Stressor Identification
for
Silver Creek
Clayton County, Iowa

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Watershed Improvement Section
and
Watershed Monitoring and Assessment Section

Iowa Geological and Water Survey

Environmental Services Division

Iowa Department of Natural Resources

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Acknowledgements

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Executive Summary

A Stressor Identification (SI) was completed for Silver Creek (Segment No. IA 01-TRK-0381_0) located in northern Clayton County near the towns of Luana and Monona, Iowa. Silver Creek flows into Roberts Creek which flows into the Turkey River. This waterbody is identified on Iowa's (Section 303(d)) list of impaired waters as impaired for aquatic life use, cause unknown. The goal of this SI was to determine the primary causes of biological impairment including any pollutant for which a Total Maximum Daily Load (TMDL) is required.

The first biological assessment of Silver Creek occurred in 1988 as part of the greater Big Spring Basin survey. The assessment uncovered evidence of biological impairment including low fish diversity and a benthic macroinvertebrate community indicative of organic enrichment. Additional biological sampling conducted in 2000 and 2005 showed that reduced biotic condition index levels existed in the watershed. Readily available stream data and information about the watershed were assembled and a weight of evidence approach was used to evaluate candidate causes of impairment. The evidence review process considered data for proximate stressors (biological, chemical, or physical agents that directly impact stream biota) and data representing intermediary steps in the causal pathways that connect stressor sources and biological effects.

Despite some data limitations, the evidence was sufficient to identify the following primary stressors, any of which is capable of causing biological impairment in the Silver Creek watershed:

- elevated and potentially lethal concentrations of un-ionized ammonia;
- elevated levels of silt accumulation and sedimentation of rock substrates;
- low / potentially lethal levels of dissolved oxygen;
- dewatering due to in-stream sinkholes.

Depending upon the causal mechanism, primary stressors can be manifested as short-term acute impacts or long-term chronic impacts to aquatic biota. To restore the biological condition of the stream to un-impaired status, TMDL and implementation plans need to address each of the primary stressors and multiple causal pathways that occur in the watershed.

Introduction

This Stressor Identification (SI) for Silver Creek (Segment No. IA 01-TRK-0381_0) has been completed to determine the causes of biological impairment including any pollutant for which a Total Maximum Daily Load (TMDL) is required. The SI includes a review of data for the entire watershed of Silver Creek (Fig. 1) including non-listed segments. A major goal of this SI was to determine whether the impairment was caused by a pollutant (e.g., ammonia) or a non-pollutant type of stressor (e.g., channelization), the latter of which would not require a TMDL. However, regardless of whether or not the stressor is defined as a pollutant or not, a complete SI should identify all causal agents and pathways that are responsible for impairing the aquatic biological community.

Watershed Features

Silver Creek is a warm water stream resource located in Clayton County, Iowa, within the Turkey River drainage system. The watershed is within the bedrock-dominated terrain of the Paleozoic Plateau ecoregion, which is strikingly different from the rest of Iowa. Steep slopes and bluffs, higher relief, sedimentary rock outcrops, dense forests, and unique boreal microhabitats differentiate this ecoregion from the Western Corn Belt Plains to the west (Prior 1991; Griffith et al., 1994). The Silurian Escarpment, a prominent physiographic feature that helps define the southern and western boundary of this ecoregion, separates the mostly cropland area of the west from the mixed land use of the Driftless Area. Dissolution of limestone and dolomite rocks results in karst features such as sinkholes, caves, and springs, and makes groundwater vulnerable to contamination. The streams in the Iowa portion of this region are located in entrenched valleys, and have cool waters with high gradients flowing over rocky substrates. The fish communities found here reflect a preference for cool clear water with relative consistency of flow.

The Silver Creek watershed includes a total of 17,909 acres (28.1 square miles) in the northwest portion of the county, extending east from Luana to the outskirts of Monona, to a point where Silver Creek empties into Roberts Creek about three miles northwest of St. Olaf. During normal conditions, the primary channel of Silver Creek flows for over 10 miles. The geological composition of Silver Creek's watershed (fractured limestone bedrock covered by a thin layer of soil) increases the threat of agricultural pollutants. The soil survey report for Clayton County documents over 60 sinkholes in the Silver Creek watershed, including locations in or adjacent to the stream channel (Fig. 2). At these points, nearly all of the surface water flow enters the groundwater system, eventually resurfacing at Big Spring (Halberg et al. 1983).

Current land use in the watershed is dominated by agriculture. According to the 2006 stream analysis done by Eric Palas, Silver Creek watershed project coordinator, approximately 87 percent of the 17,909 acres in the watershed are devoted to row crop agriculture. Livestock is also important in the area. Based on the RASCAL assessment, cattle graze more than 41percent of the stream channel, especially in the lower portion of the watershed. There are eight open feedlots (7 in the lower watershed) and one confined animal feeding operation (CAFO). This coincides with an analysis of 2002-2006 aerial imagery that shows most hay and small grains production in the watershed concentrated in the south and western portions of the watershed. The Silver Creek watershed includes two permitted point sources: the City of Monona wastewater treatment facility (WWTP) and Swiss Valley Farms Creamery. Both facilities are located on an un-named tributary of Silver Creek (Fig. 1). Facility statistics and effluent limits may be found in Table 1.

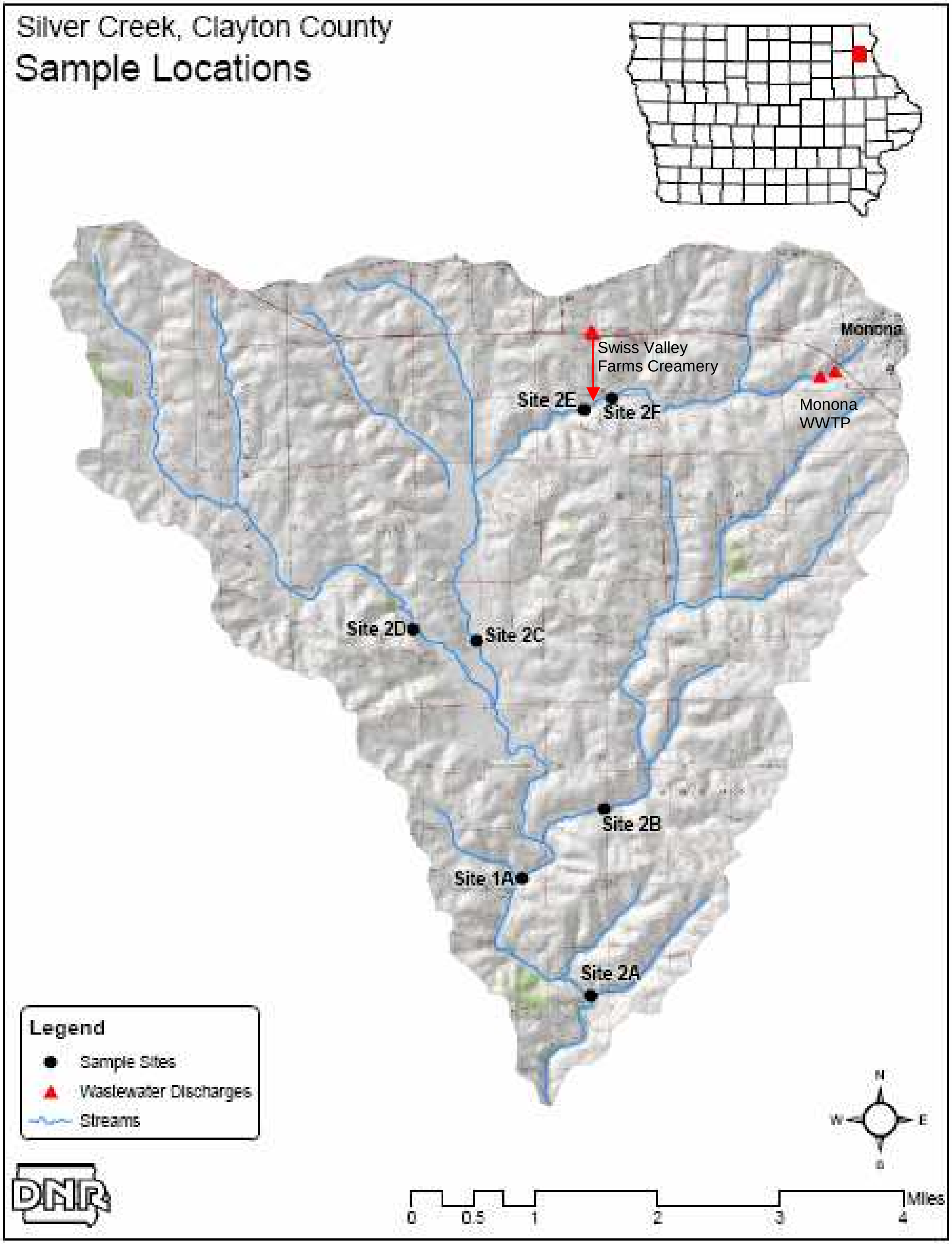

Figure 1. The Silver Creek watershed with TMDL sampling sites (Site 1A—2000, Sites 2A-F—2006) and point sources.

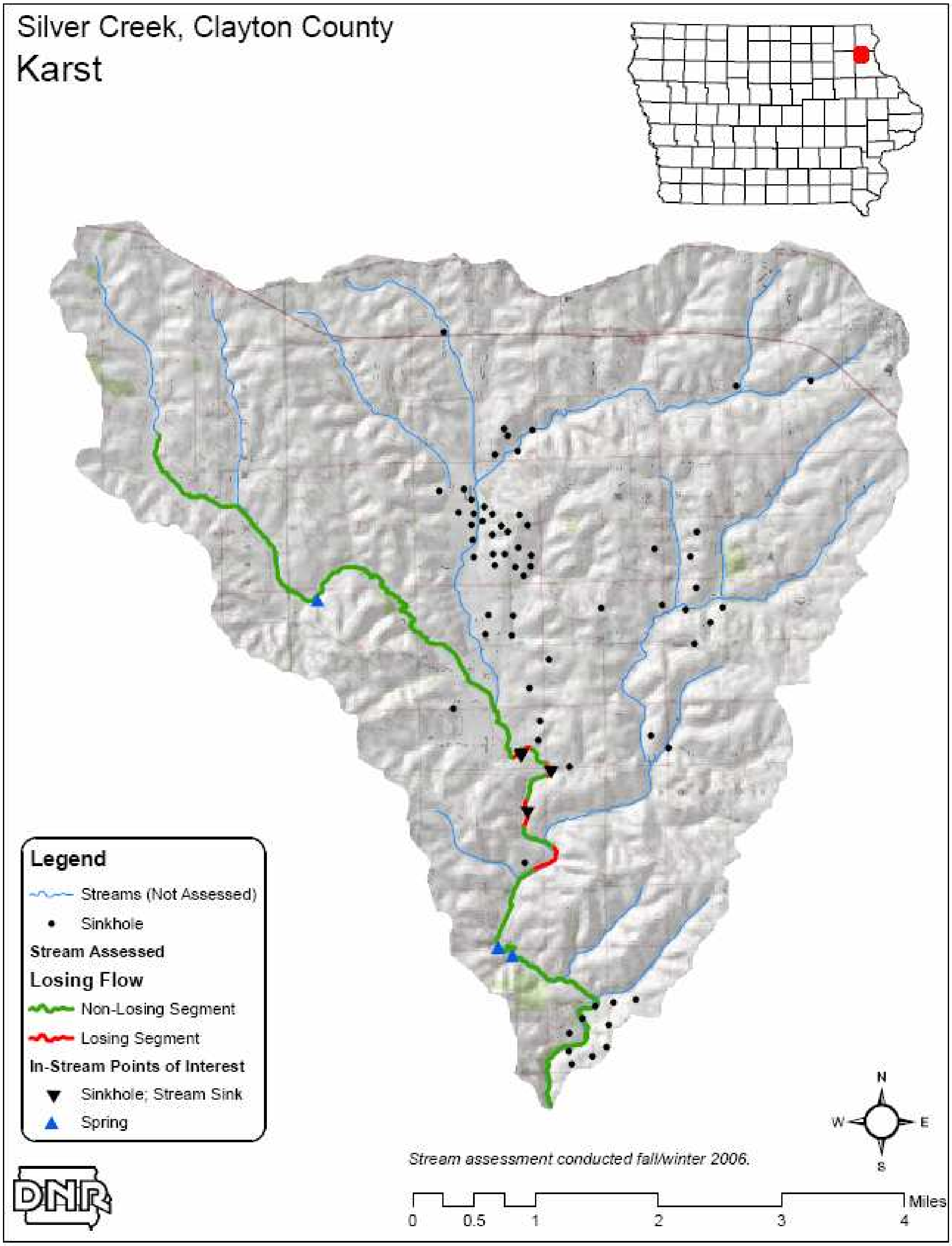

Figure 2. Locations of springs, sinkholes, and in-stream sinks in the Silver Creek watershed.

Table 1. Point sources in the Silver Creek watershed.

Facility	Monona (WWTP)	Swiss Valley Farms (Industrial)
IA NPDES #	2264001	2200100
EPA #	IA0036927	IA0003808
Treatment type	Activated sludge	Activated sludge
CBOD5 (mg/L)[1]	25 (30-d)	35[2]/19[3]/13[4] (30-d)
TSS (mg/L)[1]	30	66 (30-d)
pH[1]	6.0-9.0	6.0-9.0
Population equiv.	2179	11976
Design flow (MGD)[5]	0.312/0.1341/0.971	0.0/0.0/0.18

1. These are the NPDES permit limits for these facilities for CBOD5, TSS, and pH.
2. CBOD5 permit values for January and February for creamery
3. CBOD5 permit values for Mar. - June and Sept. – Dec. for creamery
4. CBOD5 permit values for July and August for creamery.
5. Average wet flow/Average dry flow/Maximum wet flow

Stream Flow and Water Quality

The Silver Creek watershed contains numerous sinkholes (common in the karst topography of the region), many of which are located in or around the channel. Surface flow from this and many surrounding watersheds contribute to groundwater flow, which eventually resurfaces at Big Spring (Halberg et al. 1983). These geologic features directly impact stream flow in Silver Creek. It was noted during the 2006 RASCAL assessment that a large percentage of stream flow enters the groundwater system at several sinkholes located along the channel (Fig. 2).

The nearest U.S. Geological Survey (USGS) stream flow gauge is 05412020 on the Turkey River above French Hollow Creek at Elkader, IA. While this gauge measures flow from a much larger watershed, it illustrates flow patterns in the region during the sampling period evaluated for the SI and provides a general sense of the seasonal flow patterns that occurred during the data collection period. Stream discharge data from this gauge (Fig. 3) show a seasonal flow pattern similar to those recorded at the three TMDL monitoring sites along Silver Creek (Fig. 4). Except for the spike in flows in March-April 2007, the flows appear to be near the long-term average based on limited historic data (Fig. 5). During low-flow conditions, flow at site 2A, the downstream most site, is lower than the combined flows measured at the upstream sites; this indicates that in-stream sinkholes are diverting most, if not all, base-flow before it reaches 2A.

It was determined during the 2006 RASCAL assessment that springs contribute to the stream flow of Silver Creek in several locations, possibly influencing water quality. Relatively high specific conductance and pH levels measured in Silver Creek substantiate the important influence of groundwater contributions from the underlying limestone bedrock aquifer. Water quality characteristics measured at Silver Creek sites are generally indicative of intensive agricultural land uses and point-source inputs (Appendix 2; Table 2-3). Concentrations of ammonia, nitrate-nitrogen, total phosphorus and total suspended solids measured at several TMDL monitoring sites were determined to be elevated when compared with levels occurring at least disturbed ecoregion reference stream sites. Sampling conducted in the 1970's by the University of Iowa Hygienic Laboratory (UHL 1977) show that water quality impacts have existed in the Silver Creek watershed for decades preceding the more recently documented problems, but also suggest that the creamery discharges had much greater impacts before stricter effluent limits were put in place (Appendix 2; Tables 2-1 and 2-3). The UHL survey findings include elevated levels of ammonia, fecal coliform bacteria and biochemical oxygen demand (BOD).

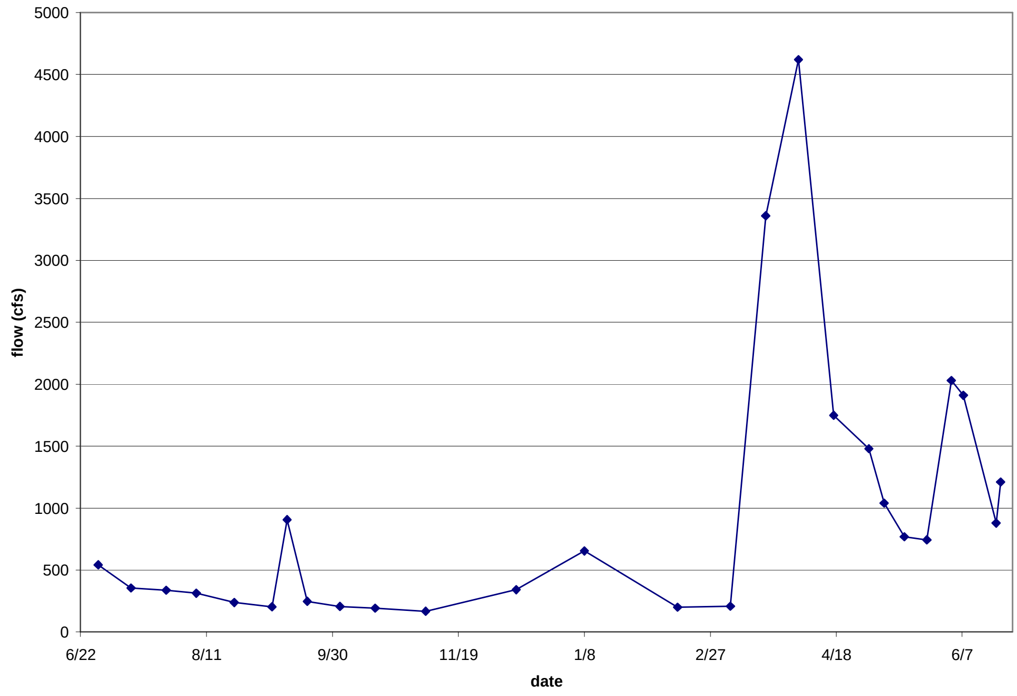

Figure 3. USGS stream flow gauge mean flow for the Turkey River near Elkader, Iowa.

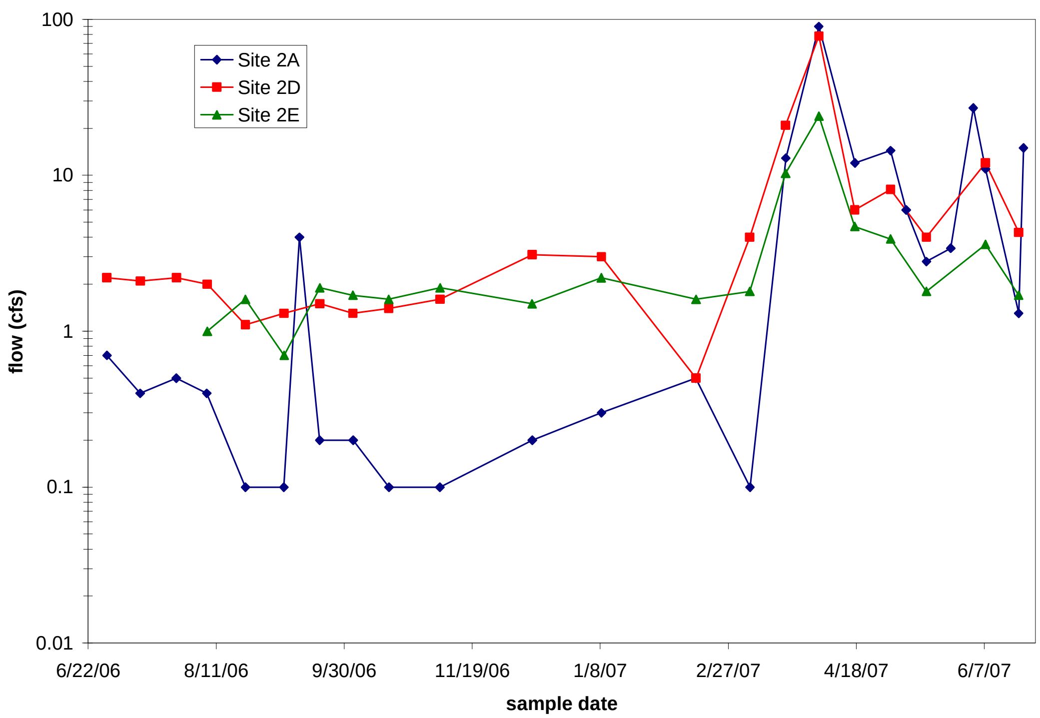

Figure 4. Silver Creek stream discharge monitoring for TMDL sites 2A (downstream), 2D (upstream main channel), and 2E (unnamed tributary downstream of creamery point source).

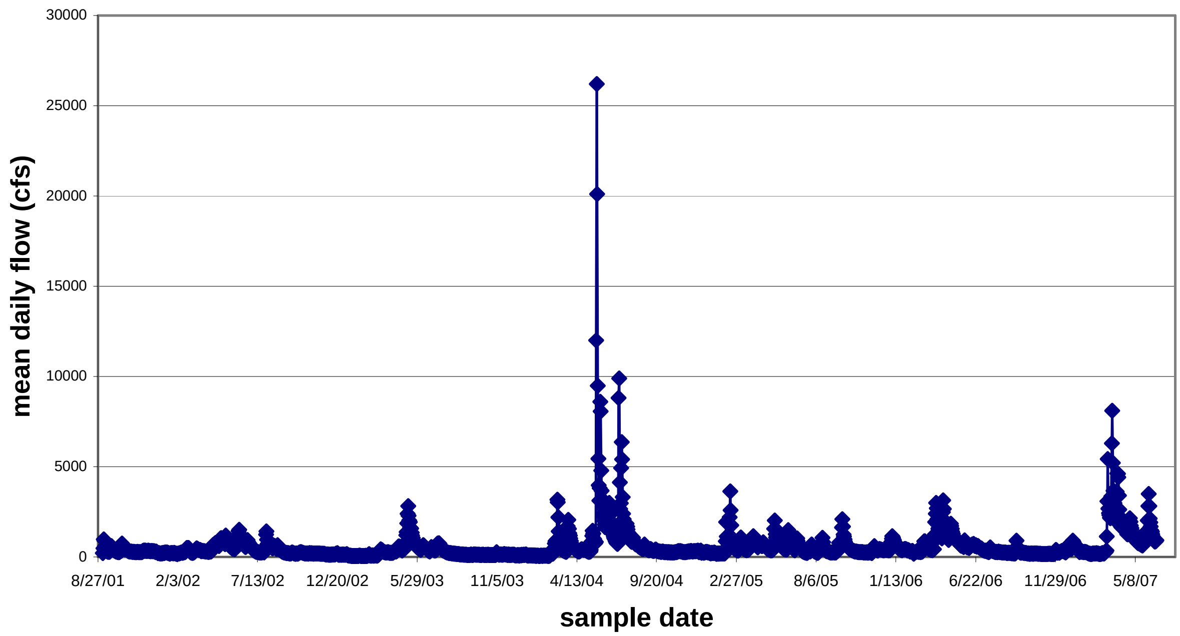

Figure 5. Historic flow data for USGS gauge on Turkey River near Elkader, Iowa.

Biological Impairment

Silver Creek has a history of poor stream biological health dating back at least two decades. During a survey of the Big Spring Basin in 1988 UHL sampled eleven sites for benthic macroinvertebrates and seven for fishes in the Silver Creek watershed. The samples spanned from the headwaters to the confluence with Roberts Creek, including the un-named tributary on which the creamery and WWTP are located. Organisms collected were generally identified to genus taxonomic level and qualitatively compared with stream characteristics. The sampling location downstream of the creamery discharge was described as follows: "*A large number of tubificids (worms) were collected…downstream from a point source discharge with high organic waste loading (creamery waste). The only other organism collected at the site was the chironomid, Chironomus sp. Both of these organisms thrive in waters with high levels of organic enrichment.*" Although seven sites in the Silver Creek watershed were sampled several times, only three species of fish were collected during the study: the bluntnose minnow (*Pimephales notatus*), southern redbelly dace (*Phoxinus erythorgaster* Rafinesque), and the brook stickleback (*Culaea inconstans*) (UHL 1988). Data from the sampling indicated that fish were present only upstream of the creamery discharge and near the confluence with Roberts Creek.

Silver Creek was first added to the Section 303(d) impaired waters list in 2002 following sampling in 2000 as part of the Iowa Dept. of Natural Resources (IDNR)/UHL stream biocriteria project. A series of biological metrics that reflect stream water quality and habitat integrity were calculated from the biocriteria sampling data. The biological metrics are based on the numbers and types of benthic macroinvertebrate taxa and fish species that were collected in the stream sampling reach. The biological metrics were combined to make a fish community index of biotic integrity (FIBI) and a benthic macroinvertebrate index (BMIBI). The indexes rank the biological integrity of a stream sampling reach on a rising scale from 0 (minimum) to 100 (maximum). The 2000 FIBI score was 41 (fair) and the BMIBI score was 46 (fair). The aquatic life use support was assessed as not supporting (=NS), based on a comparison of the FIBI and BMIBI scores with biological assessment criteria (BIC) established specifically for the 2002 Section 305(b) report. The biological assessment criteria were determined from a statistical analysis of data collected at stream ecoregion reference sites from 1994-2001 (IDNR 2005). BIC values were recently updated for the 2006 reporting cycle. The current BICs for streams in the Paleozoic Plateau (52b) ecoregion are 52 (FIBI) and 61 (BMIBI).

Biological sampling was repeated in 2006 at two sites in the Silver Creek watershed (2A and 2E) (Fig.1). The BMIBI and FIBI scores from both sites again failed to meet the BICs thus confirming the biological impairment first documented in 2000 (Table 2). Also during 2006, biological sampling was conducted using the IDNR Rapid Bioassessment Protocol (RBP) at two more sites (2D and 2F) (Appendix 2; Tables 2-5, 2-7). Two additional sites (2B and 2C) were to be sampled using RBP but were not sampled due to lack of flow. The IBI results are the primary evidence of aquatic life use impairment in the Silver Creek watershed. In terms of the diagnosis of stream problems, however, the IBIs are not as useful as the individual metrics that comprise them. Each metric contains unique information about the stream biological community and reflects somewhat distinctive responses to environmental perturbations. Therefore, the IBI metrics from Silver Creek watershed sites (Appendix 2; Tables 2-5, 2-6) have been analyzed in an effort to extract more specific information about the biological impairment and what the metric responses suggest about the types and magnitude of environmental stressors that are affecting the aquatic community.

Table 2. Scores for indices of biological integrity for fish and benthic macroinvertebrates from biological sampling in 2000 and 2006

	Site 1A (2000)	Site 2A (2006)	Site 2E (2006)	BIC for Ecoregion 52b
FIBI	41	19	30	52
BMIBI	46	26	41	61

The full biological sampling FIBI and BMIBI metric scores were analyzed two ways: 1) by comparing the metric scores to regional reference site metric scores and 2) independently analyzing by site, the metric score contribution (or lack of) to the overall index score. Based on the FIBI metric analysis, it was determined that metrics of concern were as follows: low species diversity, lack of benthic invertivores, and dominance of tolerant species. The BMIBI metric analysis indicated the metrics of concern varied by site. For site 2A the BMIBI metrics of concern were as follows: high numbers of flatworms and midges, low Hilsenhoff score, few Ephemeroptera, Plecoptera, and Tricoptera (EPT) taxa, low numbers of sensitive taxa. For site 2E the BMIBI metrics of concern were as follows: low values for EPT taxa, low percentage of EPT taxa, no sensitive taxa, high numbers of tubificids and chironomids, dominated by midges, low Hilsenhoff score. The RBP data was analyzed similarly to the full biological sampling data with respect to the two analyses. The IDNR regional reference site data were summarized to the same level as the RBP data and this allowed presence/absence metrics to be compared. The RBP FIBI metric analysis revealed the same metrics of concern as the full biological analysis. The RBP BMIBI metric analysis at site 2F agreed with the full biological analysis at site 2E, while the RBP BMIBI at site 2D suggested that the benthic macroinvertebrate community at that site appears to be acceptable.

Stakeholder observations

Several observations about the condition of Silver Creek and the stream's aquatic life were received from landowners during the RASCAL analysis in December 2006. The issue that drew the most attention from landowners was the losing nature of the stream. Nearly all of the landowners downstream of the instream sinkholes (especially those that utilized the stream as a water source for cattle) were aware that Silver Creek lost a significant amount of surface flow into sinkholes. A common comment was, "the stream used to run all year and now it doesn't…we would like something done about it".

Several residents commented that surface flows were reduced significantly following heavy rainstorms in the watershed. A severe storm that dumped more than 11 inches of rain in the area in June of 1991 was commonly cited. Theoretically, similar storms in 1999 and 2004 may have opened up additional sinks in the stream. Given the history of groundwater mapping in the county, most landowners are aware that sinkholes in the watershed had been traced to Big Spring.

Most dairy and beef producers recognized that they could have a significant impact on water quality if they removed their cattle from the stream. However, they also commented that given the recent history of storms and floods, it would be costly and time consuming to maintain additional stream fences. One of the cattlemen noted that he was still picking up debris that was carried into his pasture during the 2004 storms.

Several landowners commented that before the creamery installed current treatment facilities, it was easy to recognize when wastes were discharged into the tributaries of Silver Creek. During those times, the stream would appear discolored to the point where "Silver Creek ran white". A few landowners also commented that they fished for chubs and minnows in the stream in their youth. Although Silver Creek is considered a nursery stream for smallmouth bass that migrate from Roberts Creek and the Turkey River, given the lack of flow stability in some reaches of Silver Creek, fishing opportunities would appear to be quite limited.

Stressor Identification Process

Iowa's SI procedures (IDNR 2005) are adapted from technical guidance documents developed by the U.S. Environmental Protection Agency (EPA) (2000, 2005). The EPA also supports an on-line resource named "Causal Analysis/Diagnosis Decision Information System" (CADDIS) (http://cfpub.epa.gov/caddis/) where SI-related information and tools are available.

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Candidate Causes and Theoretical Associations

Candidate causes for SI analysis are chosen from the IDNR generalized list of aquatic life use impairment causes (IDNR 2005). The candidate cause list includes most of the pollutant and non-pollutant based causal agents that are known to adversely impact aquatic life in Iowa's rivers and streams. It is important to note that candidate causes are identified at varying scales and degrees of separation from the proximate stressor that actually elicits an adverse in-stream biological response. Conceptual models (Appendix 3) are used to illustrate the mechanisms and pathways that link activities or sources in a watershed with proximate stressors. From this perspective, an impairment cause can be viewed more broadly as encompassing the stressor itself, the activities or sources that produce the stressor, and the mechanism(s) and pathway(s) by which the stressor is manifested in a stream. Conceptual models also are a useful means of organizing the evidence review process, which is discussed in the next section. A ranking process is used to reduce the master list of candidate causes to a manageable size. After a cursory review of sampling data, watershed land use and other pertinent information, each candidate cause is assigned a rating (high, medium, low) based upon the relative probability any given cause, by itself, could be responsible for the observed impairment. The final ratings are obtained by consensus opinion among SI team members. Candidate causes ranked as high or moderate probability are selected for the analysis of causal association. While not completely eliminated, candidate causes ranked as low probability are not advanced for further consideration. Low probability candidate causes can be reconsidered should the evidence analysis process fail to identify any likely causes from the primary list.

The results of the candidate cause rating process for the Silver Creek watershed biological impairments are displayed in Table 3.

Table 3: Silver Creek aquatic life use impairment candidate causes and average probability rankings: (1) high; (2) medium; (3) low

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- **Toxins (sediment and water)**
  - o Metals
    - Arsenic (3)
    - Cadmium (3)
    - Chromium (3)
    - Copper (3)
    - Lead (3)
    - Mercury (3)
    - Selenium (3)
    - Zinc (3)
    - Other
  - o Non-Metals
    - Chlorine (3)
    - Cyanide (3)
    - Oil / grease (3)
    - PAHs (3)
    - Pharmaceuticals (3)
    - SOCs (3)
    - Unionized ammonia (1.5)
    - Other
  - o Pesticides
    - Fungicides (3)
    - Herbicides (3)
    - Insecticides (2)
    - Other

- **Water quality characteristics**
  - o Chlorophyll a (1.5)
  - o Dissolved oxygen (1)
  - o Nutrients
    - Nitrogen (2)
    - Phosphorus (1.5)
  - o pH (3)
  - o Salinity / TDS (3)
  - o Turbidity / TSS (1)
  - o Water temperature (2)

- **Habitat Alterations**
  - o Bank erosion (1)
  - o Channel incision / loss of floodplain connectivity (2)
  - o Channel Straightening (2)
  - o Dewatering (1)
  - o Excessive algae/macrophyte growth (2)
  - o Flow impoundment (3)
  - o Lack of woody debris/channel roughness/structure (2)
  - o Physical barriers (3)
  - o Riparian vegetation loss (1.5)
  - o Sedimentation (1)

- **Hydrologic Alterations**
  - o Flow diversion (3)
  - o Flow regulation (dams) (3)
  - o Pumping (withdrawals) (3)
  - o Subsurface tile drainage (3)
  - o Urban stormwater outfalls (3)
  - o Wetland loss (3)

- **Exotic/Introduced Species and Other Biotic Factors**
  - o Competition (3)
  - o Disease (3)
  - o Endocrine disruption (3)
  - o Harvest (3)
  - o Refugia depletion/isolation (1)
  - o Predation (3)

Analysis of Associations

The analysis of associations is a multi-step process comprised of thirteen types of evidence consideration (Table 4). The analysis begins with a consideration of the temporality and spatial co-occurrence of the stressor and effect. These two considerations examine the evidence indicating whether a given stressor and detrimental stream biological response occur at the same time in the same place.

Table 4. Evidence considerations that comprise the analysis of stressor-effect associations (U.S. EPA, May 2005: Handbook for characterizing causes. Eighth Edition).

Evidence Consideration	Description
Temporality	The effect occurs when the candidate cause occurs and the effect is absent when the candidate cause is absent.
Spatial Co-occurrence	The effect occurs where the candidate cause occurs, and the effect is absent where the candidate cause is absent.
Biological gradient	Effects decline as exposure declines over space and time.
Complete causal pathway	A causal pathway is present representing the sequence of events that begins with the release or production of a stressor from a source and ends with an adverse biological response.
Mechanistically plausible causal pathway	Evidence is available from the site or elsewhere that the causal mechanism is plausible.
Plausible effect given stressor-response relationship	Site exposures are at levels that cause effects in the laboratory, in the field, or in ecological process models.
Consistency of association	Repeated observation of the effect and candidate cause in different places or times especially if the methods of measurements are diverse.
Analogy	Similar candidate causes have been shown to cause similar effects.
Specificity of cause	Specific effect occurs with only a few causes
Manipulation of exposure	Toxicity tests, controlled studies, or field experiments (site specific or elsewhere) demonstrate that the candidate cause can induce the observed effect.
Predictive performance	Candidate cause results in other predicted conditions not encompassed by the initially observed effects.
Evidence Consistency	The hypothesized relationship between cause and effect is consistent across all available evidence.
Evidence Coherence	There are no inconsistencies in evidence or some inconsistencies that can be explained by a possible mechanism.

Upon review, it was concluded that the Silver Creek data set was inadequate for examining temporal relationships of stressors and effects. In this SI and others, a major hindrance to considering this line of evidence is the lack of coordinated monitoring for stressors and effects over time. With the Silver Creek case, there was not a clear sequence of evidence demonstrating the stressor(s) were introduced in the stream first and then detrimental biological effects were observed. Likewise, the available evidence was inadequate to determine that effects preceded stressor onset.

Spatial Co-occurrence and Stressor-Response Relationships

The evidence considerations for Spatial Co-occurrence and Plausible Effect Given Stressor-Response Relationship involved comparing sampling data from the Silver Creek watershed with data collected for the IDNR stream biological assessment program. Silver Creek sampling data and benchmarks reviewed for the spatial co-occurrence and stressor-response evidence considerations are summarized in Table 5. In addition to water quality and stream habitat data, diurnal temperature and dissolved oxygen fluctuations were monitored at site 2A in May (14d) and September (18d), 2007 (Appendix 2; Figure 2-10). These data were used to determine if violations of the dissolved oxygen standard have occurred and whether or not high temperatures occur in Silver Creek. The data were also used to estimate stream metabolism rates including: community respiration, net and gross primary production, and production: respiration ratio. The estimates were obtained using the single station method (Odum 1956; Bott 1996), which calculates the incremental rate of change in dissolved oxygen concentration over a 24-hour period measured at a single stream monitoring station.

For spatial co-occurrence, Silver Creek stressor indicator data and RASCAL observations were compared with interquartile data ranges (IR: 25th to 75th percentile) for stream reference sites within the Paleozoic Plateau ecoregion (52b). In cases when reference data were not available, Silver Creek sampling data were sometimes compared with data from the statewide probabilistic (random) survey of perennial streams, a sampling project adapted from the U.S. EPA's Regional Environmental Monitoring and Assessment Program (REMAP). In some cases, other benchmarks such as maximum or minimum ecoregion reference values, state water quality standards, or mean values from statewide random survey sites were applied in lieu of the reference IR. A stressor was deemed present at a site when the appropriate indicator value exceeded the benchmark value.

The next step was to determine whether the stressor exists at a level that is expected to elicit adverse effects to the aquatic community. This analysis of stressor response was done by examining stressor-response relationship curves developed from Iowa's statewide stream bioassessment database, which contains sites having BMIBI and/or FIBI scores as well as water quality and stream habitat measurements. A description of conditional probability, one technique used to evaluate stressor-response relationships may be found in Appendix 1D.

Table 5. Spatial co-occurrence and stressor response considerations for candidate causes in Silver Creek, Iowa.

*(*abbreviations: IR; Interquartile Range; NA, data indicator and/or stressor threshold not available; ?, uncertain or unknown; Qual., based upon qualitative evaluation only)*

Spatial Co-occurrence & Stressor Response						
Stressor	Indicator	Concentration or level at unimpaired sites in other waterbodies*	Concentration or level at impaired site(s) in the watershed	RASCAL and aerial photo assessment	Consistent with Spatial Co-occurrence	Consistent with Stressor Response
Altered Flow Regime (Conceptual Model 1)						
Increased max. flow	NA	NA	NA	NA	?	?
Increased frequency of low flows	Flow:Contribution area ratio	0.04-0.32 IR for statewide 3rd order monitoring sites (n=151)	2A 0.024 (n=8)	1 mile (<10%) of channel classified as losing or dry channel	Yes	Yes
Altered daily or seasonal flow patterns	NA	NA	NA	NA	?	?

Stressor	Indicator	Concentration or level at unimpaired sites in other waterbodies*	Concentration or level at impaired site(s) in the watershed	RASCAL and aerial photo assessment	Consistent with Spatial Co-occurrence	Consistent with Stressor Response
Altered Substrate (Conceptual Model 2)						
Increased suspended sediment (abrasive effects to soft tissue)	TSS (mg/L)	Baseflow 6.75-24.25 IR for regional reference sites (n=14)	Non-Event 2A 24.5 (n=8) 2D 10.5 (n=8) 2E 22.17 (n=6)	Silt/mud is dominant substrate along 91% of channel-easily re-suspended	Yes	Yes
Decreased clarity (reduced feeding efficiency)	Turbidity (ntu)	3.6-14.75 IR for regional reference sites (n=14)	Non-Event 2A 16.8 (n=8) 2D 5.65 (n=8) 2E 8.3 (n=6)		Yes	Yes
Decrease in benthic algae or macrophytes as a substrate for organisms	Periphyton Chl. A (ug/cm^2)	16.6 (7.9-19.9) median (IR) for 52b random sites (n=16)	2A 52.5 (n=2)	NA	No	No
	Sediment Chl. A (ug/cm^2)	6.7 (3.6-11.6) median (IR) for 52b random sites (n=16)	2A 15.9 (n=2)	NA	No	No
Increased deposited fine sediment	%Total fines	12.5-55.2 IR for regional reference sites (n=7)	2A 90 (n=1) 2E 72 (n=1) 1A 95 (n=1)	NA	Yes	Yes
	% Silt	8.5-29.67 IR for regional reference sites (n=7)	2A 90 (n=1) 2E 70 (n=1) 1A 60 (n=1)	NA	Yes	Yes
	%t Sand	4-18.5 IR for regional reference sites (n=7)	2A 0 (n=1) 2E 2 (n=1) 1A 35 (n=1)	NA	No	No
	% Thalweg profile w/soft sediment	1.8-53.6 IR for regional reference sites (n=5)	2A 92.9 (n=1) 2E 64.3 (n=1)	NA	Yes	Yes
	Sediment Deposition	RBP Qualitative Rating (poor >80% sediment depostition)		Silt/mud is substrate on 91% of channel and 75% of cobble is mostly embedded	Yes (Qual.)	Yes (Qual.)
	% Reach area as pool habitat	30.35-46.43 IR for regional reference sites (n=7)	2A 96.4 (n=1) 2E 3.6 (n=1) 1A 35.7 (n=1)	30% of channel length had no pools 57% had <1pool per 250 ft	2A Yes 2E Yes 1A No	2A Yes 2E Yes 1A No

Stressor	Indicator	Concentration or level at unimpaired sites in other waterbodies*	Concentration or level at impaired site(s) in the watershed	RASCAL and aerial photo assessment	Consistent with Spatial Co-occurrence	Consistent with Stressor Response
Altered Substrate (Conceptual Model 2) continued						
Loss of pool area & depth	Maximum depth (ft.)	3.8-5.5 IR for regional reference sites (n=7)	2A 2.1 (n=1) 2E 1.5 (n=1) 1A 2.1 (n=1)	Aerial photo evidence indicates a 4% loss in channel length since 1930	Inconclusive	Inconclusive
	Width:Depth Ratio	10.75-24.27 IR for regional reference sites (n=7)	2A (12.5) (n=1) 2E (9.5) (n=1) 1A (10.9) (n=1)		No	No
Embedded riffles	Embedded-ness rating (% coarse substrate area embedded by fine sediment)	1.93-2.43 IR for regional reference sites (n=7)	2A (4) (n=1) 2E (3) (n=1) 1A (5) (n=1)		Yes	yes
		RBP Qualitative Rating Range: 0-5 (poor, >75%); 6-10 (marginal 50-75%); 11-15 (sub-optimal, 25-50%; 16-20 (optimal, 0-25%)		9% of channel bottom dominated by cobble 75% of cobble classified as mostly embedded	Yes (Qual.)	Yes (Qual.)
Buried organisms	NA	NA	NA	NA	?	?
Altered Basal Food Source (Conceptual Model 3)						
Increased / altered primary producers	Seston Chl. A (ug/L)	6.5 (3.9-19.8) median (IR) for 52b random sites (n=16)	Median (IR) 2A 22.5 (8-100) (n=8) 2D 4.5 (2-6) (n=8) 2E 2.0 (1-4) (n=6)	NA	2A Yes 2D No 2E No	2A Yes 2D No 2E No
	Periphyton Chl. A (ug/cm^2)	16.6 (7.9-19.9) median (IR) for 52b random sites (n=16)	Median (IR) 2A 52.5 (n=2)	NA	Yes	Yes
	Sediment Chl. A (ug/cm^2)	6.7 (3.6-11.6) median (IR) for 52b random sites (n=16)	Median (IR) 2A 15.9 (n=2)	NA	Yes	No
	Respiration ($g\ O_2/m^2/d$)	6.0 (4.8-6.7) median (IR) for 52b random sites (n=13)	2A 10.75 May (n=14d) 2A 6.23 Sept. (n=18d)	NA	Yes	Yes
	Gross primary production (GPP) ($g\ O_2/m^2/d$)	3.5 (2.6-4.4) median (IR) for 52b random sites (n=13)	2A 9.5 May (n=14d) 2A 2.29 Sept (n=18d)	NA	Yes	Inconclusive
	Production-to-respiration ratio (P:R)	0.57 (0.47-0.99) median (IR) for 52b random sites (n=13)	2A 0.88 May (n=14d) 2A 0.37 Sept (n=18d)	NA	No	No

Stressor	Indicator	Concentration or level at unimpaired sites in other waterbodies*	Concentration or level at impaired site(s) in the watershed	RASCAL and aerial photo assessment	Consistent with Spatial Co-occurrence	Consistent with Stressor Response
Altered Basal Food Source (Conceptual Model 3) continued						
Decreased allochthonous food resources	RBP - Very Minimal Leaf Litter, Detritus, Small Woody Debris	NA		67%channel has <25% canopy coverage 54% <10% coverage	Inconclusive	Inconclusive
	RBP - Very Minimal Large Woody Debris	NA	2A 0.5% (n=1) 2E 0.0% (n=1)	22% of stream has trees on one side or other	Yes (Qual.)	Inconclusive
Decreased Dissolved Oxygen (Conceptual Model 4)						
Decreased dissolved oxygen	Range of DO (mg/L) levels from daytime grab samples	8.65-9.63 IR for regional reference sites (n=14)	Non-Event 2A 6.11 (n=8) 2D 9.36 (n=8) 2E 5.6 (n=6)	NA	Yes	Yes
	Minimum DO (mg/L) from daytime grab samples	6.8 minimum for regional reference sites (n=14)	2A 0.3 (n=8) 2D 8.4 (n=8) 2E 3.8 (n=6)	NA	Yes	Yes
	Minimum DO (mg/L) from datalogger		2A May 2007 4.22 Sept. 2007 5.53		Yes	Yes
	Meeting water quality standards designed to protect aquatic life	≥ 5.0 mg/L at least 16h/day	2A 5/15/07 violation (10.75 < 5.0)	NA	Yes	Yes
		Minimum value ≤4.0 mg/L	Site # violation (DO values) 2A Two (3.2, 0.3) 2E Two (3.8, 3.2)	NA	Yes	Yes
Increased Temperature (Conceptual Model 5)						
Increased temperature	Mean temp. (deg. C) from grab samples	13.88-18.73 IR for regional reference sites (n=14)	2A 18.6 (n=8) 2D 16.9 (n=8) 2E 25.6 (n=6)	NA	Yes	Yes
	Maximum temp. (deg. C) from grab samples	19.9 maximum for regional reference sites (n=14)	2A 28.2 (n=8) 2D 25 (n=8) 2E 30 (n=6)	NA	Yes	Yes
	Diurnal mean temp. (deg. C)	18.6 (16.8-23.1) median (IR) for 52b random sites (n=13)	2A Median (IR) 16.6 (10.8-23.8) (5/1-5/15/07) 16.2 (9.9-21.3) (9/6-9/24/07)	NA	No	No
	Diurnal maximum temp. (deg. C)	22.7 (20.8-28.1) median (IR) for 52b random sites (n=13)	2A 23.8 (5/1-5/15/07) 21.3 (9/6-9/24/07)	NA	No	No
	Diurnal minimum temp. (deg. C)	14.8 (12.3-19.5) median (IR) for 52b random sites (n=13)	2A 10.8 (5/1-5/15/07) 9.9 (9/6-9/24/07)	67% channel has <25% canopy coverage; 54% <10% coverage	No	No

Stressor	Indicator	Concentration or level at unimpaired sites in other waterbodies*	Concentration or level at impaired site(s) in the watershed	RASCAL and aerial photo assessment	Consistent with Spatial Co-occurrence	Consistent with Stressor Response
Increased Ammonia (Conceptual Model 6)						
Increased ammonia	Mean total ammonia	0.05-0.10 IR for regional reference sites (n=7)	2A 0.65 (n=8) 2D 0.07 (n=8) 2E 2.72 (n=6)	NA	Yes	Yes
	Unionized ammonia exceeds WQ stds.	(Variable criterion depending on pH and temperature)	2A-2 chronic violations (n=17) 2E-1 acute/9 chronic violations (n=14)	NA	Yes	Yes
Physical Habitat Alteration (Conceptual Model 7)						
Decreased macro-habitat complexity	%t (type) dominant channel bedform unit	IRs for regional references (n=7) 14-26.8 (Riffle) 26.8-57.2 (Run) 30.4-46.4 (Pool)	riffle/run/pool 2A (n=1) (3.6/0/96.4) 2E (n=1) (3.6/92.9/3.6) 1A (n=1) (10.7/53.6/35.7)	6% (Riffle 94% (Run) 30% of channel length contained no pools 57% had <1pool per 250 ft	Yes	Yes
	RBP - lacking variation in current velocity & depth	NA		94% of channel "run"; 87% either no pool or <1 pool per 250ft	Inconclusive	Inconclusive
	Width: Thalweg Depth Ratio	10.75-24.27 IR for regional reference sites (n=7)	2A 12.5 (n=1) 2D 10.9 (n=1) 2E 9.5 (n=1)	NA	No	No
	S.D. mean depth	0.65-0.76 IR for regional reference sites (n=7)	2A 0.48 (n=1) 2E 0.28 (n=1) 1A 0.5 (n=1)	NA	Yes	Yes
	RBP deep channel incision / no floodplain connectivity	NA	2D Yes (n=1) SC6 Yes (n=1)	NA	Yes (Qual.)	Inconclusive
Decreased micro-habitat complexity	% Instream cover (DNR method)	4-18 IR for regional reference sites (n=7)	SiCr 1 13 (n=1) SiCr 5 21.5 (n=1)	30% channel had poor habitat rating 87% had no pools or <1 pool per 250ft	No	No
	% Occurrence large woody debris (DNR method)	7.1-21.4 IR for regional reference sites (n=7)	SiCr 1 0.5 (n=1) SiCr 5 0 (n=1)	22% of stream has trees on only one side; LWD noted only once	Yes	Yes
	RBP - Very Minimal Leaf Litter, Detritus, Small Woody Debris	see CM 3		67% channel has <25% canopy coverage 54% <10% coverage	(Qual.)	Inconclusive
	RBP - Very Minimal Large Woody Debris	see CM 3		LWD noted only once	(Qual.)	Inconclusive

Complete Causal Pathway

Following the evaluation of spatial co-occurrence and stressor-response relationships, the available stream and watershed information were reviewed to determine the plausibility of hypothesized causal pathways linking sources to biological impairment. Similar to the approach used for considering co-occurrence and stressor-response relationships, data from Silver Creek were compared to interquartile data ranges from reference sites within the Paleozoic Plateau ecoregion or data ranges for statewide random survey sites. The indicator data and other relevant information were evaluated qualitatively and/or quantitatively to evaluate the evidence supporting each hypothesized causal pathway. The results of this evaluation process are shown in the causal pathway conceptual model diagrams in Appendix 3.

Strength of Evidence

The U.S. EPA (2005) handbook for characterizing causes served as the primary guidance document for evidence analysis and ranking. The main types of evidence consideration utilized in this SI are: *Spatial Co-occurrence; Plausible Effect Given Stressor-Response Relationship; Complete Causal Pathway and Consistency of Association*. All of these incorporated data from Silver Creek along with ecoregion-specific or statewide sampling data. The Silver Creek sampling data were not sufficient to perform the *Temporality* and *Biological Gradient* evidence considerations. The review team was unable to identify any analogous stressor-response scenarios; therefore, the *Analogy* line of evidence did not contribute to the SI. Other lines of evidence were selectively applied depending on the stressor and data/evidence.

Primary Causes

The results of the strength of evidence analysis are summarized in Table 5. The proximate stressors identified in the SI process (not ranked by order of importance) are: un-ionized ammonia, dissolved oxygen, sedimentation, and dewatering. The supporting evidence for each primary cause (i.e., proximate stressor and associated causal pathways) is described below.

<u>Un-ionized Ammonia</u>
Un-ionized ammonia is directly toxic to aquatic invertebrates and fish. Iowa has water quality standards criteria designed to protect aquatic life against acute or chronic toxicity from un-ionized ammonia. The criteria are expressed as total ammonium ion concentration from which un-ionized ammonia concentration can be determined as a function of pH and temperature. For a given concentration of total ammonium ion, an increase in pH and/or temperature will result in an increase in un-ionized ammonia concentration. Based on a comparison of Silver Creek sampling results to regional reference site levels, elevated pH and water temperature may be factors contributing to the occurrence of toxic unionized ammonia levels in the Silver Creek watershed. Mean total ammonia concentrations exceeded the 75^{th} percentile for regional reference streams at sites 2A and 2E (Appendix 2, Figures 2-3 and 2-4).

Sampling data provide evidence of toxic levels of ammonia that occur sporadically in the Silver Creek watershed. Total ammonia levels exceeded the chronic water quality criteria twice at the 2A site and nine times at the 2E site. Additionally, the ammonia levels at site 2E exceeded the acute water quality criteria in December 2006). Site 2E is located immediately downstream of the inputs from the Swiss Valley Farms Creamery, as well as receiving inputs from the Monona WWTP. The monitored ammonia violations were not known to be associated with a runoff event or spill of animal waste or fertilizer. Stream flow and TSS levels were not particularly elevated at the time of sampling, except for one instance at 2E on November 6, 2006.

Sedimentation

Several sediment-related indicators provide evidence of sedimentation as a primary stressor in the Silver Creek biological impairment. Embeddedness is the degree to which coarse rock substrates such as gravels, cobbles, and boulders are surrounded or embedded within fine sediment particles. Embeddedness is often evaluated in riffles or shallow runs where current velocities are normally high enough to prevent excessive fine sediment accumulation. As embeddedness increases, the large and small spaces between rocks become filled with fine sediment particles making this important habitat niche less suitable for invertebrates and fish, which utilize it for feeding, shelter, spawning, and egg incubation.

The examination of stressor-response plots from Iowa streams indicated embeddedness ratings above 3.0 (40-60 percent) are associated with a higher probability of FIBI levels that are considered biologically impaired in the Paleozoic Plateau ecoregion. There is strong evidence that embeddedness occurs at levels consistent with impairment at multiple locations in the Silver Creek watershed. The average embeddedness rating for three full biocriteria sampling sites in the watershed was 4 (Table 4), which corresponds with an embeddedness range from 60-80 percent. The ecoregion reference site 75th percentile embeddedness rating is 2.43, which is roughly equivalent to 30-50 percent.

Silt is fine-grained, unconsolidated sediment that usually covers only a small amount of the stream bottom in healthy stream systems. For example, the interquartile range for Paleozoic Plateau reference sites is 8.5-29.67 percent. Silt is easily suspended and transported downstream; therefore, it is usually found along the margins of streams and in stagnant pools. Silt can be a significant component of turbidity reducing water clarity for sight feeding fish. As silt settles to the bottom, it smothers aquatic habitat and interferes with biological processes such as organism respiration, spawning and egg incubation, and photosynthetic production. The percent stream bottom as silt, which was estimated at three full biocriteria sampling sites ranged from 72-95 percent and the average was 85.67 percent. An examination of stressor-response data from Iowa streams generally revealed an increased occurrence of BMIBI and FIBI levels considered biologically impaired as silt bottom coverage increased to 20percent or more (Appendix 2; Figures 2-8 and 2-9). Silty stretches of stream appear to be widespread in the Silver Creek watershed (Appendix 2; Figure 2-17). In addition to assessments done at the three full biocriteria sites, both rapid bioassessment sites were evaluated as having silt covering much of the stream bottom including rock substrates.

The evidence of sediment deposition impacts from the perspective of alteration of stream macro habitat characteristics such as pool size/depth, sediment bar development, and channel shape/dimension does not support this causal pathway as much as other evidence supporting impacts related more to substrate quality such as aerial amount of silt or coarse substrate embeddedness. From Table 5, indicator data from full biocriteria sample sites that did not provide evidence of sedimentation impacts from a stream habitat alteration standpoint include: percent stream reach as pool, maximum depth and stream width to thalweg depth ratio. These indicators are within the expected ranges for Paleozoic Plateau reference stream sites and do not occur at levels that are consistent with impaired BMIBI or FIBI levels.

Elevated levels of suspended solids and turbidity directly and indirectly impact stream aquatic communities leading to increased dominance of tolerant species. Direct impacts include diminished success of sight feeding fish and increased respiratory stress for sensitive invertebrates with external gill structures. Indirect impacts are related to sedimentation of fine particles, which is discussed in detail below. The highest TSS levels observed in Silver Creek were sampled in Spring 2007 during elevated flow conditions. Levels of TSS and turbidity monitored during base flow conditions at site 2A were also elevated relative to typical levels measured at least disturbed stream reference sites in the Paleozoic Plateau ecoregion. The median TSS and turbidity levels for Silver Creek watershed monitoring sites equaled or exceeded the 75th percentile of Paleozoic Plateau ecoregion reference sites at site 2A, but were within the interquartile range at sites 2D and 2E (Table 4).

Potential sources of suspended solids and turbidity in the watershed include: sheet and rill erosion from agricultural fields; gully erosion, stream bed/bank erosion; re-suspension of fine sediment by watering livestock. The estimated average potential sheet and rill erosion rate based on 2002 land cover and soil survey data is 3.4 tons/acre/year (Appendix 2; Figure 2-15). Approximately 73 percent of the watershed area is in row crop indicating relatively high sediment delivery potential, which is estimated at an average of 0.68 tons/acre/year (Appendix 2; Figure 2-16).

Evidence of streambed and bank erosion in the Silver Creek watershed is mixed. Whereby stream bank stability and vegetative conditions in some stream reaches were rated as relatively good, other areas were rated as poor condition (Appendix 2; Figure 2-20). Excessive bank erosion/sloughing, and livestock access were noted along much of the main channel during the RASCAL analysis. At the three full biocriteria sampling sites, the percentage area of vertical stream bank (55-110 degree slope), which might be considered the most vulnerable to erosion and sloughing, averaged 46 percent (range: 0-90), which is much higher than the 75th percentile (20percent) for regional reference sites. The average percentage bank area comprised of bare soil or sediment at the three biocriteria sites was high 77 percent (range: 52.5-93 percent) exceeding the reference site 75th percentile level (51.75 percent). Taken as a whole, there is sufficient evidence indicating bank erosion and cattle grazing activities are significant sources of suspended solids and turbidity in Silver Creek.

<u>Dissolved Oxygen</u>
Depending on severity, reduced levels of dissolved oxygen can cause impacts to aquatic life ranging from acute mortality to chronic stressed behavior and diminished biological functions. Available monitoring data indicate dissolved oxygen levels in the Silver Creek watershed are mostly suitable for aquatic life, but there is also evidence that oxygen levels occasionally fall below water quality standards.

The impaired segment of Silver Creek is designated for Class B(WW-2) aquatic life uses. Dissolved oxygen levels for streams of this designation must remain above 5 mg/L at least 16 hours per day and a level of 4 mg/L must be maintained at all times. Continuous diurnal monitoring was conducted at site 2A (Figure 1) in the Silver Creek watershed during May and September 2007. Dissolved oxygen levels fell between 4-5 mg/L for 10.75 hours on May 14-15, 2007 (Appendix 2; Figure 2-10), which violates water quality standards criteria. Biweekly daytime grab samples in 2006 showed that the mean DO levels at site 2A and 2E were below the interquartile range for the ecoregion reference sites (Table 4) (Appendix 2, Figures 2-11 and 2-12). Additionally there were two violations of the minimum DO levels at each of these two sites, with readings of 3.2 mg/L (July 12) and 0.3 mg/L (August 7) at 2A and 3.8 mg/L (October 3) and 3.2 mg/L (November 6) at 2E.

The continuous monitoring data from site 2A in May and September 2007 indicate moderate dissolved oxygen fluctuation between light and dark hours of the day. Average daily fluctuation (maxima – minima) was 6.29 mg/L in May and 4.87 mg/L in September. These fluctuations are driven mainly by photosynthetic activity of algae and plants covering the stream bottom. The minimum daily dissolved oxygen concentration usually occurs during the dark hours when photosynthetic production of oxygen is not taking place. The dissolved oxygen saturation level decreases with increasing water temperature. Dissolved oxygen levels in Silver Creek mostly remain acceptable during summer low flow conditions with a few exceptions.

Average community respiration rates at site 2A were estimated at 10.75 $gO_2/m_2/d$ in May and 6.23 $gO_2/m_2/d$ in September 2007. Community respiration levels above 7.5 $gO_2/m_2/d$ are associated with increased occurrence of substandard dissolved oxygen levels and reduced IBI levels in Iowa streams. Temperature and light availability in the stream also has an impact on stream productivity. Groundwater inputs most likely have a cooling effect on stream temperatures in the Silver Creek watershed; however, effluents from the creamery increase the stream temperature. Shading from riparian vegetation can also help maintain cooler stream temperatures. Riparian canopy coverage in the Silver Creek watershed is highly variable. Some areas are significantly shaded while many other areas have no shade. By helping maintain cooler water temperature and reducing light supporting excessive levels of primary production, the establishment of woody riparian vegetation in unshaded stream reaches of the Silver Creek watershed could help maintain acceptable dissolved oxygen levels.

Dewatering

There is some evidence that during low flow periods, much of the flow in Silver Creek is diverted by in-stream sinkholes. This likely exacerbates the effects of low flow on temperature and dissolved oxygen. Additionally, these sinkholes may be a barrier to fish migration upstream, leading to isolation. However, although there is some evidence that low flow has an effect on IBI scores (Appendix 2, Figures 2-13 and 2-14), we do not have sufficient information to draw conclusions effects of stream dewatering.

Table 6. Summary of strength of evidence analysis results for proximate stressors.

	Evidence Consideration													
Proximate Stressor	**Temporality**	**Co-occurrence**	**Biological gradient**	**Complete causal pathway**	**Mechanistically plausible causal pathway**	**Plausible effect given stressor-response relationship**	**Consistency of association**	**Analogy**	**Specificity of cause**	**Manipulation of exposure**	**Predictive performance**	**Evidence Consistency**	**Evidence Coherence**	**Final Rating**
↑ Ammonia	o	o	o	++	+++	+++	+	NA	o	+++	NA	+	+	+
↑ Pesticides	o	o	o	o	+	o	+	NA	o	+++	NA	NA	NA	o
↑ Seston Algae (Chl. A)	o	o	+	+	+++	+	+	NA	o	o	NA	+	+	o
↓ Dissolved Oxygen	o	+	+	++	+++	+++	+	NA	o	+++	NA	+++	+++	+
↑ Nitrogen	o	o	o	++	+++	o	+	NA	o	o	NA	+	+	o
↑ Phosphorus	o	+	o	+	+++	+	+	NA	o	o	NA	+	+	o
↑ TSS / Turbidity	o	+	+	++	+++	+	+	NA	o	+++	NA	+	+	+
↑ Temperature	o	o	o	++	+++	+	+	NA	o	o	NA	+	+	
↑ Bank erosion	o	o	+	+	+++	+	+	NA	o	o	NA	+	+	+
Channel incision /loss of floodplain connectivity	o	o	+	+	+++	+	+	NA	o	o	NA	+	+	o
Channel straightening	o	o	o	+	+++	+	+	NA	o	o	NA	+	+	-
Dewatering	o	o	+	+	+++	+	+	NA	o	o	NA	+	+	+
↑ Algae /Macrophyte growth	o	o	o	+	+++	o	-	NA	o	o	NA	---	+	o
↓ Woody Debris /Channel Roughness /Structure	o	+	+	++	+++	+	+	NA	o	o	NA	+	+	o
↓ Riparian Vegetation	o	+	+	++	+++	+	+	NA	o	o	NA	+	+	o
↑ Sedimentation	o	+	o	++	+++	+	+	NA	o	o	NA	+	+	+
↑ Aquatic Life Isolation	o	o	+	+	+++	+	+	NA	o	o	NA	+	+	+

NA = not applicable, o = ambiguous or not enough evidence; +,++,+++ = rating levels for supporting evidence; -, --, --- = rating levels for not supporting evidence (after U.S. EPA 2005)

From SI to TMDL

Because the SI process was initiated pursuant to Iowa's Section 303(d) listings for biological impairments with unknown causes, the primary stressors determined by the SI are communicated in terms of standard cause and source codes as specified in U.S. EPA guidance for the 2004 Integrated Report and the IDNR 305(b) assessment protocol (IDNR 2005). The 305(b)/303(d) candidate cause list is shown in Table 7.

The primary stressors identified by this SI translated into 305(b)/303(d) cause codes are: Unionized Ammonia (600); Siltation (1100); Organic enrichment / Low DO (1200); Flow alteration (1500).

Table 7. The candidate causes with associated cause codes as used by the 305(b) assessment/303(d) listing methodology.

Cause Code	Cause Name	Cause Code	Cause Name	Cause Code	Cause Name
0	Cause Unknown	570	Selenium	1300	Salinity/TDS/Chlorides
100	Unknown toxicity	580	Zinc	1400	Thermal modifications
200	Pesticides	600	Unionized Ammonia	1500	Flow alteration
250	Atrazine	700	Chlorine	1600	Other habitat alterations
300	Priority organics	720	Cyanide	1700	Pathogens
400	Non-priority organics	750	Sulfates	1800	Radiation
410	PCB's	800	Other inorganics	1900	Oil and grease
420	Dioxins	900	Nutrients	2000	Taste and odor
500	Metals	910	Phosphorus	2100	Suspended solids
510	Arsenic	920	Nitrogen	2200	Noxious aquatic plants
520	Cadmium	930	Nitrate	2210	Algal Growth/Chlorophyll a
530	Copper	990	Other	2400	Total toxics
540	Chromium	1000	pH	2500	Turbidity
550	Lead	1100	Siltation	2600	Exotic species
560	Mercury	1200	Organic enrichment/Low DO		

Cause Elimination and Evidence Uncertainty

It is important to remember the SI process uses a weight of evidence approach that is not synonymous with dose-response experimental studies. Therefore, the conclusions reached in this SI must be viewed cautiously with the understanding that correlation and association do not necessarily prove cause and effect.

One of the larger uncertainties in this SI results from the fact the available data were spatially and temporally limited. Because of these limitations, the importance of certain stressors either could have been downplayed or inflated. Another source of uncertainty is the lack of appropriate benchmarks or criteria for evaluating the significance of some proximate stressors or causal pathway indicators. The process is also limited by a lack of readily available data analysis techniques that could help identify useful patterns and associations in the data set. There is also uncertainty associated with ranking the relative importance of primary stressors. In this SI, it is assumed that each primary stressor is individually capable of causing the biological impairment. However, some stressors are known to exert a greater detrimental impact upon certain aspects of stream biological health than do others. For example, certain benthic-oriented metrics of the fish IBI are known to respond more strongly to sedimentation impacts that other types of stressors. These subtle distinctions are not dealt with very well within the current SI process. As the IDNR gains more experience and refines the SI process, sensitivity and confidence levels should continue to improve.

A number of candidate causes/stressors were excluded from consideration based upon best professional judgment and knowledge of the watershed. These causes/stressors were all ranked as low (Table 3) probability of contributing to the stream biological impairment. If management actions designed to alleviate the primary causal agents identified in this SI fail to restore the biological community to unimpaired status, the evidence will again be reviewed and the excluded causes/stressors can be reconsidered. An excluded candidate cause/stressor might also be reconsidered if new data or information provided compelling evidence the cause/stressor plays an important role in the impairment.

Conclusions

Despite some data limitations, the evidence was sufficient to identify the following primary stressors, any of which is capable of causing biological impairment in the Silver Creek watershed:

- elevated and potentially lethal concentrations of un-ionized ammonia;
- elevated levels of silt accumulation and sedimentation of rock substrates;
- low / potentially lethal levels of dissolved oxygen;
- dewatering due to in-stream sinkholes.

Depending upon the causal mechanism, primary stressors can be manifested as short-term acute impacts or long-term chronic impacts to aquatic biota. To restore the biological condition of the stream to un-impaired status, TMDL and implementation plans need to address each of the primary stressors and multiple causal pathways that occur in the watershed.

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Appendix 1

Methods

Reference Sites

Reference sites in Iowa represent contemporary stream conditions that are least disturbed by human activities. A number of important watershed, riparian and instream characteristics were evaluated as part of the reference site selection process (Griffith et al. 1994; Wilton 2004). Representation is also an important consideration. Reference sites strive to represent desirable, natural qualities that are attainable among other streams within the same ecoregion. As they are used in bioassessment, reference sites define biological conditions against which other streams are compared. Therefore, they should not represent stream conditions that are anomalous or unattainable within the ecoregion.

Currently, there are 96 reference sites used by IDNR for stream biological assessment purposes (Figure 1-1). Reference condition is the subject of a significant amount of research and development throughout the U.S. The IDNR will continue to refine Iowa's reference condition framework as new methods and technologies become available.

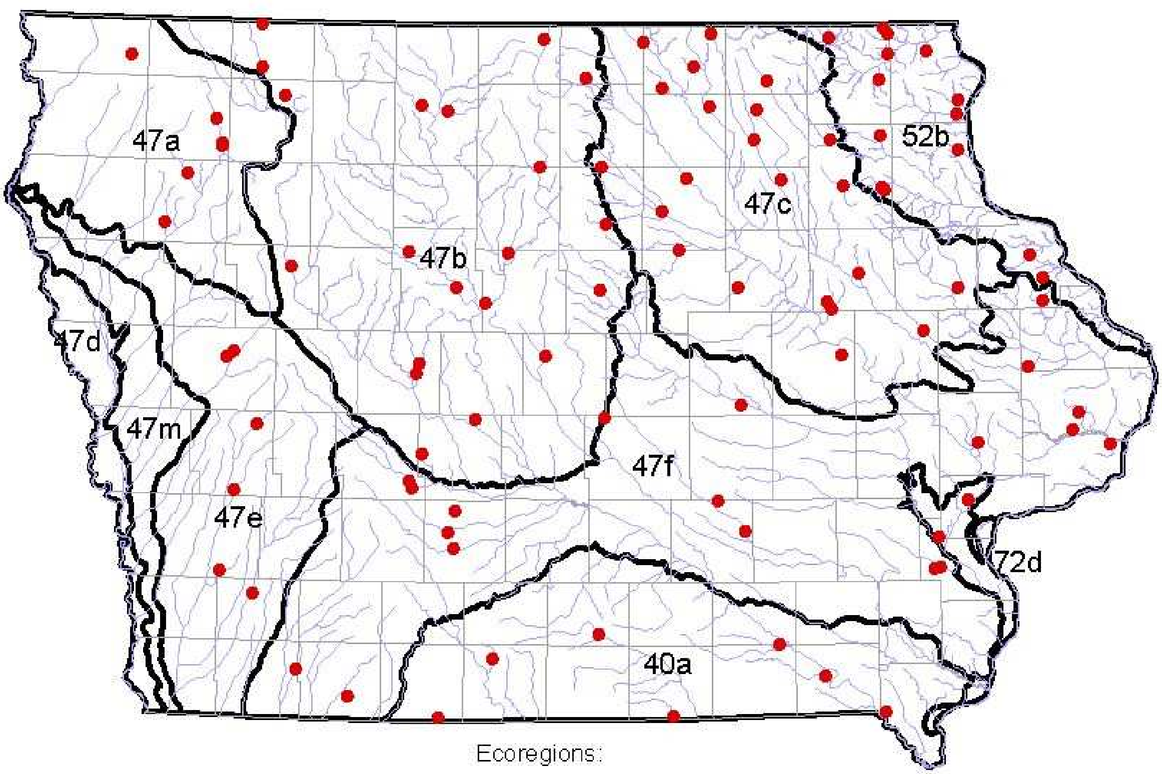


Figure 1-1. Iowa ecoregions and wadeable stream reference sites: 1994 – 2000.

Sampling Procedures

Standard procedures for sampling stream benthic macroinvertebrates and fish assemblages are used to ensure data consistency between sampling sites and sampling years (IDNR 2001a, 2001b). Sampling is conducted during a three-month index period (July 15 – October 15) in which stream conditions and the aquatic communities are relatively stable. A representative reach of stream ranging from 150-350 meters in length is defined as the sampling area.

Two types of benthic macroinvertebrate samples are collected at each site: 1) Standard-Habitat samples are collected from natural rock or artificial wood substrates in flowing water; 2) a Multi-Habitat sample is collected by handpicking organisms from all identifiable and accessible types of benthic habitat in the sampling area. The multi-habitat sample data improve the estimation of taxa richness for the entire sample reach. Benthic macroinvertebrates are identified in the laboratory to the lowest practical taxonomic endpoint.

Fish are sampled using direct current (DC) electrofishing gear. In shallow streams, one or more battery-powered backpack shockers are used, and a tote barge, generator-powered shocker is used in deeper, wadeable streams. Fish are collected in one pass through the sampling reach proceeding downstream to upstream. The number of individuals of each species is recorded, and individual fish are examined for external abnormalities, such as deformities, eroded fins, lesions, parasites, and tumors. Most fish are identified to species in the field; however, small or difficult fish to identify are examined under a dissecting microscope in the laboratory.

Physical habitat is systematically evaluated at each stream sampling site. A series of instream and riparian habitat variables are estimated or measured at 10 stream channel transects that are evenly spaced throughout the sampling reach. Summary statistics are calculated for a variety of physical habitat characteristics, and these data are used to describe the stream environment and provide a context for the interpretation of biological sampling results.

Biological Indices

Biological sampling data from reference sites were used to develop a Benthic Macroinvertebrate Index of Biotic Integrity (BMIBI) and a Fish Index of Biotic Integrity (FIBI) (Wilton 2004). The BMIBI and FIBI are described as multi-metric or composite indices because they combine several individual measures or metrics. A metric is an ecologically relevant and quantifiable attribute of the aquatic biological community. Useful metrics can be cost-effectively and reliably measured, and will respond predictably to environmental disturbances.
Each index is comprised of twelve metrics that reflect a broad range of aquatic community attributes (Table 1-1). Metric scoring criteria are used to convert raw metric data to normalized scores ranging from 0 (poor) –10 (optimum). The normalized metric scores are then combined to obtain the BMIBI and FIBI scores, which both have a possible scoring range from 0 (worst) – 100 (best). Qualitative categories for BMIBI and FIBI scores are listed in Table 1-2. A detailed description of the BMIBI and FIBI development and calibration process can be obtained at the IDNR web page: http://www.iowadnr.com/water/tmdlwqa/wqa/streambio/index.html (Wilton 2004).

Table 1-1. Data metrics of the Benthic Macroinvertebrate Index of Biotic Integrity (BMIBI) and the Fish Index of Biotic Integrity (FIBI).

BMIBI Metrics	FIBI Metrics
1. MH*-taxa richness	1. # native fish species
2. SH*-taxa richness	2. # sucker species
3. MH-EPT richness	3. # sensitive species
4. SH-EPT richness	4. # benthic invertivore species
5. MH-sensitive taxa	5. percent 3-dominant fish species
6. percent 3-dominant taxa (SH)	6. percent benthic invertivores
7. Biotic index (SH)	7. percent omnivores
8. percent EPT (SH)	8. percent top carnivores
9. percent Chironomidae (SH)	9. percent simple lithophil spawners
10. percent Ephemeroptera (SH)	10. fish assemblage tolerance index
11. percent Scrapers (SH)	11. adjusted catch per unit effort
12. percent Dom. functional feeding group (SH)	12. percent fish with DELTs

* MH, Multi-habitat sample; SH, Standard-habitat sample.

Table 1-2a. Qualitative scoring guidelines for the BMIBI.

Biological Condition Rating	Characteristics of Benthic Macroinvertebrate Assemblage
76-100 (Excellent)	High numbers of taxa are present, including many sensitive species. EPT taxa are very diverse and dominate the benthic macroinvertebrate assemblage in terms of abundance. Habitat and trophic specialists, such as scraper organisms, are present in good numbers. All major functional feeding groups (ffg) are represented, and no particular ffg is excessively dominant. The assemblage is diverse and reasonably balanced with respect to the abundance of each taxon.
56-75 (Good)	Taxa richness is slightly reduced from optimum levels; however, good numbers of taxa are present, including several sensitive species. EPT taxa are fairly diverse and numerically dominate the assemblage. The most-sensitive taxa and some habitat specialists may be reduced in abundance or absent. The assemblage is reasonably balanced, with no taxon excessively dominant. One ffg, often collector-filterers or collector-gatherers, may be somewhat dominant over other ffgs.
31-55 (Fair)	Levels of total taxa richness and EPT taxa richness are noticeably reduced from optimum levels; sensitive species and habitat specialists are rare; EPT taxa still may be dominant in abundance; however, the most-sensitive EPT taxa have been replaced by more-tolerant EPT taxa. The assemblage is not balanced; just a few taxa contribute to the majority of organisms. Collector-filterers or collector-gatherers often comprise more than 50percent of the assemblage; representation among other ffgs is low or absent.
0-30 (Poor)	Total taxa richness and EPT taxa richness are low. Sensitive species and habitat specialists are rare or absent. EPT taxa are no longer numerically dominant. A few tolerant organisms typically dominate the assemblage. Trophic structure is unbalanced; collector-filterers or collector-gatherers are often excessively dominant; usually some ffgs are not represented. Abundance of organisms is often low.

Table 1-2b. Qualitative scoring guidelines for the FIBI.

Biological Condition Rating	Characteristics of Fish Assemblage
71-100 (Excellent)	Fish (excluding tolerant species) are fairly abundant or abundant. A high number of native species are present, including many long-lived, habitat specialist, and sensitive species. Sensitive fish species and species of intermediate pollution tolerance are numerically dominant. The three most abundant fish species typically comprise 50percent or less of the total number of fish. Top carnivores are usually present in appropriate numbers and multiple life stages. Habitat specialists, such as benthic invertivore and simple lithophilous spawning fish are present at near optimal levels. Fish condition is good; typically less than 1percent of total fish exhibit external anomalies associated with disease or stress.
51-70 (Good)	Fish (excluding tolerant species) are fairly abundant to very abundant. If high numbers are present, intermediately tolerant species or tolerant species are usually dominant. A moderately high number of fish species belonging to several families are present. The three most abundant fish species typically comprise two-thirds or less of the total number of fish. Several long-lived species and benthic invertivore species are present. One or more sensitive species are usually present. Top carnivore species are usually present in low numbers and often one or more life stages are missing. Species that require silt-free, rock substrate for spawning or feeding are present in low proportion to the total number of fish. Fish condition is good; typically less than 1percent of the total number of fish exhibits external anomalies associated with disease or stress.
26-50 (Fair)	Fish abundance ranges from lower than average to very abundant. If fish are abundant, tolerant species are usually dominant. Native fish species usually equal ten or more species. The three most abundant species typically comprise two-thirds or more of the total number of fish. One or more sensitive species, long-lived fish species or benthic habitat specialists such as suckers (Catostomidae) are present. Top carnivore species are often, but not always present in low abundance. Species that are able to utilize a wide range of food items including plant, animal and detritus are usually more common than specialized feeders, such as benthic invertivore fish. Species that require silt-free, rock substrate for spawning or feeding are typically rare or absent. Fish condition is usually good; however, elevated levels of fish exhibiting external anomalies associated with disease or stress are not unusual.
0-25 (Poor)	Fish abundance is usually lower than normal or, if fish are abundant, the assemblage is dominated by a few or less tolerant species. The number of native fish species present is low. Sensitive species and habitat specialists are absent or extremely rare. The fish assemblage is dominated by just a few ubiquitous species that are tolerant of wide-ranging water quality and habitat conditions. Pioneering, introduced and/or short-lived fish species are typically the most abundant types of fish. Elevated levels of fish with external physical anomalies are more likely to occur.

Plausibility of Stressor-Response Relationships

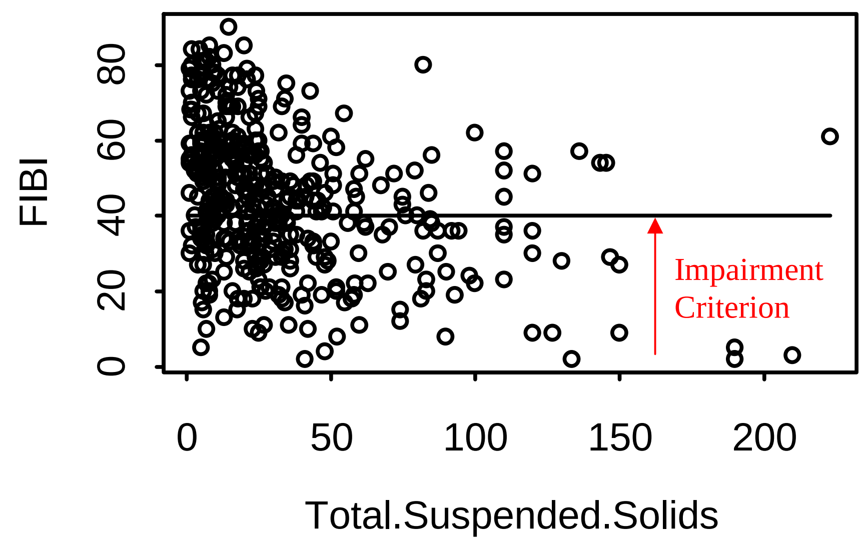
Graphical and quantitative analysis methods were used to examine the plausibility that various stressors occur at levels that are sufficient to impair the aquatic community of Silver Creek. The data analysis utilized biological and environmental indicator data collected primarily from wadeable streams during 1994-2003 as part of Iowa's stream biological assessment program. Scatter plots were created and visually examined to identify relationships between stressor indicators and biological response variables (i.e., benthic macroinvertebrate and fish IBIs). Regression coefficients were calculated to help identify stressor indicators that were significantly related with IBI levels. Examples of the scatter plot and simple regression analysis approach are displayed in Appendix 2 (Figures 2-2 – 2-10).

Conditional Probability (CP) is a promising technique for stressor-response analysis (Paul and McDonald 2004). This approach was used to evaluate SI data for the Little Floyd River, the North Fork Maquoketa River, and Silver Creek. CP computations were obtained for many stressor-response relationships, and the results were graphically displayed for visual interpretation (see Figure 1-2 [a-d]).

Essentially, the CP analysis method seeks to identify stressors that occur at levels associated with an increased probability of observing biological impairment. In the Little Floyd River example, biological impairment is defined as not achieving a BMIBI score or FIBI score that is greater than or equal to the impairment criteria established from regional reference sites in the Northwest Iowa Loess Plains (47a) ecoregion. For this ecoregion, the BMIBI criterion is 53 and the FIBI criterion is 40. Figure 1-2 shows the data analysis output from one stressor-response relationship (i.e., TSS-FIBI). Similar types of comparisons were made for stressor and causal pathway indicator data available for the Silver Creek watershed.

The example CP output shown in Figure 1-2 provides evidence of TSS as a primary stressor that is associated with impaired fish assemblage condition. Figure 1-2(a) shows the stressor-response pattern where increasing levels of the stressor (TSS) are generally associated with decreasing levels of the fish assemblage IBI. Figure 1-2(b) shows separation of the TSS Cumulative Distribution Function (CDF) for unimpaired sites compared with the CDF representing stressor levels at impaired sites. Generally, unimpaired sites have lower TSS levels than impaired sites. For example, the interquartile range of unimpaired sites is approximately 10-30 mg/L compared with 20-60 mg/L for impaired sites. Figure 1-2(c) shows CP computation output where the probability of observing impairment is plotted against stressor levels. At any given stressor level on the x-axis, the probability of impairment for sites where the stressor is less than or equal to the specified level can be obtained from the curve. For example, the probability of impairment among all sites is approximately 0.25 for sites with TSS less than or equal to 20 mg/L, the median TSS concentration of unimpaired sites. In contrast, Figure 1-2(d) shows the probability of observing an impairment at sites where the stressor level exceeds a specified level of criterion. In this case, the probability of impairment is approximately 0.5 for streams such as the Little Floyd River, O'Brien County where the TSS concentration exceeds 30 mg/L, the median level for impaired sites. The increased slope in the curve that is observable in Figure 1-2(d) is consistent with an increased probability of impairment, and the slope increase occurs in the same range as stressor levels found in the Little Floyd River. The evidence shown in these plots is evidence that TSS levels in the Little Floyd are a plausible stressor associated with increased probability of biological impairment.

(a)



(b)

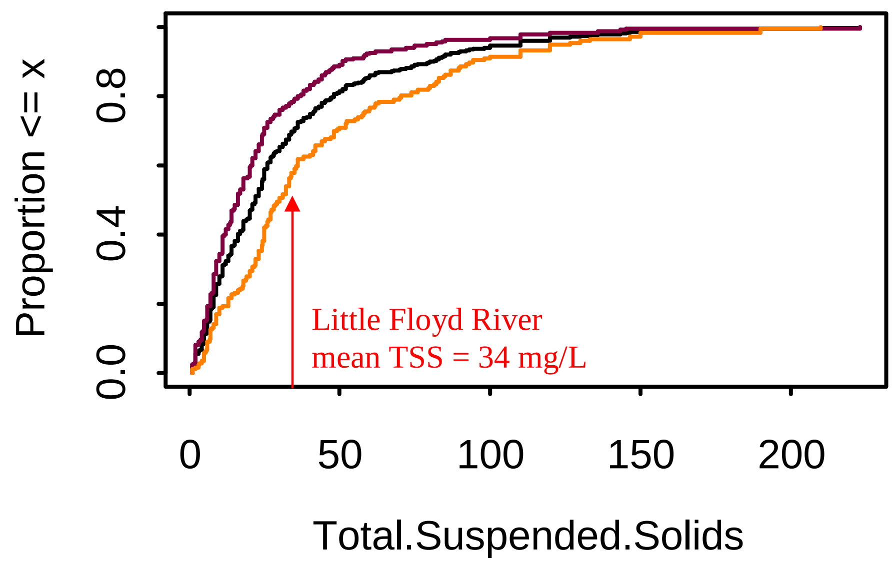
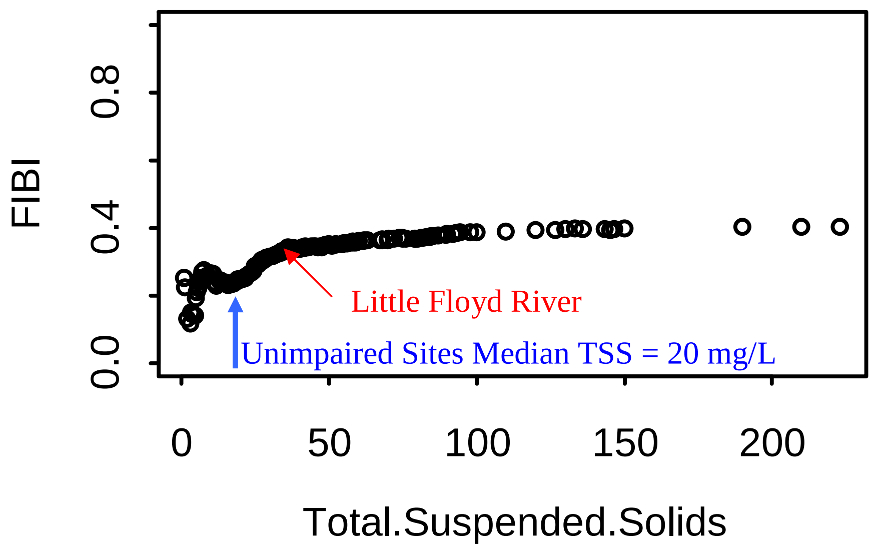


Figure 1-2. Conditional Probability (CP) analysis using example data from the Little Floyd River, O'Brien County; **(a)** Fish Index of Biotic Integrity (FIBI) relationship with Total Suspended Solids (TSS). Data are from the Iowa stream bioassessment database for summer-fall sample index period: 1994-2003. Solid black line represents biological impairment criterion (FIBI=40) for Northwest Iowa Loess Prairies (47a) ecoregion. **(b)** Cumulative Distribution Function (CDF) of TSS for unimpaired sites (FIBI≥40; maroon); impaired sites (FIBI<40; red); all sites (black). Little Floyd River mean TSS (34 mg/L) for 3 sample sites exceeds median value of impaired sites.

(c)



(d)

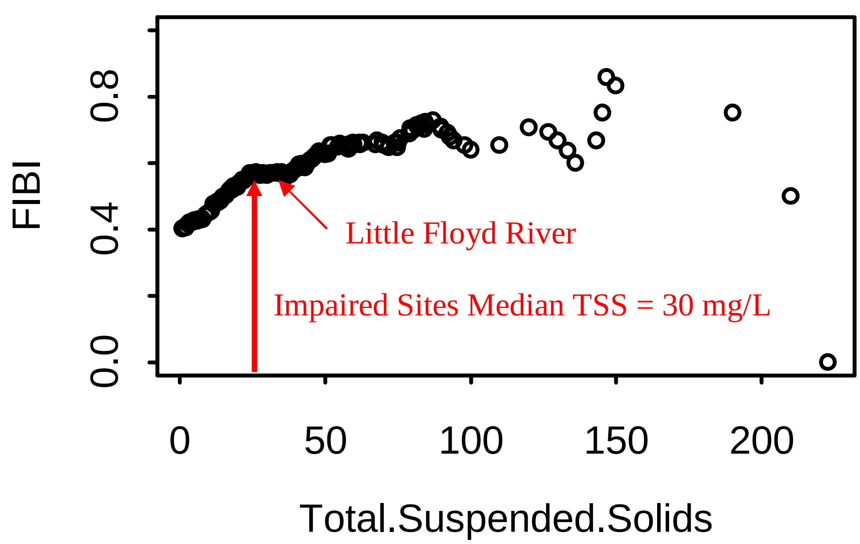


Figure 1-2 (continued). **(c)** Conditional Probability (CP) plot displaying the probability of observing an impairment (i.e., FIBI<40) when the observed stressor level is less than or equal to a specified level or criterion. For example the probability of impairment is approximately 0.25 for sites with TSS less than or equal to 20 mg/L, the median value of unimpaired sites (see Figure 1-2(a)). **(d)** CP plot displaying the probability of observing an impairment (i.e., FIBI<40) when the observed stressor level exceeds a specified level or criterion. For example the probability of impairment is approximately 0.50 for stream sites such as Little Floyd River sites with TSS exceeding 30 mg/L, the median of impaired sites (see Figure 1-2(a)).

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Appendix 2
Data Summary

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Table 2-1. Water quality data from 1977 UHL sampling.

site	site description	date	temp	pH	DO (mg/L)	fecal coliform /100 mL	conductance (µmhos)	Organic N (mg/L)	Ammonia N (mg/L)	Nitrate N (mg/L)	TSS (mg/L)	TVSS (mg/L)	total phosphate (mg/L)	BOD (mg/L)	CBOD (mg/L)	turbidity (JTU)	chloride (mg/L)	Total Organic Carbon (mg/L)	Chlorophyll a (µg/L)
1	Monona WWTP	06/22/77	18	7.3	4.4	130000	910	4.2	5.8	2.9	582	132	5.2	23	76	18	110	28.3	12
2	upstream of creamery discharge	06/23/77	21	7.55	2.7	37000	1300	2.4	2.4	1.4	832	136	5	13	49	39	200	25.7	19
3	creamery discharge	06/24/77	35	7.85	7	5300	830	1.3	1.3	0.3	566	100	3.5	2	29	9.7	71	10.5	9
4	near TMDL site 2D	06/25/77	21	7.5	5.5	5800	530	1.4	0.52	0.7	368	102	0.43	4	27	14	12	14.8	9
5	mainstem in sink area	06/26/77	22	7.55	5.6	25000	790	1.5	1	1	552	102	1.9	8	29	40	66	15.1	8
7	near TMDL site 2A	06/28/77	25	7.85	8.5	22000	460	2.9	0.1	1	420	100	0.85	7	43	36	25	22.9	52

Table 2-2. Water quality data from 2000 UHL/DNR sampling.

Date	Nitrate + Nitrite Nitrogen as N (mg/L)	Ammonia Nitrogen as N (mg/L)	Atrazine – Screen (µg/L)	Total Hardness (mg/L as CaCO3)	Total Phosphate as P (mg/L)	TKN (mg/L)	Total Dissolved Solids (mg/L)	Field pH	Specific Conductance (µmhos/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Flow Rate (cfs)	Field Temperature (℃)	Total Suspended Solids (mg/L)
Site 1A WQ sampling														
8/2/00	12	<0.1	0.15	360	0.8	1.4	420	8.3	640	22	8	3.7	19.5	38

Table 2-3. Water quality data from 2006-2007 UHL/DNR sampling.

Site 2A	**2006**													**2007**									
Date	06/29	07/12	07/26	08/07	08/22	09/06	09/11	09/12	09/20	10/03	10/17	11/06	12/12	01/08	02/14	03/07	03/21	04/03	04/17	05/01	05/07	05/15	05/24
Ammonia N as N (mg/L)	0.16	0.3	0.75	3.6	0.24	0.1	1.9	0.56	0.11	0.05	<0.05	<0.05	0.39	0.17	0.42	0.92	0.54	0.47	<0.05	<0.05	<0.05	0.18	0.69
CBOD (5 day) (mg/L)												<2		<2	<2								
Chloride(mg/L)	27	21	23	31	24	24	21	19	25	27	26	25	20	31	33	25	33	32	40	38	50	35	31
Chlorophyll a (µg/L)	4	9	100	39	29	16	21	8	12	77	8	13	5	21	20	11	5	27	22	17	13	14	34
Diss. Inorg. Carbon (mg/L)	63	65	70	63	71	68	44	30	75	70	68	64	64	69	90	69	44	40	54	55	56	60	52
DOC (mg/L)	3.1	4.3	5.9	18	5.6	4.9	14	10	4.7	5.2	6	4.1	2.9	2.9	2.8	5	5.2	7.1	2.8	2.6	2.4	2.6	8.8
DO (mg/L)	5.7	3.2	7.9	0.3	5.5	4.8		9.8	9.1	9.2	8.9	15.3	13.5	16.2	11.2	6.7	11.5	10.7	16.1	13.4	15	7	7.9
E. coli (#/100mL)	21000	3600	4300	570000	710	780	1700000	360000	2500	500	150	380	200	23	23	70	160000	160000	3000	700	240	3000	80000
pH	7.9	7.7	8.2	7.7	8	8.1		7	8.1	8.1	8	8.4	8.8	8.3	7.9	7.6	8.2	7.6	8.6	8.4	8.7	8.1	7.6
Temp. (^{o}C)	17.4	20.2	28.2	20.7	20.6	18.8		13.7	11.6	18.1	10.2	3.9	1.4	0.8	0.5	0.2	5.7	8.3	12	15	14.5	18	14.4
Flow (cfs)	0.7	0.4	0.5	0.4	0.1	0.1		4	0.2	0.2	0.1	0.1	0.2	0.3	<1.0	0.1	12.9	90	12	14.4	6	2.8	3.4
NO3+NO2 as N (mg/L)	7.3	4.4	2.4	1.3	1.5	0.82	1.6	6	2.1	1.3	2.9	4.5	6.4	12	11	6.5	11	13	15	16	15	12	8.6
Ortho Phos. as P (mg/L)	0.49	0.4	0.65	1.5	0.42	0.46	2.4	0.63	0.37	0.24	0.18	0.1	0.16	0.2	0.23	0.27	0.55	0.62	0.35	0.38	0.42	0.29	0.12
Total BOD (5 day) (mg/L)	3	5	7	25	4	5	>19	16	2	7	2	<2	3			4	6	22	<2	<2	<2	<2	<2
Total Dis Solids (mg/L)	440	390	390	400	400	380	320	270	390	370	350	360	330	450	520	460	380	330	400	400	450	440	390
TKN as N (mg/L)	1.1	1.4	2.5	8.1	1.3	0.8	8.8	2.8	0.8	1.3	0.6	0.8	1.1	1	1.2	2.4	2.2	1.2	0.9	0.4	0.6	1.1	2.7
Total Org. Carbon (mg/L)	3.9	5.7	12	32	7	6.9	45	28	7.1	7.1	6.1	5.2	3.5	4.5	3.6	7.1	8.9	49	4.1	3.6	3.2	3.8	16
Total Phos. as P (mg/L)	0.61	0.53	0.87	2.2	0.54	0.6	4.7	1.6	0.45	0.36	0.23	0.15	0.17	0.31	0.29	0.42	0.76	0.69	0.38	0.52	0.45	0.36	1.1
TSS (mg/L)	40	29	33	47	19	15	260	220	18	28	7	31	2	53	8	16	47	1300	14	19	10	7.6	93
TVSS (mg/L)	8	6	12	19	6	4	62	42	4	18	2	6	1	7	3	4	10	120	2	3	2	2	23
Turbidity (NTU)	39	26	20	33	14	10	230	160	17	10	4.7	4.3	2.5	35	2.5	2.7	21	420	6.3	7.4	4.1	7.6	93

Site 2D	2006											2007							
Date	06/29	07/12	0726	08/07	08/22	09/06	09/20	10/03	10/17	11/06	12/12	01/08	02/14	03/07	03/21	04/03	04/17	05/01	05/15
Ammonia N as N (mg/L)	<0.05	0.42	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.12	0.16	<0.05	<0.05	<0.05
CBOD (5 day) (mg/L)										<2		<2	<2						
Chloride(mg/L)	26	27	26	28	25	24	26	26	25	25	25	28	25	25	21	21	26	26	26
Chlorophyll a (µg/L)	3	4	5	5	4	3	2	5	6	4	3	2	5	2	2	23	7	14	13
Diss. Inorg. Carbon (mg/L)	73	66	66	62	62	68	69	70	68	63	65	62	66	65	39	23	46	56	58
DOC (mg/L)	1.3	5.2	2.5	7.5	9.7	2	1.7	1.5	2.2	1.6	1.3	1.4	1.2	2	2.5	7.1	2.1	2	1.8
DO (mg/L)	10	8.7	8.4	8.8	8.9	10.4	10.7	9.3	9.7	12	11.9	14.2	14.9	13.9	10.7	10.3	15.1	14.3	9.4
E. coli (#/100mL)	2000	160000	2800	7400	1500	2100	2700	3000	2000	870	180	30	2	50	130	30000	170	130	1100
pH	7.9	7.8	8	8	8.1	8.2	8	8.1	8	8.2	9.1	8.1	8.2	7.9	7.9	7.6	8.1	8.1	7.9
Temp. (^{o}C)	14	17	25	20.2	18.4	18.3	10.4	15.5	10.2	5.6	6	1.9	0.3	0.3	4.6	7.7	9.3	10.9	13.7
Flow (cfs)	2.2	2.1	2.2	2	1.1	1.3	1.5	1.3	1.4	1.6	3.1	3	<1.0	4	20.9	78	6	8.1	4
NO3+NO2 as N (mg/L)	13	12	10	9.1	11	11	11	11	12	12	13	16	14	11	12	14	16	17	14
Ortho Phos. as P (mg/L)	0.08	0.18	0.13	0.28	0.09	0.09	0.08	0.06	0.05	0.03	0.05	0.04	0.03	0.04	0.21	0.51	0.04	0.03	0.05
Total BOD (5 day) (mg/L)	<2	5	<2	<2	<2	<2	<2	<2	<2	<2	<2			<2	<2	6	<2	<2	<2
Total Dis Solids (mg/L)	420	460	420	440	440	410	410	420	410	380	380	410	420	410	320	300	370	370	410
TKN as N (mg/L)	0.7	1.4	0.7	1.3	0.5	0.4	0.2	0.4	0.3	0.4	0.2	0.3	0.3	0.4	1.1	2	0.4	0.3	0.5
Total Org. Carbon (mg/L)	3.8	7.3	3.8	8.1	17	3.3	2.3	2.8	2.5	2.4	2	1.9	1.7	2.7	7	24	2.4	2.3	2
Total Phos. as P (mg/L)	0.16	0.33	0.18	0.38	0.11	0.12	0.11	0.08	0.08	0.05	0.06	0.05	0.04	0.08	0.37	0.99	0.03	0.06	0.06
TSS (mg/L)	44	10	17	18	5	18	7	5	4	3	2	2	2	3	100	420	5	4	4
TVSS (mg/L)	5	2	3	3	1	3	1	1	1	1	<1	<1	<1	<1	12	42	1	1	1
Turbidity (NTU)	17	5	6.7	14	2.4	5.2	4.6	4.6	2.7	1.7	2	1.1	<1.0	1.2	39	170	2.3	1.7	1.3

Site 2E	2006								2007								
Date	08/07	08/22	09/06	09/20	10/03	10/17	11/06	12/12	01/08	02/14	03/07	03/21	04/03	04/17	05/01	05/15	08/07
Ammonia N as N (mg/L)	0.83	6.3	2.6	2.4	3.2	0.96	6.7	5	4.1	4.5	4.5	0.46	0.15	0.62	0.35	0.38	0.83
CBOD (5 day) (mg/L)							>52		7	64							
Chloride(mg/L)	190	58	300	160	150	130	140	120	160	72	150	66	32	68	74	55	190
Chlorophyll a (µg/L)	2	1	2	1	3	4	4	3	2	9	3	5	8	18	18	12	2
Diss. Inorg. Carbon (mg/L)	73	57	41	82	75	77	77	72	75	51	89	29	36	59	61	55	73
DOC (mg/L)	4.4	7.8	8.8	5.3	9.3	8	16	4.6	9.9	38	17	6.1	5.2	3.3	2.6	1.8	4.4
DO (mg/L)	6	4.4	8.2	6.9	3.8	4.4	3.2	6.2	8.1	17	2.1	9.4	10.6	11.5	11.3	8.7	6
E. coli (#/100mL)	370	240	400	100	1800	650		130	12	11000	>160000	300000	13000	130000	230	170	370
pH	8	8	8.2	8.1	8	7.9	8.1	8.6	8.2	7.6	7.5	7.8	7.7	8.1	8.1	8.1	8
Temp. (^{o}C)	29.3	30	23	19.7	28.6	23	24.3	19.4	12.6	17.9	21.8	7	9.1	13.7	15.2	20.7	29.3
Flow (cfs)	1	1.6	0.7	1.9	1.7	1.6	1.9	1.5	2.2	1.6	1.8	10.3	24	4.7	3.9	1.8	1
NO3+NO2 as N (mg/L)	14	4.6	28	9	12	8.4	3.5	6.8	7.3	2.4	2.4	9.5	13	12	14	8.1	14
Ortho Phos. as P (mg/L)	4.6	2.2	8.3	4.1	4.8	4.9	4.1	2.9	3.6	2.6	4.7	0.95	0.32	0.85	1.5	1.1	4.6
Total BOD (5 day) (mg/L)	3	4	<2	7	7	4	<2	18			48	18	3	7	3	<2	3
Total Dis Solids (mg/L)	800	440	1130	720	730	700	680	590	680	450	730	430	320	480	510	460	800
TKN as N (mg/L)	1.7	8	3.6	3.8	9.8	2.5	29	8.6	11	5.4	13	4	2.7	3.2	1.6	1.1	1.7
Total Org. Carbon (mg/L)	5.9	18	9.5	6.7	11	13		8.5	19	54	29	26	25	5.2	3.6	2.9	5.9
Total Phos. as P (mg/L)	2.1	2.3	8.1	4	5.3	5.8	10	3.5	4.2	3.9	6	1.9	0.99	1.3	1.7	1.1	2.1
TSS (mg/L)	12	15	27	10	40	29	250	43	49	86	52	650	700	25	24	17	12
TVSS (mg/L)	3	3	5	3	12	9	190	15	30	53	33	73	52	10	7	4	3
Turbidity (NTU)	9.1	5	7.3	4.9	14	9.2	80	7.4	22	13	13	120	220	3.6	6.7	3.2	9.1

Table 2-4. Water quality data from 1988 UHL benthic macroinvertebrate and fish surveys.

Site #	site description	Date	Temp . (^oC)	pH	DO (mg/L)
19	near TMDL site 2A	05/10/88	16	8.4	14
		06/21/88	25	8.2	6.2
		07/19/88	25	8.3	12.6
		08/09/88	24	7.9	5.7
		09/13/88	21	8.3	8.7
		10/04/88	8.5	8.2	10.8
20	near site 1A	07/19/88	28	8.1	10.6
		08/09/88	24	7.9	5.1
		09/13/88	19	8.1	11.1
		10/04/88	10	8.2	11.5
21	mainstem in sink area	05/10/88	15	8.1	10.8
		06/21/88	25	8.2	3.6
		07/19/88	21	7.7	3.6
		08/09/88	23	7.8	2.8
		09/13/88	17	7.9	5.3
		10/04/88	9	8.2	10.8
22	near TMDL site 2D	05/10/88	14	8.1	11.4
		06/21/88	25	8.2	6.2
		07/19/88	23	8.2	11.3
		08/09/88	25	8.2	7.8
		09/13/88	21	8.2	7.4
		10/04/88	12	8.3	10.8
23	upstream of site 2D	05/09/88	14	8	11.2
		06/22/88	24	7.8	
		07/19/88	21	7.7	9
		08/08/88	27	7.7	2.2
		09/12/88	21	7.7	10
		10/04/88	16	7.9	9.2
24	headwaters of mainstem	05/09/88	13	7.7	13
25	near site 2C	05/10/88	16	8	8.4
		06/21/88	23	8.1	2.6
		07/19/88	22	7.8	5.2
		08/08/88	26	7.8	3.3
		09/12/88	20	8	6.3
		10/04/88	11	7.6	9.8
26	halfway between sites 2C and 2E	05/09/88	17	7.9	6.2
		06/20/88	35	7.6	4.6
		07/19/88	26	7.7	2.8
		08/08/88	27	7.7	3.4
		09/12/88	25	7.9	5.5
		10/04/88	18	7.9	6.2
27	creamery discharge	05/09/88	28	7.9	2.6
		06/20/88	32	7.6	2.9
		07/19/88	32	7.6	1.4

Site #	site description	Date	temp	pH	DO (mg/L)
		08/08/88	31	7.8	1.3
		09/12/88	29	7.7	2
		10/04/88	25	7.7	2.5
28	upstream of creamery discharge	05/09/88	16	7.9	9.4
		06/20/88	31	7.8	6.9
		07/19/88	23	7.8	8.5
		08/08/88	24	7.6	6
		09/12/88	21	8.4	7.1
		10/04/88	12	8.3	13.8
29	Monona WWTP	05/09/88	16	7.6	9.2
		06/20/88	23	7.3	9
		07/19/88	21	8	9
		08/08/88	22	7.8	8.1
		09/12/88	20	7.8	8.2
		10/04/88	13	8.2	12.5

Table 2-5. FIBI metrics calculated from the 2000 and 2006 biological samples collected from the Silver Creek watershed. The 25percent of the 52b reference site scores can be found in ().

	Silver Creek – 1A	Silver Creek – 2A	Unn. Trib. To Silver Creek – 2E	Silver Creek – 2D (RBP)	Unn. Trib. To Silver Creek – 2F (RBP)
Sample date	8/2/2000	8/7/2006	8/7/2006	8/8/2006	8/7/2006
FIBI score	41 (52)	19 (52)	30 (52)		
Native Species	16 (12.5)	13 (12.5)	8 (12.5)	8 (12.5)	10 (12.5)
Native species metric score	6.9 (5.9)	5.5 (5.9)	8.8 (5.9)		
Sucker Species	1 (1.5)	1 (1.5)	0 (1.5)	1 (1.5)	1 (1.5)
Sucker Species metric score	2.2 (3.7)	2.1 (3.7)	0 (3.7)		
Sensitive Species	3 (2.5)	2 (2.5)	1 (2.5)	2 (2.5)	3 (2.5)
Sensitive Species metric score	3.8 (4.1)	2.4 (4.1)	3.2 (4.1)		
BINV species	2 (2.5)	2 (2.5)	0 (2.5)	1 (2.5)	1 (2.5)
BINV species metric score	2.4 (4)	2.3 (4)	0 (4)		
Pct Top 3 Abundant *	62.7 (76)	92.6 (76)	89.9 (76)		
Pct Top 3 Abundant metric score	6.8 (5.6)	1.3 (5.6)	4.7 (5.6)		
Pct Benthic Invertivores	9 (19.1)	0.3 (19.1)	0 (19.1)		
Pct BINV metric score	2.7 (5.7)	0.1 (5.7)	0 (5.7)		
Pct Omnivore *	32.7 (19.7)	86 (19.7)	33.3 (19.7)		
Pct Omnivore metric score	6.5 (8)	0 (8)	10 (8)		
Pct Top Carnivore	0 (0)	0 (0)	0 (0)		
Pct Top Carnivore metric score	0 (0)	0 (0)	0 (0)		
Pct Lithophilous spawners	0.1 (0.1)	0.1 (0.1)	0 (0.1)		
Pct Litho. Spawner metric score	0.1 (0)	0 (0)	0 (0)		
Tolerance Index *	6.9 (5.4)	8.5 (5.4)	7.3 (5.4)		
Tolerance Index metric score	4.9 (7.3)	2.3 (7.3)	4.2 (7.3)		
Adjusted CPUE	85.8 (52.8)	43.3 (52.8)	17.6 (52.8)		
Adjusted CPUE metric score	8.6 (5.3)	4.3 (5.3)	1.8 (5.3)		
Pct DELT	0 (0.05)	0.8 (0.05)	0 (0.05)		
* Indicates the 75percent was used in comparison because higher scores = poorer conditions for these metrics.					

Table 2-6. BMIBI metrics calculated from the 2000 and 2006 biological samples collected from the Silver Creek watershed. The 25percent of the 52b reference site scores can be found in ().

	Stream/Site Name		
	Silver Creek – 1A	Silver Creek – 2A	Unn. Trib. to Silver Creek – 2E
Date	8/2/2000	8/7/2006	8/7/2006
BMIBI score	45 (61)	26 (61)	41 (61)
MH Total Taxa raw value	21 (36)	32 (36)	32 (36)
MH Total Taxa metric score	4.96 (7.3)	7.43 (7.3)	10.0 (7.3)
SH Total Taxa raw value	9.67 (13)	8.67 (13)	8.33 (13)
SH Total Taxa metric score	5.79 (6)	5.1 (6)	9.28 (6)
MH EPT Taxa raw value	8 (11)	2 (11)	4 (11)
MH EPT Taxa metric score	4.02 (5.5)	0.99 (5.5)	3.5 (5.5)
SH EPT Taxa raw value	5.33 (6.8)	1 (6.8)	3 (6.8)
SH EPT Taxa metric score	4.71 (6.8)	0.87 (6.8)	5.09 (6.8)
MH Sens Taxa raw value	2 (5)	1 (5)	0 (5)
MH Sens Taxa metric score	2.24 (4.9)	1.1 (4.9)	0 (4.9)
SH Ephem Pct raw value	31.2 (11)	0 (11)	11.6 (11)
SH Ephem Pct metric score	3.99 (1.4)	0 (1.4)	1.48 (1.4)
SH EPT Pct raw value	51.72 (53.9)	1 (53.9)	12.83 (53.9)
SH EPT Pct metric score	5.42 (5.6)	0.1 (5.6)	1.34 (5.6)
SH Chiron Pct raw value	37.85 (24.1)	10.06 (24.1)	47.93 (24.1)
SH Chiron Pct metric score	6.28 (7.7)	9.09 (7.7)	5.26 (7.7)
SH Scraper Pct raw value	1.37 (5.9)	3.68 (5.9)	12.7 (5.9)
SH Scraper Pct metric score	0.31 (1.3)	0.82 (1.3)	2.84 (1.3)
SH 3Dom Pct raw value	79.22 (64.9)	91.13 (64.9)	83.3 (64.9)
SH 3Dom Pct metric score	4.25 (6.3)	1.78 (6.3)	7.53 (6.3)
SH Dom FFG Pct raw value	70.28 (66.7)	91.13 (66.7)	82.53 (66.7)
SH Dom FFG Pct metric score	4.95 (5.6)	1.48 (5.6)	2.91 (5.6)
MHBI raw value	5.16 (5.0)	6.25 (5.0)	6.99 (5.0)
MHBI metric score	6.81 (7.5)	2.78 (7.5)	0.04 (7.5)
* Indicates the 75percent was used in the comparison because higher scores = poorer conditions for these metrics.			

Table 2-7. BMIBI RBP metric results from Silver Creek Watershed sampling 2000-2007. The 25percent of the 52b reference site scores can be found in ().

	Stream/Site Name	
	Silver Creek - 2D	Unn. Trib. to Silver Creek – 2F
Total Taxa Richness	27 (22)	24 (22)
# EPT taxa	6 (6)	3 (6)
EPT proportional taxa comp.	0.22 (0.23)	0.13 (0.23)
# EOPT taxa	9 (7.5)	6 (7.5)
Insecta proportional taxa comp	0.74 (0.78)	0.75 (0.78)

Table 2-8. Fish collected in Silver Creek 2000 and 2006.

sample site	**1A**	**2A**	**2D**	**2E**	**2F**
sample date	**8/2/2000**	**8/7/2006**	**8/8/2006**	**8/7/2006**	**8/7/2006**
sampling method	**Full**	**Full**	**RBP**	**Full**	**RBP**
bluntnose minnow *Pimephales notatus*	197	7	U	1	U
sand shiner *Notropis ludibundus*	152				
common shiner *Luxilus cornutus*	92	57		82	C
bigmouth shiner *Notropis dorsalis*	67	3	U	2	
creek chub *Semotilus atromaculatus*	26	1		31	U
southern redbelly dace *Phoxinus erythrogaster*	21	1	R		U
central stone roller *Campostoma anomalum*	19	107	R	7	U
blacknose dace *Phoxinus cumberlandensis*	18				
hornyhead chub *Nocomis biguttatus*	9				
fathead minnow *Pimephales promelas*	8	1062	U	65	C
suckermouth minnow *Phenacobius mirabilis*	1	1			
brassy minnow *Hybognathus hankinsoni*	1				
largescale stoneroller *Campostoma oligolepis*					R
johnny darter *Etheostoma nigrum*	62	4	C		
brook stickleback *Culaea inconstans*	4	14	R	8	
white sucker *Catostomus commersoni*	25	250	R		
green sunfish *Lepomis cyanellus*	1	16		2	
black bullhead *Ameiurus melas*		9			
R = rare (1-5), U = uncommon (6-20), C = common (21-100), and A = abundant (>100)					

Table 2-9. Benthic macroinvertebrates collected in the Silver Creek watershed in 2000 and 2006.

Phylum: Class	Order	Family	FinalID	1A	2A	2D	2E	2F
Arthropoda: Insecta	Coleoptera	Dryopidae	Dryopidae				6--20	6--20
			Helichus striatus		1			
		Dytiscidae	Dytiscidae				1--5	6--20
			Laccophilus			8		
			Laccophilus maculosus		2	5		
			Neoporus dimidiatus		7			
		Elmidae	Elmidae				>100	21--100
			Dubiraphia quadrinotata			1		
			Optioservus	1	1			
			Optioservus fastiditus	1	1	1		
			Stenelmis		2			
			Stenelmis crenata		5	2		
		Haliplidae	Haliplidae					1--5
			Peltodytes edentulus			2		
		Hydrophilidae	Hydrophilidae				6--20	6--20
			Anacaena lutescens			3		
			Berosus peregrinus		1			
			Helophorus			1		
			Tropisternus		3	6		
			Tropisternus ellipticus		4	1		
			Tropisternus lateralis			1		
			Tropisternus natator		3	1		
	Diptera	Ceratopogonidae	Ceratopogonidae				1--5	
		Chironomidae	Chironomidae	137	34	153	6--20	>100
		Culicidae	Anopheles		3			
			Culex		1	2		
			Culicidae			1		
		Dixidae	Dixidae					1--5
		Sciomyzidae	Sciomyzidae			1		
		Simuliidae	Simuliidae				6--20	6--20
			Simulium	28	2	1		
			Simulium vittatum			2		
		Stratiomyidae	Odontomyia/Hedriodiscus		1			
	Ephemeroptera	Baetidae	Baetidae				>100	>100
			Baetis brunneicolor	16		22		
			Baetis flavistriga	90		15		
			Baetis tricaudatus	37				
			Callibaetis	4				
			Callibaetis fluctuans		9	1		
		Heptageniidae	Heptageniidae				21--100	
			Heptagenia diabasia	11				

Phylum: Class	Order	Family	FinalID	1A	2A	2D	2E	2F
Arthropoda: Insecta cont.	Hemiptera	Belostomatidae	Belostomatidae					1--5
			Belostoma flumineum		8	5		
		Corixidae	Corixidae	1	3		21--100	21--100
			Palmacorixa	1				
			Sigara	1	6	2		
			Trichocorixa		2			
		Gerridae	Aquarius remigis			1		
			Gerridae	1	2	1	>100	21--100
		Nepidae	Ranatra		1			
		Notonectidae	Notonectidae				1--5	
			Notonecta			1		
		Veliidae	Veliidae				1--5	1--5
	Lepidoptera	Crambidae	Nymphula		3			
	Odonata	Aeshnidae	Aeshnidae				21--100	6--20
			Aeshna umbrosa	5	3	2		
		Calopterygidae	Calopterygidae				6--20	6--20
		Coenagrionidae	Coenagrionidae				6--20	6--20
			Coenagrion/Enallagma	11	35	6		
		Libellulidae	Pachydiplax longipennis		3			
			Plathemis lydia		5	3		
	Trichoptera	Helicopsychidae	Helicopsyche borealis		3			
		Hydropsychidae	Hydropsychidae				>100	>100
			Ceratopsyche slossonae			1		
			Cheumatopsyche	17	1	7		
			Hydropsyche betteni	60		1		
		Hydroptilidae	Hydroptila	7				
			Hydroptilidae	2			1--5	21--100
		Leptoceridae	Leptoceridae				1--5	
		Limnephilidae	Limnephilidae				1--5	
Arthropoda: Arachnida	Trombidiformes		Hydracarina	1				
		Hydrachnidae	Hydrachnidae				1--5	
Arthropoda: Crustacea	Amphipoda	Talitridae	Hyalella	1	2			
	Decapoda	Cambaridae	Cambaridae				6--20	
			Orconectes	4	1			
	Isopoda	Asellidae	Asellidae					1--5
Annelida: Oligochaeta			Oligochaeta	3				
	Haplotaxida	Tubificidae	Tubificidae		13	73		

Phylum: Class	Order	Family	FinalID	1A	2A	2D	2E	2F
Annelida: Hirudinea	Arhynchobdellida	Erpobdellidae	Erpobdellidae					21--100
			Erpobdella punctata punctata		2			
			Mooreobdella microstoma	1	1	3		
	Rhynchobdellida	Glossiphoniidae	Glossiphoniidae				1--5	6--20
			Glossiphonia complanata		4			
			Helobdella stagnalis		8			
			Helobdella triserialis			2		
			Placobdella ornata	1		2		
			Placobdella papillifera			4		
			Placobdella parasitica		1			
Mollusca: Bivalvia			Bivalvia	1				
	Veneroida	Sphaeriidae	Sphaeriidae				1--5	
Mollusca: Gastropoda	Basommatophora	Physidae	Physa		3	40		
			Physidae	4			21--100	>100
		Planorbidae	Planorbidae				1--5	6--20
Nemata			Nemata			2		
Platyhelminthes: Turbellaria	Tricladida	Dugesiidae	Dugesiidae				1--5	6--20
			Girardia		246	4		
			Turbellaria	1				

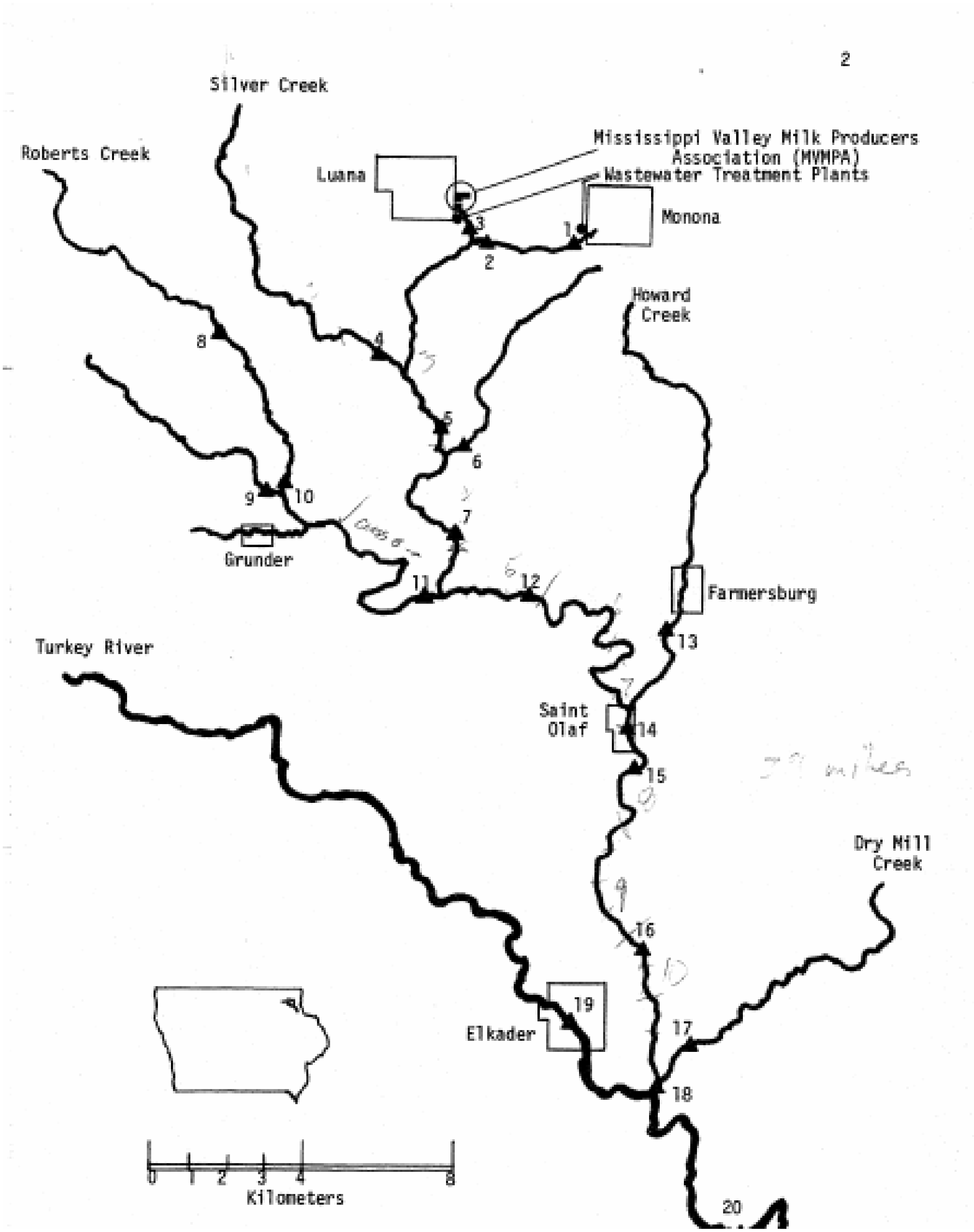


Figure 2.1. Sampling locations of 1977 UHL surveys.

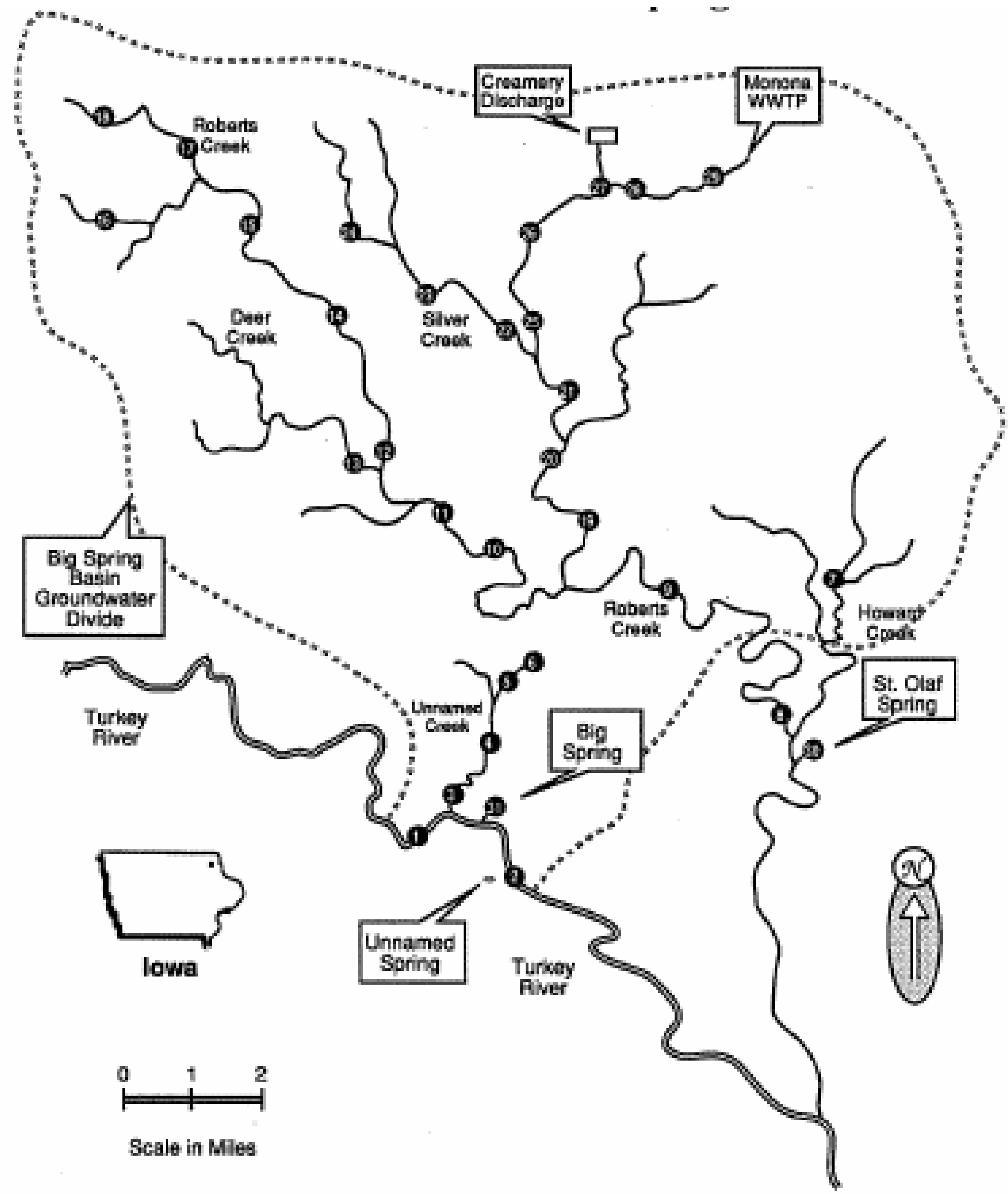


Figure 2-2. Sampling locations of 1988 UHL surveys.

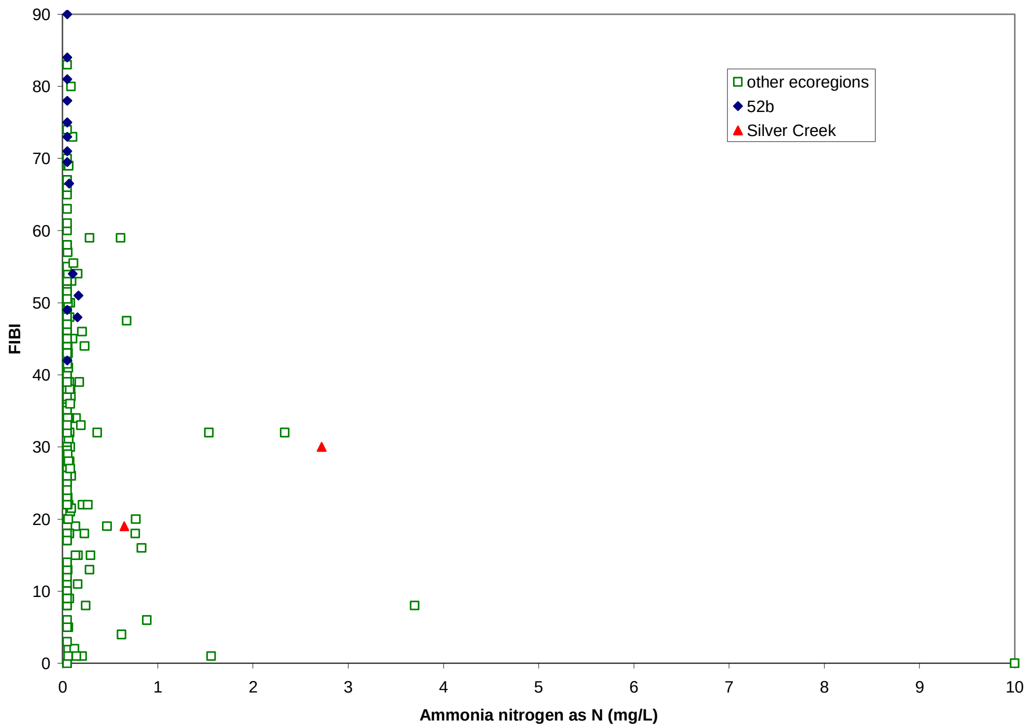


Figure 2-3. Fish Index of Biotic Integrity (FIBI) and ammonia.

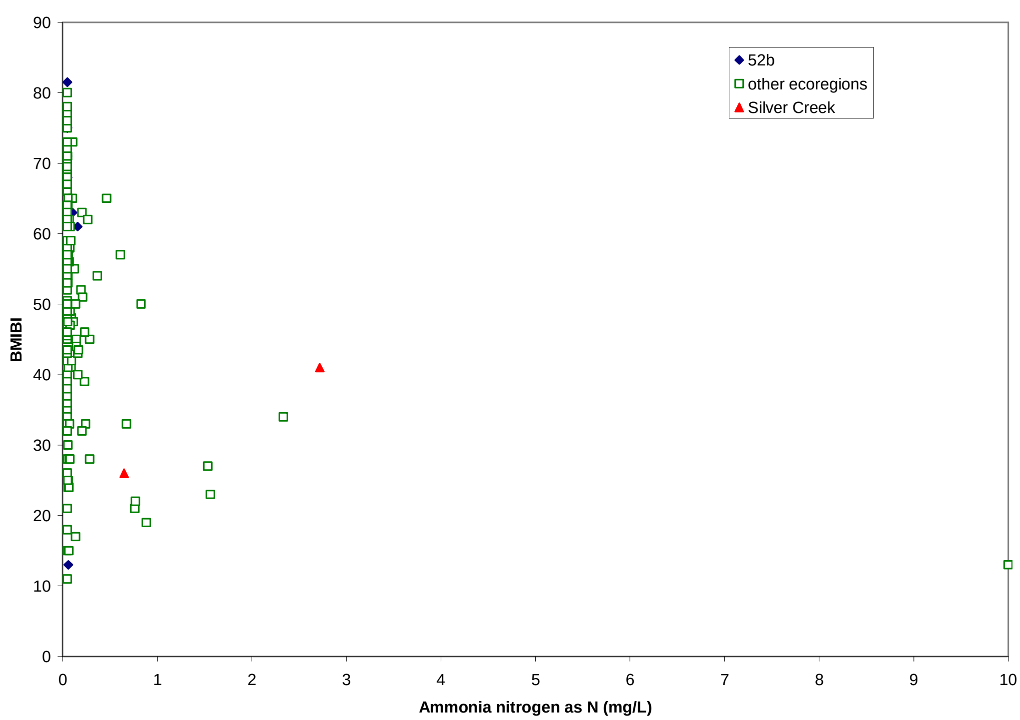


Figure 2-4. Benthic Macroinvertebrate Index of Biotic Integrity (BMIBI) and ammonia.

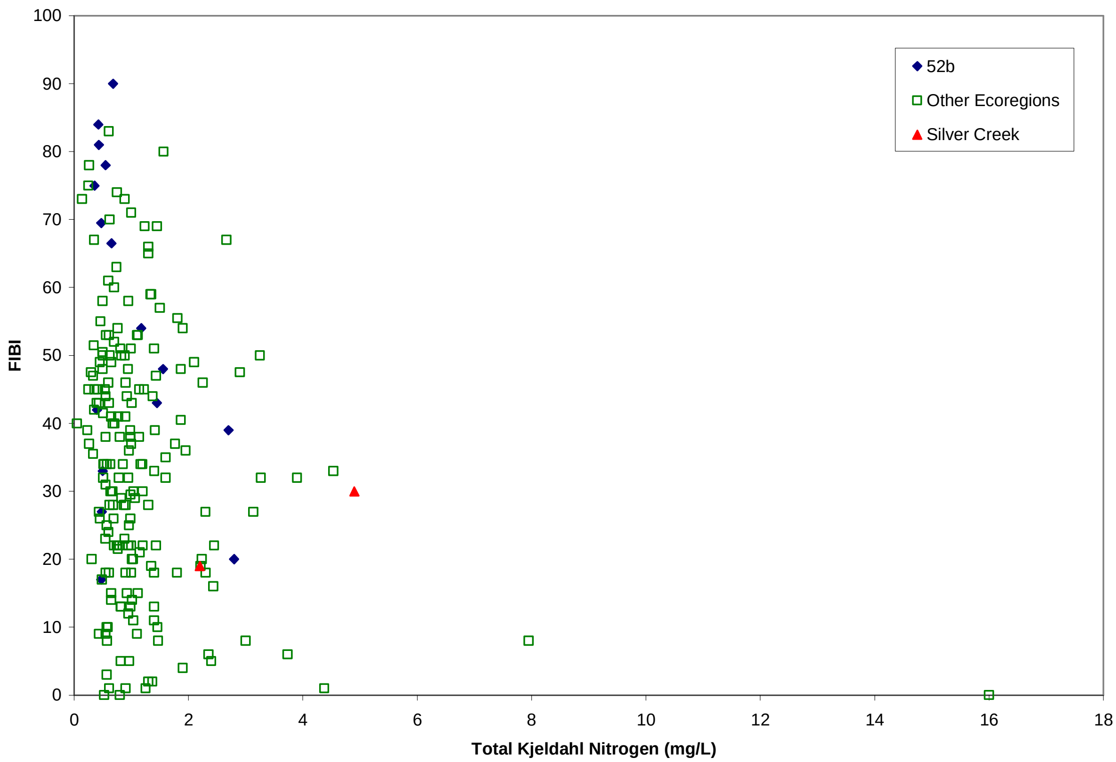


Figure 2-5. Fish Index of Biotic Integrity (FIBI) and total Kjeldahl nitrogen.

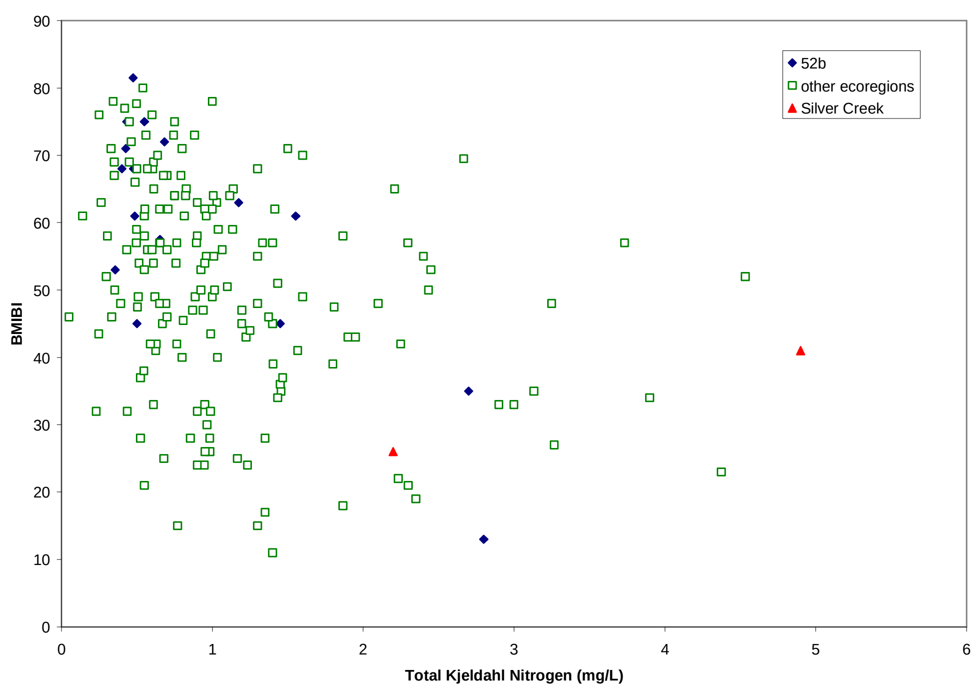


Figure 2-6. Benthic Macroinvertebrate Index of Biotic Integrity (BMIBI) and total Kjeldahl nitrogen.

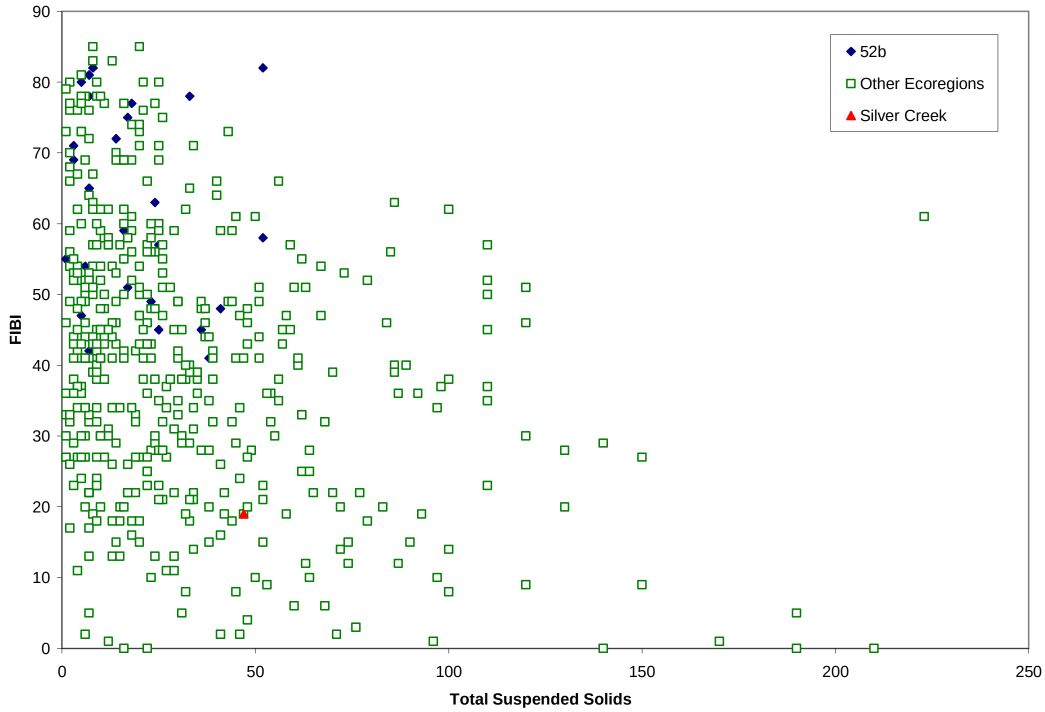


Figure 2-7. Fish Index of Biotic Integrity (FIBI) and Total Suspended Solids (TSS).

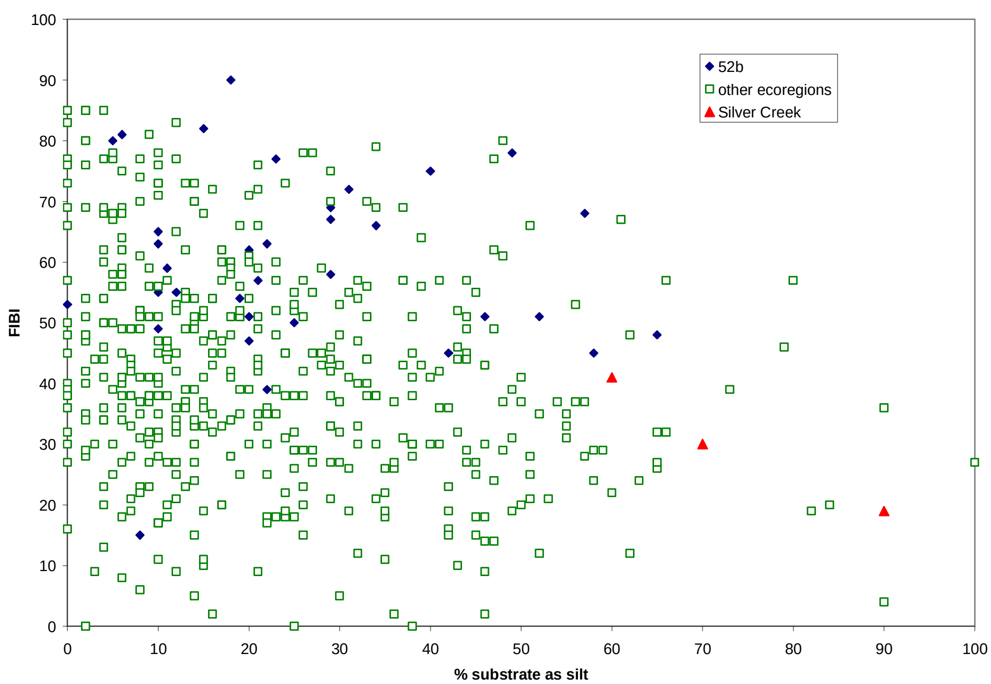


Figure 2-8. Fish Index of Biotic Integrity (FIBI) and percent stream bottom as silt.

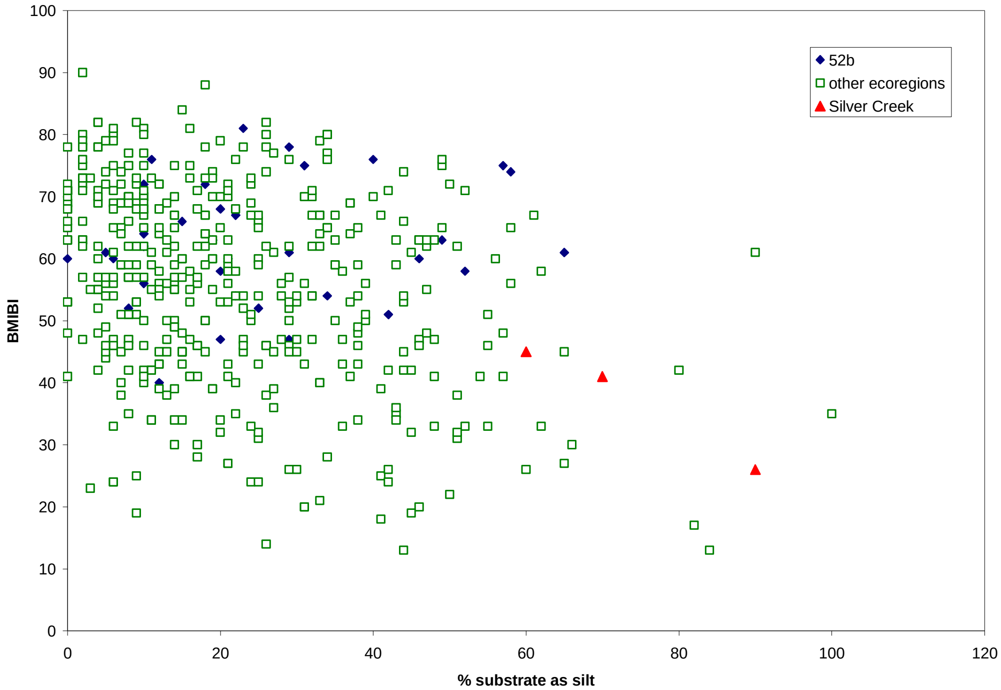
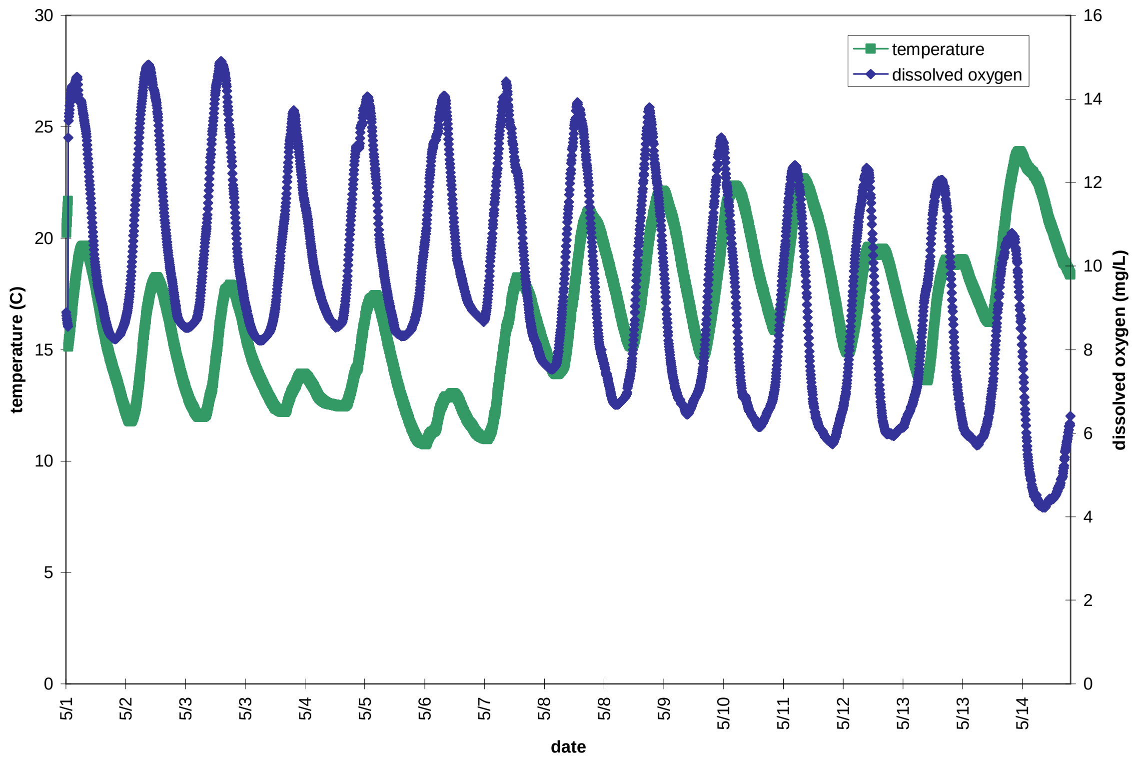


Figure 2-9. Benthic Macroinvertebrate Index of Biotic Integrity (BMIBI) and percent stream bottom as silt.



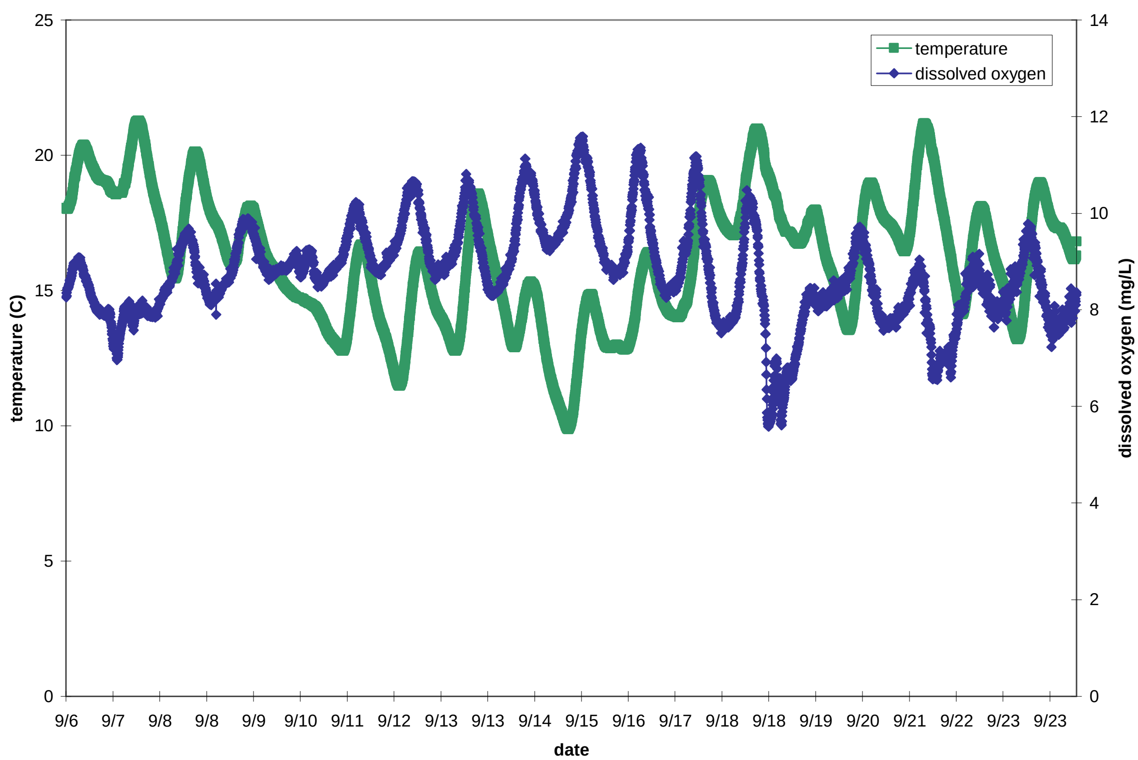


Figure 2-10. Diurnal temperature and dissolved oxygen measurements in Silver Creek at site 2A for May 1-15, 2007 and September 6-24, 2007.

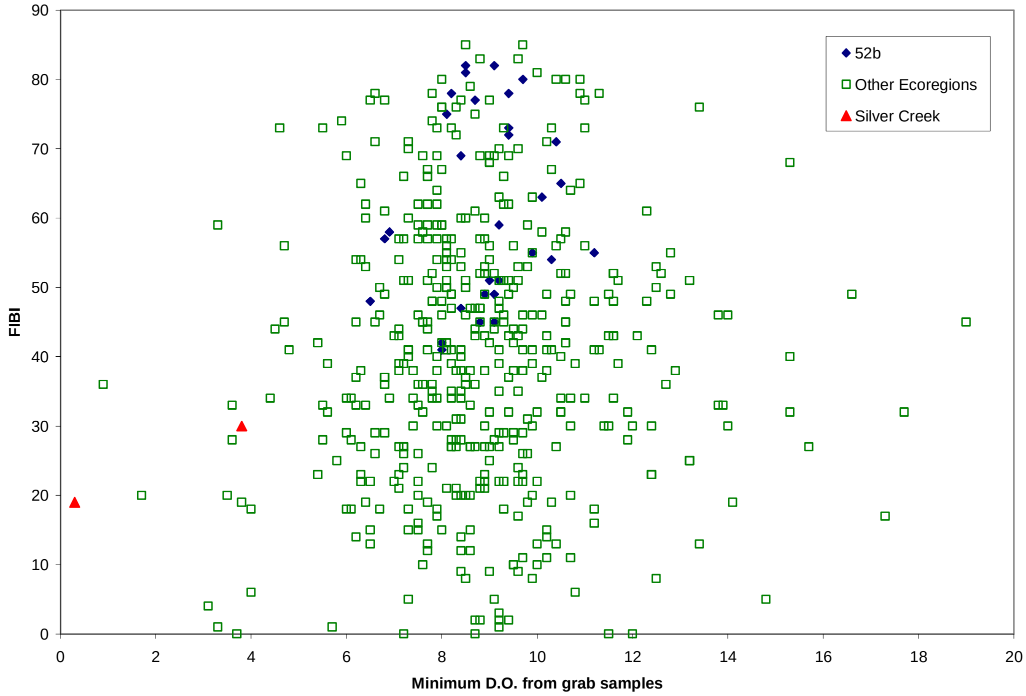


Figure 2-11. Fish Index of Biotic Integrity (FIBI) and minimum dissolved oxygen from grab samples.

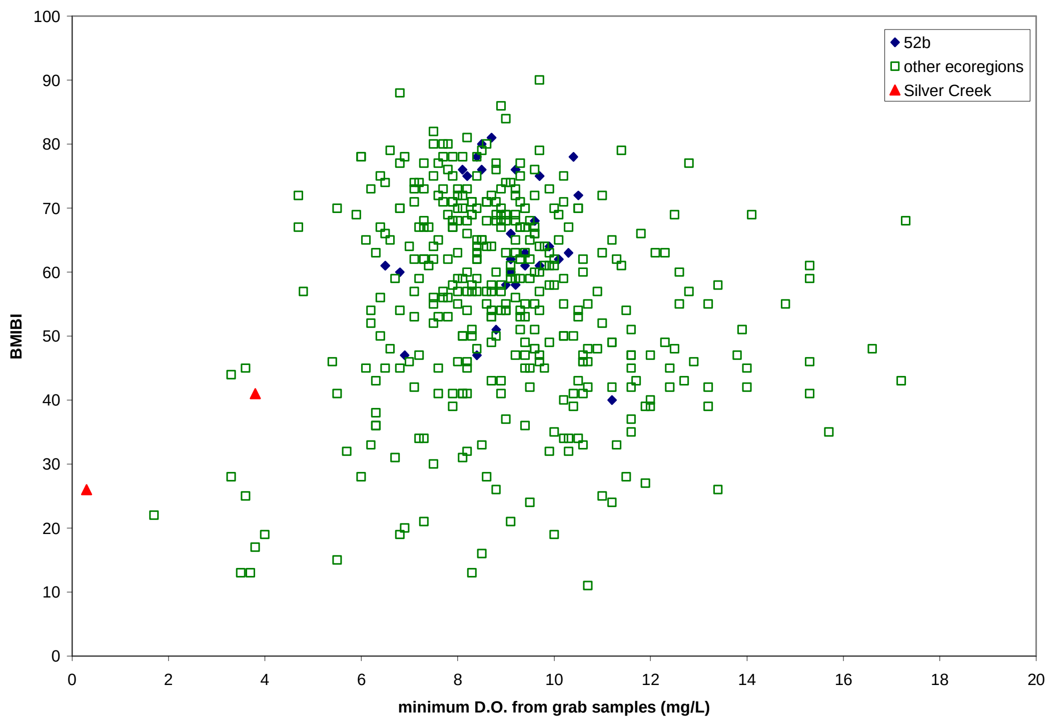


Figure 2-12. Benthic Macroinvertebrate Index of Biotic Integrity (BMIBI) and minimum dissolved oxygen from grab samples.

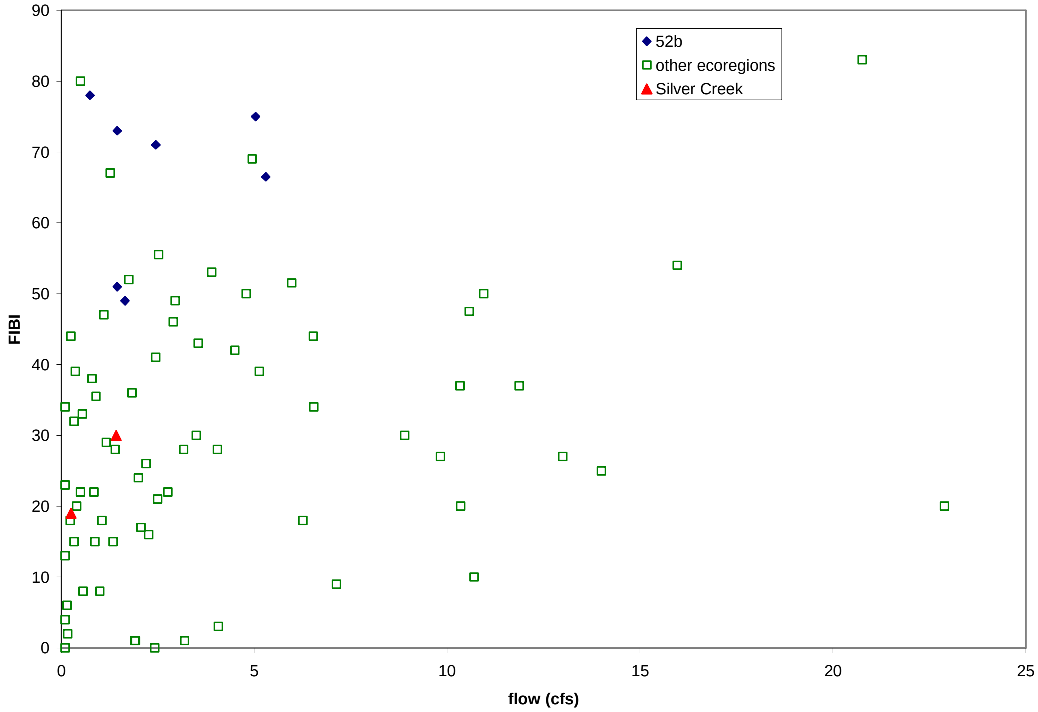


Figure 2-13. Fish Index of Biotic Integrity (FIBI) and flow in watersheds less than 30 square miles.

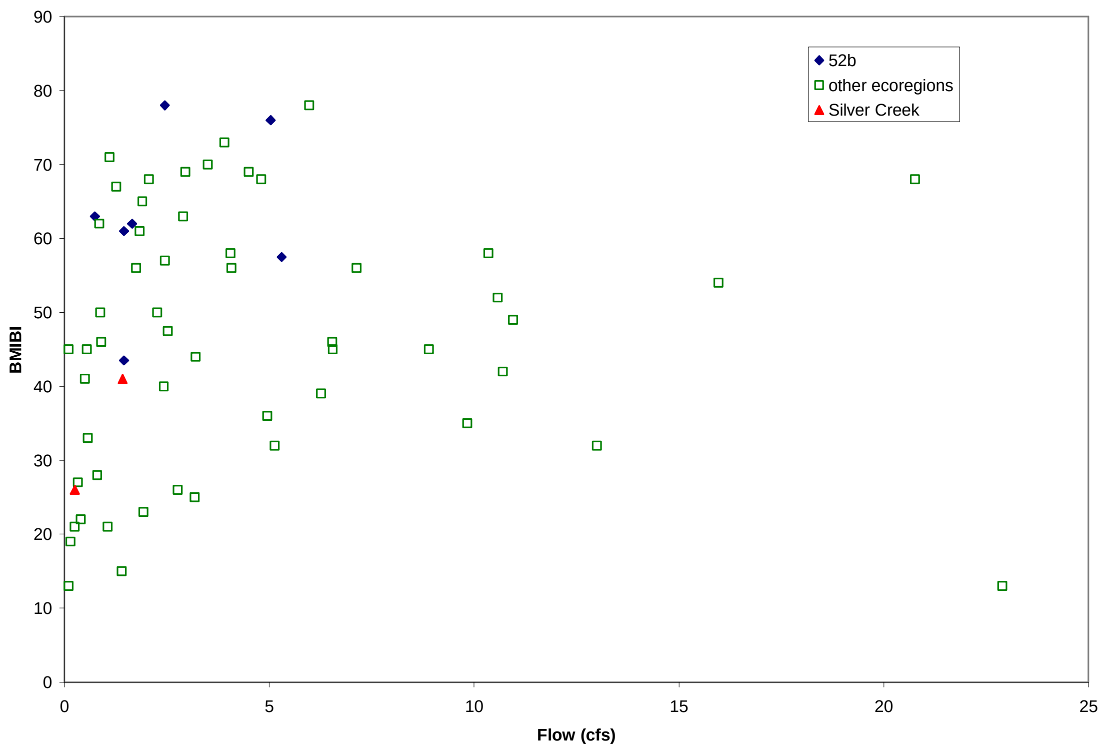


Figure 2-14. Benthic Macroinvertebrate Index of Biotic Integrity (BMIBI) and flow in watersheds less than 30 square miles.

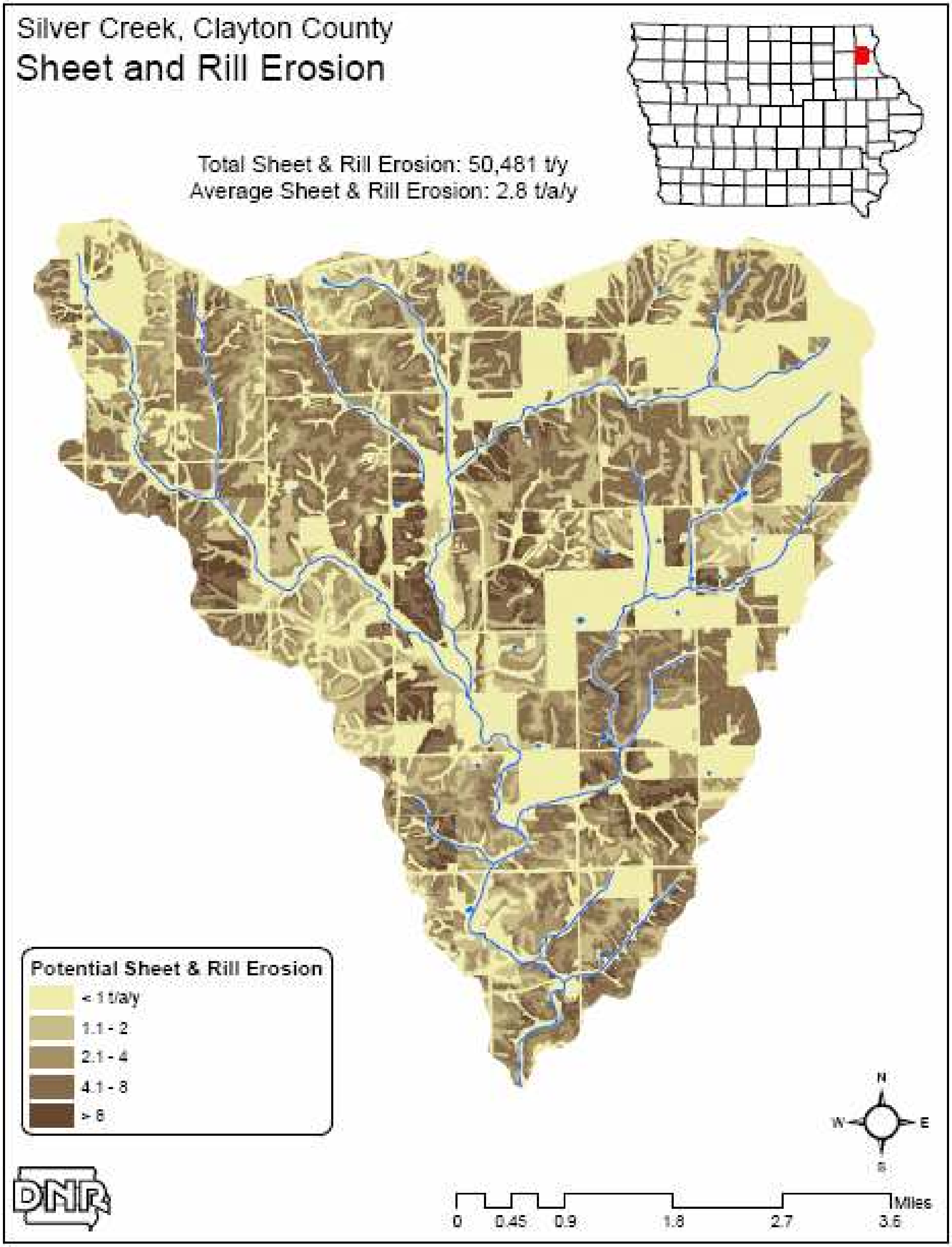


Figure 2-15. RUSLE estimate of sheet and rill erosion in the Silver Creek watershed based on 2002 photography.

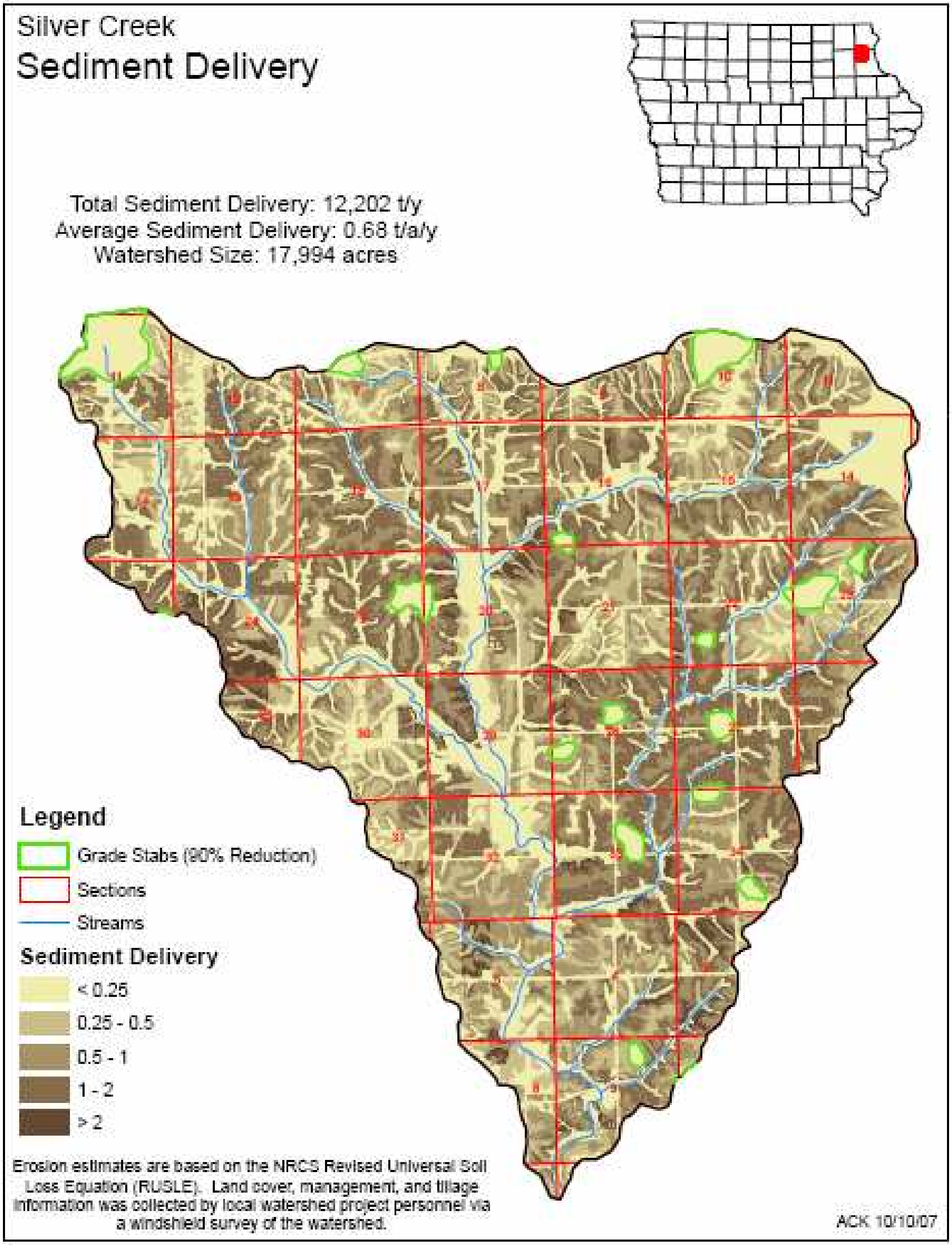


Figure 2-16. Estimate of Silver Creek sediment delivery based on 2002 photography.

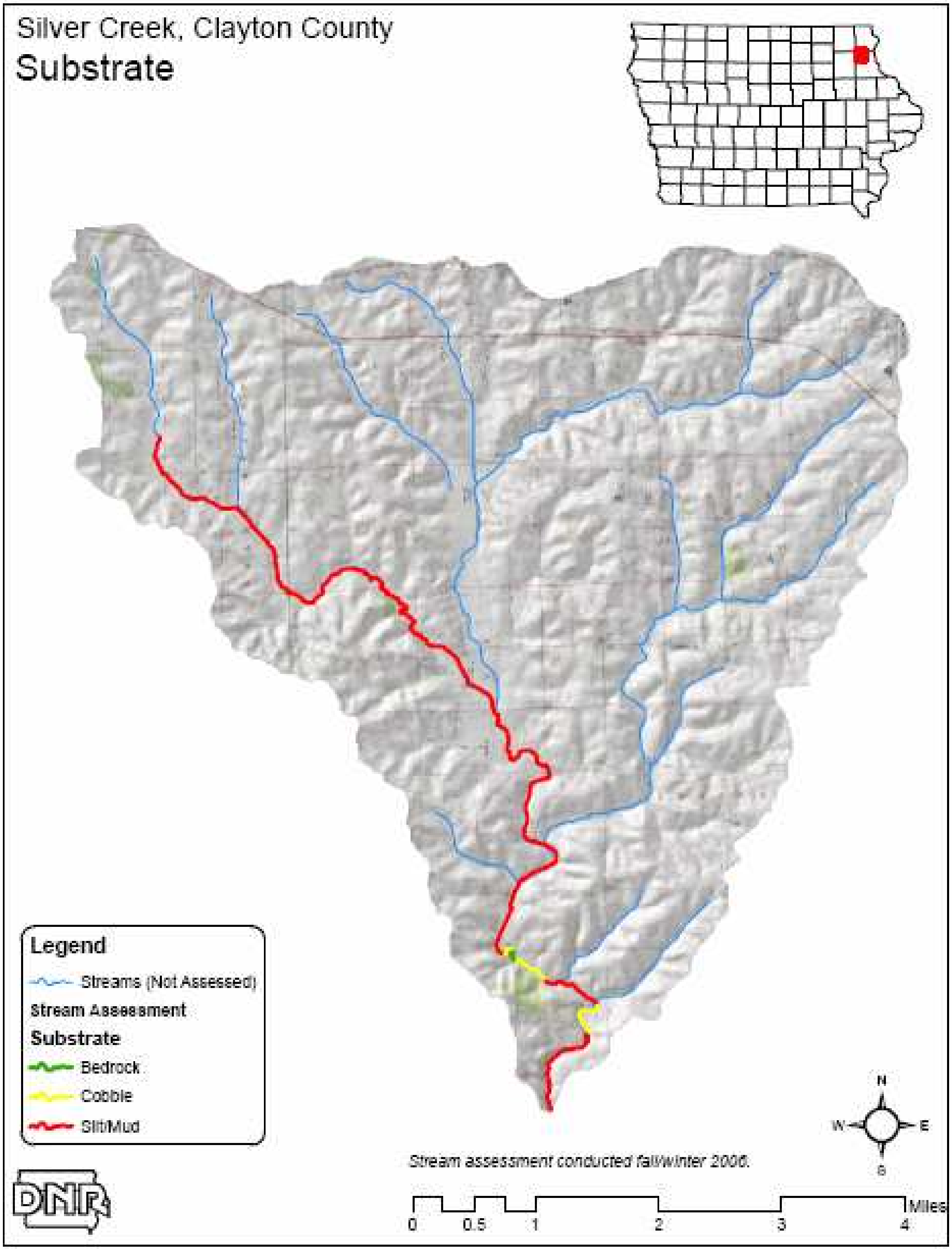


Figure 2-17. Estimates of substrate composition from 2006 RASCAL analysis.

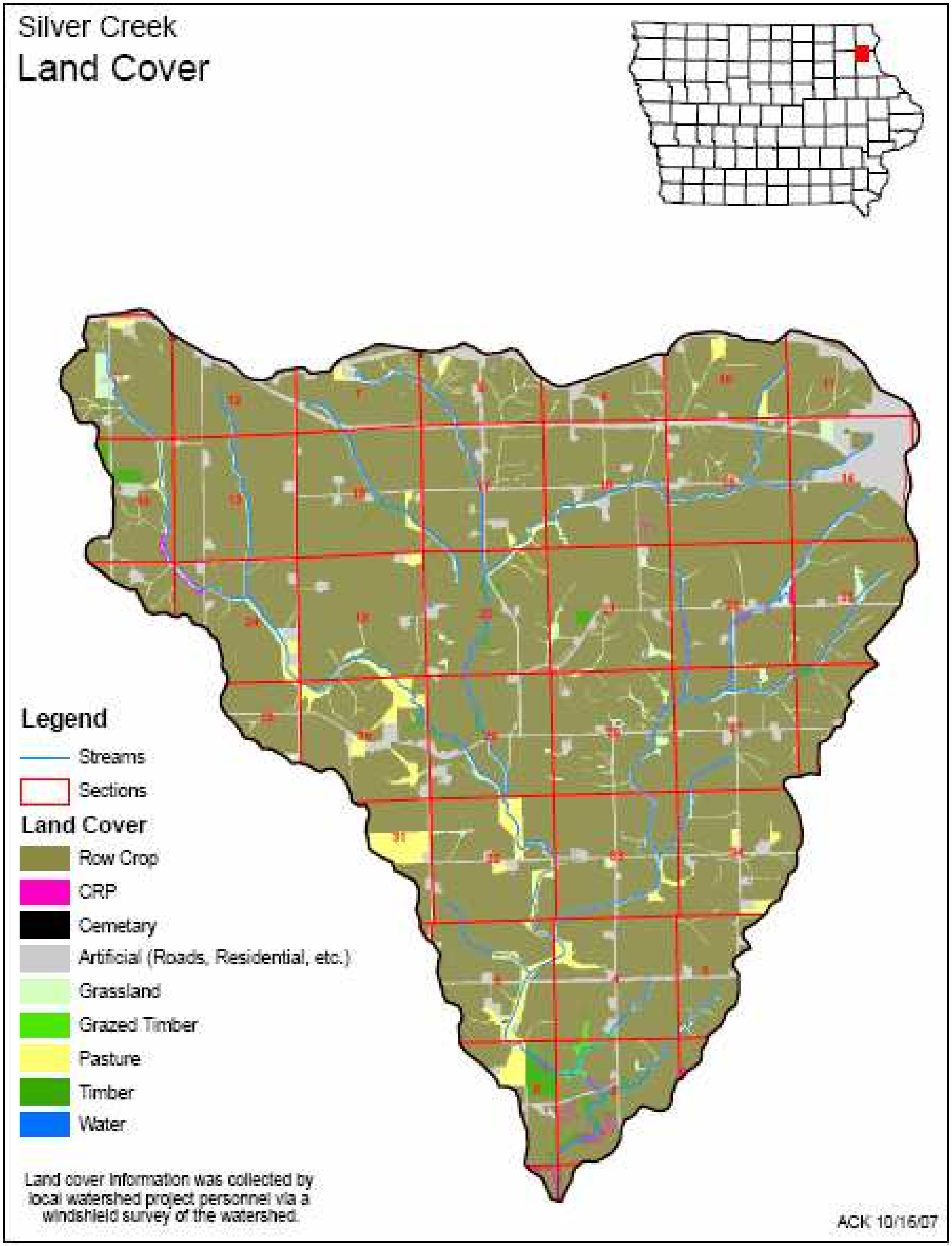


Figure 2-18. Land use in the Silver Creek watershed in 2006.

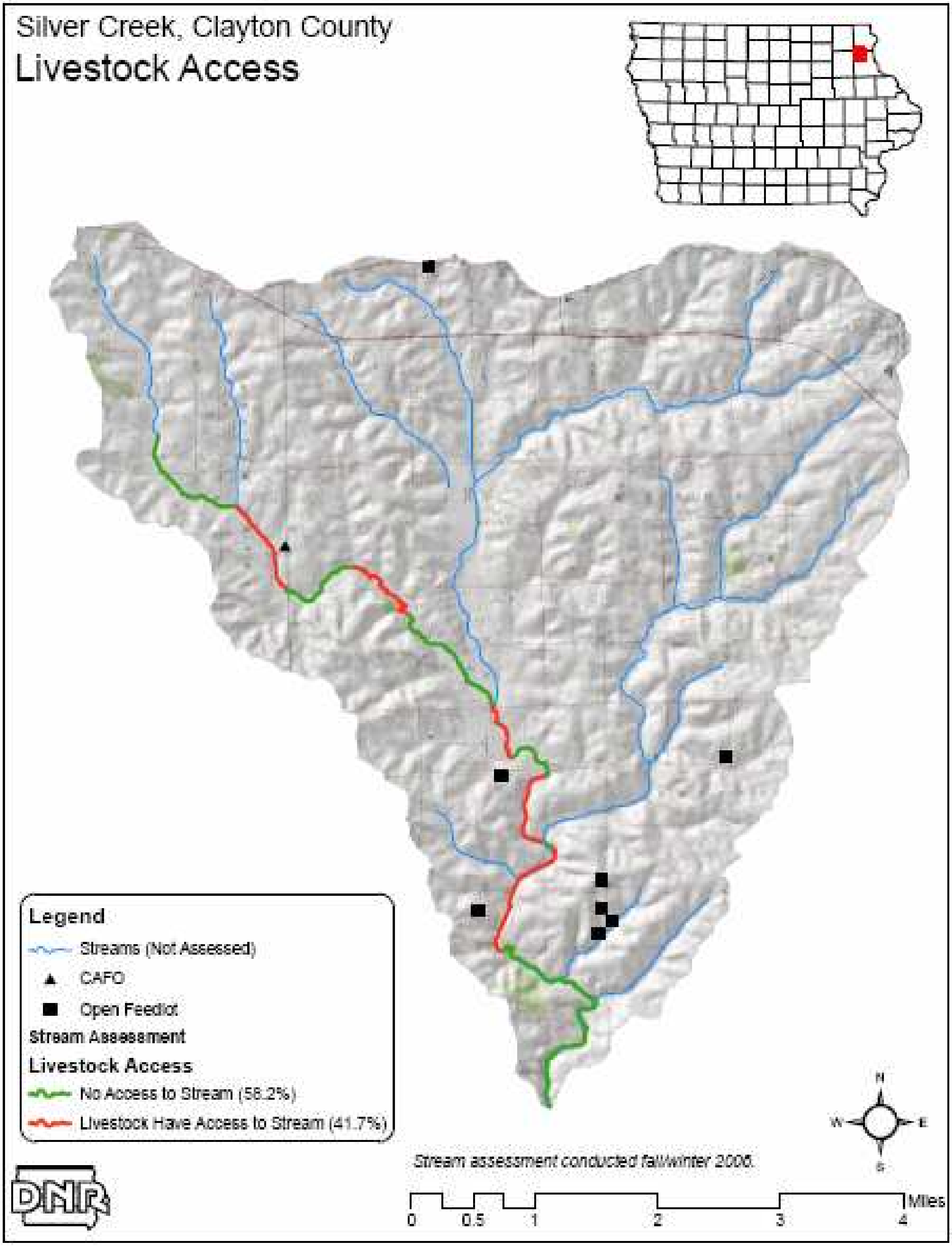


Figure 2-19. Livestock access to stream in the Silver Creek watershed in 2006.

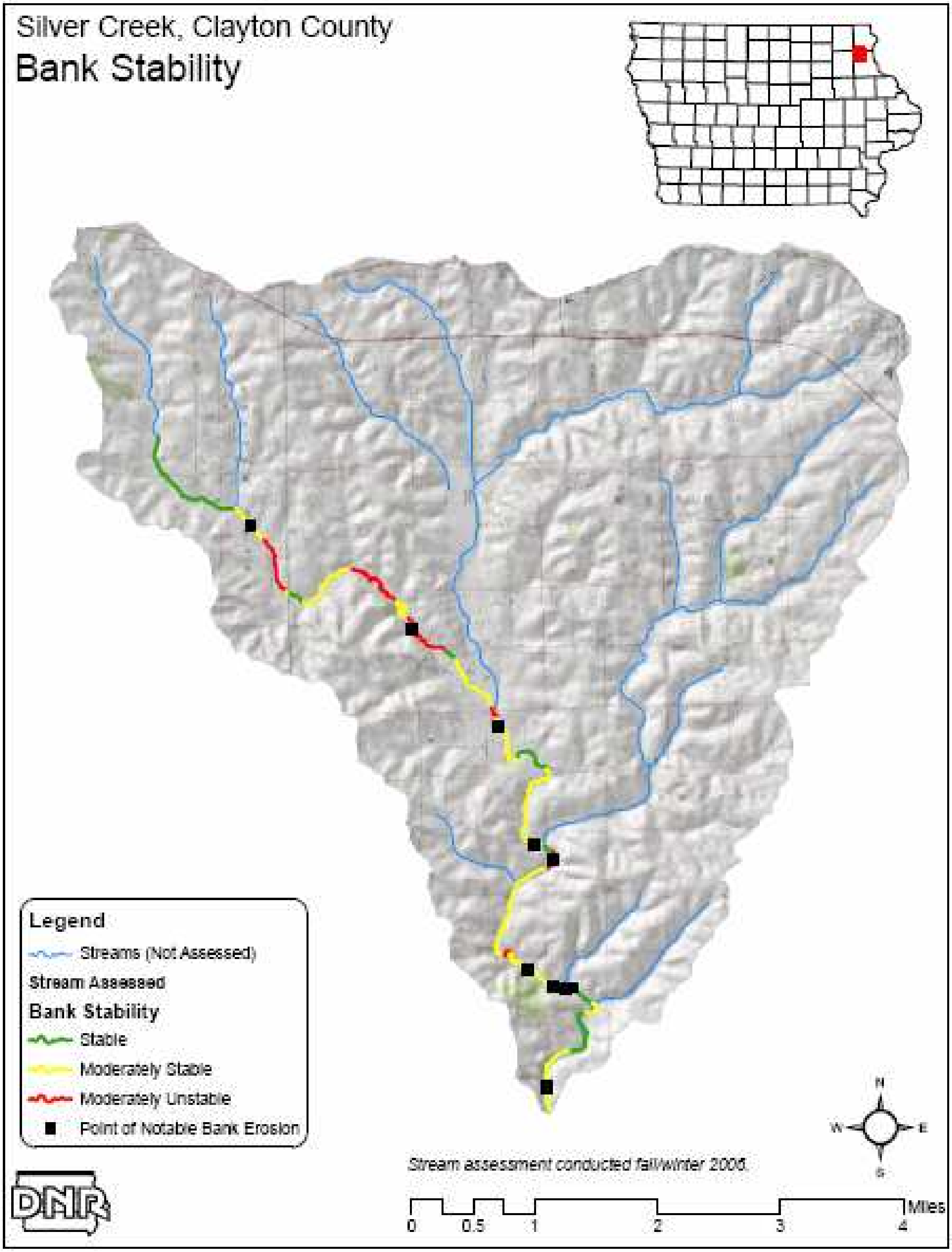


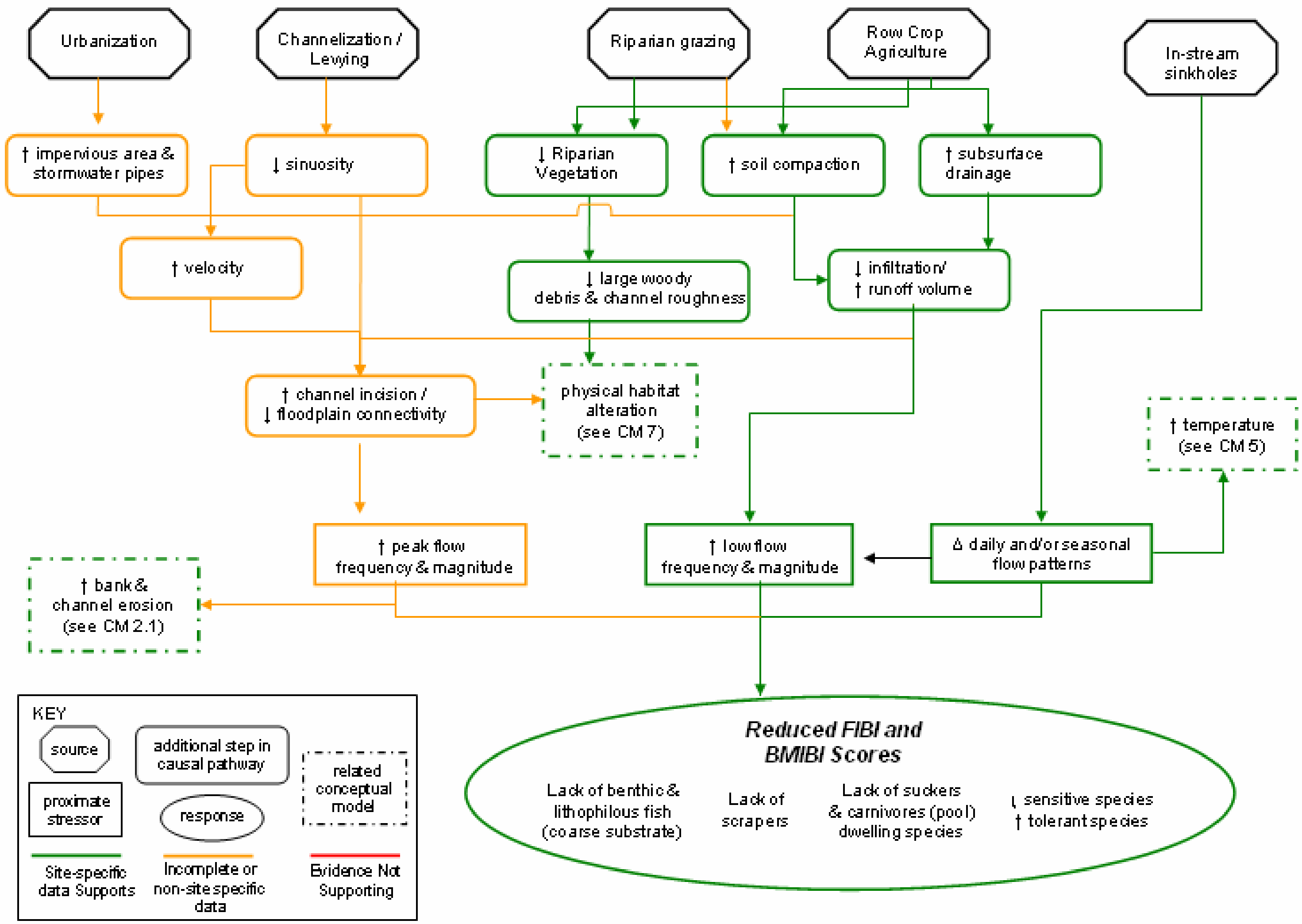
Figure 2-20. Bank stability in the Silver Creek watershed in 2006.

Appendix 3

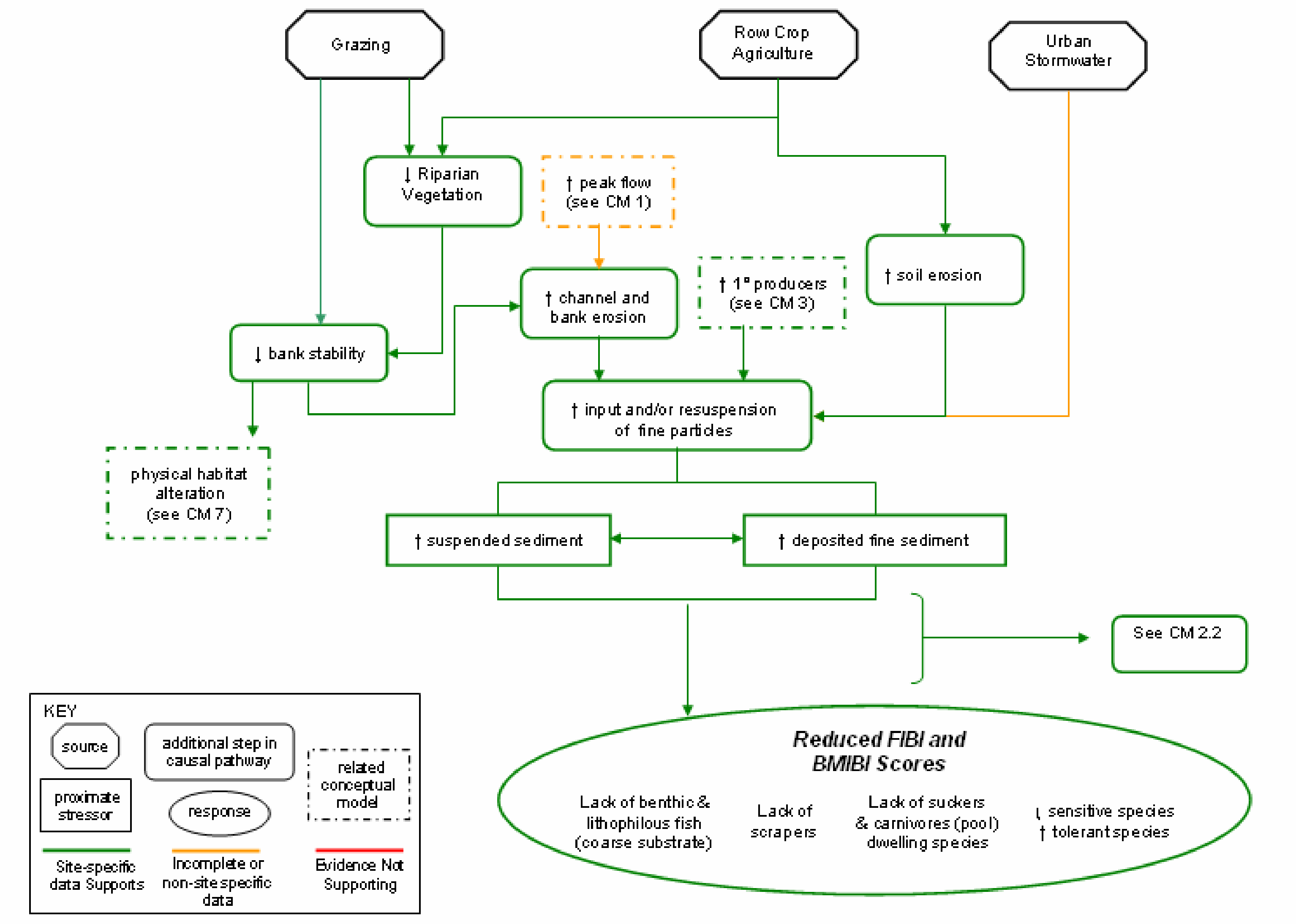
Conceptual Models of Plausible Causal Pathways

Conceptual Model 1 - Altered flow regime
Conceptual Model 2.1 - Suspended and Bedded Sediments (SABS)
Conceptual Model 2.2 - Suspended and Bedded Sediments (SABS)
Conceptual Model 3 - Altered basal food source
Conceptual Model 4 - Decreased dissolved oxygen
Conceptual Model 5 - Elevated temperature
Conceptual Model 6 - Elevated ammonia
Conceptual Model 7 - Physical Habitat Alteration
Conceptual Model 8 - Aquatic Life Depletion and Isolation

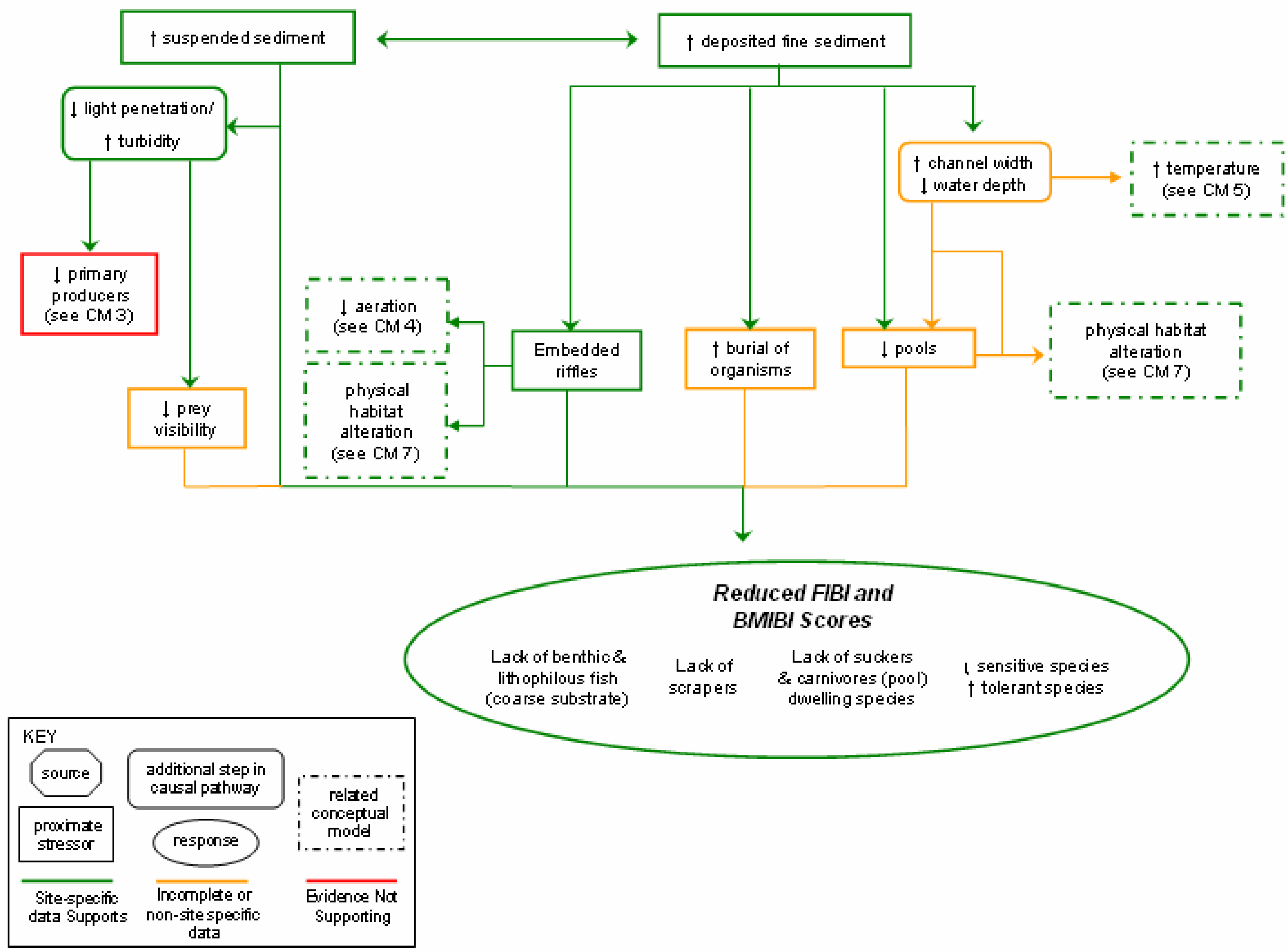
Conceptual Model 1 - Altered flow regime



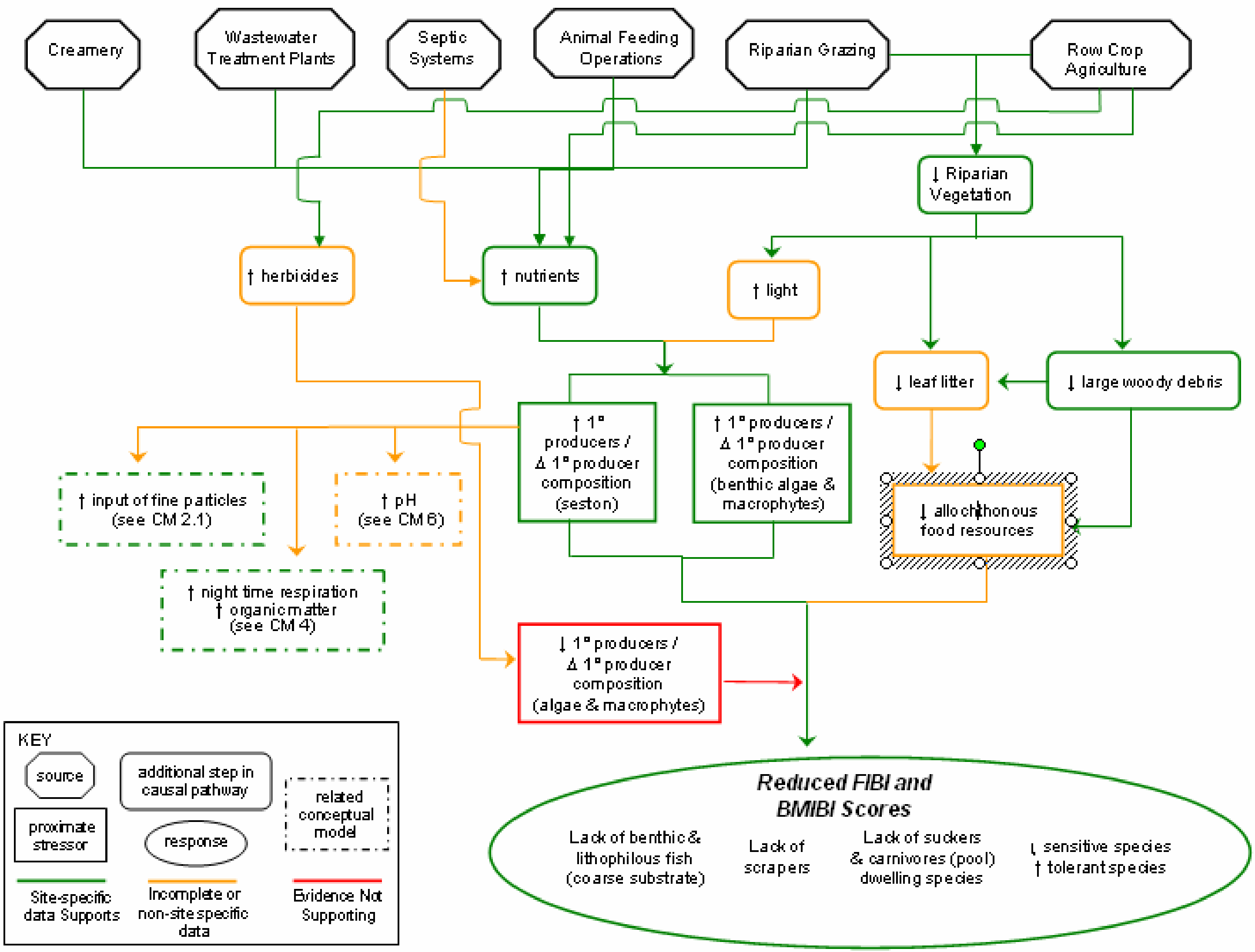
Conceptual Model 2.1 - Suspended and Bedded Sediments (SABS)



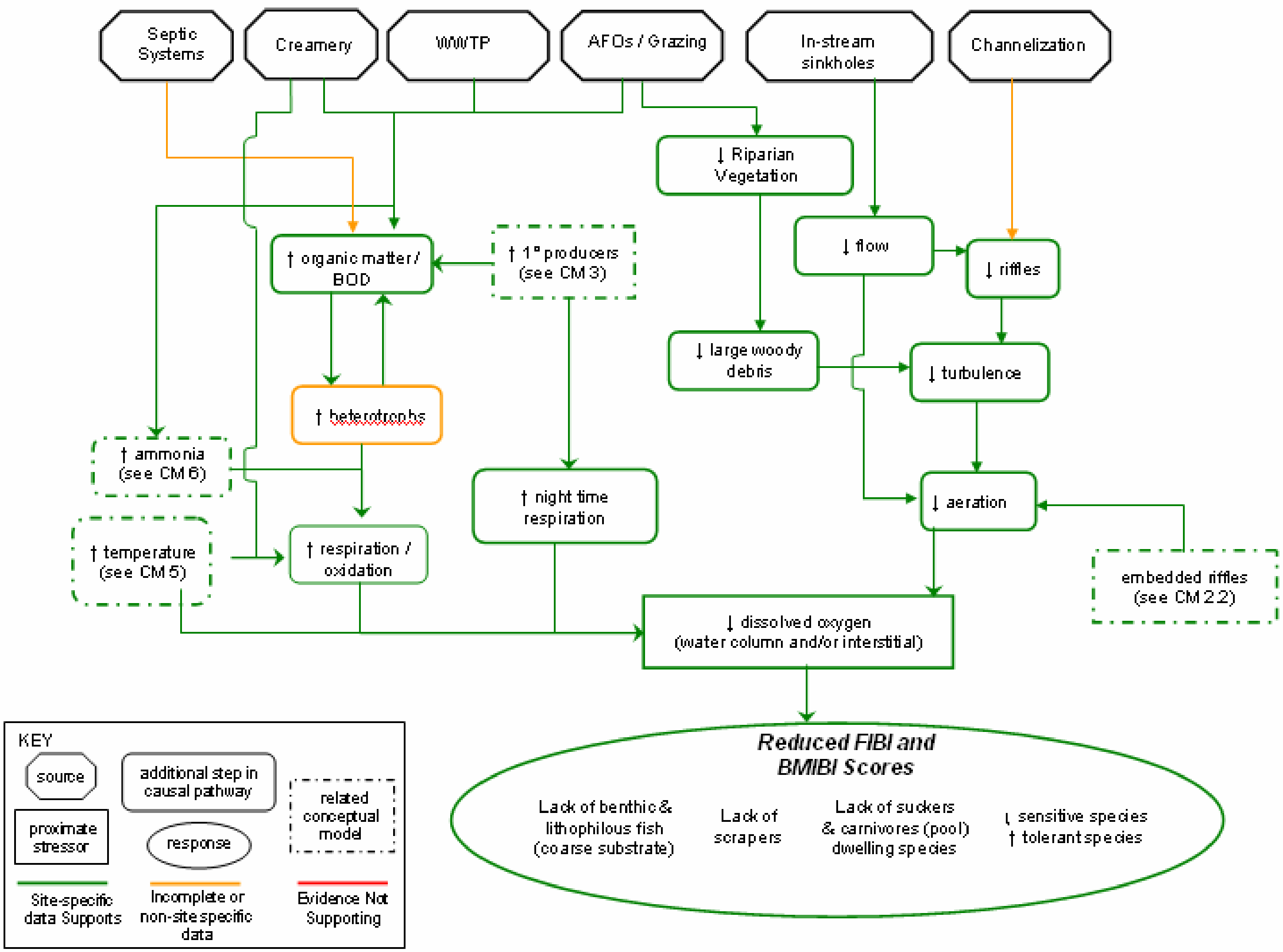
Conceptual Model 2.2 - Suspended and Bedded Sediments (SABS)



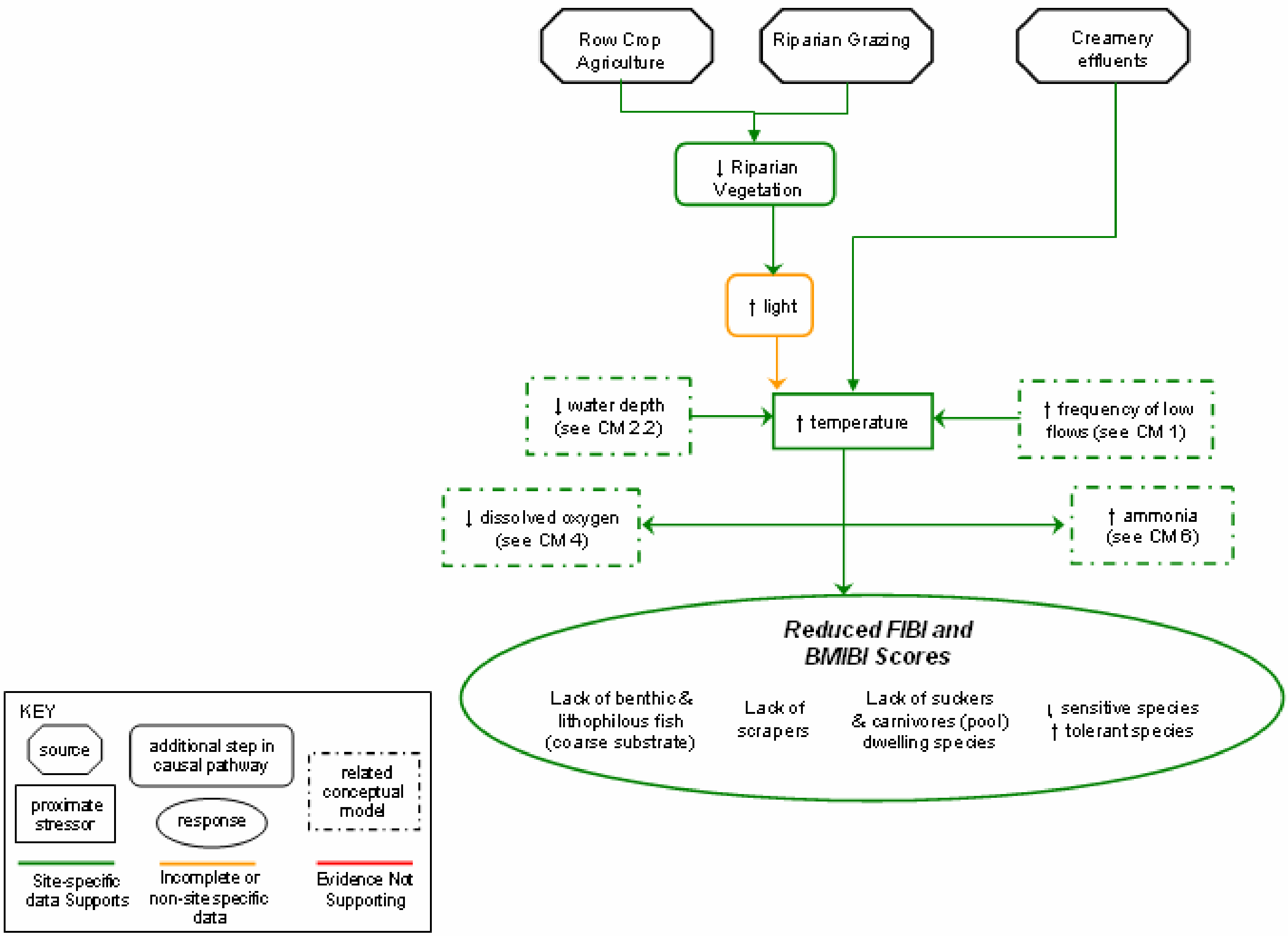
Conceptual Model 3 - Altered basal food source



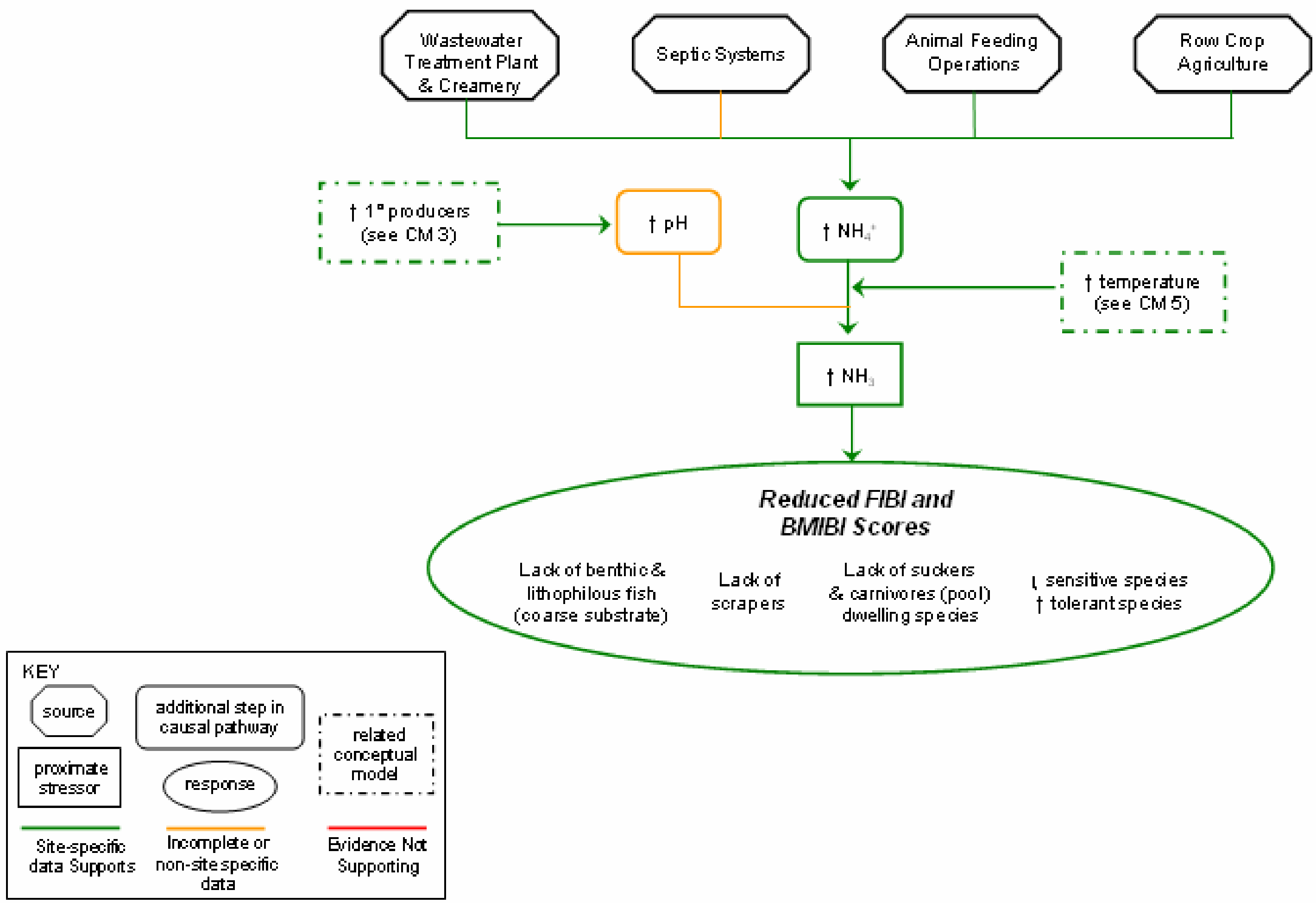
Conceptual Model 4 - Decreased dissolved oxygen



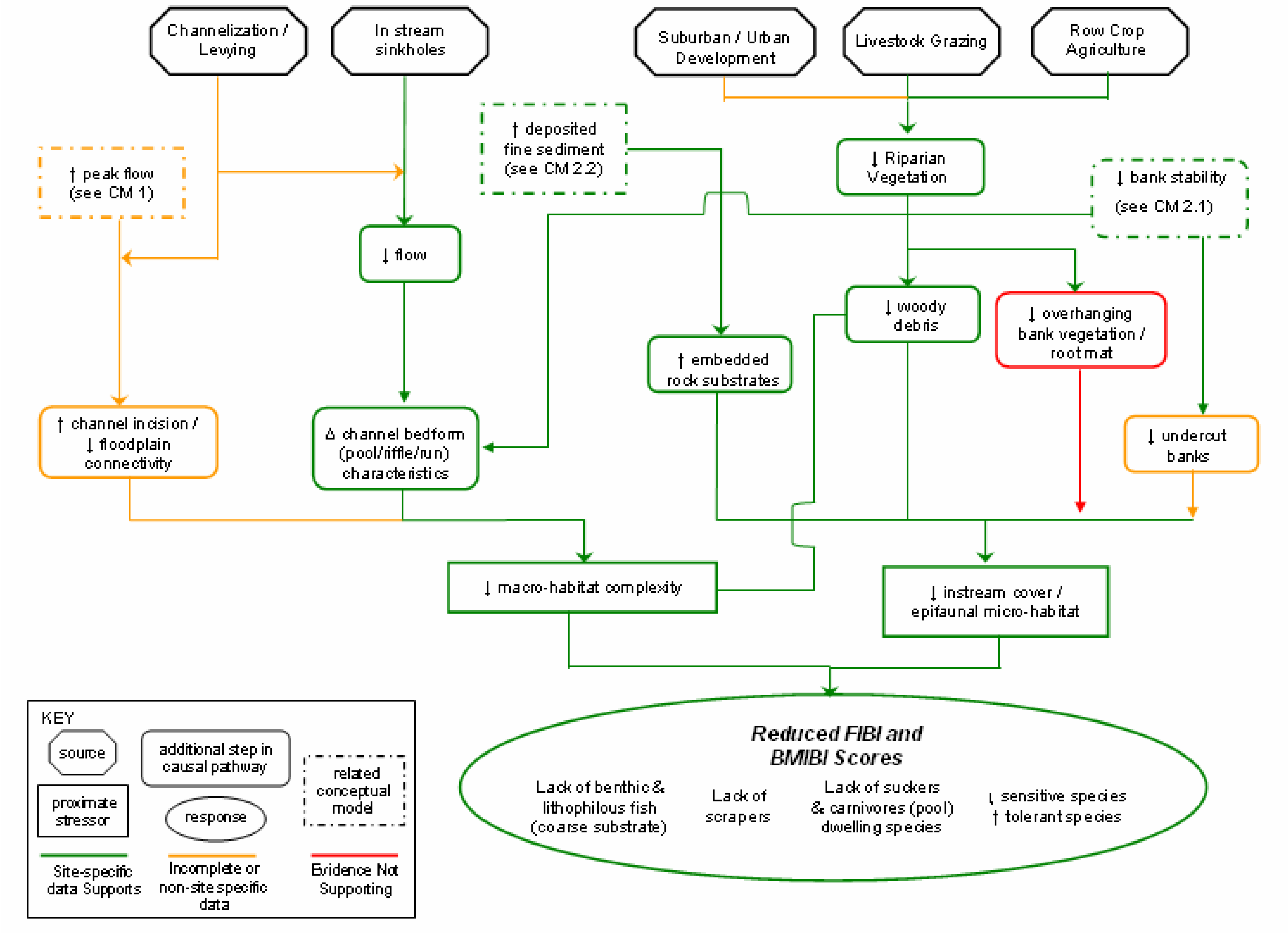
Conceptual Model 5 - Elevated temperature



Conceptual Model 6 - Elevated ammonia



Conceptual Model 7 - Physical Habitat Alteration



Conceptual Model 8 - Aquatic Life Depletion and Isolation