Snapshot Assessment of the Roaring Fork Watershed

A Synoptic Approach to Characterizing Low Flow Conditions on the Crystal and Roaring Fork Rivers in the Autumn of 2012.

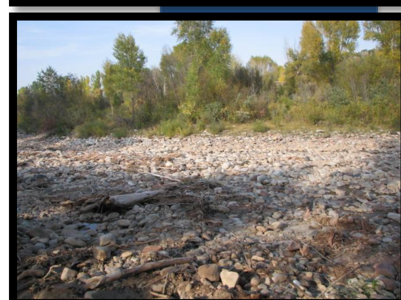
November 9, 2012

Prepared For:

FoRR Friends of Rivers & Renewables

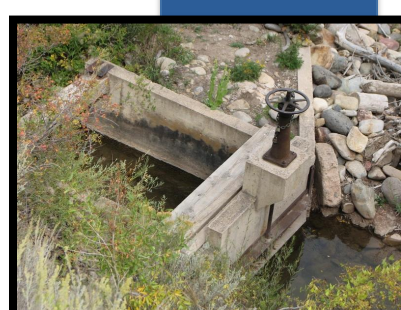
and

Roaring Fork Conservancy



In Accordance With:

Roaring Fork Watershed Plan



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Acknowledgements

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Executive Summary

The Roaring Fork and Crystal Rivers face numerous issues, including loss of streamflow from trans-basin and local diversions, loss of riparian habitat and floodplain due to development and urbanization, and potential water quality impairment. One of the most significant issues faced in the upper portion of the Roaring Fork River is streamflow depletion. In response to these concerns, Friends of Rivers and Renewables (FORR) and the Roaring Fork Conservancy (RFC) commissioned a study to assess the effects of water diversion activities on streamflow in the Roaring Fork Watershed as they relate to Instream Flow (ISF) water rights held by the Colorado Water Conservation Board (CWCB).

This assessment provides a clearer picture of those sections of the Roaring Fork and Crystal Rivers particularly vulnerable to degradation of stream health from lack of streamflow and excessively warm water temperatures. The study aims to:

1. Help local and state resource managers better understand the relationship between the area's human and natural water systems;
2. Provide scientifically credible data to inform discussions with water right holders and the local communities designed to identify, discuss and, where appropriate, implement creative water conservation solutions;
3. Communicate to the public the status of river health and integrity in the Roaring Fork and Crystal watersheds as it relates to streamflow depletion; and
4. Identify 'pinch' points of low flow in the river most likely to impair longitudinal hydrological and ecological connectivity.

The assessment presented here grew from current efforts by public, private, and government stakeholders in the greater Roaring Fork watershed to explore the way that human 'plumbing' affects the area's rivers. Streams and rivers are vital drivers of local recreation-based economies and are critical to the high quality of life enjoyed by area residents. Yet, the current demands placed on water resources in the Roaring Fork Watershed may exceed their capacity to provide important goods and services to both residents and wildlife.

Two reaches were selected for this assessment, the Roaring Fork River through the City of Aspen, and on the Crystal River from Avalanche Creek to the confluence with the Roaring Fork. A synoptic sampling approach was used to characterize upstream-downstream variability in streamflow as it is affected by tributary inputs and diversion outflows. A synoptic assessment provides a 'snapshot' of longitudinal patterns in streamflow by collecting discharge measurements at many locations, bracketing inflows and outflows to the river, over a short time period. The complex hydrological data generated by this assessment is presented in this report in an impactful and easy to interpret format.

The upper Roaring Fork River was found most vulnerable to low flows in the segment located near the City of Aspen between the Aspen Club and the confluence with Castle Creek. In July, diversions depleted incoming streamflow on this section by 80%. Several miles of the Crystal River between Thompson Creek and Prince Creek are particularly prone to de-watering. September flows at several locations on this segment were so low that they were nearly un-measurable. These conditions persist from the mouth of

Crystal Canyon to outlying subdivisions in Carbondale. Further investigation showed that river segments experiencing extreme low-flow conditions gained heat at a faster rate than other segments, sometimes achieving water temperatures known to be detrimental the region's highly-valued trout fishery.

Information in this assessment intends to enhance understanding of the location and magnitude of human impacts to local waterways. The Roaring Fork and Crystal River provide multiple economic, social, and environmental values to human and wildlife communities in the Roaring Fork Watershed. Faced with the many pressures created by growing local population, increasing Front Range demands on trans-basin supplies, and the effects of climate change on Rocky Mountain water yields, the challenge of managing rivers in a way that meets the needs of human communities without causing considerable impact to ecological function is greater than ever. In order to effectively manage these resources over the long term, relevant and timely information is required by the public at large, natural resource managers, water rights holders, policy makers and advocacy groups.

Purpose Statement

The Roaring Fork and Crystal Rivers face numerous issues, including loss of streamflow from trans-basin and local diversions, loss of riparian habitat and floodplain due to development and urbanization, and potential water quality impairment from a variety of sources (Clarke et al, 2008). One of the most significant issues faced in the upper portion of the Roaring Fork River is streamflow depletion. The Independence Pass Transmountain Diversion System diverts nearly 40% of the annual yield in the upper reaches of the Roaring Fork to augment supplies for Front Range users (Clarke et al, 2008). Additional water diversions near the City of Aspen further deplete streamflow to serve local municipal and irrigation needs. Over-appropriation of water rights on the nearby Crystal River produces a system that frequently fails to fulfill existing water right allocations or meet recommended flows for the maintenance of ecological integrity. A study of Crystal River irrigation diversions identified shortages at some time during the summer irrigation season in approximately one quarter of all years since 1955 (Clarke et al, 2008). In 2012, American Rivers named the Crystal River as one of 'America's Most Endangered Rivers' due to the impacts that proposed dams and water supply projects portend for the waterway (American Rivers, 2012). Changes in climate, population growth accompanied by growing consumptive use needs, and anticipated synergies between changes in water quantity and water quality suggest that patterns of flow depletion in the Roaring Fork Watershed will continue to be an issue of concern for many years to come.

The 2012 Water Year brought exceptionally dry conditions to the Central Rockies region of Colorado. A particularly thin snowpack produced very low flow in streams and rivers throughout the region by mid-summer. Subsequent impacts to water quantity from municipal and agricultural water diversions were particularly visible to residents or the Roaring Fork Valley as their effects were exaggerated by drought conditions. Accompanying changes in water quality likely exerted significant stress on the aquatic biota treasured by local residents and relied upon by local recreation-based economies. In response to these concerns, Friends of Rivers and Renewables (FORR) and the Roaring Fork Conservancy (RFC) commissioned a study to assess the effects of water diversion activities on streamflow in the Roaring Fork Watershed as they relate to Instream Flow (ISF) water rights held by the Colorado Water Conservation Board (CWCB). Instream flow rights are a non-consumptive use of water that allocates a specific minimum streamflow between two geographic points on a stream to protect ecosystem functions[1]. The commissioned study focuses on the portions of the Roaring Fork River and Crystal River perceived most vulnerable to de-watering and extreme low flow conditions.

This assessment intends to provide useful information to land owners, water rights holders, resource managers, policy makers, and advocacy groups as they strive to implement innovative conservation and resource management solutions on the streams and rivers of the Roaring Fork watershed. This effort sought to understand how various water diversions, return flows, and tributaries affect the discharge of a stream on a longitudinal (upstream-to-downstream) profile. The resulting information elucidates the effects of human 'plumbing' of watershed on streamflow and could, by extension, help predict spatial variation in aquatic community (e.g. fish and macroinvertebrates) health. The data presented here also suggest potential streamflow gauging locations best suited for administration of CWCB ISF Rights on the

1 For more information about ISF water rights, see the CWCB website: http://cwcb.state.co.us/environment/instream-flow-program

two study reaches. This directly supports the goals of the *Roaring Fork Watershed Stream Gauge Needs Workshop* held in April of 2012. Importantly, this assessment is *not intended as a thorough engineering analysis of the water balance on the study reaches.* Rather, this work provides foundational information useful for targeting and maximizing the efficiency of those more expensive undertakings and for facilitating dialog regarding the effects of consumptive water use in the Roaring Fork Watershed.

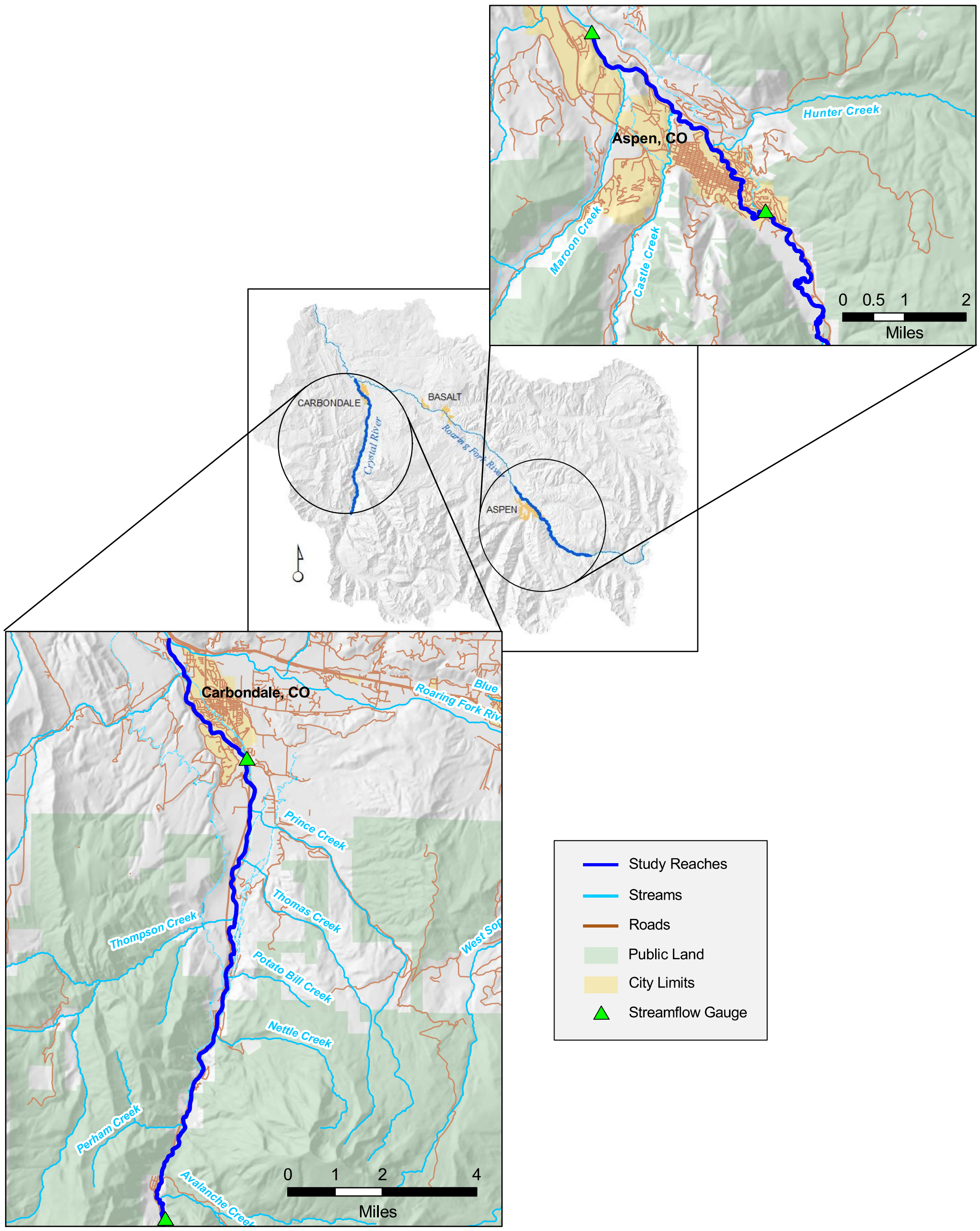

Figure 1. Study Areas

Study Areas

The two reaches selected for this study include: 1) the Roaring Fork River near the City of Aspen, extending from Difficult Creek to the Airport Business Park and 2) the lower Crystal River, extending from Avalanche Creek to the Roaring Fork confluence near Carbondale (Figure 1). Sample sites for streamflow measurements in each stream bracketed significant tributaries and diversions (Table 1). Discharge information was collected at a total of nine sites on the Roaring Fork and 14 sites on the Crystal. In the Crystal River study reach, data were collected manually at 12 sites, while United States Geological Survey (USGS) and Colorado Division of Water Resources (CDWR) gauges provided two additional data points. On the Roaring Fork, six sites were collected manually and USGS and CDWR gauges provided two additional measurement locations. The number of sample locations selected on each reach was limited by the transactional costs of travel to different sites, the actual time required to perform each discharge measurement (upwards of two hours), and the amount of equipment and personnel available to perform measurements.

Table 1. Streamflow observation locations on the Roaring Fork and Crystal River

Station Name	Stream	Latitude	Longitude
USGS Gauge above Avalanche Creek	Crystal	39.26016	-107.23172
USFS Boundary above Sweet Jessup Canal	Crystal	39.27257	-107.22487
Red Wind Point OS	Crystal	29.29029	-107.22487
Above Nettle Creek Rd	Crystal	39.29721	-107.21447
Below Bane & Thomas Ditch	Crystal	39.30463	-107.21304
Above Lowline Ditch	Crystal	39.32619	-107.20905
Thompson Creek Open Space	Crystal	39.33442	-107.20918
At Thomas Rd	Crystal	39.34866	-107.20887
Pitkin-Garfield County line	Crystal	39.36313	-107.20276
DWR Gauge At Fish Hatchery	Crystal	39.37743	-107.20451
RVR South Bridge	Crystal	39.38658	-107.20885
RVR North Bridge	Crystal	39.39277	-107.21888
Above Kaiser & Sievers Ditch	Crystal	39.40289	-107.22878
CRMS Bridge	Crystal	39.40803	-107.22974
USGS Gauge at Stillwater RD	Roaring Fork	39.18007	-106.80216
Aspen Club	Roaring Fork	39.18186	-106.80962
Mill St	Roaring Fork	39.19411	-106.81726
Aspen Institute	Roaring Fork	39.20108	-106.82676
Cemetery Ln	Roaring Fork	39.21104	-106.83991
Airport Business Park	Roaring Fork	39.22207	-106.85717

Tributary creeks dominate inflows to the Roaring Fork River study segment, although several ditch return-flows are also expected to contribute varying rates of flow to the river. The largest tributaries include Hunter Creek, Castle Creek, and Maroon Creek. Headgate diversions into municipal water and irrigation ditch systems comprise the main outflows on this reach (Table 2). Once water enters a given diversion system, it may return to the river or stream as groundwater or ditch return-flows or it may be removed from the system entirely via evaporation or transpiration (Figure 2). Diversion rates vary from one diversion point to the next, and at a single diversion point over the course of the year. Aggregated diversion rates on the Roaring Fork River study reach may vary from just a few cubic feet per second (cfs) to well over 50 cfs. The most significant diversions of streamflow from the river between the confluence with Difficult Creek and the City of Aspen are the Salvation Ditch, with a decreed diversion right of 59 cfs, and the Wheeler Ditch, with a decreed diversion right of 10 cfs. It is important to note that these numbers are the *decreed rates* listed by the CDWR for a particular diversion. They do not reflect the actual rate of water diverted at the time of this effort. These ditches were generally not diverting their decreed amounts during the sampling period. Possible reasons for diversion rates observed below decreed amounts include: limited irrigation usage needs, time of year, available stream water, senior/junior status within the prior appropriations system, private agreements, and temporal constraints on the water right and constraints from actual available stream flows in 2012. A thorough discussion of this intra-seasonal variation is beyond the scope of this report[2].

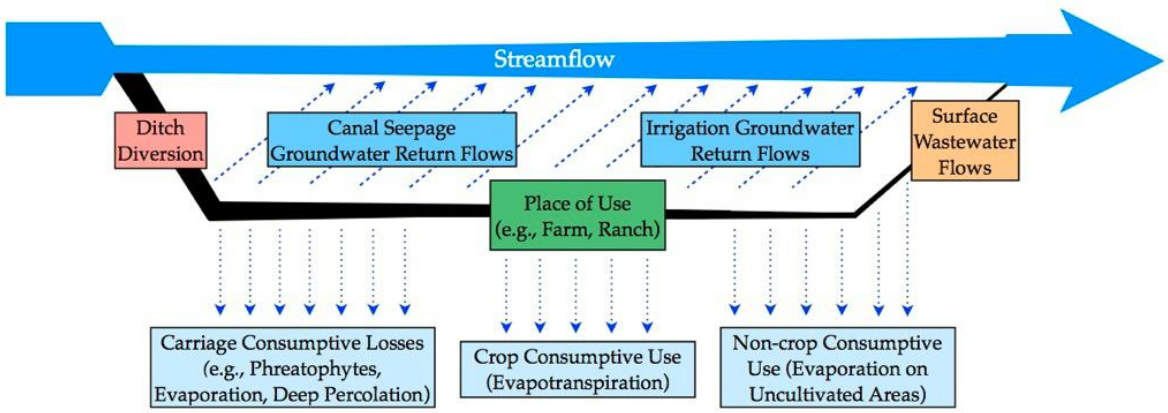

Figure 2. Conceptual model of the water balance on rivers subjected to water diversions for irrigation. The thickness of the blue arrow is proportional to streamflow in the river channel. The thickness of the black line is proportional to the rate of flow in the diversion channel (adapted from *Driscoll, 2012).*

Numerous small tributaries contribute flow to the Crystal River study reach. These include: Avalanche Creek, Potato Bill Creek, Nettle Creek, Thompson Creek, Thomas Creek, and Prince Creek. Generally, these tributaries drain relatively small, low-elevation watersheds. With the exception of Avalanche Creek, they contributed relatively little flow to the Crystal River during this assessment. Several tributaries, such as Thompson Creek and Thomas Creek, experience flow diversion and in September and October were nearly dry or un-measurable at their respective confluences with the Crystal River. Major diversions from the Crystal River occur at twelve locations (Table 3). Decreed rates for these diversions range from 75 cfs at the Sweet Jessup Canal down to 6 cfs at the Helms Ditch. Like the Roaring Fork, discharge measurement locations were selected on the Crystal to bracket tributaries and diversions. Extremely close spacing of diversions or the inability to find a suitable measurement location prohibited individual bracketing diversions and tributaries at several points along the study reach.

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2 For more information on this topic, see the Colorado Water Rights information available at the CDWR's web portal: http://water.state.co.us/SurfaceWater

Table 2. Major diversions on the Roaring Fork River study reach (Source: CDWR)

Diversion Name	Decreed Diversion Rate (cfs)
Salvation Ditch	59
Nellie Bird Ditch	4.94
Wheeler Ditch	10

Table 3. Major diversions on the Crystal River study reach. (Source: CDWR)

Diversion Name	Decreed Diversion Rate (cfs)
Sweet Jessup Canal	75
East Mesa Ditch	41.8
Carbondale Ditch	41.2
Lowline Ditch	40.5
Rockford Ditch	35.2
Kaiser and Seivers Ditch	27.1
Bowles and Holland Ditch	23.8
Southard and Cavanaugh Ditch	18.1
Ella Ditch	15.1
Weaver and Leonhardy Ditch	12.4
Bane and Thomas Ditch	6
Helms Ditch	6

Methods

This assessment modeled the two study reaches under the assumption that streamflow may only enter from a surface tributary, and may only leave from a headgate diversion. While this assumption does not strictly match a natural system, it provides a useful working model to understand the effects of human plumbing on the river system. Other natural processes may be responsible for changes in discharge on a particular reach. Interactions between the river channel and the alluvial aquifer are expected to complicate formulation of an accurate water balance on any stream or river reach. Hydraulic head gradients are expected to move water toward or away from the channel throughout each of the study areas, producing changes in measured streamflow that cannot be readily attributed to measured surface water diversions or tributaries. For the purposes of this study, the effects of groundwater-surface water interactions are assumed to be negligible.

Measuring streamflow in the Roaring Fork River above the City of Aspen

Measuring Streamflow

Streamflow (or 'discharge') data was collected on four dates on the Roaring Fork River (7/25/2012, 9/5/2012, 9/18/2012, and 10/16/2012) and on three dates on the Crystal River (9/4/2012, 9/22/2012, and 10/20/2012). Discharge was measured manually using the velocity-area method described in *USGS Techniques and Methods 3-A8* (Turnipseed and Sauer, 2010) with a handheld Sontek Flowtracker® Acoustic Doppler Velocimeter. To compute discharge, a suitable stream cross section was first identified by a combination of a desired location on the study reach, adequate channel shape, and available river access through public right-of-ways or landowner permission. Measuring discharge using the velocity-area method is based on several assumptions, including uniform flow in a downstream direction at an ideally shaped cross section. Several measurement locations on the steep and rocky reaches prevalent in the Roaring Fork and Crystal watersheds were only rated 'fair' to 'good' measurement locations due to excessive turbulence, which increased the potential for measurement error. Even though channel geometry and hydraulics at several locations pushed the boundaries of the methodological assumptions, the employment of thorough quality assurance and quality control procedures ensured that discharge measurements provided accurate estimates of flow. No large thunderstorms were noted in the area on the dates of sampling. Local water administrators affirmed that local diversions were not fluctuating on a short-term (< 1 day) basis on each of the study reaches. These conditions supported the assumption of static or near-static flow during the sampling periods.

Measuring Temperature and Specific Conductance

Three synoptic collections of temperature and specific conductance data occurred during the study to coincide with the streamflow measurements on both study reaches (Roaring Fork River: 9/9/2012, 9/23/2012, and 10/31/2012; Crystal River: 9/7/2012, 9/21/2012, and 11/1/2012). Temperature and temperature-corrected specific conductance data were collected using an Extech II® digital multimeter. The multimeter was placed in the stream thalweg (or center of flow) until a visual assessment of readings for both temperature and specific conductance showed that they stabilized. These data were collected during clear weather over a time period of 1-3 hours on both the Roaring Fork and Crystal. Observations were planned for clear afternoons to minimize the effects of rapid changes in daytime air temperature near dawn and dusk. Sampling runs began at the top of each study reach and moved in a downstream direction. Data from all sites were collected over a period of approximately 90 minutes on the Roaring Fork study reach and in 2.5-3 hours on the Crystal River. The observed longitudinal temperature and specific conductance signals may be confounded slightly by downstream heat and solute transport, the expected diurnal fluctuations in both parameter values, and the fact that some time lag between subsequent observations was inevitable. Average solute transport rates, the rate of change in either parameter value over the course of a day, and the average sampling lag time between observation locations, may account for some component of the observed signals. However, the relatively rapid pace of sampling runs likely minimized this effect. Thus, the observed profiles are taken here to be accurate representations of point-in-time upstream-downstream patterns in both parameters.

Results and Discussion

Roaring Fork River Streamflow

Interactions between tributary inflows and active water diversions produced persistent longitudinal patterns in streamflow on the Roaring Fork River study reach (Figure 3). Significant diversions below the

Independence Pass Tunnel occur at the Salvation Ditch, which services areas to the northwest of Aspen, and the Wheeler Ditch, which supplies municipal water needs. Decreed water rights at the Salvation and Wheeler ditches are 59 cfs and 10 cfs respectively. Streamflow depletions between these two points ranged from 13 cfs (observed on September 18th, 2012) to 20 cfs (observed on July 25th, 2012). The diversion of 20 cfs in July represented 80% of the river's total flow. Streamflow recovered significantly below the confluences with Castle and Maroon creeks on each of the four observation dates (Table 4). The majority of water in Hunter Creek was diverted prior to joining the Roaring Fork. Throughout the observation period, Hunter Creek did not contribute significantly to streamflow in the Roaring Fork River. Evidently, the majority of the observed streamflow in the upper Roaring Fork River downstream of Maroon Creek was sourced from Castle Creek and Maroon Creek.

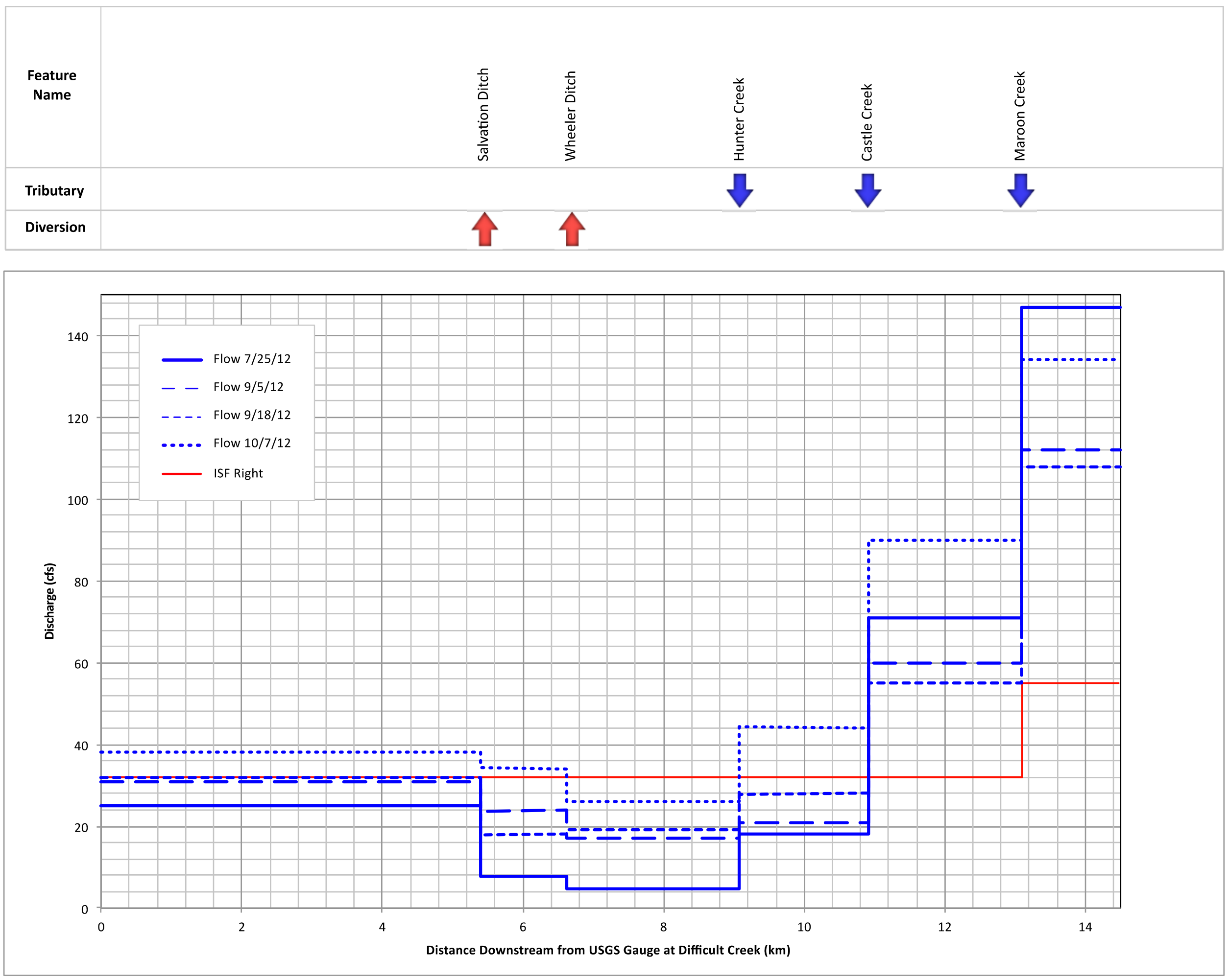


Figure 3. Observed flows on the Roaring Fork River during the study period. Profile confirms that the most de-watered section of the river extends from below the Salvation and Wheeler ditches to the confluence with Castle Creek. This figure plots longitudinal changes in streamflow under the assumption that changes in discharge occur at discrete locations where the river experiences tributary inflows or diversions.

Table 4. Observed streamflow on the Roaring Fork River study reach during three data collection campaigns in September and October of 2012. Data collected during a July 2012 pilot study also displayed.

Site Description	ISF Right (cfs)	Observed Discharge (cfs)			
		7/25**	9/5	9/18	10/16
Above Difficult Creek	32	11	24	26	29
Above Salvation Ditch	32	25	31	32	38
At Aspen Club	32	7.6	24	18	34
At Mill Street Bridge	32	4.7	17	19	26
At Aspen Institute	32	18	21	28	44
At Stein Park	32	71	60	55	90
At CoA WWTP	55	147	112	108	134

**Pilot Study

During July, the Independence Pass Tunnel was actively diverting water to the Arkansas River Basin. The aggregated effects of this diversion along with local downstream diversions produced the lowest observed streamflow in the Roaring Fork River study reach. Late in the summer of 2012, a collection of agricultural water rights in the Grand Valley area on the Colorado River known as the Cameo Call came into priority, and transmountain diversions through the Independence Pass Tunnel ceased. Roaring Fork River flows prior to the Cameo Call varied from a low of 4.7 cfs near Mill Street in Aspen, to a high of 147 cfs below the combined outputs of Castle and Maroon Creek (Table 4). Cessation of transmountain diversions coincided with measureable increases in streamflow through the most de-watered reach in the City of Aspen.

The Crystal River above Thomas Road observed on 9/24/2012. This extremely low flow condition effectively eliminated upstream-downstream hydrological (and ecological) connectivity.

Crystal River Streamflow

An intricate system of diversion ditches and persistent water use needs produced a complex but persistent patter of longitudinal streamflow on the Crystal River (Figure 4). The two September sample collection dates coincided with heavy irrigation use pressure and little thunderstorm activity. Flows ranged from 77 cfs below Avalanche Creek in early September to a low of 1 cfs at Thomas Road in mid-September (Table 5). The upper section of the study reach was relatively unaffected by diversions and consistently produced the highest streamflow. Diversion activity below Avalanche Creek coincided with large reductions in observed streamflow on all three sampling dates.

The Crystal River completely de-watered at the end of September near the Garfield-Pitkin County line.

The individual influence of several closely spaced tributaries and water diversions between Thompson Creek and the CDPW Fish Hatchery was difficult to discern. Although several significant diversions occurred, river flows also increased within this section. The increase presumably resulted from the effects of several contributing tributary watersheds, unmapped ditch return flows, groundwater influx from irrigated lands adjacent to the river, and other positive fluxes from the alluvial aquifer. Important tributary creeks on the Crystal River include Potato Bill Creek, Nettle Creek, Thompson Creek, Thomas Creek, and Prince Creek. However, the majority of these creeks experience diversions on their upper reaches. Visual observations of their respective confluences with the Crystal River suggested that they contributed little measurable surface flow during the study period.

Table 5. Observed streamflow on the Crystal River study reach during three data collection campaigns in September and October of 2012.

Site Description	May-Sept ISF (cfs)	Oct-April ISF (cfs)	Discharge (cfs)		
			9/4	9/22	10/20
USGS Gauge above Avalanche Creek	80	40	63	53	53
USFS Boundary above Sweet Jessup Canal	100	60	77	68	66
At Red Wind Point Open Space	100	60	59	58	61
Above Nettle Creek Road	100	60	29	26	38
Below Bane & Thomas Ditch	100	60	29	28	32
Above Lowline Ditch	100	60	31	24	32
At Thompson Creek Open Space	100	60	24	7	30
At Thomas Road	100	60	4	1	28
Above Garfield-Pitkin County Line	100	60	12	8	33
At CDPW Fish Hatchery	100	60	14	8	42
At South Bridge in RVR	100	60	33	24	62
At North Bridge in RVR	100	60	36	21	69
Above Kaiser-Sievers and Southard-Cavanaugh	100	60	44	31	70
At CRMS Bridge	100	60	28	22	56

Dispersed influxes added a small amount of streamflow downstream of the Thomas Creek confluence. Flows showed no significant recovery until below the CDPW Fish Hatchery, where a number of ditch returns began to spill unconsumed water back into the Crystal's main channel. Throughout the RVR subdivision, flows increased somewhat from additional ditch returns. Additional significant diversions occurred in the vicinity of the Colorado Rocky Mountain School near the confluence of the Crystal River and the Roaring Fork River.

Low flow conditions on the Crystal River below the Town of Carbondale (Source: Eco-Flight)

Table 6. Diversions on Study Reach during September and October by reported streamflow rate (Q) and by fraction of total diversions in study area. (Source: provisional data provided by the CDWR)

Diversion Structure	Week of 8/20		Week of 8/27		**Week of 9/11**		**Week of 9/24**		Week of 10/15		**Week of 10/19**		Average	
	Q (cfs)	% total	Q (cfs)	% total	Q (cfs)	% total	Q (cfs)	% total	Q (cfs)	% total	Q (cfs)	% total	Q (cfs)	% total
Sweet Jessup	31	24%	26	18%	26	22%	18	16%	8	8%	9	11%	20	17%
East Mesa	30	23%	29	20%	28	24%	28	25%	29	30%	29	34%	29	26%
Bane and Thomas	0.8	1%	2	1%		0%	3	3%	3	3%	3.85	5%	3	2%
Lowline	12.8	10%	22	16%	11.3	10%	21	19%	4.1	4%	6.02	7%	13	9%
Helms	3.6	3%	6.5	5%		0%	4	4%	3	3%	0	0%	3	2%
Ella	6.23	5%	9.5	7%	8.31	7%	13	12%	9	9%	0	0%	8	6%
Bowles & Holland	4	3%	5	4%	6	5%	4	4%	8.5	9%	6	7%	6	6%
Rockford	7.52	6%	13	9%	12	10%	10	9%	19	20%	17	20%	13	13%
Carbondale	9.2	7%	9	6%	9	8%	8.29	7%	0	0%	0	0%	6	4%
Weaver	4	3%	4	3%	4	3%	3	3%	0	0%	0	0%	3	2%
Southard & Cava.	8	6%	7	5%	6.9	6%		0%	5.4	6%	6	7%	7	6%
Kaiser & Sievers	12	9%	8.5	6%	6.9	6%		0%	7.5	8%	7.5	9%	8	8%

***Bold dates** and associated diversion rates most closely reflect conditions on the 3 observation dates from this study.*

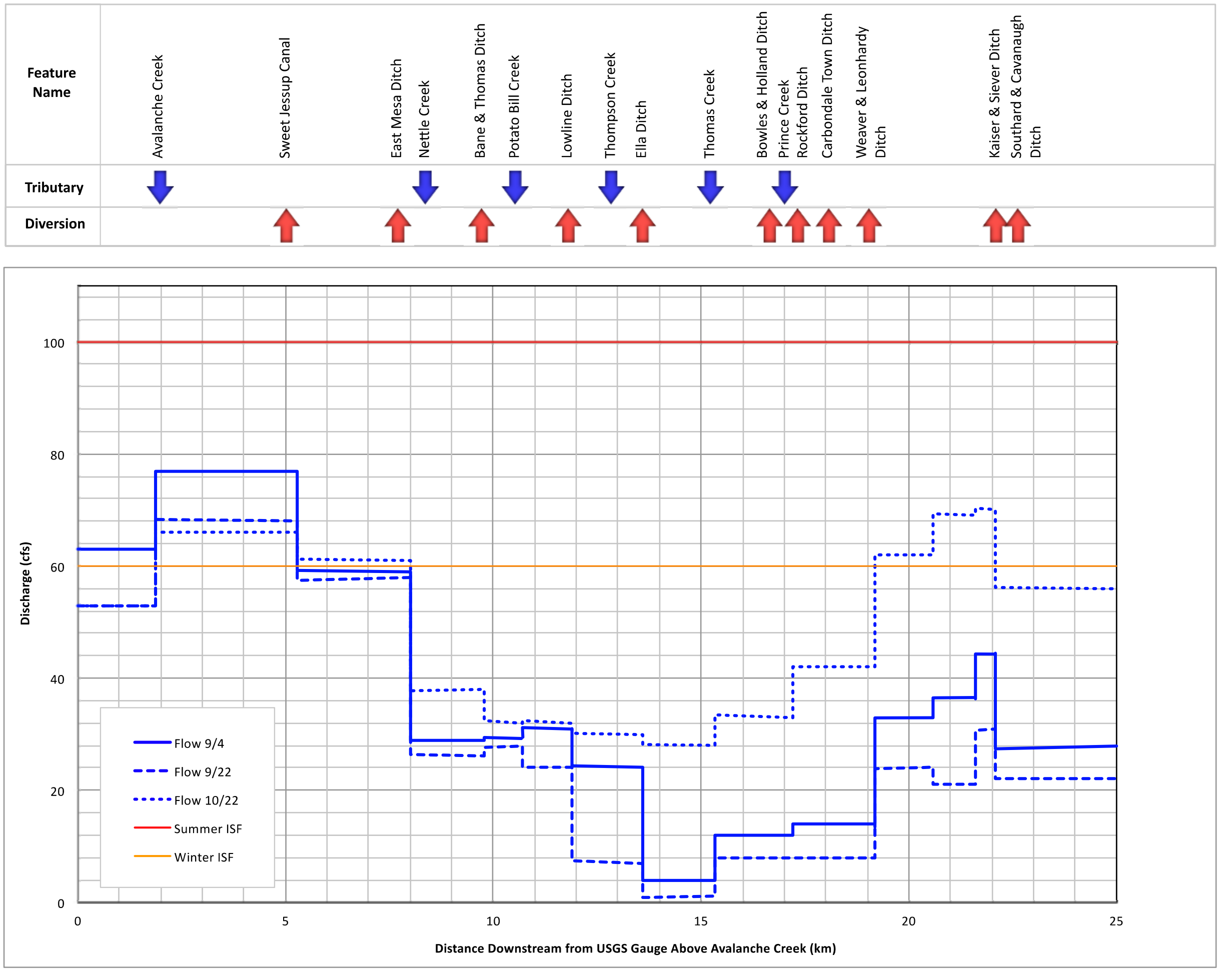
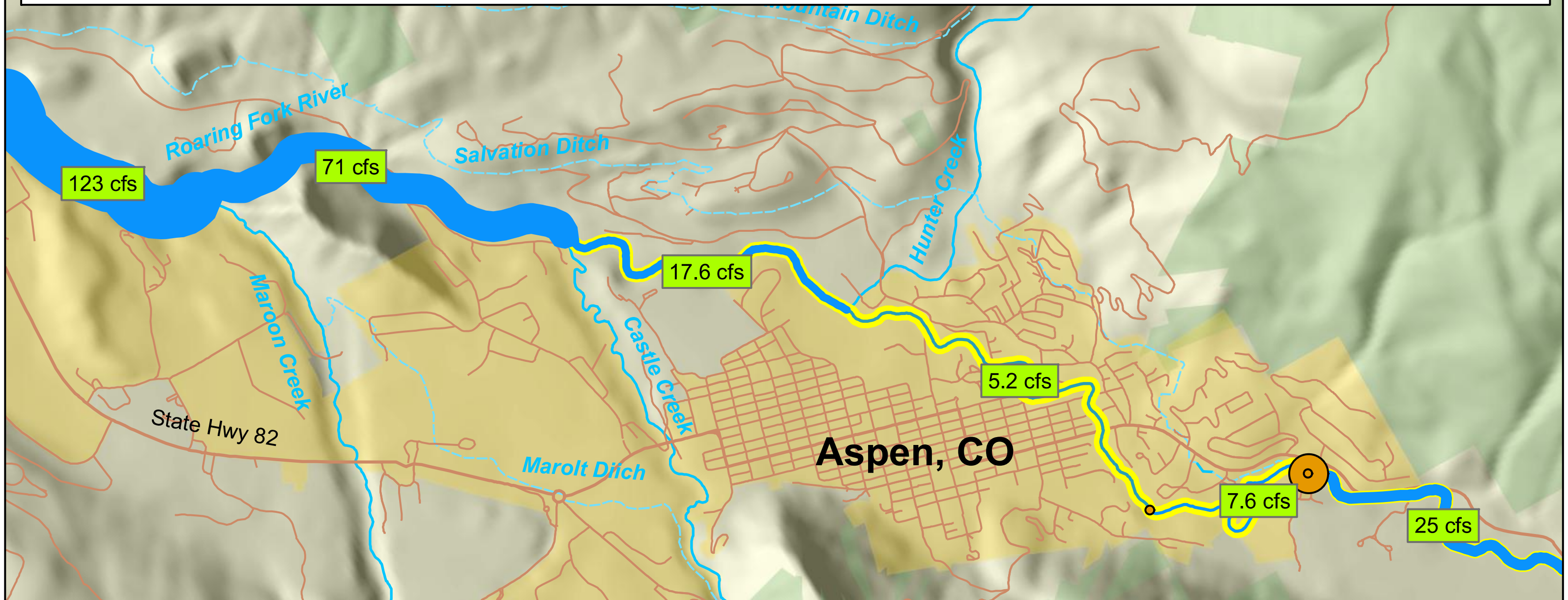


Figure 4. Observed flows on the Crystal River during the study period. Profile confirms that the most de-watered section of the river exists near Thomas Road. This figure plots longitudinal changes in streamflow under the assumption that changes in discharge occur at discrete locations where the river experiences tributary inflows or diversions.

Near the Ella and Helms ditch, the Crystal River flows through Pitkin County's Thompson Creek Open Space parcel. The downstream end of this segment was observed nearly dry on September 22nd. During September, flow in the river channel near Thomas Road was extremely low. River sections exhibiting exceptionally low streamflow, or a complete lack thereof, disrupt hydrological connectivity between upstream and downstream reaches. Importantly, dry river sections prohibit movement of migrating fish during important fall spawning periods. Although an analysis of sedimentation is beyond the scope of this study, visual observation in the flow-depleted reaches revealed extensive fine sediment covering the stream bottom and substrate which can negatively affect macroinvertebrate communities and may render the stream bottom unsuitable for redd construction by trout.

Roaring Fork River Flows: July 25th, 2012



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Created By: Bill Hoblitzell

Created On: 8/1/2012

Data Sources: S.K.Mason Environmental, LLC; CDWR; USDA; NRCS; and Pitkin County.

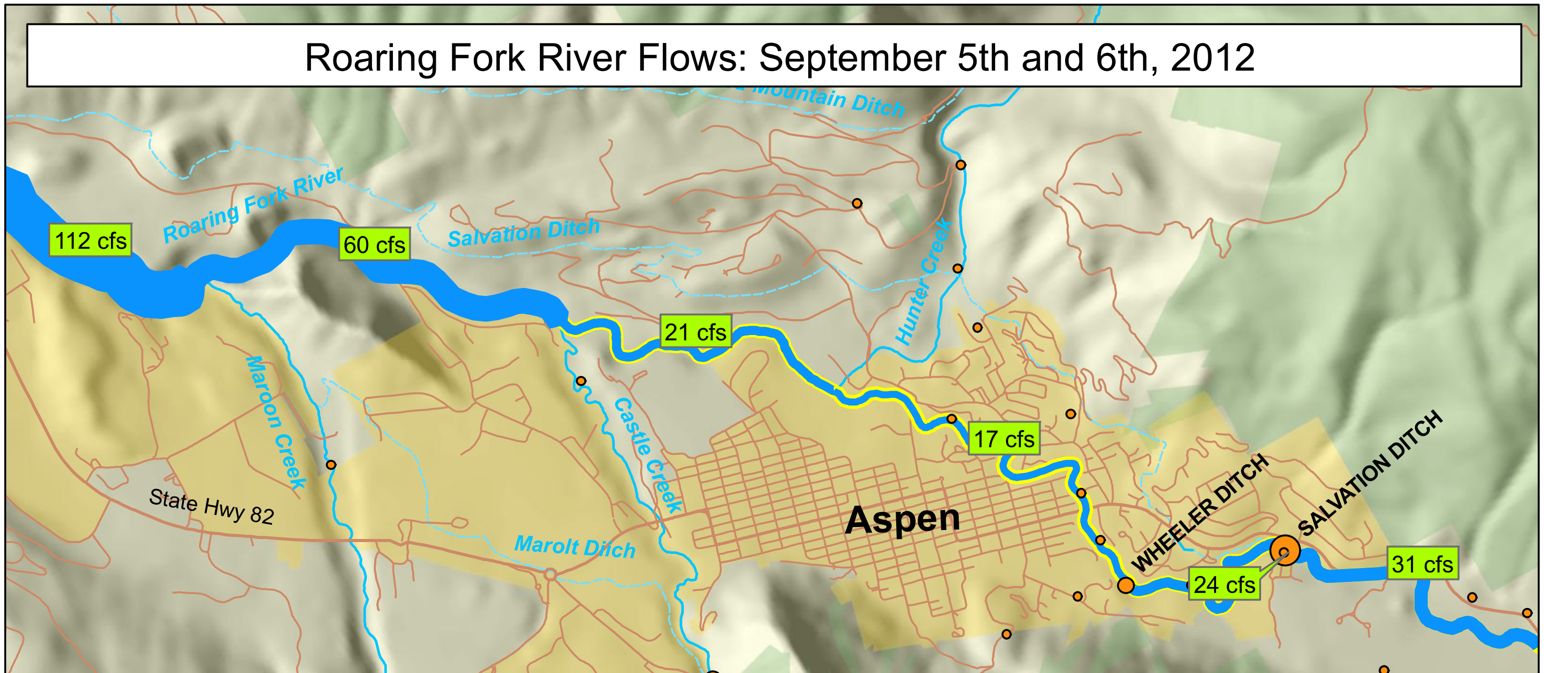
Description

This map depicts flows in different segments of the Roaring Fork River near Aspen, Colorado. The thickness of the blue line is proportional to the amount of water flowing in that segment of river. Observed stream flows are also indicated in the green callout boxes. Orange circles indicate diversion points on this section of river. Their size is proportional to the decreed diversion rate at these points. Several of the ditch names are indicated for reference.

Flows in the river increase below confluences with tributaries such, as Castle Creek. Flows generally decrease at major diversion points. The yellow band proportionally represents the 32-cfs Instream Flow (ISF) right held by the Colorado Water Conservation Board.

Legend

Figure 5. Roaring Fork River Pilot Study, July 25.



S.K.Mason Environmental, llc

Created By: Bill Hoblitzell

Created On: 11/1/2012

Data Sources: S.K.Mason Environmental, LLC; CDWR; USDA; NRCS; and Pitkin County.

Description

This map depicts flows in different segments of the Roaring Fork River near Aspen, Colorado. The thickness of the blue line is proportional to the amount of water flowing in that segment of river. Observed stream flows are also indicated in the green callout boxes. Orange circles indicate diversion points on this section of river. Their size is proportional to the decreed diversion rate at these points. Several of the ditch names are indicated for reference.

Flows in the river increase below confluences with tributaries such, as Castle Creek. Flows generally decrease at major diversion points. The yellow band proportionally represents the 32-cfs Instream Flow (ISF) right held by the Colorado Water Conservation Board.

Legend

Streamflow
ISF Right
Streams
Ditches
City Limits
Federal Land
Streets

0 - 10
10 - 18
18 - 27
27 - 42
42 - 75

0 0.25 0.5 1 Miles

Figure 6. Roaring Fork River, September 5-6.

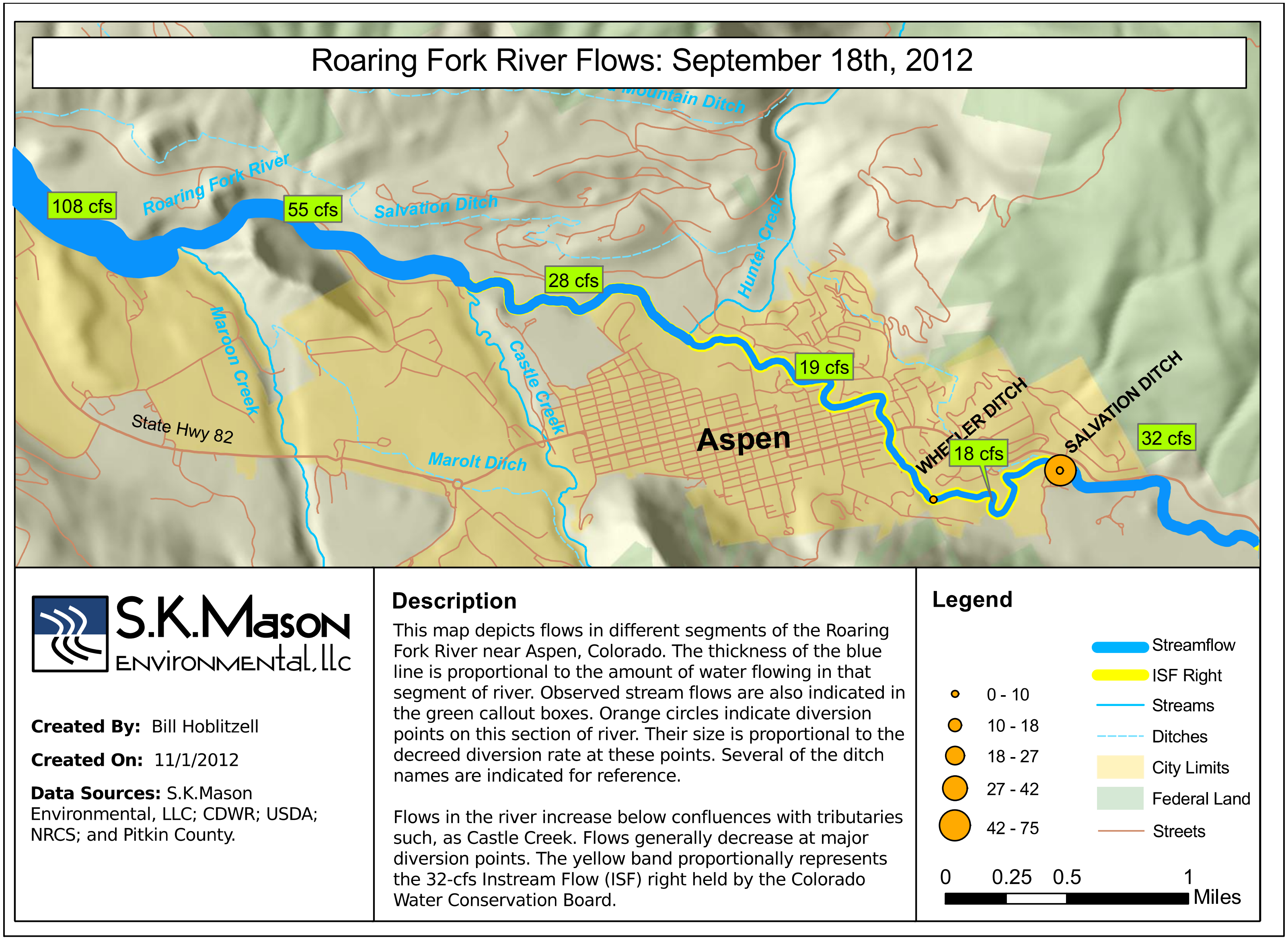
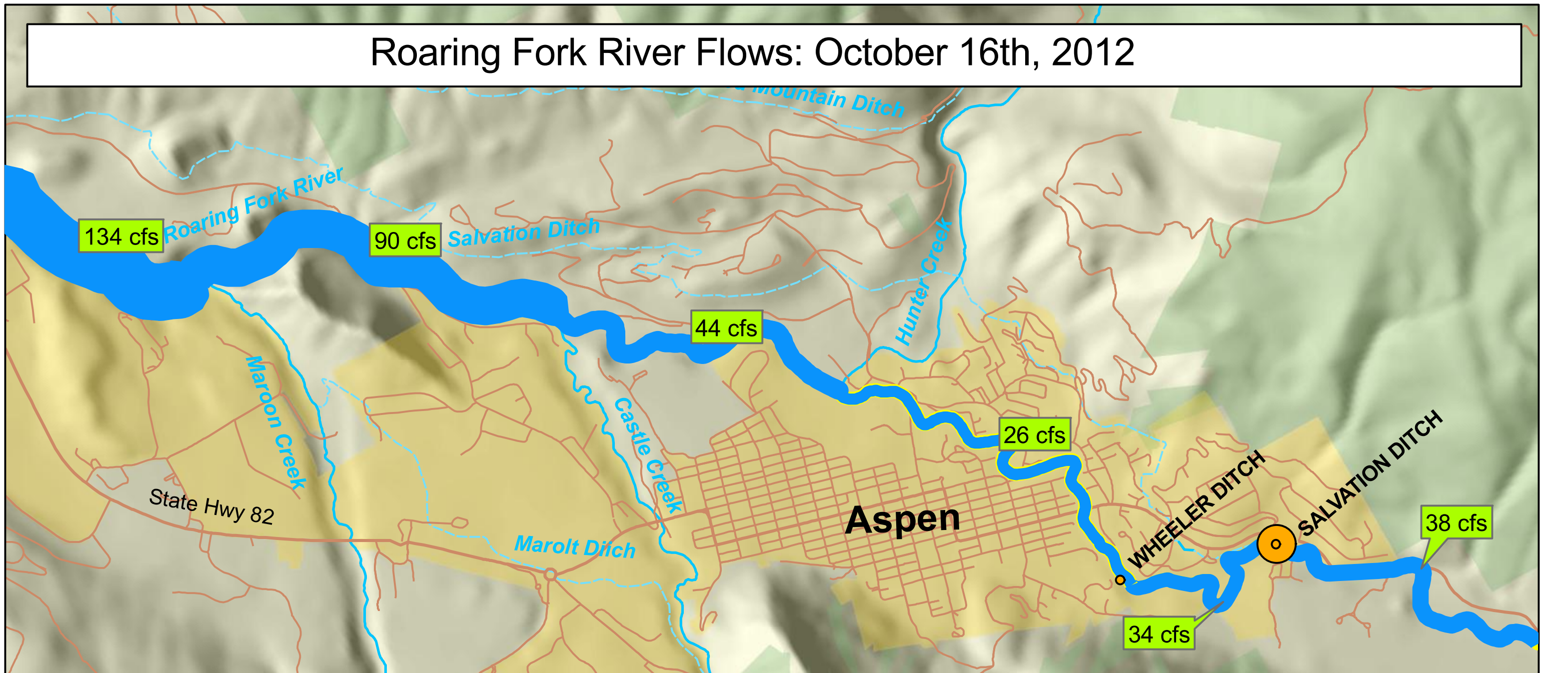


Figure 7. Roaring Fork River, September 18.



S.K.Mason Environmental, LLC

Created By: Bill Hoblitzell

Created On: 11/1/2012

Data Sources: S.K.Mason Environmental, LLC; CDWR; USDA; NRCS; and Pitkin County.

Description

This map depicts flows in different segments of the Roaring Fork River near Aspen, Colorado. The thickness of the blue line is proportional to the amount of water flowing in that segment of river. Observed stream flows are also indicated in the green callout boxes. Orange circles indicate diversion points on this section of river. Their size is proportional to the decreed diversion rate at these points. Several of the ditch names are indicated for reference.

Flows in the river increase below confluences with tributaries such, as Castle Creek. Flows generally decrease at major diversion points. The yellow band proportionally represents the 32-cfs Instream Flow (ISF) right held by the Colorado Water Conservation Board.

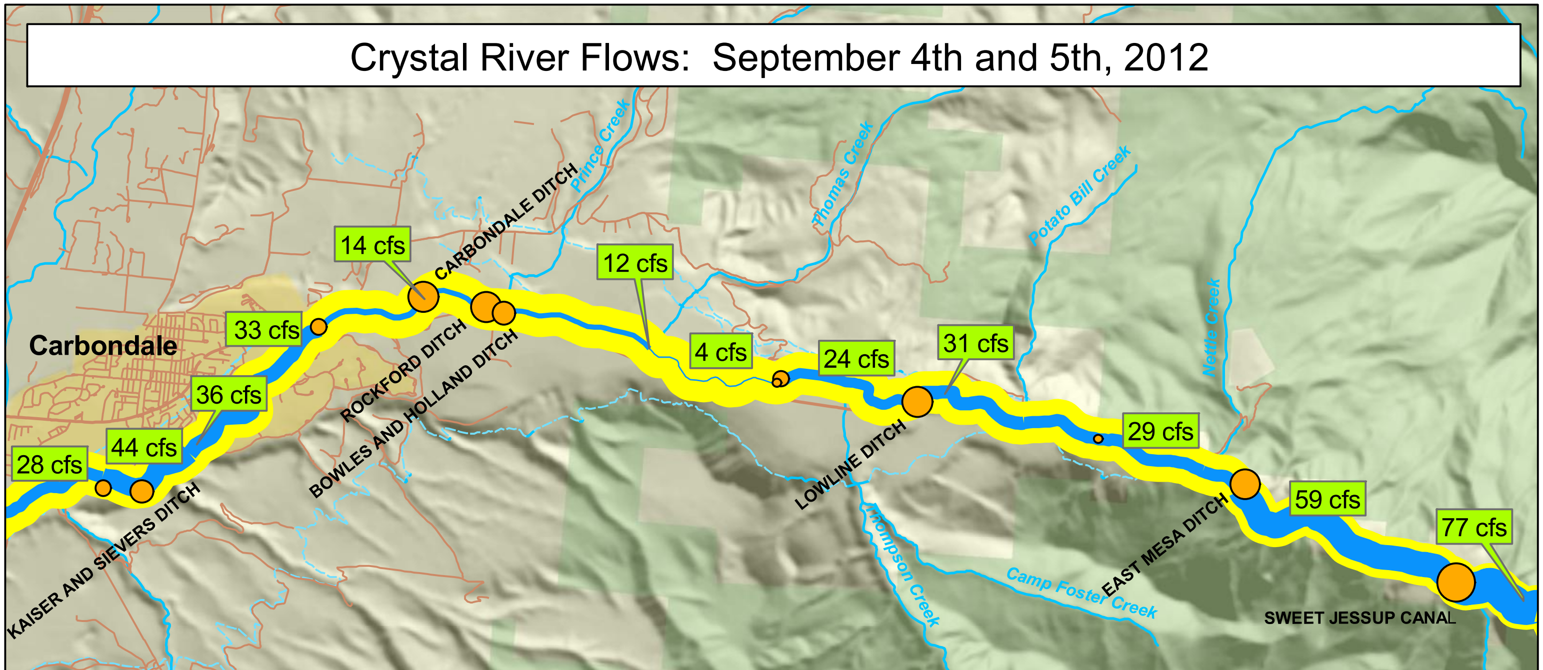
Legend

0 - 10
10 - 18
18 - 27
27 - 42
42 - 75

Streamflow
ISF Right
Streams
Ditches
City Limits
Federal Land
Streets

0 0.25 0.5 1 Miles

Figure 8. Roaring Fork River, October 16.



S.K.Mason Environmental, llc

Created By: Bill Hoblitzell

Created On: 11/1/2012

Data Sources: S.K.Mason Environmental, LLC; CDWR; USDA; NRCS; and Pitkin County.

Description

This map depicts flows in different segments of the Crystal River near Carbondale, Colorado. The thickness of the blue line is proportional to the amount of water flowing in that segment of river. Observed stream flows are also indicated in the green callout boxes. Orange circles indicate diversion points on this section of river. Their size is proportional to the decreed diversion rate at these points. Several of the ditch names are indicated for reference.

Flows in the river increase below confluences with tributaries, such as Avalanche Creek. Flows generally decrease at major diversion points. The yellow band proportionally represents the 100-cfs Instream Flow (ISF) right held by the Colorado Water Conservation Board.

Legend

0 - 10
10 - 18
18 - 27
27 - 42
42 - 75

Streamflow
ISF Right
Streams
Ditches
City Limits
Federal Land
Streets

0 0.5 1 2 Miles

Figure 9. Crystal River, September 4-5.

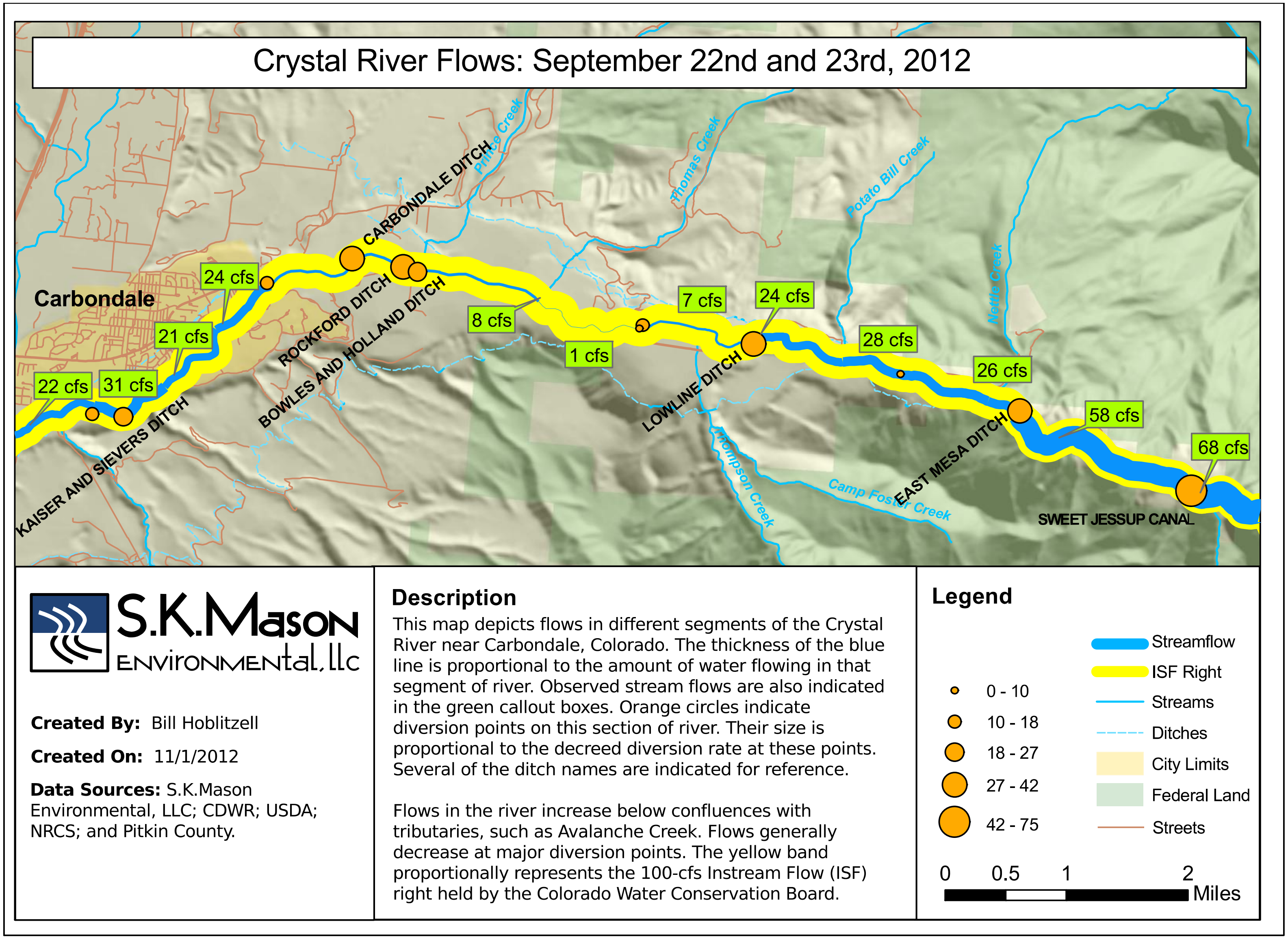
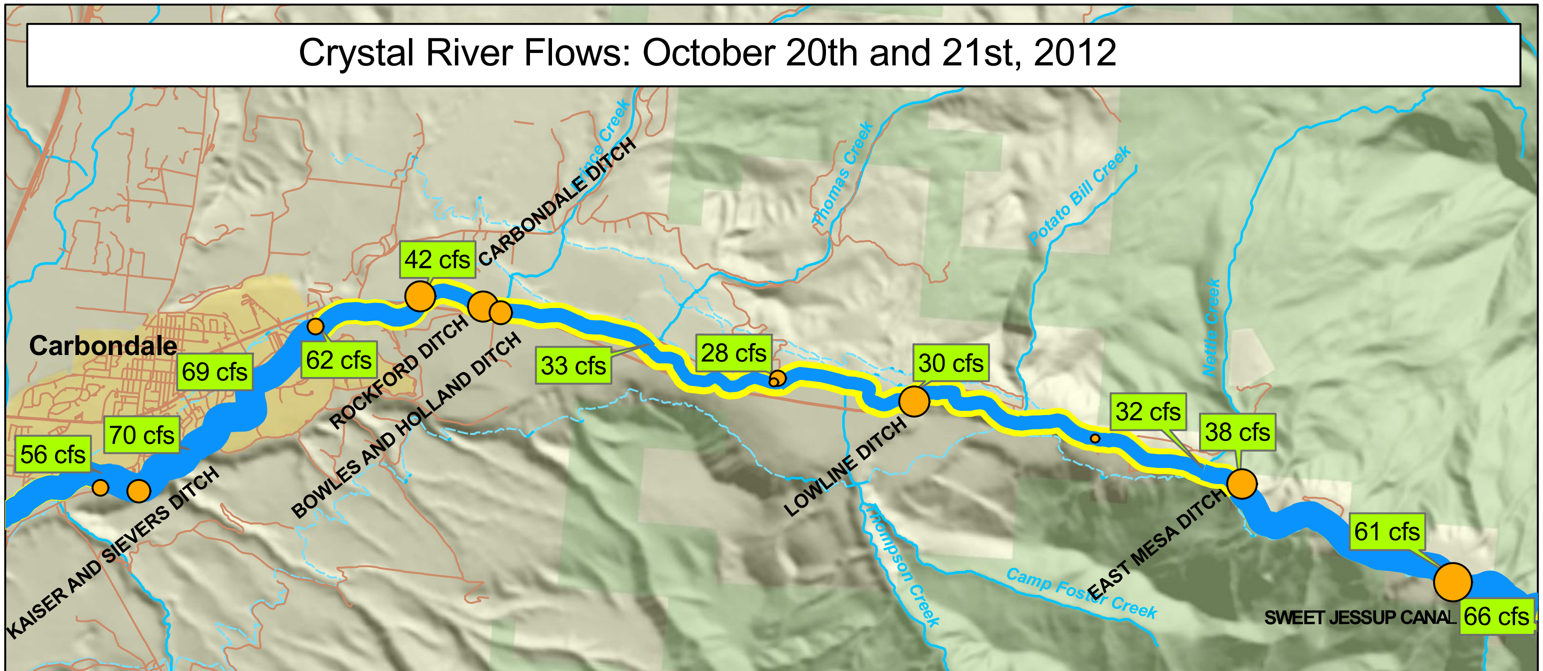


Figure 10. Crystal River, September 22-23



Created By: Bill Hoblitzell

Created On: 11/1/2012

Data Sources: S.K.Mason Environmental, LLC; CDWR; USDA; NRCS; and Pitkin County.

Description

This map depicts flows in different segments of the Crystal River near Carbondale, Colorado. The thickness of the blue line is proportional to the amount of water flowing in that segment of river. Observed stream flows are also indicated in the green callout boxes. Orange circles indicate diversion points on this section of river. Their size is proportional to the decreed diversion rate at these points. Several of the ditch names are indicated for reference.

Flows in the river increase below confluences with tributaries, such as Avalanche Creek. Flows generally decrease at major diversion points. The yellow band proportionally represents the Oct.-April 60-cfs Instream Flow (ISF) right held by the Colorado Water Conservation Board.

Legend

- 0 - 10
- 10 - 18
- 18 - 27
- 27 - 42
- 42 - 75

- Streamflow
- ISF Right
- Streams
- Ditches
- City Limits
- Federal Land
- Streets

0 0.5 1 2 Miles

Figure 11. Crystal River, October 20-21.

Temperature Profiles

Water temperature directly affects the myriad biological communities residing in the water column and in the streambed on any river or stream. Critically, as water temperature increases, the amount of oxygen that may be dissolved in it decreases. This, in turn, can place stress on fisheries and aquatic macroinvertebrates. The Colorado Department of Parks and Wildlife (CDPW) identifies 66^0 F (18.9^0 C) as an important temperature threshold beyond which degradation of brown trout fisheries is likely to occur. Other species like brook trout and cutthroat trout are less heat tolerant. A number of factors may affect spatial and temporal patterns water temperature. Variations in the rate at which a stream gains heat may be strongly related to flow; however, they should not be assumed to result from changes in streamflow alone.

The Crystal River upstream of the Town of Carbondale. Return flows on the west side of the river and at the Carbondale ditch provide a cooling inflow to dewatered sections of the Crystal which are subject to rapid heat gain.

The CDPW temperature threshold was exceeded at two locations in early September on the Crystal River. In the most flow-depleted segments (between Thompson and Thomas creeks), observed temperatures in the Crystal River were relatively high during both September sampling dates. The rapid rate at which the river absorbed heat at these locations is reflected in the relatively steep upward slopes of the temperature profiles in the segment (Figure 12). As return flows, tributaries, and assumed groundwater influxes contributed to streamflow below Thomas Creek, water temperatures began to decline. During the final round of post-irrigation season observations, the sharp temperature spike previously observed near Thomas Road did not persist. Citizens participating in the Roaring Fork Conservancy's *Hot Spots for Trout* volunteer monitoring program (www.roaringfork.org) recorded multiple observations of temperatures above the recommended standard of 66^0 F at the Fish Hatchery and Colorado Rocky Mountain School (Appendix D). The highest temperatures were recorded by RFC at these two locations on the Crystal River were as follows: 68°F on August 12 at 6:00PM at the Fish Hatchery and 72.5°F on July 12 at 2:00 PM at the CRMS Bridge.

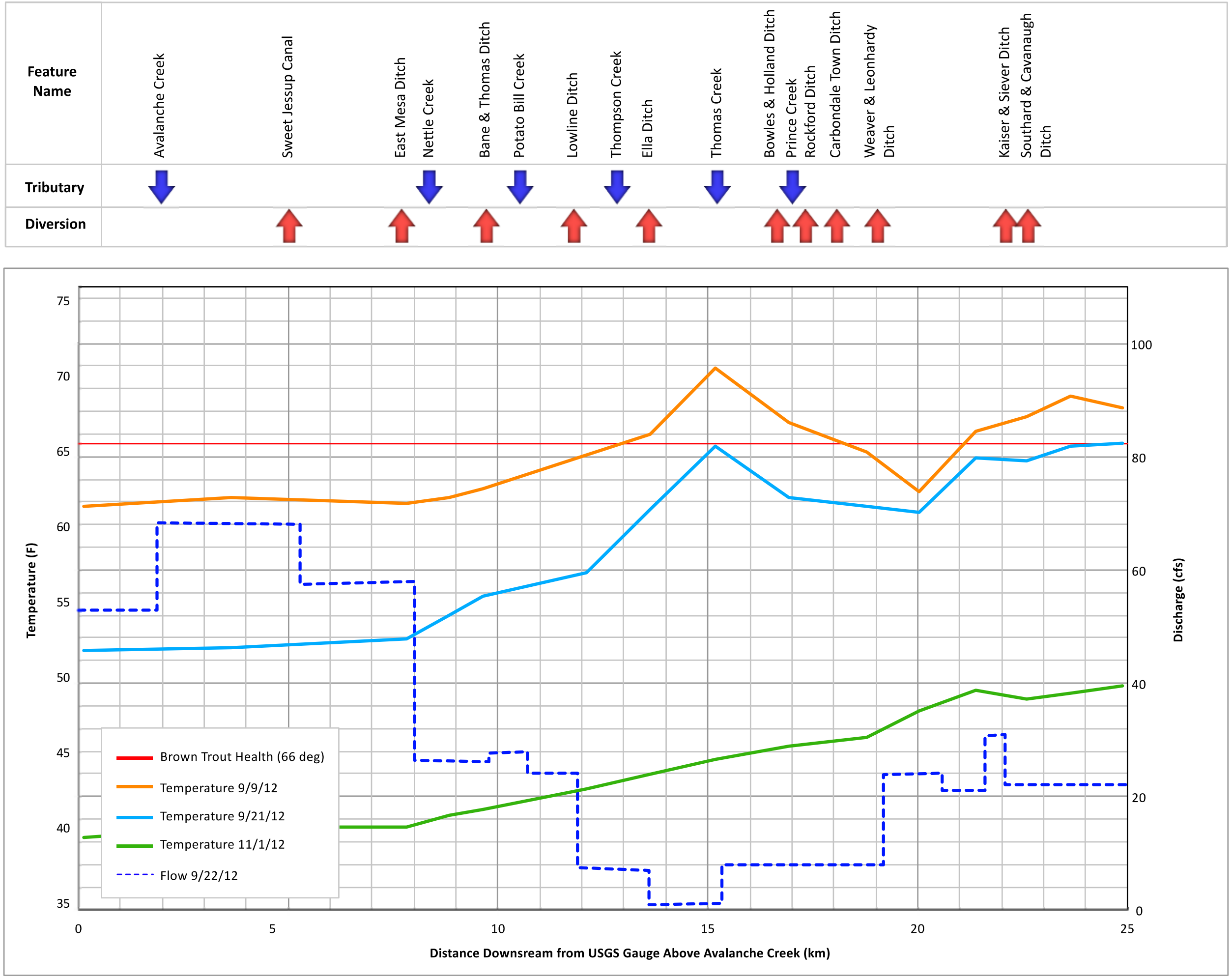


Figure 12. Observed temperatures on the Crystal River. Temperatures rise rapidly as flow decreases, peaking in the area near Thomas Road.

The Roaring Fork study reach did not reach temperature levels stressful to fish during any of the three sampling events (Figure 13). This can be largely attributed to this reach's location at a higher elevation in the watershed. However, prior to collection of data for this study, citizens participating in the Roaring Fork Conservancy's *Hot Spots for Trout* volunteer monitoring program (www.roaringfork.org) found temperatures at or above the recommended standard of 66°F at the Hopkins Street Footbridge, a flow-depleted section of the study reach upstream of Mill Street (Appendix D). These observations were made on 6/30/2012, 7/10/2012, and 7/26/2012. Sections of the river experiencing the lowest flows show the most rapid heat gain as displayed by the slope of the longitudinal temperature profile. Tributary inflows from Castle Creek and Maroon Creek had a visible cooling effect on streamflow in the Roaring Fork River.

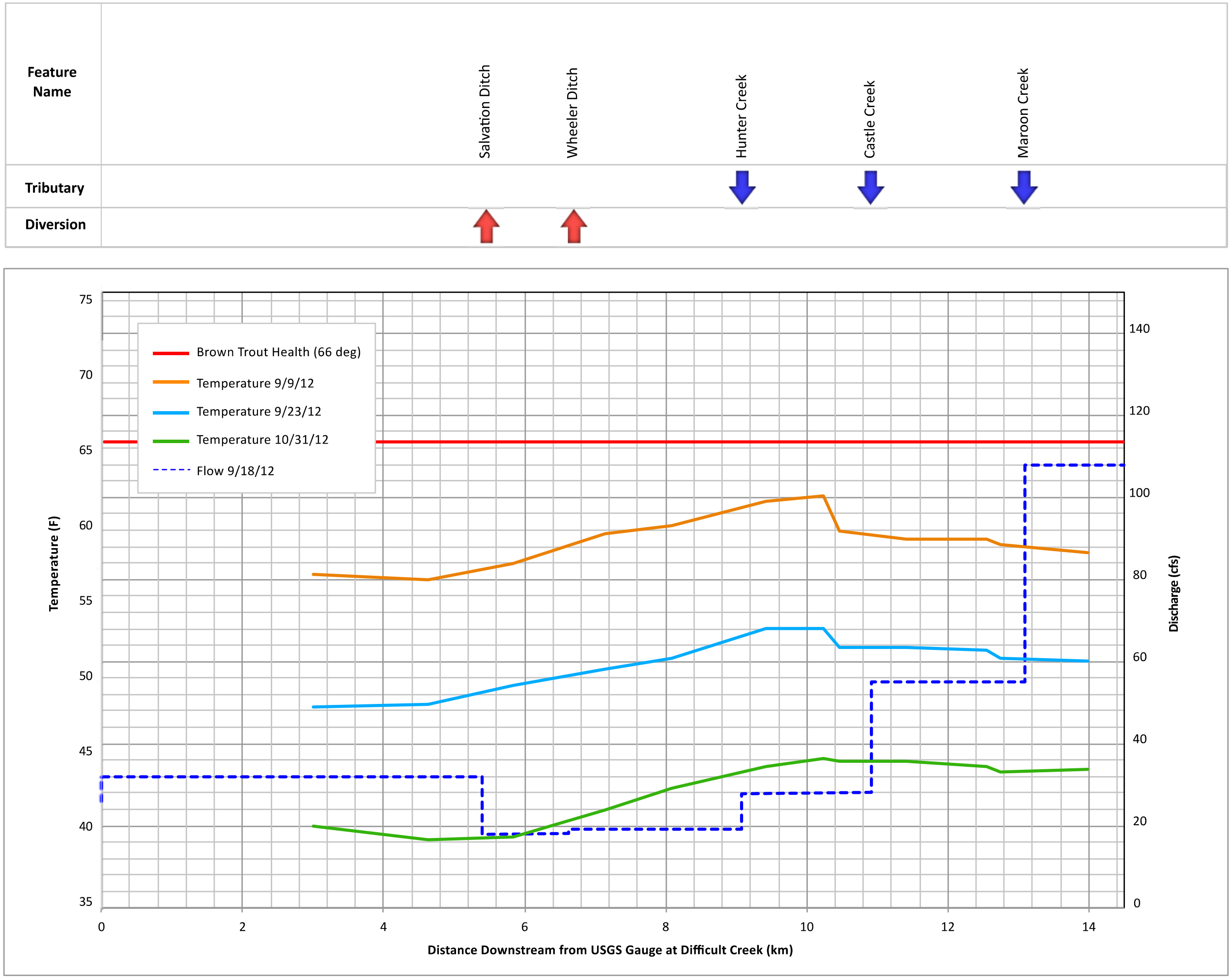


Figure 13. Observed temperatures on the Roaring Fork River near the City of Aspen. Low flow conditions coincide with relatively rapid heat gain.

Specific Conductance Profiles

Specific conductance, also commonly referred to as *conductivity*, is a measure of water's ability to conduct an electrical current. Conductance is a function of the concentration of ionized, or electrically charged, solids in water. Measuring conductance does not allow one to differentiate among sources or relative concentrations of these constituents, however it does serve as a useful proxy measurement for Total Dissolved Solids (TDS). Dissolved constituents may enter rivers from a multitude of sources, including: natural geological weathering, urban runoff from streets and yards, and agricultural runoff laden with nutrients and fertilizers. The spatial variability in TDS can yield important information to water quality monitoring efforts as it may relate to changes in land use or water management activities. High specific conductance is *not* an indicator by itself of poor water quality or pollution, and should not be interpreted as such. Rather, sharp changes in longitudinal specific conductance profiles may inform targeted investigations to determine the sources and relative quantities of constituents contributing to the overall observed pattern.

Water in the upper Roaring Fork River displayed relatively low specific conductance. Conductance increased with downstream distance as the river flowed through the City of Aspen (Figure 14). The observed increase may result from diffuse urban runoff, stormwater drains, and irrigation return flows. A sharp increase in conductance observed below the confluences with Castle Creek and Maroon Creek, suggests that these two tributaries carry relatively large TDS loads. The water quality characteristics of Maroon and Castle creeks produced disproportionately large impacts on the overall water quality characteristics of the Roaring Fork River because the streamflow contributions from the two creeks represented a large fraction of the total streamflow in the Roaring Fork below the City of Aspen. Elevated TDS concentrations in these tributary streams is likely related to natural geological weathering as both tributary watersheds are relatively undeveloped.

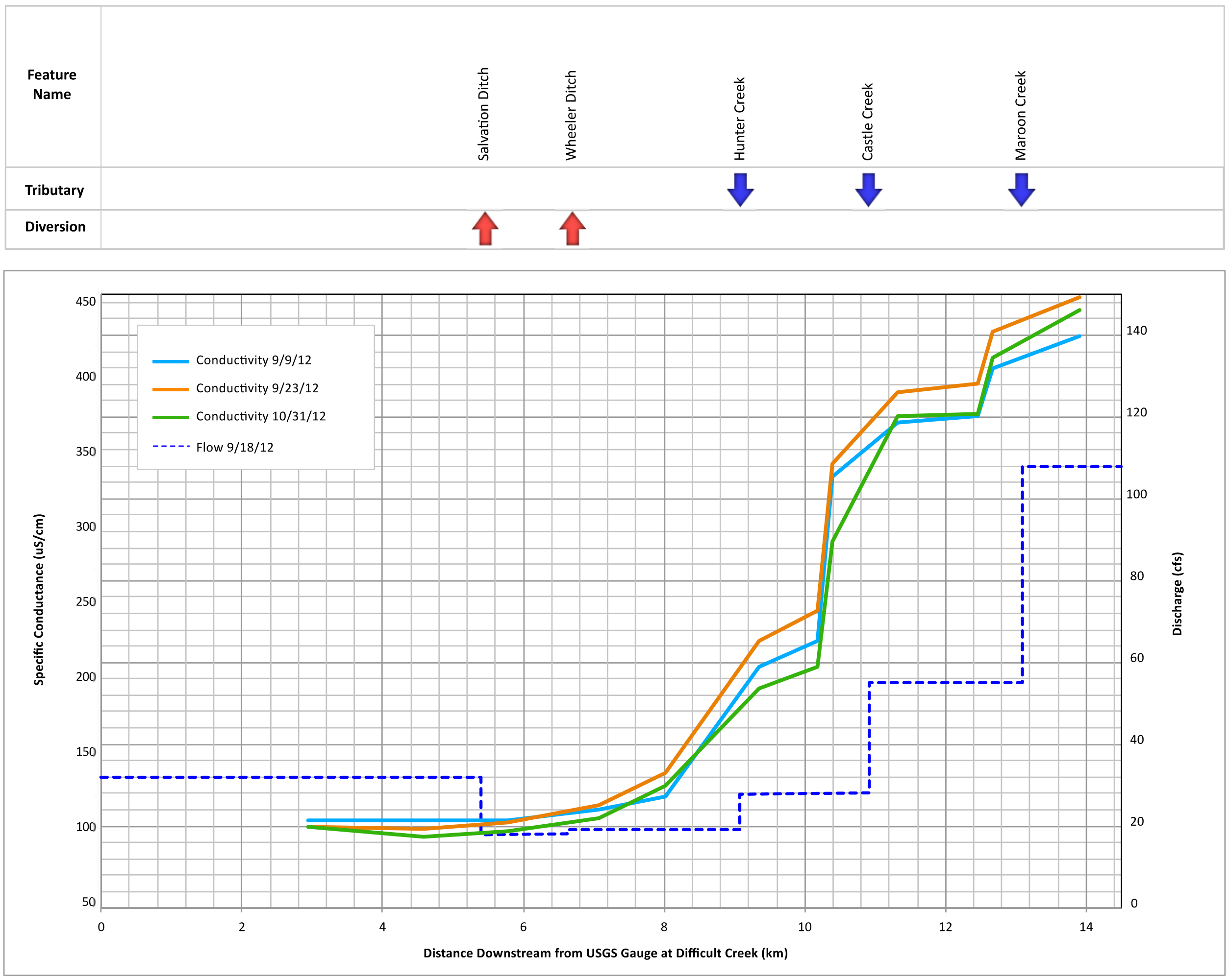


Figure 14. Observed specific conductance profiles on the Roaring Fork River.

Specific conductance remained relatively constant in the upper section of the Crystal River study reach, decreasing slowly through the most dewatered section on the reach (Figure 15). This pattern may be explained by the possibility that a large fraction of the streamflow in the Crystal River below Thompson Creek is contributed from tributaries or groundwater from the alluvial aquifer exhibiting relatively low specific conductance values. Conductance rose lower on the river where flows were likely affected by both groundwater influxes and irrigation diversion return flows. A seasonal trend was evident from early September to later in the fall. Specific conductance increased through September to its highest levels in late October. Specific conductance is generally inversely related to streamflow (e.g. dissolved solids are more concentrated when streamflow is low). As the amount of water diverted from the Crystal River decreased in October, streamflows in the river channel increased at each observation location. Surprisingly, specific conductance also increased—an unexpected trend. Without more observations to characterize inter-annual and inter-seasonal variability, it is difficult to make many conclusions regarding this pattern. However, an early snowstorm and subsequent runoff from snowmelt—which is expected to exhibit elevated conductance values—may have played an important role.

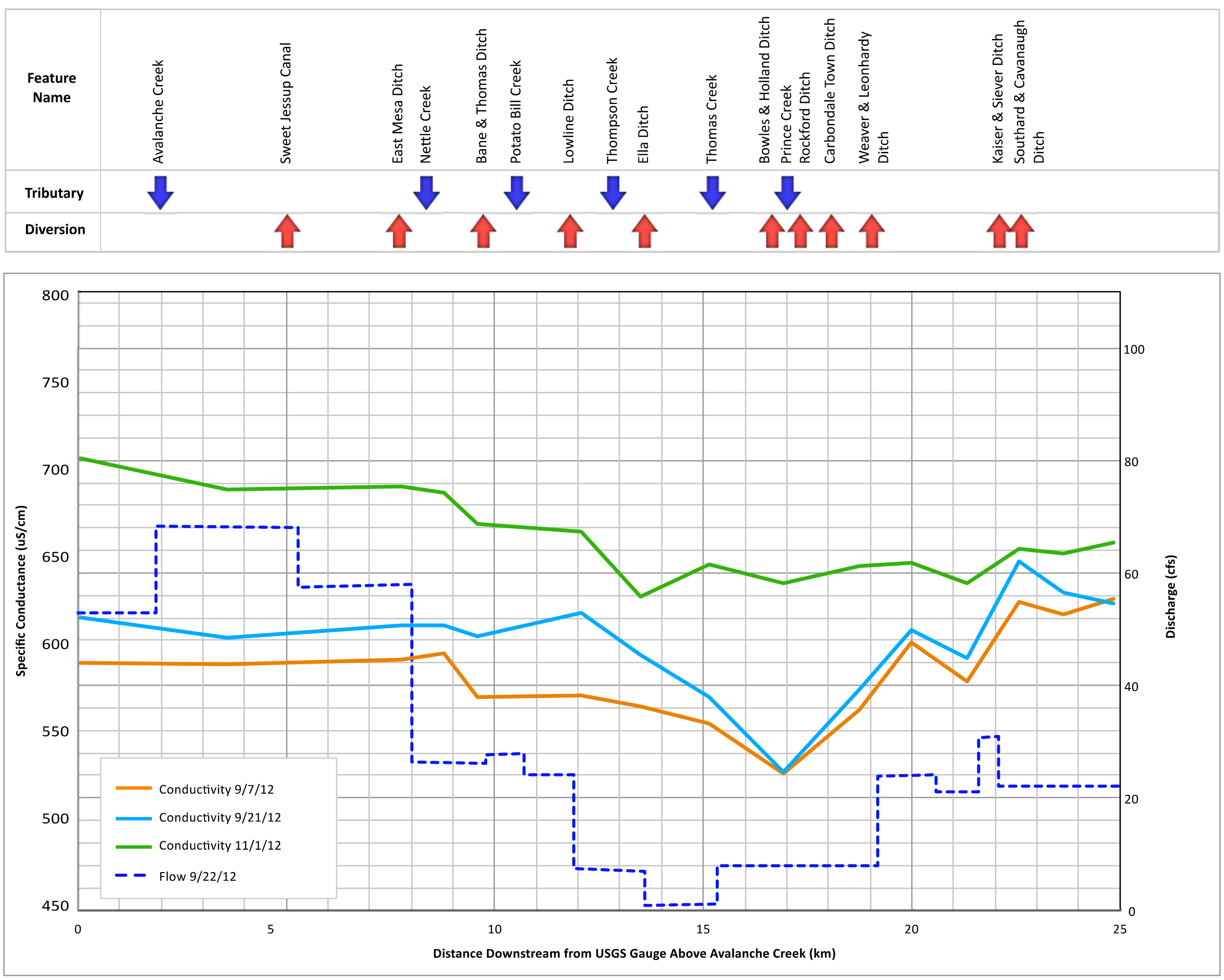


Figure 15. Observed specific conductance profile on the Crystal River.

Implications and Future Directions

This work provides a clearer picture of those sections of the Roaring Fork and Crystal Rivers particularly vulnerable to degradation of stream health from lack of streamflow and excessively warm water temperatures. The study aims to:

5. Help local and state resource managers better understand the relationship between the area's human and natural water systems;
6. Provide scientifically credible data to inform discussions with water right holders and the local communities designed to identify, discuss and, where appropriate, implement creative water conservation solutions;
7. Communicate to the public the status of river health and integrity in the Roaring Fork and Crystal watersheds as it relates to streamflow depletion and ISF rights; and
8. Identify 'pinch' points of low flow in the river most likely to impair longitudinal hydrological and ecological connectivity.

The Roaring Fork River near the City of Aspen and the Lower Crystal River are understood to be particularly vulnerable to streamflow depletion. The most flow-depleted segment of the Roaring Fork River in the fall of 2012 was found between the Salvation and Wheeler ditches and the confluence with Castle Creek. The patterns in longitudinal streamflow observed during the study presented here may are probably typical during any dry year when upstream diversion rights are exercised upstream. However, no regular streamflow monitoring exists on this segment to accurately document the frequency or magnitude of this occurrence or effectively administer the CWCB ISF right on this section of river. The segment of the lower Crystal River between the Ella and Carbondale/Rockford ditches encompasses the most flow-depleted section of this river. Near complete dewatering of the stream channel was observed through much of September at Thomas Road and near the Garfield/Pitkin County line. This section is likely vulnerable to similar low streamflow conditions in most dry years. The nearest streamflow monitoring site able to document these events is located several miles downstream at the CDPW Fish Hatchery. This streamflow gauge does not fully capture the severity of flow depletion on the Crystal River because it is located below several irrigation return flows, which increase streamflow in the river channel. As determined in this assessment, more flow-impaired reaches exist upstream of this location. These could provide more ideal locations for a stream gauge site intended to monitor low-flow conditions and corresponding water quality characteristics.

Dewatered rivers can negatively impact aquatic communities like trout fisheries (an important economic driver of the area's tourism industry) and recreational amenities that support the exceptional quality-of-life valued by local residents. A recent study published by the Northwestern Colorado Council of Governments titled *Water and Economies of Headwaters Counties* (Coley and Forrest, Inc., 2012) credited boating-based activities with $1.1 million in total economic impacts in Pitkin County alone. According to this report, seven Colorado River Watershed headwaters counties (including Pitkin County) generate a combined $180 million each year from fishing-related activities. This study also recognized proximity to healthy natural settings and wildlife as an important and extremely valuable but un-quantified (in economic terms) characteristic of the region. Local communities receive numerous goods and services from functioning natural systems including clean drinking water, increased natural storage and flood attenuation provided by intact floodplains and riparian zones, and viable wildlife communities upon which industries like fishing and recreation depend. Thus changes in the functional characteristics of local streams and rivers may portend shifts in the quality-of-life enjoyed by local residents and in the economic foundations supporting many local communities.

Dewatered section of the Crystal River above the Town of Carbondale. Without much flow, these segments experienced rapid heat gain during late summer and fall days.

The importance of instream flows to local economies and biological communities is increasingly recognized. The Roaring Fork Conservancy, with support from Pitkin County, recently published a study of water conservation options intended to enhance instream flows (Driscoll, 2012). The Colorado Water Trust launched an intensive effort to utilize short term leasing for water rights in 2012, a power authorized by the state legislature in response to a severe drought in 2002. To date, no leases in either the Crystal or Upper Roaring Fork have been utilized, but potential exists for this policy instrument to aid streamflows. Pitkin County recently engaged the use of creative and innovative policy instruments to increase instream flows in the Roaring Fork River by entering into a trust agreement to utilize water from the Stapleton Brothers Ditch for instream flows on lower Maroon Creek and the Roaring Fork. More agreements like these may be beneficial in the future to bolster flows on other stream reaches in the Roaring Fork Watershed. The data and analysis provided in this report can support future efforts to identify, evaluate, and execute action plans targeting water conservation improvements.

It is unclear to what extent low streamflow issues in the Crystal River and Roaring Fork River can be solved. Leasing programs show promise to benefit instream flows, but can add yet another layer of complexity to an already-complicated framework for resource management. Additionally, climate change brings uncertain impacts to precipitation and long-term basin yields in Colorado and the southern Rockies. Colorado's Climate Action Plan (Ritter, 2007) identified earlier thaw and snowmelt, and lower late summer and fall stream flows, as likely effects on the State's watersheds. In short: Colorado may experience many more years exhibiting low flow conditions like those observed in 2002 and 2012. It is hoped that information from this assessment helps to empower intelligent decision-making regarding the area's water resources. If the cultural, economic, and environmental values surrounding these river systems are worthy of preserving, these pressing water issues should be proactively addressed.

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Appendix A:

Data Summary

The following tables summarize the streamflow, temperature, and specific conductance measurements collected on the Roaring Fork and Crystal Rivers during this study. Streamflow (Q) measurements were made using a Sontek FlowTracker® according to the USGS methods described by Turnipseed and Sauer (2010). Temperature and specific conductance measurements were made using a handheld Extech II © digital multimeter placed in the thalweg until readings stabilized.

Table 1. Roaring Fork study reach, streamflow data summary

Site Description	Pilot Study			Run 1			Run 2			Run 3		
	Date	Time	Q (cfs)	Date	Time	Q (cfs)	Date	Time	Q (cfs)	Date	Time	Q (cfs)
Above Difficult Creek	7/25	8:00	11	9/5	12:00	24	9/18	12:00	26	10/16	12:00	29
Above Salvation Ditch	7/25	8:00	25	9/5	12:00	31	9/18	12:00	32	10/16	12:00	38
At Aspen Club	7/25	9:00	7.6	9/5	16:00	24	9/18	15:30	18	10/16	15:45	34
At Mill Street Bridge	7/27	6:15	4.7	9/6	12:15	17	9/18	13:30	19	10/16	14:30	26
At Aspen Institute	7/25	13:45	18	9/6	10:30	21	9/18	11:30	28	10/16	13:00	44
At Stein Park	7/25	15:15	71	9/5	18:30	60	9/18	9:00	55	10/16	11:30	90
At CoA WWTP	7/25	8:00	147	9/5	12:00	112	9/18	10:00	108	10/16	12:00	134

Table 2. Crystal River study reach, streamflow data summary

Site Description	Run 1			Run 2			Run 3		
	Date	Time	Q (cfs)	Date	Time	Q (cfs)	Date	Time	Q (cfs)
Above Avalanche Creek	9/4	12:00	63	9/22	12:00	53	10/20	12:00	53
Above Sweet Jessup Canal	9/4	17:00	77	9/22	7:00	68	10/20	8:30	66
At Red Wind Point Open Space	9/4	15:00	59	9/22	8:30	58	10/20	9:45	61
Above Nettle Creek Road	9/5	8:30	29	9/22	10:00	26	10/20	10:30	38
Below Bane & Thomas Ditch	9/5	10:00	29	9/22	12:45	28	10/20	11:15	32
Above Lowline Ditch	9/4	13:00	31	9/22	14:00	24	10/20	12:30	32
At Pitkin Co. open space	9/4	11:00	24	9/22	15:15	7	10/20	1:45	30
At Thomas Road	9/4	9:30	4	9/22	17:00	1	10/20	2:00	28
Above County Line	9/4	8:00	12	9/23	7:30	8	10/20	3:15	33
At Fish Hatchery	9/3	12:00	14	9/23	12:00	8	10/21	12:00	42
At South Bridge in RVR	9/3	19:30	33	9/23	10:30	24	10/20	4:30	62
At North Bridge in RVR	9/3	17:30	36	9/23	9:00	21	10/20	5:45	69
Above Kaiser-Sievers Ditch	9/3	15:00	44	9/23	12:00	31	10/21	8:00	70
At CRMS Bridge	9/3	13:30	28	9/23	13:00	22	10/21	9:15	56

Table 3. Temperature data summary

Afternoon Stream Temperatures, (^oF)							
Roaring Fork	**9/9**	**9/23**	**10/31**	**Crystal**	**9/7**	**9/21**	**11/1**
North Star, Upper	56	47	39	USGS Gauge above Avalanche Creek	62	53	41
North Star, Stillwater	56	48	38	USFS Boundary above Sweet Jessup Canal	63	53	42
Aspen Club	57	49	39	Red Wind Point Open Space	62	54	42
Neale Ave	59	50	41	Above Nettle Creek Road	63	55	43
Mill Street	60	51	42	Below Bane & Thomas Ditch	63	56	43
Aspen Institute	61	53	44	Above Lowline Ditch	65	58	44
Above Castle Creek	62	53	44	Thompson Creek Open Space	67	62	45
Below Castle Creek	59	51	44	Thomas Road	71	66	46
Cemetery Lane	59	51	44	Pitkin-Garfield County Line	67	63	47
Above Maroon Creek	59	51	44	DWR Gauge Fish Hatcher	65	62	48
Below Maroon Creek	58	51	43	RVR South Bridge	63	62	49
Airport Business Park	58	51	43	RVR North Bridge	67	65	51
				Kaiser & Sievers Ditch	68	65	50
				CRMS Bridge	69	66	50
				Confluence w/ Roaring Fork	68	66	51

Table 4. Specific conductance data summary

Specific Specific conductance (µS/cm)							
Roaring Fork	**9/9**	**9/23**	**10/31**	**Crystal**	**9/9**	**9/21**	**11/1**
North Star, Upper	96	92	90.7	USGS Gauge above Avalanche Creek	582	607	696
North Star, Stillwater	96	90	84.8	USFS Boundary above Sweet Jessup Canal	581	596	679
Aspen Club	96	95	88	Red Wind Point Open Space	584	603	681
Neale Ave	104	106	96.7	Above Nettle Creek Road	587	603	677
Mill Street	111	127	119	Below Bane & Thomas Ditch	563	597	660
Aspen Institute	198	215	184	Above Lowline Ditch	564	610	655
Above Castle Creek	215	236	199	Thompson Creek Open Space	558	587	619
Below Castle Creek	325	333	282	Thomas Road	548	563	637
Cemetery Lane	361	382	366	Pitkin-Garfield County Line	520	521	627
Above Maroon Creek	366	387	367	DWR Gauge Fish Hatcher	556	567	636
Below Maroon Creek	397	422	405	RVR South Bridge	593	600	638
Airport Business Park	419	445	436	RVR North Bridge	572	585	627
				Kaiser & Sievers Ditch	616	639	646
				CRMS Bridge	609	621	643
				Confluence w/ Roaring Fork	618	615	649

Appendix B:

Crystal River Diversion Structure Photos

The following includes photographs of the major diversion structures in the study area on the Crystal River, including GPS location information gathered from the CDWR online web portal (http://water.state.co.us/DataMaps). The decreed right is provided from CDWR and should be understood as the maximum amount of water apportioned; it does not infer that the full right is being diverted at any given time throughout the year. The amount of water diverted into a ditch can change constantly with a variety of factors. A few of these include: current usage needs, time of year, available stream water, and senior/junior status within the prior appropriations system.

Diversion structure information here is ordered parallel to the study reach, starting with the most-upstream structure and proceeding in a downstream direction towards the Roaring Fork.

Structure: Sweet Jessup Canal
Decreed Rate: 75 cfs
GPS: UTM 308048 4349399
Water Right Owner: Sue Rodgers

Structure: East Mesa Ditch
Decreed Rate: 41.8 cfs
GPS: UTM 308941 4351737
Water Right Owner: Thomas H. Harvey

Structure: Bane & Thomas Ditch
Decreed Rate: 6 cfs
GPS: UTM 309337 4353356
Water Right Owner: Mike DotzenRod

Structure: Lowline Ditch
Decreed Rate: 40.5 cfs
GPS: UTM 309583 4355324
Water Right Owner: Not listed

Structure: Ella Ditch
Decreed Rate: 15.1 cfs
GPS: UTM 309728 4356811
Water Right Owner: Ella Ditch Company (John Nieslanik)

Structure: Helms Ditch
Decreed Rate: 6 cfs
GPS: UTM 309672 4356859
Water Right Owner: Bill Fales

Structure: Bowles and Holland Ditch
Decreed Rate: 23.8 cfs
GPS: UTM 310232 4359837
Water Right Owner: Crystal River-Holland & Hart

Structure: Rockford Ditch
Decreed Rate: 35.2 cfs
GPS: UTM 310284 4360032
Water Right Owner: Mark Neislanik & DOW

Structure: Carbondale Ditch
Decreed Rate: 41.24 cfs
GPS: UTM 310343 4360715
Water Right Owner: Town of Carbondale

Structure: Weaver and Leonhardy Ditch
Decreed Rate: 12.36 cfs
GPS: UTM 309943 4361819
Water Right Owner: Not listed

Structure: Kaiser and Sievers Ditch
Decreed Rate: 27.126 cfs
GPS: UTM 208036 4363597
Water Right Owner: Aspen Glen Corporation

Structure: Southard and Cavanaugh Ditch
Decreed Rate: 18.08 cfs
GPS: UTM 308043.8 4364010
Water Right Owner: Aspen Glen Corporation

Appendix B:

Roaring Fork River Diversion Structure Photos

The following includes photographs of the major diversion structures in the study area on the Roaring Fork River, including GPS location information gathered from the CDWR online web portal (http://water.state.co.us/DataMaps). The decreed right is provided from CDWR and should be understood as the maximum amount of water apportioned; it does not infer that the full right is being diverted at any given time throughout the year. The amount of water diverted into a ditch can change constantly with a variety of factors. A few of these include: current usage needs, time of year, available stream water, and senior/junior status within the prior appropriations system.

Diversion structure information here is ordered parallel to the study reach, starting with the most-upstream structure and proceeding in a downstream direction towards the Airport Business Park.

Structure: Salvation Ditch
Decreed Rate: 59 cfs
GPS: UTM 344305 4338366
Water Right Owner: Not listed by CDWR

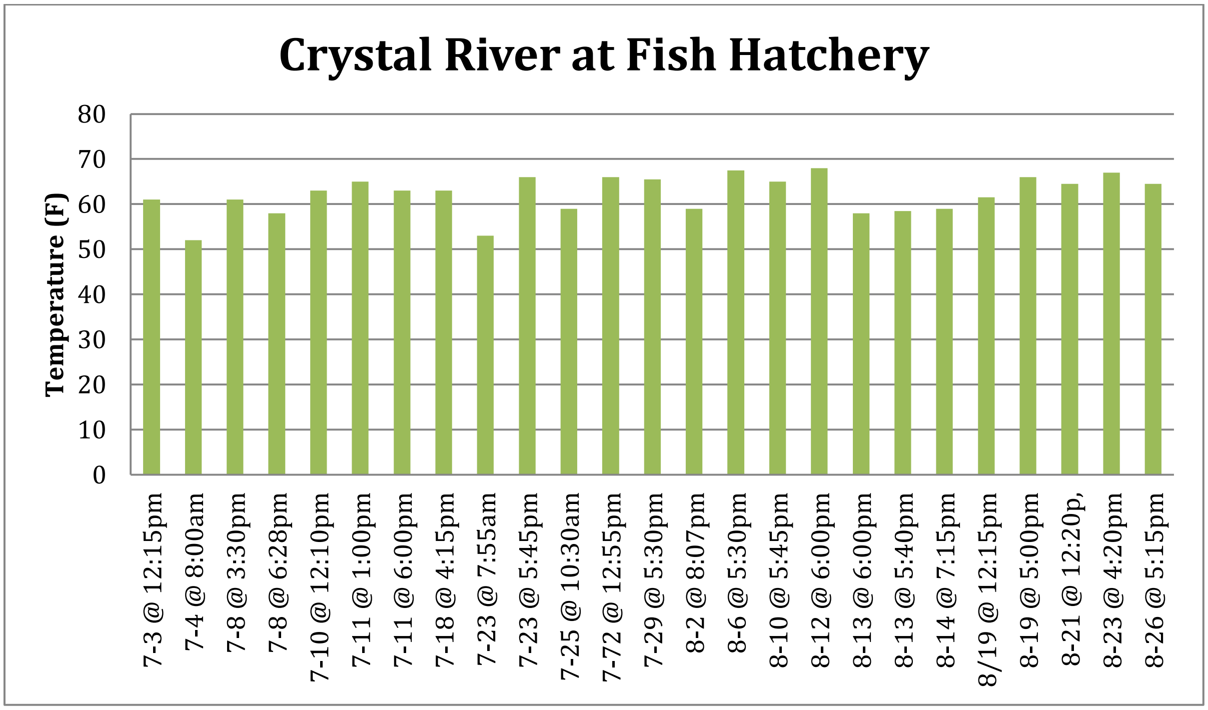
Structure: Nellie Bird Ditch
Decreed Rate: 4.64 cfs
GPS: UTM 344294 4338360
Water Right Owner: Stillwater HOA

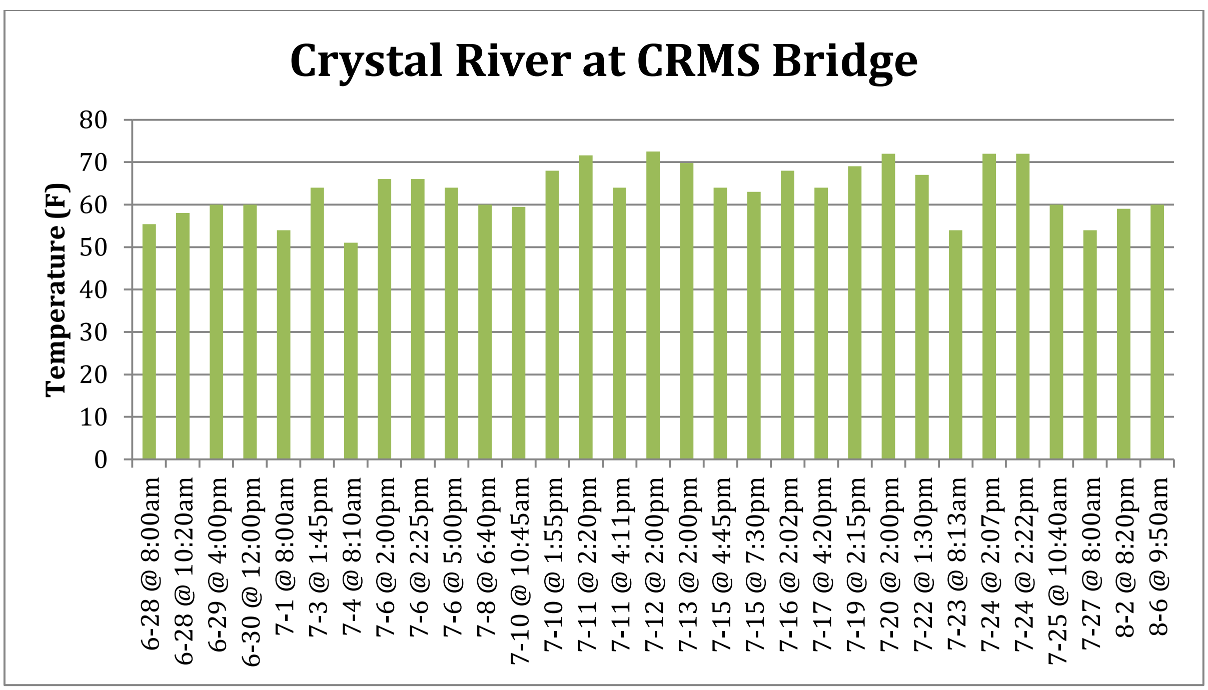
Structure: Wheeler Ditch
Decreed Rate: 10 cfs
GPS: UTM 343532 4338610
Water Right Owner: Town of Aspen

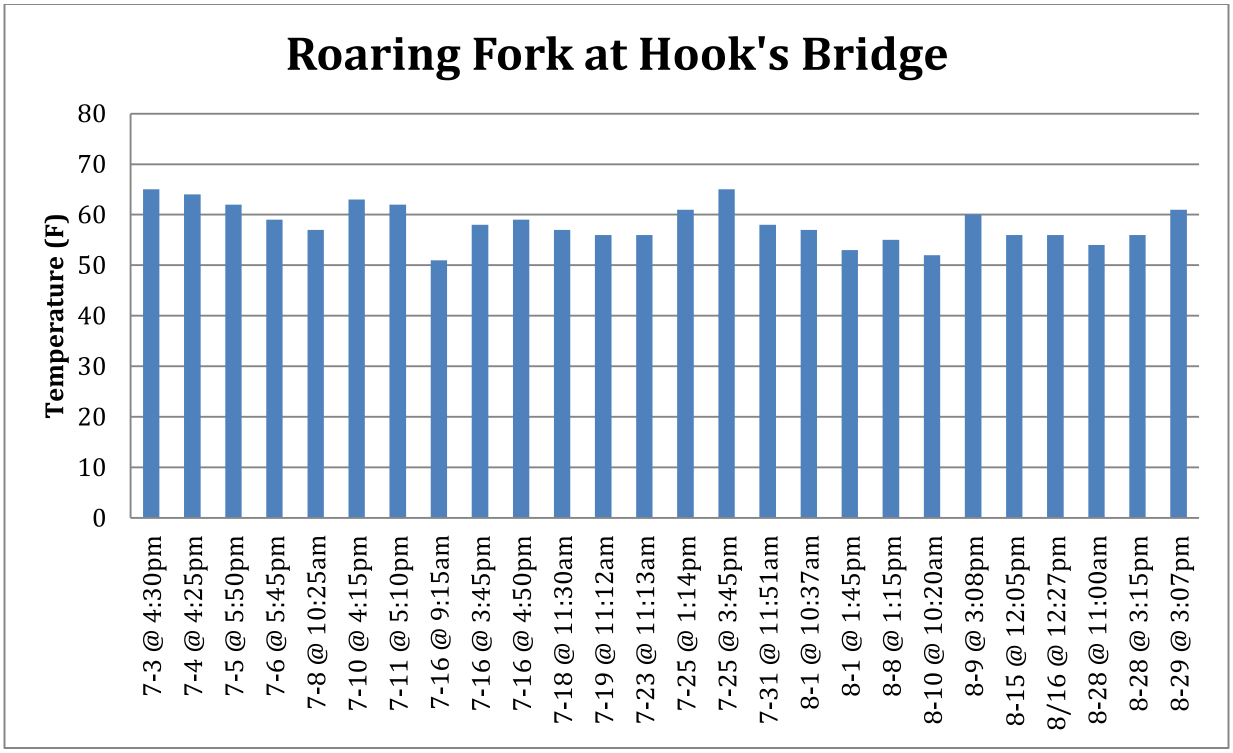
Appendix D:

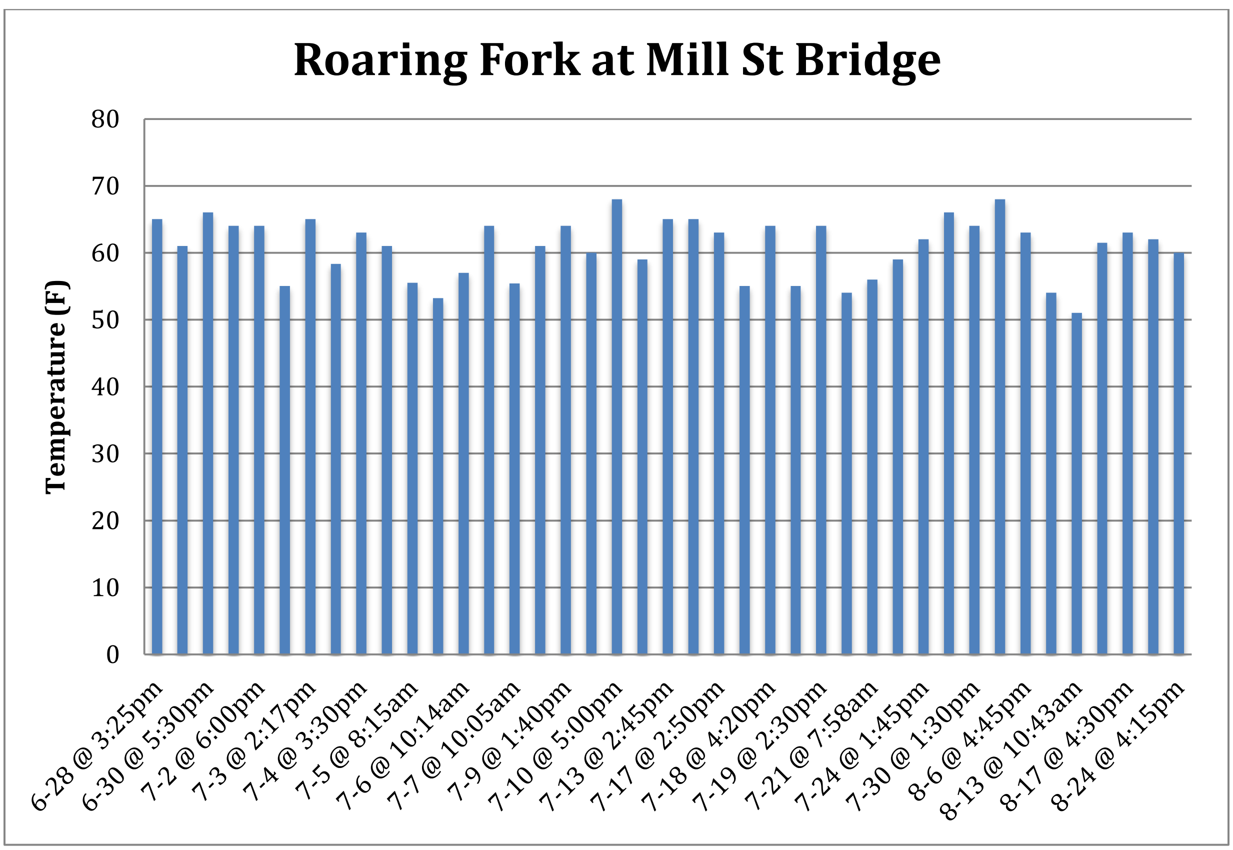
Roaring Fork Conservancy's *Hot Spots for Trout* Data

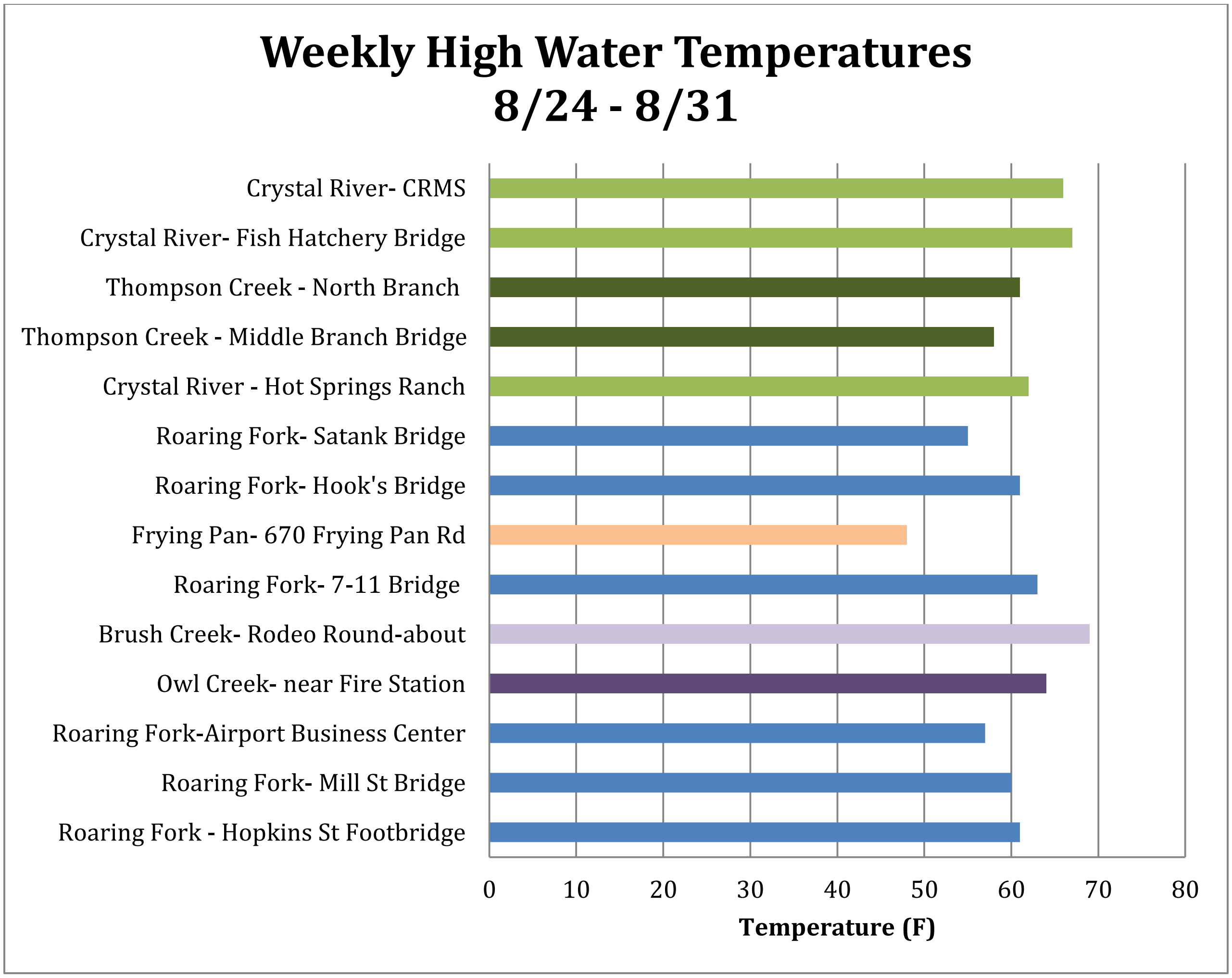
Figures provided by the Roaring Fork Conservancy. For more information see:
http://roaringfork.org






Roaring Fork at Hook's Bridge
Temperature (F)
80
70
60
50
40
30
20
10
0
7-3 @ 4:30pm
7-4 @ 4:25pm
7-5 @ 5:50pm
7-6 @ 5:45pm
7-8 @ 10:25am
7-10 @ 4:15pm
7-11 @ 5:10pm
7-16 @ 9:15am
7-16 @ 3:45pm
7-16 @ 4:50pm
7-18 @ 11:30am
7-19 @ 11:12am
7-23 @ 11:13am
7-25 @ 1:14pm
7-25 @ 3:45pm
7-31 @ 11:51am
8-1 @ 10:37am
8-1 @ 1:45pm
8-8 @ 1:15pm
8-10 @ 10:20am
8-9 @ 3:08pm
8-15 @ 12:05pm
8/16 @ 12:27pm
8-28 @ 11:00am
8-28 @ 3:15pm
8-29 @ 3:07pm


Roaring Fork at Mill St Bridge
Temperature (F)
80
70
60
50
40
30
20
10
0
6-28 @ 3:25pm
6-30 @ 5:30pm
7-2 @ 6:00pm
7-3 @ 2:17pm
7-4 @ 3:30pm
7-5 @ 8:15am
7-6 @ 10:14am
7-7 @ 10:05am
7-9 @ 1:40pm
7-10 @ 5:00pm
7-13 @ 2:45pm
7-17 @ 2:50pm
7-18 @ 4:20pm
7-19 @ 2:30pm
7-21 @ 7:58am
7-24 @ 1:45pm
7-30 @ 1:30pm
8-6 @ 4:45pm
8-13 @ 10:43am
8-17 @ 4:30pm
8-24 @ 4:15pm


Weekly High Water Temperatures
8/24 - 8/31
Crystal River- CRMS
Crystal River- Fish Hatchery Bridge
Thompson Creek - North Branch
Thompson Creek - Middle Branch Bridge
Crystal River - Hot Springs Ranch
Roaring Fork- Satank Bridge
Roaring Fork- Hook's Bridge
Frying Pan- 670 Frying Pan Rd
Roaring Fork- 7-11 Bridge
Brush Creek- Rodeo Round-about
Owl Creek- near Fire Station
Roaring Fork-Airport Business Center
Roaring Fork- Mill St Bridge
Roaring Fork - Hopkins St Footbridge
0
10
20
30
40
50
60
70
80
Temperature (F)