LEFT HAND
watershed center

Adaptive Management at Scale
Draft Framework

4/20/2022

LEFT HAND watershed center

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I. Project Summary and Background

The purpose of this project is to develop and implement a shared adaptive management framework for assessing watershed health in the St. Vrain Basin, including Left Hand Creek and Boulder Creek. Left Hand Watershed Center (Watershed Center) brought partners together in 2019 to develop this framework collaboratively. Having used an adaptive management framework to track watershed health in Left Hand and St Vrain Creek Watersheds, the Watershed Center saw that many stakeholders could benefit from scaling this adaptive management approach to the basin and complementing existing partner monitoring efforts.

Partners agreed about the need and value of a shared framework that integrates and complements existing monitoring and management efforts. Benefits of this approach include more cooperative monitoring among diverse stakeholders (e.g. government agencies, researchers, non-profits, etc.), more spreading of resources to support monitoring, more apples-to-apples comparisons of data, and collaborative data analysis and prioritization. Acknowledging that numerous entities manage and monitor watershed health in the St. Vrain Basin, all agreed about the importance of incorporating diverse stakeholders and their existing monitoring efforts in the framework development process.

Since 2020, this framework has been developed collaboratively, with input from diverse entities that currently monitor and manage watershed health in the basin. Our goal was to create a framework that will help us make more informed management decisions as a basin and better track broad progress towards watershed health goals. This framework will be used as part of a long-term annual on-the-ground adaptive management process.

For the purposes of this framework, watershed health refers primarily to the ecological conditions of a site, including physical features (e.g., habitat, hydrological connectivity), chemical features (e.g. water quality), and biota (e.g., BMI, vegetation). Watershed health is assed based on desired conditions which describe goals for ecological conditions (see Framework Criteria (III.b) and Desired Conditions (IV) sections). In the context of these desired conditions, watershed health is evaluated based on whether a site achieves performance thresholds for quantitative indicators. Performance thresholds for each indicator may vary by site or other classifications (e.g. reach, grassland/forest type, watershed zone, biophysical zone). Thus, this approach offers flexibility to define watershed health based on criteria and considerations appropriate for diverse conditions at sites across the basin.

II. Partners, Stakeholders, and Contributors

We are grateful to the project partners, stakeholders, and contributors that provided data, feedback, and review of the framework. Partners that provided funding are noted with an asterisks (**). As part of the adaptive management plan, outreach is ongoing to additional stakeholders.

Boulder County**
City of Boulder**
City of Longmont**
Colorado Water Conservation Board**
Keep it Clean Partnership**
Mile High Flood District**
St. Vrain and Left Hand Water Conservancy District**

Audubon Society
Boulder County Nature Association
Boulder Watershed Collective
Citizen Science Soil Health Project
City of Lafayette
City of Louisville
Colorado Department of Public Health and Environment
Colorado Forest Restoration Institute
Colorado Parks and Wildlife
Colorado Water Conservation Board
Left Hand Water District
Lyons Ecology Board
National Ecological Observatory Network
Niwot Ridge Long Term Ecological Research Station
Rocky Mountain Conservancy
Rocky Mountain National Park
Town of Superior
Trout Unlimited – Boulder Flycasters
Trout Unlimited – National
Trout Unlimited – St. Vrain Anglers
United States Geological Survey
USDA – Forest Service
USDA – Natural Resources Conservation Service
USFWS St. Vrain Site Conservation Team

III. Adaptive Management Process and Criteria

A. Process

Adaptive management offers the flexibility and accountability necessary to manage complex and changing ecosystems. Using adaptive management, we define watershed health goals (desired conditions), quantitatively track progress towards our goals (monitor), and adjust management or monitoring actions iteratively, based on what is learned. Figure 1 below introduces key steps in the adaptive management process. Iterating these steps is necessary to assess the status of and progress toward, desired conditions across the basin, to adjust regularly based on what is learned, and to inform project prioritization and planning. Each step is introduced here and described further in corresponding sections of this document.

As part of the adaptive management process, desired ecological conditions incorporate existing Partner monitoring and management plans, climate adaptation, stakeholder and community values, and cross-boundary collaboration. Monitoring efforts provide a quantitative assessment of trajectory towards desired conditions and how sites across the basin are changing with the climate. Monitoring efforts emphasize coordinated and complimentary monitoring with diverse Partners so that comparable data is being collected across the basin to facilitate cross-basin collaboration and project prioritization. Annual workshops support on-going collaboration for monitoring and planning among Partners. Annual State of the Watershed reports document what is learned from monitoring and collaborative workshops. Combined, monitoring, workshops, and reports inform prioritization of collaborative, climate-adapted, multi-benefit, and cross-boundary projects for restoration, management, and research. Inherent to the adaptive management process, adjusting and iterating occurs at all steps based on what is learned.

Figure 1.

The adaptive management process.

B. Criteria

The following criteria describe the lens and scope addressed by this project. Each criterion represents a focus or boundary of the adaptive management process and will be assessed on a regular (e.g. annual) basis and adjusted as necessary. The steps of the adaptive management process described in subsequent sections each apply these criteria.

1. Plan will utilize, integrate, and complement existing watershed health-related **ecological data** collection and monitoring efforts. Ecological data associated with specific indicators (see Criteria 4) will inform other watershed processes such as hydrology (e.g. flow) and geomorphology (e.g. changing form), as well as resilience (e.g. the ability of a system to rebound from fire). While ecological data is the primary focus, monitoring watershed processes such as flow or geomorphology which influence ecological data will also be incorporated (see Criterion 4).
2. Watershed health will be assessed relative to **desired conditions** which are described broadly for the basin and represent goals for ecological conditions. Desired conditions will vary by site, and some sites may already reflect some desired conditions. Further, the way that a desired condition appears at a given site may be influenced by site-, region-, or zone-specific characteristics (e.g. agricultural vs urban surrounding land-use in plains zone, or biophysical gradients that govern forest and grassland species composition and structure).
3. Monitoring data collected will be informed by the **limiting factors** that act as barriers to achieving desired conditions which may vary at different scales (e.g. a site-level limiting factor such as mine legacy impacts vs. a basin-level limiting factor such as drought).
4. Site-level (i.e. on-the-ground field measurements) **indicators** will be monitored to track site-level status of desired conditions at sites across the basin. Indicators primarily refer to ecological response variables that assess biota (e.g. benthic macroinvertebrate communities, native plant cover) and physical or chemical conditions (e.g. water chemistry, sediment transport, hydrological connectivity, soil moisture). These indicators will inform our understanding of watershed health due to their response to and relationship with drivers of watershed function (e.g. benthic macroinvertebrate community diversity reflects water quality, percent sands in riffles reflects local sediment sources, and tree density reflects forest functioning and disturbance regimes). Additional monitoring of drivers (e.g. flow) will be incorporated as prioritized.
5. Monitoring will take place at **strategically selected sites** that include long-term and discrete efforts. Long-term monitoring sites represent diverse river, riparian, grassland, and forest conditions across the basin. Site selection of long-term monitoring sites will leverage existing long-term monitoring locations. Discrete monitoring efforts represent specific, issues-related management concerns. Both types of sites can inform project prioritization and our understanding of watershed health.
6. Indicators will be analyzed and reviewed in the context of pre-selected ecological **performance thresholds** that are tied to management recommendations based on desired future conditions. Performance thresholds may vary by site or other classifications (e.g. reach, grassland type, watershed zone, biophysical zone) as appropriate, and information gained will help to inform project prioritization, trajectory toward desired conditions, and how sites across the basin are changing with the climate.

IV. Desired Conditions

Desired conditions represent goals for ecological conditions for the basin. Not all desired conditions will apply at specific sites or scales. This list was developed based on review of Partners' existing monitoring and management plans and modified to reflect project-specific goals and criteria. These ecological desired conditions incorporate considerations related to three key foundational elements: (1) climate change (e.g. climate adaptation and resilience to flood, fire, and drought), (2) community/social values (e.g. infrastructure, safety), and (3) cross-boundary collaboration (multi-benefit solutions across human and natural boundaries from headwaters to urban corridor. While the desired conditions below are stated broadly, the application of the desired conditions at the site, reach, grassland/forest type- or watershed zone will integrate specific foundational elements as appropriate (e.g. the impact of water management rights on flows, the impacts of climate change on upland forests, the impact of climate change on in-stream temperatures/aquatic habitat).

1. Water in river corridors supports current and future aquatic life and beneficial uses (e.g. other standards are more stringent or there are not applicable aquatic life standards).
2. Dynamic geomorphic processes are able to take place now and in the future, resulting in source, depositional, and transport reaches, with depositional reaches that support attenuation of flows and sediment located between critical infrastructure and transport reaches that support transport of flows and sediment located adjacent to critical infrastructure.
3. The timing, frequency, and variability of streamflows (baseflows and peak flushing flows) within the prior appropriation system should and can support current and future ecological and geomorphic function (habitat, native plant communities, and needs of aquatic life), the needs of consumptive users (domestic, agriculture), and recreation.
4. In-stream habitat is diverse (e.g. pools, large wood, backwater, side-channels, off-channel ponds), connected, and supports current and future native, wild, and desirable species.
5. The riparian corridor has a high-quality (diverse and self-sustaining) native plant community that promotes clean water and complex habitat now and in the future.
6. Uplands forest and grassland structure supports high-quality (e.g., diverse and self-sustaining) habitat for native wildlife and improves resiliency to high severity wildfires, floods, and other disturbances (e.g. forest structure includes a range of species, age classes, tree sizes, irregularly spaced tree groups, and gaps and openings of various sizes) now and in the future.

V. Monitoring

Monitoring provides a quantitative assessment of trajectory towards desired conditions and how sites across the basin are changing with the climate using quantitative indicators (data collected). Considering the cross-basin goals of this project, monitoring designs and quantitative indicators vary by system (riparian and river, grassland, forest) but follow a similar overall design. This section describes (1) the across the basin monitoring approach (Section V.A.) (2) monitoring designs for individual systems or efforts (Section V.B), and (3) the monitoring plan for 2022 (Section V.C).

A. Across the Basin Monitoring Approach

1. Where to Monitor? Long-Term and Discrete Monitoring Sites and Efforts

A strategic two-pronged monitoring approach (Figure 2) was selected to allow flexibility for a combination of on-going long-term monitoring at representative sites and periodic discrete monitoring when specific issues or management concerns occur (e.g. post-fire impairment or understanding the impacts of/changes driven by a management action such as forest thinning). While long-term monitoring leverages existing monitoring sites (e.g. established by Partners) and includes establishment of new monitoring sites, discrete monitoring supports integration of new monitoring efforts (sites or data) to help fill knowledge gaps and address watershed health priorities.

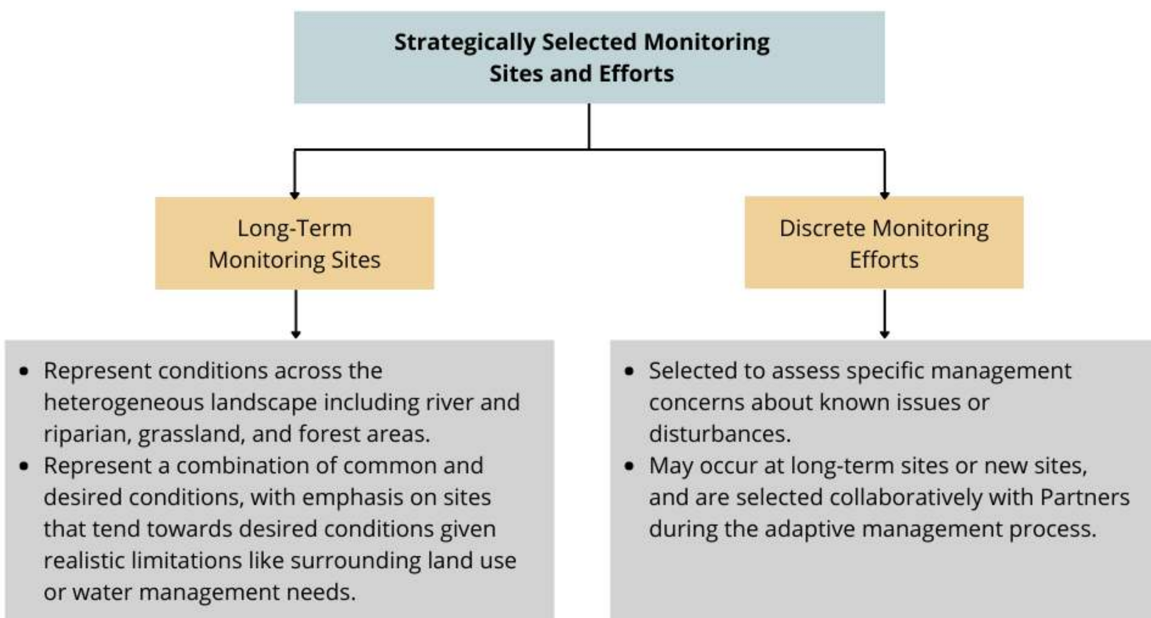

Figure 2. Long-Term and Discrete Monitoring Sites and Efforts

Long-term monitoring sites represent a mix of desired and common conditions depending on the ecosystem. Sites with common conditions can inform project prioritization and understanding of broader watershed health. Sites that tend towards desired conditions can inform understanding of the resiliency of those sites under a changing climate and disturbance events, and can also serve as a benchmark for the changes we might want to see at sites that represent common conditions. Together, these sites will track trends in watershed conditions to inform watershed health, need for management actions, project prioritization, and conceptual design elements of future restoration projects. As part of the monitoring approach each site will be characterized to describe (1) why it is characterized as common or desired and (2) information about past, current, or future land use and management (e.g. closest stream gage, weed control activities). This information will inform understanding and interpretation of monitoring data.

Discrete efforts assess specific management concerns about known issues or disturbances (e.g. sites that investigate water quality impairments related to abandoned mines or sites that investigate impacts of wildfire). Discrete monitoring efforts, which are characterized as efforts rather than sites because they may occur at existing long-term sites or new sites, are selected collaboratively with Partners during the adaptive management process. Prioritization of discrete efforts will be based on existing monitoring data, knowledge of known issues, expected impact of disturbances, and priority project opportunities (See Section V.B.4. for addition considerations regarding prioritization of discrete efforts).

2. What to Monitor? Indicators Based on Desired Conditions and Limiting Factors

Monitoring is conducted by assessing watershed health indicators. These indicators are quantitative metrics that track site-level (i.e. on-the-ground field measurements) status of desired conditions across the basin. Indicators focus on ecological response variables (or metrics) that assess both biota (e.g. benthic macroinvertebrate diversity, percent native plant cover) and physical or chemical conditions (e.g. dissolved oxygen, soil moisture, percent sand, percent accessible floodplain). Indicators inform our understanding of watershed health due to their response to and relationship with drivers of watershed function (e.g. benthic macroinvertebrate diversity tells us about water quality, percent sediment in pools tells us about sediment capture, and forest structure tells us about the resiliency of the forest to fire and climate change). Future iterations of the adaptive management process may consider additional types of indicators beyond site-level assessments (e.g. reach-scale or stand-scale indicators based on remote sensing).

To determine the most informative indicators of watershed health relative to desired conditions, we consider the limiting factors resulting from environmental stressors that are a potential barrier to desired future conditions, and select indicators that assess the impact of limiting factors on desired conditions (Figure 3). Limiting factors incorporate the impacts of several larger scale environmental stressors, including climate warming, land use/development, prior land management practices, and altered precipitation. These environmental stressors may inhibit achievement of desired conditions now and into the future. Limiting factors are the secondary symptoms of these environmental stressors. For example, more frequent drought is an example of a limiting factor, and is a secondary symptom of altered precipitation regimes due to climate change. For each desired condition, limiting factors reflect expectations of how they would directly impact a site's ability to achieve a desired condition.

Using these limiting factors, indicators are selected to measure progress toward desired conditions. For example, if the desired condition is quality instream habitat for aquatic life and we have prior knowledge that excessive sediment input into streams may limit our ability to achieve that desired condition, then an informative indicator may be percent sands in riffle habitat. While limiting factors can also have a positive influence (e.g. severe floods can reconnect floodplains), the focus is to identify factors that are barriers to desired conditions in order to select indicators that should be monitored.

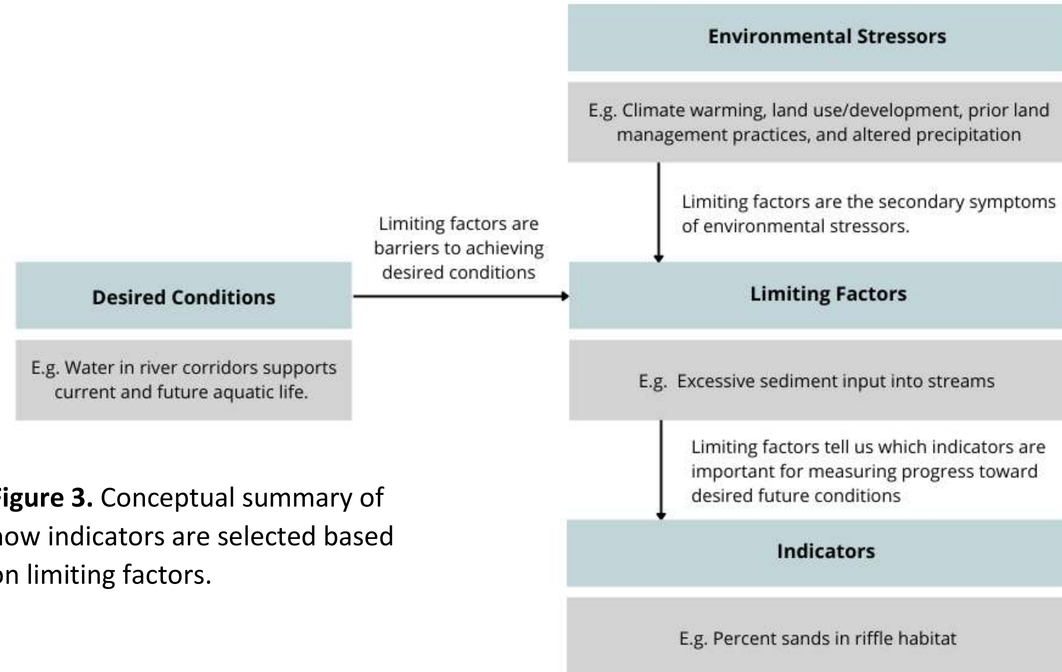

Figure 3. Conceptual summary of how indicators are selected based on limiting factors.

Limiting factors identified as potential barriers to achieving each desired condition are shown in Table 1 for each desired condition. Indicators are selected for each system based on these limiting factors.

Considering that many different indicators can be informative for each desired condition, indicators are also categorized by priority (high priority and potential priority) based on Partner needs, how much information the indicator can provide (or return on monitoring investment), how complimentary the indicator is to other monitoring efforts in the basin, and how feasible is the indicator to monitor with the selected design (e.g. methods or frequency). Given these priorities, high priority and potential priority monitoring designations are defined as:

- **Category 1:** These high priority indicators are broadly informative across relevant monitoring designs, complementary to ongoing efforts and priorities (e.g. data collection would fill Partner data collection gaps), and feasible given capacity. They offer high return on investment and are recommended for near-term monitoring (e.g. starting during the 2022 field season as feasible).

- **Category 2:** These potential priority indicators could expand on current knowledge but require additional assessment to determine how much information is gained or feasibility of monitoring given capacity. They are recommended for potential monitoring in the future with additional planning and assessment.

Indicators are shown and discussed for each system and for discrete efforts in Section V.B.

Table 1. Limiting factors associated with each desired condition.

Desired Condition	Limiting Factors
Water in river corridors supports current and future aquatic life and beneficial uses (e.g. other standards are more stringent or there are not applicable aquatic life standards).	• Excessive fine sediment input into streams (beyond natural process) due to hillslope or stream erosion • Pollution into waterways from non-point or point sources (e.g. urban stormwater runoff, agriculture runoff, wastewater runoff) • Poor riparian condition reducing buffering capacity due to development in the floodplain • Drought resulting in less stream flow and increased concentration of water quality constituents
Dynamic geomorphic processes are able to take place now and in the future, resulting in source, depositional, and transport reaches, with depositional reaches that support attenuation of flows and sediment located between critical infrastructure and transport reaches that support transport of flows and sediment located adjacent to critical infrastructure.	• Excessive fine sediment input into streams (beyond natural process) due to land use and/or poor upland (e.g. forest, grassland) or riparian condition. • Flow augmentation (e.g. surface water diversion) that reduces natural scour and sediment regime or alters ground water hydrology (e.g gravel pits) and stream flow • Disconnected floodplain (in depositional reaches) due to development and channel incision where flows and sediment could be attenuated • Inadequate infrastructure (e.g. road crossings, culverts) • Removal of instream geomorphic complexity (e.g. large wood removal or beaver extermination) in depositional reaches
The timing, frequency, and variability of streamflows (baseflows and peak flushing flows) within the prior appropriation system should and can support current and future ecological and geomorphic function (habitat, native plant communities, and needs of aquatic life), the needs of consumptive users (domestic, agriculture), and recreation.	• Surface water diversions and return flows manipulating instream flows • Drought (e.g. less annual snowpack) reducing water quantity • Increased frequency of extreme rainfall events resulting in unpredictable flow patterns • Increased demand for consumption
In-stream habitat is diverse (e.g. pools, large wood, backwater, side-channels, off-channel ponds), connected, and supports current and future native, wild, and desirable species.	• Excessive sediment input into streams (beyond natural process) • Disconnected floodplain due to development (e.g. channel straightening, bank armoring) • Removal of geomorphic complexity (e.g. large wood) due to increased development in floodplain • Drought (e.g. less annual snowpack) reducing water quantity • Surface water diversions reducing peak flows and natural scour

Desired Condition	Limiting Factors
	• Habitat fragmentation due to instream infrastructure (e.g. diversion dams, road crossings, culverts)
The riparian corridor has a high-quality (diverse and self-sustaining) native plant community that promotes clean water and complex habitat now and in the future.	• Pollution into waterways due to landuse and development (e.g. excess nutrients resulting in algal growth) • Drought (e.g. reduced precipitation and snowpack) and impacts on high flows • Altered precipitation regimes during growing season • Disconnected floodplain due to development • Riparian disturbance due to development, landuse, and/or increased recreation • Introduction of non-native species and non-native competition • Severe wildfire impacting riparian vegetation
Uplands forest and grassland structure supports high-quality (e.g., diverse and self-sustaining) habitat for native wildlife and improves resiliency to high severity wildfires, floods, and other disturbances (e.g. forest structure includes a range of species, age classes, tree sizes, irregularly spaced tree groups, and gaps and openings of various sizes) now and in the future.	• High-severity and more frequent wildfire • Altered precipitation regimes (e.g. drought) • Historical and continued fire suppression • Changes in, or stress from, land use (e.g. over-grazing, recreation)

3. How to Monitor? Framework Integrates Performance Thresholds and Actions

All indicators are monitored using a framework that incorporates methods, performance thresholds, and suggested actions. Existing and standard methods across the basin are used if they are available and feasible so that data collected as part of this project will contribute to and compliment other monitoring efforts across the basin. Methods are created or modified as needed to fill gaps or meet project goals. Performance thresholds are selected using primary literature, Partner collaboration and expertise, expected climate change impacts, and community/social values. Thresholds may be specific to the site type or classifications (e.g. reach, grassland/forest type, watershed zone, biophysical zone) across the basin. As a result, there may be multiple performance thresholds for each indicator, depending on how an indicator is expected to perform at a given site. Suggested actions are recommended if an indicator is not meeting the performance threshold. These recommendations can range from additional monitoring (e.g. launching a discrete monitoring effort to further investigate) or a management action (e.g. restoration, stewardship). The full framework can be viewed at the link below.

Monitoring Framework

https://docs.google.com/spreadsheets/d/1OB8lk41NtMRL6gkRp0Jm5vQ8suyn3W3QQcik6PKCEp0/edit#gid=0

4. Monitoring Approach Basis and Considerations

a) Interactive Map of Watershed Data

As discussed above, long-term sites were selected to leverage and compliment other existing monitoring efforts. For example, this project builds on existing water quality monitoring efforts (conducted by Partners) by adding riparian monitoring or aquatic habitat monitoring at the same site. To better understand the watershed health monitoring throughout the basin, monitoring entities provided information (as feasible) about site locations and data being collected as part of their existing monitoring efforts that are expected to continue into the future. This information is compiled in a shared interactive map which informs site selection for each system (river and riparian, grassland, forest), as well as highlights monitoring areas with gaps or overlap. While this map is not comprehensive of all monitoring efforts because some information is not readily available or ready for sharing, map development and updating will continue as part of the adaptive management process.

Shared Interactive Map

https://lhwc.maps.arcgis.com/apps/MapSeries/index.html?appid=9b7bd0b2453f4566ae1f7b3d5db05080

b) Statistical Power

Based on project goals to leverage existing monitoring efforts and gain an understanding of watershed health across diverse conditions, monitoring of long-term trends is measured at 40+ representative sites (approximately 30 river and riparian sites, 12 grassland sites, and TBD forest sites). While this number of sites captures a subset of the diverse conditions across the St. Vrain Basin, data will provide valuable insights into which indicators are stable and which fluctuate frequently. Though the monitoring design does not hold the statistical power required to make generalizations at the basin-scale due to a lack of sufficient replication because of capacity limitations, site level data will provide managers with information (e.g., descriptive statistics, trends over time) that can help prioritize or design projects, assess site-level impacts of limiting factors, increase understanding of long-term trends in data collected, and signal when more robust monitoring is required to understand new issues or disturbances that may arise. At riparian and river monitoring sites, data will be reported by site and will contribute to an understanding of watershed health across the basin, as opposed to basin-wide or at basin-scale. At grassland and forest monitoring sites, data may be reported by community type, for example, in trends observed across sites within a given grassland mosaic.

Through the monitoring design selection process, approaches were considered to harness basin-scale statistical power. For example, we considered monitoring one indicator of watershed health in a way that would provide statistical power in the observations of that variable (e.g. at many sites across diverse conditions). This approach was not selected because we prioritized collecting data on multiple indicators that would provide a holistic understanding of watershed health that addresses the diverse desired conditions described by partners. Similarly, we considered utilizing a randomized design for site selection across the basin. This approach was not selected because this would have limited our ability to leverage existing monitoring efforts, would have still lacked the ability to gain statistical power due to the lack of sufficient replication, and because we wanted to ensure that we capture responses across the heterogeneous conditions present in the basin. Despite statistical limitations for examining basin-wide or basin-scale health, it is important to note that every year of additional data collection allows for more robust data analysis on a temporal (as opposed to spatial) scale for each representative site. Long-term trends, even if measured at relatively few sites, still provide valuable insights into which indicators are stable and which or fluctuate frequently.

c) Methods Selection and Evaluation

This section describes considerations for selecting and evaluating methods for monitoring each indicator in the rivers and riparian, forest, and grassland systems. In the initial year, we use considerations one through four to select methods. Thereafter, we will evaluate the suitability of methods based on all considerations (including indicator trends and relevance of thresholds) every three years of data collection.

1) Objectives – Does the given method allow us to learn what we set out to learn about a given indicator?
    a. Does the sample represent the population (i.e., does our sample capture the known diversity of an area)?
    b. Appropriate sample size to produce summary statistics for each site where feasible (e.g. sample size of n=3 at a site when cost allows)
    c. Sampled in a way that allows for statistical analysis (modeling, descriptive statistics, or general trends)?
2) Cost – How expensive is the monitoring?
    a. Actual cost
    b. Capacity cost (actual effort per sample; frequency necessary to get meaningful data)
3) Observer accuracy – Can we trust the data?
    a. Turnover in observers
    b. Variation in observers' perceptions or skill (e.g., plant ID)
4) Stakeholder value – Do stakeholders find a particular indicator valuable?
    a. Leverage existing methods between partners when possible
5) Data trends – Are the trends over time, or are we measuring the same thing year after year?
    a. If the data collected are not changing, will the trends help us conduct more effective or appropriate management or do they provide important information about the stability/resiliency of the system? For example, if a trend is static, this can tell us that we have not reached a "tipping point" at a given site that might be expected under climate change or after a disturbance.
    b. Are multiple methods measuring the same thing?
6) Indicators and thresholds
    a. Are the thresholds for a given indicator appropriate? How were the thresholds defined?

d) Monitoring Frequency

While the adaptive management process will be utilized on an annual cycle (e.g. with annual data collection, reports, and collaborative meetings), it is not practical to monitor every indicator at every site at the same frequency because notable changes occur at different temporal scales for different indicators. The monitoring frequency for indicators was determined based on the stability of its metric on a seasonal and annual temporal scale. For example, creek temperature is a major driver of ecological processes in the aquatic system and is dynamic on a short time scale (e.g., snow melt in the spring).

Monitoring creek temperature on a monthly time scale (at minimum) helps stakeholders manage water use on a finer temporal scale (e.g., considering monthly/seasonal impacts of diverting, effluent, return flows). Alternatively, tree composition and forest structure do not significantly change month to month once the growing season has begun. Thus, it is appropriately informative to collect these data every the years. Frequency of monitoring for each indicator is listed in the monitoring framework.

e) Site Rotation

Site rotations will be considered to expand the spatial scale of monitoring efforts and broaden understanding of cross-basin watershed health while not sacrificing depth of monitoring at a site. While long-term sites are meant to represent long-term trends across the watershed, if a given indicator shows a high degree of stability, we may consider rotating through monitoring of that indicator at long-term sites which could allow addition of new sites. Discrete efforts may be rotated depending on priorities from year to year based on specific issues and concerns in the watershed. Once a discrete effort is established, associated sites will be monitored until indicators consistently meet performance standards or an alternative plan is determined (e.g. assess the efficacy of a management action, the long-term stability of the system, or the status/impact of the disturbance).

B. Monitoring Design, Indicators, and Sites for Systems or Efforts

1. Rivers and Riparian Monitoring

Monitoring plans for long-term term sites in the rivers and riparian system are described below, including monitoring design, selected and considered indicators, and site selection.

a) Monitoring Design

Long-term sites in the river and riparian system were selected to capture variability at multiple sites in different eco-geomorphologies (i.e. alpine, canyons, foothills, plains) that represent different hydrologies (e.g. main stem reaches and tributaries broken at confluences). Further, site selection controlled for surrounding land use type (i.e. forested, low residential, urban, agricultural) across the sites within each eco-geomorphology as described in Figure 4 below. All sites leverage or complement existing monitoring where possible, and tend towards desired conditions where possible.

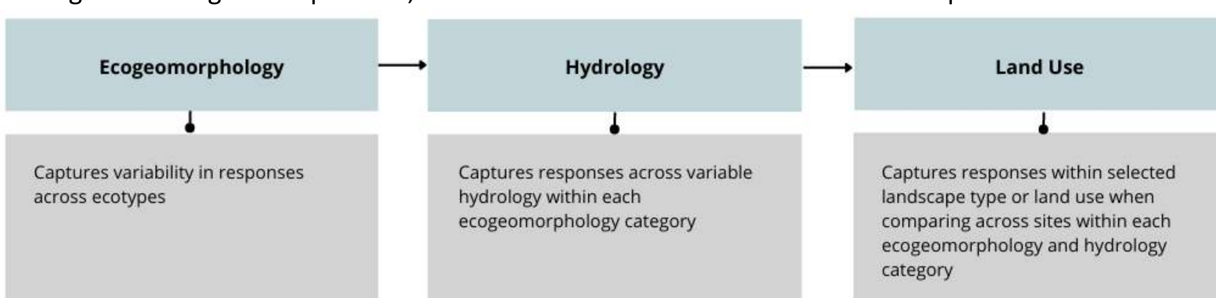

Figure 4. Site selection process for river and riparian system long-term monitoring sites.

b) Indicators

River and riparian system indicators are categorized by priority in Table 2 (Category 1 indicators) and Table 3 (Category 2 indicators) indicators. Categories represent high priority and potential priority indicators which are described in V.A.2.

Table 2. Category 1 (high priority) indicators are listed with priority justification details.

Indicator	Justification
MMI (BMI-derived metric)	This metric captures the cumulative effects of water quality impacts to the BMI community in riffles on a semi-annual or annual basis. This metric is intended to be a top-level indication of underlying water quality issues (either acute or chronic events) and is more feasible to collect across the basin than monthly or as needed water quality (e.g. chemistry). It has implications for water quality issues (e.g. runoff, water availability, surrounding land use) and habitat suitability during low and high flows (if capacity permits). Ideally, this metric will be collected during low and high flows or low flows, at minimum. This metric will be collected at all sites on an annual basis. This metric and its data collection methods overlap with multiple desired conditions.
Creek temperature	This metric is a major driver to ecological processes in the aquatic system and the impacts of varying flow regime (e.g. annual snowpack). It also has implications for impacts of water use (e.g. diverting, effluent, return flows). Ideally, this metric will be collected at minimum monthly. This metric will be collected at existing water quality monitoring sites in the first year. Additional sites may be added as capacity allows. This metric overlaps with multiple desired conditions.
DO, pH, spc	These metrics expand on temperature to assess the biotic and abiotic conditions of aquatic systems. They have implications for stream habitat suitability and impacts of surrounding land use (e.g. abandoned mines, agriculture and urban runoff/return flows). Ideally, this metric will be collected at minimum monthly. This metric will be collected at existing water quality monitoring sites in the first year. Additional sites may be added as capacity allows. These metrics overlap with multiple desired conditions.
Nutrients (total N, total P)	These metrics are the biologically available form of nutrients that may cause algal blooms or eutrophic conditions that are not favorable in streams or reservoirs/lakes. They have implications for nutrient loading from septic or sewage or runoff from fertilizers, natural deposits, and agriculture that are harmful to aquatic and human life. These metrics will be collected at least during high flows and low flows in the foothills and plains, where chronic nutrient sources are present. As such, this metric will be collected at existing water quality monitoring sites in the first year. Additional sites may be added as capacity allows.
Metals	These metrics are biologically available for uptake by aquatic organisms and can be toxic to aquatic and human life. This metric will be collected at existing water quality monitoring sites in the first year. Additional sites may be added as capacity allows.
% sands	This metric captures low flow fine sedimentation in transport units (e.g. riffles). This metric has implications for local sediment sources (e.g. bank/upland surface erosion, urban runoff) and habitat suitability. This metric will be collected at all sites in first year and every 3 years thereafter or after a significant sedimentation or high flow event. This metric overlaps with multiple desired conditions.
TIV score (BMI-derived metric)	This metric captures the cumulative effects of sedimentation events to the BMI community in riffles on an annual basis. This metric is intended to be a top-level indication of local sedimentation issues (e.g. bank/upland surface erosion, urban runoff) in mountainous and foothills reaches and is more feasible to collect across the basin than turbidity measurements. This metric will be collected during low flow at all applicable sites (plains sites do not apply) annually. This metric and its data collection methods overlap with multiple desired conditions.
% accessible floodplain	This metric captures morphological changes that impact floodplain accessibility in a quantifiable way through mapping. It has implications for impacts of varying flow regime (e.g. presence or absence of flushing flows) and development (e.g. encroachment in the floodplain). This metric would be collected every 5 years or after a significant high flow event. Due to the expense of creating DEMs for each site, this indicator will be collected for all sites within the first 3-5 years through a site rotation. This metric overlaps with multiple desired conditions.

Indicator	Justification
riparian width (mapped and ground trothed)	This metric captures the ecological response to floodplain connectivity (e.g. ground and surface water connection to the riparian vegetation) and ground truths the spatial mapping of floodplain connectivity (% accessible floodplain). This metric has implications for morphological changes such as channel aggradation or degradation. This metric will be collected on-the grounds at all sites in first year and every 3 years thereafter and mapped every 5 years or after a significant high flow event. This metric and its data collection methods overlap with multiple desired conditions.
Riparian community types	This metric may be omitted depending on selected methods. This metric expands on the riparian width metric and captures the presence and change in riparian community types (e.g. wetland, riparian, floodplain, upland) in response to flows and floodplain connectivity (e.g. ground and surface water connection to the riparian vegetation). This metric has implications for morphological changes such as channel aggradation or degradation and suitable habitat. This metric will be collected at all sites in the first year and every 3 years thereafter.
% pools per reach	This metric captures habitat availability for fish and depositional capacity at reaches throughout the basin. This metric has implications for impacts of varying flow regime (e.g. presence or absence of flushing flows that scour and maintain pools) and development (e.g. channel incision). This metric will be collected at all sites in the first year and every 3-5 years as capacity allows.
Richness of habitat features	This metric expands on the % pools and captures different habitat types (e.g. pools, riffles, runs, glides, backwater, and side channel). This metric captures habitat suitability for fish and other aquatic species. This metric will be collected at all sites in the first year and every 3-5 years as capacity allows.
Average low flow depth and width in riffles	This metric captures water and habitat availability for fish at reaches throughout the basin and impacts of water use (e.g. diverting, effluent, return flows). It also has implications for morphological changes such as channel aggradation (widening) or degradation (condensing). This metric will be collected at all sites in the first year and every 3-5 years as capacity allows.
Monthly average flow compared to median during non-irrigation (base flow) months	This metric helps define what water availability looks like during baseflow, compares it to a median metric, and potentially enables us to establish a new desired condition for baseflows. This metric will be reported for existing stream gages closest to each long term site to provide contextual information on flushing flows that drive ecological conditions at the site. In many cases these gage data will not be reflecting exact flow at each site due to water use and diversions between each site and the nearest diversion. These uses will be noted for each site.
Cumulative seasonal flushing flow volume during runoff period (late may- July)	This metric captures the channel forming capacity of peak flows throughout their duration. This metric will be reported for existing stream gages closest to each long term site to provide contextual information on channel forming capacity that drives ecological conditions at the site. In many cases these gage data will not be reflecting exact flow at each site due to water use and diversions between each site and the nearest diversion. These uses will be noted for each site.
Peak stream flow (daily average)	This metric captures the channel forming capacity of flushing flows at their peak. This metric will be reported for existing stream gages closest to each long term site to provide contextual information on channel forming capacity that drives ecological conditions at the site. In many cases these gage data will not be reflecting exact flow at each site due to water use and diversions between each site and the nearest diversion. These uses will be noted for each site.
Plant structural diversity (proportion of growth habits)	This metric captures diversity and quality of wildlife habitat. This metric has implications for habitat suitability, population maintenance/growth of wildlife species. This metric will be collected at all sites in the first year and every 3 years thereafter.
Percent native/ non-native species	This metric captures invasion by non-native plant species as well as the trajectory of native plant populations. This metric has implications for habitat suitability, maintenance of native plant populations, and signals ecological disturbance. This metric will be collected at all sites in the first year and every 3 years thereafter.

Table 3. Category 2 (potential priority) indicators are listed with priority justification details.

Indicator	Justification
Turbidity	Ideally collected continuously and would require more Requires more information or collaborative planning for monitoring.
Flow in relation to diversions	Capacity limitations. Requires more information or collaborative planning for monitoring.
E. coli	Not expected to be a limiting factor at across the basin. May consider for discrete efforts.
Water Quality Index (City of Longmont)	Weighs a variety of water quality parameters. DO, pH, ecoli, phosphorous, nitrate, chloride, sulfate with ranges into one score. Need more information on how to integrate. Consider grading scale/ color coding by site.
Stream Quantification Tool	Need more information on how to integrate. Consider scoring format.
Sediment accumulation in pools	Not expected to be a limiting factor at across the basin. May consider for discrete efforts.
Geomorphic features count, wood counts	Not expected to be a limiting factor at across the basin. May consider for discrete efforts.
High flow refugia	Capacity limitations. Not expected to be a limiting factor at across the basin. May consider for discrete efforts.
Year-round discharge at each site.	Capacity limitations. Requires more information or collaborative planning for monitoring.
Baseflow discharge at each site	Capacity limitations. Requires more information or collaborative planning for monitoring.
Average municipal water demand/ use during low flow	Capacity limitations. Requires more information or collaborative planning for monitoring.
Number of boatable days	Capacity limitations. Requires more information or collaborative planning for monitoring.
Number of fishable days	Capacity limitations. Requires more information or collaborative planning for monitoring.
Volume of water deliveries of consumptive users	Capacity limitations. Requires more information or collaborative planning for monitoring.
Frequency of dry up periods	Capacity limitations. Requires more information or collaborative planning for monitoring.
Presence of indicator species (NRD, Prebles)	Not expected to be a limiting factor at across the basin. Capacity limitations.
Percent bare ground	Not expected to be a limiting factor at across the basin.

c) Sites

Long-term monitoring sites were selected to leverage and complement existing monitoring efforts across the basin. As described in the monitoring approach section (V.A.) and monitoring design section above, sites represent diverse eco-geomorphologies, hydrologies, and surrounding land uses, and tend towards desired conditions where possible. Inherent to the adaptive management process, long term sites may change over time as we learn and adjust through continued monitoring and collaboration. A map of the site is shown in Figure 5 and a list of the site is shown in Table 4.

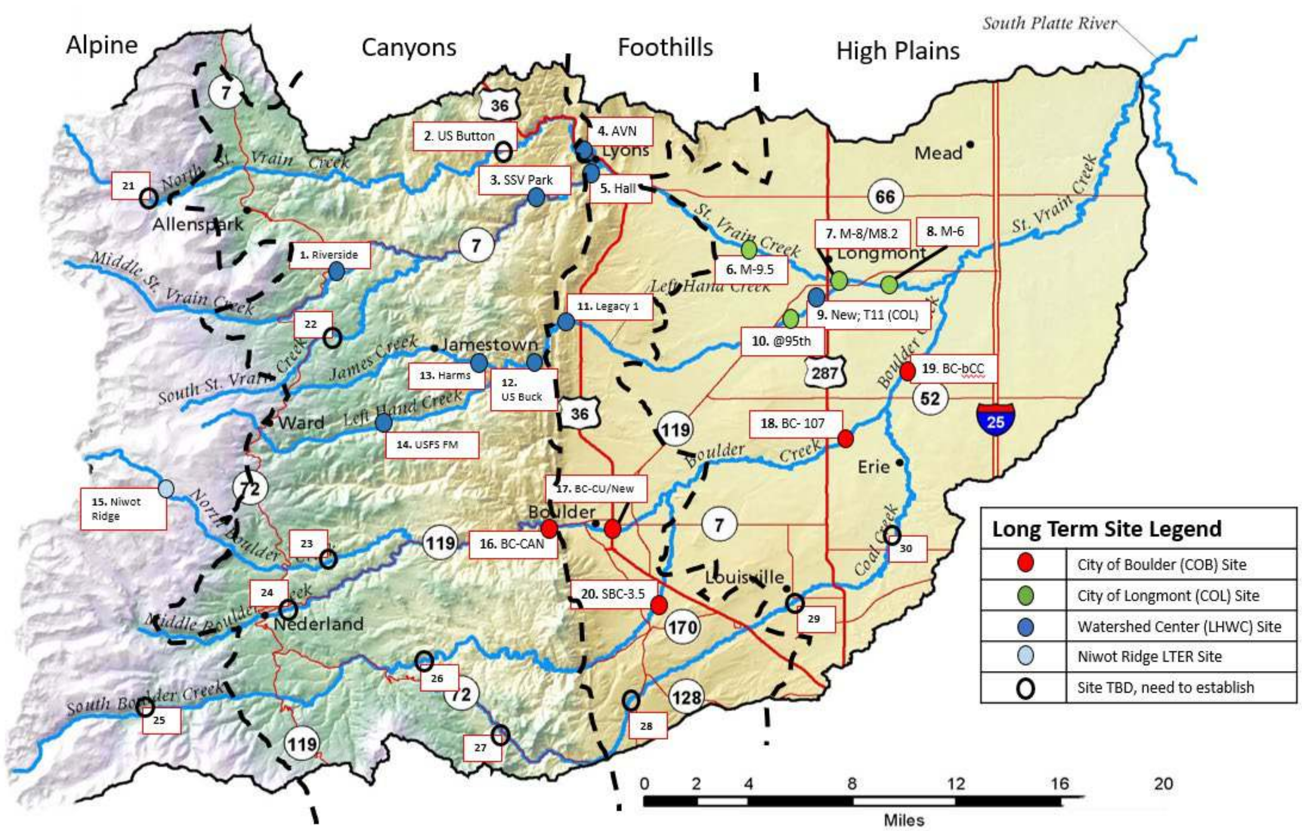

Figure 5. Map of river and riparian system long-term monitoring sites. Legend describes established and desired sites. Established sites are color coded by existing monitoring entity. Site gaps may or may not have existing monitoring and are currently in the selection process.

Table 4. Table of river and riparian system long-term monitoring sites with information about creek name, site name, description (the eco-geomorphology and land use it represents on each creek), existing monitoring entity, existing data categories, and new data categories to be collected in 2022.

#	Creek Name	Site Name	Description	Existing Monitoring Entity	Existing Data	New Data
1	North St. Vrain Creek	TBD	Alpine, North St. Vrain	N/A	N/A	TBD
2	North St. Vrain Creek	TBD	Canyons, North St. Vrain	Potential City of Longmont Site	N/A	TBD
3	North St. Vrain Creek	Apple Valley North	Foothills, North St. Vrain	Watershed Center	vegetation, habitat, BMI, pebble count	N/A
4	South St. Vrain Creek	Sawtooth	Canyons, South St. Vrain (upstream Middle St. Vrain)	Watershed Center	N/A	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
5	South St. Vrain Creek	South St. Vrain Park	Canyons, South St. Vrain (downstream Middle St. Vrain)	Watershed Center	vegetation, habitat, BMI, pebble count	nearest flow, geomorphology
6	South St. Vrain Creek	Hall	Foothills, South St. Vrain	Watershed Center	vegetation, habitat, BMI, pebble count	nearest flow, geomorphology
7	Middle St. Vrain Creek	Riverside	Canyons, Middle St. Vrain	Watershed Center	vegetation, habitat, BMI, pebble count	nearest flow, geomorphology
8	St. Vrain Creek	M-9.5	Plains, Agricultural, St. Vrain (upstream Left Hand)	City of Longmont/ Boulder County	water chemistry, BMI	vegetation, habitat, pebble count, nearest flow, geomorphology
9	St. Vrain Creek	M-8	Plains, Urban, St. Vrain	City of Longmont	water chemistry, BMI	vegetation, habitat, pebble count, nearest flow, geomorphology
10	St. Vrain Creek	M-6	Plains, Agricultural, St. Vrain (downstream Left Hand)	City of Longmont/ Boulder County	water chemistry, BMI	vegetation, habitat, pebble count, nearest flow, geomorphology
11	James Creek	Harms	Canyons, James	Watershed Center	BMI	vegetation, habitat, pebble count, nearest flow, geomorphology
12	Left Hand Creek	USFS Forest Meadow	Canyons, Left Hand (upstream James)	Watershed Center	vegetation, habitat, BMI, pebble count	nearest flow, geomorphology
13	Left Hand Creek	Upstream Buckingham	Canyons, Left Hand (downstream James)	Watershed Center	vegetation, habitat, BMI, pebble count	nearest flow, geomorphology
14	Left Hand Creek	Legacy 1	Foothills, Left Hand	Watershed Center	vegetation, habitat, BMI, pebble count	nearest flow, geomorphology
15	Left Hand Creek	at 95th	Plains, Agricultural, Left Hand	City of Longmont	water chemistry, BMI	vegetation, habitat, pebble count, nearest flow, geomorphology
16	Left Hand Creek	T11 (split site)	Plains, Urban, Left Hand	City of Longmont	water chemistry (downstream)	vegetation, habitat, BMI, pebble count (upstream), nearest flow, geomorphology
17	North Boulder Creek	Niwot Ridge	Alpine, North Boulder	CU Boulder, LTER	water chemistry	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
18	North Boulder Creek	TBD	Canyons, North Boulder	N/A	N/A	TBD
19	Middle Boulder Creek	TBD	Canyons, Middle Boulder	N/A	N/A	TBD
20	South Boulder Creek	TBD- potential USFS?	Alpine, South Boulder	Potential USFS	continuous temp	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
21	South Boulder Creek	TBD	Canyons, South Boulder	N/A	N/A	TBD
22	South Boulder Creek	SBC-3.5	Foothills, Agricultural, South Boulder	City of Boulder	water chemistry, BMI, pebble count	vegetation, habitat, nearest flow, geomorphology
23	Boulder Creek	BC-CAN	Canyons, Boulder (upstream South Boulder)	City of Boulder	water chemistry, BMI, pebble count	vegetation, habitat, nearest flow, geomorphology
24	Boulder Creek	BC-28 (split site)	Foothills, Urban, Boulder (upstream South Boulder)	City of Boulder	water chemistry (downstream)	vegetation, habitat, BMI, pebble count (upstream), nearest flow, geomorphology
25	Boulder Creek	BC-107	Plains, Agricultural, Boulder (downstream South Boulder/upstream Coal)	City of Boulder	water chemistry, BMI, pebble count	vegetation, habitat, nearest flow, geomorphology
26	Boulder Creek	BC-bcc	Plains, Agricultural, Boulder (downstream Coal Creek)	City of Boulder	water chemistry	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
27	Coal Creek	TBD	Canyons, Coal Creek	N/A	N/A	TBD
28	Coal Creek	TBD- potential CU Boulder	Foothills, Coal Creek	Potential CU Boulder site	N/A	TBD
29	Coal Creek	In progress	Plains, Urban, Coal Creek	City of Louisville	water chemistry	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
30	Coal Creek	In progress	Plains, Agricultural, Coal Creek	City of Lafayette	water chemistry	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
31	Rock Creek	In progress	Plains, Urban, Rock Creek	Town of Superior	water chemistry	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology

2. Grasslands Monitoring

Monitoring plans for long-term term sites in the grasslands system are described below, including monitoring design, selected and considered indicators, and site selection.

a) Monitoring Design

The grassland monitoring design is currently under development. Long-term monitoring will represent multiple mosaics of conservation concern that are abundant in the basin, leverage or complement existing monitoring where possible, and tend towards desired conditions where possible. Three sites will be monitored for each of four mosaic common types: mixedgrass prairie, xeric tallgrass prairie, agricultural grasslands (used for grazing, with limited control of species composition), and wetlands. This monitoring strategy will allow us to quantify changes over time and space in across the most abundant grassland community types (mosaics) and make broader generalizations about changes that are occurring within each mosaic.

b) Indicators

Grassland indicators are categorized by priority in Table 4 (Category 1 indicators) and Table 5 (Category 2 indicators) indicators. Categories represent high priority and potential priority indicators which are described in Section V.A.2.

Table 4. Category 1 (high priority) indicators are listed with priority justification details.

Indicator	Justification
Photo points	"Photo points qualitatively monitor how vegetation changes over time, and are useful for detecting changes in vegetation structure, major soil redistribution patterns, and for visually documenting measured changes." Herrick et al. 2017. This metric would be collected once annually.
Cover and composition (including percent native/non-native species) (transect)	This metric captures cover of vegetation, bare ground, rocks, litter, etc., and can be used to calculate diversity and percent of native and non-native species, among other metrics. This metric has implications for shifts in plant community composition, weed detection, habitat suitability, and more. This metric would be collected once annually.
Vertical structure	"Vegetation height provides plot-level vertical structure information necessary to predict soil erosion from wind and characterize wildlife habitat." Herrick et al. 2017. This metric is also informative of annual net primary production and would be collected once annually.
Gap intercept (bare ground)	"Gap intercept measurements provide information about the proportion of the line covered by large gaps between plants. Large gaps between plant canopies are important indicators of potential wind erosion, weed invasion, and wildlife habitat, including wildlife hiding cover and thermal environment. Together with vegetation height, canopy gap measurements can be used to characterize vegetation structure. Large gaps between plant bases are important indicators of runoff and water erosion." Herrick et al. 2017. This metric would be collected once annually.
Soil stability	"Soil stability provides information about the degree of soil structural development and erosion resistance. It also reflects soil biotic integrity, because the "glue" (organic matter) that binds soil particles together must constantly be

Indicator	Justification
	renewed by soil organisms and plant roots." Herrick et al. 2017. This indicator also provides information about infiltration rates. This metric would be collected once annually.
Species inventory (plot-level)	"A plot-level species inventory provides a rapid estimate of species richness. A thorough search of the plot can detect less-frequently occurring species that may not have been recorded in cover measurements (e.g., Line-point intercept)." Herrick et al. 2017. This metric would be collected once annually.
Soil moisture	This metric has implications for shifting abiotic conditions that might drive changes in grassland species composition, diversity, biomass production, etc. This metric would be collected once annually.

Table 5. Category 2 (potential priority) indicators are listed with priority justification details.

Indicator	Justification
Soil nutrients	Capacity limitations. May consider for discrete efforts.
Litter depth	Capacity limitations. May consider for discrete efforts.

c) Sites

Site selection is currently in progress.

3. Forest Monitoring

Monitoring plans for long-term term sites in the forests system are described below, including monitoring design, selected and considered indicators, and site selection.

a) Monitoring Design

The forests monitoring design is currently under development. We are currently assessing which type of monitoring sites will be most useful in project prioritization and in filling knowledge gaps. Potential monitoring focus areas include sites that represent: desired future conditions achieved through natural disturbance (without past treatment), historical/desired future conditions restored through forest management actions, "typical" undesirable current conditions, climate adaptation strategies, and/or sites where experimental or novel prescription design and/or operational methods have been implemented.

While ideally we would conduct monitoring that captures all of the above and which spans forest types and elevation, capacity limitations warrant a thoughtful selection of the monitoring design that will provide the biggest return on investment. Once we have obtained partner feedback on which forest sites (listed above), and which forest types (e.g. foothills, lower montane, upper montane, and sub-alpine forests) will provide the most useful information and most effectively fill critical knowledge gaps, we will select sites in collaboration with Partners.

b) Indicators

Forest indicators are categorized by priority in Table 6 (Category 1 indicators) and Table 7 (Category 2 indicators) indicators. Categories represent high priority and potential priority indicators which are described in Section V.A.2.

LEFT HAND watershed center

Table 6. Category 1 (high priority) indicators are listed with priority justification details.

Indicator	Justification
Canopy cover (over story)	This metric captures forest density. This metric has implications for habitat suitability, maintenance of healthy forest functioning and native tree populations, and resilience to climate change and wildfire. This metric would be collected every 3 years.
Understory cover and composition (including percent native/non-native species)	This metric captures cover of vegetation, bare ground, rocks, litter, etc., and can be used to calculate diversity and percent of native and non-native species, among other metrics. This metric has implications for shifts in plant community composition, weed detection, habitat suitability, and more. This metric would be collected once annually.
Tree species composition (and diversity)	This metric has implications for maintenance of healthy forest functioning, native tree populations, and resilience to climate change and wildfire. This metric would be collected every 3 years.
Tree density	This metric has implications for maintenance of healthy forest functioning, native tree populations, and resilience to climate change and wildfire. This metric would be collected every 3 years.
Regeneration/seedlings and saplings	This metric has implications for maintenance of healthy forest functioning, native tree population dynamics, and resilience to climate change and wildfire. This metric would be collected every 3 years.
Snags and mortality	This metric has implications for habitat availability (snags), and can signal changes in population dynamics with climate change and wildfire (mortality) that inform us of the resiliency of the system.
Soil moisture	This metric has implications for shifting abiotic conditions that might drive changes in species composition, diversity, biomass production, etc. This metric would be collected once annually.

Table 7. Category 2 (potential priority) indicators are listed with priority justification details.

Indicator	Justification
Tree age	Capacity limitations. May consider for discrete efforts.
Forest gaps	Capacity limitations. May consider for discrete efforts.
Tree groups	Capacity limitations. May consider for discrete efforts.
Tree size	Capacity limitations. May consider for discrete efforts.

c) Sites

Site selection is currently in progress.

4. Discrete Monitoring

Monitoring plans for discrete efforts are developed on an on-going basis depending on the need to assess discrete impacts, issues, or projects within the basin. Discrete monitoring efforts are selected by joint partner-prioritization based on monitoring data (e.g. long-term monitoring thresholds are not being met), knowledge of known issues or expected impacts of disturbances (e.g. impacts of fire, nutrient loading, or tanker spill), and projects (e.g. pre/post project monitoring on restoration or management project). As part of this process, known issues and disturbances identified by Partners are cataloged and reviewed collaboratively on an iterative (e.g. annual) basis. Table 8 provides a summary of current known issues or disturbances and potential monitoring or management to assess and/or address each issue actions based on feedback from Partners. This list will be updated iteratively with additional Partner feedback. Decisions to monitor discrete efforts will consider the following:

- Has the discrete efforts been identified as a priority (Table 8)?
- What is the monitoring need associate with the discrete effort?
- What other entities are already monitoring or have expertise related to the monitoring need?
- Is the monitoring need related to an indicator that is already included in the framework (e.g. existing methods could be used at new site related to the discrete effort)?
- What is the feasibility of monitoring (e.g. capacity, cost, time, number of sites)?
- Can support for the discrete effort be provided in other ways besides monitoring? For example, convening stakeholders or providing a subset of data for a broader effort by multiple entities?

Assessment of these questions will prioritize how discrete efforts are addressed by this project and which efforts are directly monitored using the framework. While discrete monitoring efforts are cataloged, reviewed, and prioritized on an annual basis, this framework may also accommodate immediate discrete needs (e.g. monitoring immediately after fire). Decisions to respond to immediate needs will consider the points described above, with the additional emphasis on this project's ability to monitor the issue in the context of the existing long term and discrete monitoring frameworks. Meaning, this project is more equipped to monitor immediate discrete priorities using existing and established protocols; it may have to leverage other partner expertise if immediate needs require protocols and data outside of the established frameworks.

Table 8. Catalog of potential discrete efforts identified by Partners including potential monitoring and management actions needed to address each efforts.

Potential Discrete Efforts	**Potential Monitoring or Management Action**
Nutrient sources in the upper watershed	Increased nutrient monitoring in the upper basin
Increased metals monitoring in the upper watershed	Increased metals monitoring in the upper basin
Impacts of abandoned mines and project prioritization	Identify and prioritize project areas (e.g. spatial mapping and water quality monitoring across the basin). Metals tracer study to assess reclamation success.
Crack willow encroachment	Identify and prioritize project areas and crack willow removal
Monitoring flows at higher resolution across the basin	Identify dry up locations. Increased stream gaging and optimized flow management.
Post-fire impacts to rivers	Monitor habitat and biota. Identify and prioritize depositional river reaches and restore depositional capacity.
Post-fire impacts to forests	Monitor habitat and biota. Identify and prioritize project areas (mulching, erosion control) and restore.
Post-fire weed control	Identify and prioritize weed control needs and implement.
Future flood and fire impacts on river corridors	Identify and prioritize depositional areas in rivers to restore depositional capacity.
Future fire impacts on forests	Identify and prioritize forest restoration (e.g. reduce forest stand density). Collect data to understand how/whether restoration increases fire resiliency.
Post-Tanker spill impacts to aquatic life	Monitor BMI, fish, water quality. Possible fish stocking.

C. 2022 Monitoring Plan

1. Rivers and Riparian

The first year of Adaptive Management at Scale monitoring in the river and riparian system will begin in May 2022. All immediate long-term and prioritized discrete effort indicators will be monitored in the first year in an effort to collect shared monitoring data across the basin. In this initial year of monitoring, we will first leverage existing indicator monitoring and sites. When capacity allows, we will monitor additional indicators at existing or new sites. Additional monitoring will depend on the methods and monitoring frequency required for the indicator. More details on where indicators will be monitored can be found in the indicator monitoring frameworks for long-term and discrete efforts.

While the first year of long term monitoring focuses on existing stakeholder efforts and capacity, there is opportunity to increase monitoring in future years as we learn more and adjust. As such, long term indicators may be collected at more sites over time. For example, in 2022 we plan to leverage existing water quality monitoring by stakeholders in the lower watershed (e.g. KICP) and upper watershed (e.g. Niwot Ridge). In the future, we could add on new sites in the canyons to better understand water quality across the basin. We may also consider a site rotation if more replicate sites are added to the design (e.g. adding additional sites that represent the same eco-geomorphologies, hydrologies, and landuses). Discrete effort data will be collected based on the needs of each effort from year to year.

2. Grasslands

This year, we will focus on identifying and monitoring at long-term monitoring sites, with potential to add discrete monitoring sites in future years. We will monitor immediate indicators, and potential indicators when able. We are currently selecting long-term sites in each of our 4 mosaic types (mixedgrass prairie, xeric tallgrass prairie, agricultural grasslands, and wetlands), beginning with conducting an inventory of partner efforts that are available to leverage. Once sites are selected, we will send the design out for partner review. Monitoring will occur annually in July.

3. Forests

This year, we will conduct forest monitoring at one discrete site (a Jamestown fire mitigation project), and will establish and monitor long-term sites through the process described above. We will monitor immediate indicators, and potential indicators when able or when necessary at a discrete site.

4. Discrete Efforts

Discrete monitoring priorities in 2022 are listed below. These include a combination of monitoring and Partner-led efforts related to discrete priorities.

1. Post-Marshall Fire monitoring was established by CU Boulder researchers and partners (e.g. KICP, Boulder County, City of Boulder, City of Louisville) will assess impacts on chemical and biological parameters in Coal Creek. In addition, the Watershed Center and Partners (Colorado Parks and Wildlife, Colorado Department of Public Health and Environment, KICP) will collect benthic macroinvertebrate samples at six sites. These samples will be collected, sorted and analyzed using CDPHE WQCD methods to obtain metrics that are comparable to existing BMI data collection throughout the Basin.

2. Watershed Center is working with Partners (Calwood Education Center, Boulder County, and private landowners) on post-Fire understory vegetation monitoring in the Calwood and Left Hand burn areas. Monitoring is focused on assessing the impacts of fire on vegetation community and structure in forests and meadows. Data are collected in three locations (Calwood, Heil, and Left Hand) at six different treatments (burned unmitigated forest, unburned unmitigated forest, burned mitigated forest, unburned mitigated forest, burned meadow, unburned meadow).
3. Increased flow monitoring is being considered as a potential discrete priority in support of efforts led by the St. Vrain and Left Hand Water Conservancy District. In progress, pending continued input/discussions with St. Vrain and Left Hand Water Conservancy District regarding additional stream gauging locations.

VI. Projects

Data collection and synthesis will aid in the prioritization and design of collaborative, multi-benefit, and cross-boundary projects for restoration, management, and research. Projects will be informed by data from long-term or discrete monitoring efforts, as well as monitoring efforts by other entities. Partners will work together to identify and prioritize projects considering long-term data and desired conditions. Projects may require unique desired conditions and monitoring plans to align with site-specific conditions and objectives.

VII. Collaborative Workshops

Collaborative annual workshops and working groups will provide regular opportunities for partners and stakeholders come together to collaborate on project prioritization, cross-boundary coordination, project planning, and monitoring. Partners and stakeholders will be invited to share results from their unique monitoring efforts, as well as their updated goals, needs, and priorities related to watershed health monitoring and projects. At these workshops, the Watershed Center will provide an annual update on what was learned and how the adaptive management plan was adjusted based on data collected. Collaborative workshops will occur as both an annual multi-disciplinary workshop with all partners and with subject-specific working groups (e.g. water quality working group, water management working group, riparian working group, etc.). For example, we will:

- Identify gaps in collective knowledge that warrant further monitoring.
- Bring partners together to share data from current or past monitoring efforts.
- Share planning and prioritization to ensure that restoration projects are complementary and cross-boundary.
- Discuss restoration strategies, best management practices, and potential projects that could aid in achieving desired conditions across the basin.
- Hold on-the-ground project tours and workshops.

As part of this process, community (e.g. individual landowners, public) will be gathered by leveraging others on-going meetings. Future workshops may include community meetings and input.

VIII. Watershed Report

The Watershed Center will develop and publish annual "State of the Watershed" reports based on data and workshops, as well as partner review, with versions for both stakeholder and community audiences. Data from long-term and discrete monitoring efforts will be analyzed and reported by site. The purpose of these reports is to share what was learned to from collaborative workshops, individual meetings, site visits, working groups, and monitoring, and to foster cross-boundary communication. Reports will be shared on the Watershed Center's website and in newsletters.

IX. Adjust

Adjusting and iterating at all steps based on what is learned is inherent to adaptive management, ensuring flexibility and accountability for managing dynamic and complex systems. Input is welcomed at all stages of the adaptive management process, and the annual collaborative workshop and working groups will serve as key opportunities for adjusting this framework and plan.