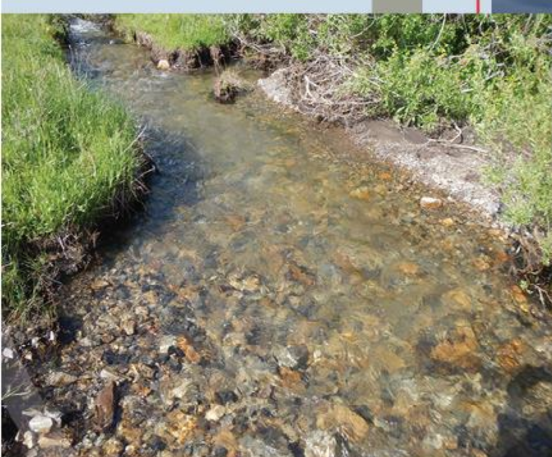
Consulting Engineers and Scientists

Substrate and Algae Assessment in the Colorado River and Fraser River Basins 2021

April 2022



Sediment and Algae Assessment in the Colorado River and Fraser River Basins 2021

GEI Consultants

Consulting Engineers and Scientists

Submitted to:
Grand County Learning By Doing
308 Byers Avenue
PO Box 264
Hot Sulphur Springs, CO 80451

Submitted by:
GEI Consultants, Inc.
4601 DTC Blvd., Ste. 900
Denver, CO 80237

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04/18/2022
Ashley Ficke, Project Manager

04/18/2022
Jeniffer Lynch, Reviewer

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1. Introduction

At the request of Grand County's Learning By Doing (LBD), GEI Consultants, Inc. (GEI) conducted assessments of the substrate and algae at multiple sampling locations in the Colorado River and Fraser River basins in Grand County in the fall of 2021. A total of seventeen sites were sampled from October 11, 2021, through October 15, 2021, with eight sites located on the Colorado River, seven sites located on the Fraser River, and two sites located on Ranch Creek. Portions of one site on the Colorado River and one site on Ranch Creek were assessed visually due to safety/wadability issues. Sites sampled by GEI for substrate and algae characteristics were previously established by LBD at various locations throughout their Cooperative Effort Area (CEA).

At fourteen of the seventeen sites, GEI performed pebble counts and measured percent fines, percent embeddedness, and algal cover. Riffle stability index was measured at nine of the seventeen sites and at five sites sediment and suspended sediment was collected with a McNeil sampler. The data collected at each site location may be used to assess potential sediment transport issues in the basin and to address questions related to biological integrity such as the Sediment Tolerance Indicator Value (TIV_{SED}) for macroinvertebrates and suitability of salmonid spawning habitat.

2. Cooperative Effort Area

All sites sampled were located within LBD's CEA in Grand County (Figure 2–1; Table 2–1). The sampling area includes eight sites on the Colorado River that extend from the town of Granby, CO to the town of Kremmling, CO. The seven sites on the Fraser River extend from the town of Winter Park, CO to upstream of the town of Granby, CO. The two sites established on Ranch Creek are located in the town of Tabernash, CO, upstream from the confluence with the Fraser River (Figure 2–1).

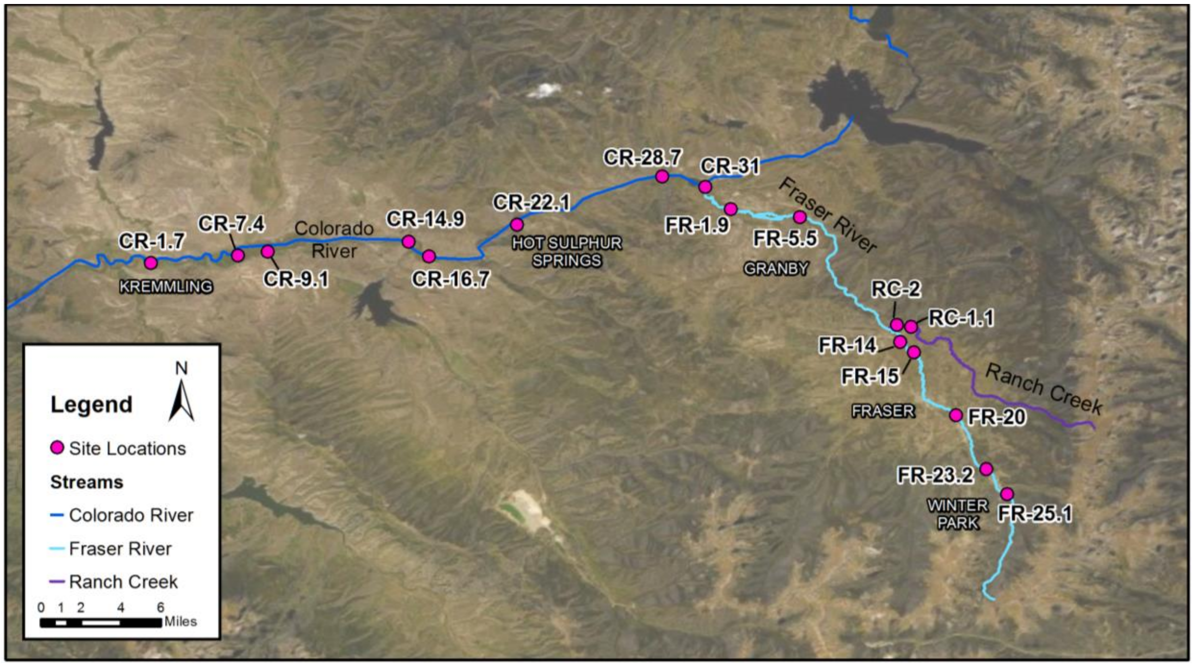


Figure 2-1: All sites on the Colorado River, Fraser River, and Ranch Creek sampled in 2021.

Table 2-1: Names and locations for all 17 sites sampled in 2021.

Site Name	Station Description	Latitude	Longitude
CR-1.7	Colorado River upstream of Blue River	40.044	-106.374
CR-7.4	Colorado River downstream of Troublesome Creek	40.051	-106.311
CR-9.1	Colorado River at CR39 Bridge at KB Ditch	40.054	-106.289
CR-14.9	Colorado River downstream of Williams Fork	40.063	-106.183
CR-16.7	Colorado River upstream of Williams Fork	40.050	-106.173
CR-22.9	Colorado River at Hot Sulphur Springs	40.080	-106.099
CR-28.7	Colorado River just downstream of Windy Gap	40.108	-106.004
CR-31	Colorado River upstream of Fraser and Windy Gap	40.101	-105.973
FR-1.9	Fraser River upstream of Granby Sanitation District	40.085	-105.954
FR-5.5	Fraser River at Granby Ranch	40.079	-105.916
FR-14	Fraser River upstream of Tabernash	39.992	-105.830

Table 2-1 (cont.):

Site Name	Station Description	Latitude	Longitude
FR-15	Fraser River upstream of Fraser Flats restoration	39.983	-105.826
FR-20	Fraser River at Rendezvous Bridge	39.935	-105.791
FR-23.4	Fraser River upstream of Winter Park Sanitation	39.896	-105.769
FR-25.1	Fraser River upstream of UP Moffat Tunnel discharge	39.878	-105.754
RC-1.1	Ranch Creek downstream of Meadow Creek	39.999	-105.828
RC-2	Ranch Creek downstream of Meadow Creek and USFS Road 129.	39.999	-105.8301

3. Methods

3.1 Pebble Counts and Embeddedness

At the fourteen sites where pebble counts were performed, the Modified Wolman Pebble Count Method outlined by Colorado Water Quality Control Division (WQCD) Policy 98-1 (Colorado Department of Public Health and Environment [CDPHE] 2014) was utilized. Ten evenly spaced transects were established along a length of stream approximately twenty times the average bankfull width. At each of these ten transects, a 60 by 60-centimeter (cm) sampling frame was used to designate four substrate particles for measurement at ten evenly spaced points across the transect (Photos 3-1 and 3-2). This accounted for a total of 40 substrate particle measurements per transect, and a total of 400 measurements per sampling location. The 60 by 60 cm sampling frame consisted of 4 aluminum bars connected to form a square, with an inside width of 60 cm, and 4 elastic bands placed forming four cross sections with a width of 50 cm. The intermediate axis of each particle designated by the elastic band cross sections on the sampling frame was measured using a gravelometer or ruler (if the particle was too large to fit through the apertures in the gravelometer). Ocular estimates were used for substrate particles that could not be removed from the bed (i.e., due to size). The measured particles were analyzed to determine the D_{50} and the D_{84} of the sample. The notation D represents the particle size in millimeters (mm), and the subscript denotes the percentile; the D_{50} and D_{84} are the diameters (in mm) that are larger than 50% and 84% of the particles in the sample, respectively. The percentage of fine substrate (i.e., < 8 mm) was also calculated to determine the availability of clean substrate and interstitial spaces (i.e., the spaces between gravel and cobble particles used by macroinvertebrates and juvenile fishes).

Photo 3-1: Substrate being measured with a gravelometer at Site CR-16.7 on the Colorado River.

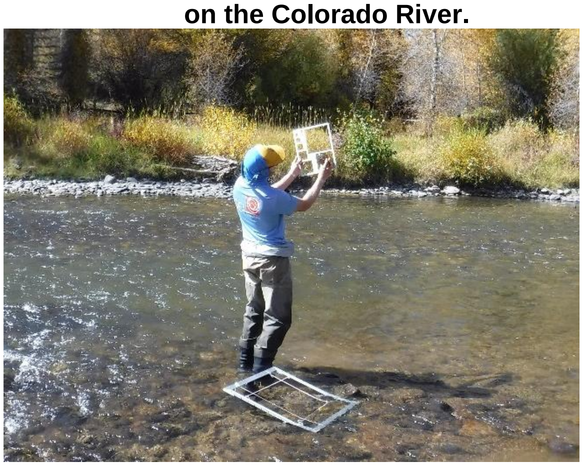
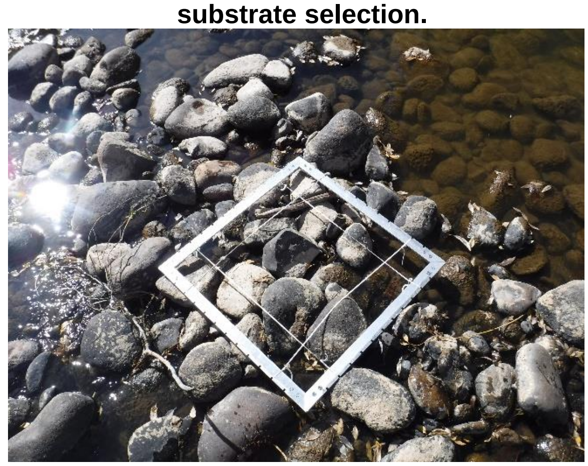


Photo 3-2: Sampling frame with four cross sections for randomized substrate selection.



A subset of the particles measured at each of the transects at each sitewere used to determine percent embeddedness, or the extent to which larger particles are surrounded by or buried in fine substrate. Four or five large gravel or cobble-sized particles at each transect were measured for percent embeddedness, for a total of 45 to 50 embeddedness measurements per sampling location[1]. Embeddedness percentages were determined by measuring the height that each representative particle was buried and dividing by the total particle height. This method allowed for a quantitative estimate of the total percent embeddedness at each site.

3.2 Riffle Stability Index

The Riffle Stability Index (RSI) was determined at nine sites using the methods outlined by Kappesser (2002). The RSI value indicates the percentage of mobile bed material in the riffle. A point bar, lateral bar, or similar depositional feature at each site was identified in close proximity to a riffle. A transect was established in a riffle across its bankfull width, and 200 substrate particles were selected. In smaller streams with insufficient width to allow selection of 200 particles, a second transect was established. The intermediate axis of each particle was measured. On the depositional feature, the intermediate axis of 10 to 30 of the largest recently deposited particles were measured, and the geometric mean of these particles was calculated. The geometric mean was then compared to the cumulative distribution of particle sizes from the 200-pebble count in the riffle. This determined the percentage of particles in the riffle that were smaller than the representative large mobile particles in the depositional feature at each site. The mobile fraction on the riffle can be estimated by comparing the relative abundance of various particle sizes present on the riffle with the dominant large particles on an adjacent bar (Kappesser 2002). A point bar, or the accumulation of gravel, cobble, and sand on the inside of a meander bend is a typical depositional feature in the CEA; depositional features at two sampling sites on the Fraser River are shown in Photos 3-3 and 3-4.

Photo 3-3: An example of a depositional point bar, from Site FR-20 on the Fraser River.

Photo 3-4: An example of a lateral depositional bar, from Site CR-31 on the Colorado River.

[1] The exceptions were sites CR-1.7 and RC-1.1; data could not be collected at ten transects because portions of both sites were not wadeable.

3.3 Algae Presence, Percent Cover, and Thickness

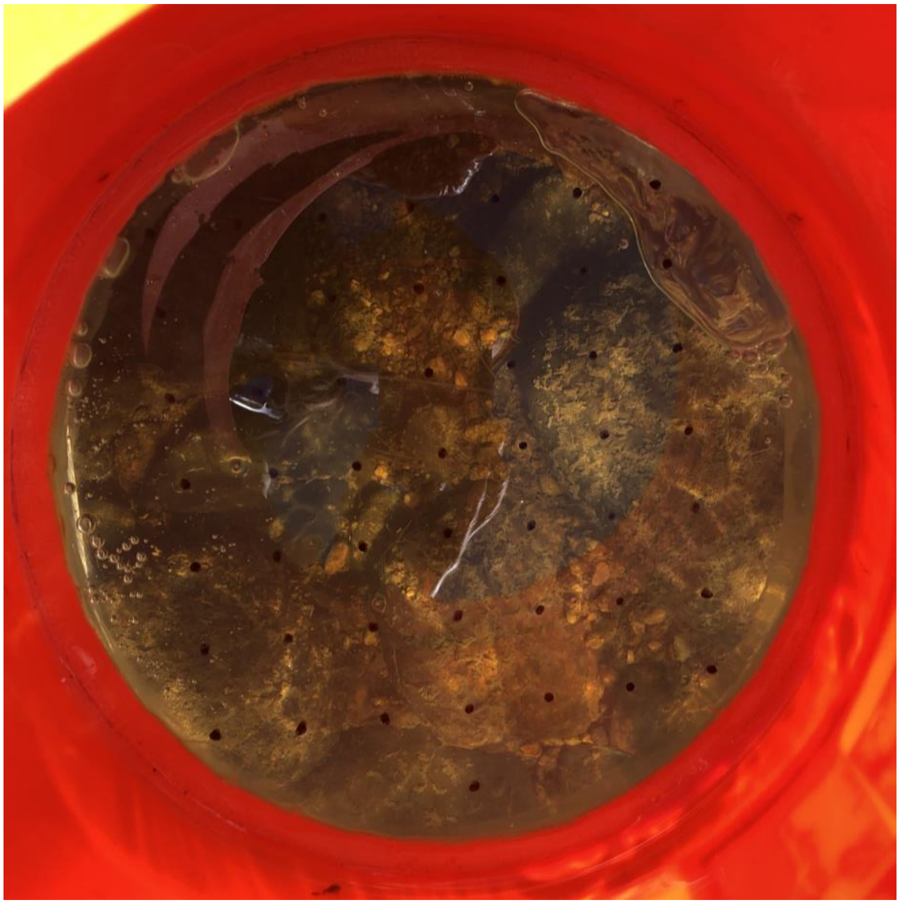
Algae presence (filamentous algae and diatoms), the percent filamentous algae cover, and diatom thickness data were recorded using a combined method that included protocols taken from the WQCD Standard Operating Procedures for the Collection of Stream Periphyton Samples (CDPHE, no year) combined with the grid-based pebble count method. Along each transect established for pebble counts, the presence of filamentous algae, the presence of diatoms, the percent filamentous algae cover, and diatom thickness were measured or visually estimated.

The algal communities were observed at three distances per transect: 25%, 50%, and 75% from the streambank, for a total of 30 points evaluated at each site. The algae viewing bucket consisted of a 5-gallon bucket with its bottom replaced with transparent plexiglass with 50 evenly spaced points marked with permanent marker (Photo 3–5). At each of the three transect positions, the presence of filamentous algae and/or diatoms was recorded. Filamentous algae was defined as algae that was green in color and formed strands or filaments. Diatoms are microscopic algae and tend not to form tall-growing colonies, with one exception. *Didymosphenia geminata* (Didymo) sometimes forms dense, brown or gray blooms that can cover much of the stream substrate. Low-growing algae and the readily identifiable Didymo were considered diatoms. For filamentous algae cover data, the viewing bucket was used twice at each of the three points along each transect. The total number of points where filamentous algae was growing was divided by 100 to calculate the percent filamentous algae cover at each of the three distances per transect (see Appendix D for example photos of algal coverage). At each of the three distances the thickness of diatom growth was visually estimated in millimeters (mm) and categorized in accordance with Stevenson and Bahls 1999 (Table 3–1).

Table 3-1: Diatom thickness categories as defined by Stevenson and Bahls 1999.

Category	Categorical Description
0	Substrate rough with no visual evidence of microalgae
0.5	Substrate slimy, but no visual accumulation of microalgae evident
1	A thin layer of microalgae is visually evident
2	Accumulation of microalgal layer from 0.5 to 1 mm thick is evident
3	Accumulation of microalgal layer from 1 to 5 mm thick is evident
4	Accumulation of microalgal layer from 5mm to 2 cm thick is evident
5	Accumulation of microalgal layer greater than 2 cm thick is evident

Photo 3-5: The 5-gallon algae viewing bucket with transparent bottom and grid. The grid encompasses an area of roughly 100 in^2.



3.4 McNeil Substrate and Suspended Sediment

The amount of fine sediment and the composition of stream gravel were sampled using a McNeil sampler at three sites on the Colorado River, one site on the Fraser River, and one site on Ranch Creek. This sediment data can be used to assess the spawning success of salmonids and other gravel-dependent spawners (McNeil and Ahnel 1964), and channel characteristic data have been used to monitor changes in channel morphology that ultimately affect fish habitat quality over time (Olson-Rutz and Marlow 1992). Six replicate samples were taken from pool tails or low-gradient riffles at each of the sampled sites. Material was removed to the depth of the armor layer, or the layer of clean substrate that forms the top layer of stream substrate and would be moved by salmonids constructing redds, or nests. Substrate material was manually removed from the streambed using the McNeil sampler and brought to the GEI Ecological Laboratory for analyses.

Photo 3-6: Side-view and top-view of the McNeil sampler. Device was driven into the streambed up to the collar and substrate material was removed for analyses from the interior area of the narrow portion.

Each sample was dried before analysis by opening the sample bag and allowing the moisture to evaporate over a period of a few weeks. Dried samples were shaken through a series of sieves, and the amount of sample retained on each sieve was weighed. The weight of the sample retained on each sieve was divided by the total sample weight to obtain the percent of the sample weight belonging to each size class. The D_{50} and D_{84} were calculated for each of the McNeil core samples. The percentage of fines, defined as the proportion of substrate with a diameter of 4.65 mm or smaller, was also calculated. The D_{50}, D_{84}, percent fines, and suspended solids values were compared between sample locations. Each sample was also compared to benchmarks established by Kondolf et al. (2008) to determine whether the grain size distribution could reduce the survival of salmonid eggs or the probability of successful emergence of salmonid fry from their redds.

The amount of suspended sediment was determined by using the American Society for Testing Materials (ASTM) method D3977-97 (ASTM 2019). At each of the sampling locations a 470 milliliter (ml) sample of water was collected from the McNeil sampler after the substrate material was removed. The samples were kept on ice below 4°C until analysis by the GEI Laboratory. A total of six replicate aliquots were taken from each sample, and the average of the six replicates was used to characterize the suspended solids at each sample location.

4. Results

4.1 Pebble Counts and Embeddedness

Pebble counts were performed at seven sites on the Colorado River, six sites on the Fraser River, and one site on Ranch Creek from October 11, 2021, through October 15, 2021. A total of 10 transects were sampled at each site except for Site CR-1.7 and Site RC-1.1. Site CR-1.7 was not wadeable at 8 of 10 transects and dominated almost entirely by soft, fine substrate. Site RC-1.1 was not wadeable at 6 of 10 transects. At both sites, the non-wadeable transects were assessed visually and found to be dominated by fine substrates. Most sites on the Colorado River and Fraser River were dominated by substrate sizes categorized as gravel or cobble (Table 4–1). Fine substrate, particles with an intermediate width less than 2 mm, was most common on the Colorado River at the farthest downstream site, Site CR-1.7, and at Site RC-1.1 on Ranch Creek (Table 4–1).

The percentage of substrate sizes observed in 2021 on the Colorado River varied between sites. Substrate between 2 mm and 128 mm was observed at all sites. There was little to no substrate greater than 256 mm at the three most downstream sites, Site CR--9.1, Site CR--7.4, and Site CR-1.7. Site CR-7.4 had a noticeably greater percentage of small gravel and gravel substrate, between 2 mm and 64 mm, than all other Colorado River sites (Figure 4–1). The Colorado River sites generally exhibited a decrease in average substrate size from upstream to downstream (Figure 4–1).

Substrate composition varied less between the Fraser River sites than on the Colorado River, with the exception of Site FR-25.1 (Figure 4–2). The proportions of gravel and small cobble increased in a downstream direction, and the proportions of fine substrate and cobble decreased slightly. Site FR-25.1 was the most upstream site on the Fraser River, and the hydraulic and geomorphic properties of this site were substantially different from the other sites sampled on the Fraser River. Site FR-25.1 had a strikingly greater percentage of larger substrate, with the most dominant substrate class being greater than 512 mm (Figure 4–2). The second most common substrate class was gravel followed by small gravel which together comprised 32 percent of the substrate at the site. There was a small amount of fine substrate at sites FR-25.1 and FR-14; both had the lowest amount of fine substrate on the Fraser River. Substrate types and proportions at Site RC-1.1 were dissimilar to those at all sites on the Fraser River in 2021, with a much greater percentage of fine substrate at RC-1.1 and small proportions of substrate other than fines or gravel (Figure 4–2).

All but two of the 15 sites surveyed with the 400-rock count had percentages of fine sediment (i.e., < 2 mm) less than 29.3%, which is the threshold set in CDPHE Policy 98-1 for the protection of macroinvertebrates for sites in the CEA. The surveys indicated that the substrate at sites CR-1.7 and RC-1.1 was comprised almost entirely of fine sediment.

Average percent embeddedness was equal to or greater than 44.3 at all sites on all streams, with the largest average percent embeddedness observed at sites CR-1.7, CR-28.7, and RC-1.1

(Table 4-2). Average percent embeddedness values were in general lower in the upper portion of the Colorado River, and greatest at Site CR-1.7 (Table 4–1). Average percent embeddedness values on the Fraser River were comparable at the sites. Values ranged from 44.5 to 59.4, with FR-25.1 having the highest value (Table 4–2). Embeddedness at Site RC-1.1 on Ranch Creek was the second-highest in the CEA at 81.6 percent.

Table 4-1: Percent average substrate size classes at all sites sampled in 2021.

Sites	Substrate Size Categories							
	Fines	Small Gravel	Gravel	Small Cobble	Cobble	Small Boulder	Boulder	Bedrock
	<2 mm	2-8 mm	8-64 mm	64-128 mm	128-256 mm	256-512 mm	>512mm	
CR-31	6.5	6.3	32.8	21.5	22.5	10	0.5	0
CR-28.7	13	1.2	19	20.7	36.2	6.7	3.2	0
CR-22.9	10.4	10.6	37.4	18.6	16.3	4.5	2.2	0
CR-16.7	18.8	3.3	19.5	17	31	7.8	2.8	0
CR-9.1	24	14	34	18.3	8.5	1	0.3	0
CR-7.4	9.8	8.8	59.3	17.5	4.5	0.3	0	0
CR-1.7	86	4.8	4.8	2.5	0	1.3	0.8	0
FR-25.1	5	14.3	17.5	5	12.3	6	40	0
FR-23.4	22.5	6.3	29	10.3	20.8	5.5	5.8	0
FR-20	13.3	7.3	29.8	14.5	22	9.5	3.8	0
FR-15	7.6	7.1	44.1	17.2	15.9	7.1	1	0
FR-14	5	15.3	34.2	17.1	19.3	7.2	2	0
FR-1.9	6.3	11.3	33.8	22.3	24.8	1.8	0	0
RC-1.1	63.8	3.3	18.3	4	6.8	1.8	2.3	0

Table 4-2: Average embeddedness by site.

Sites	Waterbody	Average Percent Embeddedness
CR-31	Colorado River	49.4
CR-28.7	Colorado River	64.3
CR-22.9	Colorado River	47.8
CR-16.7	Colorado River	51.9
CR-9.1	Colorado River	62.0
CR-7.4	Colorado River	44.3
CR-1.7	Colorado River	90.1
FR-25.1	Fraser River	59.4
FR-23.2	Fraser River	57.7
FR-20	Fraser River	50.3
FR-15	Fraser River	48.0
FR-14	Fraser River	44.9
FR-1.9	Fraser River	44.5
RC-1.1	Ranch Creek	81.6

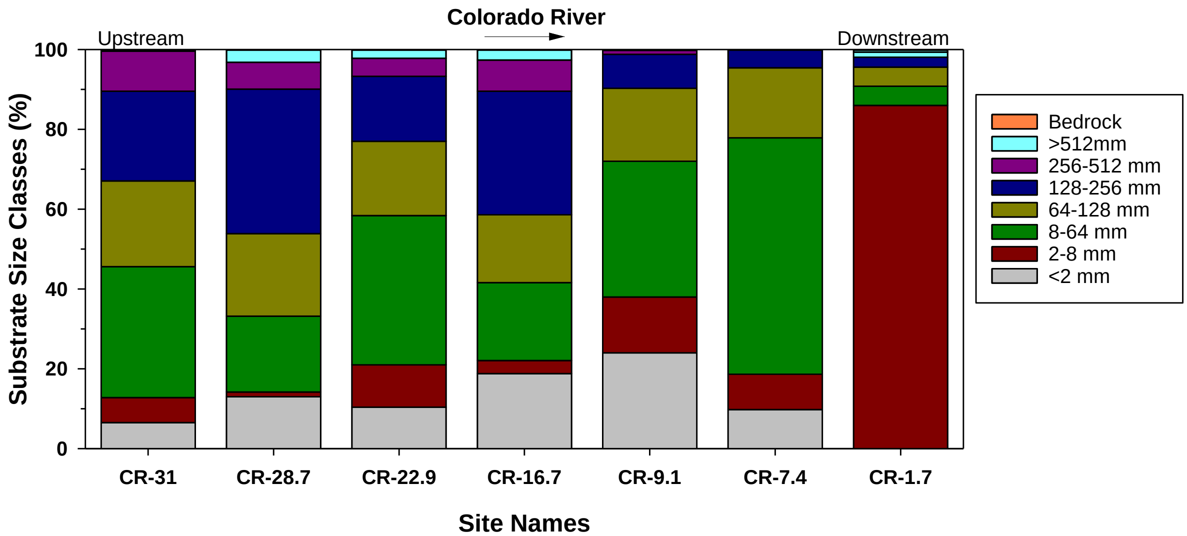


Figure 4-1: Percentage of substrate size classes for all sites on the Colorado River in 2021.

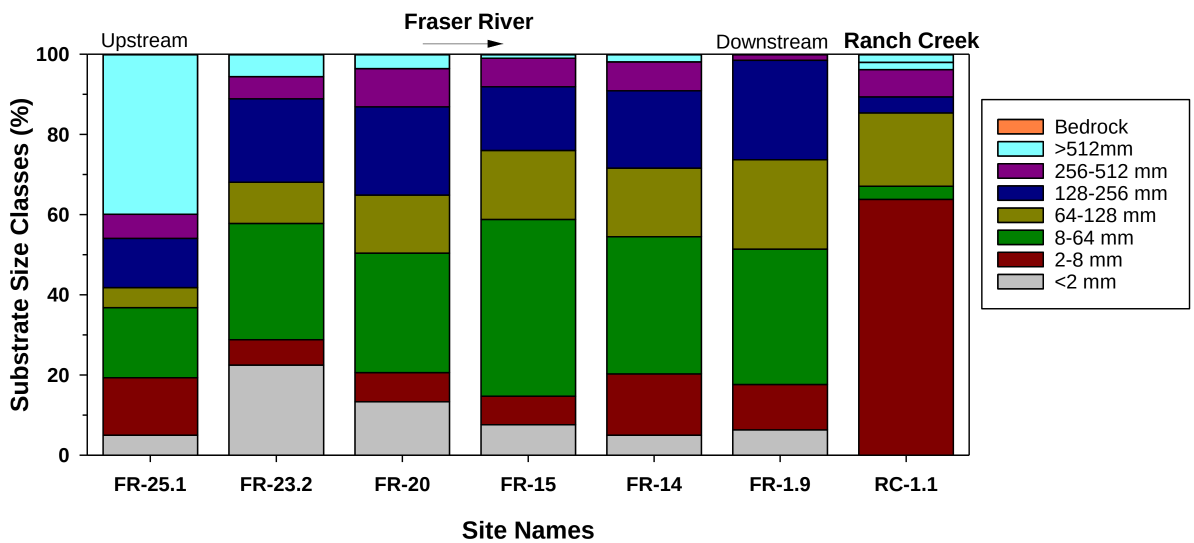


Figure 4-2: Percentage of substrate size classes for all sites on the Fraser River and Ranch Creek in 2021.

4.2 Riffle Stability Index

A 200-riffle pebble count and a 15 to 30 pebble count on a nearby depositional feature were performed at nine of the seventeen sites in 2021. The RSI value indicates the cumulative percentage of riffle particles that are smaller than the dominant large particles on a depositional bar (Kappesser 2002). Values of the RSI range from 0 to 100, with higher numbers indicating sand and small gravel loading in the riffle. Reference, or unmanaged, streams in the Kappesser study (2002) had a median RSI value of 58, indicating that RSI values in the high 50s do not indicate an unexpected number of fines. The minimum RSI value observed in 2021 occurred at Site CR-31 on the Colorado River and the maximum observed value was observed at Site CR-7.4 on the Colorado River. In general, the RSI values were moderately low on the Colorado River and Fraser River, with an average RSI of

48 on the Colorado River, and 38 on the Fraser River (Table 4–3). RSI values were not recorded on Ranch Creek in 2021.

Table 4-3: Average Riffle Stability Index (RSI) by site in 2021.

Sites	Waterbody	Riffle Stability Index
CR-31	Colorado River	19
CR-28.7	Colorado River	47
CR-22.9	Colorado River	37
CR-16.7	Colorado River	44
CR-14.9	Colorado River	48
CR-9.1	Colorado River	57
CR-7.4	Colorado River	84
FR-20	Fraser River	33
FR-14	Fraser River	43

4.3 Algae Presence, Percent Cover, and Thickness

The algae community at a total of 30 points within each site reach was assessed in conjunction with pebble count surveys from October 11, 2021, through October 15, 2021. The percent average presence of filamentous algae across these 30 points per site was 73 or greater at all but one of the surveyed sites. Values ranged from 40 percent filamentous algae presence at Site RC-1.1 on Ranch Creek, to a maximum of 100 percent presence at multiple sites on the Colorado River and the Fraser River (Table 4–4).

The percent filamentous algae cover at each site also varied widely but was generally high at all sites except for Site RC-1.1 on Ranch Creek (Table 4–4). When filamentous algae was present, it generally occurred in short strands and did not occur in large, extensive blooms.

Table 4-4: Filamentous algae and diatom data by site in 2021.

Sites	Waterbody	Percent Average Filamentous Presence	Percent Average Filamentous Algae Cover	Percent Average Diatom Presence	Average Categorical Diatom Thickness
CR-1.7	Colorado River	100	94	0	0.0
CR-7.4	Colorado River	90	85	0	0.0
CR-9.1	Colorado River	80	82	0	0.0
CR-16.7	Colorado River	93	65	0	0.0
CR-22.9	Colorado River	93	48	23	0.6
CR-28.7	Colorado River	97	89	93	2.5
CR-31	Colorado River	100	96	100	3.5
FR-1.9	Fraser River	100	42	60	1.0
FR-14	Fraser River	100	52	0	0.0
FR-15	Fraser River	100	70	100	2.4
FR-20	Fraser River	100	64	60	1.4
FR-23.2	Fraser River	73	16	23	0.6
FR-25.1	Fraser River	97	53	57	1.3
RC-1.1	Ranch Creek	40	48	3	0.1

In 2021, diatom algae were observed at each site sampled on the Fraser River and Ranch Creek with the exception of Site FR-14 and were only present at the three most upstream sites on the Colorado River. The percentage of diatom algae varied considerably when present on the Colorado River and Fraser River. The percentage of diatom presence ranged from 23 percent to 100 percent on the Colorado River and Fraser River and was low on Ranch Creek with 3 percent at Site RC-1.1 (Table 4–4).

The diatom species *Didymosphenia geminata* (Didymo) is a stalked diatom that can form nuisance blooms in rivers in the western United States (Spaulding and Elwell 2007). On the Colorado River Didymo was only present at the three most upstream sites in 2021. Didymo was present at most sites on the Fraser River and on Ranch Creek, but generally in a smaller percentages and thicknesses than on the Colorado River. Extensive and thick blooms of Didymo were present at sites CR-31 and CR-28.7 on the Colorado River in 2021, with thicknesses ranging from 0.5 mm to 2 cm within a transect (Table 4–4; Table 3–1). Diatom thickness on the Fraser River was generally lower than on the Colorado River, with only Site FR-15 having appreciable diatom thickness that ranged from 0.5 mm to 5 mm when present. Diatom thickness was low at the other Fraser River sites with an average thickness of less than 1 mm at each site. The diatom presence and thickness were very low at Site RC-1.1 on Ranch Creek; diatoms were only observed in one area along a single transect.

4.4 Volumetric Substrate and Suspended Sediment Analyses

Stream substrate was sampled with the McNeil sampler, and suspended sediment samples were collected at sites CR-9.1, CR-14.9, CR-22.9 on the Colorado River, Site FR-5.5 on the Fraser River, and at Site RC-2 on Ranch Creek. These samples provided data to help assess the quality of fish spawning and benthic macroinvertebrate habitat.

All sites on the three streams had low proportions of fine sediment, and very similar average D_{50} and D_{84} substrate sizes (Table 4–5). Both the D_{50} and D_{84} for all sites except for Site CR-22.9 were within the 8 mm to 64 mm range and categorized as gravel. Site CR-22.9 had a similar D_{50} value to the other sites but the D_{84} was slightly greater at 72.6 mm. These values show that the majority of streambed substrate in areas where trout may preferentially spawn are composed of gravel substrate that is conducive to spawning.

Average suspended sediment varied among the three streams with the lowest values present at the Fraser River site and the middle Colorado River site. Site RC-2 on Ranch Creek had a notably greater concentration of suspended sediment than at the Colorado River and Fraser Rivers sites (Table 4–5). Suspended sediment values were similar at the upstream and downstream location sampled and notably lower at Site CR-14.9. This site is a short distance downstream of the confluence of the Colorado River and the Williams Fork River and additional flow from the Williams Fork River in 2021 likely reduced the amount of suspended sediment at the site. Similar values at sites CR-22.9 and CR-9.1 may suggest that flows at each site in 2021 were not sufficient to allow the transport of fine sediment in a downstream direction on the Colorado River at most sites since 2020. The large, suspended sediment value at Site RC-2 on Ranch Creek may be due to land disturbance from recent development and/or changes to the beaver complexes just upstream of the site[2]. The beaver complexes accumulate fine sediment and attribute to the large amount of suspended sediment sampled. The D_{50} at all sites sampled in the CEA fell within the range of 5.8 mm to 50 mm. This range of values was observed in redds constructed by Brown Trout (*Salmo trutta*) in a 1993 study by Kondolf and Wolman.

Table 4-5: 2021 averages of McNeil sample data, percent fines, and suspended sediment. Standard deviation shown in parentheses for McNeil samples.

Sites	Waterbody	McNeil Samples		Average Percent Fines	Suspended Sediment (mg/L)		
		Average D_{50} (mm)	Average D_{84} (mm)		Average	Minimum	Maximum
CR-22.9	Colorado River	24.5 (13.0)	72.6 (65.8)	3.6	8,589.2	5,336.0	15,249.6
CR-14.9	Colorado River	20.7 (1.1)	44.6 (0.8)	3.2	3,720.0	1,542.5	7,008.6
CR-9.1	Colorado River	21.4 (0.6)	45.0 (0.4)	1.3	7,411.1	2,441.1	17,387.0
FR-5.5	Fraser River	19.8 (1.0)	43.9 (0.7)	5.9	2,374.7	335.1	4,510.3
RC-2	Ranch Creek	19.8 (1.2)	44.0 (0.9)	1.2	14,909.3	5,630.1	2,3976.0

[2] On a watershed scale, beaver pond complexes store large amounts of fine sediment. However, on a local scale, destruction or abandonment of individual dams can reintroduce fine sediment to a stream channel.

5. Discussion

The substrate, suspended sediment, and algae community data gathered in the fall of 2021 at multiple sites along representative stretches of the Colorado River, Fraser River, and Ranch Creek have enabled a basin-wide assessment of substrate size, substrate mobility, substrate deposition, and algae population data. This in turn allows inference about the effects of current substrate conditions on fish and macroinvertebrate habitat quality.

5.1 Pebble Counts and Embeddedness

5.1.1 Colorado River

Fine substrate less than 2 mm increased in a downstream direction from sites CR-22.9 to CR-9.1 in 2021, indicating an accumulation of fine sediment in the Colorado River through this reach. Based on observed changes between sites, sediment composition in the CEA is likely affected by large-scale factors such as reservoirs, tributary inputs, and magnitude of flow, and by local-scale factors such as hillslope erosion and stream diversion infrastructure. The major influences on sediment dynamics in the Colorado River are summarized briefly below.

Windy Gap Reservoir is located near the upstream end of the CEA on the Colorado River, just below the Colorado River and Fraser River confluence and between Site CR-31 and Site CR-28.7. Although the reservoir has been drawn down substantially over the last two years, a large proportion of the sediment transported into the reservoir is still retained. Substantial additions of new substrate into the Colorado River likely do not occur until the river reaches Byers Canyon, downstream of the town of Hot Sulphur Springs, below Site CR-22.9.

Byers Canyon and Little Muddy and Beaver creeks are both located between Site CR-22.9 and Site CR-16.7 on the Colorado River. The steep canyon walls provide material ranging from silt to boulders to the river, largely through natural processes, and the higher slope through the canyon facilitates sediment transport to downstream reaches. Muddy Creek is downstream of Byers Canyon; this small, unregulated system likely also serves as a source of new material to the Colorado River.

The Williams Fork of the Colorado River (Williams Fork) flows into the Colorado River just downstream of Site CR-16.7 in the town of Parshall, CO, and Troublesome Creek flows into the Colorado River between Site CR-9.1 and Site CR-7.4. The Williams Fork adds a relatively large volume to the flow in the Colorado River, which would increase sediment transport capacity.

The KB Ditch is located approximately 0.4 miles upstream of Site CR-9.1 on the Colorado River and diverts flow from the Colorado River for agricultural use. The diversion runs the width of the river at the ditch inlet, with the exception of a small bypass on river right (looking in a downstream direction). This structure also has the potential to trap sediment.

The KB Ditch and Williams Fork confluence with the Colorado River are both upstream of Site CR-9.1; there is no monitoring site between them. An additional site located between Williams Fork and KB Ditch might determine their relative influences on the sediment characteristics at Site CR-9.1.

Troublesome Creek is a moderately sized tributary to the Colorado River, and the confluence is located between Site CR-9.1 and CR-7.4, approximately 0.4 miles upstream from Site CR-7.4. This low-gradient, sinuous creek is unregulated and runs adjacent to agricultural fields for much of its length. Troublesome Creek is a potential source for large amounts of fine sediment and gravel.

Due to higher sinuosity, lower slope, reduced water velocity, and sediment inputs from Troublesome Creek and local bank erosion, the Colorado River downstream of Site CR-9.1 transitions from being dominated by cobble to being dominated by smaller substrate size classes. In 2021, Site CR-7.4 was dominated by gravel substrate with a relatively large proportion of fine substrate, and most of the substrate at Site CR-1.7 was smaller than 2 mm.

Between 2019 and 2021, sediment dynamics changed at many of the monitoring sites on the Colorado River. This could be due to natural and anthropogenic changes that include fire effects on landscapes, variation in spring runoff and monsoon season moisture, stream restoration, and reservoir presence. Between 2019 and 2021, there was an increase in substrate less than 64 mm (i.e., fines and gravel) at almost all of the surveyed Colorado River sites. Site CR-1.7 was not sampled in 2020, but comparisons of 2019 and 2021 data showed that substrate was dominated by fines in both years.

The increase in gravel and fine substrate throughout much of the sampled area could be a result of landscape-scale processes, such as runoff from fire-affected areas, input of materials from tributaries during the monsoon season, and a low spring runoff in 2021. Most of the sampling sites experienced an increase in the proportion of fine sediment and gravels between 2020 and 2021, but not between 2019 and 2020. Thus, it is likely that precipitation during the 2021 monsoon introduced fines and gravels into the Colorado River, either through tributary inputs or via hillslope erosion. Increased sediment loading into streams, even in periods without significant rainfall, can produce exceptionally high rates of sediment transport (Ryan et al. 2011). Furthermore, flows from tributary floods can lead to rapid deposition of smaller substrate in the Colorado River (Wiele et al. 1996). The higher proportion of fines throughout the sampling sites may also have been due to the low runoff in 2021, which probably limited the ability of the river to flush accumulated sand and silt.

On a more local scale, reservoir operations and stream restoration activities could have affected sediment dynamics at individual sites. For example, the least amount of change in the substrate characteristics between 2019 and 2021 occurred at Site CR-28.7, downstream of Windy Gap Reservoir. Windy Gap Reservoir was partially drained in the fall of 2020 and 2021 in preparation for the modification of the dam and construction of the connectivity channel in the Colorado River. Despite the drawdowns in 2020 and 2021, the reservoir still appears to be retaining most of the gravels that are introduced by the Colorado and Fraser rivers.

Substantial restoration projects have occurred in the Williams Fork and in the main stem of the Colorado River since 2018. In both cases, the work has resulted in a lower width-to-depth ratio of the stream cross section, which facilitates sediment transport. The proportions of gravel at Site CR-9.1 (downstream of the Williams Fork) increased between 2019 and 2021. Site CR-9.1 also had greater proportions of fines, small gravel, and gravel substrate in 2020 and 2021 than the next upstream site, Site CR-16.7. Although the restored reach of the Williams Fork River is below the Williams Fork Reservoir and potentially sediment-limited, the lower width-to-depth ratio of the river may have increased transport of locally-available gravels into the Colorado River. Site CR-7.4 (on the main stem, within a restored reach) receives a large amount of gravel and fine sediment annually. However, the proportion of fine sediment decreased at this site between 2020 and 2021, despite low spring runoff and a potential introduction of large amounts of sediment into the Colorado River in 2021. The decrease in fines could be due to the increased ability of the restored reach to transport sand and silt.

Embeddedness values generally increased in a downstream direction on the Colorado River in 2021. Embeddedness was relatively low at the most upstream site (CR-31) and then increased notably at the next downstream site, Site CR-28.7. This greater embeddedness value at Site CR-28.7 may be related to its proximity to the dam. Fines that were carried in suspension over the dam could have been deposited at this site on the descending limb of the spring hydrograph or after the drawdowns of Windy Gap Reservoir in the fall of 2020 and 2021. Embeddedness values decreased between Site CR-28.7 and Site CR-22.9, and then increased at each subsequent downstream site to Site CR-1.7. Embeddedness at Site CR-1.7 approached 100%. This is due to the addition of substrate from tributaries, a notable decrease in the slope of the river, and an increase in sinuosity. These factors all decrease water velocity and facilitate deposition of fine substrate.

The remaining differences in substrate composition and embeddedness between sites in 2020 and 2021 on the Colorado River are minor and probably due to a combination of natural variability and sampling variability.

5.1.2 Fraser River and Ranch Creek

As with the Colorado River, sediment composition on the Fraser River is affected by large-scale and local-scale factors. The primary large-scale factor is flow management, but local features such as unpaved roads, erodible hillslopes, beaver ponds, and man-made ponds appear to have a larger effect on the proportion of fine sediment at individual sites.

Site FR-25.1 (the upstream-most sampling site) has markedly different substrate characteristics than the remaining Fraser River sites. This site is steeper and straighter than the remaining sites; the streambed contains a step-pool system instead of the riffle-pool morphology observed at the other sites. The differences in stream morphology between this site and the others on the Fraser River best explain the differences in substrate characteristics.

The Fraser River in the CEA has four relatively large tributaries: Vasquez Creek, which enters the Fraser River between sites FR-23.2 and FR-20, Elk Creek and St. Louis Creek, both of which enter the Fraser River between sites FR-20 and FR-15, and Ranch Creek, which enters the Fraser River downstream of Site FR-14. Because these tributaries are also managed systems, they are not likely to provide substantial amounts of gravel to the Fraser River.

The local factors affecting sediment dynamics in the Fraser River Drainage include stream diversions, beaver dams, and unpaved roads/recent development higher in the watershed. The proportion of fine sediment was low at Site FR-25.1 then increased notably at Site FR-23.2 due to multiple beaver dams. The proportion of fine sediment then decreased in a downstream direction to Site FR-1.9. Hillslope inputs at Site FR-25.1 and in Fraser Canyon likely provide fine sediment and some gravel to Site FR-25.1 and Site FR-1.9, respectively, whereas a large amount of sediment is stored in beaver dams upstream of and within Site FR-23.2.

On Ranch Creek, the percentage of substrate <2 mm was high at Site RC-1.1 in 2021. The high proportion of fine sediment is due to a combination of low flows, multiple beaver dams upstream and within the site reach, and the high availability of sediment from unpaved roads and hillslopes in the watershed. There were more beaver dams at the site in 2021 than in 2019 and 2020, and the beaver dam complexes were more substantial than in previous years. Most of Site RC-1.1 was inundated by beaver ponds. Site RC-1.1 on Ranch Creek was observed to have similar sinuosity, slope, and habitat types as the lower and middle sites on the Fraser River, suggesting that similarities in substrate characteristics in 2019 and 2020 when fewer beaver dams were present at this site could be attributable to similar stream morphologies at these sites.

Embeddedness values were comparable between sites on the Fraser River in 2021 with only small changes between sites. Embeddedness decreased in a downstream direction with the greatest value at Site FR-25.1 and lower and similar values at sites FR-14 and FR-1.9. Embeddedness values were high at Site FR-25.1 due to a relatively large amount of small gravel covering larger substrate, and embeddedness values were high at Site FR-23.2 due to the relatively large amount of fine substrate present at the site. Subsequent decreases in embeddedness in a downstream direction on the Fraser River indicate that beaver ponds are storing some fines at Site FR-23.2 and flows in the river in 2021 were sufficient to enable transport of some fines. Additionally, the section of river between Site FR-15 and Site FR-14 was the focus of the Fraser Flats River Habitat Project, and the decrease in width-to-depth ratio has allowed this section of river to transport sediment successfully.

The largest changes in the Fraser River/Ranch Creek drainages from 2019 through 2021 involved an increase in the proportion of gravel in the Fraser River and higher proportions of fine sediment at Site RC-1.1 in Ranch Creek. There was an increase in the proportion of gravel at the three most downstream sites on the Fraser River in 2021 (Appendix C). The two upstream sites on the Fraser River had the least change in proportion of substrate types from 2020 values, though the beaver dam complexes upstream of Site FR-23.2 caused an increase in fine substrate in 2021. While the reason for the increase in gravel at the three Fraser River sites is unknown, it is unlikely that sampling variation is the cause. The method used to sample sediment is robust to bias in particle selection, and the same staff have been performing the sampling since 2019. The proportion of fine sediment at Site RC-1.1 in 2021 was much greater than observed in 2019 and 2020; this was due to the fact that much of the site has become inundated with beaver ponds, which have the capacity to store large amounts of sand and silt.

5.2 Riffle Stability Index

The mobile percentile of particles in a riffle, or RSI, is a useful estimate of the degree of increased sediment supply to riffles in mountain streams (Kappesser 2002). A stable stream reach in dynamic equilibrium has similar sediment size and sediment transport rates at the beginning of a reach compared to the end of a reach, so that there is no net gain or loss of sediment (Kappesser 2002).

In the Kappesser (2002) study in north Idaho, reference streams had a median RSI value of 58 and managed watersheds had a median RSI value of 80. The median RSI value was 47 for the sites on the Colorado River and 38 on the Fraser River in 2021. A higher RSI value shows that a higher proportion of the material in a riffle is smaller than the larger materials on depositional features. This indicates that a riffle is storing a higher proportion of fine materials such as sand.

The RSI values from sampling in 2021 on the Colorado River were comparable among the middle sites and differed mainly at the most upstream and most downstream sites where RSI was measured, sites CR-31 and CR-7.4. Site CR-31 had the lowest RSI among Colorado River sites, and the low value suggests that stream flows were sufficient to transport smaller substrate material out of the reach in 2021. The highest RSI value was measured at Site CR-7.4 and the relatively high value indicates a large proportion of smaller substrate material is stored within the reach. RSI values on the Fraser River in 2021 were comparable to the middle reaches of the Colorado River with relatively low values. Overall, the Colorado River and Fraser River had a relatively limited capacity to flush sand and gravel from riffles in 2021.

The RSI increased from Site CR-22.9 downstream to Site CR-7.4 in 2021. This increase is a function of increased sediment loading and lower slopes (and therefore water velocities) lower in the CEA. The somewhat abrupt increase in the RSI between Site CR-31 and CR-

28.7 is likely due to the fact that Site CR-28.7 is downstream of Windy Gap Reservoir and may have less capacity to flush fine sediment than Site CR-31. The RSI was measured at two Fraser River sites in 2021 and neither value indicated excessive sediment loading in the riffles.

5.3 Algae Presence, Percent Cover, and Thickness

Green filamentous algae were present at every site sampled in 2021 on the Colorado River, Fraser River, and Ranch Creek. There were extensive amounts of cover of filamentous algae at most sites on the Colorado River except for Site CR-22.9. Filamentous algae were less prevalent on the Fraser River in 2021 with only extensive amounts of cover at sites FR-20 and FR-15. Low flow conditions throughout much of 2021 and nutrient inputs from sources such as agricultural run-off likely attributed to the extent of filamentous algae on the Colorado River and to a lesser extent on the Fraser River. Low spring runoff may also have contributed to algal blooms because they were insufficient to scour algae and/or because lower velocities would increase nutrient retention times and make nutrients more available for algae.

Notable amounts of diatoms were present at the two most upstream sites on the Colorado River in 2021. Diatoms were observed at most sites on the Fraser River unless the substrate was occluded by green algae. Didymo was present in the CEA and formed extensive blooms at sites CR-31 and CR-28.7 where all or most of the transects had a thick covering on the substrate. This species tends to create blooms in stable, low velocity flow regimes (Kirkwood et al. 2007; Miller at al. 2009). Sustained low flow periods in addition to low spring run-off and nutrient inputs into the upper portion of the Colorado River likely attributed to the robust presence and cover of didymo.

In 2021, there was an overall increase in the amount of green filamentous algae at all sites on the Colorado River, Fraser River, and Ranch Creek since 2020. Diatom coverage increased at the upstream sites in the Colorado River and decreased at the lower sites between 2020 and 2021. The diatom coverage and thickness in the Fraser River decreased slightly at most sites between 2019 and 2021 (GEI 2021). The differences in the diatom and filamentous algae communities between 2020 and 2021 at each sampling location are likely attributable to natural variation. Blooms of diatoms and filamentous algae within each drainage are dependent on climatic conditions, peak and magnitude flows, and variations in nutrient availability.

5.4 Volumetric Substrate and Suspended Sediment

Volumetric substrate data was collected using a McNeil sampler at three sites on the Colorado River, and at one site each on the Fraser River and Ranch Creek. Calculated values for the D_{50} and D_{84} were similar among all sites in the CEA. The D_{50} and D_{84} values at each site were generally lower than the corresponding values calculated from the pebble counts at each site. This is unsurprising and attributable to differences in sampling equipment and the areas targeted for data collection (i.e., spawning beds) between the two methods. The McNeil sample data and the suspended sediment data show that the substrate composition in trout spawning habitat is comparable among the sampled sites.

An excess of fine sediment can be detrimental to trout reproduction. Incubating eggs and alevins must obtain oxygen and dispose of metabolic wastes while they inhabit the gravel, which requires that subsurface and surface water flow freely through the redd (Kondolf et al. 2008). Higher permeability of redds generally results in an increase in juvenile trout survival. The mean maximum levels of different grain sizes that allow for 50 percent salmonid emergence are: <0.85 mm, 13.6 percent; <2.00 mm, 15 percent; <3.35 mm, 29.5 percent; and <6.35 mm, 30.3 percent (Kondolf et al. 2008). Preferred substrate size for spawning trout varies with fish length, with a general increase in spawning substrate size correlated with an increase in fish length. Volumetric substrate sampling indicated that substrate sizes in spawning beds in the CEA are near the lower end of the range for spawning trout, slightly lower than the Brown Trout average, and likely not a limiting factor for trout reproduction.

Average concentrations of suspended sediment on the Colorado River in 2021 were greater than the values on the Colorado River in 2020; values increased substantially between 2020 and 2021 at the site sampled on Ranch Creek. The average concentration was only slightly greater at the Fraser River site in 2021. Low spring run-off and low annual flows throughout the study area likely attributed to the notably greater suspended sediment concentrations at most sites. The middle site on the Colorado River had the lowest suspended sediment concentration among the Colorado River sites and could be due to the additional clear-water flow from the Williams Fork. In average or greater than average flow years fine sediment likely accumulates in a downstream direction due to the addition of sediment from tributaries between each site and a decreased ability of the river to flush fine sediment due to a decrease in slope and an increase in stream width.

The concentration of suspended sediment only slightly increased at the site on the Fraser River and increased notably at Site RC-2 on Ranch Creek. Site RC-2 is located immediately downstream of large beaver complexes which can contribute large amounts of stored sediment to downstream reaches in the event of individual dam failures.

6. Conclusion

The sediment and algae conditions in the CEA in the Colorado and Fraser River drainages are typical of managed systems, and a combination of natural and man-made features influence stream sediment dynamics. The 2021, annual daily flows observed in Grand County, CO were notably less than in 2020 and 2019 and comparable to observed values in 2018 at each gage location (Appendix B). On a local scale, ditches/dams and beaver ponds trap gravels, and unpaved roads, unregulated tributaries, and erodible hillslopes provide sources of sand and gravel. Although the proportion of sand and silt at all but two sites was low enough to be supportive of aquatic life, and the proportion of gravel increased modestly at several sampling sites, gravel was still limited throughout the CEA. Embeddedness was over 44 percent at every site on all three rivers sampled, and the sediment was compacted at most of the sampling locations in the Fraser River.

Changes in substrate composition between 2020 and 2021 were largely consistent throughout the CEA. There was an overall increase in substrate less than 64 mm among almost all sites, and the proportion of fine sediments increased at many sites. The increase in gravel and fine substrate among most sites in the CEA was likely due to the combination of fire-affected watersheds, low spring run-off, low overall annual flow, and snowmelt and precipitation over burned areas on the Colorado River.

Riffles with a lower RSI value (i.e., those with a lower proportion of fine material) provide more interstitial spaces, or small spaces between clean substrate particles. These interstitial spaces provide high-quality habitat for macroinvertebrates, some species of juvenile fishes, and benthic, or bottom-dwelling, fishes. Many of the RSI values in 2021 were more typical of reference streams than of managed rivers, suggesting that these working rivers still provide useable aquatic habitat for resident fish and macroinvertebrates.

Didymo was present and extensive at the two upstream sites on the Colorado River, but generally absent or in low densities at the remaining sites in the CEA in 2021. Green filamentous algae blooms were present at a small number of sites but nuisance blooms were generally absent. The sediment and algae conditions in the CEA have some implications for aquatic habitat quality, as discussed briefly below.

The substrate sizes present in the volumetric substrate samples are favorable for trout spawning and for certain benthic macroinvertebrate groups. This implies that trout can spawn successfully at the selected sampling sites. However, gravel is limited at some of the sampling sites, which would limit the availability of spawning sites in the CEA, and substrate compaction would also limit spawning success, especially in the Fraser River. Compacted sediment limits trout spawning success because trout cannot move the gravels to construct redds.

The availability of clean substrate and interstitial spaces is limited at many sites within the CEA due to high embeddedness by fine sediment and periodic blooms of algae. A low proportion of gravels and embeddedness of cobbles limit habitat for macroinvertebrates and small fishes (Waters 1995). A limited number of studies indicate that the effects of Didymo and green algae on macroinvertebrate communities is variable (Patrick 1983; Dodds and Gudder 1992; Ellsworth 2000; Spaulding and Elwell 2007; Tonkin et al. 2014), but reduction of sensitive taxa like mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) have been documented in some studies (Kilroy et al. 2009). Historic flows in the CEA were substantially greater in magnitude and duration during spring run-off than they are in modern times, multiple instream structures disrupt sediment transport, and natural processes and human land use has altered the nutrient dynamics of the Colorado and Fraser rivers. Unsurprisingly, aquatic habitat conditions in the CEA have characteristics that are typical of working rivers. However, it appears that some of the restoration projects in the basin may have facilitated some gravel transport in the system. Therefore, it is also possible that restoration efforts such as the Windy Gap Connectivity project and the Kemp-Breeze/Colorado River channel rehabilitation will result in increased sediment continuity and the associated benefits to aquatic habitat.

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Appendix A 2021 Sediment and Algae Data

Site: CR-1.7
Date: 10/11/2021
Notes: Most of site was too deep to wade

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	7	4	15	10		4		
2	40							
3	17	15	4			1	3	
4	40							
5	40							
6	40							
7	40		Remainder of site too deep to wade, substrate estimated					
8	40							
9	40							
10	40							
Total	344	19	19	10	0	5	3	0
% of Total	**86**	**4.8**	**4.8**	**2.5**	**0**	**1.3**	**0.8**	**0**

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5	
1	40	50	50	60	40	
2	100	100	100	100	100	
3	70	50	40	--	--	*remainder of transect too deep to wade
4						
5						
6						
7		Remainder of site too deep to wade, estimated				
8						
9						
10						

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	100	0	2	100	0	3	50	0	4
2	100	0	2	100	0	3	100	0	5
3	100	0	2	100	0	3	100	0	5
4									
5									
6									
7	Remainder of site too deep to wade			Remainder of site too deep to wade			Remainder of site too deep to wade		
8									
9									
10									
Average	100	0	2	100	0	3	83.3	0	4.7

Site: CR-7.4
Date: 10/11/2021
Notes: partial areas of some transects were too deep to wade

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	1	3	23	6	6	1		
2	6	8	25	1				
3		6	32	2				
4	7	2	23	5	3			
5	6	6	24	3	1			
6		2	19	18	1			
7	8	3	24	4	1			
8		3	30	7				
9	5	2	20	13				
10	6		17	11	6			
Total	39	35	237	70	18	1	0	0
% of Total	**9.8**	**8.8**	**59.3**	**17.5**	**4.5**	**0.3**	**0**	**0**

	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
200 Riffle Count	4	21	151	24				
% of Total	2	10.5	75.5	12	0	0	0	0
Cumulative %	2	12.5	88	100	100	100	100	100

RSI	Geomean Particle Size	Slope and Intercept for RSI	
84.250	44	b=	76
		m=	0.188

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	30	30	60	25	50
2	10	10	20	40	30
3	20	15	15	30	25
4	40	30	50	50	50
5	20	50	too deep	50	100
6	40	30	10	40	50
7	50	60	60	100	100
8	30	10	20	50	50
9	25	50	60	70	70
10	60	60	70	80	75

Site: CR-7.4
Date: 10/11/2021
Notes: partial areas of some transects were too deep to wade

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	90	0	4	85	0	3	100	0	3
2	100	0	3	90	0	3	94	0	3
3	86	0	2	30	0	2	25	0	3
4	100	0	3	50	0	3		too deep	
5	84	0	3		too deep		100	0	3
6	80	0	3	88	0	2	100	0	2
7	100	0	2		too deep		50	0	3
8	92	0	3	96	0	3	94	0	3
9	72	0	2	100	0	3	100	0	3
10	94	0	3	100	0	3	100	0	3
Average	89.8	0	2.8	79.9	0	2.8	84.8	0	2.9

Site: CR-9.1
Date: 10/12/2021
Notes: Many fish redds along right bank riffle at transect 5. Portions of some transects too deep to wade

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	7	5	9	9	9	1		
2	1	10	11	12	6			
3	5	3	15	13	3	1		
4	3	6	13	12	4	1	1	
5	6	8	22	3	1			
6		6	20	8	6			
7	40							
8	1	8	20	7	4			
9	33		2	4	1			
10		10	24	5		1		
Total	96	56	136	73	34	4	1	0
% of Total	**24**	**14**	**34**	**18.3**	**8.5**	**1**	**0.3**	**0**

	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
200 Riffle Count	3	36	89	42	28	2		
% of Total	1.5	18	44.5	21	14	1	0	0
Cumulative %	1.5	19.5	64	85	99	100	100	100

RSI	Geomean Particle Size	Slope and Intercept for RSI	
57.438	44	b=	43
		m=	0.328

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	60	40	60	70	90
2	30	50	50	70	60
3	60	60	50	50	50
4	40	80	50	60	60
5	100	70	50	60	50
6	20	30	70	30	40
7	100	100	100	100	100
8	40	50	40	60	60
9	90	70	90	100	100
10	20	30	30	60	100

Site: CR-9.1
Date: 10/12/2021
Notes: Many fish redds along right bank riffle at transect 5. Portions of some transects too deep to wade

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	100	0	3	100	0	4	80	0	2
2	100	0	4	100	0	4	100	0	4
3	96	0	4	100	0	4	80	0	2
4	100	0	3		too deep		98	0	2
5	10	0	1	94	0	3	88	0	3
6	50	0	2	60	0	3	20	0	1
7		too deep			too deep			too deep	
8	100	0	3	80	0	3	100	0	3
9	10	0	1		too deep			too deep	
10	90	0	2	100	0	3	100	0	5
Average	72.9	0	2.6	90.6	0	3.4	83.3	0	2.8

Site: CR-14.9
Date: 10/12/2021
Notes:

	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
200 Riffle Count	2	5	73	56	53	8	3	
% of Total	1	2.5	36.5	28	26.5	4	1.5	0
Cumulative %	1	3.5	40	68	94.5	98.5	100	100

RSI	**Geomean Particle Size**	**Slope and Intercept for RSI**	
48.313	83	b=	12
		m=	0.438

Site: CR-16.7
Date: 10/12/2021
Notes: Transect 3 visually estimated, portion too deep to wade

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	3	3	7	6	18	1	2	
2	4	7	15	4	10			
3	40							
4	3		4	10	14	7	2	
5			11	6	17	5	1	
6		1	9	9	14	5	2	
7	6	2	11	6	10	4	1	
8	7		6	10	11	4	2	
9	12		2	7	15	3	1	
10			13	10	15	2		
Total	75	13	78	68	124	31	11	0
% of Total	**18.8**	**3.3**	**19.5**	**17**	**31**	**7.8**	**2.8**	**0**

	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
200 Riffle Count	3	23	67	54	44	13	2	
% of Total	1.5	11.2	32.5	26.2	21.4	6.3	1	0
Cumulative %	1.5	12.7	45.2	71.4	92.8	99.1	100.1	100.1

RSI	Geomean Particle Size	Slope and Intercept for RSI	
43.972	61	b=	19
		m=	0.409

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	90	50	60	20	40
2	50	30	30	50	40
3	100	100	100	100	100
4	50	50	60	50	60
5	20	20	10	60	25
6	20	30	50	60	20
7	60	50	40	40	70
8	60	60	50	40	50
9	40	50	60	50	100
10	30	50	50	50	50

Site: CR-16.7
Date: 10/12/2021
Notes: Transect 3 visually estimated, portion too deep to wade

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	100	0	2	20	0	3	78	0	3
2	25	0	3	20	0	2	80	0	2
3	5	0	1		too deep			too deep	
4	100	0	3	48	0	2	100	0	2
5	36	0	3	40	0	2	55	0	2
6	88	0	2	42	0	3	88	0	3
7	100	0	2	28	0	3	78	0	3
8	90	0	1	100	0	2	88	0	2
9	82	0	2	75	0	1	52	0	1
10	50	0	2	65	0	1	76	0	1
Average	67.6	0	2.1	48.7	0	2.1	77.2	0	2.1

Site: CR-22.9
Date: 10/12/2021
Notes: first indication of *Didymosphenia geminata* along Colorado River, not present downstream

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	8	2	15	7	7		4	
2	3	2	20	8	5	1	1	
3	1	7	10	12	7	3	1	
4	6	2	22	4	4	1	1	
5	13	4	14	4	3	2		
6	2	6	17	7	6	1	1	
7	6	1	15	10	4	4		
8	1	8	11	7	9	3	1	
9	1	5	15	8	10	1		
10	1	6	12	8	11	2		
Total	42	43	151	75	66	18	9	0
% of Total	**10.4**	**10.6**	**37.4**	**18.6**	**16.3**	**4.5**	**2.2**	**0**

	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
200 Riffle Count	6	7	68	57	58	4		
% of Total	3	3.5	34	28.5	29	2	0	0
Cumulative %	3	6.5	40.5	69	98	100	100	100

RSI	Geomean Particle Size	Slope and Intercept for RSI	
42.188	56	b=	26
		m=	0.289

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	30	40	60	30	50
2	40	30	50	50	60
3	30	50	50	60	40
4	50	50	20	50	60
5	100	100	60	50	60
6	50	60	30	60	50
7	60	50	20	60	50
8	60	40	60	50	30
9	40	40	30	50	40
10	50	30	30	40	40

Site: CR-22.9
Date: 10/12/2021
Notes: first indication of *Didymosphenia geminata* along Colorado River, not present downstream

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	50	3	3	90	4	4		too deep	
2	94	3	3	50	2	2	80	0	2
3	40	2	2	25	2	2	100	2	2
4	20	0	2	10	0	1	10	0	2
5	80	0	3	100	0	1	100	0	2
6	36	0	2	10	0	1	10	0	2
7	80	0	2	60	0	2	50	0	2
8	30	0	1	0	0	3	26	0	1
9	30	0	2	20	0	1	86	0	1
10	40	0	2	16	0	1	50	0	1
Average	50	0.8	2.2	38.1	0.8	1.8	56.9	0.2	1.7

Site: CR-28.7
Date: 10/13/2021
Notes: abundant amount of fines between larger substrate throughout most of site

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	7		5	7	17	2	2	
2	10	1	7	15	3	4		
3	10		7	7	14	2		
4	12		1	4	14	2	7	
5	3		4	11	20	2		
6	7		3	5	16	7	2	
7		1	13	12	14			
8	2		13	10	14	1		
9	1	1	10	7	15	5	2	
10		2	13	5	18	2		
Total	52	5	76	83	145	27	13	0
% of Total	**13**	**1.2**	**19**	**20.7**	**36.2**	**6.7**	**3.2**	**0**

	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
200 Riffle Count	6	3	95	44	48	6		
% of Total	3	1.5	47	21.8	23.8	3	0	0
Cumulative %	3	4.5	51.5	73.3	97.1	100.1	100.1	100.1

RSI	Geomean Particle Size	Slope and Intercept for RSI
47.425	34	b= 39.6
		m= 0.230

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	90	60	60	80	80
2	70	60	60	70	100
3	60	60	90	80	90
4	100	80	80	70	80
5	40	30	60	70	80
6	60	60	70	80	70
7	30	60	60	50	70
8	50	50	50	70	80
9	50	50	too deep	50	60
10	40	50	60	40	40

Site: CR-28.7
Date: 10/13/2021
Notes: abundant amount of fines between larger substrate throughout most of site

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	100	3	3	86	2	2	92	4	4
2	100	4	4	92	3	3	88	3	3
3	100	3	3	90	3	3	100	3	3
4	92	0	2	100	0	3	88	2	2
5	82	3	3	96	3	3	100	3	3
6	94	3	3	92	3	3	100	3	3
7	90	3	3	82	2	2	78	2	2
8	100	3	3	80	3	3	80	3	3
9	92	2	2		too deep		78	2	2
10	32	2	2	86	2	2	88	1	1
Average	88.2	2.6	2.8	89.3	2.3	2.7	89.2	2.6	2.6

Site: CR-31
Date: 10/13/2021
Notes:

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	1	3	16	6	7	7		
2	5	4	11	12	3	4	1	
3	5	1	9	10	11	3	1	
4		1	11	9	14	5		
5	2	2	10	10	11	5		
6	2	4	13	9	9	3		
7	4	1	16	9	6	4		
8	1	2	17	7	8	5		
9	6	4	12	8	8	2		
10		3	16	6	13	2		
Total	26	25	131	86	90	40	2	0
% of Total	**6.5**	**6.3**	**32.8**	**21.5**	**22.5**	**10**	**0.5**	**0**

	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
200 Riffle Count		4	68	67	47	17	1	
% of Total	0	2	33.3	32.8	23	8.3	0.5	0
Cumulative %	0	2	35.3	68.1	91.1	99.4	99.9	99.9

RSI	Geomean Particle Size	Slope and Intercept for RSI	
18.900	32	b=	2.5
		m=	0.513

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	60	60	60	40	80
2	70	50	50	60	80
3	50	60	50	50	60
4	60	50	50	60	40
5	30	40	50	50	60
6	30	40	50	40	50
7	30	50	40	50	50
8	40	40	50	40	30
9	40	40	60	40	70
10	30	40	50	50	50

Site: CR-31
Date: 10/13/2021
Notes:

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	96	3	3	100	4	4	100	4	4
2	86	2	2	38	3	3	94	2	0
3	94	4	4	100	4	4	100	4	0
4	100	4	4	100	4	4	100	4	4
5	100	4	4	100	4	4	100	4	4
6	100	4	4	100	4	4	100	3	3
7	100	3	0	100	3	0	100	3	3
8	100	4	4	86	3	3	100	4	4
9	90	3	3	100	3	3	100	3	3
10	100	4	4	100	4	4	100	4	4
Average	96.6	3.5	3.2	92.4	3.6	3.3	99.4	3.5	2.9

Site: FR-1.9
Date: 10/13/2021
Notes:

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	3	2	12	11	11	1		
2	3	3	15	8	11			
3	3	8	13	4	11	1		
4	4	3	11	8	13	1		
5	1	6	12	12	7	2		
6	1	5	17	6	10	1		
7		2	20	11	7			
8	2	2	11	12	13			
9	5	5	10	9	10	1		
10	3	9	14	8	6			
Total	25	45	135	89	99	7	0	0
% of Total	**6.3**	**11.3**	**33.8**	**22.3**	**24.8**	**1.8**	**0**	**0**

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	70	50	50	50	30
2	40	25	30	50	50
3	80	60	30	50	20
4	50	30	50	40	20
5	40	20	30	40	50
6	50	50	30	40	50
7	30	50	30	20	50
8	40	50	40	30	70
9	40	50	50	40	100
10	60	50	70	50	30

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	26	0	1	32	2	2	100	0	4
2	40	1	1	32	1	1	24	0	1
3	26	0	2	56	0	1	24	0	1
4	32	1	1	28	1	1	30	2	2
5	28	0	2	38	0	1	60	2	2
6	76	0	2	28	2	2	32	1	1
7	30	0	1	28	1	1	18	1	1
8	28	1	1	24	2	2	12	0	1
9	64	2	2	32	2	2	76	2	2
10	68	0	3	94	3	3	70	3	3
Average	41.8	0.5	1.6	39.2	1.4	1.6	44.6	1.1	1.8

Site: FR-14
Date: 10/13/2021
Notes:

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	3	3	15	8	10	1		
2	1	4	25	4	4	2		
3	1	7	19	5	3	2	3	
4	1	2	14	11	10	1	1	
5	3	6	8	7	9	6	1	
6	1	7	12	9	10	4	1	
7	2	12	12	6	6	1	1	
8	1	7	16	7	6	3		
9	1	7	7	5	13	6	1	
10	6	7	10	7	7	3		
Total	20	62	138	69	78	29	8	0
% of Total	**5**	**15.3**	**34.2**	**17.1**	**19.3**	**7.2**	**2**	**0**

	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
200 Riffle Count	5	19	77	64	32	6		
% of Total	2.5	9.4	37.9	31.5	15.8	3	0	0
Cumulative %	2.5	11.9	49.8	81.3	97.1	100.1	100.1	100.1

RSI	Geomean Particle Size	Slope and Intercept for RSI	
42.909	50	b=	18.3
		m=	0.492

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	40	50	60	40	60
2	40	40	50	40	50
3	40	60	40	40	50
4	40	30	50	50	30
5	50	40	40	40	40
6	40	50	50	60	40
7	60	50	50	60	50
8	30	25	20	40	40
9	30	50	40	50	50
10	40	50	40	60	60

Site: FR-14
Date: 10/13/2021
Notes:

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	80	0	2	56	0	1	24	0	1
2	94	0	2	14	0	1	70	0	1
3	24	0	1	74	0	2	4	0	2
4	46	0	3	16	0	2	82	0	2
5	48	0	2	34	0	2	26	0	2
6	36	0	2	18	0	2	88	0	2
7	98	0	2	48	0	2	32	0	2
8	2	0	2	28	0	2	22	0	2
9	92	0	2	82	0	2	52	0	2
10	92	0	2	92	0	2	92	0	2
Average	61.2	0	2	46.2	0	1.8	49.2	0	1.8

Site: FR-15
Date: 10/14/2021
Notes:

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	3	1	17	10	6	2	1	
2		2	18	9	8	3		
3	7	2	27	1	4	3		
4	5	5	21	7	2			
5		2	18	8	10	2		
6	4	4	17	6	8	1		
7	5	2	22	5	5	1		
8	6	4	14	8	4	4		
9		5	14	7	9	8	1	
10	1	2	12	9	9	5	2	
Total	31	29	180	70	65	29	4	0
% of Total	**7.6**	**7.1**	**44.1**	**17.2**	**15.9**	**7.1**	**1**	**0**

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	60	50	50	30	30
2	30	40	25	40	50
3	100	40	40	60	30
4	50	40	50	50	50
5	30	40	50	50	25
6	40	50	50	50	50
7	70	50	50	45	60
8	40	50	40	60	60
9	70	50	75	40	50
10					

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	100	3	3	92	3	3	52	2	2
2	38	3	3	30	3	3	48	3	3
3	98	3	3	88	3	3	100	3	3
4	28	3	3	16	2	2	82	3	3
5	90	3	3	48	3	3	76	2	2
6	100	2	2	80	2	2	84	2	2
7	80	2	2	70	2	2	88	2	2
8	90	2	2	66	2	2	58	2	2
9	68	2	2	70	2	2	90	2	2
10	48	2	2	40	2	2	80	2	2
Average	74	2.5	2.5	60	2.4	2.4	75.8	2.3	2.3

Site: FR-20
Date: 10/14/2021
Notes:

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	14	2	4	7	10	2	1	
2		1	8	12	15	4		
3	2	1	16	4	13	2	2	
4		5	7	6	11	8	3	
5	4	4	17	4	6	3	2	
6	2	1	18	7	8	1	3	
7	6	3	7	6	10	4	4	
8	11	9	9	2	5	4		
9	9	2	17	8	3	1		
10	5	1	16	2	7	9		
Total	53	29	119	58	88	38	15	0
% of Total	**13.3**	**7.3**	**29.8**	**14.5**	**22**	**9.5**	**3.8**	**0**

	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
200 Riffle Count		9	77	62	47	8		
% of Total	0	4.4	37.9	30.5	23.2	3.9	0	0
Cumulative %	0	4.4	42.3	72.8	96	99.9	99.9	99.9

RSI	Geomean Particle Size	Slope and Intercept for RSI	
32.769	44	b=	11.8
		m=	0.477

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	100	70	60	70	100
2	50	40	30	20	40
3	50	25	30	50	70
4	70	60	20	40	60
5	20	50	30	60	80
6	25	20	30	30	20
7	50	90	60	40	50
8	90	70	50	60	70
9	40	0	30	25	100
10	70	60	50	40	50

Site: FR-20
Date: 10/14/2021
Notes:

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	74	3	3	78	3	3	86	3	3
2	70	2	2	88	0	2	76	2	2
3	12	1	1	66	0	2	76	0	1
4	64	0	3	66	2	2	74	3	3
5	48	2	2	56	2	2	38	2	2
6	70	0	2	72	0	2	50	2	2
7	22	0	2	46	2	2	60	2	2
8	20	0	2	72	0	3	50	0	2
9	64	0	2	86	2	2	80	3	3
10	80	0	3	82	3	3	78	2	2
Average	52.4	0.8	2.2	71.2	1.4	2.3	66.8	1.9	2.2

Site: FR-23.2
Date: 10/14/2021
Notes:

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	1	3	14	6	11	5		
2	4		9	5	10	9	3	
3	2	7	12	2	10	2	5	
4			11	8	17	1	3	
5		1	10	7	16		6	
6	1	2	20	5	6	2	4	
7		7	21	5	5		2	
8	2	5	19	3	8	3		
9	40	Too deep to wade, beaver dam, visually estimated						
10	40							
Total	90	25	116	41	83	22	23	0
% of Total	**22.5**	**6.3**	**29**	**10.3**	**20.8**	**5.5**	**5.8**	**0**

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	50	40	20	50	40
2	40	50	40	60	100
3	90	40	30	20	60
4	50	40	50	20	40
5	40	40	50	30	60
6	50	40	50	60	40
7	25	60	50	30	50
8	80	60	50	70	20
9	100	100	100	100	100
10	100	100	100	100	100

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	16	0	3	18	2	2	4	0	3
2	10	0	2	14	0	3	32	0	3
3	4	0	3	14	0	2	12	0	3
4	6	0	2	14	0	3	44	0	3
5	24	2	2	16	0	3	4	0	3
6	6	0	2	58	0	3	24	2	0
7	24	2	0	12	2	0	0	0	0
8	18	2	0	0	0	0	20	2	0
9	Little to no algae, beaver dam, too deep to wade			Little to no algae, beaver dam, too deep to wade			Little to no algae, beaver dam, too deep to wade		
10									
Average	13.5	0.8	1.8	18.3	0.5	2	17.5	0.5	1.9

Site: FR-25.1
Date: 10/14/2021
Notes:

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	2	11	21	2	2		2	
2	3	1	8		1	4	23	
3	3	5	5	2	7	1	17	
4	2	3	8	2	4	3	18	
5	1	7	8	3	11	4	6	
6	1	4	3	3	10	4	15	
7	5	13	4	1	1	1	15	
8	1	2	7	2	3	6	19	
9	2	5	3	4	7	1	18	
10		6	3	1	3		27	
Total	20	57	70	20	49	24	160	0
% of Total	**5**	**14.3**	**17.5**	**5**	**12.3**	**6**	**40**	**0**

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	30	30	40	30	50
2	20	30	60	60	50
3	60	70	30	50	50
4	50	50	60	30	70
5	50	60	50	80	50
6	80	70	70	60	60
7	100	100	100	100	60
8	70	80	60	60	50
9	70	70	50	60	80
10	40	50	50	80	90

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	16	0	3	8	0	2	10	0	2
2	14	0	2	80	0	2	20	0	2
3	94	0	2	38	0	3	84	0	2
4	88	2	2	30	0	2	26	0	1
5	76	1	1	36	0	3	78	3	3
6	56	3	3	48	3	3	100	1	0
7	0	0	0	36	2	2	68	3	3
8	84	3	3	60	3	3	38	3	3
9	60	1	0	94	3	3	36	2	2
10	82	2	2	34	2	2	88	1	0
Average	57	1.2	1.8	46.4	1.3	2.5	54.8	1.3	1.8

Site: RC-1.1
Date: 10/14/2021
Notes: Some redds in riffle areas just downstream of beaver dam

Transect Substrate Count

Transect	Fines <2mm	Sm. Gravel 2-8mm	Gravel 8-64mm	Sm. Cobble 64-128mm	Cobble 128-256mm	Sm. Boulder 256-512mm	Boulder >512mm	Bedrock Bedrock
1	6	5	16	3	8	1	1	
2	6	2	10	4	11	6	1	
3	3	3	26	3	4		1	
4		3	21	6	4		6	
5	40	Too deep to wade, beaver dams throughout upstream portion, visually estimated						
6	40							
7	40							
8	40							
9	40							
10	40							
Total	255	13	73	16	27	7	9	0
% of Total	**63.8**	**3.3**	**18.3**	**4**	**6.8**	**1.8**	**2.3**	**0**

Embeddedness

Transect	Emb. 1	Emb. 2	Emb. 3	Emb. 4	Emb. 5
1	60	40	40	60	90
2	100	60	40	30	80
3	20	60	50	30	80
4	50	40	30	50	70
5*	100	100	100	100	100
6*	100	100	100	100	100
7*	100	100	100	100	100
8*	100	100	100	100	100
9*	100	100	100	100	100
10*	100	100	100	100	100

*Too deep to wade, beaver dams, visually estimated

Algae Data

Transect	25% Fil. Cover	25% Diatom Thickness	25% Fil. Thickness	50% Fil. Cover	50% Diatom Thickness	50% Fil. Thickness	75% Fil. Cover	75% Diatom Thickness	75% Fil. Thickness
1	14	0	2	30	0	2	100	0	4
2	6	0	1	32	1	1	66	0	3
3	28	0	3	16	0	3	100	0	4
4	54	0	3	100	0	4	24	0	2
5	Too deep to wade			Too deep to wade			Too deep to wade		
6									
7									
8									
9									
10									
Average	25.5	0	2.3	44.5	0.3	2.5	72.5	0	3.3

Appendix B Long-term Flow Data

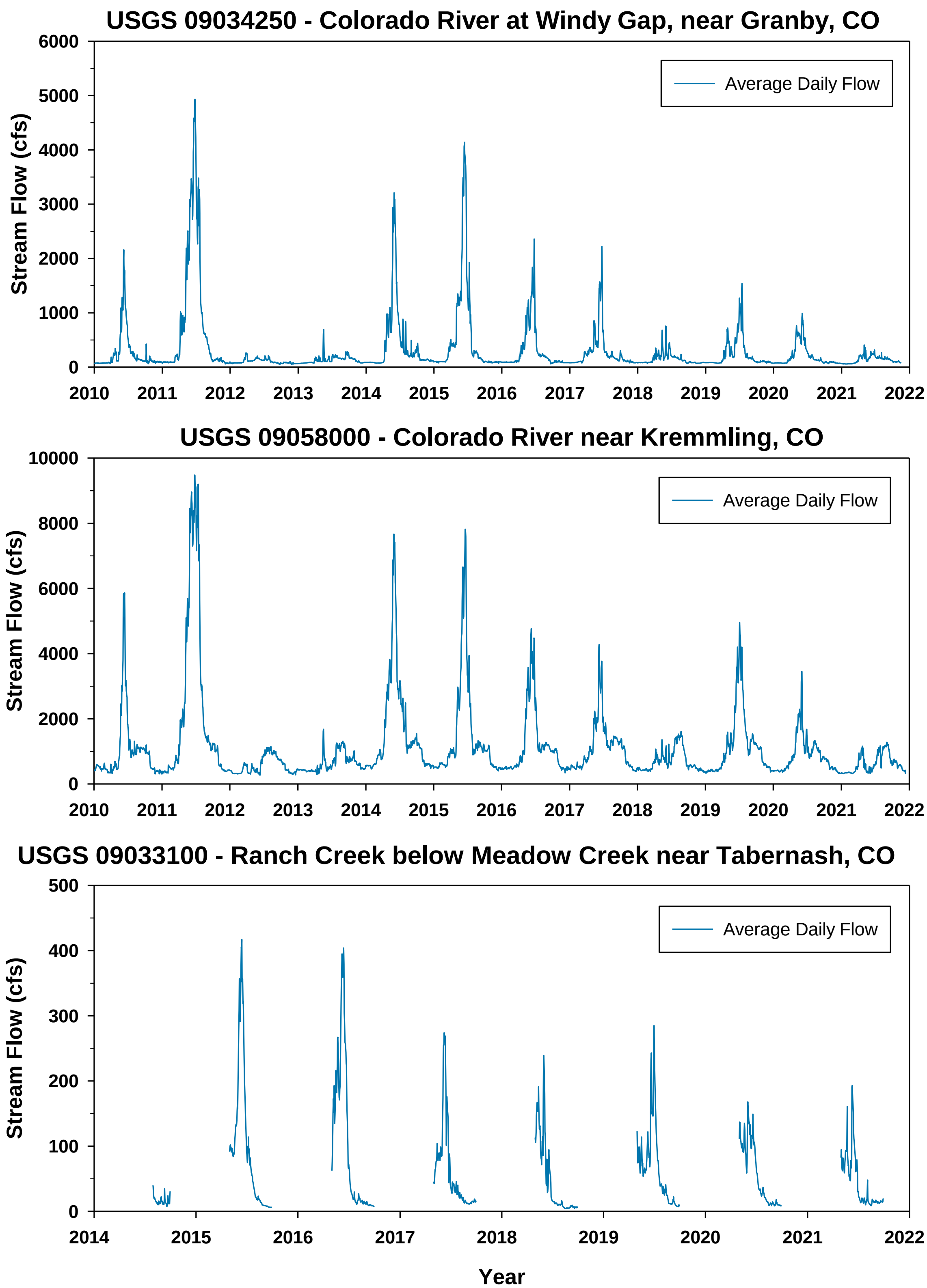


Figure B-1: **Average daily flow data for USGS stream gages on the Colorado River and Ranch Creek in Grand County, CO.**

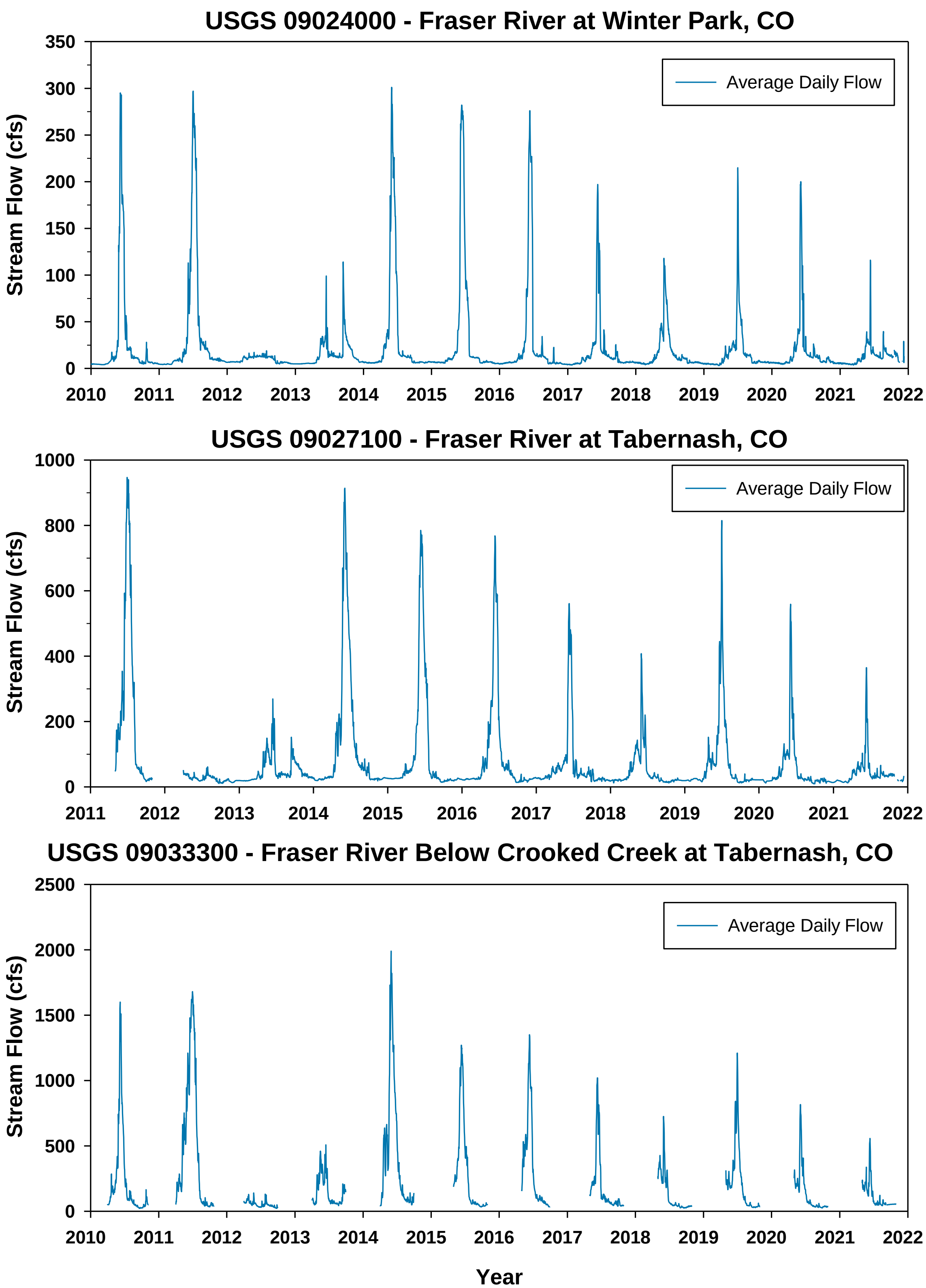


Figure B-2: Average daily flow data for USGS stream gages on the Fraser River in Grand County, CO.

Appendix C 2019 to 2021 Pebble Count Data

Table C-1: Percent average substrate size classes at all sites sampled in 2019.

Sites	Substrate Size Categories							
	Fines	Small Gravel	Gravel	Small Cobble	Cobble	Small Boulder	Boulder	Bedrock
	<2 mm	2-8 mm	8-64 mm	64-128 mm	128-256 mm	256-512 mm	>512mm	
CR-1.7	65.8	13.8	6.5	5.8	7.0	1.3	0.0	0.0
CR-7.4	25.7	5.5	33.9	27.7	7.2	0.0	0.0	0.0
CR-9.1	12.0	1.7	17.7	27.2	38.7	2.7	0.0	0.0
CR-16.7	12.3	3.8	23.5	27.0	26.0	4.0	2	1.5
CR-22.9	4.1	2.7	15.2	20.7	46.0	10.6	0.7	0.0
CR-28.7	5.8	3.5	16.1	27.9	36.4	10.3	0.0	0.0
CR-31	5.5	3.3	18.8	32.0	29.0	11.5	0.0	0.0
FR-1.9	8.8	3.8	22.8	35.8	22.3	6.5	0.0	0.0
FR-14	5.9	5.1	23.3	26.2	30.9	8.1	0.5	0.0
FR-15	13.4	2.5	21.3	24.3	22.3	13.6	2.5	0.0
FR-20	15.5	4.0	18.0	28.8	17.3	11.8	4.8	0.0
FR-23.2	4.7	2.5	24.6	35.2	28.3	3.5	1.2	0.0
FR-25.1	8.5	3.0	7.2	8.2	8.0	14.7	50.4	0.0
RC-1.1	21.0	4.5	24.0	27.0	17.5	2.5	3.5	0.0

Table C-2: Percent average substrate size classes at all sites sampled in 2020.

Sites	Substrate Size Categories							
	Fines	Small Gravel	Gravel	Small Cobble	Cobble	Small Boulder	Boulder	Bedrock
	<2 mm	2-8 mm	8-64 mm	64-128 mm	128-256 mm	256-512 mm	>512mm	
CR-7.4	22.9	9.0	49.9	15.0	3.0	0.2	0.0	0.0
CR-9.1	8.5	4.0	28.0	35.3	19.8	4.3	0.3	0.0
CR-16.7	11.2	5.7	12.0	19.0	32.9	15.5	3.5	0.2
CR-22.9	5.2	6.0	18.5	20.4	36.2	12.7	1.0	0.0
CR-28.7	7.8	3.5	18.0	12.0	46.8	12.0	0.0	0.0
CR-31	6.8	2.5	11.0	18.8	47.9	13.0	0.0	0.0
FR-5.5	5.0	9.0	20.0	37.0	27.0	2.0	0.0	0.0
FR-12.4	8.8	10.3	18.5	26.5	24.5	11.3	0.3	0.0
FR-14	3.8	7.5	11.5	20.3	34.3	22.5	0.3	0.0
FR-15	7.8	6.0	15.0	21.8	33.3	15.5	0.5	0.0
FR-20	8.3	3.0	15.4	25.0	28.0	18.7	1.5	0.0
FR-23.2	12.8	10.3	15.0	16.3	23.3	12.8	9.8	0.0
FR-25.1	10.3	3.0	6.5	5.3	10.0	22.3	42.8	0.0
RC-1.1	13.0	8.5	25.3	27.5	19.3	2.8	3.8	0.0
FRC-2	5.0	32.7	45.5	13.9	3.0	0.0	0.0	0.0

Table C-3: Percent average substrate size classes at all sites sampled in 2021.

Sites	Substrate Size Categories							
	Fines	Small Gravel	Gravel	Small Cobble	Cobble	Small Boulder	Boulder	Bedrock
	<2 mm	2-8 mm	8-64 mm	64-128 mm	128-256 mm	256-512 mm	>512mm	
CR-1.7	86.0	4.8	4.8	2.5	0.0	1.3	0.8	0.0
CR-7.4	9.8	8.8	59.3	17.5	4.5	0.3	0.0	0.0
CR-9.1	24.0	14.0	34.0	18.3	8.5	1.0	0.3	0.0
CR-16.7	18.8	3.3	19.5	17.0	31.0	7.8	2.8	0.0
CR-22.9	10.4	10.6	37.4	18.6	16.3	4.5	2.2	0.0
CR-28.7	13.0	1.2	19.0	20.7	36.2	6.7	3.2	0.0
CR-31	6.5	6.3	32.8	21.5	22.5	10.0	0.5	0.0
FR-1.9	6.3	11.3	33.8	22.3	24.8	1.8	0.0	0.0
FR-14	5.0	15.3	34.2	17.1	19.3	7.2	2.0	0.0
FR-15	7.6	7.1	44.1	17.2	15.9	7.1	1.0	0.0
FR-20	13.3	7.3	29.8	14.5	22.0	9.5	3.8	0.0
FR-23.2	22.5	6.3	29.0	10.3	20.8	5.5	5.8	0.0
FR-25.1	5.0	14.3	17.5	5.0	12.3	6.0	40.0	0.0
RC-1.1	63.8	3.3	18.3	4.0	6.8	1.8	2.3	0.0

Appendix D Algae Cover Photos

Photo D-1: Examples of approximately 25 percent (left) and 50 percent (right) algae cover.

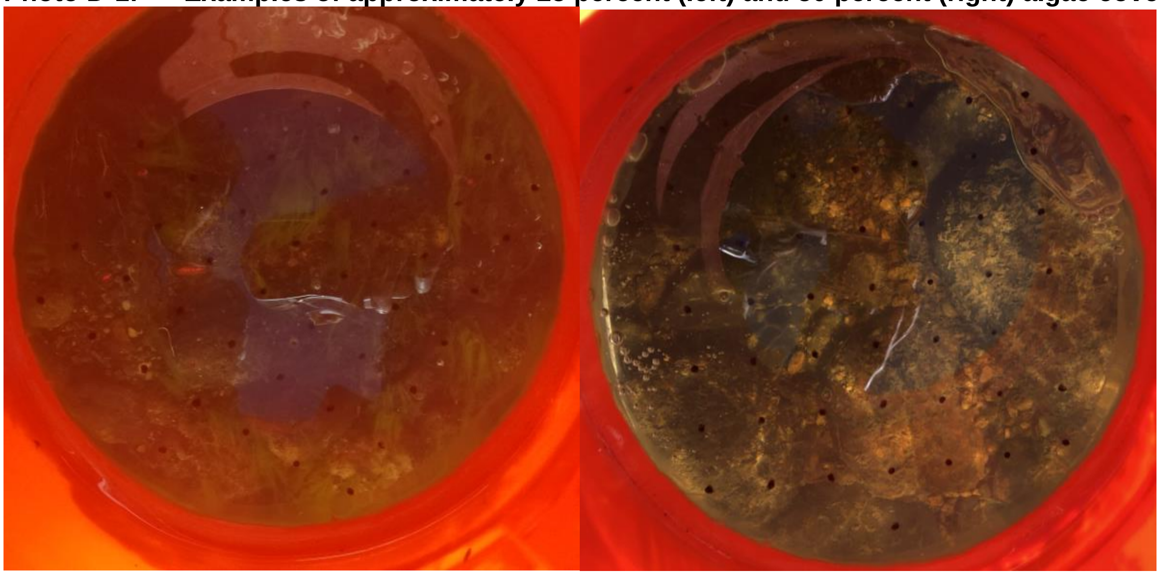
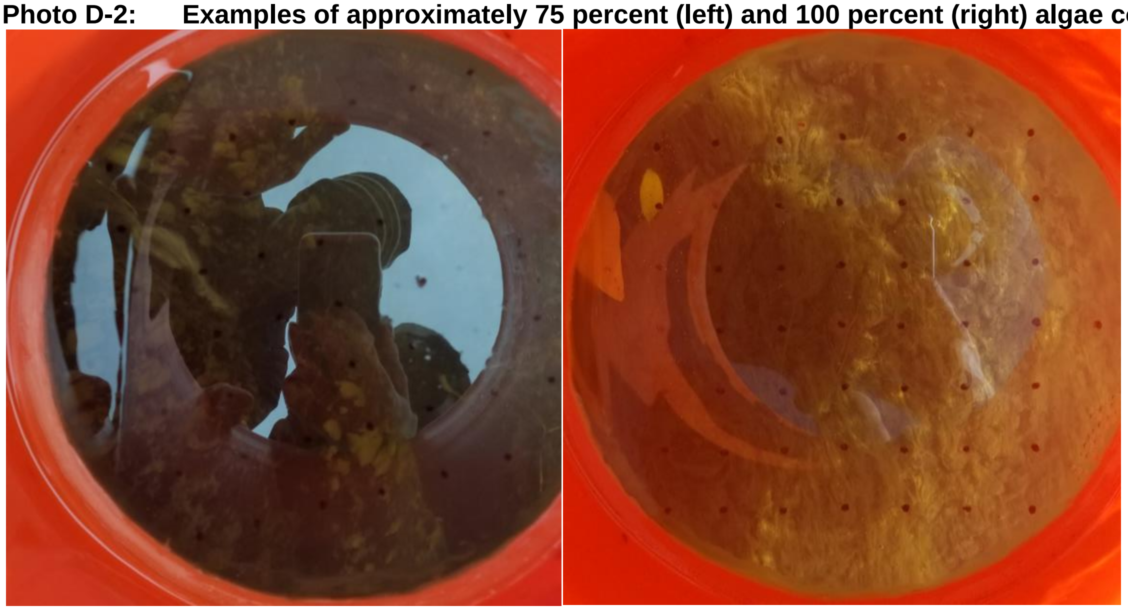


Photo D-2: Examples of approximately 75 percent (left) and 100 percent (right) algae cover.



Appendix E Long-term Embeddedness Data

Table E-1: Long-term embeddedness data from 2019 - 2021. NS = Not Sampled.

Sites	Waterbody	Average Percent Embeddedness		
		2019	2020	2021
CR-31	Colorado River	44.8	22.6	49.4
CR-28.7	Colorado River	48.8	48.7	64.3
CR-22.9	Colorado River	43.7	39.8	47.8
CR-16.7	Colorado River	49.0	31.5	51.9
CR-9.1	Colorado River	42.3	40.5	62.0
CR-7.4	Colorado River	55.5	54.3	44.3
CR-1.7	Colorado River	65.5	NS	90.1
FR-25.1	Fraser River	51.8	37.3	59.4
FR-23.2	Fraser River	39.4	34.7	57.7
FR-20	Fraser River	37.4	37.9	50.3
FR-15	Fraser River	46.9	35.4	48.0
FR-14	Fraser River	40.5	38.1	44.9
FR-12.4	Fraser River	NS	35.9	NS
FR-1.9	Fraser River	40.0	NS	44.5
RC-1.1	Ranch Creek	51.4	45.4	81.6