ADAPTIVE MANAGEMENT AT SCALE

Plan and Framework for the St. Vrain Basin

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 would benefit from scaling this adaptive management approach to the basin in addition to complementing existing partner monitoring efforts.

Partners agreed to the need and value of the shared framework that integrated 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.), better sharing of resources to support monitoring, better apples-to-apples comparisons of data, and robust 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 additional diverse stakeholders and their existing monitoring efforts in the framework development process.

Since 2020, this monitoring framework has been collaboratively developed, with robust engagement from diverse entities that currently monitor and manage watershed health in the basin. The project goal was to create and implement a framework that 1) helps diverse entities across the basin make more informed management decisions as a basin community and better tracking of broad progress towards watershed health goals, and 2) continues as part of the long-term annual on-the-ground adaptive management process.

This framework frequently uses the term “watershed health,” which 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 assessed on criteria derived from “desired conditions” that are integrated and synthesized for each ecological community. The desired conditions encompass the goals for ecological conditions (see Framework Criteria (IV.B) and Desired Conditions (V) sections). In the context of these desired conditions, quantitative indicators provide the assessment of watershed health. Performance thresholds for each indicator may vary by site or other classifications (e.g., reach, grassland/forest type, watershed zone, biophysical zone). Thus, the definition of watershed health is appropriate to the site and watershed as a whole considering the diverse conditions of sites across the basin.

II. Partners, Stakeholders, and Contributors

This work would not be possible without the many partners, stakeholders, contributors, and funders. We would like to extend our deepest gratitude for your time, energy, ideas, enthusiasm, and support. As part of the adaptive management process, outreach is ongoing to additional stakeholders and we welcome ongoing input and feedback from all.

Argosy Foundation
Audubon Society
Boulder County
Boulder County Nature Association
Boulder Valley Conservation District
Boulder Watershed Collective
Burns and McDonnell
CEMEX
Citizen Science Soil Health Project
City of Lafayette
City of Longmont
City of Louisville
Colorado Department of Public Health and Environment
Colorado Forest Restoration Institute
Colorado Parks and Wildlife
Colorado Water Conservation Board
Community Foundation Boulder County
Garney Construction
Justin Brooks Fisher Foundation
Keep It Clean Partnership
Left Hand Water District
Longmont Conservation District
Lyons Ecology Board
Mile High Flood District
National Ecological Observatory Network
Niwot Ridge Long Term Ecological Research Station
Rocky Mountain Conservancy
Rocky Mountain National Park
St. Vrain and Left Hand Water Conservancy District
Town of Superior
Trout Unlimited – Boulder Flycasters
Trout Unlimited – National
Trout Unlimited – St. Vrain Anglers
United States Bureau of Reclamation
United States Geological Survey
USDA – Forest Service
USDA – Natural Resources Conservation Service
USFWS St. Vrain Site Conservation Team

III. Framework and Maps

The three links below are part of this plan and provide relevant information as described.

Monitoring Framework

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

The Monitoring Framework outlines indicators to track river and riparian, grassland, and forest conditions at long-term and discrete sites across the St. Vrain Basin. Each indicator includes a description of why it was chosen as well as associated information such as and methods, samples per site, sampling frequency, rotation, performance thresholds, and suggested action.

Shared Interactive Map

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

The Shared Interactive Map displays information about current monitoring efforts across the St. Vrain Basin done by Adaptive Management at Scale partners and by the Watershed Center. Information includes the type of data collected (e.g., water quality) and the monitoring entity.

Adaptive Management Forests and Rivers Map

https://lhwc.maps.arcgis.com/apps/webappviewer/index.html?id=1abfd13256434b8d902e53e3f6c04d3a

The Adaptive Management Forests and Rivers Map displays information about areas of concern and potential future projects collected from St. Vrain Forest Health Partnership Community Planning Meetings and from our partners through the Adaptive Management at Scale project.

IV. Adaptive Management Process and Criteria

A. Process

Adaptive management offers the accountability and flexibility necessary to manage complex and changing ecosystems and management. 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. 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.

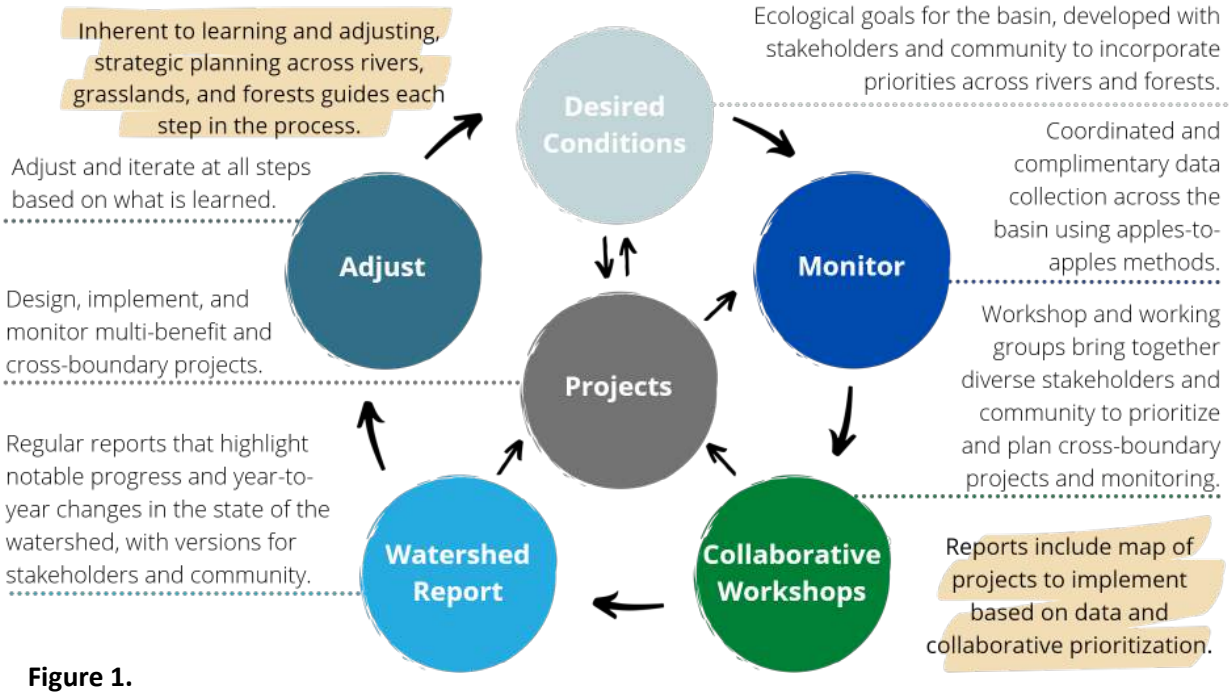

Figure 1.

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. The plan utilizes, integrates, and complements existing watershed health-related **ecological data** collection and monitoring efforts. Ecological data associated with specific indicators (see Criteria 4) 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 are also incorporated (see Criteria 4 below).
2. Watershed health is assessed relative to **desired conditions** which are described broadly for the basin and represent goals for ecological conditions. Desired conditions 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 is 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** are 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 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) is incorporated as prioritized.
5. Monitoring takes 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 leverages existing long-term monitoring locations. Discrete monitoring efforts represent specific, issues-related management concerns. Both types of sites inform project prioritization and understanding of watershed health.
6. Indicators are 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 informs project prioritization, trajectory toward desired conditions, and how sites across the basin are changing with the climate.

V. Desired Conditions

Desired conditions are the benchmark ecological conditions across the basin. Not all desired conditions apply at specific sites or scales. We developed the list of desired conditions below based on a review of partners' existing monitoring and management plans 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 quality 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 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, industrial), and recreation.
4. In-stream habitat is complex with multiple types of habitat (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 (high number of native species 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., high number of native species 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.

VI. Monitoring

Monitoring uses quantitative indicators (data collected) to provide a quantitative assessment of trajectory towards desired conditions and how sites across the basin are changing with the climate. 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 VI.A.), 2) monitoring designs for individual systems or efforts (Section VI.B), and 3) the monitoring plan for 2022 (Section VI.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) allows 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.

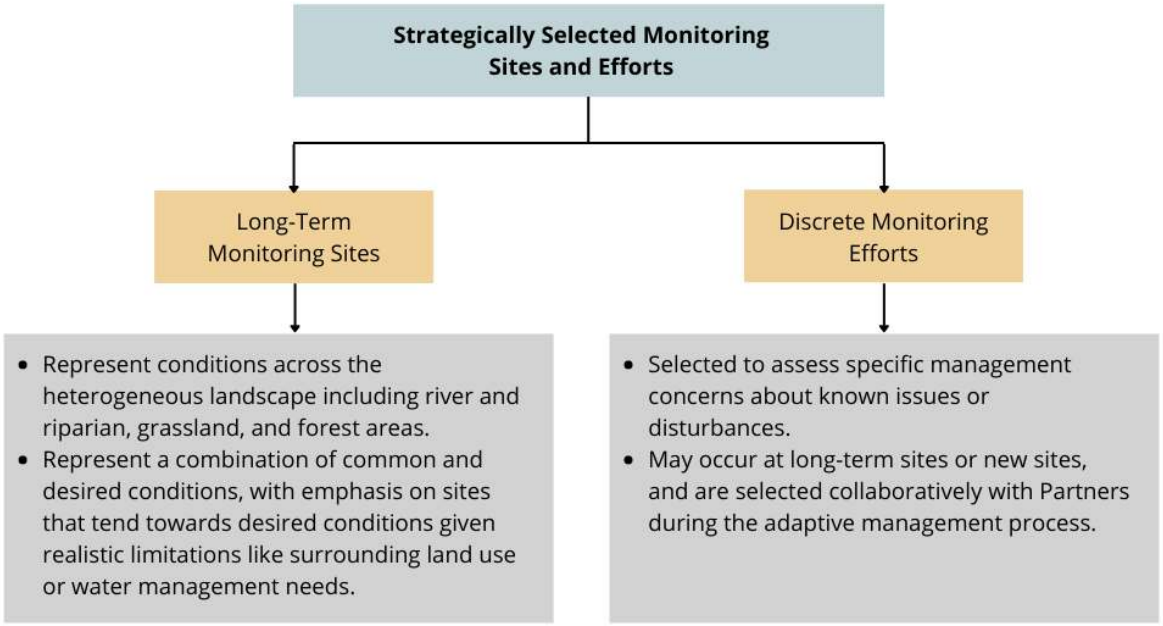

Figure 2. Long-Term and Discrete Monitoring Sites and Efforts

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 is 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 informs 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 is based on existing monitoring data, knowledge of known issues, expected impact of disturbances, and priority project opportunities (See Section VI.B.4. for additional 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.

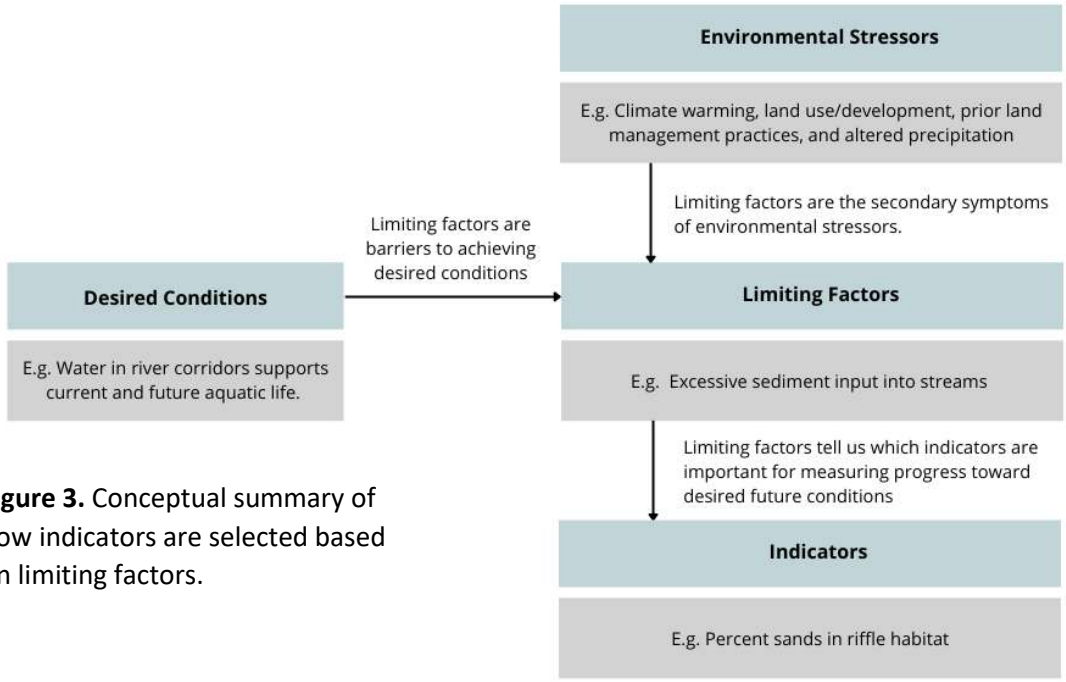

Figure 3. Conceptual summary of how indicators are selected based on limiting factors.

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. Note that limiting factors are not "bad" per se, but rather something that we must work around (e.g., surface water diversions undoubtedly significantly contribute to variability in streamflows, but they are also necessary in meeting water user needs).

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 effluent) • 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, industrial), 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 complex with multiple types of habitat (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 (high number of native species and self-sustaining) native plant community that promotes clean water and complex habitat now and in the future.	• Pollution into waterways due to land use 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, land use, 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., high number of native species and self-sustaining) habitat for native wildlife and improves resiliency to high severity wildfires, floods, and other disturbances (e.g., lower montane forest structure includes a range of species, age classes, tree sizes, irregularly spaced tree groups, and gaps and openings of various sizes, upper montane forests are able to regenerate post-fire) 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) • Increased urban development

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 are 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 (link below) 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 30+ representative sites. While this number of sites captures a subset of the diverse conditions across the St. Vrain Basin, data provides 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 (monitoring locations selected to be representative of entire sites) provides 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 is reported by site and contributes to an understanding of watershed health across the basin, as opposed to basin-wide or at basin-scale. At grassland and forest monitoring sites, which are still in the selection process, data may be reported by community type, for example, as trends observed across sites within a given grassland community type.

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 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 there 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 is 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 is 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 three years. Frequency of monitoring for each indicator is listed in the monitoring framework.

Monitoring Framework

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

e) Site Rotation

Site rotations 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 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 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.

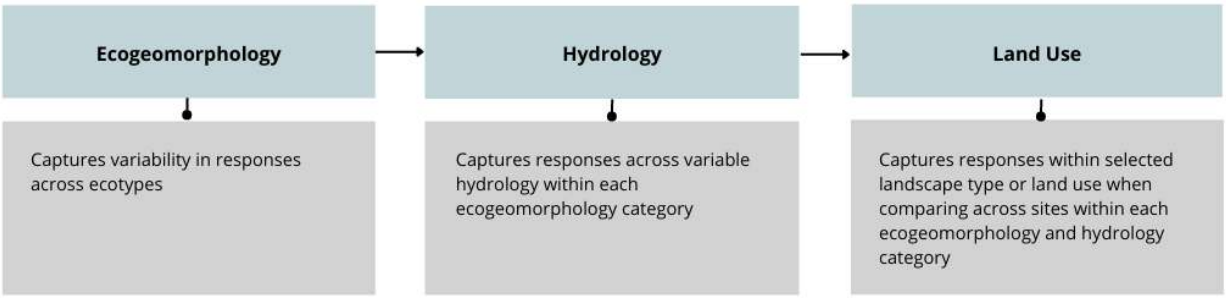

Figure 4. Site selection process for river and riparian system long-term monitoring sites.

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 VI.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 every 3-5 years or as needed 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 at monitoring locations. 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 Relative Elevation Models (REMs) 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.
riparian width (mapped)	This metric captures the ecological response to floodplain connectivity (e.g., ground and surface water connection to the riparian vegetation) and surrounding land use. This metric has implications for morphological changes such as channel aggradation or degradation. This metric would be collected every 5 years or after a significant high flow event. Due to the expense of creating REMs for each site, this

Indicator	Justification
	indicator will be collected for all sites within the first 3-5 years through a site rotation. This metric overlaps with multiple desired conditions.
Lower riparian width	This metric captures a more direct ecological response to floodplain connectivity (e.g., ground and surface water connection to the riparian vegetation) compared to total riparian width. This metric has implications for morphological changes such as channel aggradation or degradation. This metric will be collected every 3 years or as needed after disturbance.
Greenline width	This metric captures the width of the first perennial vegetation perpendicular to the creek edge that forms a lineal group of community types on or near the water's edge. It is important for determining stability of the stream bank.
% pools per reach	This metric captures habitat complexity and availability for fish, effectiveness of flushing flows (e.g., annual scour and maintenance of pools), and depositional capacity at reaches (defined as 20 times the wetted width) 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 every 3-5 years or as needed after disturbance.
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 every 3-5 years or as needed after disturbance.
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 every 3-5 years or as needed after disturbance.
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 every 3 years or as needed after disturbance.
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 every 3 years or as needed after disturbance.

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 leverage and complement existing monitoring efforts across the basin. As described 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.

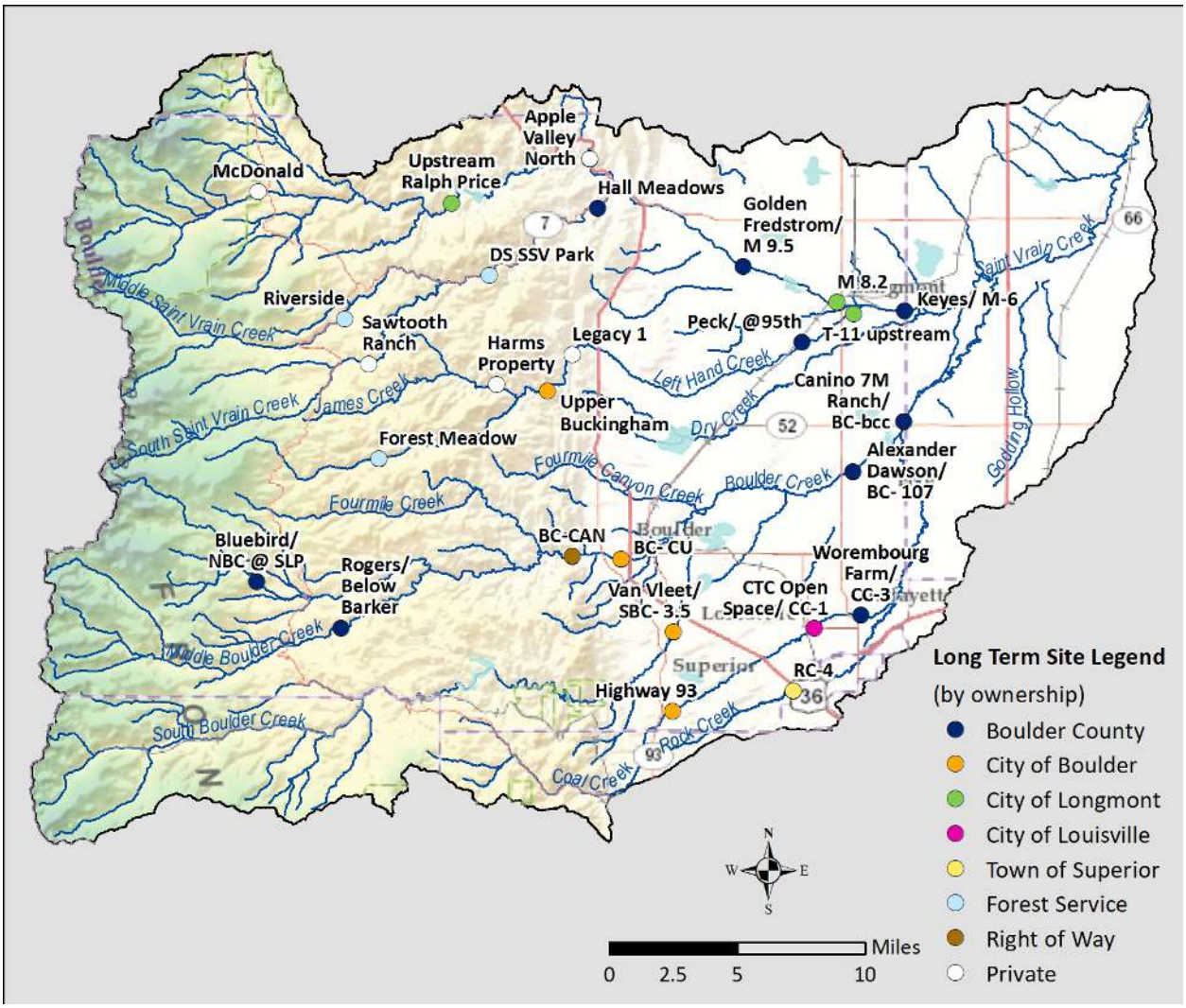

Figure 5. Map of river and riparian system long-term monitoring sites. Legend describes established and desired sites. Established sites are color coded by existing monitoring entity.

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 data categories to by collected through Adaptive Management at Scale. Note abbreviations for upstream, "US" and downstream, "DS" are used throughout.

#	Creek Name	Site Name	Description	Existing Monitoring Entity	Existing Data	AM at Scale Data
1	North St. Vrain Creek	McDonald	Canyons, North St. Vrain Creek	N/A	N/A	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
2	North St. Vrain Creek	Upstream Ralph Price	Canyons, North St. Vrain Creek	City of Longmont	water chemistry	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
3	North St. Vrain Creek	Apple Valley North	Foothills, North St. Vrain Creek	Watershed Center	vegetation, habitat, BMI, pebble count	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
4	South St. Vrain Creek	Sawtooth	Canyons, South St. Vrain Creek (US Middle St. Vrain Creek)	Watershed Center	N/A	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
5	South St. Vrain Creek	DS South St. Vrain Park	Canyons, South St. Vrain (DS Middle St. Vrain Creek)	Watershed Center	vegetation, habitat, BMI, pebble count	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
6	South St. Vrain Creek	Hall	Foothills, South St. Vrain Creek	Watershed Center	vegetation, habitat, BMI, pebble count	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
7	Middle St. Vrain Creek	Riverside	Canyons, Middle St. Vrain Creek	Watershed Center	vegetation, habitat, BMI, pebble count	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
8	St. Vrain Creek	Golden Fredstrom/ M 9.5	Plains, Agricultural, St. Vrain Creek (US Left Hand Creek)	City of Longmont/ Boulder County	water chemistry, BMI	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
9	St. Vrain Creek	M 8.2	Plains, Urban, St. Vrain Creek	City of Longmont	water chemistry, BMI	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
10	St. Vrain Creek	Keyes/ M-6	Plains, Agricultural, St. Vrain Creek (DS Left Hand Creek)	City of Longmont/ Boulder County	water chemistry, BMI	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
11	James Creek	Harms	Canyons, James Creek	Watershed Center	BMI	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
12	Left Hand Creek	Forest Meadow	Canyons, Left Hand Creek (US James Creek)	Watershed Center	vegetation, habitat, BMI, pebble count	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
13	Left Hand Creek	Upper Buckingham	Canyons, Left Hand Creek (DS James Creek)	Watershed Center	vegetation, habitat, BMI, pebble count	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
14	Left Hand Creek	Legacy 1	Foothills, Left Hand Creek	Watershed Center	vegetation, habitat, BMI, pebble count	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
15	Left Hand Creek	Peck/ @95th	Plains, Agricultural, Left Hand Creek	City of Longmont	water chemistry, BMI	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
16	Left Hand Creek	Upstream T11	Plains, Urban, Left Hand Creek	City of Longmont	water chemistry (downstream at T-11)	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
17	North Boulder Creek	Bluebird/ NBC @ SLP	Canyons, North Boulder Creek	City of Boulder	water chemistry (upstream at Silver Lake)	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
18	Middle Boulder Creek	Rogers/ Below Barker	Canyons, Middle Boulder Creek	City of Boulder	water chemistry (upstream at Below Barker)	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
19	South Boulder Creek	Van Vleet/ SBC- 3.5	Foothills, Agricultural, South Boulder Creek	City of Boulder	water chemistry, BMI, pebble count	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
20	Boulder Creek	BC-CAN	Canyons, Boulder Creek (US South Boulder Creek)	City of Boulder	water chemistry, BMI, pebble count	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
21	Boulder Creek	BC-CU	Foothills, Urban, Boulder Creek (US South Boulder Creek)	City of Boulder	water chemistry (downstream)	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
22	Boulder Creek	Alexander Dawson/ BC- 107	Plains, Agricultural, Boulder Creek (DS South Boulder/US Coal Creeks)	City of Boulder	water chemistry, BMI, pebble count	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
23	Boulder Creek	Canino 7M Ranch/ BC-bcc	Plains, Agricultural, Boulder Creek (DS Coal Creek)	City of Boulder	water chemistry	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
24	Coal Creek	Highway 93	Foothills, Coal Creek	N/A	N/A	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology
25	Coal Creek	CTC Open Space/ CC-1	Plains, Urban, Coal Creek	City of Louisville	water chemistry	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
26	Coal Creek	Worembourg Farm/ CC-3	Plains, Agricultural, Coal Creek	City of Lafayette	water chemistry	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry
27	Rock Creek	RC-4	Plains, Urban, Rock Creek	Town of Superior	water chemistry	vegetation, habitat, BMI, pebble count, nearest flow, geomorphology, water chemistry

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 under development to ensure that existing efforts are effectively complimented and integrated. Project partners, including Boulder County Parks and Open Space and the City of Boulder Open Space and Mountain Parks, have existing grassland monitoring programs. These programs provide extensive information about grassland conditions across the basin and warrant further consideration about which sites may be most informative in the context of cross-basin monitoring goals. Partner collaboration will continue to prioritize grassland monitoring needs and coordination opportunities.

Site criteria considered for long-term grassland monitoring are 1) sites that fill spatial gaps in existing monitoring efforts; 2) sites that represent multiple community types of conservation concern that are abundant in the basin; 3) sites that leverage or complement existing monitoring where possible; and 4) sites that tend towards desired conditions where possible. Ideally, the selected monitoring design will quantify changes over time and space across the most abundant grassland community types for broad generalizations about changes that are occurring within each community type.

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 VI.A.2.

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

Indicator	Justification
Cover and native/non-native species composition	Species composition and proportion of native and non-native species along transect. This metric has implications for shifts in plant community composition, weed detection, and habitat suitability. This metric would be collected in the first year of data collection and then every three years thereafter.
Structural diversity	Proportion of growth habit types (grass, herb/forb, shrub, tree, vine, etc.) along transect. This metric has implications for shifts in vegetation structure and habitat suitability. This metric would be collected in the first year of data collection and then every three years thereafter.
Species inventory	Species composition (including native/non-native proportions) occurring within 1 meter of transect. This metric captures less-frequently detected species not captured by transect monitoring by that occur in grasslands. This metric would be collected in the first year of data collection and then every three years thereafter.
Gap intercept (bare ground)	Proportion of bare ground along transect. Large gaps between plant canopies are important indicators of potential wind erosion, weed invasion, and wildlife habitat, including wildlife hiding cover and thermal environment. This metric would be collected in the first year of data collection and then every three years thereafter.
Vertical structure	Average vegetation height along transect. Vegetation height provides vertical structure information necessary to predict soil erosion from wind and characterize

Indicator	Justification
	wildlife habitat. This metric would be collected in the first year of data collection and then every three years thereafter.
Soil stability	Average soil stability measurement along transect. This metric provides information about the degree of soil structural development and erosion resistance. This metric would be collected in the first year of data collection and then every three years thereafter.
Soil moisture	Average soil moisture along transect. 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 in the first year of data collection and then every three years thereafter.
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.

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

Grassland site selection is in progress. Sites will be selected based on spatial gaps identified by conversations with partners. We are considering monitoring in the mixed grass prairie mosaic, xeric tallgrass prairie, agricultural grasslands (used for grazing, with limited control of species composition), and wetlands. The number and exact location of sites to be established in each community type will depend on how much of each community type is currently monitored and where new sites will increase statistical power. We will continue these conversations into 2023, visit potential sites in 2023, and begin monitoring in 2024.

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. 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. We conducted a survey in 2022 of our forest practitioner and researcher partners to ask which type of monitoring sites will be most useful in project prioritization and in filling knowledge gaps. We received feedback that they would recommend monitoring at: 1) project sites where climate adaptation strategies are being utilized to test their efficacy and track changes long-term, 2) in upper montane both at long-term representative sites and where projects take place, and 3) recent burns in order to track where and when conversions to different cover types are taking place.

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 VI.A.2.

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

Indicator	Justification
Canopy cover (over story) (gross proportional general canopy intercept via NAIP imagery)	This metric captures forest cover. This metric has implications for habitat suitability, maintenance of healthy forest function, native tree populations, and resilience to climate change and wildfire. This metric would be collected every 5 years, and data will be reported alongside the biophysical zone-scale desired future conditions outlined in the St. Vrain Forest Health Partnership's Adaptive Management Process.
Understory cover and composition (including percent native/non-native species) (via understory plots)	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. At long-term sites, this metric would be collected once annually. At discrete and/or project-related sites, this metric would be collected annually for the first 3 years, and then every 5 years following.
Tree species composition (and diversity) (via variable radius and fixed area sub plots)	This metric has implications for maintenance of healthy forest functioning, native tree populations, and resilience to climate change and wildfire. At long-term sites, this metric would be collected every 5 years. At discrete and/or project-related sites, this metric would be collected annually for the first 3 years, and then every 5 years following. Data will be reported alongside the biophysical zone-scale desired future conditions outlined in the St. Vrain Forest Health Partnership's Adaptive Management Process.
Tree density (via variable radius and fixed area sub plots)	This metric has implications for maintenance of healthy forest functioning, native tree populations, and resilience to climate change and wildfire. At long term sites, this metric would be collected every 5 years. At discrete and/or project-related sites, this metric would be collected 1 year post-implementation and every 5 years following. Data will be reported alongside the biophysical zone-scale desired future conditions outlined in the St. Vrain Forest Health Partnership's Adaptive Management Process.
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. At long-term sites, this metric would be collected every 5 years. At discrete and/or project-related sites, this metric would be collected annually for the first 3 years, and then every 5 years following.
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. This metric would be collected every 5 years.
Soil moisture	This metric has implications for shifting abiotic conditions that might drive changes in species composition, diversity, biomass production, etc. We are hoping to collect continuous soil moisture data at a subset of sites, due to the limitations of making inferences from single time point measurements.

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. In November of 2022, we are hosting the St. Vrain Forest Health Partnership Annual Adaptive Management Workshop. At this workshop, we will identify sites to monitor in 2023, and will confirm with partners the above list of priority indicators.

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 (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 is updated iteratively with additional partner feedback. Decisions to monitor discrete efforts 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 or protocols could be used at new site without the need to develop new methods or protocols)?
- What is the feasibility of monitoring (e.g., capacity, cost, time, and 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?

These questions 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).

Each of the efforts below is informed by information gathered as part of the collaborative process described in Section VII. Collaborative Workshops, below.

Table 8. Catalog of potential discrete efforts identified by partners and cross-basin stakeholders in collaborative meetings including potential monitoring and management actions needed to address each effort.

Potential Discrete Efforts	Potential Monitoring or Management Action
Benefits of beaver dams or dam analogs in depositional areas	Coordinate among stakeholders to identify and prioritize project areas that could benefit from beaver dam analogs or similar.
Channelization around infrastructure throughout all watershed zones	Coordinate among stakeholders to identify and prioritize project areas that reduce channelization.
Crack willow encroachment in riparian corridors	Coordinate existing efforts to identify and prioritize project areas and crack willow removal.
Floodplain connectivity in depositional areas of foothills and plains streams	Coordinate among stakeholders to identify and prioritize project areas to improve floodplain connectivity.
Dry up points in augmented streams	Coordinate among stakeholders to identify and prioritize project areas that reduce dry up periods and locations.
Fish passage in foothills and plains streams	Coordinate among stakeholders to identify and prioritize project areas that improve fish passage.
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.
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.
Increased metals monitoring in the upper watershed	Increased metals monitoring in the upper basin
Lack of sediment continuity in foothills/plains streams due to ditch operations. Results in channel incision or sediment accumulation behind dams	Coordinate among stakeholders to identify and prioritize project areas that improve sediment continuity in plains streams.
Monitoring flows at higher resolution across the basin	Identify dry up locations. Increased stream gaging and optimized flow management.
Non-native riparian vegetation establishment in lower watersheds.	Coordinate existing efforts to identify and prioritize project areas.
Nutrient loading in urban and agricultural streams/ lower watershed	Coordinate existing efforts to identify and prioritize project areas.
Nutrient sources in the upper watershed	Coordinate among stakeholders to identify sources in the upper basin.
Overgrazing in riparian areas of foothills and plains streams	Coordinate among stakeholders to identify and prioritize project areas that reduce overgrazing.
Pools are not maintaining in plains streams	Identify and prioritize projects to improve pool habitat in plains streams.
Post-fire impacts to rivers	Monitor habitat and biota. Identify and prioritize depositional river reaches and restore depositional capacity.
Post-fire impacts to reservoirs/lakes	Monitor habitat and biota.
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.
Post-spill impacts to aquatic life	Monitor BMI, fish, water quality. Possible fish stocking.
Sediment sources due to excess erosion in upper watersheds (e.g., Jamestown, Button Rock road, Chapman Drive, Lickskillet, Magnolia trails)	Coordinate among stakeholders to identify and prioritize projects to reduce sedimentation.
Spread of New Zealand mud snail distribution in plains streams	Coordinate monitoring efforts to reduce spread of species.
Water quality concern with CBT effluent in boulder Creek (significant color change).	Coordinate among stakeholders to identify source or conduct water quality monitoring.

C. 2022 Monitoring Plan

1. Rivers and Riparian

Monitoring in the river and riparian system started in May 2022. While the first year of long-term monitoring focused on existing stakeholder efforts and capacity, there is opportunity to increase monitoring in future years as we learn and adjust. Therefore, long-term indicators may be collected at more sites over time. For example, in 2022, we leveraged existing water quality monitoring by partners in the lower watershed (e.g., Keep It Clean Partnership) and upper watershed (e.g., Niwot Ridge). In the future, additional new sites in the canyons may be added 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 land uses). Discrete effort data will be collected based on the needs of each effort from year to year.

2. Grasslands

In 2022, we began conversations with our partners (e.g., Boulder County and City of Boulder) who have extensive grassland monitoring programs already established about how to leverage existing data and how the Watershed Center can complement their efforts. We plan to continue these conversations into 2023, visit potential sites in 2023, and begin monitoring in 2024. After the first year of monitoring, we plan to monitor every three years thereafter.

3. Forests

In 2022, we conducted forest monitoring at one discrete site (a Jamestown fire mitigation project) and began establishing 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 University of Colorado Boulder researchers and partners (e.g., Keep It Clean Partnership, Boulder County, City of Boulder, City of Louisville) and assessed 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, Keep It Clean Partnership) collected benthic macroinvertebrate samples at six sites. These samples were 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 worked with partners and stakeholders (Calwood Education Center, Boulder County, and private landowners) on post-fire understory vegetation monitoring in the Calwood and Left Hand burn areas. Monitoring focused on assessing the impacts of fire on vegetation community and structure in forests and meadows. Data were 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 currently being considered as a potential discrete priority in support of efforts led by the St. Vrain and Left Hand Water Conservancy District pending continued input/discussions with St. Vrain and Left Hand Water Conservancy District regarding additional stream gauging locations.

VII. Collaborative Workshops

Collaborative annual workshops and working groups provide regular opportunities for partners, stakeholders, and community members to collaborate on known issues, project prioritization, cross-boundary coordination, project planning, funding planning, and monitoring. Collaborative workshops will occur as both an annual multi-disciplinary workshop with all partners and stakeholders and with subject-specific working groups (e.g., water quality working group, riparian working group, etc.). As part of this process, community input (e.g., individual landowners, public) will also be gathered by leveraging other on-going meetings (e.g., St. Vrain Forest Health Partnership Community Planning Meeting). Future workshops aim to expand community engagement.

A. Aspects of Collaborative Meetings

The collaboration process includes the following elements, which all contribute to project prioritization.

- Identification of gaps in collective knowledge that warrant further monitoring.
- Sharing of data and lessons learned from current or past monitoring efforts.
- Reporting and gathering of information on cross-basin conditions such as known desired conditions, issues, and projects (either future or current).
- Discussion of project planning and prioritization to ensure that restoration and management projects are complementary and cross-boundary.
- Discussion of restoration strategies, best management practices, and potential projects that could aid in achieving desired conditions across the basin.
- Discussion of funding strategies that leverage shared resources.
- On-the-ground project tours and workshops.

B. Information Gathered on Cross-Basin Conditions

Information gathered about conditions across the Basin is documented in the Adaptive Management – Forests and Rivers Map (in the Layer List, select “Cross-Basin Reported Conditions” – see Figure 6). Using this map, we work with Partners to identify priority projects types (described in the following section VIII. Projects).

Adaptive Management Forests and Rivers Map

https://lhwc.maps.arcgis.com/apps/webappviewer/index.html?id=1abfd13256434b8d902e53e3f6c04d3a

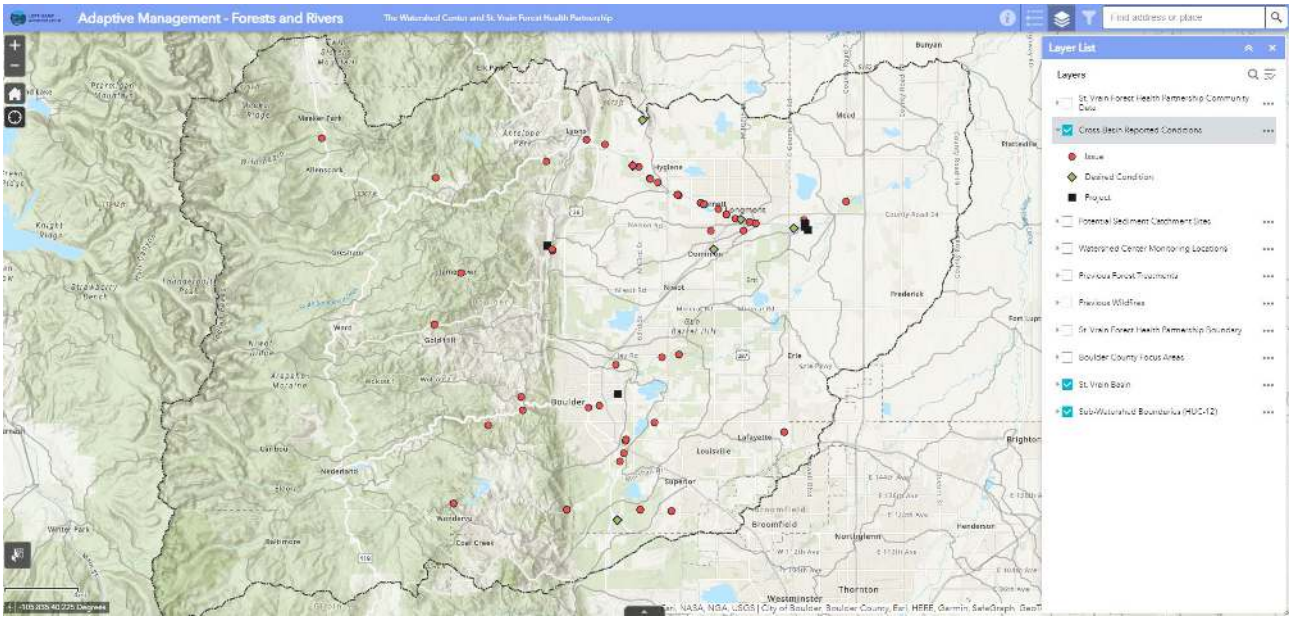

Figure 6. Adaptive Management- Forests and Rivers interactive map. Map can be found HERE.

VIII. Projects

Data collection (long-term and discrete monitoring, partner and stakeholder monitoring) and collaboration (community meetings, collaborative partner meetings and working groups) guide prioritization and design of collaborative, multi-benefit, and cross-boundary (jurisdictional and/or property) projects for restoration, management, and research. Our process of getting from known issues to projects includes 1) Information Gathering, 2) Prioritization, and 3) Focused Planning.

Information gathering encompasses sharing data and reporting out on known issues during collaborative meetings and workshops with all partners and stakeholders. From there, partners work together on an annual basis to **prioritize** known issues for projects. During this step, partners consider various specifications around reported issues, relevant data, and desired conditions. More specifically, partners may consider the following in project prioritization of issues:

- Frequency. How often does the issue come up?
- Scale. What is the spatial extent of the issue?
- Multi-benefit potential. In a similar geographic area what types of issues are reported? Could a project address more than one?
- Severity of issue. How severe is the issue relative to desired conditions?
- Funding. What funding sources exist to address the issue?

The final step is **focused planning**, where an interdisciplinary team of relevant partners and/or stakeholders will work together on priority issues and create a project plan. Projects may require unique desired conditions and monitoring plans to align with site-specific conditions and objectives.

IX. Watershed Report

The Watershed Center will develop and publish "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 communication across jurisdictional and property boundaries. Reports will be shared on the Watershed Center's website and newsletters.

Given the comprehensive and iterative nature of the adaptive management process, reporting will ensure that information shared is succinct and digestible for readers and builds on previous reports. Additionally, reports will lead to actionable restoration or management outcomes and must be feasible for the Watershed Center to develop on an annual basis given capacity limits. To balance these considerations, we plan to develop a full report periodically (e.g., every five years) and interim reports in years that the full report is not released (e.g. annually). Both are described below.

- **Full reports:** Full reports will report out on all or most of the data collected in recent years to provide a broad, high-level understanding of the current state of basin health and to provide general context for the interim reports that will follow in subsequent years. All or most indicators at all long-term sites throughout the basin will be included with the potential to include discrete monitoring efforts at discrete sites if it would contribute to a broad understanding of basin health.
- **Interim reports:** Interim reports will report out on data relating to one system (e.g., rivers, forests, or grasslands), one or several related desired conditions or indicators (e.g., vegetation across all three systems), or gaps identified by partners (e.g., one particular indicator across one sub-watershed). The purpose of the interim reports is to provide an in-depth analysis on just part of the data collected from the basin to gain the most complete understanding as we know it on that particular topic. Interim reports will aim to use more informative statistical modelling methods that will be useful for decision making by stakeholders as opposed to the basic descriptive statistics used in the full report.

Reporting will also be adjusted in response to watershed and community needs. For example, reporting may be adjusted in the event of a flood or fire in an effort to disseminate the highest priority information related to disturbances and to inform restoration and/or management actions.

A. Monitoring vs. Reporting Frequency

Monitoring and reporting frequencies differ due to differences in monitoring and reporting goals. Monitoring aims to capture data on long-term trends and discrete impacts as necessary and feasible, and will occur at the frequencies described in the monitoring framework. Reporting aims to disseminate information that is a comprehensive analysis of indicators, is digestible and relevant for stakeholder and community audiences, and is feasible for the Watershed Center to develop on an annual basis given capacity limits. In practice, this means that we may collect more data annually than we report on each year. For example, we may collect data on post-fire impacts to forest regeneration for three straight years, yet we will only report out after the third year of monitoring. This allows us to provide a more comprehensive understanding of the impact at a meaningful timescale.

X. 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.