Environmental Flow Issues in the Poudre River, Colorado, USA

Robert T Milhous
Torries Peak Analysis
1812 Marlborough Court
Fort Collins, Colorado; USA

John M. Bartholow
Fossil Creek Software
5402 Old Mill Rd.
Fort Collins, Colorado; USA

Abstract: The Cache la Poudre River (Poudre River) has its upper watershed in the Rocky Mountains and its lower watershed in the transition zone between the mountains and the Great Plains to the east. The river flows through the City of Fort Collins where it is a significant environmental attribute; nevertheless, the river is also a "working river" with many diversions and return flows in the lower watershed. The river's status as both a working river and as an environmental amenity must be considered when determining an acceptable environmental flow regime. This paper presents issues that should be considered in the determination of an environmental flow need. One issue is the increase of operational flashiness of a working river during the irrigation season, a second is reduction of winter habitat, a third is reduction of the river's capacity to scour and flush sediment, and the last is unnaturally high flows attributable to water accounting.

Keywords: Environmental flows, Cache la Poudre River, flashiness, physical habitat, sediment movement capacity

Introduction

The Poudre River is a 'working river'. We use the term 'working river' to refer to a river that has been harnessed to produce a mix of goods and services different from those produced by a 'natural' river, often with some goods and services supplied in or near the river (e.g., hydropower or recreation) and some distant from the river (e.g., irrigation or municipal water supply). Both working rivers and natural rivers may have water in them – at least part of the time – but in many cases, working rivers may be called on to support more uses than can be accommodated simultaneously.

The key environmental flow issue in a working river is selecting how to allocate scarce financial resources in river rehabilitation. Should resources be spent restoring 'natural' flows, improving physical habitat, adjusting the details of the flow patterns (for example reducing flashiness) increasing flushing flows, using water to maintain the channel, increasing winter streams flows, or something else? The objective of this paper is to outline the issues in the Poudre River in Colorado (USA) as the beginning of a process that could lead to an efficient, appropriate, and reasonable allocation of resources.

In this introduction we will first describe a 'working river.' Following sections will describe selected environmental flow issues in the Poudre River. The prime objective of this paper is to stimulate thinking about environmental flows from a process applicable to rivers with major environmental flow issues but with a somewhat natural setting to rivers that also have major conflicts but relatively unnatural settings.

A working river

Just what is a 'working river'? There are three possible answers. The first is a river with infrastructure such as docks, factories that need water from the river, and so forth. An example is the Merrimack River in Lowell, Massachusetts USA (Malone, 2009). (The Merrimack River powered factories that were very important in the development of early North American industries.) The second is a river that 'works' to transport sediment and maintain a channel, e.g., the Mississippi (Brown, 1976). The Mississippi River is also a working river because the river has been modified for navigation (locks and dams in the upper river and river retaining works in the lower river). A third example is a river that supplies water for irrigation, municipal (urban) uses, industrial uses, and hydropower. An example is the Orange-Senqu Rivers in southern Africa (Burnett, 2009), but there are many others. The first working river example is where uses modify the pattern of flows but do not diminish streamflow quantity significantly; the second is where the river itself is modified; the third example is the type of working river this paper will consider.

The following statement about a 'working river' in southern Africa pretty well sums up the concerns:

> *"The issues raised by three of the biggest users of water in the Orange-Senqu system - industry, mining and agriculture – speak to the challenge of managing the resource in a water-scarce environment. Having enough water to support development needs, while also tackling environmental concerns, issues of access to water and future threats posed by climate change are all factors that need to be balanced." (Burnett, 2009)*

From the viewpoint of environmental flows, the objective is to improve the aquatic health of a river by determining ways water can be managed without unduly impacting other uses. Any change in water management must be shown to be a beneficial change that improves the health of the aquatic ecosystem.

Poudre River

The Cache la Poudre River is located in northeastern Colorado, USA, and is a tributary of the South Platte River. This river is usually called the Poudre River and that convention is used in this paper. A map of the river reach near Fort Collins, Colorado is presented as Figure 1. Data from three gaging stations were used in writing this paper: Cache la Poudre River at Mouth of Canyon near Fort Collins, Colorado (USGS gage 06752000) located just above the northwest edge of the map; Cache la Poudre River at Fort Collins, Colorado (06752260) shown by the triangle; and Cache la Poudre River above Boxelder Creek near Timnath, Colorado (06752280), just upstream from Interstate-25 on the map. Water is diverted into the Poudre River watershed from adjacent watersheds in the upper basin. The water stored in Horsetooth Reservoir (west side of Figure 1) is imported from the Colorado Basin and enters the Poudre below the Canyon Mouth.

Figure 1. The Cache la Poudre River in the vicinity of Fort Collins, Colorado, USA. The triangle shows the USGS gage on the Poudre River at Fort Collins. The map also shows the many water-filled gravel pits along the river, many storage reservoirs, and a major canal diverting water downstream of the river's Taft Hill Road crossing.

Daily streamflows during water year 2005 in the Poudre River at two locations are presented in Figure 2. Water year 2005 was selected because 1) the estimated natural flows at the Canyon Mouth are near the median (exceeded by 57% of the years) and 2) the year reflects relatively recent water management practices. The daily streamflows at the Canyon Mouth are not 'natural' because there is a significant diversion a short distance upstream, there are several small upstream reservoirs, and there are also imports from adjacent watersheds into the Poudre watershed. The estimated 'natural' discharge in water year 2005 is 324 hm^3, 24% larger than the measured discharge of 262 hm^3.

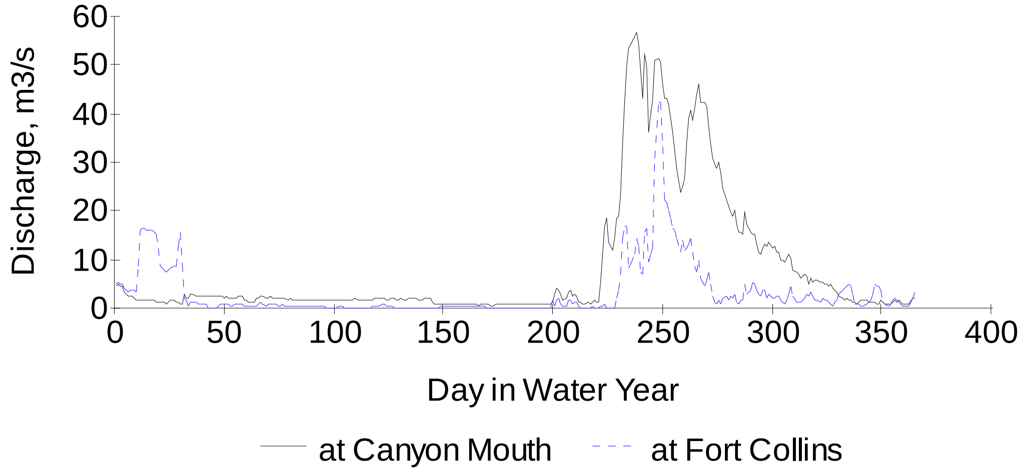

Figure 2. Daily streamflows at the Canyon Mouth and at Fort Collins on the Poudre River in Water Year 2005. The North American Water Year extends from 1 October- 30 September.

We will now examine Figure 2 and discuss issues that might be important to consider in selecting the best ways to invest limited resources in the improvement of environmental flows.

The first item of interest is the observation that the streamflows near the beginning of the water year between 12 October and 31 October are much larger at the Fort Collins gage than at the Canyon Mouth (~1.6 m^3/s at the Canyon Mouth compared to ~15.9 m^3/s in Fort Collins). This "extra" water was released from Horsetooth Reservoir, a component of the Colorado-Big Thompson project. The end of the accounting year for the project is 31 October; in recent years, water has been transferred from Horsetooth Reservoir to downstream reservoirs near the end of the accounting year, resulting in streamflows much larger than natural for October.

The second item is the low streamflows during the winter months (November – mid-April). Some of the impacts of water management on winter streamflows are due to reservoir storage above the Canyon Mouth. On 21 February (day 144) the discharge was 1.87 m^3/s but on 23 February the discharge was 0.65 m^3/s. Most likely there was a change in water management on 22 February. The streamflows at Fort Collins were low but reasonably constant during this period (about 0.14 m^3/s).

The third item is the magnitude and timing of the peak discharge. In 2005 the maximum daily discharge was 56.9 m^3/s on 26 May. The maximum daily discharge at the Fort Collins gage was 42.5 m^3/s 11 days latter on 6 June. Peak discharges are important in maintaining the substrate, the channel form, and river bars free of vegetation. Finally, we note the rapid reduction in streamflows following the peak discharge and the high fluctuation of streamflows during the remainder of the irrigation season.

We have identified four issues that should be considered in selecting the most important investments in environmental flow alternatives. Each of the issues is analyzed in the following four sections. River temperature is also important and a few comments on river temperature follow the four sections.

October High Flows and Habitat Loss

The first issue is the transport of large volumes of water through the river in October followed by low winter strreamflows In most Colorado rivers there is significant physical habitat loss over the fall and winter because river discharges tend to decline from October to a low just before spring runoff. The Animas River formulation of winter habitat loss model (Milhous, 2002) was used to show the potential loss of spawned redds of fall spawning fish (brook and brown trout) over the incubation period (the fall and winter). The model was called a spawning loss model and was calculated using the following equation: $SL = 1 - (Q_{win}/Q_{Oct})^b$ where SL is the spawning loss, Q_{Oct} is the average discharge in

October, and Q_{win} is a representative winter discharge (Milhous 2002). The power term, b, is from the hydraulic geometry relation between width and discharge: $width = aQ^b$.

The representative discharge used in the Animas River analysis was the minimum 10-day discharge between 1 December and 28 February. The same concept can be applied to the Poudre River both from the viewpoint of spawning loss but also from the viewpoint of habitat loss in general caused by high flows in October when the aquatic system would be expected to adjust to the on-coming winter and sudden loss of water from the river during the winter. The value of b at the Fort Collins gage is 0.42 (Milhous, 2009). In this paper we rename SL to Width Reduction Fraction because we are interested in both possible loss of habitat for fall spawning fish and loss of habitat for all aquatic animals in the river. Results of the analysis for the 'at Fort Collins' gage are presented as Figure 3.

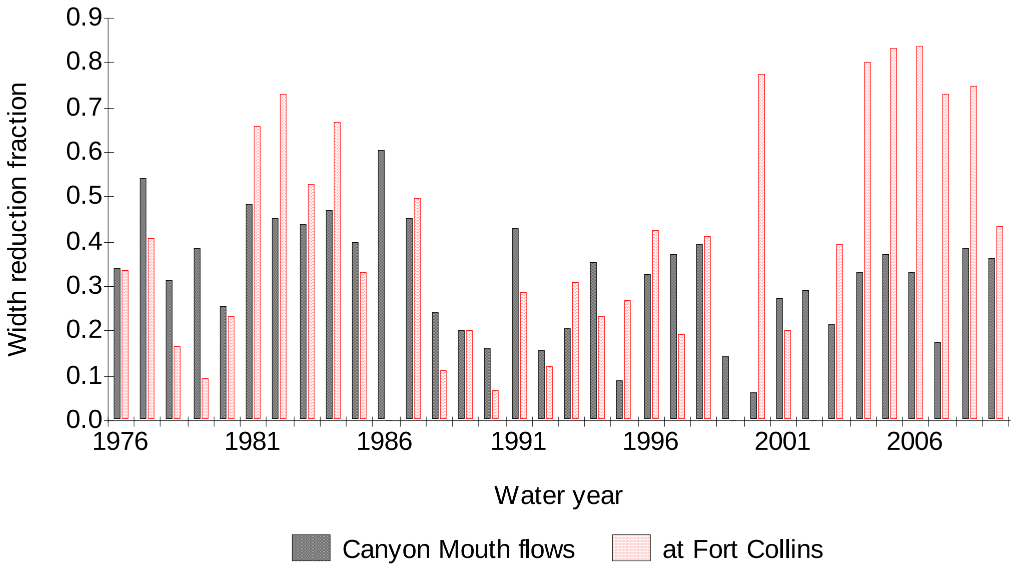

Figure 3. Width reduction from fall (October) streamflows to winter streamflows (1 November to 15 March).

There are two general causes of width reduction in the Poudre River. The first is the loss of habitat caused by a sudden reduction of streamflows during the winter period. An example is water year 2000. On 28 February the daily discharge was 1.5 m^3/s which was reduced to 0.033 m^3/s on the 29^{th}. The width reduction was 80% just for that one day. The width reduction fraction shown in Figure 3 for 2000 is 0.77. If there had not been the sudden reduction, the factor would have been 0.06. The higher width reduction fractions in the 1980's appear to be a mix of sudden reductions described above plus October flows being relatively high because the years were relatively wet. The second general cause of width reduction has only occurred beginning in water year 2004 when there is a high discharge caused by releases from Horsetooth Reservoir followed by a sudden drop in the discharge on the first of November.

Winter Habitat

The second, but related, issue is low winter aquatic habitat. The type of habitat analysis presented in this section was previously used in a winter habitat analysis of the Animas River in southwestern Colorado (Milhous, 2002). Gaging station discharge measurement summary data and invertebrate habitat preference values were used as input to the HABVD program in PHABSIM (Milhous, et al., 1989). The HABVD program should be used with species and life stages that use runs and riffles as the principle habitat; benthic invertebrates meet these criteria. Figure 4 denotes the results for two locations and the average of both.

A time series of the annual winter benthic invertebrate habitat was developed using the minimum 10-day streamflow (average discharge during a ten day period) between 1 November and 15 March of each water year. Results are presented in Figure 5 for 1977-2009. The average winter habitat for benthic invertebrates is 5.72 m^2/m based on the streamflows at the Canyon Mouth compared to 2.58 m^2/m based on the Fort Collins' streamflows. The variation from year to year in Fort Collins is much larger at present (coefficient of variation of 0.79) than would occur with the Canyon Mouth flows (CV of 0.25).

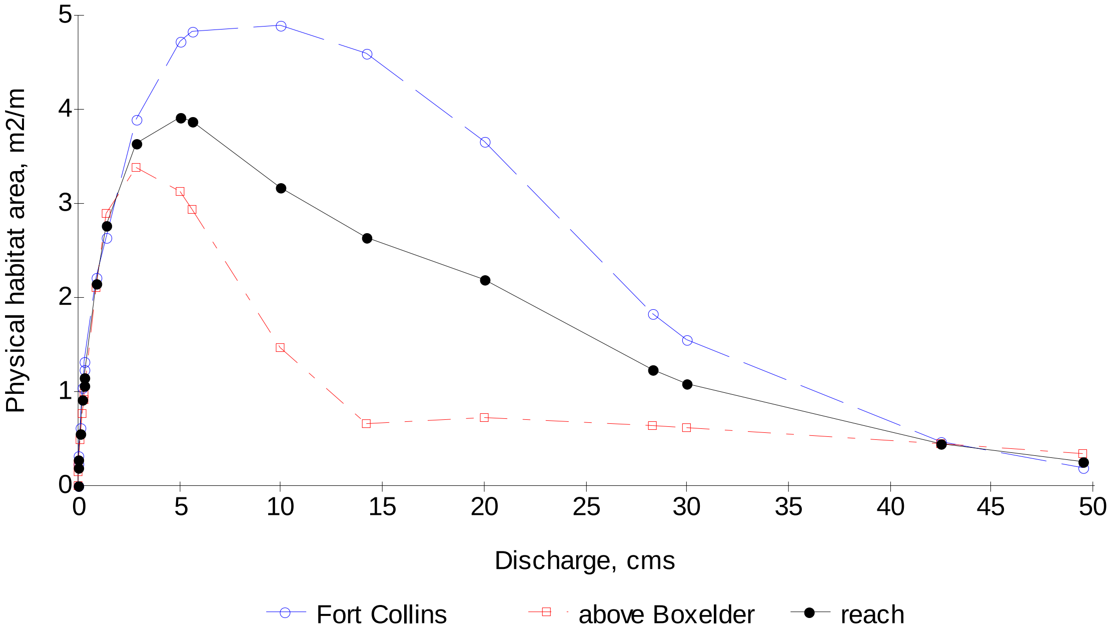

Figure 4. Invertebrate physical habitat as a function of discharge in the Fort Collins reach of the Poudre River. Habitat value for the reach is the average of the habitat determined using data at the Fort Collins gage and for the gage above Boxelder Creek.

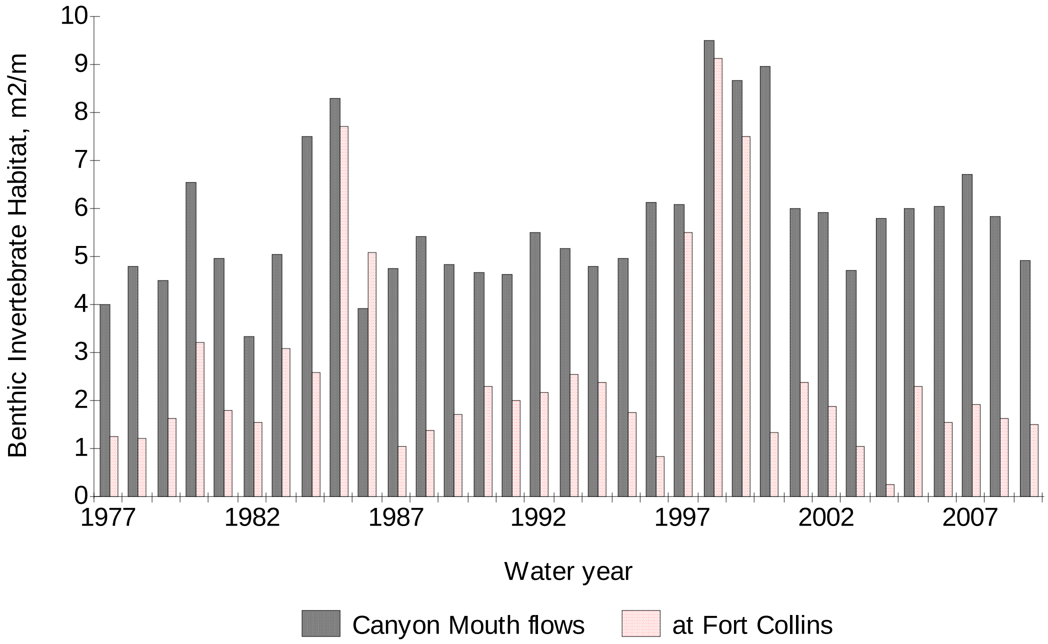

Figure 5. Time series of winter benthic invertebrate habitat in the Fort Collins reach of the Poudre River developed using habitat values from Figure 4. The habitat is for the reach calculated using the Canyon Mouth flows and the Fort Collins flows as if they occurred in the whole of the reach.

Maintenance of the channel and substrate

The third issue is the maintenance of the substrate and the channel. In a previous paper (Milhous, 2009) discharge measurement summary data and limited field data were combined to develop a relation between discharge and a substrate movement parameter for the Poudre River above Boxelder Creek. The value of the substrate movement parameter critical for movement of sand and fines is known from other studies. This known critical value is combined with the relation between discharge and the substrate movement parameter to calculate the discharge in the Poudre River in the Fort Collins reach required to flush sand and fines from the river. The discharge - sediment transport parameter relation determined from the analysis is:

$$\beta = 0.00226Q^{0.549}$$

where Q is the discharge (m^3/s) and ß is the substrate movement parameter. The critical value of the substrate movement parameter is 0.021, resulting in a flushing flow calculated to be 58 m^3/s. A Substrate Movement Index (SMI) has been formulated to show the variation from year to year of the ability of the river to disturb the substrate. The equation is:

$$SMI = \sum_{i=1,n} \{(Q(i) - Q_{crt}) / Q_{ref}\}^{\beta}$$

where Q(i) is the daily discharge on day i, Q is the critical discharge (58 m^3/s), Qref is an arbitrary discharge (30 m^3/s is used here), ß is the power term in the ß discharge relation (0.549) and n is the number of days in a year in which the critical discharge is larger than the daily discharge. The results are presented in Figure 6.

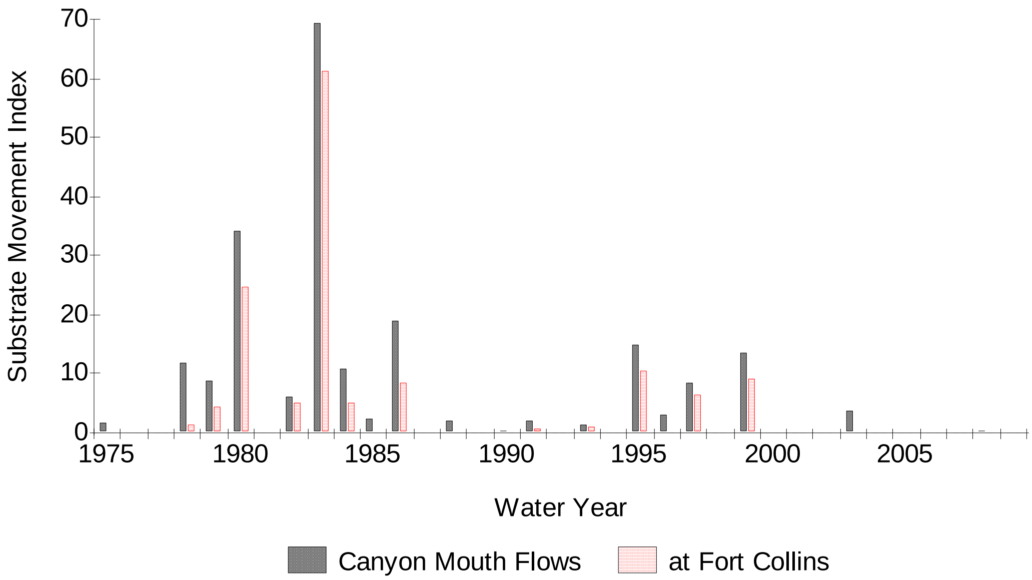

Figure 6. Annual Substrate Movement Index in the Poudre River at two gages in the Fort Collins area for 1975 thru 2008.

There are 35 years of record at the Fort Collins gage with 12 years with SMI larger than zero. The SMI indicates that the last 10 years (2000-2009) likely had no substrate flushing in the Fort Collins reach. This compares to 19 years with SMI larger than zero and a maximum length of years without a SMI larger than zero of 4 years based on Canyon Mouth data. Prior to 1975 the SMI calculated using the complete record for the Canyon Mouth Gage shows the average SMI for 1975-2009 (6.33) is less than the overall average of (8.72). Between 1951 and 1953, the diversion from the river was constructed for a canal a short distance upstream of the gage. The average SMI prior to the diversion was 11.44 and after the diversion 5.80. The maximum interval between substrate disturbances was probably not more than three years based on the largest interval in the period 1885-1950. After 1950 the maximum interval of no substrate disturbance was four years using the Canyon Mouth data.

There is a significant observation based on Figure 6. The 10 year interval from 2000 – 2009 at the Fort

Collins gage would probably not have occurred with 'natural' conditions and did not occur based on Canyon Mouth flows. Vegetation is covering many if not most gravel bars in the river which is what would be expected with no substrate movement.

Summer short term streamflow changes

The fourth issue is the flashiness of the river caused by irrigation operations in the summer. One of the characteristics of a working river is an increase in short period streamflow fluctuation due to abruptly starting and stopping diversions and reservoir releases to satisfy water rights. In this section the Richards-Baker Flashiness Index (R-BI), described in Baker (2004), is used to illustrate the impact of water management on the flashiness of the Poudre River during the irrigation season following spring runoff (July-September). Cassin et al. (2005) suggest that the R-BI can reveal changes in the streamflow rate-of-change and that an increase in the daily rate-of-change could be a significant disturbance for organisms adapted to more stable high- or low-flow periods and more gradual ramping up and down of flows following storm events. The equation for the Richards-Baker Flashiness Index (R-BI) is:

$$R - BI(k) = \sum_{j=1,n} abs[dv(j,k) - dv(i-1,k)] \Big/ \sum_{j=1,n} dv(i,k)$$

where k is the year, dv(j,k) is the daily discharge on day j in year k, and n is the number of days in the period (92). The R-BI for three locations on the Poudre River are shown in Figure 7. It is clear from Figure 7 that flashiness of the Poudre River has increased as a result of the operation of many diversions, releases, and return flows between the gages.

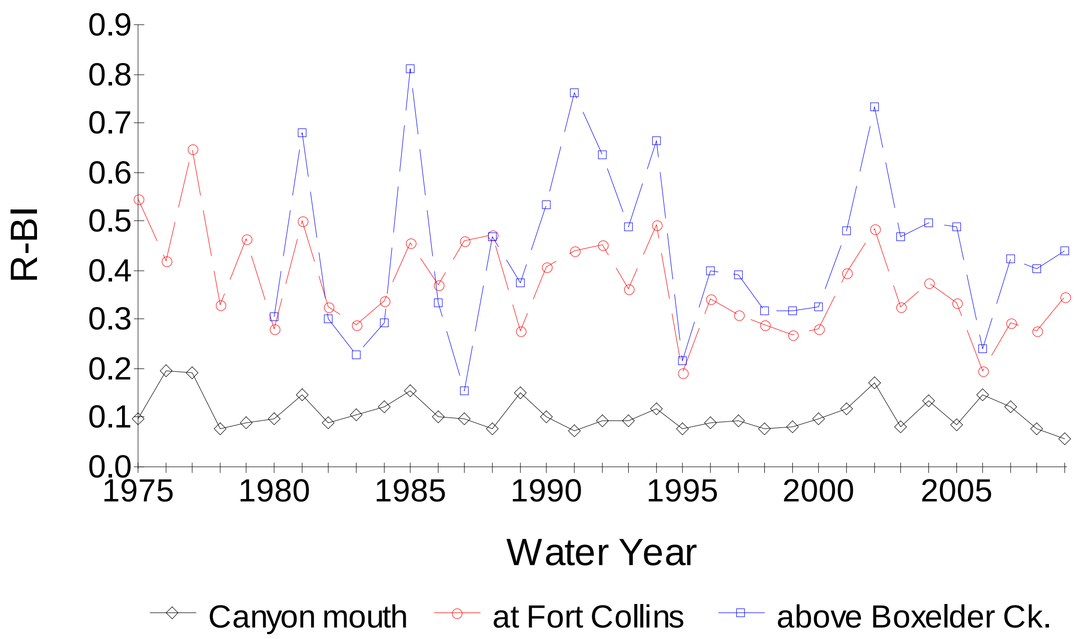

Figure 7. The Richards-Baker Flashiness Index (R-BI) for three locations on the Poudre River during the irrigation season following spring runoff (July-September).

Water Temperature

Thermal factors are not the central focus of this paper, but it is worth mentioning two specific water temperature issues. First, both reduction of, and rapid changes in, streamflow may result in elevation of or unnatural fluctuation in suitable water temperatures for aquatic organisms. Second, relatively cold hypolemnetic water periodically released from Horsetooth Reservoir during the irrigation season may 'shock' the ambient riverine ecosystem. Water temperature is a topic for future investigation.

Discussion

The objective of this paper was to stimulate thinking about environmental flows in working rivers by presenting a case study of the Poudre River and to review where investment of resources could be made to improve the aquatic health of the river.

The first item of interest is the observation that there have been rather high discharges in October followed by a sudden reduction of streamflows in November in the Fort Collins reach of the river. This was found to be a recent phenomena and may have a significant impact on the health of the river because of the potential to strand aquatic animals just prior to winter's high environmental stress period. The high flows meet demands downstream and, in at least two of the years, water was diverted from the South Platte downstream of the Poudre River to plains reservoirs. It is likely that investments could be made to release flows from Horsetooth Reservoir over a longer period of time thus reducing the rapid reduction in stream width.

The second item is the low streamflows during the winter months. Winter flows have been shown to be a significant limiting factor on the health of the river (Figure 5). These low flows could be increased by spreading out October high flows (see above), by reducing extractions from the river, and by increasing releases from reservoirs upstream of the Canyon Mouth.

The third item is the magnitude of the peak discharge. The last 10 years have not had discharges adequate to move the substrate. There have been two years of the past ten with flows adequate for substrate maintenance. Peak flows could be increased in the Fort Collins reach by curtailing diversions during the peak flow period.

The fourth item is the high variation in streamflow during the summer months. The analysis presented in this paper shows the R-B Index of flashiness is much higher in the Fort Collins reach than at the canyon mouth. Figure 7 clearly shows there is considerable flashiness during summer months in the Fort Collins reach. The aquatic health of the river could be significantly improved by investing in water control and instrumentation that would reduce the operationally-induced flashiness.

What we have presented is a case study of a 'working river' where the demands for the water exceed the supply and have shown the need to identify environmental flow issues that must be considered in order to provide or improve environmental flows in the river. As was said by Burnett about Orange-Senqu Rivers the issues described for the Poudre River '*speak to the challenge of managing the resource in a water-scarce environment*'.

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