CREX MEADOWS WILDLIFE AREA WATER QUALITY ASSESSMENT

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CREX MEADOWS WILDLIFE AREA WATER QUALITY ASSESSMENT

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Cover photo: Hay Creek downstream of Benson Road

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CREX MEADOWS WILDLIFE AREA WATER QUALITY ASSESSMENT

EXECUTIVE SUMMARY

Crex Meadows Wildlife Area (CMWA) encompasses more than 30,000 acres of brush prairie, wetland, and forest in Burnett County, Wisconsin, northeast of Grantsburg (figure 1, p.3). Since 1945, the Wisconsin DNR has constructed more than 18 miles of dikes to form about 5,000 acres of deep-water marshes and more than 15,000 acres of additional wetland wildlife habitat.

Streams downstream of CMWA have high iron concentrations and are frequently turbid due to an abundance of suspended rust-colored iron floc (iron hydroxide precipitate) (figure 2-4, p. 4-5). This has generated inquiries and complaints from the public.

A monitoring project was conducted at CMWA in 2014 to assess the distribution and transport of iron. The project included monitoring of soils, streams, flowages, springs, and sediment. Existing data on groundwater was reviewed. Biological communities in streams were also assessed. Fish communities were surveyed at 28 sites and macroinvertebrate communities were sampled at 14 sites.

Multiple lines of evidence indicate that flowage (impoundment) creation has resulted in increased release of soil iron to downstream waters:

- Groundwater iron concentrations in monitoring wells downgradient of flowages averaged 18 times higher than in upgradient wells.

- Iron concentrations in streams draining flowage areas averaged 14 times higher than in nearby streams not influenced by flowage drainage.

- 2008 and 2010 air photos show iron floc turbidity in flowages and ditches that have upgradient flowages. Flowages without another upgradient flowage do not show iron floc turbidity.

- High iron concentrations in a drainage ditch 1.4 miles downgradient from the Sandberg Flowage disappeared after a complete drawdown of the flowage, and re-appeared after the flowage was re-filled.

- Observed conditions were consistent with known patterns of iron behavior:

    - Iron in drained oxic (oxygen present) soils is stable with minimal transport of iron to groundwater.

    - When previously oxic soils are inundated with water they become anoxic (oxygen absent). Iron reducing bacteria can then reduce soil iron, making it soluble and transportable by groundwater.

- When iron rich groundwater discharges to surface water, iron is oxidized and rust-colored iron floc turbidity is produced.

Iron floc turbidity causes aesthetic impairment in streams downstream of CMWA. The three streams most directly affected by iron releases (Hay, Whiskey, and "North Fork" Creeks) have average summer iron concentrations of 12-25 mg/l, while local background streams have iron concentrations less than 1 mg/l. Average summer water transparencies in these three streams were 19-35 cm (0.6-1.2 feet).

These three streams are estimated to discharge 320,000 kg of iron per year to the Wood River. The iron content of CMWA soils can probably maintain this level of iron discharge for at least many decades.

Some impacts of iron floc turbidity to the biological communities in streams were found. The lower 1.5 miles of Hay Creek is listed as a class II trout water. A reproducing brook trout population was present in 1964. Additional flowages and drainage ditches were constructed in the Hay Creek watershed since that time. Trout are no longer present, probably due to increased iron turbidity.

Fish indices of biotic integrity (IBI), number of species, and fish densities in the streams with highest iron concentrations are comparable to those in unaffected streams nearby. Hay Creek, which had the highest stream iron concentrations, had "small stream" fish IBI's of good to excellent.

Fish IBI's were developed largely to reflect the degree of human disturbance of a stream and its watershed. At CMWA typical human disturbances such as intense land use development are of minor significance, so the value of applying IBI's is uncertain.

To further assess fish populations non-metric multidimensional scaling was applied to assess how fish assemblages reflect environmental gradients. The fish species occurring in greatest abundance in streams with high iron turbidity are pearl dace, finescale dace, fathead minnow, and brook stickleback. It appears these species are well adapted to stream conditions resulting from high iron concentrations.

Macroinvertebrate communities in streams with high iron concentrations show indications of poorer quality than those in low iron concentration streams. High iron streams have fewer mayflies, stoneflies, and caddisflies (% EPT individuals), more fly larvae (% Dipteran individuals), and more chironomids (a sub-group of fly larvae) (% Chironomid individuals).

Mussel surveys previously done in the Wood River showed excellent mussel populations were present downstream of Grantsburg (below the Memory Lake dam), where noticeable iron floc turbidity is present.

Conclusions:

- CMWA flowage construction has resulted in aesthetic and biological impacts to downstream waters resulting from soil iron release and transport.

- No feasible methods of controlling iron release and transport could be identified (other than flowage dewatering).

- CMWA flowages have high value for waterfowl, wetland species, and recreation. The environmental trade-offs need to be considered.

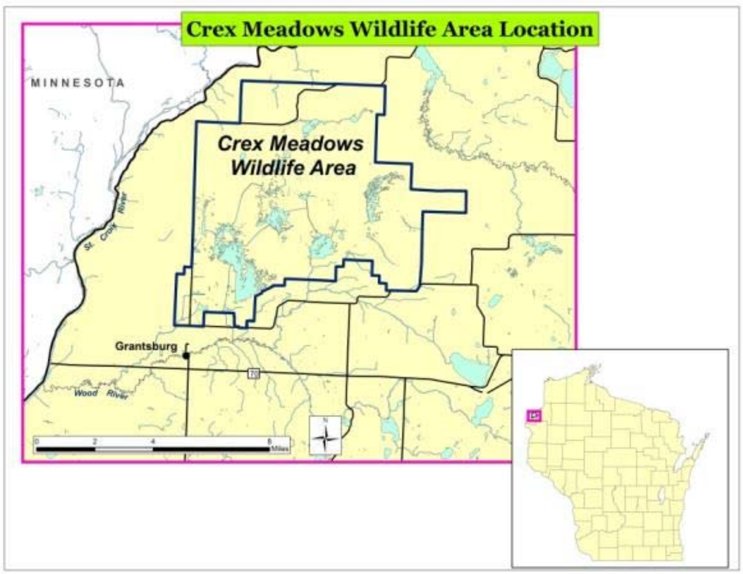
- Similar iron release and transport is likely to occur elsewhere where inundation of formerly oxic, iron-bearing soils has occurred.

- Consideration should be given to potential iron release and transport, and impacts to downstream surface waters and groundwater where ever new flowages are constructed.

INTRODUCTION

Crex Meadows Wildlife Area (CMWA) encompasses more than 30,000 acres of brush prairie, wetland, and forest in Burnett County, Wisconsin, northeast of Grantsburg (figure 1). Since 1945, the Wisconsin DNR has constructed more than 18 miles of dikes to form about 5,000 acres of deep-water marshes and more than 15,000 acres of additional wetland wildlife habitat . During fall migration CMWA hosts thousands of sandhill cranes, geese, and ducks. It has a number of endangered and threatened species present. It receives more than 100,000 visitors each year.

Figure 1



Drainage from much of the area flows to the south via several tributaries to the North Fork Wood River and the Wood River. The Wood River drains to the St. Croix River which is a National Wild and Scenic River.

The DNR and the Burnett County Land and Water Conservation Dept. periodically receive inquiries or complaints about the water quality in the Wood River and its tributaries downstream of Crex Meadows. Frequently turbid water due to an abundance of suspended iron floc (iron hydroxide precipitate) is the reason for the concerns (figures 2-4).

A monitoring project was conducted at CMWA in 2014 to assess the distribution and transport of iron. Biological communities in streams were also assessed to determine what impacts iron floc turbidity may be causing. The project extended beyond the boundaries of CMWA to assess conditions in upgradient and downgradient streams to the south and north of CMWA.

Figure 2. Hay Creek Upstream of CTH F

Figure 3. Whiskey Creek Downstream of CTH D

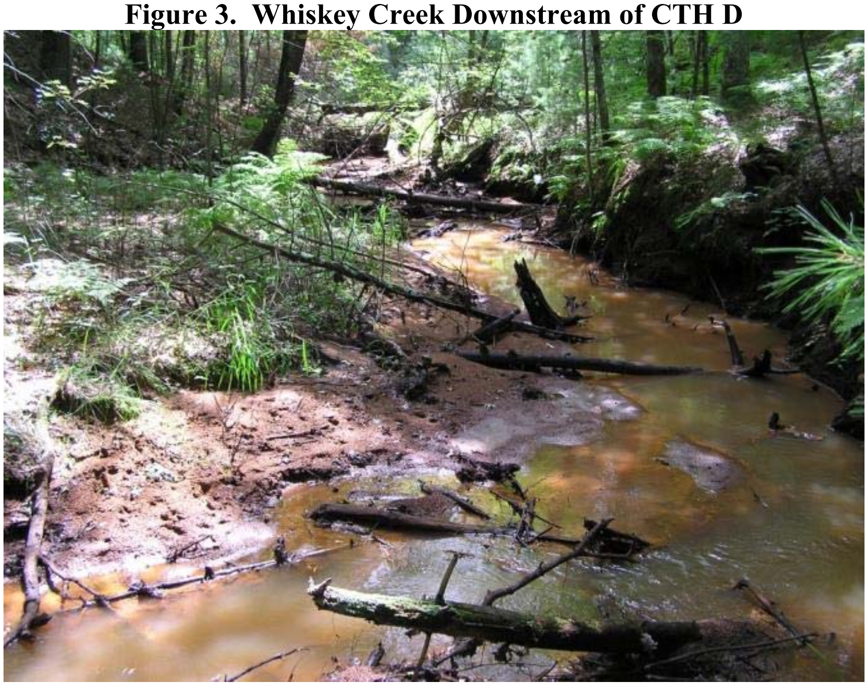


Figure 4. South Refuge Flowage Dike Drainage Joining Surface Outflow

METHODS

Monitoring was done for soils, stream and flowage (impoundment) water quality, streamflow, stream fish and macroinvertebrate communities, and flowage sediment.

Soil Sampling

Thirty soil samples were collected from 22 sites (figure 5). A four-inch diameter stainless steel bucket auger with a 5 feet handle was used. Bulk density samples were collected by tapping a four-inch length of a thin-walled stainless steel tube into the side of a shovel-excavated hole. After the tube was fully embedded in the soil, it was gradually excavated with a shovel while the soil at the two ends was trimmed smooth with a flat metal blade.

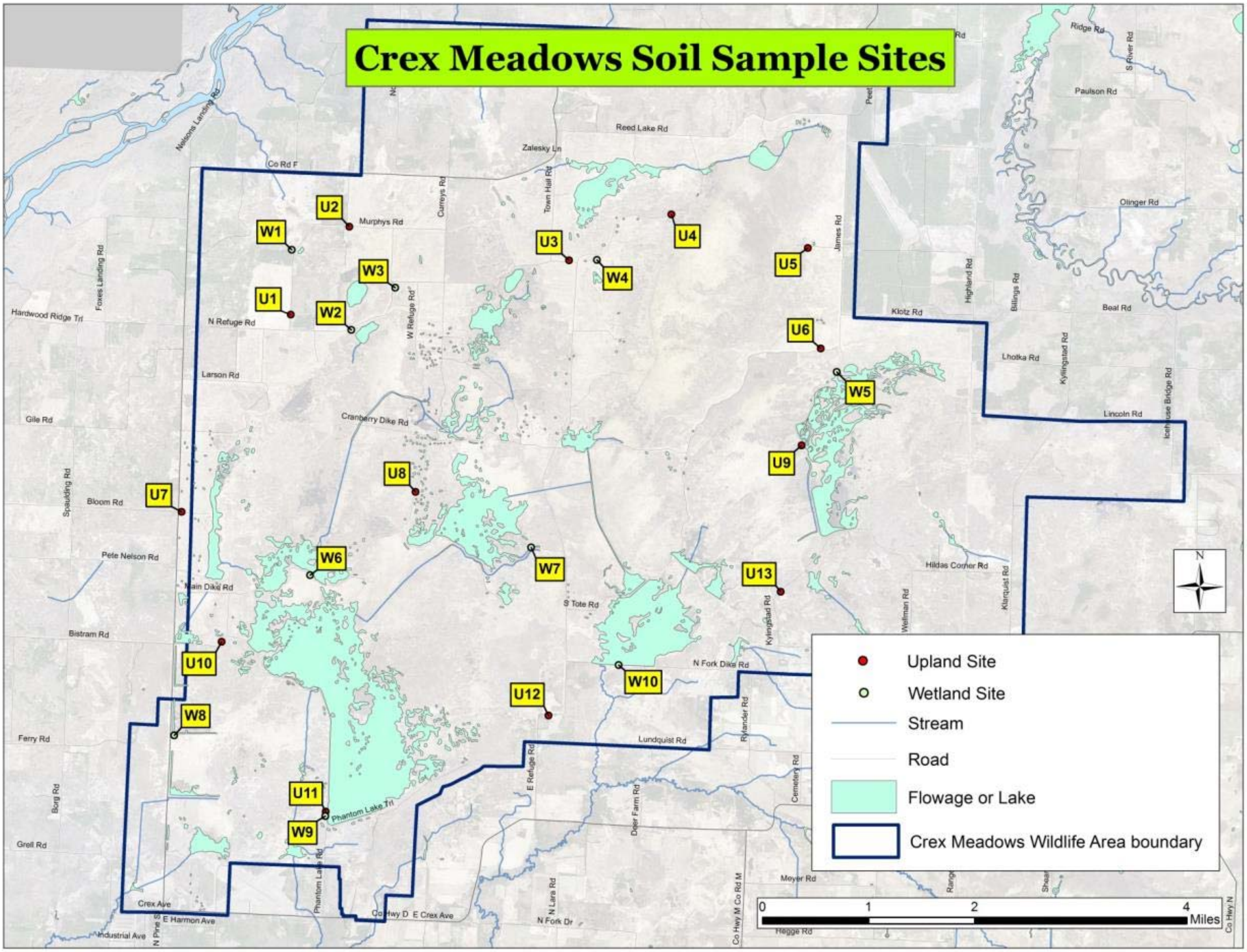
Observations of soil characteristics and changes with depth were recorded. A five feet profile was examined at most sites. Water table depth was recorded when encountered.

Most soil samples were collected from a depth of 24–30 inches, and most bulk density samples were collected at a depth of 18 inches. Multiple samples were collected at some sites to assess profile variability.

Soil samples were shipped to the UW Soil and Plant Analysis Lab for analyses. Lab parameters tested were:

- Total iron (and total phosphorus, potassium, calcium, magnesium, sulfur, zinc, boron, manganese, copper, aluminum, and sodium)
- Total organic carbon
- % Sand, silt, clay
- Bulk density

Figure 5


Crex Meadows Soil Sample Sites
Upland Site
Wetland Site
Stream
Road
Flowage or Lake
Crex Meadows Wildlife Area boundary
0 1 2 4 Miles
U1
U2
U3
U4
U5
U6
U7
U8
U9
U10
U11
U12
U13
W1
W2
W3
W4
W5
W6
W7
W8
W9
W10

Stream, Flowage Outlet, Spring, and Ditch Water Quality Monitoring

Twenty-four sites with flowing surface water were monitored (figure 6). Three primary stream monitoring sites (Hay, Whiskey, and "North Fork" Creeks) were the most intensely monitored, since they conduct most of the surface drainage flowing southward out of CMWA. Six secondary sites that included both streams and flowage outlets were monitored on 29-32 dates. An additional 15 sites that included 9 streams, 4 springs, and 2 ditches were infrequently monitored.

Water samples were collected and field parameters were measured following standard DNR protocols. Water samples were preserved, as needed, and shipped on ice to the Wisconsin State Lab of Hygiene for analysis. Field parameters measured were:

- Temperature
- pH
- Dissolved oxygen
- Conductivity
- Transparency (using a transparency tube)
- Continuous temperature (at 3 primary stream sites)

Lab parameters were:

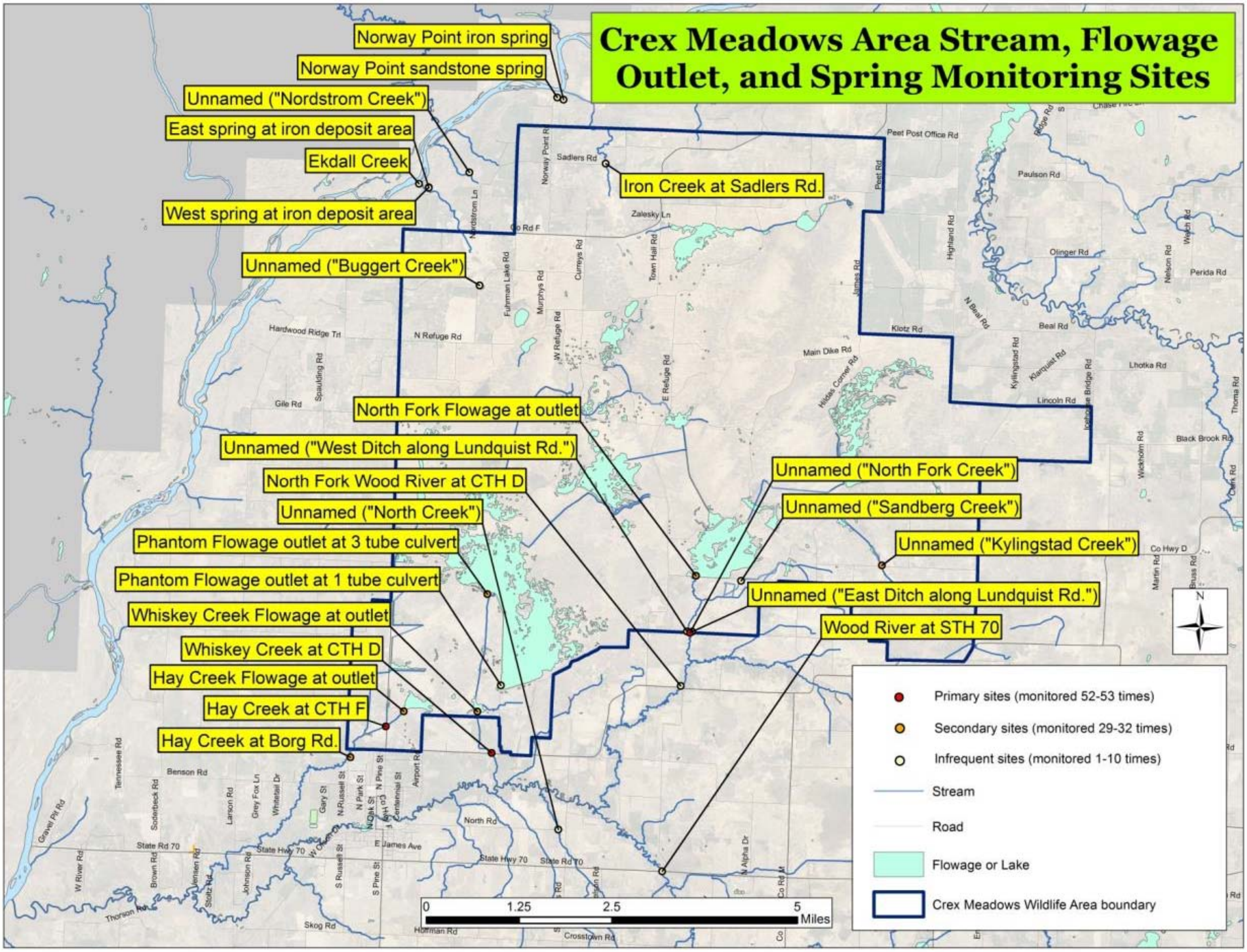
- Iron
- Total phosphorus
- Total suspended solids
- Turbidity
- True color

Streamflow Monitoring

Flow measurements were made on ten dates at the three primary stream monitoring sites (Hay, Whiskey, and "North Fork" Creeks). Measurements were made with a Swoffer current meter following standard DNR protocols. Staff gages were used to measure stream stages. Staff gage readings were made once or twice a week or more during April through October.

Stage-discharge curves were developed and used to estimate flows on all dates with stage readings.

Figure 6



Flowage (Impoundment) Water Quality Monitoring

Flowage water samples were collected and field parameters were measured at eight sites (figure 7) on two dates (Sept. 18th, 2014 and March 2nd, 2015). Water samples were collected and field parameters were measured following standard DNR protocols. Water samples were preserved, as needed, and shipped on ice to the Wisconsin State Lab of Hygiene for analysis. Field parameters measured were:

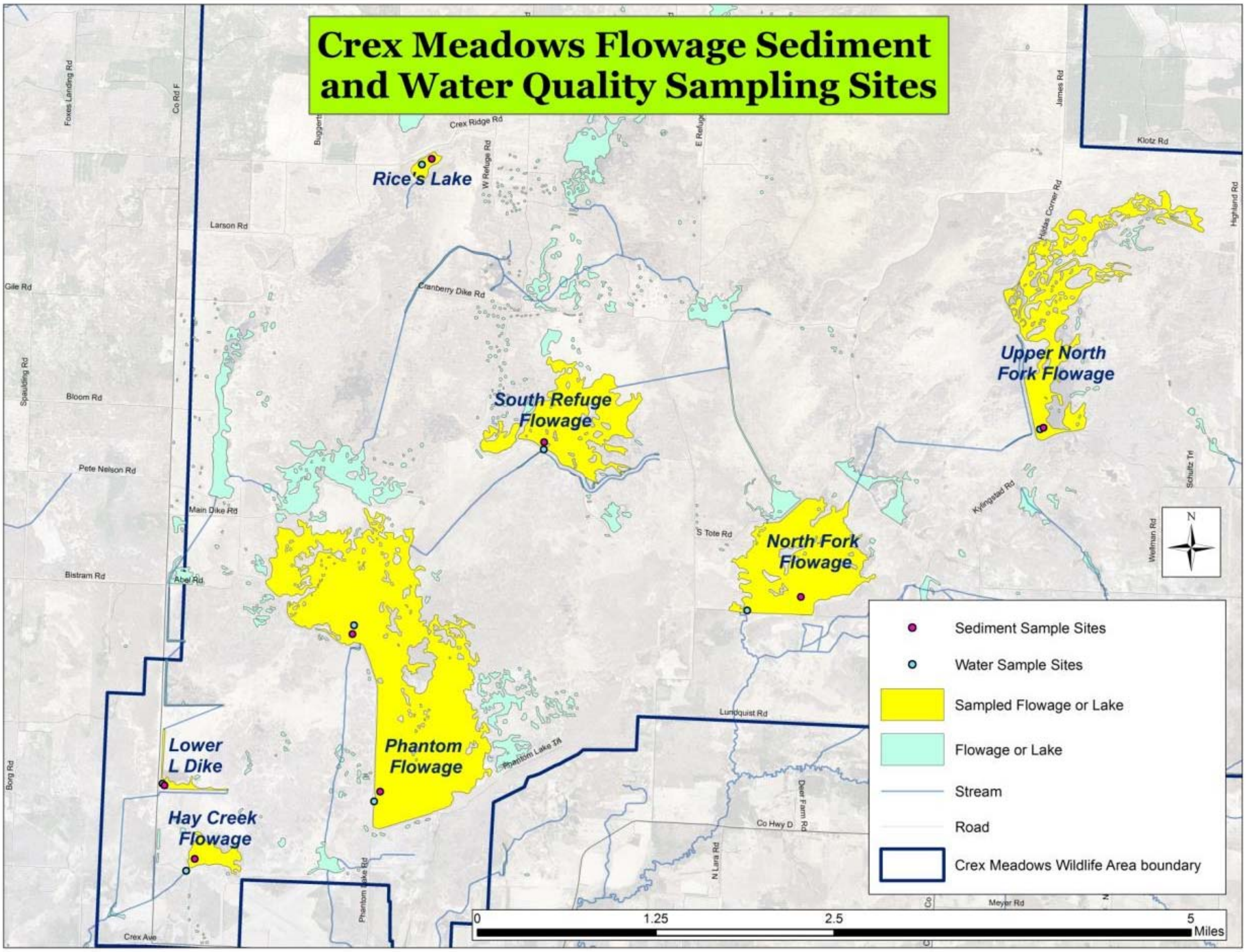
- Temperature
- pH
- Dissolved oxygen

- Conductivity
- Transparency (using a Secchi disk)

Lab parameters were:

- Iron
- Total phosphorus

Figure 7



Additionally, field parameters were measured once or twice a week during June through September at four flowage outlets (Lower Hay Creek, Whiskey Creek, Phantom, and North Fork Flowages). Field parameters measured were:

- Temperature
- Conductivity
- Transparency (using a transparency tube)

Flowage Sediment Sampling

Sediment samples were collected from eight flowage and lake sites (figure 7). Samples were collected with a stainless steel Ekman bottom grab. The top 6 inches of sediment was sampled. Soft sediment depth was measured with a fiberglass rod.

Sediment samples were shipped on ice to the Wisconsin State Lab of Hygiene for analysis. Lab parameters tested were:

- Iron
- Total phosphorus
- % Solids
- % Volatile solids
- % Sand, silt, clay
- Bulk density

Fish Community Assessment

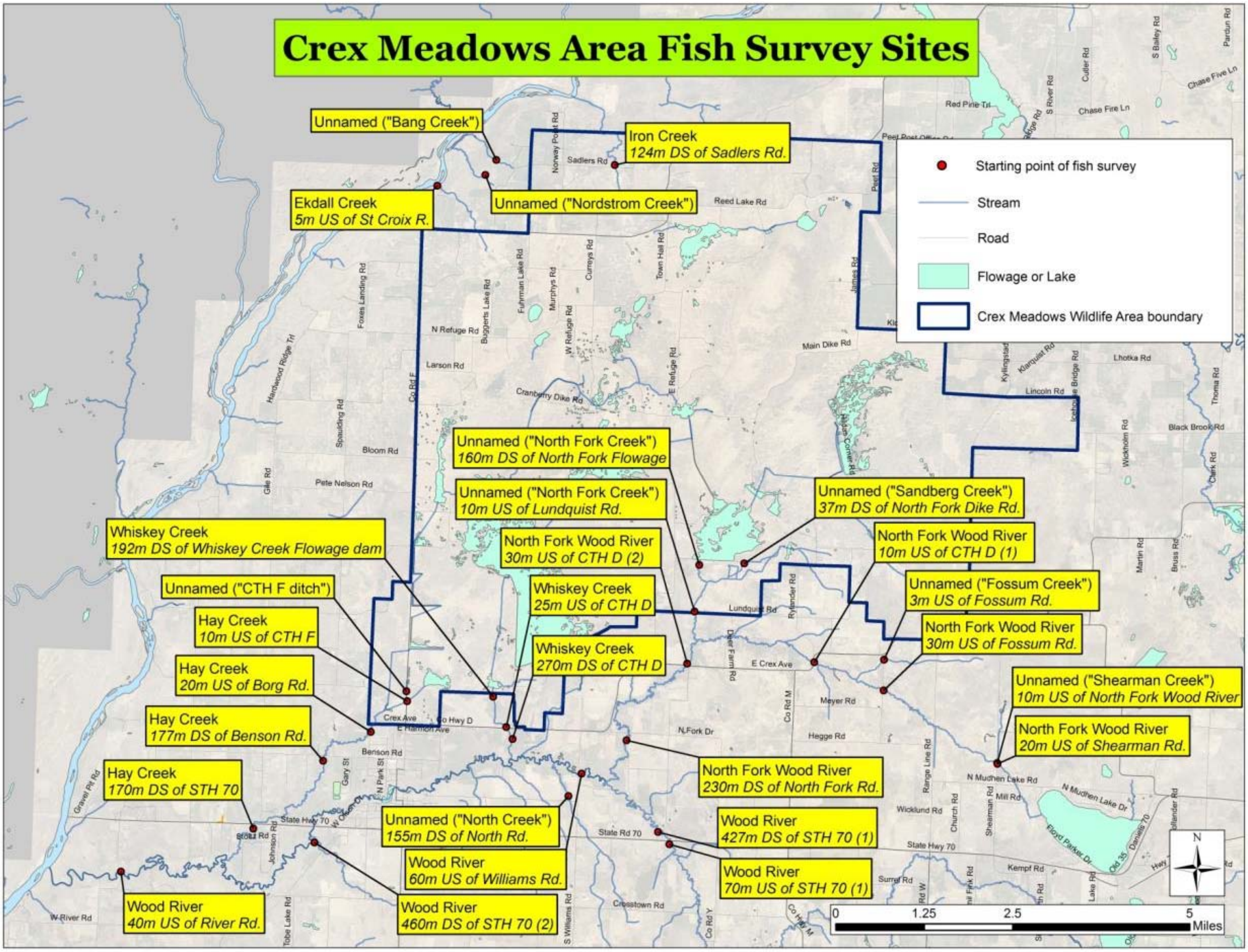
Fish communities were surveyed at 28 stream sites (figure 8). Fish communities were assessed by electrofishing with one or two single anode backpack shockers on small to medium-sized stream sites, and a double or triple anode tow barge stream shocker on larger stream sites. As many fish as possible were captured with a single upstream pass. Station lengths were 35 times the mean stream width, with a minimum length of 100 meters and a maximum length of 400 meters. Fish captured were counted and identified to species. Fish community data was used to determine the natural community of the stream, and to calculate biotic indices.

Macroinvertebrate Community Assessment

Macroinvertebrate samples were collected from 14 stream sites (figure 9). Macroinvertebrate communities were assessed by collecting kick samples in October using a 500 um mesh rectangular frame net. Most stream sites had sandy substrates and gravel/cobble riffle habitat was not present. To maximize consistency between sites, whenever possible, samples were collected from woody debris which was draped with leaf snags or other vegetative fragments.

Samples were preserved in 85% ethanol and were processed by UW – Stevens Point's Aquatic Biomonitoring Lab. Macroinvertebrates were counted and identified to the lowest possible taxa. Biotic indices and other statistics were generated.

Figure 8


Crex Meadows Area Fish Survey Sites
Starting point of fish survey
Stream
Road
Flowage or Lake
Crex Meadows Wildlife Area boundary
Unnamed ("Bang Creek")
Iron Creek
124m DS of Sadlers Rd.
Ekdall Creek
5m US of St Croix R.
Unnamed ("Nordstrom Creek")
Unnamed ("North Fork Creek")
160m DS of North Fork Flowage
Unnamed ("North Fork Creek")
10m US of Lundquist Rd.
Unnamed ("Sandberg Creek")
37m DS of North Fork Dike Rd.
Whiskey Creek
192m DS of Whiskey Creek Flowage dam
North Fork Wood River
30m US of CTH D (2)
North Fork Wood River
10m US of CTH D (1)
Unnamed ("CTH F ditch")
Whiskey Creek
25m US of CTH D
Unnamed ("Fossum Creek")
3m US of Fossum Rd.
Hay Creek
10m US of CTH F
North Fork Wood River
30m US of Fossum Rd.
Hay Creek
20m US of Borg Rd.
Whiskey Creek
270m DS of CTH D
Unnamed ("Shearman Creek")
10m US of North Fork Wood River
Hay Creek
177m DS of Benson Rd.
North Fork Wood River
20m US of Shearman Rd.
North Fork Wood River
230m DS of North Fork Rd.
Hay Creek
170m DS of STH 70
Unnamed ("North Creek")
155m DS of North Rd.
Wood River
427m DS of STH 70 (1)
Wood River
60m US of Williams Rd.
Wood River
70m US of STH 70 (1)
Wood River
40m US of River Rd.
Wood River
460m DS of STH 70 (2)
0
1.25
2.5
5
Miles
N

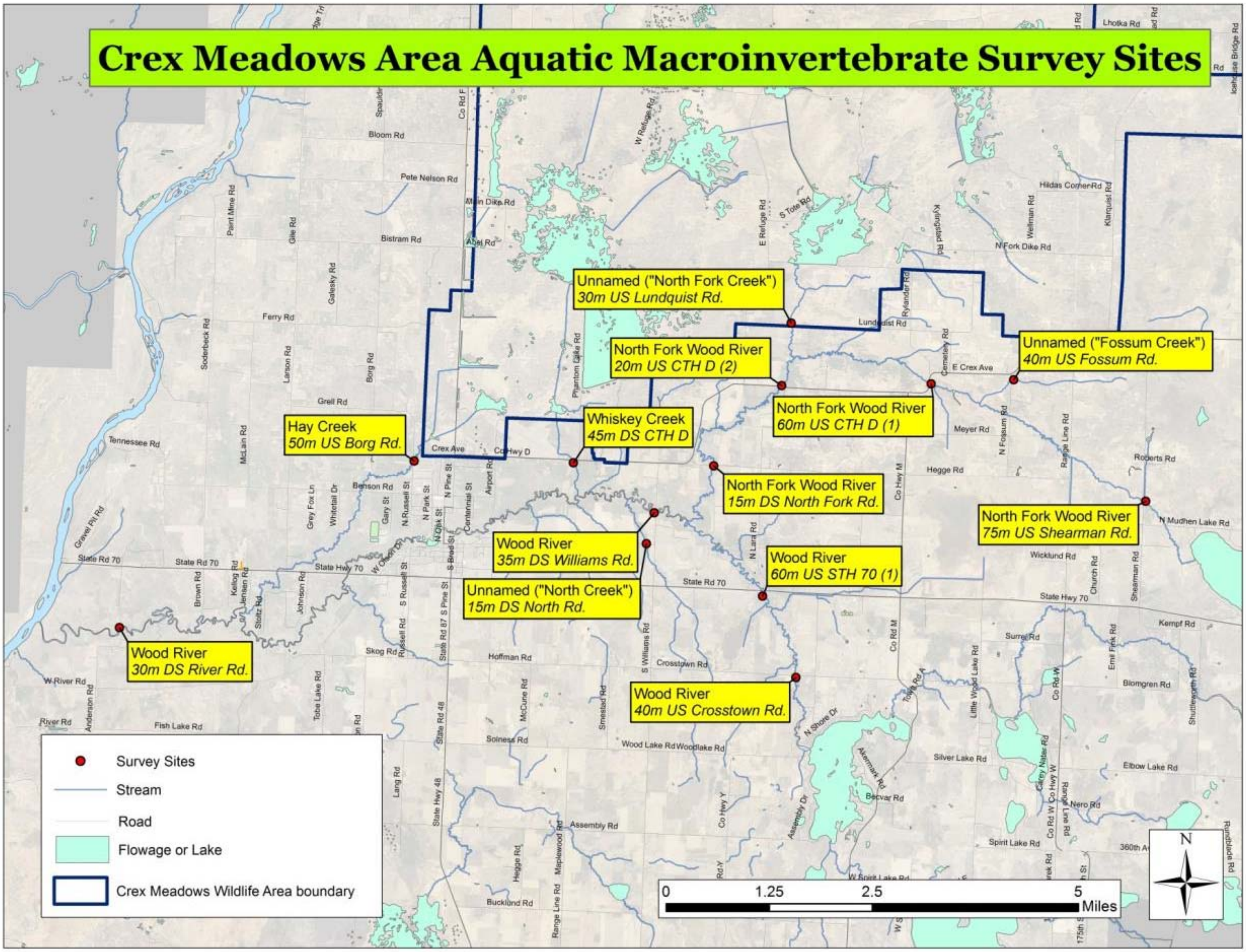


Figure 9.

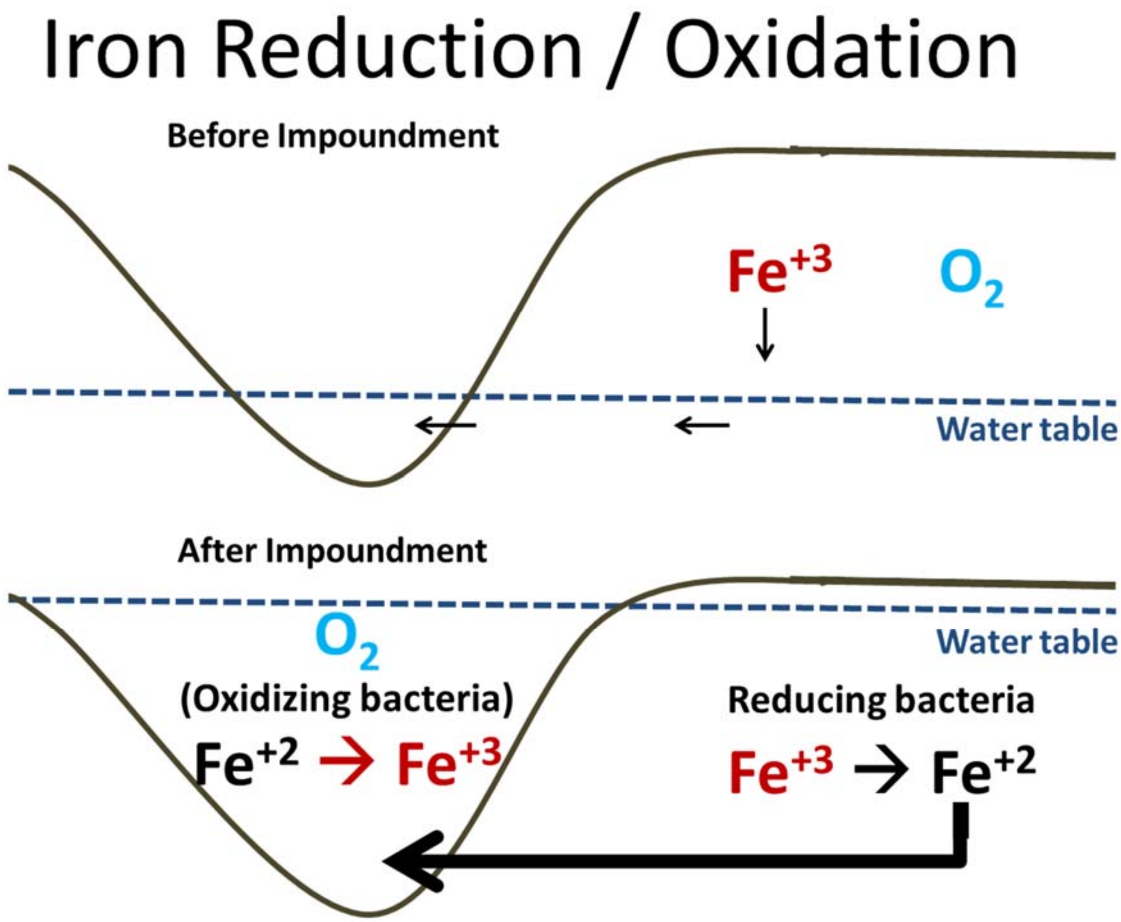
FINDINGS AND DISCUSSION

Iron Chemistry/Mobility

Iron commonly occurs in two forms in the environment – ferric iron (oxidized, Fe^{+3}) and ferrous iron (reduced, Fe^{+2}). The occurrence of the two iron forms is largely dependent on the presence or absence of oxygen (oxic or anoxic) (Wetzel 2001).

In oxic, sandy soils, iron is mostly present as iron oxide (ferric iron; Fe^{+3}) coatings on sand grains (Fletcher and Veneman 2014). Very little iron is leached to groundwater, and surface waters receiving groundwater inflow have low iron concentrations (figure 10).

Figure 10.



When soils are inundated with water, anoxic conditions usually develop quickly, especially when the inundating water contains dissolved organic matter. Continued decomposition of this dissolved organic matter by bacteria in the soil and aquifer consumes available oxygen and produces anoxic conditions.

Anoxic conditions in soil allow iron-reducing bacteria to convert the iron oxide in soils to reduced ferrous iron which is water soluble (figure 10). In addition to anoxic conditions, iron-reducing bacteria also require organic matter and a temperature above 41°F to reduce ferric iron (Fletcher and Veneman 2012). Iron reduction requires iron-reducing bacteria, and bacterial activity is temperature dependent. The rate of iron reduction will increase with increasing temperature, and ceases when soil temperatures fall below 41°F.

Since reduced ferrous iron is water soluble, it can be transported with groundwater movement. Reduced ferrous iron will be converted back to oxidized ferric iron when oxygen is encountered. This can happen in the groundwater aquifer if the anoxic, iron-rich plume of groundwater mixes with oxic groundwater. It also happens when anoxic, iron-rich groundwater discharges to surface waters where oxygen is present (figure 10).

Unlike iron reduction, iron oxidation is not dependent on bacteria (Wetzel 2001). However, iron-oxidizing bacteria are frequently associated with iron oxidation and can enhance the process. A variety of bacterial genera are iron oxidizers including *Leptothrix, Gallionella*, *Siderocapsa*, *Siderocystis*, and *Toxothrix* (Robbins et al. 1997).

Ferrous iron in groundwater discharging to surface water is oxidized to iron hydroxides (iron oxyhydroxides). Iron hydroxide colloids aggregate to form larger particles (Gunnars et al. 2002). These floc-like particles cause turbidity and reduced water clarity. Iron bacteria and their associated iron hydroxide films can also contribute particulates and reduced water clarity to surface waters.

Iron hydroxide particulates will eventually settle to the bottom in standing water, such as in flowages. This will enrich the sediment with iron. If anoxic conditions develop in the water overlying the sediment surface, and temperatures are adequate, iron-reducing bacteria can convert this iron back into a reduced form.

Iron oxidation in surface water is also influenced by dissolved organic matter (DOM). Iron hydroxide colloids can be stabilized by the presence of DOM (Gunnars et al. 2002). This slows the rate of colloid aggregation and the rate of iron settling.

Water Color

Color is another notable characteristic of surface water at CMWA. Water in wetlands often contains substantial amounts of dissolved organic matter (DOM) in the form of humic and fulvic acids. These are produced by the decomposition of the abundant plant tissue in wetlands in close contact with water. Plant decomposition products in upland areas are well captured by soils and usually don't influence surface water.

This DOM produces a stained or tea-like appearance to the water. Measurement of water color (true color in platinum-cobalt units) provides an index of the relative amount of DOM present in water. Water color measurements > 100 Pt-Co units in Wisconsin lakes are considered to be high values (Lillie and Mason 1983). Continued decomposition of DOM by bacteria in flowages and streams creates an oxygen demand that contributes to lower dissolved oxygen concentrations.

2014 Precipitation

Precipitation was well above normal at the CMWA in 2014 (table 1). An initial spring snowmelt was underway when stream monitoring began on April 10th. A heavy snowfall (18 inches) occurred on April 16-17th, which resulted in a second period of snowmelt.

Precipitation during the three month period of April through June was 10 inches (94%) above normal. Total June precipitation was 8.63 inches. Robert Hanson, DNR Wildlife Biologist who managed water levels at CMWA, commented that this was the longest period of above average precipitation that he had seen or heard of at CMWA. Monthly precipitation was below normal in

July and October, but above normal precipitation occurred again in August, September and November. Total precipitation for 2014 was 41.87 inches (28 %) above normal.

Table 1

GRANTSBURG PRECIPITATION RECORD FOR 2014												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
This Month's Pptn.	1.04	1.15	1.01	5.87	6.09	8.63	2.40	5.54	4.84	1.85	2.54	0.91
Monthly Normal	0.91	0.85	1.58	2.73	3.61	4.25	4.13	4.52	3.88	2.98	1.91	1.31
Yr to Date Total	1.04	2.19	3.20	9.07	15.16	23.79	26.19	31.73	36.57	38.42	40.96	41.87
YTD Normal	0.91	1.77	3.35	6.08	9.69	13.95	18.07	22.59	26.47	29.45	31.36	32.67
+/- for the Month	0.13	0.30	-0.57	3.14	2.48	4.38	-1.73	1.02	0.96	-1.13	0.63	-0.40
+/- for the Year	0.13	0.42	-0.15	2.99	5.47	9.84	8.12	9.14	10.10	8.97	9.60	9.20

Geology/Groundwater Information

Geology

Bedrock beneath CMWA is sandstone found at depths of 60 to 100 feet. A 20 to 25 feet layer of varved lake clay overlies the sandstone. The clay was deposited in what was Glacial Lake Grantsburg. A 40 to 75 feet layer of sandy outwash deposits overlies the clay (Patterson 1990). Sandy soils are present in upland areas. Organic soils have formed in wetland areas.

The clay layer is important because its low permeability restricts further downward movement of groundwater in the overlying sand aquifer. Groundwater will tend to flow laterally in the sand above the clay toward discharge areas.

Three USGS wells at CMWA (Patterson 1990) showed the top of the clay layer at elevations ranging from 869 feet - 893 feet (above sea level), with 37 - 67 feet of overlying sand. North of CMWA, the top of the clay layer is exposed at multiple locations on the slope near the St. Croix River. Iron springs (with iron oxidation and deposition) are also present in these locations. Clay layer elevations are about 890-910 feet.

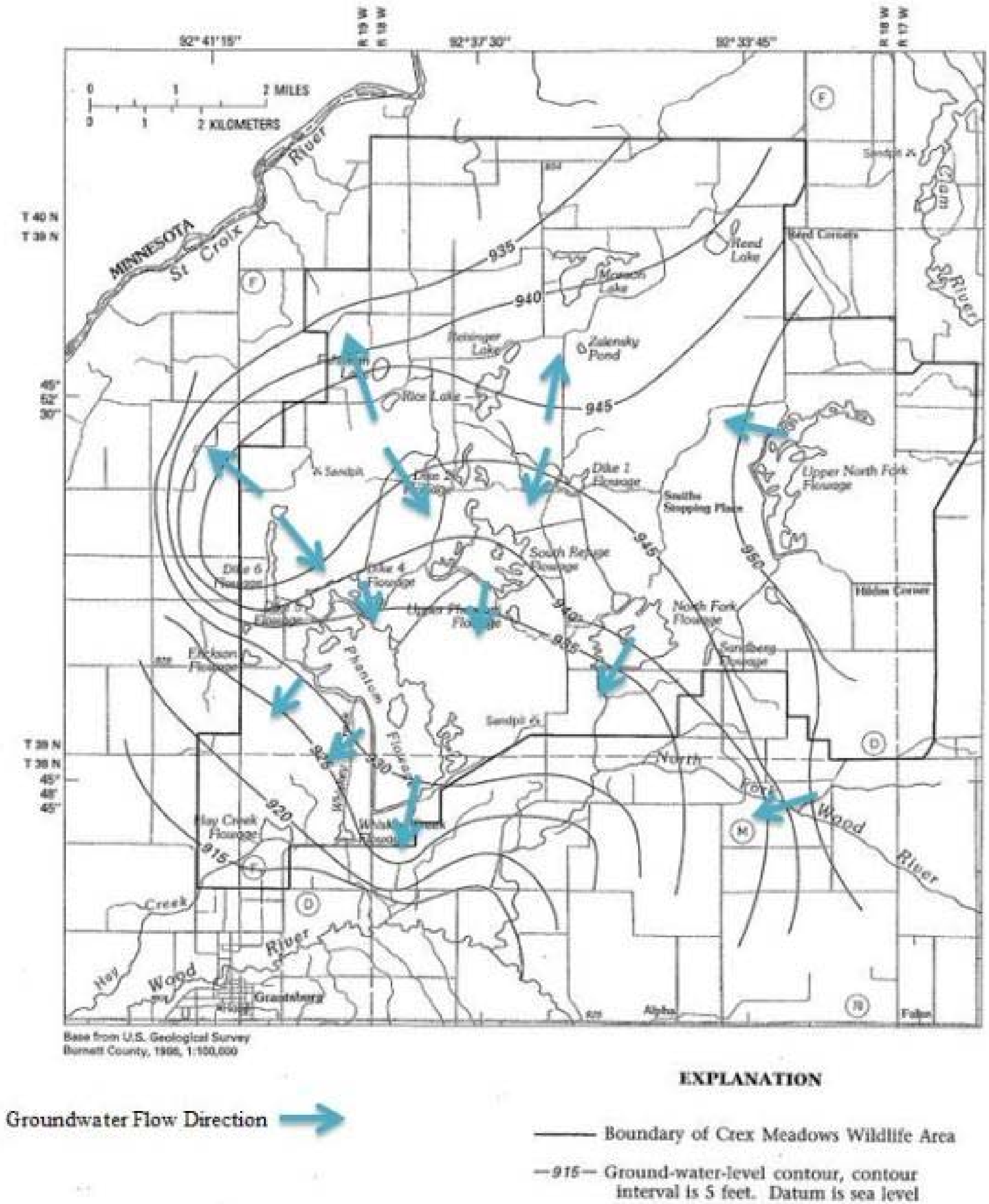
A review of well drillers' construction reports showed that, south of CMWA, the clay layer extends beneath and south of the North Fork Wood River and the upper Wood River. Further downstream, the clay layer is exposed on the banks of the Wood River. Upstream of STH 70 below Grantsburg, clay layer exposures (figure 11) on both banks are at an elevation of about 875 ft. Upstream of River Road clay layer exposures on both banks are at an elevation of about 835 ft. Springs at the two areas of clay exposure on the Wood River do not show signs of iron oxidation and deposition.

Figure 11. Clay Layer Exposure on Wood River Upstream of Lower STH 70 Crossing

Groundwater Levels and Flow Direction

Groundwater levels at CMWA were evaluated in 1985-1987 (Patterson 1990). The 1986 groundwater level map is shown in figure 12. Groundwater flow direction arrows have been added. There is a groundwater divide near the center of CMWA. Groundwater north of the divide flows to the north and northwest, while groundwater south of the divide flows to the south and southwest.

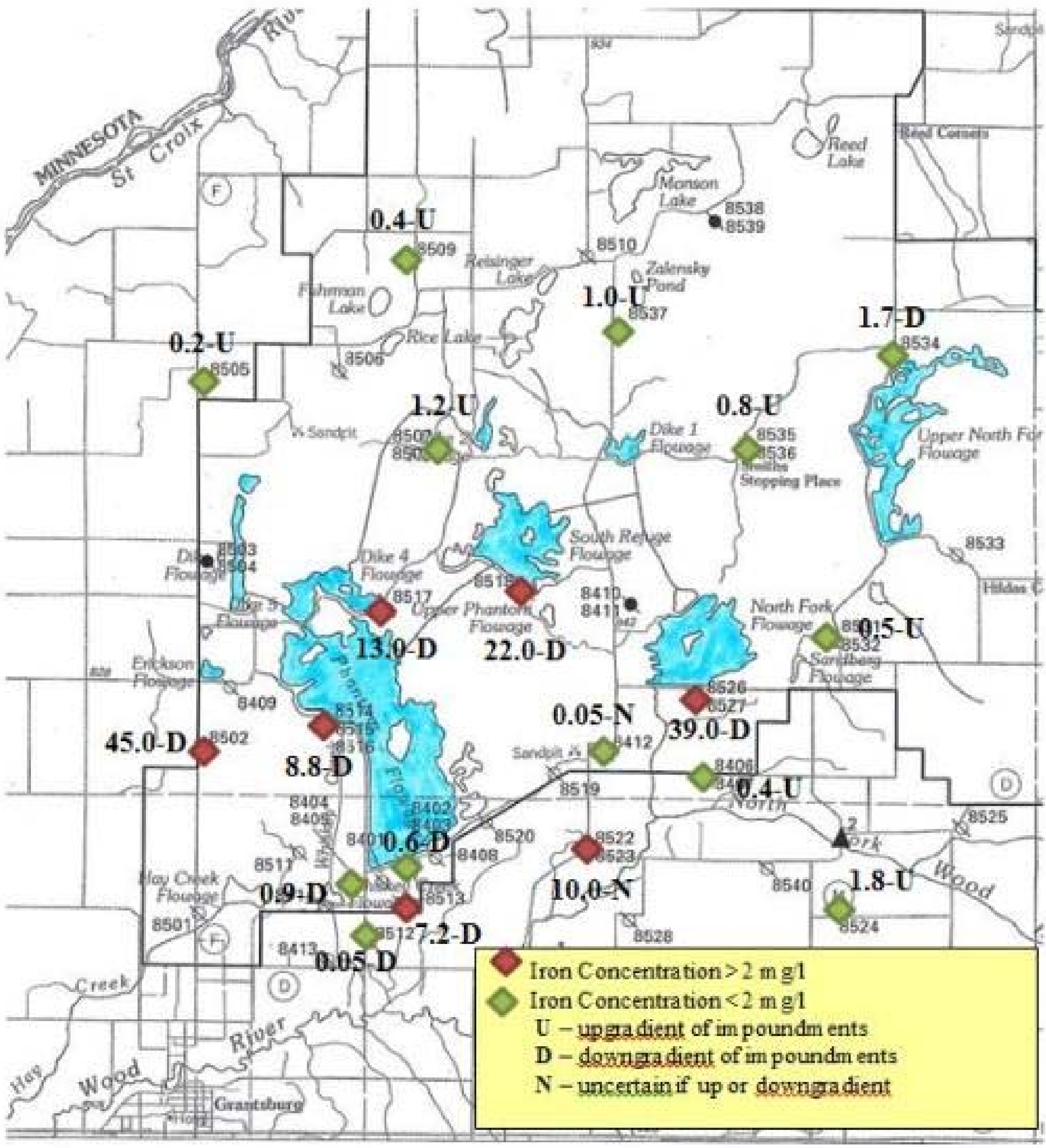
Figure 12. 1986 Water table contours and groundwater flow directions in the Crex Meadows Wildlife Area (base map and contours from Patterson, 1990).



Groundwater Iron Concentrations

Patterson (1990) also tested monitoring wells at CMWA for iron concentrations. Figure 13 shows the distribution of iron concentrations in these wells. Along with the iron concentrations,

Figure 13. Dissolved iron concentrations in monitoring wells in the Crex Meadows Wildlife Area (base map and iron concentration data from Patterson, 1990).

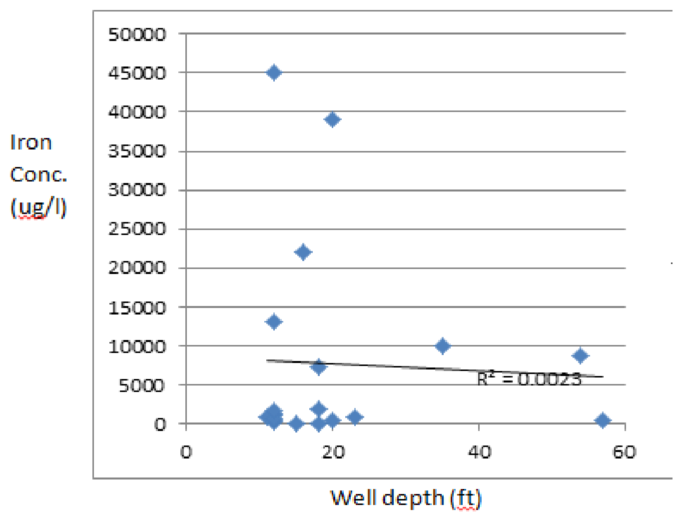


each well in the figure is identified as being upgradient of flowages (U), downgradient of flowages (D), or uncertain gradient status (N). Red-colored well locations had iron concentrations greater than 2 mg/l. Six of the seven wells with iron concentrations greater than 2 mg/l are located downstream of flowages. The seventh well has been identified as having uncertain gradient status, but may quite possibly also be downgradient of flowages. Wells downgradient of flowages have iron concentrations as high as 45 mg/l. All of the upgradient wells have iron concentrations less than 2 mg/l (green-colored well locations).

The average iron concentration of the downgradient wells is 14 mg/l, which is 18 times higher than the average iron concentration of the upgradient wells, 0.8 mg/l. The average depth of upgradient wells (20.8 ft) is very similar to that for downgradient wells (19.0 ft). There is no significant correlation between well depth and iron concentration (table 2), so differences in well depths do not account for differences in iron concentrations.

TABLE 2. CREX MEADOWS WELL DEPTH AND IRON CONCENTRATION RELATIONSHIP

DEPTH (FT)	FE CONC (UG/L)
12	220
12	360
12	990
12	1,200
23	770
57	470
20	390
18	1,800
12	45,000
54	8,800
12	13,000
16	22,000
20	39,000
18	7,200
18	46
11	940
12	638
15	45
35	10,000
12	1,700



Higher iron concentrations in wells downgradient of flowages is most likely the result of iron reduction and mobilization in the soils inundated by the flowages. The iron released from soils will be carried by groundwater to downgradient locations.

Iron concentrations in wells downgradient of flowages are variable (figure 8). This may partially reflect differing sources of groundwater at individual wells. Groundwater recharge rates from upland areas of sandy soils are high, typically around 10 inches per year. Some wells may be receiving much of their water from this localized recharge and so would have lower iron concentrations. Natural recharge from upland areas of oxic sandy soils does not mobilize much soil iron.

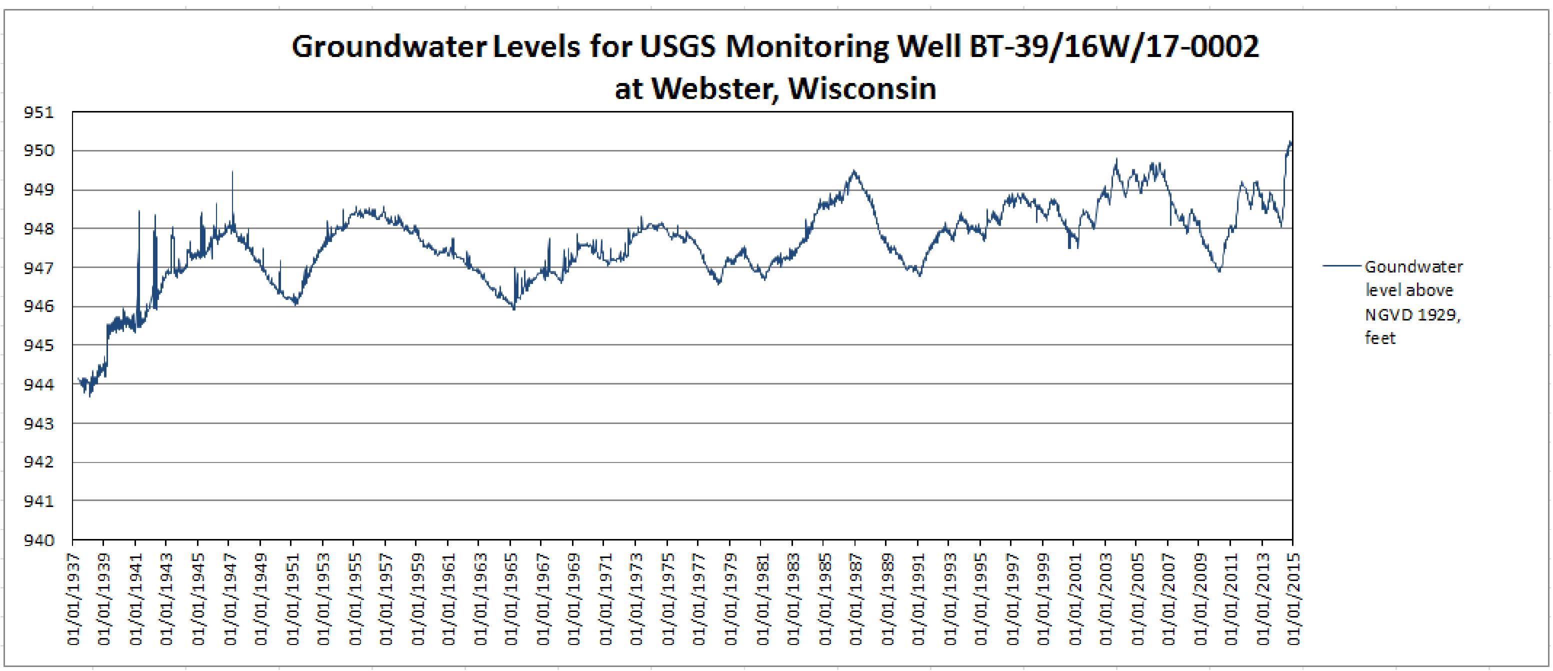
Variablility of iron concentrations in wells downgradient of flowages is probably also influenced by groundwater flow paths out of, and downgradient of flowages. Low permeability layers are found in most areas with organic wetland soils and in flowage sediment. Localized areas with low permeability mineral soil are also present at CMWA. Patterson (1990) found a layer of clayey till 5 feet below the surface near Sandberg Flowage on the southeast side of CMWA. Soil borings in 2014 found a clayey layer 30 inches below the near-shore lake bottom of Buggert Lake on the northwest side of CMWA. The irregular distribution of low permeability materials will result in more complex groundwater flow paths than would occur in uniform sands.

Additional variability of iron concentrations in wells downgradient of flowages may also result from "re-oxidation" of reduced iron along some flow paths. If anoxic groundwater mixes with oxic groundwater, reduced iron can be oxidized and will bond to soil surfaces in the aquifer.

Trends in Groundwater Levels

Figure 14 shows trends in groundwater levels from the nearest USGS monitoring well in Webster, Wisconsin, about 11 miles east of CMWA. This well is in the sand and gravel aquifer and has a depth of 46 feet. Groundwater levels in this well reached their highest level on record (950.27 ft) on October 31st, 2014. During 2014 groundwater levels rose 2.24 feet between April 11th and October 31st in response to the greatly above normal rainfall.

Figure 14



Soil Characteristics

Soils at CMWA have developed in sandy outwash materials. All soil samples collected at upland sites had a soil texture of sand (appendix 1). Some organic enrichment of upland soils was usually evident in the top 6-12 inches.

Wetland areas have an organic soil layer at the surface. Eight of the ten wetland sites sampled had organic soil layer thicknesses ≤ 24 inches. Two sites had thicknesses > 36 inches. The wetland organic layers are usually underlain by sand. A sandy loam layer with a 13% clay content and 27% silt content was found beneath the wetland organic layer at site W1(figure 5).

The water table in most locations at CMWA is very shallow. Water table depth was ≤ 5.5 feet at all but one of the 11 measured upland soil sampling sites (appendix 1). Standing water was present at the 10 wetland sites.

Iron concentrations (% dry weight) in soil samples are summarized below (table 3):

Table 3

CMWA SOIL IRON CONCENTRATIONS (% DRY WEIGHT)				
	All Soil	Upland Soil	Wetland Organic Soil	Wetland Inorganic Soil
Range	0.073 – 2.20	0.402 – 0.841	0.073 – 2.20	0.105 – 0.855
Mean	0.70	0.60	1.08	0.39

Soil iron concentrations at CMWA, with a mean of 0.70%, may not be especially high. Soils in the eastern U.S. were found to have a mean iron concentration of 1.4% (Shacklette and Boerngen 1984). Silica sands presumably have lower iron concentrations due to small total surface areas for iron oxide attachment and lack of iron in their mineral composition. Since iron is rarely tested in soils, data for iron concentrations in sands elsewhere in Wisconsin could not be found for comparison.

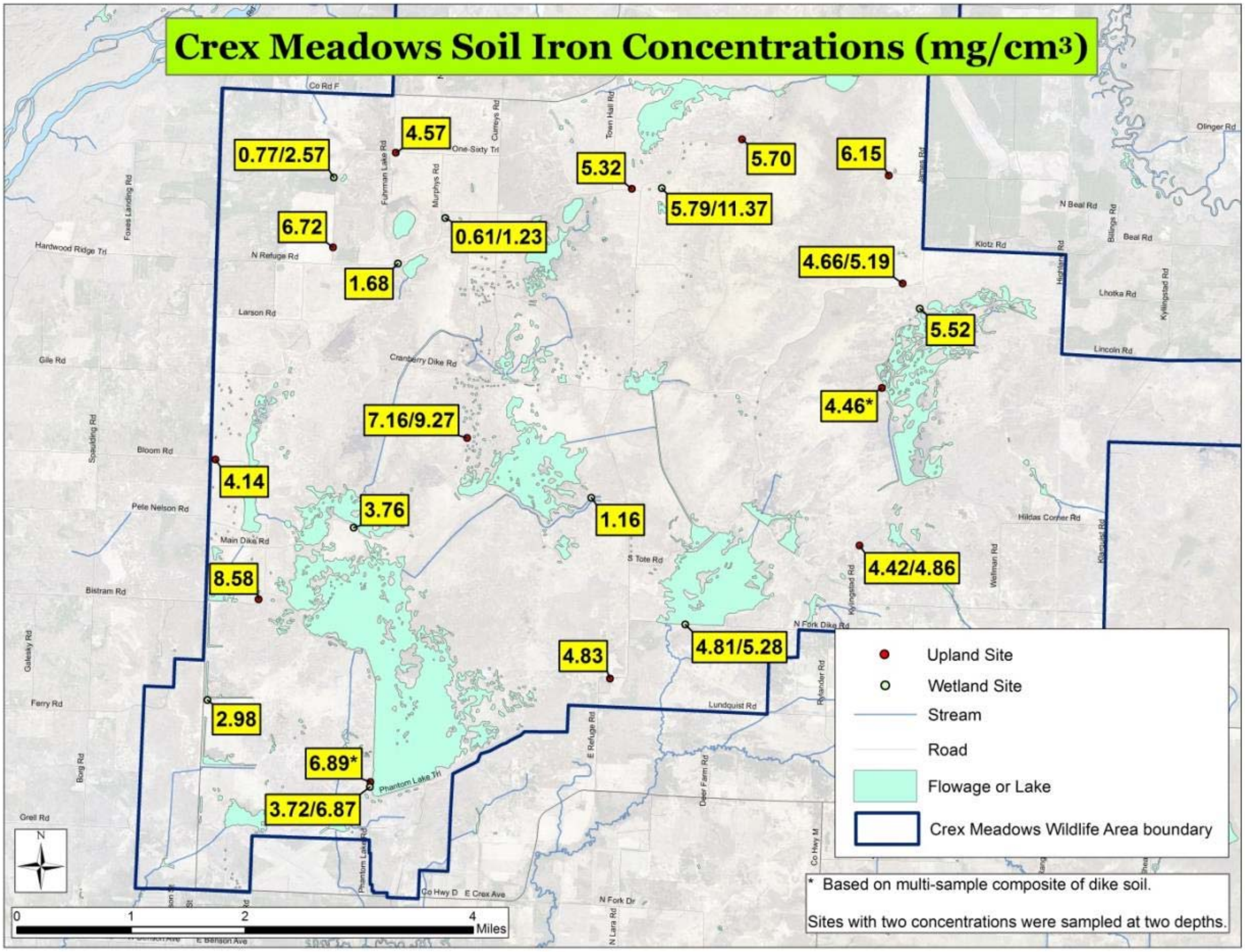
The outwash sands at CMWA were probably derived from the glacial erosion of iron-rich sandstone. This would account for the substantial presence of iron in the sands.

Mass per volume iron concentrations (mg/cm^3) can also be used in comparing CMWA soils to allow a more meaningful comparison between organic soils with low bulk densities and inorganic soils with relatively high bulk densities. The spatial distribution of iron is more relevant when examining iron transport and storage.

Soil iron concentrations ranged from 0.61 – 11.37 mg/cm^3 (figure 15). Upland site soil iron concentrations ranged from 4.14 – 9.27mg/cm^3, with a mean of 5.81 mg/cm^3. Upland sites show some tendency to have higher iron concentrations in the southwest half of CMWA than in the northeast half. However, the difference in mean values for the two areas is not significant at the 90% confidence level.

Upland soils have significantly higher (90% C.L.) iron concentrations (mean = 5.81 mg/cm^3) than wetland organic soils (mean = 3.11 mg/cm^3). Wetland inorganic soils have a higher mean iron concentration (5.03 mg/cm^3) than wetland organic soils (3.11 mg/cm^3), but this difference is not significant at the 90% confidence level. Inorganic soils (sands) are the source of iron at CMWA. While organic soils are capturing some iron, they are not concentrating it at higher levels than those found in inorganic soils.

Figure 15.



SURFACE WATER CHARACTERISTICS

Stream Data Locations and Naming Conventions

A complete set of stream monitoring data is contained in appendix 2. Locations of stream monitoring sites are shown in figure 6 (p. 9). Unnamed streams are identified with an unofficial name in quotation marks, based on the nearest road, flowage, or lake. US means upstream; DS means downstream. CTH means County trunk highway; STH means State trunk highway.

Stream Iron Concentrations and Water Quality

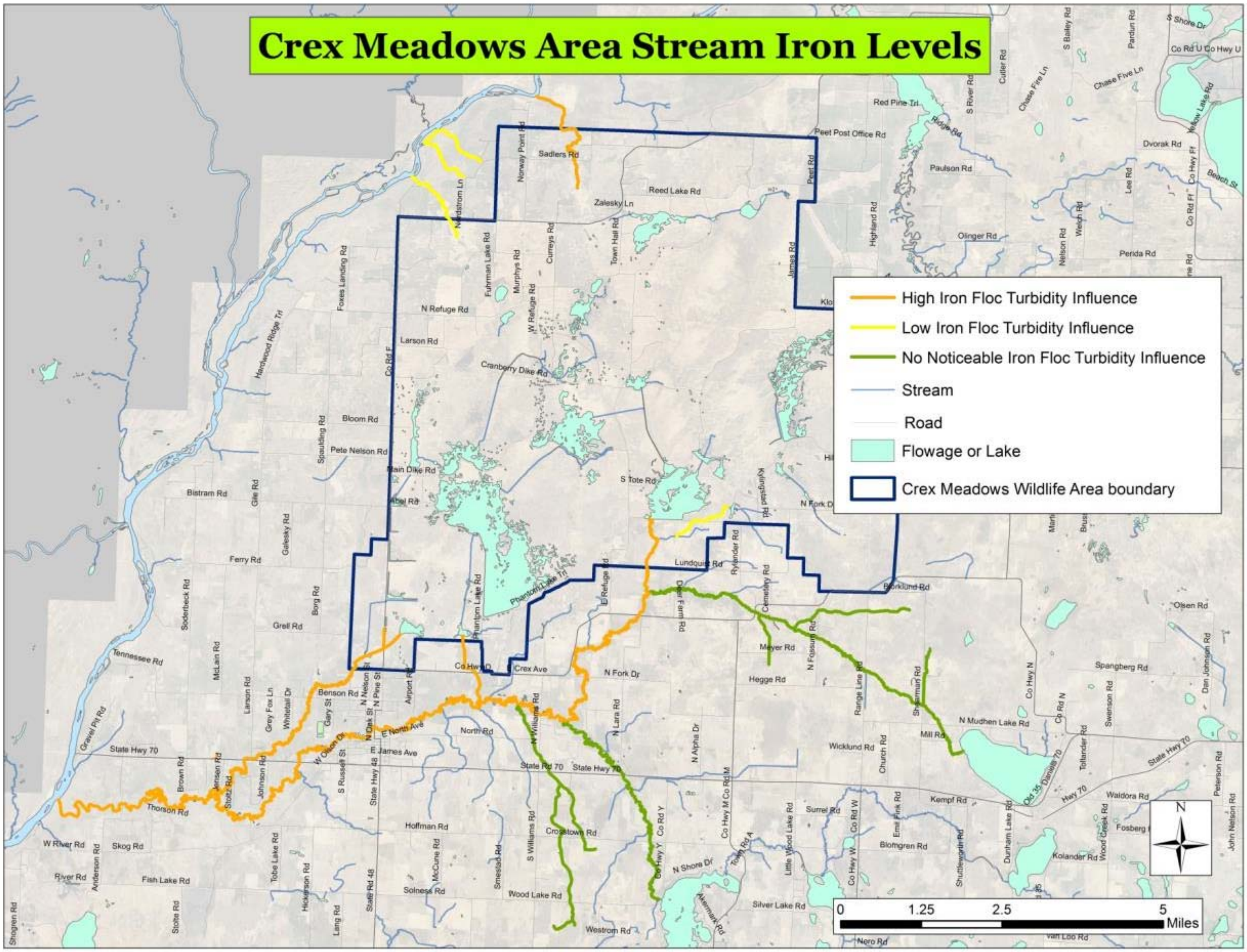
Table 4, below, summarizes stream iron concentration data. The distribution of these streams and their levels of visible iron floc turbidity are shown in figure 16.

Table 4

COMPARISON OF STREAM IRON CONCENTRATIONS

	Single Sample Iron (mg/L)	Multiple Sample Range Iron (mg/L)	Multiple Sample Mean Iron (mg/L)
STREAMS WITH HIGH LEVELS OF VISIBLE IRON FLOC TURBIDITY			
Hay Creek @ CTH F		2.1 - 35.2	17.5
Whiskey Creek @ CTH D		2.5 - 18.4	10.6
"North Fork Ck." (Unnamed @ Lundquist Rd)		1.3 - 14.8	9.3
Iron Creek @ Sadlers Rd	9.9		
STREAMS WITH LOW LEVELS OF VISIBLE IRON FLOC TURBIDITY			
"Nordstrom Creek" (Unnamed near Nordstrom Rd)		1.8 - 3.0	2.4
Ekdall Creek 5m above mouth		2.9 - 4.8	3.8
"Sandberg Creek" (Unnamed DS of Sandberg Flowage)		1.2 - 3.3	1.8
STREAMS WITH NO VISIBLE IRON FLOC TURBIDITY			
Wood R. @ STH 70 (first crossing)		0.4 - 0.8	0.5
North Fork Wood R. @ CTH D (first crossing)		0.4 - 1.5	0.8
"Fossum Creek" (Unnamed @ Fossum Rd)	1		
"North Creek" (Unnamed @ North Rd)	0.99		
"Buggert Creek"(Unnamed US Buggert Lake) in May	0.4		
"Kylingstad Creek"(Unnamed US Kylingstad Flowage)		0.6 - 4.1	2.8

Figure 16



Streams with High Levels of Visible Iron Floc Turbidity

The four monitored streams with high levels of visible iron floc turbidity (Hay, Whiskey, "North Fork", and Iron Creeks) had mean iron concentrations ranging from 9.3 - 17.5 mg/l, with concentrations as high as 35.2 mg/l found in Hay Creek. These four streams are all located downgradient of CMWA flowages. Reduced iron being generated in soils inundated by flowages is being carried to these streams by groundwater. The reduced iron is oxidized in the streams to form iron floc. Similar iron concentrations (mean = 12.2 mg/l) were found in a drainage ditch below a flowage at the Powell Marsh Wildlife Area in Vilas County, Wisconsin (Kreitlow 2007).

In some cases groundwater with reduced iron is discharging to flowages, being oxidized there, and then draining to the streams. High levels of visible iron floc turbidity were observed in Hay

Creek Flowage and the three "L" dikes which drain to Hay Creek. High levels of visible iron floc turbidity were also observed in a central area of the Phantom Flowage and in Whiskey Creek Flowage which drain to Whiskey Creek.

Three of the streams with high levels of visible iron floc turbidity (Hay, Whiskey, and "North Fork" Creeks) were more intensely monitored (table 5). Iron concentrations in all three showed some similar patterns over the season (figure 17):

- Lowest iron concentrations occurred on May 14th, a period of high flows dominated by surface runoff. Surface runoff at CMWA has low iron concentrations while groundwater discharge often has high iron concentrations.
- A period of high iron concentrations occurred between May 31st and September 2nd.
- Lower iron concentrations (about ½ of the summer period concentrations) occurred between September 15th and December 5th. Less bacterial reduction of soil iron due to cooler soil temperatures is likely to be the primary cause of this seasonal decline.

Flowage water temperature is likely to be good indicator of inundated soil temperature. Temperatures of Hay Creek, Phantom, and North Fork Flowages declined substantially between September 2nd and September 15th (6.6 to 10ºC temp declines). This coincided closely with the declines in iron concentrations in the three streams.

The high iron concentration streams were observed in late winter (March 3, 2015) when flowage water samples were being collected. Turbidity levels appeared similar to those found in mid-summer. High iron concentrations were found in flowage water on that date (see flowage water quality and sediment characteristics section). Discharge of flowage water with high iron concentrations probably accounted for the increased stream turbidities.

Iron concentrations in these three streams were poorly to weakly correlated with streamflow, with R^2 values ranging from 0.02 to 0.30. Iron concentrations are inversely correlated to flow. Higher flows tend to have lower iron concentrations. High flows tend to occur when more surface runoff, with low iron concentrations, is occurring. Low flows tend to occur when groundwater discharge, with high iron concentrations, provides a larger percentage of streamflow.

Iron concentrations in streams are probably also influenced by temporary storage and release of iron floc. Iron floc deposits that develop on stream beds and margins during low flow periods can be re-suspended and flushed when higher flows develop. Iron floc deposits on stream margins exposed by declining stream levels can be easily eroded by rainfall and re-suspended in the stream.

Iron concentrations were strongly and inversely correlated with transparency, with R^2 values ranging from 0.77 to 0.88. Reductions in stream transparency are mostly caused by increasing concentrations of oxidized iron floc. Transparency measurements could provide fairly good estimates of iron concentrations if needed in the future.

Iron concentrations were positively correlated with total phosphorus concentrations and turbidity. Iron and total phosphorus concentration correlations had R^2 values ranging from 0.66 to 0.93. Phosphorus is often associated with iron since phosphorus will attach to, or become incorporated in various forms of oxidized iron. When oxidized iron is reduced, both the iron and the phosphorus can become mobile.

Iron concentration and turbidity correlations had high R^2 values ranging from 0.73 to 0.89. Increases in stream turbidity are mostly caused by increasing concentrations of oxidized iron floc.

True color values for these three streams were high, with means ranging from 183 to 250 Pt-Co units. This results from the substantial influence of wetland drainage, which has high concentrations of dissolved organic matter.

Total phosphorus (TP) concentrations were moderately high, with means for all samples ranging from 60.8 - 78.5 ug/l. TP impairment evaluation of streams is based on medians of single monthly samples rather than overall means. May-October stream TP concentration medians greater than 75 ug/l are considered to indicate impaired conditions (WisCALM,WDNR 2013). 90% confidence limits of the median are also taken into consideration. For Whiskey Creek the median TP (40.1 ug/l) and the upper 90% confidence limit (73.4 ug/l) are both less than 75 ug/l, so this stream clearly meets the 75 ug/l TP stream standard. For Hay Creek and North Fork Creek the median TP's (41.0, 44.7 ug/l) are less than 75 ug/l, but the upper 90% confidence limits (83.5, 93.9 ug/l) are greater than 75 ug/l. These streams "may meet" the 75 ug/l TP standard. Additional sampling would be needed to make a definitive determination of impairment status.

Stream pH values were slightly acidic, with means ranging from 6.6 to 6.8.

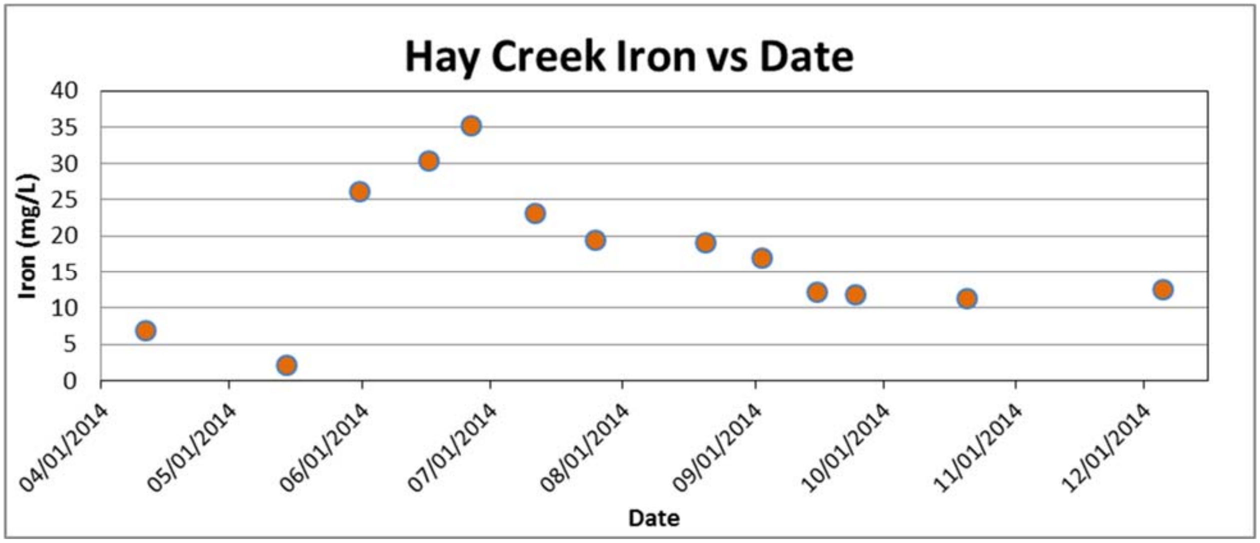
Flows for these three streams are shown in figure 18. The three streams showed similar patterns of flow. A prolonged period of highest flow occurred from mid-April to early July in response to the above normal precipitation in April through June. Flows declined in July and August. Flows increased following a heavy rainfall on September 3rd. Stream response to that rainfall varied depending on the timing of managed releases from upstream flowages.

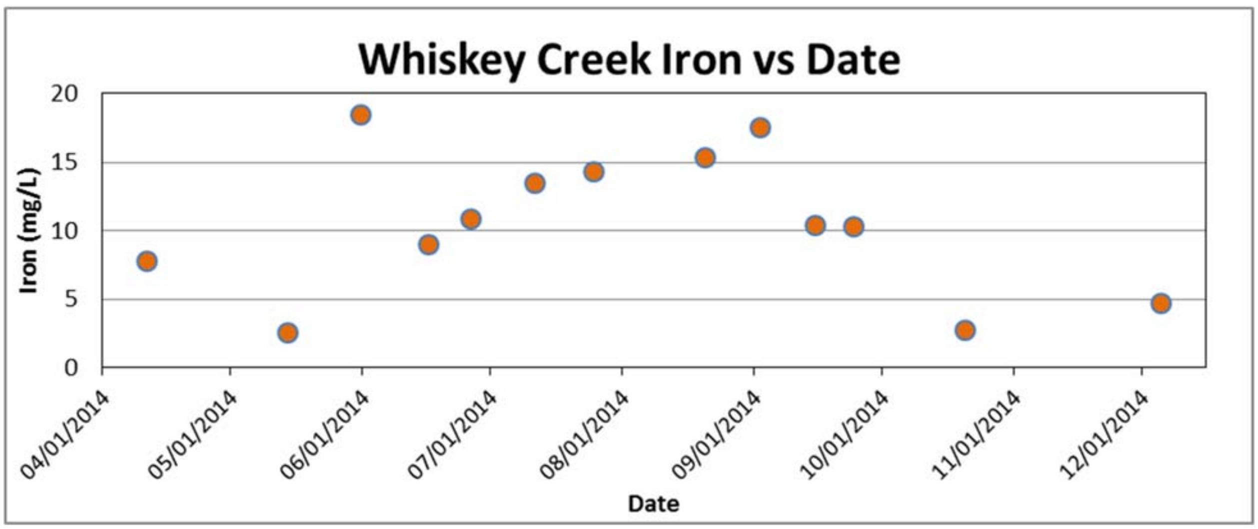
Managed drawdowns of flowages were minimal due to the above normal precipitation. Sandberg Flowage did have a summer drawdown for cattail control. The Hay Creek Flowage outlet was left fully open for the season. However, beaver dams were frequently built and removed from the outlet resulting in somewhat erratic flows in Hay Creek downstream.

Table 5

SUMMARIZED WATER QUALITY DATA FOR HAY, WHISKEY, AND "NORTH FORK" CREEKS			
Parameter	**Hay Creek**	**Whiskey Creek**	**"North Fork Creek"**
Iron (mg/l)			
Range	2.1 - 35.2	2.5 - 18.4	1.3 - 14.8
Mean	17.5	10.6	9.3
Total Phosphorus (ug/l)			
Range	22 - 103	30 - 89	23 - 116
Mean	69.8	60.8	78.5
Total Suspended Solids (mg/l)			
Range	3.3 - 35	4.7 - 26	1.2 - 19
Mean	14.7	11.2	9.1
Turbidity (ntu)			
Range	2.7 - 122	4.2 - 76.7	2.1 - 36.3
Mean	51.0	35.2	19.0
True Color (Pt-Co units)			
Range	150 -325	125 - 325	150 - 225
Mean	250	200	183
Dissolved Oxygen (mg/l)			
Range	1.7 - 8.8	3.4 - 12.5	3.8 - 10.3
Mean	5.5	7.5	7.0
pH (s.u.)			
Range	6.1 - 7.0	6.1 - 6.8	6.1 - 7.1
Mean	6.7	6.6	6.8
Transparency (cm)			
Range	10 -120	16 - 120	23 - 120
Mean	37.2	46.8	50.0
Temperature (oC)			
Range	0.6 - 22.8	0.6 - 21.7	3.4 - 25.9
Mean	17.1	14.5	21.3
Conductivity (umhos/cm)			
Range	26 - 177	21 - 96	36 - 182
Mean	85.9	59.2	82.1

Figure 17. Iron concentrations in Hay, Whiskey, and “North Fork” Creeks





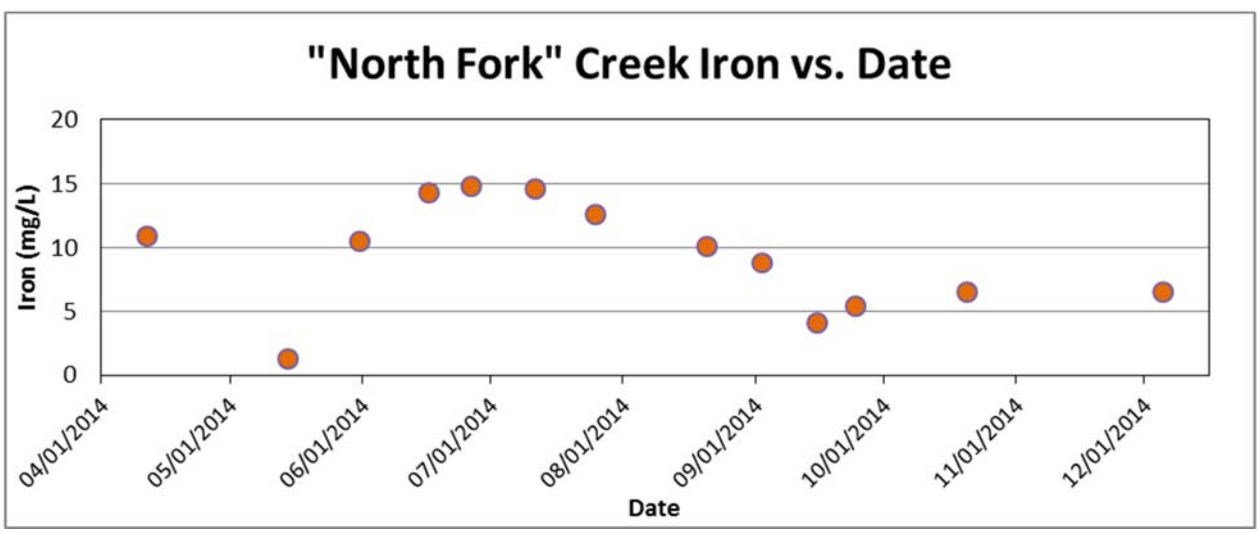
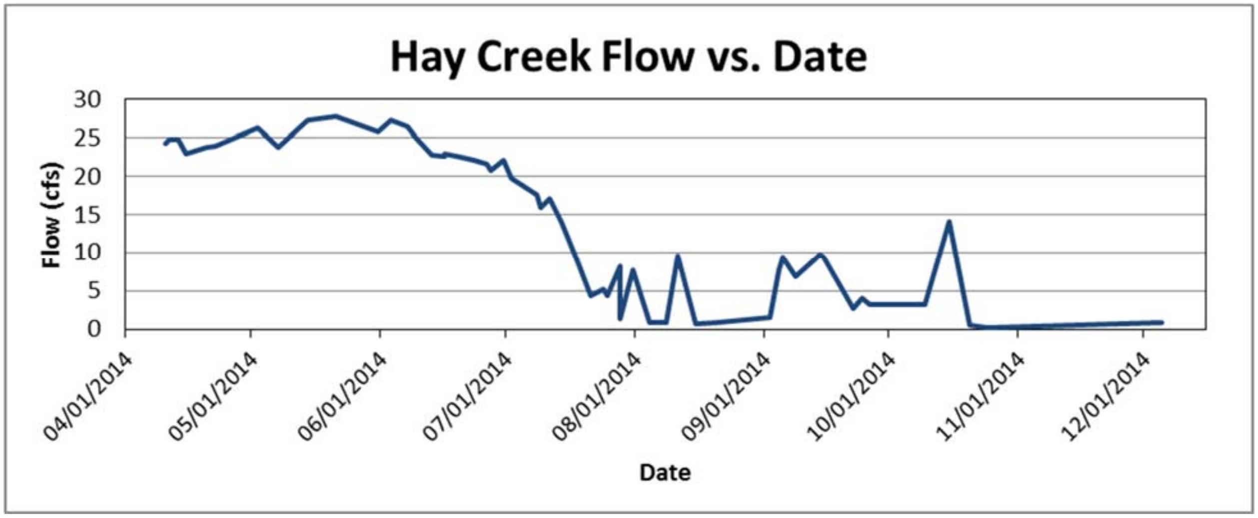
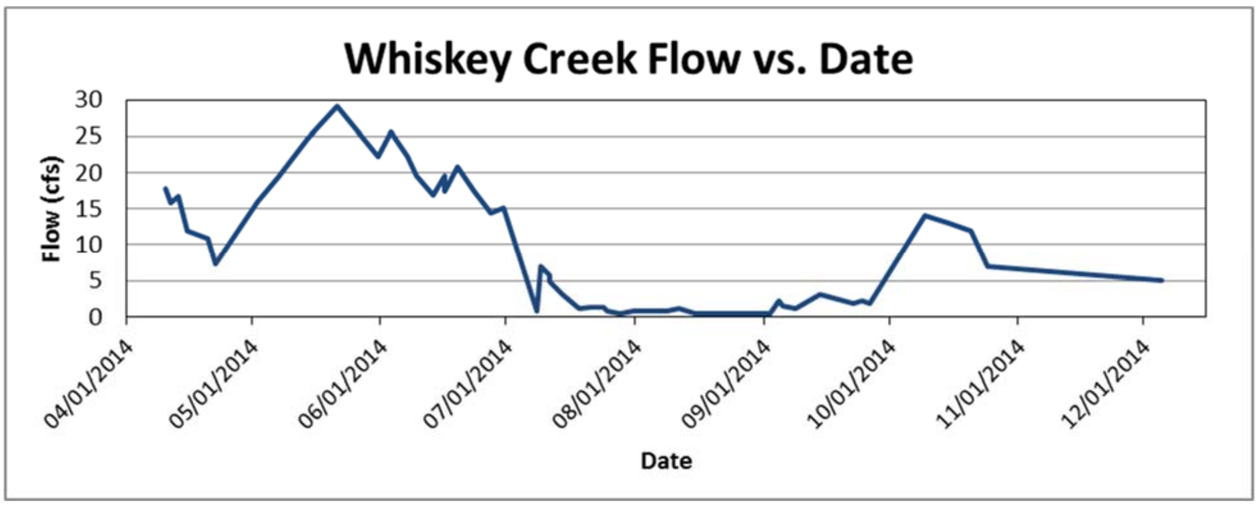
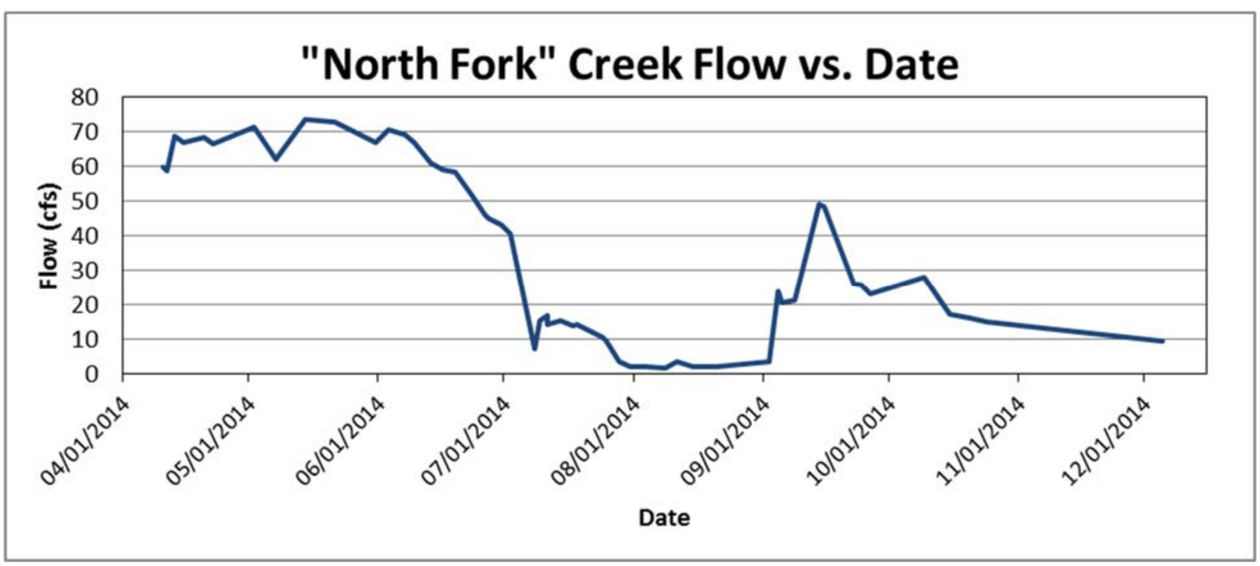


Figure 18. Flows in Hay, Whiskey, and “North Fork” Creek







Iron oxidizing bacteria were analyzed in water samples collected on two dates in September. Total iron oxidizing bacteria counts (number/ml) ranged from 80 to 1100. Bacteria were identified as *Leptothrix*, *Gallionella*, *Crenothrix*, and “Other”. *Leptothrix* was the most commonly occurring bacteria and made up 75% of all bacteria counted. Bacteria counts were not clearly related to iron concentration, temperature, or collection date.

Growths of iron oxidizing bacteria attached to submerged grass and other substrates were often noticeable at streams with high levels of visible iron floc turbidity (figure 19). The growths were rust colored and often had a cottony appearance due to an abundance of *Leptothrix*, which is a filamentous iron bacteria. Other types of iron bacteria produce a variety of other growth forms.

Figure 19. Iron bacteria in East ditch along Lundquist Rd.

Deposits of iron floc up to several inches deep were observed at times on some stream margins (figure 20). These deposits probably contained both iron bacteria and bacterially and chemically oxidized iron.

Oil-like surface films that are a by-product of iron bacteria were also observed at sites with high iron concentrations. These films have a bluish, oil-like sheen. Unlike actual oil films, these bacterial produced films will fracture and separate when disturbed (figure 21).

Figure 20. Iron floc deposits on edge of Iron Creek.

Figure 21. Iron bacteria surface film.

Hay, Whiskey and North Fork Creek are estimated to discharge 320,391 kg of iron/yr. to the Wood River during a year with normal flow (41.9 mi2 drainage area; 10.2 in/yr discharge rate; 11.4 mg/l flow-weighted iron concentration). 5,000 acre-feet of inundated soil with an iron concentration of 5.81 mg/cm3 contains 71,637,300 kg of iron. Since 20,000 acres of wetlands have been created at CMWA, 5,000 acre-feet of inundated soil is probably a very conservative estimate. 5,000 acre-feet of soil contains 112 times the estimated annual iron discharge rate. This indicates that existing soil iron content can maintain current stream iron discharge rates for many decades or more.

Streams with No Visible Iron Floc Turbidity

Four of the six streams with no visible iron floc turbidity (Wood R., North Fork Wood R.,"Fossum Ck.", "North Ck.") are located upstream of the CMWA, and so are uninfluenced by CMWA flowages. These four streams have iron concentrations $\leq$ 1 mg/l. The streams with high levels of visible iron floc turbidity have iron concentrations that average 14 times higher than these streams.

Two of the six streams with no visible iron floc turbidity are located within the CMWA. "Buggert Creek" is an unnamed stream that flows into Buggert Lake. This creek was very clear in spring and had a May 14th iron concentration of 0.4 mg/l when the diked lake upstream (Fuhrman Lake) had low water levels. Fuhrman Lake was overflowing its dike by May 21st, and Buggert Creek showed increased color and the development of iron floc on vegetation by May 31st. Iron concentrations were apparently increasing, but additional samples were not taken. This probably was the result of increased groundwater discharge to Buggert Creek caused by high water levels in Fuhrman Lake.

"Kylingstad Creek" is an unnamed stream that flows into the Kylingstad Flowage. It does not have a flowage upgradient of it. Water in the flowage was backed up well upstream of the sampling site by a large beaver dam near the center of the flowage. The water had very low daytime dissolved oxygen concentrations ranging from 0.4 to 3.0 mg/l, and low pH values ranging from 5.9 to 6.1. The water was also very heavily stained indicating high concentrations of dissolved organic matter.

All these conditions would have promoted iron reduction in the inundated soils around the flowage and resulted in somewhat more iron moving into the flowage as soils drained back. The iron concentration was only 0.6 mg/l on May 14th, gradually increased to 4.1 mg/l on June 26th, and then declined slightly, after that. Lack of any visible iron floc formation was probably due to the high concentrations of dissolved organic matter, which can stabilize colloidal iron hydroxide and limit the formation of iron floc.

Streams with Low Levels of Visible Iron Floc Turbidity

Two of the streams with low levels of visible iron floc turbidity (Ekdall and "Nordstrom" Creeks) are small spring fed streams that flow down the slope to the St. Croix River. They are located to the north of CMWA (figure 6). Average iron concentrations in these creeks were 3.8 and 2.4 mg/l. "Bang Creek" is a third stream in that area that appears similar to Ekdall and "Nordstom" Creeks, but was not sampled for iron.

It is uncertain if these streams are influenced by CMWA flowages. There is some potential for influence from Fuhrman Lake and Reisinger Lake via Rice's Lake (see flowage water quality discussion below).

Springs with iron deposits form the headwaters of Ekdall and "Nordstom" Creeks. The springs are located where the Glacial Lake Grantsburg clay layer intersects the slope to the St. Croix River. "Bang" Creek originates from springs without iron deposits further up the slope, suggesting the presence of another low permeability layer within the sand in that area. Springs with iron deposits also discharge to "Bang" Creek further down the slope where the lake clay layer occurs.

All three streams have bottom substrates that are rusty orange colored due to a thin coating of iron hydroxide, and presumably iron oxidizing bacteria. Iron floc tubidity is relatively low and transparency is relatively high. Summer transparency in "Bang" and "Nordstom" Creeks was >120 cm. Summer transparency in Ekdall Creek was 85 cm. True color is low in these streams, ranging from 15 to 30 Pt-Co units.

"Sandberg Creek" is an unnamed stream downstream of the Sandberg Flowage. It had an average iron concentration of 1.8 mg/l. It presumably receives most of its flow from surface discharge from the flowage and from surficial wetland drainage. Transparency was relatively high, ranging from 94 to 101 cm. True color was moderately high ranging from 175 to 200 Pt-Co units.

Wood and North Fork Wood River Total Phosphorus Concentrations

Total phosphorus (TP) samples were collected from the lower ends of the Wood River (at River Road) and the North Fork Wood River (at North Fork Drive). Six monthly samples were collected during May to October to evaluate these streams for impairment due to TP concentrations. A median TP concentration of 75 ug/l is the threshold for stream impairment, but upper and lower 90% confidence limits are taken into consideration (WisCALM; WDNR 2013). The median TP concentration for the North Fork Wood River was 49.0 ug/l, and the upper 90% confidence limit was 72.5 ug/l. This indicates the North Fork Wood River "clearly meets" the stream TP standard and is not impaired. The median TP concentration for the Wood River was 54.5 ug/l, and the upper 90% confidence limit was 80.1 ug/l. This indicates the Wood River "may meet" the stream TP standard. Additional sampling would be needed to make a definitive determination of impairment status.

Spring and Ditch Iron Concentrations

Iron concentrations were measured at four springs north of CMWA and two drainage ditches along Lundquist Road (see figure 6 for locations). Three of the springs were iron springs with iron oxidation and deposition evident. The "east and west springs at iron deposit area" are located in a drainageway just north of Ekdall Creek. There is a massive deposit of oxidized iron at this location (figure 22).

Figure 22. Iron deposit area north of Ekdall Creek

Probing in one area of this deposit found thicknesses of 10-15 feet. This deposit has probably been developing since the last glaciers receded.

A presumably similar iron deposit once existed on another drainageway to the St. Croix River west of CMWA, near the north end of Paint Mine Road. That deposit was mined from 1894-1913 and used as a paint pigment. Iron oxide was used in red barn paint.

The three iron spring samples had low iron concentrations (< 0.1- 0.3 mg/l). An iron concentration of 0.3 mg/l is the recommended maximum level for drinking water, due to staining and odor problems that can occur from iron oxidation and iron bacteria growth, so it is possible such concentrations could produce iron deposits over long time periods. Groundwater iron concentrations found in two nearby shallow wells (12-20 ft.) (Patterson 1990) had similar iron concentrations (0.22-0.36 mg/l).

It's possible that the spring samples, collected at the top edge of the discharge area, had lower than average iron concentrations due to high amounts of recent local groundwater recharge. The shallow monitoring wells may have lower iron concentrations than are found at greater depths near the top of the clay layer.

Average iron concentrations in streams fed by iron springs ("Nordstrom", "Bang", and Ekdall Creeks) ranged from 2.3-3.8 mg/l. These concentrations may be more representative of average iron spring iron concentrations. However, these streams have substrates coated with oxidized iron, which can be easily suspended at times, so the measured concentrations may not represent good long term averages for the streams. A more detailed investigation would be needed to resolve these uncertainties.

One sampled spring (Norway Point sandstone spring, figure 6) was assumed to be discharging from the sandstone underlying the clay layer, since no iron deposition was present. It had an iron concentration of <0.1 mg/l. It had a conductivity of 141 umhos/cm, which was higher than conductivities in the three iron springs (average conductivity = 76 umhos/cm), which also suggests it is a sandstone spring. However, elevation estimates for this spring were similar to that for the iron springs, so there are uncertainties about this spring's source.

Iron concentrations were measured in two drainage ditches along Lundquist Road ("east and west ditches along Lundquist Rd."; figure 6). Both ditches drain to "North Fork" Creek. The east ditch had a very high iron concentration of 23.3 mg/l. High amounts of visible iron floc and iron bacteria were usually noticeable in this ditch (figure 23), indicating this ditch was receiving inflow of groundwater with high iron concentrations.

The west ditch had a much lower iron concentration of 3.5 mg/l. The water was highly stained, but no iron floc or iron bacteria were visible (figure 24), indicating flows in this ditch were mostly surface drainage from wetlands. The high dissolved organic matter concentration was probably preventing iron hydroxide colloids from aggregating into visible floc. The wetlands draining to this ditch had been flooded earlier in the year by "North Fork" Creek water with a high iron content. Some of the iron deposited by floodwater was probably contributing to iron concentrations in the ditch. Surface water drainage from wetlands without floodwater iron deposition is likely to have lower iron concentrations.

Figure 23. East ditch along Lundquist Road

Figure 24. West ditch along Lundquist Road

Sandberg Flowage Drawdown Effects on Lundquist Road Ditch

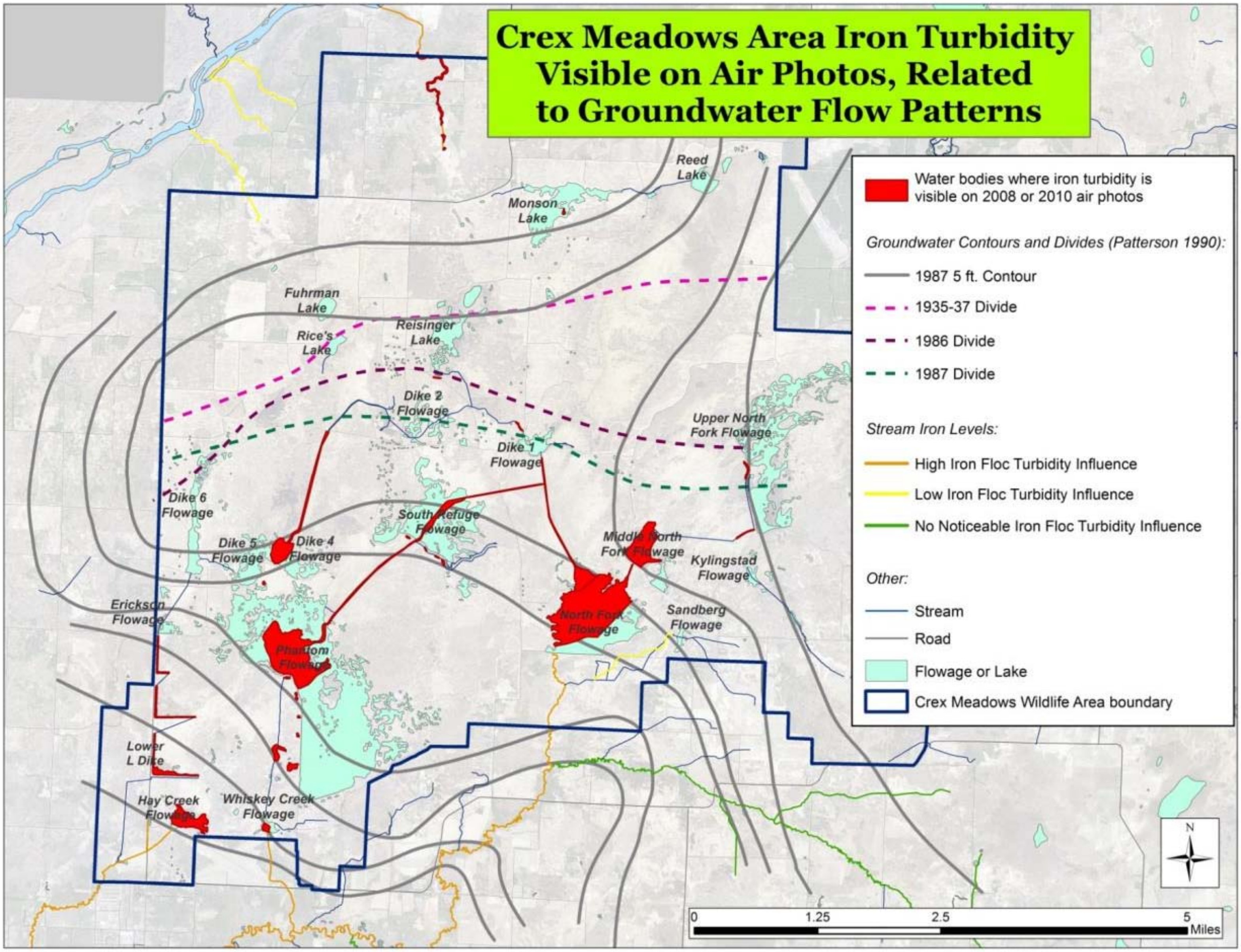
Sandberg Flowage was completely drawn down in the summer to allow for cattail control. Iron presence in a downgradient drainage ditch 1.4 miles from the flowage was observed to fluctuate in response to the drawdown. The drainage ditch runs along the north side of Lundquist Road and is labeled "Unnamed ("East Ditch along Lundquist Rd.")" in figure 3. It drains into "North Fork" Creek. The ditch had heavy growths of iron bacteria and deposits of iron floc prior to the flowage drawdown. On June 26th, the ditch iron concentration was 23.3 mg/l. The visible presence of iron in the ditch largely disappeared when the flowage was drawn down, and re-appeared after the flowage was filled. The timeline of the drawdown and observations is listed below. There would be some time lag for groundwater to flow from the flowage to the ditch. It appears that Sandberg Flowage is the major source of iron for the ditch, and this source is eliminated when the flowage is completely drawn down.

- Drawdown started about a month prior to July 24th
- July 24th Last water control boards pulled
- July 26th East ditch iron concentration = 23.3 mg/l, iron bacteria and floc abundant
- August 4-12th cattail removal
- August 12th two water control boards added
- August 20th East ditch was fairly clear with almost no iron bacteria, which is atypical
- September 3rd about 6" of rain occurred which filled flowage
- September 4th after heavy rain, high flow in East ditch, but no iron turbidity
- September 8th East ditch iron bacteria and floc deposits beginning to reform on banks and bottom

Distribution of Visible Iron Floc Turbidity in Air Photos

Iron floc turbidity in flowages and ditches at CMWA is visible in 2008 (summer) and 2010 (early spring) air photos. Figure 25 highlights areas where turbidity in air photos is seen, and relates them to water table contours. Groundwater generally flows perpendicular to these contours.

Figure 25.



Turbidity is absent at sites that are not downgradient of flowages (Upper North Fork, Sandberg, Kylingstad, Dike 6, Dike 2 Flowages; Reisinger, Reed, Monson Lakes). Turbidity is present at sites which are downgradient of flowages (Middle North Fork, North Fork, South Refuge, Dike 4, Phantom, Hay Creek , Whiskey Creek, and “L”Dike Flowages and several drainage ditches). This is further evidence that iron reduction in soils inundated by flowages is the major source of iron in surface waters at CMWA.

The air photos also show that turbidity is not uniformly distributed in areas downgradient of flowages. The turbidity will occur where groundwater inflow is a substantial water source. Where surface drainage from wetlands is the major water source, turbidity is minimal. Wetland drainage has high concentrations of dissolved organic matter, which gives the water a stained “tea colored" appearance, but iron concentrations and turbidity are relatively low (see figure 4, p. 5 for a visual comparison of surface drainage dominated flow and groundwater inflow influenced flow).

At North Fork Flowage, the 2008 summer air photos (figure 26) show much of the iron floc turbidity entering at the north end is settling out before reaching the outlet on the south end. Inflow of wetland surface drainage on the southeast side may also be contributing to clearer water on the south end.

Figure 26. North Fork Flowage summer 2008 air photo.

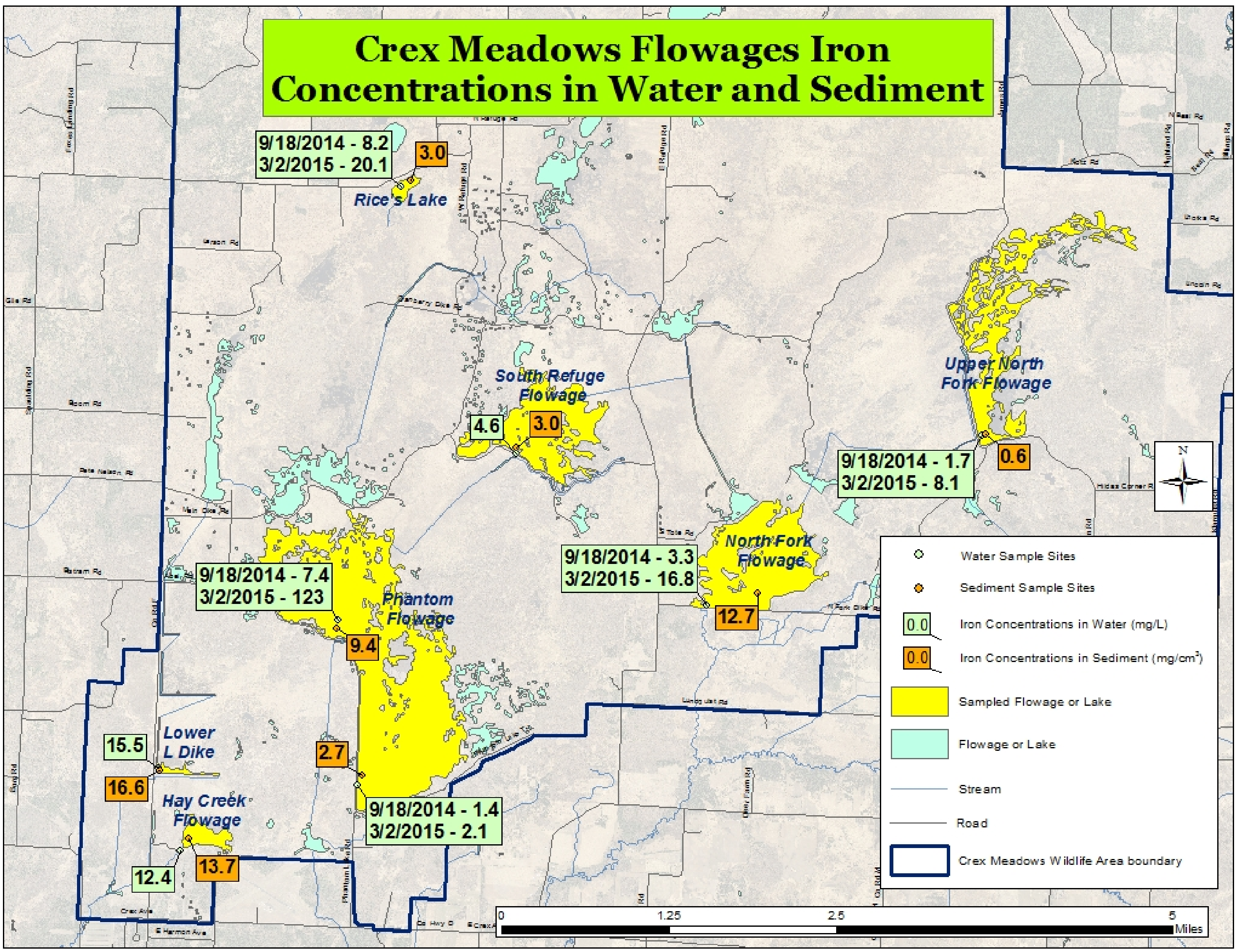
The early spring 2010 air photos show far less turbidity than the summer 2008 air photos. Many flowages that are turbid in 2008 are clear in 2010. This is consistent with the seasonal variation in the activity of iron reducing bacteria. Little soil iron is being reduced during the winter due to inactivity of iron reducing bacteria in cold soil temperatures. Increased iron concentrations were observed in some flowages in March of 2015 (see next section). This may also contribute to early spring turbidity in some locations.

Differences between the summer 2008 air photos and the early spring 2010 air photos may also be partially influenced by differences in groundwater levels. The USGS monitoring well at Webster showed groundwater levels that were 1.36 feet above average in the summer of 2008, and 0.14 feet below average in early spring 2010. Higher groundwater levels would probably result in more groundwater discharge to surface water and possibly more iron floc turbidity.

Flowage Water Quality and Sediment Characteristics

Eight flowage and lake sites were sampled for water quality and sediment chemistry on September 18th, 2014. Iron concentrations in water and sediment at these sites are shown in figure 27. Water iron concentrations were also tested in late winter (March 2, 2015) at five of the sites. Late winter water samples could not be collected at three of the sites (South Refuge Flowage, Lower L Dike, Hay Creek Flowage) because they were frozen to the bottom.

Figure 27.



Summer sample results

Upper North Fork Flowage had low iron concentrations in water (1.7 mg/l) and sediment (0.6 mg/cm^3). As previously mentioned, Upper North Fork Flowage is not influenced by any upgradient flowages.

The south section of Phantom Flowage also has low iron concentrations in water (1.4 mg/l) and sediment (2.7 mg/cm^3). This portion of Phantom Flowage has clear water on air photos and probably receives most of its water from surficial wetland drainage.

Lower "L" Dike and Hay Creek Flowages have the highest iron concentrations in water (15.5, 12.4 mg/l) and sediment (16.5 and 13.7 mg/cm^3). These are both in locations likely to be heavily influenced by groundwater generated at upgradient flowages.

South Refuge and North Fork Flowages, and the central Phantom Flowage sites have intermediate iron concentrations in water (3.3-7.4 mg/l) and sediment (3.0-12.7 mg/cm^3). Air photos show the presence of iron floc turbidity at these three sites.

Rice's Lake also has intermediate iron concentrations in water (8.2 mg/l) and sediment (3.0 mg/cm^3). Iron floc turbidity is not present in the air photos for the lake. Rice's Lake is located near the estimated groundwater divides. There is the potential for localized groundwater flow to be westward in this location. Surface topography shows Reisinger Lake (an impounded water body) is at a higher elevation (about 5 feet higher) than Rice's Lake, and the land surface slopes continuously downward from Reisinger to Rice's Lake. It is probable that, at least during years of high groundwater levels like 2014, some groundwater generated at Reisinger Lake is discharging to Rice's Lake.

The mean iron concentration in flowage sediment was 7.7 mg/cm^3. This is 57% higher than the mean iron concentration in soil samples (4.9 mg/cm^3). Some iron enrichment of flowage sediment would be expected due to oxidation and settling of iron in flowages.

True color in flowages was high, ranging from 200-375, and averaging 256 Pt- Co units. Color in flowages was somewhat higher than in monitored streams. Flowages are more heavily influenced by highly colored wetland drainage, while streams are more influenced by groundwater inflow with little color.

Soft sediment thickness in most flowages ranged from 2-3.4 feet. North Fork Flowage had a soft sediment thickness >5 feet.

Winter sample results

Water iron concentrations were higher in late winter than in summer at the five sites sampled. Concentration of iron due to ice formation accounts for some of the increases. As ice forms, dissolved and suspended substances in the water are excluded from the ice layer and concentrated in the remaining water. The ice to water ratio in Rice's Lake can account for all of the iron increase there (30 in. ice over 12 in. water).

Release of sediment iron may also be occurring. Dissolved oxygen concentrations in the water column were less than 0.5 mg/l at the Phantom Flowage north site, North Fork Flowage, and Upper North Fork Flowage. With anoxic conditions at the sediment surface, and sediment temperatures that might reach 41°F (the minimum reported to be necessary for iron reducing bacteria activity) due to heat generated by bacterial decomposition of organic matter, reduction and release of sediment iron is possible.

The extremely high iron concentration found at the Phantom Flowage north site (123 mg/l) may be due to a number of factors. Most of the surrounding area was frozen to the bottom, so extreme concentration by ice formation is likely. Sediment iron release is also possible. Additionally, concentration of entrapped fish such as bullheads in the small area of remaining water might have caused sediment resuspension.

Air Photos of Wood River Mouth

Air photos of the Wood River mouth area at the St. Croix River from 1938, 1995, and 2008 were examined (figures 28-31).

The 1938 black and white air photo was taken on August 18th (figure 28 and 29).There was no heavy precipitation shortly before that date, so Wood River flows were probably at baseflow levels and not influenced by a runoff event. There appears to be iron deposition on the bottom of the Wood River and along the bank of the St. Croix River for a distance of about 1,400 feet below the Wood River mouth. The distinctively shaded area that is visible in the 1938 photo appears likely to be bottom deposition rather than turbidity since there is no evidence of a mixing zone, as seen in the later photos. Coatings of iron deposits on stream bottoms are seen today in the small spring-fed streams on the north side of CMWA (Ekdall, "Nordstrum", and "Bang" Creeks; figure 8). This indicates some level of iron deposition was occurring downstream of the CMWA area prior to flowage construction. Naturally occurring rates of soil iron release were probably adequate to produce iron deposition in some surface waters.

A summer 1995 air photo (figure 30) (date unknown) shows a very distinct turbidity plume extending from the river mouth to the edge of the photo (4,400 feet). It seems likely the plume extended a considerable distance further. Since the date is unknown, the conditions that produced this distinctive plume can't be determined.

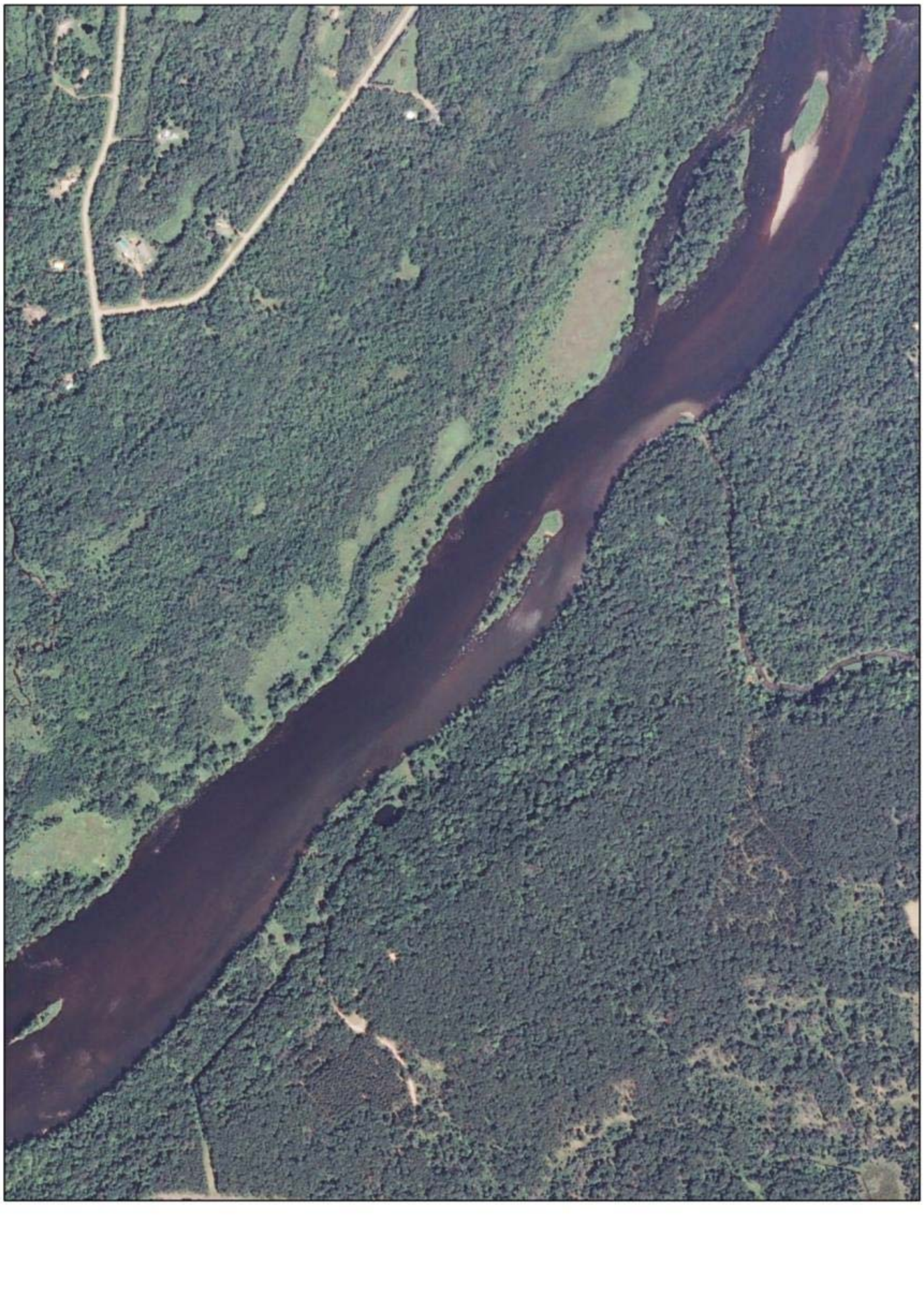
A summer 2008 air photo (figure 31) (date unknown) shows a more diffused turbidity plume. It seems likely a higher flow rate in the Wood River was occurring at the time, based on the greater plume width. It is possible the turbidity in this photo was due more to sediment from watershed runoff than from iron. The plume is visible for a distance of about 6,400 feet.

Figure 28. Wood River Mouth, August 18, 1938

Figure 29. Wood River Mouth, August 18, 1938 (zoomed in)

Figure 30. Wood River Mouth, Summer 1995

Figure 31. Wood River Mouth, Summer 2008



STREAM BIOTA

Stream Macroinvertebrate Communities

Fourteen stream sites were sampled for macroinvertebrates in the fall of 2014 (table 6 below, and figure 9, p. 13). Due to the lack of gravel or cobble substrates at most sample sites, woody debris with snags of dead vegetative material was targeted as the sampling substrate to maintain as much uniformity as possible. This substrate was present at twelve of the fourteen sites. Other substrates needed to be sampled at two sites (white-celled streams in table 6; unnamed DS North Road = gravel/cobble, unnamed US Fossum Road = dead reed canary grass hanging in stream).

Table 6. Stream Macroinvertebrate Sample Summary

Station Name	SWIMS ID	Macroinvertebrate index of biotic integrity (MIBI)	MIBI condition category	Hilsenhoff biotic index (HBI)	HBI condition category	Species richness	% EPT individuals	% EPT genera	% Chironomidae individuals
North Fork Wood River 20 m US Shearman Rd	10042430	10.64	Excellent	4.28	Very good	21	89	40	5
Wood River at Hwy 70 Upstr Of Grantsburg	73029	3.95	Fair	6.94	Fairly poor	23	12	26	11
Wood River North Fork - Upper Cth D Xing	73115	4.13	Fair	5.31	Good	18	57	41	36
Wood River-upstrm. Crosstown Rd	10029120	3.03	Fair	5.5	Good	20	56	25	26
North Fork Wood River at Cth D Lower Crossing	73114	6.85	Good	5.56	Fair	27	48	38	13
Wood River at North Williams Rd Near Grantsburg WI	73106	4.56	Fair	6.29	Fair	25	10	25	48
Wood River At West River Road (1 Mi Above St Croix R)	73030	6.77	Good	2.47	Excellent	32	89	48	4
Wood River North Fork - Sec 8 T38n R18w	73032	6.5	Good	5.39	Good	21	52	57	34
Hay Creek 20 m US Borg Rd.	10042528	7.42	Good	6.1	Fair	23	1	9	74
Unnamed stream 10m DS of Lundquist Rd.	10041943	3.82	Fair	6.73	Fairly poor	17	6	29	38
Whiskey Creek 110m DS CTH D	10037789	6.13	Good	5.92	Fair	31	17	10	55
Unnamed stream 155 m DS North Rd	10042428	2.18	Poor	4.6	Good	13	20	23	16
Unnamed stream 3 m US Fossum Rd	10042429	3.08	Fair	6.39	Fair	17	10	18	89

(light blue)	low iron site
(yellow)	medium iron site
(peach)	high iron site
(white)	non-similar substrate sampled

Macroinvertebrate index of biotic integrity (MIBI) values range from fair to excellent. Hilsenhoff biotic index (HBI) values range from fairly poor, indicating significant organic pollution, to excellent, indicating no apparent organic pollution. "Organic pollution" in this area probably reflects lowered dissolved oxygen concentrations due to wetland influence. Species richness ranges from 13 to 32.

Macroinvertebrate sample results are related to stream iron concentrations in table 7, below. The two sites with non-similar substrates were eliminated from this evaluation. Average MIBI values do not show significant differences related to stream iron concentrations. The MIBI is insensitive to iron concentrations, since it was developed primarily to detect differences due to human influences, such as the intensity of land use development. These influences are fairly low in the streams sampled.

Macroinvertebrate parameters that do show differences related to stream iron concentrations are shown in table 7. Parameters showing significant differences are:

- % Dipteran individuals
- HBI
- % EPT individuals (ephemeroptera, plecoptera, trichoptera)
- % Chironomid indivduals
-

The differences shown by these parameters in high iron concentration streams are commonly interpreted to indicate declining water quality. Two additional parameters are close to being significantly different - %filterers and % scrapers. Reductions in these parameters are also commonly interpreted to indicate declining water quality. A larger sample size might produce significant differences in these two parameters.

Table 7. Macroinvertebrate Parameter Differences Related to Iron Concentrations

MACROINVERTEBRATE PARAMETER STATISTICS	STREAM IRON CONCENTRATION LOW (n = 4)	MED (n = 4)	HIGH (n = 3)	NOTABLE DIFFERENCES
MIBI average	5.44	6.17	5.79	NO SIGNIFICANT DIFFERENCES
MIBI standard error	1.75	0.54	1.05	
% Dipteran individuals average	38.35	42.75	82.43	HIGH IRON SITES SIGNIFICANTLY HIGHER THAN MEDIUM AND LOW IRON SITES
% Dipteran individuals standard error	11.30	14.82	8.86	INCREASING AVERAGE % DIPTERA WITH INCREASING IRON CONCENTRATION
Species richness average	20.5	26.25	23.67	MEDIUM IRON SITES SIGNIFICANTLY HIGHER THAN LOW IRON SITES
Species richness standard error	1.04	2.29	4.06	
HBI average	5.51	4.92	6.25	HIGH IRON SITES SIGNIFICANTLY HIGHER (POORER) THAN MEDIUM IRON SITES
HBI standard error	0.55	0.84	0.25	
% EPT individuals average	53.50	49.75	8.00	HIGH IRON SITES SIGNIFICANTLY LOWER THAN MEDIUM AND LOW IRON SITES
% EPT individuals standard error	15.81	16.15	4.73	DECREASING AVERAGE % EPT WITH INCREASING IRON
% Chironomid individuals average	19.50	24.75	55.67	HIGH IRON SITES SIGNIFICANTLY HIGHER THAN MEDIUM AND LOW IRON SITES
% Chironomid individuals standard error	7.05	9.98	4.73	INCREASING AVERAGE % CHIRON WITH INCREASING IRON
Shannon diversity index average	2.63	3.15	3.23	NO SIGNIFICANT DIFFERENCES
Shannon diversity index standard error	0.23	0.18	0.43	
% Scrapers average	4.75	3.00	0.67	NO SIGNIFICANT DIFFERENCES
% Scrapers standard error	3.82	2.12	0.33	
% Filterers average	48.25	53.25	20.00	NO SIGNIFICANT DIFFERENCES
% Filterers standard error	24.13	26.63	6.66	
% Shredders average	11.50	15.50	10.00	NO SIGNIFICANT DIFFERENCES
% Shredders standard error	4.73	10.56	8.02	
% Gatherers average	33.50	24.25	43.67	HIGH IRON SITES SIGNIFICANTLY HIGHER THAN MEDIUM IRON SITES
% Gatherers standard error	17.73	4.35	9.70	

Wood River Mussel Surveys 2003 - 2011

Mussel surveys conducted on the Lower Wood River during 2003 to 2011 (Berg 2012) found a healthy mussel population was present. The 2003 survey at 16 Wood River sites found 16 live and 3 relict mussel species. Seven of the sites were downstream of CMWA drainage influence.

A site below the Memory Lake dam, which is influenced by CMWA drainage, had the highest mussel densities and the most mussel species. At that site, over 200 mussels were found in the hundred 0.25 m^2 quadrants sampled in both 2005 and 2011. Seventeen to twenty live mussel species were found.

Similar surveys were done on eight other Wisconsin tributaries of the St. Croix River (including the Namekagon River). The Wood River had more mussel species than any of the other eight tributaries surveyed. The Memory Lake dam site had more mussel species than any site on the other tributaries.

Stream Fish Communities

Fish index of biotic integrity (IBI) ratings for the 28 stream sites surveyed near the CMWA are shown in figure 32 (see figure 8, p. 12 for site names). Four different IBI's were used depending on stream size or thermal regime (Lyons et al. 1996, Lyons et al. 2001, Lyons 2006, Lyons 2012). Figure 33 shows the results for number of species, and number of fish captured per 100 meters. Detailed fish survey data and natural community assessments (Lyons 2013) are contained in appendix 4.

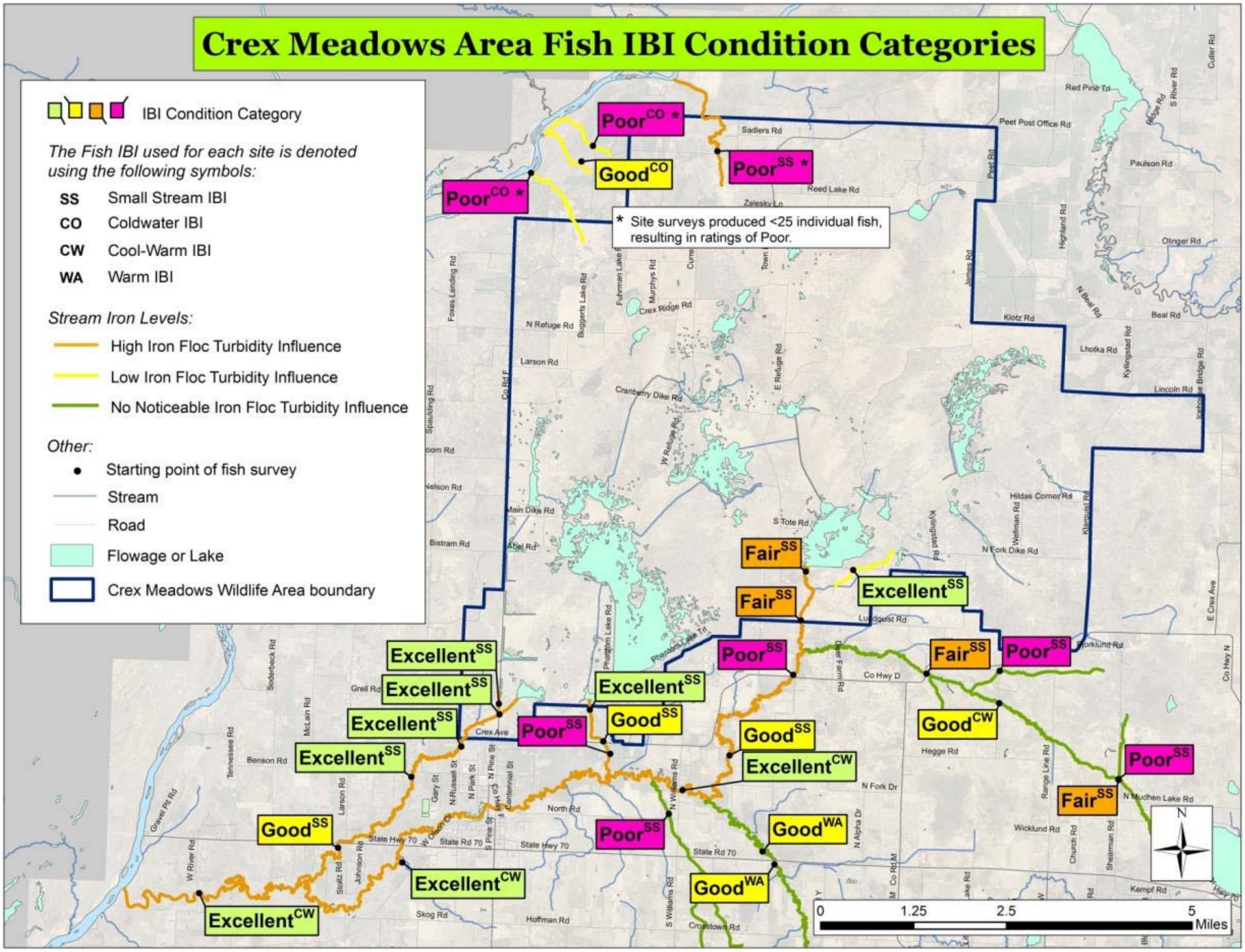
Most streams surveyed had substrates that are primarily sand or silty sand, so fish species dependent on gravel and/or cobble substrates were not present. Gravel/cobble substrates were present in the Wood River, downstream of Grantsburg, and in "North Creek". Ekdall Creek and "Nordstom Creek" had limited areas of small gravel substrate.

There is a dam on the Wood River at Memory Lake in Grantsburg. The dam is a barrier to upstream fish movement and may influence the distribution of some fish species.

Two to five sites were surveyed on each of the three main drainage streams on the south side of CMWA (Hay, Whiskey, and "North Fork" Creeks). These streams have high iron concentrations, high levels of iron floc turbidity, and low transparency. The "small stream" IBI was applied to all sites on these streams. IBI's were similar to, or better than other comparable low iron level streams in the area. Species richness and capture rates were also similar to, or better than other comparable low iron level streams in the area.

Hay Creek, with the highest iron concentrations of any area stream, had good to excellent small stream IBI's. However, the lower 1.5 miles of Hay Creek is identified as a class II trout water in "Wisconsin Trout Streams" (WDNR PUB-FH-806-2002). The classification is based on a stream survey from 1964 which found 16 brook trout present in a 1,500 feet segment upstream of STH 70. The trout included 4 year classes and had lengths ranging from 2.8-14.3 inches. No trout were found in the 2014 survey downstream from STH 70. An additional fish survey was done in 2015 for a 430 m segment upstream of Larson Road (shortly above STH 70) which also found no trout present. Additional flowages and drainage ditches were constructed in the Hay Creek watershed after 1964. These have probably resulted in increased iron turbidity levels in Hay Creek which may have caused the elimination of the trout population.

Figure 32.

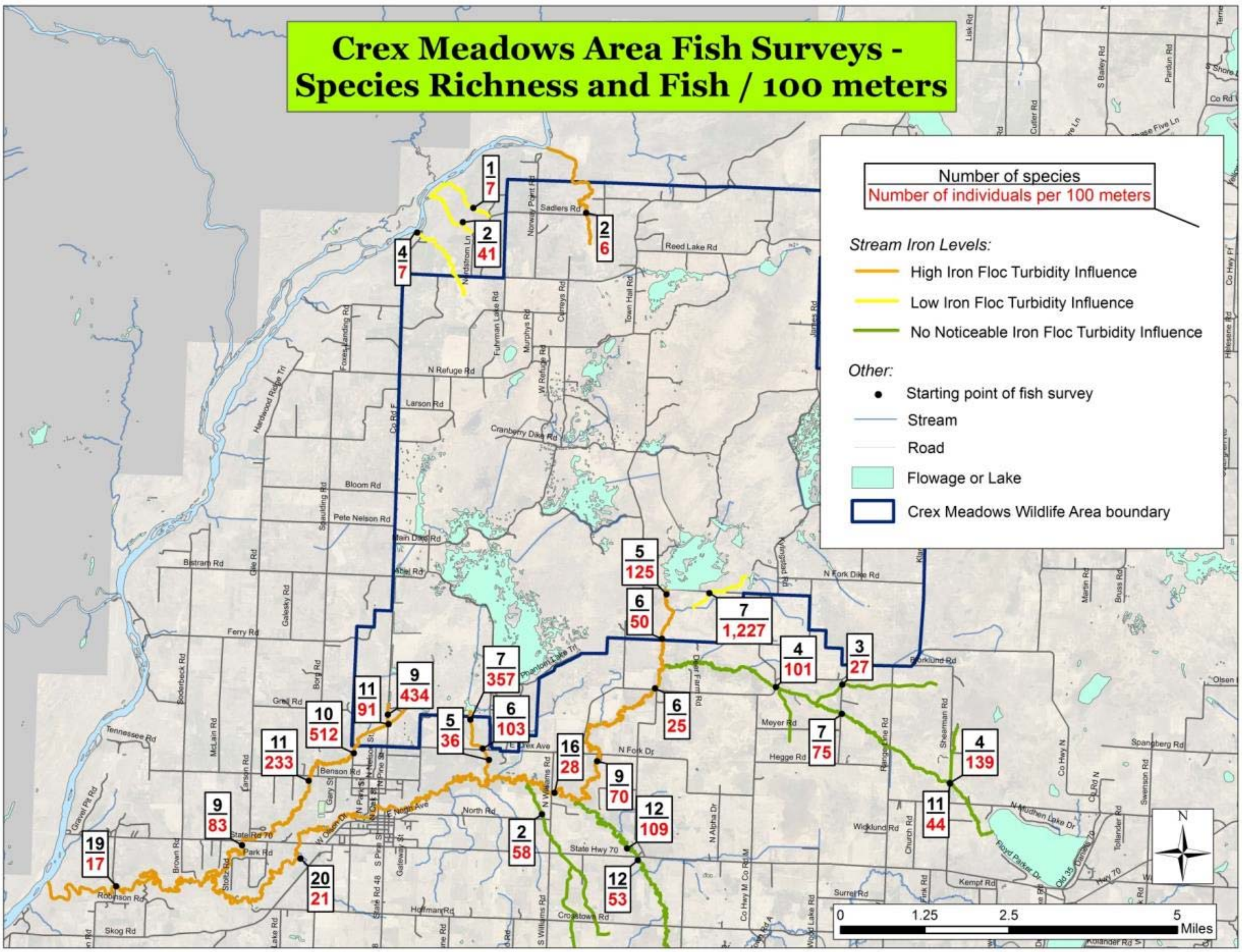


Hay Creek sites also had moderate species richness (9-11 species) and moderate to high capture rates (83-512 fish/100 m). Fish communities indicated "cool-warm headwater" was the appropriate natural community. Two of the five sites had no intolerant individuals present, which is atypical for cool-warm headwaters. Occasional low dissolved oxygen (D.O.) concentrations may account for this. Daytime D.O. concentrations as low as 1.7 mg/l were measured in Hay Creek downstream of CTH F. Fish species that comprised more than 20% of the catch at a site included central mudminnows, pearl dace, and johnny darters.

Whiskey Creek had variable IBI's, ranging from poor to excellent. Whiskey Creek sites had low to moderate species richness (5-7 species) and low to high capture rates (36-357 fish/100 m).

Fish communities indicated “cool-warm headwater” was the appropriate natural community. However, all three sites had no intolerant individuals present, which is atypical for cool-warm headwaters. D.O. concentrations are higher in Whiskey Creek than in Hay Creek, with a lowest measured daytime oxygen concentration of 3.4 mg/l. Daytime D.O. concentrations at the outfall of Whiskey Creek Flowage were as low as 0.7 mg/l. Occasionally low D.O. may have influenced the lack of intolerant individuals. Fish species that comprised more than 20% of the catch at a site included central mudminnows, brook stickleback, pearl dace, fathead minnows, and northern pike (juvenile).

Figure 33.



The two sites on “North Fork” Creek had fair IBI’s. Species richness was low (5-6 species) and capture rates were moderate (50-125 fish/100 m). Fish communities indicated “cool-warm headwater” was the appropriate natural community. However, both sites had no intolerant individuals present, which is atypical for cool-warm headwaters. D.O. concentrations are somewhat higher in "North Fork" Creek than in Hay or Whiskey Creek, with a lowest measured daytime oxygen concentration of 3.8 mg/l. Extensive wetland areas drain to the stream. Occasional low D.O. may have influenced the lack of intolerant individuals. Fish species that comprised more than 20% of the catch at a site included central mudminnows, and northern pike (juvenile).

Five sites on the Wood River had good to excellent IBI's. Fish communities at the two furthest upstream sites, with no noticeable iron turbidity, indicated "warmwater mainstem" was the appropriate natural community. Species richness (12 species) and catch rates (53-109 fish/100 m) were moderate at these two sites. Spotfin shiners comprised 60-77% of the catch at these sites, with no other species comprising more than 20% of the catch.

Fish communities at the three Wood River downstream sites, with higher levels of noticeable iron turbidity, indicated "cool-warm mainstem" was the appropriate natural community. Species richness (16-20 species) was high, but catch rates (17-28 fish/100 m) were low. High flows and turbidity probably had a large influence on the low catch rates. An August 28, 2008 fish survey at the River Road site found 24 species and had a catch rate of 76 fish/100 m compared to 19 species and a catch rate of 17 fish/100 m in 2014. It is likely that more normal base flows allowed more effective fish capture in 2008. Spotfin shiners and central mudminnows comprised more than 20% of the catch at the William Road site. No species comprised more than 20% of the catch at the two sites downstream of Grantsburg.

Three upstream sites on the North Fork Wood River, with no noticeable iron turbidity, had fair to good IBI's. Species richness (4-11 species) and capture rates (44-101 fish/100 m) were low to moderate. Fish communities indicated "cool-warm headwater" or "cool-warm mainstem" was the appropriate natural community. However, two of the sites had no intolerant individuals present, which is atypical for cool-warm headwaters. Fairly extensive wetland areas drain to the stream. Occasional low D.O. may have influenced the lack of intolerant individuals.

Three small streams north of CMWA (Ekdall, "Nordstrom", and "Bang" Creeks) are coldwater streams with brook trout present. These streams are mostly fed by springs discharging at the top of the clay layer along the slope to the St. Croix River. Deposits of oxidized iron are present at the springs, and stream substrates are coated with a thin layer of oxidized iron.

Very low catch rates (7 fish/100 m) resulted in IBI's defaulting to poor for Ekdall and "Bang" Creek. "Nordstrom" Creek had a better catch rate (41 fish/100 m) and a good IBI. Young of year (YOY) brook trout were present in Ekdall and "Nordstrom" Creeks, indicating successful reproduction. Some areas of gravel substrate, necessary for brook trout spawning, were present. No YOY brook trout were found in "Bang" Creek, and no gravel substrate was observed.

Iron Creek on the north edge of CMWA, with high levels of noticeable iron turbidity, had too few fish to apply the small stream IBI. Only 6 fish/100 m were captured. Cool-warm headwater is likely to be the appropriate natural community. Central mudminnows and pearl dace were the two species present. The stream segment surveyed at Sadler Road was observed to be dry in the summer of 2013. There are multiple beaver dams above and below the segment that may restrict fish movement and recolonization. There was also a non-wadeable beaver pond downstream of the stream segment surveyed, and most fish may have preferentially located in the pond.

Fish IBI's were developed largely to reflect the degree of human disturbance of a stream and its watershed. At CMWA typical human disturbances such as intense land use development are of minor significance, so the value of applying IBI's is uncertain.

To further assess fish populations in the CMWA non-metric multidimensional scaling (NMDS ordination) was applied to assess how fish assemblages reflect environmental gradients. This ordination reflects the similarities and differences in species composition and abundance across the stream sites.

An evaluation of environmental associations with fish assemblages found six significant influences along the two axes (figure 34). Axis 1 represents a gradient of water temperature, total phosphorus and conductivity. Axis 2 represents a gradient of pH, flow, and transparency.

The most apparent difference is along NMDS axis 1, where coldwater brook trout streams are separated from the sites containing cool and warm water fish assemblages. NMDS axis 2 separates most of the remaining variation among sites with cool and warmwater species.

In figure 35 a transparency gradient was added using the ordsurf function in program R. Transparency is a good surrogate for iron concentration and iron turbidity. Transparency vs. iron concentration plots for CMWA streams show good correlations with r^2 values around 0.85. The fish species occurring in greatest abundance in streams with high iron turbidity are pearl dace, finescale dace, fathead minnow, and brook stickleback.

It appears these species are well adapted to stream conditions resulting from high iron concentrations. Three of these species (pearl dace, finescale dace, brook stickleback) are insectivores. The fourth species (fathead minnow) is an omnivore. Examination of pearl dace stomach contents found that chironomids were commonly present. Perhaps the dominance of chironomid and other fly larvae observed in high iron concentration streams provides a food source that can be well utilized by these species.

Figure 34.

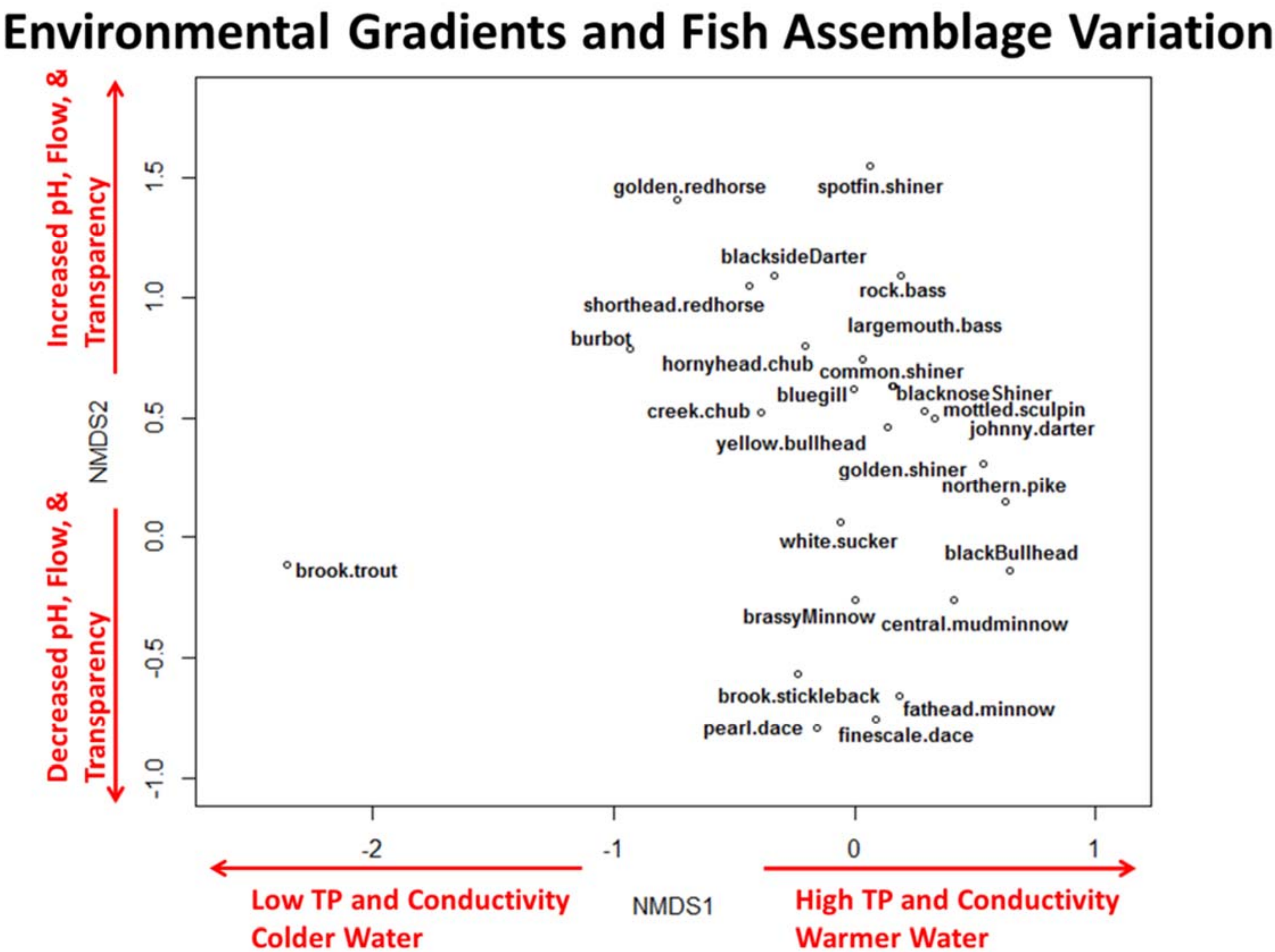
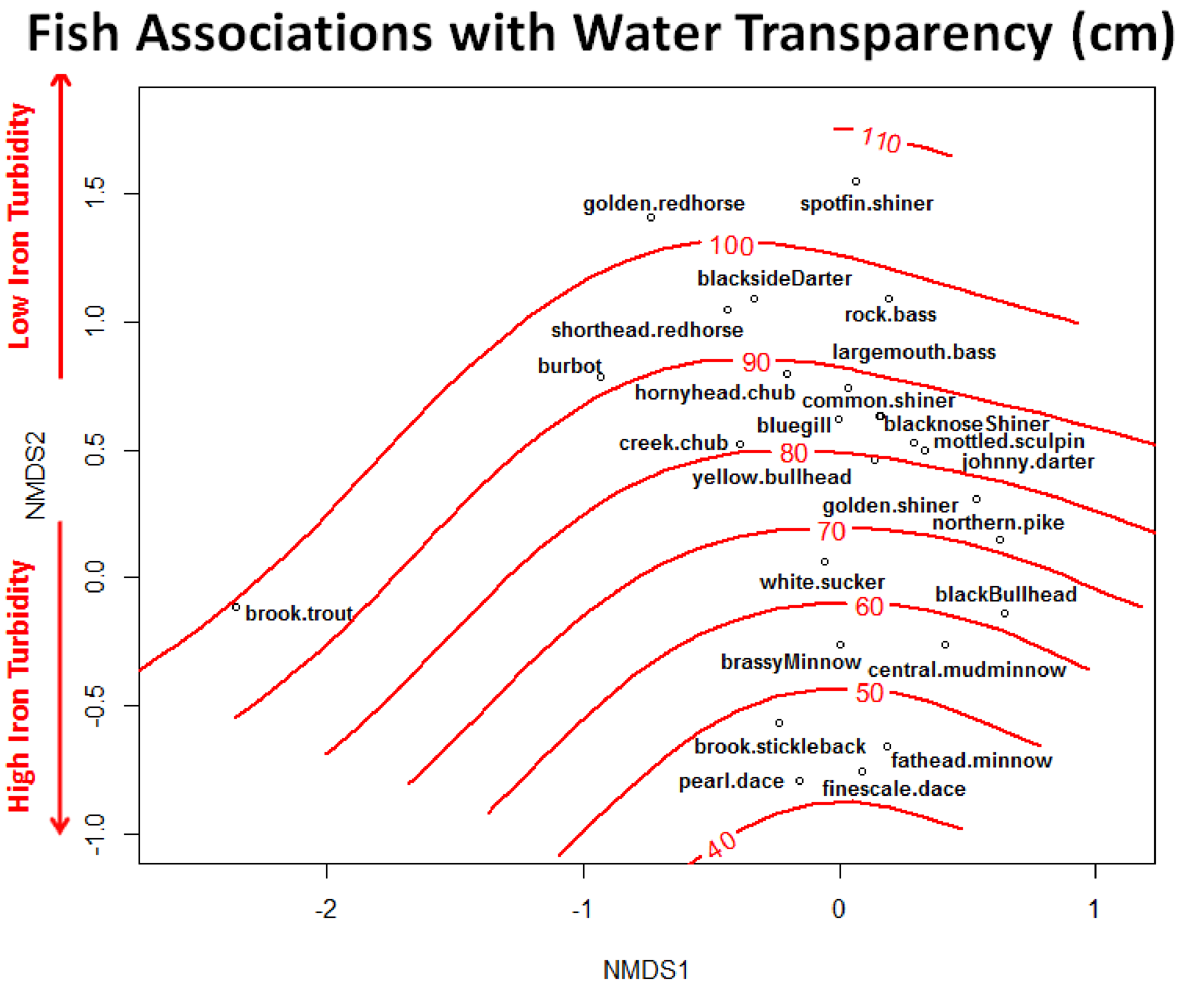

Environmental Gradients and Fish Assemblage Variation
Increased pH, Flow, & Transparency
Decreased pH, Flow, & Transparency
NMDS2
NMDS1
Low TP and Conductivity
Colder Water
High TP and Conductivity
Warmer Water
golden.redhorse
spotfin.shiner
blacksideDarter
rock.bass
shorthead.redhorse
largemouth.bass
burbot
hornyhead.chub
common.shiner
bluegill
blacknose Shiner
creek.chub
mottled.sculpin
johnny.darter
yellow.bullhead
golden.shiner
northern.pike
white.sucker
blackBullhead
brook.trout
brassyMinnow
central.mudminnow
brook.stickleback
fathead.minnow
pearl.dace
finescale.dace
1.5
1.0
0.5
0.0
-0.5
-1.0
-2
-1
0
1

Figure 35.



Fish Associations with Water Transparency (cm)
Low Iron Turbidity
High Iron Turbidity
NMDS2
NMDS1
1.5
1.0
0.5
0.0
-0.5
-1.0
-2
-1
0
1
110
100
90
80
70
60
50
40
golden.redhorse
spotfin.shiner
blacksideDarter
rock.bass
shorthead.redhorse
largemouth.bass
burbot
hornyhead.chub
common.shiner
bluegill
blacknose Shiner
creek.chub
mottled.sculpin
johnny.darter
yellow.bullhead
golden.shiner
northern.pike
white.sucker
blackBullhead
brook.trout
brassyMinnow
central.mudminnow
brook.stickleback
fathead.minnow
pearl.dace
finescale.dace

POTENTIAL METHODS TO REDUCE IRON TURBIDITY

Releasing Flowage Water to Improve Stream Water Transparency

Providing a continuous release of relatively clear flowage water was believed to improve downstream water transparency at Powell Marsh Wildlife Area (Kreitlow 2013). The flowage water release dilutes the more turbid stream water that has been supplied with iron by groundwater discharge.

A mixing test was run at CMWA on September 26th, to evaluate the potential for this approach. Water from the Erickson Flowage ("clear" water, transparency = 106 cm) was mixed with water from Whiskey Creek ("turbid" water, transparency = 26 cm). Results are listed below:

- 1 part clear to 1 part turbid = 43 cm trans
- 2 part clear to 1 part turbid = 52 cm trans
- 1 part clear to 2 part turbid = 33 cm trans
- 1 part clear to 3 part turbid = 30 cm trans

Stream water transparency could be increased by releasing water from clearer flowages. However, fairly high release rates would be needed to provide a substantially noticeable improvement in stream transparency. Average June – August transparencies for Hay, Whiskey, and "North Fork" Creek were 18.9 cm, 33.0 cm, and 35.4 cm, respectively. A transparency of about 60 cm is probably needed to provide a substantially noticeable improvement. A flowage water release that is at least double the summer base stream flow would be needed. It is unlikely such rates of release are feasible.

Dispersion/Redirection of Ditch Drainage

Ditches receiving discharge of groundwater that was generated at flowages often contain high levels of iron turbidity. These ditches usually flow directly to streams or flowages. Dispersing this water through wetlands may provide some potential for reducing the delivery of iron to downstream waters. The ability of the wetlands to capture and provide long term storage of iron would need further evaluation. The potential for most wetlands to develop anoxic conditions at times would probably prevent long term iron storage.

CONCLUSIONS

- CMWA flowage construction has resulted in the inundation of previously oxic iron-bearing sandy soils. This has allowed iron reducing bacteria to release iron from the soils by converting oxidized ferric iron to reduced ferrous iron.

- The reduced ferrous iron is transported with groundwater flow. Groundwater downgradient of flowages has high iron concentrations. As this groundwater discharges to streams the iron is oxidized and iron floc turbidity is produced.

- Increased iron concentrations have resulted in aesthetic degradation of the streams.

- Increased iron concentrations have resulted in declining quality of stream macroinvertebrate communities (less mayflies, stoneflies, and caddisflies, and more fly larvae).

- Increased iron concentrations in streams have some influences on fish communities. The loss of a brook trout population in the lower 1.5 miles of Hay Creek is probably due to increased iron floc turbidity and reduced transparency. Some forage fish species do well in streams with high iron concentrations (pearl dace, finescale dace, fathead minnow, brook stickleback). Fish IBI's, number of species, and fish density are similar in high iron concentration streams and low iron concentration streams.

- No feasible methods of controlling iron release and transport could be identified (other than flowage dewatering).

- CMWA flowages have high value for waterfowl, wetland species, and recreation. The environmental trade-offs need to be considered.

- Similar iron release and transport is likely to occur elsewhere where inundation of formerly oxic, iron-bearing soils has occurred.

- Consideration should be given to potential iron release and transport, and impacts to downstream surface waters and groundwater where ever new flowages are constructed.

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