Hinkson Creek Collaborative Adaptive Management Science Strategy

Draft August 15, 2024

Hinkson Creek Science Team

Executive Summary

Hinkson Creek originates in northeastern Boone County and flows southwest through the city of Columbia before joining Perche Creek, which then flows south into the Missouri River. The Hinkson Creek watershed covers approximately 90 square miles (mi^2) and drains roughly 60 percent of the land area within the city of Columbia. The water body is considered a Missouri Ozark border stream, located in in the transition zone between the Glaciated Plains and the Ozark Natural Divisions (Thom and Wilson 1980).

Hinkson Creek was originally placed on the 1998 Missouri 303(d) List of impaired waters for unspecified pollutants due to urban nonpoint source runoff. These unspecified pollutants are the suspected cause of the poor aquatic invertebrate community observed throughout portions of Hinkson Creek. The impaired portion of Hinkson Creek begins near Interstate 70 and flows through the city of Columbia to the stream's confluence with Perche Creek. Streams that flow through urbanized areas typically receive multiple pollutants and are subjected to environmental conditions that can cause nonpoint source impairment. Although multiple stressors - conditions and pollutants -- are collectively causing the impairment of Hinkson Creek, it is not known whether all the stressors have been identified or their relative importance. What is known, is that water quality problems typically associated with impaired streams in urban areas include the following:

1. Larger and more frequent floods, as well as lower base flows, due to the increase in impervious surfaces (e.g., rooftops, paved roads and parking lots) in the watershed.
2. Increased soil erosion in construction and development areas and instream erosion with subsequent deposition of the sediment in streams.
3. Increased concentrations of pollutants carried in storm water flows from urban, agricultural, and other land uses within the watershed. Examples include chloride, sulfate, metals, ions, organic chemicals, nutrients, sediment, and bacteria. These pollutants can also cause secondary issues such as low dissolved oxygen, increased water temperature, and eutrophication.
4. Degradation of habitat for aquatic organisms (mainly fish and invertebrates) due to the causes listed above.
5. Degradation of aquatic habitat due to the physical alteration of stream channels and adjacent streamside (riparian) corridors which also impacts problems 1 and 2.

The cumulative effect of these problems can be measured or tracked through monitoring the aquatic invertebrate community. Aquatic invertebrates spend the largest portions of their life cycle in the water. The health of the aquatic invertebrate community is generally representative of the overall health of a stream. A poor invertebrate community is often indicative of poor stream health but is rarely diagnostic of the cause. The aquatic invertebrate community in Hinkson Creek has been monitored from the headwaters to near the mouth. Generally, the community degrades from upstream to downstream. The population of Boone County and the City of Columbia continues to increase at approximately two percent per year. Due to the increasing urbanization, significant widespread efforts to address the water quantity and quality problems should continue.

In 2011, The US EPA established a Total Maximum Daily Load (TMDL) in order to comply with the 2001 Consent Decree, *American Canoe Association, et al. v. EPA,* which prescribes the reduction of stormwater runoff and the associated pollutants carried within. In 2012, Boone County, the City of Columbia, the University of Missouri-Columbia, the US Environmental Protection Agency and the Missouri Department of Natural Resources jointly agreed to use a Collaborative Adaptive Management (CAM) approach to address water quality concerns in Hinkson Creek. CAM is a proven tool for use in complex systems with significant scientific uncertainties as CAM expressly provides a framework for learning and putting new knowledge and understanding to use to solve complex challenges. As part of this agreement, a Science Team was created to provide advice to the stakeholder committee for the CAM process. The Science Team is composed of experts in hydrology, bioassessments, water quality, engineering, geomorphology, and sediment transport. In the TMDL EPA noted "*Additional data and information collection may be warranted to further assess the sources of the impairment and to assess the [effect] of water quality improvement measures put in place…"* The science team is charged with identifying, evaluating, and recommending the studies necessary to support the CAM process and further refine the pollutants and causes of impairment. Because an understanding of cause and effect is necessary to manage stressors, the science team emphasizes understanding processes that produce relevant stressors.

The science team has drafted this living document to describe the CAM process as it applies to Hinkson Creek and how the studies might be adapted as progress is made or projects are completed. This includes a recurring prioritization of potential studies to further define potential problems or concerns. The prioritization process includes identification of any new potential stressors. For example, USGS has recently conducted sampling to identify chemical urban stressors some of which are episodic and can be difficult to observe. Integration of scientific information indicates chlorides, sediment deposition, and stream temperatures are likely relevant to the poor aquatic invertebrate community. Due to the variable nature of the known pollutants, further study is needed to assist with better understanding of causes to guide investment in best management practices and to evaluate their success in mitigating adverse water quality.

Studies to date have:

- Documented high specific conductance and chloride concentrations; chloride is a variable pollutant that is difficult to characterize due to variable weather patterns.
- Documented the extent and variability of specific conductance, a surrogate for the variability of chloride and other ions.
- Documented the occurrence of less-common urban and agriculturally related toxic chemicals.
- Developed a hypothesis supporting streambank erosion as a source of sediment deposition.

Progress toward improved stormwater management has been made through the regulation of commercial and residential development in the Hinkson Creek watershed. Both Boone County and the City of Columbia require any proposed new and substantial redevelopment to address stormwater using best management practices. These practices address some common urban pollutants associated with stormwater flow. However, these practices do not appreciably reduce chloride. Additionally, these ordinances do not address pre-ordinance development, which needs to be evaluated as potential sources of pollution.

Boone County has established a Chloride Task Force, partnering with members of the community to discuss how to best address proper application and reduction of the use of chloride-based de-icing agents.

Purpose of this Document

This document presents a summary of the current state of knowledge of Hinkson Creek science, a discussion of some of the major scientific questions yet to be resolved, and discussion of the challenges in addressing those uncertainties. The intention is to provide a road map for developing the information needed to support Hinkson Creek stakeholders' decision processes.

The *fundamental objective* of the Hinkson Creek Collaborative Adaptive Management (CAM) process is to implement the Hinkson Creek TMDL and improve Hinkson Creek, with the ultimate goal of having the creek meet all applicable water-quality standards (Hinkson Creek Collaborative Adaptive Management Partners, 2012). Although the CAM document also notes *means objectives* that include improving diversity of invertebrate communities, ecosystem health, and general water quality, the focus articulated by stakeholders is to remove the creek's impaired status. Removing the impaired status – and keeping impaired status from returning – depends on improving understanding of the processes at work in the watershed through the application of scientific knowledge and techniques.

The CAM agreement indicates that the purpose of the Science Team is:

> *"…to identify, evaluate and advance the necessary scientific studies needed to support the*

> *collaborative adaptive management processes described herein. The Science Team will coordinate monitoring and modeling for Hinkson Creek related to the collaborative adaptive management process. This team will respond to inquiries from and make recommendations to the Stakeholder Committee. The Science Team is responsible for understanding available scientific information that is applicable to the questions at hand, selecting the best and most relevant information, and synthesizing it into reports for the Stakeholder Committee."*

Within time and funding constraints the Science Team has defined its primary roles as evaluating potential factors contributing to the impairment of Hinkson Creek, evaluating the optimum application of science to resolve uncertainties, determining the efficacy of actions that would improve water quality conditions, and advising Stakeholders and the Action Team on science strategies. The recommendations in this document are intended to provide the Stakeholders with the information needed to make informed decisions about investment in science, based on what is known, what is not known, and what needs to be known to satisfy their risk tolerance.

The Science Team believes this document is particularly useful to serve as institutional memory about the role of science as membership in the Stakeholder, Action, and Science teams changes over time. The CAM agreement emphasizes the role of scientific uncertainties as a motivation for adaptive management: *"CAM is a stakeholder-based adaptive management process for decision-making, dealing with the scientific and socioeconomic complexities and uncertainties inherent in many ecosystems."* The importance of the role of science in addressing uncertainties has been reiterated by many practitioners, including CAMnet (The Collaborative Adaptive Management Network, http://adaptivemanagement.net/): *"A collaborative adaptive management approach incorporates and links knowledge and credible science with the experience and values of stakeholders and managers for more effective management decision-making."*

Within this understanding of CAM, the role of science is to provide the information needed to allow stakeholders to make effective decisions. Although this perspective places science in a supporting role, scientists take on substantial responsibility to assure that the science has the attributes needed by decision makers --- credibility, relevance, and legitimacy (Cash et al., 2003). Central to this responsibility is the assurance that science investments provide information that is relevant to decisions. The objective of this document is to affirm a strategy to continue to provide decision-relevant science.

Adaptive management is a multistep process that can usually be viewed in an iterative, circular framework (Williams et al., 2007). The concept of "learning by doing" is implicit in the *implement – monitor – evaluate – adjust* steps (fig. 1).

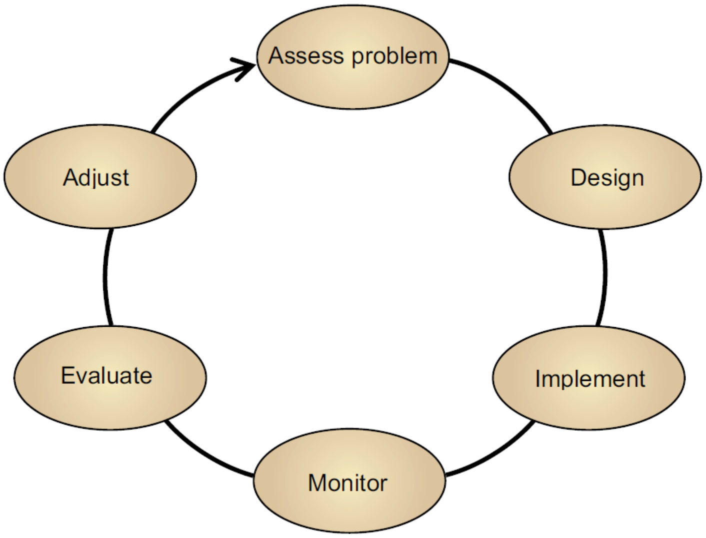

Figure 1. Adaptive-management cycle, from Williams and others (2007).

Within the adaptive-management cycle, however, science is particularly important in the "*Assess problem*" stage because if the problem is not understood, mitigations cannot be designed to address the problem effectively. As Hinkson Creek was originally listed for unknown causes, it is not surprising that assessing the problem has been a central concern of the Science Team. Science is also important within the adaptive-management cycle in design of management experiments, developing effective monitoring, evaluating results, and recommending adjustments. However: if the problem is not adequately assessed, the remainder of the adaptive-management cycle cannot be effectively implemented.

We emphasize that although a great deal of progress has been made in the Hinkson Creek CAM process, and in Hinkson Creek science, substantial uncertainty persists about the cause(s) and the cure(s) for stream impairment. The persistent uncertainty arises from the inherent complexity of watershed ecosystems and persistent gaps in information. Managing a perturbed watershed ecosystem to restore some ecological processes while maintaining the goods and services expected by society (housing, businesses, public safety, and infrastructure) is a challenging task.

Background

Hinkson Creek (fig. 2) flows from rural Boone County through the City of Columbia to Perche Creek just upstream of its confluence with the Missouri River. Hinkson Creek was listed as impaired in 1998 for two separate reasons. Hinkson Creek does not support the "protection of aquatic life" designated use as specified in Missouri's Water Quality Standards although no pollutant has been identified that accounts for this assessment. Separately, parts of Hinkson Creek are also listed as impaired for bacteria as measured in the creek. The decision to address bacteria as part of the CAM process came only after nearly three years had passed and thus that topic has received far less attention to date. Bacteria will not be addressed in this strategy document.

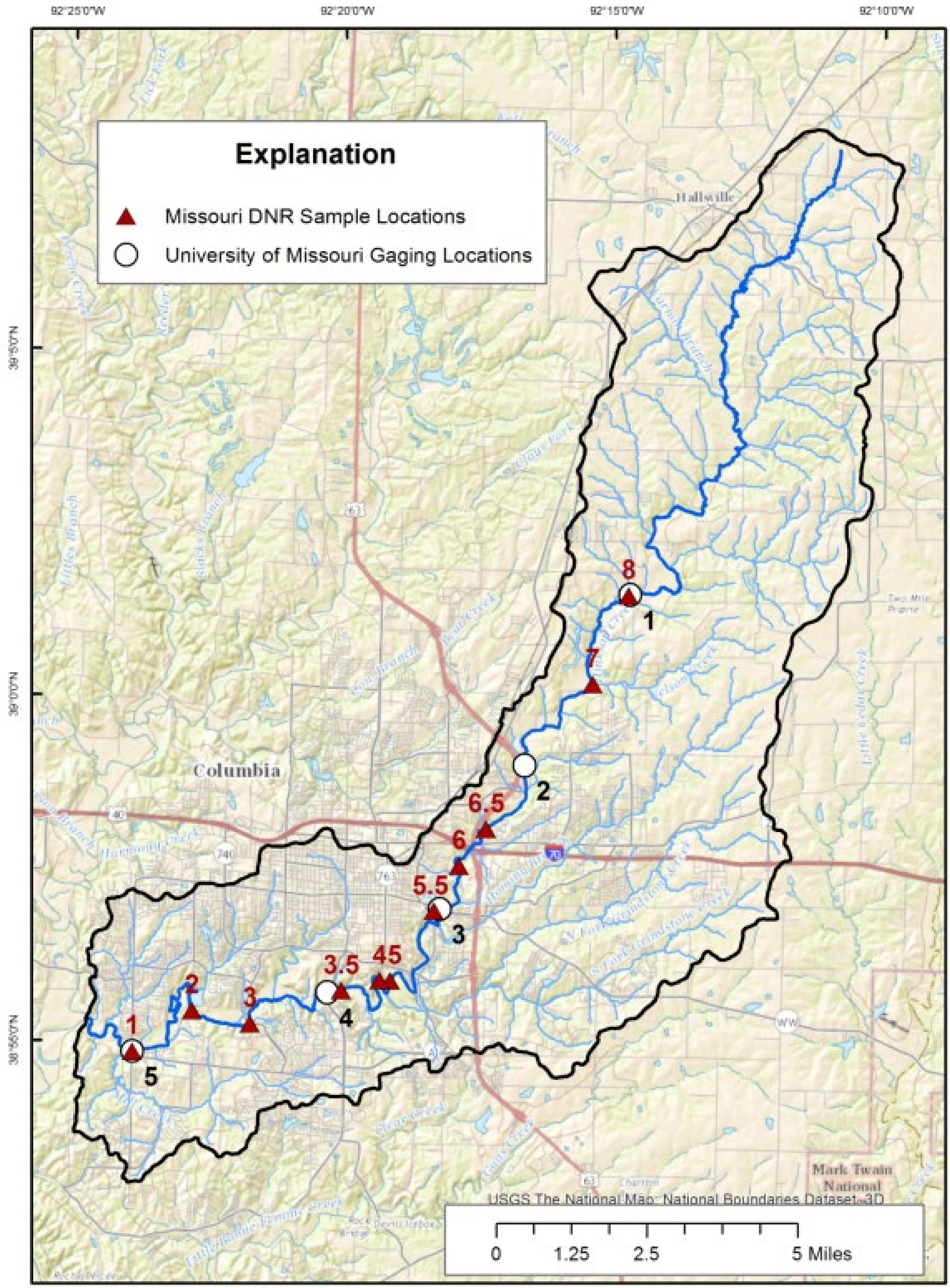

Figure 2. Location map of Hinkson Creek, showing Missouri Department of Natural Resources (DNR) sample locations and University of Missouri stream gaging sites.

Normally, when a stream or other water body is listed as impaired, a Total Maximum Daily Load (TMDL) analysis is completed to define the maximum pollutant load that will allow the stream to return to conditions fully compliant with its designated uses. This approach does not lend itself well to a situation where no specific pollutant has been identified.

CAM Agreement and Science Team

In 2012, Boone County, the City of Columbia, the University of Missouri-Columbia, the US Environmental Protection Agency and the Missouri Department of Natural Resources jointly agreed to use a Collaborative Adaptive Management (CAM) approach to address water quality concerns in Hinkson Creek. CAM is a proven tool for use in complex systems with significant scientific unknowns as it expressly provides a framework for learning and putting new knowledge and understanding to use to solve complex challenges. While it has been used in biological restoration efforts, the Hinkson Creek CAM process is its first application to an impaired watershed in lieu of a TMDL.

As part of this agreement, a Science Team was created to provide advice to the stakeholder committee for the CAM process. The Science Team is composed of experts in hydrology, bioassessments, water quality, engineering, geomorphology, and sediment transport. Team members serve as volunteers or their time is contributed by their host institutions. The members of the Science Team work together with the understanding that their advisory role on the Team requires them to maintain independence from the policy goals of their host institutions. While it is impossible to eliminate all potential for perceptions of conflict of interest, the Team relies on the individual scientific integrity of members and the team’s jointly held understanding of the value of credibility, relevance, and legitimacy to guide participation. Essentially, Team members agree to take off their institution hat and put on a Team hat while participating. Where this is not possible, members are encouraged to recuse themselves from specific recommendations.

Status of Hinkson Creek

The Missouri Department of Natural Resources (DNR) conducted invertebrate monitoring at 11 sites 2012-2017 to track progress in mitigating impairment. Three of the sites (1-3, fig. 2) are in the segment of Hinkson Creek designated as permanently flowing (Class P) whereas the other 8 (3.5 – 8) are in the segment classified as Class C, subject to seasonal drying. The Class P part of Hinkson Creek is water body identification (WBID) 1007 and the Class C part is WBID 1008.

The fundamental metric for the invertebrate monitoring is the Macroinvertebrate Stream Condition Index (MSCI) score. The MSCI is a multi-metric score calculated based on macroinvertebrate community attributes, and it is used to assess whether a stream is fully supporting of the beneficial use designation of aquatic life protection as defined in Missouri’s Water Quality Standards. Scores averaged through 2017 show that some sampling stations in the upper part of Hinkson Creek have invertebrate community scores greater than or equal to 16, suggesting that all uses are being supported (table 1). Averaged scores are more frequently lower downstream (fig. 3).

Table 1. Macroinvertebrate Stream Condition Index (MSCI) scores by sampling location and date, 2001 - 2017. Fall 2017 was the most recent sample. Cells are colored from red to green, low to high scores. Cells with values greater than or equal to 16 are fully supporting. Gray cells indicate insufficient samples collected. The delineation between WBID 1007 (downstream) and WBID 1008 (upstream) is at Providence Road, near location 3.5. WBID 1007 is desgnated Class P (permanent flow) whereas WBID 1008 is designated Class C (potential to dry to isolated pools during drought).

	Date of Sample																		Averages			Calculated Probabilities*					
Sample Location	Fall 2001	Spring 2002	Fall 2003	Spring 2004	Spring 2005	Fall 2005	Spring 2006	Spring 2012	Fall 2012	Spring 2013	Spring 2014	Fall 2014	Spring 2015	Fall 2015	Spring 2016	Fall 2016	Spring 2017	Fall 2017	2001-2017	2012-2017	2001-2006	Passing scores	Failing Scores	% Passing	% Failing	Reference %	Binomial Probability*
1008																						**57**	**36**	**61%**	**39%**	77.6%	**0.000**
HC 8		16.0						18.0		14.0	16.0	18.0	16.0		12.0	14.0	14.0		15.3	15.3	16.0	5	4	56%	44%	77.6%	0.121
HC 7		16.0	18.0	16.0	16.0	18.0		16.0		16.0	14.0	20.0	16.0		14.0	20.0	16.0		16.6	16.5	16.8	11	2	85%	15%	77.6%	0.824
HC 6.5				16.0				16.0		16.0	14.0	18.0	16.0	16.0	16.0	16.0	14.0		15.8	15.8	16.0	8	2	80%	20%	77.6%	0.692
HC 6	12.0		16.0	14.0	18.0	16.0		14.0		16.0	14.0	20.0	16.0	18.0	12.0	12.0	16.0	12.0	15.1	15.0	15.2	8	7	53%	47%	77.6%	0.033
HC 5.5			14.0	16.0	16.0			16.0		16.0	16.0	18.0	12.0	16.0	16.0	14.0	14.0	16.0	15.4	15.4	15.3	9	4	69%	31%	77.6%	0.329
HC 5								16.0		16.0	12.0	20.0	12.0	14.0	16.0	14.0	14.0	14.0	14.8	14.8		4	6	40%	60%	77.6%	0.011
HC 4		12.0						16.0		16.0	16.0	18.0	14.0	14.0	16.0	14.0	16.0	14.0	15.1	15.4	12.0	6	5	55%	45%	77.6%	0.077
HC 3.5					12.0	12.0		14.0		16.0	16.0	14.0	12.0	16.0	16.0	16.0	12.0	16.0	14.3	14.8	12.0	6	6	50%	50%	77.6%	0.033
1007																						**12**	**23**	**34%**	**66%**	77.6%	**0.000**
HC 3	16.0	12.0					16.0			10.0	12.0	14.0	12.0	16.0	16.0	16.0	16.0	14.0	14.2	14.0	14.7	6	6	50%	50%	77.6%	0.033
HC 2	14.0	12.0					12.0			14.0	12.0	16.0	12.0	16.0	16.0	14.0	14.0	14.0	13.8	14.2	12.7	3	9	25%	75%	77.6%	0.000
HC 1	14.0	14.0					14.0			12.0		14.0	12.0	20.0	16.0	16.0	12.0	14.0	14.4	14.5	14.0	3	8	27%	73%	77.6%	0.001

*The binomial calculations for assessing Hinkson Creek’s compliance with Missouri’s Water Quality Standards were made using Microsoft Excel’s BINOMDIST function given the following set of conditions.

1) To determine whether results are statistically similar/dissimilar, a binomial probability with an appropriate level of significance (α=alpha) is calculated based on the null hypothesis that the test stream (Hinkson Creek) would have a similar percentage of MSCI scores that are 16 or greater as Ozark/Moreau/Loutre EDU biocriteria reference streams (2022 Listing Methodology Document).

2) Excel BINOMDIST Variables: Number_s=number of successes; Trials=number of independent trials; Probability_s=probability of success on each trial; Cumulative=TRUE.

3) The percentage of fully supporting scores in the Ozark/Moreau/Loutre EDU BIOREF streams) is 0.826.

4) From the 2022 Listing Methodology Document: “…rate a stream as impaired if biological criteria reference stream frequency of fully supporting scores is greater than five percent more than the test stream….” Based on that language, Probability_s =0.826-0.05.

5) Probability_s=0.776

6) Test level significance is α=0.1.

7) Null hypothesis: “The test stream has the same percent of fully biologically supporting scores as the BIOREF streams.”

8) Conclusion: if the Cumulative Probability is greater than α=0.1, the null hypothesis is accepted, and the conclusion is “unimpaired.”

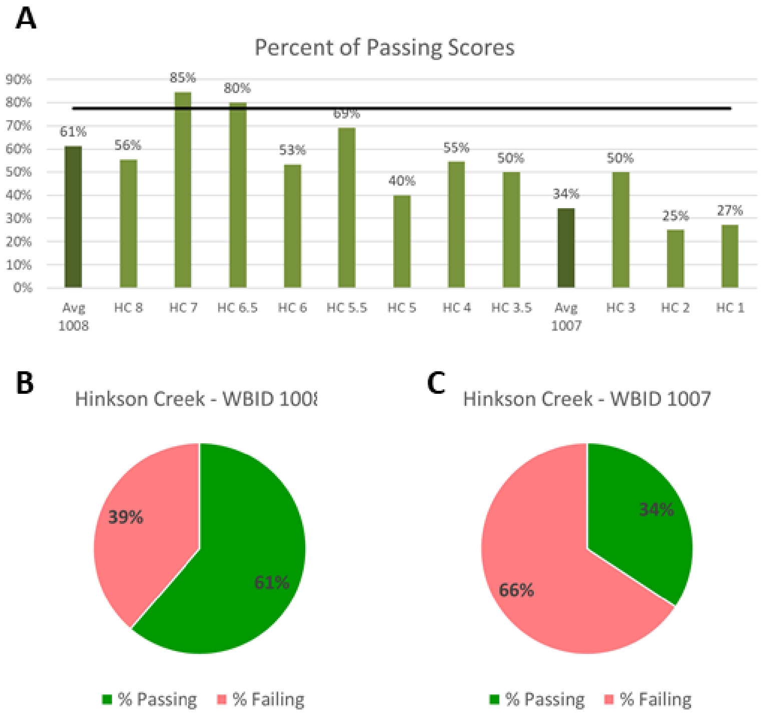

Figure 3. A. Distribution of average MSCI scores by sample site. B. Distribution of passing and failing scores in the downstream WBID 1008 segment. B. Distribution of passing and failing scores in the upstream non-permanent WBID 1007 segment.

The LMD provides a detailed description of how streams are evaluated in determining whether to be included on the 303(d) List of Impaired Waters. Conversely, the LMD also provides an explanation of conditions that have to be met for a stream to be excluded from the list; it is this latter condition that the CAM seeks to attain. Table 2 includes pertinent language from Appendix C in the 2022 LMD as it applies to Hinkson Creek.

<table>
<tr><td colspan="3">Table 2.</td></tr>
<tr><td colspan="3">Appendix C
Methods for assessing compliance with water quality standards used for 303(d) listing purposes: narrative criteria based on numeric thresholds not contained in state water quality standards (10 CSR 20-7.031)</td></tr>
<tr><td>Beneficial Uses</td><td>Data Type</td><td>Compliance with Water Quality Standards</td></tr>
<tr><td>Protection of Aquatic Life</td><td>Biological: Aquatic Macroinvertebrates sampled using DNR Protocol</td><td>Full: For greater than seven samples or for other sampling and evaluation protocols, results must be statistically similar to representative reference or control stream.

Non-Attainment: For more than seven samples or for other sampling and evaluation protocols, results must be statistically dissimilar to control or representative reference streams.</td></tr>
</table>

The LMD states that when eight or more samples are available, results must be statistically similar or dissimilar to reference or control conditions to make an attainment decision (“attainment” meaning to be in compliance with Missouri’s Water Quality Standards). A binomial probability analysis with a level of significance set at α=0.1 will test the null hypothesis that Hinkson Creek has a similar percentage of MSCI scores that are 16 or greater as reference streams. For comparing samples from Hinkson Creek to reference streams, the percentage of samples from reference streams scoring ≥ 16 is used to determine the probability of “success” and “failure’ in the binomial probability equation. In the case of the Ozark/Moreau/Loutre EDU, 82.6 percent of reference stream MSCI scores are ≥ 16, which means that 0.826 would be used as the probability of success and 0.174 would be the probability of failure. Appendix D of the 2022 LMD states to “rate a stream as impaired if biological criteria reference stream frequency of fully biologically supporting scores is greater than five percent more than the test stream,” thus a value of 0.776 (0.826 - 0.05) would actually be used as the probability of success in the binomial distribution equation (Table 3). Binomial distribution calculations for Hinkson Creek are presented in table 1.

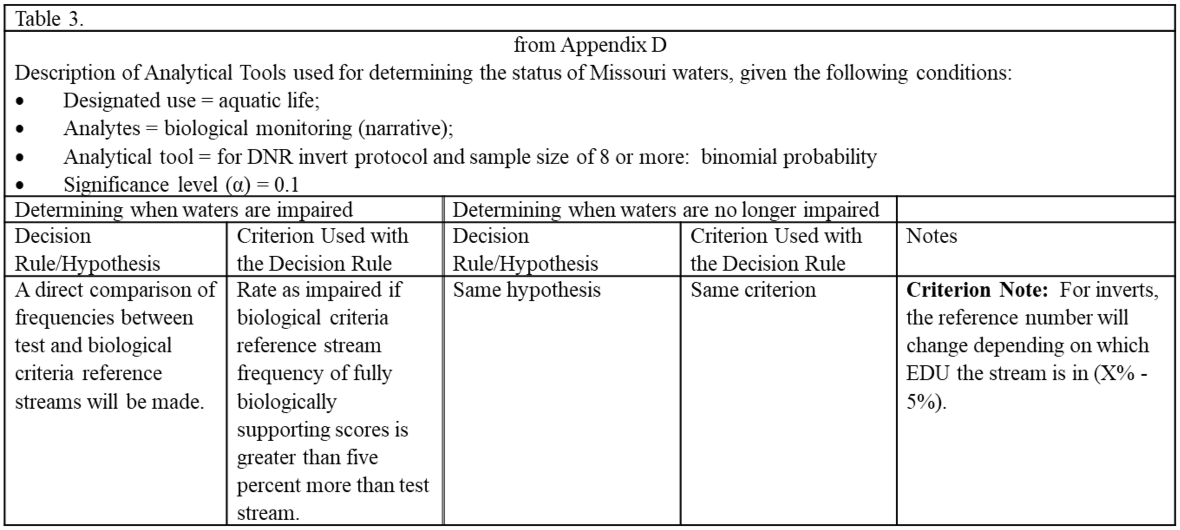

Table 3.

from Appendix D

Description of Analytical Tools used for determining the status of Missouri waters, given the following conditions:

- Designated use = aquatic life;
- Analytes = biological monitoring (narrative);
- Analytical tool = for DNR invert protocol and sample size of 8 or more: binomial probability
- Significance level (α) = 0.1

Determining when waters are impaired		Determining when waters are no longer impaired		
Decision Rule/Hypothesis	Criterion Used with the Decision Rule	Decision Rule/Hypothesis	Criterion Used with the Decision Rule	Notes
A direct comparison of frequencies between test and biological criteria reference streams will be made.	Rate as impaired if biological criteria reference stream frequency of fully biologically supporting scores is greater than five percent more than test stream.	Same hypothesis	Same criterion	**Criterion Note:** For inverts, the reference number will change depending on which EDU the stream is in (X% - 5%).

Generally, scores in the upper part of the basin are better than the lower (fig. 3) but year to year and season to season variability are substantial (table 1), thereby obscuring any temporal trends. Only two sites have averaged scores with passing binomial probabilities. The trends in Hinkson Creek are consistent with the hypothesis that the creek is impaired from stressors associated with developed areas in and around Columbia.

In the following, we present a conceptual ecological model for Hinkson Creek and summarize the substantial amount of scientific information presently available for Hinkson Creek. Notwithstanding the strong foundation of science established, the cause or causes for impairment of Hinkson Creek remain unknown, hence solutions to removing impairment are also unknown. There continues to be a need to invest in scientific information to reduce these uncertainties and design effective mitigations. The objective of the science strategy is to focus the science investment on the most relevant questions to provide the best return on that investment. Questions of impacts, complexity, and scalability are central to finding robust, cost-effective solutions. These questions can only be addressed through a combination of measurement, modeling, and hypothesis testing.

Conceptual Ecological Models

The Science Team developed a conceptual ecological model (CEM) for assessing Hinkson Creek (fig. 4). The model illustrates a set of driver-stressor-response relations that are thought to apply to the creek. That is, the CEM serves as a graphical map of the multiple hypotheses that need to be considered in understanding how the creek is impaired and how impairment may be mitigated.

The need for a conceptual model is driven by two major scientific factors: the large uncertainty or lack of understanding of the watershed and the complexity of the multiple interactions that may influence the invertebrate community and the stream’s health. The CEM also shows the potential interactions of any given management action with other ecological and socio-economic processes in the watershed.

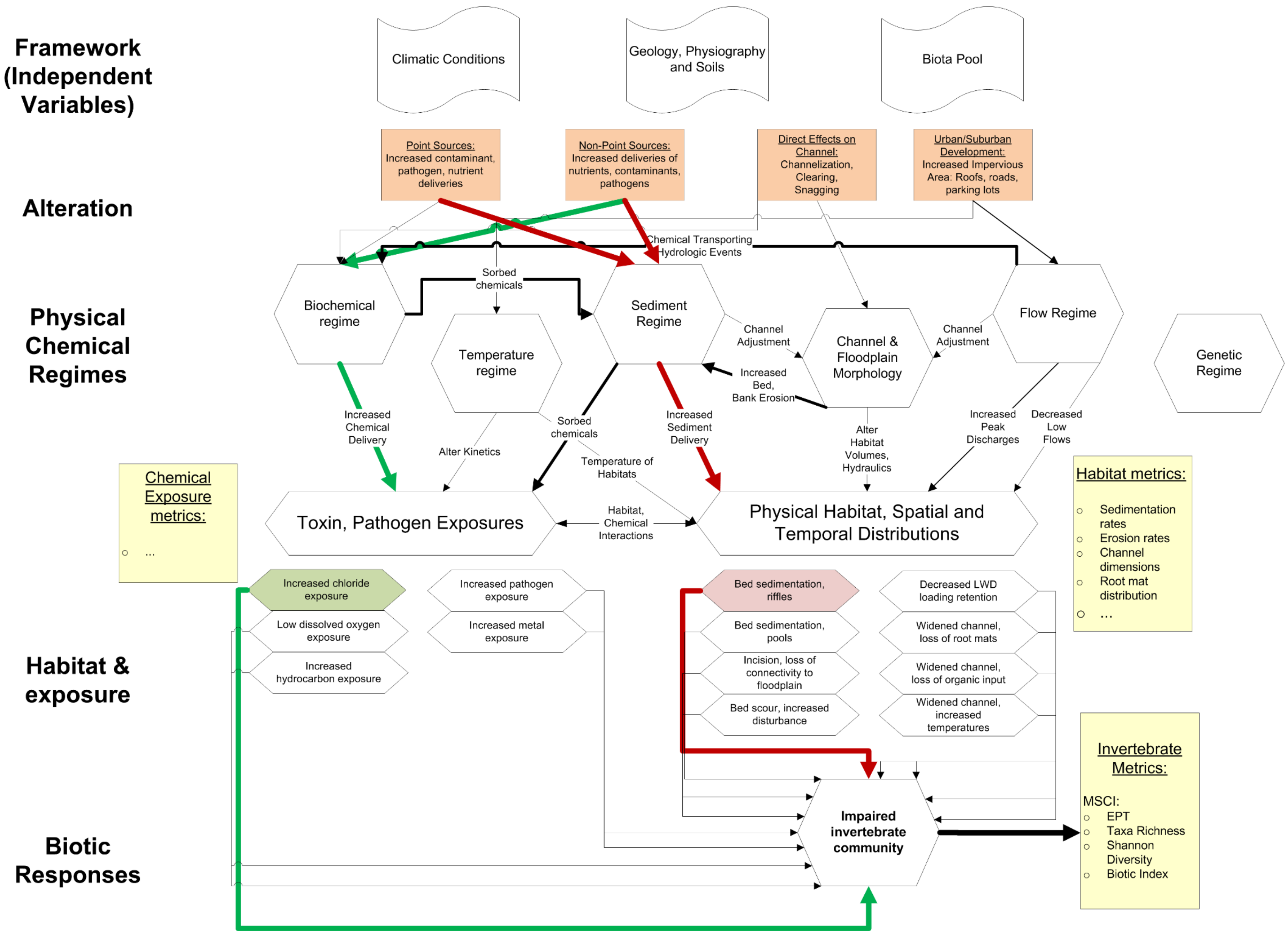

Figure 4. Conceptual ecological model for Hinkson Creek, with emphasis on two hypothetical pathways. Chloride contamination is in green and sediment delivery is in red.

This CEM serves as a framework for understanding how the Hinkson Creek watershed works. The structure reflects the current thinking of the Science Team and is designed to be updated as new information is developed. The CEM is hierarchical from top to bottom, with independent variables at the top and dependent at the bottom. The highest level recognizes the physical framework of Hinkson Creek – soils, physiography, and climate – independent factors that are resistant to change over management time frames. The alteration level indicates changes in the drainage basin and riparian zone that are likely to affect stream processes. Arrows indicate how changes affect physical and chemical regime of the river, and how these changes may propagate to habitat, exposures, and endpoints comprised of stream biota and human interests. The present structure divides potential pathways to impairment between chemical and physical processes, although interactions between the two are expected. This dichotomy is fundamental to understanding of impairment because chemical and physical stresses are likely to arise from different watershed alterations and processes. Moreover, approaches and costs for mitigation of physical and chemical stresses are likely to be substantially different.

State of the science on Hinkson Creek

As part of the CAM agreement, the DNR agreed to a minimum of three years of invertebrate data collection and analysis at 11 sites within Hinkson Creek; sampling was subsequently extended to fall 2017 (table 1). These data are central to assessing the status of the creek relative to water quality standards. Invertebrate communities respond to a broad array of conditions and stressors and thus provide an integrative measure of an important "response variable," one that reflects conditions, but may not, by itself, provide much insight into the *causes* of the trends observed. These data show that Hinkson Creek as a whole is not fully meeting water quality standards, but also indicate that parts of the creek are doing well and meeting standards (table 1, fig. 3). These data can be interpreted to indicate that Hinkson Creek is not irreversibly impaired and that actions can be taken to improve the creek. The seasonal, annual, and geographic variability seen in these data and their dependence on many environmental variables strongly support the use of CAM to address Hinkson Creek.

It is important to emphasize that understanding of cause/effect linkages is necessary to understand why the creek is impaired and therefore, to design and implement mitigations. Invertebrate communities may vary over time and space and may at some point improve to a level that would support delisting. But if the cause for the variation is not understood, there will be little confidence about what caused the improvement or that improvement can be sustained, especially as development continues in the watershed.

Foundational science projects

Biological assessments

The Missouri Department of Natural Resources (DNR) developed background science information on Hinkson Creek 2003 - 2017. Phase I of DNR studies during fall 2001 and spring 2002 involved the water quality triad consisting of assessment of the aquatic community, chemical analyses, and toxicity testing (Missouri Department of Natural Resources, 2004). The Phase I studies confirmed that the aquatic community was impaired between Interstate 70 and Broadway and potentially downstream from Broadway. The toxicity tests indicated that some storm water discharges were toxic to test organisms; implicated chemicals were polycyclic aromatic hydrocarbons (PAHs), pesticides, petroleum compounds, and metals. The studies also documented high levels of sodium and calcium chloride in snowmelt samples, and instream toxicity was established for one snowmelt event. Toxicity effects in this event were concentrated near the former Missouri Department of Transportation salt storage facility and the Conley Road shopping center. Bacteria (*E. coli*) counts exceeding recommended levels were also documented but the source for bacteria was not determined. The survey also noted increased sedimentation in the impaired segment compared to the local control stream Bonne Femme Creek, and that sedimentation increased from upstream to downstream. The report also noted that the duration of turbidity in Hinkson Creek was longer than that in Bonne Femme Creek and that prominent gully incision was associated with storm water discharge points.

Phase II studies (July 2004 – June 2005) found elevated turbidity (during low flow and associated with the US Highway 63 connector), elevated low-flow chloride values, sporadic toxicity, and community metrics that showed some improvement compared to Phase I (Missouri Department of Natural Resources, 2005). Nevertheless, Phase II biological samples documented urban effects, including an increase in tubificid worms in some sections.

Phase III studies (Fall 2005 - June 2006) extended assessments downstream to the confluence with Perche Creek (Missouri Department of Natural Resources, 2006). The macroinvertebrate data indicated that sites in the urban parts of Hinkson Creek continued to be impaired (partially supporting). Base-flow chloride concentrations in the lower sections of the creek were higher than those measured in the upper sections and particularly high concentrations were measured in Flat Branch (283 mg/L compared to EPA chronic criterion of 230 mg/L). Dissolved oxygen (DO) measurements during this study linked low DO to warm, dry periods when pools became stagnant.

Following the three phases of the initial study, Missouri DNR continued fall and spring sampling 2012 – 2017. As of this date, the MSCI scores are available through fall of 2017 (table 1). Note that the data in table 1 summarize a great deal of taxonomic and contextual data for this sampling program into one metric; a substantial amount of additional information is available for the individual components of the MSCI. The heavy, blue horizontal line in table 1 is a general boundary between upstream sites that have, on average, supporting MSCI scores greater than 14 and downstream sites that are generally characterized by partially supporting scores.

The DNR data have been subsequently analyzed as part of the CAM project "Aquatic Macroinvertebrate Data Mining Report, Hinkson Creek". The results and implications of that report are discussed under "Biological Structure and Process".

Physical context assessments

The conceptual model and knowledge of studies in other urbanizing watersheds led to the decision to recommend a 2-part habitat assessment to the stakeholder committee. The objectives of the assessment were 1) quantify the spatial framework of Hinkson Creek, including "hard" factors that are not amenable to change, such as structure of the stream network, large infrastructure, bedrock geologic controls, and hydraulic effects of the Missouri River, and 2) to explore whether spatial distributions of some physical habitat features could provide insight into the sources of stress and impairment. An example of the latter is whether the distribution of sedimentation in the creek would be concentrated downstream from tributaries with specific land uses or sources of disturbance.

The first part of the study (Missouri Resource Assessment Partnership, 2013) used remotely sensed data to provide an overview of the fundamental physical parameters of the watershed, compiled in geographic information system (GIS) context. The second part (Hooper, 2015) was a detailed, field-based longitudinal assessment of Hinkson Creek that provided a wealth of data on the basic form and structure of the creek and its floodplain. This assessment produced a framework especially well-suited for designing additional studies for examining the creek at a finer scale (Kellner and Hubbart, 2019b; Zeiger and Hubbart, 2019). It also provides information necessary to understand the scalability of certain specific actions under consideration. Interpretations of physical habitat assessment data is discussed below under "Sediment".

Several key findings came from the two foundational assessments. One is understanding of the range of physical variation of Hinkson Creek and how that variation interacts with stream processes. Some physical factors in the watershed can be viewed as independent variables – like types and distributions of soils and bedrock, the stream channel network, and much of the physical infrastructure. We do not expect those things to change and they determine a lot of the biophysical capacity of the watershed. Climatic influences are also mostly independent [although see Hubbart et al. (2014a) about urban heat-island effect] and subject to non-stationarity. Land use and land cover also are treated as independent variables although they can be influenced through management decisions.

Other factors that were quantified in the GIS and field assessments can be considered dependent or response variables, depending on time frame of consideration. For example, channel sinuosity, channel position, interaction of the channel with bedrock in the valley wall, channel slope, and bankfull channel width and depth are all adjustable geomorphic variables over time frames of seasons to centuries, and therefore can be evaluated as characteristics that might change in response to independent drivers like land-use, land-cover, and climate. On the other hand, when evaluating invertebrate assemblages, these physical variables are typically treated as independent. That is, one expects the biota to respond to variation in the physical variables. Both physical assessments document variables that can be considered independent or dependent; confusion can arise if analyses are not clear about the hypothesized roles.

The GIS assessment documented methodologies for delineating channel and valley dimensions from LiDAR elevation data collected in 2009; this documentation may be useful for future change analysis based on 2015 or later LiDAR. The analysis confirmed the upstream-downstream gradient of land uses from agricultural to suburban to urban. The analysis also documented substantial longitudinal variation in channel widths, channel sinuosity, valley width, and channel interactions with the valley wall. Channel width may be useful as a dependent variable indicating sources of disturbance and interaction with the valley wall will be useful as an indicator of where channel adjustments are controlled by bedrock and where stream habitats may be influenced by bedrock type and delivery of large substrate from adjacent slopes.

The field-based physical habitat assessment provided important insights about physical characteristics that could not be captured in the GIS analysis because of scale limitations. The longitudinal assessments of physical habitat variables reveal trends at varying scales. Trends of many variables over the entire 56 km of Hinkson Creek are notably interrupted by anomalies measured in several to tens of km. In addition, the high resolution of the data (100 m intervals) also documents anomalies on the order of 100 to several hundred meters. These anomalies may be evidence of specific disturbances. Specific insights are:

- Most of the Hinkson Creek channel starting 26 km downstream of the headwaters is adjacent to bedrock on one bank or both.
- Although channel widths predictably increase in the downstream direction, the trend is interrupted by anomalies of narrower channel between Nelson Creek and Grindstone Creek. The channel narrows again from the Flat Branch confluence to the Perche Creek confluence. These anomalies may be related to bedrock and backwater influences, respectively.
- Bank height and thalweg depth similarly show broad increasing trends in the downstream direction, but are interrupted by anomalies that may indicate fundamental, extrinsic controls on channel processes.
- Channel sinuosity is fairly constant in the upstream 2/3 of the watershed, with values rarely spiking above 1.5. In the lower 1/3 of the watershed sinuosity magnitude and variability increase markedly.
- Canopy cover shows broad trends of decrease from the headwaters to a minimum near the confluence with Hominy Branch, followed by a broad trend of increasing cover in the downstream direction. Within those broad trends, canopy cover is notable for extremely high-frequency variability along the channel.
- Pebble counts in the thalweg documented that Hinkson Creek is dominated by mud (silt + clay particles, < 0.06 mm) and sand (0.06 – 2 mm). Coarser materials (gravel through boulders) increase downstream of Varnon Branch and occur in broad, patchy distribution through the confluence with County House Branch. Downstream of County House Branch coarse sediment is rare, which likely relates to backwater effects from the Missouri River. Bedrock and boulders occur mostly in the middle reaches of Hinkson Creek from upstream of Nelson Creek to just downstream of Flat Branch.
- Embeddedness of fine sediment into gravel or cobble interstices is high at the headwaters and at the downstream section, with a minimum between Nelson and Grindstone Creeks. Embeddedness is thought to be particularly important as a stressor on invertebrate communities in riffle habitats; this distribution may indicate a trend in habitat degradation directly relatable to invertebrate assemblages.
- The distributions of root mat numbers and volume reflect broad trends of peaks associated with confluences of Vernon Branch and Nelson Creek, followed by a minimum of numbers in reaches associated with Hominy Branch and Grindstone Creek. Because root mat volume stays relatively high in this area, it is reasonable to assume that root mats are fewer but larger. Downstream from Flat Branch numbers of root mat stay fairly constant but volume is highly variable, and around the Flat Branch confluence, volumes are some of the highest measured. Because root mats are key habitats for some invertebrates, root mat distributions may be highly influential in macroinvertebrate distributions. Moreover, because root mats are a sampling stratum for DNR invertebrate collections, their distribution may have a strong influence on stream condition scores.
- Related to root mats, the physical survey also evaluated the width of the riparian zone and the longitudinal distribution of woody vegetation on banks. Overall, over 80% of the stream had riparian corridors > 20 width, although more than 75% of the banks themselves had less than 40% vegetative cover. This combination of observations is owed to the definition of riparian corridor used which included any non-developed land.
- At the top of the banks, the distribution of woody vegetation was surprising in that it increased steadily in the downstream direction from about 10% in the headwaters to a peak of near 100% just upstream from the Hominy Branch confluence. Woody vegetation percent stayed, on average, above 50% downstream to the Flat Branch confluence, and then decreased to near 10% at the confluence with Perche Creek.

The complex and sometimes surprising longitudinal relations documented in the field assessment have been analyzed in part and reported in recent publications (Kellner and Hubbart, 2019b; Zeiger and Hubbart, 2019). A fertile area for information growth is to place understanding gained from the process science projects discussed in the next section, in the spatial context of the physical assessments.

Social context assessment

The concept that Hinkson Creek should be fishable and swimmable, beyond the letter of the Clean Water Act, implies that people value and use the creek for those purposes, or would if they felt it was safe to do so. Public perceptions and values are therefore a key to determining how ecological values in Hinkson Creek might translate to socio-economic values and public support. A study of awareness and attitudes about water quality documented several interesting trends among Hinkson Creek residents (Baumer, 2007). One of particular importance was the lack of understanding of the term "non-point-source pollution" among most study respondents. This may reflect a prevailing understanding that pollution continues to be dominantly an end-of-pipe problem, with the implication that the population does not understand the difficulties of identifying and quantifying non-point sources. Although most respondents identified development as an environmental concern in the watershed, 30% did not know that Hinkson Creek was considered polluted or impaired. Relevant to how residents of Hinkson Creek watershed value the creek, most of the respondents did not hunt or fish, indicating they would not value Hinkson Creek for those purposes.

Process-related studies

In addition to the monitoring data collected through Missouri DNR, a suite of studies on hydrology, floodplain processes, and water quality has been developed under the direction of Dr. Jason Hubbart, University of Missouri (presently, West Virginia University). These studies address fundamental processes in the watershed and provide important contextual understanding. In addition, the CAM-supported study on aquatic macroinvertebrate data mining by Geoyntec has produced a new level of understanding of biological structure and process along Hinkson Creek.

Basin hydrology

Hinkson Creek has been gaged at the USGS site off Providence Road. The gage was installed in 1966 and operated until 1981. The gage was discontinued from October 1, 1981 to mid-September 1986 (fig. 4). It then operated through September 1991 and was discontinued again until March 2007. The USGS gage was supplemented with additional 4 gages 2008 – 2014 operated by Dr. Hubbart's research program.

The premise of the TMDL listing of Hinkson Creek is that the runoff has increased due to development of the watershed. Although the record of daily mean and mean annual discharges (fig. 4) suggests an increase in runoff over time, runoff needs to be compared to the amount of rainfall to assess trends that can be attributed to development. Moreover, understanding of development effects on hydrology should also consider whether effects are seen as changes in base flow or in direct runoff. A detailed analysis of the daily record at the USGS stream gage indicated that no statistically significant trends were detectable from 1967 to 2010 in annual streamflow metrics (Hubbart and Zell, 2013). It is notable that this lack of trend coincides with a time interval during which population in Columbia increased from 50,000 to 100,000 and developed area increased from 12% of the Hinkson Creek watershed to about 26%. These results do not mean that urbanization has not influenced the hydrology of Hinkson Creek; it only establishes that effects are not significant after 1996. A pre-development hydrologic record is not available for reference.

Although the empirical data did not show an urbanization effect, a forward modeling study predicted that runoff and streamflow would increase by significant amounts based on growth scenarios (Sunde et al., 2016). This study coupled a rule-based urban growth model, 3 growth scenarios, and a watershed model (Soil Water Assessment Tool, SWAT). The SWAT model was calibrated on monthly streamflow data from 2007-2010, and validated 2011 – 2014. The three growth scenarios produced increases in streamflow of 12.8 – 19.7% and runoff 14.3-16.8%. The analysis indicates that under likely growth scenarios, runoff into Hinkson Creek is likely to continue to increase, unless actions are taken to mitigate it. The models did not include BMP scenarios which might be implemented to mitigate runoff; such modeling capability would be useful in scaling BMP implementation to quantify a cumulative watershed effect.

A more recent analysis Hinkson watershed hydrology focused on variation in runoff ratios by sub-basin (Kellner and Hubbart, 2016a) and documented that downstream, more-urbanized sub-basins contributed a greater proportion of runoff (compared to rainfall) when compared to upstream agricultural basins. The study also documented linear relations decreasing runoff ratio with increasing agricultural land, as well as increasing runoff ratio with increasing urbanization. The study concluded that vegetation management in the watershed may therefore be indicated as a measure to decrease runoff, but the amount of re-vegetation that would be needed to mitigate urban area effects was not addressed.

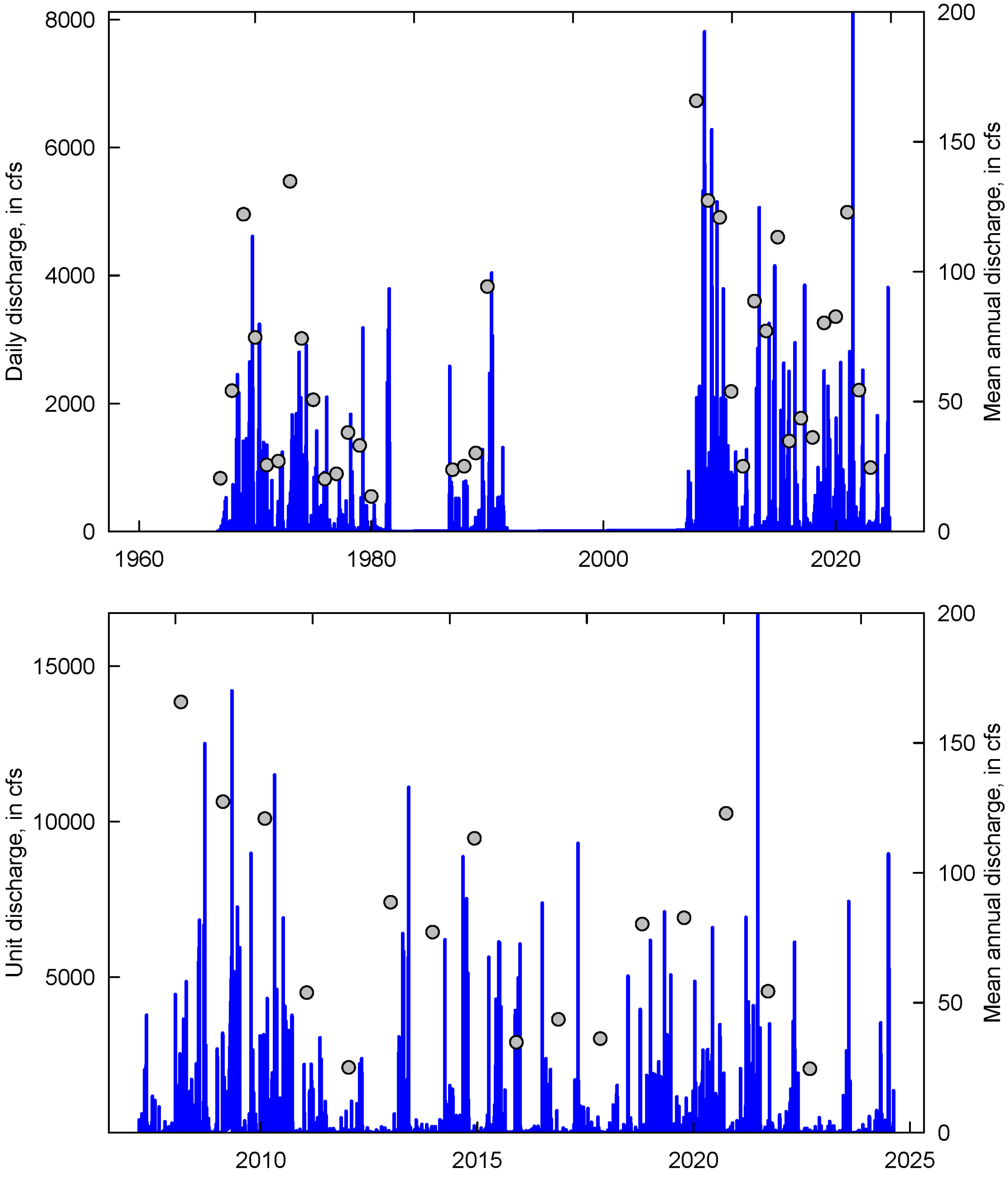

Figure 4. Hydrologic record of Hinkson Creek. Top panel: total record with gaps, daily mean and mean annual discharges as points. Bottom panel: continuous daily record 2007 – 2024 with mean annual discharges as point.

In analysis of the 5 streamflow gaging stations in Hinkson Creek, Zeiger and Hubbart (2018c) documented increased sensitivity of small flow pulses during dry periods in the rural-urban interface. Increasing streamflow variation in this dataset was correlated with increasing urbanization, and data indicated a decreased lag time between rainfall and peak flows at urbanized gages, results that are consistent with conventional understanding of urban hydrology. A modeling approach to assessing pre-settlement environmental flows as a reference for setting modern environmental flow targets inferred that modern land use has resulted in a 115% decrease in median daily streamflow, a 22% increase in maximum daily streamflow, and 34% increase in daily flow variability(Zeiger and Hubbart, 2018a; Zeiger and Hubbart, 2018b). Although using an uncalibrated model based on pre-settlement land use is fraught with potential uncertainties, the results supported the general understanding of hydrologic changes that have been associated with urban development of Hinkson Creek. The authors go on to interpret the validity of environmental flow targets that may not be achievable because of irreversible land-use changes. Although hydrologic changes due to urbanization are included in the science committee's conceptual ecological model (fig. 3), the use of environmental flow targets as a management action has not been discussed, largely because of the lack of managed storage in the basin that would be needed to achieve targets, assuming they could be identified based on known impairments to biota.

In an analysis based on the physical habitat assessment dataset (Hooper, 2015), Kellner and Hubbart (2019b) looked at anomalies in the longitudinal distribution of channel metrics (thalweg depth, cross-sectional area, bankfull width). The authors concluded that anomalous shallowing or decrease in cross-sectional area compared to high-flow metrics could be associated with land-use effects, and these effects could propagate to increased flood hazard. These results support the hypothesis that localized geomorphic adjustments could influence hydrology and hydraulics, which may in turn influence the spatial distribution of disturbances to the channel and benthic communities.

Sediment

Anecdotal accounts of growth of muddy areas adjacent to the channel (B. Hoppe, pers.. com.) and evident sedimentation in the channel (fig. 5) support the hypothesis that Hinkson Creek has been affected by increased sedimentation in recent years. In the physical habitat assessment, mud was the dominant sediment mapped along the Hinkson Creek mainstem (Hooper, 2015).

Figure 5. Photograph of Hinkson Creek near Twin Lakes, August, 2016.

Studies on sediment in Hinkson Creek include analysis of suspended sediment monitoring data and modeling of suspended sediment concentrations and particle-size distributions (discussed further in following section on future/ongoing science). In addition, a study was conducted on sediment sources, comparing sediment additions from streambank erosion to fluxes in the channel (Huang, 2012). This study attributed significant differences between bank erosion adjacent to bottomland hardwood forest (BHF) and abandoned agricultural land (AG) floodplains to the prevailing land use. The study did not, however, account for other factors, like channel curvature, which varied substantially between the two sites. Although the author concluded that bank erosion adjacent to the AG land use contributed significantly to suspended sediment loads, the calculations were based on one year of data and the sampling design was not spatially randomized, hence generalizing beyond the pilot sites is tenuous. Notably, studies documenting variation in suspended sediment loads in the watershed have implicated increased channel incision and streambank erosion to explain downstream increases in suspended sediment concentrations and loads (Freeman, 2011; Zeiger and Hubbart, 2016a). Together, these data suggest that additional direct studies of bank and bed erosion contributions to sediment load should be pursued.

Studies on particle-size distributions of suspended sediment on Hinkson Creek document intriguing downstream fining wherein particles in the 0.3 – 0.5 mm are common upstream but not downstream (Freeman, 2011; Hubbart et al., 2014b). These authors also found that average sediment particle density apparently decreased in the downstream direction, making it unlikely that fining could be attributed to break up of soil aggregates. An alternative interpretation is that downstream fining and decreasing density could be explained if the proportion of particulate organic matter in the suspended sediment flux increased in the downstream direction. Additional work would be needed to follow up on this hypothesis.

Downstream increases in finer sediment particles (ranging 0.005 – 0.01 mm) might be an indicator of urban influence or it could be a downstream trend that would occur in the absence of urban influence. The nested structure of the sampling stations on Hinkson Creek results in simultaneous increases in urbanization and drainage area moving downstream along the mainstem; hence, it is difficult to separate the two effects to implicate one or the other. In addition, it is not clear how the documented changes in particle size distribution of the suspended load would affect biological resources of Hinkson Creek. Additional research would need to be pursued to link the particle-size changes to biological responses.

Subsequent to the Freeman (2011) study, additional analysis of sediment concentrations and loads expanded analysis based on four years of record and using gravimetric rather than laser diffraction data (Zeiger and Hubbart, 2016a). The study confirmed a persistent pattern of decreasing suspended sediment concentrations from upstream agricultural-dominated sites to suburban sites, followed by downstream increases in concentrations in areas with greater urban influence. The authors interpreted the spatial variation to imply that increased runoff in the downstream urban areas is accompanied by increased sediment delivery due to channel incision and bank erosion. Data from one year also indicated that sediment may be stored temporarily in one section of Hinkson Creek; transient storage of sediment is likely to lead to complex flow-sediment concentration relations as sediment load may be transport limited at some times and supply limited at others. This analysis contributes to understanding of suspended sediment dynamics in the Hinkson Creek but does not link sediment dynamics to biological resources.

Continuing study of sediment dynamics in the Hinkson Creek watershed has indicated:

- High sediment loads are correlated with moderate and high flow events during wet periods; correlations are much less between load and flow during dry periods (Zeiger and Hubbart, 2017).
- Urban and agricultural effects on concentrations and particle sizes of suspended sediment are due to interactions of sediment supply (high in agricultural areas and some urban sites) and runoff (lower in agricultural sites, increasing downstream in urban areas). This study also documented seasonal decreases in sediment concentrations during the growing season, presumably as agricultural areas became more stabilized with annual crops (Kellner and Hubbart, 2017b; Kellner and Hubbart, 2018, 2019a).
- In an analysis based on the physical habitat assessment (Hubbart et al., 2017), Zeiger and Hubbart (2019) concluded that streambed embeddedness decreased from upstream to downstream through the urban sections of Hinkson Creek, and then increased in the downstream-most sites. The authors inferred that the observed patten of embeddedness resulted from a combination of increased runoff associated with the urbanization gradient, increased sedimentation associated with supply from agricultural and urbanized areas, and the effects of extrinsic controls (such as bedrock influences that would limit embeddedness of gravel substrate). Interestingly, the authors did not seem to consider the effect of backwater from Missouri River flooding (Holmes, unpublished data) to explain channel morphology and embeddedness in the lowermost reaches of Hinkson Creek.
- In 2018 an extension of the physical habitat assessment was added as a pilot to evaluate thickness of deposited sediment over about ¼ of the domain of the physical habitat assessment (Hooper and Engeln, unpublished data). The approach was to assess thickness of fine sediment at closely spaced

locations in the thalweg of the mainstem of Hinkson Creek using a metal rod that can be inserted into the bed for measuring the depth of refusal. The intent is to evaluate spatial variation in the thickness of deposited sediment with other physical habitat assessment data to infer the origins of sediment in the channel. Analysis to date indicates systematic – but not statistically significant -- variation of fine-sediment thickness with channel gradient, valley width, and distance to valley wall. An increase in sediment thickness may exist at the confluence with Grindstone, but this is also where the gradient decreases, which would promote deposition regardless of influx from the Grindstone watershed. Extension of this approach to the full physical habitat domain is included in the recommendations.

Floodplain processes

Comparisons between BHF and AG floodplains indicate that the previously cultivated agricultural fields generally have lower mean volumetric water content, lower mean infiltration rates, and slightly higher porosity (Hubbart et al., 2011). The increase in mean porosity from AG to BHF – reflecting the maximum water holding capacity – was 1%. In a subsequent study with instrumented volumetric water content (VMC) measurements, VMC increased from 32.8% to 33.1% from AG to BHF (Kellner and Hubbart, 2016b), a small but statistically significant difference. One of the pervasive differences noted between AG and BHF was the much greater spatial variability under BHF, presumably reflecting secondary porosity distributions associated with tree roots. One modeling study estimated 28% greater storage in the vadose zone in the BHF compared to AG, confirming measurements that indicate greater infiltration and water-holding capacity in floodplains underlying BHF; increased storage under BHF was attributed to greater evapotranspiration and effects of macropores (Zell et al., 2015). Additional studies documented differences in spatial variability of VMC that were attributed to differences in land-use practices, specifically that the history of cultivation in the AG site had spatially homogenized soil characteristics compared to woodland; other components of spatial variation, especially at depths greater than cultivation or rooting, were attributed to geologic difference at the sites (Kellner and Hubbart, 2016b). Another analysis of groundwater flow data (Kellner and Hubbart, 2016c) concluded that horizontal groundwater flow was substantially more variable at the BHF site compared to the AG site, and somewhat higher.

The body of information developed on the BHF and AG sites on Hinkson Creek establishes the potential for BHF sites to have statistically different hydrologic rates compared to AG sites; furthermore, most of the rates established are positive from the perspective that they would tend to increase floodplain water storage. Turning this information into decision relevant information requires scaling up from the site-specific studies to assess overall effects on Hinkson Creek. Although BHF land use has been shown to have positive hydrologic effects, it is not clear that implementation of BHF riparian land use could take place at a scale sufficient to have substantive hydrologic effect. To be substantive, the modest increases in water-holding capacity and infiltration rates in BHF dominated floodplains (a maximum of 6% of the watershed) would need to compensate for the increased runoff associated with impervious area and other land uses in 94% of the watershed. The scaling question is generic to the application of science to decision making on Hinkson Creek. In the case of floodplain functions, the scaling analysis would need to address floodplain storage relative to flood volumes, floodplain volume available for storage along the creek, and floodplain infiltration rates relative to flood longevity. With horizontal groundwater flow rates on the order of 0.01 m/day (Kellner and Hubbart, 2016c), flow rate is likely to limit infiltration to an extremely small percentage of a bankfull flood volume.

Water Quality and Nutrients

Data on Hinkson Creek water chemistry have been collected in conjunction with the DNR bioassessment sampling. The data include *in situ* measurements of discharge, temperature, conductivity, dissolved oxygen, and pH. Additionally, surface water grab samples are submitted for laboratory analysis of turbidity, ammonia, nitrate+nitrite, total nitrogen, total phosphorus, sulfate, non-filterable residue, calcium, magnesium, and total hardness. The sampling protocol is intended to provide contextual covariates for the spring and fall bioassessment samples rather than a long-term or comprehensive monitoring of water quality.

Additional data on chloride were collected in a USGS study (Allert et al., 2012); this project was intended mainly to explore sensitivity of aquatic organisms to peak chloride concentrations in Hinkson Creek during a winter snowmelt event. Chloride in two of the samples substantially exceeded EPA standard (1250-4300 mg/l compared to 230 mg/l standard). Toxicity tests with *Ceriodaphnia dubia* documented significant effects on survival and reproduction with prevailing chloride concentrations. This study, too, was not intended as a long-term monitoring program, but did establish a possible link between water chemistry and impairment of stream biota. An extended analysis of chloride concentrations and loads in Hinkson Creek documented increasing chloride concentrations from upstream to downstream as sources of chloride (assumed to be road salt) increased (Hubbart et al., 2017). Modest decreases in concentrations at downstream stations 4 and 5 were attributed to a greater proportional increase in runoff that served to dilute concentrations. Chloride concentrations rose above chronic and acute EPA levels for substantive time intervals 2009 – 2014, with highest concentrations in the late-winter and spring. Persistent chloride concentrations (below chronic exposure levels) in summer were explained as releases from storage in alluvial aquifers. These two studies, together with the invertebrate results of Nichols and others (2016), document potential for chloride to affect Hinkson Creek invertebrate communities. Chloride contamination was also addressed in the invertebrate data mining report (Geosyntec, 2020). That report includes conductivity monitoring data that indicated substantial variability of conductivity (presumably resulting mostly from road salt) with streamflow as well as spatial variability that may indicate spatially variable loading. Improved understanding of the role of chloride would need to be developed through exposure studies with typical Hinkson Creek invertebrate assemblages. As noted in Hubbart and other (2017) mitigation for chloride may be problematic because of the value of road salt applications in public safety. This same factor would complicate field-based adaptive management experiments with reduced chloride because substantive areas of the watershed would have to forego road-salt treatment.

The effects of urbanization on stream temperatures were explored with the nested gage design (Zeiger and Hubbart, 2015). The authors found that daily mean water temperatures data at the upstream, agriculturally dominated site had consistently lower water temperatures by 0.2 – 0.7 ºC (Zeiger et al., 2016) compared to the more urbanized downstream sites. Increases in temperature in the downstream sites was interpreted as the effect of runoff from heated, impervious surfaces that were more common in downstream areas (Hubbart et al., 2014a; Zeiger and Hubbart, 2015). During a three-year period, site 3 in the middle of the stream section had 55 days when water temperatures exceeded 32ºC. Water temperatures were also correlated with canopy opening over the creek, indicating that riparian management could affect stream temperatures. Summer storms had a substantive effect on stream temperatures, raising mean water temperature by 2.7ºC and lasting an average of 5.1 hours; temperature surge magnitude and duration were positively correlated with percent urban land use and negatively correlated with width of the riparian buffer. The authors also explored modeling of runoff and surface water temperatures with SWAT (Zeiger et al., 2016). This work documented that SWAT tends to underestimate peak discharges but that water temperature modeling, using various algorithms, can be modeled with useful accuracy.

Assessment of nutrient concentrations and fluxes at nested mainstem gages documented spatial variability related in expected and unexpected ways to land-use patterns (Zeiger and Hubbart, 2016b). Over four years of monitoring, average total nitrogen and total phosphorous concentrations are highest in upstream agricultural areas and decrease downstream with increasing drainage area and suburban influence. Further downstream, as drainage area and urban influence increase, both total nitrogen and total phosphorous increase somewhat, leading to speculation that sources of nutrients and sources of water interact in ways that provide a mid-basin zone of relatively low nutrient effect. Increased nutrient loading in the urban areas of Hinkson Creek may result from lawn fertilization. Temporal and spatial patterns can also be interpreted to indicate seasonal and multi-year lags, possibly indicating transient storage of nutrients (possibly bound to sediment) and later release. Inorganic nitrogen concentrations did not exceed federal or state water quality standards during the study; maximum total phosphorous concentrations frequently exceeded EPA recommended concentrations. Elevated nutrient concentrations in Hinkson Creek could lead to increased primary productivity, algae blooms, high biochemical dissolved oxygen demand, and shifts in the invertebrate communities toward scrapers.

Exploration of modeling of Hinkson Creek nutrient and sediment dynamics, calibrated and validated against the datasets described above (Zeiger and Hubbart, 2016c), indicated some promise, but also multiple areas of improvement that are needed to accurately model nitrogen, phosphorous, and sediment fluxes. Difficulties in modeling extreme events and instream nutrient processing were apparent. Additional model complexity may be necessary to provide useful modeling tools for managing nutrients and sediment.

Study of groundwater chemistry at the BHF and AG sites discussed above also showed significant differences in nutrients and trace elements (Kellner et al., 2015). Although the authors deferred many interpretations to further study, they attributed much of the change to the land-use history. As indicated by the authors, the specific hydrology of the sites probably plays a role and it is worth noting that the AG site has a large managed wetland adjacent on the same valley bottom, and the BHF site is fed by a local tributary that drains the MU golf course; clearly, these local hydrologic influences may be affecting groundwater chemistry.

A recent (2020) initiative on assessment of chlorides in Hinkson Creek was motivated by results from the aquatic macro-invertebrate data-mining study (Geosyntec, 2020) and has enhanced understanding of the spatial and temporal distribution of chlorides (see Science Team Chloride Statement, 2021). New data and retrospective analysis of some available chloride data confirm strong spatial variability, with low chloride concentrations upstream and increasing concentrations downstream, as well as substantial seasonal variation.

Biological Structure and Process

Whereas the DNR bioassessment monitoring and resultant MSCI metrics provide the foundation for assessing regulatory status and trends for Hinkson Creek, additional studies have addressed information needed to understand cause and effect. An assessment associated with the 5 gaging sites evaluated systematic effects of land use, instream habitat quality, and water quality on macroinvertebrate assemblages during 2011, based on taxonomic and trait metrics (Nichols et al., 2016). This study confirmed that the agriculture-urban gradient is reflected in many macroinvertebrate trends, including upstream to downstream decrease in sensitive species (Ephemeroptera, Plecoptera, and Tricoptera, EPT). Habitat variables showed similar trends, notably a fining of substrate in riffles and decline in root mat volume from upstream to downstream. Community richness and diversity were not significantly different between dominantly agricultural sites and those that had more than 10% urban area, a surprising result that was interpreted as evidence that even the agriculturally dominated sites in Hinkson Creek have been significantly affected by disturbance. Many of the relations explored among habitat variables, land-use, and invertebrate metrics varied by season and by position in the stream network, indicating the potentially complex relations among assemblages and stressors. The most significant trend related to urbanization was the decrease in small-bodied invertebrates in urban areas.

Nichols et al. (2016) also documented relatively high chloride concentrations. Similar to Allert et al. (2012), they found concentrations were higher in urban areas and exceeded EPA chronic limits in some cases. Because the respiration traits and body sizes of invertebrates sampled did not correlate with dissolved oxygen (DO), it was concluded that DO is probably not limiting for assemblages. Presence of multi-life-stage organisms in downstream riffles was negatively correlated with peak flows, which was interpreted as evidence that disturbance may be a factor structuring those assemblages. Burrowing organisms were more abundant in downstream reaches that also had more fine sediment, indicating that fine sediment deposition can be a factor in structuring assemblages. A downstream decrease in rheophilic invertebrates was correlated with downstream decrease in root mat volume, indicating that factors determining occurrence and persistence of root mats, such as occurrence of large, scouring floods, may be important to assemblages.

The data-mining study commissioned by the Hinkson Creek CAM process provided additional insights into structure and process of aquatic macroinvertebrate communities by analyzing community metrics with respect to candidate water-quality stressor variables (Geosyntec, 2020). This study noted:

- Substantial and systematic variation between spring and fall macroinvertebrate communities, indicating the seasonal variation needs to be considered in evaluation of trends in invertebrate-based stream condition scores.
- Evaluation of correlations among invertebrate-community metrics helped to indicate where redundant information exists among metric (that is, correlations that don't provide additional information) and therefore indicating approaches to simplifying analysis.
- Although spring season trends were apparent, none of the seasonal trends in community metrics were *statistically* significant over time. The implication is that although urban and rural land uses have changed substantially over the time frame (2001-2017), these trends in stressors have not resulted in unambiguous changes in stream macroinvertebrate biota.
- Many aquatic macroinvertebrate community metrics failed to show hypothesized relations to the environmental variables explored in the analysis. The authors interpreted the lack of relation to stressors that are usually associated with urban stream degradation likely resulted from either limited range of variation in the stressors (not that much variation in water quality parameters) or inadequacies in the data collection.
- Some patterns that emerged indicated Total Taxa richness, EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa richness, and scrapers/filterers ratio were inversely correlated to levels of specific conductance, chloride, and sulfate at multiple treatment groups and in both seasons. These results enforce concerns about toxic of behavioral effects of salts from road treatment, legacy coal mining, and/or other sources of leached anions.
- Variation with nutrient concentrations indicated association with percent Intolerant Taxa and percent Oligochaeta.

- For improved efficacy of future aquatic macroinvertebrate monitoring, the authors recommended Total Taxa richness, EPT richness, clinger/climber richness, percent Intolerant Taxa, and scraper/filterer ratio as useful metrics.
- Continuous conductance meter data indicated upstream to downstream increase in conductance and seasonal variation in conductance related to snow events. These patterns implicate road treatments as a source of chloride-induced increases in conductance.

Synthetic interpretations

The data-mining report (Geosyntec, 2020) concluded that many candidate water quality variables – notably temperature, dissolved oxygen, and nutrients – were not significantly different between rural and urbanized parts of Hinkson Creek or were not correlated with aquatic macroinvertebrate metrics. They noted that among the water-quality variables, chloride (also represented by conductance) was measured at times near water quality thresholds. This result was consistent with previous studies that implicated chloride toxicity of Hinkson Creek (Allert et al., 2012; Missouri Department of Natural Resources, 2004) in impairment. The authors also noted limitations in analyzing the effects of hydrology and instream habitat due to lack of data. This limitation is significant because it means that analyses cannot look at the independent or interactive effects of physical habitat with water quality (fig. 3). The authors further concluded that other sources of toxicity cannot be ruled out by their analyses because trends and associations could not be established due to episodic variation and lack of long-term, consistent monitoring.

In a provocative synthesis of a broad selection of data and analyses completed by the Hubbart Lab (MU and WVU) Kellner and Hubbart inferred that a legacy of long-term landscape evolution and early 20th century land uses in the basin – particularly coal mining -- could be responsible for present-day hydrologic anomalies and water-quality impairment (Kellner and Hubbart, 2017a). In reviewing this article, the Hinkson Creek science committee concluded that while long-term legacy effects may relate to some measures of physical habitats, they were unlikely to contribute to chemical factors – for example chloride loading – that have short residence times on the landscape. The article's assessment of hydrologic anomalies and inference that they could relate to minor early 20th century coal strip mining pits was unconvincing due to the lack of detail in the assessment. Whether continued leaching of sulfate from the strip-mining pits may be contributing to Hinkson Creek conductivity, however, presented a useful hypothesis that could be tested with increased spatial coverage of conductivity monitoring. Speculated long-term landscape evolution factors apply to both Hinkson Creek and its reference streams, so differential impairment could not be ascribed to those factors.

As of 2024, Hinkson Creek has a substantial quantity of information available and synthesis and data-mining efforts have demonstrated what can be gleaned about impairments and process. On the chemical side of the conceptual ecological model, synthesis of results begins to point toward chloride (perhaps with sulfate) as a specific cause of toxicity. On the physical side of the conceptual ecological model, synthesis indicates substantial variation of hydrologic, geomorphic, and sedimentological characteristics along the stream. From this, sediment – in terms of embeddedness and degradation of substrate – emerges as a strongly suspected stressor, but linkages from sources to the streambed and to benthic communities remain obscure. Further, effects on the Hinkson Creek macroinvertebrate community may relate to sequencing of flows – for example, relatively small flow pulses during dry periods -- that may deliver chloride, or sediment, or other constituents without extensive dilution.

Projects to mitigate impairment of Hinkson Creek, completed and in progress

Multiple projects intended to mitigate impairment of Hinkson Creek have been completed to date, and other projects are planned or in progress. Project designs have been guided by the general objective of diminishing point and non-point sources of potential pollutants and decreasing runoff. Although all the projects make use of best management practices and clearly contribute to improving runoff condition for Hinkson Creek, designs have been handicapped by a lack of understanding of the specific processes which have led to impairment. Without this understanding, it is not clear whether the efforts demonstrate the optimal use of resources.

Categories of projects

Since Hinkson Creek was listed in 1998 many projects have been completed. The projects fall into 7 broad categories:

- Elimination of substandard private sewage treatment systems (both private common collection

elimination and publicly owned systems). These projects have undoubtedly contributed to decreases in nutrient and bacterial loads to Hinkson Creek.
- Elimination of specific presumed sources of contamination. Relocation of the Missouri Department of Transportation salt storage facility is a specific project that presumably decreased direct chloride loading to Hinkson Creek.
- Projects to intercept, spread runoff for infiltration (level spreaders). These projects are designed to intercept runoff from channelized flow and spread it out over low-gradient surfaces (swales or floodplains) where it can infiltrate into groundwater. One of these projects has been completed and has been evaluated (Wiseman, 2020). While this study indicates that an individual level spreader can infiltrate substantial amounts of runoff under some conditions, the study did not evaluate the storms in terms of frequency so it is not possible to extrapolate results to evaluate an effect on Hinkson Creek flood discharges. The study includes a suitability analysis, but it was not at a scale or scope that could be used to evaluate actual sites along Hinkson Creek. The cumulative effect of existing and planned level spreaders remains unknown.
- Large retention or detention systems[1] (basins, ponds, and lakes, construction or retrofits). A variety of lakes and ponds exists in Columbia and county areas in the watershed. Some have been designed as detention basins although most were designed for retention or other aesthetic or recreational value. Although these basins are presumed to have beneficial effects in decreasing peak flows and increasing water quality, the cumulative benefits are not quantified.
- Small, widely distributed retention/detention projects (rain gardens, rain barrels, bioswales, and pervious pavement). These projects are located throughout Columbia, MU campus, and suburban county areas. They should contribute to decreasing runoff and increasing water quality, but their cumulative effect is unknown.
- Land stabilization (uplands, streambanks). Most of these projects are streambank stabilization projects designed to protect infrastructure but with other potential benefits in decreasing sediment and nutrient loading to streams. Net benefits of streambank stabilization are difficult to quantify because stabilization of one section of stream often transfers erosive energy to the next bend downstream. Moreover, streambank stabilization disrupts natural ecological processes of delivery of large woody debris to the stream and rejuvenation of floodplain habitats associated with channel migration. As noted above, streambanks probably contribute substantial sediment to streams, but the amounts, and therefore the benefits of stabilization, are poorly quantified. Upland stabilization of disturbed areas through erosion controls and revegetation acts to decrease sediment delivery to the stream.
- Riparian buffers (purchase, easement, planting). These projects are intended to provide stream shading (to decrease water temperatures), bank stabilization, interception of some runoff, and enhanced infiltration into floodplains. Extensive research has been completed on floodplain processes on Hinkson Creek (discussed above). Opportunities for establishment of woody riparian buffers is limited in the city because most riparian areas already have woody vegetation corridors; greater opportunities exist upstream in the county (Hooper, 2015).

Monitoring, assessment, and evaluation of projects

Under adaptive management, projects are informed by and designed with the best available science (*design, implement stages* of the adaptive management cycle, fig. 1). *Monitoring* and *evaluation* of projects are intended to provide additional scientific information to reduce uncertainties and provide for improved designs and decisions (*adjust* stage). Assuming that the problem has been adequately assessed, learning from projects includes three fundamental questions. These three questions are discussed here with respect to a generic level spreader project:

1. **Does the project work as designed?** This is an engineering question and focuses on whether the project meets design specifications. The objectives and design of a project are presumably based on best available scientific information indicating that the project will contribute to mitigation of stream impairment. In the case of a level spreader project, design specifications may be related to how much water is diverted into the

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[1] Retention basins are ponds or lakes that are intended to have water in them most of the time. Depending on specifics of construction they may have some limited flood storage capability. Because they have water in them, they provide water quality benefits by allowing for sediment and nutrient sequestration and processing. Detention basins are usually dry and operate to detain runoff peak flows and drain slowly after storm events. Retrofits of detention basins may be used to increase permanent pools to increase water quality benefits. Retrofits to retention basins serve to change the characteristics of the drainage system and spillway to add flood storage.

infiltration field, when this occurs, how much peak flow from the contributing drainage area is decreased, or how much change in water quality occurred.

2. **Does the project measurably mitigate impairments to Hinkson Creek?** This is a more complex and challenging question, in large part because the cause(s) for impairment are not yet known. In terms of chemical impairment, one can ask whether a level spreader mitigates runoff from lawn and garden chemicals or other urban contaminants that could be an impairment to invertebrate populations. On the physical side one can ask whether a level spreader will store floodwaters, decrease peak flows downstream, decrease sediment yield to the creek, or decrease bed disturbance that could be an impairment to stream biota. These questions are all preconditioned on knowing what the likely impairments are.

    - Every project has the potential to increase relevant learning about Hinkson Creek, but when the causes for impairment are unknown, the project learning objectives are likely to be unfocused as well. Lack of focus in learning objectives is likely to lead to assessments that are overly broad and ineffective in providing decision-relevant information.

3. **How does the level of effort in the project scale up to make a difference in Hinkson Creek?** This question would logically come after answers to the first and second, because it assumes that impairment is understood and effect of the project on the impairment is measurable. This question differs from the others, however, in additionally addressing the question of *how much is needed*. For example, how much does a level spreader affect Hinkson Creek, and how many more similar projects would need to be implemented to have a positive, mitigating effect on impairments to the creek? The Science Team refers to this type of question as a “scalability” question.

    - Understanding how project implementation would scale almost always requires the ability to use computer-based simulations similar to the SWAT modeling efforts discussed above. Models need to be reliable enough to accurately quantify effects of projects. Scalability is highly relevant to decisions because it addresses the scope of future investment needed to mitigate impairment. How much is needed and how much can be done given practical constraints? Is this a practical solution?

Questions 2 and 3 should not necessarily be addressed sequentially. They are both critical to the success of a project and should be, in most cases, addressed simultaneously.

A riparian corridor project shares the same assessment questions discussed above. Will it perform as designed? Will it mitigate causes of impairment? How much will it affect the creek -- is it enough to make a difference? Clearly, the answers to all these questions are preconditioned on knowing (or hypothesizing) the cause for impairment and having an objective to mitigate that cause. While there are many potential ecological benefits of increased riparian corridor, there is also risk that it will not mitigate the actual causes of impairment if those causes are undefined. Moreover, if project objectives are not focused, it is difficult to narrow down to the important metrics that are needed for project performance monitoring. A wide range of responses would dilute the investment in monitoring and assessment among many potential response variables instead of focusing on the responses that are relevant to impairment and that would provide the highest information value. A too-narrow range can miss measurement of relevant performance. Scalability of a riparian corridor project is key: how much riparian corridor is available to be managed and is it enough to make a difference? If the impairment is related to elevated water temperature, the riparian corridor may act to shade and lower temperatures considerably. On the other hand, if the impairment is related to peak flood flows, it is unlikely that enough riparian corridor with enough groundwater storage is available to mediate flood peaks.

Decisions on whether to act or learn are generic to adaptive management under conditions of pervasive uncertainty. The tradeoff is between early investment in science and learning compared to early investment in management projects. The former risks a lack of progress in doing on-the-ground projects while information and learning is prioritized. The latter risks construction of projects with insufficient information to guide the objectives, especially if the problem has not been adequately assessed. Such projects can be expensive and lack of return on investment in mitigating impairments can lead to dissatisfaction with the adaptive-management process. The preferred balance is a question of the level of risk that stakeholders are willing to tolerate.

Decision-relevant science priorities

Scientific understanding of Hinkson Creek has grown tremendously since 2012. Important information on the structure of Hinkson Creek, the physical habitat context, and process-level understanding of runoff, sediment transport, floodplain hydrologic processes, macroinvertebrate communities, and nutrient fluxes now exists that did not before. The original science strategy plan was developed in 2017 at the 5-year mark, when it was thought to be appropriate to assess what is known, what is not known, and what needs to be known to mitigate the impairment(s) of Hinkson Creek. The science pursued to date has been mostly within the "*Assess problem*" stage (fig. 1) although some syntheses have provided useful insights about relevant management actions. The science priorities described below continue in the problem assessment stage because causes(s) for impairment have yet to be identified with confidence. The priorities outlined, however, rely on the solid foundation of science that now exists, to focus specifically on identifying causes. Diagnosing the impairment(s) continues to be the fundamental challenge.

The following section presents the Science Team's consensus on high-priority science topics as of Fall 2023. The discussion is presented in terms of hypotheses that relate to the Hinkson Creek CEM (fig. 3), with emphasis on the physical and chemical sides of the CEM. These projects have been selected because of their perceived high benefit: cost ratio; results of a survey of indices of benefits, costs, and benefit: cost ratios are shown in table 3.

Macroinvertebrate Community

The focus of the CAM process is on the stream macroinvertebrate community and its contribution to the MSCI score. The characteristics of that community are therefore foundational to prioritization of science, especially if the community can provide diagnostic indicators of the source(s) of impairment.

Studies on the stream macroinvertebrate community

These studies address the base of the CEM, reasoning from characteristics of the macroinvertebrate community upward to determine the likely source(s) of impairment. The macroinvertebrate community studies are important to Hinkson Creek management and restoration decisions because they start with the direct evidence of impairment. Basing prioritization of future science efforts on what is learned from the macroinvertebrate community should focus learning on those processes that are most relevant to identifying impairment of the creek.

1. **Additional analysis of existing macroinvertebrate data.** This science component has been substantially addressed by the data-mining project (Geosyntec, 2020). But as recognized in the report, additional information on concentrations and spatial distribution of chloride in the watershed would help to address uncertainties and point to possible solutions (component 1.2). New efforts to compile conductivity records throughout the watershed are now (2024) underway. In addition, the report notes that interacting effects of physical habitat could not be completely addressed given the existing data. The report contains several additional recommendations for expanding Hinkson Creek monitoring. Specific to aquatic macroinvertebrate data, the report recommends monitoring for indicator taxa and indicator metrics. Various recommendations from the data-mining report have been incorporated in specific science components in the following.

2. **Colonization experiment on uniform substrate.** An approach to separating chemical stressors from physical habitat stressors is to provide uniform habitat along the creek using rock baskets. This serves to eliminate the physical habitat effects so the invertebrate community colonizing the baskets should be affected almost completely by water-column chemistry. The approach would be to place rock baskets in common hydraulic environments in 20 or more locations along the stream during a period of time in the summer. Replicates of the experiment during different seasons could address seasonal issues like chloride or PAH loading. The locations would be informed by the physical habitat assessment, water quality variability, and location of tributaries and storm water inputs. Water-quality covariates would be measured periodically during the experiment with emphasis on indicators such as DO, conductivity, and temperature. If there is little or no difference among invertebrate communities that have colonized the substrates, one would conclude that water chemistry is not a major stressor and attention would turn to physical habitat. On the other hand, if communities did vary, water quality would be implicated as a source of impairment. Covariate water quality samples may prove useful in interpreting the cause of impairment, or the results may point toward the need for more detailed water-quality assessments. The project would have moderate cost and potentially large benefit in

defining the type, and possibly location, of stressors.

3. **Aquatic organism exposure studies**. After identifying potential impairment to the macroinvertebrate community from chemicals of concern, the importance of those chemicals in stressing the insect community can be addressed in targeted exposure studies. Exposure studies would determine if the magnitude of the effect of chemical pollution is likely to influence the specific macroinvertebrate community of Hinkson Creek (in contrast to conventional test organisms). One type of study would be an in-situ sampling of benthic insect communities using artificial substrates. Use of artificial substrates removes the interaction of the community with available habitat and will serve to isolate water-column chemistry effects on the communities. Another type of study is putting caged test subjects into the creek to assess mortality and chemical uptake, or under controlled laboratory conditions to test effects of specific chemicals or mixtures. Exposure studies can be moderately expensive but have the benefit of making the clear connection to impairment of biota.

4. **Evaluation of Hinkson Creek fish community responses to stressors**. This study would be a longitudinal assessment of the Hinkson Creek fish community. The objective would be to refine cause/effect understanding of impairment(s) by associating fish community composition with stressors along the stream. The study would involve longitudinal sampling of the fish community including seasonal sampling, replicated over years to explore relations between valley-scale and watershed-origin stressors and fish communities. The study would provide additional diagnostic understanding of stressors in Hinkson Creek. It would be complex but could be a graduate student project with proper technical oversight.

5. **Evaluation of invertebrate community responses in streams affected by Missouri River backwater**. This study would compare invertebrate communities and habitats in the backwater-affected parts of Hinkson Creek with those of other Missouri River affected stream communities. The objective would be to develop a rationale for segmentation of Hinkson Creek and definition of improved reference streams. The study would involve a hydrologic and geomorphic analysis to identify backwater-affected parts of Missouri River tributaries and coordinated sampling to determine whether there are affinities among the invertebrate communities of identified streams. This is likely a complex and multi-year project.

Physical Habitat

Physical habitat degradation or disturbance, such as bed sedimentation, or bed scour, originate from sources that are quite different from chemical disturbances, and therefore have different solutions. Although there may be multiple sources of stress on the macroinvertebrate community, determining whether stresses are dominated by the chemical pathway, the physical pathway, or both would help narrow the field for more effective learning and management.

Assessment of sedimentation, channel dynamics, and invertebrate habitats

Studies that document source, transport, and fate of sediment in Hinkson Creek will provide powerful inference about linkages from sediment to stream biota. In general, scientists are confident in their knowledge that sedimentation that overwhelms a stream, filling pools and clogging interstices of available riffle habitats is injurious to the benthic ecosystem and will result in degraded insect and fish communities. On the other hand, if the stream is not overwhelmed, but still affected by sedimentation or suspended sediment, benthic communities may shift in subtle ways that would require additional study to define the cause for impairment.

If sediment is determined to be a significant impairment to the macroinvertebrate community in Hinkson Creek, additional work may or may not be needed to determine the source and solution (Geosyntec, 2020). This will depend on the magnitude of the problem documented and the spatial distribution. If areas of Hinkson Creek are discovered that are overwhelmed with sediment, where those areas exist may give sufficient insight into the upstream origins. It is possible, maybe likely, that the spatial distribution will not provide that information, and additional work will be needed to assess where the sediment is coming from. In many cases, sediment sources can be classified into streambank erosion, gullies associated with intensive land disturbance, and broadly distributed non-point sources from agricultural lands. As discussed above, once the impairment and the source are understood, mitigation processes would need to be designed to address whether the mitigation is effective and can be scaled to make a difference.

One of the dominant hypotheses for impairment is excessive deposition of fine sediments that thereby degrades habitat for benthic macroinvertebrates. A common result of deposition is to shift the invertebrate community away from EPT taxa to more tolerant taxa such as tubificid worms. Although suspended sediment fluxes at the 5 gages can indicate sources and possibly sinks of sediment, assessment of deposition is necessary to document that the sediment is actually impairing the benthos. The data-mining project did not, however, identify a strong effect of measured environmental variables on deposited sediment tolerant taxa; the data-mining reported noted that deposited sediment was incompletely characterized in Hinkson Creek and future efforts would benefit from systematic sediment characterization. We identify four relatively simple and low-cost approaches to developing understanding of bed deposition.

6. **Intensive longitudinal mapping of fine sediment**. This project is an enhancement to the field-based physical habitat assessment; a pilot project with enhanced methodology was completed in 2018 and results have been evaluated by the science committee. The approach is to assess thickness of fine sediment at closely spaced locations in the thalweg of the mainstem of Hinkson Creek. The 2018 pilot (component 3.1) covered about ¼ of the total physical habitat assessment domain and, as such, did not include a complete range of physical settings. An additional sampling and analysis (component 6.2) would provide a measurement of temporal variability for the sites already measured and would extend the assessment to a wider range of conditions in the basin. Multivariate analysis would be used to evaluate basin-scale land-use influences on sediment accumulation and to provide additional information on the effects of Missouri River backwater on bed sedimentation. This is a relatively low-cost project with potentially substantial benefits in documenting where sedimentation is acute.

7. **Transect based surveys of bed sedimentation and erosion.** In addition to the spatial distribution of acute sedimentation and possible inference of sediment sources, variation in sedimentation over time is of interest, especially if sedimentation is increasing or decreasing in severity, or moving downstream. Temporal sedimentation is best documented through resurveys of channel transects. Transects would be located through a randomized design, perhaps stratified by creek segment. Randomization will allow for unbiased interpolations of results. Transects would be surveyed at least annually and after major sediment-transporting flows; variation through time will indicate whether sedimentation is moving downstream, and if so, at what rates. The cost of transect resurveys is moderate if carried out by students and the benefits in terms of understanding whether sedimentation is accelerating or decelerating would be substantial. The decision to invest in this project may logically be delayed until invertebrate distribution data indicate that sedimentation is a likely cause of impairment.

    - The same transect approach could be used for a corollary hypothesis: invertebrate communities are impaired by bed scour and disturbance. This hypothesis typically applies to coarse sediment remobilization and may occur with or without excess delivery of coarse bedload sediment. That is, it could be linked to increased peak flows capable of transporting coarse sediment, with or without increased sediment loading. Transect resurveys will indicate the extent to which bed disturbance by scour -- especially in riffles – is likely to affect invertebrate communities.

8. **Evaluation of level-spreader application to stormwater detention.** A pilot level-spreader project was completed in 2020 (Wiseman, 2020). This project (component 8.1) explored how runoff from a creek draining a small watershed could be intercepted and spread out over a section of floodplain to infiltrate into the soil, thereby diminishing runoff. The pilot project provided an initial quantification of efficacy and included a preliminary assessment of an approach to scale up to consider where within the Hinkson Creek drainage basin level spreaders could be applied. Component 8.2 would be a more complete GIS analysis of how level spreaders could be deployed in Hinkson Creek. Science team members have noted that designs of hiking and biking trails could be enhanced to operate as level spreaders.

9. **Photo documentation of Hinkson Creek changes through time**. This project has elements of both scientific documentation and outreach. Historical photographs would provide useful context for understanding the nature of change in Hinkson Creek, including whether bed material, large woody

debris, or bank conditions have changed significantly. Historical photos for which the location can be verified can be replicated to document changes. If served on a website, the project would provide opportunities for citizens to be part of the Hinkson Creek management effort through contribution and documentation of photos and would provide documentation of how much or how little Hinkson Creek has really changed. An example of a similar project has been completed by the University of Vermont (http://www.uvm.edu/landscape/). This would be a project with moderate cost because of the staffing needed to curate the collection and keep the website up to date; the benefits could be substantial, both in documentation of change and in outreach. Some work on compilation of historical photos has begun.

10. **Evaluation of Missouri River backwater effects**. This question addresses the extent to which backwater flooding from the Missouri River influences the lower parts of Hinkson Creek. This question has been assessed by science team members (but not published) using data from both Missouri River and Hinkson Creek hydraulic models and Hinkson Creek LiDAR. Having delineated the zone of backwater effects, the effect on macroinvertebrate communities can be addressed in more detail through 1) evaluating how existing physical habitat variables change in this reach and 2) evaluate how invertebrate communities and MSCI metrics vary upstream and downstream of the zone of influence. The results of these studies may indicate that upstream and downstream parts of the creek are affected by substantially different sediment-transport processes, some of which may be amenable to mitigation (upland sediment yield) and some of which (backwater effects) will not be. These analyses can be initiated with existing data from the physical habitat assessment and DNR invertebrate data (site 1 is in the backwater zone and site 2 is just upstream). The cost for initial analysis is very low and the benefits may be quite high if they lead to reclassifying the impaired reach of Hinkson Creek; however, discussions with Missouri DNR indicate that reclassification could be impractical given time and data requirements.

Evaluation of bank erosion as contributor to sediment delivery

The hypothesis that excess sediment is being delivered to Hinkson Creek carries with it the fundamental question about the source of the sediment. Many reviews of sediment loading in the literature confirm the conclusions of recent work on Hinkson Creek (Huang, 2012) that bank erosion is a potentially significant source of sediment delivery to stream (Gellis and Gorman Sanisaca, 2018). We recommend a two-phase approach to address this question and to scale up from the spatially limited results of Huang (2012).

11. **LiDAR measurement of bank retreat and sediment delivery.** A cost-effective first phase would be to use the 2019 and 2009 county LiDAR datasets to automatically map bank retreat. The phase 1 GIS-based physical habitat assessment developed tools to process LiDAR to automatically delineate the top of the bank. This method, with or without some level of manual intervention, would provide 2019 bank lines that can be compared with the 2009 bank lines to quantify bank retreat in the intervening 10 years. With bank heights measured by the field based physical habitat assessment, locations and quantities of bank erosion can be calculated with a high degree of accuracy. Alternatively, the lidar-derived digital elevation models could be differenced to provide direct volumetric estimates of erosion and sedimentation. A pilot effort by Boone County GIS demonstrated proof of concept but later assessment by the Science Team indicated that without robust masking of water surfaces, the differencing method is likely to result in highly biased volumes. The masking process is time consuming and has not been completed by the date of this report. Bank erosion analysis would either confirm or contradict the hypothesis that bank erosion is contributing significantly to sediment delivery to the creek. The project might be postponed until sedimentation has been confirmed as a stressor on macroinvertebrate communities. Because this analysis is based on analysis of existing data it would be relatively inexpensive while providing fundamental information on Hinkson Creek channel dynamics.

12. **Transect based resurveys of bank erosion.** If the first phase confirms a substantive role for bank erosion, the next phase would be to put in place more detailed transect-based surveys to refine quantities of sediment delivery and improve documentation of events that contribute to bank erosion. The optimal approach to providing unbiased estimates for the magnitude of bank erosion would require randomized erosion transects throughout the Hinkson Creek mainstem. Resurveys of transects would quantify magnitude, location, and timing of bank erosion, and it is possible that a common set of survey transects could be used for assessment of bank erosion and channel deposition and scour. To

capture segment- and reach-scale variability along the creek would require a large number of transects, potentially numbering several hundred. Annual or event-based resurveys would be time consuming, requiring a crew of at least two and several hours of field time per transect. The benefit of the data, however, would be substantial because it would refine estimates of sediment loading from bank erosion and indicate where and how often it occurs, pursuant to identifying sedimentation as a significant stressor. The number of transects could possibly be minimized by stratifying by erosion intensity classes identified in the first phase before randomizing.

Identification of intensively eroding banks may lead to prioritization of sites for bank stabilization. Caution is warranted, however, in implementing bank stabilization as a measure to mitigate sediment delivery, because bank stabilization often results in transfer of energy to downstream unprotected banks, moving the problem without solving it and perhaps amplifying the problem (Fonstad and Marcus, 2003). Moreover, bank erosion is a fundamental ecological process in streams providing a disturbance mechanism, delivery of large woody debris to the channel, and opportunities for deposition of new surfaces for colonization of woody seedlings (Florsheim et al., 2008; Johnson, 2000; Trush et al., 2000). Stakeholders may want to compare these potential ecological benefits with benefits and costs of bank stabilization.

Chemical Pollutants

Chemicals may not only kill individuals but can act as a disturbance or reduce the ability of species to reproduce through several mechanisms. Chloride has been shown in a number of studies to impact aquatic species and the removal of the MoDOT salt storage facility is likely to have increased water quality downstream of that point (see Science Team Chloride Statement, 2021). However, many chemicals have multiple sources with the watershed, and it is possible that a complex combination of chemicals is impairing the stream ecosystem. The original Phase I-III DNR stream surveys employed toxicity testing and indicated some concerns about PAH's, petroleum products, pesticides, metals, and chloride, but apparently not at a level consistent with listing these chemicals as a cause of impairment. The left-hand side of the CEM (fig. 2) depicts the pathways for chemical contaminants to affect macroinvertebrate communities. Importantly, sediment and flow regimes are shown to interact with biogeochemical regimes, indicating the interdependencies among these processes. The following studies are discussed in terms of their benefits and relative costs in addressing chemical pollutant stressors.

Expanded water quality monitoring

An expanded water-quality monitoring network would provide useful information about how common water-quality variables – DO, conductivity, temperature, pH – vary over time and space. Analysis of such data would provide insights into origins of water-quality stressors by correlating where and when anomalies occur with potential sources. In particular, following on results and recommendations in the data-mining study (Geosyntec, 2020), investment in extensive monitoring of conductivity (as a surrogate for chloride concentrations) may be especially warranted.

13. **Comprehensive chemical sampling of major constituents**. Sampling of major constituents (chloride, dissolved oxygen, phosphorus), in addition to pH and temperature, would help to refine understanding of possible chemical stressors in Hinkson Creek. Based on the data-mining report, emphasis on conductivity monitoring is likely warranted. Because temperature monitoring is included with conductivity meters, stream temperature data would come along with the investment. Because of the investment in deployment of conductivity meters, deployment of sondes for pH, dissolved oxygen, and turbidity may also be warranted. High-frequency monitoring stations should try to capture hourly variation in conductivity (and perhaps other variables) with as many as 12 sites along the creek. High-frequency water quality monitoring data may be accompanied by a water sampling regime to evaluate additional water-quality constituents – for example to determine the ionic origin of conductance. Although water quality sampling can be expensive, this level of detailed information is needed to narrow down potential chemical stressors. After an initial deployment of water quality stations, the network may be reduced in scope to concentrate on emerging problem areas.

14. **Targeted chemical sampling**. This component includes several complementary assessments that are targeted toward more specific chemical stressors.

    - Component 14.1 is deployment of a series of continuous monitors for conductivity and temperature. This was a recommendation of the data-mining report and is intended to address the need to understand sources and transport of chloride (and other ions) using conductivity as a cost-effective surrogate. Continuous monitoring by sondes will be accompanied with periodic water sampling and lab analysis for calibration, QA/QC, and determination of what ions are contributing to conductivity. This component is presently (2024) being addressed by a coordinated Geosyntec/Lincoln University study with deployment of conductivity meters throughout the watershed.

- Component 14.2 is a study on the distribution of major nutrients. The synoptic sampling currently under way by Dr. Argerich (University of Missouri) is intended to evaluate source of nutrients and how they may be affecting stream biota.

- Component 14.2 is a study that would sample for a wide range of organic chemicals using passive, integrative sampling technology. The study was proposed in 2020 by USGS but was delayed because of the pandemic. This study will provide insights into emerging and relatively rare (but toxic) chemicals that could be impairing the biota of Hinkson Creek. This study would provide updated methodology and sensitivity to chemicals that were not available during previous DNR water quality study phases. Sampling of 5 sites were completed in spring and fall 2022 and a portion of the data was delivered in Spring 2023. A final report is expected in Summer 2024.

15. **Reanalysis of existing chemical data**. The motivation for this study is new understanding from the data-mining study on macroinvertebrate distributions. In light of the macroinvertebrate trends, data reported in a wide variety of studies by the Hubbart lab would be reanalyzed to evaluate additional chemical-biotic relations. This would be contingent on increased access to the Hubbart datasets.

16. **Adaptive management on salt applications**. This study has been motivated through the multiple lines of evidence that support the hypothesis that excess chlorides may be a source of impairment on Hinkson Creek (see Science Committee Statement on Chlorides, 2021). The question is whether alternative salt-application procedures on roadways, parking lots, and side walks could result in lowered transmission of chlorides to Hinkson Creek while maintaining public safety. The Science Team has discussed the potential for paired or sequential experiments in parking lots that would have varying salt treatments. This science component would follow the concept of an adaptive management experiment (fig. 1).

17. **Integrative watershed modeling to assess cumulative effects.** This study would develop, calibrate, and deploy a watershed model to evaluate the cumulative effects of implementation of best-management practices (BMPs). The objective would be to develop a framework to evaluate cumulative effects of BMPs as they scale up throughout the watershed. How much area, how many projects would be needed to have a measurable effect on physical and chemical processes in Hinkson Creek? The modeling framework will be used to evaluate the level of implementation needed to have an effect on the mainstem as well as to determine optimum placement of BMPs. Success will require a well-calibrated model that can accurately predict present-day flows, sediment transport, and chemical fluxes, combined with accurate representations of how BMPs will alter conditions. This is an ambitious project especially as some BMPs will be challenging to model.

18. **The role of physical habitat disturbance in Hinkson Creek.** This study is an analysis of existing data to evaluate disturbance potential of mainstem Hinkson channel segments. The objective is to determine relative disturbance potential of parts of Hinkson Creek by calculating stream power (a measure of stream energy based on the product of depth and slope). Ability to calculate water-surface slopes is afforded by existing HEC-RAS modeling results recently provided to the Science Team and some initial analyses have been completed. Assessment of the longitudinal variability in stream power may provide insights into potential for habitat disturbance, sediment transport, and habitat disturbance along the mainstem. Data needed to make these calculations are readily available, so level of effort is limited to data analysis and reporting. The information would be highly complementary to the physical habitat assessment.

19. **Updated geospatial datasets.** The intent of this study is to update and compile GIS data that are

fundamental to understanding sources and transmission pathways for potential stressors. Specifically, the Science Team perceives the need to update land use/land cover data to evaluate ongoing changes to development in the watershed, to update maps of stormwater BMPs to evaluate potential cumulative mitigation, to update maps of stormwater drains and outfalls, and to compile maps of

Science-operational infrastructure

In addition to science components, the Science Team has identified two operational components with the potential to increase progress toward developing decision-relevant science.

20. **Develop a full-time science and data-support position.** The Science Team has noted that many moderate-size analytical and data-management tasks could be accomplished if a dedicated support technician were available to the team. This technician could address the myriad of ideas that emerge in Science Team meetings yet go unaddressed because of a lack resources. In particular, this technician could be tasked with working with geospatial datasets (component 11, 19), completing analysis and reporting on components characterized as “low-hanging fruit” (components 6.1, 11, 18), and helping coordinate many of the other science components.
21. **Increase participation of academic institutions in Hinkson Creek Science.** The Science Team recognizes the potential for strong collaboration between the Hinkson Creek CAM process and MU, Lincoln University, and perhaps other institutions. Ad hoc Interactions have been useful and continue. The Team recognizes that Hinkson Creek could become a model for collaborative science and science education in urban hydrology. Initiatives such as the proposed outdoor classroom have the potential to support this collaboration.

Socio-economic investigations into Hinkson Creek values

The Science Team did not prioritize socio-economic investigations but recognized that a survey of stakeholders’ values and interests may be useful to long-term management planning. Listing of Hinkson Creek on the 303(d) list as an impaired waterbody is an articulation, through the regulatory process, of societal values supporting safe, fishable, and swimmable water. Possibly, the residents of Columbia and Boone County would value additional characteristics and would be willing to pay for management actions that would support them. For example, Hinkson Creek could be fishable and swimmable but still be subject to household trash accumulations and therefore suffer diminished aesthetic appeal. Residents might be unaware of the potential that Hinkson Creek has to offer for recreational and aesthetic benefits. Provision of additional benefits could have implications for real estate values and tax base. Understanding citizens’ values is also important in setting reference conditions for assessing current and future state of the stream. Do citizens value a pre-settlement, pristine environment, a stream that provides specific recreational opportunities, a MSCI score greater than 16, or a future condition that may not look anything like a natural stream (see Flat Branch Park for an example)? A socio-economic survey of citizens would provide context for how the stream may be valued beyond its impairment status. The study would use social science survey techniques similar to Baumer (2007) to evaluate community values and vision, and extend that analysis into assessment of willingness to pay for envisioned amenities.

A five-year science plan

The scientific studies discussed above provide a core of efforts that will provide decision-relevant science information for Hinkson Creek (table 4), in particular to refine the “*Assess problem*” stage of the adaptive management cycle (fig. 1) to the point where relevant mitigation actions can be designed and implemented. A cost-effective approach to obtaining this information would be to prioritize and sequence studies to provide high benefit: cost and mutually supportive information. The science team completed a prioritization exercise by estimating benefit (1 low, 10 high) and relative cost (1 low, 10 high) of each study. The ratio of these two values provides an initial metric for prioritizing the studies. In addition, table 4 provides notes on duration and sequencing of the studies.

Table 4. Listing of science components and Science Team benefit, cost, and benefit:cost scores, March 2023.

				2023 Results			
Category	**Serial Number**	**Component description**	**Status, January 2023**	**Average benefit responses**	**Average cost responses**	**Average benefit: cost**	**Notes on sequencing, mechanisms**
Biotic responses	1.1	Additional analysis of existing macroinvertebrate data	**Completed**, with recommendations for follow up.				Completed
Biotic responses	1.2	Follow on analyses not covered in Geosyntec report	No progress	6.3	2.7	2.3	Natural follow on to Geosyntec (2020) data-mining report. This would include additional datamining and could be a 1-2 year project
Biotic responses	2	Colonization experiment on uniform substrate to evaluate water quality effects independent of benthic habitat.	No progress	8.1	6.3	1.3	Given results in data-mining report that indicate difficulty in separating habitat variables from water-column chemistry variables, this component increases in value. Duration probably 2 years.
Biotic responses	3	Aquatic organism exposure studies to evaluate effects of expected contaminants on aquatic macroinvertebrate behavior, growth, survival. Initial emphasis would be on effects of chloride.	No progress	7.4	7.3	1.0	The data-mining report indicates support for testing chloride as a contaminant of concern. Laboratory studies with invertebrate assemblages common to Hinkson Creek could evaluate levels at which chloride or other ions affect growth, survivial, reproduction, and behavior. 2-3 years duration.
Biotic responses	4	Evaluation of Hinkson Creek fish community responses to stressors.	No progress. A proposal was considered in 2014 but was not funded.	5.3	5.9	0.9	This project has more value given results of data-mining study as that study suggests patterns of disturbance that could then be further evaluated with fish communities. To capture hydroclimatic variation this would be 2-3 years duration.
Biotic responses	5	Evaluation of invertebrate community responses in other streams affected by Missouri River backwater to improve understanding of reference conditions.	No progress	4.5	6.1	0.7	This component would add evidence to hypothesis that the downstream-most stations on Hinkson Creek are affected by backwater conditions and that such conditions can be systematically identified in macroinvertebrate communities on other streams. Likely long duration to complete enought sampling.
Physical stressors	6.1	Intensive longitudinal mapping of fine sediment	Phase 1 sampling **completed** 2018 (Hooper and Engeln), results are being analyzed on ad hoc basis (Jacobson) in comparison to physical habitat assessment data (comp. 14).				Phase 1 completed
Physical stressors	6.2	Phase 2 intensive longitudinal sampling over entire mainstem.	No progress	6.7	4.8	1.4	Phase 2 would take at least a year to sample, although it would be done more efficiently having the phase 1 experience.
Physical stressors	7	Transect-based surveys of bed sedimentation and erosion.	No progress	6.0	4.7	1.3	This component would logically follow the lidar survey (component 11, which would indicate the scope of the problem). It could be coordinated with component 12.
Physical stressors	8.1	Field-based AM experiment with level spreader.	Proof of concept and evaluation **completed** (Wiseman, 2020).				Completed
Physical stressors	8.2	Scaling up level spreader results to Hinkson basin.	Introduced March 2021. No progress.	6.6	4.9	1.3	This would be a 1-year GIS-based component as a follow on to 8.1: could enough level spreaders be deployed in the Hinkson to make a difference?
Physical framework	9	Photodocumentation of Hinkson Creek changes through time.	Initial exploration of available historical imagery. Status needs to be updated (Woolbright).	5.9	2.6	2.3	This could happen any time. Once established, the website would need to be maintained.

Table 4. Listing of science components and Science Team benefit, cost, and benefit:cost scores, March 2023.

				2023 Results			
Category	**Serial Number**	**Component description**	**Status, January 2023**	**Average benefit responses**	**Average cost responses**	**Average benefit: cost**	**Notes on sequencing, mechanisms**
Physical stressors	10	Evaluation of Missouri River backwater effects on MSCI, benthic habitat.	HEC-RAS runs have been assessed to **complete** delineate zone of potential influence. Decision relevance has been questioned because of perceptions that re-segmenting Hinkson Creek would be arduous administrative task. Data indicate processes likely responsible for sedimentation and low MSCI scores in lower river.				Completed but lacks publication.
Physical stressors	11	Lidar analysis of bank retreat and sediment delivery.	First attempt by County resulted in substantially biased rates.	7.8	5.1	1.5	Jacobson looked at methods snd data and determined that without careful consideration of water area results will be biased. Time to edit water mask is non-trivial.
Physical stressors	12	Transect based survey of bank erosion.	No progress	6.5	4.7	1.4	This is a long-term project, requiring 3+ years of sampling and would logically follow after the longitudinal sediment phase 2, component 6.1.
Chemical stressors	13	Comprehensive chemical sampling of major water quality parameters or suspected contaminants, high temporal frequency, fixed stations.	Different approach from conductivity, nutrients, or passive samplers. No progress	7.7	7.4	1.0	This is a long-term project requiring 3+ years of sampling to cover hydroclimatic variability. This investment may be more justified after targeted water quality investigations.
Chemical stressors	14.1	Targeted chemical sampling	Deployment of continous conductivity and temperature monitoring stations. Recommended by data-mining report. Will be accompanied with periodic water sampling and lab analysis for calibration, QA/QC, and determination of what ions are contributing to conductivity.	7.7	4.7	1.6	Coordinated Geosyntec/Lincoln University effort underway. Could be coordinated with chloride task force.
Chemical stressors	14.2	Targeted chemical sampling	Argerich study on nutrients. Ongoing.	7.2	4.2	1.7	Under way. 3+ years would be required to cover hydroclimatic variability.
Chemical stressors	14.3	Targeted chemical sampling	USGS (Alvarez) passive sampler study on contaminants. Completed, waiting for results.				Two deployments, 5 sites completed. Awaiting results Spring 2023.
Chemical stressors	15	Re-analysis of existing (Hubbart) data	Strategy under discussion; was not able to incorporate in data-mining study	4.6	2.0	2.3	Contingent on obtaining data, this is a logical follow on from the Geosyntec data-mining study and could be accomplished in one year.
Chemical stressors	16	Salt adaptive management experiment, treatment and controls, to better evaluate efficacy of management options.	Under discussion.	7.7	5.0	1.5	This is a logical follow on to converging lines of evidence about potential for chloride stressors. It would require 3+ years of data to evaluate hydroclimatic variability.
Physical framework	17	Integrative watershed modeling to assess cumulative effects.	No new progress. Previous work from Hubbart team informs at a coarse scale. Potential expansion by Zeiger, Aloysius	7.6	5.4	1.4	This could occur at any time, would provide a useful modeling framework to support other science components. 2+ years.
Physical stressors	18	Role of physical habitat disturbance in Hinkson Creek	Stream power distributions from HEC-RAS runs have been evaluated on an ad hoc basis (Holmes, Jacobson) in comparison with longitudinal sediment survey and physical habitat assessment data. Needs to be formalized, written up.	7.0	2.4	2.9	Complete except for formalized analysis and write up. 1 year.
Physical framework	19	Add updated landuse/land cover, BMPSs stormwater inputs, impervious area pathways, salt treatment loading areas --- parking lots, public roads -- to our spatial information infrastructure	No progress.	7.5	3.4	2.2	This could happen any time. This is a one-year project.
Operations	20	Development of a full-time Hinkson Creek science technician position.	Concept was proposed previously. Not approved by CAM.	7.8	6.2	1.3	Useful at any time and would continue through life of the Hinkson CAM process.
Operations	21	Increase participation of University of Missouri and other academic institutions in Hinkson Creek science.	Interactions with University of Missouri researchers continue. Grant proposal for expansion of Hinkson Creek as an outdoor classroom and laboratory through MU funds failed.	8.1	3.4	2.4	Useful at any time and would continue through life of the Hinkson CAM process.

Implementation of the Science Priorities

There are two general approaches to implementing science studies to inform management. In the sequential approach, studies are designed to provide packages of information, with each subsequent study only being implemented as the precursor study is completed and indicates it is necessary for decision making. This approach is arguably the most systematic and cost-effective because the science investment is limited to developing priority, relevant information. On the other hand, the sequential approach is also the slowest and can result in long delays in decision-making as the science process proceeds. In contrast, a parallel approach can be used that will invest in carrying out multiple studies at the same time. In the parallel approach some of the information collected may not be directly relevant to decision needs and will therefore not be optimally cost-effective. The value of parallel approaches is that they minimize the time devoted to scientific inquiry before informed decisions can be made. The value of information developed through parallel processes can be maximized, however, if studies are selected that are fundamental to understanding stream processes.

The science components in table 4 address fundamental information about the nature of the impairment to Hinkson Creek, but with varying benefits and costs. As information is developed in pursuit of these science priorities some questions will be answered; as a result some hypotheses and studies will become irrelevant and will fall out of the priority list. However, new information may also be developed, which can result in new hypotheses and new suggestions for related studies. Annual re-evaluations of existing information and priorities will allow the CAM process to adjust science investments to assure highest cost effectiveness. That is, the priorities in table 4 should be seen as a working set that should be re-evaluated and re-prioritized at least annually.

The highest-ranking science components, tied for the highest ranking, are component 21 (the operational increase in collaboration with academic institutions in science efforts) and component 16 (the salt application adaptive management experiment). The next 3 components in rank order are 14.1 (deployment of conductivity monitoring), 13 (comprehensive water quality sampling), and 14.2 (ongoing nutrient assessment).

In terms of benefit:cost, however, the ranking process identifies two components that are “low-hanging fruit”, that is, modest-size project that can be accomplished with perceived low cost. The highest-ranking component in terms of benefit:cost is 15 (re-analysis of Hubbart Lab data), followed by 18 (modeling evaluation of the role of physical disturbance). Notably, component 21 (increased academic collaboration) ranks third in benefit:cost. The number 4 component based on benefit:cost is 14.2 (ongoing nutrient study) and number 5 is 19 (expansion of spatial data infrastructure). Notably, the component tied for first in terms of benefits (the adaptive management salt experiment) ranks 14th in benefit:cost because of the perceived costs. The component that ranks third in terms of benefits (deployment of conductivity monitoring) ranks 11th in terms of perceived benefit:cost.

On a benefit basis, the 2023 ranking emphasizes studies that will evaluate the role of chlorides in impairment of Hinkson Creek. Studies that address physical stressors have less emphasis compared to earlier surveys. This pivot reflects the learning that has accrued over the last two years.

An adaptive management experiment

The emerging and reinforcing information indicating road salt as a direct stressor of Hinkson Creek biota supports a specific adaptive-management experiment – component 16. The objective of the experiment would be to evaluate whether alternative road de-icing methods can result in significantly lowered fluxes of salts to Hinkson Creek, with the goal of identifying methods to achieve loads that would keep concentrations of chloride below toxic levels. The experimental structure would require paired, instrumented roadways or parking lots that would receive default and experimental treatments (brines, precision delivery systems, varying application rates). Although evidence is strong that chloride from road salt applications is a likely chemical stressor on Hinkson Creek, the Team has been conflicted about whether a field-based experiment (or demonstration project) would be feasible in the watershed because of lack of experimental controls and public safety concerns. The objective of this experiment/demonstration would be to evaluate a) whether applications or formulations can be optimized through best-management practices to reduce chloride concentrations and loads while maintaining safe streets, sidewalks, and parking lots and b) whether that level of chloride reduction be significant in reducing exposure to stream organisms.

Science Process and CAM

The promise of CAM is that investment in evidence-based learning – in a collaborative management environment – is the most cost-effective route to solving difficult environmental problems. For CAM to work, science information must be perceived by all Stakeholders as credible, unbiased, and relevant to decisions. To achieve this, information must be:

- peer reviewed for quality;

- vetted by management as relevant;
- freely available in the public domain;
- provided in a timeframe that is relevant to management decisions;
- clearly and frequently communicated to engaged Stakeholders.

Numerous CAM efforts have realized that to achieve these properties, the science effort needs to be guided strongly by CAM priorities. Provision of science information needed by the Hinkson CAM process ultimately will require directed application of resources to specific science questions. We suggest the following changes to the CAM process:

- Increase interaction between the Stakeholder Team and the science and Action Teams. Although Action Team members regularly attend Science Team meeting and participate in discussions, Stakeholders have only rarely attended. As a result, Stakeholders have not been aware of the range of discussion on scientific progress and communication of science to the Stakeholders has suffered. Moreover, the formal format of stakeholder meetings has minimized scientists' input. Science team members should regularly attend the stakeholder meetings and engage in the conversation. Joint meetings of the three groups should occur to ensure communication and common understanding.

- Develop a systematic and periodic process for funding decision-relevant science. The process should evaluate proposals based on relevance to management decisions, quality of science, and cost effectiveness. The most direct approach to attracting high-quality science proposals is a request for proposals (RFP) process (assuming that appropriate funds are available to carry this out). A realistic level of investment will be required to make progress on critical science questions.

- Require quarterly progress updates for all funded projects. Require written annual reports to be submitted to the Stakeholders, and the Action and Science Teams.

- Require that data collected through funded projects be freely available to the public and distributable after a reasonable quality-assurance time period.

- Develop a peer-review process to support Hinkson Creek CAM decisions. This technical review process would be specifically for vetting the value of the information for the Hinkson Creek CAM process.

    - The Science Team may be able to carry out the review function.

    - Two factors need to be considered. One is that Science Team's work been essentially voluntary from the beginning and increasing workload may not continue to be possible on a voluntary basis. The second factor is the need to ensure that the reviews are viewed as independent and fair.

    - Faculty at the University of Missouri, USGS, MDC and DNR who are not directly involved in the Hinkson Creek work could perform much of this review work, if the workload is well distributed.

Financing Science Efforts

These suggestions are made with full knowledge that they will be challenging to fulfill. Paramount is the need for a reliable, substantive source of funds for science efforts. A strong funding commitment will assure timely delivery of decision-relevant science.

Effective CAM requires strong engagement from scientists, and many programs have struggled with how to structure the science input to accomplish the best engagement. For academic scientists, the engagement and sharing required by CAM can be counter to typical academic reward systems. Some specific CAM research efforts may fit well within a 2-4-year graduate school cycle, but others require longer, persistent commitment to maintaining data systems as in long-term monitoring. The recently completed Geosyntec report on macroinvertebrate data mining indicates the positive role that can be played by private-sector investigators. Some institutions may be good at collecting data, whereas others may be better at analyzing and integrating. Hence, many CAM programs distribute some science projects to universities, some to agencies, some to private sector science providers, and some to internally paid staff. The Hinkson Creek CAM process will need to strategize for the optimum distribution.

Structurally, the CAM process needs to have a dedicated person or team that serves to assimilate information, provide opportunistic and necessary data analysis, assure QA/QC, address data management and archiving concerns, communicate results with the Stakeholders, Action, and Science Teams, and produce annual reports. It is notable that the CAM agreement (Hinkson Creek Collaborative Adaptive Management Partners, 2012) states that the Science Team is responsible for these functions, and in particular for synthesizing reports; however, the Team lacks resources to carry out these functions. Ability to function as indicated in the CAM agreement would require support of one or more staff members with technical stream-ecology or hydrology expertise. As a starting point, this is estimated at about 1 FTE @ about $75,000/year. The costs to cover the 5 highest-ranking science components in table 4 have not been evaluated in detail, but the minimum annual cost is likely to be about $200,000 per year. This estimate assumes most of the work is done through university contracts or consultants.

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