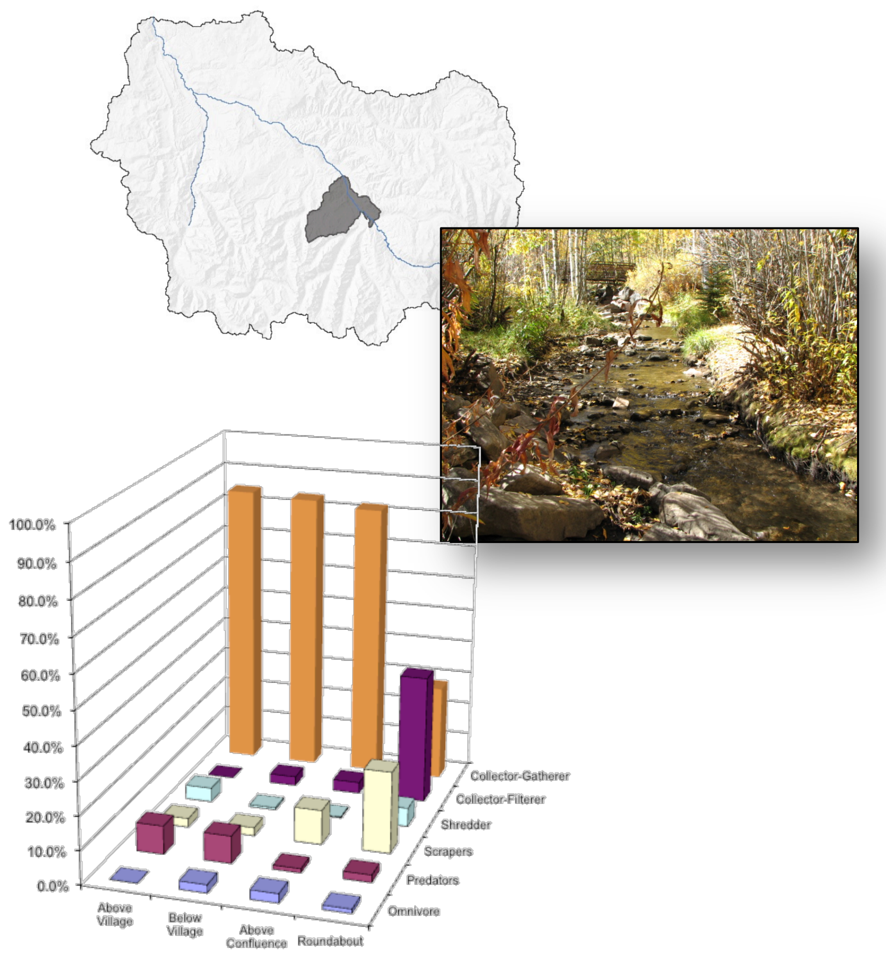
2012 Brush Creek Focused Water Quality Assessment

S.K.Mason Environmental, LLC



SUBMITTED: 12/20/13

A Project of The:

ROARING FORK WATERSHED PLAN

Prepared For:

ROARING FORK CONSERVANCY

PO Box 3349
Basalt, CO 81621

Prepared By:

S.K.Mason Environmental, LLC

PO Box 1524
Carbondale, CO 81623

And:

Timberline Aquatics, Inc.

155 West Harvard, Suite 302
Fort Collins, CO 80525

Acknowledgements

Roaring Fork Conservancy would like to thank all partners who contributed to this work in 2012. Funding for this report was provided by Snowmass Water and Sanitation District. Macroinvertebrate sorting, identification and analysis was performed by Timberline Aquatics, Inc. Nutrient data was collected by S.K.Mason Environmental, LLC in conjunction Snowmass Water and Sanitation District. Analysis of nutrient samples was completed at the Snowmass Water and Sanitation District lab. This report was compiled by S.K.Mason Environmental, LLC, Roaring Fork Conservancy, and Timberline Aquatics, Inc.

Table of Contents

I. Executive Summary

Snowmass area stakeholders maintain an interest in understanding the effects of land use and active water resource management on water quality and the biological integrity of aquatic and riparian communities in the Brush Creek drainage. Decision-makers and conservation groups require clarification of these critical relationships in order to guide future resource management actions.

Brush Creek was provisionally listed on the State of Colorado's 2012 303(d) Impaired Waters List for Aquatic Life. Results from benthic macroinvertebrate sampling conducted in 2012 support this designation with three out of four sites indicating use impairment as defined by the State of Colorado. Brush Creek's current designation may trigger State action for planning and implementation of water quality improvement measures on the stream. However, the provisional status of the listing indicates that causes of impairment remain unclear. The State will make a final determination of causes of impairment within 10 years of the initial provisional listing (WQCD 2011).

In response to the impaired waters designation on Brush Creek, Roaring Fork Conservancy and Snowmass Water and Sanitation District initiated a study in 2012 to better understand spatial relationships between patterns of nutrient loading and measures of macroinvertebrate community health near Snowmass Village. Results indicated continued impairment of aquatic biology, as assessed by the State's Multi-metric Index (MMI) methodology. The MMI combines several individual metrics for benthic macroinvertebrate communities into a normalized score which may be compared to healthy reference streams. A sampling location below the wastewater treatment plant produced the only passing score for aquatic life use attainment. Sample sites in the upper watershed indicated low background nutrient levels. Higher concentrations of nitrate and phosphate observed below the wastewater treatment plant rapidly attenuated as the stream exited the developed portion of the resort community and entered range and pasture land in the lower portion of the drainage. Concentrations did not exceed existing state water quality standards for nutrients at any sampling location. Anthropogenic sourcing associated with wastewater treatment plant operations appeared to contribute the majority of nutrient loading to Brush Creek. However, spatial patterns of nutrient loading and macroinvertebrate community health assessments did not indicate nutrient pollution as a primary cause of aquatic life impairment.

Although not assessed by this study, stormwater inputs from the heavily urbanized village area likely influence water quality in Brush Creek during episodic precipitation and runoff events. Turf care and pest management chemicals carried by non-point source runoff may also influence water quality due to the high proportion landscaped streamside land. Studies targeting the magnitude and timing of these water quality impacts can increase understanding of their contribution to water quality conditions and trends.

Roaring Fork Conservancy recommends that local stakeholders on Brush Creek work collaboratively and engage the State to coordinate the planning and development of further assessment activities on Brush Creek. In this way, the process might remain locally initiated and directed, while potentially benefiting from outside resources and expertise. Primary stakeholders on Brush Creek include Snowmass Water and Sanitation District, Town of Snowmass Village, Snowmass Golf Club, Roaring Fork Conservancy, Aspen Skiing Company, and any other interested members of the Roaring Fork watershed community. Achievement of water quality goals on Brush Creek requires a basin-wide approach that jointly considers point- and non-point sources of water quality impairment. Collaborative problem identification and data/information ownership amongst Brush Creek stakeholders can proactively allay potential disagreements about causes of impairment and the appropriate actions required for improvement of water quality conditions.

1. Introduction

1.1 Background

The Brush Creek drainage, a small watershed located in the Elk Mountains of Pitkin County, Colorado drains much of the developed land areas associated with the Snowmass Ski Resort and Snowmass Village. In 2012, the State of Colorado placed the primary water body in this drainage, Brush Creek, on the 303(d) list for Impaired Aquatic Life Use. In Colorado, a designation of Impaired Aquatic Life Use means that certain measures of benthic macroinvertebrate communities are diminished or compromised in comparison to healthy reference streams in similar regions. This regulatory action, required as a component of Clean Water Act reporting to the federal government, stemmed from assessments of macroinvertebrate communities on Brush Creek that indicated aquatic life health impairment. In addition to action by the State of Colorado, the 2008 State of the Roaring Fork Watershed Report (Clarke et al. 2008) identified one or more exceedances of State or federal standards for the following constituents on Brush Creek: temperature, pH dissolved oxygen, total phosphorus, aluminum, iron, and selenium. The Roaring Fork Conservancy (RFC) previously characterized Brush Creek as *Impacted* in its 2006 Water Quality Report. Reasons for listing Brush Creek as *Impacted* included 1) a number of water sample observations with dissolved concentrations of selenium, manganese, and aluminum above State standards, 2) macroinvertebrate samples indicating some level of water quality impairment, 3) alteration of flows, and 4) significant physical alterations from development in the watershed. Local resource managers suspect urban runoff, golf course and landscaping runoff, wastewater treatment plant effluent, physical alteration and habitat destruction, and natural inputs from local geology contribute to the observed conditions on Brush Creek. Snowmass area stakeholders maintain an interest in understanding the effects of land use and active water resource management on water quality and the biological integrity of aquatic and riparian communities in the Brush Creek drainage. Decision-makers and conservation groups require clarification of these critical relationships in order to guide future resource management actions.

Snowmass Water and Sanitation District (SWSD), the only entity potentially affected by the Brush Creek listing during future Colorado Department of Public Health and Environment (CDHPE) wastewater discharge permitting processes, and Roaring Fork Conservancy hope to better understand potential causes of the observed macroinvertebrate impairment on the creek. Unfortunately, a relatively small amount of archived historical data exists for the Brush Creek watershed and no coordinated or long-term water quality monitoring plan operates. Thus, any assessment of water quality conditions on Brush Creek currently requires field data collection, consultation with local experts, and review of relevant scientific literature. During September of 2012 and in conjunction with efforts by Roaring Fork Conservancy and Snowmass Water and Sanitation District, S.K.Mason Environmental, LLC conducted a baseline water quality assessment in the Brush Creek watershed that focused on characterizing nutrient sources and macroinvertebrate community health. This assessment endeavored to:

- Identify the location(s) and magnitude of aquatic life use impairment;
- Characterize longitudinal patterns of select water chemistry parameters and physical attributes;
- Assess data collected in 2012 in the context of existing water quality information;
- Identify suitable long-term monitoring sites to form the basis for an ongoing monitoring program; and
- Generate high quality data from Brush Creek that meets criteria for use in resource use decision-making by both local and State entities.

Two primary activities comprised this assessment: macroinvertebrate community health assessment and a fine spatial resolution sampling effort to characterize spatial patterns in measures of water quality. Sampling locations bracketed the major areas of development in the upper portion of the Brush Creek drainage. Long-term monitoring efforts may continue to utilize these sampling locations to characterize water quality use attainment and identify intra- and inter-annual patterns in water quality conditions, and trends, and elucidate how human activity in the watershed relates to those trends.

1.2 Setting

Geology and Vegetation

Brush Creek is located within the Upper Middle Roaring Fork Watershed, designated by the 12 digit Hydrologic Unit Code (HUC) 140100040602. At its outlet to the oaring Fork River, Brush Creek drains an area of approximately 16.3 square miles characterized by a mean elevation of 9130 feet, with peak elevations near 12,800 feet (USGS Stream Stats 2013). Much of the middle and lower Brush Creek watershed contains Mancos shale hill slopes and valley bottoms of mixed alluvial fill. The Mancos shale formation, which consists of multiple fine-grained marine deposits, is commonly responsible for high salinity and other natural contaminants like selenium in groundwater over large areas of the Southern Rockies and Four Corners Southwest (DOE 2011). Mancos shale is also highly erosive and subject to instability and landslides, potentially generating large sediment influxes to surface waters during heavy rain. Various mixed glacial deposits compose many higher elevation areas in the watershed (e.g. above the resort village).

Ecosystem types in the lower watershed predominantly include big sage and upland shrub, while Snowmass Village sits in a transition zone to aspen and mixed conifer forests. Riparian vegetation generally includes deciduous species typical of the region such as willow, alder, and aspen. Riparian vegetation and channel morphology is significantly impacted, altered, or absent in some locations due to urbanization and recreation-based land uses throughout the majority of the study reach (Clarke et al. 2008). The large variation in elevation, topography, and precipitation in the watershed contribute to a complex patchwork of microclimates, which in turn sustain highly diverse ecosystem types. Thorough physical and biological descriptions of the basin can be found in State of the Roaring Fork Watershed Report (Clarke et al. 2008).

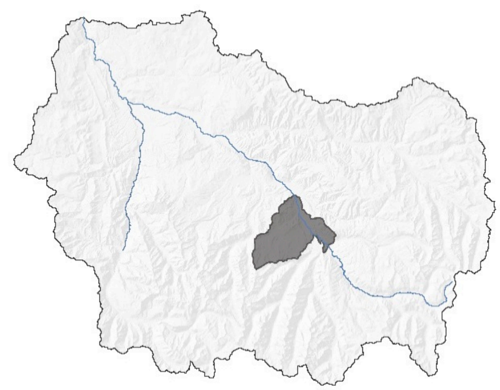


Figure 1. The darkly shaded area shows the location of Brush Creek subwatershed (HUC 140100040602) within the greater Roaring Fork River Basin.

Hydrology

Typical of semi-arid high mountain watersheds in the Rockies, Brush Creek experiences an annual flow regime dominated by snowmelt runoff. Snowpack accumulates throughout the winter and begins melting most years during April or May. Streams experience high flows throughout May and June. Peak streamflow usually occurs between the first and third week of June. Convective summer thunderstorms, sometimes in conjunction with the North American Monsoon, may cause isolated and highly variable increase in stream flows from the end of June to mid-September. From late summer to early spring, streams are at their lowest levels. In Brush Creek, this may range from 2 or 3 cubic feet per second (cfs) to less than 1 cfs when low winter temperatures slow the flow of groundwater into the stream to negligible levels. Brush Creek is not gauged, and long term records describing annual water yield in the basin are not available at this time.

The hydrological regime has special implications for water quality; certain impacts may only be observed during specific times of the year with limited and unpredictable duration. For example, the low-flow assessment described in this report captured conditions of a relatively static system during stable fall weather, and does not characterize the high flow conditions (and concurrent elevations in suspended sediment and total suspended solids (TSS) levels) that occur during snowmelt or heavy rain events.

Brush Creek is part of a highly plumbed stream system. Water diversions from East Snowmass Creek over a low divide into the upper portion of West Brush Creek supply municipal drinking water and irrigation needs of the Snowmass Village resort community, as well as water for snowmaking on the ski area. Recent enlargement of

Ziegler Reservoir aims to enhance system reliability for municipal water supplies. Prior to trans-basin diversions from Snowmass Creek to Brush Creek (established in the late 1800s), flows on Brush Creek may have been fully intermittent or ephemeral.

High visitor occupancy rates in the Town of Snowmass Village and the desire for snowmaking during winter drive peak water demands during times when flows are lowest in Brush Creek. Irrigation demands for limited agriculture in the lower basin, resort landscaping, and the Snowmass Golf Club, are highest from early summer through fall. This seasonal mismatch of water availability and human use likely impacts water quality in Brush Creek.

2. Methods and Results

2.1 Review of Historical Data

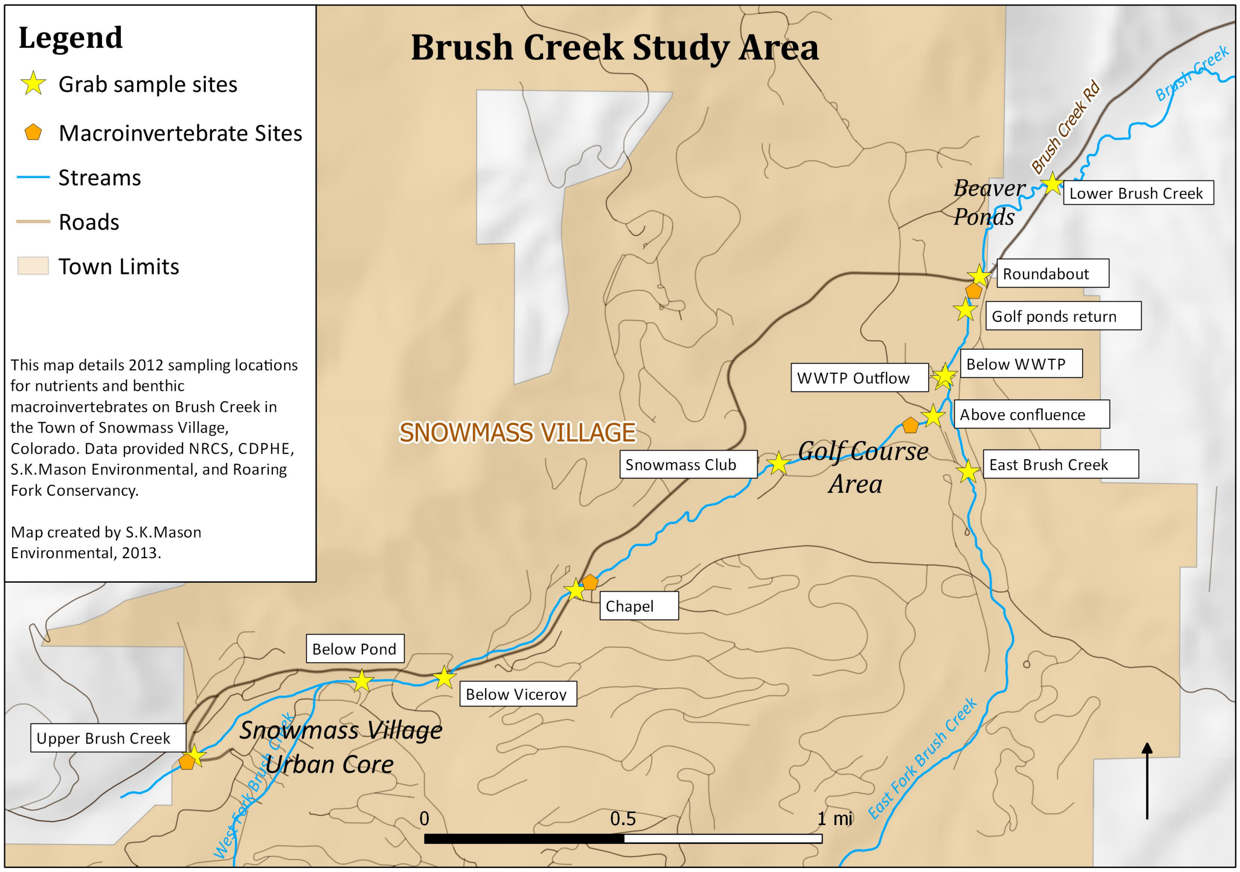
A literature search identified historical water quality information for Brush Creek. The study reach extended from the upper crossing of Brush Creek Road near Snowmass Village core to the lower Brush Creek Road crossing approximately 0.3 miles below the intersection with Highline Road (aka the "Roundabout"). Data sources included reports produced by Roaring Fork Conservancy, data collected by CDPHE Water Quality Control Division (WQCD), and planning documents from the Northwest Colorado Council of Governments (NWCCOG). Existing water quality summaries for Brush Creek may be found in the 2008 State of the Watershed Report compiled by RFC and Ruedi Water and Power Authority, and the 2011 Northwest Colorado Council of Governments Section 208 Regional Water Quality Management Plan. One additional site outside of the study is reported here for additional reference (Highway 82 Bridge/River Watch 771) because it contains the longest time record of water quality sampling for Brush Creek.

The 2008 State of the Watershed Report identified infrequent exceedances of State standards for pH at one site near the Highway 82 bridge between 2000 and 2003. The State standard for pH in Brush Creek is 6.5-9.0, and nine observations at the Highway 82 site exceeded a value of 9.0 between 2000 and 2003 (Clarke et al. 2008). Phosphorous levels above Environmental Protection Agency (EPA) recommendations also occurred in a number of samples at the same location during a similar time period. Roaring Fork Conservancy conducted a targeted water quality study in 2006 that found no pH or phosphate exceedances, but did indicate a correlation between higher pH levels and low flows in the fall (RFC 2007). High pH was suggested to occur concurrently with low flows, while high phosphorous values were observed at both low and high flows (Clarke et al. 2008). Total phosphorous values were defined as 'high' based on recommended EPA concentrations of 0.1 mg/l for rivers and streams not entering lakes. Prior to 2013, Colorado had no approved instream standard for phosphorous.

Section 208 of the Federal Clean Water Act mandates regional Water Quality Management Planning (WQMP) for non-point source pollution via a designated regional planning agency. NWCCOG undertakes these activities for the region, including Eagle and Pitkin Counties in the Roaring Fork watershed. As part of its 2012 WQMP Update, NWCCOG summarized past information on Brush Creek and concluded, based on River Watch data from 2006-2011, that exceedances of State water quality standards for nutrients were not a consistent major concern (NWCCOG 2012).

Limited data for the study reach prior to 1999 was available in EPA's STORET Legacy Data Warehouse and the USGS Colorado Water-Quality Data Repository. Historical data archived in these data stores primarily includes United States Forest Service (USFS) sampling conducted in the 1970's. Because this study focused on post-development conditions in the watershed and did not include long-term trend analysis, that data was excluded from consideration. Water quality data collected from 2000-2011 was retrieved from EPA's Modern STORET database. Data extracted from STORET were collected either by River Watch or CDPHE at five sites collocated or nearby to sites sampled in the field data collection phase of this assessment. A majority of samples were collected in either February or June, suggesting that sampling times were targeted to capture low and high flow specifically. Data summaries are provided in Section 2.3 *Water Sampling*.

Figure 2. Water sampling locations, from the most upstream site at Upper Brush Creek Rd to the most downstream site at Lower Brush Creek Rd.



2.2 Macroinvertebrate Assessment Methodologies

During this study, benthic macroinvertebrate sampling occurred at four sites bracketing various land uses in the study reach (Figure 2, Table 1). Previous macroinvertebrate data for Brush Creek is reported for one site, the Roundabout, and included in RFC's 2012 report *A Review of Aquatic Life and Stream Health in the Roaring Fork Watershed*. Samples were collected during low flow in the fall, when the best representation of the aquatic insect community is typically found. One site above resort development (Upper Brush Creek) was expected to have few impacts associated with anthropogenic sources. Further downstream, sites bracketed various major land uses and potential point source influences. Using a 1 ft^2 Surber Sampler, a total of 10 stream bottom samples were combined into a composite sample for each site. This collection methodology was based on White River National Forest macroinvertebrate sampling protocols (Grove 2012) and developed in conjunction with RFC and Timberline Aquatics, Inc. This sampling methodology is considered semi-quantitative and admissible for yearly State-level data calls. Samples were preserved in 80% ethyl alcohol and transported to Timberline Aquatics, Inc. in Fort Collins, CO for sorting and identification.

In the fall of 2010, WQCD published specific guidelines for benthic macroinvertebrate sampling and analysis using an MMI to assist in the evaluation of aquatic life in Colorado (CDPHE 2010). The MMI provides a single index score based on five or six equally weighted metrics. The group of metrics used in MMI calculations depends on the location of the sampling site and corresponding Biotype (Mountains, Transitional, or Plains). Each of the metrics used in the MMI produces a value that is adjusted to a scale from 1 to 100 based on the range of metric scores found at "reference sites" in the state of Colorado (Tables 2 & 3).

All sampling sites in the Brush Creek study area were contained within Biotypes 1 and 2. Biotype 1 includes streams in the Transitional Zone between higher elevation and low elevation habitats in Colorado. Sites in Biotype

2 are considered higher gradient, mountain streams. Individual metrics currently used to assess data collected in Biotype 1 include: Percent Non-insect Taxa, EP Taxa, Percent Chironomidae, Percent Sensitive Plains Families, Predator-Shredder Taxa, and Clinger Taxa. Individual metrics currently recommended for assessments in Biotype 2 include: Total Taxa, Predator and Shredder Taxa, Percent Ephemeroptera, Beck's Biotic Index, and Clinger Taxa. These metrics were employed at the appropriate sites to assist in data analysis for this study. See Appendix A for full site descriptions.

Table 1. Macroinvertebrate sampling site locations for the Brush Creek study area in the fall of 2012.

Site	Site Name	Description
1	Upper Brush Creek	Upstream of culvert at top of Brush Creek Rd
2	Chapel	Below nature trail bridge at Snowmass Chapel
3	Above Confluence	Upstream of confluence with East Brush Creek
4	Roundabout	Downstream of roundabout below bike path bridge

Threshold MMI values that determine attainment or impairment for aquatic life use differ depending on the Biotype (Table 2). Metric scores that fall between the thresholds for attainment and impairment (the "grey zone") require further evaluation using two auxiliary metrics, the Shannon Diversity (Diversity) and Hilsenhoff Biotic Index (HBI), in order to determine if the site is in attainment or impaired for aquatic life use (Table 3). If a study site produces an MMI score in the "grey zone" the auxiliary metric scores must be less than the HBI threshold *and* greater than the Diversity threshold to achieve an aquatic life use attainment designation.

Diversity values are used to detect changes in macroinvertebrate community structure. In unpolluted waters, Diversity values typically range from near 3.0 to 4.0. In polluted waters this value is generally less than 1.0. The HBI metric is a measure of a community assemblage's tolerance to organic enrichment; lower numbers indicate a more sensitive community. Values for the HBI range from 0.0 to 10.0, and increase as water quality decreases.

In order to assist in the evaluation of aquatic life in the study area, additional individual metrics were applied and compared among sites. These individual metrics were selected because they are widely used in western streams and can provide additional insight into MMI score interpretation. A description of each of these metrics has been provided below:

Table 2. MMI scores for aquatic life use Attainment and Impairment in the two biotypes represented in the Brush Creek Watershed.

Biotype	Attainment Threshold	Impairment Threshold
Transition (Biotype 1)	>52	<42
Mountains (Biotype 2)	>50	<42

Table 3. Auxiliary metric scores applied to determine aquatic life use Attainment/Impairment for those sites that initially score in the 'grey zone'.

Biotype	HBI	Diversity
Transition (Biotype 1)	<5.4	>2.4
Mountains (Biotype 2)	<5.1	>3.0

<u>Taxa Richness:</u> Taxa Richness is a metric often used to provide an indication of habitat adequacy and water quality. Taxa Richness, or the total spectrum of taxonomic groups present at a given site, will generally decrease when exposed to decreasing water quality or habitat degradation (Resh and Jackson 1993). The Taxa Richness measurement is reported as the total number of identifiable taxa collected from each sampling location. This metric is utilized as part of the Biotype 2 MMI calculation.

<u>Ephemeroptera Plecoptera Trichoptera (EPT):</u> The design of this metric is based on the assumption that the orders of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) are generally more sensitive to pollution and environmental stress than other benthic macroinvertebrate orders (Lenat 1988). The value for this metric will naturally vary among river systems, but it can be an excellent relative indicator of

disturbance within a specific drainage. The EPT value is expected to decrease in response to a variety of stressors including nutrients (Wang et al. 2007).

Clinger Taxa: This metric is included in both the Biotype 1 and Biotype 2 MMI calculations. Excessive sedimentation, rapid changes in discharge, or excessive algal growth can cause a reduction in this metric value (Hughes & Brossett 2009).

Insect Taxa: The number of insect taxa is used as an individual evaluation tool in this study because it is effective at detecting stress in Colorado mountain streams (CDPHE 2010). Insect Taxa is reported as a total count of insect taxa at each site. It is expected that the number of insect taxa will decrease as a response to disturbance. Insect taxa are generally considered more sensitive to disturbance than non-insect taxa.

Analysis of macroinvertebrate data from the four sites included in the Brush Creek study area indicated that much of the upstream portion of the study area was impaired for aquatic life use in the fall of 2012 (Table 4, Figure 3). The two sites above and below Snowmass Village both produced MMI scores in the "grey zone" and auxiliary metrics subsequently indicated impairment. Downstream of these two sites (above the confluence of the East Fork of Brush Creek) aquatic conditions appeared to decline further with an MMI score of 35.9 firmly below the impairment threshold. The farthest downstream site in this study area (Roundabout) produced the highest MMI score among the four sites, and although the MMI score was again initially in the "grey zone", assessment of auxiliary metrics indicated aquatic life use attainment (Table 4, Figure 3). Full descriptions, including site photos, are included for each site in Appendix A.

Comparison of functional feeding group proportions also supported MMI scores and provided additional insight into changes in macroinvertebrate community function that occurred in Brush Creek (Table 5, Figure 4). Healthy macroinvertebrate communities display a population diversified across multiple feeding groups, with a measurable presence of the more-specialized and selective feeders such as predators, scrapers, and shredders. On Brush Creek, the Collector-Gatherer feeding group dominated the three upstream sites (Above Village, Below Chapel, and Above Confluence), with relatively low representation by more specialized groups. The most downstream site on Brush Creek (Roundabout) exhibited better proportional balance among feeding groups, which was an indication of improved aquatic conditions and helped produce a higher MMI score (Tables 4 & 5, Figure 4).

Table 4. Metric results from 2012 sampling on Brush Creek. MMI scores which are not in attainment for aquatic life use are RED. For sites initially in the grey zone, auxiliary metrics are applied, and final designation is either reported in RED (Impaired) or GREEN (Attainment). Both the Diversity and HBI auxiliary scores must be in attainment in order to designate a site in attainment for aquatic life use.

Metric	Biotype 2	Biotype 1		
	Upper Brush Creek	Chapel	Above Confluence	Roundabout
Taxa Richness	25	25	23	23
EPT	8	8	5	8
Clinger Taxa	5	6	5	8
Insect Taxa	18	19	16	18
Diversity	2.05	2.09	1.81	3.00
HBI	4.42	4.23	4.47	3.40
MMI	**43.5**	**43.7**	**35.9**	**50.2**

S.K.Mason Environmental, LLC

Table 5. Relative abundance of functional feeding groups at 2012 sampling locations along Brush Creek.

Functional Feeding Group	Above Village	Below Village	Above Confluence	Roundabout
Collector-Gatherer	84.7%	83.7%	82.1%	28.4%
Collector-Filterer	0.0%	2.7%	3.3%	38.3%
Shredder	4.2%	0.6%	0.3%	5.6%
Scrapers	2.6%	2.4%	10.3%	24.3%
Predators	8.5%	8.2%	1.2%	2.2%
Omnivore	0.0%	2.4%	2.7%	1.2%

Figure 3. MMI scores for fall 2012 on Brush Creek. The green dashed line represents aquatic life use Attainment thresholds; the red represents the Impairment threshold. After applying auxiliary metrics, only the Roundabout site achieved Attainment of aquatic life use.

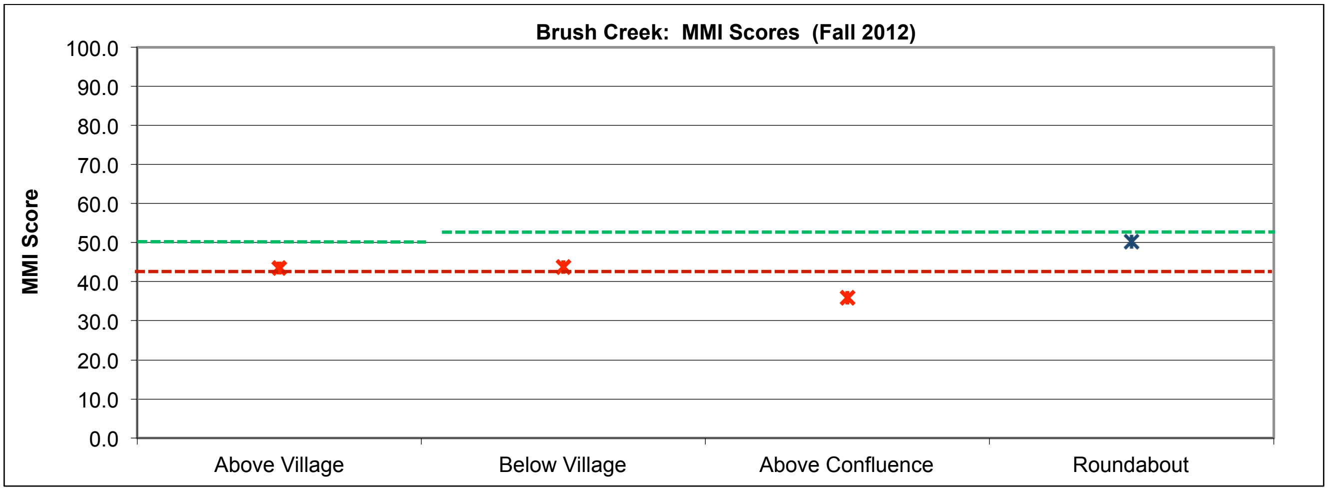
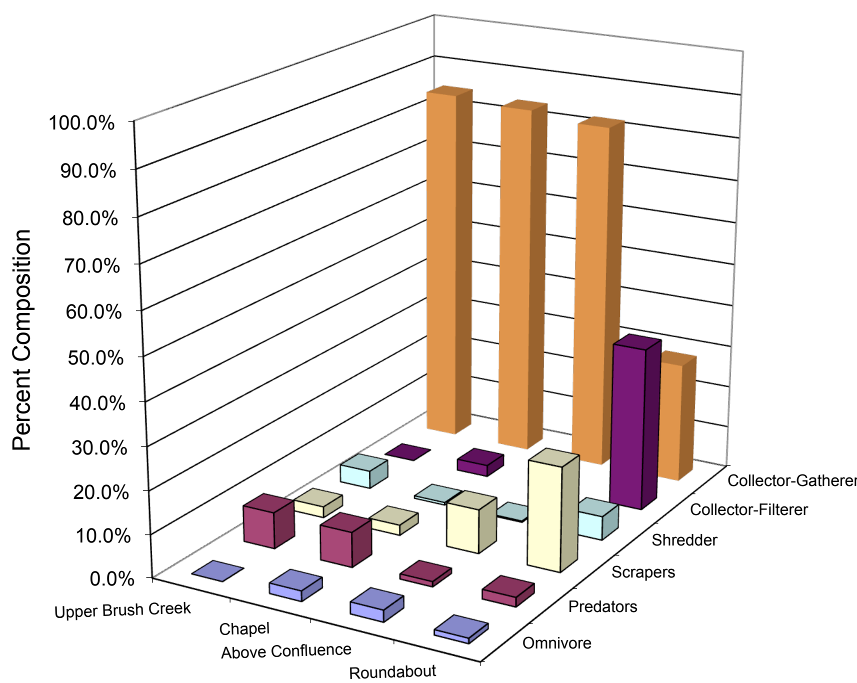


Figure 4. Functional feeding group percent compositions for 2012 sites in the Brush Creek study area.



2.3 Water Sampling

Water chemistry sampling occurred at 12 locations along Brush Creek on 9/19/2012. The goal of this quasi-synoptic sampling effort was to identify discrete segments on Brush Creek where pollutant levels may change and subsequently estimate nutrient loading for each segment. Locations were selected to characterize gradients of water quality conditions along the study reach from top to bottom. Sites bracketed major land use classifications as well as potential point-source water quality impacts (Table 6, Figure 2). The Upper Brush Creek site was used to characterize background levels for the basin. Although that site has experienced some physical alteration, the watershed draining to that point is predominantly forested or relatively undeveloped, grass-covered ski slopes. The downstream sites traversed a gradient of increasing urban-influenced stream segments near Snowmass Village. The Chapel site provided a transition point between the urbanized resort village and the less-dense residential development surrounding the golf course. Samples collected near the confluence of Brush Creek and East Brush Creek bracketed the golf course and Wastewater Treatment Plant (WWTP) outfall. The two sites at the Roundabout and Lower Brush Creek Road bridge captured the integrated effects of all land uses and point discharges.

Table 6. Grab sample site locations (as shown on Figure 2).

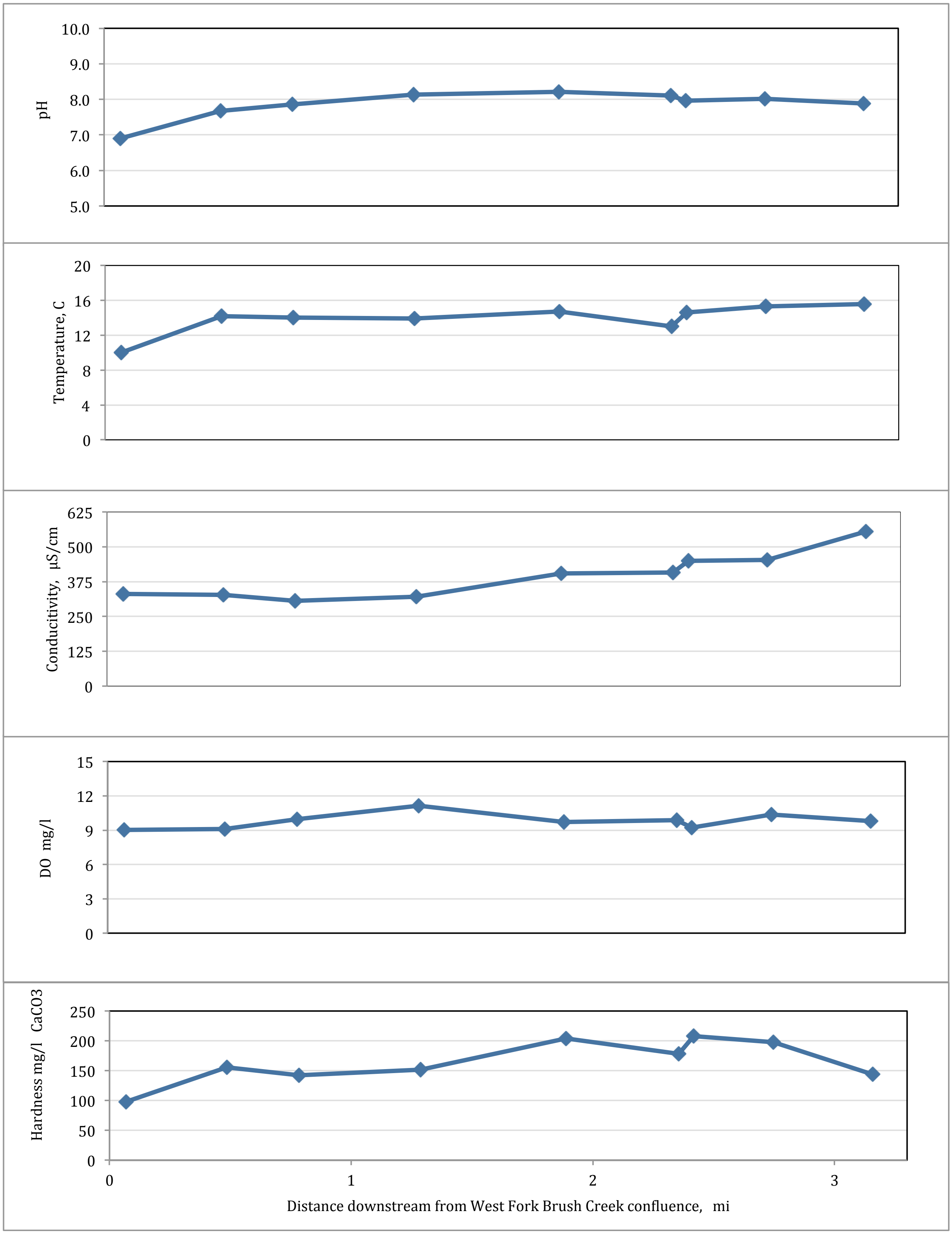
Site	Site Name	Description
1	Upper Brush Creek	Upstream of culvert at top of Brush Creek Road
2	Below Pond	Next to stormwater pond at Tamarack Circle
3	Below Viceroy	Upstream of Wood Road Bridge
4	Chapel	Below nature trail bridge at Snowmass Chapel
5	Snowmass Club Circle	Above stream culvert at top of Snowmass Club Circle
6	Above Confluence	Upstream of confluence with East Brush Creek
7	East Brush Creek	Upstream of Snowmass Club Circle road crossing
8	WWTP Outflow	Effluent pipe from WWTP ponds
9	Below WWTP	Upstream of headgate to Golf course ponds canal loop
10	Golf Pond Return	Below cart path bridge before joining Brush Creek
11	Roundabout	Downstream of roundabout below bike path bridge
12	Lower Brush Creek Rd	At bike path bridge below lower Brush Creek Road crossing

Physical Parameters

Physical field parameters were collected at each site with a portable water quality probe. A YSI 55 multimeter, calibrated in the lab prior to sampling, measured dissolved oxygen and water temperature in situ at each site. An Extech II © temperature-compensating meter measured pH and specific conductance. Temperature, conductivity, pH, and dissolved oxygen exhibited uniform patterns through most of the study reach (Figure 5). Although pH showed a slight downstream increase near the top of the drainage, it remained near or just below 8.0. Temperature rose slightly as the stream moved from the upper, forested site into the village area then maintained relatively constant levels. A slight drop coincided with the addition of cooler water from the East Fork of Brush Creek. Conductivity, a surrogate for the total amount of dissolved ions present in the water column, gradually increased between the Chapel site and the Roundabout site. A slightly sharper increase occurred below the Roundabout site. Dissolved oxygen concentrations showed the stream well-saturated at all sampling locations.

Hardness (a measure of dissolved magnesium and calcium reported as equivalent mg/l of $CaCO_3$), is primarily derived from chemical weathering of rocks and soils within the watershed. Hardness increased initially as the stream entered the Village, a second increase occurred below the Chapel site near the golf course. Levels began to decrease below the Roundabout.

Figure 5. Longitudinal profiles for physical parameters on Brush Creek, starting from site "Upper Brush Creek Road".



S.K.Mason Environmental, LLC

Nutrients

Grab samples at each site were collected in 1000 ml polyethylene bottles prepared at SWSD. Bottles were triple rinsed with stream water prior to sample collection at each site. The (SWSD) analyzed water samples in its WWTP lab. In the lab, an additional pH measurement was collected from each grab sample. A Hach Intellical ISEN03181 probe and HQ440d meter measured nitrate concentrations. A Hach DR4000 Spectrophotometer analyzed samples for ammonia, nitrite, and nitrate concentrations using procedures outlined by Standard Method 4500 for NH3 C, NO2-B and NO3-D. Phosphorous concentrations were analyzed using EPA method 365.3.

Mean nutrient concentrations at each site were generally low and consistent with expectations for area streams; however they were slightly above previously observed ranges for Brush Creek (Tables 7, 8). A noticeable jump occurred below the WWTP outflow for all parameters, an expected trend for nutrients below a treatment plant (Figure 6). Due to the very low flows present in Brush Creek during fall of 2012, the increase is pronounced. However, concentrations remain below existing WQCD standards. The highest nitrate observation occurs immediately below the WWTP with a concentration of 11.4 mg/l, before dropping to 6.2 mg/l at the next site. The state instream standard for nitrate in Brush Creek (Segment 4 of the Roaring Fork Basin in Regulation 33) is 100 mg/l based on a use classification of Aquatic Life Cold 1, Recreation E, and Agriculture (WQCC Regulation 33).

Concentrations of most parameters peak at the site below the WWTP then decrease over several hundred meters towards the final two sites. Notable exceptions are the ammonia observations at the mid-village site (Below Viceroy) in the upper portion of the creek, and at the lowest site (Lower Brush Creek Road) (Figure 7, Table 7).

Comparing the 2012 levels for select nutrient parameters to previous River Watch and CDPHE, observed values for inorganic nitrogen and ammonia from September 2012 are generally similar to previous (Table 8). River Watch reports Total Phosphorus in STORET, while current and previous sampling conducted by RFC in 2006 and 2012 is reported in Total Orthophosphates by SWSD lab.

Table 7. Nutrient concentrations and field parameters by site, Brush Creek.

Site Name	**pH** -	**DO** *mg/l*	**SC** *µS/cm*	**NH_3** *mg/l Total*	**NH_3** *mg/l Unionized*	**NO_3** *mg/l*	**NO_2** *mg/l*	**PO_4** *mg/l*	**Hardness** *mg/l as $CaCO_3$*	**Inorg. N** *mg/l (NO_3+NO_2)*	**Total N** *mg/l*
Upper Brush Cr.	6.9	9.0	330	0.073	0.000	0.24	0.0026	0.09	98	0.24	0.32
Below Ponds	7.7	9.1	327	0.037	0.000	0.42	0.0033	0.14	156	0.42	0.46
Below Viceroy	7.9	9.9	306	0.22	0.003	0.51	0.0023	0.23	142	0.51	0.73
Chapel	8.1	11	321	0.070	0.002	0.39	0.0040	0.12	152	0.40	0.47
Club Circle	8.2	9.7	404	0.054	0.002	0.72	0.0042	0.11	204	0.72	0.78
Above EBC	8.1	9.9	408	0.068	0.001	0.57	0.0028	0.10	178	0.57	0.64
Below WWTP	8.0	9.2	449	0.11	0.003	11	0.0058	4.50	208	11	12
Roundabout	8.0	10	453	0.087	0.002	6.2	0.031	2.20	198	6.2	6.3
Lower Brush Cr.	7.9	9.8	555	0.28	0.004	3.8	0.019	1.56	144	3.8	4.12
E. Fork Brush Cr.	7.9	8.9	456	0.12	0.001	0.30	0.0064	0.28	242	0.31	0.42
WWTP Outfall	7.8	11	382	0.064	0.001	19.6	0.0057	7.50	198	20	20
Golf Return	7.9	8.6	474	0.13	0.003	5.5	0.046	2.01	198	5.6	5.7
Summary Statistics											
Mean	7.9	9.8	395	0.11	0.0018	2.7	0.0083	1.0	176.5	4.1	4.3
Min	6.9	8.6	306	0.0	0.0001	0.2	0.0	0.1	98	0.24	0.32
Max	8.2	11.2	555	0.3	0.0044	19.6	0.0	7.5	242	20	20
Std Dev	0.34	0.78	76	0.07	0.012	6.0	0.01	0.01	39	6.0	6.0
CO Water Quality Standard (Cold Water I, Agriculture, Recreation)											
	6.5-9	>6.0	--	--	0.02 Site specific for Brush Ck.	100	0.05	0.11 annual median	--	--	1.25 annual median

Figure 6. Longitudinal profile of nutrient concentrations on Brush Creek, starting from site "Upper Brush Creek Road."

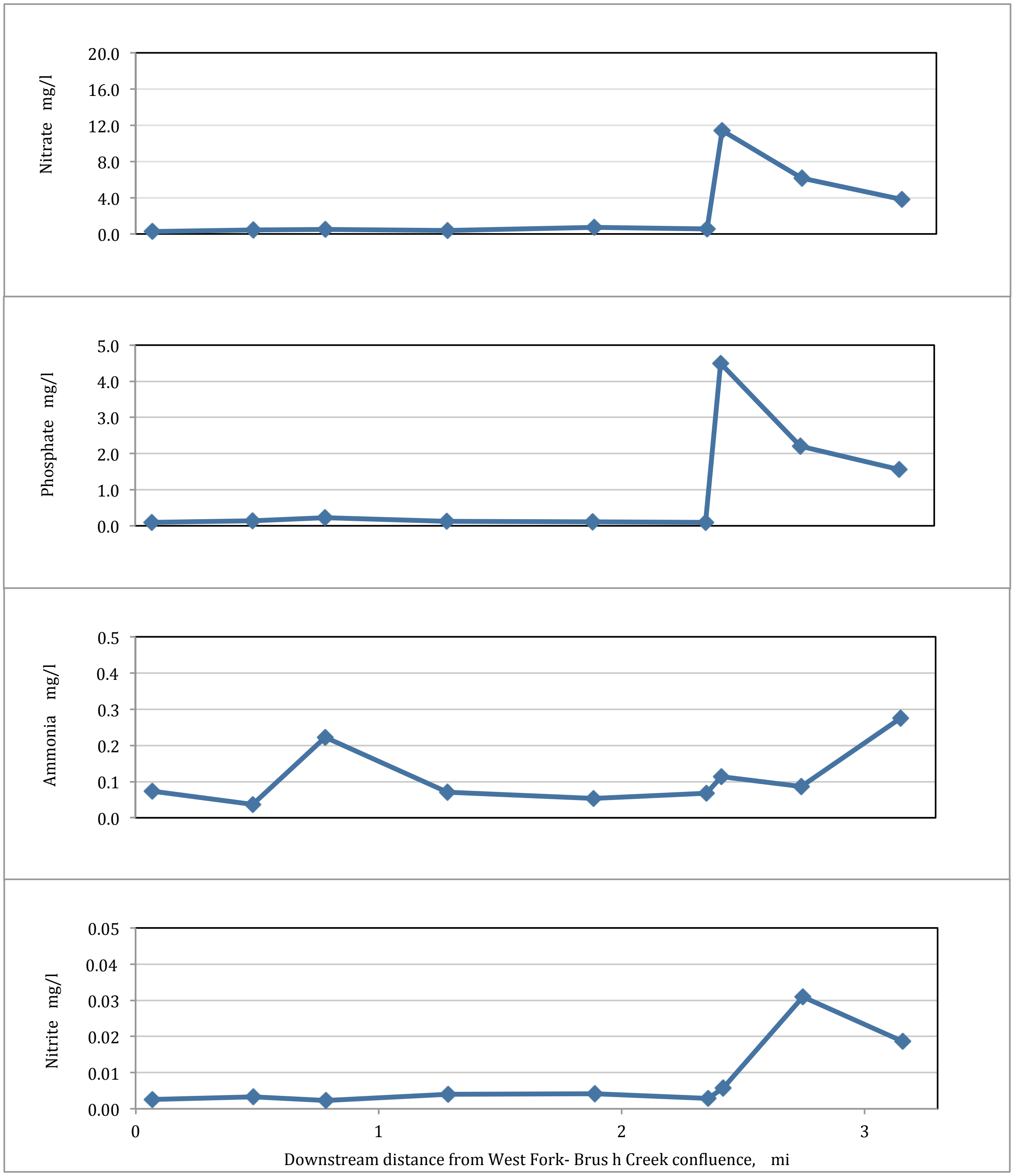


Table 8. Descriptive statistics for water samples collected by River Watch on Brush Creek, 2001-2011. September 2012 values are included in the right column for comparison. Values of 'ND' are produced by samples containing concentrations below the methodological detection limit.

Inorganic N (Nitrate + Nitrite), 2001-2011				**Inorganic N (Nitrate + Nitrite), 2012**	
Site	*# Samples*	*Median (mg/l)*	*Range (mg/l)*	*# Samples*	*(mg/l)*
Village	0	-		1	0.51
Chapel	9	0.11	0.00 - 1.24	1	0.40
Snowmass Club	9	0.15	0.00 - 0.66	1	0.72
Roundabout	9	0.54	0.27 - 10.1	1	6.2
Lower BC Road	1	0.82		1	3.9
Ammonia N (Total), 2001-2011				**Ammonia N (Total), 2012**	
Site	*# Samples*	*Median (mg/l)*	*Range (mg/l)*	*# Samples*	*(mg/l)*
Village	0	-		1	0.22
Chapel	9	ND	0.00 - 0.02	1	0.070
Snowmass Club	8	0.22	0.00 - 21	1	0.054
Roundabout	9	ND	0.00 - 0.05	1	0.087
Lower BC Road	1	ND		1	0.28
Phosphate (Total), 2006		**(From *RFC 2007*)**		**Phosphate (Total), 2012**	
Site	*# Samples*	*Median (mg/l)*	*Range (mg/l)*	*# Samples*	*(mg/l)*
Village	0			1	0.23
Chapel	4		0.13 - 1.39	1	0.12
Snowmass Club	0		-	1	0.11
Roundabout	4		0.23 - 2.72	1	2.2
Lower BC Road	0			1	1.6

2.4 Load Calculations

Load is the mass flux of a dissolved chemical parameter and is calculated from the dissolved concentration of the parameter multiplied times the volumetric flow of the stream for that site.

Load = Concentration x Discharge (Reported here in pounds per day)

Instantaneous load is the mass of nutrients carried in the stream at each discrete sampling site. For this study, *cumulative load* was calculated as the sum of all positive load increases for each individual reach over the entire study length. This was calculated to understand the relative contribution of each individual sampled segment.

Table 9. Discharge by location on sampling date

Site	**cfs**	**gpm**	**l/s**
Upper Brush Creek	0.3	135	8.5
Chapel	0.3	135	8.5
WWTP Outflow	0.9	404	25
Roundabout	1.9	853	54

Estimating loading for water quality parameters required the measurement of streamflows in Brush Creek. Discharge measurements were collected at four sites: Upper Brush Creek, near the Chapel, the WWTP Outflow pipe, and the Roundabout (Table 9). No established gages exist in the watershed; therefore, stream discharge was measured manually, except the WWTP Outfall. Measuring flow in steep and rocky mountain streams is problematic for traditional velocity-area methods because few suitable stream cross sections are available for measurement. On Brush Creek, one suitable cross section existed below the culvert at the Roundabout site. A SONTEK Flowtracker current velocimeter measured discharge at this site. On the upper portions of Brush Creek, discharge was measured at two additional culverts in the upper study area using a volume-time method: one at the upper Brush Creek Road crossing, and the other near the Chapel site. A 14.5 gallon bucket was placed under the culverts and timed with a stopwatch until full, with 3 repetitions averaged at each site. SWSD records provided WWTP outflow rates. Discharge numbers were subsequently used to estimate daily loads, or mass flux, for all nutrient parameters. Assuming that discharge only increased significantly at major tributary junctions, it was possible to estimate an approximate discharge at all sites from these four observations. Flow in East Brush Creek was approximated by subtracting the WWTP outflow and Brush Creek discharge at the Chapel from the measured value at the Roundabout site.

The instantaneous nutrient load of Brush Creek generally remained low throughout the upper study reach, increasing rapidly below the WWTP (Table 10, Figure 7). With the exception of ammonia, instantaneous stream load decreased over the last half mile of the study area between the WWTP and the final downstream sampling site. Over the entire study reach, the cumulative load of nitrate was 117 lbs./day and phosphate was 46 lbs./day. Effluent from the WWTP plant comprised a majority of the nitrate loading to Brush Creek (Table 11). Below the WWTP outfall, nitrate and phosphate loads rapidly attenuated, although concentrations remained above background levels at the lowest sampled location. Ammonia loads increased at the bottom of the study reach.

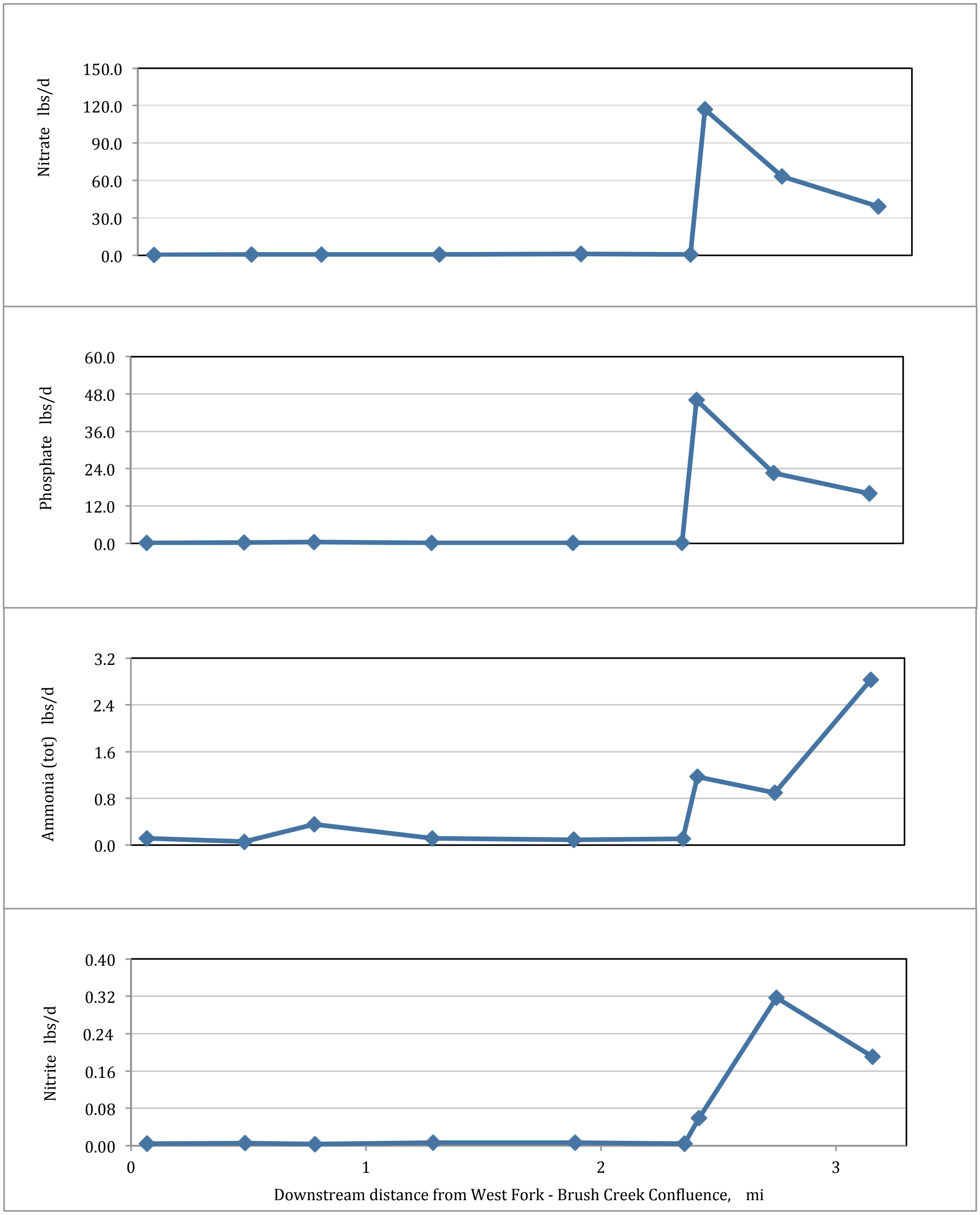
Table 10. Nutrient loads.

Site Name	Distance *mi*	Flow *cfs*	NH_3 (tot) *lbs/d*	NO_3 *lbs/d*	NO_2 *lbs/d*	PO_4 *lbs/d*	
Upper Brush Cr.	0.07	**0.3**	**0.12**	**0.39**	**0.00**	**0.15**	*Loads in **bold** are based on actual discharge measurements, the rest use estimated discharge.*
Below Ponds	0.5	0.3	0.06	0.68	0.01	0.23	
Below Viceroy	0.8	0.3	0.36	0.82	0.00	0.37	
Chapel	1.3	**0.3**	**0.11**	**0.64**	**0.01**	**0.19**	
Club Circle	1.9	0.3	0.09	1.16	0.01	0.18	
Above EBC	2.3	0.3	0.11	0.91	0.00	0.16	
Below WWTP	2.4	1.9	1.17	116.84	0.06	46.12	
Roundabout	2.7	**1.9**	**0.89**	**63.24**	**0.32**	**22.55**	
Lower Brush Cr.	3.2	1.9	2.83	39.25	0.19	15.99	
E Fork	-	0.7	0.43	1.14	0.02	1.06	
WWTP Outfall	2.4	**0.9**	**0.31**	**95.16**	**0.03**	**36.41**	
Golf Return	2.6	-	-	-	-	-	

Table 11. Absolute load by stream segment, and percent of total cumulative nutrient load by segment, nitrate and phosphate (tributary sites not listed).

Brush Creek Sites	Nitrate (NO_3)			Phosphate (PO_3)		
	Gain, lb/d	Loss lb/d	% Load	Gain, lb/d	Loss lb/d	% Load
Upper Brush Cr.	0.11	0.00	*0.1%*	0.20	0.00	*0.4%*
Below Ponds	0.29	0.00	*0.3%*	0.08	0.00	*0.2%*
Below Viceroy	0.14	0.00	*0.1%*	0.15	0.00	*0.3%*
Chapel	0.00	0.18	*0.0%*	0.00	0.18	*0.0%*
Club Circle	0.52	0.00	*0.4%*	0.00	0.02	*0.0%*
Above EBC	0.00	0.25	*0.0%*	0.00	0.02	*0.0%*
Below WWTP	115.93	0.00	*99.1%*	44.96	0.00	*99.1%*
Roundabout	0.00	53.60	*0.0%*	0.00	23.57	*0.0%*
Lower Brush Cr.	0.00	23.98	*0.0%*	0.00	6.56	*0.0%*
Total	**117.0**	**78.0**	**100%**	**46.4**	**30.3**	**100%**

Figure 7. Longitudinal profile of select nutrient loads (lbs/day) in Brush Creek during 2012 base flow sampling.



3. Explanation of Results

3.1 Macroinvertebrate Community Health

Biological monitoring, also known as biomonitoring, refers to the systematic use of living organisms to evaluate the aquatic environment (Merritt et al. 2008). Aquatic macroinvertebrates have been used more than any other group of organisms to assess impacts to streams and aquatic life from urban areas (Paul and Meyer 2001). In recent years, biomonitoring has become an important tool in assessing the quality of rivers and streams (Plafkin et al., 1989, Barbour et al., 1999, Paul et al. 2005, Hawkins 2006). Results provided by consistent sampling practices and accurate identifications can provide valuable information regarding aquatic conditions. Sustained biological monitoring is essential to understanding the effects of long-term influences such as population growth, urban development, and changes in land-use practices (Likens and Lambert 1998, Voelz et al. 2005).

Biomonitoring programs that assess benthic macroinvertebrates realize advantages not achieved through physical or chemistry-based water quality assessments alone (Ward et al. 2002). Individual aquatic macroinvertebrate species depend on specific environmental conditions for their survival. Consequently, macroinvertebrate assemblages integrate a wide range of environmental conditions and/or disturbances experienced by a stream across space and through time. The Colorado WQCD has adopted the MMI scoring system to determine the level of impairment in streams using benthic macroinvertebrates. The MMI evaluates macroinvertebrate communities at test sites using several measures of community health relative to high quality reference streams in similar regions across the state.

In Colorado, a designation of Impaired Aquatic Life usage means that certain measures of benthic macroinvertebrate communities are diminished or compromised in comparison to healthy reference streams in similar regions. Ongoing macroinvertebrate sampling can help illuminate the nature and geographic distribution of this impairment, as well as extend the depth of the dataset that determines the legal designation. However, unlike a statutory water quality standard for a chemical constituent, Impaired Aquatic Life is an integrative measure and does not readily identify a cause or source of impairment. Continued water chemistry sampling for a spectrum of water quality parameters generally improves understanding of the sources of impairment.

Macroinvertebrate samples collected at four sites (Figure 2) on Brush Creek bracketed changes in land use along the stream corridor. Results indicated that Brush Creek is generally impaired for aquatic life use as a result of some individual stressor or combination of multiple stressors. The upper three sites, (Upper Brush Creek, Chapel, and Confluence), all produced scores in the “grey zone” and auxiliary metrics indicated aquatic life use impairment. The fourth site (Roundabout), below the WWTP, golf course, and village, received an MMI score also in the “grey zone”, but auxiliary metrics indicated this site was in attainment for aquatic life use. This spatial arrangement of MMI scores does not parallel patterns of nutrient enrichment in the creek, suggesting ambient nutrients are not the primary contributor to poor aquatic life conditions. Functional feeding group composition analysis further supported MMI scores. Little diversity and balance in feeding group compositions occurred in the upper three sites. The under-representation in various functional feeding groups at the three upper sites suggested that one or more perturbations prevented the normal development of community balance and function. The distribution of feeding groups at the lower site near the Roundabout included more diversity in specialized feeding groups—consistent with improved conditions for aquatic life.

MMI scores cannot speak to a specific cause of impairment; rather they indicate the general presence of one or more perturbations in the stream that result in macroinvertebrate communities that are less functional or balanced than healthy reference streams. In this case, multiple stressors may contribute to stream impairment, including stormwater runoff from the densely urbanized village or heavily landscaped areas, physical channel alteration and riparian habitat destruction from multiple phases of resort development, and altered flow regimes from diversions and drought years. Regardless of cause, both sites near the village produced scores in the “grey zone” between MMI thresholds for attainment/impairment, and the site above the confluence between Brush

Creek and East Brush Creek scored below the threshold. These scores have regulatory importance to area stakeholders, as they confirm the appropriateness of Brush Creek's designation as a 303(d) listed water body.

Of additional concern is that the most upstream site, expected to represent non-impacted reference conditions, also scored below the threshold for aquatic life use impairment. This may indicate that the upper Brush Creek road site is not an adequate location for background characterization. Although the site is above the majority of development, some level of physical alteration or presence of a chemical stressor appears to impact upper Brush Creek. Previous sampling by the USFS above the town limits of Snowmass Village produced scores in attainment for aquatic life use on the East Fork and West Fork tributaries of Brush Creek (Prehearing Statement Reg 93 WQCD 2011). Further investigation into those results may be helpful in identifying a suitable location for characterizing background conditions.

3.2 Stream Chemistry and Nutrient Loading

Stakeholders previously identified nutrients as a water quality constituent of concern in Brush Creek. This study sampled instream concentrations of nutrients at specific sites to bracket various land use changes and assess the spatial relationship between measures of macroinvertebrate community health and point and non-point source discharges of nutrients. Nutrients of concern in surface waters include nitrogen and phosphorous in various dissolved, colloidal, and microscopic particulate forms. Rocky mountain headwater streams like Brush Creek are typically oligotrophic (i.e. nutrient poor). In such systems, small amounts of nutrient enrichment can significantly alter aquatic life conditions.

In 2012 Colorado implemented Regulation 85, "Nutrients Management Control Regulation" (5 CCR 1002-85). Subsequently, Colorado amended Regulation 31, "Basic Standards and Methodologies for Surface Waters", to address nutrients including total nitrogen, total phosphorous, and chlorophyll *a*. The interim standards for phosphorous in headwaters streams are set for cold water streams at 110 μg/L (0.11 mg/l) for annual median total phosphorous, with an allowable exceedance frequency of 1-in-5 years. Prior to 2022, these standards may apply to headwaters streams upstream of existing permitted WWTP dischargers, and in other discretionary situations where implementation of Regulation 85 does not appear to effectively control nutrients. After 2022, the Water Quality Control Commission (WQCC) may adopt segment and site-specific standards more or less stringent than the interim standard based on ongoing results and learning. The interim nitrogen standard for headwaters streams above permitted dischargers will be effective in 2017 and is set for cold water streams at 1,250 μg/l for annual median total nitrogen, with an allowable exceedance frequency of 1-in-5 years.

State in-stream water quality standards for Brush Creek are enumerated in 5 CCR 1002-33 by the WQCC. Brush Creek's designated uses include Aquatic Life Cold, Recreation, and Agriculture. Thus, numeric standards for major nutrients are as follows: NO_3 =100 mg/L, NO_2 = 0.05 mg/L, Ammonia = 0.02 mg/L. The unionized ammonia standard is a special-case adopted standard by WQCC for the Brush Creek below the WWTP (WQCC 2012). No standard for phosphorous existed in 2012, but eventual implementation of Regulation 85 will likely influence in-stream target levels of phosphorous and nitrate (via total nitrogen).

During this study, nutrient concentrations remained low in the upper sections of the creek, rose below the WWTP, and then decreased. The segment receiving the WWTP discharge contained the highest nutrient load. Levels of nitrate and phosphate persisted for a short distance downstream of the WWTP. In just over one half mile, the concentrations of nitrate and phosphorous decreased to less than half the levels observed below the WWTP. Montane watersheds are often nutrient-limited, and autotrophic organisms can rapidly make use of bioavailable nitrogen and phosphorous for growth and reproduction. Despite the elevated levels below the WWTP, concentrations of nutrients did not exceed applicable State standards in September 2012 at any sites. Ammonia showed a small increase in the Village area before decreasing to the WWTP outflow. Reasons for the elevated reading at the upper site are unclear but may indicate an un-quantified ammonia source, or sample analysis error. As both nitrate and phosphate declined below the WWTP, nitrite increased slightly and then declined. Nitrite may persist for short periods in natural waters as an intermediate breakdown product of nitrate, before it is fully converted to ammonia (Boyd 2000). The small rise and subsequent decline in nitrite concentrations may reflect this chemical transformation pathway. Denitrification, the conversion of bio-available nitrate and ammonium (ionized ammonia) into mineralized nitrogen in the form of un-ionized ammonia or nitrogen gas may produce the observed spike in ammonia concentrations in the lower watershed. The ponds draining the golf course were suspected receiving bodies for nutrient-enriched runoff and other landscaping chemicals such as pesticides and herbicides. Based on the results produced by this assessment, nutrient concentrations in the pond return flow channel do not appear enriched to a higher degree than the creek water during dry-weather, baseflow stream conditions.

Nutrient concentrations and discharge values were used together to calculate loading (i.e. the mass flux of a chemical parameter in the stream) to Brush Creek. Load may increase at discrete points from additional dissolved or suspended material entering the stream via inputs like tributaries or point-source discharges. Load may also increase gradually over a given segment based on non-point source inputs deriving from a particular land use type in the stream corridor. Results from September 2012 indicated that the upper segment of Brush Creek draining the forested hillslopes of the ski area, as well as the heavily urbanized area of the village core, were not significant contributors to nutrient load in Brush Creek during baseflow. The primary load (approximately 99%) of nitrogen and phosphate at low flow and dry weather derived from the effluent outflow of the community's wastewater treatment plant. The golf course, which was identified as a potential nutrient source, did not appear to contribute a significant portion of the load during the observation period. Nutrient loads decreased downstream from the WWTP. This pattern fits expectations for low summer flows with little WWTP dilution (i.e. load attenuates as nutrients are utilized in microbial, plant, and sediment interactions).

Critically, discharge was only measured at four sample collection sites and estimated for the remaining sites. Based on visual estimation of East Brush Creek and Brush Creek at their confluence, calculated values over-estimated the flow of East Brush Creek. Although attempts were made to identify all significant tributary sources to the creek, it is possible that another source contributed measurable amounts of discharge at some unknown location. Additional surface or groundwater flows may enter Brush Creek between the Chapel site and the confluence, which cannot be resolved by data from these streamflow measurement locations. Errors in discharge estimates likely affected the reliability of nutrient loading estimates at some locations.

Due to the potential error in estimated discharge values, discharge and calculated nutrient load below the Chapel site were suspected to be low, and the nutrient load of East Brush Creek was likely over-estimated. A greater actual discharge of approximately 0.5 or 0.6 cfs in Brush Creek above the confluence with East Brush Creek would result in a lower estimation for flow in East Brush Creek. This would slightly increase the estimate for any nutrient loading along the golf course reach between the Chapel and WWTP. This discrepancy is also emphasized by the difference in nitrate loads between the calculated load increase at the WWTP sample site and the actual measured load of the WWTP outflow. The WWTP outflow is approximately 43 kg/d, while the calculated load increase along the reach is approximately 53 kg/day (Table 10). This difference of about 20% is not accounted for by the existing nitrate loads in Brush Creek and East Brush Creek; however a higher discharge estimate in Brush Creek would only slightly close the gap. Discharge for the WWTP outflow is based on the reported 24 hour average, the instantaneous flow value at the time of sampling is not known from SWSD records. The time resolution mismatch between observations at the other 3 sites and the WWTP outflow may also account for some error; at the actual time of sampling the WWTP outflow may have been slightly greater or less than the reported 0.9 cfs, which would affect discharge and load estimates in the upstream segments.

The WWTP contributed the majority of nutrient loading to Brush Creek during this study. This was not unexpected, as Brush Creek is a headwaters stream draining crystalline rocks and forested slopes in its upper reaches, and dry upland shrub terrain in its lower reaches. Mountain streams are often nutrient-poor due to geology and contributing surface conditions in the watershed. Anthropogenic sources are commonly the primary drivers of nutrient load in these stream systems. This situation is likely exacerbated by the plumbed nature of the watershed. The municipal water supply for Snowmass Village and the surrounding developments of neighborhoods, subdivisions, and recreational uses, is sourced from East Snowmass Creek. Once the water is used and treated, it discharges to Brush Creek instead of returning to the Snowmass Creek basin. Brush Creek, potentially an intermittent stream prior to development of the Village, receives the discharge of a significant urbanized area.

Field parameters like pH maintained fairly consistent levels throughout the study reach. In the final stream segment, conductivity increased while hardness decreased. This downward trend in hardness in the final segment, indicating a decrease in major cations, seemed to move in opposition to the conductivity levels—an unexpected divergence. However, without additional information regarding specific chemical processes occurring in the water column in those reaches, it is difficult to infer more. Physical parameters did not exceed applicable State standards in September 2012 at any sites.

Results reported from the fall sampling during dry weather baseflow conditions should not be extrapolated to other flow regimes or climatic conditions. During heavy precipitation events, fertilizers and other chemicals from large contributing areas such as the golf course and irrigated resort landscaping may constitute significant sources of nutrient load from surficial runoff and groundwater percolation.

3.3 Future Monitoring

Although this effort utilized a high-resolution sampling scheme covering 12 sites on a relatively short stream reach in order to identify gradients of change in macroinvertebrate community condition and nutrient loading over very short reaches, future water chemistry monitoring could be limited to 3-5 sites bracketing the major land uses present in the drainage. Further investigation or review of previously published reports and data may be necessary to identify a more suitable reference location in the upper portion of Brush Creek than the site utilized in this study. The Chapel site provides a central transition location between the urbanized village and the less dense residential development of the golf course area. A site should be positioned above the WWTP to characterize stream conditions before wastewater effluent contributions. A site located near the Roundabout will provide an integrated picture of all potential upstream impacts. Appendix 2 details information and recommendations for ongoing monitoring in the Brush Creek Watershed.

4. Next Steps

4.1 Recommendations for Further Action

- Engage all stakeholders on Brush Creek in a coordinated effort to support long-term water quality monitoring and action; potentially through formation of a joint water quality committee, task force, or workshop.
- Explore additional datasets which may be available outside of STORET including USFS and private contractors.
- Develop an ongoing water quality monitoring plan for Brush Creek (See Appendix B).
- Ensure that all data collection efforts utilize established field and laboratory methods admissible at the State level, and data freely available to all stakeholders via open reports or timely presentations.
- Proactively engage the WQCD regarding the 303(d) listing of Brush Creek, data collection campaigns, and any future Total Maximum Daily Load (TMDL) development processes.

4.2 Considerations for Further Investigation

- Targeted investigation of water quality during snowmelt runoff may aid understanding of the Brush Creek system during high flow.
- An investigation into water quality during heavy rain runoff may aid understanding of the Brush Creek system during stormwater events.
- Future low flow inquiry for nutrients can begin below the majority of the Village, focusing primarily on the area of the golf course and WWTP; nutrient loading in the upper watershed appears insignificant.

- Comparative studies of nutrient load at similar discharge, but variable Village occupancy, may illuminate the variability of WWTP effects on the creek.
- Repetition of nutrient grabs during low flows will reduce overall error in load contribution estimations by segment.
- A sample site immediately above the WWTP but below the E. Brush Creek confluence would aid in more accurately assessing loading additions due purely to the WWTP. This site would fit in with monitoring requirements in Regulation 85 for WWTPs.
- Installation of a staff gage, small weir/flume, or other similar basic stream gauging capability just above the WWTP can generate dependable discharge estimates for quick and accurate loading calculation; outflow volumes from the WWTP are already known and can be combined to sort out watershed versus WWTP loading using only two sites.
- Long term water sampling could be limited to approximately 3-5 sites to adequately characterize the different regions of the watershed in a time and cost-effective program. Suggested sites are: Upper Brush Creek background site, Chapel, immediately above the WWTP but below the confluence with E. Brush Creek, either Roundabout or Lower Road Crossing site, and the watershed mouth.
- This study did not address selenium or manganese, but based on other studies in Colorado and, investigations into these constituents might best begin by assuming geologic sources as causes, expanding from there.

4.3 Considerations for Data Archival

Nutrient and field parameters collections occurred in accordance with generally approved methods in the water quality profession, federal and state agencies, and water treatment industry. This information may be submitted for provisional approval to both state agencies and federal water quality clearinghouses such as Colorado Data Sharing Network (CDSN) or STORET. Doing so can ensure that contributions made to understanding Brush Creek will be available for all current and potential future uses. This also removes the burden of record keeping, storage, and public access, from local entities by ensuring long term security and accessibility in the nationwide database. It is recommended that sampling results be organized and prepared in the format suitable for WQX (Water Quality Exchange) and submitted via web portal in a timely fashion. WQX is a framework consisting of a standardized data schema (submission template) and online portal through which states and watershed organizations may submit and share data online; once submitted, data is housed in STORET.

5. References

Barbour, M. T., J. Gerritsen, B. D. Snyder, and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish, second edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Boyd, Claude E. Water quality: an introduction. Kluwer Academic Publishers. 2000

Clarke, S., K. Crandall, J. Emerick, M. Fuller, J. Katzenberger, D. Malone, M. Masone, A. Slap, and J. Thomas. 2008. State of the Roaring Fork Watershed report 2008. Sponsor: Ruedi Water and Power Authority. Lead Consultant: Roaring Fork Conservancy. http://www.roaringfork.org/watershedplan.

Roaring Fork Conservancy 2006. Roaring Fork Watershed Water Quality Report. http://www.roaringfork.org/publications.

Water Quality Control Commission 2012. 5 CCR 1002-33 Regulation No. 33 – Classifications and numeric standards for Upper Colorado River Basin and North Platte River (Planning Region 12). PDF.

Colorado Department of Public Health and Environment. 2010. Aquatic life use attainment: Methodology to determine use attainment for rivers and streams. Policy Statement 2010-1.

Department of Energy (DOE). 2011. Natural Contamination from the Mancos shale. Doc No S07480. PDF.

Grove, Matt. 2012. Benthic macroinvertebrate sampling plan for White River National Forest. USDA Forest Service.

Hawkins, C. P. 2006. Quantifying biological integrity by taxonomic completeness: Its utility in regional and global assessments. Ecological Applications 16 (4): 1277-1294.

Hilsenhoff, W. L. 1988. Rapid field assessment of organic pollution with a family level biotic index. Journal of the North American Benthological Society 7(1): 65-68.

Hughes, D.L. and M.O. Brossett. 2009. Rapid bioassessment of stream health. CRC Press, Taylor & Francis Group. Boca Raton, FL.

Integrated Water Quality Monitoring and Assessment Report 2012. Water Quality Control Division and Colorado Department of Public Health and Environment.

Lenat, D.R. 1988. Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. Journal of the North American Benthological Society 7:222-33.

Likens, G. E., and Lambert, K.F. 1998. The importance of long-term data in addressing regional environmental issues. Northeastern Naturalist 5: 127-136.

Merritt, R. W., K. W. Cummins and M. B. Berg. 2008. An introduction to the aquatic insects of North America. Fourth Edition, Kendall/Hunt. Dubuque, Iowa.

Paul, M. J., J. Gerritsen, C. Hawkins, and E. Leppo. 2005. Draft. Development of biological assessment tools for Colorado. Colorado Department of Public Health and Environment, Water Quality Control Division – Monitoring Unit. Denver, Colorado.

Paul, M.J., and J. L. Meyer. 2001. Streams in the urban landscape. *Annual Review of Ecology and Systematics*. 32:333-365

Plafkin, J. L., M. T. Barbour, K. D. Porter, S. K. Gross, and R. M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. EPA/444/4-89/001.

Resh, V.H. and J.K. Jackson. 1993. Rapid assessment approaches in biomonitoring using benthic macroinvertebrates. In Rosenberg, D.M, V.H. Resh. (Editors). Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman & Hall, New York: 195-223.

Roaring Fork Conservancy and Timberline Aquatics. 2012. A review of aquatic life and stream health in the Roaring Fork Watershed. www.roaringfork.org/publications.

Roaring Fork Conservancy. 2007. Brush Creek Water Quality Study. http://www.roaringfork.org/publications. PDF.

Northwest Colorado Council of Governments (NWCCOG). 2012 Roaring Fork Watershed Management Plan. http://www.nwccog.org/index.php/programs/watershed-services/. PDF.

U.S. Geological Survey, 2012, The StreamStats program for Colorado, online at http://water.usgs.gov/osw/streamstats/colorado.html. (Accessed March 31, 2013)

Voelz, N. J., R. E. Zuellig, S. Shieh, and J. V. Ward. 2005. The effects of urban areas on benthic macroinvertebrates in two Colorado plains rivers. Environmental Monitoring and Assessment 101: 175-202.

Wang, L., D. M. Robertson, and P. J. Garrison. 2007. Linkages between nutrients and assemblages of macroinvertebrates and fish in wadeable streams: implication to nutrient criteria development. Environmental Management 39: 194-212.

Ward, J. V., B. C. Kondratieff, and R. E. Zuellig. 2002. An illustrated guide to the mountain stream insects of Colorado. Second Edition. University Press of Colorado. Boulder, Colorado.

Water Quality Control Division. 2011. Prehearing Statement In the Matter of the 2012 List of Water-Quality-Limited Segments Requiring Total Maximum Daily Loads and Colorado's Monitoring and Evaluation List (Regulation No. 93).

Water Quality Control Division. 2011. 2012 303(d) Listing Methodology. Colorado Department of Public Health and Environment

Appendix A. Macroinvertebrate Site Descriptions

A.1 SECTION OVERVIEW

Appendix A includes specific location information and site descriptions for each macroinvertebrate sampling site. A short discussion accompanies each site description, including any previous sampling, and specifically identified stream issues from other reports or expert local knowledge. Macroinvertebrate samples were collected by S.K.Mason Environmental, LLC and analyzed by Timberline Aquatics, Inc. in Fort Collins, Colorado. Site information provided by Roaring Fork Conservancy and S.K.Mason Environmental, LLC.

A.2 UPPER BRUSH CREEK ROAD

River/Stream: Brush Creek
Site ID: Upper Brush Creek
Location: Above Snowmass Village near upper Brush Creek Road crossing
River Watch Site Name and (Number): N/A
WQCD Site ID: N/A
Coordinates (NAD 83): N 39.207117 W -106.957262

Site Description

Upper Brush Creek Road is the farthest upstream site located on Brush Creek sampled in 2012. The surrounding area includes Snowmass Ski Area, which is located above and around this sampling site and has potential to influence water quality and macroinvertebrate communities with associated activities and runoff. This site has a riparian corridor of 15 feet on the right bank and 60 feet on the left bank. Above the highest road crossing upstream, Brush Creek flows through wetlands and willow cover.

Benthic Macroinvertebrate Review

This upstream site is located in Biotype 2. In the fall of 2012, this site produced an MMI score of 43.5, which was in the "grey zone" for aquatic life use. The HBI metric produced a value of 4.42, suggesting attainment. However, the Diversity metric produced a value of 2.05, which was below the threshold for aquatic life use. This evaluation resulted in an impairment designation for Brush Creek above Snowmass Village during the fall of 2012. Additional metrics supported the results produced by the MMI and detected moderate impacts to the aquatic community. Values for Insect Taxa (18) and EPT taxa (8) were lower than expected and provided some evidence of stress despite the presence of several sensitive species. A somewhat low Clinger Taxa value of 5 suggests that part of the perturbation may have been related to fluctuating flows or sedimentation. Aquatic life at this site may have been influenced by the Snowmass Ski Area and/or other associated anthropogenic activities in the fall of 2012.

Site Photos

Downstream view (2012)

Upstream view (2012)

Substrate (2012)

A.3 CHAPEL

River/Stream: Brush Creek
Site ID: Chapel
Location: Below Snowmass Village at Snowmass Chapel
River Watch Site Name and (Number): (889)
WQCD Site ID: N/A
Coordinates (NAD 83): N 39.213771 W -106.93731

Site Description

The Chapel site is located downstream of the Upper Brush Creek Road site. There were several anthropogenic developments surrounding this sampling location, with low density houses and maintained dirt foot trails nearby. The resort road is located within 100 meters of the creek, as well as a parking lot on the left bank. This site's location suggested continued potential impacts associated with the Snowmass Ski Area. The riparian corridor extends 45 feet on both the right and left bank.

Benthic Macroinvertebrate Review

The Chapel site produced results comparable with the Upper Brush Creek Road site. The site is located in Biotype 1 and produced an MMI score of 43.7 in the "grey zone" for aquatic life use. The HBI metric value of 4.23, indicated attainment. Although, the Diversity metric value of 2.09 was below the attainment threshold, indicating that Chapel was impaired for aquatic life use. Similarities between several individual metric values (Taxa Richness, EPT, Clinger Taxa, and Insect Taxa) from this site and the upstream site on Brush Creek suggest there is a consistency in the level of stress between these two locations. These consistencies also imply that the stressors influencing macroinvertebrate communities below the village are similar to those affecting the upstream location.

Site Photos

Downstream view (2012)

S.K.Mason Environmental, LLC

Upstream view (2012)

Substrate (2012)

A.4 ABOVE CONFLUENCE

River/Stream: Brush Creek
Site ID: Above Confluence
Location: in Snowmass Village above confluence
River Watch Site Name and (Number): N/A
WQCD Site ID: N/A
Coordinates (NAD 83): N 39.219712 W -106.928648

Site Description

Brush Creek Above Confluence is located upstream from the East Fork of Brush Creek within the Town of Snowmass Village limits. This site is surrounded by densely populated golf course townhomes on both the right and left bank with multiple residential streets crossing above and below macroinvertebrate sampling location. A riparian corridor of 10 feet exists on both the right and left banks, although grass is mowed to streamside on some left bank locations.

Benthic Macroinvertebrate Review

This site has potential for greater influence by anthropogenic stressors than either of the upstream sampling locations on Brush Creek due its position downstream of the Town of Snowmass Village and associated storm-water runoff, and its proximity to the heavily landscaped golf course and residential developments. This site is located in Biotype 1 and produced an MMI score of 35.9, below the impairment threshold for aquatic life use, despite the auxiliary metric scores. The Diversity metric score of 1.81 was also below the threshold for attainment and suggested that perturbation had increased compared to upstream sites. The HBI value of 4.47 was not at a level of impairment for aquatic life use and consequently indicated that organic enrichment may not be a primary driver of disturbance. The application of additional metrics also detected impacts to macroinvertebrate communities with lower numbers of sensitive taxa (EPT) and specialized taxa (Clinger Taxa) at this site. The increased urbanization located immediately upstream from this site, coupled with detectable impacts to aquatic conditions upstream (Upper Brush Creek Road and Chapel) likely combined to increase the level of stress to aquatic life at the Brush Creek above Confluence site.

Site Photos

Downstream view (2012)

S.K.Mason Environmental, LLC

Upstream view (2012)

Substrate (2012)

A.5 ROUNDABOUT

River/Stream: Brush Creek
Site ID: Roundabout
Location: Below Snowmass above Brush Crk Rd/Highline Rd Roundabout
River Watch Site Name and (Number): Above Roundabout (887)
WQCD Site ID: 12761C
Coordinates (NAD 83): N 39.2247 W -106.921

Site Description

This site is located on Brush Creek below the Town of Snowmass Village and near the Brush Creek Road/Highline Road Intersection (i.e. the Roundabout). This site is downstream of nearly all of Snowmass Village and the Snowmass Club Golf Course. It is also downstream of the confluence with the East Fork and roughly 5 miles upstream of Brush Creek's confluence with the Roaring Fork River. This site is likely influenced by related urban impacts, as well as the golf course and residential development. Approximately 0.25 mile upstream of this site is the Snowmass Village Wastewater Treatment Plant.

At the sample location, the creek is approximately 11 ft. wide and averages 0.5 ft. deep with primarily riffles and runs. Substrate is predominately cobble and the riparian zone extends approximately 6 ft. on left bank and 15 ft. on the right bank. Beyond the immediate riparian zone, the surrounding area is primarily grasses/golf course.

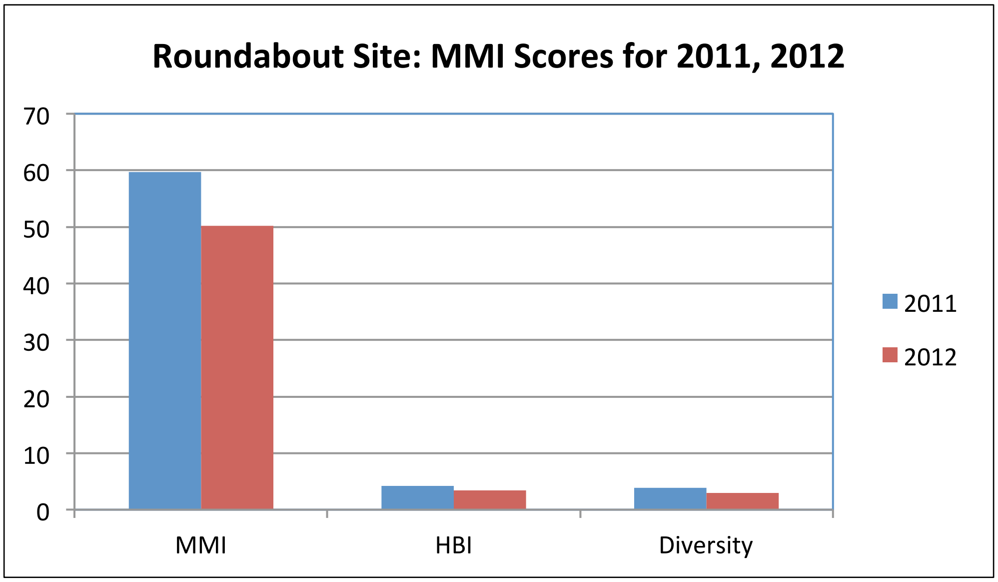
The 2006 Roaring Fork Watershed Water Quality Report, based primarily on River Watch data, placed this stream on the Impacted List due to periodic pH standard exceedances, high phosphorous levels, and a Family Biotic Index indicating some organic pollution probable. These results led to a follow-up targeted study, the 2007 Brush Creek Water Quality Study. This study continued to produce the high phosphorous levels seen in the 2006 study but did not produce any pH exceedances. This study concluded the pH exceedances were possibly related to low flow years.

Benthic Macroinvertebrate Review

Roundabout site has potential impacts from all urban development and other anthropogenic activities (ski area, golf course, Snowmass Village Wastewater Treatment, etc.) that exist upstream. This site is located in Biotype 1 and produced an MMI score of 50.2, which fell within the "grey zone" for aquatic life use. Results from the auxiliary metrics (Diversity and HBI) determined that Brush Creek at Roundabout was in attainment for aquatic life use in the fall of 2012. The HBI value of 3.40 and Diversity value of 3.00 both demonstrated improvement compared to upstream sites on Brush Creek and suggested that aquatic conditions had improved in a downstream direction. Additional metrics measuring sensitive taxa (EPT) and specialized taxa (Clinger Taxa) also improved compared to upstream sites and detected less impacts from perturbations. Despite potential impacts associated with urbanization, Brush Creek at Roundabout was in attainment for aquatic life use in 2012 and demonstrated improved aquatic conditions compared to upstream sites.

Comparison to 2011

Macroinvertebrate data at this site in 2011 indicated a relatively high proportion of non-insect taxa which caused some decline in the MMI value. This is an expected response to stress in many Colorado streams. The MMI value of 59.7 produced at this site was above the attainment threshold, indicating conditions were adequate for supporting aquatic life. Other metrics, including the EPT and Clinger Taxa metrics, suggested that aquatic conditions were less than optimal but not impaired at this site. The HBI value of 4.23 for this site appeared to be slightly elevated by the presence of nutrients, but was not at a level indicating impairment.



Site Photos

Downstream view (2012)

Upstream view (2012)

Substrate (2012)

S.K.Mason Environmental, LLC

Appendix B: Recommendations for Ongoing Monitoring

B.1 SECTION OVERVIEW

A functional monitoring plan specifically addresses how a monitoring program, with defined objectives, operates and provides information for management decisions. Monitoring programs with an absence of routine data analysis and reporting of analytical results can produce situations which are "data rich but information poor," wasting stakeholder resources and providing little useful information for watershed management (Ward et al. 1986). RFC recommended that stakeholders in Brush Creek develop and implement a formal Sampling and Analysis Plan (SAP) to aid in ongoing monitoring, enhancement, or rehabilitation efforts in the watershed.

A SAP formalizes the collection, analysis, reporting, and action/response process; simultaneously promoting collaboration among stakeholders, transparency of activities and information, continuity between subsequent operators, and attainment of minimum scientific credibility. Information gained from monitoring may directly target goals related to the state's 303(d) list responsibilities, as well as other collaboratively defined goals and objectives of local watershed stakeholders.

Concerted efforts by parties to avoid monitoring redundancy, optimize data collection efficiency, and maximize spatial coverage of sampling in the watershed, may yield substantial dividends for all parties in terms of avoiding resource waste and producing actionable information about Brush Creek. SAPs are best utilized within the context of an Adaptive Management Framework for water quality monitoring. A full explanation of adaptive management is not intended for this appendix; however a short overview is included at the end for context.

B.2 BRUSH CREEK SAMPLING AND ANALYSIS PLAN ELEMENTS

A brief overview of the minimum elements suggested for a Brush Creek SAP follows. This provides an outline to understand what a SAP provides, and should be viewed as a recommendation or organizational framework for formal SAP development.

Monitoring Goals & Objectives

Clearly defined goals and objectives ensure that monitoring is targeted, specific, and efficient. Stream data that is not designed to answer a specific resource management question, legal obligation, or stakeholder interest, can consume funding and resources that may be better directed to other watershed activities such as habitat improvement or targeted studies. *Goals* are generally defined intentions and desired outcomes of the monitoring program, while *objectives* are specific and measurable steps, actions, or milestones for monitoring actions. Both should be developed in collaboration with watershed stakeholders in order to promote a shared sense of problem identification for Brush Creek, and ample buy-in from all parties affected by watershed management. Examples goals and objectives include:

- Baseline monitoring: Identify baseline conditions, including areas of special concern
- Variability of watershed conditions: Characterize seasonal variability and trends, as well as inter-annual variability and trends
- Statutory/Regulatory: Provide data for water quality standards attainment
- Provide data for continuing investigation of causes/sources as related to provisional 303(d) listing
- Formulate causal linkages between water quality changes/exceedances and sources
- Characterize type and quantity of stormwater inputs from Snowmass Village or Golf Course

- Quantify seasonal nutrient loading from WWTP, watershed background, or landscaping areas

Participants and Responsibilities

The parties participating in monitoring and their respective roles should be explicitly stated, as well as a process for adding new stakeholders or leaving the group. Shared funding, labor, and other local efficiencies may be utilized. For example, Snowmass Water and Sanitation District has a lab suitable for the analysis of many common water quality parameters. However, when exploiting such local resources, all potential conflicts of interest should be openly considered among stakeholders before agreeing on final arrangements. Specifically, the SAP should delineate:

- Who is collecting samples?
- Where and when those parties will collect samples?
- What parameters will be collected, what procedures will be used for collection and QA/QC?
- Who will analyze samples?
- Who will review, store, and communicate the data?
- What actions will occur based on data results and by whom?

Monitoring Locations

The following locations are recommended at a minimum to bracket the areas of major land use change in the upper Brush Creek Watershed, other location arrangements or numbers may also meet stakeholder requirements depending on what specific objectives are defined for monitoring.

Table 1. Minimum recommended sampling locations.

Site	Description	Purpose
1	Upper Brush Creek	Above all village development, background stream conditions
2	Chapel	Boundary transition between dense urban development and less dense golf course residential area
3	Above WWTP outflow	Boundary transition above WWTP effluent influences
4	Roundabout	Integrates effects of all upstream development prior to transitioning to undeveloped pasturelands
5	Highway 82 Bridge	Watershed outlet, total basin integration

Monitoring Frequency

Table 2. Minimum recommended sampling frequency.

Time	Purpose
June	High flow, hydrograph peak
September	Late summer low flow, warm temp regime
February	Winter low flow
April	Hydrograph Ascension, spring flush

Selection of monitoring frequency will depend on the defined monitoring goals and resources availability. A minimum frequency of four sampling events per year is recommended. Under this sampling regime, specific times on the yearly hydrograph cycle are targeted based on existing understanding of water quality conditions, expert knowledge, and shared stakeholder problem identification. For example, Brush Creek faces its lowest flows during winter, when human population in the resort village is highest, so this should be a time targeted for sampling. Such targeted sampling regimes focus on specific stakeholder concerns and help to minimize costs, but may not describe seasonal or inter-annual conditions as well as more frequent sampling schedules. Three alternative suggestions for monitoring frequency are described below:

<u>Alternative 1, High Frequency:</u> (12 samples per year, once per month) In a watershed that is relatively undocumented and not well described, a high-resolution sampling timing can provide better description of water quality conditions and seasonal variations. This sampling regime may only be necessary in the first 1-5 years until seasonal variability is understood and a more targeted timing regime develops to focus on specific times of year when water quality concerns are most prominent.

<u>Alternative 2, Medium Frequency: (</u>6 per year, approx. every two months, alternating even/odd months each year) This provides a similar characterization as the High Frequency regime, although initial development of watershed understanding may require more years of data collection to adequately understand seasonal variability. Advantages are a reduced sampling costs and time.

<u>Alternative 3, Minimum Frequency</u>: (2 samples per year during high flow and low flow) This sampling regime would target high and low flow periods by sampling in June/July, and later in the fall or winter such as January/February. While costs are minimized, the low time resolution will not provide a sharp picture of annual variation and may miss times of year when specific concerns are suspected to be more prominent. Overall this is the cheapest and simplest, but provides the least amount of information.

Monitoring Parameters

The specific goals and objectives of stakeholders will help identify which water quality samples will be sampled. Water quality monitoring in Colorado commonly includes field parameters and physical measures tied to aquatic life health such as pH, temperature, and dissolved oxygen; nutrients; metals; and biological indices such as benthic macroinvertebrate community assessments, periphyton assessments, or fish counts.

Nutrients have been identified as a potential concern on Brush Creek; monitoring above and below WWTP facilities is required of operators by Regulation 85. A limited number of observations at the watershed mouth (Highway 82 crossing) have indicated potential concerns with pH, as well as manganese and selenium—metals likely associated with natural geologic weathering. Trace metals and increases in Total Suspended Solids (TSS) may be associated with stormwater runoff from urbanized areas. The large amount of irrigated landscape and golf course area may be potential sources for nutrient loading, as well as runoff containing complex organics such as fertilizers and insecticides.

Sample Collection Analysis

Collection of samples should utilize generally accepted methods in the scientific and regulatory community to ensure data quality, minimize human error in results, and remain within CDPHE WQCD Credible Evidence Guidelines. Roaring Fork Conservancy already conducts sampling via protocols that meet or exceed these guideline at many sites in the greater Roaring Fork Watershed. Lab analysis should also use generally accepted methods in the State of Colorado and scientific community at large so that data may be admissible for all purposes. Both field collection activities and lab analysis should be appropriately documented.

Data Analysis

Analytical purposes of data collection, as well as statistical methods for data analysis should be determined prior to data collection. Analysis should focus on answering specific questions stated as scientifically testable hypotheses. These should relate to stakeholder objectives and generate information specifically required by stakeholders for watershed resource management.

Data Storage and Communication

Management of water quality monitoring data is an important but often overlooked component of many programs. Without appropriate management, data will not automatically generate useful information for stakeholder learning and actions. Important questions to be answered are:

- Who owns the monitoring data?
- Who is responsible for storage and backup of the data?
- What level of data quality and review is required?
- What level of data control and accessibility (i.e. general public, all stakeholders, some specific stakeholders) is required?
- How will requests from data by specific stakeholders or other parties be handled?
- What sort of metadata needs to be managed with the data and how should it be formatted?

Many templates and existing schemes can be cheaply and effectively used. For example, one simple solution will be to collect all data to the standard required for entry into STORET or the CDSN, and then use either online database for long-term storage.

For water quality data to become useful information that can actually benefit watershed management, a formal structure and timing for reporting results to stakeholders must be determined and implemented. Raw data on water quality parameters must be transformed into information that answers specific questions, aids organizational management objectives, and can effectively communicate the current state and future direction of water resource conditions to stakeholders and the public.

Other Targeted Monitoring Activities

Specific monitoring objectives may be difficult to achieve within the constraints of an annual basin-wide monitoring regime. For example, attempts to quantify stormwater loading can only occur during periods of stormwater runoff, which may be irregular and difficult to predict. *Targeted Water Quality Assessments* that complement the SAP but are not specifically delineated within it may be necessary to achieve these goals. Targeted assessments should be developed separately within a collaborative stakeholder decision-making framework based on specific concerns and available resources.

B.3 CONCEPTS IN SAP DESIGN AND DEVELOPMENT

Effective monitoring program designs are complete prior to implementation (Ward et al. 1986). Not only must Brush Creek watershed stakeholders annually develop clear goals, objectives, site locations, and sampling regimes, a clear process should be evident for data collection and archiving, data analysis, reporting, and integration of new information into the next cycle of monitoring activity. A decision support system may guide stakeholders by helping to structure and formalize the process. Structured decision making is proven within the adaptive management framework to allow resource managers to explicitly consider stakeholder values, existing information, and resource tradeoffs in a transparent fashion (e.g. McDonald-Madden et al. 2011; Ward et al. 1986; Williams 2011).

Step 1 Evaluate information expectations

Water quality goals
Water quality problems
Management goals and strategy
Monitoring role in management
Monitoring questions (Stated as hypotheses when possible)

Step 2 Establish statistical design criteria

Statistically characterize "population" to be sampled
Variation in quality
Seasonal impacts
Correlations present (independence)
Applicable probability distributions
From many statistical tests, select most appropriate

Step 3 Design monitoring network

Where to sample (from monitoring role in management)
What to measure (from water quality goals and problems)
How frequently to sample (from analytical/statistical needs)

Step 4 Develop operating plans and procedures

Sampling locations (and division of labor)
Field sampling and analysis procedures
Sample preservation and transportation
Lab analysis procedures and QA/QC
Data storage and retrieval hardware and database management
Data analysis software

Step 5 Develop information reporting procedures

Type of format of reports
Frequency of report publication
Distribution of reports
Evaluation of report ability to meet initial information expectations

Example design process for water quality monitoring plans. Adapted from Ward et al. (1986).

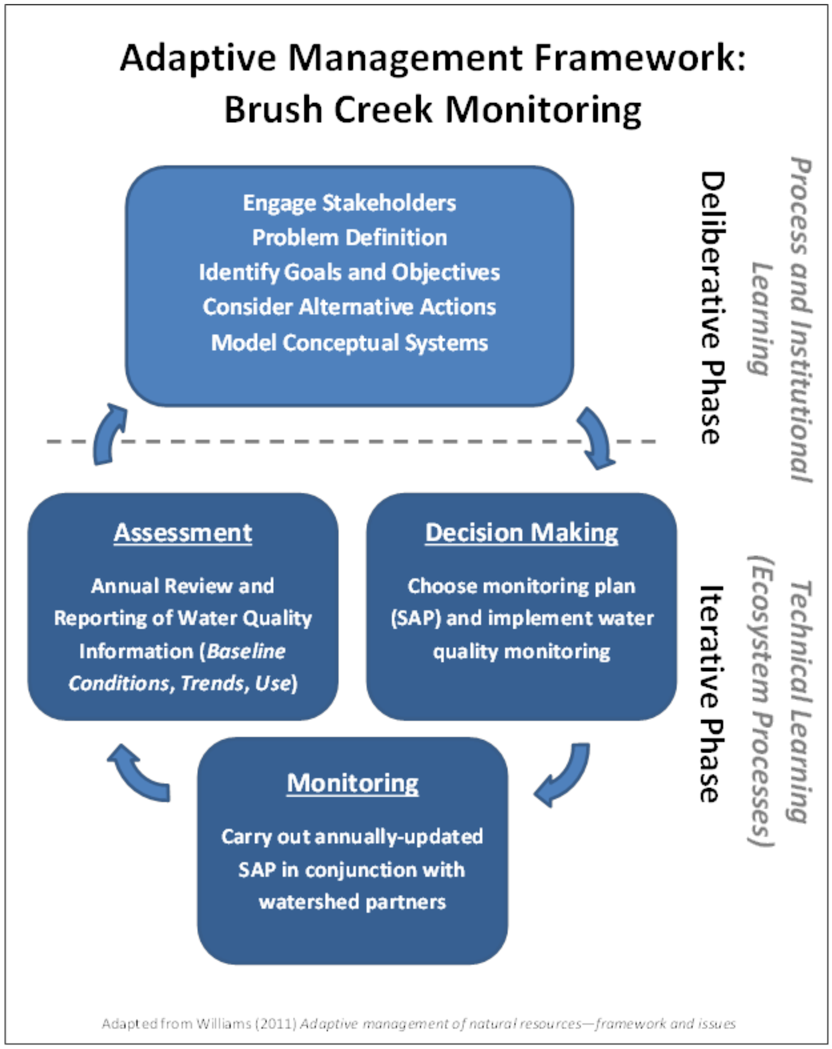
B.4 ADAPTIVE MANAGEMENT AND WATER QUALITY MONITORING

Adaptive Management in Water Quality Monitoring

Adaptive management is not the appropriate tool for all environmental resource problems; it functions optimally when uncertainty and controllability are both high (Allen 2011). Uncertainty in this context refers to fact that the timing and size of river ecosystem responses to a particular management action are difficult to predict with confidence. Water quality conditions in Brush Creek result from a complex interplay of natural processes including climate, land cover, and geology; as well as numerous human processes such as urbanization, land use change, and physical stream alteration. In addition to a high degree of uncertainty regarding ecological processes and response, water quality regulation and monitoring are further complicated by multiple stakeholder objectives and overlapping governmental jurisdictions (Allen et al 2011).

Water quality influences fall on a spectrum from fully controllable to completely uncontrollable. For example, structural setback distances, stormwater runoff collection and treatment, and the type and amount of fertilizers or pesticide applications allowable, are factors which are highly controllable by management actions at various jurisdictional levels. Shifting climate and drought, catastrophic fire, and erosive marine shale soils also influence water quality, but are beyond local control.

For those controllable factors, adaptively managed monitoring can effectively inform Brush Creek stakeholders regarding the direction and severity of impacts to the watershed. For the uncontrollable factors, targeted and continually-evaluated monitoring regimes can help determine where, when, and how to optimally detect these impacts, generating information that could potentially help mitigate the impacts to whatever extent possible (Allen 2011).



B.5 REFERENCES

Allen, C.R., J.J. Fontaine, K.L. Pope, and A.S. Garmestani. 2011. Adaptive management for a turbulent future: Nebraska Cooperative Fish & Wildlife Research Unit. Staff Publications Paper 80.

McDonald-Madden E, P.W. Baxter, R.A. Fuller, T.G. Martin, E.T. Game, J. Montambault, H.P. Possingham. 2010. Monitoring does not always count: Trends in Ecology and Evolution. 25-10.

Ward, R.C., J.C. Loftis, and G.B. McBride. 1986. The "Data-rich but Information-poor" Syndrome in Water Quality Monitoring. Environmental Management 10-3. pp 291-297.

Williams, B.K. 2011. Adaptive management of natural resources—framework and issues. Journal of Environmental Management 92. p 1346-1353.