Brush Creek
Stream Health Survey

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ROARING FORK WATERSHED PLAN

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Definition of Terms

AL: Aquatic Life

AG: Agriculture

BMP: Best Management Practice

CDPHE: Colorado Department of Public Health and Environment

CPW: Colorado Parks and Wildlife

CRWN: Colorado River Watch Network, a.k.a. River Watch

CWA: Clean Water Act

DM: Diurnal Maximum

EPA: Environmental Protection Agency

HUC: Hydrologic Unit Code

LID: Low Impact Development

MCDA: Multi-criteria Decision Analysis

MMI: Multi-metric Index

MS4: Municipal Separate Storm Sewer System

MWAT: Maximum Weekly Average Temperature

M&E: Monitoring and Evaluation

NWCCOG: Northwest Colorado Council of Governments

QA/QC: Quality Assurance and Quality Control

RFC: Roaring Fork Conservancy

STORET: Storage and Retrieval System

SWSD: Snowmass Water and Sanitation District

TMDL: Total Maximum Daily Load

TOSV: Town of Snowmass Village

TVS: Table Value Standard

USFS: United States Forest Service

USGS: United States Geological Survey

WQCC: Water Quality Control Commission

WQCD: Water Quality Control Division

WQCV: Water Quality Capture Volume

WQS: Water Quality Standard

WRNF: White River National Forest

Summary

Biological monitoring conducted from 2006 and 2012 on Brush Creek identified impaired aquatic life health, as defined by the Colorado Department of Health and Environment Water Quality Control Commission. Benthic macroinvertebrate samples from multiple sites in the watershed indicated water quality degradation, as compared to healthy reference streams. This condition triggered provisional listing of Brush Creek on the Water Quality Control Division's 2012 303(d) List of Impaired Waters. Provisional listing indicates that causes of impairment are unclear.

Water resource decision makers need information identifying causes and sources of stress to aquatic life to identify and implement potential mitigation and remediation actions. The Brush Creek Stream Health Survey reviewed water quality data between 2002 and 2013 to determine whether existing ambient water quality data and biological data might yield potential causes of degradation. Three analyses comprise the body of the report: a review of existing water quality information, an expanded macroinvertebrate data review, and an impervious area analysis to understand how development intensity may correlate with stream conditions.

The data review combined water quality observations from multiple sources into a single dataset and compared to instream water quality standards for field parameters, trace elements and metals, and nutrients. A limited number of observations exceeded standards during the period of record for pH, dissolved oxygen, total recoverable aluminum, total recoverable iron, dissolved lead, and dissolved selenium. For all parameters, exceedance frequencies fell below the regulatory threshold for legal designation of impairment. Total iron and total aluminum, parameters with recent exceedances, often coincided with spring runoff, indicating natural sources from erosive soils. Overall, ambient water chemistry does not appear to be a primary driver of aquatic life impairment.

The lowest macroinvertebrate community MMI scores coincided with the areas of highest urbanization and development intensity in the watershed. Attaining MMI scores at undeveloped reaches above Snowmass Village declined through the town and golf course area then rebounded in a downstream direction from towards Highway 82. Imbalances in feeding group representation at upstream sites in the village also indicated elevated stress in those areas. The decline in macroinvertebrate community scores correlates with increasing impervious surface area in the watershed. This relationship indicates urbanization and its associated effects may be an important contributor to degraded aquatic life conditions.

An established body of scientific literature links urbanization to water quality impairment via polluted runoff, altered hydrology, riparian buffer impacts, and physical channel alteration. These conditions are all present on Brush Creek, and are the most probable drivers of stream impairment. In 2014, continued monitoring for additional pollutants, including targeted stormwater monitoring, may better-characterize these impairment sources. Inventory of current urban drainage infrastructure and better-integrated stormwater planning can set the stage for implementation of BMPs targeting urban runoff. A feasibility assessment for riparian improvement should identify locations for potential remediation actions. Brush Creek stakeholders are encouraged to develop a multi-criteria decision analysis framework to consider all these factors in an explicitly structured manner and help drive strategic planning for future water quality improvement actions.

Brush Creek Stream Health Survey

1. Introduction

1.1 Overview

The Brush Creek Stream Health Survey (SHS) provides a synopsis of current information regarding stream conditions on Brush Creek and recommends future actions to improve or protect water quality. This study presents an analysis of existing water chemistry and macroinvertebrate data collected between 2002 and 2013. The work also includes recommended actions for mitigation, remediation, and future water quality monitoring.

Biological monitoring conducted between 2006 and 2012 on Brush Creek identified impaired aquatic life health, as defined by the Colorado Department of Public Health and Environment (CDPHE) Water Quality Control Division (WQCD) water quality standards. Although some sampling locations on Brush Creek have met standards, macroinvertebrate observations collected at multiple sites between 2006 and 2013 indicate degradation to aquatic life in the upper portion of the creek near the urbanized sections of Town of Snowmass Village and the Snowmass Club golf course. Historical water chemistry monitoring identifies limited instances of water quality standards exceedances; however these exceedances do not indicate a specific stressor or cause of impairment to aquatic communities.

Brush Creek stakeholders directly engaged in the Stream Health Survey include Snowmass Water and Sanitation District (SWSD) and Roaring Fork Conservancy (RFC). Additional stakeholders in the watershed include: TOSV, Snowmass Club, Aspen Skiing Company (SkiCo), Snowmass area homeowners with properties near Brush Creek, CDHPE, and the US Environmental Protection Agency (EPA). Together, these stakeholders represent a diverse range of values, interests, and legal obligations.

The community of Snowmass Village and surrounding Pitkin County feature a tourism and recreation-based economy, which places high value on the health and integrity of natural ecosystems side-by-side with human communities. Through various mission statements and long term planning documents[1], TOSV, SWSD, RFC, RWAPA, and Pitkin County voice a continuing commitment to healthy functioning natural environments. Implementing effective resource management strategies that reflect these values will best occur by processes that engage all relevant stakeholders in the watershed. The Stream Health Survey aims to provide up-to-date scientific knowledge for Brush Creek, which may be used by stakeholders to collaboratively determine the future direction of water quality and aquatic health conditions in Brush Creek.

1.2 Purpose and objectives

The primary purpose of the Brush Creek Stream Health Survey is to organize and analyze existing water quality information to inform future resource management strategies and actions to improve macroinvertebrate community metrics. These metrics are the primary biological and regulatory indicators for attainment of state aquatic life health standards in Brush Creek. In 2012, CDPHE WQCD placed Brush Creek on the 303(d) list of impaired waters for aquatic life use impairment, signifying that

[1] Including the 2012 Roaring Fork Watershed Plan (Clarke et al. 2012)

aquatic macroinvertebrate communities in the stream are degraded or unbalanced in comparison to un-impacted reference streams in similar ecoregions.

Identifying management strategies and options for improvement actions requires better understanding of the water quality stressors affecting Brush Creek. Existing water quality data from 2002-2013 was reviewed to determine if specific stressors existed. The data review also highlighted important data gaps that may impede causal identification. Where appropriate, relevant scientific literature reviews provided further support for causal source identification. This work consisted of four phases:

- Water quality data analysis. Investigation of spatial and seasonal patterns and long term trends.
- Potential pollutant source identification. Comparison of water quality data analysis results to known source areas for various stressor types.
- Inventory and prioritization of potential corrective actions based on identified stressors and causes.
- Development of recommendations for ongoing monitoring and/or targeted studies.

While RFC and SWSD commissioned this report, it may also benefit other local and state government entities tasked with water quality responsibilities. The work strives to lay a credible scientific basis to guide resource management decision-making in the watershed, while simultaneously highlighting areas in need of further investigation.

1.3 Existing reports and documentation

Various entities produced scientific information about Brush Creek between 2002 and 2013, including TOSV, RFC, and CDPHE (Table 1.1). These investigations, each tailored to the specific needs of the sponsoring organization, comprise the most recent source of data and information for Brush Creek.

Table 1.1. Timeline of scientific work for Brush Creek.

Year	Work summary
2001 *sponsor:*	**Draft Brush Creek Watershed Management Plan** *Town of Snowmass Village* This work focused on identifying watershed pollutants, sources, and potential management/control strategies. It included a stormwater assessment of the upper watershed in the village area.
2001-2009 *sponsor:*	**Macroinvertebrate sampling, unpublished data** *CDPHE Water Quality Control Division* CDPHE sampled 5 sites in the time period. A 2006 sample from the Chapel site is the basis for the provisional 303(d) listing for impaired aquatic life.
2006 *sponsor:*	**Roaring Fork Watershed Water Quality Report** *Roaring Fork Conservancy* The report compiled data from RFC's watershed monitoring activities from 2000-2006. Brush Creek received an 'Impacted' rating for chemical, biological, and physical concerns.
2007 *sponsor:*	**Roaring Fork Stream Health Inventory (SHI)** *Roaring Fork Stream Health Initiative* The SHI rated instream and riparian habitat conditions. Brush Creek segment scores ranged from *Slightly Modified* in the upper and lower watershed, to *Severely Degraded* in the Village and Golf Course areas.
2007 *sponsor:*	**Brush Creek Water Quality Study** *Roaring Fork Conservancy* This work monitored 4 stations to establish new baseline conditions for physical parameters and macroinvertebrates, and explored previously identified pH and phosphorus concerns.

Table 1.1 (continued from previous page). Timeline of scientific work for Brush Creek.

2011 *sponsor:*	**Aquatic Life and Stream Health in the Roaring Fork Watershed** *Roaring Fork Conservancy* RFC sampled macroinvertebrates throughout the Roaring Fork watershed, including Brush Creek. Samples from the Roundabout site on Brush Creek received 'attaining' MMI scores.
2012 *sponsor:*	**208 Regional Water Quality Management Plan Update** *Northwest Colorado Council of Governments (NWCCOG)* NWCCOG conducted an unpublished review of River Watch data from 2006 to 2011. Although limited exceedances for Fe, Se, and Pb were noted, they were not considered a major concern.
2013 *sponsor:*	**2012 Brush Creek Focused Water Quality Assessment** *Snowmass Water and Sanitation District, Roaring Fork Conservancy* The assessment conducted spatially-detailed macroinvertebrate and nutrient sampling, and found impaired MMI scores at 3 of 4 sites in the Village and Golf Course area. Nutrient loading patterns did not align with MMI impairment patterns.
2013 *sponsor:*	**Nutrient monitoring, unpublished data** *Snowmass Water and Sanitation District* SWSD continued in 2013 to explore sources and magnitudes of nutrient loading at select locations on Brush Creek and tributaries. Patterns continued to show that high nutrient sites do not align with low MMI site scores.
2013 *sponsor:*	**Stormwater outflow inventory** *Snowmass Water and Sanitation District* SGM Inc. conducted an inventory of location, type, size, and other attributes for stormwater tributaries to Brush Creek.

Planning documents produced by local governments also provide guidance regarding the future of the watershed (Table 1.2). Collectively, these works illustrate the values surrounding Brush Creek espoused by various stakeholders, as well as current directions of development activities involving the creek. In particular, the 2001 Draft Brush Creek Watershed Management Plan (WWE, 2000) served as a previous reference point for this document. Prepared for Town of Snowmass Village by Wright Water Engineers, that work reviewed existing water quality data prior to 2000, assessed some stormwater sources, and prioritized work plans for Best Management Practices (BMP) in the town. This Stream Health Survey effort complements and builds on previous work by updating the water quality data analysis. The watershed has since experienced many changes, such as redevelopments to the base village and newly completed stream and riparian habitat rehabilitation projects.

Table 1.2. Timeline of planning documents for Brush Creek.

Year	Work summary
2001 *sponsor:*	**Brush Creek Watershed Management Plan** *Town of Snowmass Village* In addition to pollution source assessment, this plain suggested a framework for stakeholder involvement and prioritized stream segments for BMP implementation.
2003 *sponsor:*	**Brush Creek Master Plan** *Town of Snowmass Village* An update to the 1987 Down Valley Comprehensive Plan, this 'big picture' planning document sets goals for land use planning that directly and indirectly affect water quality in Brush Creek.
2007 *sponsor:*	**Town of Snowmass Village Greenway Master Plan** *Town of Snowmass Village* Intended as a decision-making framework for stream projects, the plan envisions Brush Creek as a shared resource that is both an asset to wildlife, residents, and visitors, while still functioning as a healthy headwater stream.
2008 *sponsor:*	**State of the Watershed** *Roaring Fork Conservancy, Ruedi Water and Power Authority* The report identified riparian and in-channel conditions as a primary concern for Brush Creek. It highlighted data gaps for the watershed including reliable flow data, groundwater quality data, and missing data for select constituents.
2009 *sponsor:*	**Town of Snowmass Village Environmental Sustainability Plan** *Town of Snowmass Village* The plan encourages environmental thinking in all town activities. Specific goals include "minimizing negative impacts to watershed water quality" and eliminating Brush Creek's "Impacted" designation by RFC.
2010 *sponsor:*	**Town of Snowmass Village Comprehensive Plan** *Town of Snowmass Village* The wide-ranging document articulates a shared vision for land use, economic and infrastructure development, and environmental stewardship. Several portions specifically address values and actions regarding Brush Creek.
2013 *sponsor:* (Draft)	**Snowmass Water and Sanitation District Source Water Protection Plan** *Snowmass Water and Sanitation District* This plan identifies and ranks potential contamination sources to the town's drinking water supply. Options for decreasing source risks are outlined.
	Update to TOSV Greenway Master Plan (in progress) **Update to TOSV Trails Master Plan** (in progress)

1.4 Stream impairment and regulatory setting

The Colorado Water Control Commission (CWCC) is certified by the federal government to administer the Federal Clean Water Act (CWA) at the state level, and does so under the powers of the Colorado Water Quality Control Act (Colorado Water Act). This law requires that streams to be classified by their beneficial uses (e.g. drinking water, recreation, agriculture) and assigned protective standards for chemical, physical, and biological parameters that maintain those uses. Streams failing to meet standards for one or more classified uses are considered impaired for that use. CDPHE WQCD biannually assesses the condition of state waters and submits a report to EPA classifying streams and rivers into one of five categories (Table 1.3). Category 5 Streams, known as the 303(d) list of impaired waters, are those that fail to attain one or more designated uses (WQCD, 2012). Brush Creek received 303(d) list status for Impaired Aquatic Life Use because macroinvertebrate scores were below the standard set for healthy reference streams in similar Colorado ecoregions.

Table 1.3. Stream Reporting Categories.

Category 1	Attaining water quality standards.
Category 2	Attaining some classified uses. Incudes M&E category.
Category 3	Insufficient data to determine whether or not the classified uses are being attained.
Category 4	Not supporting a standard for one or more classified uses, but a TMDL is not needed. (Includes subcategories 4a-4c)
Category 5	Not meeting applicable water quality standards for one or more designated uses by one or more pollutants. (303(d) waterbodies).

Once a stream is placed on the Monitoring and Evaluation (M&E) list, the CDPHE WQCD initiates a 'pollution budgeting' process among entities holding permits for polluting discharges on the stream reach. The process is called Total Maximum Daily Load (TMDL) allocation, and is an effort to quantify the maximum amount of pollutant, known as 'load', that a stream can assimilate and still meet water quality standards. Pollutants are divided between waste-load allocations (point sources) and load allocations (nonpoint sources). Either source may be natural or anthropogenic, but it must be accounted. Streams with completed TMDLs move from Category 5 to Category 4a, streams with EPA-approved TMDLs (Table 1.4). This process works adequately for point-source pollution discharges that can be addressed through technological improvement or regulatory discharge curtailment. Brush Creek's listing is *provisional*, meaning that causes of impairment are unknown. In this situation, the TMDL process may not function appropriately to identify and target impairment through pollution load allocation. Category 4 includes several other subcategories that may provide regulatory alternatives to TMDLs (Table 1.4). CDPHE WQCD may work cooperatively with interested stakeholders in further monitoring and investigation to determine causes, with a general goal of making the determination within 10 years (CDPHE, 2010). Streams with causes which cannot be addressed by the TMDL process may be removed from the 303(d) list if conditions improve to a point of standards attainment, or they are found suitable for Category 4b or 4c designation. Category 4c covers streams which are impaired by pollution but not a pollutant (e.g. naturally derived sedimentation, highly mineralized groundwater, irreversible physical alteration, etc.). Category 4b indicates that a pollution control program other than a TMDL is expected to remedy the condition within a reasonable time period.

Table 1.4. Category 4 stream subcategories.

Category 4a	TMDL completed and approved by EPA.
Category 4b	Waters with pollution control programs in place other than a TMDL that are expected to meet standards within a reasonable timeframe.
Category 4c	Waters impaired by pollution, but not pollutants (i.e. flow impairment, physical alteration)

1.5 Brush Creek watershed overview

1.51 Physical and ecologic setting

Brush Creek watershed is located on the northeastern slope of the Elk Mountains in Pitkin County Colorado, covering approximately 16.4 square miles with elevations ranging from 12,600 ft. on Baldy Mountain to 7,400 ft. at its confluence with the Roaring Fork River. It is classified by the CDPHE WQCC as Segment 4 of the Roaring Fork River Basin in Regulation 33 *Classifications and Standards for the Upper Colorado River Basin and North Platte River*. The 12 digit Hydrologic Unit Code (HUC) for the subwatershed is 140100040603, although this mapping unit also contains the adjacent Owl Creek watershed, which drains directly to the Roaring Fork River.

Figure 1.1. The darkly shaded area shows the location of Brush Creek subwatershed (HUC 140100040602) within the greater Roaring Fork River watershed. The HUC subwatershed delineation also includes adjacent Owl Creek on the east side, which drains directly to the Roaring Fork River.

The watershed's southern boundary borders the Maroon Bells-Snowmass Wilderness Area. Two primary tributaries feed Brush Creek in the headwaters, the East Fork and the West Fork. Brush Creek Ditch brings transbasin diversion water from East Snowmass Creek. Average precipitation ranges from 15 in (38 cm) in the lowest portions of the valley to 41 in (104 cm) at the watershed divide. The large variation in elevation, aspect, and precipitation in the watershed contributes to a complex patchwork of microclimates that sustain highly diverse ecosystem types.

The State of the Roaring Fork Watershed Report (Clarke et al., 2008) contains thorough physical and biological descriptions of the basin. Ecosystem types in the lower watershed predominantly include big sage and upland shrub, while the Snowmass Village core sits in a transition zone of aspen and mixed conifer forests. The upper watershed elevations consist primarily of spruce-fir dominated subalpine forest up to tree line where tundra occurs. Riparian vegetation includes mixed deciduous species typical of the region such as willow, alder, saskatoon, and aspen.

Erosive marine shale hillslopes comprise much of the lower watershed below Snowmass Village, along with landslide deposits, alluvial fans, and alluvial fill. The golf course area in particular is on a large area of alluvial fill. The shale hillslopes can generate high levels of total suspended solids as well as high alkalinity and naturally occurring contaminants like selenium (DOE, 2011). Various sandstone formations and mixed glacial deposits occur frequently in the upper watershed.

1.52 Hydrology: natural and modified

Brush Creek features a snowmelt-driven hydrologic regime common to many Rocky Mountain streams. Winter snowpack accumulates from fall to late spring then warming spring temperatures produce runoff that swells streams to capacity for a period of several weeks in late May through mid-June. Streamflows in the region generally peak by the end of June and begin to recede. Localized heavy thunderstorms increase flows again during summer and early fall. Baseflow conditions persist from fall to late winter. During runoff, many nonpoint pollutants may mobilize to streams by the initial snowmelt that has been in contact with the ground surface all winter. This phenomenon is termed 'first flush'. Summer thunderstorms may initiate rapid runoff from urban and landscaped surfaces, also generating short-lived fluxes of pollutants to the stream.

Brush Creek watershed contains no existing long term gages and annual yield and seasonal flow estimates are difficult. Earth Resources Investigations Inc. (ERI) conducted the most extensive recent flow monitoring for upper Brush Creek in the mid 1990's using a staff gage in the Yarrow Park area, approximately 1000 feet above the East Brush Creek confluence (ERI, 1998). WWE established 4 staff gages as part of a storm water monitoring assessment in 2000. The current state of these gages is not clear.

Brush Creek receives approximately 1500 acre feet annually of transbasin water diverted from East Snowmass Creek to supply municipal drinking water for SWSD and meet the irrigation needs of multiple other private water rights holders in the watershed. An additional pump station can divert water directly from Snowmass Creek to the SWSD storage and treatment system in the Brush Creek watershed.

1.53 Water rights and diversions

Although East Snowmass Creek is the primary municipal water source for SWSD, a number of water rights and diversion points are active in the Brush Creek Watershed. Table 1.5 outlines significant water rights, including ownership and general use purposes.

Table 1.5. Water rights in Brush Creek Watershed.

Name	Decreed rate (cfs)
West Fork Brush Creek Pipeline	11.5
East Brush Creek Ditch (East Fork)	6.3
Stern Ditch No 3	6.2
Roberts Ditch (East Fork)	6.2
Lemond Ditch	6.0
Brush Creek Ditch	5.5
Carroll Ditch	3.6
Ziegler Reservoir (storage right)	357 AF

1.54 Land use and land cover

A wide variety of land uses presently exist in the basin. In the high elevation hill slopes, recreation dominates use with summer trails, ski runs, and other ski area infrastructure including unimproved roads, lifts, snowmaking infrastructure, dining structures, and maintenance facilities. Patchy, discontinuous forest covers most other ski area lands. Recreation continues to be an important land use in the middle watershed, where Snowmass Golf Club covers a large swath of valley floor. Although small parks, foot trails, and the valley bike path account for a small overall percentage of land use, their generally close proximity to the stream corridor make them important influences to stream conditions.

Human development ranges from the dense urban core of the village, with high amounts of impervious surfaces, transitioning to mid and low density residential development around the golf course and outlying subdivisions, and dispersed rural residential dwellings on the valley edges. Brush Creek Road serves as a trunk road for the infrastructure system and parallels the creek from mouth to source, experiencing seasonally heavy traffic tied to resort occupancy. Four lane State Highway 82 crosses Brush Creek just above its confluence with the Roaring Fork River. In the lower watershed (from the intersection between Brush Creek and Highline Roads down to Highway 82) irrigated pastureland maintains open space and allows for a relatively intact stream corridor with more riparian cover and less physical channel alteration.

2. Water quality analysis

2.1 Data sources

Several entities conducted water quality monitoring at a number of sites from 2002-2013. The length and continuity of records varies by site, but is relatively less comprehensive compared to other locations in the greater Roaring Fork watershed. EPA's Legacy STORET database contains limited records for several sites back to 1977. TOSV sponsored the 2001 Brush Creek Watershed Management Plan (WWE, 2001), which summarizes water quality data from STORET between 1977 and 2000. RFC-led monitoring accounted for the majority of sampling activities since then, with lesser amounts by SWSD, CDHPE, and USFS. Prior to 2001, USFS, USGS, and TOSV collected limited water quality data. This review excludes that older data but makes some narrative references to previous works. Recent observations contain wide variation in the period of record, frequency, and suite of parameters observed. Sample data are summarized in Table 2.1 and monitoring locations are shown in Figure 2.1.

Figure 2.1. Existing monitoring locations in Brush Creek watershed.

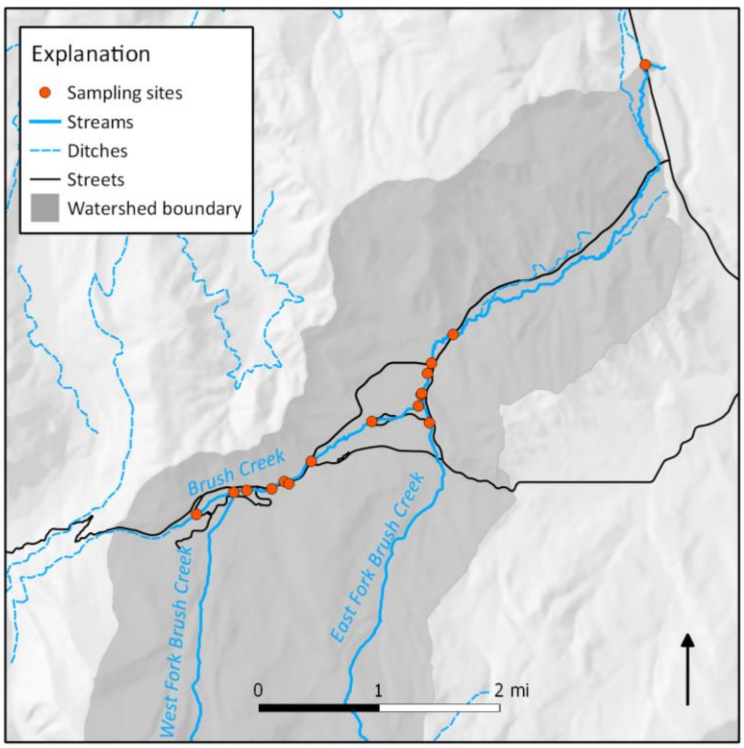


Table 2.1. Sample site data summary.

WC, water chemistry; MC, macroinvertebrates; TE, trace elements; MI, major ions; N, nutrients; B, biological; P, physical; IQ, Instantaneous flow; Q, proximal flow

Station Name	Data Source	Station ID (Alternate ID))	Data Type	No. of Samp.	Period of Record	Latitude (WGS84)	Longitude
Village							
Upper Brush Ck.	RFC		MC	1	2012	39.20723	-106.95701
Woodbridge Ln	CDPHE	12761A	WC (P, MI, N, TE)	4	2006-2007	39.21118	-106.94345
Below Pond	SWSD	Below Pond	WC (P, N)	13	2013	39.21010	-106.94923
Below Viceroy	SWSD	Below Viceroy	WC (P, N)	13	2013	39.21029	-106.94537
Snowmass Chapel	RFC	Chapel	MC	1	2012	39.21358	-106.93928
	RW	889	WC (P, MI, N, TE)	9	2006-2011		
	SWSD	Chapel	WC (P, N)	13	2013		
Vidal Gulch (trib.)	SWSD	Vidal Gulch	WC (P, N)	13	2013	39.21091	-106.94273
Golf Course							
Snowmass Club Cir	RFC	Abv. Confluence	MC	1	2012	39.21837	-106.92990
	RW	888	WC (P, N, TE)	8	2007-9, 2011-12		
	SWSD	Clubhouse Dr. Br.	WC (P, N)	13	2013		
Below SMV WWTP	RW	811	WC (P,MI,N,TE)	6	2007, 2011-2013	39.22173	-106.92218
Roundabout	RW	887	WC (P, N, TE)	10	2007-9, 2011-13	39.22534	-106.92068
	SWSD	Below Roundabout	WC (P, N)	13	2013		
East Brush Ck (trib.)	SWSD	East Brush Ck.	WC (P, N)	13	2013	39.21822	-106.92101
Lower Brush Creek							
Blw. Snowmass V Br.	CDPHE	12761	MC	1	2001	39.22877	-106.91734
Hwy. 82 Bridge	RW	771	WC (P, N, TE)	61	2002-2009, 2013	39.26106	-106.88763

2.2 Ambient water chemistry

2.21 Introduction and methods

RFC sampling provides the majority of all water quality data since 2001, this data submitted to and hosted in the CPW-administered River Watch database. Data was accessed via the Water Quality Portal (WQP), a cooperative data server administered by USGS, EPA, and the National Water Quality Monitoring Council. In 2013, SWSD sampled 13 sites in the watershed approximately twice a month to develop a better understanding of nutrients in Brush Creek and tributaries. The final dataset for the SHS included observations from RFC, SWSD, and CDPHE. These data were assembled and analyzed to characterize ambient water quality conditions in Brush Creek. This report compares data to applicable water quality standards to provide context for understanding water quality condition, only CDPHE may legally declare water quality standards exceedances and designate stream impairment.

2.22 Standards background

Brush Creek beneficial use classification

The Clean Water Act, as administered by CDHPE WQCC, classifies all streams in the state with one or more beneficial uses to which the water is currently applied or may potentially be suitable. Both numeric and narrative water quality standards deemed protective of these beneficial uses are detailed in 5 CCR 1002-31 *Basic Standards and Methodologies for Surface Water* (Regulation 31). More specific information for regional segment standards is provided in the biennially updated 5 CCR 1002-33 *Classification and Numeric Standards for Upper Colorado River Basin and North Platte River* (Regulation 33). Brush Creek is currently designated for:

- Cold-water Class I Aquatic Life,
- Recreation E (primary contact), and
- Agriculture.

Brush Creek is identified as Segment 4 in the Roaring Fork River Basin, with the segment ID code COUCRF04. This segment includes the headwaters and all source tributaries to the confluence with the Roaring Fork River. Exceedances of state standards identified may help identify stressors to aquatic life that could cause impaired stream conditions. Water quality standards for Brush Creek are included in Tables 2.2-2.3. The legislature adopted interim nutrient standards into Regulation 31 in 2012. Nutrient standards apply to headwaters upstream of major dischargers and are displayed in Table 2.4

Table 2.2 Physical and inorganic water quality standards.

Physical, biological, and inorganic water quality standards for Brush Creek (Roaring Fork Segment 4)
Beneficial use classifications: Aq Life Cold 1 (AL), Recreation E (R), Agriculture (AG)
Beneficial Use Types: AL, Aquatic Life; AG, Agriculture; WS, Water Supply; R, Recreation.

Parameter		Type	Classification	Standard	Units
Physical					
Temperature			AL		°C
	Jun-Sep	Chronic		MWAT = 17	
		Acute		DM = 21.2	
	Oct-May	Chronic		MWAT = 9	
		Acute		DM = 13	
Dissolved Oxygen, DO (AL)		Acute	AL, R, AG	> 6.0	mg/L
Dissolved Oxygen, DO (spawning, AL)		Acute		> 7.0	mg/L
pH, (AL)		Acute	AL,R	6.5-9.0	s.u.
Inorganics					
Ammonia, NH_3 (unionized)		Acute	AL	TVS based on T(°C), pH(s.u.)	mg/L
		Chronic			
Chlorine, Cl_2 (AL)		Acute	AL	0.019	mg/L
		Chronic	AL	0.011	mg/L
Cyanide, CN, (AL)		Acute	AL, AG	0.005	mg/L
Boron, B, (AG)		Chronic	AG	0.75	mg/L
Nitrate, NO_3^- (WS)		Acute	AG	100	mg/L
Nitrite, NO_2^-(WS)		Acute	AL, AG	0.05	mg/L
Sulfide, S, (AL)		Chronic	AL, AG	0.002	mg/L
Biological					
E.coli, (R)		Acute	R	126	colonies/100mL

Table 2.3. Metals water quality standards (dissolved unless specified, Trec = Total Recoverable, tot=total).

Parameter		Use	WQS µg/l	Equation
Aluminum	Acute, (Trec)	AL	6455	$e^{(1.3695[\ln(hardness)]+1.8308)}$
	Chronic, (Trec)	AL	922	$e^{(1.3695[\ln(hardness)-.1158)}$
Arsenic, As	Acute	AL	340	
	Chronic, (Trec)	AL	7.6	
Cadmium, Cd	Acute	AL	4.10	$(1.136672-[\ln(hardness) \times (0.041838)]) \times e^{0.9151[\ln(hardness)]-3.1485}$
	Acute, (trout)	AL	2.55	$(1.136672-[\ln(hardness) \times (0.041838)]) \times e^{0.9151[\ln(hardness)]-3.6236}$
	Chronic	AL, AG	0.6	$(1.101672-[\ln(hardness) \times (0.041838)]) \times e^{0.7998[\ln(hardness)]-4.4451}$
Trivalent Chromium, CrIII	Acute	AL	833	$e^{(0.819[\ln(hardness)]+2.5736)}$
	Chronic	AL, AG	108	$e^{(0.819[\ln(hardness)]+0.5340)}$
Hexvlnt. Chromium, CrVI	Acute	AL	11	
	Chronic	AL, AG	11	
Copper, Cu	Acute	AL	20.8	$e^{(0.9422[\ln(hardness)]-1.7408)}$
	Chronic	AL, AG	13.3	$e^{(0.8545[\ln(hardness)]-1.7428)}$
Iron, Fe	Chronic (Trec)	AL	1000	
Lead, Pb	Acute	AL	106.6	$(1.46203-[(\ln hardness)*(0.145712)])* e^{(1.273[\ln(hardness)]-1.46)}$
	Chronic	AL, AG	4.15	$(1.46203-[(\ln hardness)* (0.145712)])* e^{(1.273[\ln(hardness)]-4.705)}$
Manganese, Mn	Acute	AL	3848	$e^{(0.3331[\ln(hardness)]+6.4676)}$
	Chronic	AL, AG	1925	$e^{(0.3331 [\ln (hardness)]+5.8743)}$
Mercury, Hg	Chronic (tot)	AL	0.01	
Nickel, Ni	Acute	AL	693	$e^{(0.846[\ln(hardness)]+2.253)}$
	Chronic	AL, AG	77.0	$e^{(0.846[\ln(hardness)]+0.0554)}$
Selenium, Se	Acute	AL	18.4	
	Chronic	AL, AG	4.6	
Silver, Ag	Acute	AL	4.51	$1/2e^{(1.72[\ln(hardness)]-6.52)}$
	Chronic	AL	0.17	$e^{(1.72[\ln(hardness)]-9.06)}$
	Chronic (trout)	AL	0.71	$e^{(1.72[\ln(hardness)]-10.51)}$
Zinc, Zn	Acute	AL	213	$0.978\, e^{(0.8525[\ln(hardness)]+1.0617)}$
	Chronic	AL, AG	183	$0.986\, e^{(0.8525[\ln(hardness)]+0.9109)}$
	Chronic (sculpin)	AL, AG	294	$e^{(2.227[\ln(hardness)]-5.604)}$

Table 2.4. Interim nutrient standards.

Interim nutrient numeric criteria;
Updated in Regulation 31 Basic Standards and Methodologies for Surface Water, Section 31.17

Parameter	Standard	Units	Comments
Total Nitrogen	1250	µg/L	Annual median Total Nitrogen (µg/L), 1-in-5 years allowable exceedance frequency
Total Phosphorus	110	µg/L	Annual median Total Phosphorus (µg/L), 1-in-5 years allowable exceedance frequency
Chlorophyll a	150	mg/m^2	Summer (July 1- September 30) maximum attached algae, must not exceed.

Reg 31 §31.17 (e) i-iii identifies the limited circumstances in which these nutrient standards apply instream prior to May 31, 2022. This includes "*headwaters located upstream of all permitted domestic wastewater treatment facilities discharging prior to May 31, 2012, or with preliminary effluent limits requested prior to May 31, 2013*" and "*Circumstances where the Commission [WQCC] has determined that adoption of numerical standards is necessary to address existing or potential nutrient pollution because the provisions of Regulation #85 will not result in adequate control of such pollution.*"

Metals: Many instream standards for dissolved metals use a hardness-based equation to calculate the Table Value Standard (TVS) because metals toxicity to aquatic life decreases with increasing hardness. The mean hardness value for Brush Creek is 159 mg/l per River Watch site observations from 2002-2013. For reference and understanding downstream watershed trends, additional hardness values are reported for specific sites in Table 2.5.

Table 2.5. Hardness summary.

Site Name	River Watch Site Code	Dates	n	**Mean**	Std. Dev.
Brush Creek Watershed	--	2002-2013	77	**159**	56
Chapel	889	2007-2013	6	**110**	57
Clubhouse Dr.	888	2007-2013	5	**120**	68
Blw SMV WWTP	811	2011-2013	4	**123**	37
Roundabout	887	2007-2013	6	**125**	45
Hwy 82	771	2002-2013	54	**175**	51

Temperature: Temperature directly influences aquatic life through controls on organism metabolism and dissolved oxygen levels. Extended warm temperatures can have deleterious impacts to cold water-adapted fish species like trout, especially during spawning periods in late summer and fall. Temperature standards are assessed both as an averaged 2 hour daily maximum (Diurnal Max, or DM) and the maximum Mean Weekly Average Temperature of the season (MWAT). Although spot temperatures are recorded for many samples in the data period, they are not of sufficient time resolution to allow for standards assessment in this work. The highest temperature observation was 21°C, indicating that at times Brush Creek approached the Diurnal Maximum Standard for Cold Water Tier 1 streams of 21.2^{o}C.

Nutrients: CDHPE WQCC amended Regulation 31 to specifically address instream nutrient standards in 2012. Although instream standards can apply in specific situations, the primary thrust of the state was to address nutrient pollution through technological improvements by permitted WWTP dischargers via Regulation 85, *Nutrients Management Control*. Interim total phosphorus standards may apply prior to 2022 in 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. Interim total nitrogen standards for headwaters streams above permitted dischargers may become effective in 2017.

Stream subreach segmentation

Although the entire length of Brush Creek is designated as the single segment COUCRF04 (Roaring Fork Basin Segment 4) by CDPHE WQCD, this study breaks the segment into subreaches based on major transitions in land use types. This segmentation allows better exploration of potential stressors on a small spatial scale. These segments parallel other work by SHI and TOSV (e.g. Malone and Emerick., 2007; TOSV, 2007; S.K.Mason Env[2]., 2013), however this work combines some segments identified in those reports due to relatively short lengths, lack of major land use change, or a dearth of water quality information.

The Village subreach includes Brush Creek from the top-most crossing of Brush Creek Road downstream to the Chapel area near the intersection of Brush Creek and Owl Creek Roads. The urban core of the ski area base village contains the most-dense development in the watershed. Roads consistently parallel the creek on both sides, with multiple culverted road crossings and many stormwater outfalls. Successive development phases altered, straightened, and/or armored the stream channel significantly throughout. TOSV completed a number of greenway enhancement projects on portions of this reach in the last decade.

The Golf Course subreach begins at the Chapel and extends below the rodeo grounds at the intersection of Brush Creek Rd and Highline Rd (the Roundabout). In this subreach, Brush Creek enters an area of

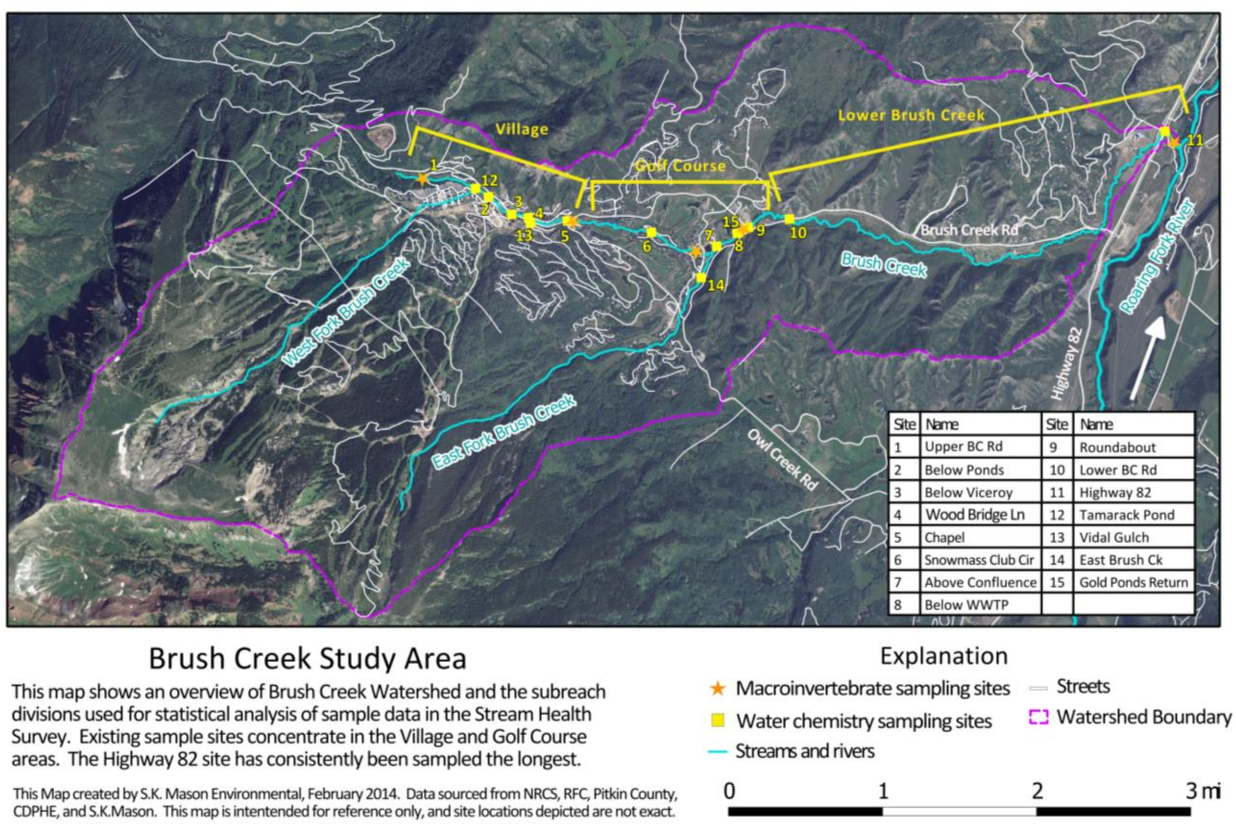
[2] Now Lotic Hydrological, LLC.

less-dense residential development surrounding the Snowmass Golf Club. The stream dissects the golf course and multiple subdivisions. In some locations, property owners and managers mow or landscape the riparian directly to the stream edge; more-intact riparian vegetation zones exist elsewhere. Development created significant physical alteration in this reach.

Lower Brush Creek subreach begins downstream of the Roundabout and extends to the confluence with the Roaring Fork River. Light density residential development and limited grazing activities characterize the lower basin. Brushy hillslopes, irrigated pastures in the bottomland, and fairly intact riparian vegetation surround the creek. The stream channel meanders and demonstrates much less physical alteration. Significant beaver dam activity occurs below the Roundabout, slowing water velocities, increasing sediment storage, and likely attenuating some water quality impacts from the golf course and village areas. The Lower Brush Creek subreach contains a major road crossing at Highway 82 prior to joining the Roaring Fork. The River Watch/CDPHE sampling site below the highway crossing is the oldest and most-continually sampled water quality station in the watershed.

In some cases, this work combined sample locations utilized by different entities that are in close vicinity and not separated by significant land use change or suspected stressor(s). This occurred for efficiency, and to increase statistical strength. Analysis further aggregated sampling using the 3 subreaches described above, although results of subreach analysis are not all reported here. The locations in the Village and Golf Course subreaches have a similar depth of record focused in the last five years, while the site at Brush Creek's mouth near Hwy 82 extends longer in time to 2002. Figure 2.2 shows the location of subreaches.

Figure 2.2 Consolidated sampling locations by subreach.



Data screening

The parameters reported for sampling events vary widely due to the different goals of each entity. Since the primary purpose of this Stream Health Survey is to explore potential chemical stressors as opposed to making a case for statutory attainment/impairment, a liberal approach to data inclusion was taken to cast a wide net for available information. This report assumes the front-end Quality Assurance/Quality Control (QA/QC) procedures of CDPHE, SWSD, and River Watch, are appropriate and adequate. After compiling available water quality data, a limited amount of further QA/QC included eliminating duplicate database records, elimination of unclear or inconsistent parameter types, and limited exclusion of observations with strongly improbable results.

Reported observations for many parameters, especially trace elements were below the methodological detection limit (MDL) of the analysis method, or 'non-detects'. CDHPE WQCD assigns a value of "0" to non-detects when assessing standards attainment. While this practice can bias analysis results downward, and result in poor parameter estimates and incorrect statistical tests, it is adopted here for consistency with WQCD practice. The numbers of observations listed in the summary tables that follow vary for many parameters even at single locations due to inconsistencies or gaps in the parameters reported for a particular sampling event on a given date.

2.23 Results and discussion

Water chemistry summaries

Tables 2.6 (a-d) summarize the field parameters, major ions and trace elements, nutrients, and biological parameters for Brush Creek watershed.

Table 2.6 a-d. Watershed water quality summary.

2.6a. Field parameters.

Parameter	No. of	Percentile				
	Samples	0 (Min)	15	50 (Median)	85	100 (Max.)
pH (s.u.)	*166*	6.7	7.7	8.1	8.6	9.6
Dissolved Oxygen (mg/l)	*149*	5.8	7.4	8.8	10.0	13.5
Temp (°C)	*79*	-1	0.85	6.5	12	21
Total Suspended Solids (mg/l)	*44*	0	0	0.01	0.06	0.11
Hardness (mg/l as $CaCO_3$)	*93*	52	86	163	204	278

2.6b Major ions and trace elements.

Parameter	No. of Samples	0 (Min.)	15	Percentile 50 (Median)	85	100 (Max.)
Calcium (mg/L)	*77*	5.5	25	51	59	94
Magnesium (mg/L)	*77*	2.0	4	11	16	26
Potassium (mg/L)	*49*	0.6	1	2.2	4.1	6.0
Sodium (mg/L)	*49*	1.3	2	9.3	15	20
Alkalinity, total (mg/L)	*80*	22	62	126	168	200
Chloride (mg/L)	*44*	1.5	2.5	8.9	23	32
Sulfate (mg/L)	*48*	13	16	24	36	55
Aluminum, dissolved (μg/l)	*80*	0	0	0	24	385
Aluminum, total (μg/l)	*77*	0	59	192	837	5064
Arsenic, dissolved (μg/l)	*78*	0	0	0	0	18
Arsenic, total (μg/l)	*77*	0	0	0	0	329
Cadmium, dissolved (μg/l)	*81*	0	0	0	0	0.48
Cadmium, total (μg/l)	*79*	0	0	0	0.17	2.3
Copper, dissolved (μg/l)	*81*	0	0	0	3.3	10
Copper, total (μg/l)	*77*	0	0	1.6	4.1	10
Iron, dissolved (μg/l)	*81*	0	15	25	43	626
Iron total (μg/l)	*81*	0	99	304	1043	4704
Lead, dissolved (μg/l)	*81*	0	0	0	0	5.9
Lead, total (μg/l)	*76*	0	0	0	1.7	10.2
Manganese, dissolved (μg/l)	*81*	0	0	6.6	11	33
Manganese, total (μg/l)	*77*	0	8.1	15	35	122
Selenium, dissolved (μg/l)	*81*	0	0	0	0	7.8
Selenium, total (μg/l)	*77*	0	0	0	0	37
Uranium, dissolved (μg/l)	*2*	0	0	0	0	0
Zinc, dissolved (μg/l)	*81*	0	0	4.4	17	60
Zinc, total (μg/l)	*77*	0	0	9.3	27	130

2.6c. Nutrients.

Parameter	No. of Samples	0 (Min.)	15	Percentile 50 (Median)	85	100 (Max.)
Ammonia, total NH_3 (μg/l)	*136*	0	0	50	148	1070
Inorganic nitrogen (NO_3+NO_2) (μg/l)	*129*	0	241	702	2795	13000
Phosphorus, total P (μg/l)	*125*	0	28	75	236	3030

2.6d. Biological.

Parameter	No. of Samples	0 (Min.)	15	Percentile 50 (Median)	85	100 (Max.)
E.coli, (R) (colonies/100ml)	*4*	1	2.4	17	42	53

Comparison to water quality standards

Table 2.7 compares parameter values for all Brush Creek sites to instream standards for Brush Creek. Regulation 31 and the 2012 Aquatic Life Use Assessment Methodology provided guidance to determine instream-standards. For parameters with exceedances, a more in-depth analysis follows. Table 2.8 highlights information for exceedances of select water quality parameters. Figures 2.3-2.5 visually detail the distribution of water quality data compared to water quality standards for each parameter.

Table 2.7. Water quality standards comparison.

Parameter	Type	Use	WQS	50%	85%	100%	Exceed
Physical							
pH (s.u.)	Acute	AL,R	6.5-9.0		8.60	9.58	
Dissolved Oxygen, DO (mg/l)	Acute	AL, R, AG	> 6.0		7.39(15%)	5.80(min)	x
DO (spawning) (mg/l)	Acute		> 7.0				
Temperature (^oC) Jun-Sep	Chronic	AL	MWAT = 17				
	Acute		DM = 21.2			12	
Oct-May	Chronic		MWAT = 9				
	Acute		DM = 13				
Metals							
Aluminum, Al (µg/l)	Acute, (Trec)		6455	192	837	5064	
	Chronic, (Trec)		922	192	837	5064	x
Arsenic, As (µg/l)	Acute	AL	340		0	18	
	Chronic, (Trec)		7.6	0	0	329	x
Cadmium, Cd (µg/l)	Acute	AL	4.10		0	0.48	
	Acute (trout)	AL	2.55		0	0.48	
	Chronic	AL, AG	0.60	0	0.18	0.48	
Trivalent Chromium, CrIII (µg/l)	Acute	AL	833		No data		
	Chronic	AL, AG	108.4		No data		
Hexavalent Chromium, CrVI (µg/l)	Acute	AL	16		No data		
	Chronic	AL, AG	11		No data		
Copper, Cu (µg/l)	Acute	AL	20.8		3.3	10.1	
	Chronic	AL, AG	13.3		3.3	10.1	
Iron, Fe (µg/l)	Chronic (Trec)	AL	1000	302	941	4704	x
Lead, Pb (µg/l)	Acute	AL	106.6		0	5.9	
	Chronic	AL, AG	4.15		0	5.9	x
Manganese, Mn (µg/l)	Acute	AL	46.7		16.3	26.0	
	Chronic	AL, AG	38.3		16.3	26.0	
Mercury, Hg (µg/l)	Chronic (Tot)	AL	0.01		No data		
Nickel, Ni (µg/l)	Acute	AL	693		No data		
	Chronic	AL, AG	77.0		No data		
Selenium, Se (µg/l)	Acute	AL	18.4		0	7.8	
	Chronic	AL, AG	4.6		0	7.8	x
Silver, Ag (µg/l)	Acute	AL	4.51		0	0	
	Chronic	AL	0.167	0	0	0	
	Chronic (trout)	AL	0.71		0	0	
Zinc, Zn (µg/l)	Acute	AL	213		17.4	59.6	
	Chronic	AL, AG	183		17.4	59.6	
	Chronic (sculpin)	AL, AG	294.3		17.4	59.6	
Nutrients			**mg/l**				
Ammonia, Total (mg/l as N) (ref. pH 7, T 10^oC)	Acute	AL	24.1		0.15	1.1	
	Chronic	AL	3.31		0.15	1.1	
Chlorine, Cl_2	Acute	AL	0.019		No data		
	Chronic	AL	0.011		No data		
Cyanide, CN	Acute	AL, AG	0.005		No data		
Boron, B	Chronic	AG	0.75		No data		
Nitrate, NO_3^-	Acute	AG	100	0.7	1.5	4.5	
Nitrite, NO_2^-	Acute	AL, AG	0.05	0.0029	0.0057	0.026	
Sulfide, S	Chronic	AL, AG	0.002		No data		
Biological							
E.coli, (R) (colonies/100ml)	Acute	R	126		42.3	52.6	

Figure 2.3. Field Parameters.

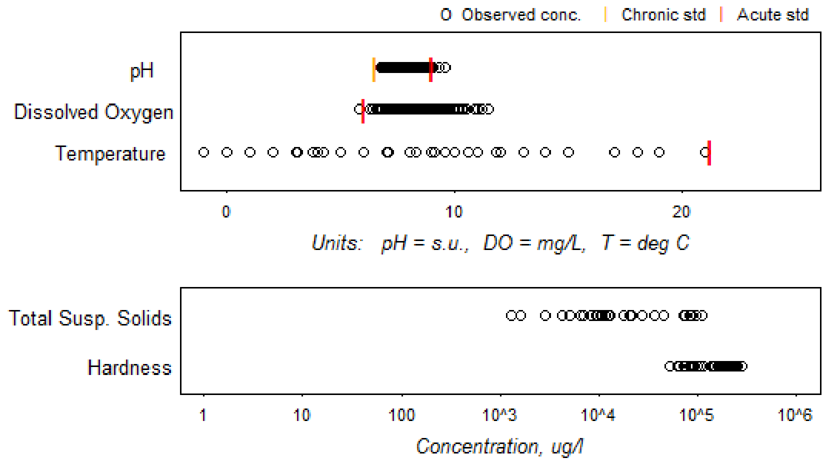


Figure 2.4. Metals and trace elements.

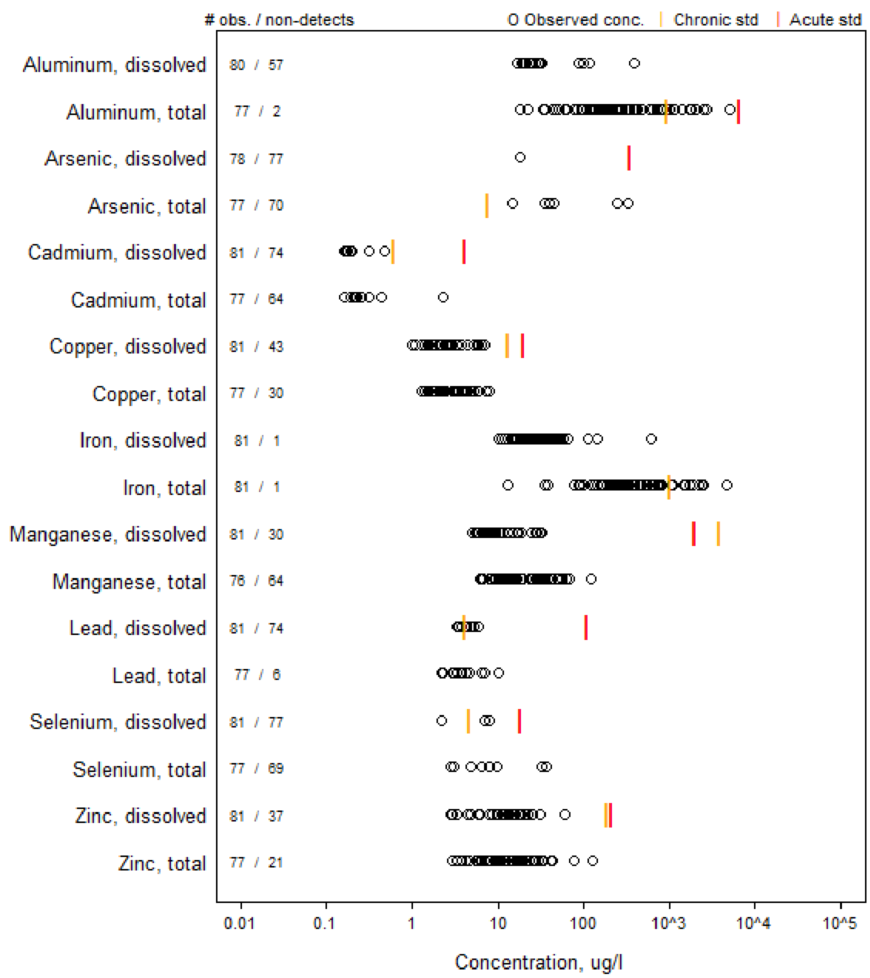
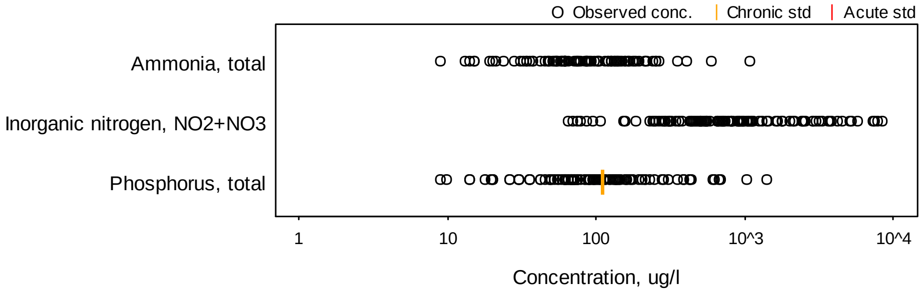


Figure 2.5. Nutrients.



Additional notes for Figure 2.5: This table features the nutrient parameters identified in Regulation 31, which differ from the parameters and standards detailed by Regulation 33 and listed in table 2.7. Although standards bars are provided for reference, standards for Total Nitrogen and Total Phosphorus are interim standards and could only specifically apply in Brush Creek above the WWTP, where nutrient concentrations are generally very low.

Ambient chemistry concerns

Since 2002, a small number of water quality standards exceedances occurred for pH, dissolved oxygen, total aluminum, total cadmium, total iron, lead, and selenium. Of these, only total iron and total aluminum were consistent and recent concerns, with multiple exceedances occurring in the last 3 years (Table 2.8).

Table 2.8. Water quality exceedance summary (Exceedances highlighted in red).

Parameter	*n*	Min.	Med.	Max	50% or 85% (for Chr. std.)	Acute Std. (# Exceed.)	Chronic Std. (# Exceed.)	Exceed last 3 years (# Exceed)	Month/Year
pH	166	6.7	8.1	9.6	8.6	6.5 - 9.0 (3)	--	N	10/2002, 9/2003, 10/2003
DO	166	5.8	8.7	13.5	6.7	6.0 (3)	--	Y (1)	8/2008, 7/2013, 8/2013
Al (TR)	79	0	183	5064	183	6455 (0)	922 (10)	Y (4)	3/2002, 6/2007, 6/2008, 6/2011
As (TR)	77	0	0	329	0	--	3.6 (7)	N	2006,2007,2008
Fe (TR)	84	0	302	4704	302	--	1000 (13)	Y (4)	2002, 2003, 2007, 6/2008, 6/2011
Lead	85	0	0	5.9	0	102 (0)	4.0 (4)	N	10/2006, 12/2007, 2/2008, 8/2008
Selenium	84	0	0	7.8	0	18.4 (0)	4.6 (2)	N	12/2005, 6/2007

One dissolved oxygen observation (5.8 mg/L) exceeded the minimum standard of 6.0 mg/L at the Highway 82 site in 2008. The three pH exceedances (9.06, 9.30, and 9.58) occurred in 2002 and 2003 during base flow conditions in August and September, also at the Highway 82 monitoring location. The 85 percentile of observations for both parameters did not exceed standards so the creek did not approach the regulatory benchmark for impairment designation, and more recent exceedances have not occurred.

Two selenium observations (6.9, 7.8 µg/L) exceeded the chronic standard of 4.6 µg/L. Both observations occurred in the Lower Brush Creek subreach; one at the Lower Brush Creek Rd site and one at Highway 82. Unlike many trace metals, the selenium standard does not vary as a function of hardness. Initially using the mean hardness value for Brush Creek, four lead observations exceeded the chronic standard. After recalculating the standard using paired hardness data from the individual samples, only two samples, (5.3, 5.9 µg/L) remained as exceedances. Both observations occurred at the Highway 82 location. Total recoverable arsenic observations exceeded the standard 7 times in 2006-2008. However, the arsenic standard has shifted over time, and the current standard in the 2012 update to

Regulation 33 is stricter than previous years, creating a ‘shifting target’ for assessment. Exceedances in the last 5 years did not occur.

The chronic standard for total iron is 1000 µg/l. Between 2002 and 2013, thirteen observations exceeded this standard at multiple sites in all three subreaches (Chapel, Snowmass Club Dr., Below WWTP, Roundabout, and Highway 82). Although four observations occurred in the last three years, three were on one single date in June 2011, at three sites in the Golf Course subreach. These data indicate total iron is a potential concern on Brush Creek. The 50th percentile (302 µg/l) of observations did not exceed the standard so the creek did not meet the regulatory benchmark for impairment designation. Regulation 31 directs that closely-timed observations be averaged as one single observation for a 30 day period. This would effectively decrease the actual number of exceedances and push total iron percentiles further away from the regulatory benchmark for impairment. The chronic standard for total aluminum is 922 µg/l. Ten observations exceeded this standard at multiple sites in the Golf Course subreach, and at Highway 82. On two sampling dates in June 2008 and 2011, all three sites in the Golf Course subreach produced exceedances, suggesting that segment of the creek may be prone to high total metals flux during runoff. Similar to iron, these observations would be averaged within a 30 day time period to one single observation, so total aluminum results stayed below the regulatory benchmark for impairment.

Multiple exceedances in the last 3 years for both total iron and total aluminum warrant closer evaluation of these parameters. The timing of high observations coincides with high flow periods (spring runoff) in the watershed (Figures 2.6, 2.7). Total metals includes both dissolved ions (metal ions and compounds < 0.45 microns in diameter) and metal atoms bound in colloids or sorbed to larger particles such as fine silt sediments. The timing indicates that the most probable source of high observation levels for these parameters is the large flux of sediment from area soils and bedrock carried to the stream during snowmelt, rather than human-sourced pollutants.

Figure 2.6. Total Iron by month and during entire observation period.

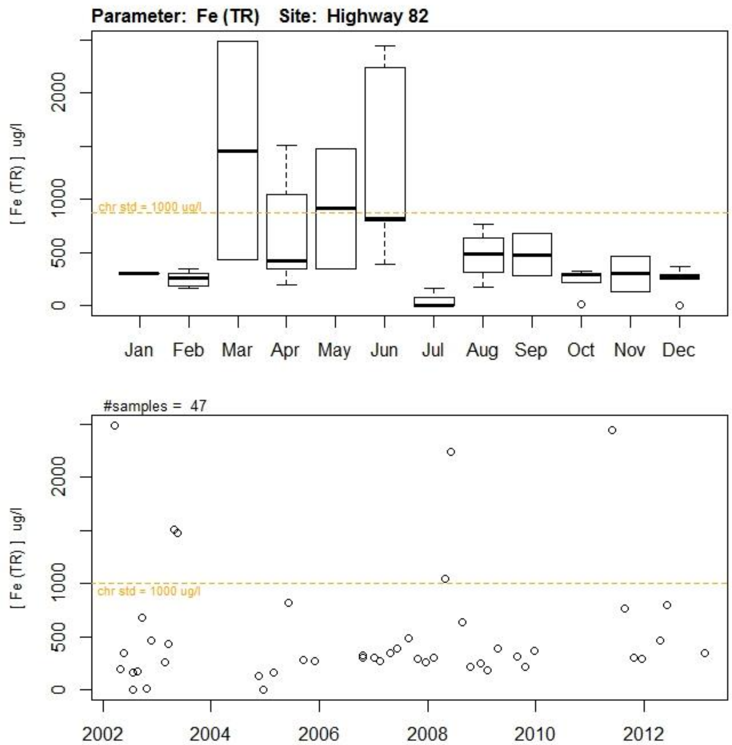
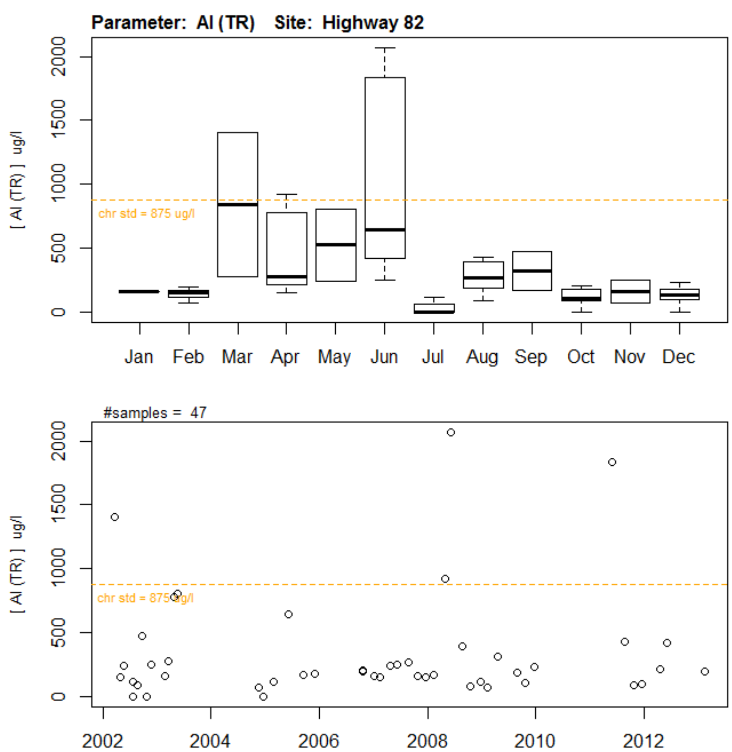


Figure 2.7. Total Aluminum by month and during entire observation period.



2.3 Macroinvertebrate analysis

2.31 Introduction and methods

Complete assessment of the effects of human-induced influences on aquatic environments requires monitoring physical, chemical, and biological components of rivers and streams. Benthic macroinvertebrate communities represent a valuable tool as biological indicators of water quality and aquatic conditions (Plafkin et al., 1989; Barbour et al., 1999; Paul et al., 2005; Hawkins, 2006; Merritt et al., 2008). The structure of a benthic macroinvertebrate assemblage reflects ecological pressures and the existing aquatic conditions. Individual taxa typically have specific adaptations to their environment and therefore exhibit a wide range of sensitivity to environmental disturbances or pollution. For these reasons, benthic macroinvertebrates are the most commonly used organisms in biomonitoring programs (Bonada et al., 2006). They are also utilized more than any other group of aquatic organisms to assess impacts from urban areas on aquatic life (Paul and Meyer, 2001).

Since 2001, biological communities in Brush Creek have been monitored to assist in the evaluation of spatial and temporal changes in biological conditions. Throughout western mountain regions, population growth and urbanization increased during recent decades, and this trend may continue into the future. Because continued residential and urban development is expected in these areas, the results of annual biomonitoring should provide a reliable measure of potentially changing aquatic conditions in the study area.

Stress-induced changes in macroinvertebrate community structure are best ascertained through analysis of benthic data using a variety of analysis tools (metrics). In this study, analysis of individual metrics and a Multi-metric Index (MMI) provides information regarding areas of greatest impact and recovery within the study area. Data was sourced from samples collected between 2001 and 2013 by CDPHE, River Watch, RFC, Timberline Aquatics, and S.K.Mason Environmental. Although each utilized slightly different field collection methods, all are approved for robust MMI results by CDHPE WQCD.

2.32 Standards background

Multi-metric Index (MMI)

In the fall of 2010, the CDPHE WQCD published specific guidelines for benthic macroinvertebrate sampling and analysis to assist in the evaluation of aquatic life in Colorado (CDPHE, 2010). These guidelines described specific protocols for the analysis of benthic macroinvertebrate data using the MMI. For the purpose of this study, the MMI was applied to historic macroinvertebrate data collected from Brush Creek regardless of the collection method or agency responsible for collections. The following section provides a brief description of the MMI and its components.

The group of metrics used in MMI calculations depends on the location of the sampling site and corresponding Biotype (Mountains, Transitional, or Plains). For Brush Creek, the MMI provides a single index score based on five or six equally weighted metrics. 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.

The study area for Brush Creek is located within both Biotype 1 (Transition Zone) and Biotype 2 (Mountain Zone). The thresholds for MMI scores that determine attainment or impairment for aquatic life use in Biotypes 1 and 2 are as follows:

Table 2.9. MMI standards.

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

Metric scores that fall between the thresholds for attainment and impairment require further evaluation using additional metrics in order to determine an aquatic life designation. The additional metrics include the Shannon Diversity (Diversity) and Hilsenhoff Biotic Index (HBI). Thresholds determined by the CDPHE WQCD for these metrics are as follows:

Table 2.10. Auxiliary metric attainment thresholds.

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

Additional metrics

Several individual metrics were applied to the data from Brush Creek to assist in the evaluation of aquatic conditions. Additional metrics included the following:

Total Taxa: This metric (also referred to as taxa richness) is often used to provide an indication of habitat adequacy and water quality. This measurement is reported as the total number of identifiable taxa collected on each date from each sampling location. Taxa richness typically increases with increasing water quality and habitat complexity.

EPT Taxa: The Ephemeroptera, Plecoptera, Trichoptera (EPT) index was also employed to assist in the analysis of this data. It is a direct measure of taxa richness among species that are typically considered pollution sensitive and is recommended as a valuable metric for most regions of the country (Barbour et al. 1999). The EPT value is simply given as the total number of distinguishable taxa in the orders Ephemeroptera, Plecoptera and Trichoptera found at each site. This number will naturally vary among river systems, but it can be a good indicator of disturbance within a specific drainage.

Percent Ephemeroptera Taxa: This metric is a measure of the percent composition of mayflies within the sample. Ephemeroptera taxa are considered relatively sensitive to a variety of anthropogenic disturbances and are consequently good indicators of stress to the aquatic environment (Lenat, 1988). The Percent Ephemeroptera Taxa metric is expected to decrease in response to increasing stress.

Percent EPT Taxa: This metric is similar to the number of EPT Taxa metric; however, the Percent EPT value is expressed as a percent composition of mayflies, stoneflies, and caddisflies rather than the total number of taxa. A greater percent composition of these orders is expected to indicate low levels of stress to the aquatic environment.

Percent Chironomidae: Chironomidae taxa are generally considered to be more tolerant of environmental stress than other aquatic insect families (Plafkin et al., 1989). The Percent Chironomidae metric relies on the assumption that Chironomidae density will increase with decreasing water quality. Streams that are undisturbed often have a relatively even distribution of Ephemeroptera, Plecoptera, Trichoptera, and Chironomidae (Mandaville, 2002); while the Chironomidae family often dominates (75% or more of the macroinvertebrate density) at sites degraded by metals or other pollutants (Barton and Metcalf-Smith, 1992).

Percent Non-Insect Taxa: The Percent Non-Insect Taxa metric relies on the assumption that aquatic macroinvertebrates other than insects (such as worms, mites, etc.) are generally more tolerant to perturbations than insect taxa. Since many insect taxa are thought to be relatively sensitive to perturbations, the Percent Non-Insect Taxa value is expected to increase in response to impacts from heavy metal toxicity, nutrients, and other sources of stress.

DAT: The Diversity and Taxa Index (DAT) metric was used in this study to evaluate water quality based on benthic community structure and diversity. Calculated DAT values fall within a range of numbers that are correlated to a scale describing stream condition (Mangum, 1986). The DAT scale is as follows:

Table 2.11. DAT metrics.

DAT Value	SCALE
18-30	Excellent
11-17	Good
6-10	Fair
0-5	Poor

2.33 Results and discussion

Macroinvertebrate data were compiled over a twelve year timespan (2001-2012) to assess changing aquatic conditions in Brush Creek and locate potential sources of stress. A general evaluation of these data was performed using the MMI tool (Table 2.12), several individual metrics (Table 2.13), and functional feeding group analysis (Table 2.14). Overall, aquatic conditions appeared to be impaired in portions of West Fork Brush Creek that are contiguous with residential development in Snowmass Village; however, aquatic conditions improved downstream of the confluence between the East Fork and West Fork of Brush Creek.

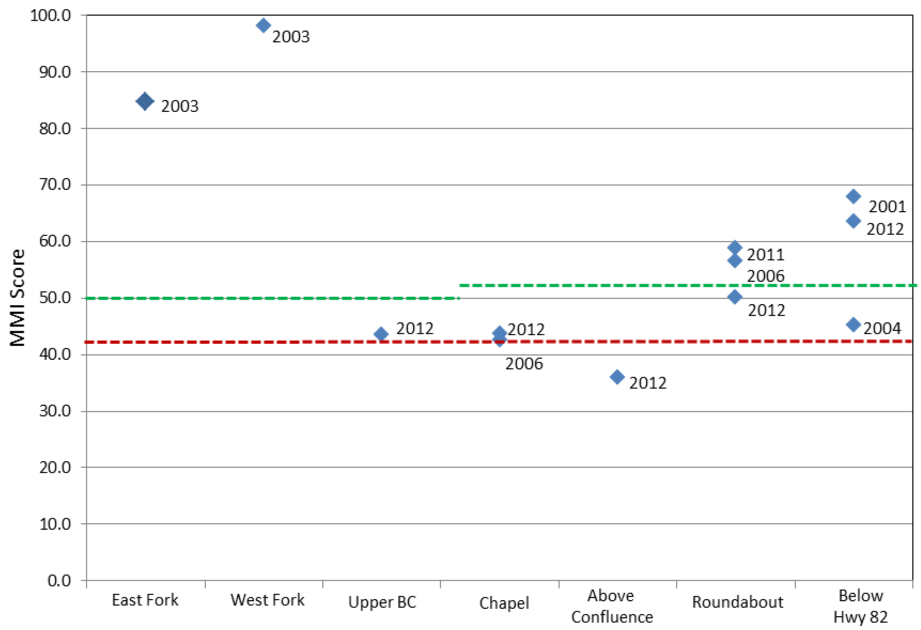
MMI scores

Limited data were available at most study sites, particularly at sites located upstream from the confluence of the east and west forks of Brush Creek. The two USFS sites (East Fork and West Fork) were both sampled once in 2003 and produced data indicating excellent aquatic conditions; however, these MMI scores were provided to Timberline Aquatics, Inc. without the raw macroinvertebrate data, so the accuracy of these calculations could not be verified. The Brush Creek site above Snowmass Village was only sampled once in 2012 and produced an MMI score in the “grey zone” (Table 2.12, Figure 2.8). The Diversity (auxiliary) metric produced an impaired value, indicating that Upper Brush Creek Rd. site had impaired aquatic conditions. The Chapel site was sampled twice (2006 and 2012) and consistently produced MMI values in the “grey zone” (Table 2.12, Figure 2.8). Auxiliary metrics (Diversity and HBI) produced values at the Chapel site confirming that aquatic conditions at this site score impaired for aquatic life use. Brush Creek above the confluence of east and west forks (Above Confluence) was sampled once in 2012 and produced an MMI score below the impairment threshold for aquatic life use (Table 2.12, Figure 2.8). The two most downstream sites in the study area (Roundabout and Hwy 82) were both sampled three times over the twelve year period and consistently produced MMI scores above the attainment threshold for aquatic life use, indicating improved aquatic conditions in a downstream direction below development associated with Snowmass Village.

Table 2.12. MMI, Diversity, and HBI values for Brush Creek study sites from 2001-2012. Values in red indicate impaired aquatic conditions.

Date		Site ID						
		East Fork	West Fork	Upper BC	Chapel	Abv. Conf.	Roundabout	Blw. Hwy 82
		Biotype 2			Biotype 1			
2001	MMI							67.90
	Diversity							3.86
	HBI							4.37
2003	MMI	84.71	98.27					
	Diversity	3.35	3.74					
	HBI	2.40	1.74					
2004	MMI							45.30
	Diversity							3.77
	HBI							4.69
2006	MMI				42.60		56.50	
	Diversity				2.66		3.59	
	HBI				5.49		4.13	
2009	MMI							63.50
	Diversity							2.75
	HBI							3.99
2011	MMI						58.80	
	Diversity						3.91	
	HBI						4.24	
2012	MMI			43.50	43.70	35.90	50.20	
	Diversity			2.05	2.09	1.81	3.00	
	HBI			4.42	4.23	4.47	3.40	

Figure 2.8. MMI scores from the Brush Creek study area, 2001 -2012.



Auxiliary metrics

Additional metrics (Total Taxa, EPT Taxa, Percent Ephemeroptera Taxa, Percent EPT Taxa, Percent Chironomidae, Percent Non-Insect Taxa, and DAT) were applied to the Brush Creek data for further evaluation of macroinvertebrate communities and aquatic conditions at these sites. In general, metric values confirmed the results of MMI analysis and detected similar levels of stress at most sites on Brush Creek (Table 2.13). Metrics designed to measure taxa richness (Total Taxa and EPT) produced relatively high values at upstream east fork and west fork sites; however, these metric values declined in the vicinity of Snowmass Village (starting at the Upper Brush Creek Rd. site), with slight improvements observed downstream of the confluence of the east and west forks of Brush Creek (Table 2.13). DAT metric values could not be calculated for the farthest upstream sites (due to the absence of raw data in this evaluation); however, the DAT metric detected some stress at sites in Snowmass Village, with improvement generally occurring in a downstream direction (Table 2.13). Percent composition of sensitive insect Orders (Ephemeroptera, Plecoptera, and Trichoptera) were measured by the Percent Ephemeroptera and Percent EPT metrics. The farthest upstream sites (East Fork and West Fork) produced high proportions of sensitive taxa, while declining values were observed as Brush Creek entered Snowmass Village (again beginning at the Upper Brush Creek Rd. site). Proportions of sensitive taxa downstream of the East Fork and West Fork of Brush Creek showed general improvement during most sampling years; however, Percent EPT values in particular were never restored to the values observed at the most upstream sites (Table 2.13). Metrics designed to measure disturbance-tolerant taxa (Percent Chironomidae and Percent Non-Insect Taxa) were somewhat variable throughout the Brush Creek study area, with no consistent impacts detected at a specific location. In general, the additional metrics applied in this study complimented results produced by the MMI and suggested that aquatic conditions in the Brush Creek study area generally declined within Snowmass Village, but exhibited some improvement downstream of the confluence of the east and west forks of Brush Creek.

Table 2.13. Additional individual metrics (including Total Taxa, EPT Taxa, %Ephemeroptera Taxa, %EPT, %Chironomidae, %Non-Insect Taxa, and DAT) applied to Brush Creek study sites from 2001-2012.

Date	Site ID							
		E. Fork (USFS)	W. Fork (USFS)	Above Village	Below Village	Above Confluence	Roundabout	Below Hwy 82
	Total Taxa							35
	EPT Taxa							14
	% Ephemeroptera							20.94%
2001	%EPT							43.75%
	% Chironomidae							28.75%
	% Non-Insect							1.88%
	DAT							30.2
	Total Taxa	27	35					
	EPT Taxa	16	22					
	% Ephemeroptera	12.50%	13.88%					
2003	%EPT	66.37%	78.31%					
	% Chironomidae	2.08%	4.58%					
	% Non-Insect	--	--					
	DAT	--	--					
	Total Taxa							33
	EPT Taxa							8
	% Ephemeroptera							13.71%
2004	%EPT							27.85%
	% Chironomidae							20.25%
	% Non-Insect							9.28%
	DAT							28.5
	Total Taxa				25		30	
	EPT Taxa				8		12	
	% Ephemeroptera				3.03%		5.44%	
2006	%EPT				13.94%		49.24%	
	% Chironomidae				3.64%		6.04%	
	% Non-Insect				42.12%		19.64%	
	DAT				17.7		25.2	
	Total Taxa							26
	EPT Taxa							13
	% Ephemeroptera							14.24%
2009	%EPT							41.21%
	% Chironomidae							0.91%
	% Non-Insect							9.09%
	DAT							18.8
	Total Taxa						34	
	EPT Taxa						15	
	% Ephemeroptera						7.98%	
2011	%EPT						37.41%	
	% Chironomidae						22.69%	
	% Non-Insect						10.47%	
	DAT						29.4	
	Total Taxa			24	25	23	23	
	EPT Taxa			8	8	5	8	
	% Ephemeroptera			2.61%	7.25%	1.21%	2.18%	
2012	%EPT			7.49%	11.48%	4.85%	47.57%	
	% Chironomidae			11.07%	4.23%	5.15%	3.64%	
	% Non-Insect			5.86%	10.57%	14.24%	19.17%	
	DAT			12.1	12.5	10.2	17.8	

Functional feeding groups

An evaluation of functional feeding groups generally supported the results from the previously described metrics and offered additional insight into changes in the macroinvertebrate community throughout the study area (Table 2.14). Data for the East Fork and West Fork sites was unavailable. Results from this analysis produced a distinct pattern of change in community function occurring within the Snowmass Village area (Table 2.14). Upstream sites in the village area were dominated by the collector-gatherer group, while specialized feeding groups (scrapers and shredders) occurred in relatively low proportions. Farther downstream (below the confluences with the East Fork and West Fork), there was an adequate representation of each feeding group, and no single group was disproportionately dominant. The dominance of the collector-gatherer group and poor representation of other feeding groups at upstream sites in the village is a typical response of macroinvertebrate communities that are exposed to elevated stress. The disproportion of functional feeding groups at Brush Creek's upstream sites may be related to flow stress in addition to anthropogenic influences. This stream segment may be partially intermittent or completely dewatered during drought years, however flow data is lacking. These negative impacts appeared to alleviate downstream (Table 2.14).

Table 2.14. Relative abundance of functional feeding groups at Brush Creek study sites from 2001-2012.

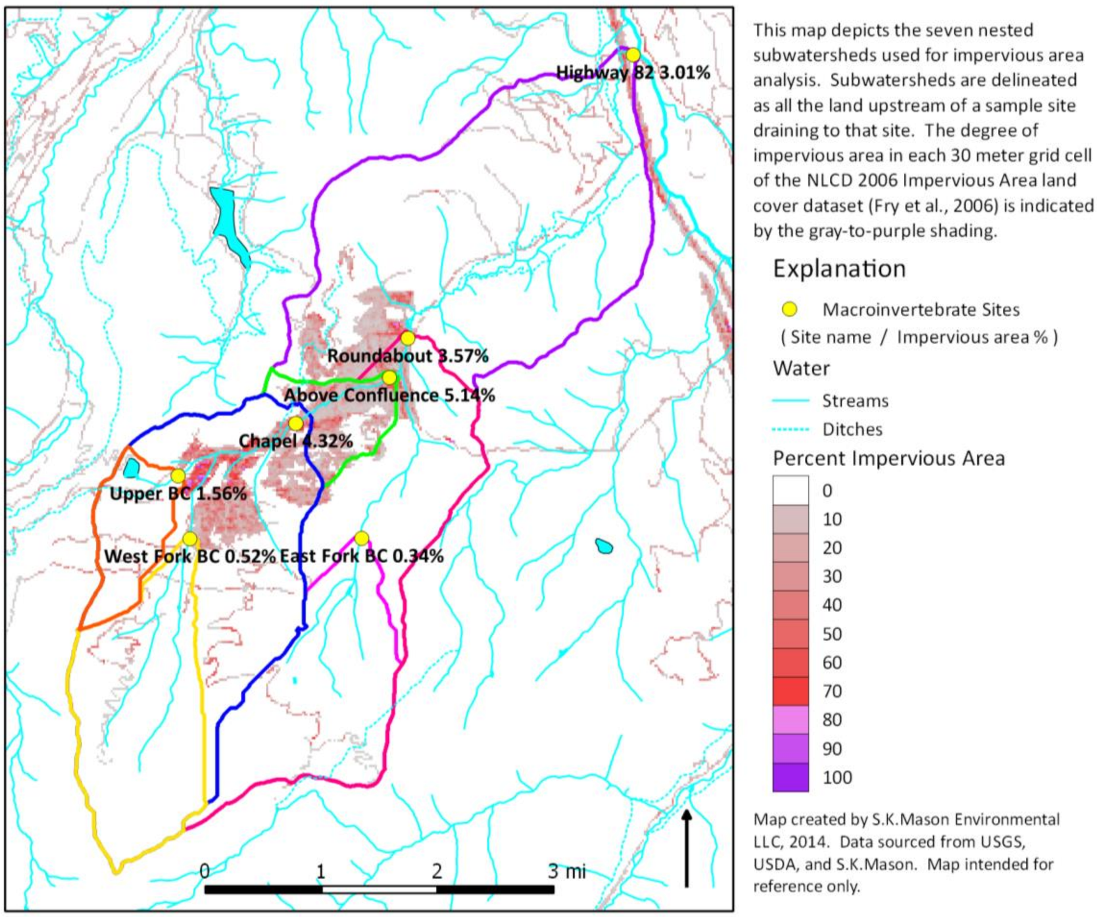
Date	Site ID							
		E. Fork (USFS)	W. Fork (USFS)	Upper BC	Chapel	Above Confluence	Roundabout	Below Hwy 82
2001	Collector-Gatherer							47.50%
	Collector-Filterer							16.25%
	Shredders							6.25%
	Scrapers							20.94%
	Omnivores							0.00%
	Predators							9.06%
2004	Collector-Gatherer							47.26%
	Collector-Filterer							17.93%
	Shredders							0.425
	Scrapers							28.90%
	Omnivores							0.00%
	Predators							5.49%
2006	Collector-Gatherer				82.73%		34.44%	
	Collector-Filterer				4.24%		38.07%	
	Shredders				2.12%		2.11%	
	Scrapers				0.30%		22.36%	
	Omnivores				0.00%		0.00%	
	Predators				10.61%		3.02%	
2009	Collector-Gatherer							17.88%
	Collector-Filterer							22.125
	Shredders							0.91%
	Scrapers							46.36%
	Omnivores							6.06%
	Predators							6.67%
2011	Collector-Gatherer						45.64%	
	Collector-Filterer						22.94%	
	Shredders						7.48%	
	Scrapers						15.21%	
	Omnivores						4.49%	
	Predators						4.24%	
2012	Collector-Gatherer			84.69%	83.69%	82.12%	28.40%	
	Collector-Filterer			0.00%	2.72%	3.33%	38.35%	
	Shredders			4.23%	0.60%	0.30%	5.58%	
	Scrapers			2.61%	2.42%	10.30%	24.27%	
	Omnivores			0.00%	2.42%	2.73%	1.21%	
	Predators			8.47%	8.16%	1.21%	2.18%	

2.4 Impervious surface area analysis

2.41 Introduction and methods

The amount and intensity of developed land in a watershed may impact water quality conditions negatively (Allan, 2004). One measure of development is the amount of impervious surface area in a given land area such as an entire watershed, or a subbasin within that watershed. Impervious surfaces are surfaces that are hardened via paving or building and construction that cause water to rapidly run off to streams, rather than percolate into soils. This analysis delineated seven individual subwatersheds nested within Brush Creek above each macroinvertebrate sampling location and averaged the percent of impervious surface area for each nested subwatershed using a GIS software package (Figure 2.9). Spatial datasets for percent-impervious area and subwatershed delineation are sourced from the USGS National Land Cover Database 2006 (Fry et al., 2011).

Figure 2.9. Subwatershed delineation for impervious surface area analysis.



2.42 Background

Although the relationship between increased impervious surface area and degraded aquatic life communities is strong and consistently reported in numerous studies, impervious area is essentially a surrogate variable for multiple stressors and does not differentiate the individual effects of altered hydrology, increased pollutants, or physical stream alteration. Some researchers reported aquatic life degradation in watersheds with *any* impervious area >0%, while others reported thresholds ranging from 2-20% impervious area before large scale negative impacts developed (Allan, 2004; Novotny et al., 2005, Walsh et al., 2005). Additionally, many impervious areas may represent irreversible conditions such as an existing urban core, so the variable provides watershed managers with few tools and solutions for restoration planning. Despite some limitations, impervious area analysis is useful to understand relationships between land use in Brush Creek watershed and MMI scores at individual sampling sites.

2.43 Results and discussion

A visual trend of decreasing MMI scores with increasing impervious area is evident in Brush Creek, although with the low sample numbers no statistical trend was tested (Table 2.15, Figure 2.10). East Fork and West Fork sites, which have little or no impervious area in the watershed above them, produced very high MMI results, although sampling has not re-occurred in over 10 years. The subwatersheds above the Chapel, Above Confluence, and Roundabout sites contain the relatively highest percentages of impervious area, and consistently produced the lowest scores. With the highest subwatershed impervious surface rating, the Above Confluence site also displayed the lowest measured MMI score on Brush Creek in 2012. Impervious surface area is a surrogate variable for the level of urbanization present in each subbasin. These results indicate that urbanization and its associated effects to aquatic life should be considered a likely driver of impairment in Brush Creek.

Table 2.15. MMI scores and percent-impervious area by subbasin.

Sample Site	MMI	Year	Average % Impervious Area for Subbasin
Upper BC	43.5	2012	1.56
Chapel	42.6	2006	4.32
Chapel	43.7	2012	4.32
Above Confluence	35.9	2012	5.14
Roundabout	56.6	2006	3.57
Roundabout	58.8	2011	3.57
Roundabout	50.2	2012	3.57
Highway 82	67.9	2001	3.01
Highway 82	45.3	2004	3.01
Highway 82	63.5	2009	3.01
East BC	84.7	2003	0.34
West BC	98.2	2003	0.52

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Figure 2.10. MMI scores versus impervious area.

3. Water quality stressor identification

3.1 Overview

This section discusses the likely stressors affecting Brush Creek, including the mechanisms influencing aquatic life. Although not enough data exists for Brush Creek to establish well-defined causal links between any particular stressor and current conditions, a weight of evidence approach and review of relevant scientific research literature suggests several factors, acting independently or in conjunction, negatively impact stream conditions. Walsh et al. (2005) describe development-induced changes to hydrology, water chemistry, contaminant loading, channel morphology, and stream energy inputs, with resulting shifts in aquatic and terrestrial species assemblages towards pollution-tolerant varieties, as the defining characteristics of the *urban stream syndrome*.

A relationship is consistently identified between degraded biological conditions and the amount of impervious or urbanized surface area in the catchment (Allan, 2004). However, whether the primary driver of degraded conditions is altered hydrology (i.e., increased flashiness, lower baseflows), episodic pollutant loading (i.e., stormwater contaminants), or both, varies among studies. Most scientific models linking Indices of Biological Integrity (IBIs) such as Colorado's MMI to measureable watershed parameters frequently rely on a single or few surrogate variables. As noted in the previous section, a common variable is watershed impervious area, which aggregates the effects of individual stressors and makes discrete causal relationships between degraded biological conditions and stressors difficult to discern (Novotny et al., 2005). This does not mean causes of biological impairment are a mystery, but emphasizes that separating and ranking the individual causes effect level remains a difficult exercise and hampers the prioritization of remediation efforts on many streams. In spring of 2013, EPA released findings from its National Rivers and Streams Assessment, 2008-2009. In the Western Mountains Region, which encompasses the Colorado Rockies, the most widespread indicators of stress were phosphorus, nitrogen, riparian disturbance, [reduced or absent] riparian vegetative cover, and [excessive] streambed sediments (EPA, 2013). Although Brush Creek data does not indicate excessive nutrients in the upper reach, each EPA-identified stressor is present in the greater watershed. Below the WWTP, where Brush Creek is an effluent-dominated stream during low flows, nutrients may cause some amount of stress. However, recent water quality samples collected below the WWTP did not exceed water quality standards and MMI scores generally ranked higher than those from other sites.

3.2 Ambient water chemistry

Natural and human-sourced chemical pollutants such as nutrients and trace metals may degrade aquatic life conditions. Scientifically-identified levels for these parameters that protect aquatic life in Brush Creek are the basis for state water quality standards. Based on exceedances of standards identified here and in past analysis, potential pollutants of concern include total iron, total aluminum, dissolved lead, and dissolved selenium. Additionally, high pH and low dissolved oxygen are potential field parameters of concern. However, the small number and inconsistent nature of exceedances during the time period indicate these are not likely major drivers of aquatic life impairment.

Overall, available water chemistry data for field parameters, major ions, trace elements, and nutrients in Brush Creek is of sufficient quantity and quality to provide a useful picture of ambient water quality. Since these parameters are generally within state standards, naturally occurring and human-sourced chemical pollutants do not appear to cause macroinvertebrate community impairment. Total iron is the only parameter with exceedances within last 3 years. Iron is a necessary dietary mineral for most organisms in low quantities, however high amounts may have a toxicity effect to aquatic life. Debate over the level appropriate to protect aquatic life still exists in the scientific and resource management community; for example, in 2012 the Colorado Mining Association requested a change in total iron standards citing a lack of scientific consensus regarding iron toxicity in streams and WQCC's reliance on EPA guidelines dating to 1976 (footnotes to Regulation 33, 2012). However, WQCC retained a precautionary approach with the 2012 update to Regulation 31, retaining a 1000 µg/L instream standard for total iron. In considering the variation of total iron and total aluminum observations on monthly basis between 2002 and 2013, the highest levels are found during the months of March – June. This indicates a relationship with high flows (spring snowmelt runoff) and likely source from natural geology and soils in the Brush Creek watershed. Scattered exceedances for selenium and total iron are also noted in Clarke et al. (2008) for sites on the Roaring Fork below Woody Creek and the Roaring Fork above Frying Pan Confluence (USGS sites 10 and 14 in the Upper Middle Roaring Fork Subwatershed). That report lists natural sediment sources as the most likely origin. Mancos Shale, which underlies a majority of the lower Brush Creek watershed and forms erosive hillslopes throughout, occurs across a large geographical area from the Roaring Fork watershed to southeastern Utah. As previously noted, it is known source of natural contamination (DOE, 2011).

3.3 Stormwater load: urban and impervious surfaces runoff

Untreated runoff from urban surfaces and impervious cover contributes sediment, metals, hydrocarbons, nutrients, organic compounds, and other pollutants to urban streams via stormwater infrastructure systems that are designed to quickly concentrate and remove water from developed areas (Paul and Meyer, 2001; Walsh et al., 2005, Hughes et al., 2014). Stormwater loads to Brush Creek occur at unpredictable time intervals and locations, making this aquatic life stressor a resource-intensive phenomenon to observe, both logistically and financially. Although the magnitude and location of loading is difficult to monitor, stormwater pollutants negatively impact aquatic life conditions in streams. Impervious surfaces may directly connect to streams through stormwater infrastructure, or connect indirectly across pervious surfaces like lawns, landscaping, and riparian buffers. The degree of connection provides an important control on the speed and magnitude of pollutant loading (Hatt et al., 2004). Stream restoration efforts focusing solely on riparian or physical habitat rehabilitation may not produce desired results if watershed-scale efforts to slow the transport of stormwater runoff to the stream and attenuate runoff contaminant loads are not also implemented via enhancement projects focused on TOSV's stormwater drainage systems (Walsh et al., 2005).

The last effort to quantify sources and amounts of pollutant loads in stormwater runoff occurred in 2000 as part of the Draft Brush Creek Watershed Management Plan created for TOSV. Since then, developers completed several large development projects and initiated others. TOSV completed several major stream and riparian enhancement projects in the Village segment. Locations and magnitudes of primary stormwater outfalls to the creek likely varied across this time period in conjunction with shifting locations of major development projects. Current conditions may not reflect those observed over a decade ago. Town of Snowmass Village, with just under 3,000 full time residents, falls well-below CDPHE's population size thresholds for permitting of Municipal Separate Storm Sewer System (MS4) discharges, therefore stormwater outfalls and runoff pollution from town infrastructure are unregulated by the state. Stormwater infrastructure development previously occurred in a piecemeal, project-by-project fashion, resulting in a patchwork system. Integration of stormwater infrastructure between various individual phases of village development and subdivision construction is largely non-existent. Design information lies buried in hardcopy project plan submissions, or is held anecdotally by long-term town personnel. This inhibits establishment of a secure institutional knowledge base and good records-continuity for stormwater infrastructure discharges to Brush Creek.

SWSD commissioned SGM Inc. to perform a detailed inventory of nonpoint source contributions to Brush Creek in the Village and Golf Course areas in 2013. This inventory may serve as a foundation for a more-detailed analysis of stormwater infrastructure and pollutant loading to Brush Creek. In personal communications with RFC and SWSD during early 2014, TOSV expressed an interest in voluntary partnering to explore the potential for improvements to stormwater outfalls to Brush Creek, where such projects would not pose an unreasonable burden to town resources. Up-to-date and accurate information detailing the location and magnitude of stormwater loading to Brush Creek is an important data gap that hinders understanding the causes of impairment to aquatic life conditions.

3.4 Stormwater load: pervious land use practices

Untreated, dispersed runoff from undeveloped and pervious surfaces may contribute water quality impacts which negatively affect aquatic life in Brush Creek. Pollutants from resort and residential land use activities include sediment, pesticides with potentially high toxicity to aquatic life, and various other chemicals. Monitoring this nonpoint source pollution can be logistically and financially difficult due to unpredictable locations and timing of pollutant load to streams. Work by WWE during the 2000 snowmelt runoff concluded that outflows draining the lower portions of the ski runs contributed most of the sediment load to upper Brush Creek (WWE, 2001). Source-managements solutions for problems like ski area-derived sediment may prove more fruitful than end-of-pipe solutions to slow runoff such as detention wetlands.

Many herbicides and pesticides pose high toxicity to fish and aquatic macroinvertebrates. Likely sources include land surfaces that border or are more-directly connected to Brush Creek within the intensively landscaped areas of the resort village, residential developments, and the golf course area. Treated roadside areas may also be important runoff sources for these pollutants. Significant data gaps currently exist regarding the existence, location, and magnitude of land-use related pollutant loading to Brush Creek.

3.5 Riparian degradation

Intact riparian areas promote healthy ecologic function in streams by contributing to habitat structure and complexity, providing energy inputs in the form of leaf litter and organic detritus, cooling water temperatures, and attenuating the effects of nonpoint source runoff pollution by trapping sediment and filtering pollutants. Even in heavily urbanized areas, streams with intact riparian buffers may retain high macroinvertebrate diversity and numbers (Moore and Palmer, 2005). However, research results are mixed on the ability of riparian restoration alone to promote healthy aquatic conditions or significantly change water chemistry characteristics. For example, Roy et al. (2006) found the negative effects of unmitigated hydrologic alteration overwhelmed the positive influence of riparian forests on stream life. In streams with highly-connected impervious areas, stormwater infrastructure can effectively bypass riparian buffers and reduce their ability to trap sediment, filter pollutants, attenuate hydrographic peaks, and generally provide attenuation of urban runoff effects (Walsh et al., 2005). The degree and type of hydrologic alteration, as well as land use in residential or low-density development areas adjacent to streams, heavily influences stream conditions and may relate to observed levels of degradation better than impervious area or urbanized area alone (Booth et al., 2004). The long lag time between removal or restoration of riparian vegetation and the realization of water quality degradation or benefits makes the relationship between vegetation treatments and water chemistry or stream biota difficult to quantify (Dosskey et al., 2010). Because of these difficulties, water resource managers' expectations of direct and short-term changes in water quality and aquatic life conditions should be tempered.

During successive phases of resort development from the 1960's to present, many of Brush Creek's riparian areas experienced alteration, degradation, or total removal. This likely contributed to degraded aquatic life conditions historically, and continues to do so currently. Considering the uncertainty in aquatic life outcomes, benefits of riparian rehabilitation should not be viewed solely through the lens of water quality. Through various planning documents (e.g. TOSV Environmental Sustainability Plan, Greenway Master Plan, TOSV Comprehensive Plan), TOSV and Pitkin County have explicitly identified numerous additional social values that are maintained or realized through intact and functional riparian areas on Brush Creek. These include mountain resort scenery, wildlife habitat, and opportunities for quiet, foot-based recreation. Attempts to realize these values through riparian rehabilitation or stream enhancement projects may effectively couple with watershed-scale remedies like addressing stormwater and disconnecting impervious area to produce measureable water quality benefits in the long term.

The most recent report of riparian conditions on Brush Creek is the inventory completed during the Stream Health Initiative (SHI) (Malone and Emerick, 2007). The SHI utilized the NRCS Riparian Assessment methodology, a mid-level screening tool for riparian condition and function. The authors classified Brush Creek in the Village and Golf Course areas as *Severely Degraded* on both banks, with some small sections receiving a *Heavily Modified* designation. A small distance of stream near the divide scored as *Moderately Modified* and *Slightly Modified*. While this effort provides an excellent medium-scale portrait of riparian habitat conditions in the subwatershed, it does not provide detail at an appropriate fine-scale for relating existing riparian conditions to macroinvertebrate scores on a site-by-site basis.

Some development bordering or within Brush Creek's riparian zone may be irreversible at this time. Dense urban construction in the Village reach and road infrastructure throughout the project area is unlikely to change. Other riparian areas that experienced alteration or destruction through mowing, landscaping, or some lesser physical alteration, may be degraded but possess an intact, undeveloped corridor suitable for rehabilitation or enhancement. Challenges to rehabilitation remain numerous; many reaches of Brush Creek are squeezed by irreversible development, while others feature steep, confined banks with no available floodplain or little room to increase lateral connectivity and riparian area. Significant data gaps currently exist regarding locations and magnitude of riparian degradation on a scale fine enough for correlation to aquatic community conditions and planning for remediation priorities and projects. Assessment and planning for new remediation and enhancement efforts would benefit from characterizing stream reaches in segments of < 100 m length to accurately identify areas in functional condition and those in which rehabilitation would be both beneficial and technically or socially feasible.

3.6 Physical alteration

During successive phases of urbanization, Brush Creek experienced physical alteration including channel straightening and relocation, armoring of the banks and stream bottom, removal of large woody debris, and increased channel bottom incision. These actions contribute to degraded aquatic life conditions by reducing the amount, diversity, and quality of available aquatic habitat, as well as altering the hydrologic regime and inhibiting lateral connections between the stream and riparian zones. Scientific studies on the effects of physical restoration on benthic macroinvertebrates indicate that physical restoration to improve habitat heterogeneity may not by itself produce improvements to diversity or community structure and function without addressing other watershed processes which also influence biota (Bernhardt and Palmer, 2007; Ernst et al., 2011). In other words, if catchment scale effects from altered hydrology and water chemistry are the root cause of degradation, reach-scale physical remediation will not alter aquatic life conditions significantly in a positive direction without also addressing the other drivers of degradation (Walsh et al., 2005).

Like riparian zone destruction, many physical alterations related to Village construction or road infrastructure may ultimately be irreversible in the Brush Creek watershed. Some stream segments may still respond positively to physical remediation and enhancement efforts. TOSV initiated and completed several physical and riparian rehabilitation projects in the last decade. One example is the improvements made to the Mayfly Park are in the Village Reach. The Greenway Plan outlines additional projects and priorities including daylighting the creek at several locations and eventual conversion of several road culverts to bridges, which would allow for natural substrate and sediment accumulation and transport conditions in the creek. The majority of these remain as conceptual ideas and proposals at this time.

The SHI rated instream channel habitat as *Severely Degraded* throughout the Village and Golf Course areas, and completed a cursory Rosgen-based stream type classification for multiple channel reaches in Brush Creek. Like the information concerning riparian zones, the SHI inventory does not provide channel condition data on a scale appropriately fine to relate to aquatic life conditions at individual monitoring sites. Significant data gaps exist regarding the location and magnitude of physical stream alteration in the Brush Creek Watershed.

3.7 Altered hydrologic regime

Brush Creek's yearly hydrologic regime is altered in timing and magnitude from typical conditions in the greater Roaring Fork Watershed by increased development, localized diversions, and augmented seasonal flows from transbasin diversions. Hydrologic alteration is directly tied to urbanization in the watershed and the increased amount of stream-connected impervious surfaces. It degrades aquatic life conditions by generating a seasonal flow regime that does not coincide with the life-history strategies of native stream life. The most often-reported effects of urbanization and increased impervious areas include a shortened lag time between precipitation and runoff, increased frequency of high flows, higher peak flows from short duration precipitation events, and decreased baseflows (Paul and Meyer, 2001; Konrad and Booth, 2005). Increased impervious surface areas associated with urbanization generate high discharge-short duration flows, producing quick but intense contaminant loading events and negative channel alterations (Hatt et al., 2004; Walsh et al., 2005). Increased 'flashiness' from stormwater discharge also increases bank shear stress, potentially increasing lateral erosion and channel incision.

An important data gap exists for Brush Creek's annual flow regime, including typical discharges for runoff and baseflows in average hydrological conditions, and the timing and magnitude of important hydrologic milestones during the water year, such as peak snowmelt. A study produced by ERI in 1997 appears to be the most comprehensive and recent information on hydrologic conditions in the watershed, however that work has not been located in town records. WWE established four or more staff gages and began calibrating stage-discharge curves for each in 1999 and 2000. Although locations for these gages are reported in the Draft Brush Creek Watershed Management Plan, the current state of each is unknown, and a decade of sediment transport in this narrow and steep mountain stream has likely rendered the established stage-discharge relationship for each gage obsolete.

4. Recommendations for monitoring

4.1 Data admissibility

All data used by CDHPE WQCD must meet a Credible Evidence standard for use in 303(d) listing decisions; therefore all data collected in Brush Creek by stakeholders should meet this requirement for process admission. Data requirements include adequate metadata for all samples including documented methods for field collection and analysis, lab analysis, and full information for sampling locations and sampling parties. Additionally, a Sampling and Analysis Plan (SAP) and QA/QC should support sampling programs and be readily available to WQCD if requested. These requirements are enumerated in detail in Section III B of the 2012 Listing Methodology. For all monitoring activities including water chemistry, macroinvertebrates, and targeted studies, a Brush Creek SAP should pre-define collection or sampling methods, locations, frequencies, field protocols, and analytical and statistical methods for data review. Yearly review of the SAP will allow for adaptive management of water quality monitoring programs on Brush Creek and better integrate changing stakeholder needs.

4.2 Macroinvertebrates

Since the provisional 303(d) listing for Brush Creek is based on impaired Aquatic Life use, macroinvertebrate monitoring should continue as a primary monitoring activity on Brush Creek. Results from the 2012 Brush Creek Focused Water Quality Assessment indicate the Upper Brush Creek Road site experiences some degradation and is unsuitable for background reference, therefore a new background site should be re-established on East Brush Creek above all resort development. Although the Chapel area serves as a land use transition between the urban village and residential golf course zone, impervious area analysis suggests that the Above Confluence site receives water from the largest proportion of developed area (compared to other existing macroinvertebrate sites) and is a better location to capture the full effects of upper watershed land use and urbanization on the stream. Existing sites at both the Roundabout and Highway 82 integrate water quality conditions from the entire contributing watershed area. Since they both produced multiple attaining MMI scores in the past, a sampling frequency of alternating years for the two sites may be suitable and more resource-efficient. Macroinvertebrate collection occurs in the fall during low flow conditions and should be completed prior to the end of September to be eligible for WQCD data submission in the current calendar year. Sampling protocols should continue to follow current methodologies utilized by River Watch, RFC, WRNF, Timberline Aquatics, or other methods deemed acceptable by WQCD.

4.3 Ambient water quality

Water quality sampling for field parameters, nutrients, and metals should continue at a minimum of four times per year at the watershed mouth (Highway 82 site), Roundabout, Clubhouse Dr., and Chapel. Natural background chemistry without human influences in the watershed is poorly characterized by existing sites, an additional reference site for water chemistry should be established on the East Fork above all resort development. Sampling dates may either target calendar seasons, or the important hydrographic milestones of runoff, recession, fall baseflow, and winter baseflow. This will continue to provide baseline information on ambient water quality conditions in the creek and provide for detection of directional trends of ambient water quality in Brush Creek long term. Sampling protocols should continue to follow current methodologies utilized by River Watch, RFC, SWSD, or other methods deemed acceptable by CDPHE WQCD. If SWSD opts to continue its focused nutrient sampling effort on Brush Creek in 2014, it would be better to explicitly include these activities in a Brush Creek SAP in order to streamline stakeholder data sharing and ensure admissibility in the Credible Evidence framework required for 303(d) process actions.

4.4 Discharge/hydrography

Brush Creek Watershed hosts no short-term or long-term gauging infrastructure, making assessment of the basin's hydrologic regime difficult. One or more discharge measurement locations should be established or reestablished at the sites of former staff gages installed in previous efforts by ERI and WWE. A site between the Chapel and East Fork confluence allows quantification of pollutant loading from the village area infrastructure. A site between the Roundabout and basin mouth captures flows from the East Fork and effluent from the WWTP, enabling analysis of lower-watershed pollutant load. Calibration of stage curve and real-time, periodically-downloadable logging capabilities for the lower site could also aid in documenting Brush Creek's annual flow regime. Gauging information would provide realistic basin yield estimates, and more importantly, allow for accurate calculation of episodic pollutant loading during snowmelt and stormwater runoff events that is not currently captured by ambient water quality sampling. Ideally, rapid discharge monitoring capabilities would exist at enough locations to quantify differences in pollutant load between major changes in land use or major stormwater tributary inputs. At a minimum, manually-measured discharge on water quality sampling dates from locations in the Village, Golf Course, and Lower BC subreaches will provide rough calculations of pollutant load distributions

4.5 Stormwater

Stormwater monitoring includes stormwater runoff from urban/impervious surfaces and stormwater runoff from land use practices. Stormwater is likely one of the most important components contributing stress to aquatic life in Brush Creek through hydrologic alteration and inputs of sediment and contaminants, yet it is currently poorly understood and is logistically and financially resource-intensive to monitor. Stormwater monitoring is beyond the scope of yearly ambient water quality monitoring programs, and is best approached through specially designed targeted studies. During a visual assessment and inventory in June 2013, SGM identified four outfalls to the creek with *Substantial* flow, and six additional with *Moderate* flow. Three of the *Substantial* outfalls occur in the Village subreach, and one in the Golf Course subreach. These locations can serve as initial points of investigation for stormwater monitoring, although more observations of outfalls over a variety of a hydrologic conditions could combine with drainage area mapping (Section 5.2) to identify and prioritize sites. Although they would be stand-alone products, a stormwater study should be included in the framework of a yearly SAP for Brush Creek.

4.6 Solid phase organics

Many soluble pollutants can sorb to stream sediments on a long-term basis and contribute toxicity effects to aquatic life over a drawn-out time period. These chemical compounds may source from land use treatments, such as pesticide/herbicide application on resort landscaping and golf course areas, or derive from road and urban surfaces such as petroleum-based products from roads and urban surfaces. An exploratory and targeted solid-phase sampling effort may provide evidence of whether this issue exists in Brush Creek and warrants further investigation.

4.7 Illicit discharges

Illicit discharges are illegal or improper connections to municipal storm sewer systems, which would otherwise require an NPDES permit. They may be intentional, or unknown/accidental by a building owner or business operator. A targeted effort of dry weather monitoring during summer (defined by no precipitation events for 72 hours or more) of stormwater outfalls to Brush Creek may indicate whether illicit discharges are an issue. Monitoring sites can be prioritized using the nonpoint inventory completed by SGM, focusing on outfalls of larger size, or ones from which odors, greasy luster, or other indicators of potential non-stormwater constituents were previously noted. An important component of illicit discharge monitoring is authorization by city officials to investigate properties believed to be intentionally or inadvertently contributing contaminated discharge to storm sewers, as well as some form of compliance mechanism for those found to be doing so.

5. Implementation plan

5.1 Multi-criteria decision analysis

Brush Creek's provisional 303(d) listing presents difficult challenges to watershed stakeholders to understand and address the causes of aquatic life impairment. Continuous and sustainable attainment of water quality standards is the end goal. Short and long-term restoration choices will ultimately depend on stakeholder preferences and the anticipated costs/benefits of a given action (e.g. community interests, resource constraints, technical feasibility, uncertainty of outcomes, and regulatory obligations). Water quality stressors frequently interact in complex ways, making it difficult to predict if manipulation of single component will effect positive change without concurrently addressing other watershed issues. For example, the benefits of extensive riparian restoration on stream stabilization and habitat structure may not be realized if increased stream bank erosional stress from flashy stormwater hydrography is not also addressed (Walsh et al., 2005). Thus, implementing appropriate and timely measures to improve stream conditions requires stakeholders to make complex decisions involving multiple action alternatives. These decisions require credible scientific information and balanced consideration of stakeholder values regarding Brush Creek's overall future in the community of Snowmass. Data gaps currently exist for many potential stressors in the watershed, making decision-making about these issues difficult (Table 5.1)

Table 5.1. Data availability and data Gaps

This table summarizes potential and known water quality influences in Brush Creek Watershed.
Data status explanation: "Good" Parameters have multiple samples over multiple years, "Limited" Parameters have a limited number of samples or limited time period, "Poor" Parameters with no data, or data not readily available

Issue	Data Sources	Potential cause	Data status
Riparian alteration/ destruction	SHI (Malone and Emerick, 2007)	Irreversible development Unrestricted mowing/landscaping Physical channel alteration	Limited **Poor** Limited
Sedimentation	TOSV (WWE 2001) River Watch (RFC) (raw data)	Construction Stormwater Road sanding Soils/geology (sedimentation)	**Poor** Limited **Poor** Limited
Physical alteration	SHI (Malone and Emerick, 2007)	Development	**Poor**
Ambient water chemistry *Physical: pH, Temp, DO*	Riverwatch (RFC), RFC, SWSD (raw data)	Riparian degradation Soils/geology WWTP effluent	Limited Good Good
Metals	River Watch (RFC) (raw data)	Stormwater runoff Soils/geology (dissolved ions)	Limited Good
Organics	River Watch (RFC), SWSD (raw data)	Landscaping/maintenance chemicals Stormwater runoff	**Poor** **Poor**
Nutrients	SWSD, River Watch (raw data)	WWTP effluent Landscaping/maintenance chemicals Soils/geology Animal waste (Pets , kennels, rodeo) Dispersed septic (ISDS)	Good **Poor** Good Limited Limited
Pathogens, fecal matter	CDPHE (raw data)	Animal waste (Pets, kennels, rodeo) Dispersed septic (ISDS)	Limited Limited
Altered hydrologic regime	(ERI 1997)	Flashy stormwater runoff Stream diversions	**Poor** **Poor**

The use of Multi-criteria decision analysis (MCDA), a formalized decision-support structure, is recommended to identify acceptable solutions to water quality issues in Brush Creek. MCDA explicitly recognizes and incorporates competing perspectives and values to identify a consensus-based solution to a given problem. In this case, the factors driving impaired aquatic life conditions in Brush Creek result from multiple potential causes that are not the fault of one particular entity and cannot by addressed by any single party in the watershed acting alone. Short term actions involving Brush Creek outlined below focus primarily on resolving scientific uncertainty regarding causes of impairment to the maximum extent possible, within the time and resource constraints of stakeholders.

5.2 Urban drainage planning

Understanding the location and magnitude of urban drainage to Brush Creek, and mitigating future new impacts, is difficult without better knowledge of the current system's source areas and outflow locations. Creation of an Urban Drainage Plan would help prioritize both source area treatments for upslope regions found to be significant contributors of pollutant-laden stormwater, and end-of-pipe locations for BMP construction or redesign. The purpose the planning effort is to protect water resources from further degradation, promote enhancement or improvement of current resources, and ensure future development proceeds in a manner that is protective of watershed assets. Although TOSV is below the size and population threshold for MS4 permitting, pre-emptive consideration of stormwater effects to the watershed can benefit Brush Creek and the human-built environment. Two components of a plan that are easily approached in the short term are drainage area mapping, and a complete inventory of stormwater infrastructure.

Drainage area mapping delineates the extent of each stormwater feature's contributing area in order in order to prioritize features for BMP treatments. The size of each micro-catchment contributing to a particular stormwater outfall or outfalls, along with key land use or pollutant-generating features in the catchment can be catalogued and used to prioritize treatment area plans. Urban stormwater systems that alter the natural hydraulic regimes of streams and deliver contaminant-laden runoff during episodic high-discharge events are a primary driver of aquatic life impairment according to the body of scientific literature on urbanized streams. Brush Creek's stormwater system is a complex patchwork of infrastructure built during successive phases of community development without centralized planning or records. Efforts in 2013 by SWSD inventoried the number and location of stormwater and nonpoint source outfalls to the creek. Stormwater systems can be addressed both by source area treatment and end-of-pipe Best Management Practices (BMPs), but doing so requires an understanding of the relative importance of each outfall to the overall system. Drainage area mapping should be considered an important input to any engineering analysis and project planning for Brush Creek's stormwater infrastructure. Combining this effort with the results of targeted stormwater pollutant load monitoring would produce load maps that identify hotspots of nonpoint source pollution in the upper watershed.

It is recommended to develop a **spatial database of stormwater infrastructure** in the village core and less dense residential areas near the golf course. Because current knowledge of stormwater infrastructure in the Brush Creek Watershed is largely held in dispersed planning documents and local knowledge of town staff, institutional memory and understanding of how and where the major components of stormwater systems affect the creek is difficult to maintain and utilize effectively in rehabilitation planning. This effort might use existing GIS resources maintained by TOSV or SWSD, or create a new and independent tool for managers in the town and utilities involved in watershed planning and projects.

In the long term, protecting future watershed impacts and reversing past impacts wherever possible can pose a difficult challenge for community leaders in a local economy based in-part on construction and development of resort residences and amenities. Additional vital components to an Urban Drainage Plan should include revisiting and updating land-use and construction codes to more explicitly approach watershed resource impacts. This includes reconsideration of current rules for setbacks, reviewing water quality capture volumes (WQCV) for new BMP construction or replacement, guidelines for stream-friendly BMPs. In general, Brush Creek should benefit from a shift towards Low-Impact Development Techniques (LID). LID is a set of principles for building design and community development intended to keep stormwater runoff as clean as possible prior to entering waterways (For a primer, see http://www2.epa.gov/region8/green-infrastructure.

5.3 Riparian feasibility assessment

New riparian and floodplain remediation projects are often constrained or entirely impracticable due to irreversible development, road and utility alignments, private land ownership, or other reasons. A feasibility assessment will strategically identify locations where remediation is possible within these constraints in order to build a realistic picture of resource costs and potential benefits of riparian projects. A riparian feasibility assessment should identify where degraded segments of vegetative cover intersect with public and private stream ownership, thus highlighting the segments which hold remediation potential. It should occur on a fine-enough scale (<100 meter reaches) for project planning. A feasibility assessment should also couple with the nonpoint inventory and stormwater BMP planning to identify areas for improvement which will actually target significant overland flow paths or stormwater outfalls to Brush Creek.

5.4 Stormwater load estimation

The last effort to understand the sediment and pollutant load deriving from Brush Creek's stormwater infrastructure occurred over a decade ago. A targeted sampling effort to understand mass loads of water quality parameters during snowmelt peak, and again during summer thunderstorms, will identify locations for prioritization of end-of-pipe BMP and source-area control projects in the watershed. This couples with drainage area mapping and infrastructure inventories to more-effectively resolve scientific uncertainty regarding stressors to Brush Creek. This provides watershed managers with the appropriate information for decisions on stream improvement actions and navigation of the 303(d) process in order to move the stream towards an appropriate legal objective. That might include attainment of water quality standards, Category 4b or 4c classification, or some other objective for Brush Creek's legal status. Stormwater load estimation requires both timely sampling of the creek and major outfalls during pre-identified discharge events, and adequate characterization of Brush Creek's physical hydrology to make reasonable contaminant load calculations.

5.5 Pesticide-herbicide inventory

During the landscaping and irrigating season, a concerted effort should be made to catalog the types of chemicals used for pest-prevention by land and property managers in the watershed. Many pesticides and herbicides have high toxicities to aquatic life including macroinvertebrates and fish. A voluntary-participation inventory of resort property managers, businesses, city grounds keepers, residents, and any other parties who use these chemicals in the watershed can provide an estimate of the types and amounts that are typically used, and which ones might potentially be impacting the creek. Specific chemicals or application areas of concern might be useful outputs from the inventory, as well as information to inform future town ordinances or policy frameworks for model pest-management activities in the watershed.

5.6 Strategic planning

At the soonest time in which the necessary components for MCDA decision making are assembled, stakeholders should convene to consider the available information and formulate a strategy to address Brush Creek's impairment. Planning should explicitly consider end goals, timelines, legal milestones, and stakeholder accountability. Parties should include local Brush Creek stakeholders like SWSD, TOSV, Ski Co, RFC, Pitkin County, and private residents, as well as CDHPE WQCD, EPA, and any other parties with standing in Brush Creek water quality. One important objective of strategic planning is to investigate possible regulatory outcomes for Brush Creek, and select via group consensus the regulatory pathway stakeholders prefer to pursue. Once stakeholders identify stream project priorities, all work should proceed from an upstream to downstream direction to ensure that resultant changes to stream conditions are specifically and successfully tied to a particular management action.

Policy options and outcomes for Brush Creek include full 303(d) listing and TMDL development (as opposed to the current provisional status), Category 4c designation, Category 4b designation, or other potential options to be explored with WQCD and EPA. A Category 4b Demonstration Plan may be a viable route to prevent Brush Creek's full addition to the 303(d) and remove it from Category 5 waters. Category 4b waters are those for which a "TMDL is not needed because other pollution control requirements are expected to result in the attainment of an applicable water quality standard (WQS) in a reasonable period of time." In the past, Category 4b has primarily applied to waters for which new technology implementation at point-source discharges such as pipe outlets will result in adequate pollution reduction to achieve use-attainment. However, CDHPE WQCD has signaled a cautious interest to work with water resource managers in conjunction with EPA to explore the use of Category 4b plans to address nonpoint source pollution of impaired streams in Colorado.

This use of the policy framework is relatively uncharted territory, and close interaction with EPA and CDPHE WQCD will ensure both water quality objectives of local stakeholders and statutory obligations of government agencies are met. Category 4b plans require, among other things, provisions for measurable pollution reduction and legal enforceability. A large amount of scientific uncertainty surrounds watershed rehabilitation efforts such as stormwater management and riparian restoration; the magnitude and timeframe of water quality improvement after such rehabilitation efforts is difficult to predict. Despite these difficulties, this may be a viable route for Brush Creek within the existing policy context of the Clean Water Act, and it is recommended stakeholders continue to pursue this possibility with partner agencies.

Figure 5.2. Seasonal timeline for projects and recommendations implementation.

	Recommended time of year for action								
Action	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ambient chemistry monitoring									
Macroinvertebrate monitoring									
Riparian feasibility assessment								**Report**	
Stormwater load study: Snowmelt								**Report**	
Stormwater load study: summer thunderstorms									
Pesticide-herbicide inventory								**Report**	
Stakeholder strategy and planning (MCDA)									
Stormwater Inventory, Spatial Database Creation									
Public outreach: riparian zone management, pest management		**Initiate campaigns in spring, early during landscaping season.**							

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