination (see Tharme 2003, Caissie and El-Jabi 2003, Rosenfeld and Ptolemy 2012, and references therein for each). The resulting limitation of PHABSIM is well illustrated by Conder and Annear (1987) who tested the methodology on a large sample of Wyoming streams (n = 60). The authors found that trout densities showed no correspondence to weighted useable area among streams and little correspondence within streams. Within streams the results were particularly poor for those with a low gradient (slope of 0.3% or less), suggesting PHABSIM may have limited utility in setting flow guidelines for protecting salmonids in settings such as the UCFR. Some caution is warranted regarding Conder and Annear's findings, as improvements to PHABSIM have been made since their analysis was conducted. However, these improvements have primarily been to the physical habitat models, while considerable uncertainty remains regarding the habitat suitability curves (Rosenfeld and Ptolemy 2012). Recent studies continue to raise concerns regarding PHABSIM's ability to predict fish biomass and thus the ability to make appropriate instream flow recommendations (Rosenfeld and Ptolemy 2012 and references therein). Using PHABSIM as part of a broader instream flow incremental methodology where flow effects are also considered on other potentially limiting factors (i.e. temperatures, water quality, and food production) may improve the results, but issues with the habitat suitability curves still would remain problematic. Further, relative to the other methods reviewed herein, PHABSIM requires more data collection and analysis. In general, it seems that PHABSIM in its current rendition is most useful for quantifying the effects of flow on physical habitat availability, and thus in the UCFR could provide a useful technique to cross reference other instream flow methods but should not be used alone to set minimum flows.

References

Annear, T.C. and A.L Conder. 1984. Relative bias of several fisheries instream flow methods. North American Journal of Fisheries Management 4: 531-539.

Brummond, A. 2011. Inflection Point Determination Upper Clark Fork River Basin. Report by Montana FWP.

Caissie, D. and N. El-Jabi. 2003. Instream flow assessment: from holistic approaches to habitat modelling. Canadian Water Resources Journal 28: 173-183,

Condor, A.L. and T.C. Annear. 1987. Test of weighted usable area estimates derived from a PHABSIM model for instream flow studies on trout streams. North American Journal of Fisheries Management 7: 339-350.

FWP. 1986. Application for Reservations of Water in the Upper Clark Fork River Basin. Water reservation application by Montana FWP for Montana DNRC.

Gippel, C.J. and M.J. Stewardson. 1998. Use of wetter perimeter in defining minimum environmental flows. Regulated Rivers: Research and Management 15: 53-67.

Jowett, I.G. 1997. Instream flow methods: a comparison of approaches. Regulated Rivers 13: 115-127.

Liu, S. and seven co-authors. 2006. Estimating the minimum in-stream flow requirements via wetter perimeter method based on curvature and slope techniques. Journal of Geographic Sciences 16: 242-250.

Mayfield, M.P. 2013. Limiting Factors for Trout Populations in the Upper Clark Fork River Superfund Site, Montana. M.S. thesis, Montana State Univeristy.

Nelson, F.A. 1980. An Evaluation of Four Instream Flow Methods Applied to Four Trout Rivers in Southwest Montana. Report by Montana FWP for U.S. Fish and Wildlife Service.

Pyrce, R. 2004. Hydrological Low Flow Indices and Their Uses. WSC Report No. 04-2004. Report by Watershed Science Center, Trent University.

Rosenfeld, J.S. and R. Ptolemy. 2012. Modelling available habitat versus available energy flux: do PHABSIM applications that neglect prey abundance underestimate optimal flows for juvenile salmonids? Canadian Journal of Fisheries and Aquatic Sciences 69: 1920 -1934.

Schmetterling, D.A. 2003. Reconnecting a fragmented river: movements of westslope cutthroat trout and bull trout after transport upstream of Milltown Dam, Montana. North American Journal of Fisheries Management 23: 721-731.

Tenet, D.L. 1976. Instream flow regimes for fish, wildlife, recreation and related environmental resources. Fisheries 1: 6-10.

Tharme, R.E. 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19: 397-441.

CHAPTER 4:

Discharge Patterns in the Upper Clark Fork River

Introduction

The Upper Clark Fork River (UCFR) exhibits a mostly natural pattern of discharge with the notable exception of diminished summer flows. Relatively few impoundments exist in the UCFR basin (<10% of total flow, DNRC 2014) allowing for a generally natural pattern of low winter flows and high discharge in late the spring and early summer. Water withdrawals during the summer are presumably the largest relative change in the seasonal discharge patterns, although this impact is partly offset by releases from water storage facilities. Given the concerns for low flow impacts on the fishery, analyses of the seasonal and longitudinal discharge patterns were conducted on the UCFR with a focus on low summer flows. The major goal of this chapter is to help identify the extent, timing, and location of dewatering concerns in the UCFR mainstem to provide information for flow augmentation efforts.

Seasonal Patterns

To describe the seasonal discharge pattern, USGS data were used from the Deer Lodge gage due to the long period of record (1978-current) and central position in the upper watershed where dewatering concerns are substantial. As expected, considerable seasonal variation existed among years in the hydrograph. The lowest flow (22 cfs) was observed in August of 1988 and 1991, and the highest discharge (2,390 cfs) occurred in May of 1981. To put the discharge patterns into the context of habitat considerations, the lower and upper inflection points (90 cfs and 180 cfs, respectively) for the Warm Springs Creek confluence to the Little Blackfoot confluence are shown (FWP 1986). It is apparent that summer flows usually fell below the upper inflection point and often fell below the lower inflection point (Figures 1-4).

To describe the average yearly hydrograph, flows from October 1978 through September 2014 were calculated as daily means using the USGS data from Deer Lodge. Flows increased steeply in mid May, peaked in early June, and then fell rapidly until late July. Low flow conditions existed from late July through August with a minimum of 95 cfs on August 10. Discharge steadily increased from mid August to the end of October and then fell slightly through November to mid December. Flows were relatively stable from mid December until mid February and then began increasing moderately until mid May. Late summer flows fell below the upper inflection point to just above the lower inflection point (Figure 5).

To investigate how minimum summer flows varied among years, the effects of time (i.e. 1979 to 2014) as well as water yield were examined using USGS data from Deer Lodge. The timing of summer minimum flows was quantified for each year based on the lowest 15 day mean flow from June to September, and the eight day of this period was used in the subsequent analyses (see Figures 1-4 for timing of minimum summer flows). A weak positive relationship existed between the timing of minimum flows and year (p = 0.09) from 1979-2014, which was suggestive (but not statistically significant) that through time minimum flows may be occurring later in the summer. The predicted minimum flow for 1979 was August 5 and for 2014 was August 16 (Figure 6). To investigate the relationship between water yield and the timing of minimum flows a separate analysis was conducted. Water yield was indexed using daily average discharge for each year from 1979 to 2013. A positive relationship existed between the date of minimum flows and average yearly discharge, indicating that in low water years minimum flows occurred earlier in the season. The trend line from this relationship predicts that when average yearly flows were lowest (121 cfs) that the minimum flow occurred on August 3, and conversely when average yearly flows were highest (479 cfs) minimum flow occurred on August 23 (Figure 7).

Given that the timing of minimum flows varied with water yield and possibly through time, a second characterization of the average Deer Lodge hydrograph was made using recent low flow data from the early 2000s. Yearly water yield (again indexed by average daily cfs) showed a 10 to 15 year cycle from 1979 to 2013 with the most recent full cycle of low flows occurring from 2000-2007 (Figure 8). Accordingly, data from 2000-2007 were used to create an average daily hydrograph to describe the timing of low flows during recent low water years and plotted against the previously shown 1978-2014 data for comparison. Not surprisingly, average discharge was lower throughout the year in 2000-2007, including the period of low summer flows. More relevantly in the context of this analysis is that curvature of the hydrograph was more gradual as it approach the minimum in 2000-2007, indicating that low flows arrived earlier in the summer and were sustained for longer in these relatively low flow years. The lowest 15 day mean flow had a midpoint of August 10 in the 2000-2007 data (the same date as the 1978-2014 analysis, possibly the trends with discharge and the suggestive trend with time offset each other) at 55 cfs. Flows in 2000-2007 fell below the lower inflection point from mid July to early September (Figure 9). The small increase in the 2000-2007 hydrograph around August 9 was due to unusually high increase in discharge around this date in 2002. The summer hydrographs for each year from 2000-2007 as well as the mean for this period with 2002 removed are shown in Figure 10.

Seasonal Patterns Synthesis

The Deer Lodge gage data reveals the basic pattern of low flows as well as how the timing of low flows shifts in low discharge years and through time. Considerable variation existed in the seasonal hydrograph among years, and in low discharge years summer flows commonly fell below the lower inflection point. Variation in the yearly discharge patterns does not seem random as a 10 to 15 year flow cycle was evident. From 1978 to 2014 average low flow conditions existed from late July through August, but the initiation of low flows began in mid July during the relatively low flow period from 2000 to 2007. When each year was considered separately it is evident that the lowest 15 day mean flow from 1979 to 2013 arrived earlier in low flow years with a predicted range from August 3 on the lowest flow year and August 23 on the highest flow year. Through time, there is some indication that low flows are arriving later in the season which may partly explain why the timing of the lowest 15 day mean flow was the same (August 10) in both the 1978 to 2014 overall and 2000 to 2007 lower flow data sets. Given that the fishery is presumably at the greatest risk during low flow years, the 2000-2007 Deer Lodge analysis suggests flow augmentation in the upper UCFR should focus on the period from mid July through early September to provide the greatest benefit during years of low discharge. Looking forward, if low flows continue to arrive later in the summer through time there may be value in extending the period of flow augmentation into mid September.

Longitudinal Patterns

To examine the longitudinal differences in flows, particularly during summer low flows, USGS sites along the main stem were compared during periods of overlapping data collection. Flow data from October 1988 through September 2013 from Galen, Deer Lodge, Gold Creek and Turah were averaged by day to create yearly average hydrographs. As expected, flows increased downstream. A discernable drop in flows was evident during the late summer at all sites, although the drop was minor at Galen (Figure 11). To better illustrate this flow change during low flows an enlargement of Figure 11 was created from June 1 to December 1. Low flows at the Galen site were relatively homogenous with flows below 90 cfs occurring from August 7 through October 6, and minimum flows of 75 cfs occurred September 4 and 5. The Deer Lodge flows were, to a relatively constant degree, higher than those from Galen with the exception of the late summer. From late July to mid August flows were only slightly higher at Deer Lodge relative to Galen. Minimum flows at Deer Lodge occurred on August 15 at 96 cfs (as compared to August 10 based on the previously described 1978-2014 and 2000-2007 data). Moving further downstream, the same basic pattern of summer low flows occurred, but later in the season. At Gold Creek and Turah flows both were minimized on August 20 at 220 cfs and 620 cfs, respectively (Figure 12).

To put the 1988-2013 average daily flow patterns into a habitat context the 1986 upper and lower inflection point flows (FWP 1986) were examined relative to the observed flows. The Deer Lodge site was used to represent the Warm Springs confluence to Little Blackfoot stretch. Although the Galen site falls in the upper part of this river segment, a more recent analysis determined the lower inflection point for Galen is 40 cfs and thus this value was used. No upper inflection point was evident at the Galen site (UCFBSC 2006). The upper and lower inflection points (400 cfs and 200 cfs, respectively) for Little Blackfoot confluence to the Flint Creek confluence were represented by the Gold Creek site, while the Turah site was used for the Rock Creek confluence to the Blackfoot River confluence (600 cfs and 300 cfs for the upper and lower inflection points, respectively). Flows at Turah remained above the upper inflection point while at Gold Creek and Deer Lodge flows fell below the upper inflection point to just above the lower inflection point during late summer. Minimum flows at Deer Lodge were slightly closer to the lower inflection point than at Gold Creek from both an absolute and relative (i.e. percentage) perspective. Flows at Galen remained well above the lower inflection point (Figure 12). This habitat based approach suggests low flow issues are of particular concern beginning between Galen and Deer Lodge and improve slightly by Gold Creek (i.e. below the Little Blackfoot), and are less of a concern at Turah (i.e. below Rock Creek).

A follow up analysis of longitudinal discharge patterns was made using two additional USGS sites (Above Little Blackfoot and Drummond) with shorter running data sets to add additional spatial resolution. Average daily hydrographs were created using data from January 1, 2010 to December 31, 2012 (more recent data were not used do to unresolved ice issues in 2013 and 2014 that created missing flow data for some sites in this data set). Flows were moderately higher on average from 2010-2012 than 1988-2013, but otherwise the seasonal patterns generally were similar in the four overlapping sites between the two time periods. However, the 2010 to 2012 sites provided site additional information on the longitudinal discharge patterns. Flows at Deer Lodge and Above Little Blackfoot tracked each other very closely, with very slightly higher flows at Above Little Blackfoot during most of the season. The exception was during high discharge when greater discharge at Above Little Blackfoot was more evident relative to Deer Lodge. Flows at Drummond were moderately higher than Gold Creek, and this difference was relatively constant for most of the season (Figure 13).

To evaluate the 2010 to 2012 average daily flows relative to habitat considerations an enlargement of Figure 13 was created with the lower inflection point flow for each river segment (FWP 1986). The river segments and associated gaging stations are the same as in the 1988-2013 analysis described previously, except an additional river segment was considered from the confluence of Flint Creek to the confluence of Rock Creek. This river segment has a lower inflection point of flow of 180 cfs (and the upper inflection point flow is 500 cfs) and was indexed by the USGS Drummond gage that is located in the upper part of this stretch. The Deer Lodge and Above Little Blackfoot gages both are within the river segment from the Warm Springs confluence to the Little Blackfoot confluence designated by FWP (1986). Given that Deer Lodge is the most centrally located gage in this river segment it was used as the representative site. In the 2010 to 2012 period of moderately high average flows the lower inflection point flows were exceeded year round at all sites. From a relative (i.e. percentage) perspective, the late summer exceedance was relatively large at Galen, diminished substantially at Deer Lodge, then improved slightly at Gold Creek in an absolute sense (but was similar from a percentage perspective than Deer Lodge), and then progressively increased at Drummond and Turah. Based on these years of moderately high average flow, it appears the area of greatest low flow concern is from between Galen and Deer Lodge and extends to Gold Creek and improves beginning at Drummond (Figure 14). This work supports the conclusions from the 1988-2013 inflection point analysis that the area of summer dewatering concern begins between Galen and Deer Lodge, and improved the spatial resolution to show that flow based habitat conditions were substantially improved by Drummond (which was lacking in the 1988-2013 analysis) instead of Turah.

To provide further context for the pattern of low summer flows in the UCFR a yearly hydrograph from an undeveloped river (South Fork of the Flathead River at Twin Creeks) was created using USGS data from October 1988 through September 2103. Although the S.F. Flathead River certainly varied from the UCFR's undisturbed hydrograph, the assumption is that these differences modest enough that some insights regarding water removal can be gained by comparing the discharge patterns. Both rivers peaked in early June [June 7-8 for the four 1988-2013 UCFR sites (see Figure 11) and June 7 for the S.F. Flathead, although a slightly smaller peak existed around May 19 for the later]. Peaks flows diminished rapidly in both systems, but the pattern of low August flows was less evident in the S.F. Flathead hydrograph where minimum flows occurred later - at the end of September. In the UCFR sites flows increased appreciably in the first half of October as irrigation removals diminished, a pattern that largely was absent in the S.F. Flathead hydrograph. Assuming the undisturbed hydrographs would exhibit similar seasonality between drainages, the major insight from this comparison is that water removal is particularly affecting the UCFR hydrograph from approximately mid July to the end of September (Figure 15, see Figure 11 for comparison).

Given that the UCFR seems to be particularly impacted in later summer by water removal, an effort was made to quantify the relative impacts longitudinally from a hydrological statistics perspective using the previously described average hydrographs from 1988 to 2013 and 2010 to 2012. Specifically, to evaluate the relative degree to which the UCFR sites were affected by water removal the average flows during the lowest month (August) were expressed as a percent relative to those after irrigation season (November). This approach was also used for the S.F. Flathead for both time periods to provide general context. A key point with this approach is that sites should be compared only within the same year to evaluate longitudinal differences in flow patterns. The 1988 to 2013 analysis shows that August flows relative to November were moderately lower at Galen, dropped sharply at Deer Lodge and then increased moderately at Gold Creek and again at Turah. All of the UCFR sites were lower than the S.F. Flathead, with a minimum difference of 9.6% at Galen. The 2010 to 2012 results improved the spatial resolution of the 1988-2013 hydrological statastics analysis, showing that in a period of moderately high average flows the August flow diminishment at Deer Lodge extends to Above Little Blackfoot with only slight improvement. Low flow conditions generally improved moving further downstream but a small exception to this general pattern existed between Gold Creek and Drummond. The higher average flows observed in 2010 to 2012 (relative to 1988 to 2013) enhanced flows in August more than November, explaining the greater values in the 2010 to 2012 flow index calculations. Based on the combination of both time frames, it appears from a hydrological statistics view the area of greatest dewatering concern begins between Galen and Deer Lodge and then conditions improve slightly at Above Little Blackfoot. At Gold Creek (below the Little Blackfoot confluence) conditions improve appreciably, then drop slightly downstream at Drummond, and are much improved below at Turah (below the Rock Creek confluence) (Table 1).

Because 2010 to 2012 was a period of moderately high average flows and the longitudinal rankings could be affected by discharge, a follow up analysis examined how the longitudinal rankings vary between high and low flow years. USGS data from 2011 and 2013 were used as high and low flow years, respectively, and graphed from June through November for six sites. In the high flow year of 2011 all sites exceeded the lower inflection point, and from a relative view point these exceedances were lowest at Gold Creek and modestly higher at Deer Lodge but vice versa in absolute terms (Figure 16). In the low discharge year of 2013 flows at Galen fell slightly below the lower inflection point while at Deer Lodge and Gold Creek flows fell substantially below the lower inflection point to a similar degree from a percentage (i.e. relative) perspective, but vice versa from an absolute stand point. A substantial improvement was evident at Drummond where flows remained at least slightly above the lower inflection point, and by Turah conditions improved substantially (Figure 17).

The high versus low flow analysis provided additional insights regarding the longitudinal flow patterns. In agreement with the earlier Deer Lodge analyses, during the low water year (2013) low flows arrived earlier in the summer and were sustained for longer. However, this pattern varied longitudinally. Specifically, the time frame where flows were minimized increased from upstream to downstream in the low flow year, but this generally was not evident in the high flow year (2011). Another insight from the flow comparison is that in the high flow year discharge was greater during late summer at Above Little Blackfoot relative to Deer Lodge, but during the summer of the low flow year discharge was similar between site (Figures 16 and 17). Given the greatest risk to the fishery is in low flow years the 2013 results are particularly relevant. Based on habitat considerations, these results suggest that the area of greatest dewatering concern in low water years begins between Galen and Deer Lodge and continues downstream to between Gold Creek and Drummond. Within this stretch, 2013 late summer flows did not improve between Deer Lodge and Above Little Blackfoot. Downstream at Gold Creek the time frame of sustained minimum flows was shorter than at Deer Lodge and Above Little Blackfoot in 2013, suggesting low flow conditions may be less stressful to fish at Gold Creek due to their shorter duration.

The August/November hydrological statistic was used on the 2011 (high discharge) and 2013 (low discharge hydrographs) to further evaluate the conclusions based on the lower inflection point approach. The results support the notion that between Galen and Deer Lodge to Above Little Blackfoot is the area of greatest concern for summer low flows, but the ranking of Deer Lodge relative to Above Little Blackfoot depended on flow conditions. Specifically, when flows were lower in 2013 the flow index was slightly lower at Above Little Blackfoot relative to Deer Lodge, and the opposite held true in 2011 when flows were high (Table 2). In general, the 2013 hydrological statistic approach provided a similar result to the 2013 hydrograph analysis.

Specifically, both analyses suggest that the area of greatest dewatering concern begin between Galen and Deer Lodge, remains marginal at Above Little Blackfoot, some improvement is evident at Gold Creek, and then conditions progressively improve at Drummond and then again at Turah.

Given that the upper river seems to be the area of greatest dewatering concern in low flow years, additional flow information from non USGS sources was evaluated. The area between Galen and Deer Lodge is of particular interest because of the large volume of water removal. Fortunately, flow data for this section of river were collected from August 5 to August 7, 2013 from multiple sites during a low water year (Clark Fork Coalition 2013). From just above the Helen-Johnson Ditch (river mile 337) downstream to just above the Whalen Ditch (river mile 330), flows varied but overall increased from 48 cfs to 65 cfs. Flows dropped below the Whalen Ditch and then dropped more substantially slightly downstream below the Westside Ditch to 20 cfs. From just below the Westside Ditch flows varied but remained low to below Sager Lane (river mile 323) where flows fell to their lowest level at 13 cfs. No measures below this site were made until above Kohrs-Manning Ditch (river mile 314) at which point flows increased to 58 cfs but were then diminished by this diversion to 38 cfs. Based on this survey, it is apparent that the area of particular concern within the Galen to Deer Lodge stretch is from below the Westside Ditch to somewhere between below Sager Lane and the Kohrs-Manning Ditch. This conclusion is further supported by an earlier assessment that identified the area between Westside Ditch to Sager Lane as the area of greatest dewatering concern in the UCFR between Perkins Lane and the Little Blackfoot confluence (UCFRBSC 2006).

Longitudinal Patterns Synthesis

The longitudinal flow and habitat analysis provided insights into how low flow patterns varied through space and time in the UCFR. The 1988 to 2013 data shows that summer flow diminishment is less evident at Galen than the other sites. Based on the remaining three sites it is apparent that the period of minimum flow occurred earlier in the upper river at Deer Lodge relative to Gold Creek and particularly relative to Turah. The 1988 to 2013 data also provided a basis to examine low flows in the context of habitat considerations (i.e. the inflection point) showing flows at Deer Lodge were of particular concern. However, even below the Little Blackfoot at Gold Creek habitat conditions based on flows were only slightly improved. Using data from additional sites during a period of moderately high average flows (2010 to 2012) provided a similar general longitudinal pattern, and improved the spatial resolution to show that habitat conditions started substantially improving at Drummond (instead of Turah as in the 1988-2013 analysis). Further analyses were conducted focusing on recent high (2011) and low (2013) discharge years, and the results from the low flow year particularly were emphasized for flow augmentation efforts to benefit fisheries. In 2013 sustained low flows arrived earlier and occurred for longer relative to 2011, and this pattern was increasingly evident moving upstream. Accordingly, although minimum flows in 2013 fell below the lower inflection point to a similar relative (i.e. percentage) degree at Deer Lodge and Gold Creek in 2013, the time period of sustained minimum flows was lower at Gold Creek and this became progressively more evident downstream at Drummond and Turah. Further, during 2013 low flow conditions did not improve from Deer Lodge to Above Little Blackfoot, contrasting with 2011. Although the current assessment suggests Galen to Deer Lodge and Deer Lodge to Above Little Blackfoot are of similar dewatering concern, others studies have identified major dewatering issues between Galen and Deer Lodge that are not fully evident at the Deer Lodge gage. Based on flow versus habitat considerations (particularly during low flows) and discharge data from non USGS sources collected between Galen and Deer Lodge, it seems the area between Galen and Deer Lodge is of greatest concern, Deer Lodge to Above Little Blackfoot is of second greatest concern, and Above Little Blackfoot to Gold Creek is the third priority area. If flow augmentation is pursued in the later priority area based on habitat conditions, the time frame could be adjusted to start in late July rather than the recommended mid July time for Deer Lodge that was determined in the seasonal patterns analysis. It should be noted that the Montana Department of Justice recently has identified the Bearmouth vicinity as a priority area for restoration (NRDP 2012), contrasting to the current analysis. This difference is largely related to differing criteria, specifically low flow considerations alone in the current analysis versus depressed fish populations for the Department of Justice's assessment (NRDP 2012, Naughton 2015).

The hydrological statistic approach (based on the % August/November discharge) largely complimented the habitat analyses. The 1988 to 2013 data showed that August flows (relative to November) diminished greatly from Galen to Deer Lodge then increased appreciably at Gold Creek and again at Turah. However, during the moderately high average flows observed from 2010 to 2012 the August diminishment at Deer Lodge was less evident relative to the downstream sites. Like the habitat approach, these analyses suggest that the upper stretch of the UCFR is of particular concern during lower discharge years and that flow enhancement efforts should focus on the longitudinal patterns based on years of low flow. Accordingly, the 2011 (high flow) versus 2013 (low flow) comparison is particularly germane and also added more sites relative to the 1988 to 2013 investigation. The results show that August flow diminishment was of concern at Deer Lodge and slightly deteriorated further at Above Little Blackfoot during 2013 (low flow) but not 2011 (high flow). In further general agreement with the habitat based approach, August flow conditions progressively improved downstream beginning at Gold Creek in 2013. Because the hydrological statistic and hydrograph analyses generally provided similar longitudinal rankings, particularly during the low flow year of 2013, no changes to the suggested priority scheme for flow augmentation (presented in the previous paragraph) were made.

References

Clark Fork Coalition. 2013. Unpublished data collected for and provided by Montana DOJ NRDP.

DNRC. 2014. Montana State Water Plan, A Watershed Approach to the 2015 Montana State Water Plan. Report by Montana DNRC.

FWP. 1986. Application for Reservations of Water in the Upper Clark Fork River Basin. Water reservation application by Montana FWP for Montana DNRC.

Naughton, J. 2015. Clark Fork River Fishery Assessment: Flint Creek to Rock Creek Reach. Draft Report by RESPEC for Montana DOJ.

NRDP. 2012. Final Upper Clark Fork River Basin Aquatic and Terrestrial Resources Restoration Plans. Report by Montana Natural Resources Damage Program, Department of Justice.

UCFRBSC. 2006. Upper Clark Fork River Flow Study. Report by the Upper Clark Fork River Basin Steering Committee.

Table 1. Average % August cfs/November cfs based on USGS gaging sites from 1988 to 2013 and 2010 to 2012 in the UCFR and South Fork Flathead.

USGS Gage Site	1988-2013 % Aug. cfs/Nov. cfs	2010-2012 % Aug. cfs/Nov. cfs
Galen	80.3	110.7
Deer Lodge	46.7	62.8
Above Little Blackfoot		66.1
Gold Creek	63.0	77.3
Drummond		73.9
Turah	78.3	91.0
S.F. Flathead	89.9	141.7

Table 2. % August cfs/November cfs based on six USGS gaging sites from a high (2011) and low (2013) discharge years in the UCFR.

Site	2011 (high flows) % Aug. cfs/Nov. cfs	2013 (low flows) % Aug. cfs/Nov. cfs
Galen	126.8	39.9
Deer Lodge	79.1	32.0
Above Little Blackfoot	80.9	29.5
Gold Creek	96.0	38.1
Drummond	89.4	45.1
Turah	107.4	58.5

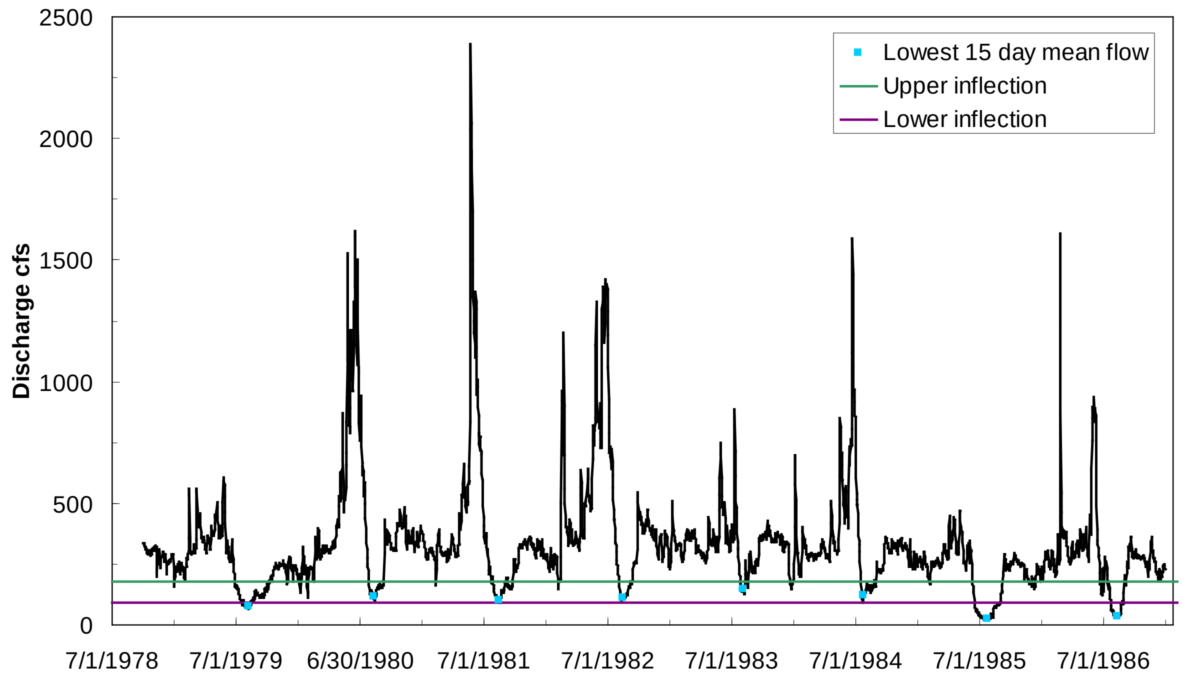

Figure 1. Daily discharge versus time at the USGS Deer Lodge gage from 1978 to 1986.

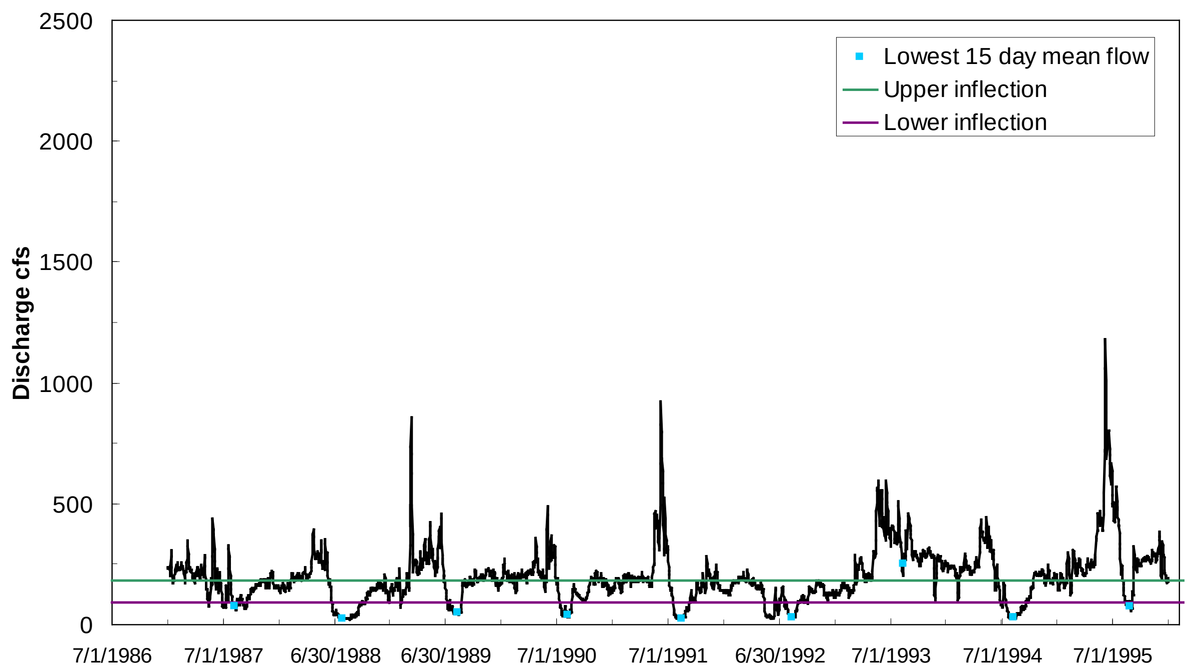

Figure 2. Daily discharge versus time at the USGS Deer Lodge gage from 1987 to 1995.

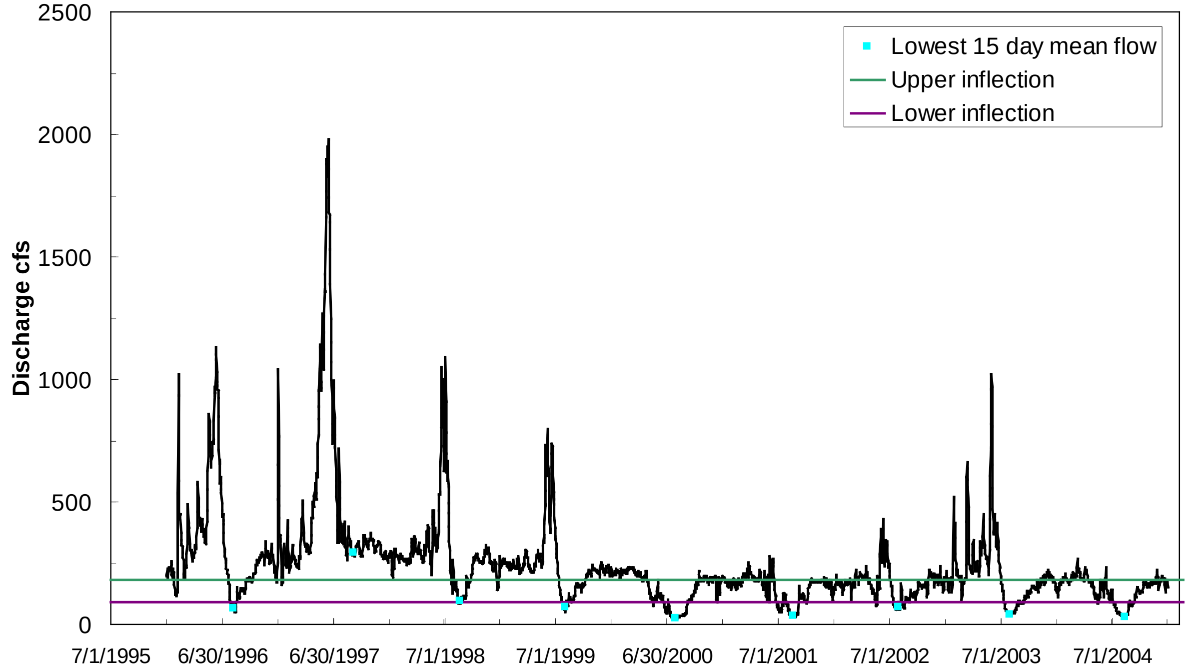

Figure 3. Daily discharge versus time at the USGS Deer Lodge gage from 1996 to 2004.

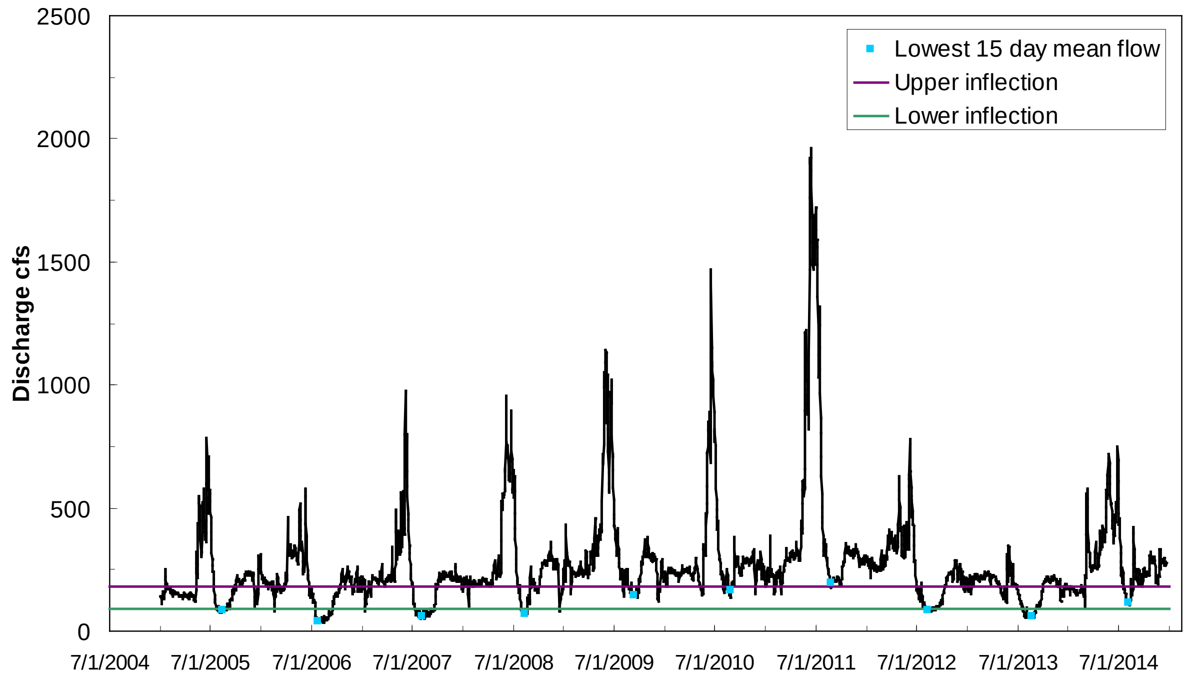

Figure 4. Daily discharge versus time at the USGS Deer Lodge gage from 2005 to 2014.

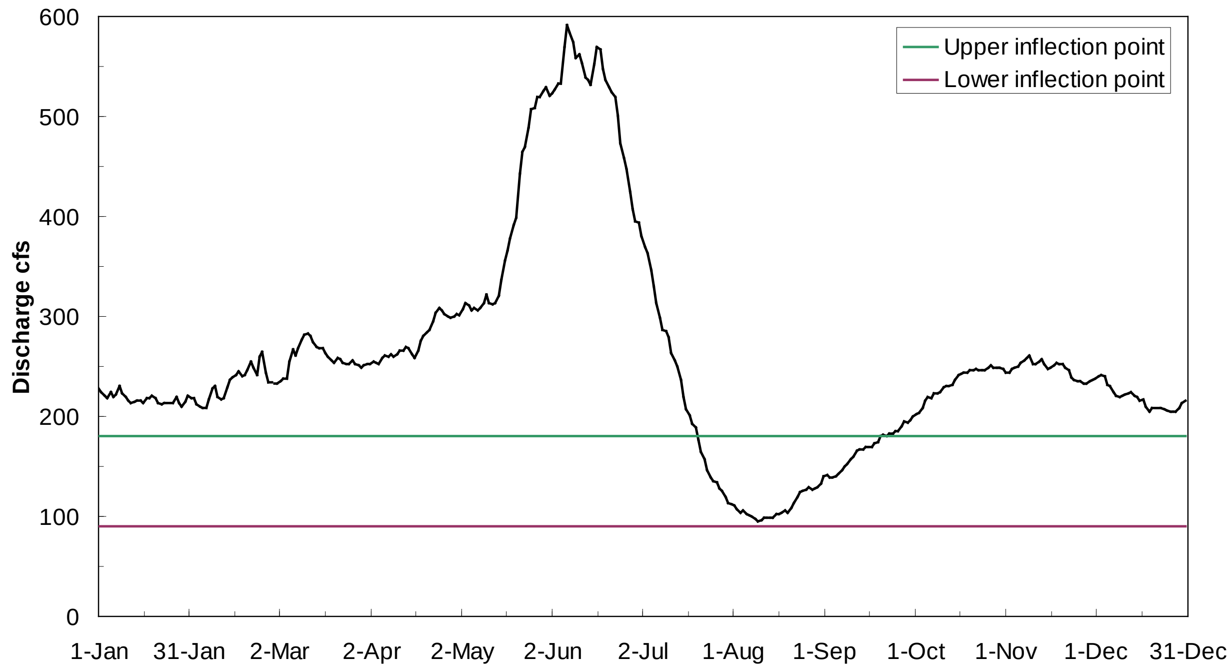

Figure 5. Average daily discharge versus time at the USGS Deer Lodge gage from 1978 to 2014.

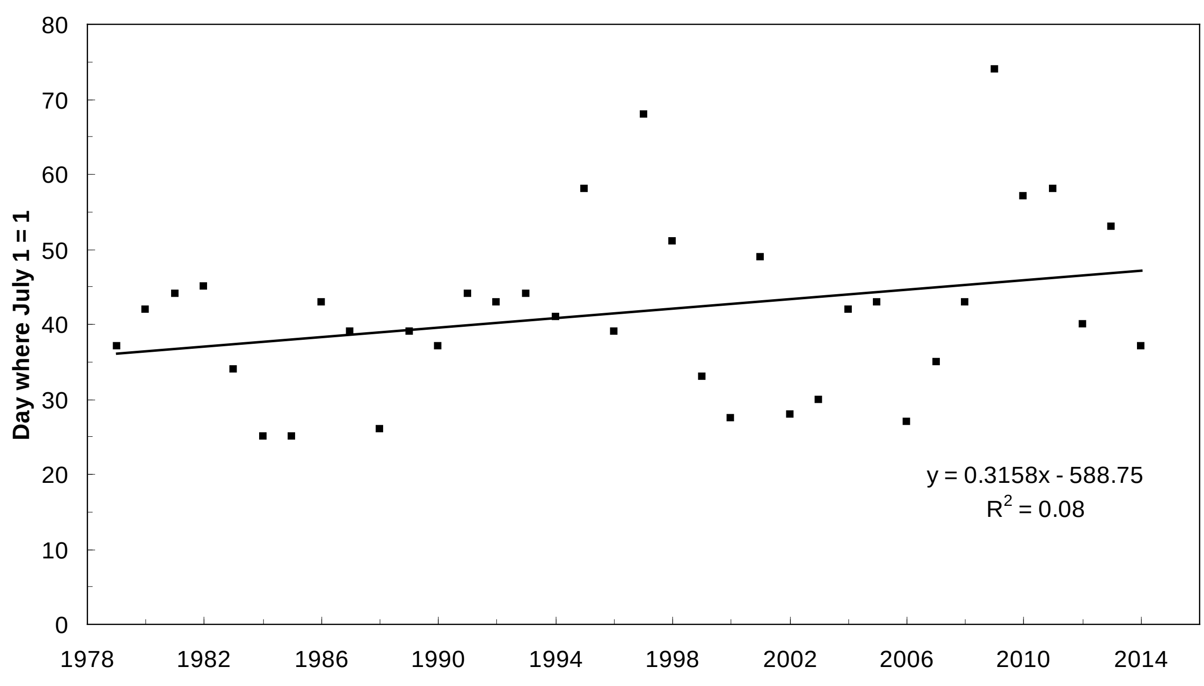

Figure 6. Middle day of 15 day lowest mean flow (where July 1 = 1) versus year (p = 0.09) based on data from the USGS Deer Lodge gage from 1979 to 2014.

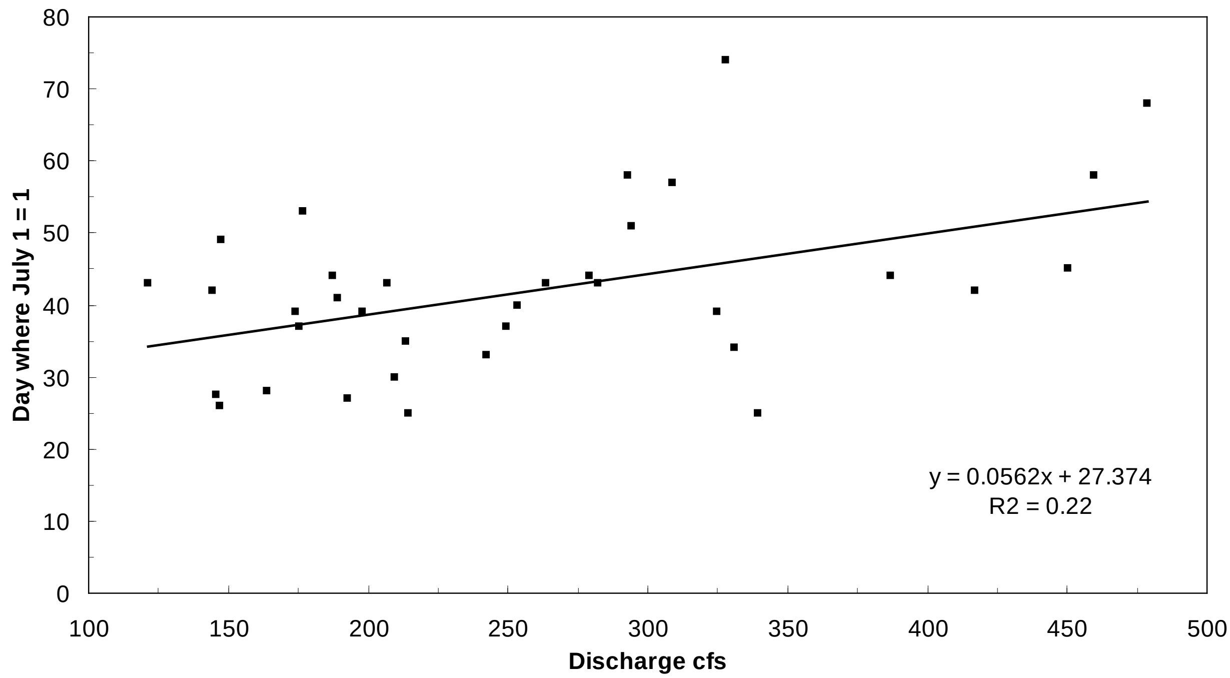

Figure 7. Middle day of 15 day lowest mean flow (where July 1 = 1) versus yearly average discharge ($p < 0.01$) based on data from the USGS Deer Lodge gage from 1979 to 2013.

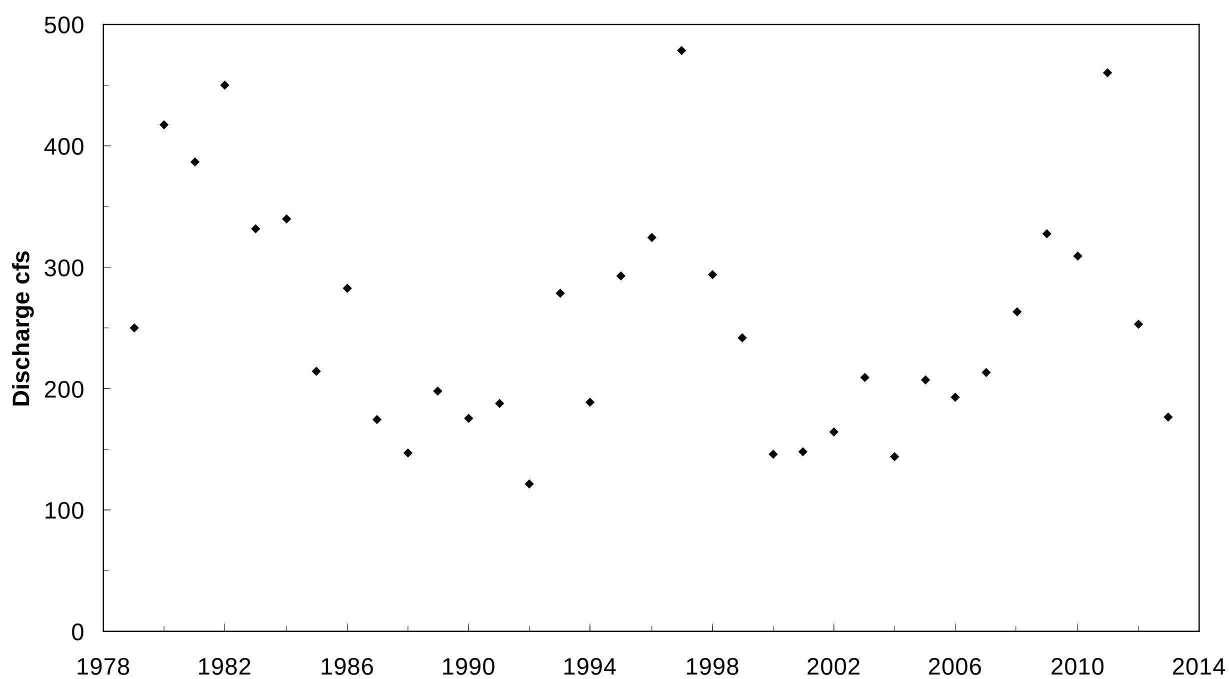

Figure 8. Yearly average discharge versus year based on data from the USGS Deer Lodge gage from 1979 to 2013.

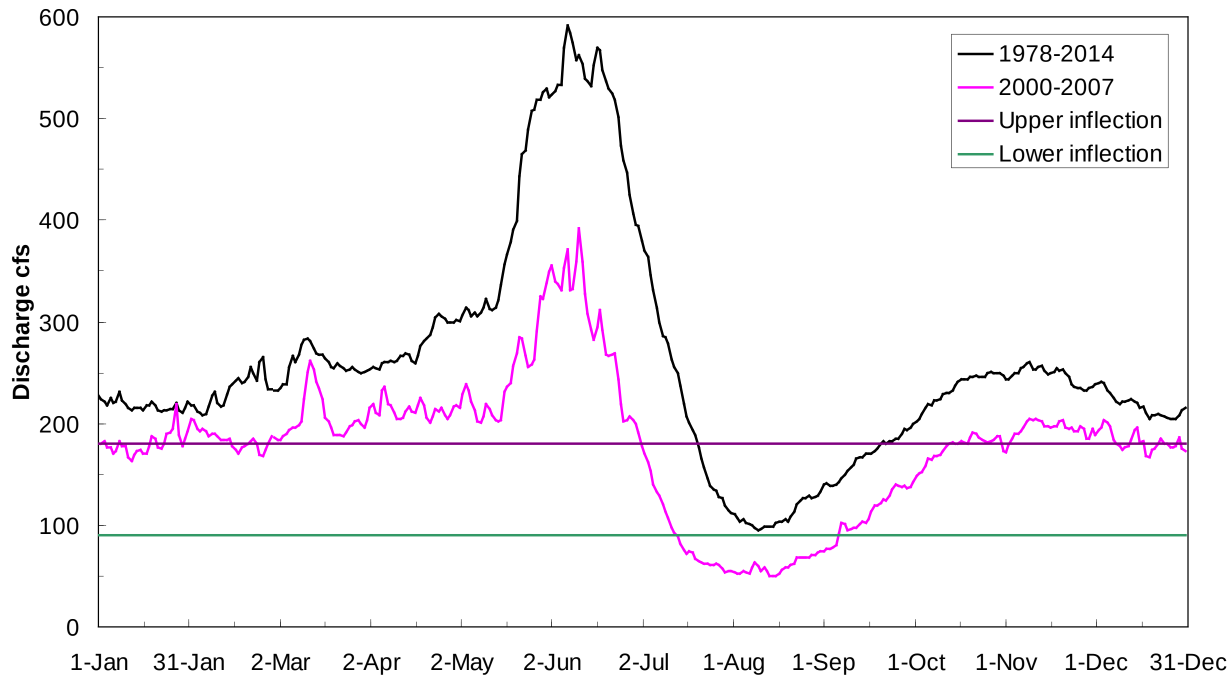

Figure 9. Yearly average discharge versus year based on data from the USGS Deer Lodge gage from 1978 to 2014 and 2000 to 2007.

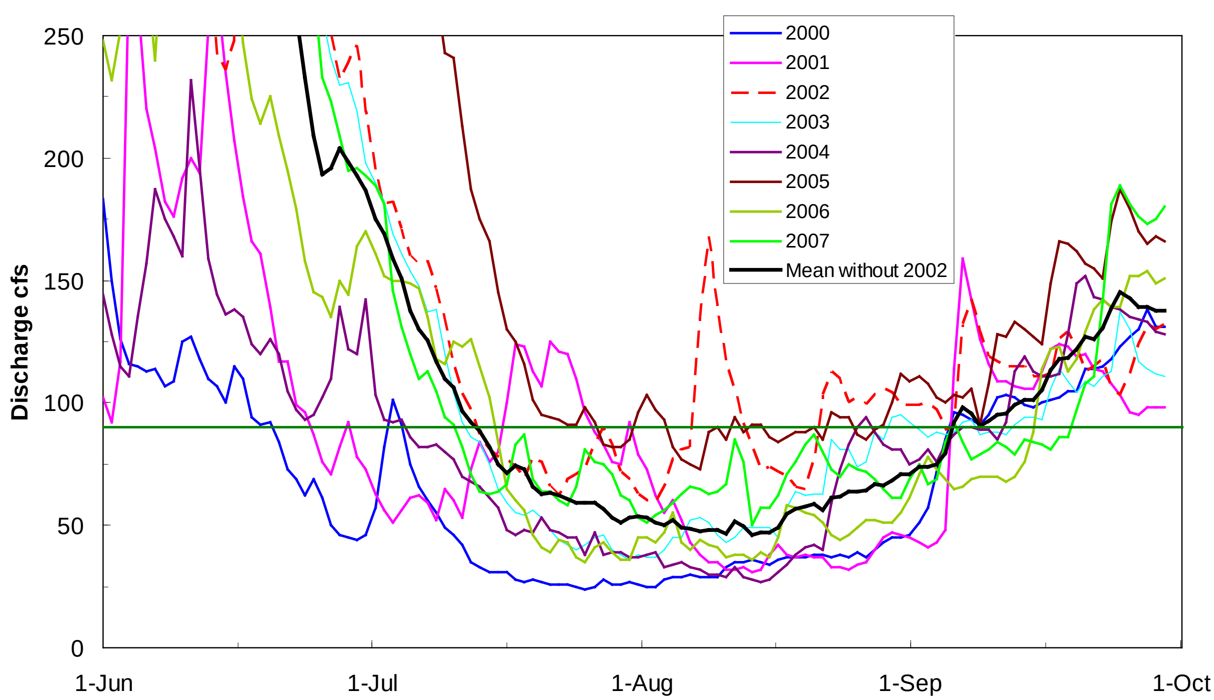

Figure 10. Discharge versus date for each year from 2000 to 2007 based on data from the USGS Deer Lodge gage with associated lower inflection point.

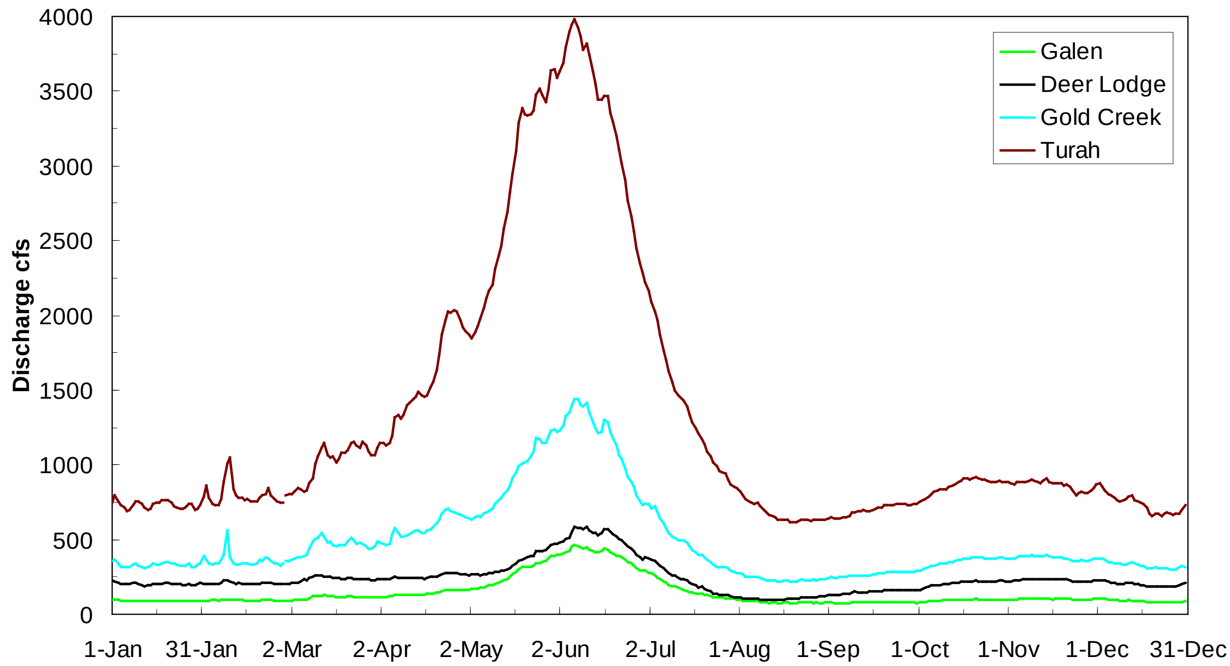

Figure 11. Average daily discharge from 1988 to 2013 at four USGS gaging sites on the UCFR.

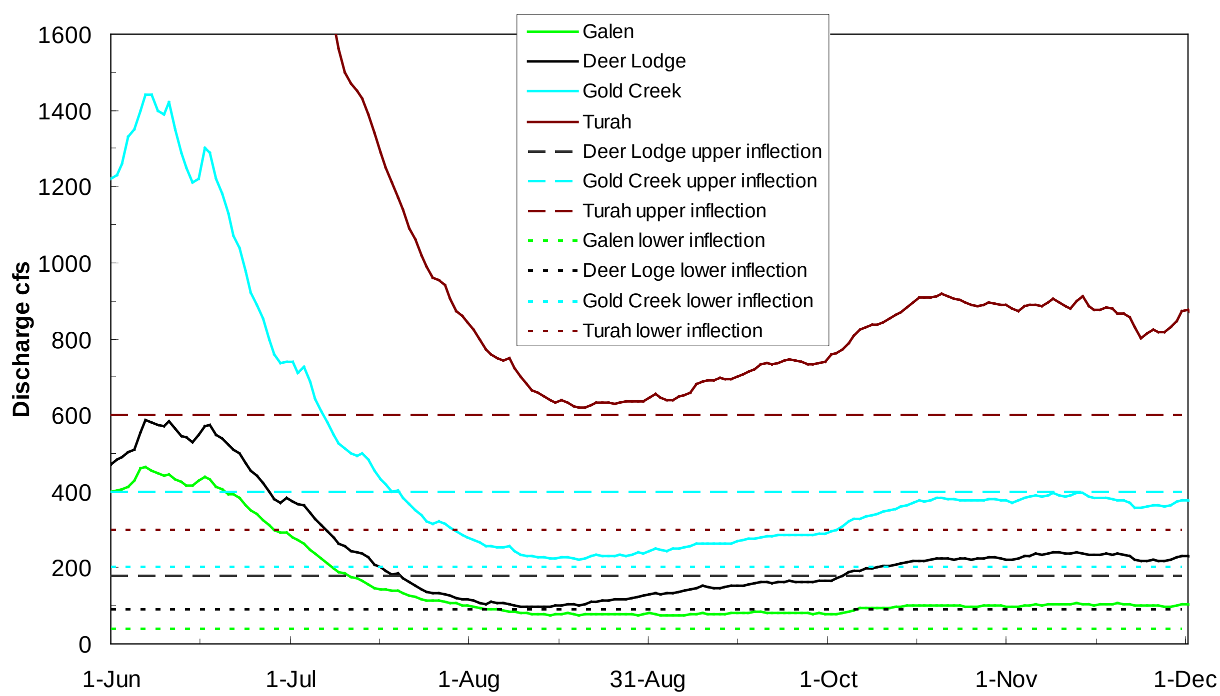

Figure 12. Average daily discharge from 1988 to 2013 at four USGS gaging sites on the UCFR with upper and lower inflection points associated with each gaging station.

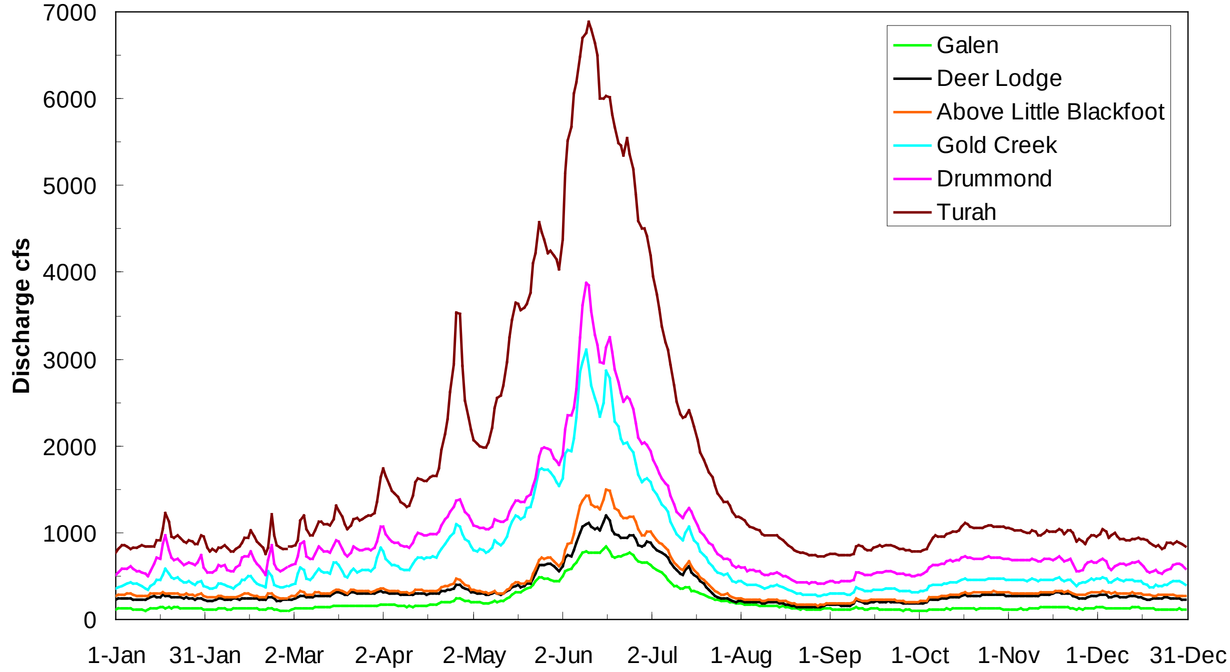

Figure 13. Average daily discharge from 2010 to 2012 (moderately high discharge) at six USGS gaging sites on the UCFR.

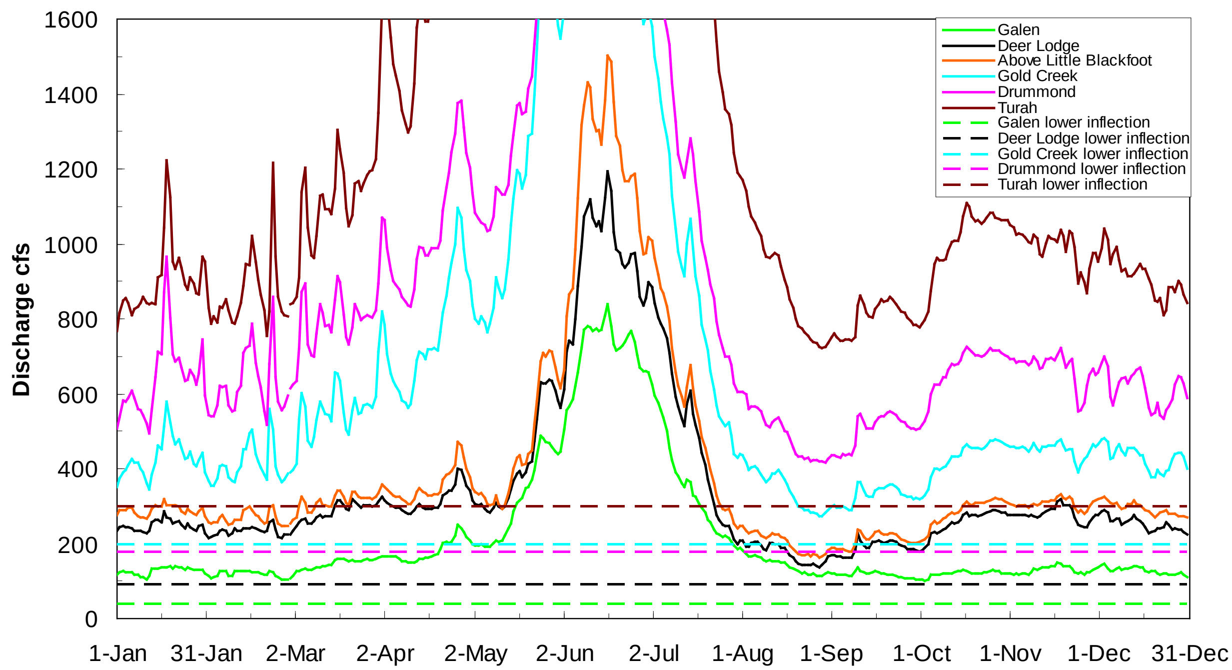

Figure 14. Average daily discharge from 2010 to 2012 (moderately high discharge) at six USGS gaging sites on the UCFR with lower inflection points associated with each gaging station.

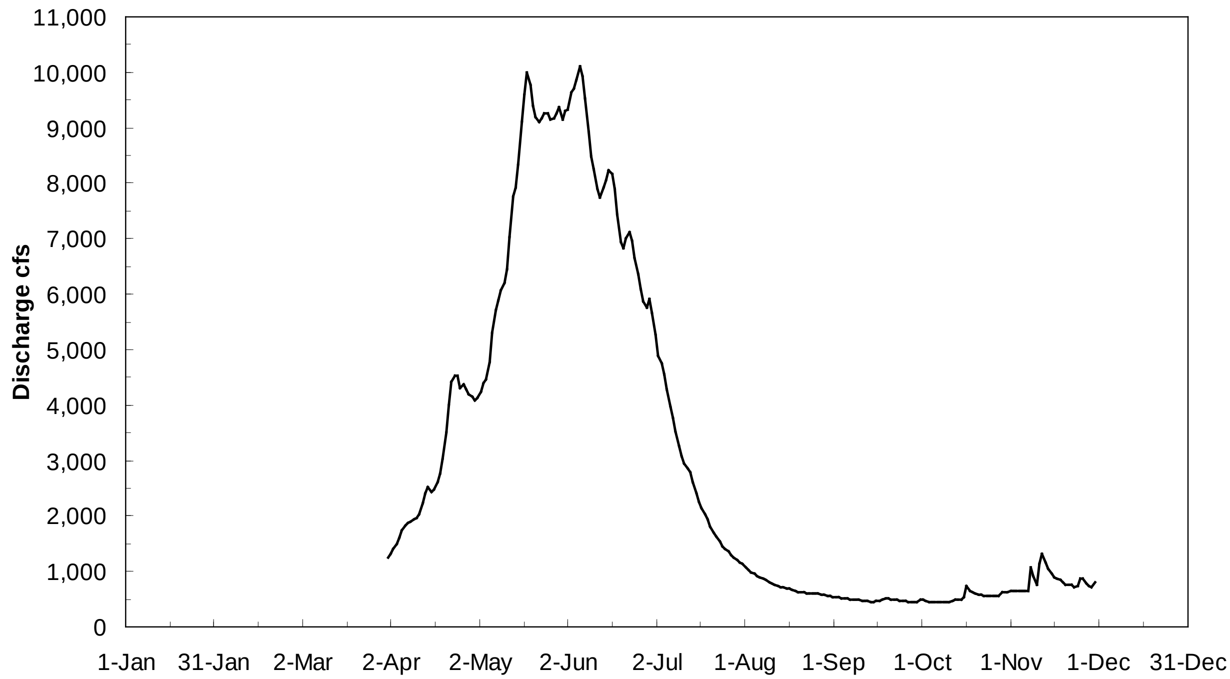

Figure 15. Average daily discharge from 1988 to 2013 for the South Fork of the Flathead River at the Twin Creek USGS gaging site.

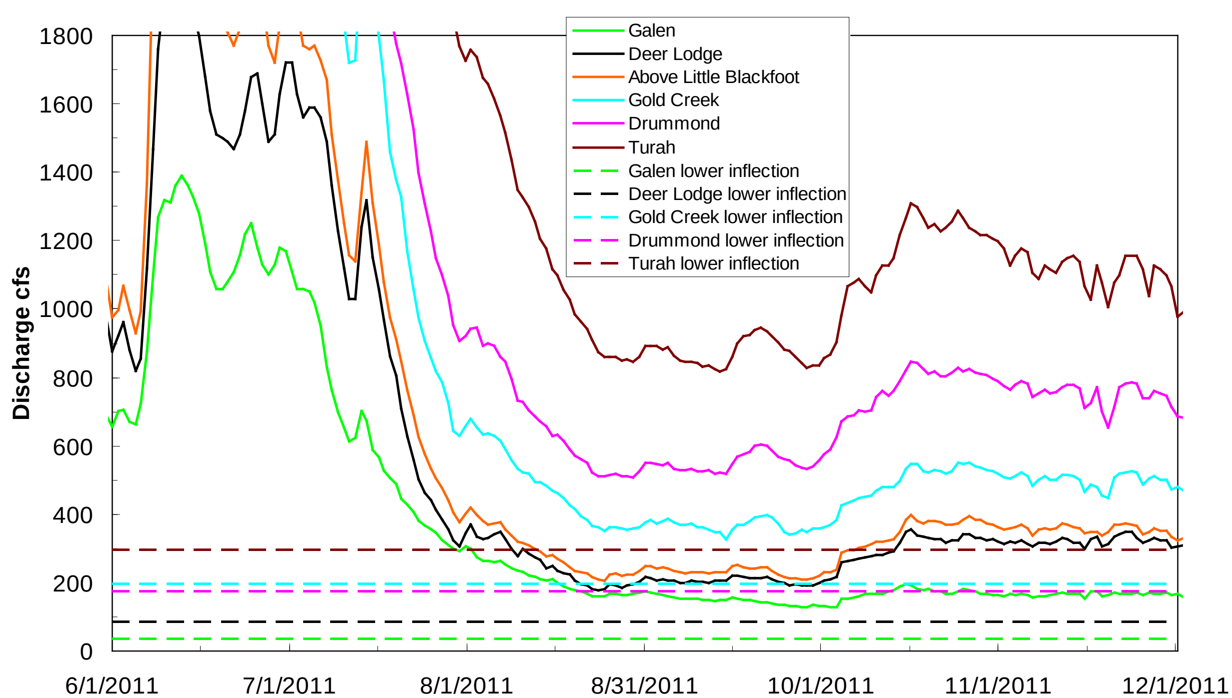

Figure 16. Daily discharge from 2011 (high flow year) at six USGS gaging sites on the UCFR with lower inflection points associated with each gaging station.

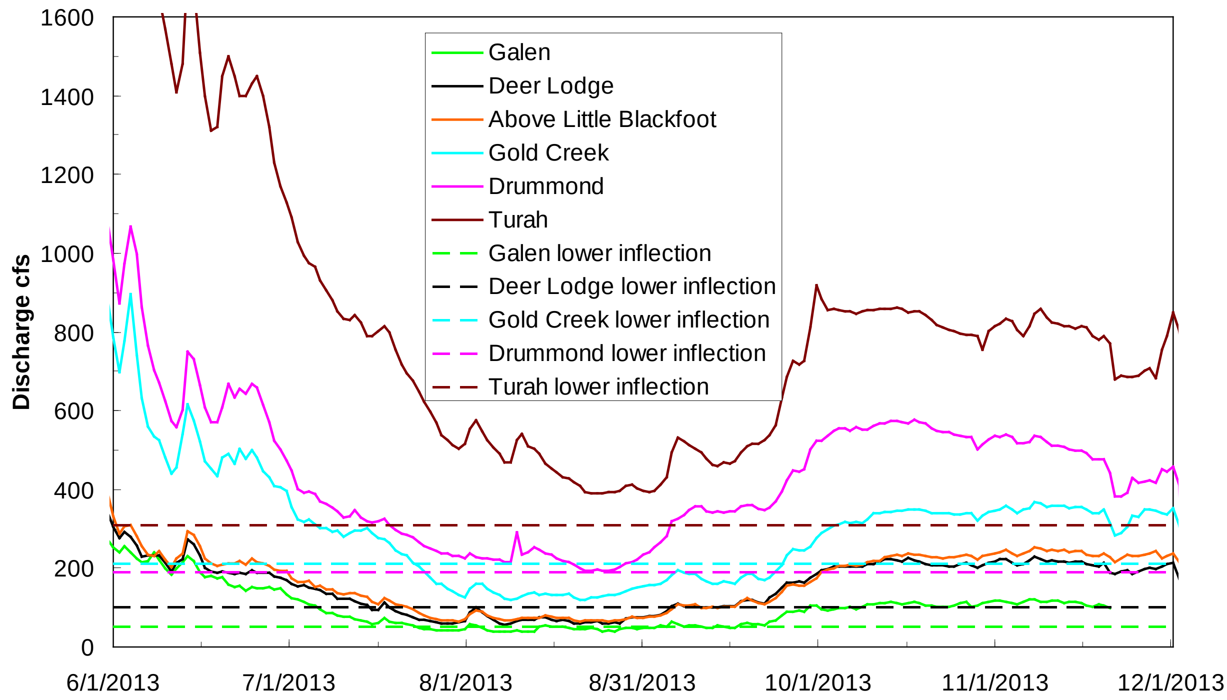

Figure 17. Daily discharge from 2013 (low flow year) at six USGS gaging sites on the UCFR with lower inflection points associated with each gaging station.

CHAPTER 5:

Temperature Patterns in the Upper Clark Fork River

Introduction

Summer water temperatures in the Upper Clark Fork River (UCFR) can be warm enough to create issues for the salmonid fishery. Bull trout growth is maximized at 13 C and temperatures above 21 C are lethal (Selong et al. 2001), similar to cutthroat trout who maximize growth at 14 C and reach lethality at 20 C (Bear et al. 2007). Further, even when temperatures are below lethality for cutthroat and bull trout, they are vulnerable to competitive displacement as water temperatures increasingly exceed their growth optima. Accordingly, several studies have linked the competitive displacement of bull trout and cutthroat by introduced salmonids to warm yet sublethal temperatures (for example, Bear et al. 2007, McMahon et al. 2007). Rainbow trout, brook trout, and brown trout can tolerate higher water temperatures (Bear et al. 2007, Selong et al. 2001) and thus can survive in warmer river reaches where cutthroat trout and bull trout are at least seasonally excluded. However, even thermally tolerant salmonids such as brown trout can suffer mortality from the combination of high water temperatures and degraded water quality in the UCFR (Richards et al. 2013).

Two major factors that contribute to the elevated summer temperature conditions are diminishment of the riparian vegetation and low discharge. The diminishment of riparian vegetation is caused by numerous factors such as metals contamination of the floodplain, heavy grazing, direct removal, and confinement/degradation of the floodplain by the highway, railroad, and rip rapping. The resulting loss of shading by the riparian vegetation allows water temperatures to increase, particularly in smaller channels where vegetation assumes a larger role in shading the water. Low flows contribute to higher water temperatures, particularly by increasing the time for heating from the water's emergence as cool groundwater and also by providing a shallower mass of water to absorb the sun's energy. The purpose of this chapter is to examine seasonal and longitudinal temperature conditions in the UCFR, focusing on summer, to provide information for efforts to increase instream flow to benefit salmonid fisheries.

Seasonal Patterns

To describe the basic seasonal temperature pattern, the average of daily mean temperatures from October 1991 through September 2004 was calculated using USGS data from Galen as this site had the longest running data set. Low temperatures (i.e. 2.0 C and below) occurred from late November to mid February. Temperatures climbed steadily from March to late May and then paused briefly from late May to mid June in association with peak runoff. Temperatures resumed their climb in mid June and peaked on July 28 and 29, then diminished relatively steadily until early November. This diminishment was slightly more rapid than the increase through the spring and early summer (Figure 1).

To examine yearly variation in the seasonal temperature pattern, the maximum daily temperature from October 1991 through September 2004 was plotted using Galen data. Maximum temperatures are of particular interest for cold water fisheries. These data show that there was considerable variation in the timing of the yearly temperature peak, ranging from June 20 to August 5 with the distribution of peaks skewed towards the August date. Temperatures as high as 25.5 C occurred in 1992, and temperatures above 20 C were common during most summers (Figure 2).

Yearly Patterns

A preliminary investigation of summer water temperatures by year was conducted using the data from the Galen gage from 1992 to 2004, and it should be recognized that the time frame of the available data was short for this type of analysis. Monthly mean water temperatures were calculated for July as well as August and used in regressions versus year. No significant relationships between temperature and year were observed for July ($p = 0.25$) or August ($p = 0.85$) (Figure 3).

Discharge Patterns

Given that many stretches of UCFR has marginal thermal conditions for salmonids during summer, a relevant consideration is the relationship between summer discharge and temperature. Low discharge has the potential to increase summer temperatures by providing a shallower mass of water to heat, increasing the time it takes for water to flow from the cooler uplands, and possibly by reducing the proportion of the water's surface that is shaded by riparian vegetation (particularly in smaller channels). However, it should also be noted that high summer water temperatures also have a non-causal linkage to discharge. Specifically, the hot conditions that increase water temperatures also reduce flows by increasing evapo-transpiration (including on irrigated lands) and are also typically associated with lower summer precipitation. The degree to which high summer temperatures are caused by low flows versus correlated with low flows is beyond the scope of this report, but likely both causation and correlation play an appreciable role.

To examine the relationship between summer temperature conditions and discharge USGS data from Galen were used as this site had the most extensive record (1991 to 2004). Because 20 C is often used as an upper bench mark for cold water fisheries, the number of days each year where the maximum temperature was 20 C or greater was calculated for use in subsequent analyses. A negative relationship existed between the annual number of days 20 C and July mean discharge ($p < 0.01$), and this relationship was even stronger (i.e. steeper slope and less unexplained variation) when August mean discharge was used as the independent variable ($p < 0.01$). This analysis shows the striking correspondence between low summer flows, particularly in August, and the temporal duration of stressful thermal conditions (Figures 4 and 5). The major implication for the fishery is that extended periods of high water temperatures and low discharge often come together.

To specifically look at sustained stressful thermal conditions, further analyses were conducted that investigated the relationships between the timing of the hottest week and discharge based on USGS data from Galen. The hottest week was calculated based on the highest average maximum daily temperature over seven days (using day four as the date in the analyses where July 1 = 1, July 2 = 2, etc.) and used in subsequent analyses. No strong relationship existed between the date of the hottest week and July mean discharge ($p = 0.17$) (Figure 6). However, the average maximum daily temperature in the hottest week exhibited a strong negative relationship with July mean discharge ($p < 0.01$). Based on the regression equation and the range of observed July mean flows, the predicted hottest week ranged from 19.5 C during the highest discharge year and 23.4 C during the lowest discharge year (Figure 7).

Longitudinal Patterns

To understand how temperature conditions at Galen reflect those at the downstream USGS sites (with shorter data sets) average maximum daily temperature comparisons were made during the periods of overlapping data collections, and the subsequent interpretations were restricted to summer. Four UCFR sites provided temperature data, beginning from the most upstream gage and moving downstream: Galen (1991-2004), Deer Lodge (2000-2004), Gold Creek (1991-1998), and Turah (1991-1999). Because of the varied time frame, paired site comparisons were based on periods of temporal overlap. Based on data from May 2001 through September 2004, temperatures were higher at Deer Lodge relative to Galen as temperatures increased through the summer and peaked, but were only slightly higher at Deer Lodge on the descending limb of the summer thermograph (Figure 8). Based on temperatures from May 1992 through September 1998, the Gold Creek exhibited higher temperatures relative to Galen throughout the summer (Figure 9) while those at Turah were similar to Galen in the summer (Figure 10). The emergent pattern from these comparisons is that summer temperature conditions vary modestly amongst sites, but do become increasingly challenging for cold water fishes from Galen to Deer Lodge to Gold Creek. Relative to Galen, the challenge at Deer Lodge is the warmer temperatures on the ascending limb and peak of the thermograph. The Gold Creek site shared this pattern to a similar thermal extent but also had elevated temperatures on the descending limb during summer, providing a longer period of thermal stress. Far downstream at Turah the similar summer temperatures relative to Galen presumably are mostly due to the cooling influence of Rock Creek. An assumption of this longitudinal analysis is that the relative differences between Galen and the other sites did not vary appreciably between the 2001 to 2004 and 1992 to 1998 comparisons.

Because the USGS data had varied periods of temporal overlap and somewhat limited spatial coverage, more recent data from FWP's caged fish studies (Richards et al. 2013, Leon et al. 2014, raw data provided by Nathan Cook) was used in a second analysis of longitudinal temperature patterns. Maximum daily temperature was used at sites from 2011 to 2014 from June to late August, and the available data varied among years within sites (i.e. data was not available for every site in each year). In 2013 data from two Galen sites (left and right) were provided by FWP, and thus temperatures were averaged by day to create one Galen data set.

The longitudinal patterns of summer maximum temperatures in the FWP data set resembled those from the USGS analyses with the highest temperatures observed in the middle part of the UCFR. However, the FWP provided additional spatial information to evaluate the longitudinal temperature patterns. During the hottest part of each summer from 2011 to 2013 temperatures tended to be lowest at Galen and Turah, with the exception the high water year of 2011 where temperatures at Turah were substantially warmer than Galen. No data from Turah were available for 2014, but Galen remained the coolest site during this year. In each summer from 2011 to 2014 Upstream of Little Blackfoot had the highest single day maximum temperature. This site also tended to have the highest temperature during the hottest part of each summer, although this was less evident in the high water year of 2011 where thermal differences among sites tended to be lowest (with the notable exception of Galen) (Figures 11 to 14).

Thermal comparisons for the remaining sites were somewhat hindered by the year to year variation in both the data available for a given site, and the variation in thermal patterns by year presumably related largely to differences in discharge. In 2012 average discharge was typical (see Chapter 4, Figure 8) and this year also had the greatest number of sites. In this year during the period of maximum sustained temperatures (using July 7 through August 22 in this analysis) Upstream of Little Blackfoot had the highest maximum average daily temperature (22.7 C) followed by (in decending order): Bearmouth (22.3 C), Deer Lodge (21.8 C), Gold Creek (21.7 C), Turah (20.5 C), and Galen (20.4 C). Accordingly, the area of greatest temperature concern based on the 2012 data (typical average discharge year) is from Deer Lodge to Bearmouth, and the warmest site within this stretch was Upstream of Little Blackfoot and the second warmest site was Bearmouth. The more limited sites from 2014 (using July 7 to August 19 as the period of sustained maximum temperatures) had the following average maximum temperatures: Upstream of Little Blackfoot (22.6 C), Deer Lodge (22.1 C), Bearmouth (22.0 C), and Galen (20.4 C). The difference relative to 2012 is that in 2014 Deer Lodge was slightly warmer than Bearmouth. In both analysis, Deer Lodge to Bearmouth was identified as the area of thermal concern, and the greatest issue was at Upstream of Little Blackfoot.

The FWP data analysis raises the question: does the influx of Little Blackfoot water cool the UCFR below the confluence and thus limit the downstream spatial extent of the high summer temperatures? This question was addressed by comparing 2013 and 2014 summer temperatures in the Little Blackfoot (again using FWP data from the caged fish study) to those at the Upstream of Little Blackfoot site using data from 2013 and 2014. In both years water was cooler in the Little Blackfoot during the early period of sustained high temperatures. However, in 2013 (low discharge year) both rivers had similar temperatures by late July while in 2014 (which had higher average discharge than 2013) the Little Blackfoot remained cooler during the period of sustained maximum temperatures (Figures 15 and 16). The insight is that when discharge is low and water temperatures are high, the Little Blackfoot is unlikely to appreciably cool the UCFR below their confluence after late July. Accordingly, the highly marginal thermal conditions at the Upstream of Little Blackfoot site likely extend some distance downstream, at least in low water years during the later period of sustained maximum summer water temperatures.

The high summer temperatures in the middle UCFR are likely a limitation to the salmonid fishery, particularly for cutthroat trout and bull trout which require colder water than the other salmonids of the UCFR. A less obvious issue is how the "warm in the middle" longitudinal pattern of the UCFR may constrain salmonid migration to reach cooler upstream temperatures. For example, if a fish residing in the UCFR near Gold Creek begins to migrate upstream for cooler water in late summer they could be deterred by the warmer water in the vicinity of the Little Blackfoot confluence.

Synthesis

The Galen site shows that considerable inter-annual variation exists in the timing and extent of summer temperature maximums, and that these temperatures are often high enough to pose a risk to the salmonid fishery – particularly cutthroat and bull trout. In years when summer discharge was low, more days exceeded 20 C at Galen and the maximum weekly temperatures were higher. Thus at low discharge UCFR salmonids are exposed to a longer (more days) and more severe (higher temperatures) period of thermal stress. The analysis of USGS data shows that moving downstream to Deer Lodge and Gold Creek summer temperature conditions become progressively more stressful, while at Turah the cooling influence of Rock Creek creates conditions that are similar again to Galen. A second longitudinal analysis of temperature using recent FWP data provided greater spatial resolution than the USGS data. Based on the FWP analysis, the area from Deer Lodge to Bearmouth was identified as the area of summer thermal concern, and within this stretch the highest temperatures existed at Upstream of Little Blackfoot. Comparisons of temperatures between the Little Blackfoot at UCFR at Upstream of Little Blackfoot suggest that later in the summer during low discharge years that the Little Blackfoot is unlikely to substantially cool the UCFR. Accordingly, on low discharge years it is likely that the high summer temperature conditions observed at Upstream of Little Blackfoot extend downstream some distance in the UCFR.

Determining the temperature priority period is difficult because the timing of sustained high temperatures varies among years, largely due to the varying influences of summer weather and discharge on water temperature. For example, with the low discharge and warm summer weather of 2013 the highest maximum daily temperatures occurred on July 1 (Figure 13) while in the high water year of 2011 maximum temperatures showed their greatest peak in late August (Figure 11). Given that water temperatures are higher in low discharge years and arrive earlier in the summer, flow augmentation for temperature benefits should focus on low water years. Thus although mid July to mid August tends to be the time period of concern in the UCFR, it is suggested that the thermal priority period should be from early July to at least mid August in light of the earlier arrival of high water temperatures observed in low discharge years.

References

Bear, E.A., T.E. McMahon, and A.V. Zale. 2007. Comparative thermal requirements of westslope cutthroat trout and rainbow trout: implications for species interactions and development of thermal protective standards. Transactions of the American Fisheries Society 136: 1113-1121.

Leon, J., P. Saffel, B. Liermann, J.Lindstrom, and T. Selch. 2014. Upper Clark Fork River Fisheries Monitoring Study: 2013 Annual Report. Report by Montana FWP for Montana DEQ.

McMahon, T.E., A.V. Zale, F.T. Barrows, J.H. Selong, and R.J. Danehy. 2007. Temperature and competition between bull trout and brook trout: a test of the elevation refuge hypothesis. Transactions of the American Fisheries Society 136: 1313-1326.

Richards, R., W. Schreck, P. Saffel, B. Liermann, J. Lindstrom, and T. Selch. 2013. Upper Clark Fork River Caged Fish Study: The Distribution and Timing of Trout Mortality Final report 2011-2012. Report by Montana FWP for Montana DEQ.

Selong, J.H., T.E. McMahon, A.V. Zale, and F.T. Barrows. 2001. Effect of temperature and growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. Transactions of the American Fisheries Society 130:1026-1037.

Figure 1. Average of mean daily temperatures versus day based on USGS data from the Galen gage from 1991 to 2004.

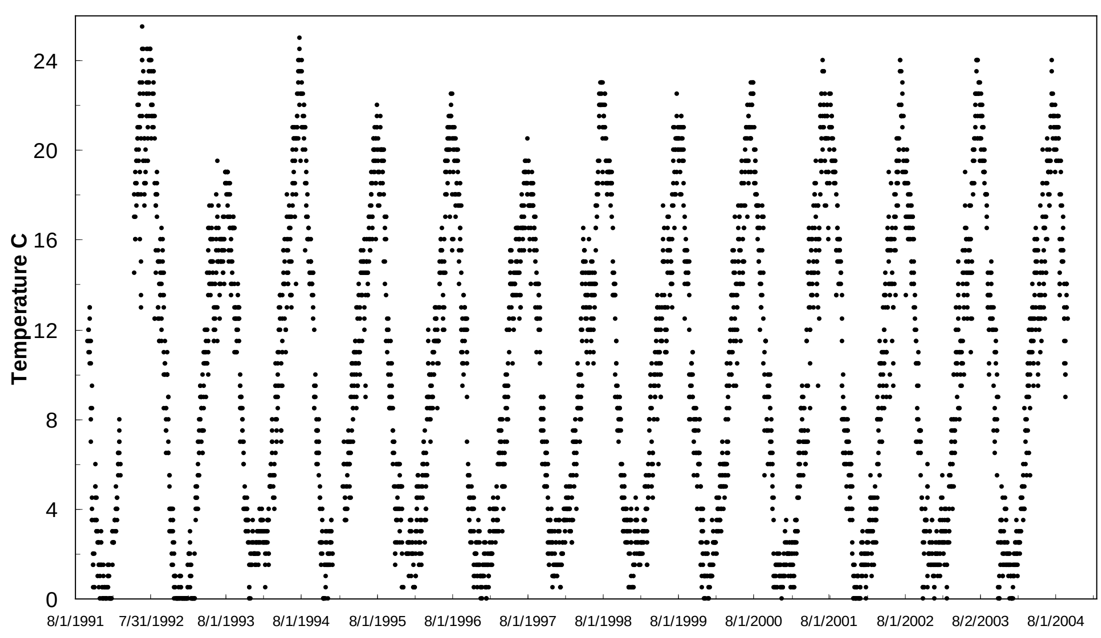

Figure 2. Maximum daily temperatures versus date based on USGS data from the Galen gage from 1991 to 2004.

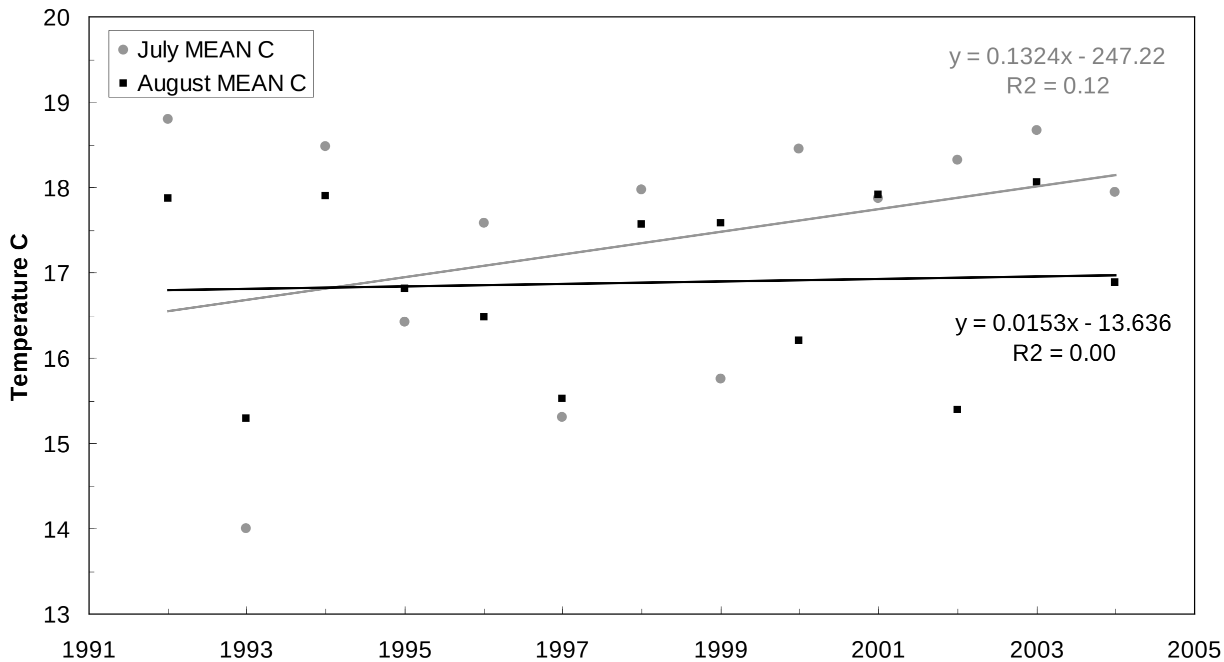

Figure 3. Mean monthly temperature versus year based on USGS Galen data in July (p = 0.25) and August (p = 0.85) from 1992 to 2004.

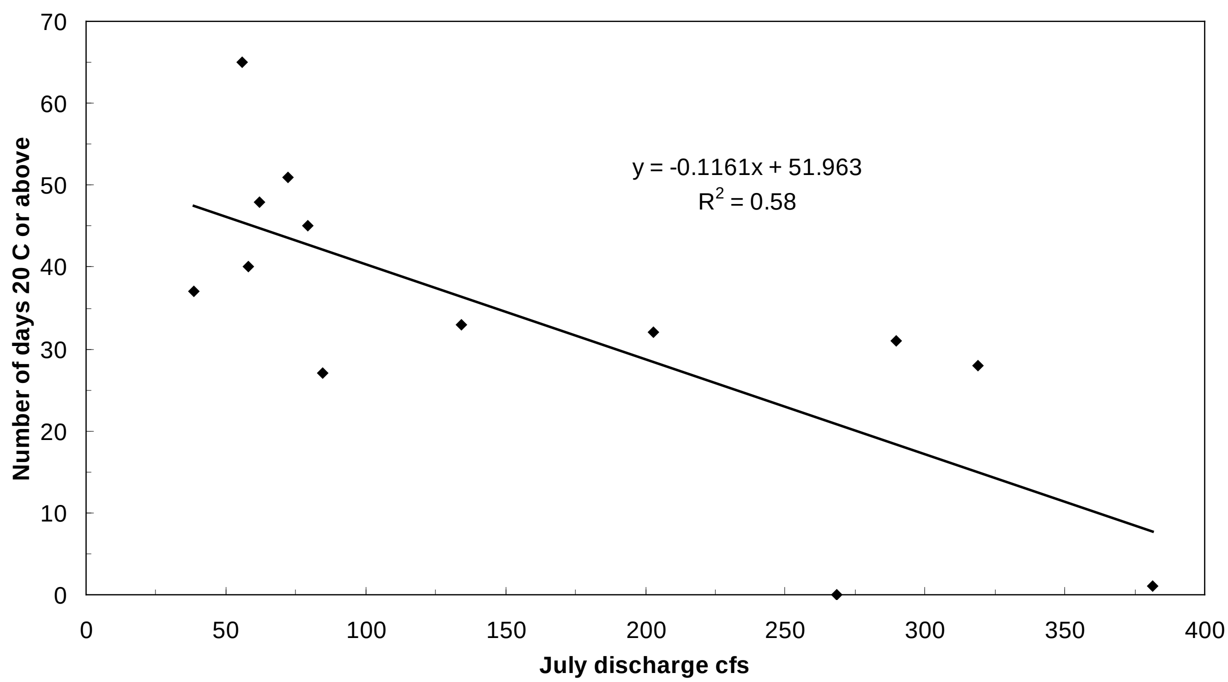

Figure 4. Relationship between annual number of days 20 C or above and July mean monthly discharge ($p < 0.01$) based on USGS Galen data from 1992 to 2004.

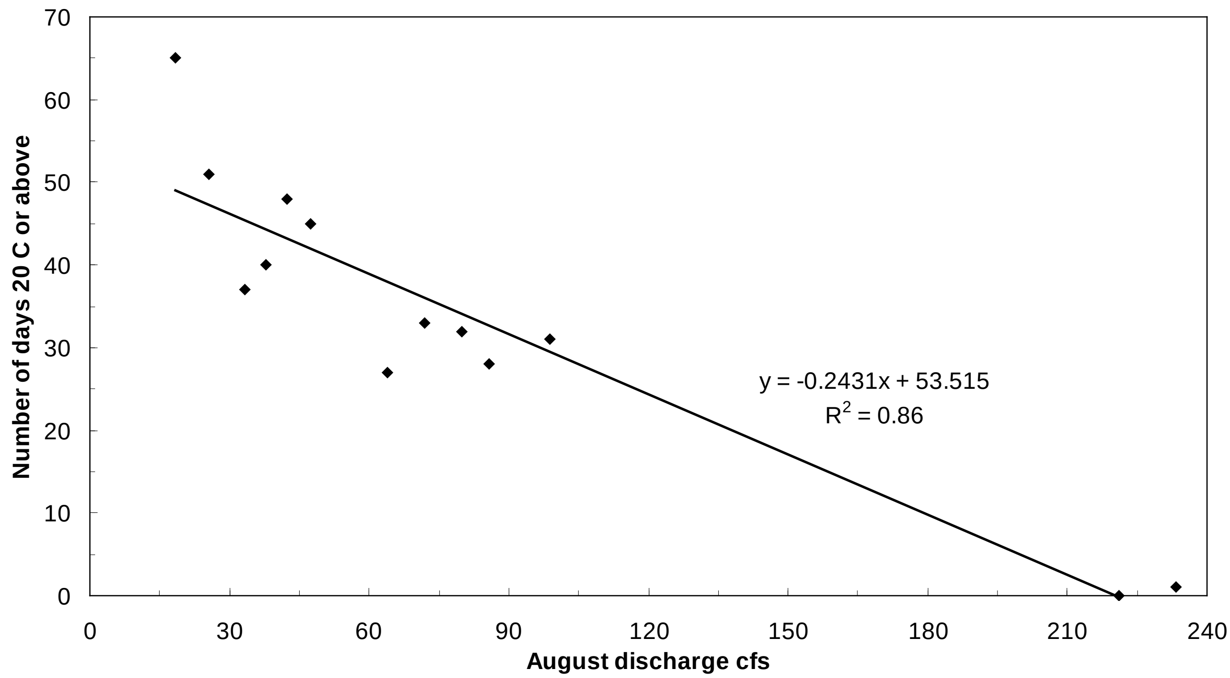

Figure 5. Relationship between annual number of days 20 C or above and August mean monthly discharge ($p < 0.01$) based on USGS Galen data from 1992 to 2004.

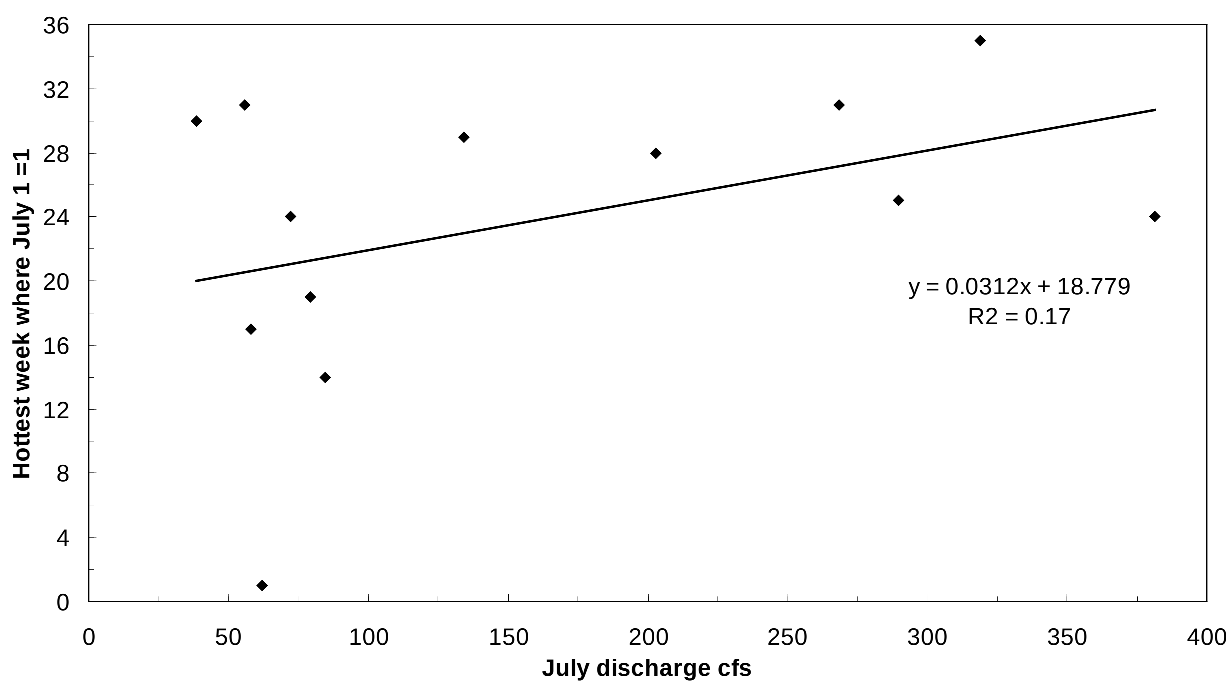

Figure 6. Relationship between timing of the hottest week (using average maximum daily temperatures) and July mean discharge ($p = 0.17$) based on USGS Galen data from 1992 to 2004.

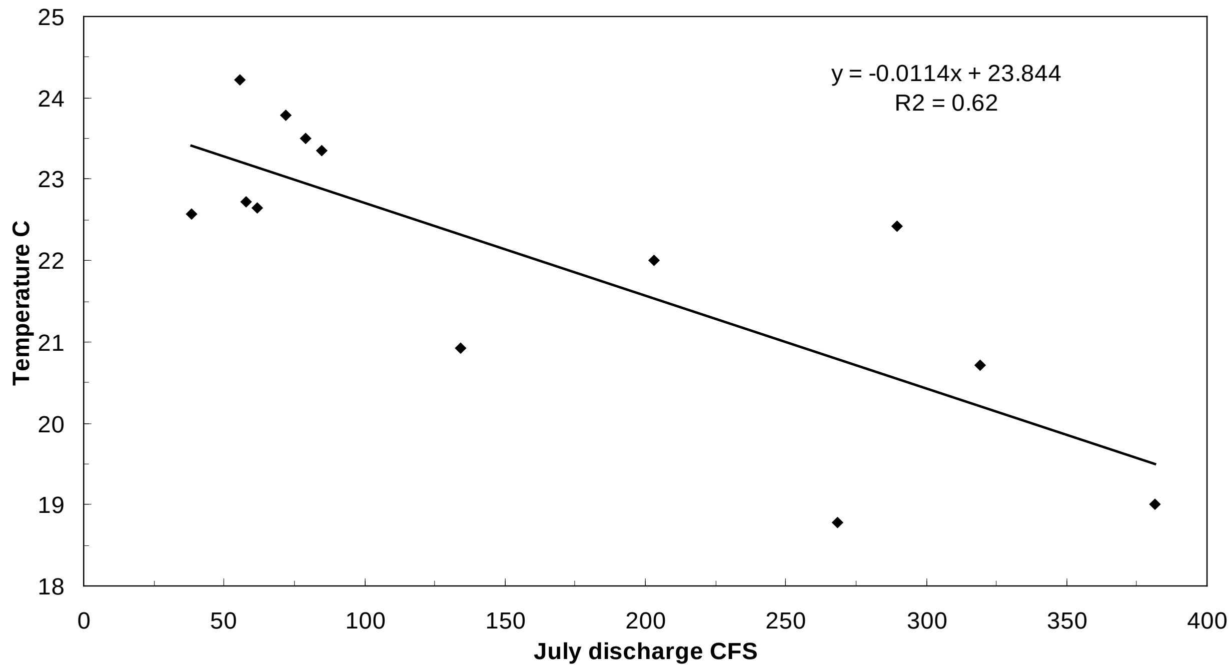

Figure 7. Relationship between the temperature of the hottest week (using average maximum daily temperatures) and July mean discharge ($p < 0.01$) based on USGS Galen data from 1992 to 2004.

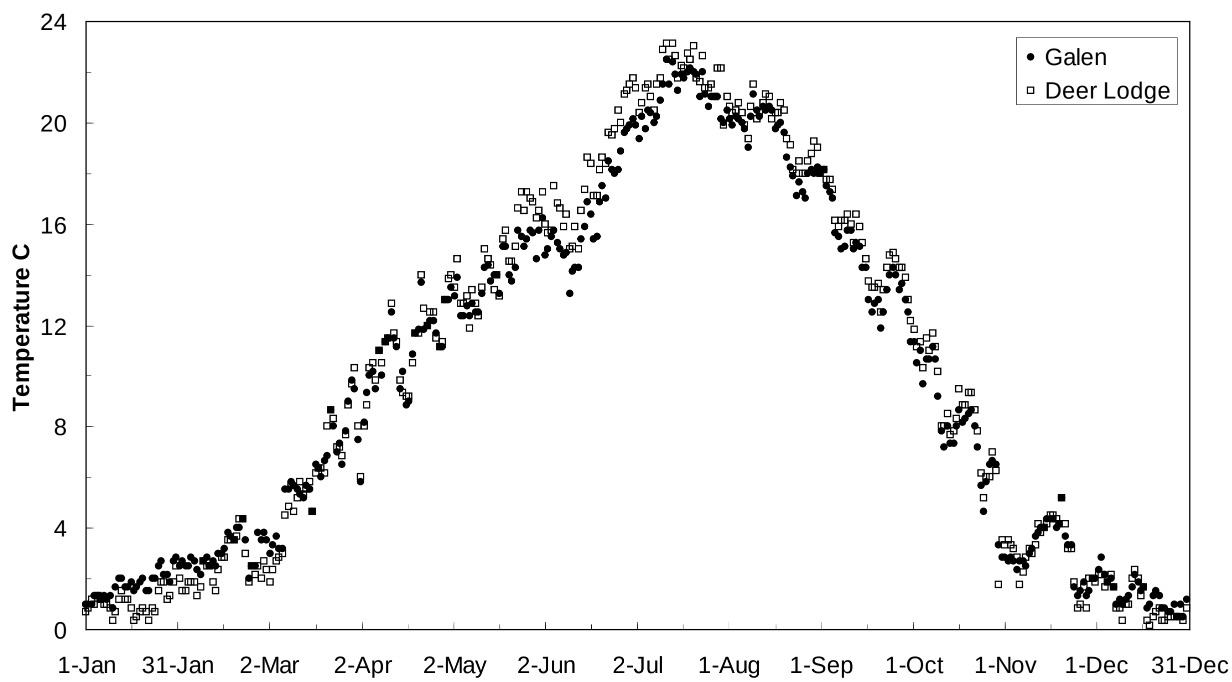

Figure 8. Average of maximum daily temperatures versus day based on USGS data from the Galen and Deer Lodge gages from May 2001 through September 2004.

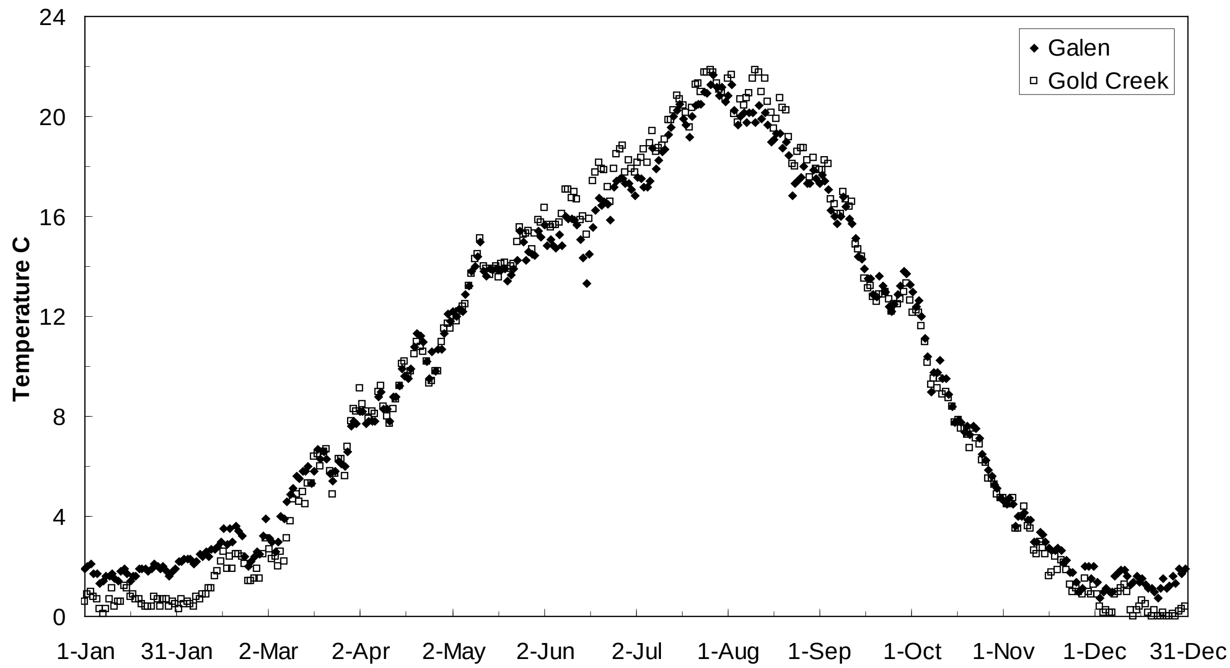

Figure 9. Average of maximum daily temperatures versus day based on USGS data from the Galen and Gold Creek gages from May 1992 through September 1998.

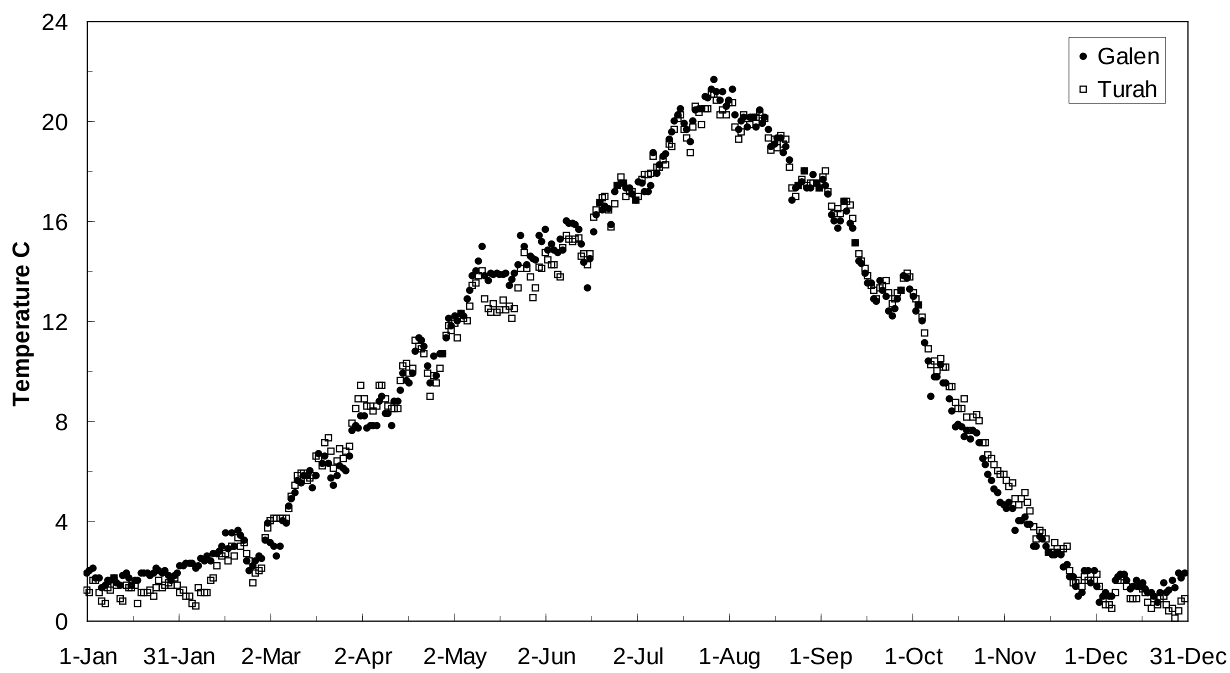

Figure 10. Average of maximum daily temperatures versus day based on USGS data from the Galen and Turah gages from May 1992 through September 1998.

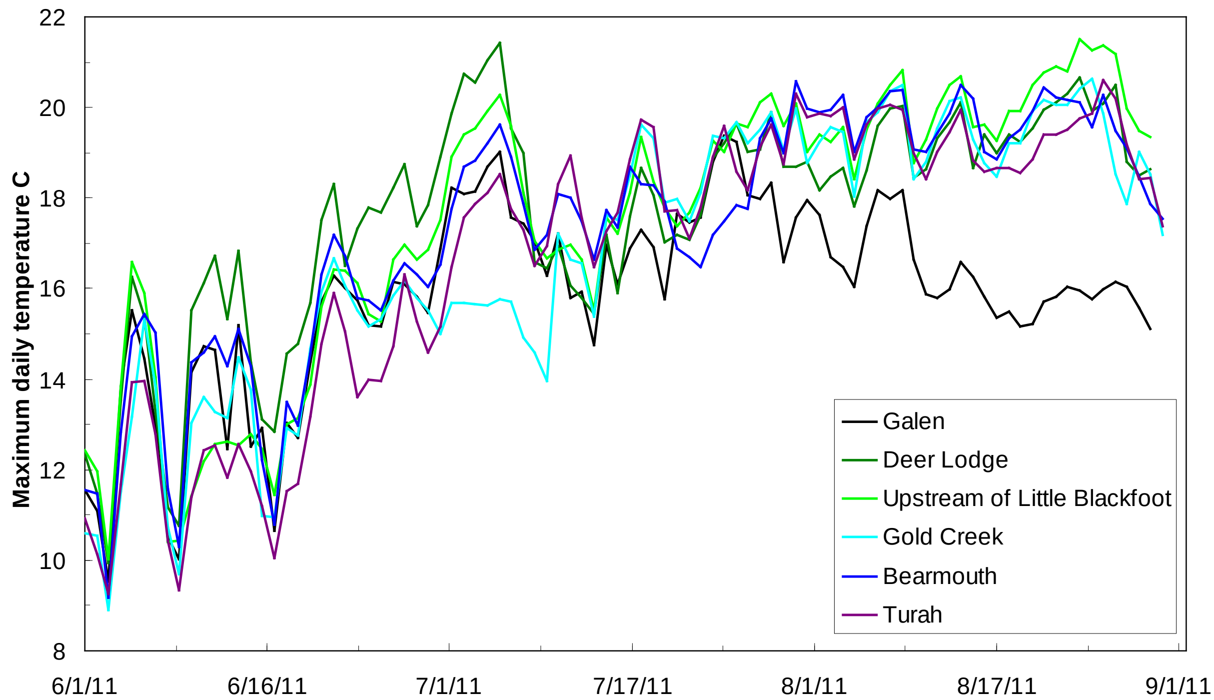

Figure 11. Maximum daily temperature from June to late August 2011 in the UCFR.

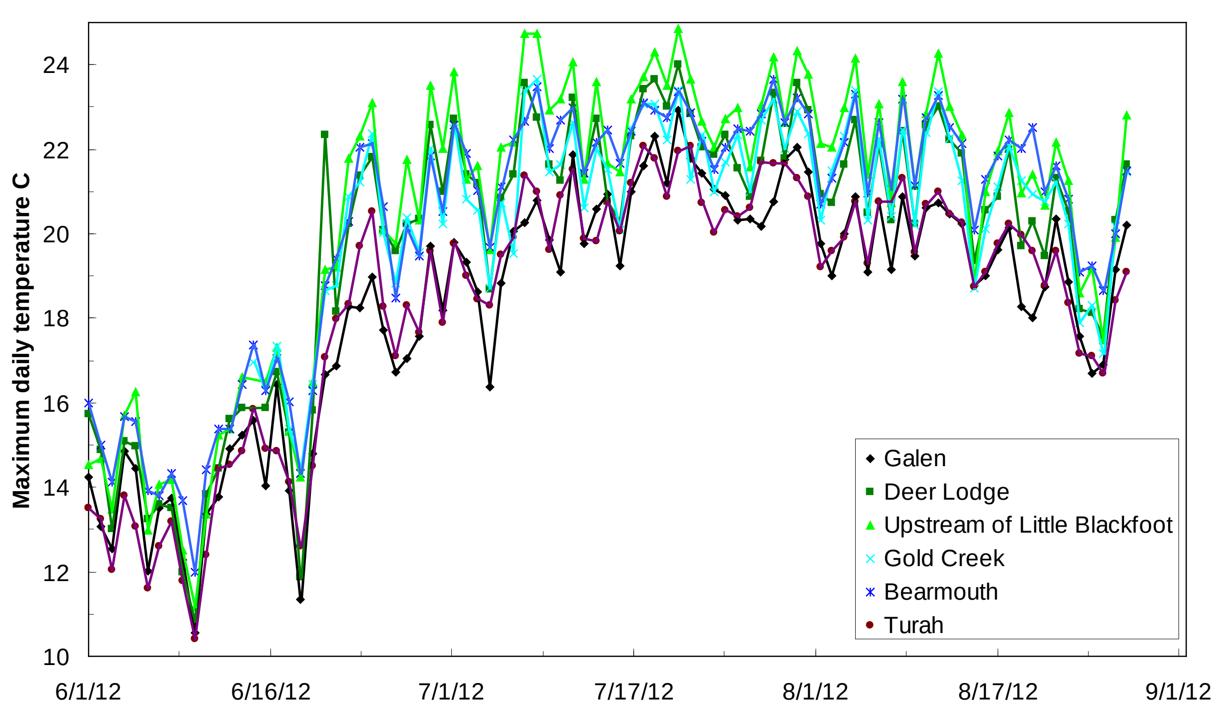

Figure 12. Maximum daily temperature from June to late August 2012 in the UCFR.

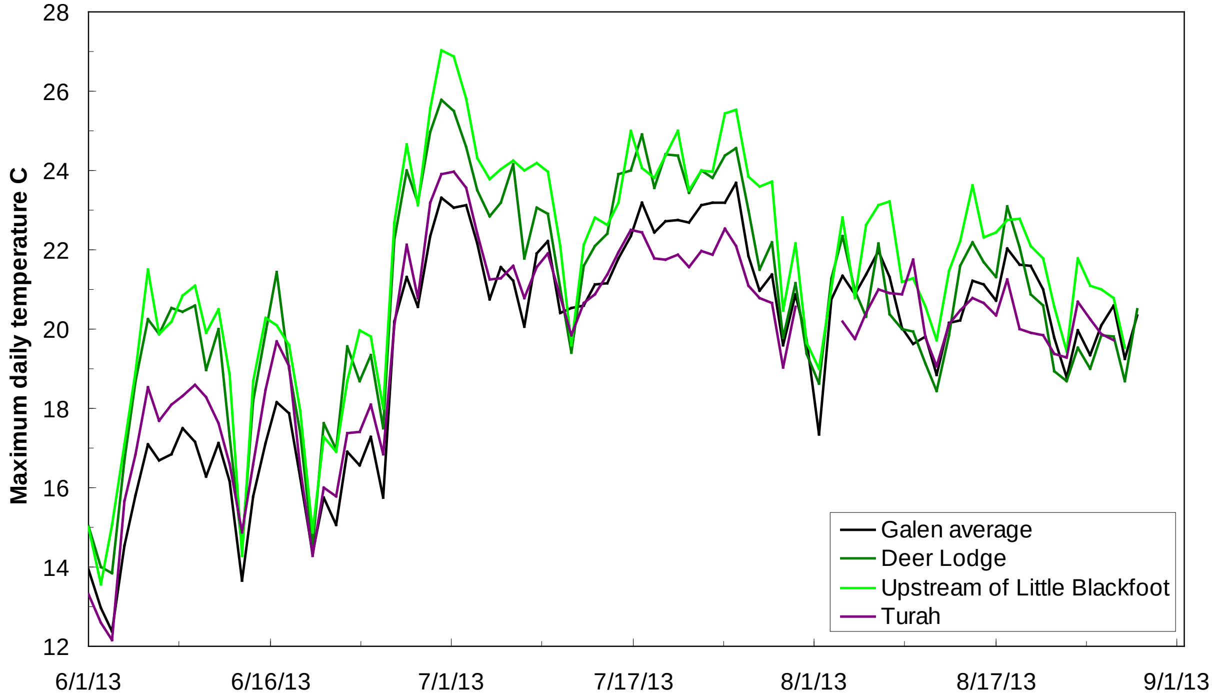

Figure 13. Maximum daily temperature from June to late August 2013 in the UCFR.

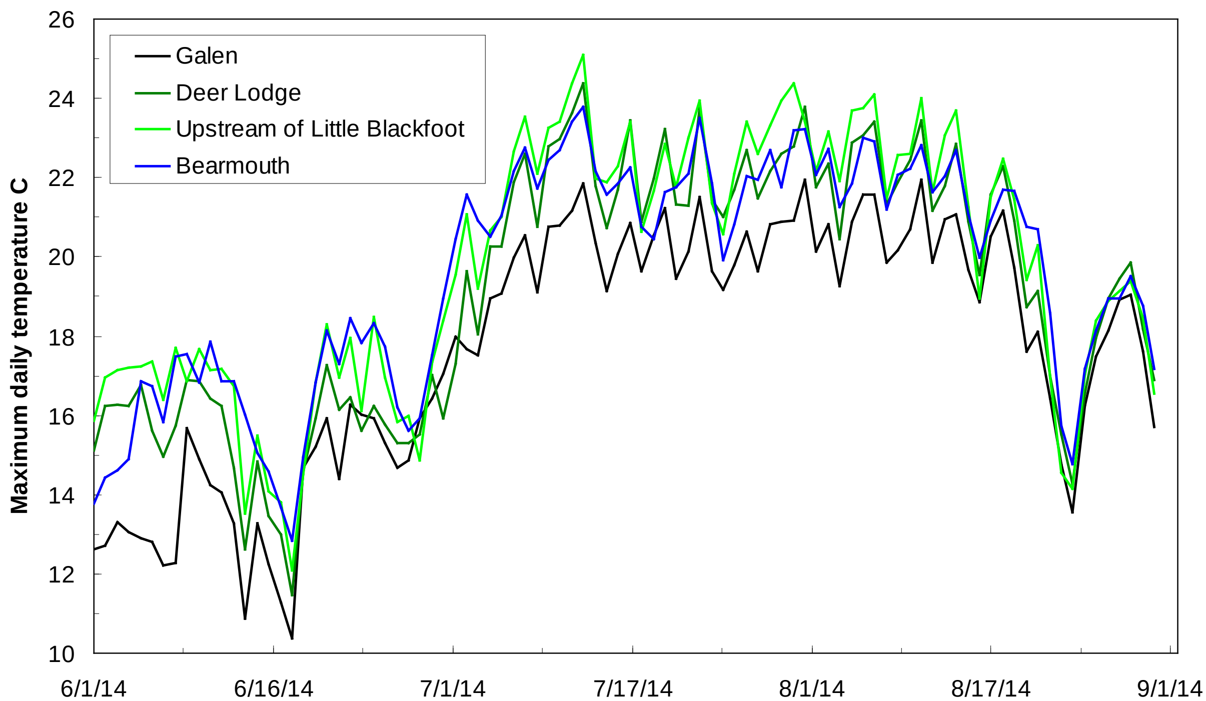

Figure 14. Maximum daily temperature from June to late August 2014 in the UCFR.

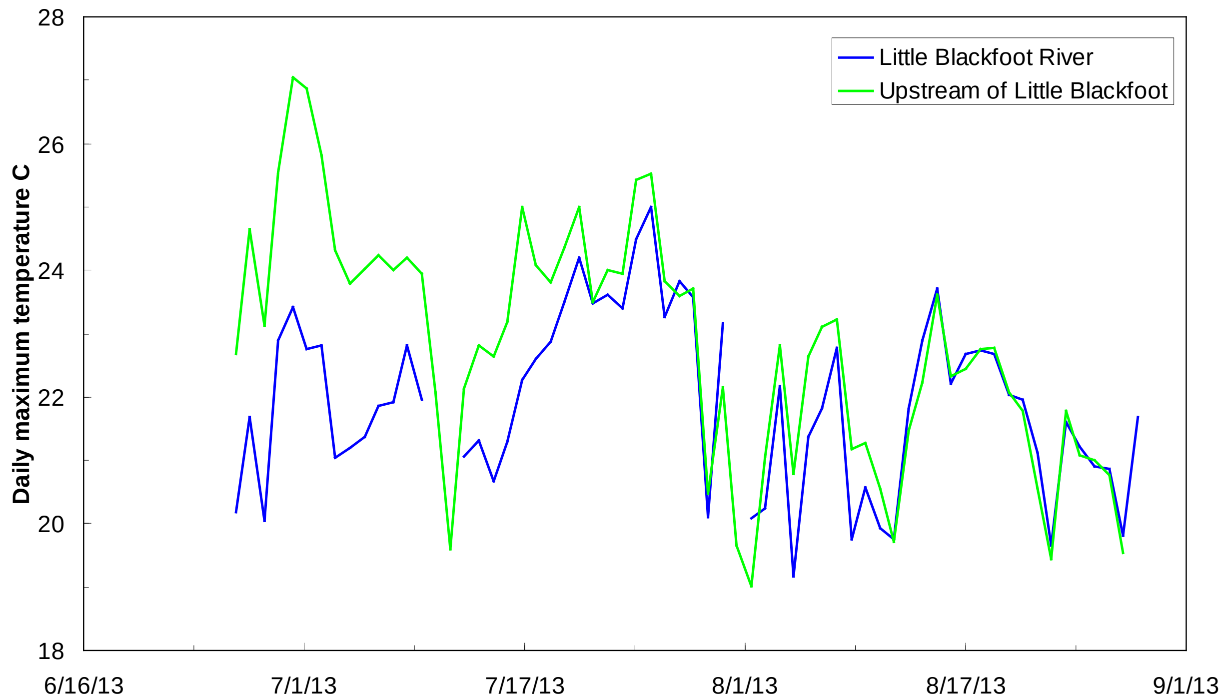

Figure 15. Maximum daily temperature from late June to late August 2013 (low discharge year) in the UCFR at Upstream of Little Blackfoot and in the Little Blackfoot River.

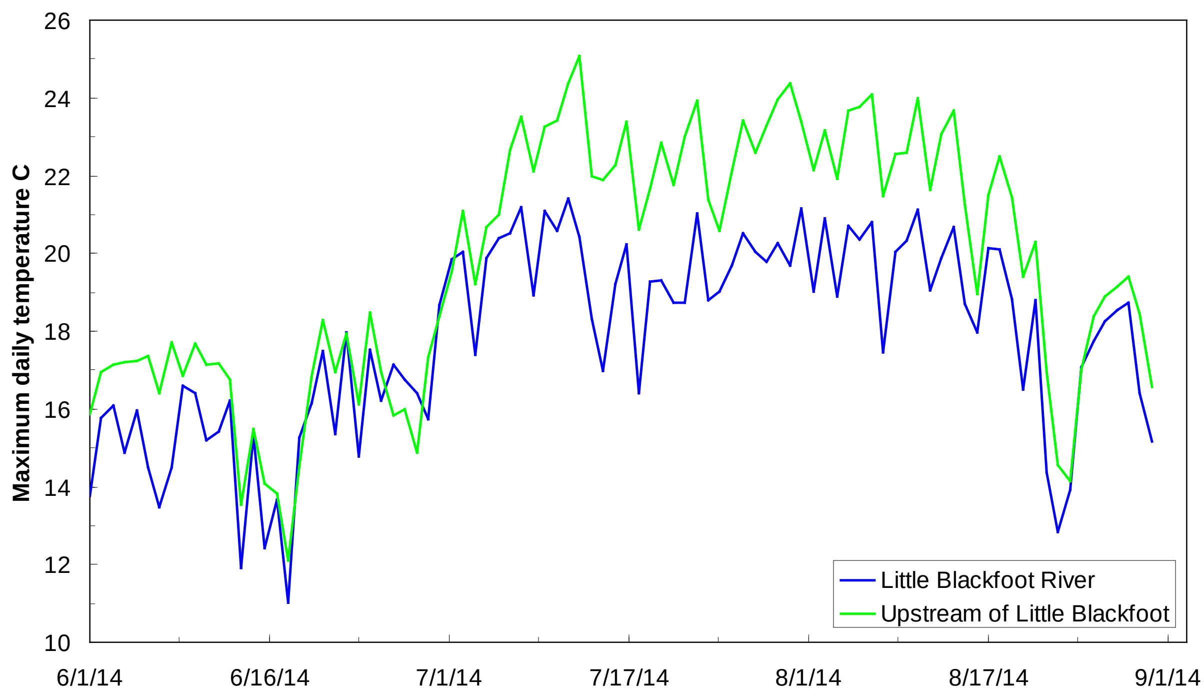

Figure 16. Maximum daily temperature from June to late August 2014 in the UCFR at Upstream of Little Blackfoot and in the Little Blackfoot River.

CHAPTER 6:

When and Where to Provide Water for Instream Flow in the Upper Clark Fork River

Introduction

Low summer flows are a limitation on the salmonid fishery of the Upper Clark Fork River (UCFR), particularly looking forward as metals contamination continues to decline. Concerns for low flows include elevated temperatures, lower water volume to dilute pollution, reduced dissolved oxygen concentration, reduced aquatic area, inhibition of fish migration, and increased predation risk to salmonids (Chapter 2). As a result of these types of concerns restoration efforts are underway to enhance UCFR flows by many organizations, including a large scale effort being coordinated by the NRDP (2012). Efforts to enhance summer flows on the UCFR will continue to benefit from consideration of where and when the water is needed, the advantages and disadvantages of a given water source, and the potential availability of a given water source. This goal of this report chapter is to provide information for ongoing and future flow augmentation efforts to benefit salmonids in the UCFR.

UCFR Mainstem Priority Areas

Several efforts have identified priority areas in the UCFR mainstem for flow augmentation, and some variation is exists among the different information sources. The NRDP designated the UCFR from Galen to Deer Lodge as highest priority for restoration, and also recently identified the stretch from Flint Creek to Rock Creek as another area of highest priority based on low salmonid abundance (NRDP 2012). In both these areas flow augmentation is a major component of the proposed restoration (NRDP 2012). Similarly, FWP and NRDP together (Saffel et al. 2011) identified the UCFR from Warm Springs Creek (near Galen) to Deer Lodge as an area of emphasis for improving instream flows. Berg (2013) concluded that Warm Springs to the Little Blackfoot is the mainstem area of greatest dewatering concern, which is based on her evaluation of several organizations' assessments including the CFC (2011) and UCFRBSC (2006). The CFC (2011) and UCFRBSC (2006) also identified the same priority area for flow enhancement. The UCFRBSC (2006) broke their overall prioritization into three reaches wherein Perkins Lane to Westside Ditch and Sager Lane to Little Blackfoot were considered less severely dewatered than Westside Ditch to Sager Lane. Lastly, this report (Chapter 5) identifies priority stretches for flow augmentation based on flow considerations only: Galen to Deer Lodge is the first priority, Deer Lodge to Above Little Blackfoot is the next priority, and Above Little Blackfoot to Gold Creek as the third priority area (sites based on USGS gages).

In summary, all of the reviewed sources identified Galen/Warm Springs to Deer Lodge, or at least a larger stretch that includes Galen to Deer Lodge, as a top priority for flow augmentation. It would seem the next priority area is the stretch from Deer Lodge to the Little Blackfoot, or possibly the stretch from Flint Creek to Rock Creek. However, this later stretch does not seem to be severely dewatered relative to upstream reaches (Chapter 4) but rather suffers from elevated water temperatures (Chapter 5), poor habitat conditions, limited tributaries suitable for salmonid thermal refugia/spawning, and restricted fish access to these tributaries (Workman 2009, Naughton 2015). As such, it is suggested that flow restoration in the stretch from Flint Creek to Rock Creek should focus on improving tributary flow volumes and fish access to tributaries, particularly on colder streams, more than providing additional water in the mainstem per se.

Timing of Flow Augmentation

The suggested timing of flow augmentation for the UCFR mainstem is based on Chapters 4 & 5 (discharge and thermal conditions in the UCFR, respectively), and focuses on low flow years where dewatering and the associated issues are of the greatest concern. In general, the upper river has more severe dewatering issues based on physical habitat conditions, and these issues are expressed earlier in the summer. In contrast, high water temperatures are more of an issue moving downstream, at least until the Rock Creek confluence.

For the UCFR from Galen to the Little Blackfoot, the priority period for flow augmentation based on physical habitat conditions (i.e. wetted perimeter) is from mid July to early September. If the weak pattern ($p = 0.09$) of minimum flows arriving later in the season continues to manifest itself in the future, this flow augmentation priority period could be extended to mid September. Moving downstream, dewatering concerns based on physical habitat considerations occur progressively later in summer and also become progressively less severe. However, dewatering concerns remains problematic particularly from the Little Blackfoot to Gold Creek. Based on discharge patterns alone (particularly the low flow year of 2013) it is suggested that flow augmentation in this stretch could start slightly later than upstream, beginning in late July.

Determining the temperature priority period is difficult because the timing of sustained high temperatures varies among years, largely due to the varying influences of summer weather and discharge on water temperature. For example, with the low discharge and warm summer weather of 2013 the highest maximum daily temperatures occurred on July 1 (Chapter 5, Figure 13) while in the high water year of 2011 maximum temperatures showed their greatest peak in late August (Chapter 5, Figure 11). Given that water temperatures are higher in low discharge years and arrive earlier in the summer, flow augmentation for temperature benefits should focus on low water years. Thus although mid July to mid August on average tends to be the time period of concern in the UCFR, it is suggested that the thermal priority period should be from early July to at least mid August in light of the earlier arrival of high water temperatures observed in low discharge years.

Tributary Versus Mainstem Water Sources

An important consideration for flow enhancement in the UCFR mainstem is the advantages and disadvantages of tributary versus mainstem water sources. In general, it seems that tributaries offer the greatest fishery advantage provided the additional water reaches the mainstem. If so, advantages of tributary sources include the additional distances of improved habitat (i.e. in the tributary), generally cooler water than the mainstem, and increased prospects for fish passage. If the tributary is accessible to fish (i.e. no barriers), increased discharge can improve thermal refugia and spawning success of the mainstem salmonids. Further, a relatively small volume of water is more likely to provide a noticeable improvement in the fishery in a tributary relative to the mainstem. The advantages of mainstem flow augmentation are mostly logistical. Mainstem diversions tend to be larger which may simplify water acquisition efforts by requiring fewer projects for a given water volume. Further, mainstem diversions may provide the best option in certain locations where tributaries are nonexistent or have no available water for instream flow.

References

Berg, C.B. 2013. Prioritizing the Upper Clark Fork River Tributaries for Instream Flow Restoration. M.S. thesis, University of Montana.

CFC. 2011. Aquatic Restoration Strategy for the Upper Clark Fork Basin. Report by the Clark Fork Coalition.

Naughton, J. 2015. Clark Fork River Fishery Assessment: Flint Creek to Rock Creek Reach. Draft Report by RESPEC for Montana DOJ.

NRDP. 2012. Final Upper Clark Fork River Basin Aquatic and Terrestrial Resources Restoration Plans. Report by Montana Natural Resources Damage Program, Department of Justice.

Richards, R., W. Schreck, P. Saffel, B. Liermann, J. Lindstrom, and T. Selch. 2013. Upper Clark Fork River Caged Fish Study: The Distribution and Timing of Trout Mortality Final report 2011-2012. Report by Montana FWP for Montana DEQ.

Saffel, P., B. Liermann, J. Lindstrom, L. Knotek, T. Mostad, and C. Fox. 2011. Prioritization of Areas in the Upper Clark Fork River Basin for Fishery Enhancement. Report by Montana Fish, Wildlife and Parks and Natural Resource Damage Program.

UCFRBSC. 2006. Upper Clark Fork River Flow Study. Report by the Upper Clark Fork River Basin Steering Committee.

Workman, D. 2009. Qualitative Assessment of Habitat in Eight Tributaries to Upper Clark Fork River. Report to Montana FWP and NRDP.

CHAPTER 7:

Reducing Impacts of Water Use

Introduction

In Montana agricultural irrigation is the largest consumer of water thus management of this consumption has the largest potential for benefiting fisheries affected by low summer flows. Statewide, 67% of the water consumed is by irrigation, 28% reservoir evaporation, 2% municipal, 1% stock water, and <1% industrial, thermoelectric, and domestic combined (calculations based on DNRC 2014). Further, 96% of the surface water diverted and groundwater withdrawn is used for agricultural irrigation (DNRC 2014), although an appreciable portion of this water enters into the groundwater pool, much of which is later delivered back to streams as return flows.

Irrigation withdraws most water during the summer months as stream flows are naturally diminishing, exacerbating low stream flow conditions. Fisheries concerns related to low flows include elevated temperature, degraded physical habitat conditions, and reduced water quality. Further, many irrigation structures entrain fish and also constrain their migration. Impeded migration is of particular concern when fish are denied access to spawning areas or, in summer, cooler water. Although livestock watering and domestic water use consume little water relative to irrigated crops, the lack of flow control valves on stock watering tanks has been identified by the DNRC (2014) as a topic of water conservation concern. Another concern regarding livestock water and domestic water use is that they can create issues for water quality and habitat conditions in streams. The purpose of this chapter is to describe management options to reduce the impacts of irrigation, grazing, and domestic water use on fisheries of the Upper Clark Fork River (UCFR), including a review of methods to acquire water for instream flows.

Improving Instream Flows for Fisheries

The UCFR exhibits and mostly natural hydrograph, largely owing to the limited amount of reservoir storage (<10% of total flow) in the watershed (DNRC 2014). The notable exception is diminished summer flows which are largely caused by irrigation withdrawals. In May and June UCFR water generally is abundant, and even without water withdrawals flows would tend to diminish for the rest of the summer. Irrigation use of water is maximized in mid summer, thus the timing of supplies and demand conspire to particularly reduce UCFR flows during mid to late summer. This issue is of particular evident in the upper areas of the UCFR where dewatering issues are most pronounced. Fishery concerns regarding low summer flows in the UCFR include elevated water temperature, reduced dissolved oxygen, reduced dilution of pollutants (including nutrients and metals), reduced habitat area/depth, impediment of migration, and greater predation risk.

Water leasing provides the most obvious management option for using private water rights to enhance instream flows. Temporary change of use (including instream flow) can run for up to 10 years, and changes have no limits on the number of renewals. When temporary change is used to provide water for instream flow this can be voluntary or, more typically, based on a lease. When the temporary change of use ends the original use is restored and the priority date is unaffected. With temporary change of use for instream flow, only the portion of the water that was historically consumed (i.e. evaporated or transpired) is a potentially protectable water right for instream flow (§85-2-408, MCA). A limitation of these leases is that they cannot have adverse effects on other water users. For example, if other users are reliant on irrigation return flows then restoring water to instream flow may create adverse effects. In Montana most change of use leases for instream flows have been undertaken by FWP, Trout Unlimited, and the Montana Water Trust (acquired by Clark Fork Coalition in 2010). If the lease is held by FWP it can be converted permanently to instream flow, but legislation dictates that this can be done on a maximum of 12 stream reaches until 2019. Temporary water leases were approved by the legislature in 2013 that allow for leasing of a water right for two of the years in a 10 year period. An advantage of temporary leases is a simpler and faster application procedure. Like 10 year year instream flow changes, the volume for two year leases cannot exceed the historic consumptive use. Further, when the lease is based on an irrigation right, the consumptive volume must be one acre foot or less per irrigated acre. The maximum volume that can be leased is 180 acre-feet per year. For reference, if 180 acre-feet per year was leased at 1 cfs it would take approximately 91 days to delivery this water. Based on the modest water volume available, temporary leases seem particularly well suited for enhancing flows in tributaries or, especially for shorter time periods, in the UCFR main stem. Temporary leases are designed to meet short term water needs, and thus could be a useful tool for supplying instream flows in low discharge years.

Water leases do not have to cover the entire time frame provided by the original water right, and thus can be split seasonally. Split season leases where water is returned to instream flow later in the summer offer certain advantages in the UCFR. Most irrigation water is used for hay crops that are harvested several times over the course of the growing season. The timing of a split season lease can allow one or perhaps two hay crops, and then water can be leased for instream flow during the critical late summer period. This strategy allows for agricultural water use in the early and middle part of the growing season when flows are higher, and also enhances ground water in the uplands that often provides return flows later in the summer. Advantages of this approach are that it reduces minimum flow impacts during the critical late summer period and keeps lands in agricultural production when solar energy is maximized (roughly late May to late July).

Many flow enhancement efforts in the UCFR focus on increasing the efficiency of water delivery to irrigated crops, however these projects have limitations in terms of generating a protectable water right for instream flows. Irrigation ditches in the UCFR have been shown to exhibit considerable seepage loss (Roberts 2002), however much of this loss is returned to the stream via groundwater return flows [for a local example on Flint Creek see (Voeller and Waren 1997)]. Accordingly, lining or piping of ditches does reduce water loss to infiltration but the fundamental issue is that increasing delivery efficiency generally does not substantially reduce water consumption, and in many instances actually leads to higher consumption or has adverse effects on other water users (DNRC 2014). Montana water law only considers the amount of water historically consumed as the potential maximum volume that can be changed to instream flow. As a result the DNRC generally does not consider the water that was procured by reducing conveyance losses as a protectable water right for instream flow. However, certain exceptions apply. Water returned to the stream may be protectable from the point of diversion to downstream areas of (former) infiltration from the ditch. Piping ditches slightly reduces evaporation, thus reducing consumption and creating a small volume of potentially protectable water for instream flows. Ditch loss which feeds subirrigation or which otherwise evaporates may be considered consumptive use and changed to instream flow.

Even when water made available by improved delivery efficiency is not protected by a water right for instream flow, it can still enhance stream discharge. Most obviously, this applies to situations where downstream water users do not remove the added flows or, at least, removal does not occur for a considerable distance. A particularly beneficial situation exists where the added water allows dewatered tributaries to reconnect with a larger stream or river, allowing for salmonid movement. It should be noted that although much of the recovered water would otherwise seep back to the river via ground water return flows, these returns are delayed. The result is that increasing efficiency and diverting less is particularly beneficial for maintaining flows during low discharge. However, to varying degrees, this benefit can be offset when increased efficiency leads to less groundwater recharge during higher flows, later reducing return flows during low discharge.

Reducing Impacts Not Directly Related to Flow

A major fisheries impact associated with many irrigation diversions in the UCFR is the barriers they create to salmonid migration. Much of the salmonid spawning that occurs is the UCFR is in tributaries and thus barriers to migration are a major concern (Mayfield 2013). Further, the UCFR has marginal summer thermal conditions for salmonids, especially for bull trout and cutthroat trout that are particularly sensitive to elevated temperatures (Selong et al. 2001, Bear et al. 2007). Accordingly, barriers that deny salmonids access to cooler tributary waters in the summer can have a large impact. Barriers also fragment upstream populations, and the resulting small population sizes create concerns for local extinctions and genetic inbreeding. However, in some cases there is a benefit to barriers in that they prevent non native fish from colonizing tributary areas where they do not occur. Major concerns from non natives include hybridization (cutthroat X rainbow and bull trout X brook trout) and increased competition with native fishes. Options for reducing barrier impacts on salmonids include modifying irrigation structures to allow fish passage year round or making seasonal changes to the structures that allow for fish movement during the non irrigation season. The nature and implementation feasibility of these changes vary widely with the design of the diversion, the size of the stream, and the streamside setting. Creating a pool immediately below small barriers can aid salmonid jumping performance, improving upstream passage.

Irrigation diversion can impact salmonids by entrainment in the irrigation canal, particularly when a large portion of the flow is diverted. Many of these fish will perish, particularly after the diversion is shut down for the season. Screening of ditches is one option for greatly reducing these impacts. Another option is to shut the water off gradually at the end of the irrigation season so that fish will be encouraged to return to the stream. This is only feasible if the flows in the ditch are slower than the swimming velocity of the fish which may not be the case, particularly near the point of diversion. This points to the value of constructing diversions with slower water flows, and this will also help allow the allow fish to leave the ditch at any time.

Stock watering can impact fisheries, particularly when animals are allowed to drink directly from the stream in an unregulated fashion. The resulting high volume of animals near the water degrades riparian vegetation that is particularly important for reducing solar heating of the water and sediment inputs, both of which are of concern for salmonids in the UCFR. Management options include fencing that allow stock access to the stream in one small area or providing water at locations that are not immediately adjacent to the stream. The later option also helps with reducing nutrients associated with animal wastes into the streams which contribute to the eutrophication issues (especially high primary producer biomass and low dissolved oxygen levels) that are of concern in the UCFR, particularly in the upper reaches.

Other agricultural practices such as crop raising and grazing also create water quality concerns by increasing the input of sediments, nutrients, and in the case of crops other pollutants to waterways. Providing an undisturbed riparian buffer strip of natural vegetation between the waterway and crop greatly reduces inputs of these pollutants and also helps reduce summer water temperatures. Riparian fencing can help reduce thermal, nutrient, and sediments impacts caused by grazing even if livestock are allowed periodic access to the riparian zone. In certain settings reducing livestock access to the riparian zone can provide a long term benefit to forage conditions. Specifically, heavy riparian grazing can cause streams to incise (downcut) into their floodplain by degrading riparian vegetation and bank trampling, and when this occurs it typically is most evident in smaller streams with low gradient. The incised channel facilitates groundwater drainage in a similar manner to intentional land drainage through ditching. In these types of settings reducing grazing pressure allows the channel elevation and thus nearby ground water elevation to gradually rise, promoting greater riparian productivity and thus improved forage conditions in the long term. Higher channel bottom elevations relative to the floodplain and more complex channels associated with healthy riparian vegetation also increase groundwater storage during high discharge, providing for enhanced ground water delivery to streams during low flows.

Domestic water use also creates some concerns over water quality, particularly given the increasing number of homes near waterways in the UCFR watershed. Septic tanks that are located too close to waterways, improperly designed, or poorly maintained can cause nutrient and other pollution issues. Lawn fertilization also creates concerns for nutrient pollution, particularly when fertilizer is applied near waterways. Leaving a buffer strip of natural riparian vegetation helps reduce delivery of nutrients, sediments, and other pollutants to water ways, and also reduce over heating of the water during summer.

References

Bear, E.A., T.E. McMahon, and A.V. Zale. 2007. Comparative thermal requirements of westslope cutthroat trout and rainbow trout: implications for species interactions and development of thermal protective standards. Transactions of the American Fisheries Society 136: 1113-1121.

DNRC. 2014. Montana State Water Plan, A Watershed Approach to the 2015 Montana State Water Plan. Report by Montana DNRC.

Mayfield, M.P. 2013. Limiting Factors for Trout Populations in the upper Clark Fork River Superfund Site, Montana. M.S. thesis, Montana State Univeristy.

Roberts, M. 2002. Upper Clark Fork River Ditch Efficiency Assessment DNRC Report WR-3.C.2.UCF. Report to Montana DNRC.

Selong, J.H., T.E. McMahon, A.V. Zale, and F.T. Barrows. 2001. Effect of temperature and growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. Transactions of the American Fisheries Society 130:1026-1037.

Voeller, T. and K. Waren. 1997. Flint Creek Return Flow Study. Report by Montana Bureau of Mines and Geology for Montana DNRC.