Stressor Identification

North Fork Maquoketa River, Iowa

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Watershed Assessment Section
and
Watershed Improvement Section

Iowa Geological Survey and Land Quality Bureau

Environmental Services Division

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Executive Summary

A Stressor Identification (SI) was completed for the North Fork Maquoketa River (Segment No. IA 01-NMQ-0020_2) and Hickory Creek (IA 01-NMQ-0160) located in the northernmost part of the North Fork Maquoketa River watershed in Delaware and Dubuque counties. These waterbodies are identified on Iowa's (Section 303(d)) list of impaired waters as biologically impaired due to unknown causes. 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.

Dating back to the mid 1970's, evidence of biological impairment includes periodic fish kills and reduced biotic condition index levels at multiple locations 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 NFMR watershed:

- lethal concentrations of unionized-ammonia;
- elevated levels of total suspended solids and turbidity;
- elevated levels of silt accumulation and sedimentation of rock substrates;
- low / potentially lethal levels of dissolved oxygen and extreme fluctuations in dissolved oxygen levels;
- excessive growth of benthic algae.

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 the North Fork Maquoketa River (Segment No. IA 01-NMQ-0020_2) 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 Hickory Creek (IA 01-NMQ-0160), an impaired tributary of the North Fork Maquoketa River (NFMR) (Figure 1) with similar stream impairment and watershed characteristics.

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

The surface watershed contributing flow to the NFMR upstream from Dyersville, Iowa occupies a transitional area between two ecological regions of Iowa (Figure 1). Roughly, two-thirds of the lower portion of the watershed is located in the Iowan Surface of the Western Corn Belt Plains, and the upper one-third of the watershed is located in the Paleozoic Plateau (Driftless Area) ecoregion.

The Iowan Surface ecoregion is a geologically complex region located between the bedrock-dominated landforms of the Paleozoic Plateau region and the relatively recent glacial drift landforms of the Des Moines Lobe (Prior 1991; Griffith et al., 1994). The southern and southeastern border of this ecoregion is irregular and crossed by major northwest-to southeast-trending stream valleys. In the northern portion of the region, the glacial deposits are thin, and shallow limestone bedrock creates karst features such as sinkholes and sags. There are no natural lakes of glacial origin in this region, but overflow areas and backwater ponds occur on some of the larger river channels contributing to some diversity of aquatic habitat and a large number of fish species.

The bedrock-dominated terrain of the Paleozoic Plateau ecoregion 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. 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 the 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 occupy entrenched valleys, and have cool waters with high gradients flowing over rocky substrates. The fish communities found here reflect this preference for cool clear water with relative consistency of flow.

At the confluence with Bear Creek in Dyersville, the NFMR is a fourth-order stream draining 28,250 acres in northwestern Dubuque County and northeastern Delaware County (Figure 1). Current land use in the watershed is dominated by agriculture (Figure 2). According to the 2002 land cover data, approximately 60% of the watershed area is devoted to row crop agriculture. Grasslands, including hay fields, pasture and conservation set aside encompass approximately 33% of the watershed area. Pastures are predominantly located in streamside areas that allow access for livestock watering. Preliminary estimates of livestock in the watershed include approximately 5,300 beef cattle, 1,500 dairy cattle, and 31,200 hogs (cattle were derived using GIS; swine was determined by reviewing aerial photos and estimating the number of hogs in the buildings). Although livestock operations are not permitted to discharge waste directly into surface waters, the mishandling and over-application animal waste and fertilizer may impact water quality.

The NFMR watershed includes three permitted point sources: the City of Luxemburg wastewater treatment facility (WWTP), the City of Holy Cross WWTP, and the City of New Vienna WWTP. Facility statistics including treatment type and effluent limits may be found in Table 1. None of the WWTPs receives waste from industrial contributors. The city of New Vienna upgraded their WWTP facility in 2006.

Table 1. Waste Water Treatment Plants (WWTPs) in the NFMR watershed.

Municipality	Luxemburg	Holy Cross	New Vienna
IA NPDES #	3158001	3146001	3165001
EPA #	IA0074781	IA0025992	IA0027391
Treatment type	3-cell lagoon[1]	2-cell lagoon[1]	Aerated lagoon[2]
CBOD5 (mg/l)[3]	25 (30-d)	25 (30-d)	25 (30-d)
TSS (mg/l)[3]	80 (30-d)	80 (30-d)	80 (30-d)
pH[3]	6.0 to 9.0	6.0 to 9.0	6.0 to 9.0
ADW / AWW (mgd)[4]	0.075	0.054	0.0278 / 0.0416
Population Equiv.	331	587	428

1. These lagoons are classified as facultative lagoons and are controlled discharge treatment facilities that provide 180 days of wastewater storage.
2. Aerated lagoons are continuous discharge treatment facilities.
3. These are the NPDES permit limits for these facilities for CBOD5, TSS, and pH.
4. These are the average permit flow limits for the facilities. For the two controlled discharge lagoons, the AWW is 180-day average wet weather flow. For the New Vienna WWTP, the AWW flow is the 30-day average wet weather flow and ADW is the 30-day average dry weather flow.

From its headwaters, the NFMR flows in a southwesterly direction to New Vienna where it turns and runs south towards Dyersville (Figure 1). In Dyersville, the NFMR receives Hewitt Creek, which includes the sub-watershed of Hickory Creek. Flowing from the northwest, Bear Creek also enters the NFMR in Dyersville. The NFMR watershed outlet is marked at the confluence with Bear Creek; however, this sub-watershed is not included in the SI.

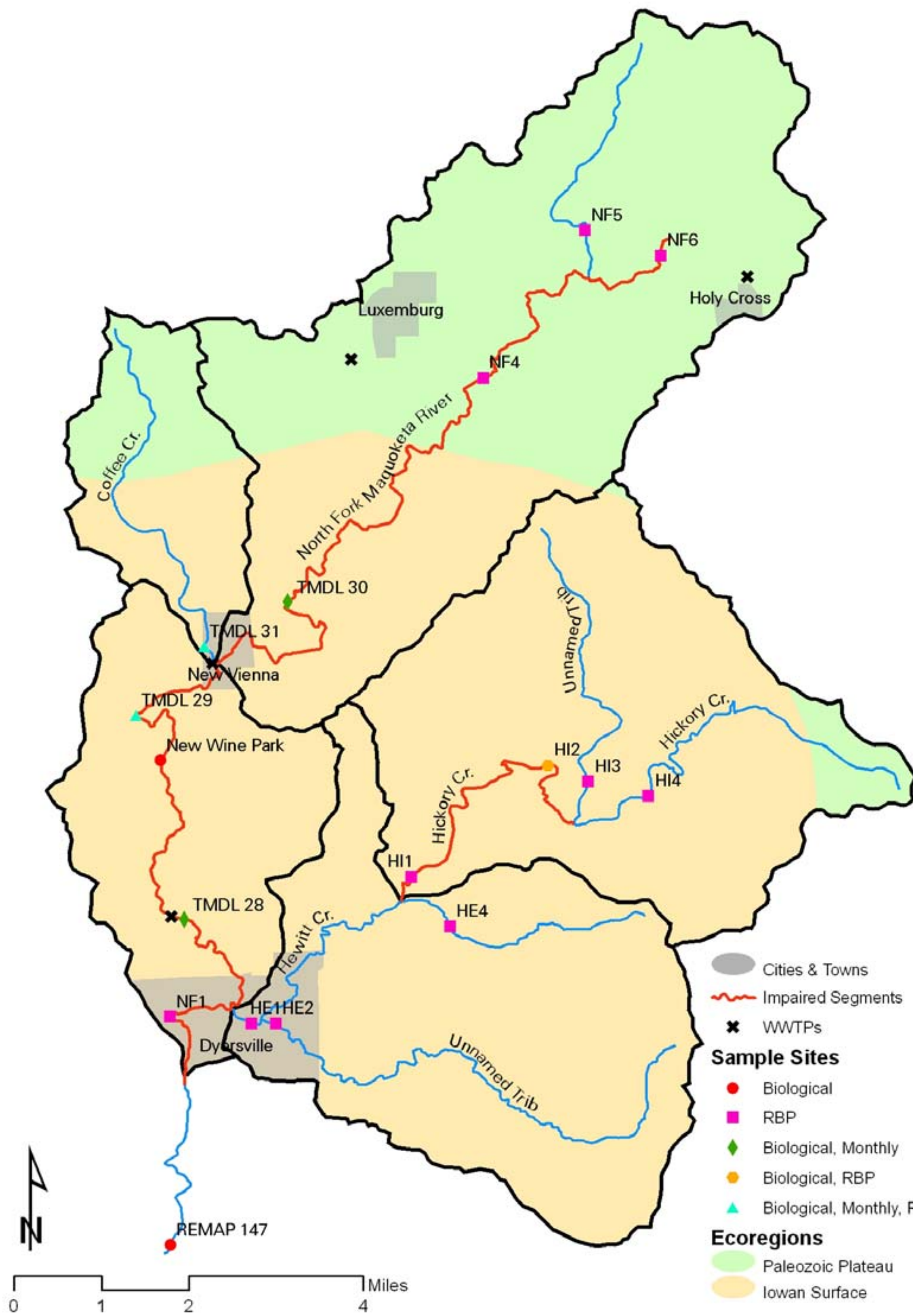

Figure 1. The watershed of the NFMR, including the locations of the impaired segments, bioassessment and water quality sampling sites, wastewater facilities, and urban areas.

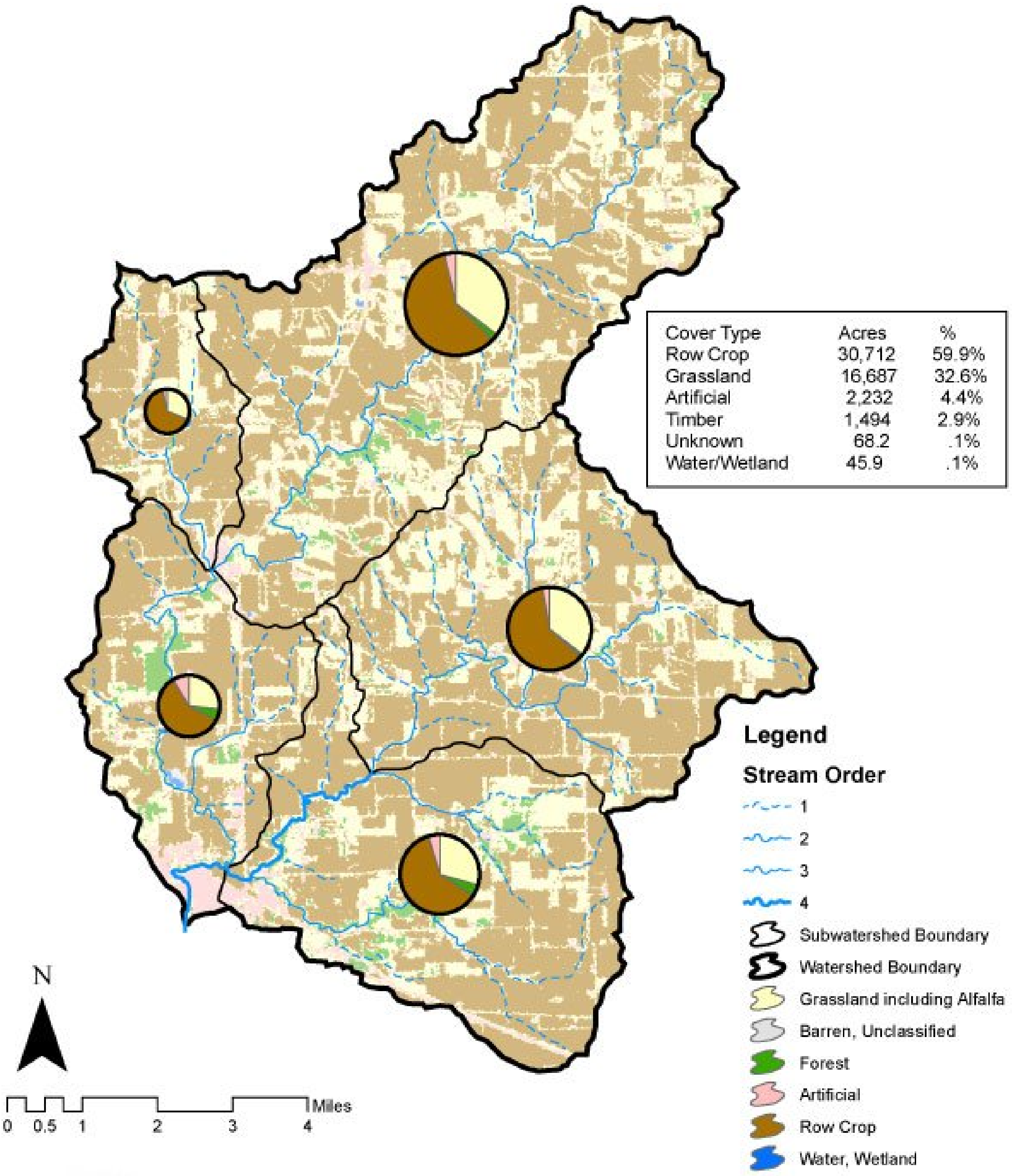

Figure 2. Land uses in the NFMR watershed based on 2002 satellite imagery.

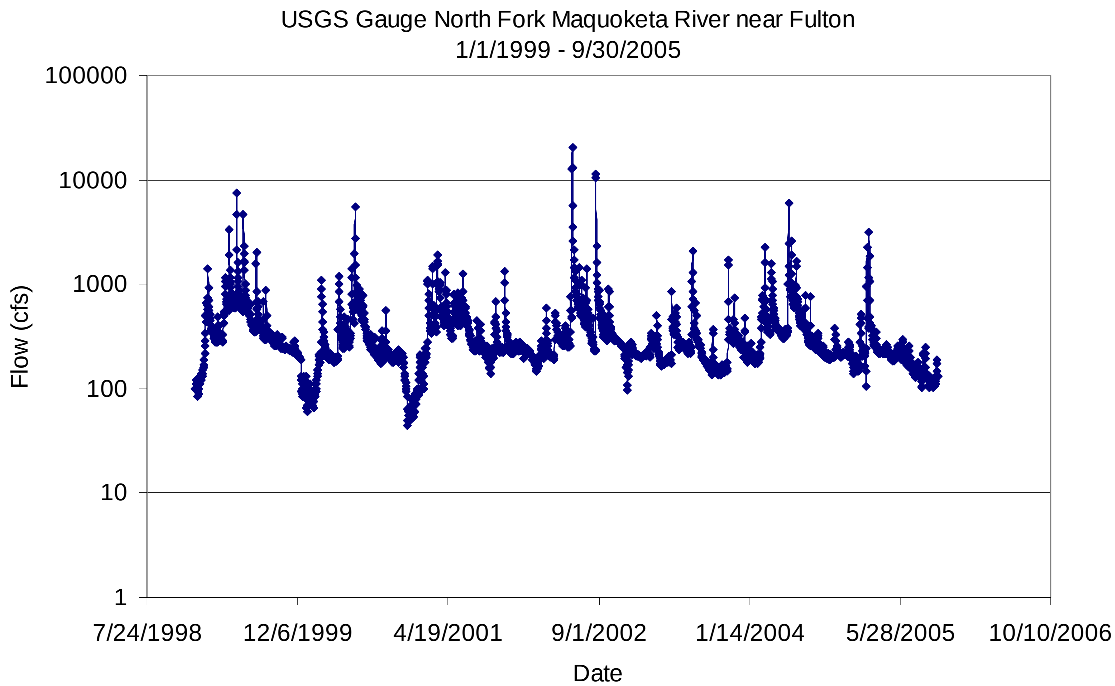

Figure 3. USGS stream flow gauge for the North Fork Maquoketa River near Fulton, Iowa.

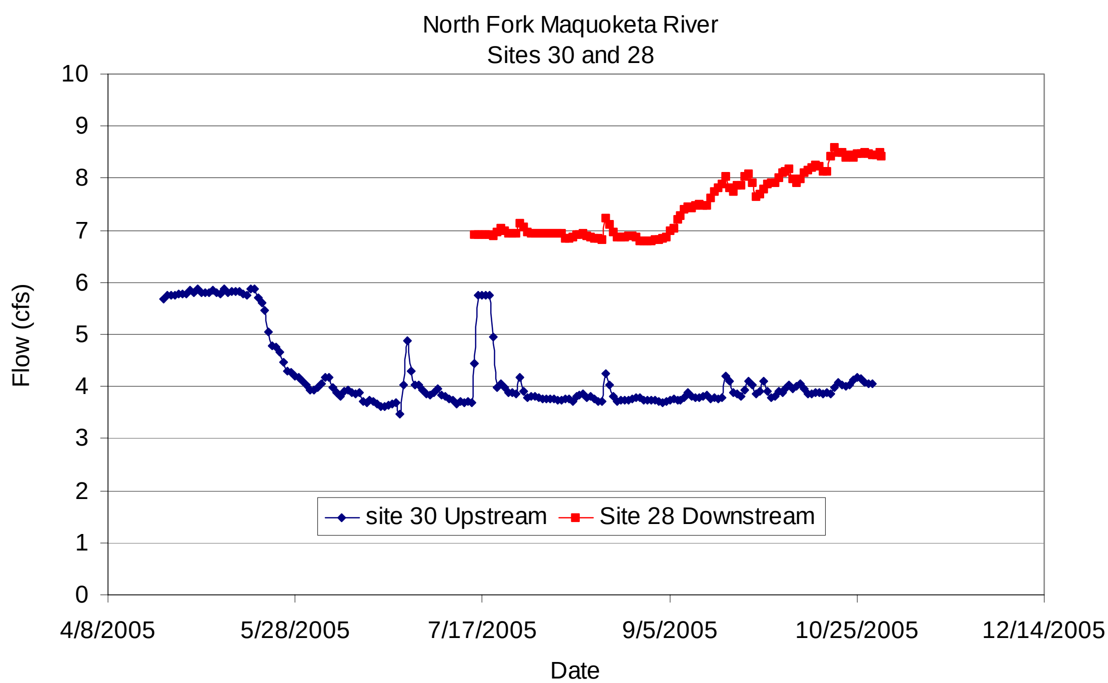

Figure 4. North Fork Maquoketa River 2005 stream discharge monitoring for TMDL sites 30 and 28.

Stream Flow and Water Quality

Stream discharge data (Figure 3) from the gauge at Fulton located near the mouth of the NFMR illustrates flow patterns during the sampling period evaluated for the SI. This gauging station integrates many sub-watersheds besides the SI watershed, but does provide a general sense of the annual and seasonal flow patterns that occurred during the data collection period. Typical of Iowa streams, the Fulton gauge data show the tendency for annual low flow to occur during the fall or winter months. Peak flows usually occur during the spring or early summer months. In addition, there is a consistent declining trend in flows during the second half of each year. Like most Iowa streams, there is a large difference between annual low flow and peak flow. In the case of the NFMR, the difference is approximately two orders of magnitude.

Figure 4 shows a limited amount of continuous stream flow data from 2005 at sites located in the SI watershed. Similar to the Fulton gauge, Site 30 flow data indicate 2005 was unusual from the standpoint that high flow events were absent during late spring and early summer. Flow conditions appeared to have been stable throughout the normal biological assessment interval lasting from July through October. The stable base flow pattern is also noteworthy because it indicates sustained groundwater inputs and a lack of karst geological features, which causes stream dewatering in some watersheds of the Iowan Surface and Paleozoic Plateau ecoregions.

Water quality characteristics measured at NFMR sampling sites (Appendix 2; Table 2-1) are generally indicative of intensive agricultural land uses and to a lesser extent urban land uses present in the watershed. The elevated concentrations of parameters like ammonia, nitrate-nitrogen, total phosphorus and total suspended solids found at several monitoring sites indicate water quality impacts when compared with levels occurring at least disturbed ecoregion reference stream sites. Sampling conducted in the 1970's by the University Hygienic Laboratory (UHL 1975) show that water quality impacts have existed in the upper part of the NFMR watershed for decades preceding the more recently documented problems. The UHL survey findings include elevated levels of ammonia, fecal coliform bacteria and biochemical oxygen demand (BOD).

Although there are no widely reported spring sources in the watershed, the relatively cool water temperatures found in the NFMR during summer months are indicative of sustained groundwater inputs. As discussed later, the cooling effect of groundwater inputs could be an important factor in the maintenance of acceptable stream dissolved oxygen concentrations. Relatively high specific conductance and pH levels measured in the NFMR further substantiate the important influence of groundwater contributions from the underlying limestone bedrock aquifer.

Biological Impairment

The SI watershed includes biologically impaired segments of the NFMR (IA 01 NMQ-0020_2) and Hickory Creek (IA 01-NMQ-0160) (Figure 1). Hickory Creek is included as parts of the SI because the biological impairment and watershed characteristics are similar and sufficient data were available for evaluating many of the candidate causes. A segment of Bear Creek in a neighboring watershed is also impaired. The impairment is attributed to a 2002 fish kill caused by lethal concentrations of ammonia, the apparent source of which is livestock waste. Bear Creek could not be included in this SI because stream monitoring and biological assessment data were not available.

As part of a water quality survey conducted by UHL in 1974, five locations spanning from the headwaters to the mouth of the NFMR were sampled for benthic macroinvertebrates (UHL 1975). The organisms were generally identified to genus taxonomic level and qualitatively compared with stream characteristics. The headwaters sampling location upstream from New Vienna was dominated by black fly larvae (*Simulium* sp.) described as follows: "*This organism which is commonly found growing in the trickling-filter beds of sewage treatment plants, does quite well in well-aerated streams of elevated organic content."* The authors went on to describe the stream condition: *"In general the biological condition of the stream was not good…. Apparently, localized contamination from livestock as well as high stream flows and heavy solids loads during runoff periods combine to reduce the abundance and diversity of the aquatic community*."

Stream assessments conducted in 1989 and 1991 by the Iowa Department of Natural Resources (IDNR) provide more recent historical evidence of biological impairment (Figure 5). The assessment results indicated low diversity in the NFMR fish assemblage and fewer than the expected number of species from the region. A series of four fish kills documented between June 1995 and July 1998 (Appendix 2; Table 2-4) were cited as additional evidence of aquatic life use impairment in the NFMR leading to its inclusion on the 1998 303(d) impaired waters list. The causes of biological impairment were listed as unknown.

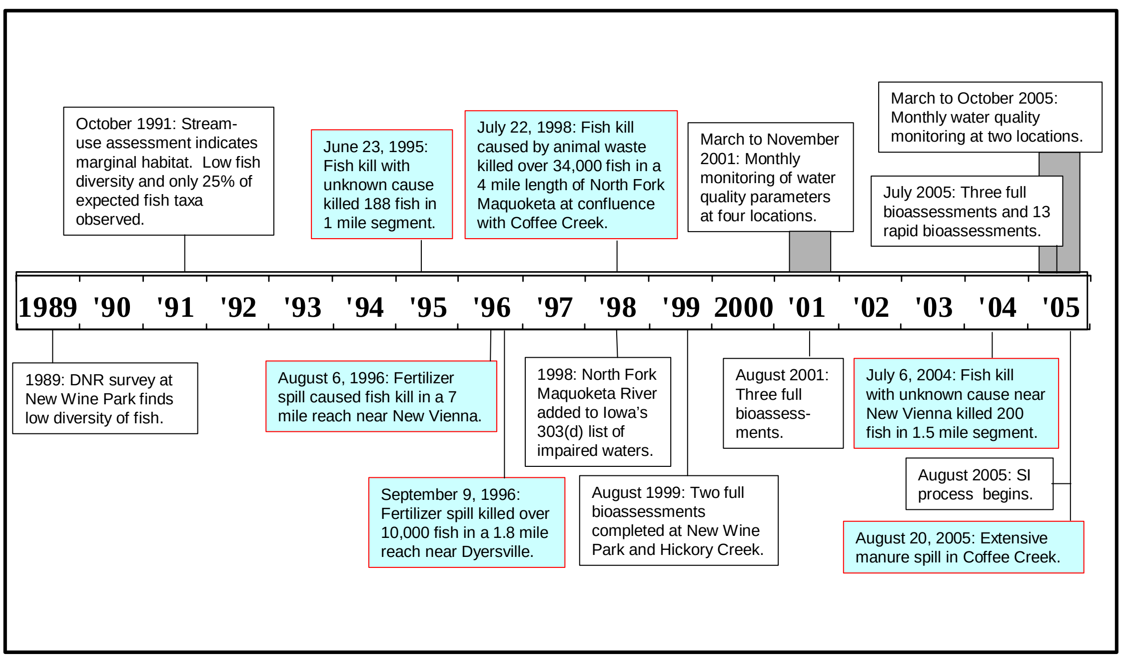

Figure 5. NFMR chronology leading to the Stressor Identification.

Benthic macroinvertebrate and fish sampling results from the NFMR watershed are summarized in Appendix 2 (Tables 2-5, 2-6). Follow-up sampling was conducted in 1999 to further investigate the aquatic life use impairment. The 1999 Fish Index of Biotic Integrity (FIBI) score from the NFMR at New Wine Park (Figure 1) was significantly lower than the reference biological impairment criterion (BIC) used to determine aquatic life use support status. Because unusually low numbers of organisms were collected using the standard sample device, a valid score for the Benthic Macroinvertebrate Index of Biotic Integrity (BMIBI) could not be calculated. In order to calculate the BMIBI, at least one of three quantitative benthic macroinvertebrate sample replicates must contain 85 or more individual specimens. The three replicates had 70, 25, and 54 specimens.

In 2001, additional biological sampling was conducted at three NFMR locations (Figure 1; sites 28, 29, 30) to further define the extent of the impairment. Standard biological data assessment procedures (IDNR 2004) were applied to sampling results from 1999 and 2001. Based upon this analysis, the Section 305(b) water quality assessments for 2002 and 2004 biennial reporting cycles reported the status of Class B (aquatic life) designated uses as “not supporting” and the NFMR remains on the Section 303(d) list of impaired waters.

Biological sampling was repeated in 2005 at NFMR sites 28 & 30 and concurrent sampling was done at a statewide probabilistic (random) survey site located in the adjacent downstream segment of the NFMR (Figure 1). Also during 2005, biological sampling was conducted using the IDNR Rapid Bioassessment Protocol (RBP) at 13 sites located in the NFMR and Hewitt/Hickory Creek watersheds (Figure 1). The RBP data set was obtained to provide a broader characterization of stream biological conditions across the watershed.

The BMIBI and FIBI rank the stream biological condition on a rising scale from 0 (minimum) to 100 (maximum) (Appendix 1; Table 1-2). BMIBI and FIBI scores from sampling locations in the NFMR watershed are mostly in the range described as *“Fair”* stream biological condition (Table 2). The shaded columns list the Biological Impairment Criteria (BIC) that are determined from ecoregion reference stream sites (Wilton 2004; IDNR 2005). BMIBI and FIBI scores from all sampling years and locations in the NFMR watershed are below the reference BICs. These results provide reasonably strong evidence that the biological impairment’s occurrence is consistent across space and time.

The IBI results are the primary evidence of aquatic life use impairment in the NFMR 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 NFMR watershed sites (Appendix 2; Tables 2-2, 2-3) 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. Index of Biotic Integrity scores for benthic macroinvertebrates (BMIBI) and fish (FIBI) from the NFMR watershed.

Site (Stream)	Year	BMIBI	BMIBI Biological Impairment Criterion (BIC)	FIBI	FIBI Biological Impairment Criterion (BIC)
REMAP 147 (NFMR)	2005	42	59	34	UND
TMDL 28 (NFMR)	2001	47	59	29	43
TMDL 28 (NFMR)	2005	26	59	37	43
New Wine Park (NFMR)	1999	N/A	59	32	71
TMDL 29 (NFMR)	2001	47	59	26	43
TMDL 30 (NFMR)	2001	51	59	33	43
TMDL 30 (NFMR)	2005	48	59	37	43
HI2 (Hickory Creek)	1999	53	59	37	71

N/A - Insufficient numbers of organisms for BMIBI calculation; UND – Currently undetermined

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: 1) # of sucker species, 2) # of sensitive species, 3,4) # and % of benthic invertivore species, 5) % top carnivores, and 6) % lithophilous spawners. The BMIBI metric analysis indicated the metrics of concern were as follows: 1) Multi-habitat (MH) sensitive taxa, 2) Standard-habitat (SH) % Ephemeroptera taxa, 3) SH % scraper taxa, and 4) SH top 3 dominant.

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 with the exception of # sucker species (but was close). The RBP BMIBI metric analysis agreed with the full biological analysis with the addition of MH EPT taxa.

Stakeholder Observations

Several observations about the condition of the NFMR and the stream's aquatic life were received from private citizens during a public meeting held in New Vienna (May 2005). One person suggested that insecticides applied to agricultural fields were being washed into the stream and negatively impacting the aquatic life. Another person noted that deep pools that existed long ago had filled in with sediment and no longer contain catchable size fish, such as bullheads. It was also suggested there are too many carp in the stream. The large number of carp could be damaging water quality and preventing more desirable fish populations from using the stream. Another person suggested that fish kills and other long-term water quality problems have decimated the stream to the point where there are no longer any desirable species present to populate the stream.

Stressor Identification Process

Iowa's SI procedures (IDNR 2005) are adapted from technical guidance documents developed by the U.S. 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 instream 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 (usually 3 or 4 individuals). 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 North Fork Maquoketa River and Hickory Creek biological impairments are displayed in Table 3.

Table 3. North Fork Maquoketa River and Hickory Creek aquatic life use impairment candidate causes and probability rankings: (1) high; (2) medium; (3) low.

- Toxins (sediment and water)
  - Metals
    - Arsenic (2)
    - Cadmium (2)
    - Chromium (2)
    - Copper (2)
    - Lead (2)
    - Mercury (2)
    - Selenium (2)
    - Zinc (2)
    - Other
  - Non-Metals
    - Chlorine (3)
    - Cyanide (3)
    - Oil / grease (3)
    - PAHs (3)
    - Pharmaceuticals (3)
    - SOCs (3)
    - Unionized ammonia (2)
    - Other
  - Pesticides
    - Fungicides (3)
    - Herbicides (2)
    - Insecticides (2)
    - Other
- Water quality characteristics
  - Chlorophyll a (2)
  - Dissolved oxygen (1)
  - Nutrients
    - Nitrogen (2)
    - Phosphorus (1)
  - pH (3)
  - Salinity / TDS (3)
  - Turbidity / TSS (1)
  - Water temperature (2)
- Habitat Alterations
  - Bank erosion (2)
  - Channel incision / loss of floodplain connectivity (2)
  - Channel Straightening (2)
  - Dewatering (3)
  - Excessive algae/macrophyte growth (2)
  - Flow impoundment (3)
  - Lack of woody debris / channel roughness and structure (2)
  - Physical barriers (3)
  - Riparian vegetation loss (2)
  - Sedimentation (1)
- Hydrologic Alterations
  - Flow diversion (3)
  - Flow regulation (dams) (3)
  - Pumping (withdrawals) (3)
  - Subsurface tile drainage (2)
  - Urban stormwater outfalls (3)
  - Wetland loss (3)
- Exotic/Introduced Species and Other Biotic Factors
  - Competition (2)
  - Disease (3)
  - Endrocrine disruption (3)
  - Harvest (3)
  - Refugia depletion/isolation (2)
  - 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, the NFMR data set was determined 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 NFMR 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 comparison of sampling data from the NFMR watershed with data collected for the IDNR stream biological assessment program initiated in 1994. NFMR 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 fluctuation were monitored at two sites (Appendix 2; Figure 2-1). These data were used to determine if violations of the dissolved oxygen standard have occurred and whether or not high temperatures occur in the NFMR. 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 (produced or consumed) in dissolved oxygen concentration over a 24-hour period measured at a single stream monitoring station.

For spatial co-occurrence, NFMR stressor indicator data were compared with interquartile data ranges (IQR: 25th to 75th percentile) for stream reference sites within the Iowan Surface ecoregion (47c). In cases when reference data were not available, NFMR 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 IQR. 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 the North Fork Maquoketa River, 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 the ecoregion or other threshold	Concentration or level at impaired site(s) in the watershed	Consistent with Spatial Co-occurrence	Consistent with Stressor Response
Altered Flow Regime (Conceptual Model 1)					
Increased maximum flow	NA	NA	NA	?	?
Increased frequency of low flows	NA	NA	NA	?	?
Altered daily or seasonal flow patterns	NA	NA	NA	?	?

Stressor	Indicator	Concentration or level at unimpaired sites in the ecoregion or other threshold	Concentration or level at impaired site(s) in the watershed	Consistent with Spatial Co-occurrence	Consistent with Stressor Response
Altered Substrate (Conceptual Model 2)					
Increased suspended sediment (abrasive effects to soft tissue)	Total Suspended Solids (mg/L)	Baseflow 5-15 IR for regional reference sites (n=53)	Non-Event Median (Range) # 31: 15 (2-91) # 30: 21 (5-120) # 29: 28 (15-170) # 28: 15 (5-230)	Yes	Yes
Decreased clarity (reduced feeding efficiency)	Turbidity (ntu)	4-9.5 IR for regional reference sites (n=53)	Non-Event Median (Range) # 30: 13 (8-43) # 28: 7.6 (3.1-18)	Yes	Yes
Decrease in benthic algae or macrophytes as a substrate for organisms	Periphyton Chl. A (ug/cm^2)	15.0 (8.4-27.5) median (IR) for statewide random sites (n=81)	Median (Range) # 30: 28.5 (18-44) # 28: 25 (18-29)	No	No
	Sediment Chl. A (ug/cm^2)	12.0 (7.0-26.5) median (IR) for statewide random sites (n=81)	Median (Range) # 30: 13 (2.5-67) # 28: 25 (3.1-31)	No	No
Increased deposited fine sediment	% Total fines	35-84 IR for regional reference sites (n=47)	# 30: 61, 66 NWP: 44 # 28: 64,72 HI2: 57	No	No
	% Silt	4-19 IR for regional reference sites (n=47)	# 30: 57, 60 NWP: 24 # 28: 49, 30 HI2: 30	Yes	Yes
	% Sand	22-66 IR for regional reference sites (n=47)	# 30: 2, 6 NWP: 17 # 28: 15, 42 HI2: 25	No	No
	Sediment Deposition	RBP Qualitative Rating Range: 0 (poor) - 20 (optimal)	RBP Sites Rating Median = 7 (marginal); Range: 5 (poor) – 11 (sub-optimal)	Yes (Qual.)	Yes (Qual.)
	% Reach area as pool habitat	11-48 IR for regional reference sites (n=47)	# 30: 68, 75 NWP: 53 # 28: 34, 57 HI2: 41	No	No
Loss of pool area & depth	Maximum depth (ft.)	3-4.5 IR for regional reference sites (n=47)	# 30: 4.5, 5+ NWP: 3.9 # 28: 5, 5 HI2: 1.9	No	No
	Width:Depth Ratio	19.7-30.5 IR for regional reference sites (n=47)	# 30: 12.3, 12.8 NWP: 26 # 28: 11.5, 19.3 HI2: 18.8	No	No

Stressor	Indicator	Concentration or level at unimpaired sites in the ecoregion or other threshold	Concentration or level at impaired site(s) in the watershed	Consistent with Spatial Co-occurrence	Consistent with Stressor Response
Embedded riffles	Embedded-ness rating (% coarse substrate area embedded by fine sediment)	1.74-2.53 IR for regional reference sites (n=28)	# 30: 3, 3.7 (40-70%) # 28: 3, 3.2 (40-60%) HI2: 3.3 (40-60%)	Yes	Yes
Embedded riffles continued	Embedded-ness rating (% coarse substrate area embedded by fine sediment)	RBP Qualitative Rating Range: 0-5 (poor, >75%); 6-10 (marginal 50-75%); 11-15 (sub-optimal, 25-50%; 16-20 (optimal, 0-25%)	RBP Site Ratings Median = 7 (marginal); Range: 1 (poor) – 11 (sub-optimal)	Yes (Qual.)	Yes (Qual.)
Burial of organisms	NA	NA	NA	?	?
Altered Basal Food Source (Conceptual Model 3)					
Increased / altered primary producers	Seston Chl. A (ug/L)	5.8-34.8 IR for statewide random sites (n=82)	Median (Range) # 30: 21(8-81) # 28: 16 (10-52)	No	No
	Periphyton Chl. A (ug/cm^2)	8.4-27.5 IR for statewide random sites (n=82)	Median (Range) # 30: 28.5 (18-44) # 28: 25 (18-29)	Yes	No
	Sediment Chl. A (ug/cm^2)	7.0-26.5 IR for statewide random sites (n=82)	Median (Range) # 30: 13 (2.5-67) # 28: 25 (3.1-31)	No	No
	Gross primary production (GPP) (g O_2/m^2/d)	3.4 (1.9-7.1) median (IR) for statewide random sites (n=72)	6-Day Average # 30: 16.2 # 28: 12.5	Yes	Yes
	Production-to-respiration ratio (P:R)	0.56 (0.29-0.93) median (IR) for statewide random sites (n=72)	6-Day Average # 30: 1.60 # 28: 0.96	Yes	No
Decreased allochthonous food resources	RBP - Very Minimal Leaf Litter, Detritus, Small Woody Debris	NA	RBP Sites 5 of 13 (38%)	No (Qual.)	?

Stressor	Indicator	Concentration or level at unimpaired sites in the ecoregion or other threshold	Concentration or level at impaired site(s) in the watershed	Consistent with Spatial Co-occurrence	Consistent with Stressor Response
Decreased allochthonous food resources -continued	RBP - Very Minimal Large Woody Debris	NA	RBP Sites 8 of 13 (61%)	Yes (Qual.)	?
Decreased Dissolved Oxygen (Conceptual Model 4)					
	Median DO (mg/L) levels from daytime grab samples	7.7-10.0 IR for regional reference sites (n=51)	Non-Event Median # 31: 8.6 # 30: 8.3 # 29: 10.5 # 28: 10.2	No	No
Decreased dissolved oxygen	Minimum DO (mg/L) from daytime grab samples	4.4 minimum for regional reference sites (n=51)	Non-Event Minimum # 31: 5.4 # 30: 4.0 # 29: 6.9 # 28: 6.7 NF4 (RBP): 4.7	Yes	Yes
	Meeting water quality standards designed to protect aquatic life	≥ 5.0 mg/L at least 16 hours per day	# 30: 1.5 # 28: 0	No	Yes
		Minimum value ≥ 4.0 mg/L	Grab or Diurnal Minimum # 31: 5.4 # 30: 4.0 # 29: 6.9 # 28: 5.9 NF4 (RBP): 4.7 Klann, UIU measured 2.0 mg/L Hickory Creek Site 3 (RBP site HI1) during August runoff event	Yes	Yes
Increased Temperature (Conceptual Model 5)					
Increased temperature	Mean temp. (deg. C) from grab samples	14.5-20.3 IR for regional reference sites (n=51)	# 31: 12.0 # 30: 18.0 # 29: 13.5 # 28: 16.6	No	No
	Maximum temp. (deg. C) from grab samples	24.5 maximum for regional reference sites (n=51)	# 31: 25.0 # 30: 25.0 # 29: 26.0 # 28: 26.0	Yes	No

Stressor	Indicator	Concentration or level at unimpaired sites in the ecoregion or other threshold	Concentration or level at impaired site(s) in the watershed	Consistent with Spatial Co-occurrence	Consistent with Stressor Response
Increased temperature continued	Diurnal mean temp. (deg. C)	21.2 (16.0-23.3) median (IR) for statewide random sites (n=73)	Non-Event mean # 30: 20.8 # 28: 20.3	No	No
	Diurnal maximum temp. (deg. C)	27.0 (22.6-29.4) median (IR) for statewide random sites (n=73)	Non-Event maximum # 30: 24.0 # 28: 25.0	No	No
	Diurnal minimum temp. (deg. C)	15.3 (10.1-18.6) median (IR) for statewide random sites (n=73)	Non-Event minimum # 30: 17.2 # 28: 15.9	No	No
Increased Ammonia (Conceptual Model 6)					
Increased ammonia	Mean total ammonia	<0.1-0.10 IR for regional reference sites (n=51)	Non-Event Median (Range) # 31: <0.1 (<0.1-2.9) # 30: 0.11 (<0.1-3.6) # 29: <0.1 (<0.1-2.7) # 28: 0.8 (<0.1-1.8)	Yes	Yes
	Unionized ammonia exceeds WQ stds.	(Variable criterion depending on pH and temperature)	Value (Criterion) # 31: 2.9 (2.8) # 30: 3.6 (2.3) # 29: 2.7 (2.3)	Yes	Yes
Physical Habitat Alteration (Conceptual Model 7)					
Decreased macro-habitat complexity	% (type) dominant channel bedform unit	0-13.5 (Riffle) 45-77 (Run) 11-44 (Pool) IRs for regional reference sites (n=47)	Riffle/Run/Pool # 30: 9/23/68; 7/18/75; NWP: 11/36/53 # 28: 7/59/34; 5/38/57; HC2: 9/50/41	No	No
	RBP - lacking variation in current velocity & depth	NA	RBP Sites 1 of 13 (7.7%)	No (Qual.)	No (Qual.)
	Width: Thalweg Depth Ratio	19.7-30.5 IR for regional reference sites (n=47)	# 30: 12.3; 12.8 NWP: 26.0 # 28: 11.5; 19.3 HC2: 18.8	No	No
	S.D. mean depth	0.40-0.69 IR for regional reference sites (n=39)	# 30: 0.84; 1.0 NWP: 0.63 # 28: 0.85; 0.64 HC2: 0.38	No	No

Stressor	Indicator	Concentration or level at unimpaired sites in the ecoregion or other threshold	Concentration or level at impaired site(s) in the watershed	Consistent with Spatial Co-occurrence	Consistent with Stressor Response
Decreased macro-habitat complexity continued	RBP deep channel incision / no floodplain connectivity	NA	RBP Sites 3 of 13 (23%)	No (Qual.)	?
Decreased micro-habitat complexity	Embeddedness rating (DNR method)	see CM 2		Yes	Yes
Decreased micro-habitat complexity continued	% Instream cover (DNR method)	2-10 IR for regional reference sites (n=47)	# 30: 10 NWP: 10 # 28: 9 HC2: 0	No	No
	% Occurrence large woody debris (DNR method)	14-43 IR for regional reference sites (n=47)	# 30: 0 NWP: 25 # 28: 32 HC2: 3.6	No	No
	RBP - Very Minimal Leaf Litter, Detritus, Small Woody Debris	see CM 3	RBP Sites 5 of 13 (38%)	No (Qual.)	?
	RBP - Very Minimal Large Woody Debris	see CM 3	RBP Sites 8 of 13 (61%)	Yes (Qual.)	?

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 the NFMR were compared to interquartile data ranges from reference sites within the Iowan Surface 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 the NFMR along with ecoregion-specific or statewide sampling data. The NFMR 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 contributed nothing 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 4. The proximate stressors identified in the SI process (not ranked by order of importance) are: unionized-ammonia, total suspended solids/turbidity, sedimentation, dissolved oxygen, and benthic algae. The supporting evidence for each primary cause (i.e., proximate stressor and associated causal pathways) is described below.

Un-ionized Ammonia

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 NFMR sampling results to regional reference site levels, elevated pH and water temperature do not appear to be major factors contributing to the occurrence of toxic unionized ammonia levels in the NFMR watershed.

Sampling data and information from fish kill investigations provide evidence of toxic levels of ammonia that occur sporadically in the NFMR watershed. Total ammonia levels exceeded the chronic water quality criteria on one occasion in September 2001 at three NFMR watershed sampling locations. Violations occurred both upstream and downstream from New Vienna indicating the wastewater treatment plant was not the primary source. 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; however, total phosphorus and $CBOD_5$ were elevated above previously sampled levels.

Ammonia has also been explicitly or implicitly linked to several fish kill events in the watershed, the most recent of which occurred after a heavy rain on July 27, 2006. This fish kill was caused by manure runoff from an open feedlot. Animal waste runoff was also responsible for fish kills near New Vienna in July 1998 and July 2004 (Appendix 2, Table 2-4). An ammonia fertilizer spill was responsible for a fish kill near Dyersville in September 1996. The segment of the NFMR upstream and downstream from New Vienna, including the Coffee Creek sub-watershed seems particularly susceptible to experiencing toxic ammonia levels.

Dissolved Oxygen

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 NFMR watershed are mostly suitable for aquatic life, but there is also evidence that oxygen levels occasionally fall below water quality standards. For example, during monthly sampling conducted in 2001 and 2005 just one sample in sixty (1.7%) was below the most protective criterion (5.0 mg/L) for warmwater streams.

The impaired segment of the NFMR is designated for Class B(LR) "Limited Resource" warmwater 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 sites 28 and 30 (Figure 1) in the NFMR watershed during August 2005. Dissolved oxygen levels at Site 30 fell between 4-5 mg/L for 1.5 hours on August 27, 2005 (Appendix 2; Figure 2-1), which marginally complied with water quality standards criteria.

The continuous monitoring data from sites 28 and 30 indicate substantial dissolved oxygen fluctuation between light and dark hours of the day. Daily fluctuation (maxima – minima) was 8.6 mg/L and 16.1 mg/L at sites 28 and 30, respectively. 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. Sampling data the statewide random survey of perennial streams indicate that fluctuations of 10 mg/L or more are associated with increased occurrence of substandard dissolved oxygen levels and reduced IBI levels (Appendix 2; Figures 2-2, 2-3). These levels are indicative of highly supersaturated oxygen levels under which harmful levels of gas bubbles may form. In a Wisconsin lake, thousands of fish were killed from gas bubble disease during a period of extremely high dissolved oxygen concentrations (30-32 mg/L) that were associated with a localized algal bloom (Woodbury 1941). Such conditions might occur in streams like the NFMR among dense mats of filamentous algae that develop during stable stream conditions.

The dissolved oxygen saturation level decreases with increasing water temperature. Despite large fluctuations, dissolved oxygen levels in the NFMR mostly remain acceptable during summer low flow conditions. Average community respiration rates at sites 28 and 30 were estimated at 13.0 and 10.1 $gO_2/m_2/d$, respectively. Community respiration levels above approximately 7.5 $gO_2/m_2/d$ are associated with increased occurrence of substandard dissolved oxygen levels and reduced IBI levels in Iowa streams (Appendix 2; Figures 2-4, 2-5). Maintenance of relatively cool water temperature in the NFMR apparently helps counteract the large respiratory oxygen demand, particularly during dark hours of the day. Significant groundwater inputs most likely have a significant cooling effect on stream temperatures in the NFMR watershed. Shading from riparian vegetation can also help maintain cooler stream temperatures. Riparian canopy coverage in the NFMR 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 NFMR watershed could help maintain acceptable dissolved oxygen levels.

There is evidence that substandard dissolved oxygen levels occur during rainfall/runoff events in the NFMR watershed. A dissolved oxygen concentration of 4.7 mg/L was measured at Site NF4 on the afternoon of July 26, 2006. While in the stream, the bioassessment field crew observed recently deceased fish and invertebrates and the sediment had an odor of animal waste. Cattle access to the stream was noted and manure was observed on the stream banks. In August 2005, a dissolved oxygen concentration of 2.0 mg/L was measured in Hickory Creek (Rick Klann, Upper Iowa University) during a rain event. Both of these rainfall/runoff events were minor in terms of stream flow rise (<15%), thus suggesting animal waste and/or other organic matter deposited close to the stream are an important source of biochemical oxygen demand.

Low dissolved oxygen is likely to occur in conjunction with elevated ammonia levels during runoff events containing livestock waste. Both the ammonia and the organic matter associated with livestock waste exert an oxygen demand that can exceed the stream's capacity to maintain acceptable levels. As ammonia is oxidized to nitrate and microbial decomposition of organic matter occurs, dissolved oxygen is consumed at a rate that exceeds the stream's ability to sustain suitable oxygen levels. The precise stressor mechanism leading to fish mortality in the NFMR is unclear. For example, it is not clear how much of the mortality in these cases is caused by un-ionized ammonia, oxygen depletion, or a combination of both stressors.

Total Suspended Solids and Turbidity

Elevated levels of suspended solids and turbidity directly and indirectly impact stream aquatic communities leading to increased dominance of tolerant species such as common carp. 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 the NFMR were sampled in Spring 2001 during elevated flow conditions. Levels of TSS and turbidity levels monitored during base flow conditions were also elevated relative to typical levels measured at least disturbed stream reference sites in the Iowan Surface ecoregion. The median TSS and turbidity levels for NFMR watershed monitoring sites equaled or exceeded the 75^{th} percentile of Iowan Surface reference sites in all but one case (Table 5). Based on a qualitative evaluation during rapid bioassessment visits, turbidity was judged excessive at 6 of 13 (46%) sites in the watershed. The examination of stressor-response plots developed from statewide bioassessment sampling data indicated that TSS levels equivalent to the highest levels measured in the NFMR watershed tend to be associated with FIBI levels considered as biologically impaired for the Iowan Surface ecoregion (Appendix 2; Figure 2-6).

Potential sources of suspended solids and turbidity in the watershed include: stormwater runoff from construction sites and urban areas; sheet and rill erosion from agricultural fields; gully erosion, stream bed/bank erosion; re-suspension of fine sediment by common carp and watering livestock. The estimated potential sheet and rill erosion rate based on 2002 land cover and soil survey data is 13.2 tons/acre/year (Appendix 2; Figure 2-11). The average basin slope is 4.8% and approximately 60% of the watershed area is in row crop indicating relatively high sediment delivery potential, which is estimated at 2.47 tons/acre/year (Appendix 2; Figure 2-12).

Evidence of streambed and bank erosion in the NFMR 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 2-13). Active gullies leading to the stream, excessive bank erosion/sloughing, and livestock access were noted at 7 of 13 (54%) rapid bioassessment sites. At the four 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 23% (range: 0-50), which is slightly higher than the 75th percentile (20%) for regional reference sites. The average percentage bank area comprised of bare soil or sediment at the four biocriteria sites was relatively high 64% (range: 27-80%) but did not exceed the reference site 75th percentile level (78%). Taken as a whole, there is sufficient evidence indicating bank erosion and cattle grazing activities are significant sources of suspended solids and turbidity in the NFMR.

The common carp (*Cyprinus carpio*) is known for its aggressive feeding behavior, which involves foraging through soft bottom sediments and uprooting vegetation. Carp foraging activities directly re-suspend fine sediment particles and eliminate rooted vegetation, which helps anchor lake sediments against wind and wave action. Fish sampling data from rapid bioassessment sites and full biocriteria sampling sites indicate that common carp are widely distributed in the NFMR watershed. Carp were present at more than half of the fish sampling sites (9/16) and considered abundant (>100) at 31% (5/16) of the sites. A maximum of 495 carp (1 per 2 lineal foot of stream channel) were sampled from Site 29 downstream from New Vienna. Based on the relatively high density of carp at many locations in the watershed, it seems plausible that common carp contribute to the elevated suspended solids and turbidity levels observed during base flow conditions. For example, the average TSS concentration during the low flow July – November 2001 period was more than twice as high at Site 29 (24 mg/L) where carp were very abundant (495 sampled) compared with the TSS concentration at Site 28 (10 mg/L) where carp were rare (1).

<u>Sedimentation</u>

Several sediment-related indicators provide evidence of sedimentation as a primary stressor in the NFMR 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 embeddings 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%) are associated with a higher probability of FIBI levels that are considered biologically impaired in the Iowan Surface ecoregion. There is strong evidence that embeddedness levels occur at levels consistent with impairment at multiple locations in the NFMR watershed. The average embeddings rating for three full biocriteria sampling sites in the watershed was 3.25 (Table 5), which corresponds with an embeddedness range from 40-60%. The ecoregion reference site 75th percentile embeddings rating is 2.53, which is roughly equivalent to 30-50%. Qualitative embeddedness ratings at 13 rapid bioassessment sites ranged from poor to sub-optimal with a median rating of marginal (50-75%). On the stressor checklist, field staff rated embeddedness as excessive at 11 of the 13 (85%) sites.

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 Iowan Surface reference sites is 4%-20%. 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 examination of stressor-response plots from Iowa streams suggests that as silt levels generally increase above 20% there is an increased occurrence of BMIBI and FIBI levels that are considered biologically impaired in the Iowan Surface ecoregion. The percent stream bottom as silt, which was estimated at four full biocriteria sampling sites ranged from 24-60% and the average was 38%. 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 20% or more (Appendix 2; Figures 2-7). Silty stretches of stream appear to be widespread in the NFMR watershed (Appendix 2; Figure 2-17). In addition to assessments done at the four full biocriteria sites, 8 of 13 (61%) 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: % total fine substrates, % stream reach as pool, maximum depth, stream width:thalweg depth ratio, channel bedform composition (% pool, % riffle, % run). All of these indicators are within the expected ranges for Iowan Surface reference stream sites and do not occur at levels that are consistent with impaired BMIBI or FIBI levels.

The sediment indicators evaluated at rapid bioassessment sites provide somewhat contradictory evidence suggesting that reach-scale sediment deposition and pool filling is potentially significant stressor to the aquatic community. The sediment deposition rating ranged from poor to sub-optimal with a median rating of marginal (50-80% stream bottom affected). In the stressor field checklist, 8 of 13 (61%) rapid bioassessment sites were evaluated as having significant reduction of pool depth due to sedimentation. The rapid bioassessment sites offer a broader perspective of conditions in the watershed including stream reaches located near the headwaters where sediment delivery rates are often higher. Taken in the appropriate context, the RBP evidence is generally supportive that sedimentation impacts are a major contributing factor in the NFMR biological impairment.

Sources of sediment in the NFMR were discussed above in the paragraphs under Total Suspended Solids and Turbidity. All of the sources and pathways discussed in that section apply to sedimentation related impacts.

<u>Benthic Algae</u>

The growth of algae on the stream bottom represents an important part of the aquatic ecosystem food web. Excessive algal growth (see Appendix 2; Figure 2-16), most often in the form of long filaments or mats, can develop when nutrient supplies and growing conditions are suitable. These types of growth can directly impact aquatic invertebrates and fish by physically covering important microhabitat niches and by changing the type and availability of food resources, both of which cause undesirable shifts in species composition and reduced diversity.

Benthic algal biomass is often expressed as chlorophyll A pigment concentration in periphyton (attached to rocks, wood) or fine sediment samples (largely unattached algal forms). Benthic chlorophyll A concentrations were relatively high at two locations in the NFMR when compared to median levels from random sites sampled in perennial streams throughout Iowa (Table 5).

An examination of stressor-response plots, however, did not find these levels to be associated with increased probability of impaired levels of the BMBI or FIBI.

Other data indicators provide evidence that benthic algae growth is a primary stressor. At 10 of 13 (77%) rapid bioassessment sites in the NFMR watershed, the level of filamentous algae growth was qualitatively evaluated as excessive. Estimates of gross primary production (the rate of oxygen production or organic carbon accrual from photosynthesis) that were derived from diurnal dissolved oxygen and temperature monitoring over a 6-day period at Sites 28 and 30 in the NFMR, were substantially higher than the 75th percentile level for statewide random sampling sites. Average levels of GPP approximately 11 $gO_2/m^2/d$ and more are associated with increased probability of impaired BMBI and FIBI levels for the Iowan Surface ecoregion (Appendix 2; Figures 2-8). The 6-day average GPP levels for sites 28 and 30 were 12.5 and 16.2 $gO_2/m^2/d$, respectively.

GPP is correlated with diurnal dissolved oxygen fluctuation, which can range from supersaturated levels during the day when oxygen is being produced by photosynthesis, to under saturated levels at night when oxygen is being consumed through biological respiration. Wide fluctuations (daily maxima – daily minima) at levels of approximately 10 mg/L or higher are associated with increased probability of impaired BMIBI and FIBI levels. Dissolved oxygen fluctuation at sites 28 and 30 in the NFMR were 8.6 and 16.1 mg/L respectively.

Adequate nutrient supplies, light and stable flow conditions are needed for significant accrual of benthic algae to occur. The available evidence from the NFMR watershed indicates that all three of these requirements are met and conditions are conducive for high levels of algal production. Flow gauging data from 2005 (Figure 3) indicate that prolonged periods of stable base flow can occur during the summer months. Current velocity was moderately slow (<1 feet per second) at sites where multiple velocity and depth measurements were taken to obtain a re-aeration coefficient. The relatively constant flow and relatively low current velocity provides a good environment for attached and unattached forms of algae to reproduce and expand in aerial coverage.

Light availability or extinction near the stream bottom was not measured or estimated at NFMR sample sites. Riparian canopy conditions were qualitatively evaluated as providing little or no stream shade at 8 of 13 (62%) RBP sample sites. The median rating for riparian vegetation zone width was “poor” among the 13 RBP sites, although a few sites had high ratings. At the full biocriteria sample sites 28 and 30 where primary production estimates and chlorophyll A samples were obtained, the average percentage of sampling area that was shaded was 52% and 20%, respectively. Both sample sites had areas that were virtually not shaded. The average water depth at these sites was less than 1.5 feet, which seems conducive for light penetration to the stream bottom.

Nutrient data indicate that both nitrogen and phosphorus levels are not in short supply for algal production. The overall mean of Nitrate+nitrite nitrogen levels at NFMR watershed sample sites was 7.6 mg/l, which is just inside the interquartile range of levels for Iowan Surface reference sites (7.7 mg/L). The overall mean concentrations for total Kjeldahl nitrogen (1.4 mg/L) and total phosphorus (0.35 mg/L) were substantially higher than the 75th percentile levels for Iowan Surface reference sites (0.74 and 0.11 mg/L, respectively). Average total phosphorus levels found in the NFMR are associated with increased probability of excessive gross primary production (GPP) (algal growth) and IBI levels considered impaired for the Iowan Surface ecoregion (Appendix 2; Figures 2-9, 2-10). Generally, there appears to be a higher risk of excessive algal growth that is associated with impaired IBI levels when TP exceed approximately 0.1 mg/L. Many sources of nutrients exist in the NFMR watershed including animal feeding operations, lawns, pastures, private septic systems, row crop fields, urban stormwater discharges, and wastewater discharges.

Table 4. 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
↑ Flood Flow Frequency & Intensity	o	---	o	o	+	-	+	na	o	o	---	---	+	-
↑ Low Flow Frequency & Intensity	o	---	o	o	+	-	+	na	o	+++	---	---	-	-
↑ Insecticides	o	o	o	o	+	o	+	na	o	o	o	---	-	-
↑ Un-ionized Ammonia	o	+	o	+	+++	+++	+	na	o	+++	o	+	+	+
↓ Dissolved Oxygen	o	+	o	+	+++	+	+	na	o	+++	o	+	+	+
↑ TSS / Turbidity	o	+	o	++	+++	+++	+	na	o	na	na	+	+	+
↑ Sedimentation	o	+	o	++	+++	+++	+	na	++	na	na	+	+	+
↑ Seston Algae (Chl. A)	o	+	o	++	+	-	-	na	o	na	na	---	-	-
↑ Benthic Algae (Chl. A)	o	+	o	++	+++	+	+	na	o	na	na	+	+	+
↓ Allochthonous Inputs	o	+	o	o	o	o	-	na	o	na	o	---	-	-
↓ Macro-habitat Complexity	o	o	o	o	+	o	+	na	o	+++	na	---	+	-
↓ Instream Cover / Epifaunal Micro-habitat	o	+	o	++	+++	+	+	na	o	+++	na	+	+	o
↑ Species Competition	o	+	o	+	+	+	-	na	o	na	na	---	-	o
↑ Aquatic Life Depletion	o	o	o	+	+	+	-	na	o	na	na	---	-	o
↑ Aquatic Life Isolation	o	na	o	o	+	o	-	na	o	na	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 6.

The primary stressors identified by this SI translated into 305(b)/303(d) cause codes are: Unionized Ammonia (600); Phosphorus (910); Siltation (1100); Organic enrichment / Low DO (1200); Suspended Solids (2100) / Turbidity (2500); Algal Growth/Chlorophyll a (2210).

Table 6. 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. For example, the data were not adequate to support a quantitative analysis of some primary stressors in the Hickory Creek impaired segment, for example, low dissolved oxygen and excessive benthic algae growth. Qualitative observations and limited sampling data from Hickory Creek indicated these stressors were present at significant levels; therefore, the more quantitative-based conclusions from the NFMR were extrapolated to Hickory Creek.

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 NFMR watershed:

- lethal concentrations of unionized-ammonia;
- elevated levels of total suspended solids and turbidity;
- elevated levels of silt accumulation and sedimentation of rock substrates;
- low / potentially lethal levels of dissolved oxygen and extreme fluctuations in dissolved oxygen levels;
- excessive growth of benthic algae.

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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Appendices

Appendix 1

Methods

A. 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.

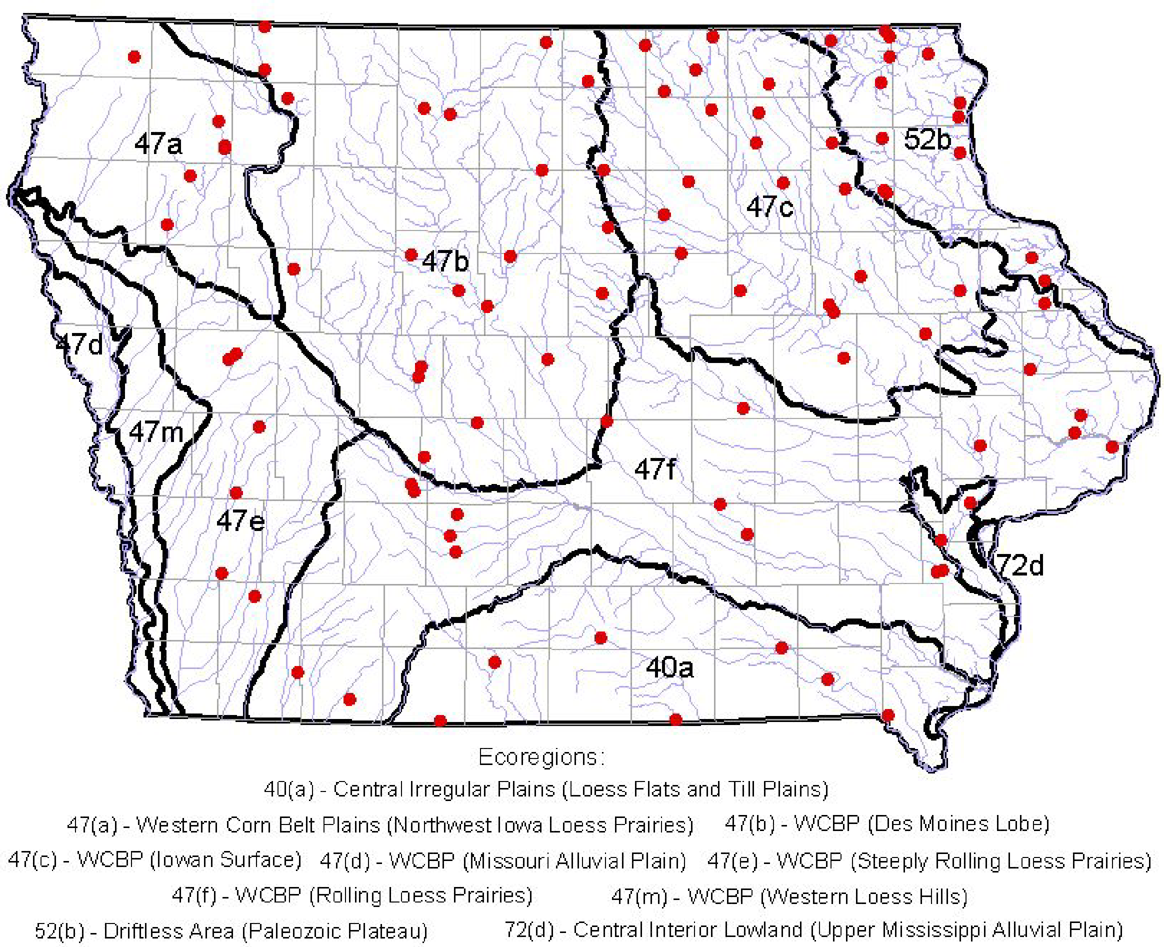


Figure 1-1. Iowa ecoregions and wadeable stream reference sites: 1994 – 2000.

B. 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 community 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.

C. 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. % 3-dominant fish species
6. % 3-dominant taxa (SH)	6. % benthic invertivores
7. Biotic index (SH)	7. % omnivores
8. % EPT (SH)	8. % top carnivores
9. % Chironomidae (SH)	9. % simple lithophil spawners
10. % Ephemeroptera (SH)	10. fish assemblage tolerance index
11. % Scrapers (SH)	11. adjusted catch per unit effort
12. % Dom. functional feeding group (SH)	12. % 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 50% 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 50% 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 1% 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 1% 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.

D. 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 the North Fork Maquoketa River. 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, O'Brien County and the North Fork Maquoketa River. 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 North Fork Maquoketa River 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)

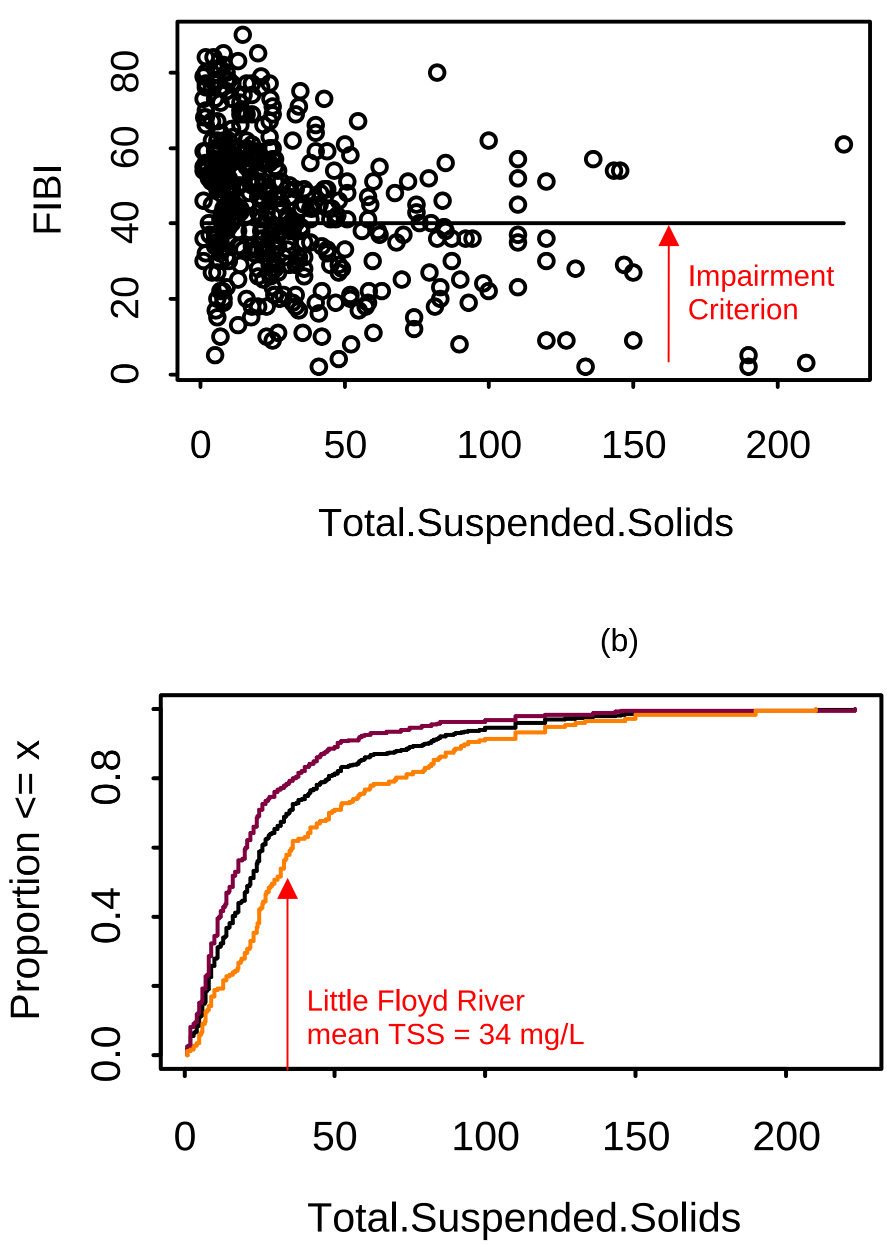
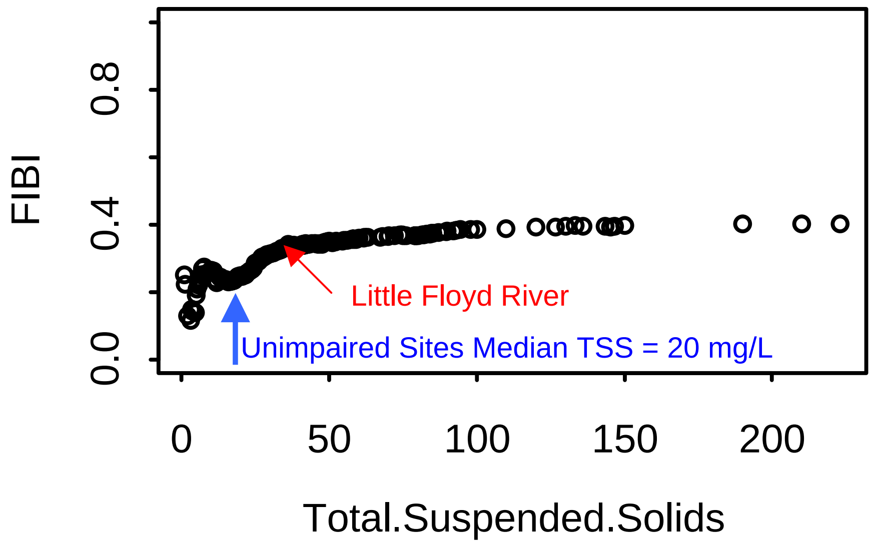


Figure 1-2. Conditional Probability (CP) analysis using example data from the Little Floyd River, O'Brien County; **(a)** Fish Index of Biotic Integrity (FIBI) relationship with Total Suspended Solids (TSS). Data are from the Iowa stream bioassessment database for summer-fall sample index period: 1994-2003. 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)

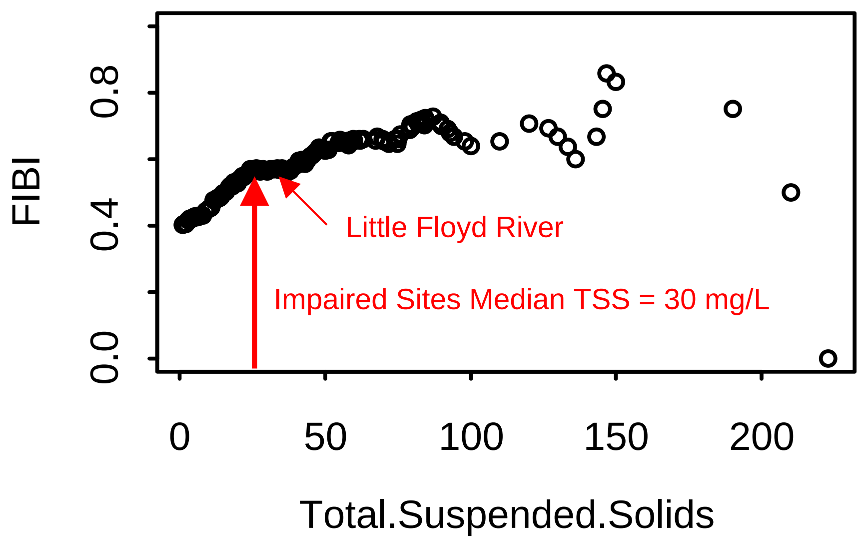


Figure 1-2 (continued). **(c)** Conditional Probability (CP) plot displaying the probability of observing an impairment (i.e., FIBI<40) when the observed stressor level is less than or equal to a specified level or criterion. For example the probability of impairment is approximately 0.25 for sites with 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. Monitoring results on the North Fork Maquoketa River at sites TMDL 28, 29, and 30.

Date	Flow Rate (cfs)	DO (mg/L)	Temp. (°C)	pH	Ammonia Nitrogen as N (mg/L)	TKN as N (mg/L)	NO3 + NO2 as N (mg/L)	CBOD (5 day) (mg/L)	Total Phosphorus as P (mg/L)	Ortho-phosphate as P (mg/L)	TSS (mg/L)	TVSS (mg/L)	Silica as SiO2 (mg/L)	Specific Cond. (umhos/cm)
TMDL 28 Monthly Sampling														
3/15/2001	165	12.8	2.5	7.8	1.2	4.9	8.2	8	1.1	0	180			410
4/10/2001	145	10.6	8	7.6	0.2	1.7	16	3	0.6	0.1	230			540
5/9/2001	57	9.5	13.5	7.8	0	0.3	14	0	0.2	0.12	43			630
6/13/2001	38	10.2	19	8.1	0	0.4	12	0	0.2	0.22	36			670
7/10/2001	16	11.8	26	8.5	0	0.6	7.4	0	0.1	0.13	8			670
8/8/2001	10.3	10.5	25	8	0	1.2	5	0	0.1	0.12	16			700
9/10/2001	13	8.1	16	8	1.8	4	3.8	4	0.68	0.89	7			690
10/4/2001	13	8.3	13	7.6	0	0.61	6.2	0	0.15	0.06	5			710
11/8/2001	16	9.2	10.5	7.9	0	0.55	6.2	0	0.14	0.12	13			690
4/13/2005	30	11.1	9.6	8.2	0.85	2.5	5.6	8	0.73	0.42	31	7		700
5/17/2005	12	11.8	14.5	8.3	0.12	0.91	5.3	<2	0.19	0.12	11	2		700
6/8/2005	11	8.3	21.9	8.2	0.08	0.87	4.1	<2	0.24	0.18	21	3		680
7/7/2005	12	10.3	21.5	8.3	<0.05	0.49	3.9	<2	0.23	0.17	6	1		650
7/27/2005	10	8.1	18.1	8	0.08	1.1	2.9		0.27	0.15	16		14	600
8/1/2005	8.4	9	22.2	8.1	0.08	0.9	3.5		0.24	0.13	13		17	660
8/4/2005	6.8	6.7	22.7	7.9	0.11	0.83	3.1	<2	0.19	0.13	15	4		670
8/15/2005	7	11	21.4	8.2	<0.05	0.54	3.9		0.16	0.12	12	2	17	
8/22/2005	6.1	8.7	18.2	8.1	<0.05	0.78	3.9		0.22	0.14	33	12	15	
8/29/2005	6.7	9.1	17.7	8.3	<0.05	0.97	3.6		0.19	0.09	23	11	16	
9/15/2005	6.5	12	16.6	8.3	<0.05	0.3	3.8		0.16	0.08	8	3		650
10/13/2005	6.3	10.2	13.4	7.8	<0.05	0.5	4.9	<2	0.11	0.07	11	4		720
TMDL 28 Event Sampling														
9/19/05 (pre-peak)					0.08	1.3	3.6	4	0.35	0.15	67	10	28	610
9/19/05 (post-peak)					<0.05	1.8	3.3	5	0.31	0.08	130	27	42	640
9/20/05 (grab)	8	6.9	17.3	7.8										
9/25/05 (pre-peak)					0.27	2.1	3.5	7	0.39	0.21	60	11	30	650
9/25/05 (post-peak)					0.31	2	3.5	6	0.48	0.22	64	10	29	650
9/26/05 (grab)	8.5	9.3	17.8	8.1										

Table 2-1 continued. Monitoring results on the North Fork Maquoketa River at sites TMDL 28, 29, and 30.

Date	Flow Rate (cfs)	DO (mg/L)	Temp. (°C)	pH	Ammonia Nitrogen as N (mg/L)	TKN as N (mg/L)	NO3 + NO2 as N (mg/L)	CBOD (5 day) (mg/L)	Total Phosphorus as P (mg/L)	Ortho-phosphate as P (mg/L)	TSS (mg/L)	TVSS (mg/L)	Silica as SiO2 (mg/L)	Specific Cond. (umhos/cm)
TMDL 29 Monthly Sampling														
3/15/2001	150	11.6	3	7.6	1.1	2.8	8.8		1	0	100			430
4/10/2001	118	10.5	7.5	7.6	0.2	1.8	16		0.4	0.1	170			550
5/9/2001	54	9.9	13.5	7.9	0	0.1	14		0.2	0.12	40			640
6/13/2001	21	10.7	19	8.1	0.2	1.3	11		0.3	0.36	94			680
7/10/2001	14	11.5	26	8.5	0	0.8	7.1		0.1	0.14	15			680
8/8/2001	7.9	10.9	25	8	0	1.6	4.3		0.1	0.15	26			700
9/10/2001	12	7.8	16	7.9	2.7	5.2	2.4		1	1.3	24			730
10/4/2001	11	6.9	12	7.6	0	0.63	5.7		0.16	0	25			720
11/8/2001	13	9.1	10	7.8	0	0.81	6		0.17	0.08	28			710
TMDL 30 Monthly Sampling														
3/15/2001	89	11.4	3	7.5	1.1	3.5	9.3	6	0.9	0	100			440
4/10/2001	97	11.1	7.5	7.7	0.2	1.5	16	4	0.3	0.1	120			540
5/9/2001	28	10.5	14	7.9	0	0.2	14	0	0.3	0.13	32			620
6/13/2001	19	8.2	18	8	0.3	2.7	10	4	0.6	0.26	85			670
7/10/2001	9.3	8.3	24.5	8.2	0.1	0.7	6.9	0	0.2	0.14	50			700
8/8/2001	4.3	7.3	25	8	0	1.4	4.2	0	0	0.14	20			700
9/10/2001	6	6	15	7.9	3.6	5.6	2	6	1.1	1.2	16			700
10/4/2001	6	4	12	7.9	0	0.58	5.3	0	0.17	0	5			720
11/8/2001	6.3	9.8	9.5	7.7	0	0.72	5.8	2	0.14	0.08	9			720
4/13/2005	18	9.7	8.1	8	1.2	4.3	6.4	11	1	0.67	50	14		720
5/17/2005	6.2	10.1	12.4	8.1	0.15	0.98	5.1	<2	0.18	0.1	21	4		720
6/8/2005	6	5.7	21.1	8	0.15	1	3.4	<2	0.27	0.15	42	7		690
7/7/2005	5.4	8.2	21.2	7.9	<0.05	0.4	3		0.24	0.16	20	3		670
7/28/2005	4.6	6.1	18.1	8	0.29	1.4	2.3		0.3	0.16	20		17	700
8/1/2005	3.7	8.3	23.9	8.1	0.08	0.79	2.1	<2	0.28	0.14	17		15	660
8/4/2005	2.9	5.4	23.6	7.8	0.11	0.88	1.6		0.24	0.13	20	5		660
8/15/2005	4.5	10	20.1	8.2	0.07	0.78	2.2		0.15	0.1	15	3	18	
8/22/2005	5.1	11	19.9	8.3	<0.05	1.5	2		0.32	0.13	14	3	17	
8/29/2005	3	6.4	18.1	8.1	0.11	0.87	2.3		0.25	0.07	45	8	17	
9/15/2005	4.4	8.8	17.1	8	0.06	0.5	2		0.16	0.06	21	6		670
10/13/2005	3.8	8.3	13	7.5	<0.05	0.7	3.7	<2	0.12	0.05	27	6		710

Table 2-2. BMIBI metrics calculated from the biological samples collected from the North Fork Maquoketa River and Hickory Creek from 1999-2005.

Stream Name	Nearest Landmark	Date	MH Total Taxa		SH Total Taxa		MH EPT Taxa		SH EPT Taxa		MH Sensitive Taxa		SH % Ephemeroptera	
			#	Score	#	Score	#	Score	#	Score	#	Score	%	Score
Hickory Creek	New Vienna - HI2	8/11/1999	30	8.29	11.33	8.03	8	4.69	7.5	7.9	2	2.63	15.29	1.96
NF Maquoketa River	Dyersville - REMAP 147	7/25/2005	30	5.77	12.33	5.43	10	3.73	6.67	4.54	2	1.82	4.36	0.56
NF Maquoketa River	Dyersville- TMDL #28	8/20/2001	33	7.17	7	3.84	12	5.56	5	4.04	2	2.06	13.63	1.74
NF Maquoketa River	Dyersville- TMDL #28	7/25/2005	33	7.17	6.33	3.47	11	5.1	3.33	2.69	3	3.09	1.03	0.13
NF Maquoketa River	New Vienna- TMDL #29	8/21/2001	33	7.34	10	5.62	11	5.22	6.67	5.52	0	0	4.28	0.55
NF Maquoketa River	New Vienna- TMDL #30	8/21/2001	37	8.74	9	5.39	12	6.04	6.67	5.9	2	2.24	6.45	0.82
NF Maquoketa River	New Vienna- TMDL #30	7/28/2005	36	8.5	11.67	6.99	9	4.53	7.67	6.78	1	1.12	4.31	0.55
NF Maquoketa River*	New Wine Park- New Vienna	8/10/1999	32	7.02			13	6.08			2	2.08		

Stream Name	Nearest Landmark	SH % EPT		SH % Chironomid		SH % Scraper		SH % Top 3 Dominant		SH % Dominant FFG		MHBI		BMIBI
		%	Score	%	Score	%	Score	%	Score	%	Score	Value	Score	Score
Hickory Creek	New Vienna - HI2	53.69	5.62	40.2	6.04	0	0	76.81	5.81	56.98	7.17	5.65	5	53
NF Maquoketa River	Dyersville - REMAP 147	60	6.28	32.7	6.8	2.72	0.61	81.38	2.96	59.3	6.78	5.57	5.3	42
NF Maquoketa River	Dyersville- TMDL #28	77.51	8.12	19.9	8.09	4.17	0.93	86.94	2.41	62.83	6.2	5.34	6.15	47
NF Maquoketa River	Dyersville- TMDL #28	9.59	1	87.4	1.27	2	0.45	95.09	0.91	88.79	1.87	5.99	3.74	26
NF Maquoketa River	New Vienna- TMDL #29	74.6	7.81	21.8	7.9	2.07	0.46	73.82	4.98	69.06	5.16	5.5	5.56	47
NF Maquoketa River	New Vienna- TMDL #30	70.32	7.36	27.7	7.3	1.62	0.36	71.84	5.77	62.89	6.18	5.56	5.33	51
NF Maquoketa River	New Vienna- TMDL #30	54.32	5.69	42	5.86	1.87	0.42	75.82	4.95	59.36	6.77	5.67	4.93	48
NF Maquoketa River*	New Wine Park- New Vienna													

* A valid SH sample was not collected at this site; therefore, no SH metrics or BMIBI score was calculated.

MH - Multi-habitat; SH - Standard habitat; EPT - Ephemeroptera, Plecoptera, and Trichoptera; FFG - Functional feeding group

Table 2-3. FIBI metrics calculated from the 1999-2005 biological samples collected from the NF Maquoketa River and Hickory Creek.

Stream Name	Nearest Landmark	Date	Drainage Area	Native Species #	Native Species Score	Sucker Species #	Sucker Species Score	Sensitive Species #	Sensitive Species Score	BINV Species #	BINV Species Score	% Top 3 Abundant %	% Top 3 Abundant Score	% BINV %	% BINV Score
Hickory Creek	New Vienna	8/11/1999	13	9	4.8	1	2.8	1	1.6	1	1.5	80.6	4.5	4.7	1.8
North Fork Maquoketa River	New Vienna- Tmdl30	8/21/2001	25	13	5.6	1	2.2	1	1.3	2	2.4	72.4	5.1	9.3	2.8
North Fork Maquoketa River	New Vienna- Tmdl30	7/28/2005	25	14	6.0	1	2.2	2	2.5	4	4.8	63.7	6.7	4.4	1.3
North Fork Maquoketa River	New Vienna- Tmdl29	8/21/2001	33	12	4.7	1	2.0	1	1.2	2	2.2	80.1	3.4	2.3	0.6
North Fork Maquoketa River	New Wine Park- New Vienna	8/10/1999	35.4	12	4.6	1	2.0	2	2.3	3	3.2	68.7	5.2	1.6	0.4
North Fork Maquoketa River	Dyersville- Tmdl28	8/20/2001	37	15	5.7	1	2.0	1	1.1	3	3.2	79.0	3.4	0.9	0.2
North Fork Maquoketa River	Dyersville- Tmdl28	7/27/2005	37	14	5.4	1	2.0	1	1.1	3	3.2	64.2	5.9	3.4	0.9
North Fork Maquoketa River	Dyersville - REMAP 147	7/25/2005	124.9	17	4.9	3	4.4	2	1.7	4	3.3	73.0	4.2	3.3	0.7

Stream Name	Nearest Landmark	Date	% Omnivore %	% Omnivore Score	% Top Carnivore %	% Top Carnivore Score	% Lithophilus Spawner %	% Lithophilus Spawner Score	Tolerance Index Value	Tolerance Index Score	Adjusted CPUE Value	Adjusted CPUE Score	% Delts %	% Delts Score	FIBI Score
Hickory Creek	New Vienna	8/11/1999	9.9	10.0	0	0	0.0	0.0	5.9	6.5	71.6	7.2	0.3	0	37
North Fork Maquoketa River	New Vienna- Tmdl30	8/21/2001	38.7	5.7	0	0	1.5	0.9	6.5	5.6	52.9	5.3	1.1	0	33
North Fork Maquoketa River	New Vienna- Tmdl30	7/28/2005	49.6	4.2	0	0	0.4	0.2	7.4	4.1	82.1	8.2	0.3	0	37
North Fork Maquoketa River	New Vienna- Tmdl29	8/21/2001	62.2	2.4	0	0	0.5	0.3	7.4	4.1	78.9	7.9	1.1	0	26
North Fork Maquoketa River	New Wine Park- New Vienna	8/10/1999	34.5	6.0	0	0	0.7	0.4	6.5	5.5	56.5	5.6	3.3	-5	32
North Fork Maquoketa River	Dyersville- Tmdl28	8/20/2001	46.5	4.4	0	0	0.4	0.2	6.2	6.0	53.9	5.4	0.4	0	29
North Fork Maquoketa River	Dyersville- Tmdl28	7/27/2005	39.0	5.4	0	0	0.5	0.3	5.9	6.5	155.4	10.0	0.2	0	37
North Fork Maquoketa River	Dyersville - REMAP 147	7/25/2005	35.6	5.9	0	0	0.7	0.3	6.4	5.7	66.8	6.7	0.8	0	34

Table 2-4. Details of fish kills that have occurred in the North Fork Maquoketa River watershed 1984-2004.

Stream	County	Date	Cause of Kill	# Fish Killed	Comments
Coffee Creek	DELAWARE	7/12/1984	Animal Waste/Unknown/Other	700	
Hickory Creek	DUBUQUE	8/12/1985	Temperature/Natural	unk	Natural Causes, High Water Temperature
North Fork Maquoketa River	DUBUQUE	6/23/1995	Unknown	188	Stream contained an unusual amount of rooted aquatic vegetation.
North Fork Maquoketa River	DUBUQUE	9/9/1996	Fertilizer	10716	
Confluence of Coffee Creek and NFMR	DUBUQUE	7/22/1998	Animal Waste/Unknown	34326	The stream was turbid and visibility was less than 12".
Bear Creek	DELAWARE	8/9/1998	Temperature/Natural	3	Probably due to low stream flow, high temps and spotty rains.
Bear Creek	DELAWARE	7/26/2002	Animal Waste/Unknown/Other	96418	Elevated ammonia levels in Bear Creek and unnamed tributaries.
North Fork Maquoketa River	DUBUQUE	7/6/2004	Unknown	200	Late discovery, kill affected New Wine Park and upstream.

Table 2-5. Fish collected in the North Fork Maquoketa River 1999-2005.

Stream Name	Site	Date	Site Type	Bigmouth Shiner	Black Bullhead	Blacknose Dace	Bluntnose Minnow	Central Stoneroller	Common Carp	Common Shiner	Creek Chub	Fantail Darter	Fathead Minnow	Green Sunfish	Johnny Darter	Largemouth Bass	Longnose Dace	Northern Hog Sucker	Quillback Carpsucker	Sand Shiner	Southern Redbelly Dac	Spotfin Shiner	Stonecat	Suckermouth Minnow	White Sucker
NF Maquoketa River	New Wine Park	8/10/1999	Full	64		178	16	52	4		77		26		4	3	2			15	1			4	165
Hickory Creek	HI2	8/11/1999	Full	41	394		3	1			62		58		30						47				2
NF Maquoketa River	Tmdl28	8/20/2001	Full	23		183	44	25	1	24	95	2	9	3	1					4	4	2		3	267
NF Maquoketa River	Tmdl29	8/21/2001	Full		8	394	135	9	495	25	39		6		26					21	6			7	243
NF Maquoketa River	Tmdl30	8/21/2001	Full	20	1	254	107	15	41	2	17		6		48					2	9			9	84
NF Maquoketa River	REMAP 147	7/25/2005	Full	210	1	273	64	64	2	18	36	6	7		22			5	4	44	8	10		3	310
Hewitt Creek	HE1	7/26/2005	RBP	C		A	C	A		U	C	U	R		C			R		R	C	R			A
Unn. Trib to Hewitt Creek	HE2	7/26/2005	RBP	C		A	R	R			C				R						R				U
Coffee Creek	CC1	7/26/2005	RBP	U		A	U		A		A		U		R						U				A
NF Maquoketa River	NF1	7/26/2005	RBP	U		C	C	C			C	C	R		U		R	U		R	C	R	R		A
NF Maquoketa River	NF4	7/26/2005	RBP	C		C	A	A	A		U		A								A	R			A
Unn. Trib to NFMR	NF5	7/26/2005	RBP	C		U	U		C		C		A		C						A				C
NF Maquoketa River	NF6	7/26/2005	RBP	U	R	C	C		A		C		A								A	R			A
NF Maquoketa River	Tmdl28	7/27/2005	Full	158		278	117	319	10	14	112	6	20		46					59	88	1		9	549
Hickory Creek	HI2	7/27/2005	RBP	R		A	R	C			U	R	R		C						C				U
NF Maquoketa River	Tmdl29	7/27/2005	RBP	A		A	A	C	A	R	R		C		C		R			A	C	U		U	U
Hickory Creek	HI1	7/27/2005	RBP	A		A	C	A	R				U		A						A				A
Unn. Trib To Hickory Creek	HI3	7/27/2005	RBP	U		U	R				C		A	R							A				C
Hewitt Creek	HE4	7/27/2005	RBP	U		A					C				U						C				C
NF Maquoketa River	Tmdl30	7/28/2005	Full	81		300	386	40	133		16	8	12		43		1			137	6	15		5	110
Hickory Creek	HI4	8/4/2005	RBP	C		U	U				U		A								R				C

R = Rare (1-5), U = Uncommon (6-20), C = Common (21-100), and A = Abundant (>100).

Table 2-6. Benthic macroinvertebrates (grouped by family) collected in the North Fork Maquoketa River 1999-2005.

Stream/Site Name	Nearest Landmark	Date	Aeshnidae	Ancylidae	Asellidae	Baetidae	Belostomatidae	Brachycentridae	Caenidae	Calopterygidae	Cambaridae	Chironomidae	Coenagrionidae	Corduliidae	Corixidae	Culicidae	Curculionidae	Dixidae	Dryopidae	Dugesiidae	Dytiscidae	Elmidae	Empididae	Ephydridae	Erpobdellidae	Gammaridae	Gerridae	Glossiphoniidae	Gomphidae
NF Maquoketa River	New Wine Park- NV	8/10/1999			7	10	5			8		17	7		8					6	1			1	4				1
NF Maquoketa River	New Vienna- Tmdl29	8/21/2001		2		20	2			1	1	14	16		2	1	1		2	4	1	4					4		
NF Maquoketa River	Dyersville- Tmdl28	8/20/2001		4	7	8	2			9		6	8		6	4				1		5			6			1	1
NF Maquoketa River	Dyersville- Tmdl28	7/25/2005	1	1	10	12		1	1	4		9	5		6				1	4	6	2			1			2	
NF Maquoketa River	New Vienna- Tmdl30	8/21/2001				45	11			10	1	4	39		17	10			1	1	6	1			6		1	1	1
NF Maquoketa River	New Vienna- Tmdl30	7/28/2005	4	5	14	23	2			2	3	4	36		10	1		8		6	3	1			1		1	1	
NF Maquoketa River	Dyersville - REMAP 147	7/25/2005	1	2	9	16	1		1	3	1	5	17		6	7				4	5				2				
Hickory Creek	New Vienna	8/11/1999				29	2					16	18		1				3	8	6			1	5		1	1	
Hickory Creek	New Vienna	7/27/2005	U			A	R			U	A	A	A		U	R		R		A	U			R	R	R	U	R	
NF Maquoketa River	New Vienna- Tmdl29	7/27/2005	R		A	U	R		U		C	A	C		C					C	A	R			U		U		
Hickory Creek	Dyersville - HI1	7/27/2005	R			R	R		U	R	R	A	C		C				R		R				R		U		
Unn Trib To Hickory Cr	Bankston - HI3	7/27/2005	U			A	A				A	U	A		C	R				R					R		C	R	
Hickory Creek	Bankston - HI4	8/4/2005	U								A		C																
Hewitt Creek	Dyersville - HE1	7/26/2005	U	U	A	A	R	R	U	C	U	A	C		C			R	U	U	U	R	R			R			R
Unn Trib to Hewitt Cr	Dyersville - HE2	7/26/2005	U		A				U	U	C	A	U						C	U	R	U			R		C	R	
Hewitt Creek	Dyersville - HE4	7/27/2005	U			A					U	A			A			U	U		R					A	A		
Coffee Creek	New Vienna - CC1	7/26/2005			A	A	C				C	U	A		U	R		R	R	A	R				R		C		
NF Maquoketa River	Dyersville - NF1	7/26/2005		C	A	C				U		A	A		C					C					U		U	U	
NF Maquoketa River	Holy Cross - NF4	7/26/2005	R		A	A	A		R		U	U	A			R		U		A	R	R					A	R	
Unn. Trib to NFMR	Holy Cross - NF5	7/26/2005	U		A	A	U					R	A		C					A	U						A	R	
NF Maquoketa River	Holy Cross - NF6	7/26/2005	C		A	A	C				C	R	A	R	A	R				A	U				R	R	A		

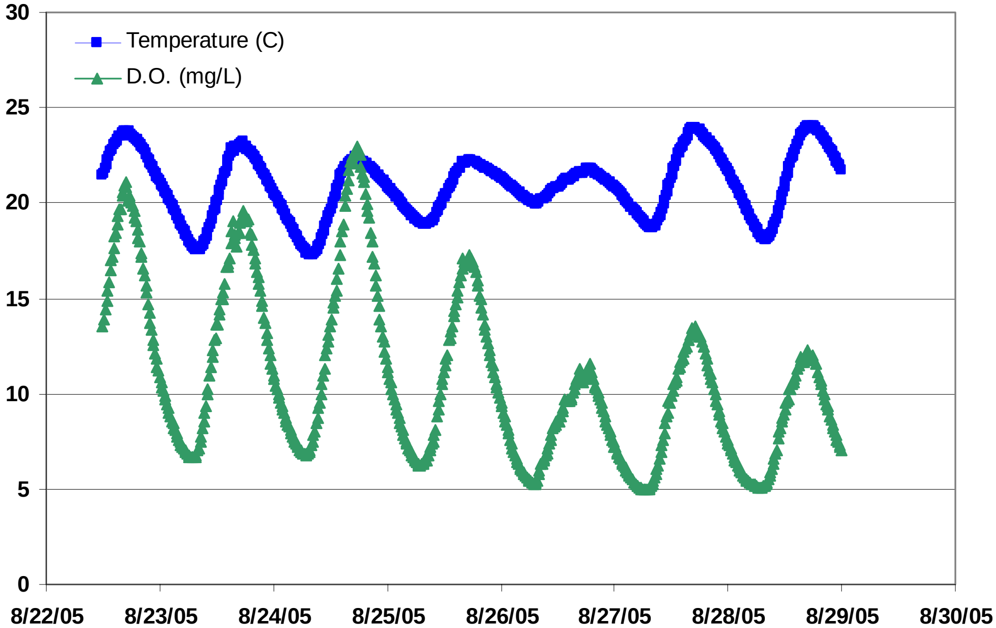
R = Rare (1-5), U = Uncommon (6-20), C = Common (21-100), and A = Abundant (>100).

Table 2-6 continued. Benthic macroinvertebrates (grouped by family) collected in the North Fork Maquoketa River 1999-2005.

Stream/Site Name	Nearest Landmark	Date	Gyrinidae	Haliplidae	Helodidae	Heptageniidae	Hydrophilidae	Hydropsychidae	Hydroptilidae	Isonychiidae	Leptoceridae	Leptohyphidae	Libellulidae	Lumbricidae	Lymnaeidae	Muscidae	Nepidae	Notonectidae	Phoridae	Physidae	Planorbidae	Pleidae	Pyralidae	Simuliidae	Sphaeriidae	Stratiomyidae	Tipulidae	Tubificidae	Veliidae
NF Maquoketa River	New Wine Park- NV	8/10/1999			1	24	2	47				3								10				4					
NF Maquoketa River	New Vienna- Tmdl29	8/21/2001		3		8	6	63												5				1					
NF Maquoketa River	Dyersville- Tmdl28	8/20/2001	1			33	3	66		1		1								8									
NF Maquoketa River	Dyersville- Tmdl28	7/25/2005					5	13	1	1		5								10				1	1		2	1	
NF Maquoketa River	New Vienna- Tmdl30	8/21/2001		1		6	6	45				2	2					1		5				4		1	1		
NF Maquoketa River	New Vienna- Tmdl30	7/28/2005				1	1	50	2						2		1		1	7			1	2					
NF Maquoketa River	Dyersville - REMAP 147	7/25/2005	2	1			7	35			3									1									
Hickory Creek	New Vienna	8/11/1999		4		5	2	16	4				1							9				2					
Hickory Creek	New Vienna	7/27/2005	R			U	U	A	A											A					R	R			
NF Maquoketa River	New Vienna- Tmdl29	7/27/2005	R	R			U	A	U											A								R	R
Hickory Creek	Dyersville - HI1	7/27/2005				R		C												A					R			R	
Unn Trib To Hickory Cr	Bankston - HI3	7/27/2005		U			R													A									
Hickory Creek	Bankston - HI4	8/4/2005																R											
Hewitt Creek	Dyersville - HE1	7/26/2005		R		R	U	A	U		U									A		R		U			R	R	
Unn Trib to Hewitt Cr	Dyersville - HE2	7/26/2005					R	C	U		U					R				A						R	R	R	
Hewitt Creek	Dyersville - HE4	7/27/2005					R	A						R													U		
Coffee Creek	New Vienna - CC1	7/26/2005		R			R													A									
NF Maquoketa River	Dyersville - NF1	7/26/2005					R	A												A	R								U
NF Maquoketa River	Holy Cross - NF4	7/26/2005		U			R											R		A	R								
Unn. Trib to NFMR	Holy Cross - NF5	7/26/2005		R			R													A		U			R				C
NF Maquoketa River	Holy Cross - NF6	7/26/2005		U			U											R		A									R

R = Rare (1-5), U = Uncommon (6-20), C = Common (21-100), and A = Abundant (>100).

(a)



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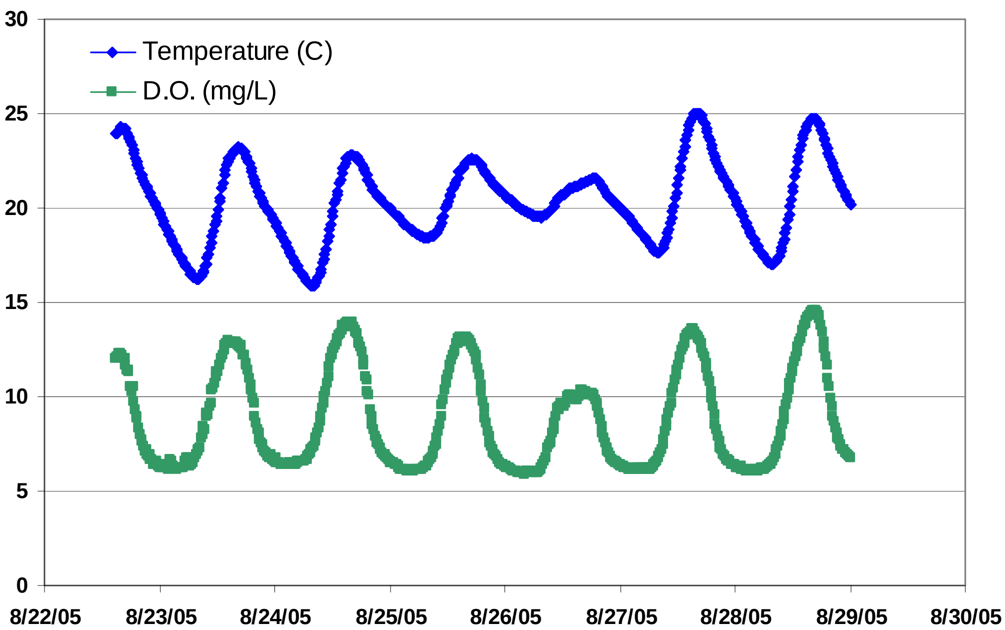


Figure 2-1. Diurnal temperature and dissolved oxygen measurements in the North Fork Maquoketa River **(a)** at site TMDL 30 from August 22 to August 28, 2005; **(b)** at site TMDL 28 from August 22 to August 28, 2005

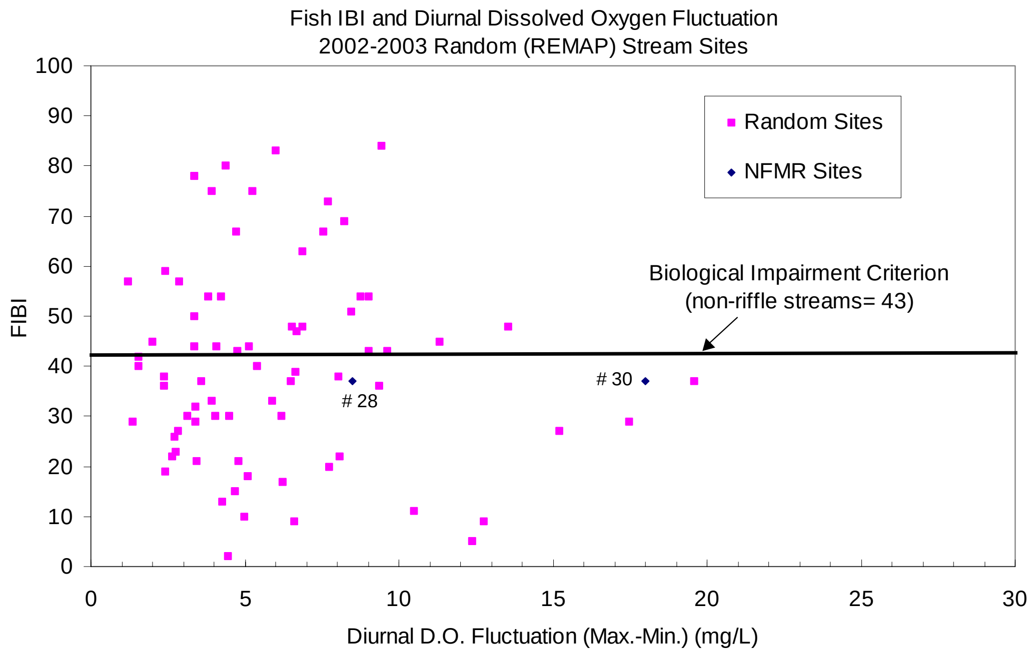


Figure 2-2. Fish Index of Biotic Integrity (FIBI) and diurnal dissolved oxygen fluctuation.

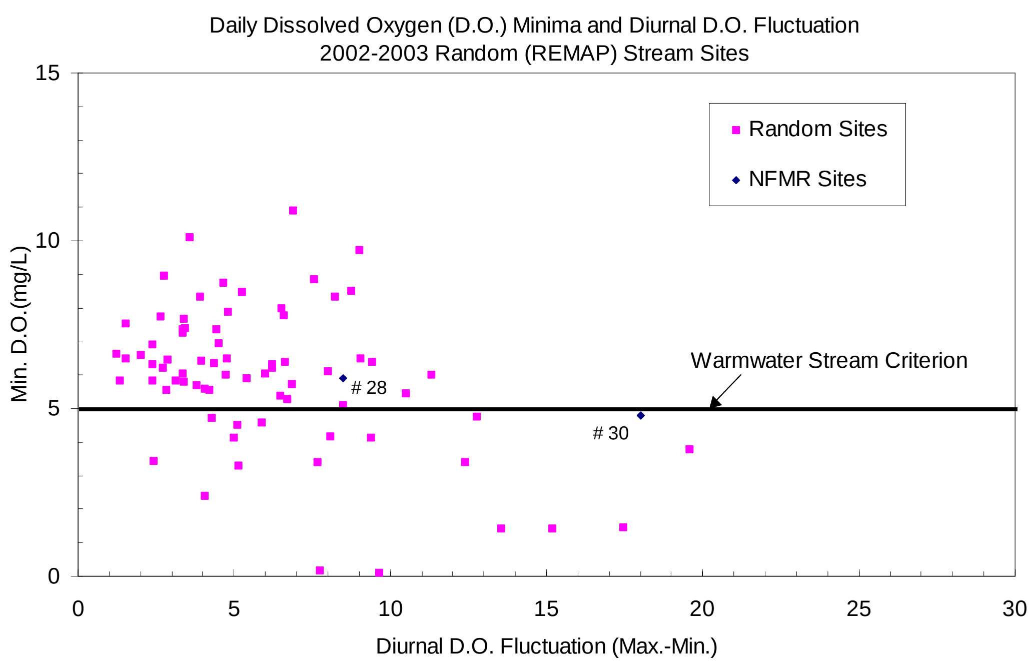


Figure 2-3. Daily dissolved oxygen (d.o.) minima and diurnal d.o. fluctuation.

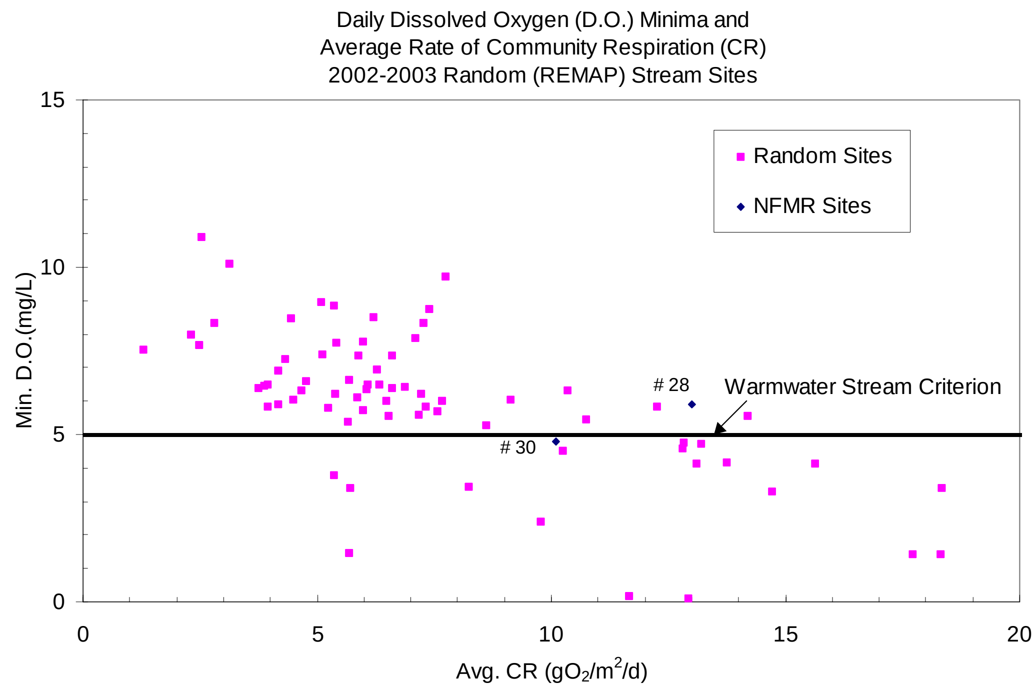


Figure 2-4. Daily dissolved oxygen (d.o.) minima and average rate of community respiration.

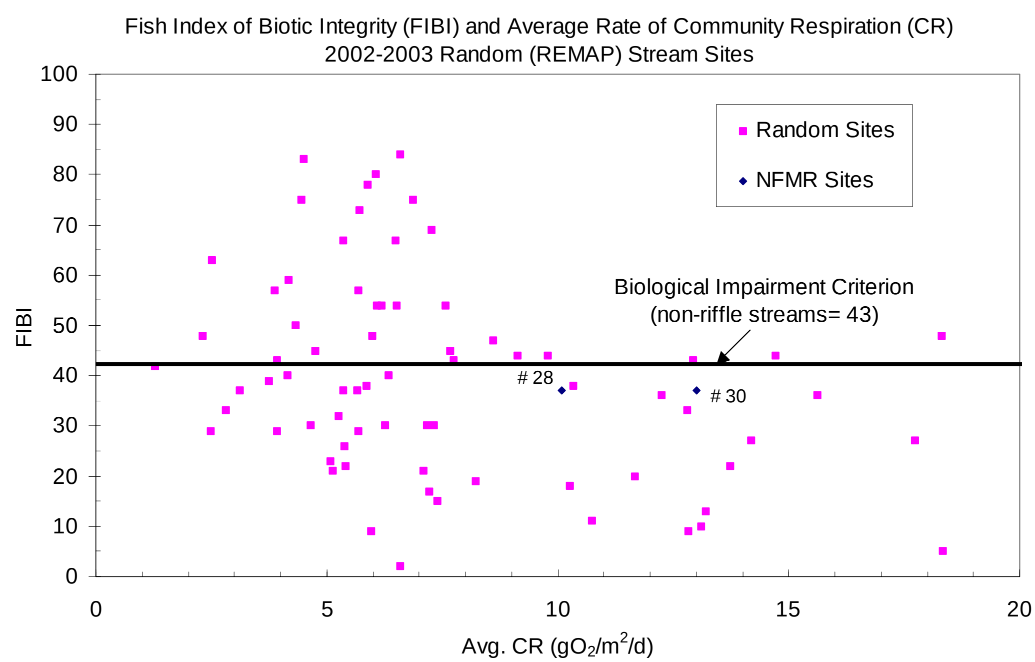


Figure 2-5. Fish Index of Biotic Integrity (FIBI) and average rate of community respiration.

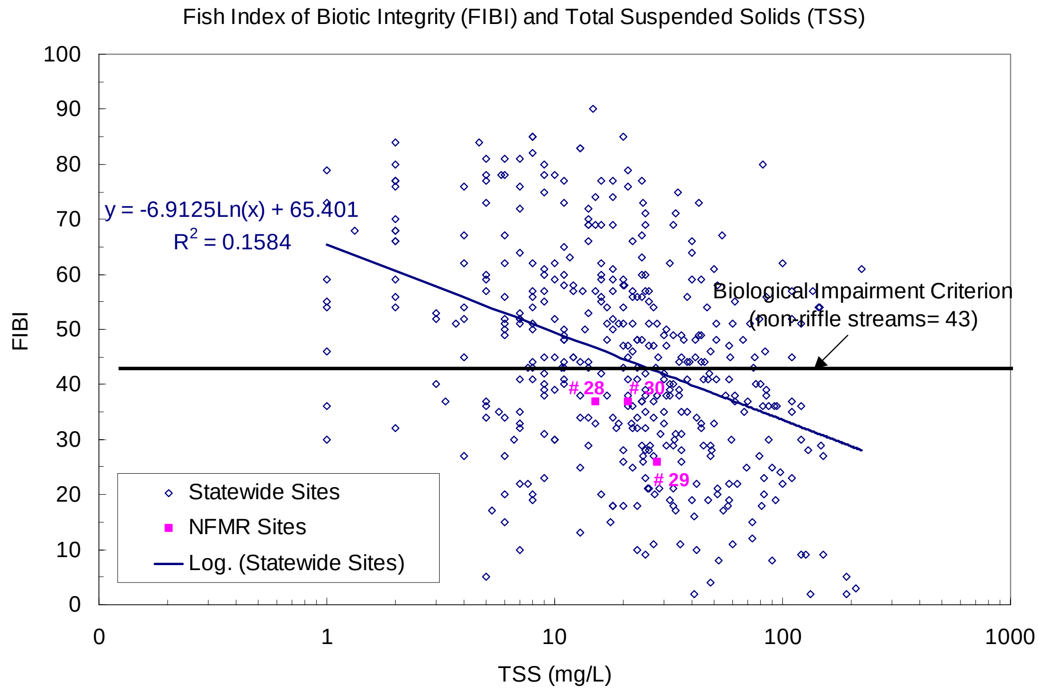


Figure 2-6. Fish Index of Biotic Integrity (FIBI) and Total Suspended Solids (TSS).

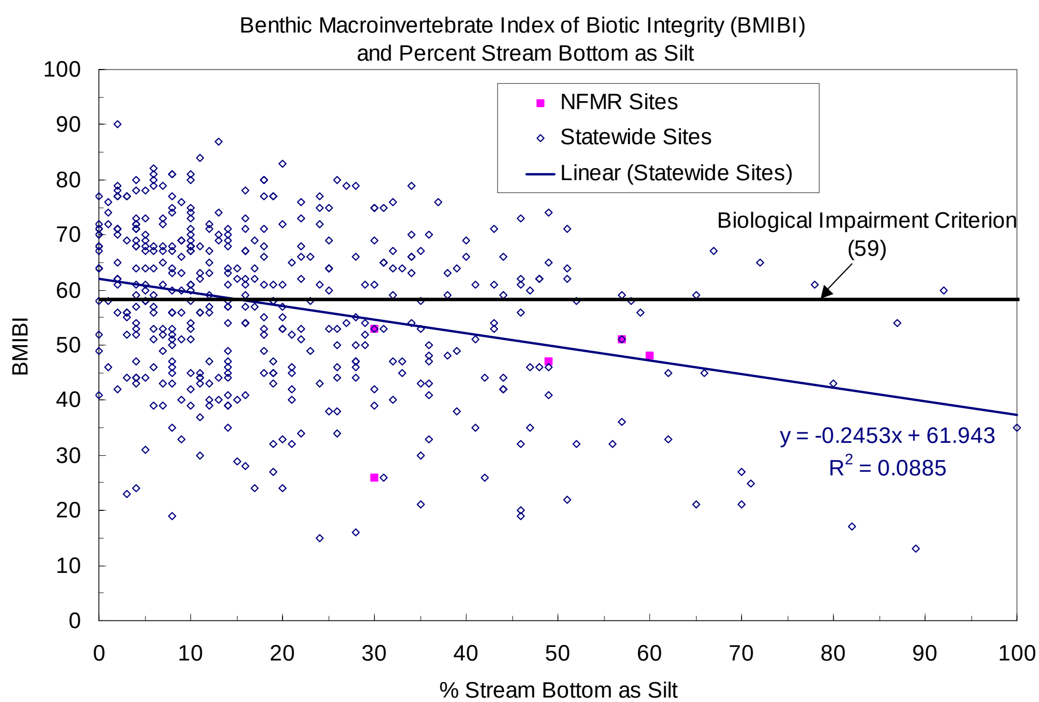


Figure 2-7. Benthic Macroinvertebrate Index of Biotic Integrity (BMIBI) and percent stream bottom as silt.

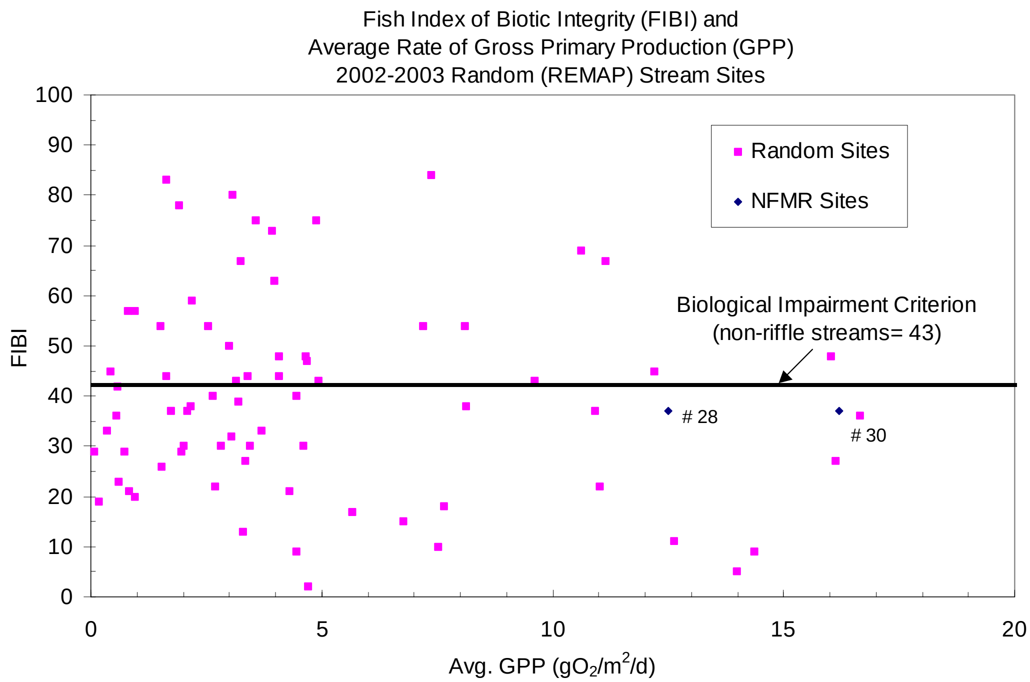


Figure 2-8. Fish Index of Biotic Integrity (FIBI) and average rate of gross primary production (GPP).

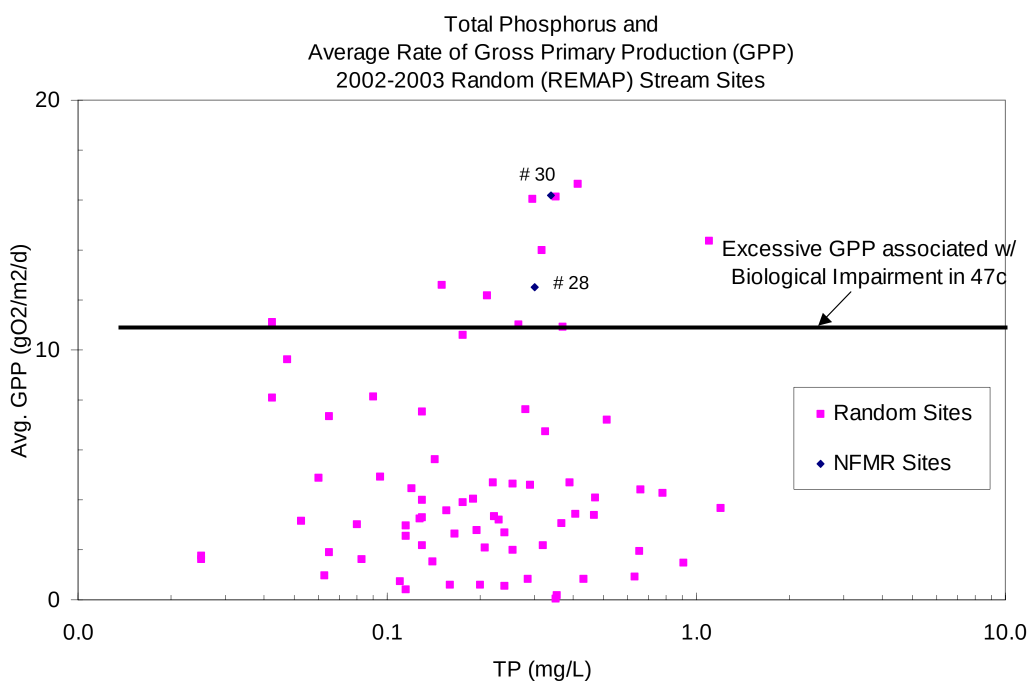


Figure 2-9. Average rate of gross primary production (GPP) and total phosphorus.

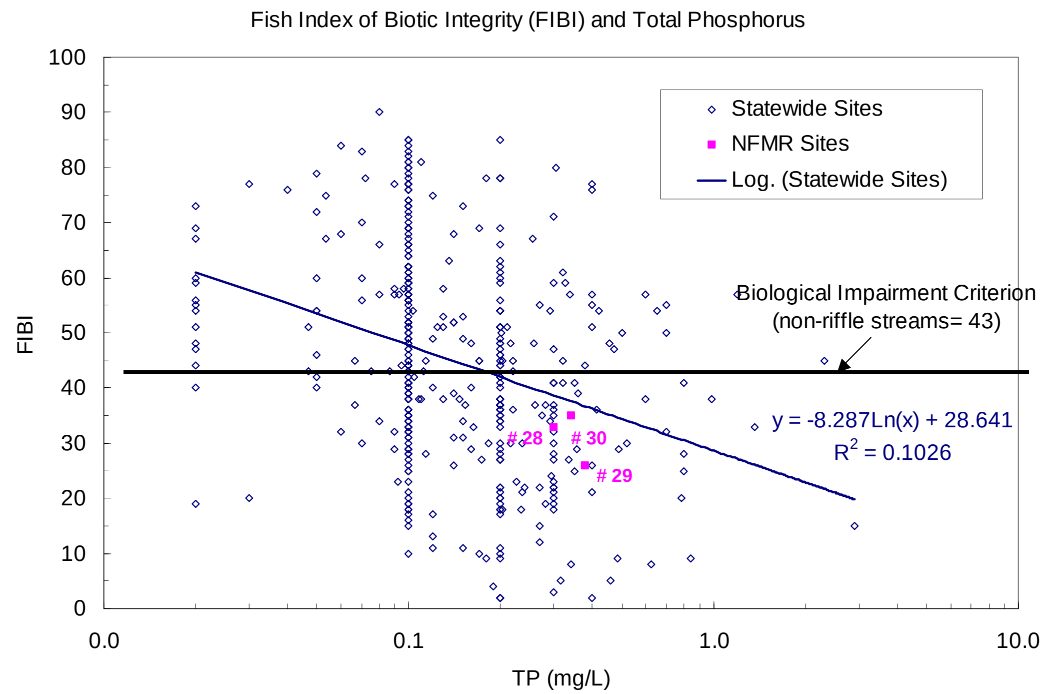


Figure 2-10. Fish Index of Biotic Integrity (FIBI) and total phosphorus.

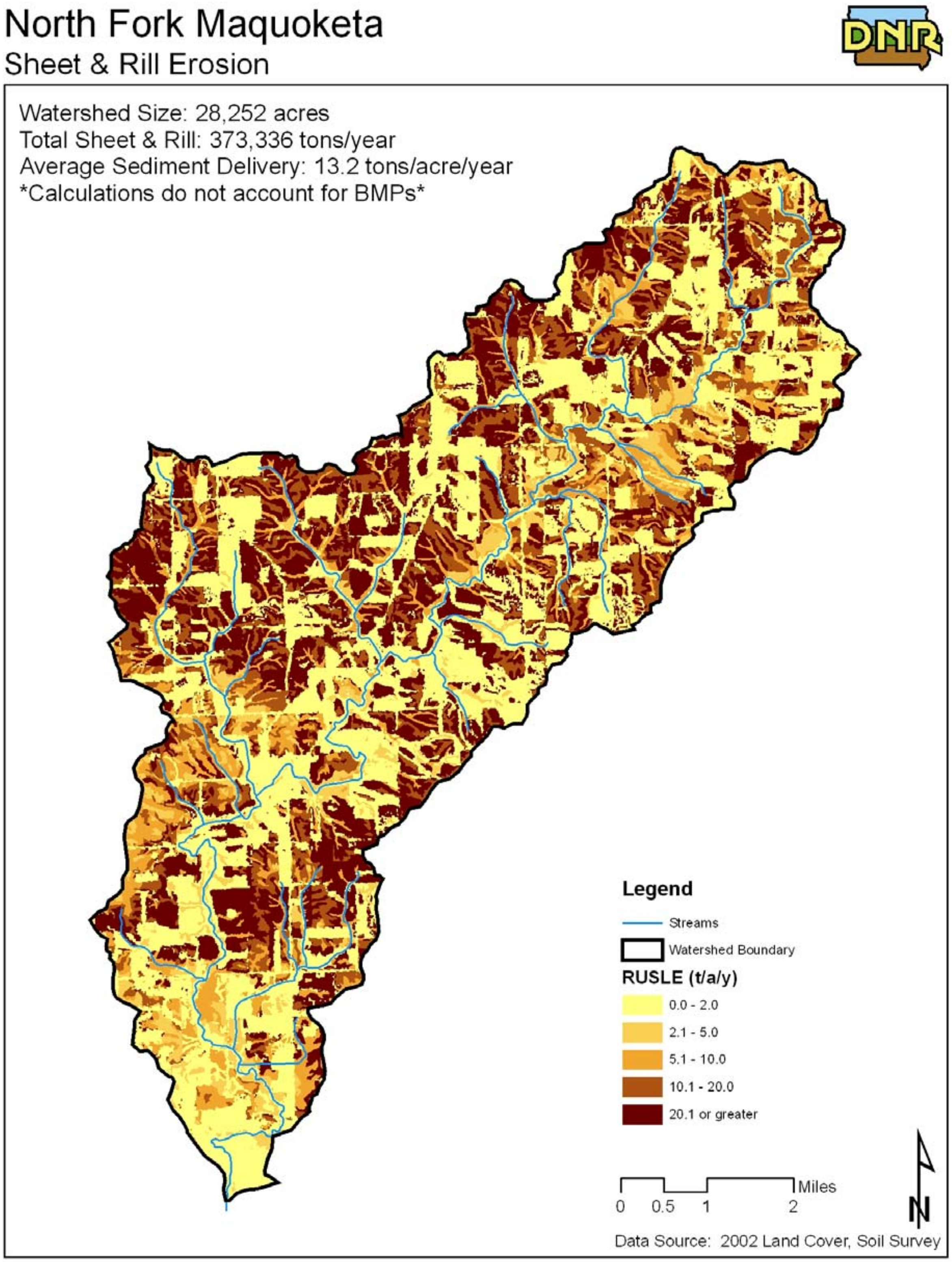


Figure 2-11. RUSLE estimate of sheet and rill erosion in the NFMR watershed based on 2002 photography.

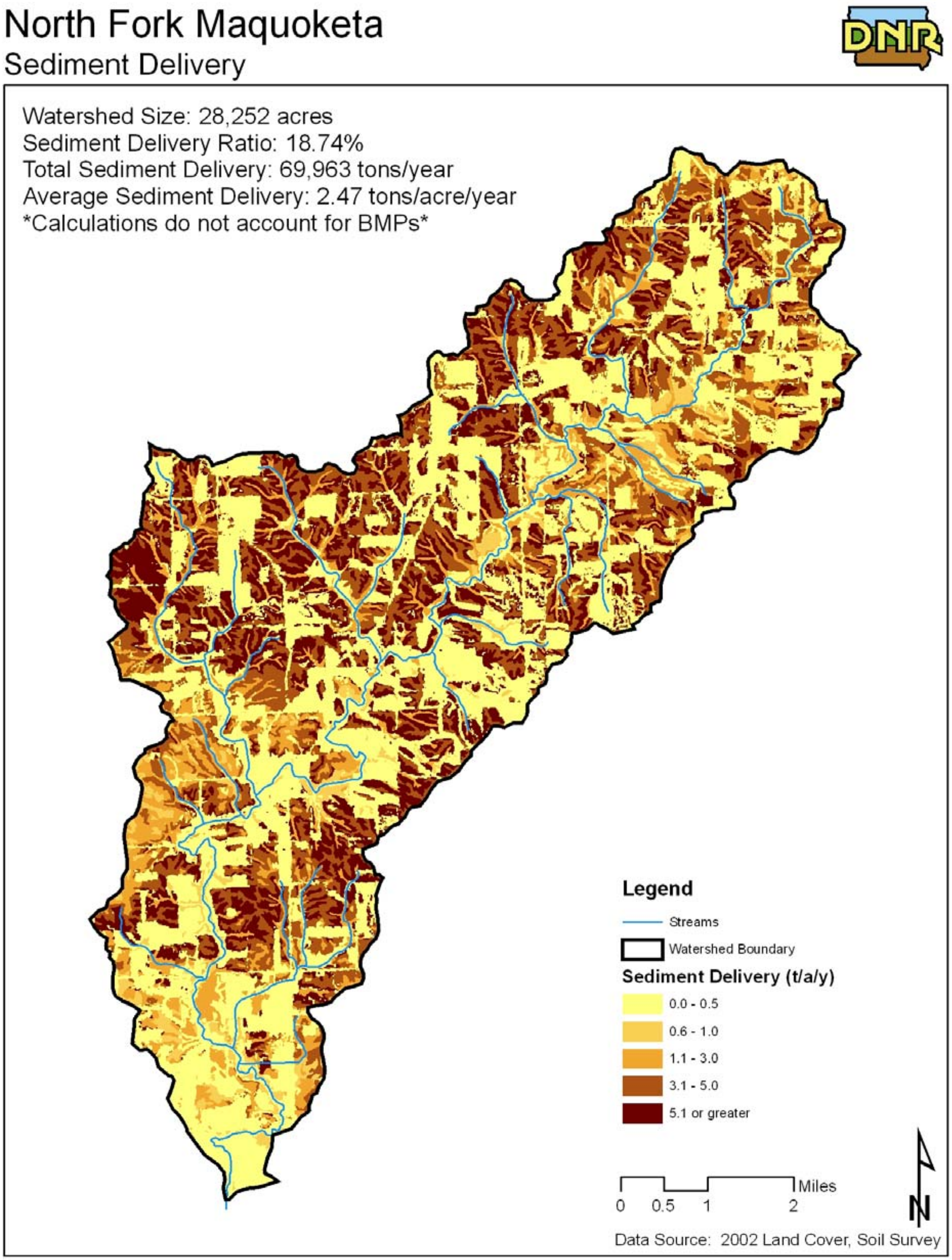


Figure 2-12. Estimate of NFMR sediment delivery based on 2002 photography.

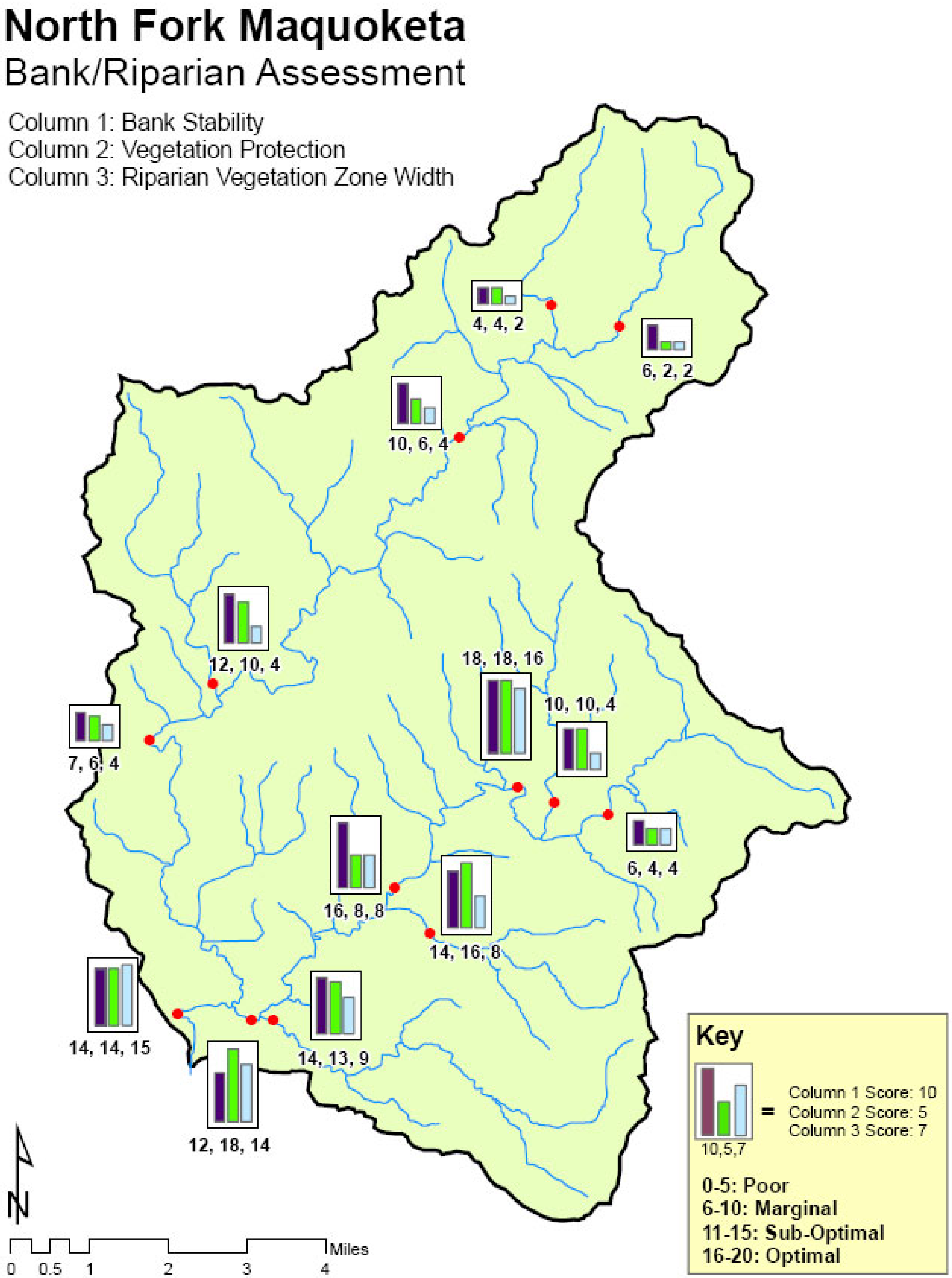


Figure 2-13. NFMR bank and riparian estimate from the 2005 IDNR RBP habitat assessment.

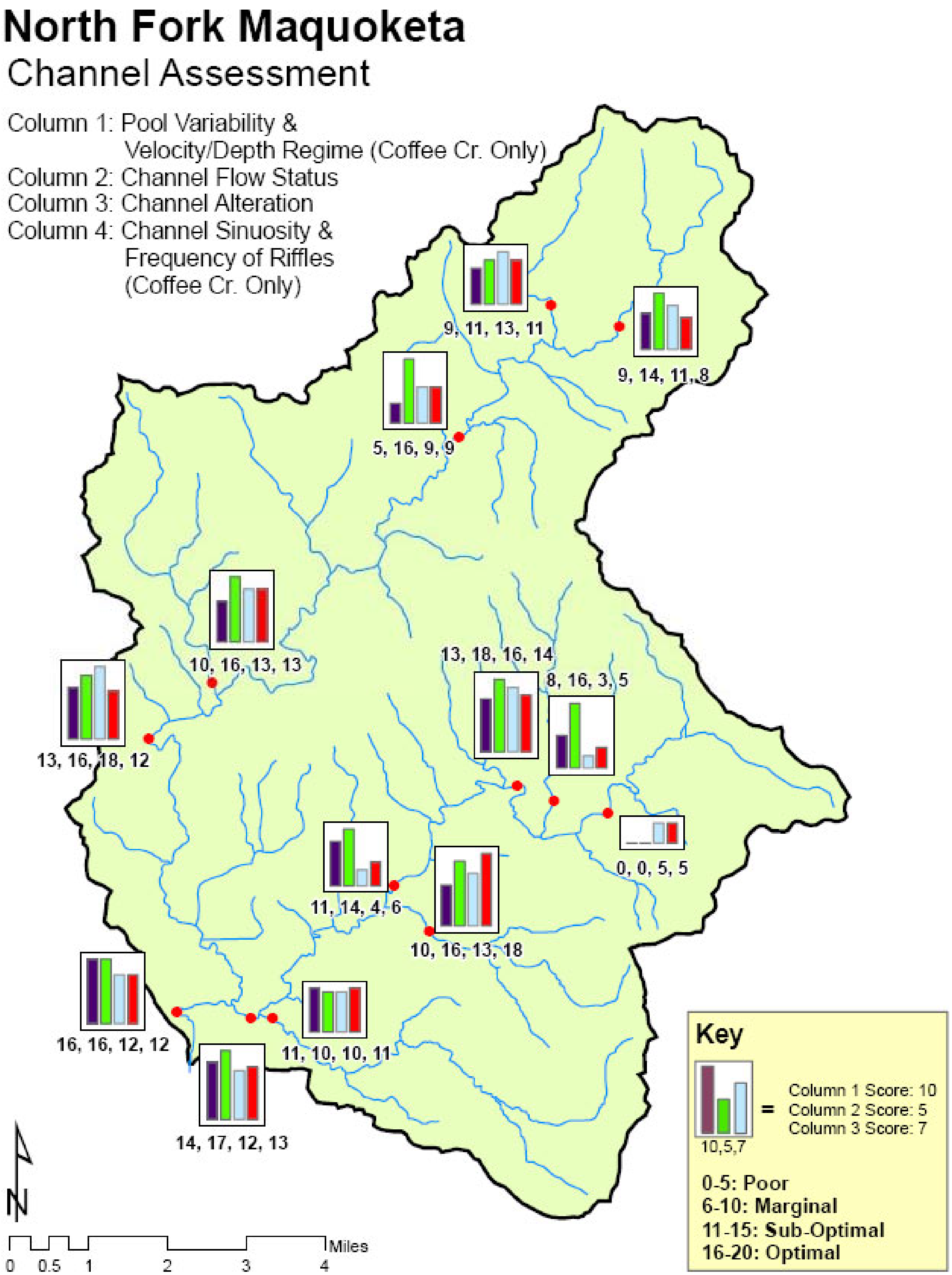


Figure 2-14. NFMR stream channel assessment from the 2005 IDNR RBP habitat assessment.

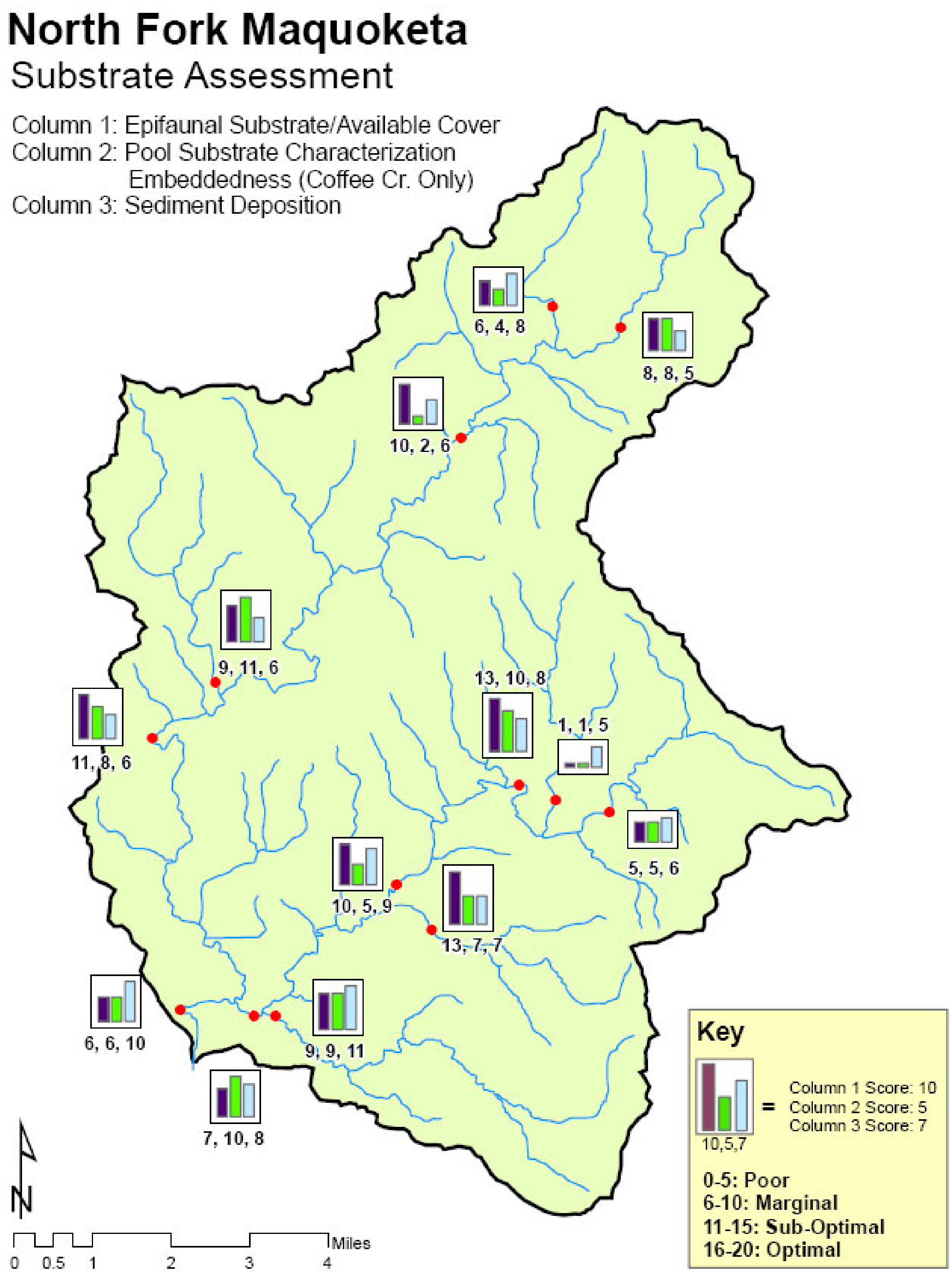


Figure 2-15. NFMR stream substrate assessment from the 2005 IDNR RBP habitat assessment.

Figure 2-16. – Examples of excessive algal growth in the NFMR watershed.

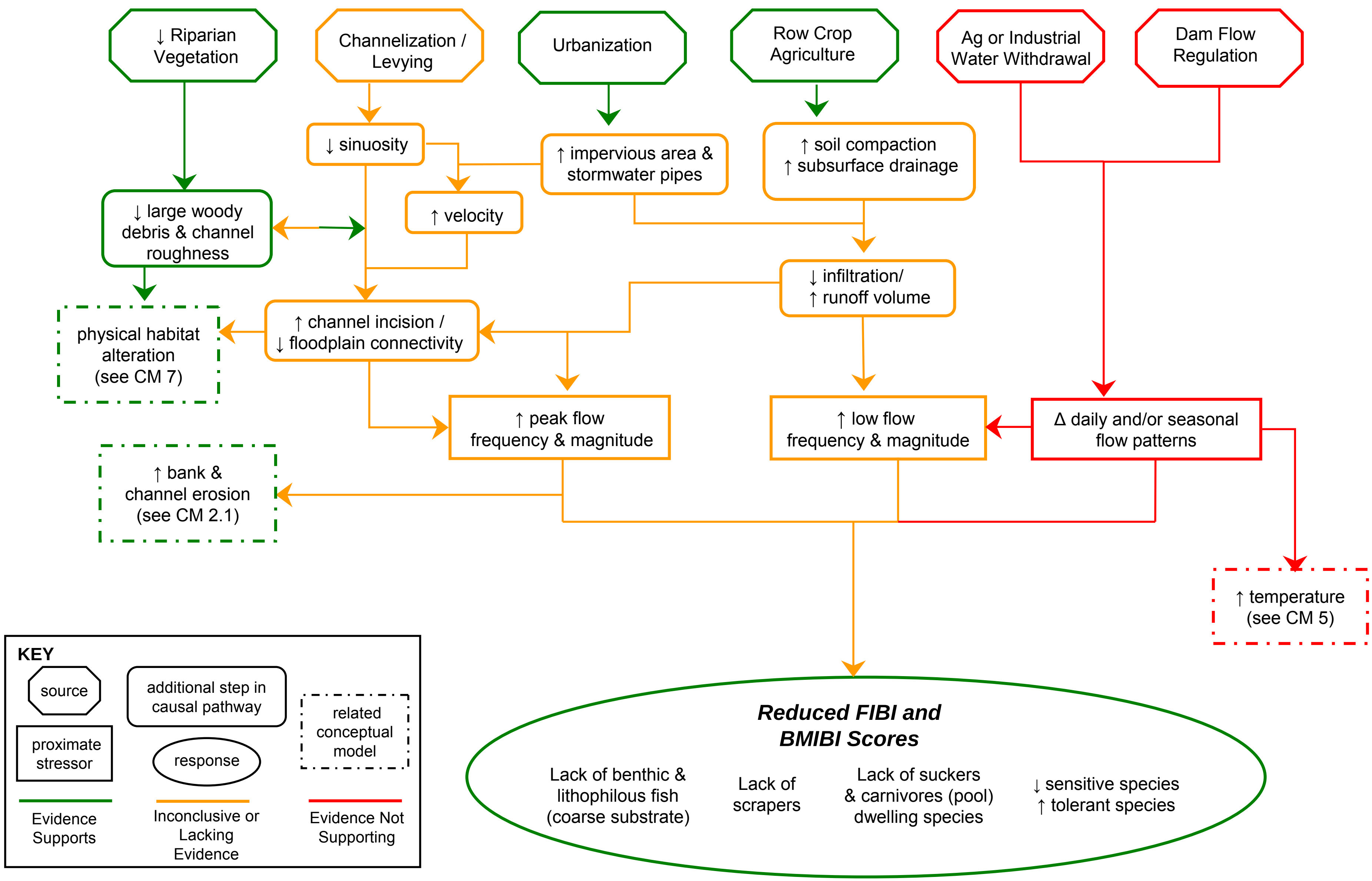
Figure 2-17. – Examples of excessive bottom silt/sediment in the NFMR watershed.

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 - Common Carp
Conceptual Model 9 - Aquatic Life Depletion and Isolation

Conceptual Model 1 - Altered flow regime



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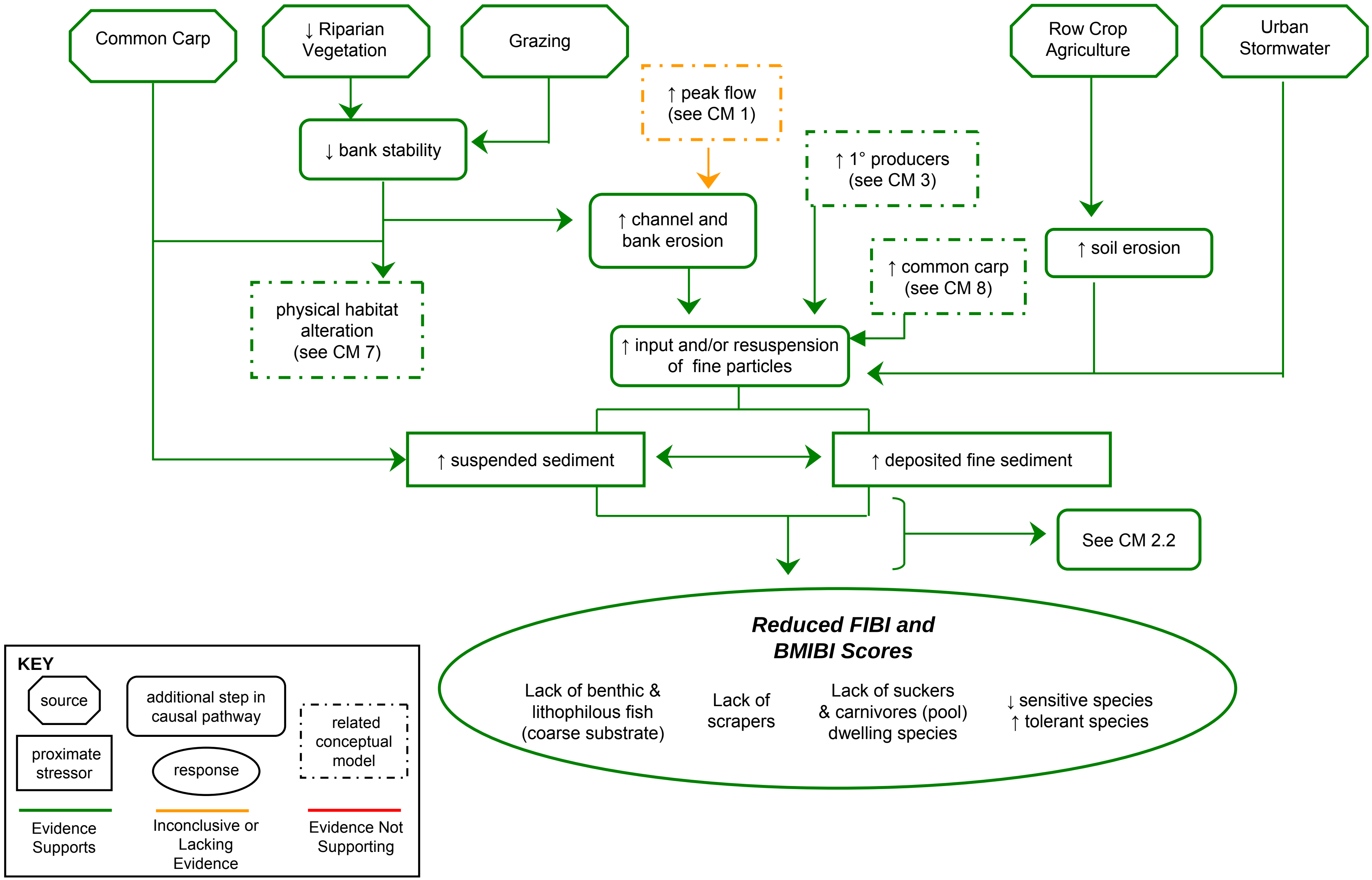
Conceptual Model 2.1 - Suspended and Bedded Sediments (SABS)



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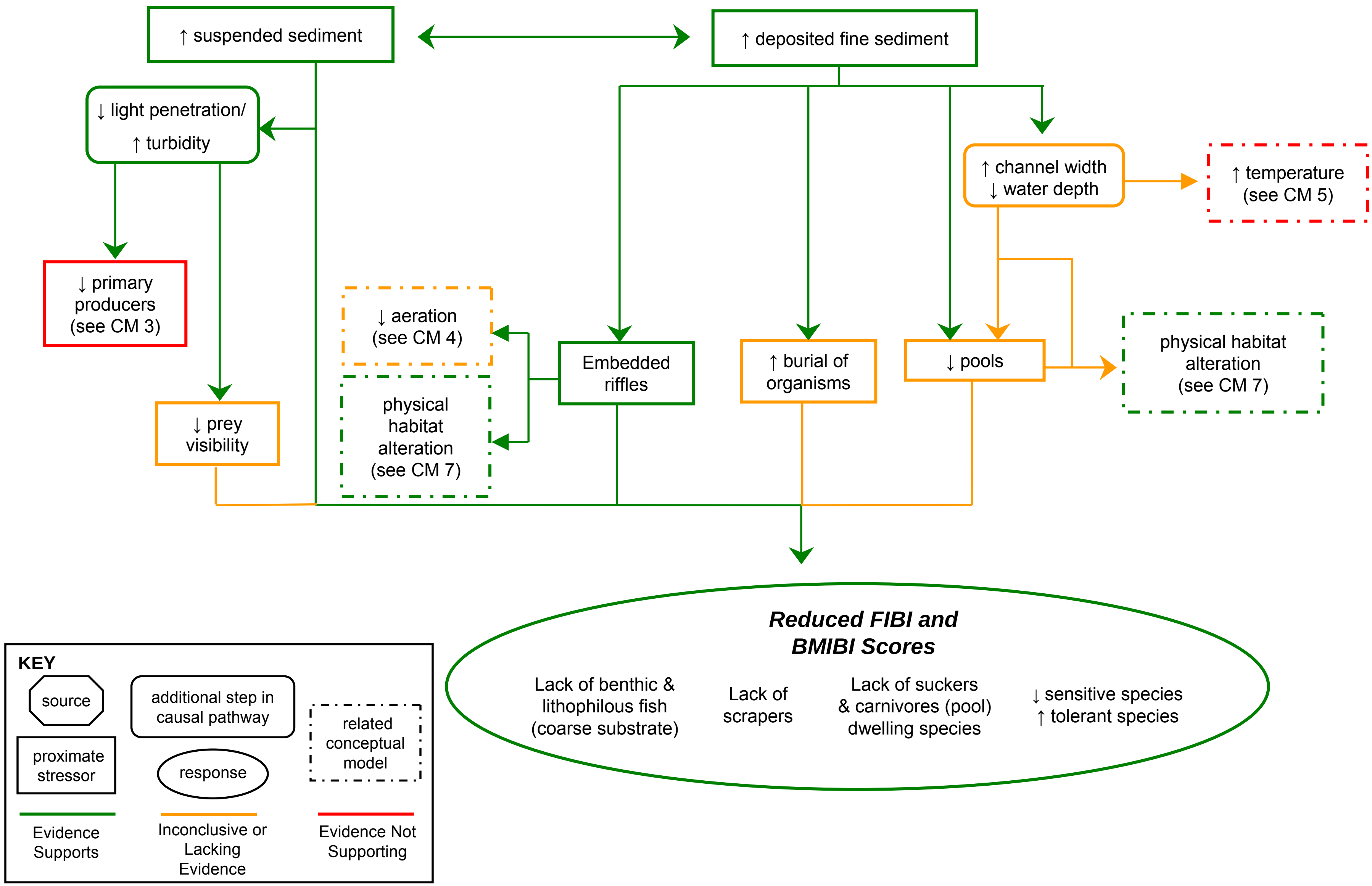
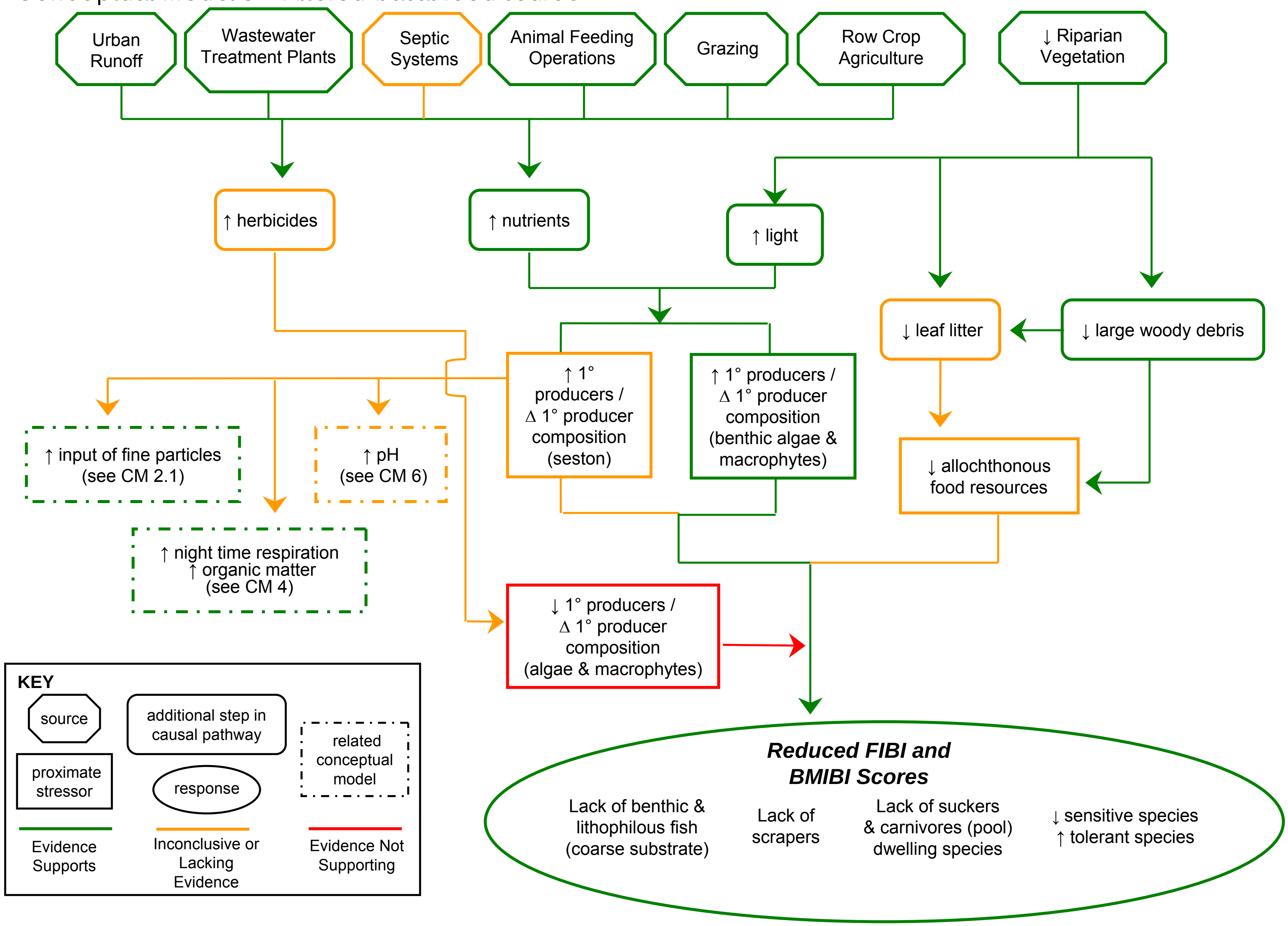
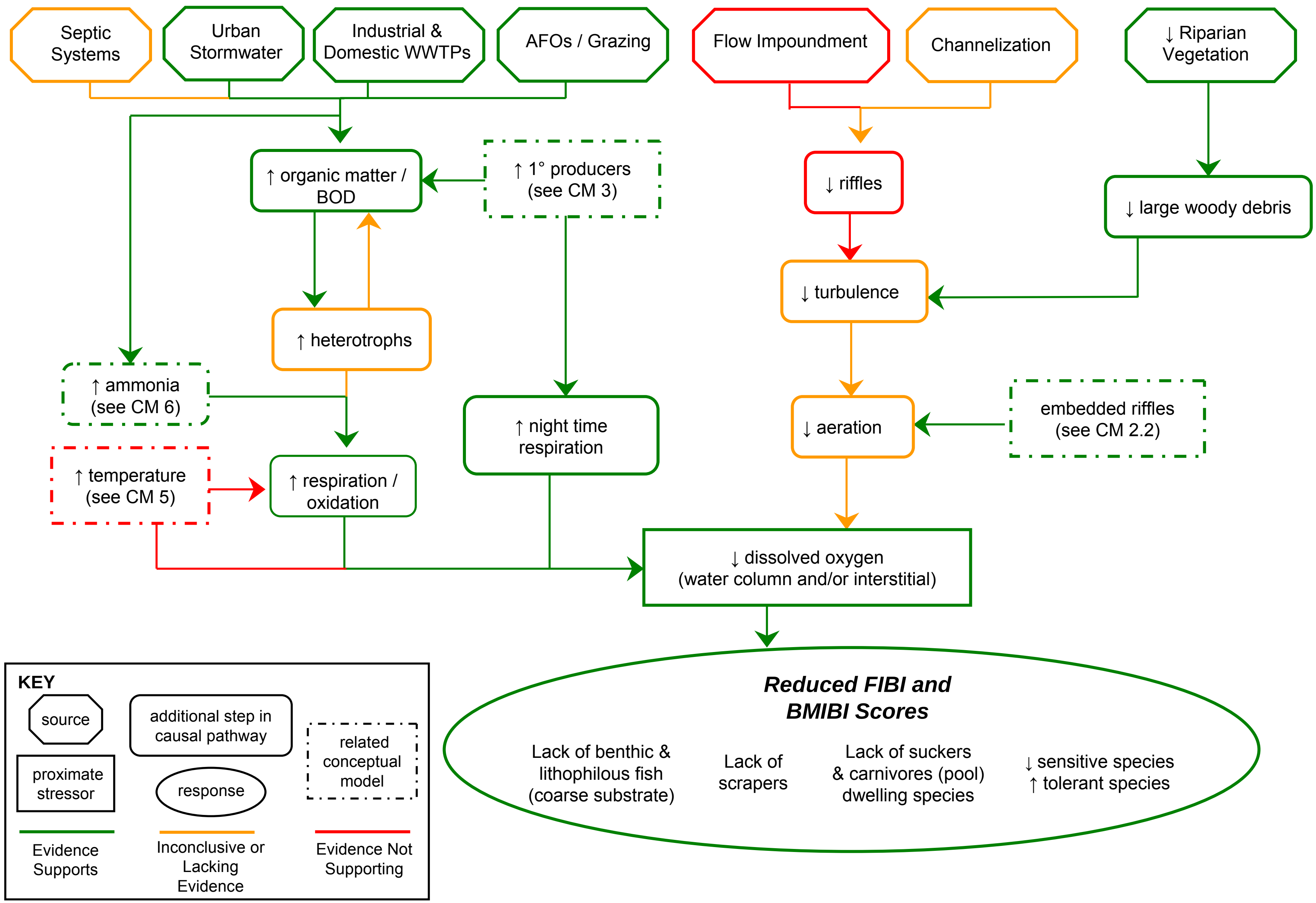
Conceptual Model 2.2 - Suspended and Bedded Sediments (SABS)



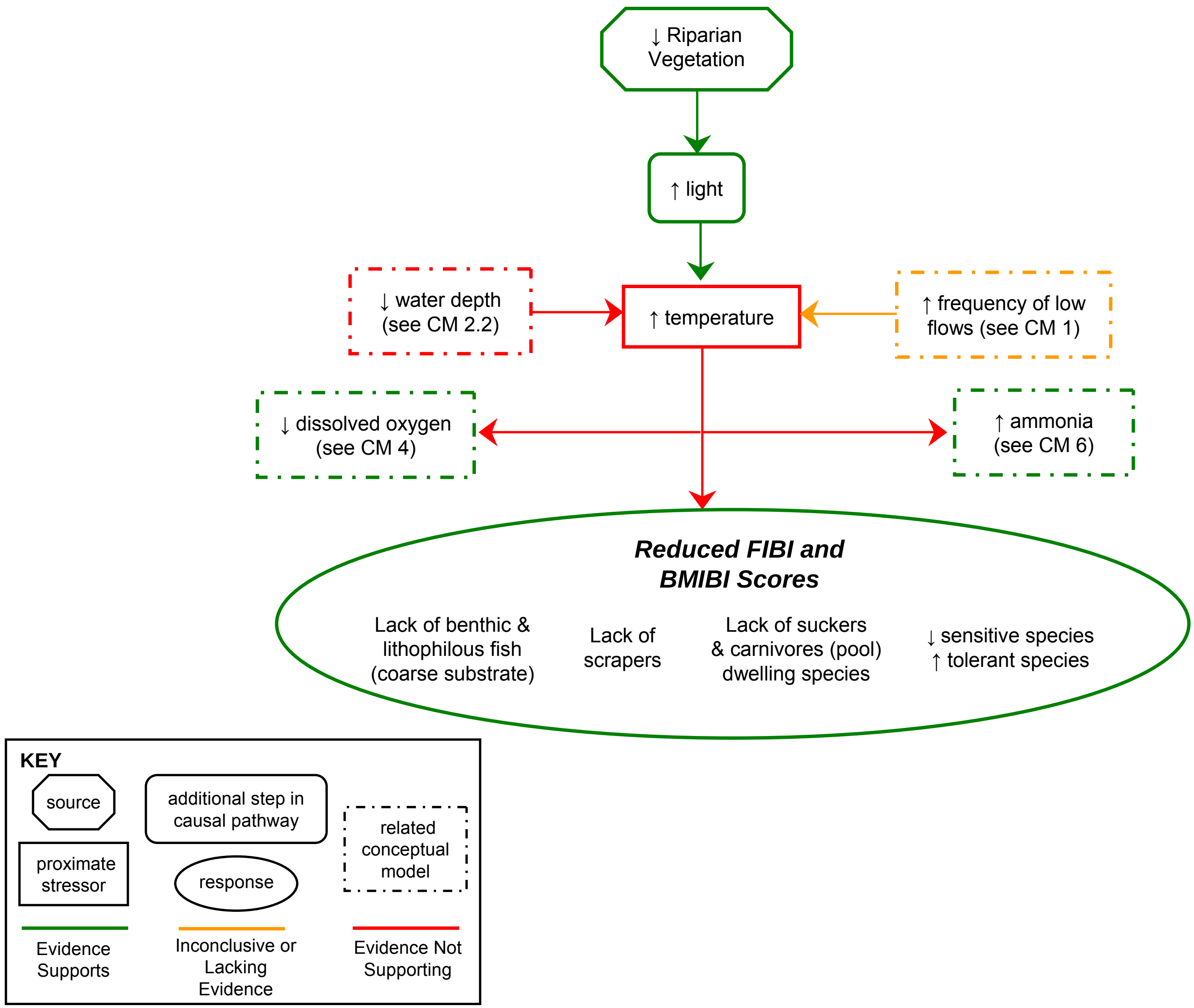
Conceptual Model 3 - Altered basal food source



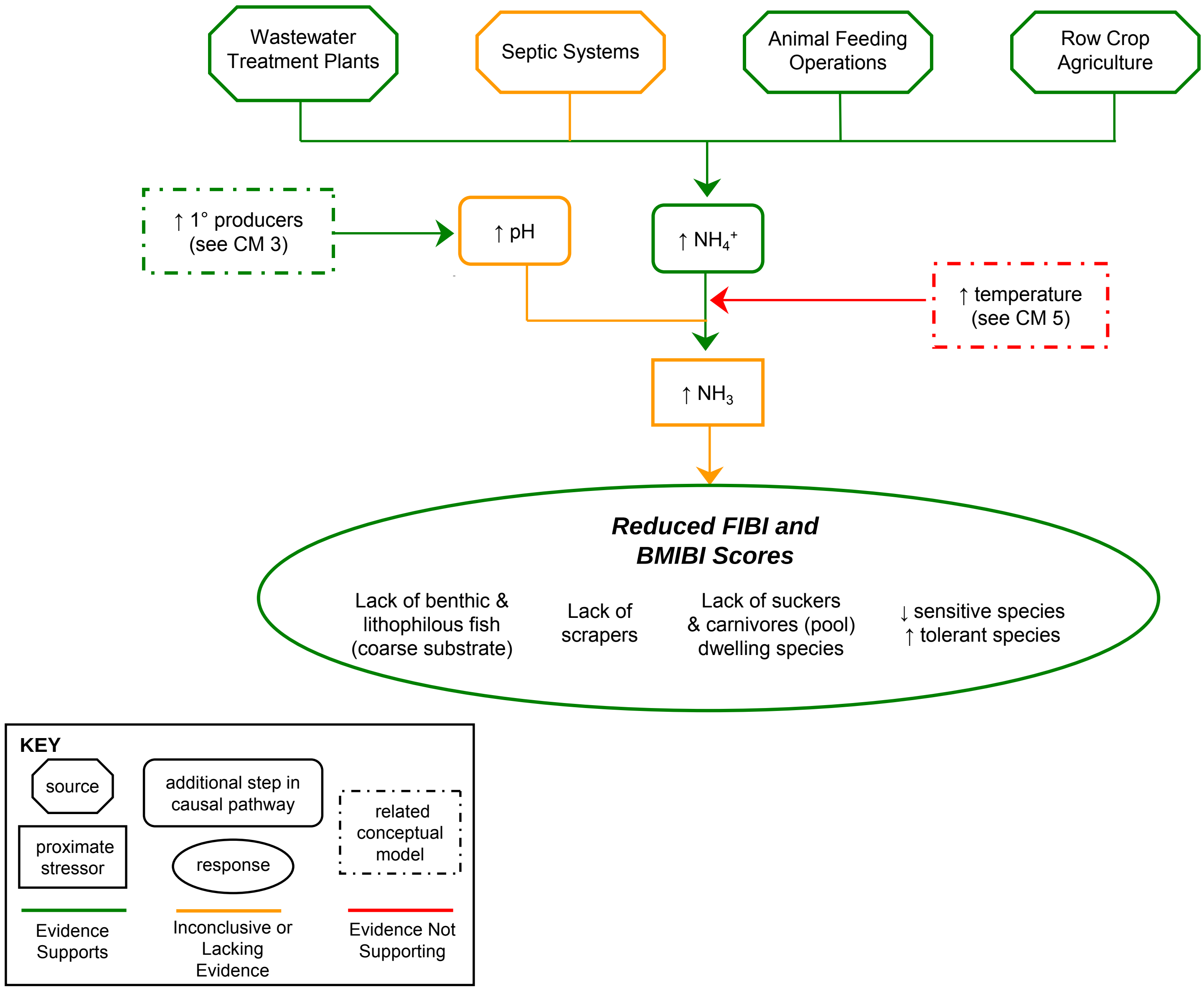
Conceptual Model 4 - Decreased dissolved oxygen



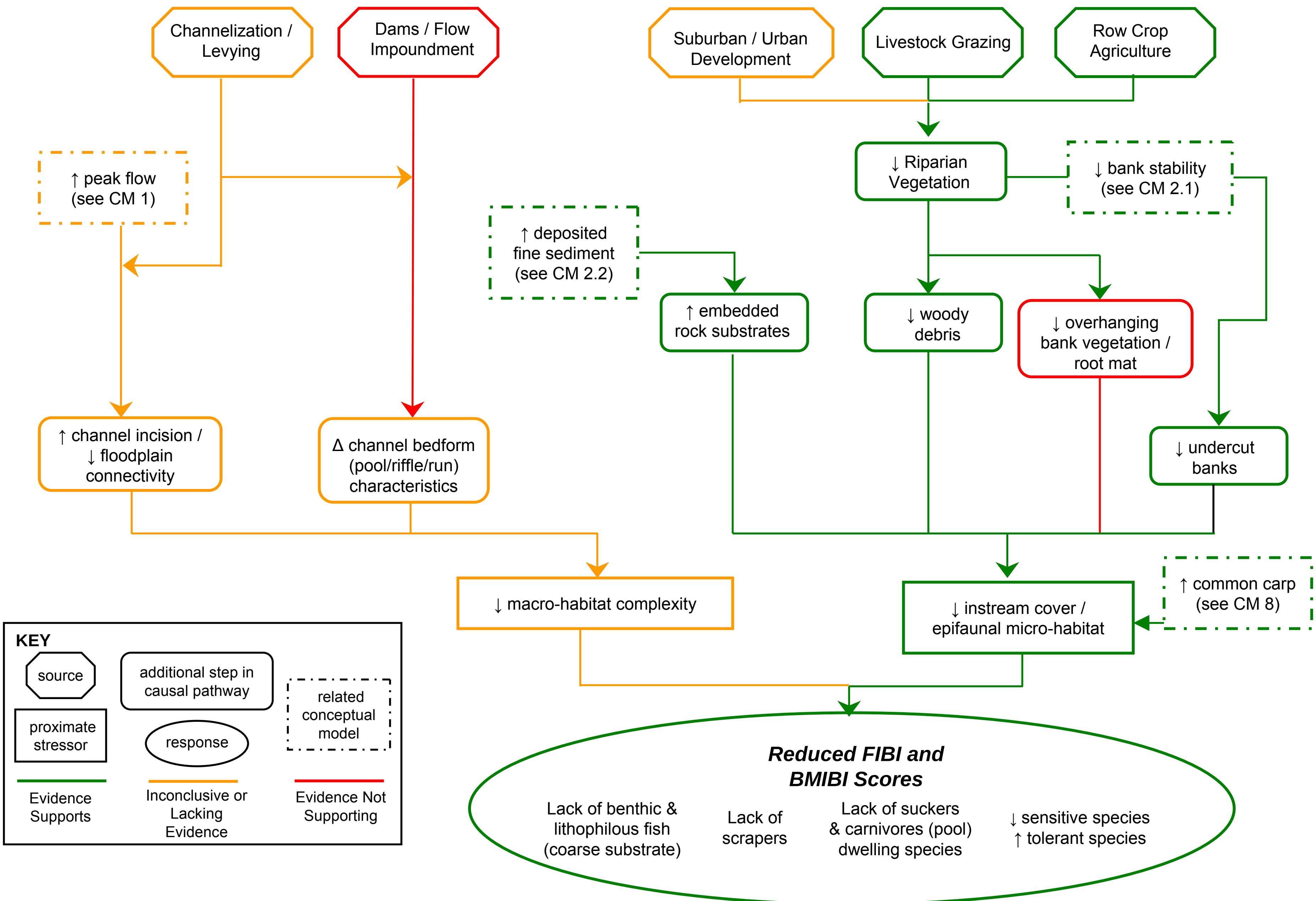
Conceptual Model 5 - Elevated temperature



Conceptual Model 6 - Elevated ammonia



Conceptual Model 7 - Physical Habitat Alteration



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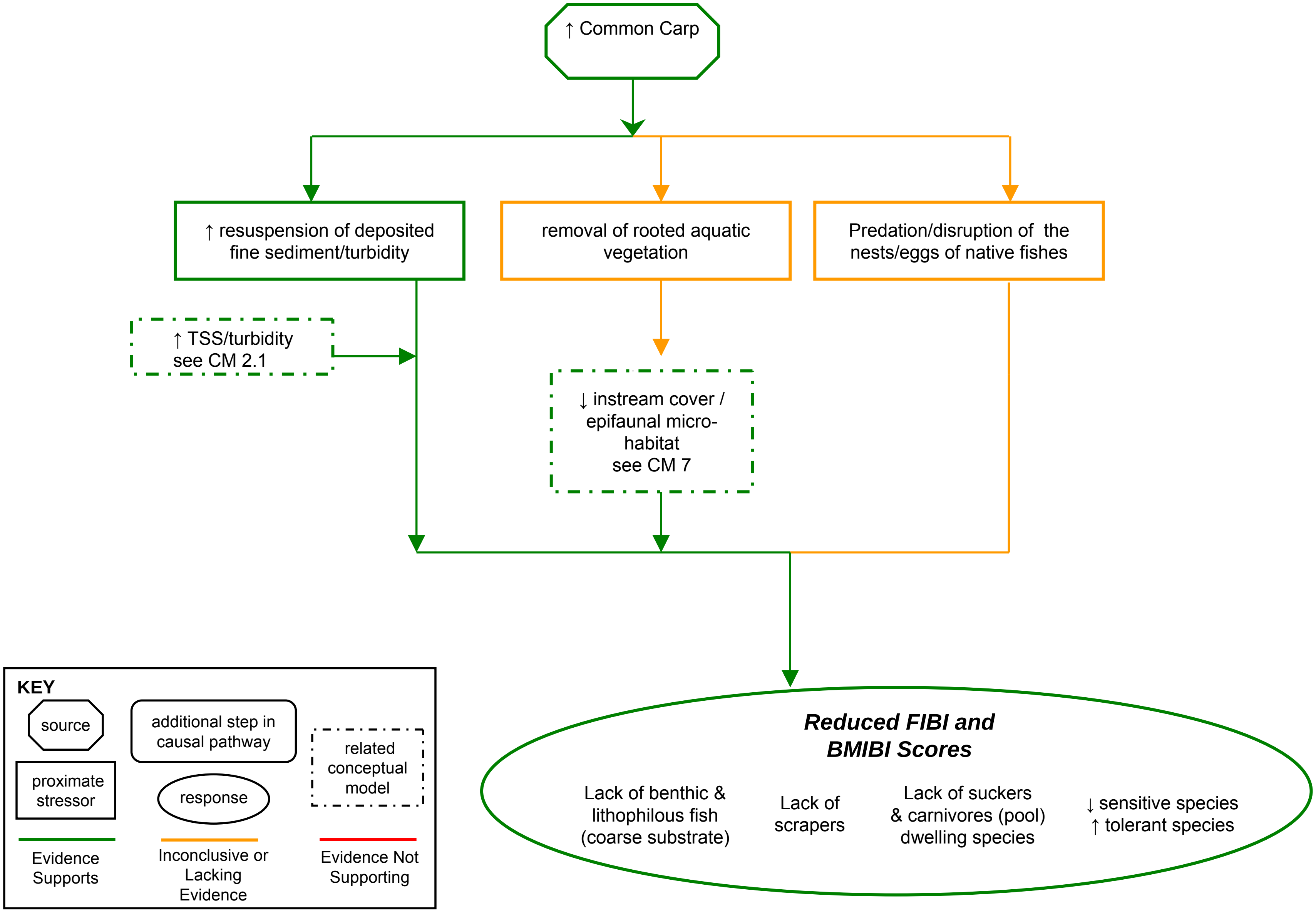
Conceptual Model 8 - Common Carp



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Conceptual Model 9 - Aquatic Life Depletion and Isolation