Draft Report

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Upper Beaverhead Sediment Project Preliminary Flushing Flow Plan --DRAFT--

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1 Introduction

This document summarizes the development of a preliminary flushing flow plan for the Beaverhead River at Clark Canyon Dam near Dillon, Montana. The need for a flushing flow from Clark Canyon Dam stems from problematic "sediment events" originating from Clark Canyon Creek, a tributary that enters the Beaverhead River approximately 1.5 miles downstream of the dam (Figure 1). When Clark Canyon Creek experiences a significant runoff event, it delivers large quantities of fine sediment to the Beaverhead River. If Beaverhead streamflows are low, the sediment is not effectively flushed downstream, which results in fine sediment deposition that has been associated with impacts to spawning habitat, macroinvertebrate populations, and significantly reduced trout populations (Figure 2).

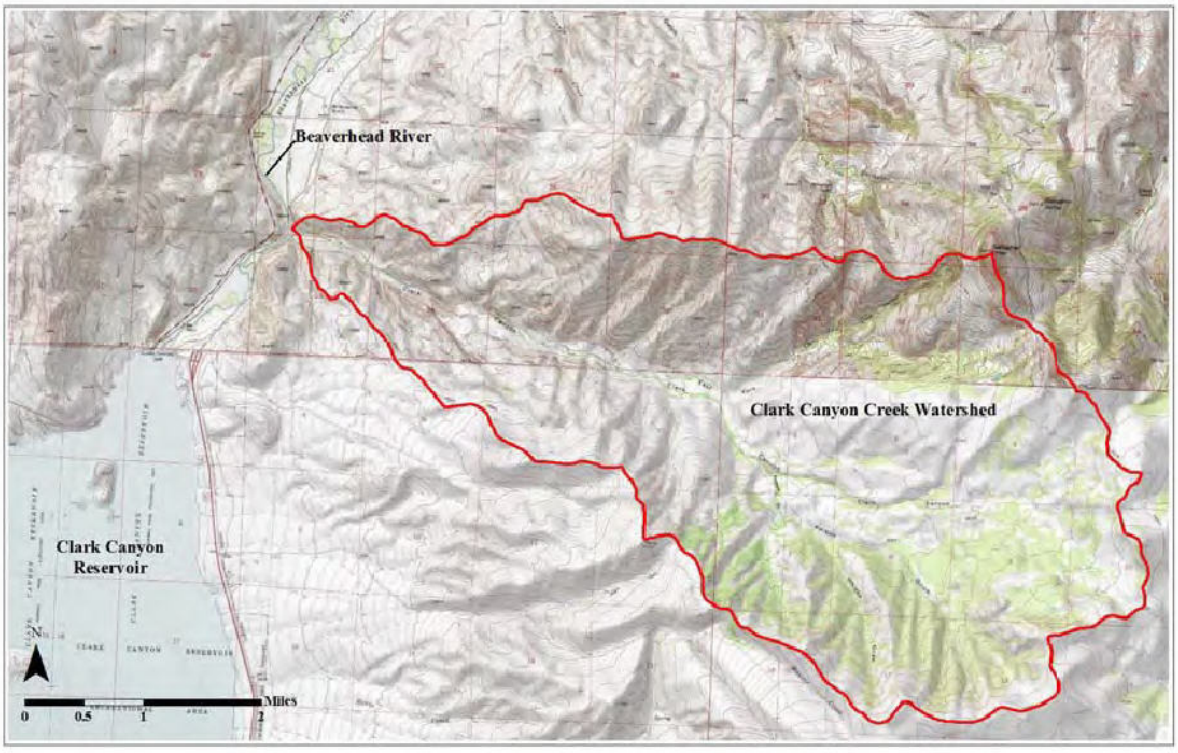

Figure 1. Location Map, Clark Canyon Reservoir and Clark Canyon Creek Watershed (Allied Engineering, 2013).

Figure 2. View upstream showing Clark Canyon Creek fine sediment contributions from left of photo; Beaverhead Watershed Committee (Allied Engineering, 2013).

The consequences of a sediment event and associated fisheries impacts on the Beaverhead are not trivial. Immediately downstream of Clark Canyon dam, the Beaverhead River hosts some of the highest fish abundances and sizes in the state of Montana relative to its size (M. Jaeger, pers comm.). Fish abundances of approximately 2,000 to 3,000 trout per mile are estimated below the dam. The river supports over forty thousand angler days per year, and almost $6 million per year is estimated to be spent annually by Beaverhead River anglers in Beaverhead County.

Sediment events on the Beaverhead River have likely increased in frequency since the construction of Clark Canyon Dam. As the reservoir is currently managed primarily in support of irrigation, the natural hydrograph has been altered to store water during winter and spring, and then release that water later during the irrigation season (Allied Engineering, 2013). Beaverhead River flows in winter and spring are consequently suppressed, which has increased the potential for sediment events to occur before the irrigation season which typically starts in early June.

The Beaverhead River fishery is also affected by overwintering flow releases from the reservoir, however that issue is not addressed here.

Efforts to address sediment loading from Clark Canyon Creek have focused reducing sediment sourcing in the Clark Canyon Creek watershed, trapping sediment before it reaches the Beaverhead River, and maintaining sufficient sediment transport capacities in the Beaverhead River should a sediment event occur. The sediment transport capacity issue is being addressed through the development of a “flushing flow”, or a strategically-developed hydrograph that can be released from Clark Canyon Dam to minimize

fisheries impacts of a sediment event. This flushing flow has been evaluated by the US Bureau of Reclamation, which has released two reports with recommendations (BOR 2010; BOR, 2013).

Additionally, source area sediment management strategies have been described in several previous efforts, including Total Maximum Daily Load (TMDL) assessments (MTDEQ, 2012), and a sediment management alternatives report (Allied Engineering, 2013).

The intent of this document is to present recommendations for a flushing flow hydrograph on the Beaverhead River, and to provide additional recommendations to integrate the flushing flow strategy with previously described sediment control methods for the Clark Canyon Creek watershed.

This project encompasses three primary tasks:

1. Review previous flushing flow and sediment management reports.
2. Develop a Flushing Flow Plan to be used by the Bureau of Reclamation, Montana Fish Wildlife and Parks, and the Clark Canyon Joint Board of Irrigation.
3. Assess feasibility, benefits, limitations, and overall effectiveness of implementing both sediment management and flushing flow alternatives independently or synchronously.

2 Report Review

The following section contains a general summary of documents relevant to the flushing flow plan development, including results of two individual hydraulics/sediment transport analyses performed by the Bureau of Reclamation (BOR, 2010; BOR, 2013), a Clark Canyon Creek Sediment Reduction Alternatives report by Allied Engineering, Inc. (Allied Engineering, 2013), and a TMDL-driven sediment source assessment completed by Montana DEQ.

2.1 BOR Flushing Flow Studies

Two flushing flow studies have been released by the Bureau of Reclamation. They are both based on a hydraulic analysis of the Beaverhead River below Clark Canyon Dam, and an assessment of sediment transport capacity under a range of flows relative to pebble count sediment gradation data. The general objective of each effort is to define a critical discharge at which point transport will be initiated for a given grain size. Each of the reports provides a recommended flushing flow for the Beaverhead River; the 2010 report recommends a 350 cfs flushing flow, and the 2013 report recommends 600cfs.

In reviewing the two BOR documents, it is apparent that the 2013 had more detailed topographic data available for the hydraulic model, more recent substrate data that reflected coarsening following the 2011 flood event, and a more rigorous requirement for flushing flow criteria (mobilization of the D90* particle size versus the D50* particle size). All of these issues combine to result in an almost doubling of the recommended flushing flow.

In the first study (BOR, 2010), the BOR concluded that the D50 of approximately 20mm would mobilize at 350 cfs. Using the Meyer-Peter-Mueller sediment transport equation, they concluded that 200 cfs would mobilize a 15-17mm particle size, and then suggested that the D90 of 39mm would move at relatively low flows as well. There is no clear documentation as to the flows required to mobilize the D90 particle size, however 350cfs was presented as an appropriate flushing flow.

In the second report, the BOR utilized better topographic data for the hydraulic model and the Parker sediment transport equation. The approach assumed that in order to flush fine sediment of less than 1 mm from the interstitial spaces of a gravel bed river, the discharge needs to be high enough to just mobilize the largest gravel or cobble size based on other studies (Kondolf et al 1996). To that end, BOR used the D90 as the critical grain size for initiation of movement. The conclusion was that at most pebble count locations, 600 cfs would mobilize the D90 and thus allow interstitial fine sediment to be flushed downstream (Figure 3).

**Note: the "D90" is the grain size measured at a pebble count site of which 90% of the measured particles are finer. The D100 is the maximum grain size measured, and the D50 is the median value. Thus the D90 represents the coarse component of the overall sediment gradation.*

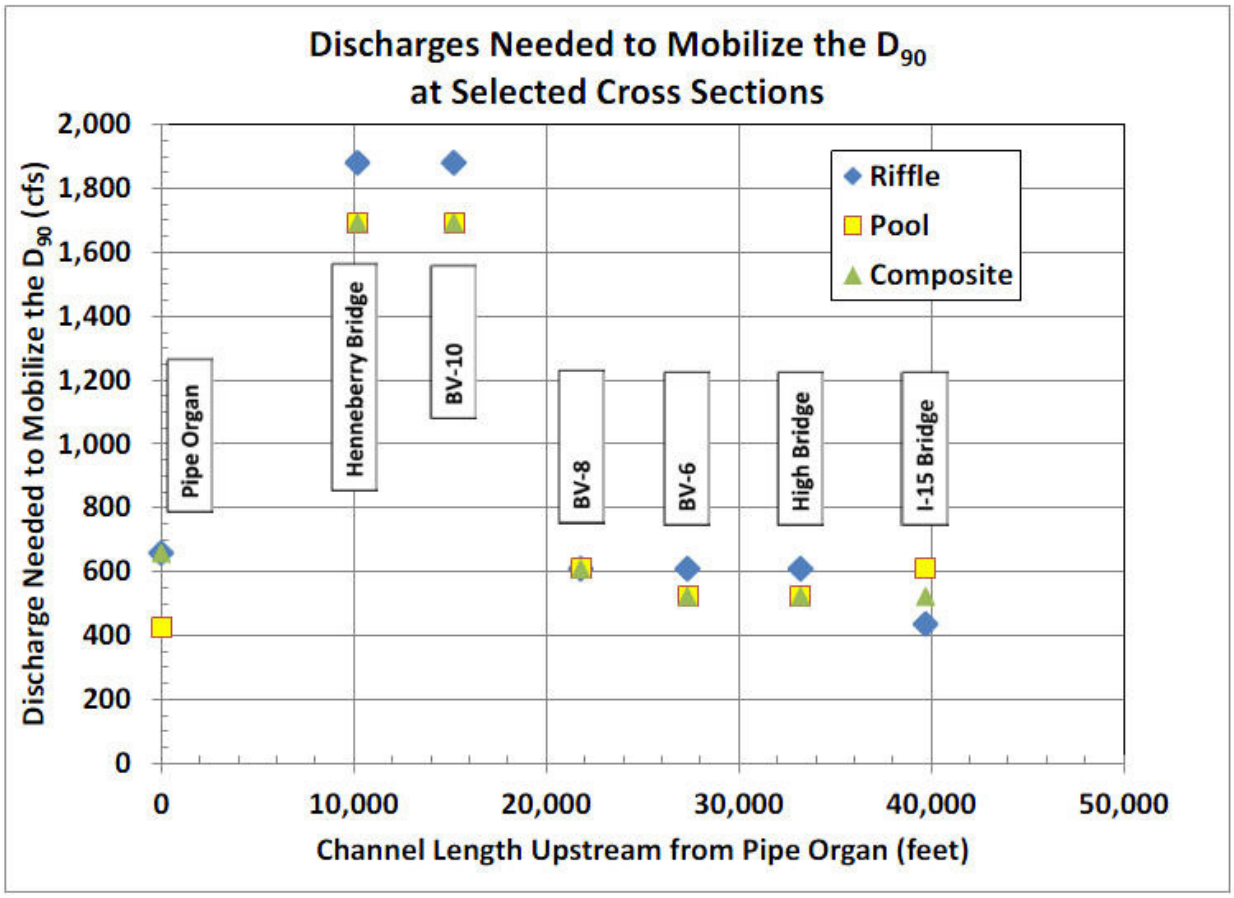

Figure 3. Discharges necessary to mobilize the D90 particle size at selected cross sections (BOR, 2013).

As described later in this document, the original BOR flushing flow recommendation of 350 cfs is typically exceeded on the Beaverhead during Clark Canyon Creek runoff events, indicating that 350cfs is probably not sufficient to consistently flush fine sediment. Based on an evaluation of the technical approach, input data quality, and results of both reports, the revised flushing flow of 600 cfs recommended most recently by BOR has been used in the development of a preliminary flushing flow plan in this document. It is important to note that the original 350 cfs value has been used as a recommended flushing flow in other reports, such as the Montana Department of Environmental Quality TMDL water quality protection plan. These recommendations were made prior to the release of the 2013 BOR study.

2.2 Clark Canyon Creek Sediment Reduction Project

In January of 2013, Allied Engineering Inc. (Allied) released a report entitled "Final Technical Report: Clark Canyon Creek Sediment Reduction Project" (Allied Engineering, 2013). The purpose of this report was to develop and evaluate several alternatives to reduce or manage sediment loading from Clark Canyon Creek into the Beaverhead River.

Allied looked at five alternatives to mitigate sediment delivery to the Beaverhead including a settling pond, water spreading, flushing flows on the Beaverhead, irrigation practice modifications, and check dams. The only alternative selected for further consideration was on on-stream settling pond on the lowermost reach of East Fork Clark Canyon Creek, just upstream of its confluence with the main fork (Figure 4). The estimated cost to construct a single on-stream storage/settling pond was approximately $11,000 per acre-foot of storage.

Primary results of this effort include the following:

1. Sediment production in Clark Canyon watershed is primarily from the East Fork Clark Canyon Creek and most likely reflects natural inputs with minimal anthropogenic contributions.
2. Estimated hillslope sediment contributions from the Clark Canon Creek watershed are 146 tons per year, which is estimated at an average of about 137 cubic yards per year delivered to the Beaverhead River.
3. Estimated runoff volumes for the 5-year and 25-year storm events (precipitation) are 20 acre-feet and 50 acre feet. These events produce discharges in the creek on the order of 82cfs and 235cfs, respectively.
4. The offending sediment is silt characterized as silt with a particle size greater than 0.01mm.

Results of the Allied report indicate that problem sediment sourced in the Canyon Creek watershed is largely silt, which is large enough to gravitationally settle out in a detention basin. Allied also indicates that the construction of a settling pond that has a storage volume of 19 acre-feet would store the runoff from the estimated 5-year storm event. A 49 acre-foot settling pond would impound estimated excess runoff from East Fork Clark Canyon Creek up to a 25-year storm event. The excess runoff from a 5-year storm event is estimated to result in a Clark Canyon Creek discharge of 82cfs, and a 25-year storm results in a 235cfs streamflow. Anything over the 5-year storm event is thus quite capable of creating a sediment event on the Beaverhead River, as described in Section 3.1.

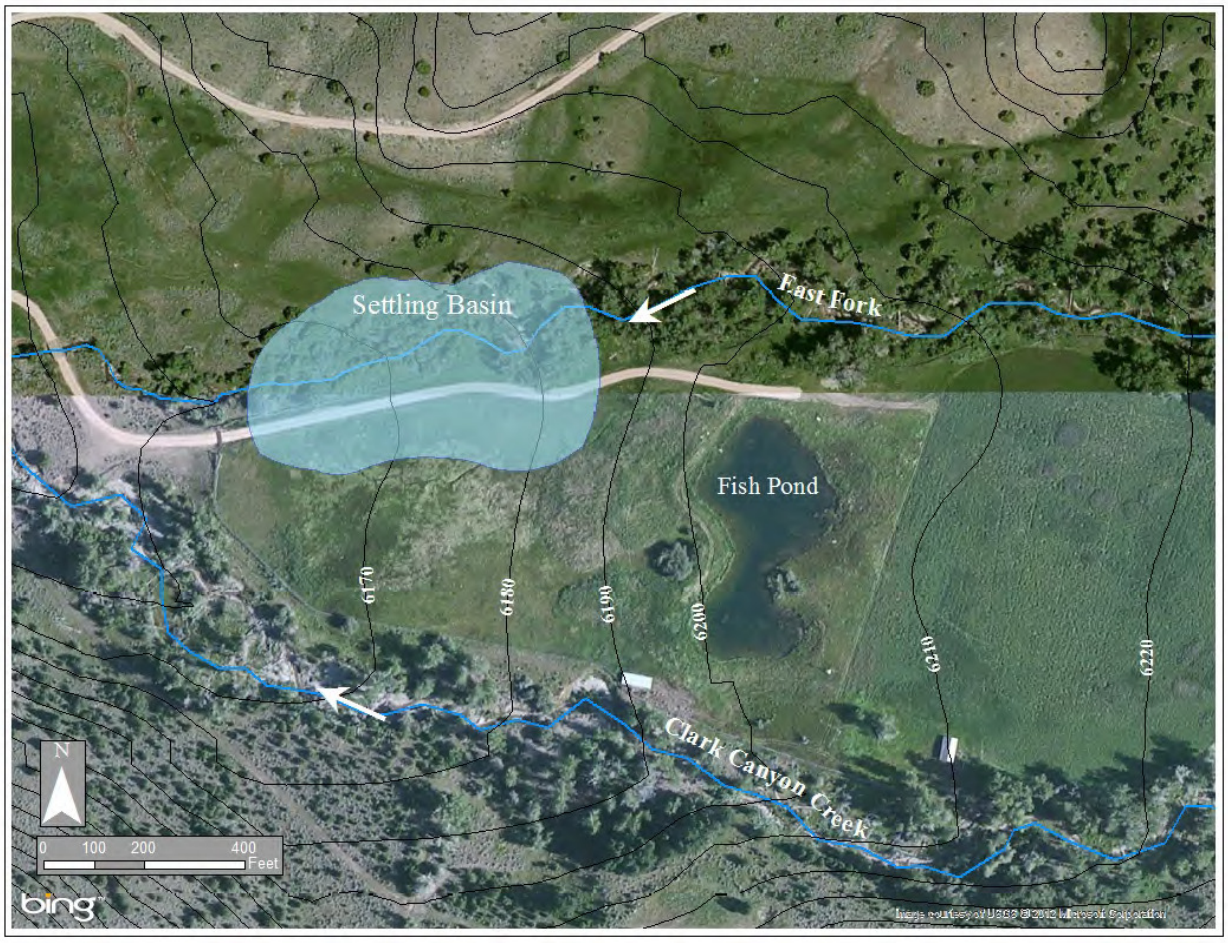

Figure 4. Conceptual layout of a settling pond near the outlet of the East Fork Clark Canyon Creek (Allied Engineering, 2013).

To further refine the alternatives analysis, Allied recommended the following:

1. Better characterize problematic sediment deposits in the Beaverhead;
2. Evaluate the feasibility of a settling pond with a minimum storage volume of 19 acre-feet and maximum storage volume of approximately 49 acre-feet; and,
3. Perform a site evaluation to further explore the potential of using check dams to address gully erosion.

2.3 Beaverhead TMDL

The TMDL development for the Beaverhead Planning area describes the need for a flushing flow on the Beaverhead River below Clark Canyon dam to flush fine sediment delivered by Clark Canyon Creek (MTDEQ, 2012). The recommended flushing flow is 350cfs, taken from the 2010 BOR report.

Whereas previous reports have indicated that most of the sediment sourced from the Clark Canyon Creek watershed is derived from hillslope and gully erosion, the results of the TMDL sediment source assessment conclude that 88% of the total sediment load is from bank erosion, and furthermore, 80% of that sediment is anthropogenically influenced by factors such as riparian grazing (Table 1). The TMDL document approximates that over 1,000 tons of sediment is sourced annually from eroding banks in the watershed. The TMDL issued for Clark Canyon Creek prescribes a 59% reduction in total sediment loading from the watershed, with reduced sediment input from roads, streambanks, and upland erosion.

The total sediment load estimated from Clark Canyon Creek estimated in the TMDL is 1,230 tons per year. This equates to over 1,100 cubic yards of sediment delivered to the Beaverhead River on an annual basis, or approximately 0.7 acre-feet of sediment per year. In the event that a settling basin option is pursued, the discrepancy in estimated sediment delivery volumes will have to be considered in assessing how often the pond will have to be cleaned out.

Table 1. Sediment Source Assessment, Allocations and TMDL for Clark Canyon Creek (MTDEQ, 2012).

Sediment Sources		Current Estimated Load (Tons/Year)	Total Allowable Load (Tons/Year)	Load Allocations (% Reduction)
Roads		0.3	0.1	67%
Eroding Banks	Anthropogenically Influenced	807	409	62%
	Natural	277		
Upland Erosion	All Land Uses	146	91	38%
Total Sediment Load		1,230	500	59%

3 Flushing Flow Plan

The following section describes the development of a flushing flow plan to address sediment events on the Beaverhead River below Clark Canyon Dam. This includes a discussion of what constitutes a sediment event, the identification of specific criteria for the flushing flow, and the presentation of scenario-based flushing flow hydrographs.

3.1 Defining a Sediment Event

Thus far, characterizations of sediment events on the Beaverhead River have been based on observed relationships between Clark Canyon runoff events, sediment deposition in the Beaverhead River, and reduced fish abundances below Clark Canyon Dam. These events have occurred when flow in the Beaverhead River is relatively low. Although the reduced fish abundances following an event have been quantified, there has been no similar quantitative characterization of the size of the storm event to hit the Clark Canyon Creek watershed, the discharge from the creek, or the discharge of the receiving Beaverhead River.

Existing information regarding sediment events is limited. In general, the events tend to occur when discharges from Clark Canyon Creek are relatively high prior to June 1st when Clark Canyon Reservoir releases are low. Based on reports from FWP, a total of four events occurred between 1974 and 2004, two of which occurred before June 1. Between 2005 and 2012, five events occurred, two of which occurred prior to June 1. One of the sediment events occurred in March 2009.

3.1.1 Clark Canyon Peak Flow Record

The USGS gaging station at Clark Canyon Creek (USGS 06015430) has a peak annual discharge record extending from 1975 to 2012 (Figure 5). The records show that during that timeframe, the highest peak flow on Clark Canyon Creek occurred on May 17, 1984 when a peak flow of 415cfs was measured. The second largest event from Clark Canyon occurred on June 8 2011, with an event that measured 315cfs. Since 1975, a total of 25 annual peak discharges exceeded 30cfs. Since the record only provides one peak discharge per year, there may have been additional significant runoff events during any given year that were not recorded because they were less than the maximum peak.

For the purposes of looking at the historic record, a 30cfs Clark Canyon Creek annual peak discharge has been used here as a fairly conservative minimum flow that might be associated with a sediment event.

3.1.1 Relating Clark Canyon Creek Flows to Beaverhead Flows

Since 1975 there have been a total of 25 events on Clark Canyon Creek that exceeded 30 cfs, however whether or not these or any other events resulted in a "sediment event" is largely dependent on the flows in the Beaverhead at the time. To try and identify specific events in the record, the specific dates of the Clark Fork Canyon peak discharges were compared to the flow released from Clark Canyon Reservoir on that day (Figure 6). As the USGS gage below the reservoir has been discontinued, the reservoir release data were obtained from archived BOR records (http://www.usbr.gov/gp/hydromet/). The results show that since 1975, there were six instances where the Clark Canyon flows exceeded 30cfs on the same day that Clark Canyon Reservoir releases were less than 100cfs (Figure 7). These years

include 1977, 1990, 1991, 1994, 2005, and 2006. All of these events occurred between mid-March and mid-May (Figure 7 and Table 2). In each of these years, the discharge from Clark Canyon Creek was approximately 30% of the flow release from the reservoir or greater.

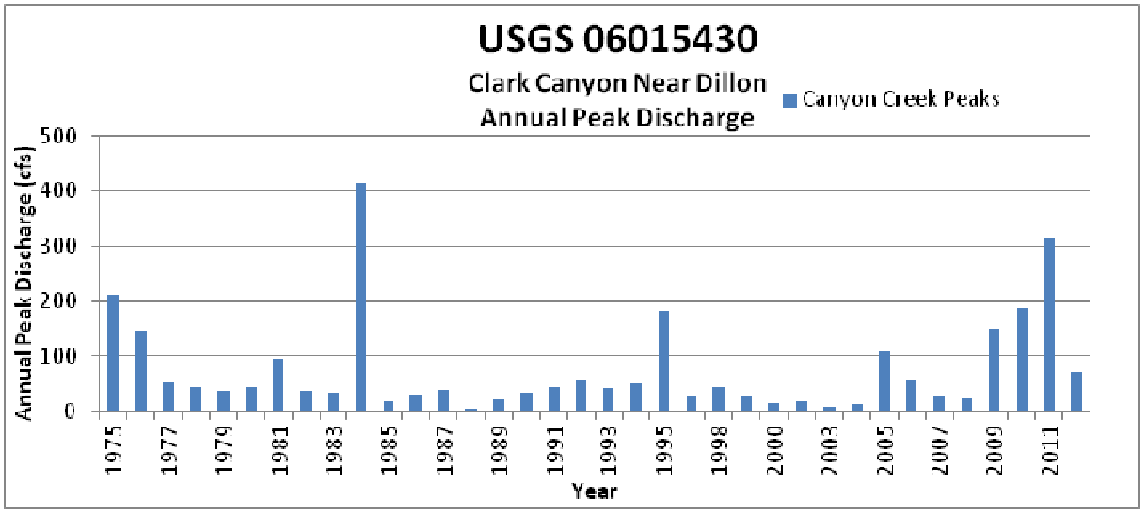

Figure 5. Peak discharge record, Clark Canyon Creek (USGS 06015430)

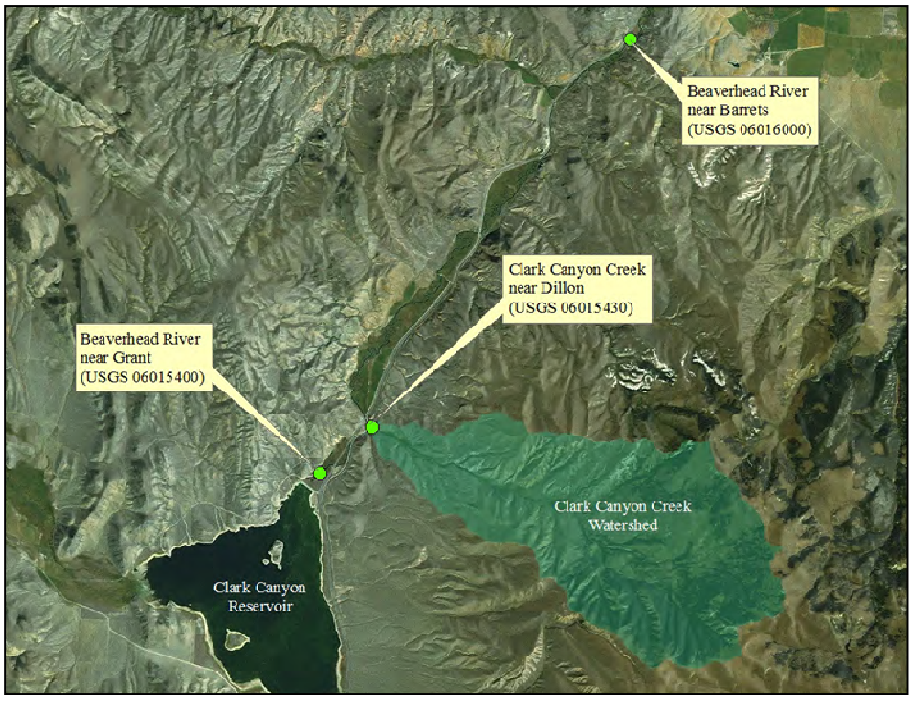

Figure 6. Gage locations in the project area (Allied, 2013); reservoir releases are also recorded by BOR.

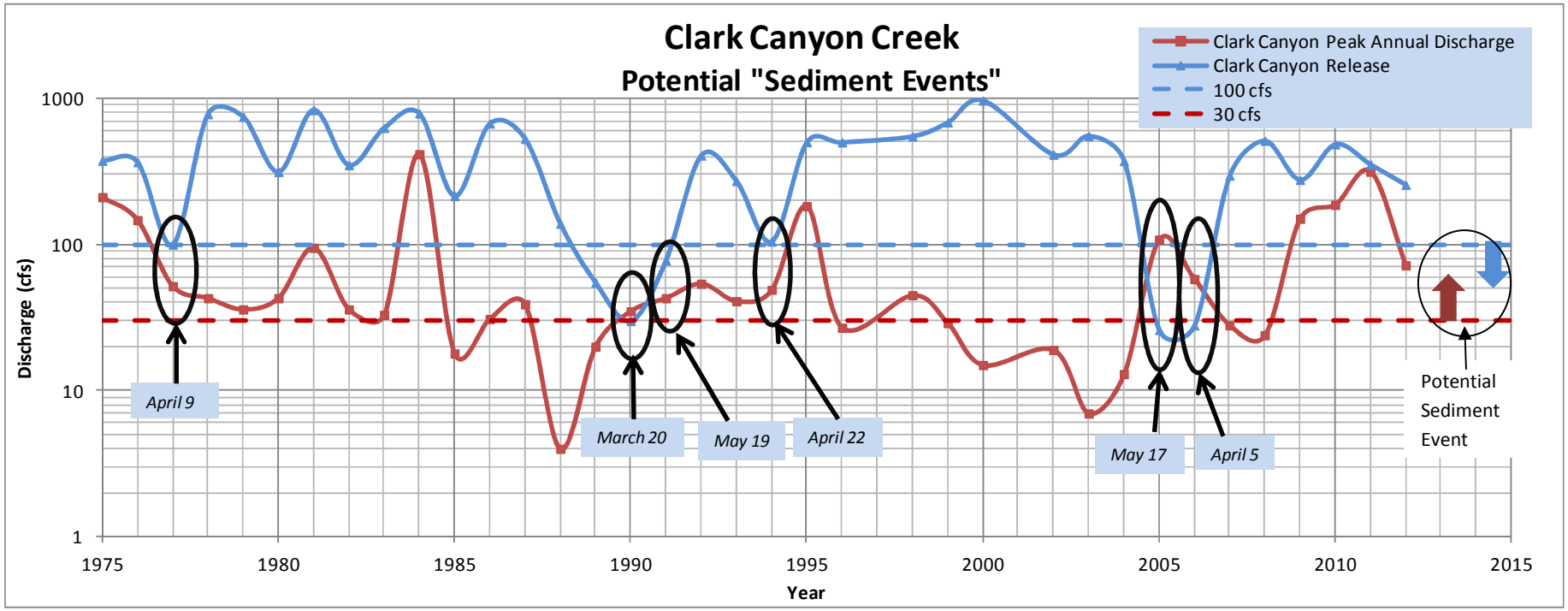

Figure 7. Peak annual discharge on Clark Canyon Creek (red solid line) showing reservoir releases on same day (blue solid line); black circles identify conditions where Clark Canyon flows exceeded 30cfs and releases were less than 100cfs on same day.

Table 2. Flow relationships between Clark Canyon Creek and Beaverhead River with potential sediment events highlighted.

Year	*Date*	*Clark Canyon Peak Discharge (cfs)*	*Return Interval (HEC-HMS)*	*Clark Canyon Reservoir Release (cfs)*	*Mean Daily Flow Beaverhead at Barretts (cfs)*	*Clark Canyon/Reservoir Outflow*
1975	6/19/1975	211	10-25 year	375	1340	56%
1976	5/12/1976	147	10-25 year	366	648	40%
1977	4/9/1977	52	2-5 year	100	197	52%
1978	5/20/1978	43	2-5 year	780	925	6%
1979	5/29/1979	36	2-5 year	748	690	5%
1980	5/26/1980	43	2-5 year	314	848	14%
1981	5/27/1981	95	5-10 year	833	1110	11%
1982	5/2/1982	36	2-5 year	350	471	10%
1983	7/9/1983	33	2-5 year	627	668	5%
1984	5/17/1984	415	50-100 year	788	1240	53%
1985	4/10/1985	18	<2 year	215	411	8%
1986	5/27/1986	31	2-5 year	672	828	5%
1987	5/17/1987	39	2-5 year	529	986	7%
1988	4/26/1988	4	<2 year	139	274	3%
1989	3/11/1989	20	2 year	55	135	36%
1990	3/20/1990	35	2-5 year	30	161	117%
1991	5/19/1991	43	2-5 year	78	229	55%
1992	6/16/1992	54	2-5 year	406	717	13%
1993	5/17/1993	41	2-5 year	272	331	15%
1994	4/22/1994	49	2-5 year	105	266	47%
1995	6/6/1995	183	10-25 year	501	1320	37%
1996	4/9/1996	27	2-5 year	500	826	5%
1998	4/24/1998	45	2-5 year	550	686	8%
1999	5/30/1999	29	2-5 year	685	1000	4%
2000	7/19/2000	15	<2 year	966	898	2%
2002	6/4/2002	19	<2 year	412	559	5%
2003	5/28/2003	7	<2 year	553	634	1%
2004	6/11/2004	13	<2 year	373	467	3%
2005	5/17/2005	108	5-10 year	26	229	415%
2006	4/5/2006	58	2-5 year	28	206	207%
2007	6/7/2007	28	2-5 year	296	698	9%
2008	5/22/2008	24	2-5 year	512	703	5%
2009	6/20/2009	150	10-25 year	277	604	54%
2010	6/16/2010	187	10-25 year	485	775	39%
2011	6/8/2011	315	25-50 year	353	791	89%
2012	3/19/2012	72	2-5 year	256	320	28%
Likely Sediment Event						

A sediment event was recorded on the Beaverhead River in early spring of 2009, although that year does not meet the criteria (Figure 7). On June 20th 2009, the annual peak flow recorded on Clark Canyon Creek was 150cfs. On that same day, the release from Clark Canyon Reservoir was 277cfs, which is significantly exceeds the minimum criteria of 100cfs. However, a plot of flow hydrographs earlier in the season shows distinct pulses at the Barretts gage in late March and April when reservoir releases were around 35cfs (Figure 8). This demonstrates the fact the annual peak flow data for Clark Canyon Creek likely misses other significant events. Data collection in support of the Beaverhead Flushing Flow Plan would greatly benefit from upgrades to the gaging station at the mouth of Clark Canyon Creek to record mean daily flow as well as annual peaks.

Defining the conditions that create a sediment event will help managers anticipate and quickly respond so as to minimize impacts to the Beaverhead River fishery. This document provides an initial attempt to define those conditions, but with more information the criteria should be refined. Based on the available data, the minimum conditions that are considered likely to result in a sediment event are:

1. Flow release from the reservoir of less than 100cfs; and,
2. A greater than 30cfs event on Clark Fork Canyon Creek on the same day.

These criteria identify a total of six likely events since 1975 (Figure 7 and Table 2). It's interesting to note that all of these events do not reflect rare floods on Clark Canyon Creek; most are less than a 5-year event. If the 30cfs minimum discharge for a Clark Canyon Creek event is raised to 50cfs, only three historic occurrences meet the criteria. Alternatively, if 200cfs is used as the maximum flow threshold from the reservoir releases, the same 6 events meet the criteria.

This characterization of sediment events will evolve as more information and monitoring results become available. Appendix A contains a series plots showing the Beaverhead River hydrograph with the Clark Canyon Creek peak discharge plotted for all years that Clark Canyon Creek experienced a discharge in excess of 30cfs. The plots show the timing of and magnitude of the Clark Canyon Creek event relative to Beaverhead flows at both the reservoir and Barretts diversion, and the hydrographs commonly capture a distinct rise in the Beaverhead flows due to the Clark Canyon Creek inputs. Stakeholders who are familiar with the history of sediment events can use these plots to see if the six events identified here are correct, and to identify additional events that will help guide any necessary revisions to the criteria.

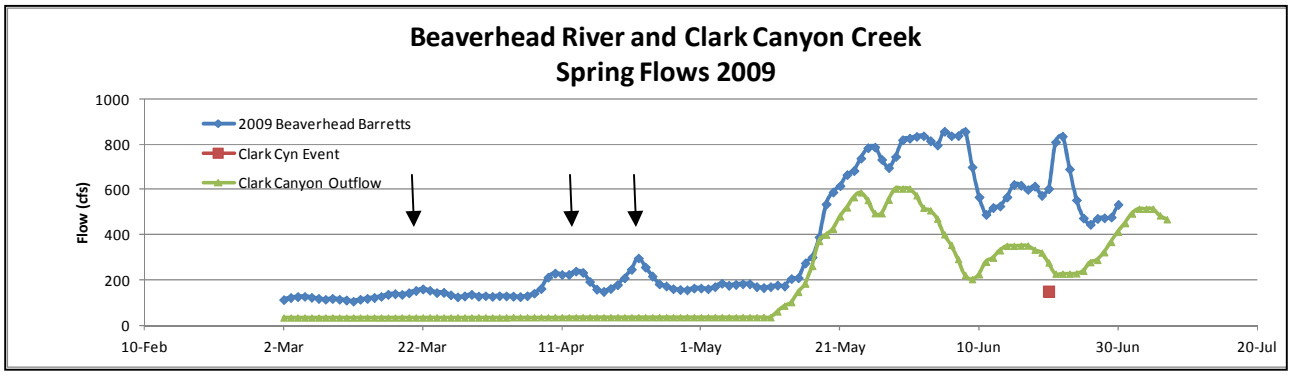

Figure 8. Spring hydrographs from 2009 showing annual peak Clark Canyon Creek discharge in mid-June.

3.1.2 Relating Peak Flow Events to Precipitation

The HEC-HMS modeling results for the Clark Canyon watershed (Allied, 2013) can be used to approximate the magnitude of a rainfall event that would have resulted in a given peak discharge entering the Beaverhead River. For example, the results of the modeling indicated that a precipitation event of 2.8 inches (a 50-year storm) over the Clark Canyon Creek watershed would be expected to create excess runoff that would result in the neighborhood of a 415 cfs peak discharge (Table 3). This relationship allows the estimation of a precipitation event that would likely be capable of generating a sediment event on the Beaverhead River. Based on these results, a sediment event can be considered to be likely any time the Clark Canyon Reservoir Releases are less than 100 cfs and the Clark Canyon Creek watershed receives anything over approximately 1.6 inches of rain. This ~3-year storm event produces about a 40cfs discharge. A ~3-year storm frequency indicates that sediment events are likely to be quite common if Beaverhead River flows are consistently suppressed in the late winter and early spring months.

Table 3. Summary of Allied (2013) modeling results showing modeled peak Clark Canyon Creek outflows (HEC-HMS) for given storm events.

Storm Return Interval (years)	*Precipitation (in)*	*Peak Discharge HEC-HMS Model(cfs)*
2	1.4	20
5	1.8	82
10	2.0	120
25	2.4	235
50	2.8	411
100	2.9	490

3.2 Flushing Flow Criteria

The following section contains criteria used to develop the Flushing Flow Plan. These criteria are based on the assumption that a sediment event has occurred, and that an MOU is in place for rapid implementation of a flushing flow release at Clark Canyon Dam. The overall objective is to create a programmed release of a high-magnitude, short-duration flow event that will initiate bedload transport, flush interstitial fine sediment, and enhance natural recruitment of salmonids (Wiley et al, 1995).

The development of flushing flow criteria draws heavily from a similar effort on the Bighorn River (Wiley et al, 1995). That flushing flow plan development was based largely on an assessment of a trial flushing flow in the Bighorn River in March of 1994. Data obtained from this test release provided information used to develop a flushing flow magnitude, duration, and timing with goals of scouring pool habitat, flushing fines from spawning gravel, and inundating seasonal channels. The intent is to develop a preliminary plan with available information, and then to modify that plan upon monitoring to maximize its effectiveness on the Beaverhead River.

3.2.1 Total Available Flushing Flow Volume

For the purposes of this preliminary plan, the total amount of water assumed to be available for a flushing flow is 2,100 acre-feet. This is equal to the amount stored in Clark Canyon Reservoir during the winter of 2013-2014 for a flushing flow (M. Jaeger, pers. comm.). If the total amount of water available for a flushing flow changes, the proposed release hydrograph can be modified. To facilitate any necessary modifications to the release hydrograph, additional criteria regarding the shape of the flushing flow hydrograph are provided below.

Total Volume Criteria: 2,100 acre feet

3.2.2 Peak Discharge

The criteria for peak flushing flow is a maximum discharge of 600 cfs as prescribed by the BOR flushing flow study (BOR, 2013). According to that study, a 600cfs flow will mobilize the D90 particle size at most cross sections, allowing flushing of both surficial and interstitial fine sediment.

Peak Discharge Criteria: 600 cfs

3.2.3 Peak Discharge Duration

The duration of the peak flushing flow refers to the amount of time that the maximum discharge is sustained. In their work on developing a flushing flow on the Bighorn River, Wiley and others (1995) provide a literature review of other flushing flow studies. Although the original reports they reference were not available for review here, these authors describe one flushing flow study on the Yampa River that concluded that flows approaching the natural peak of the hydrograph for 24-48 hours might be necessary for the long-term maintenance of a relatively sand-free cobble bed (Obrien, 1987). On a flushing flow study on the Henry's Fork of the Snake River, Idaho, Wesche (1994) recommended a peak flow duration of 9 hours. For the Beaverhead, the 2013 BOR flushing flow study recommended that a peak flushing flow event be at least 6 hours long (BOR, 2013).

In developing an appropriate flushing flow duration, Wiley and others (1995) considered how far the fine sediment would travel during the peak flow period. They assumed that the amount of time for the sediment to travel a given distance is 1.5 times that of the water. Applying that assumption and the reported hydraulic parameters in the BOR flushing flow study allows an estimation of the distance the sediment will travel during a flush. The hydraulics modeling output indicates that a typical flow velocity between Clark Canyon Dam and Barretts diversion dam is 3.7 feet per second at ~700cfs (BOR, 2013). Thus the water would travel at approximately 2.5 miles per hour, and fine sediment would therefore travel at 1.7 miles per hour. The distance from the mouth of Clark Canyon Creek to Barretts Diversion Dam is 13.5 miles, so at a flow velocity of 3.7 feet per second, it would take an estimated 7.9 hours for the sediment to travel from the mouth of Clark Canyon Creek to Barretts diversion.

Using this logic, Wiley and others (1995) concluded that a nine hour peak flow duration was appropriate for the Bighorn River flushing flow. Similarly, on the Beaverhead River it appears that if the primary flushing area extends from Clark Canyon Creek to Barretts diversion, a peak duration of at least eight hours is appropriate. This will promote that transport of fine sediment downstream of the confluence of Grasshopper Creek.

Peak Discharge Duration Criteria: Minimum of 8 hours

3.2.4 Rising and Falling Limb Criteria

Transport of suspended sediment typically creates a hysteresis pattern with respect to discharge. That is, suspended sediment concentrations tend to be highest on the rising limb of hydrograph. This is apparent during the spring snowmelt in Montana, as early runoff is characterized by the highest turbidity. Figure 9 shows a graphic example of hysteresis on an annual basis, with suspended sediment concentrations peaking on a South African River in November, in the early part of the wet season, prior to the peak in discharge in January (Grenfell and Ellery, 2009).

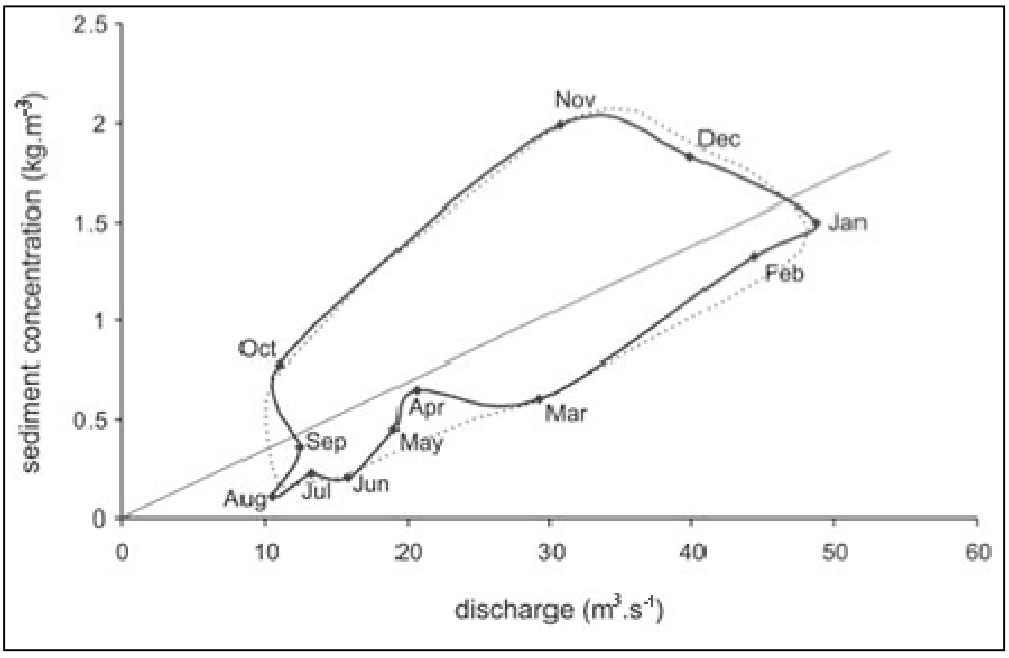

Figure 9. Mean monthly discharge and suspended sediment concentrations on the Mfolozi River, South Africa (Grenfell and Ellery, 2009).

Flushing flows were monitoried in the Bighorn study for suspended sediment concentrations at several locations on the Bighorn River (Wiley et al, 1995). Figure 10 and Figure 11 show the results of the monitoring at two sites. At the most upstream site (Figure 10) stepped increases in discharge were associated with suspended sediment concentration spikes immediately following each increase. Further downstream (Figure 11), the sediment spike was most pronounced only with the first step. Based on this information and other studies that show hysteresis in suspended sediment transport, the rising limb and peak portions of the flushing flow hydrograph will likely be the most effective timeframe for sediment transport. In addition, stepping the hydrograph on the rising limb can result in sequential sediment flushing events as larger particle sizes are mobilized. Falling limbs can then be used for coarse sediment sorting and habitat creation.

Based on the results shown in Figure 10 and Figure 11, a stepped ascending limb is recommended for the flushing flow criteria. This will allow for longer duration flows on the rising limb to mobilize and transport surficial fine sediment, followed by a shorter, more intensive pulse to mobilize interstitial sediment. In the event that there is enough water available after the peak, the descending limb could also include a step at moderate durations to transport the fines further downstream and contribute to habitat rejuvination.

Rising and Falling Limb Criteria: Stepped rising Limb, falling limb less important, but stepped as flow volume allows.

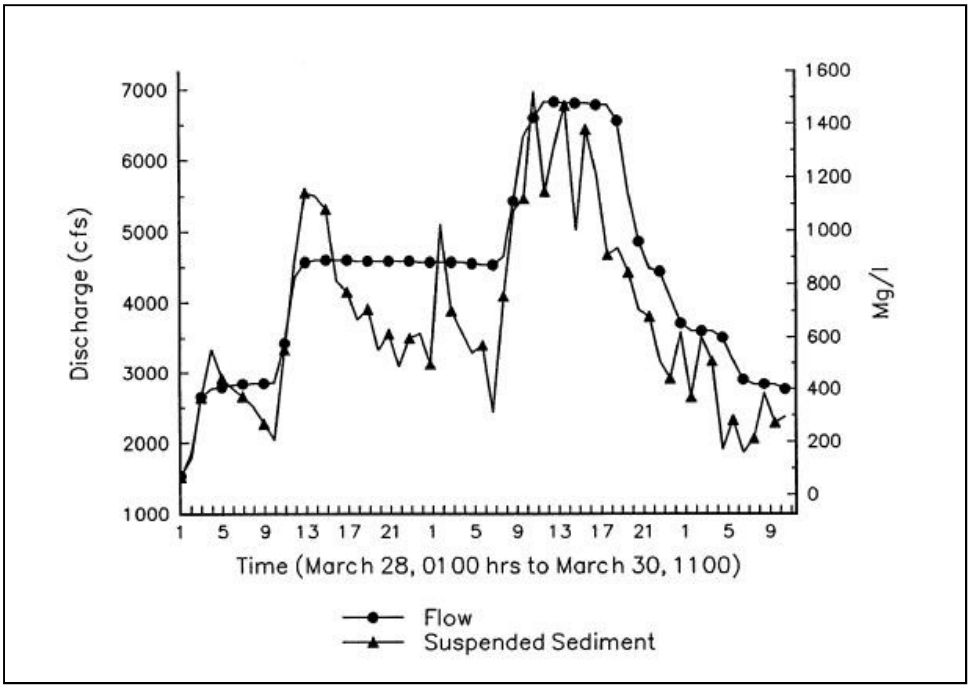

Figure 10. Mean hourly hydrograph and suspended sediment concentrations (mg/l) for Wedding of the Waters, Bighorn River, Wyoming, March 28-30, 1994 (Wiley, et al, 1995).

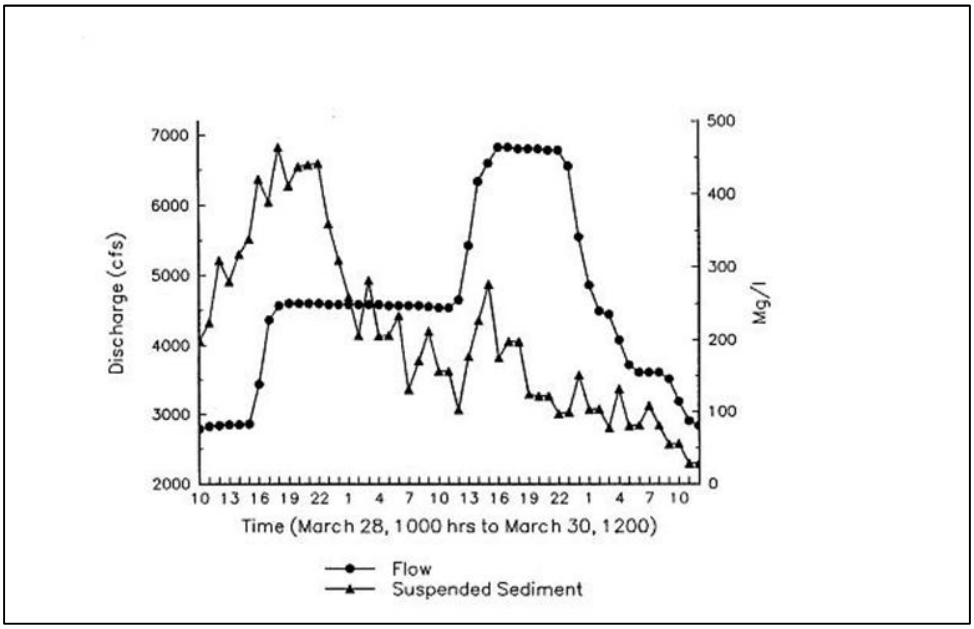

Figure 11. Mean hourly hydrograph and suspended sediment concentrations (mg/l) for the Mills Main Channel, Bighorn River, Wyoming, March 28-30, 1994 (Wiley et al, 1995).

3.3 Timing of Flushing Flows

In some instances such as on the Bighorn River, the recommended timing for flushing flows relates directly to fisheries biology; for example the Bighorn recommendation was for a flushing flow in mid- to late- March to precede rainbow trout spawning. One interesting additional benefit cited for a March flushing flow on the Bighorn is a lower water temperature that will increase water density and sediment transport capacity (Wiley et al, 1995).

In this case, flushing flows will be released in response to an event on Clark Canyon Creek. To that end, it will be important to develop an adaptive management component of the flushing flow time, to determine the potential responsiveness of managers to a flushing flow request. In the event that reservoir releases are going to be increased above 600 cfs shortly after a sediment event for irrigation purposes, a flushing flow may be unnecessary. If not, a flushing flow immediately following an event may be most beneficial. However, there may be specific time periods when a flushing flow is undesirable for other aspects of river function and use such as irrigation, fisheries biology, or recreation The temporal aspect of the flushing flow criteria will therefore require some collaboration between stakeholders in the river corridor.

In general, however, it is anticipated that flushing flows will occur between mid-March and mid-May, when sediment events are most likely to occur (Section 3.1).

Timing Criteria: To be negotiated with stakeholders, but most likely Mid-March through Mid-May.

4 Example Flushing Flow Hydrographs

Table 4 summarizes the flushing flow criteria developed in Section 3.2.

Table 4. Flushing Flow Criteria for Developing Hydrographs

Criteria	*Value (units)*
Total Volume	2100 acre feet
Peak Discharge	600 cfs
Duration of Peak Discharge	8 hours
Rising Limb	Stepped
Falling Limb	Stepped only if flow volume available allows
Timing	Most likely mid-March through mid-May, but to be negotiated in MOU.

Two example flushing flow hydrographs are presented below that meet the criteria listed in Table 4 (Figure 12 and Figure 13). The variation in the hydrographs is only with regard to the total discharge, and reflects differences in the Beaverhead River base flows at the time the flushing flow is applied. The release patterns and timing for both scenarios are exactly the same, and show that whether the Beaverhead River base flows are 25cfs or 100cfs, the criteria can be met or exceeded. Using a total flushing flow volume of 2091 acre-feet, the hydrograph includes the following:

1. Steep ramping to 400 cfs to initiate mobilization of surface fines. Eight hours at 400cfs.
2. Gradual ramping over 8 hours to 600 cfs for maximum flushing flow.
3. Twelve hours at 600 cfs flushing flow
4. Reduced flows to 500 cfs for 7 hours to continue flushing sediment downstream and to sort habitat elements.
5. Reduced flows to 400 cfs for 8 hours for continued sorting.
6. Flow reductions over 9 hours to return to baseflow condition.

Based on the criteria established, the volume of water available allows for a stepped receding limb to facilitate habitat development with declining flows. This is similar to the proposed hydrograph for the Bighorn River project (Figure 14; Wiley et al, 1995).

Appendix B contains tabulated hourly flow release rates and resulting Beaverhead River discharges for the two scenarios.

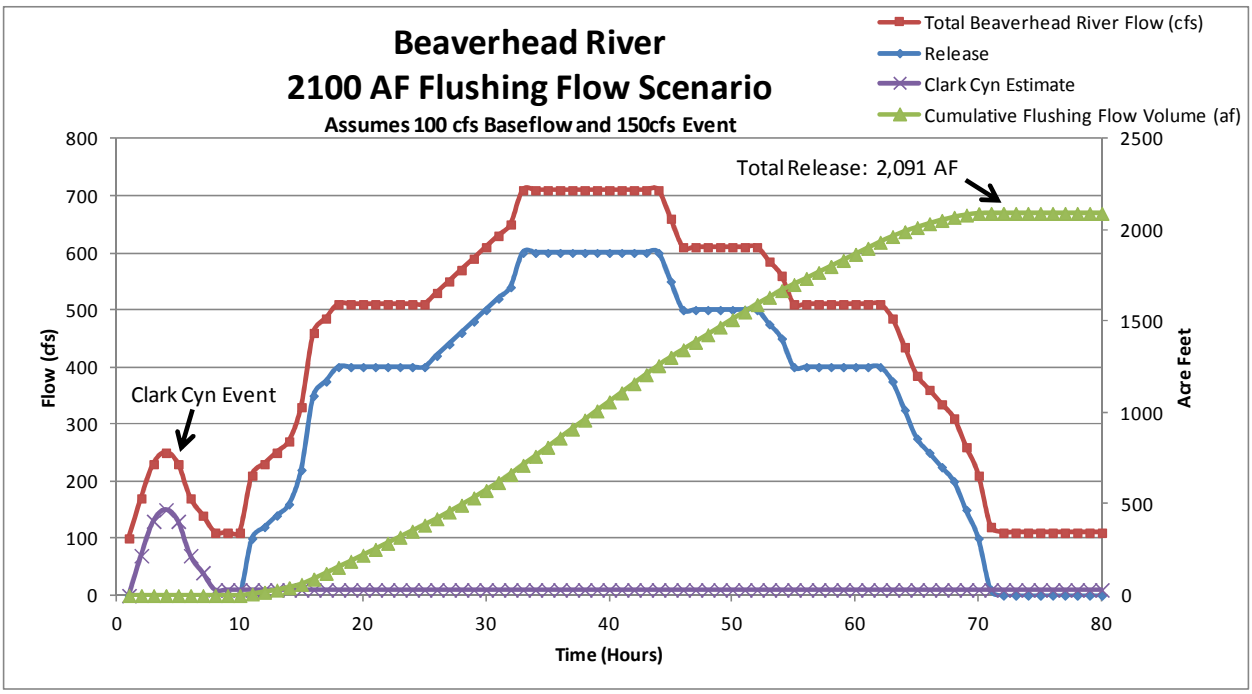

Figure 12. Flushing flow hydrograph scenario with 100cfs base flows from Clark Canyon Dam.

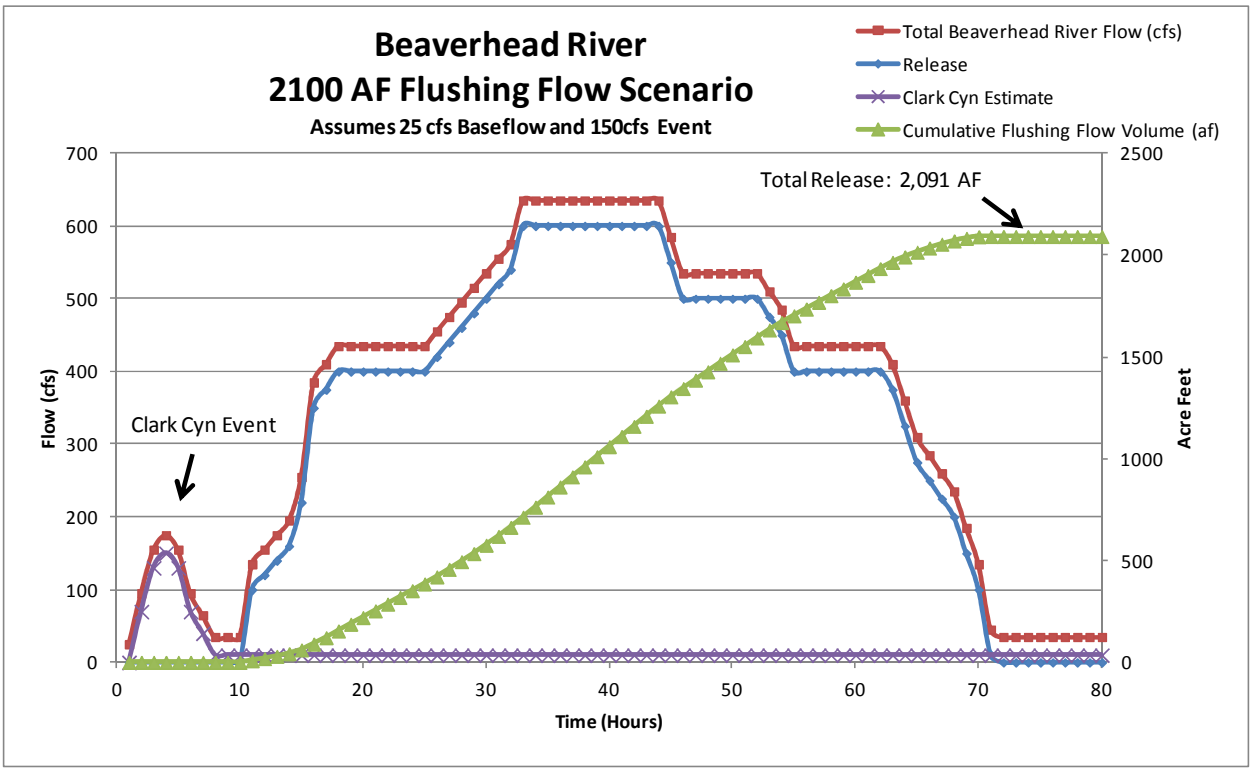

Figure 13. Flushing flow hydrograph scenario with 100cfs base flows from Clark Canyon Dam.

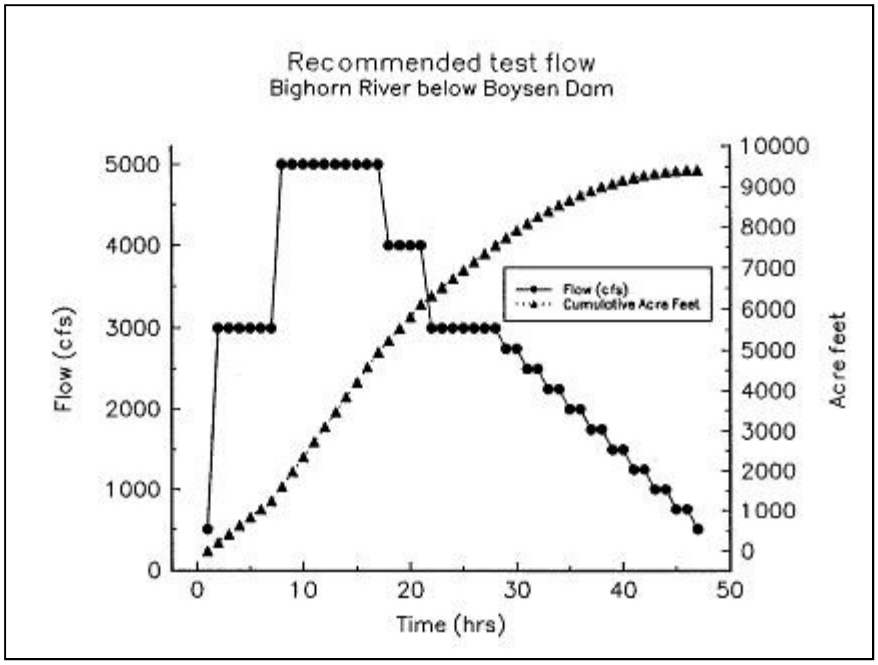

Figure 14. Proposed hourly hydrograph with cumulative acre feet for proposed test flow, Bighorn River (Wiley et al, 1995).

5 A Combined Alternative: Feasibility and Recommended Timelines

Considering the impact of fine sediment on the Beaverhead River fishery and the results of work performed to date, adopting an integrated approach to preventing and managing sediment events is appropriate. Encouraging the implementation of the TMDL water quality management plan and thus reducing sediment sourcing in the basin will help reduce loading from its source. As these loading and allocation values are reported in the TMDL document, the Beaverhead Watershed Committee should be able to pursue 319 funding to apply best management practices to reduce sourcing. According to the TMDL Plan, the sediment load derived from Clark Canyon Creek could be reduced by 59% with the implementation of BMPs alone (MTDEQ, 2012). However, it is not clear as to whether the implementation of BMPs alone will solve the problem of sediment events on the Beaverhead River. Field observations indicate that hillslope and gully erosion is a major source of fine sediment in Clark Canyon Creek, and it is not clear as to whether the sediment source assessment effectively captured these processes. Furthermore, the geology in the watershed consists of erosive volcanic units that are prone to mass failure and gullying, and these processes can be difficult to arrest by implementing BMPs such as grazing management alone.

It is my professional judgment that excessive fine sediment sourcing from Clark Canyon Creek that is capable of creating sediment events on the Beaverhead River will continue even with the concerted implementation of BMP strategies such as grazing management. As such, a settling pond in the middle basin area on the lower East Fork confluence appears to be a good means of trapping excessive fine sediment that continues to be produced.

The third tier of the integrated approach is the release of flushing flows from Clark Canyon Dam during or shortly following a sediment event. This is an appropriate third component of the management plan, and as described in previous sections of this document, appears entirely feasible.

As far as the timing of implementation, the following approach is recommended:

1. The results of the TMDL sediment source assessment indicates that eroding streambanks are the primary sediment source in the Clark Canyon Creek watershed, and that 80% of that volume is related to human influences such as grazing land uses. If that is the case, the implementation of BMPs to reduce that volume should immediately commence. Implementing BMPs such as grazing exclosures will also facilitate riparian buffer establishment, which will help trap and store upland-derived sediment in the valley bottoms.

2. Based on field observations and evaluation of watershed geology, I have concerns that the implementation of BMPS alone will not reduce sediment loading to the point where sediment events cease to occur. The volcanic ash-dominated geology, “lollipop” drainage pattern, extensive gullying, and mass wasting processes in this relatively small watershed indicate that it is inherently prone to high sediment loads. To that end, I recommend pursuing the further design and implement of a settling pond in the basin as proposed by

Allied Engineering (Allied, 2013). To maximize longevity and minimize maintenance requirements at the pond, any areas upstream that were inventoried in the TMDL sediment source assessment as having high anthropogenic-influenced bank sediment loading rates should be treated with appropriate BMPs prior to pond construction.

3. Flushing flows from Clark Canyon Dam provide the third component of the sediment management plan. As these flows are used in a responsive fashion, they will have to be proactively stored in the reservoir and then released using an adaptive management/response strategy.

6 Monitoring Effectiveness

Monitoring the effectiveness of the overall sediment management plan will be crucial. The following strategies are recommended for consideration:

1. Install a rain gage in the Clark Canyon Creek watershed to measure precipitation events;
2. Upgrade the existing stream gage at the mouth of Clark Canyon Creek to measure mean daily discharge in addition to instantaneous peak flow;
3. Place transects on the Beaverhead River to monitor sedimentation patterns and habitat conditions before and after an event;
4. Repeat BOR pebble count sampling after events;
5. Carefully document each flushing flow event, measuring discharge, suspended sediment concentrations, and qualitative aspects of system response.

The criteria for defining an anticipated sediment event (Section 3.1) include a Clark Canyon Creek discharge in excess of 30cfs Clark Canyon Creek and synchronous reservoir releases of less than 100cfs. These estimated criteria are based purely on an evaluation of flow data, and are not calibrated by actual reported dates of sediment events. To that end, it is critical that the assessment provided here be expanded on with more information regarding reservoir releases, Clark Canyon Creek floods, and resulting impacts to the Beaverhead River so that local managers can most accurately predict sediment events, and most rapidly respond with a flushing flow release.

7 Flushing Flow MOU

The anticipated components of a flushing flow MOU between the BOR and MTFWP include the following:

1. Describe the objective of water banking for purposes of a spring flushing flow from Clark Canyon Reservoir.
2. Identify those provisions that would trigger conducting a flushing flow.
3. Determine potential flushing flow release quantity, shape, duration, and timeframe.
4. Identify roles and procedures for coordinating, determining, and releasing the call of stored water.
5. Outline the terms agreed to by the parties of the MOU.
6. Identify representatives for each of the parties responsible for monitoring and implementing the MOU.

It is anticipated that this document will help develop items 1-3 in the MOU.

8 References

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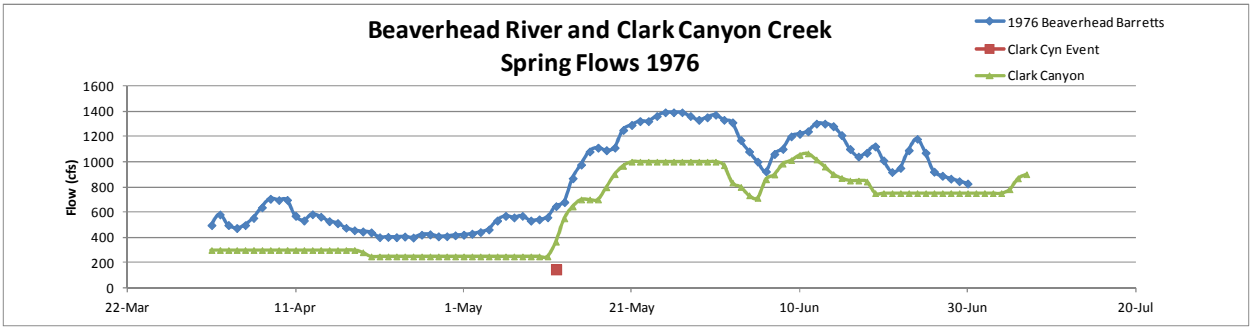
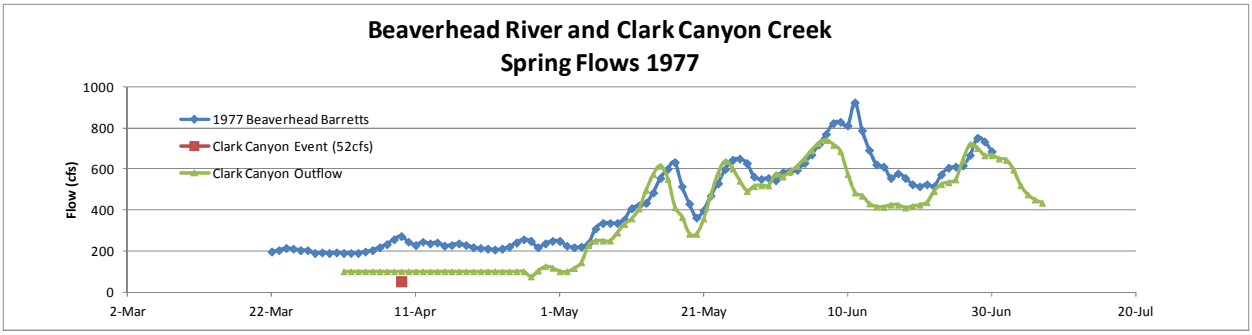
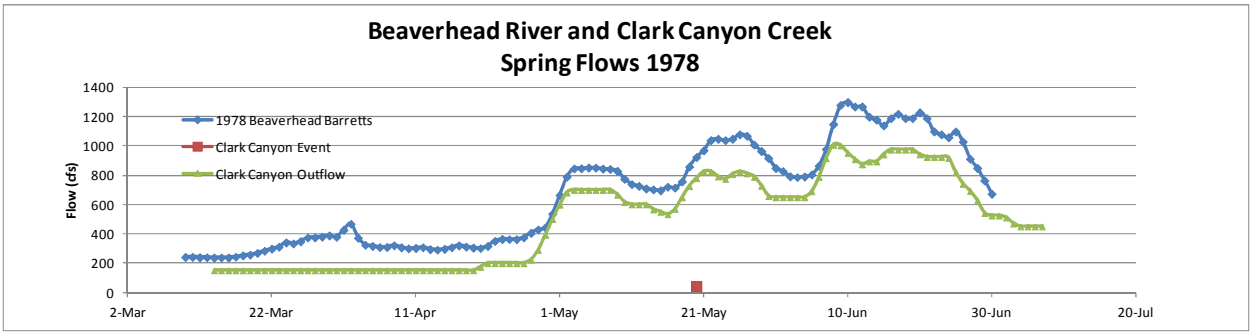
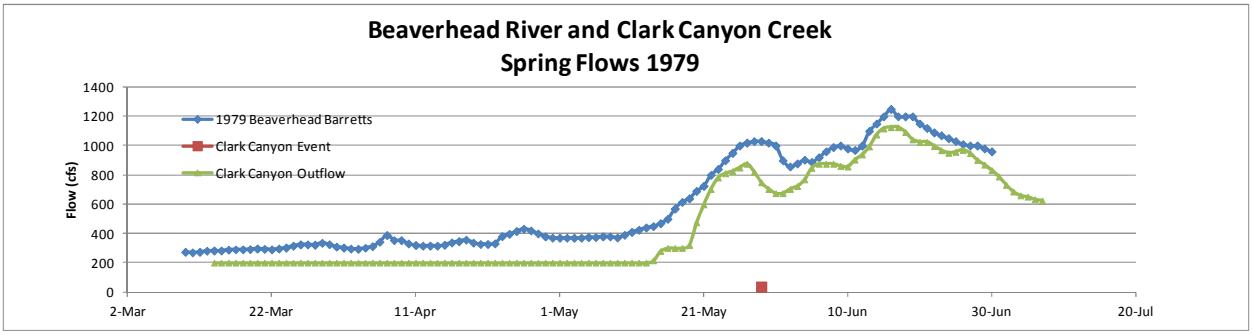
9 Appendix A: Selected Spring Hydrographs

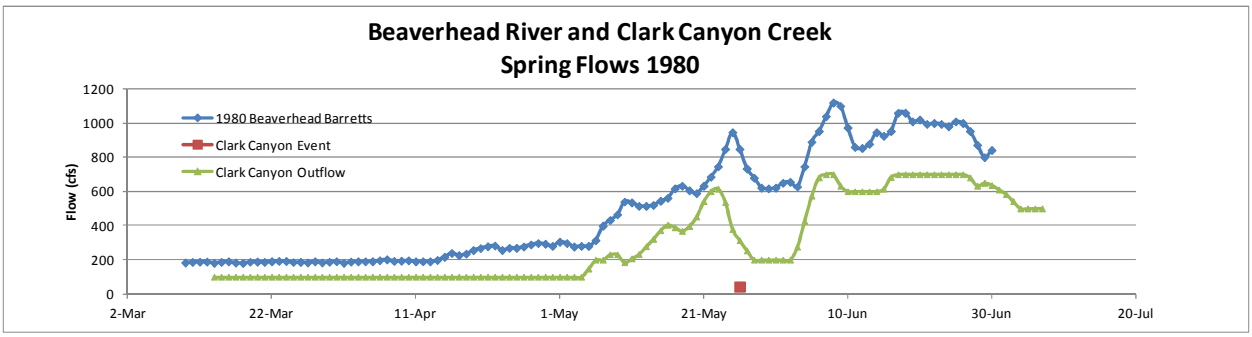
The following plots show spring hydrographs for every year that peak discharge on Canyon Creek exceeded 30cfs. The Beaverhead River discharges are from BOR Records at Clark Canyon Reservoir and USGS 06016000 Beaverhead River at Barretts. The Clark Canyon event measurements are from annual peak discharge data measured at USGS 06015430 Clark Canyon near Dillon MT.

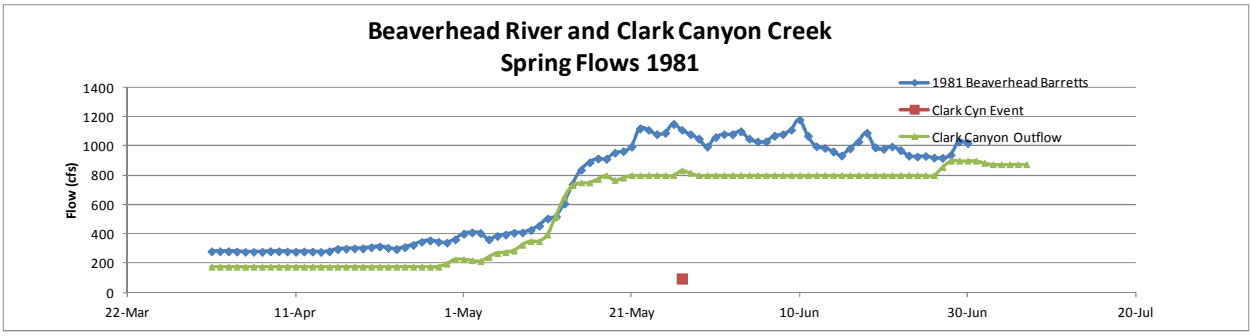









Beaverhead River and Clark Canyon Creek
Spring Flows 1980
1980 Beaverhead Barretts
Clark Canyon Event
Clark Canyon Outflow
Flow (cfs)
0
200
400
600
800
1000
1200
2-Mar
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul


Beaverhead River and Clark Canyon Creek
Spring Flows 1981
1981 Beaverhead Barretts
Clark Cyn Event
Clark Canyon Outflow
Flow (cfs)
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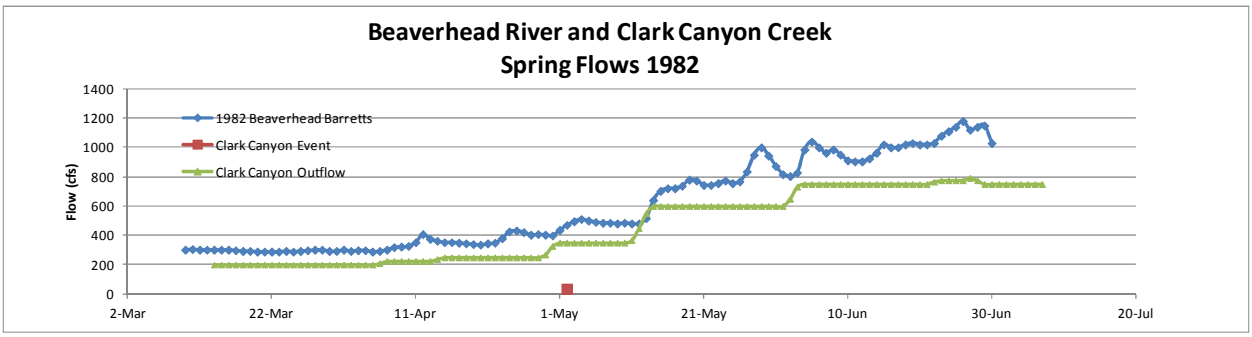
600
800
1000
1200
1400
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul


Beaverhead River and Clark Canyon Creek
Spring Flows 1982
1982 Beaverhead Barretts
Clark Canyon Event
Clark Canyon Outflow
Flow (cfs)
0
200
400
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1200
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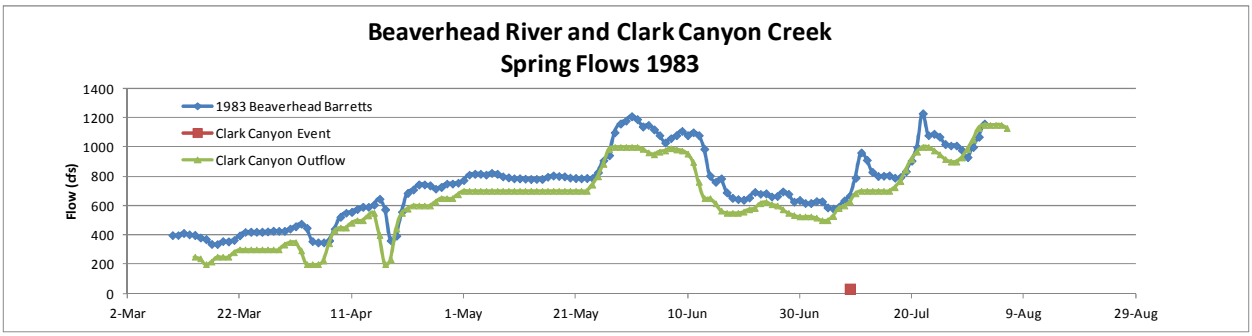
21-May
10-Jun
30-Jun
20-Jul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Spring Flows 1983
1983 Beaverhead Barretts
Clark Canyon Event
Clark Canyon Outflow
Flow (cfs)
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200
400
600
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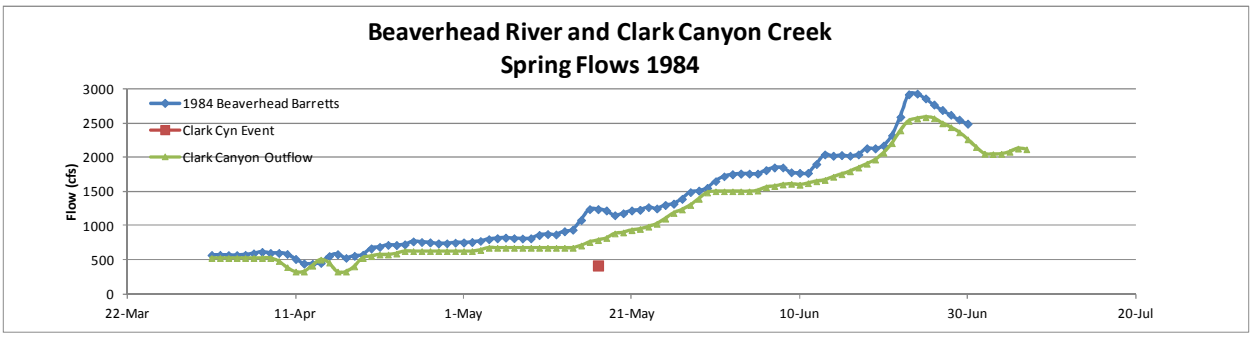
9-Aug
29-Aug


Beaverhead River and Clark Canyon Creek
Spring Flows 1984
1984 Beaverhead Barretts
Clark Cyn Event
Clark Canyon Outflow
Flow (cfs)
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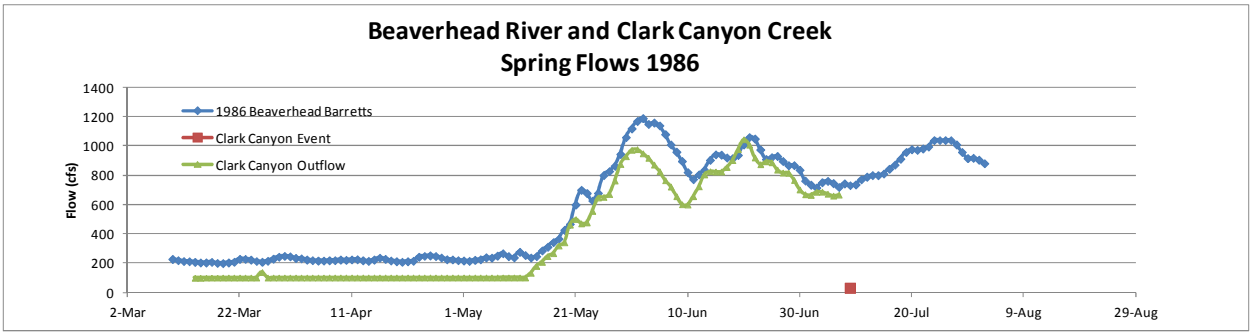
2000
1500
1000
500
0
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul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Spring Flows 1986
1986 Beaverhead Barretts
Clark Canyon Event
Clark Canyon Outflow
Flow (cfs)
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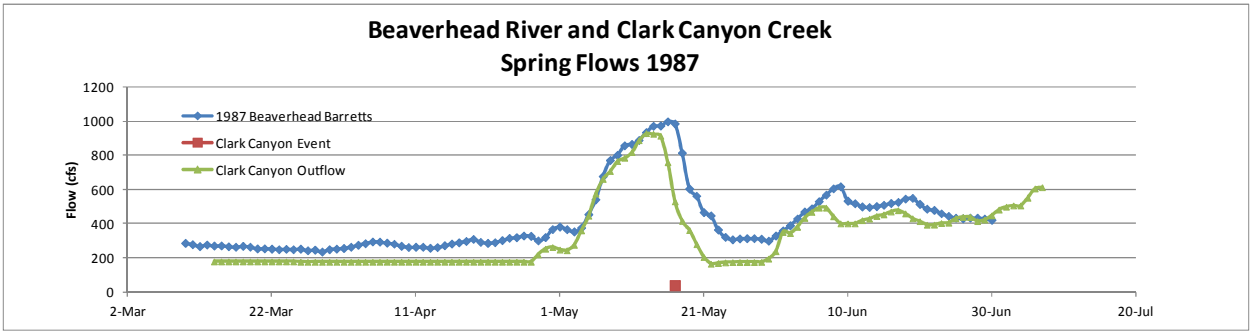
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Spring Flows 1987
1987 Beaverhead Barretts
Clark Canyon Event
Clark Canyon Outflow
Flow (cfs)
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10-Jun
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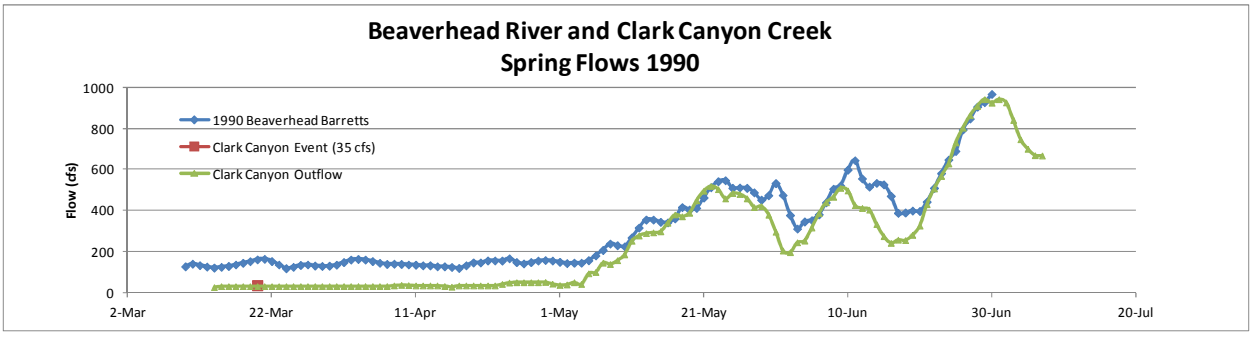
20-Jul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1990 Beaverhead Barretts
Clark Canyon Event (35 cfs)
Clark Canyon Outflow
Flow (cfs)
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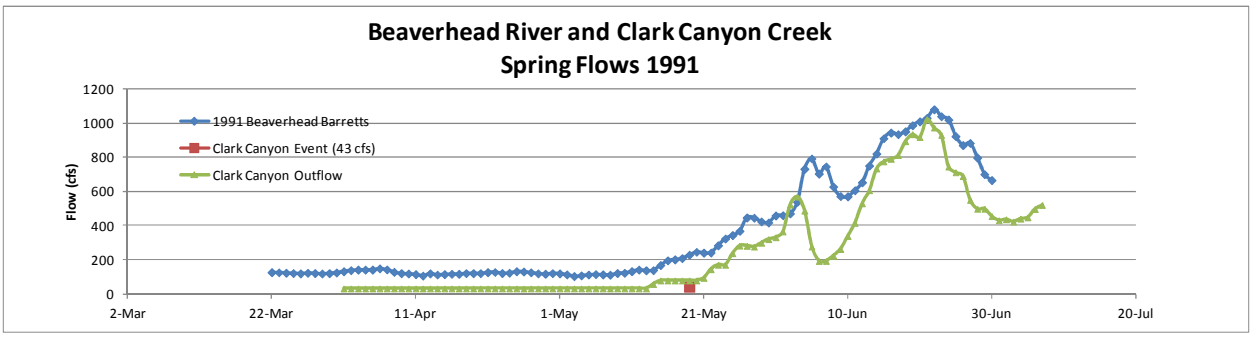
30-Jun
20-Jul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Flow (cfs)
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400
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1991 Beaverhead Barretts
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Clark Canyon Outflow
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22-Mar
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1-May
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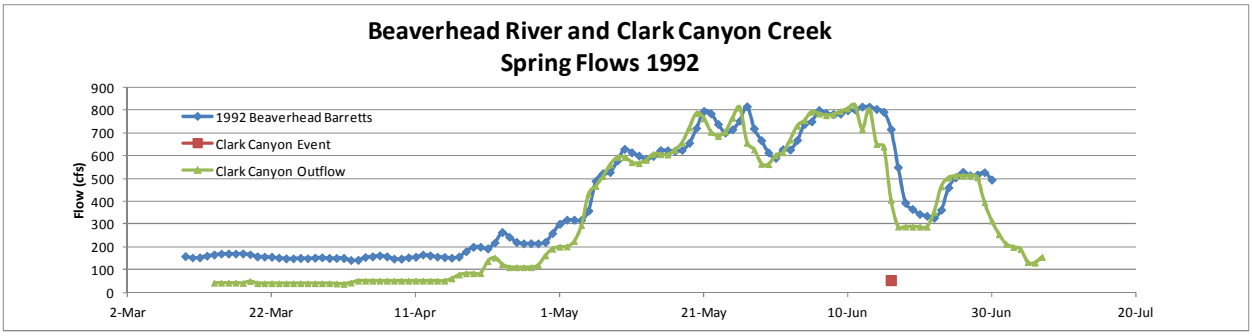
Beaverhead River and Clark Canyon Creek
Spring Flows 1992
Flow (cfs)
900
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300
200
100
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1992 Beaverhead Barretts
Clark Canyon Event
Clark Canyon Outflow
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1-May
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10-Jun
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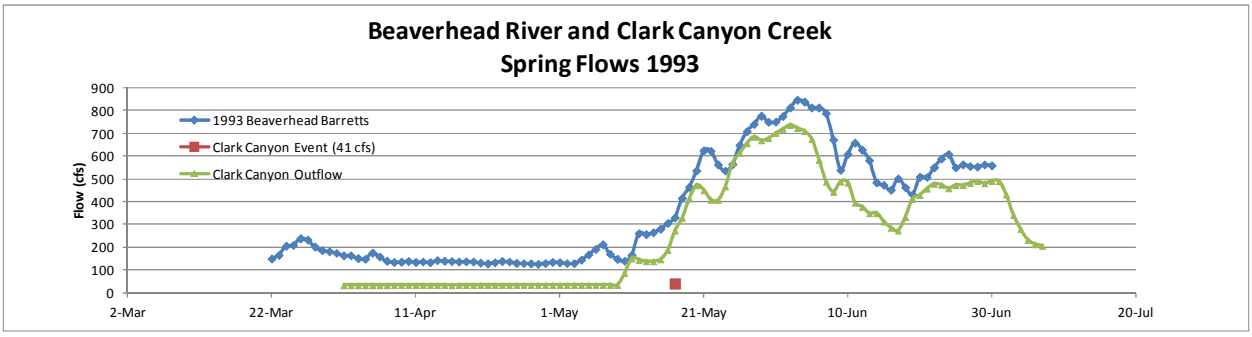
20-Jul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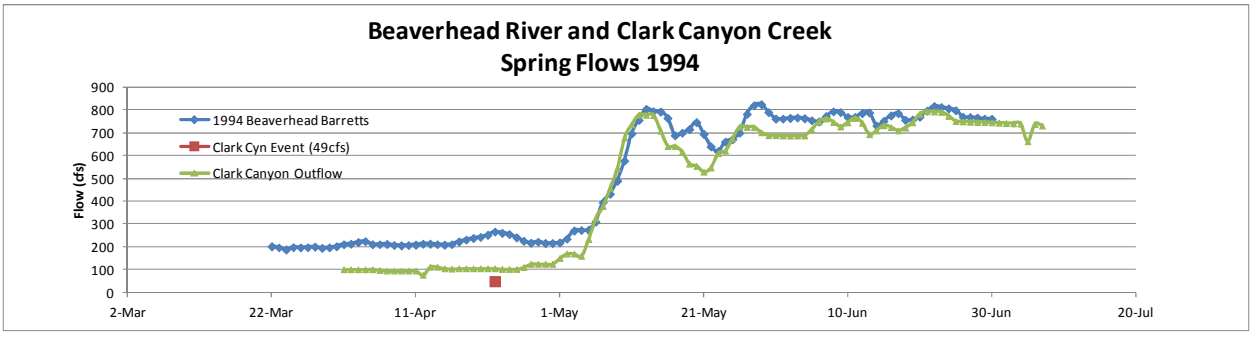
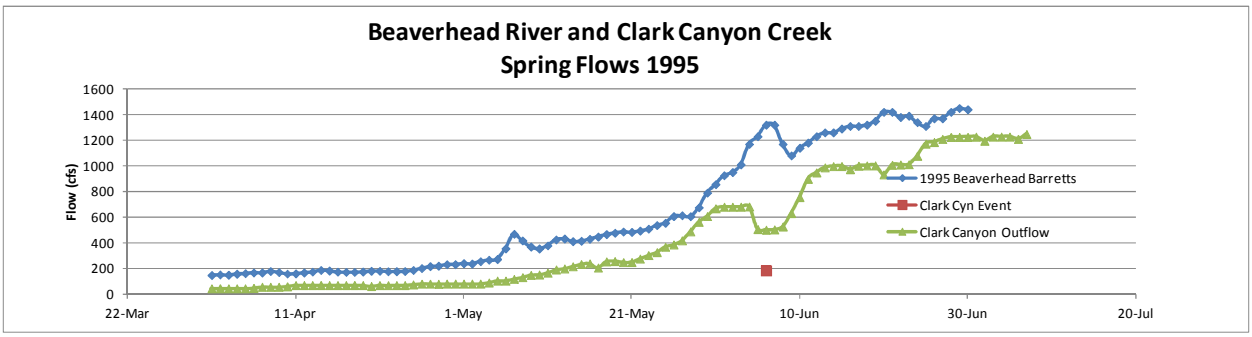
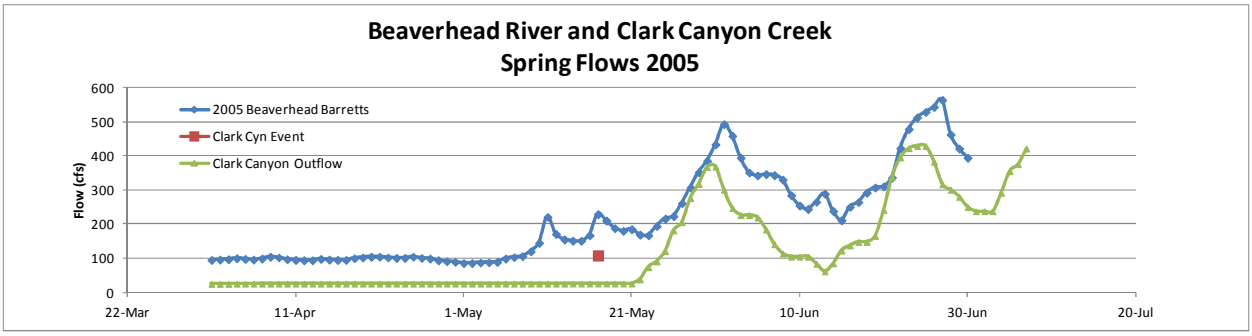
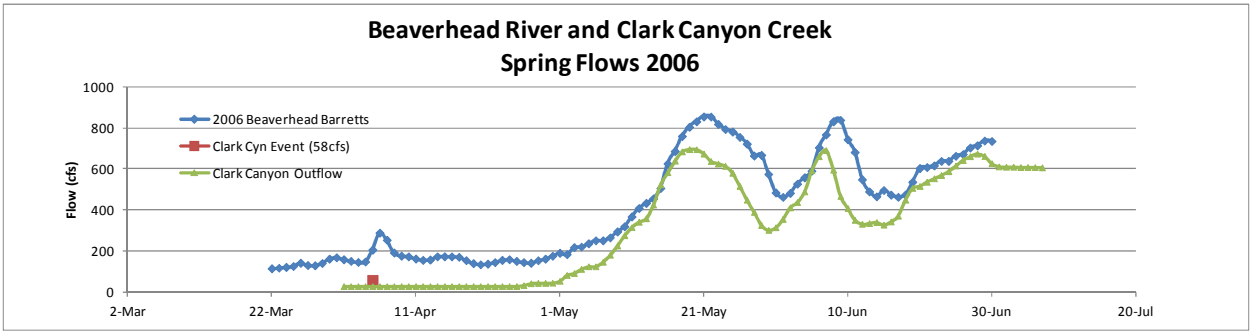
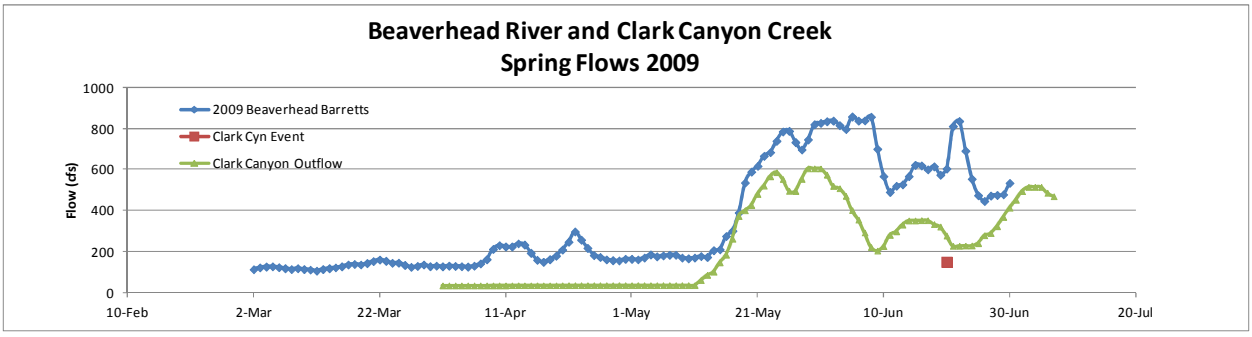
Spring Flows 1993
Flow (cfs)
900
800
700
600
500
400
300
200
100
0
1993 Beaverhead Barretts
Clark Canyon Event (41 cfs)
Clark Canyon Outflow
2-Mar
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul

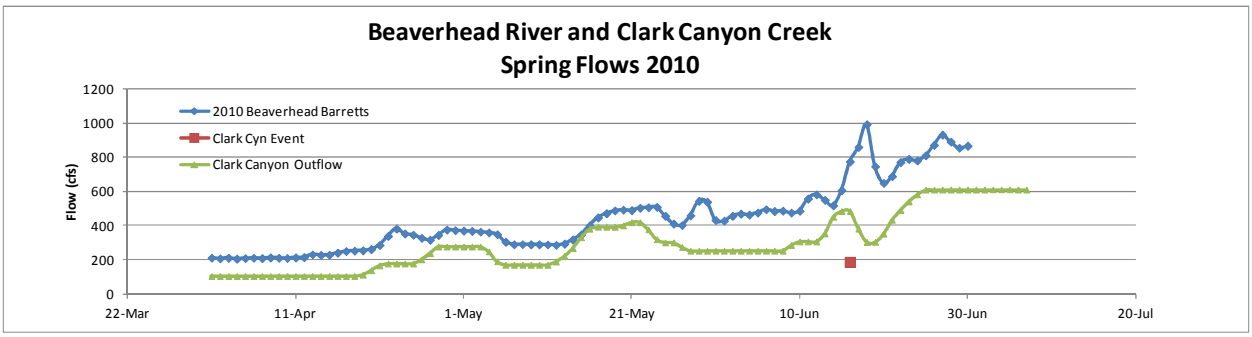

Beaverhead River and Clark Canyon Creek
Spring Flows 1994
Flow (cfs)
900
800
700
600
500
400
300
200
100
0
1994 Beaverhead Barretts
Clark Cyn Event (49cfs)
Clark Canyon Outflow
2-Mar
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul

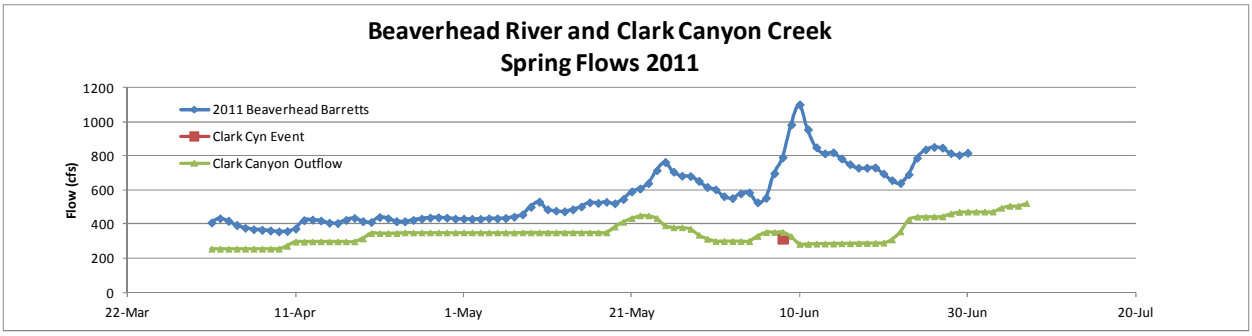

Beaverhead River and Clark Canyon Creek
Spring Flows 1995
Flow (cfs)
1600
1400
1200
1000
800
600
400
200
0
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul
1995 Beaverhead Barretts
Clark Cyn Event
Clark Canyon Outflow

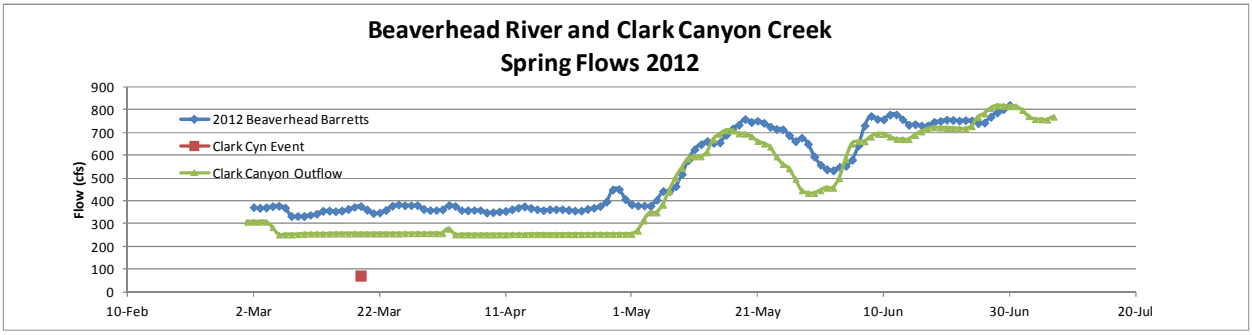

Beaverhead River and Clark Canyon Creek
Spring Flows 2005
Flow (cfs)
600
500
400
300
200
100
0
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul
2005 Beaverhead Barretts
Clark Cyn Event
Clark Canyon Outflow


Beaverhead River and Clark Canyon Creek
Spring Flows 2006
Flow (cfs)
1000
800
600
400
200
0
2-Mar
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul
2006 Beaverhead Barretts
Clark Cyn Event (58cfs)
Clark Canyon Outflow


Beaverhead River and Clark Canyon Creek
Spring Flows 2009
Flow (cfs)
1000
800
600
400
200
0
10-Feb
2-Mar
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul
2009 Beaverhead Barretts
Clark Cyn Event
Clark Canyon Outflow


Beaverhead River and Clark Canyon Creek
Spring Flows 2010
Flow (cfs)
1200
1000
800
600
400
200
0
2010 Beaverhead Barretts
Clark Cyn Event
Clark Canyon Outflow
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul


Beaverhead River and Clark Canyon Creek
Spring Flows 2011
Flow (cfs)
1200
1000
800
600
400
200
0
2011 Beaverhead Barretts
Clark Cyn Event
Clark Canyon Outflow
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul


Beaverhead River and Clark Canyon Creek
Spring Flows 2012
Flow (cfs)
900
800
700
600
500
400
300
200
100
0
2012 Beaverhead Barretts
Clark Cyn Event
Clark Canyon Outflow
10-Feb
2-Mar
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul

10 Appendix B: Flushing Flow Tables

Table 5. Flushing flow prescription for a 100 cfs dam release baseflow.

Hour	*Day*	*Baseflow*	*Clark Cyn Estimate*	*Release*	*Portion of day*	*Acre Feet per time increment*	*Total Beaverhead River Flow (cfs)*	*Cumulative Flushing Flow Volume (af)*
1	1	100	0	0	0.042	0	100	0
2	1	100	70	0	0.042	0	170	0.0
3	1	100	130	0	0.042	0	230	0.0
4	1	100	150	0	0.042	0.0	250	0.0
5	1	100	130	0	0.042	0.0	230	0.0
6	1	100	70	0	0.042	0.0	170	0.0
7	1	100	40	0	0.042	0.0	140	0.0
8	1	100	10	0	0.042	0.0	110	0.0
9	1	100	10	0	0.042	0.0	110	0.0
10	1	100	10	0	0.042	0.0	110	0.0
11	1	100	10	100	0.042	8.3	210	8.3
12	1	100	10	120	0.042	9.9	230	18.2
13	1	100	10	140	0.042	11.6	250	29.7
14	1	100	10	160	0.042	13.2	270	43.0
15	1	100	10	220	0.042	18.2	330	61.1
16	1	100	10	350	0.042	28.9	460	90.1
17	1	100	10	375	0.042	31.0	485	121.0
18	1	100	10	400	0.042	33.1	510	154.1
19	1	100	10	400	0.042	33.1	510	187.1
20	1	100	10	400	0.042	33.1	510	220.2
21	1	100	10	400	0.042	33.1	510	253.2
22	1	100	10	400	0.042	33.1	510	286.3
23	1	100	10	400	0.042	33.1	510	319.3
24	2	100	10	400	0.042	33.1	510	352.4
25	2	100	10	400	0.042	33.1	510	385.4
26	2	100	10	420	0.042	34.7	530	420.1
27	2	100	10	440	0.042	36.4	550	456.5
28	2	100	10	460	0.042	38.0	570	494.5
29	2	100	10	480	0.042	39.7	590	534.2
30	2	100	10	500	0.042	41.3	610	575.5
31	2	100	10	520	0.042	43.0	630	618.4
32	2	100	10	540	0.042	44.6	650	663.1
33	2	100	10	600	0.042	49.6	710	712.6
34	2	100	10	600	0.042	49.6	710	762.2
35	2	100	10	600	0.042	49.6	710	811.8
36	2	100	10	600	0.042	49.6	710	861.4
37	2	100	10	600	0.042	49.6	710	910.9
38	2	100	10	600	0.042	49.6	710	960.5
39	2	100	10	600	0.042	49.6	710	1010.1
40	2	100	10	600	0.042	49.6	710	1059.7
41	2	100	10	600	0.042	49.6	710	1109.2
42	2	100	10	600	0.042	49.6	710	1158.8
43	2	100	10	600	0.042	49.6	710	1208.4
44	2	100	10	600	0.042	49.6	710	1258.0
45	2	100	10	550	0.042	45.4	660	1303.4
46	2	100	10	500	0.042	41.3	610	1344.7
47	2	100	10	500	0.042	41.3	610	1386.0
48	2	100	10	500	0.042	41.3	610	1427.3
49	3	100	10	500	0.042	41.3	610	1468.7

Hour	*Day*	*Baseflow*	*Clark Cyn Estimate*	*Release*	*Portion of day*	*Acre Feet per time increment*	*Total Beaverhead River Flow (cfs)*	*Cumulative Flushing Flow Volume (af)*
50	3	100	10	500	0.042	41.3	610	1510.0
51	3	100	10	500	0.042	41.3	610	1551.3
52	3	100	10	500	0.042	41.3	610	1592.6
53	3	100	10	475	0.042	39.2	585	1631.8
54	3	100	10	450	0.042	37.2	560	1669.0
55	3	100	10	400	0.042	33.1	510	1702.1
56	3	100	10	400	0.042	33.1	510	1735.1
57	3	100	10	400	0.042	33.1	510	1768.2
58	3	100	10	400	0.042	33.1	510	1801.2
59	3	100	10	400	0.042	33.1	510	1834.3
60	3	100	10	400	0.042	33.1	510	1867.3
61	3	100	10	400	0.042	33.1	510	1900.4
62	3	100	10	400	0.042	33.1	510	1933.4
63	3	100	10	375	0.042	31.0	485	1964.4
64	3	100	10	325	0.042	26.9	435	1991.3
65	3	100	10	275	0.042	22.7	385	2014.0
66	3	100	10	250	0.042	20.7	360	2034.6
67	3	100	10	225	0.042	18.6	335	2053.2
68	3	100	10	200	0.042	16.5	310	2069.8
69	3	100	10	150	0.042	12.4	260	2082.2
70	3	100	10	100	0.042	8.3	210	2090.4
71	3	100	10	10	0.042	0.8	120	2091.2
72	3	100	10	0	0.042	0.0	110	2091.2
73	3	100	10	0	0.042	0.0	110	2091.2
74	3	100	10	0	0.042	0.0	110	2091.2
75	3	100	10	0	0.042	0.0	110	2091.2
76	3	100	10	0	0.042	0.0	110	2091.2
77	3	100	10	0	0.042	0.0	110	2091.2
78	3	100	10	0	0.042	0.0	110	2091.2
79	3	100	10	0	0.042	0.0	110	2091.2
80	3	100	10	0	0.042	0.0	110	2091.2

Table 6. Flushing flow prescription for a 25 cfs dam release baseflow.

Hour	*Day*	*Baseflow*	*Clark Cyn Estimate*	*Release*	*Portion of day*	*Acre Feet per time increment*	*Total Beaverhead River Flow (cfs)*	*Cumulative Flushing Flow Volume (af)*
1	1	100	0	0	0.042	0	100	0
2	1	100	70	0	0.042	0	170	0.0
3	1	100	130	0	0.042	0	230	0.0
4	1	100	150	0	0.042	0.0	250	0.0
5	1	100	130	0	0.042	0.0	230	0.0
6	1	100	70	0	0.042	0.0	170	0.0
7	1	100	40	0	0.042	0.0	140	0.0
8	1	100	10	0	0.042	0.0	110	0.0
9	1	100	10	0	0.042	0.0	110	0.0
10	1	100	10	0	0.042	0.0	110	0.0
11	1	100	10	100	0.042	8.3	210	8.3
12	1	100	10	120	0.042	9.9	230	18.2
13	1	100	10	140	0.042	11.6	250	29.7
14	1	100	10	160	0.042	13.2	270	43.0
15	1	100	10	220	0.042	18.2	330	61.1
16	1	100	10	350	0.042	28.9	460	90.1
17	1	100	10	375	0.042	31.0	485	121.0
18	1	100	10	400	0.042	33.1	510	154.1
19	1	100	10	400	0.042	33.1	510	187.1
20	1	100	10	400	0.042	33.1	510	220.2
21	1	100	10	400	0.042	33.1	510	253.2
22	1	100	10	400	0.042	33.1	510	286.3
23	1	100	10	400	0.042	33.1	510	319.3
24	2	100	10	400	0.042	33.1	510	352.4
25	2	100	10	400	0.042	33.1	510	385.4
26	2	100	10	420	0.042	34.7	530	420.1
27	2	100	10	440	0.042	36.4	550	456.5
28	2	100	10	460	0.042	38.0	570	494.5
29	2	100	10	480	0.042	39.7	590	534.2
30	2	100	10	500	0.042	41.3	610	575.5
31	2	100	10	520	0.042	43.0	630	618.4
32	2	100	10	540	0.042	44.6	650	663.1
33	2	100	10	600	0.042	49.6	710	712.6
34	2	100	10	600	0.042	49.6	710	762.2
35	2	100	10	600	0.042	49.6	710	811.8
36	2	100	10	600	0.042	49.6	710	861.4
37	2	100	10	600	0.042	49.6	710	910.9
38	2	100	10	600	0.042	49.6	710	960.5
39	2	100	10	600	0.042	49.6	710	1010.1
40	2	100	10	600	0.042	49.6	710	1059.7
41	2	100	10	600	0.042	49.6	710	1109.2
42	2	100	10	600	0.042	49.6	710	1158.8
43	2	100	10	600	0.042	49.6	710	1208.4
44	2	100	10	600	0.042	49.6	710	1258.0
45	2	100	10	550	0.042	45.4	660	1303.4
46	2	100	10	500	0.042	41.3	610	1344.7
47	2	100	10	500	0.042	41.3	610	1386.0
48	2	100	10	500	0.042	41.3	610	1427.3
49	3	100	10	500	0.042	41.3	610	1468.7
50	3	100	10	500	0.042	41.3	610	1510.0
51	3	100	10	500	0.042	41.3	610	1551.3
52	3	100	10	500	0.042	41.3	610	1592.6

Hour	*Day*	*Baseflow*	*Clark Cyn Estimate*	*Release*	*Portion of day*	*Acre Feet per time increment*	*Total Beaverhead River Flow (cfs)*	*Cumulative Flushing Flow Volume (af)*
53	3	100	10	475	0.042	39.2	585	1631.8
54	3	100	10	450	0.042	37.2	560	1669.0
55	3	100	10	400	0.042	33.1	510	1702.1
56	3	100	10	400	0.042	33.1	510	1735.1
57	3	100	10	400	0.042	33.1	510	1768.2
58	3	100	10	400	0.042	33.1	510	1801.2
59	3	100	10	400	0.042	33.1	510	1834.3
60	3	100	10	400	0.042	33.1	510	1867.3
61	3	100	10	400	0.042	33.1	510	1900.4
62	3	100	10	400	0.042	33.1	510	1933.4
63	3	100	10	375	0.042	31.0	485	1964.4
64	3	100	10	325	0.042	26.9	435	1991.3
65	3	100	10	275	0.042	22.7	385	2014.0
66	3	100	10	250	0.042	20.7	360	2034.6
67	3	100	10	225	0.042	18.6	335	2053.2
68	3	100	10	200	0.042	16.5	310	2069.8
69	3	100	10	150	0.042	12.4	260	2082.2
70	3	100	10	100	0.042	8.3	210	2090.4
71	3	100	10	10	0.042	0.8	120	2091.2
72	3	100	10	0	0.042	0.0	110	2091.2
73	3	100	10	0	0.042	0.0	110	2091.2
74	3	100	10	0	0.042	0.0	110	2091.2
75	3	100	10	0	0.042	0.0	110	2091.2
76	3	100	10	0	0.042	0.0	110	2091.2
77	3	100	10	0	0.042	0.0	110	2091.2
78	3	100	10	0	0.042	0.0	110	2091.2
79	3	100	10	0	0.042	0.0	110	2091.2
80	3	100	10	0	0.042	0.0	110	2091.2