

**The Vegetation and Hydrology of Impoundments after Dam Removal in
Southern Wisconsin**

by

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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

History and Use of Dams in Wisconsin

Dam removal has been increasing in the U.S. (Reisner, 1998), particularly in Wisconsin during the 1990's. There are large numbers of aging dams in the state that have become unsafe and no longer serve the purpose for which they were built. However, small dams and their associated mills were an integral part of early Wisconsin settlement and community activity.

Wisconsin has over 33,000 miles of rivers and streams (Addis et al, 1995). This abundant supply of water resources provided tremendous opportunity for the development of hydraulic power in the mid 1800's to early 1900's. Euro-American settlers began arriving in Wisconsin in mass during the 1850's and 60's. These early settlers most often chose town sites where dams could be built on nearby streams so they would have power for saw and gristmills (Apps and Strang, 1980). As a result, most early Wisconsin towns were built near sites where dams could be built. Some of the earliest dams included those in De Pere in 1809, Prairie du Chien in 1818, and Hebron in 1836. All major towns along the Rock River in Southern Wisconsin (Janesville, Beloit, Jefferson, Fort Atkinson and Watertown) were located at their respective sites because they had good water power potential (Hudson 1997, Smith 1908).

In 1840, the Mill Dam Act was passed by the State of Wisconsin, spurring the construction of many dams by granting water-use preferences to millers who built dams on non-navigable

streams. The act was passed to encourage dam building which was seen as a community necessity, providing power to produce flour and/or lumber for local use or sale. These mills often served as a center for farmers to do business and socialize. Power for the lumber industry was also a driving factor for dam construction, but more so in northern Wisconsin than in the south because of their proximity to the vast white pine forests. (Apps and Strang 1980). With the development of electricity and the concentration of milling industries in cities, the need for small mills dissipated. A few were converted to produce hydropower, some were maintained for use in ice production and as a source of water for fighting fires, but many fell into disuse by the mid 1900's.

In all, over 3600 dams have been built in Wisconsin, on every navigable river in Wisconsin and most small streams (Addis et al, 1995). Most of these dams were built between 1850 and 1950, especially from 1880-1900 (Smith, 1908). Today the use of dams for flour and saw milling is virtually non-existent, with the exception of a few sites maintained for historic preservation purposes (Johnson, 1995). About 200 larger dams, such as the Prairie du Sac dam, built specifically to produce hydropower, produce about 1% of the state's energy supply (Born *et al*, 1998).

Small dams¹, then, have strong ties with Wisconsin history and are valued by many people for this reason. However, dams have caused many ecological problems in rivers.

¹ *Small Dams are defined here as those with 15 feet or less of head, impounding 100 acre feet or less (based on Wisconsin Department of Natural Resources guidelines).*

Ecological Effects of Dams

Dams have contributed greatly to the alteration and degradation of stream/floodplain ecosystems in Wisconsin (Addis et al, 1995). They have many negative effects on river ecosystems and remain major obstacles to healthy river/floodplain ecosystems. The literature on the impacts of dams increased rapidly in the 1980's as their effects were clarified through research. Summaries of these impacts are provided in Stanford and Ward (1987), Bravard et al., (1985), Addis *et al*, (1996), and National Research Council, (1992). Generally, dams fragment river habitat and convert riverine habitat to lake-like areas. Dams often block upstream passage of fish, confining fish to downstream portions of the river. While the blocking of fish migration by dams has received the most attention, (the Pacific Northwest salmonid species are of particular interest), dams have caused severe declines in many other riverine species, including reptiles and amphibians that occupy riparian wetlands (Addis *et al*, 1996). Habitat for freshwater mussels may also become fragmented since their larval stages rely on fish for dispersal (Cummings and Mayer, 1992). Dams also alter water quality, raise water temperatures, and create eutrophic reservoirs. They change stream flow characteristics, alter floodplain-river interactions, change sediment transport above and below the dam, and block migration of aquatic species. Frequently large amounts of sediment are deposited behind dams, creating one of the main problems for dam and reservoir maintenance.

In Wisconsin, the vast majority of dams built in the state are small milldams that have a smaller ecological impact than the large hydroelectric dams in the Western U.S. While the

small millpond-forming dams in Wisconsin do have many of the negative ecological impacts described above, they usually impound only small areas (10-100 acres). Run-of-the-river dams impound even less water than mill dams, as they form more of an enlargement in the river than a distinct pond. Furthermore, the impact of dams in Wisconsin streams has been lessened by the fact that most streams in southern Wisconsin are also severely degraded by agricultural runoff and pollution. Dams in Wisconsin have blocked the migration of some highly migratory fish species, such as lake sturgeon and destroyed good trout streams by raising water temperatures. However in many Wisconsin streams, siltation and eutrophication have done as much or more to degrade streams, particularly in the heavily farmed watersheds of southern and central Wisconsin (Knox, 1977).

Riparian wetland and floodplain communities are also influenced by dams and dam removals, though research is less well developed than for rivers. Altered flood peaks and flow regimes, as well as the disconnection of streams from floodplains are all well documented effects of dams (Petts 1987, Stanford and Ward 1987, and Collier *et al* 1996). Dams change flood frequencies on floodplains and disconnect floodplains from the main channel by lowering peak flood flows downstream of the dam. Immediately upstream of the dam, wetlands are submerged or subject to higher water levels.

Dams always trap some sediment in their reservoirs (Morris, 1998). In a study of Wisconsin reservoirs, sedimentation rates were found to range from 0.16 – 2.9 cm/yr (Water Resources Management Workshop, 1981). At the upper rate of 2.9cm/yr or 1.14 inches/year, a 10 foot

deep reservoir would fill in with sediment completely in 105 years, the age of many Wisconsin reservoirs.

Bravard et al, (1985) and Decamps et al, (1988) examined the effects of civil engineering works on stream and floodplain communities, finding that dams can change floodplain hydrology causing irreversible changes to plant succession. Petts (1984) found that trees often encroach into herbaceous wetlands downstream of dams in response to changes in flood hydrology. More recently, Toner and Keady (1998) found that the reduction of peak flows along with augmentation of minimum flows has led to the succession of herbaceous wetlands into wooded wetlands. This effect was also noted in the Platte River by Johnson, (1994).

Dam Removal

Today small impoundments in Southern Wisconsin are most often maintained because of their role in property value, fishing, recreation and aesthetics. However, few of these aging dams serve any industrial function at this time. Because of the age (75-150 years) and lack of maintenance of many of these dams, many have fallen into disrepair. More importantly they often become safety hazards as they degrade, posing the threat of dam collapse and consequent mass flooding, property damage, and possible loss of life.

Dam Safety

To prevent potential dam failures, the Wisconsin Department of Natural Resources (DNR) inspects dams and orders unsafe dams to be repaired or removed. If a dam is determined to

be unsafe by the DNR or US Army Corps of Engineers, an order is given to repair or remove the dam. Dams in Wisconsin must be inspected at least every ten years (s.31.19, Wisconsin Statutes). If dams are found to be unsafe according to DNR standards, they must be repaired to meet the standards or removed (NR 333, Wis. Admn. Code). Because DNR recommendations themselves are not enforceable, dam owners often wait for a repair order to act.

Social and Economic Issues

The conflict between the costs and benefits of extant dams has led to difficult decisions regarding dam removal. Many aging dams in Southern Wisconsin are owned by small communities or by individuals who frequently do not want the dams removed. There are often strong feelings against removal since the millponds have historic, recreational and aesthetic values to many community members (Born *et al*, 1997 and 1998 and Esposito, 1999). As a result, relatively few dams have been removed. Since 1990, only 19 of 174 dams that failed safety inspection have been removed (Born *et al*, 1998). Although some dams have been removed to improve in stream conditions for trout (for example the dam in Cross Plains, Wisconsin), dam safety and the high costs of repair continue to be the main driving factors behind removal.

The cost of repairing the dams is generally 3 times the cost of removal ranging from \$30,000-3 million for repair (Born *et al*, 1998). Therefore, the removal option is usually more economically feasible for dam owners lacking funds, especially because the DNR may

provide financial support for removal . Despite the higher costs most dams are repaired, illustrating the affinity of many people for millponds, particularly riparian landowners.

However, because of the large number of aging dams, dam removal has become an increasingly frequent event in recent years, particularly in Wisconsin. There have been at least 30 documented dam removals in Wisconsin, 19 of which occurred in only the last eight years (Born *et al*, 1998). Dam removal has also been motivated by the increasing awareness of the negative impacts of dams on river ecosystems. Many groups, particularly the Wisconsin Department of Natural Resources and several non-profit organizations, have targeted dam removal as an important means of improving the health of river ecosystems.

Physical Process of Dam Removal

Once a dam is targeted for removal, the pond is first drawn down to reduce the threat of floods washing out the dam. At this point, most of the water in the pond is gone, and the river forms a distinct channel again. The dam will still hold back a greatly reduced head of water until the dam is removed. Some sites may remain drawn down for years until the dam is actually removed or repaired. The removal process involves demolition of the dam itself as well as sediment stabilization efforts in some cases. Demolition may be done with a wrecking ball or hydraulic hammer, although explosives are occasionally used in the removal process. Silt booms, silt fences, and catch-basins may be used to contain sediment during removal. In very few cases, pilot channels are constructed in an attempt to direct the flow of the channel following removal. Once the dam is completely removed, management of the site itself sometimes includes shaping of the stream channel, contouring of the floodplain and

seeding of the streambanks and floodplains. Frequently these last steps are not undertaken. The former pond area is left to revegetate itself and the stream channel left to cut its own channel.

Research on Dam Removals

Until recently dams were removed infrequently and there was little awareness of the issue. Because of this, ecological research on dam removal did not really begin until the 1990's. Perhaps the major concern following removal is the effect it will have on fish species composition and migration routes. Dam removal has been proposed as a way to improve populations of threatened salmon populations in the Northwestern and Northeastern U.S. by removing blockage to spawning grounds. Because several Snake River salmon species are facing extinction, research on dam removal or improved fish passage has increased in recent years, although little actual data is available on the affects of dam removal.

Kanehl *et al*, 1997 examined changes in fish habitat and populations after dam removal on the Milwaukee River in West Bend, Wisconsin documenting increased smallmouth bass and decreased carp populations. The presence of residual fine-particle sediment in streams can be a major obstacle to re-establishing healthy fish communities and may be a problem following dam removal (Grunder and Griffith 1983). Changes in stream temperatures, wetland habitat, and bird populations are also concerns (Shuman, 1995).

Perhaps the most pressing management concerns following removal are sediment transport and floodplain dynamics. First, sediments trapped behind the dam may contain toxins such

as heavy metals (Pb, Hg, Cd, or others) or PCB's (Shuman, 1995). Secondly large amounts of sediment may wash downstream if sediments aren't contained during dam removal.

Floodplain dynamics change after dam removal and may require re-contouring to assure connectivity between stream and floodplain and revegetation to prevent soil erosion (Shuman, 1995). Many environmental assessments have been done for proposed removals, examining the sediment transport issue (Shuman, 1995). In the removal of the Newaygo Dam in Michigan, it was estimated that 40% of the original volume of impounded sediment was washed downstream immediately following removal. It was estimated that it will take 50-80 years for this sediment to wash out of the system (Simons and Simons, 1991).

Altogether there have been very few published articles documenting the ecological effects of dam removals on river ecosystems. I found no studies on the effects of dam removal on floodplain or wetland ecosystems, although the problem of sediment in the former pond area has received some attention (Shuman, 1995). Generally, the benefits of dam removal have been well recognized, but actual biological and geomorphic conditions following dam removal have not been well documented yet. The floodplains in the former pond areas are vital areas for the success of dam removals, however. They serve as the primary access site to the river after dam removal for fishing, walking, or canoeing. Secondly, there is good potential for ecological restoration and the establishment of natural areas in these areas of freshly exposed land.

In these drained impoundment areas, there are many questions that are yet to be adequately described or understood. Understanding the physical and ecological dynamics of removed

dam sites will become increasingly important due to the large number of dams reaching old age and decrepitude, as well as the push by conservation groups to get them removed. Within the next 50 years there will be hundreds of these sites in Wisconsin and they will require management and/or restoration in order to realize their potential as natural areas, parks, or recreation sites.

1.2 STATEMENT OF RESEARCH QUESTIONS AND PROJECT OBJECTIVES

Previous research on dams has shown that dams alter stream and floodplain ecosystems.

Preliminary research shows that considerable change occurs following dam removal also.

Dam removal is known to restore many aspects of the stream ecosystem, such as stream flow regimes and fish migration routes. However, many questions remain unanswered. With the exception of fish populations, there has been little published research documenting ecological changes after dam removal, particularly regarding riparian vegetation.

Purpose of research

The goal of my project is to characterize the vegetation, hydrology, and sediment deposits at sites that had dams removed from 3 to 49 years ago. I plan to use this information to clarify the major management issues at dam removal sites and assist in the development of management and/or ecological restoration plans.

Project goals

1. To characterize plant communities and hydrology within former pond areas at sites of dam removal.
2. To compare recently removed sites and older sites in order to determine if there are any trends in plant succession and hydrology that may be applicable to other dam removal sites in Wisconsin.
3. To relate patterns in vegetation to hydrologic, soil and site history variables.
4. To identify constraints and opportunities for restoration and management at dam removal sites.
5. To identify some predictive factors for future removal sites to inform decision-makers of possible conditions after dam removal.

Research questions

I addressed the following specific questions in my research:

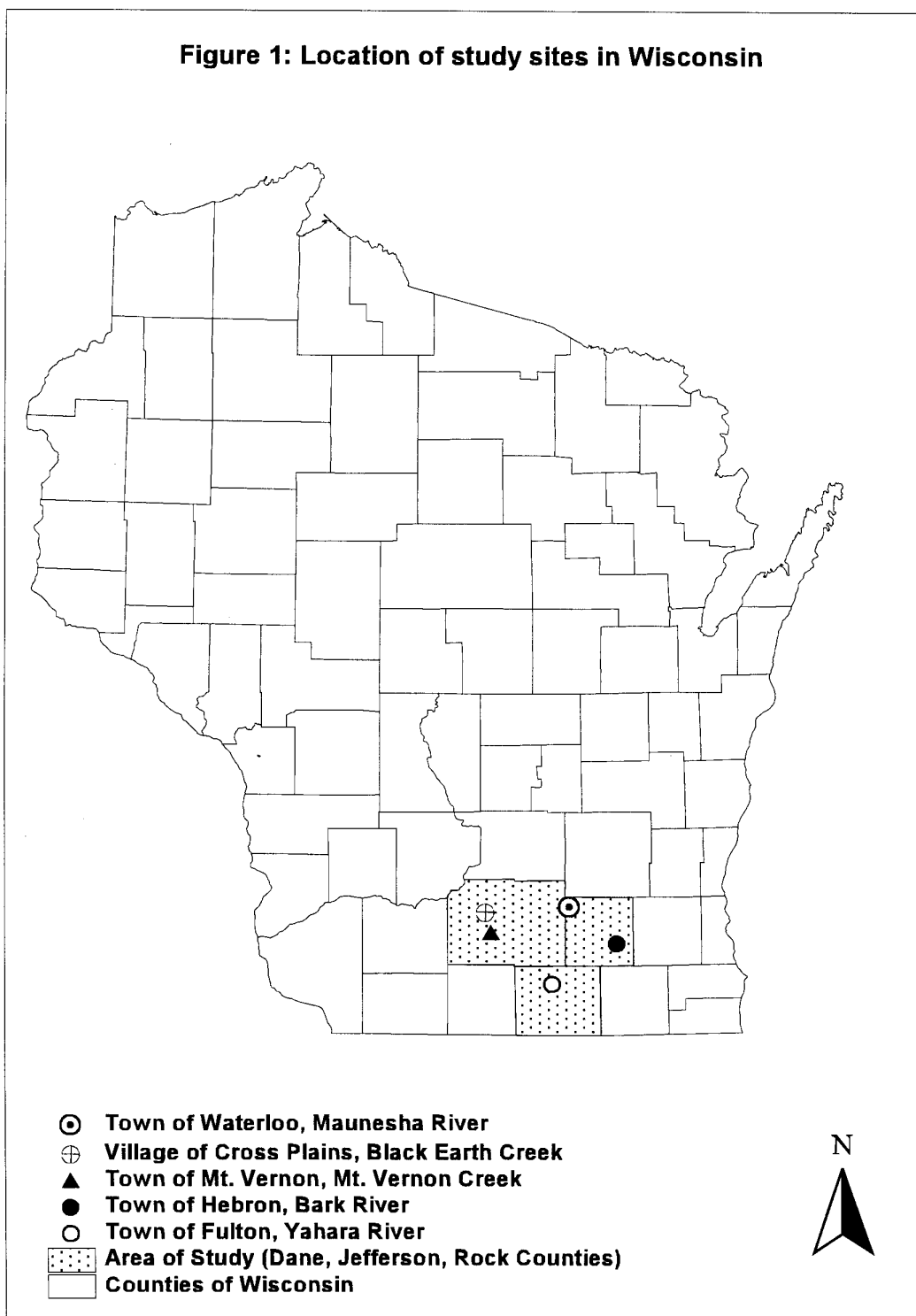
- What are the vegetation, hydrologic, and soil conditions in formerly impounded areas?
- How do vegetation, hydrology, and soil develop over time following dam removal?
- How does depth of sediment deposits, flood frequency, and groundwater discharge influence plant community composition?
- What are the major management and/or restoration issues in former impoundments following dam removal?

CHAPTER 2: METHODS

2.1 SELECTION OF SITES

I chose potential dam removal sites from the Wisconsin Department of Natural Resources retired and removed dam lists, limiting my choices to Southern Wisconsin. I consulted the retired dam list as well as the removed list because I learned that some of the retired dams had actually been removed. I then performed a reconnaissance survey to examine the suitability of various dam sites for research. In all, I visited 16 sites, 8 of which actually had dams removed. I chose five sites for further analysis, those at Fulton, Hebron, Waterloo, Cross Plains, and Mt. Vernon (Figure 1), using the following selection criteria:

- A. Sites that had been allowed to undergo unaltered plant succession since removal were given priority, in order to understand what plant species naturally thrive in drained pond areas.
- B. Variation in time since dam removal was required to document differences in vegetation, hydrology, and soil over time at similar sites. Time since removal ranged from 3 to 49 years. The dams at Waterloo, Fulton and Hebron had been removed for 3-5 years at the time of study while those at Black Earth Creek and Mt. Vernon were removed over 40 years ago.
- C. Variation in stream size was important for documenting scale-dependent responses of these ecosystems to dam removal. Study sites included small groundwater-fed trout streams (Black Earth Creek and Mt. Vernon with mean annual discharges of 10-30 cfs),

Figure 1: Location of study sites in Wisconsin

to medium sized rivers fed by primarily by surface water (the Yahara River at Fulton has a mean annual discharge of 371 cfs).

- D. Proximity to Madison was important since sites more than 50 miles away were not feasible for me to get to.
- E. Sites located on public land were given preference over privately owned sites, because of easier access to the site and more background information.

2.2 COLLECTION OF BACKGROUND DATA

Site History, Dam, and Pond Information

The primary source of background data on the dams was the Wisconsin Department of Natural Resources (WI DNR) dam files. Background data consisted of technical information concerning the date of dam construction, year of dam removal, uses of the dam while in operation, dam and pond dimensions, and safety inspection records. Historic management practices of the former dam and pond may have important effects on sediment levels at the site following removal, particularly peaking and flushing practices. The height of the dam, as well as pond dimensions were useful for explaining variation in the amount of sediment trapped by the reservoirs, the effects of which remained on the floodplain after dam removal.

Information on pre-dam and reservoir vegetation, soils, hydrology, and glacial geography were gathered from aerial photos, previous reports done on three of the sites (WI DNR, 1993 and Wilke, 1996), General Land Office (GLO) land surveys (1830's-1850's), county histories, and National Resource Conservation Service (NRCS) and Wisconsin Geological and Natural History Survey (WGNHS) soil maps.

USGS Stream gage & watershed data

United States Geological Survey (U.S.G.S.) stream gage data on stream discharge and annual instantaneous peak flows were used in calculating the flood frequency of the sites (USGS Water Resources Data, Years 1935?-1998 and USGS web site). I obtained the watershed areas at each study site from Heinrich and Daniel, (1985).

Other Background Information: Literature Review, Interviews

I reviewed the current literature on dam removal (see Chapter 1 and References) and conducted informal interviews. Informal interviews were done with some owners of privately owned sites at Hebron and Waterloo to gain information about former pond conditions, post-dam removal management and site usage (Kroll and Buschkopf, personal communication). On publicly owned sites (Mt. Vernon, Cross Plains, and Fulton), I communicated with the managers of the sites, users of the sites, and people knowledgeable about the history of the dam (Kroll, Pauly, Stewart, Haack, Virgic, and Kautz, 1998-1999, personal communications). Information about the sites is provided in Chapter 3: Site Descriptions.

2.3 VEGETATION METHODS

I sampled the vegetation over the period of June 1998 to August 1999. The goal of the plant survey was to characterize the present communities by determining the species composition, abundance as measured by frequency of all plant species, community structure, and relative amount of hydrophytic vegetation. Community structure is characterized by taxonomic groupings at the family level, life forms, and the percentage of native species.

A. Field Sampling Technique

I established 50 one square meter quadrat samples at each site and recorded the presence of a species in each quadrat. I located the quadrats along five evenly spaced transects running perpendicular to the stream, across the width of the former pond and into to the adjacent plant communities. I placed 45 of the quadrats within the pond area, and five on the edge of the former pond. These data enabled me to characterize the relative abundance of species and make comparisons between the adjacent communities and “drained pond” vegetation.

B. Classification of Vegetation

- *Community Characterization: U.S. Fish and Wildlife Service Hydrophytic Vegetation Categories*

The United States Fish and Wildlife Service (USFWS) has compiled a list of plants that occur in wetlands (USFWS, 1998). The list can be used to delineate wetlands by characterizing vegetation as hydrophytic or not. The USFWS classify species as being obligate (OBL), facultative wetland (FACW), facultative (FAC), facultative upland (FACU), and upland (UPL). (Table 1 provides definitions of these terms.)

Wetland researchers can use these categories to delineate wetlands or to simply characterize vegetation (see Kirkman et al, 1998). Plants classified as obligate wetland (OBL) or facultative wetland (FACW) are hydrophytic or “wetland” species ; those classified as facultative (FAC), facultative upland (FACU), and upland (UPL) are considered “non-wetland” species. Those sites with a majority of OBL and FACW species are designated as

Table 1: Explanation of USFWS plant categories		
Category	Abbreviation	Meaning
UPLAND	UPL	Almost always occur in non-wetlands (estimated probability > 99%) under natural conditions
FACULTATIVE UPLAND	FACU	Usually occur in non-wetlands (estimated probability 67 – 99%) but occasionally found in wetlands (estimated probability 1 - 33%)
FACULTATIVE	FAC	Equally likely to occur in wetlands (estimated probability 34 – 66%) or non-wetlands
FACULTATIVE WETLAND	FACW	Usually occur in wetland (estimated probability 67 – 99%)
OBLIGATE WETLAND	OBL	Occur almost always in wetlands (estimated probability > 99%)
(USFWS, 1996 and Eggers and Reed, 1996)		

sites supporting “wetland vegetation” (Wisconsin Coastal Management Program, 1995). I used this system to calculate percentages of hydrophytic vegetation versus non-hydrophytic vegetation. Percentages were calculated for each transect to facilitate comparison with soil cores taken along the same transects.

I used a weighted average of the USFWS plant categories to characterize the relative contribution of each wetland category within the site. Scores were assigned to each class: OBL=1, FACW+ =2, FACW =3, FACW- =4, FAC+ = 5, FAC =6, FAC- =7, FACU+ =8, FACU =9, FACU- =10, and UPL =11 (National Research Council, 1995). A “+” indicates greater adaptation to saturated conditions, a “-” indicates less adaptation. The total weighted score can then be used to characterize the hydrophytic status of the vegetation at each site. For example, suppose a plant community consists of the following species: Reed canary grass, Kentucky blue grass and stinging nettle with frequencies of 8, 9, and 4 found in 10 quadrat samples (Table 2). The frequency is then multiplied by the score for each

category. In the example found in Table 2, the total weighted average equals 4.13 which corresponds to a USFWS category of facultative wetland (-) or FACW- .

Species	Frequency	USFWS plant category and score	Frequency • score
Reed canary grass	8	FACW+ = 2	16
Kentucky blue grass	9	FAC- = 7	63
Stinging nettle	4	FACW- = 4	16
TOTALS	23		95

TOTAL WEIGHTED AVERAGE IN EXAMPLE = $95/23 = 4.13 = \text{FACW-}$

- *Functional Diversity*

Classification by Family and Life Form

I also grouped plants by family and life form (forb, vine, graminoid, tree, or shrub) to characterize functional diversity. I also compared the structure of the plant communities to Curtis (1959) and Eggers and Reed (1998) descriptions of native Wisconsin plant communities.

- *Species level*

Diversity, Density, and Exotic Species

I calculated species diversity at each site as the total number of species found in 45 1m^2 quadrats. The percentage of species that were exotic was calculated for each site as an indicator of disturbance at each site. Species density was calculated as the average number of species found in each 1m^2 quadrat.

2.4 SEDIMENT SAMPLING PROCEDURES

A. Characterizing underlying soil horizons

I collected soil cores on each site to characterize underlying soil horizons and to determine the depth of reservoir-deposited sediment. Using a 1 ½ inch bucket auger, I extracted cores at 4-8 locations to the point of refusal. Soil texture, structure, redoxomorphic features, and water-restraining layers were noted. The presence of water retaining layers, particularly clay, was noted because of their importance in retaining soil moisture and supporting wetland vegetation. As a means of verifying my soil core descriptions, I consulted the NRCS county soil surveys for Dane, Jefferson, and Rock counties (USDA, 1974, 1978 and 1979). For sites with dams removed more than thirty years ago, these surveys provided reliable general descriptions of soils lying in the former pond area. For more recently removed dams, the pond area was simply labeled "water" in the surveys since the pond had not been drained yet. At these sites the soil surveys were of little help, although I did examine the soils adjacent to the pond to see if any of these soils matched my soil cores in the underlying horizons of the pond area.

B. Surficial sediment deposit depth and type

In order to determine the amount and character of sediment deposited on top of the original floodplain soils, I extracted samples using a ½" soil probe. Soil cores were examined until the underlying soil horizons were detected. Generally the boundary was easy to detect because there was a distinct change in soil character below the pond-deposited sediment. The cores were taken along two transects: one perpendicular to the stream and one running parallel to the stream, in the middle of the former pond. A total of ten cores were taken at

each site, seven parallel to the stream to detect upstream gradients and three across the width of the former pond, to detect lateral gradients. I noted the depth of the surface sediment (if any) above the underlying soil horizons at the 10 locations mentioned above and calculated the average depth for each site. The 7 cores taken parallel to the stream were located on the plant sampling transects to facilitate comparison between sediment depth and vegetation.

Soil horizons at the streambanks were also examined since they provided a clear view of the underlying soil horizons.

Conditions of streambanks were recorded, noting collapsing or slumping banks. Exposed soil horizons on the streambanks were also used to obtain the elevation of the lower boundary of pond-deposited sediment: I used this elevation to determine whether the stream had cut through the pond sediments by the time of sampling.

C. Particle Size Analysis

To determine the textural class (e.g. silt loam or sandy clay) of the surface soil in the former pond area, one sample was withdrawn 300 feet upstream of the former dam location at each site. I sent samples to the UW-Madison Soil and Plant Analysis lab for particle size and organic matter content analysis. Due to the small sample size, these the samples were used primarily to verify the qualitative assessment of soil texture (See Appendix A for results of particle size analysis).

2.5 HYDROLOGIC METHODS

I investigated groundwater gradients, water table depths and flood frequencies to characterize the hydrology at these drained millponds. This basic data yielded some information on water table variability or hydroperiod, groundwater gradients in the upper 3-7 feet of soil, the horizontal gradient of groundwater towards the stream, and channel morphology. Combined with soil coring data, I was able to make some comparison of pre-dam and post-dam hydrology for depth to water table and flood frequency.

Depth to Water Table and Groundwater Discharge

I investigated groundwater conditions through the installation and monitoring of wells placed strategically at each site. The procedure for installation and monitoring was as follows:

1. I installed one set of wells and peizometers next to the stream bank and one pair on the outer pond edge. The bottom of the well and peizometer were placed at the same depths. I placed the wells so that the water table fell within the range of the open, slotted section of pipe.
2. Wells and peizometers were made of 1½" pvc pipe with very small slots cut in them. Slot size was determined by the texture of the soils in the pond, which was predominantly silt.
3. Wells were 5-7 ft in length with 36" of screen on bottom.
4. Peizometers were 5-7 ft in length with 8" of screen on bottom. The opening of all peizometers was approximately 28" below the opening of its paired well.
5. Both wells and peizometers were capped on top and bottom.

6. Depth to water was recorded and normalized by obtaining elevations of the pipes and referenced to a common elevation for comparison. Readings were obtained every one to two months over a period of seven to twelve months (June 1998 to September 1999).
7. To estimate the average elevation of the water table at points in a straight line between the two wells, I extrapolated by calculating a horizontal water table gradient between the two well locations using the following equation:

$$\frac{\text{elevation of water table at well 1} - \text{elevation of water table at well 2}}{\text{horizontal distance between the two wells}}$$

Well readings are recorded as depth of the water table below the ground surface. Accuracy of these measurements was determined to be $\pm 1/8$ of an inch. Groundwater gradients are recorded as the difference in elevation between the well and peizometer in each pair. If the water surface elevation was higher in the peizometer than in the adjacent well, then groundwater discharge was assumed. If the water level was lower in the peizometer than in the nearby well, then groundwater recharge was assumed.

Flood Frequency

In order to characterize the frequency and duration of flood events at my study sites, I first determined the discharge of water required to flood the former reservoir areas. The frequency and duration of these flood events could then be calculated using stream flow data from USGS stream gages at nearby locations.

1. Estimation of Pond-Flooding or Channel Capacity Flow

I estimated the flow required to flood the current floodplain of the area lying within the former reservoir using the velocity-area method. This discharge is referred to here as the channel-capacity discharge or pond-flooding flow rather than the bankful discharge. The term bankful discharge is usually associated with floods that occur frequently and actively shape the floodplain (Leopold, Wolman, and Miller, 1992). Because most of the floodplains in my research are elevated terraces that are not frequently flooded, the term bankful discharge was not used here. The channel capacity discharge was calculated using the equation, $Q=VA$, where Q = discharge (cfs), V = velocity ft/sec), and A = cross sectional area of stream (ft^2) (Dunne and Leopold, 1996). The discharge was recorded as cubic feet per second (cfs), to facilitate comparison with USGS gage records, which are recorded as cfs.

I took two measurements of cross sectional area at each site and averaged the two. Elevations were taken at least at 6 points across each cross section, while one width measurement was taken for each cross-section. The cross-sectional area was measured using the dimensions of the channel at the level which would flood the former pond. All relative depths were obtained using a standard stadia rod and transit.

To obtain an estimate of velocity, I used Manning's Equation: $(V=R^{2/3} S^{1/2} / n)$, where V = velocity, R = hydraulic radius, and S = energy slope, estimated by water surface slope. An "n" value was estimated using photographs of similar streams and guidelines for determining Manning's n values (Arcement et al, 1989, Coon, 1998, and Barnes, 1967). Slope (S) was estimated by measuring the water surface slope over a distance equal to or greater than 30

times the stream width (in this case, ranging from 350-2700 feet). The hydraulic radius (R) was obtained from cross-section measurements. The discharge (Q) was then obtained by multiplying $V \times A$.

2. Estimating frequency of channel capacity discharge.

Using the above calculation of the channel capacity discharge (Q), I calculated the frequency of that discharge using USGS stream gage data from the nearest available gage. Gage data was used only where gages were located near enough to the research stream that the watershed area of the gage site did not exceed the watershed area of the research site by more than two times (This applied to Mt. Vernon, Fulton, Hebron, and Black Earth Creek). The annual peak instantaneous flows for the gage nearest to my research sites were plotted using a Gumbel Type I Extreme Distribution (EV-1) (See Appendix B for a list of the data used in flood frequency calculations). To adjust for differences in watershed size between the site of interest and the gage, I used the following equation found in Conger, 1981:

$$Q_{ud} = Q_g (A_{ud}/A_g)^n$$

Where, Q_{ud} is the flow at the site near the gage

Q_g is the flow at the gage

A_{ud} = Area of watershed at the site

A_g = Area of watershed at the gage

n = exponent = 0.63 for Southeastern Wisconsin

The frequency of the channel capacity discharge could then be established by using the method of moments. An equation fitting the method of moments to an extreme value distribution was used to obtain an estimate of frequency or probability. In this case the Gumbel extreme value type I distribution, or EV-1 was used (Chow, 1988). I used an extreme value distribution to make flood frequency estimations because annual peak instantaneous flows are a type of extreme value representing the highest single momentary discharge recorded for each year (See Appendix B).

Regional Regression for sites with no USGS gages nearby

At Waterloo, located on the Maunsha River, no gages were located close enough to my study site to use the previous method. In order to estimate the flood frequency for the floodplain at this site, I used a regional regression equation described in Krug *et al.*, 1994:

$$Q_2 = (8.17A^{0.914})(S^{0.454})(ST^{-0.264})(SP^{-0.195})$$

Where, Q_2 = Two year flood

A=area of watershed at site

S= main-channel slope in feet per mile

ST= storage, in percent of basin area plus 1.0

SP= soil permeability of the least-permeable soil horizon in inches per hour

3. Duration of Flood Flows

I estimated the duration of flood flows by referring to the historical daily streamflow records kept by the USGS. Examination of daily hydrographs reveal the amount of time a certain discharge was exceeded and how long the floodplain was under water. While flood frequency estimations are based on instantaneous peak flows (extreme values), daily hydrographs plot discharges that are averaged over a given time interval, generally one hour. Because of the averaging, instantaneous peaks do not show up on many of the daily hydrographs. For example the largest flood ever recorded at Black Earth Creek in 1954 had a peak of 1750 cfs. The peak on the daily hydrograph only shows about 750 cfs, however. Apparently the flow of water only reached 1750 for a very short time, which would have to be less than one hour.

CHAPTER 3: DESCRIPTION of STUDY SITES

3.1 SITE BACKGROUND AND HISTORIES

Similarities of Sites

The five sites were similar in geographic location, climate, soil, hydrology, and condition after removal (Table 3a). Because most topsoil in this region is silt loam in texture, much of the sediment remaining in the former pond areas after dam removal consisted of silt, although in some ponds sand was more abundant than silt (as in Fulton and Waterloo). All of the sites had nearly level floodplain surfaces. All of the former ponds and dams were similar in size with ponds ranging in size from 10 to 81 acres and dams ranging in height from 9 to 14 feet (Table 3b). Some quantity of sediment remained on the floodplain at all sites. The similarities in climate, soil conditions, topography, and hydrology at all of these sites facilitated the comparison of sites.

TABLE 3a: SITE and STREAM INFORMATION

Site	Location (township, range, section)	River	Drainage Basin	Stream Order	Drainage Area at Site
Cross Plains, Dane County	T 7N, R 7E , S 3 NE ¼	Black Earth Creek	Lower Wisconsin River	III	22.4 mi ²
Fulton, Rock County	T4N, R11- 12E, S 13 SE ¼ , and S 18 SW ¼	Yahara	Rock River	III	530 mi ²
Hebron, Jefferson County	N ½ , T 5 N, R15 E, S 2 NE ¼	Bark	Rock River	III	163mi ²
Mt. Vernon, Dane County	R 7E, T 6 N, S 34 SW ¼	Mt. Vernon Creek	Sugar River	II	10.2 mi ²
Waterloo, Jefferson and Dane Counties	T 8N, R 13E, S 7 NW ¼	Maunsha	Rock River	III	90.4 mi ²

TABLE 3b: DAM and RESERVOIR INFORMATION						
SITE	Date dam was built	Date of dam removal	Pond size (acres)	Dam height (feet)	Pond length x width (miles)	Uses of dam and reservoir
Cross Plains	1856	1958-1960	8	9	0.50 x 0.04	Grist mill, ice and fire-fighting water supply
Mt. Vernon	1852*	1950	13	9	0.4 x 0.08	Saw mill, then flour mill
Fulton	1841	1993	49	14	0.68 x .17	Saw mill, grist mill, later hydroelectricity
Waterloo	1847**	1995	81	11	1.39 x 0.13	Grist mill, mill for malting co.
Hebron	1836** *	1994	28	10	0.4 x 0.25	Grist mill, saw mill
*A dam was built near the site in 1849 but washed out						
** Dam was rebuilt in 1915-1916						
*** This dam was rebuilt a couple hundred feet away in 1857						

Dam Uses and History

All of the study sites had very old dams, built originally between 1836 and 1856 (Table 3b). Some of these original dams were destroyed or rebuilt in later years, often at slightly different locations. The dates of the original dam construction remain important because they increased the total time-span when silt accumulation was occurring in the pond. These dams were generally made of concrete. Long earthen embankments or dikes would support the concrete abutments while wooden sluice gates were often used to control the amount of water passing through the dam.

Most of these dams served different purposes throughout their lifespan. Originally many of them powered sawmills (Hebron, Fulton, Mt. Vernon) until the late 1800's or early 1900's. Many of them also powered grist mills at later dates, often replacing the sawmill use. When electricity became widely used in the 1910's and 1920's the need for water-powered mills decreased. Over time, the mills became dysfunctional and the ponds were maintained for recreational and aesthetic reasons only. The exception was Fulton, which was converted in the early 1900's to produce up to 150 kilowatts of electricity to help the Janesville Electric Company during peak loads of power demand. The dam was not being used for power when it was removed in 1993 however.

Reasons for Removal

While the dam at Black Earth Creek may have been partially removed for the benefit of the trout fishery, the other dams were removed for economic or safety reasons. Mt. Vernon's dam was removed to make way for a new highway which was constructed over the location of the old dam. The old dam was serving no function at that point in time. In the early 1990's, the dams remaining at Hebron, Waterloo, and Fulton were removed for safety reasons. At that point the ponds were used primarily for fishing. The area right below Fulton dam was an excellent spot for walleye fishing because their migration upstream was blocked at that point. At Hebron, Green Isle Lake, as the impoundment was known, also supported a decent fishery with reported catches of bluegill and northern pike (Kroll, personal communication). These three dams were taken out largely because for economic reasons. The cost of removal was considerably less than the cost of repairing the aging dams.

Sedimentation of Impoundments

Sedimentation of impoundments can limit a pond's usefulness and aesthetic attraction (Morris, 1998), which can lend support to the dam removal option. Sediment is also one of the major management issues following dam removal. The quantity of sediment remaining in the pond area following removal is important because it may limit the potential for restoration of historic wetland areas, raise costs for stream restoration, and may contribute sediment to downstream areas.

Ultimately it is watershed and pond characteristics, such as pond trap efficiency and sediment yield, that determine how much sediment is deposited in a reservoir. For instance, watersheds in the non-glaciated Driftless Area of Wisconsin, including Mt. Vernon and Black Earth Creeks, have steep topography and highly erodible soils. They are known to have had much higher sediment yields and reservoir sedimentation rates historically than ponds in glaciated southeastern Wisconsin (where Waterloo, Hebron, and Fulton are located) (Hindall and Flint, 1970). Collier et al, (1963) found that the Mt. Vernon Creek watershed carried a very high 95.8 tons of suspended sediment per square mile of watershed per year, based on data gathered in the 1950's. While streams located in the glaciated areas had less sediment yield (25-50 tons/mi²/year), there were generally poor agricultural practices across the country between 1850 and 1950 leading to high soil loss and siltation of reservoirs. The importance of the historic sediment yield is this: After 100 or more years of receiving sediment loads at 25-100 tons per square mile of watershed per year, many small reservoirs in this region are nearly filled with sediment.

Dam management practices may have limited sediment deposition at Black Earth Creek and increased it at Mt. Vernon. Mt. Vernon had more than twice as much sediment as Black Earth Creek (average depth of 58.8 inches versus 25.5 inches), even though both ponds had similar size, location, topography, soil, and life-span (about 100 years). Peaking practices increase sediment deposition by shutting off the flow of water and turning the pond into a settling pool. Flushing and dredging operations remove sediment from the pond area. At Black Earth Creek, dredging was done several times with the pond in place and sediment flushing was practiced at high flows. In contrast, Mt. Vernon dam operators used peaking practices, to maximize available power. Management practices are only possible explanation for the disproportionately large sediment quantities found at Mt. Vernon.

In summary:

- Due to historically high soil loss rates and other factors, reservoirs in south-central Wisconsin most often contain much sediment.
- Reservoirs in the Driftless area are particularly prone to sediment problems
- Dredging and flushing operations may have reduced the amount of sediment that remained after dam removal at Black Earth Creek.

Dam Removal and Post-Removal Management

Attempts were made at most of the sites during dam removal to control the downstream flux of sediment from the pond. Several techniques exist for doing this, including the use of silt fences and larger silt booms which are more effective. Occasionally, containment “fences”

or trenches are dug downstream of the dam to capture sediment washing out of the pond area although this technique was not used at any of these sites. Following removal, generally no management has been done at the privately owned sites, while publicly owned sites have undergone varying degrees of management. Black Earth Creek and Mt. Vernon received a good deal of management because of the importance of the streams for the trout fishery. At both sites, considerable expense was also put into purchasing land for buffer strips along the streams.

Site histories are important for gaining an understanding of the conditions at the sites after dam removal. Dam usage practices such as peaking (shutting off the dam gates to block flow) as well as flushing practices may have a particularly strong influence on post-removal sediment levels. Peaking practices may increase sedimentation in reservoirs by shutting of the flow of water completely with the dam gates, allowing more sediment to settle out in the reservoir. Flushing on the other hand may decrease the amount of sediment in a reservoir. Dredging activities also have a strong role in determining post-dam removal conditions. Dredging is one of the most effective, though expensive, ways of removing sediment from a millpond. Black Earth Creek was the only one of the sites with reported dredging activities.

3.2 SITE DESCRIPTIONS

3.2.1 Cross Plains, WI Black Earth Creek (Figures 2a and 2b)

Physical Setting

- *Geography*

Located on the eastern edge of the unglaciated or Driftless Region of Wisconsin, Black Earth Creek is a tributary of the Wisconsin River (Clayton and Attig, 1997). The watershed has very steep topography, draining an area of 22.4 square miles at the old dam location. The site of the old millpond lies in the Village of Cross Plains just downstream of where Brewery Creek joins Black Earth Creek. It is bordered by a gravel road to the north and a set of railroad tracks to the south (Figure 2a).

- *Soils*

Soil surveys conducted in 1978 labeled soils in the pond area as Otter silt loam, an alluvial soil characteristic of poorly drained floodplain areas (USDA, 1978). The soil lying on the surface of the floodplain today was deposited in the former reservoir. There was relatively little sediment deposited here compared to the other sites.

- *Stream and Hydrologic Characteristics*

Black Earth Creek is a high-gradient trout stream fed by groundwater. While the baseflow in groundwater fed streams like this one are fairly constant, flood events in the Driftless Area are extremely flashy, with sharp rises in stream discharge occurring very quickly. The baseflow of Black Earth Creek was listed as 21.4 cubic feet per second (cfs) by Day et al., 1995, while the maximum peak instantaneous flow ever recorded was 1750 cfs in 1954.

Figure 2a: Map showing location of transects and wells at the former Cross Plains millpond on Black Earth Creek (B.E.C.), Dane County, WI



Figure 2a: Map showing location of transects and wells at the former Cross Plains millpond on Black Earth Creek (B.E.C.), Dane County, WI

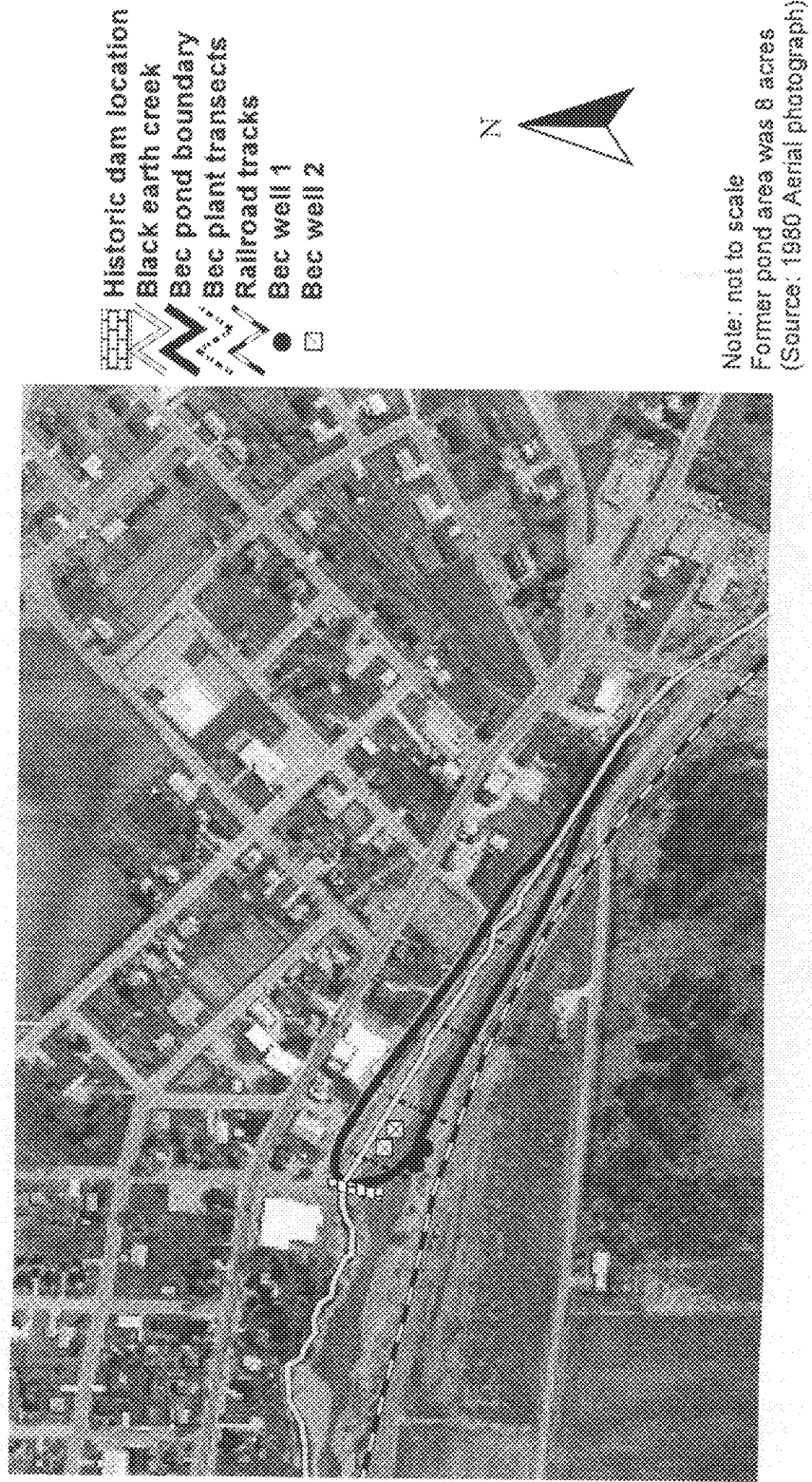


Figure 2b: Map showing location of plant communities at the former Cross Plains millpond on Black Earth Creek (B.E.C.), Dane County, WI

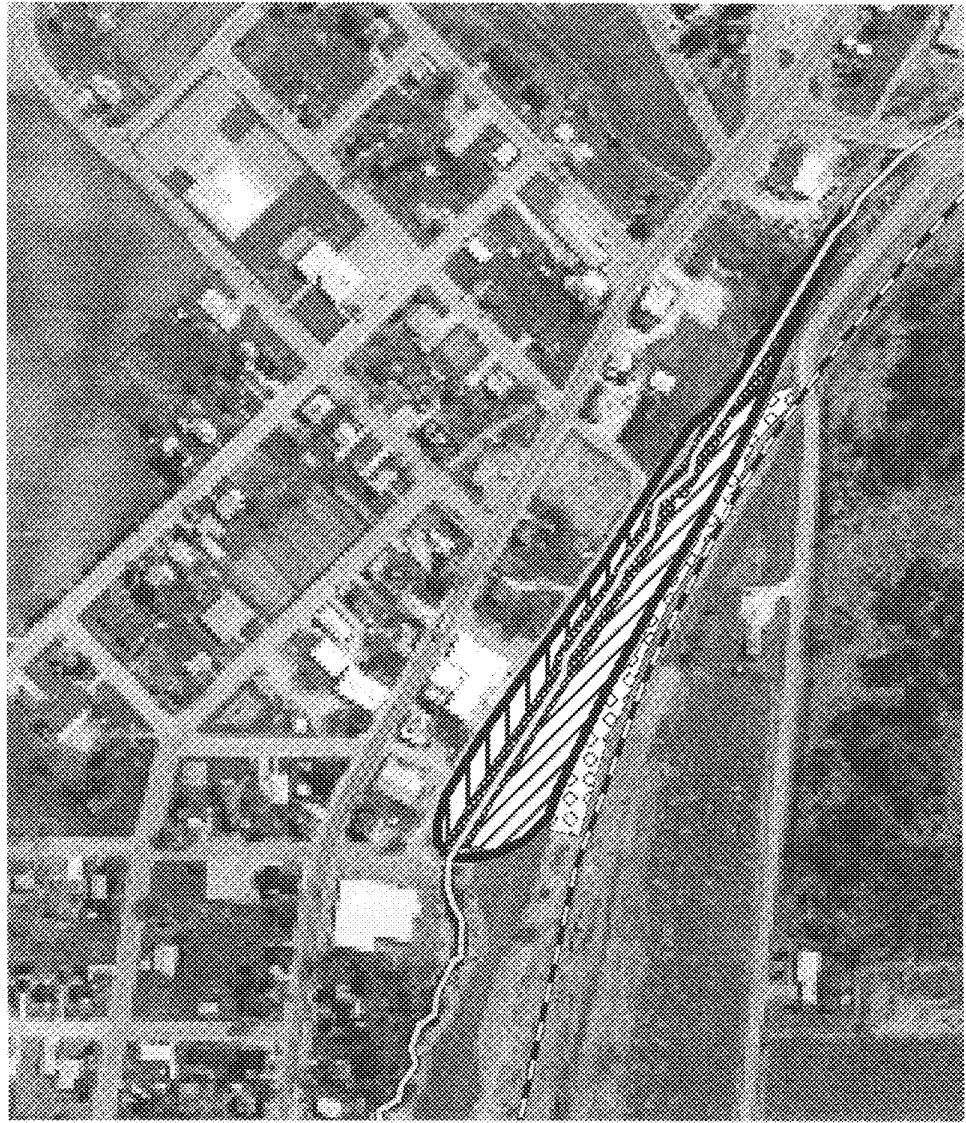
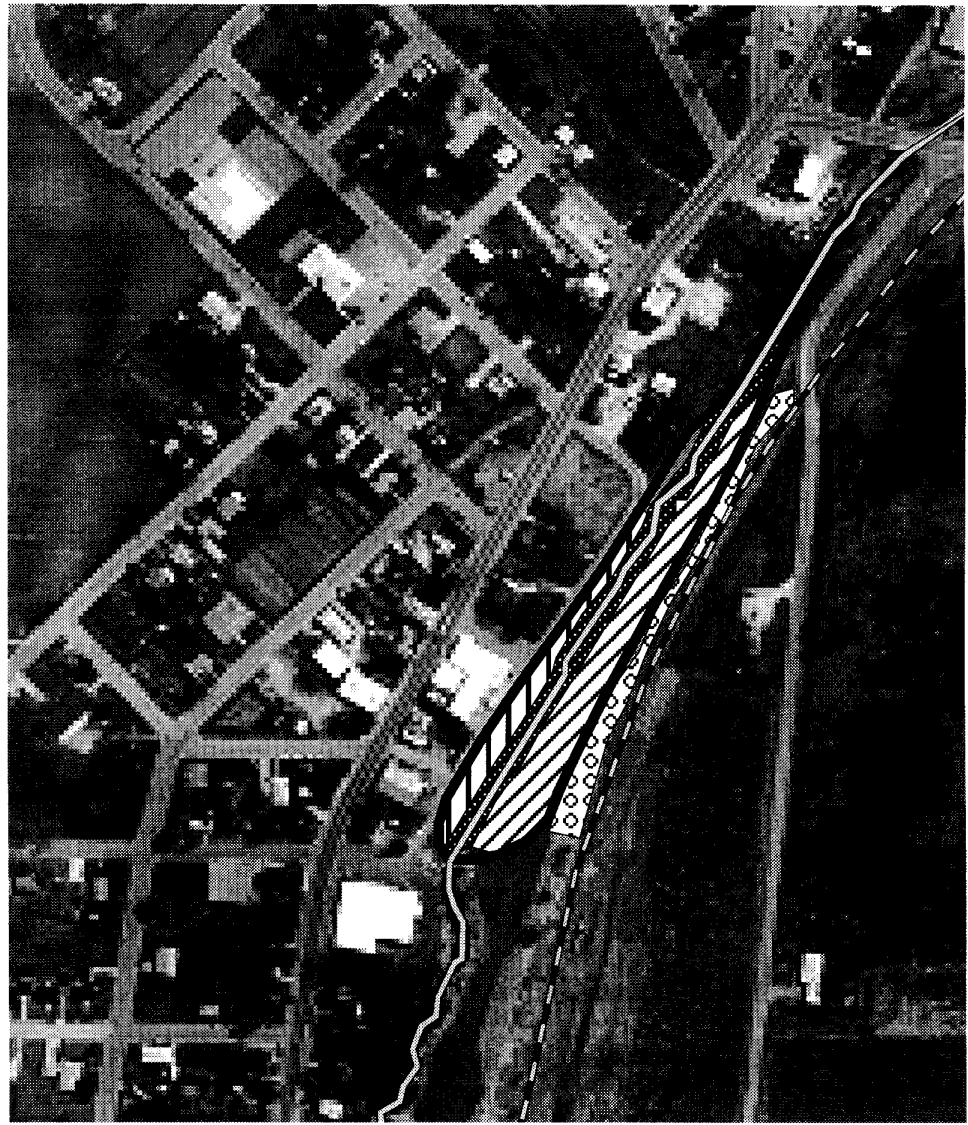


Figure 2b: Map showing location of plant communities at the former Cross Plains millipond on Black Earth Creek (B.E.C.), Dane County, WI



- Black earth creek
- Bec pond boundary
- Railroad tracks
- Reed canary/willows/forbs
- Prairie remnant
- Grasses/prairie species
- Road/lawn



Note: not to scale
 Former pond area was 8 acres
 (Source: 1980 Aerial photograph)

Flora and Fauna

- *Vegetation*

Historically the vegetation in the area was described as “prairie” in the 1830’s land surveys (Lyon, 1834). Nearby floodplain areas that were never impounded consist mostly of sedge meadows today. The vegetation in the former pond area today is very open and covered by mostly exotic “old-field” species with some native wet and wet-mesic prairie species (Figure 2b). Most species in the former reservoir area are facultative or facultative upland species. Exotic species such as Kentucky blue-grass and wild parsnip are very common. A remnant prairie/sedge meadow area has existed between the former pond and some railroad tracks since at least the 1940’s as evidenced by photos of the site. After several months with no mowing, many prairie species appeared and species diversity was high. Over sixty species were observed in both walk-through survey and quadrat sampling.

- *Wildlife*

Black Earth Creek supports an excellent trout fishery today of primarily brown trout, although some brook trout are present also. The stream supports diverse invertebrate and aquatic vegetation populations as well.

History and Public Usage

Currently the site is a community nature park owned by the Town of Cross Plains. The north side of the former pond area was paved over to make a road. People use the park for trout fishing, dog walking, bird watching, school field trips and other events. The dam was built in 1856 in the middle of the Town of Cross Plains to power a grist mill. It was abandoned, drawn down and then removed in 1961 (Table 3 and Figure 2a). Following grist mill usage,

it served as a source of ice for commercial use and as a water source for the fire department. During its operation from 1856 until at least the 1940's, the site was dredged several times and flushing of sediments was attempted many times (Virgic, personal communication). These factors may have limited the amount of sediment remaining at the site after dam removal. The dam was taken out 39 years ago to improve the trout fishery, as the reservoir had damaged the brown and brook trout populations in Black Earth Creek. Following removal the site was graded and some sand and gravel were added to firm up the surface of the park.

Post-Dam Removal Management History

The site was graded after removal and some sand and gravel was placed on the surface to firm it up. Currently the park is mowed about every two weeks by the Cross Plains Public Works Office. At times the vegetation has been allowed to grow up. When I sampled the vegetation it had been allowed to grow uncut for several weeks.

3.2.2 Mt. Vernon, WI, Mt. Vernon Creek (Figures 3a and 3b)

Physical Setting

- *Geography*

Like Black Earth Creek, Mt. Vernon Creek lies near the eastern edge of the unglaciated region. At the point of where the former dam lay, Mt. Vernon Creek has a watershed area of 10.2 square miles with very steep and rocky topography. The old millpond was located right in the town of Mt. Vernon, and is bordered by a forested ridge to the south and the town of

Figure 3a: Map showing location of transects and wells at former Mt. Vernon millpond on Mt. Vernon Creek, Dane County, Wisconsin

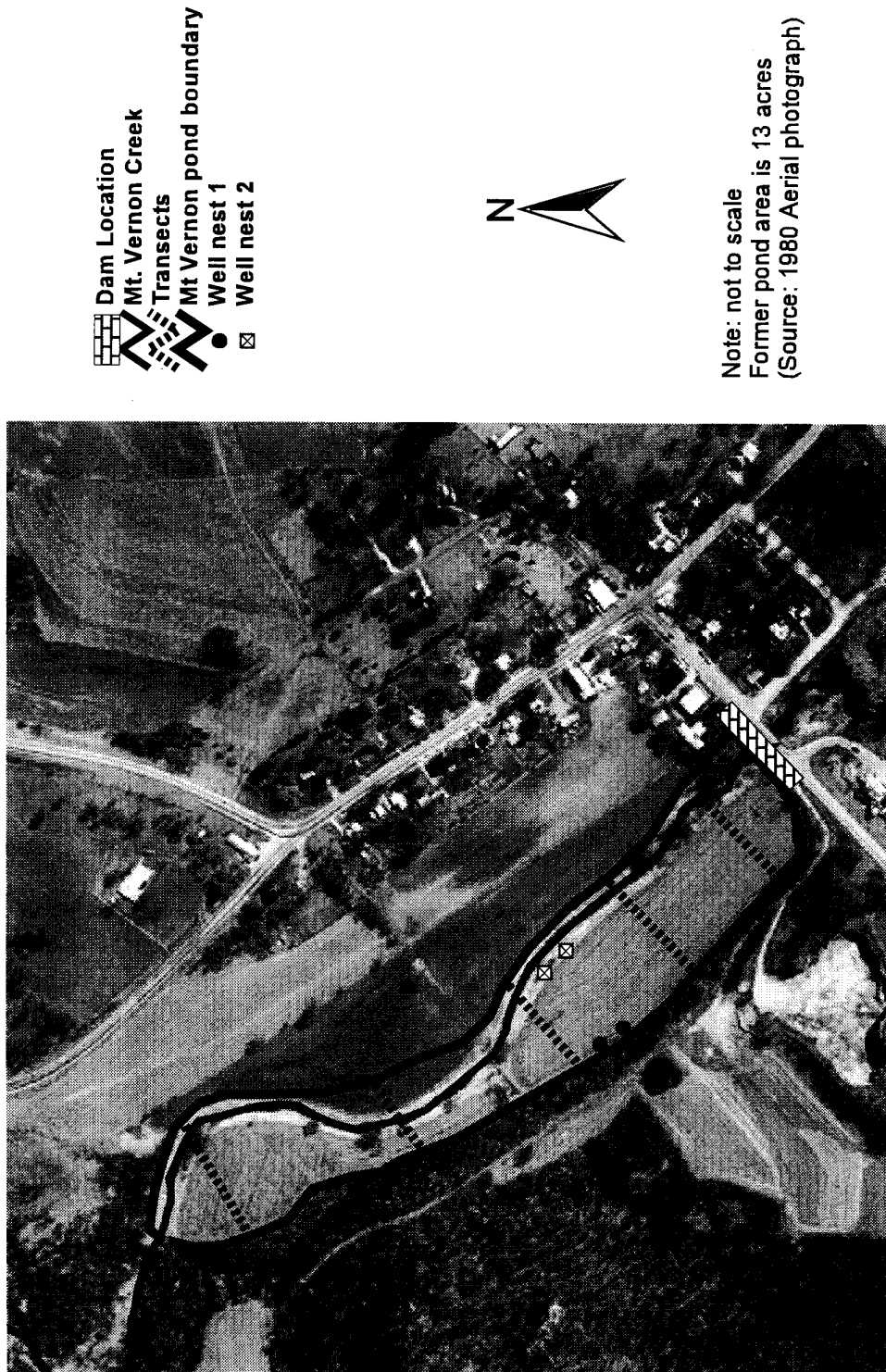


Figure 3a: Map showing location of transects and wells at former Mt. Vernon millpond on Mt. Vernon Creek, Dane County, Wisconsin

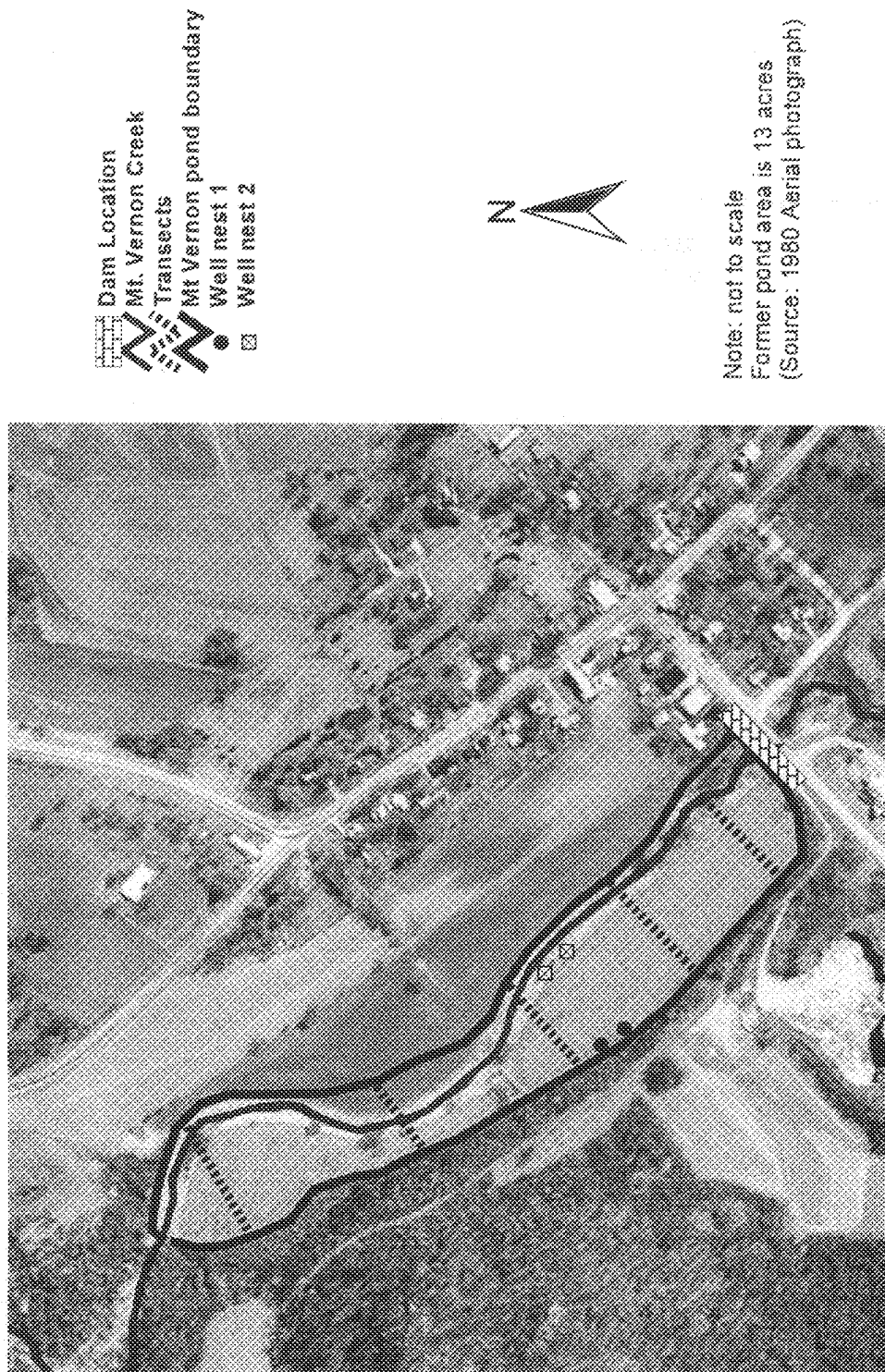


Figure 3b: Map of plant communities at former Mt. Vernon millpond on Mt. Vernon Creek, Dane County, Wisconsin

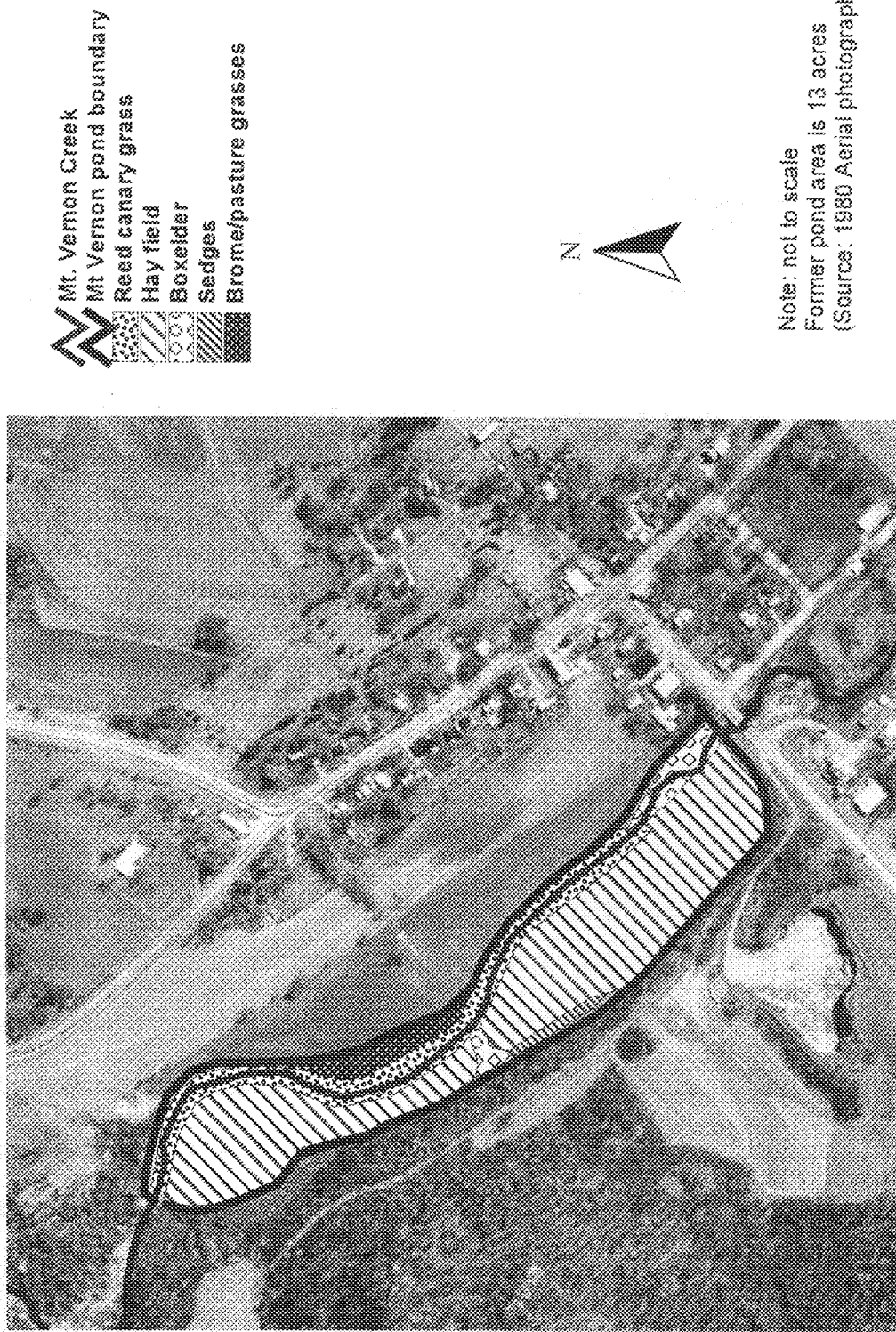
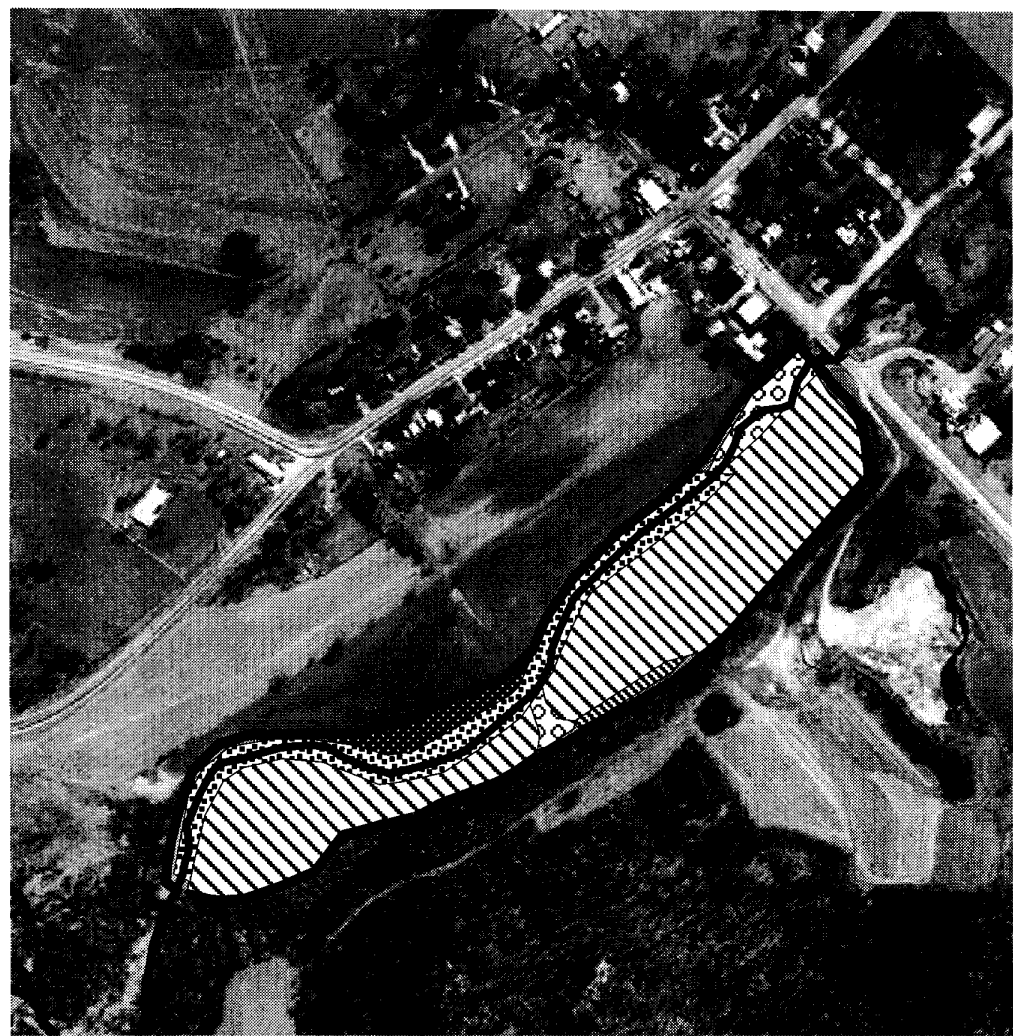


Figure 3b: Map of plant communities at former Mt. Vernon millpond on Mt. Vernon Creek, Dane County, Wisconsin



- Mt. Vernon Creek
- Mt. Vernon pond boundary
- Reed canary grass
- Hay field
- Boxelder
- Sedges
- Brome/pasture grasses



Note: not to scale
 Former pond area is 13 acres
 (Source: 1980 Aerial photograph)

Mt. Vernon to the north. The stream is seven miles long in total and drains into the Sugar River several miles downstream from the old dam site.

- *Soils*

Soil surveys conducted in 1978 labeled soils in and bordering the stream as Otter silt loam, an alluvial soil characteristic of poorly drained floodplain areas (USDA, 1978). On most of the floodplain, the soil is labeled Orion silt loam, a slightly better drained soil than Otter. These soils originated from sediment deposition in the former reservoir.

- *Stream and Hydrology Characteristics*

Mt. Vernon Creek is a small ground-water-fed trout stream. The stream's gradient has been estimated to be between 18 and 23.3 feet per mile, while the baseflow for the entire stream was listed by Day et al. (1995) as 19.7 cfs. Flooding in Mt. Vernon Creek, as the rest of the Driftless area is very "flashy" with rapidly forming large flood peaks that rapidly recede back to baseflow levels. Within the former pond area, a drainage ditch exists on the southern edge of the old pond. The ditch is not maintained at this time, but may still contribute to drainage of the site.

Flora and Fauna

- *Vegetation*

1830's land survey records described the Mt. Vernon area as hilly and rocky with burr oak openings dominating the uplands and some "marsh" in the lowlands near creeks (Miller, 1833). Today the vegetation consists of timothy (*Phleum pratense*), alfalfa (*Medicago sativa*), and clover (*Trifolium pratense*) grown for hay in the southwest half of pond (Figure 3b). On the north side of the stream, reed canary, sedges, and old field grasses dominate.

Near the base of the adjacent hill, some sedge meadow and wet prairie species exist where there is a very high water table and evidence of ground water discharge.

- *Wildlife*

The site supports excellent trout habitat and is one of the best trout streams in south-central Wisconsin. Aside from brook and brown trout, the floodplain is used by deer and as nesting sites for red-winged blackbirds.

History and Public Usage

The first dam in Mt. Vernon was built by George Britts in 1849 to power a saw mill (Lyon, 1834). This dam soon washed out and was replaced by a dam powering a grist mill in 1852. The dam was removed around 1950 when a new highway (Highway G) was built across the location of the dam. Aerial photos from July of 1937 show a very shallow millpond with very little open water. It seems likely that decreased reservoir depth may have limited the reservoir's usefulness by 1950. Dam removal improved the conditions for brown and brook trout and now the stream is one of the premier trout streams in Southern Wisconsin.

Currently the site is part of Donald Park, which is owned by Dane County Parks. This park is undergoing expansion to expand the buffer area for the trout stream. Part of the former pond along the stream is owned by the WI DNR. The south end of pond is leased to a farmer who raises hay on the site.

Post-Dam Removal Management History

The site was planted several years after dam removal in the 1960's by Madison school groups. Since then, parts of it have been leased out for farming, with buffer areas preserved

to protect water quality in the stream. The pond is mostly used for trout fishing, horse riding, and dog walking .

3.2.3 Waterloo, Mauneshia River (Figures 4a and 4b)

The Physical Setting

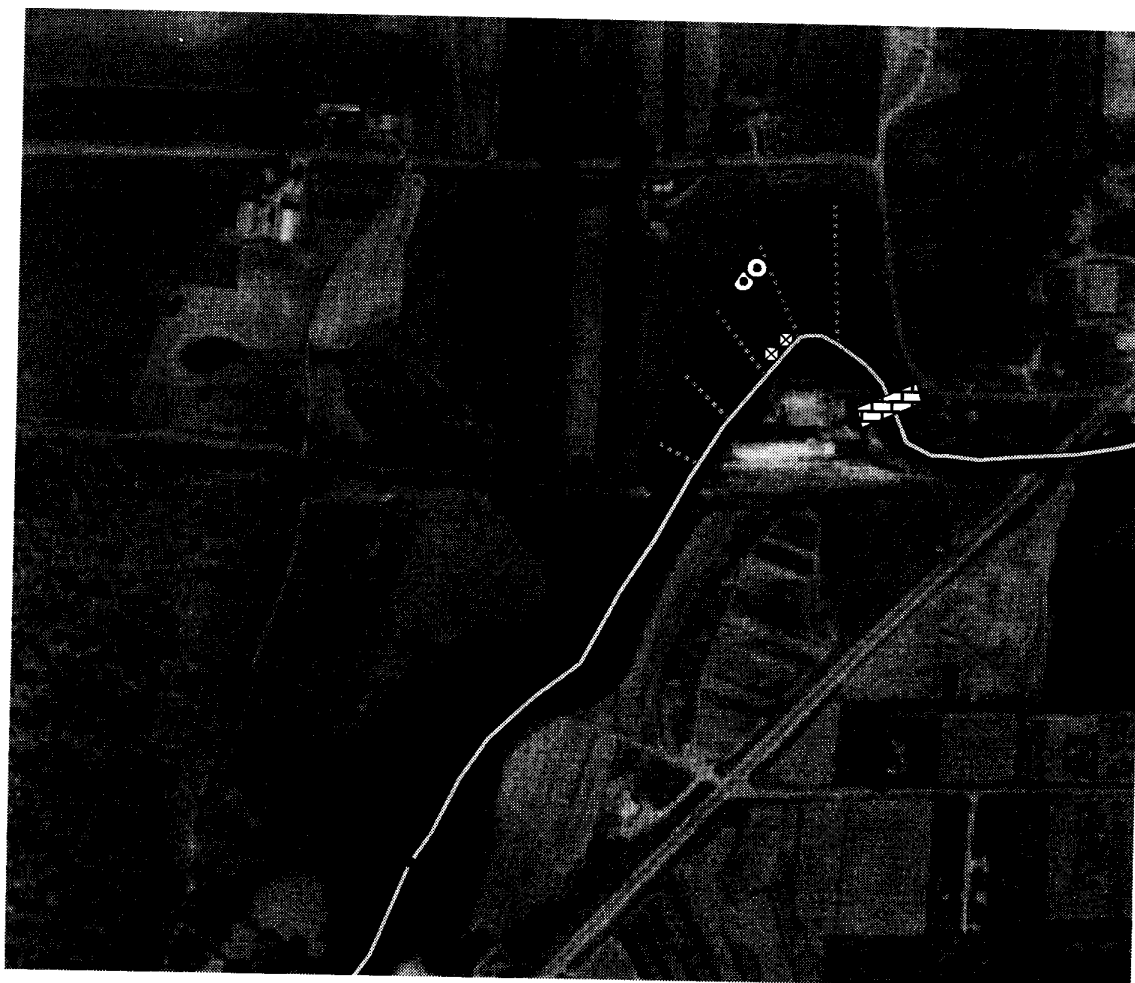
- *Geography*







The old Waterloo millpond lies in the extreme northwest corner of Jefferson County, with some of the pond overlapping into Dane County (Figure 4a). It lies in the glaciated region of Wisconsin in an area with numerous drumlins oriented in a northeast-southwest direction. The pond lies on glacio-lacustrine plains in between the drumlin fields. The Mauneshia River, a tributary to the Crawfish River, has a watershed area of 90.4 square miles at the removed dam site. Most of this watershed is agricultural land with high soil loss and a large amount of ditched and drained wetlands. As a result there have been numerous water quality and sedimentation problems in this stream.

- *Soils*

The lower pond area is located on lacustrine silt/clays lying between glacial drumlins (UW-Extension, 1966). In the large pool area of the former pond, on the extreme downstream end of the reservoir there was very little pond-deposited sediment (10.8 inches on average). However upstream of the pool area there appeared to be much larger quantities of residual sediment. The soil in the pond area was loamy in texture, consisting of slightly more sand than silt in particle size analysis (Appendix A). Outside of the pond, adjacent drumlins have silt loam soils, such as St. Charles Silt Loam (USDA, 1979).

Figure 4a: Map showing location of transects and wells at the former Waterloo millpond along the Maunsha River, Jefferson County, WI

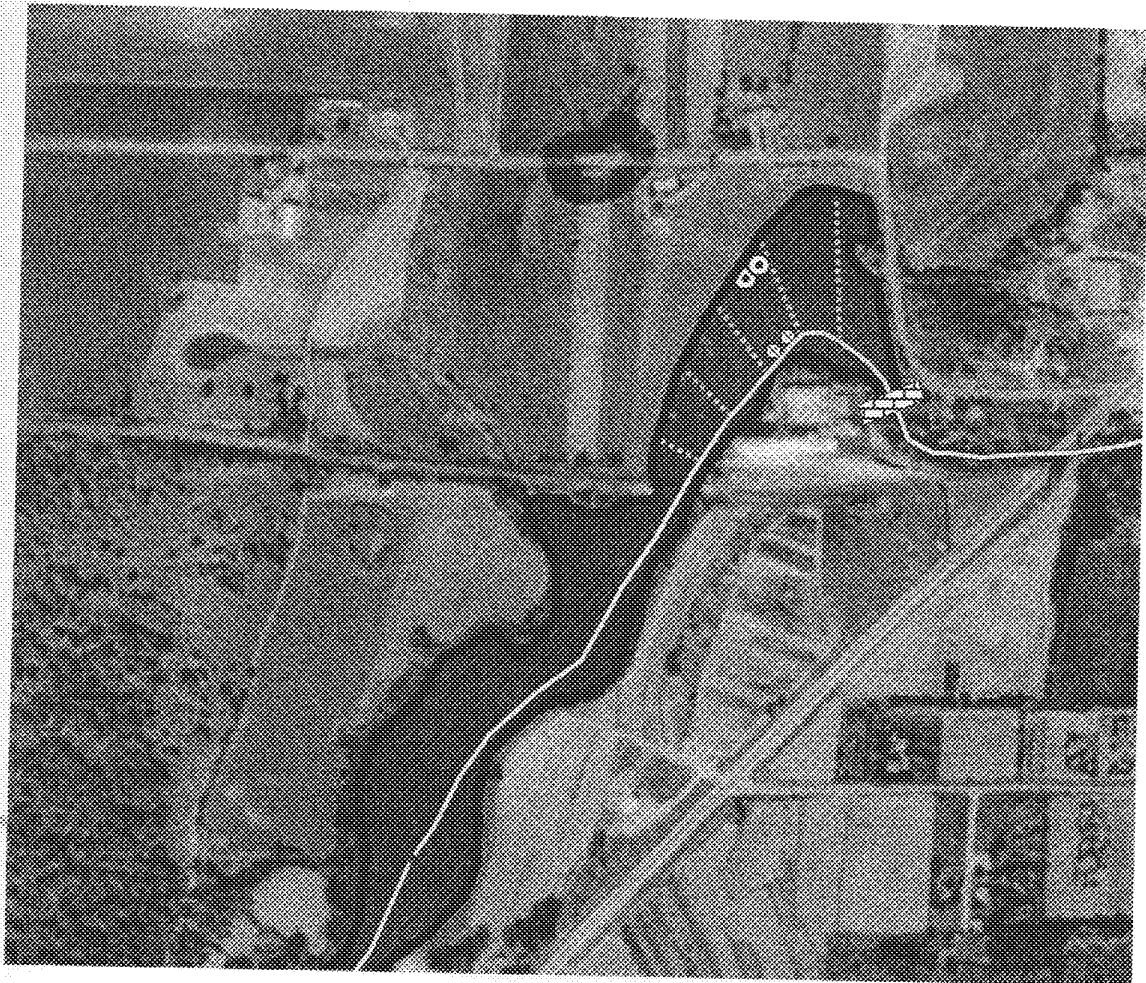








-  Waterloo dam location
-  Maunsha River
-  Old Waterloo pond boundary
-  Waterloo well 2
-  Waterloo well 1
-  Vegetation transects



Note: not to scale
Waterloo Pond was 81 acres
(Source: 1979 Aerial photograph)

Figure 4a: Map showing location of transects and wells at the former Waterloo millpond along the Maunasha River, Jefferson County, WI

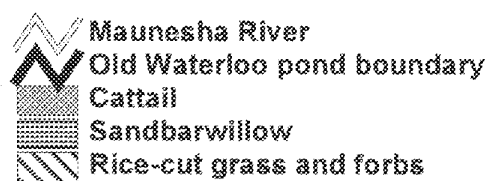
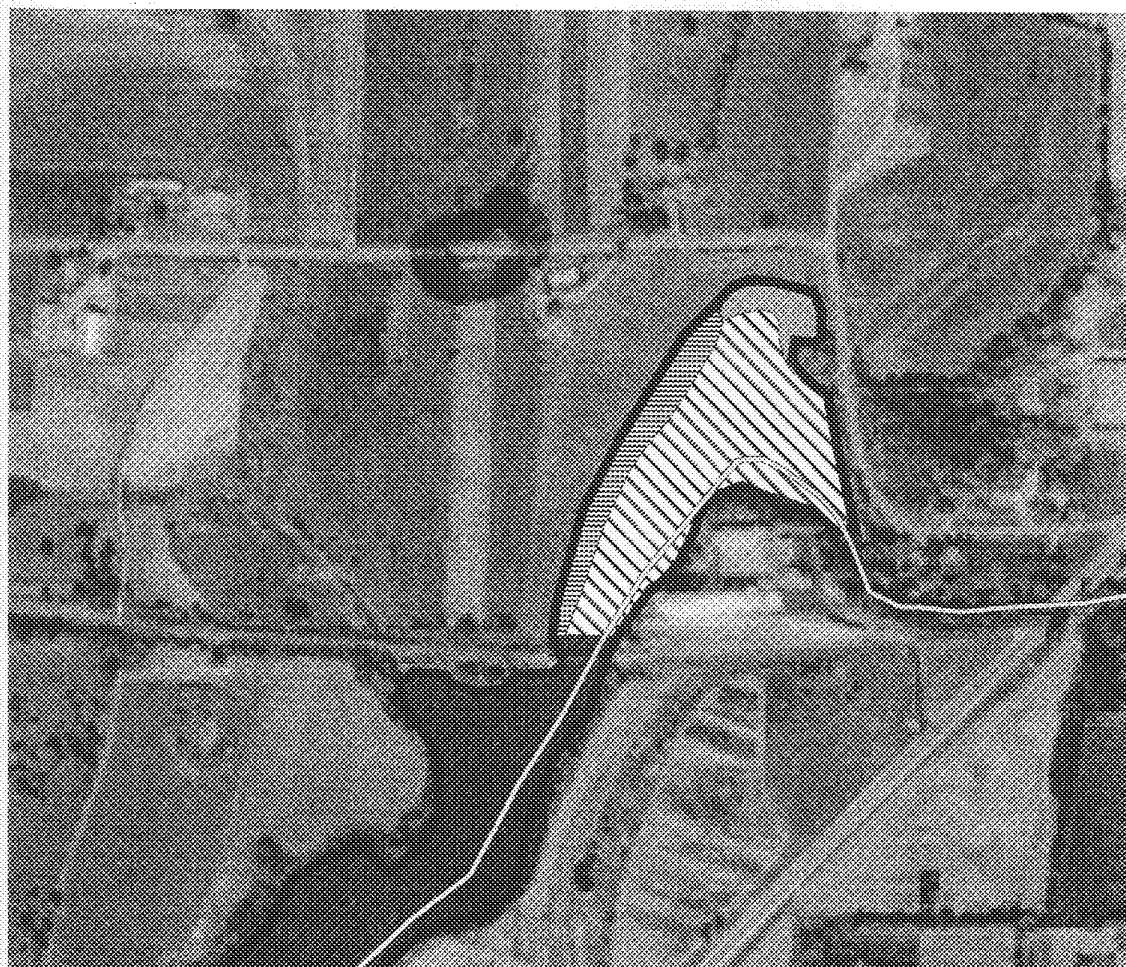


-  Waterloo dam location
-  Maunasha River
-  Old Waterloo pond boundary
-  Waterloo well 2
-  Waterloo well 1
-  Vegetation transects



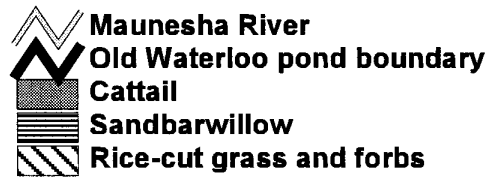
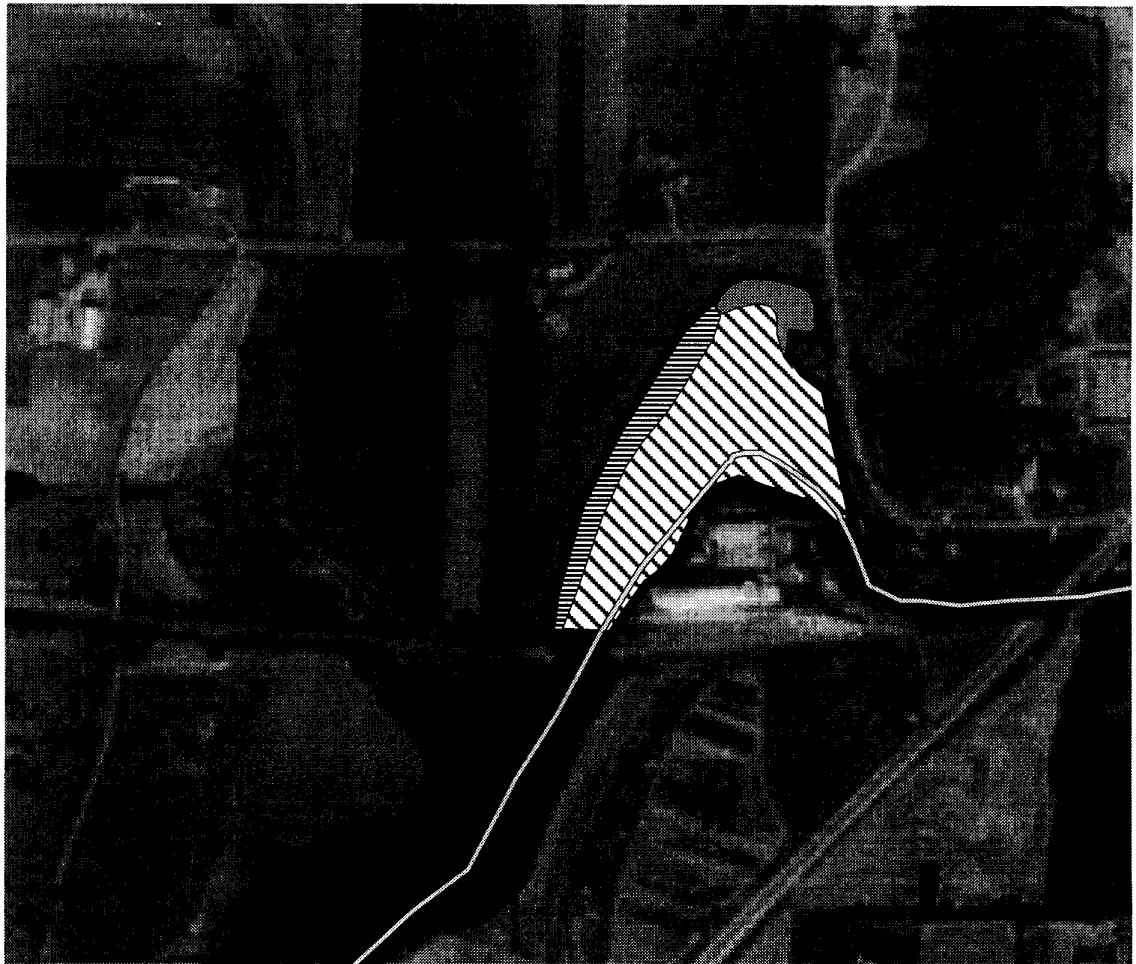
Note: not to scale
Waterloo Pond was 81 acres
(Source: 1979 Aerial photograph)

Figure 4b: Map of plant communities at the former Waterloo millpond on the Maunasha River, Jefferson County, WI



Note: not to scale
Waterloo Pond was 81 acres
(Source: 1979 Aerial photograph)

Figure 4b: Map of plant communities at the former Waterloo millpond on the Mauneshia River, Jefferson County, WI



Note: not to scale
Waterloo Pond was 81 acres
(Source: 1979 Aerial photograph)

- *Stream and Hydrology characteristics*

The Maunsha is a medium gradient stream (5.8 feet/mile), running for a length of 20 miles before draining into the Crawfish River in Dodge County (Poff et al., 1968). The stream has a reported baseflow of 67 cfs, although the larger volume of water is surface water (Day et al., 1985)

Flora and Fauna

- *Vegetation*

Early land survey records describe the area as burr oak openings interspersed with marsh in low-lying areas between the drumlins (Brink, 1836). The pond area supported wetland vegetation in pre-dam times (before 1847), most likely a shrub-carr. The vegetation on site is now primarily native wetland species including willows (*Salix sp.*), goldenrods (*Solidago canadensis* and *S. gigantea*), marsh aster (*Aster lanceolatus*), jewelweed (*Impatiens capensis*), sedges (*Carex sp.*), and floodplain tree seedlings (*Acer negundo*, *Populus tremuloides*, and *Acer saccharinum*) (Figure 4b). A zone of sandbar willow (*Salix exigua*) exists on the outer edge of the former pond, bordering the adjacent hillslope.

- *Wildlife*

The site is used by great blue heron, Canadian geese, and deer. Large carp were also observed swimming in the river on several occasions.

History and Public Usage

The Waterloo Dam, located on the Maunsha River was constructed in 1847 and was used for power at a malting operation most recently. Owned by Miller Brewing Company at the time of removal in 1995, the dam had not been used for hydropower since 1972. The dam had developed a seep in the left wall and had been declared unsafe in 1980. Although the malting company still operates there today, they now use other sources of power.

I sampled only the major surface area of the former pond area which lay in a large pool near the old dam. This area is now privately owned. The long narrow portion of the pond upstream of the major pool was not sampled because I was unable to determine who owned the site.

Post-Dam Removal Management History

During dam removal a pilot channel several hundred feet long was constructed at a 2% slope to control the path of the channel and minimize headcutting and sediment transport during removal. While the river flowed through the pilot channel for a couple of months, a large flood during the winter of 1995 washed out the pilot channel and the river cut its own path. Currently the river flows in both paths now, the pilot channel and the naturally formed channel. No management has been done since removal although some rudimentary trails have been cleared and used for ATV and other recreation by pond owners.

3.2.4. Town of Hebron, Bark River (Figures 5a and 5b)

The Physical Setting

- *Geography*

Located in southeastern Jefferson County, Hebron lies in the glaciated area of Wisconsin in a glacial till area interspersed with glacio-lacustrine lake beds. The Bark River watershed is 163 square miles at this point, draining a largely agricultural area. The pond itself, which used to be known as Green Isle Lake is surrounded by a ring of mesic forest, with several houses bordering the historic pond area (Figure 5a).

- *Soils*







Soils in this vicinity are described as “soils formed in low terraces of old lake basins” including Martinton and Saylesville silt loams. These soils have 10-11 inches of silt loam underlain by silty clay or silty clay loam (UW-Extension, 1966). A blue-gray silt/clay layer, likely the bottom an old lake basin or poorly drained marsh, lies underneath most of the old pond. Soil deposits of up to five feet lie on top of the historic floodplain today.

- *Stream and Hydrology Characteristics*

The Bark River has a low gradient of 1.7 feet per mile over its 29.3 mile length, although the last 20 miles of river, (containing my study site), have a slope of 3.8 feet/mile. The river was reportedly “clear and fertile over a generally hard bottom” by Poff et al. (1968). This river also supports a large amount of adjacent wetland area, totaling 2657 acres in the year 1968. Most of this wetland is shallow emergent marsh. Within the former pond area, the river forms a meander that turns a 180 degree loop, forming a horse-shoe shape immediately upstream of the former dam. The Bark empties into the Rock River several miles downstream, near Ft. Atkinson Wisconsin.

Figure 5a: Map showing location of transects and wells at former Hebron millpond on the Bark River, Jefferson County, WI









-  Historic dam
-  Bark river
-  Hebron millpond boundary
-  Plant transects
-  Hebron well 2
-  Hebron well 1



Note: not to scale
 Hebron pond was 28 acres
 (Source: 1969 Aerial photograph)

Figure 5a: Map showing location of transects and wells at former Hebron millpond on the Bark River, Jefferson County, WI

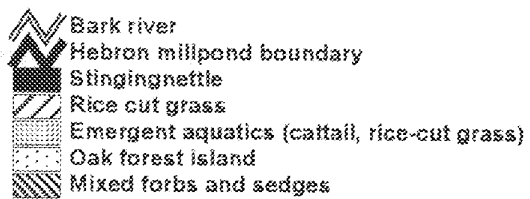
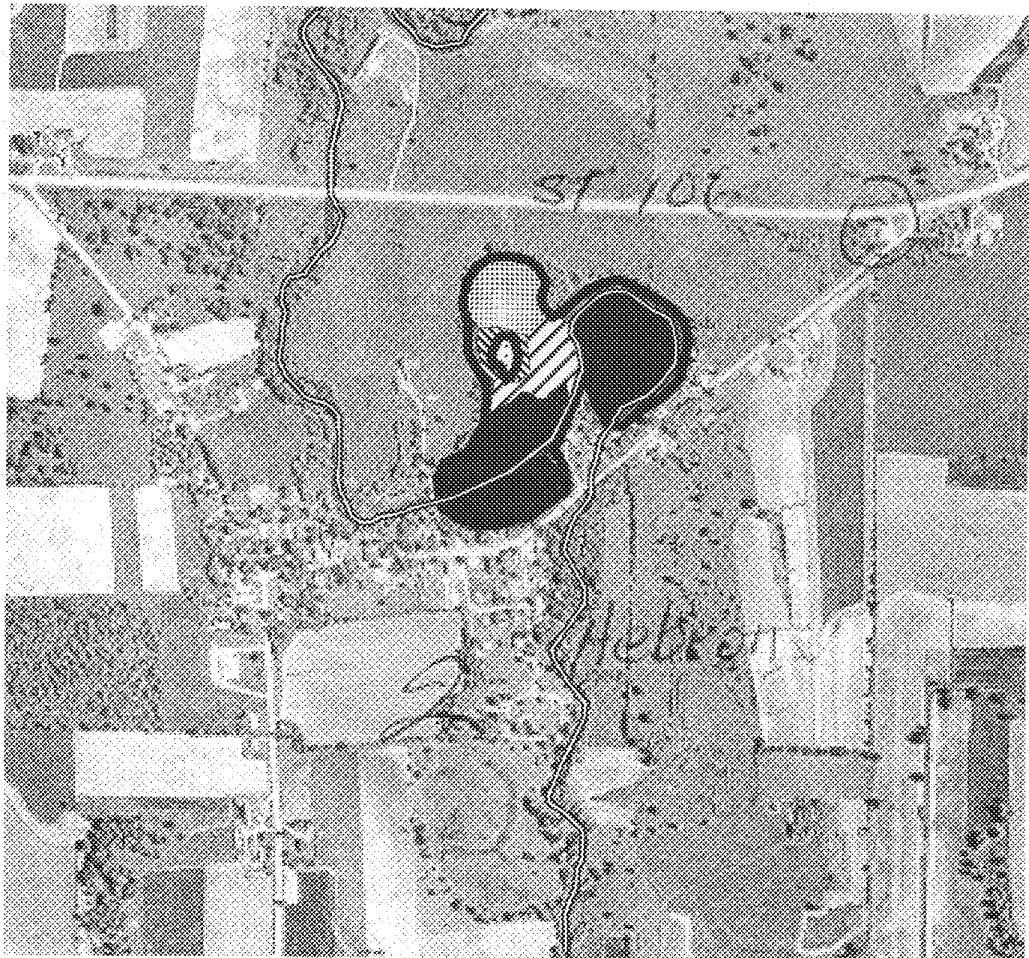


-  Historic dam
-  Bark river
-  Hebron millpond boundary
-  Plant transects
-  Hebron well 2
-  Hebron well 1



Note: not to scale
 Hebron pond was 28 acres
 (Source: 1969 Aerial photograph)








Figure 5b: Map of plant communities at former Hebron millpond on the Bark River, Jefferson County, WI



Note: not to scale
 Hebron pond was 28 acres
 (Source: 1969 Aerial photograph)

Figure 5b: Map of plant communities at former Hebron millpond on the Bark River, Jefferson County, WI



-  Bark river
-  Hebron millpond boundary
-  Stinging nettle
-  Rice cut grass
-  Emergent aquatics (cattail, rice-cut grass)
-  Oak forest island
-  Mixed forbs and sedges



Note: not to scale
 Hebron pond was 28 acres
 (Source: 1969 Aerial photograph)

Flora and Fauna

- *Vegetation*

Historically the vegetation described in land surveys was southern mesic forest areas interspersed with abundant wetlands on low-lying lacustrine soils (General Land Office, 1835). Low lying wooded swamps in the area were described as “black ash swamps” although elm and tamarack were common in the swamp areas also. Vegetation evidence, along with the presence of underlying lacustrine silt and clay soils indicate this site was probably a forested hardwood swamp in a seepage area before dam installation (Reed, 1998).

Currently the western part of the pond and the “horseshoe” area is covered mostly by stinging nettles (Figure 5b). Areas with a high water table to the north and east are covered by rice-cut grass, cattails, and smartweeds. An island in the middle of the pond has southern mesic forest vegetation, including bur oak, red oak, white oak, sugar maple, linden, and shagbark hickory. Currently the former pond area is used little due to the stinging nettle coverage and treacherous “sink-holes” where springs discharge. The island is used frequently for campfires and gatherings.

- *Wildlife*

The impoundment, known as Green Isle Lake, was used heavily for recreation, supporting a good northern pike and panfish fishery until dam removal in 1994. Today the site is frequently used by Canada geese, ducks, and great blue herons. This location provides excellent amphibian and reptile habitat supporting many frogs and some turtles. Year round sources of spring water are excellent for wildlife and seemed to attract many species. In the former pond area, hundreds of mussel shells were found, but no living organisms.

History and Public Usage

The Hebron Dam was one of the oldest in the state, with a dam originally built in 1836. Solomon Juneau, one of the first mayors of Milwaukee and an early land speculator, was involved in financing construction of this dam (Western Historical Company, 1879). The dam powered a saw mill originally and a grist mill operation by the late 1800's. In the area a large mussel harvesting business existed, as well as a fish hatchery. Due to heavy siltation from the mostly agricultural watershed, as well as other factors, enormous amounts of silt remain deposited on the floodplain today (up to 6 feet). When the pond was removed for safety reasons, there was considerable opposition from the local community.

Post-Dam Removal Management History

During dam removal, abutments were left in to protect a nearby downstream house from flooding. In between the abutments a concrete skirt remains on the stream bottom, maintaining a drop of one-two feet with large rapids existing. No management has been done since removal perhaps because the pond area is privately owned. Although currently ownership of the pond is uncertain, the pond is likely owned by at least 2 riparian landowners.

3.2.5 Town of Fulton, Yahara River (Figures 6a and 6b)

Physical Setting

- *Geography*

Fulton lies in the glaciated area of Wisconsin on glacial till plains near the terminal moraine. Topographically, there is relatively high relief in the area. The Yahara river watershed is

Figure 6a: Map showing location of transects and wells at Fulton on the Yahara River, Rock County, Wisconsin

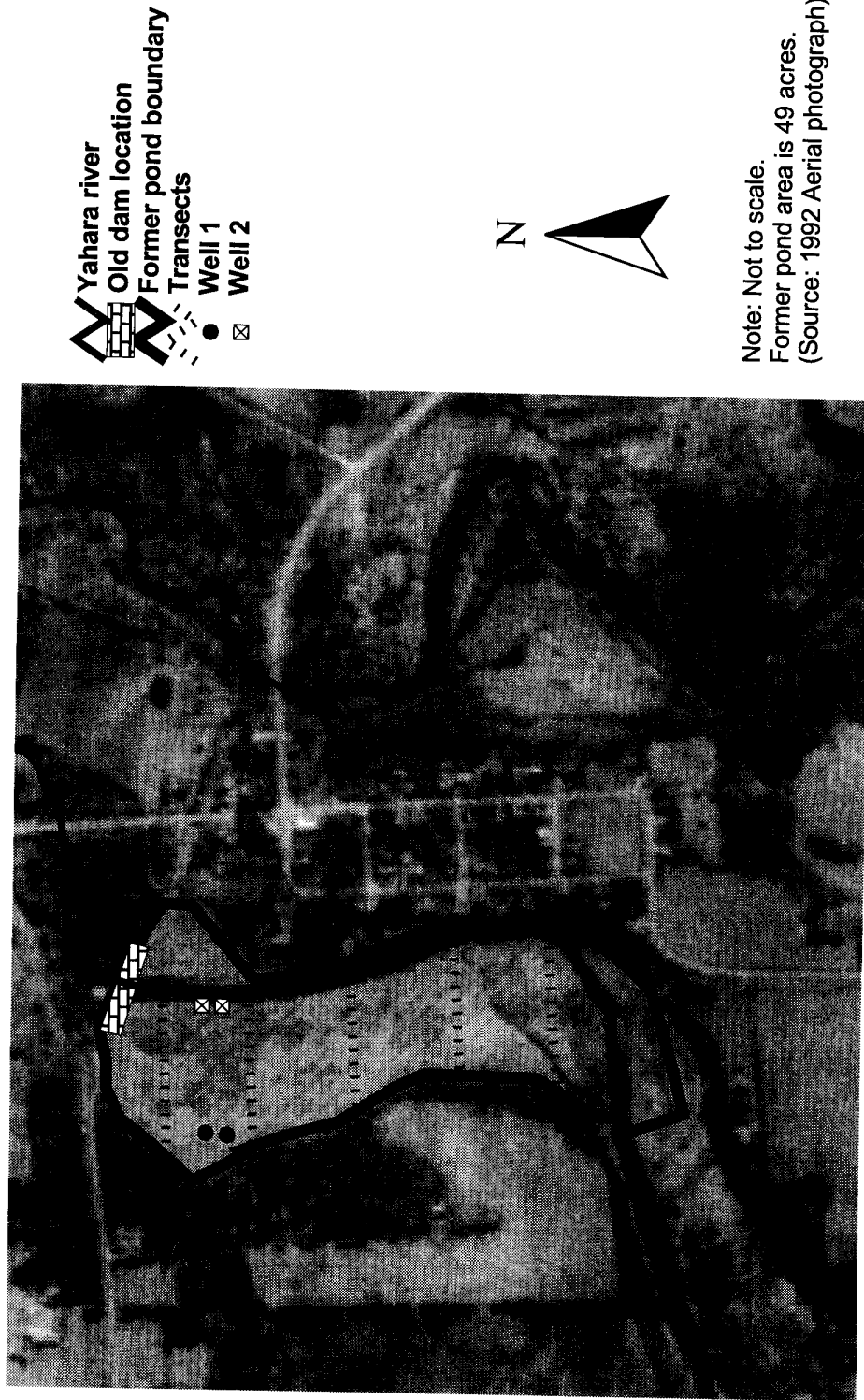


Figure 6a: Map showing location of transects and wells at Fulton on the Yahara River, Rock County, Wisconsin

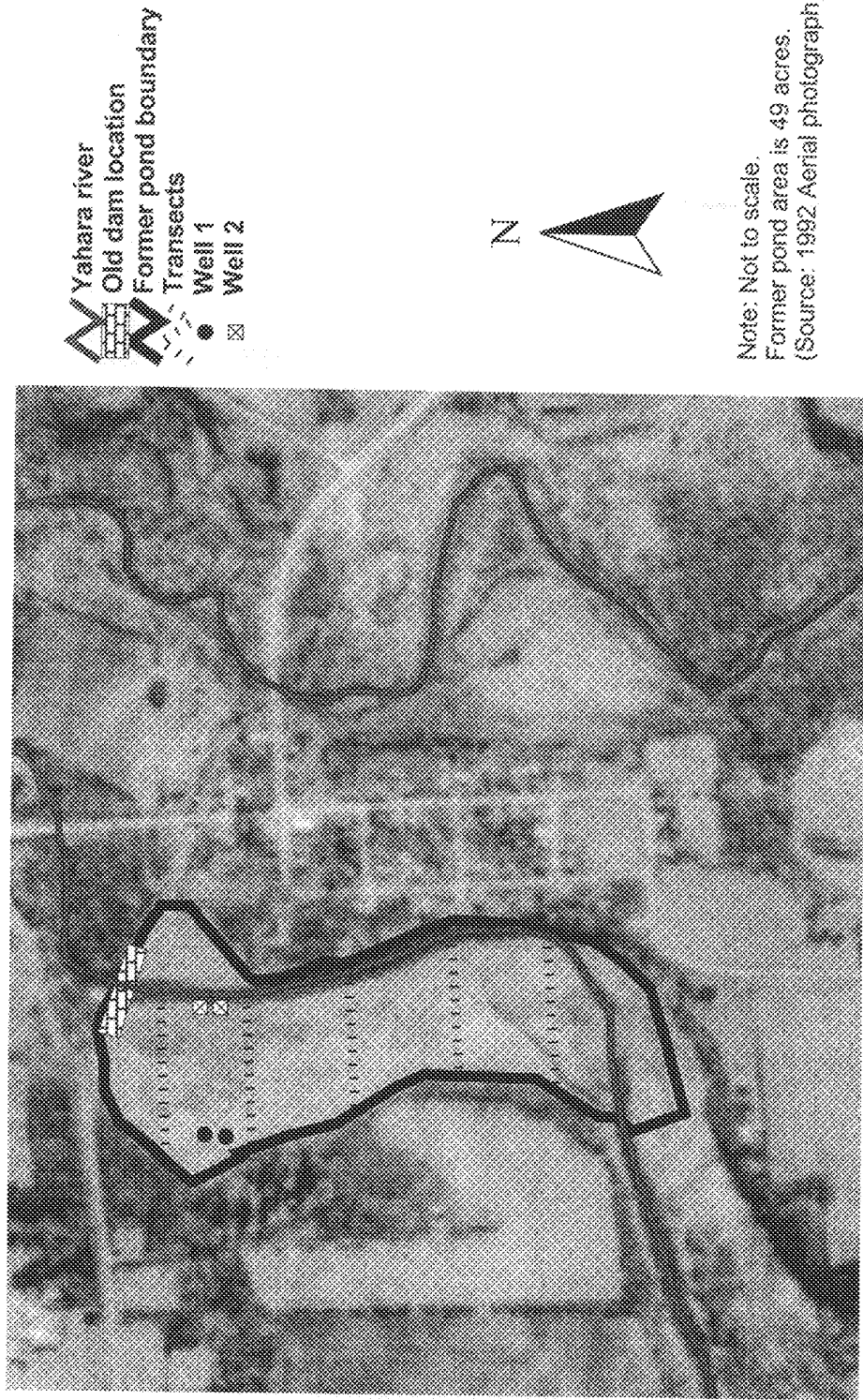


Figure 6b: Map showing location of plant communities at Fulton on the Yahara River, Rock County, Wisconsin

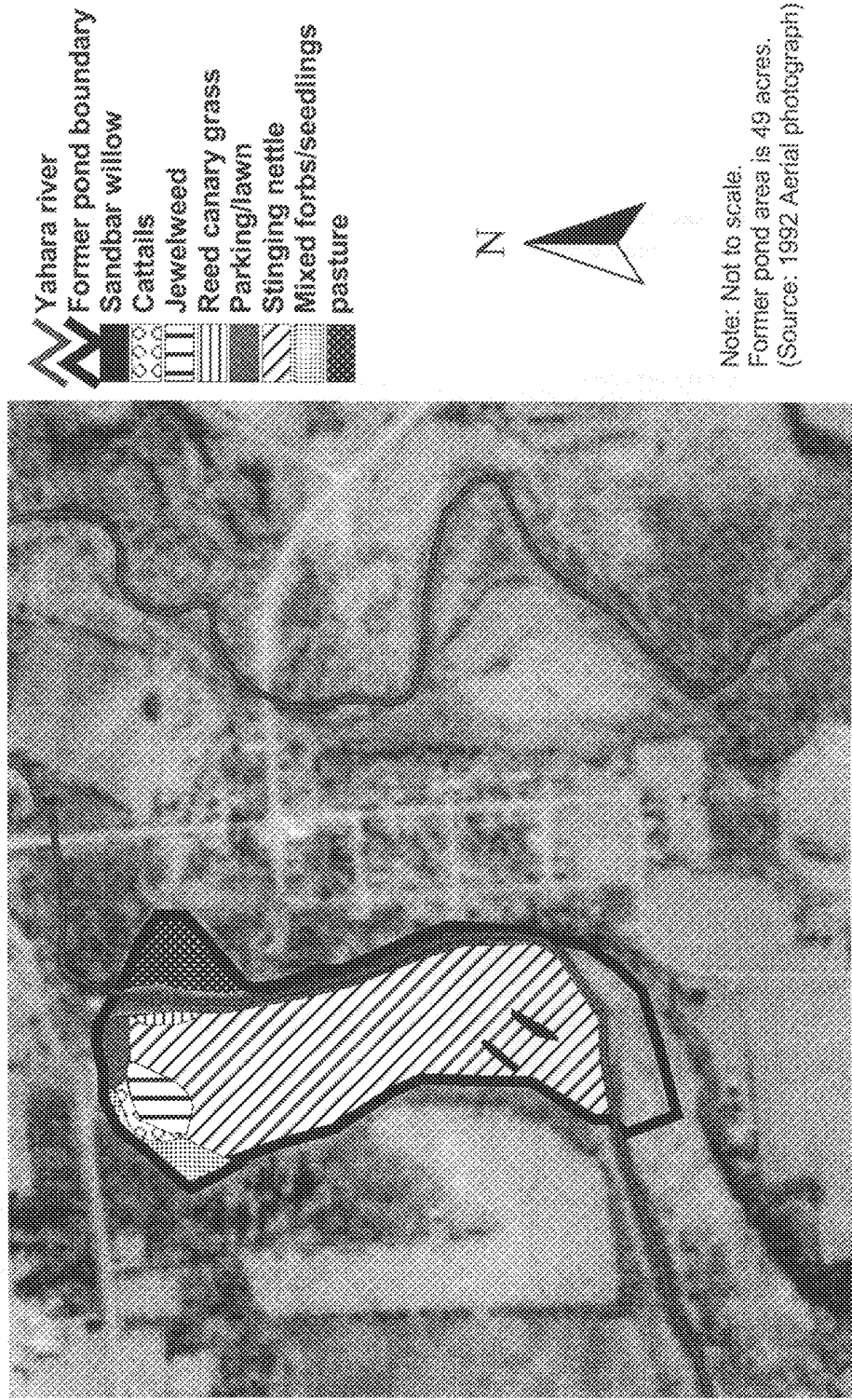


Figure 6b: Map showing location of plant communities at Fulton on the Yahara River, Rock County, Wisconsin



530 square miles at Fulton, draining all of the Madison Lakes and much of Dane County, Wisconsin. Towards the mouth of the Yahara River there are numerous wetlands, including 296 acres of “fresh meadow” and wooded swamp (Ball et al., 1970). The site of the old dam is only about 2 miles from the confluence with the Rock River. This old pond itself is bordered by two areas of swamp forest and a dry oak forest along a sandy ridge.

- *Soils*

Because the pond area was under water at the time of the last soil survey, no USDA soil survey information is available concerning the pond area. Soils in nearby floodplains are alluvium. While the hills adjacent to the millpond are sandy loam. Low-lying areas adjacent to the pond consists of Sebewa silt loam, a poorly drained soil with much calcareous material and/or an organic surface layer up to 14 inches thick. Within the pond, many feet of sand and silt lie on top of the old floodplain.

- *Stream and Hydrology characteristics*

The Yahara River was the largest river in my study with a mean annual flow of 371 cfs reported at the gage near Fulton (USGS, 1998). Its baseflow, however is reported to be only 68.8 cfs (Day et al., 1985). This indicates that the river is dominated by surface water inputs rather than groundwater as are Black Earth and Mt. Vernon Creeks.

Flora and Fauna

- *Vegetation*

Historically the vegetation was described as “thin timber” in original land surveys done in the 1830’s (Harrison, 1833). A large prairie also existed just northwest of the former pond area. A layer of woody peat was found in underlying horizons, indicating the presence of woody

vegetation growing on top of an organic soil. Based on this evidence it appears the site was probably a shrub-carr or forested swamp. The Lower Yahara and Rock River Valley is interesting in that it supports an extreme northern extension of the range of several southerly species, including: sycamore (*Platanus occidentalis*) and Ohio buckeye (*Aesculus glabra*) (Fassett, 1978 and Ware, 1955). Currently the vegetation in the former pond is a mixture of pioneer weeds, both wetland and upland species, with a few scattered tree saplings (Figure 6b). Stinging nettle, sandbar willow, jewelweed, garlic mustard, and reed canary grass are some of the more common species. The majority of the old pond is covered by a colony of stinging nettle up to 8' high. This segment of river is also used by canoeists occasionally.

- *Wildlife*

The area now is used heavily by deer, although little other wildlife was observed. The stinging nettle monocultures seem to support little wildlife.

History and Public Usage

The dam built here in 1841 was the largest dam in my study at 14 feet high. It was removed in 1993 for safety reasons. Today Rock County Parks owns the area of the former pond that borders the river. The northern half of the pond that borders adjacent forests is privately owned. Part of the former pond area is now used for fishing access to the Yahara River along a small strip of Murwin Park.

Post-Dam Removal Management History

Some tree planting has been done by Rock County Parks across the river from the pond near the old raceway in Murwin Park. Some planting of tamarack trees was recently done in the

former pond, after I did all of my vegetation sampling. Plans are in progress to continue the plantings (Kautz, 1998 personal communication)

CHAPTER 4: PHYSICAL and VEGETATIVE CONDITIONS IN THE DRAINED RESERVOIR AREA at DAM REMOVAL SITES

4.1. SEDIMENT

4.1.1 Surficial Deposits (Reservoir - Deposited Sediment)

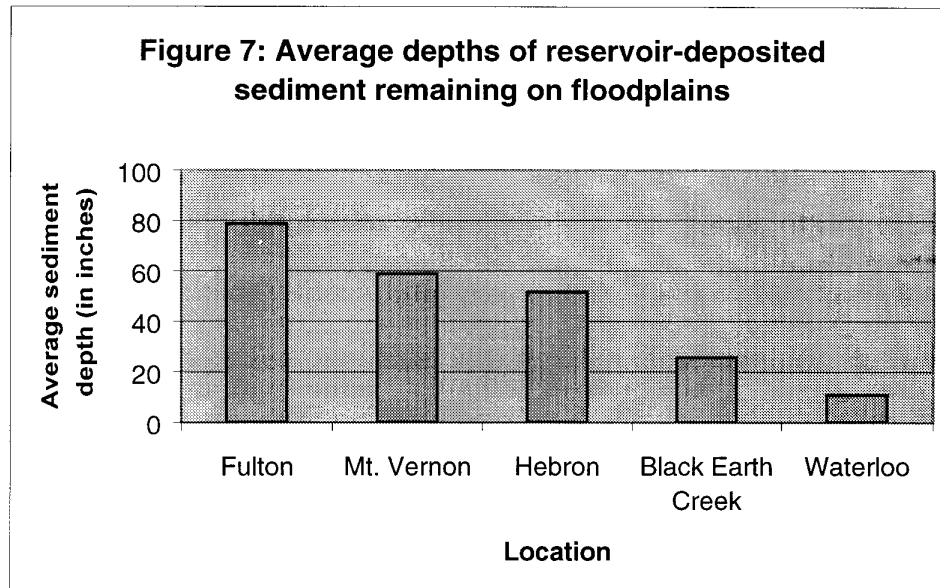
Depth

While the dams were still in place at these sites, large amounts of sediment were trapped in the pond. Following dam removal, a good deal of sediment remains on the floodplain of all the sites and in some of the streams where dams were removed five years ago or less.

Sediment depths on top of the historic (pre-dam) floodplains ranged from 0 - 114 inches, with averages ranging from 10.8 to 78.7 inches (Table 4 and Figure 7).

SITE	Depth range of Pond-deposited soil (inches)	Standard deviation	Average Depth of Pond-deposited soil (inches)	Textural Class of Surface deposits	Number of soil cores
Cross plains	8-55	15.0	25.5	Silt loam	10
Fulton	24-114	20.0	78.7	Sandy loam	10
Hebron	27-66	12.5	51.6	Silt loam	10
Mt. Vernon	38-72	9.9	58.8	Silt loam	10
Waterloo	0 -26	8.5	10.8	Loam	10

Fulton had the greatest amount of sediment deposition, followed by Mt. Vernon, Hebron and Black Earth Creek. Waterloo had considerably less sediment (10.8" average) and no sediment at all in much of the lower part of the former reservoir.



Pattern of deposited sediment

At all five sites, the surface is nearly level across the entire pond, similar to an exposed lakebed. The edge of the floodplain or former pond bottom terminates abruptly into upland areas at most sites, due to bank erosion when the pond was intact. During the winter considerable bank erosion may occur in these ponds because of ice scour (Morris and Fan, 1998). In contrast, sediment depth was distributed unevenly, probably partly because of variation in the topography of the pre-dam floodplain. Depths often varied up to several feet at soil cores taken only 10-20 feet apart. For instance, soil cores at Fulton revealed depths of 24 to 114 inches of sediment, with a standard deviation of 20.0 inches. There were no clear increases or decreases in sediment depth moving upstream from the dam. It is possible that a larger sample size may reveal that there was in fact a pattern.

However, there was frequently less sediment near the very edge of the pond, behind obstructions such as railroad bridges, and at points far from the channel, if the former pond was very wide (at Waterloo and Hebron). At Waterloo there was no pond-deposited sediment along a strip of 50-75 feet, parallel to the edge of the former pond. At Hebron, the relicts of deltaic deposits (clearly visible in aerial photos) were noticeable where the stream entered the former pond. In these areas, elevations were higher on the streambanks, sloping down slightly towards the floodplain (at Hebron and Fulton).

Characteristics of Deposited Sediment

- Particle Size

Most of the deposited sediment consisted of silt and/or sand. Particle size analysis showed that sediment at Mt. Vernon, Hebron, and Black Earth Creek had 69%, 50%, and 58% silt, respectively. These soils were silt loams in texture (Table 4 and Appendix A). Fulton and Waterloo had noticeably sandier soils, with 62% and 49% sand, and were classified as sandy loam and loam. Clay composed a small percentage of the particles at all of the sites, likely because clay is carried in suspension by streams, usually preventing it from settling out in ponds. Organic matter was low for wetland areas in all samples, ranging from 4.2 – 10.9%. (For comparison, histosols, which are wetland soils dominated by organic material, contain from 20 - 98% organic matter. Mollisols, a typical upland soil type in Wisconsin usually have from 1-7% organic matter (Brady and Weil, 1999)). Most of this organic matter was undecayed plant litter lying on the soil surface. Beneath the surface there was almost no organic material.

- Structure and Density

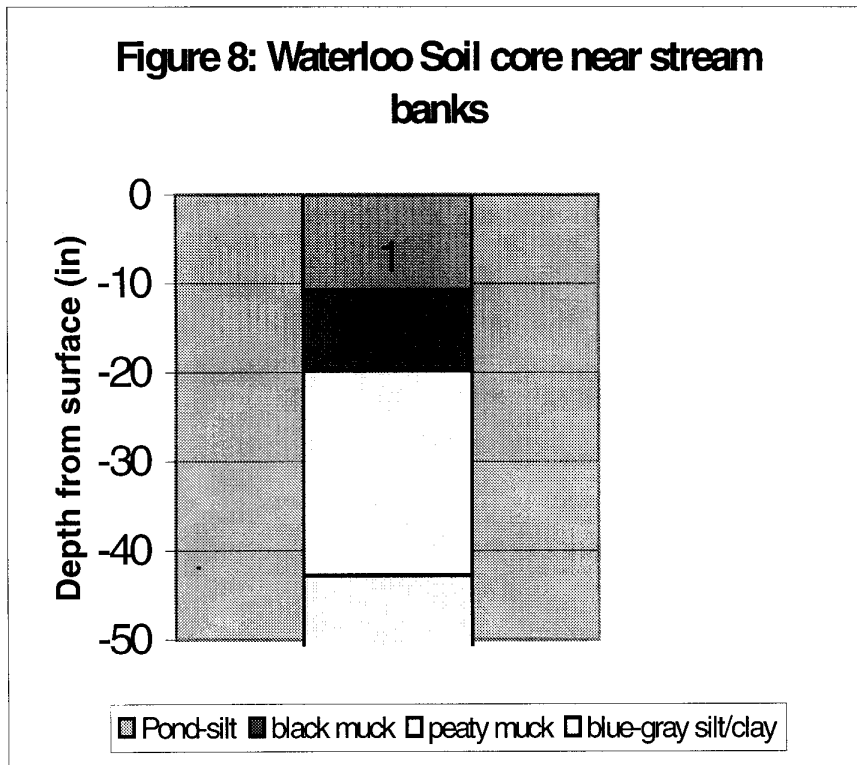
The most notable structural characteristic of the soils at recently removed sites (Waterloo-3 years, Hebron 4 years, and Fulton -5 years since removal) was the soils' loose, unconsolidated nature often with large cracks or fissures caused by drying. These gaps were up to 5 inches wide, extending down several feet in some locations. This surface was very difficult to walk on as one's leg would often sink up to knee level. More importantly it would be very difficult to move machinery such as tractors or back-hoes on this surface for management purposes.

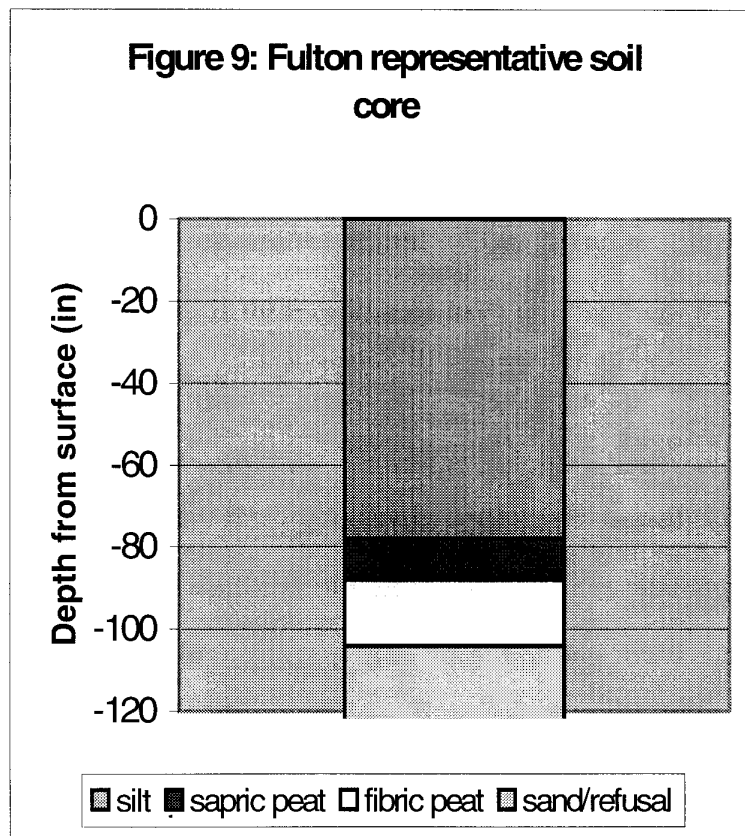
At sites where dams were removed more than 35 years ago (Mt. Vernon and Black Earth Creek) the soil was very dense and no fissures were present. When I withdrew soil cores with a two inch bucket auger, it was possible to stick the auger down 1-2 feet with little resistance at recently removed sites. At the older sites it took up to 30 minutes to auger down several feet. The low percentage of organic matter at older sites, a large determinate of bulk density, may contribute to the density of soils at the older sites (Appendix A). One possible explanation for the increased soil density may simply be that soil increases in density after de-watering because of gravity fall and compaction. Tractors used for mowing and haying at Black Earth Creek and Mt. Vernon, as well as pedestrian traffic may have contributed to compaction of the soils there also.

4.1.2 Underlying Soil Horizons

Underlying soils, representing the pre-dam floodplain surface differed from the surficial sediment deposits in all cases. Most of the underlying soils had at least patches of organic

soils (Table 5). Fulton and Waterloo had the most extensive peat deposits with much undecayed woody plant material characteristic of fibric peat (Figures 8 and 9).





The peat was often patchy, varying in depth from a 2 - 20 inches and was often found lying on top of tightly compressed blue-gray silt or clay. In other areas, black muck (with more decomposed plant material than the peat) and silt loam were found on top of the old floodplain. The overtopping of organic soils with mineral soils at many of these sites has important ecological consequences, effecting hydraulic conductivity, porosity, and other factors that affect plant community composition. The presence of peat and black muck on the original floodplain indicate that these sites supported at least some area of wetland

vegetation before the dams were constructed. (Peat soils only develop in water saturated conditions and are characteristic of sedge meadows, bogs, and some forested wetland communities, while black mucks are characteristic of shallow marshes (Eggers and Reed, 1997).) At sites that had areas of silt loam lying on the original floodplain surface (Mt. Vernon, Black Earth Creek, and Fulton), the surface soil texture may be more similar to the original floodplain soils. In these cases a silt loam or sandy loam was deposited on existing silt loams of alluvial origin.

Soils with layers that have limiting hydraulic conductivity (usually clay or fine compressed silt) are important for maintaining moisture in the soil by by retarding the downward percolation of water. A dense blue-gray silt/clay layer was found underlying most of Waterloo. Hebron also had large areas of silt/clay of glacio-lacustrine origin, although this layer lay 4-6 feet below the surface. Black Earth Creek had only small patches of clay, while Fulton and Mt. Vernon had no clay layer (Table 5). The sandy soil of Fulton most likely has greater hydraulic conductivity than the silt loam soils found at the other sites. This would allow Fulton to drain more quickly. The consequence of these soil differences is that the floodplain at Fulton is likely to experience the driest conditions of the five sites. The soil at Hebron, on the other hand, may favor moisture retention because of the lower conductivity of silt loam as well as the presence of a clay layer that slows the downward percolation of water.

Table 5: Soil Coring Data: Underlying Horizons*			
Site	Predominate underlying soil type	Variations in underlying soils	Soil Map Description**
Cross plains	Silt loam with high organic content underlain by coarse sand and gravel	There were patches of peat and areas with a tight blue-gray silt/clay layer 3-4 feet below the surface	Alluvium - Otter silt loam
Fulton	Silt loam underlain by sand or gravel with calcareous material	Areas close to the river had very fibric peat underlain by the same sand/gravel	Alluvial silt loam soils formed on top of glacial till
Hebron	Black muck with much calcareous material, underlain by sand or gravel	Patches of peat underlain by tight blue-gray silt or clay	Glacio-lacustrine soils underlying pond area
Mt. Vernon	Silt loam underlain by sand or gravel with calcareous material	Peat underlain by sand or gravel with calcareous material	Alluvium: Otter silt loam along stream and Orion silt loam on floodplain
Waterloo	Fibric Peat underlain by lacustrine silt/clay	Along the lower edge of the adjacent drumlin, a clay loam soil underlain by sand or sandy loam, lay in part of the former pond area	Glacio-lacustrine soils in pond area that lie in between drumlins
*6-10 cores taken below surface deposits at each site. Above descriptions generalized for the entire site.			
** (USDA, 1974, 1978, and 1979)			

SUMMARY OF SOIL FINDINGS

SURFACE DEPOSITS

- Large amounts of sediment remain on all floodplains, ranging from 0 – 114 inches
- Average depths for each site ranged from 10.8 – 78.7 inches.
- Most of the sediment is either silt or sand in particle size
- Sedimentation overtopped organic soils with mineral soils at several sites.

- Sediment has influenced hydrology by raising the elevation of the ground surface above the water table and creating high floodplains that are less frequently flooded.

UNDERLYING SOILS

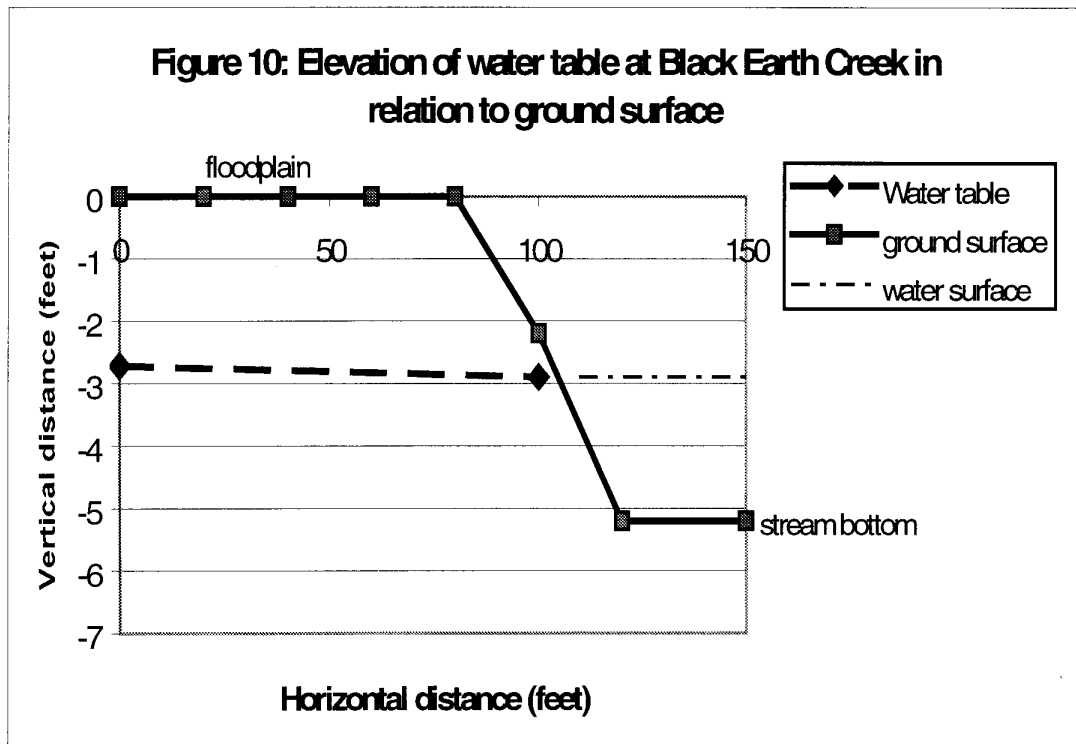
- Waterloo and areas of Hebron had clay layers with limiting hydraulic conductivity within 2-4 feet of the surface
- Fulton had the sandiest soil and no water-restraining layers

4.2 HYDROLOGY AND CHANNEL MORPHOLOGY

4.2.1 WELL DATA (See Figures 2a, 3a, 4a, 5a, and 6a for well locations.)

- *Depth to Water Table*

Well data were used to determine the average depth of the water table beneath the ground surface, the horizontal slope or gradient of the water table and to gain some information on water level variability. At all sites the water table elevation slopes from the edge of the former pond toward the stream, a characteristic of influent streams. In other words, water flows downhill from the adjacent landscape into the stream. The ground surface is nearly level in the current floodplain area and so the downward sloping water table is generally closer to the ground surface at the edge of the former pond area than near the stream, with the exception of Waterloo. Figure 10 shows the relationship between ground surface and water table at Black Earth Creek, which was representative of most of the sites. At Waterloo, Hebron and much of Fulton, the floodplain is level all the way up to the stream edge, where it then drops nearly vertically down to the stream. At the older sites streambanks sloped more gradually back to the upper floodplain surface. Along these gradually sloping banks the water table was closer to the ground surface there than in the



upper adjacent floodplain. These sites included Fulton well #2, Mt. Vernon well #2, and Black Earth Creek well #2, where the well locations were at an elevation of 1-3 feet below the elevated floodplain (Table 6).

Wetland delineation guidelines describe water table depths of 20 inches or less at any time during the growing season as an indicator of “wetland hydrology” (Wisconsin Coastal Management Program, 1995). Depths of less than 20 inches were recorded at eight of ten well locations at least once during the growing season (Table 6). Hebron well #2, (near the stream channel) and Black Earth Creek well #1, on the edge of the former pond never rose above 20 inches below ground surface. The limited sampling numbers (5 - 7 readings) were

probably insufficient to accurately characterize the true range of water levels (hydroperiod) (Randall et al., 1999). However the samples were taken over a long period of time (6-12 months), extending through several seasons of the year, and thus captured large ranges in water table depths.

Fulton had the driest conditions with mean depth to water of 24.74 inches at the edge of the pond and 44.47 inches near the stream (32.27 inches along streambanks) (Table 6). Wells at Fulton had the greatest variability in water table depths also, with a range between minimum and maximum recorded depths of 34.18 inches at Well # 2 and 21.83 inches at Well #1. The variability at these wells is also represented by the high standard deviation of 14.08 and 7.25, the first and third highest standard deviations all the wells. Waterloo had the highest average water table as a whole, with mean depths of 20.50 inches at the edge of the pond and 16.44 inches near the stream channel. Hebron was the only area with standing water present in any part of the former pond area. I observed water at the ground surface on each of eight to ten visits over a 14 month period from June 1998-August 1999, although no wells were located in this area.

The difference in depth to water table between the edge of the pond and the streambanks was extreme at some sites. Mt. Vernon had the greatest differential between the pond edge and the stream channel with mean depths of 8.80 inches at the edge and 48.01 inches near the channel. Hebron and Fulton also displayed large differentials. The ecological effect of these water table differences is that more wetland vegetation is supported near the outer edge of the

pond and along the streambanks, than on most of the floodplain area (See Figures 2-6). This effect was most pronounced at Mt. Vernon and Black Earth Creek.

Table 6: Summary of Well Data: Depth to Water Table					
<i>Water table depths recorded as depth below ground surface in inches</i>					
Well	Dates	Depth to water table at wells*			Standard Deviation
		Minimum	Maximum	mean	
Waterloo 1	12/3/98 - 6/3/99	-13.85	-28.85	-20.50	5.77
Waterloo 2	12/3/98 - 6/3/99	-14.08	-19.02	-16.44	2.03
Fulton 1	9/5/98 - 4/8/99	-14.36	-36.19	-24.74	7.25
Fulton 2	9/5/98 - 4/8/99	-11.60	-45.78	-32.27	14.08
Black Earth Creek 1	11/3/98 - 6/15/99	-25.14	-34.44	-32.58	5.51
Black Earth Creek 2	8/25/98 - 6/15/99	-17.60	-25.85	-21.98	3.11
Mt. Vernon 1	8/2/98 - 6/26/99	-1.04	-17.13	-8.80	7.18
Mt. Vernon 2	8/2/98 - 6/26/99	-11.25	-33.51	-20.49	9.25
Hebron 1	9/30/98 - 7/1/99	-9.20	-24.83	-15.84	6.30
Hebron 2	9/30/98 - 7/1/99	-30.58	-48.83	-37.54	7.01
Wells labeled 1 were located at the edge of the former pond area Wells labeled 2 were located by stream banks. * negative values in water table column indicate depth below ground surface					

Summary of Water Table Findings

- Water table depths lie between ground level and 48 inches below ground surface at all ten well locations at the five sites.
- Depth to water table is shallow enough (<20 inches below ground surface during growing season) to support wetland vegetation at most sites.
- The water table is closer to the ground surface near the outer edge of the former pond area than near the stream channel at four of five sites.

4.2.2 Groundwater gradients

Based on differences in water surface elevation between paired wells and piezometers (pairs are referred to as well nests), groundwater gradients were established (Table 7). The results of monitoring done over a 6 to 12 month period indicate that most sites displayed both recharge and discharge at different times of the year. Ecologically, consistent groundwater discharge is important because the constant water supply favors hydrophytic vegetation and the formation of hydric soils. Waterloo Well Nest #1, Black Earth Creek Well Nest #1, and Hebron Well Nest #2 were the only well nests that displayed groundwater discharge in 100% of readings (See Figures 2a, 4a, and 5a). Groundwater discharge, was recorded more frequently at the edge of the pond, often near the bottom of a slope, than near the stream. Waterloo and Black Earth Creek had strong upward gradients at the edge of the pond (Well Nest #1), but not near the stream (100% of readings at the edge for both, 20% and 43% of readings near the stream).

Hebron had strong upward gradients at both locations. In one area of Hebron ground water appeared to be discharging at the surface, though no wells were located there. The evidence included: standing water year-round, despite the lack of any surface water inlets, loose unconsolidated soil or "sink holes" where groundwater welled up, and anecdotal comments that this part of the reservoir never used to freeze (Kroll, personal communication).

Fulton was the only site that displayed strong downward gradients or recharge at both well locations. No readings indicated groundwater discharge at Well Nest #2 and only one out of seven (14%) readings indicated discharge at Well Nest #1.

Table 7: Vertical groundwater gradients
(Recorded as difference in water surface elevation between well and peizometer.)

Site	n	mean	Min	Max	stand. dev.	% readings Groundwater discharge	Classification: Groundwater discharge or recharge
Waterloo 1	5	2.44	1.32	3.07	0.673	100	Discharge
Waterloo 2	5	-0.27	-1.59	1.63	1.251	20	Recharge
Fulton 1	7	-1.20	-2.89	0.29	1.183	14	Recharge
Fulton 2	6	-1.99	-2.88	-1.08	0.667	0	Recharge
Black Earth Creek 1	5	1.89	1.28	2.45	0.417	100	Discharge
Black Earth Creek 2	7	-0.11	-1.46	1.67	1.233	43	Intermediate
Mt. Vernon 1	4	0.29	-0.01	7.98	3.742	25	Intermediate
Mt. Vernon 2	4	-2.61	-9.96	0.83	4.997	50	Intermediate
Hebron 1	5	0.49	-0.82	1.18	0.819	80	Discharge
Hebron 2	5	2.72	0.51	4.76	0.726	100	Discharge

Positive numbers indicate an upward gradient (groundwater discharge).
Negative numbers indicate a downward gradient (groundwater recharge).
Well and peizometer nests labeled **1** were located at the edge of the former pond area.
Well and peizometer nests labeled **2** were located by stream banks.

Summary of groundwater gradients

- Six of ten well nests fluctuated between groundwater discharge and recharge.
- Groundwater discharge was more common along the outer edge of the floodplain than near the stream channel.
- Hebron displayed strong groundwater discharge over the whole site
- Waterloo and Black Earth Creek displayed strong groundwater discharge at well #1, near the outer edge of the former pond area
- Fulton had the strongest downward gradients (groundwater recharge) and was the only site displaying groundwater recharge over the entire floodplain

4.2.3 Flood Frequency and Duration

Flood frequency calculations for these former reservoir areas indicate that increases in channel capacity due to sedimentation of the floodplain have created high terraces that are rarely flooded at Mt. Vernon and part of Hebron (Tables 8 and 9). Hebron had the highest recurrence interval with 31.4 years, while Waterloo had the lowest recurrence at less than 2 years. The older sites (Black Earth Creek and Mt. Vernon) had developed small shelves adjacent to the channel that would be flooded more frequently. However the upper terraces did not appear to be frequently flooded.

Table 8: Flood Frequency Estimates of Former Pond Area

Site	Flood Flow (cfs)	Estimated Frequency (Years)	x-sectional area (ft ²)	Mannings N	Water surface Slope (ft/mile)
BEC	446	6.2	262.33	0.046	11.590
WATERL OO	416	< 2	126.92	0.028	7.160
MT VERNON	665	15.2	286.42	0.045	4.680
FULTON	2738	6.9	614.23	0.036	5.444
HEBRON	637	31.4	262.87	0.050	5.635

At Black Earth Creek, Hebron, and Mt. Vernon there was no evidence of overbank flooding since the dams have been removed. There was no sand or sediment deposits, characteristic of alluvial deposition, on the surface of the current floodplain. At Fulton there appeared to be sporadic layers of sand on the floodplain surface that may have been deposited by overbank flooding. It is very possible that a flood in 1996, the highest recorded flow in 20 years of record at 3230 cfs, overtopped the floodplain. I found further evidence for flooding at Waterloo as I observed the Maunsha River nearly overtopping the banks on several occasions during my sampling over a period of one year.

Table 9. Duration of flood events				
Site	Years of record	Period of record	Number of events exceeding pond flooding flow in period of record	Total Duration of flows exceeding pond flooding flow
BEC	45	1954-1998	5	0-5 hours
WATERLOO	0	--	-	-
MT VERNON	16	1955-1965, 1976-1980	2	0-2 hours
FULTON	21	1978-1998	4	4-8 hours
HEBRON	15	1984-1998	0	0
(from USGS historical daily streamflow records)				

The increase in flood recurrence intervals appeared to affect small streams more than large rivers. Fulton had the largest amount of sediment deposition, creating banks up to 9 feet above the stream bottom. However, because the Yahara River carries a much larger volume of water than the other rivers in my study with a mean annual flow of 371 cfs, the flood discharge at Fulton had a relatively low recurrence interval of 6.9 years. The smallest streams, Black Earth Creek and Mt. Vernon, with mean annual flows of less than 30 cfs, had long recurrence intervals, despite having less elevated floodplains than Fulton. This is because smaller streams carry less water and so require a more extreme flood event to overtop the elevated floodplain. So, given that sediment deposition is equal at two sites, the site with the smaller stream will tend to overtop its floodplains less frequently.

These high recurrence intervals indicate that floodplains lying on the former pond bottom often become very disconnected from the stream channels. Active floodplains generally have a flood frequency that falls between 1 – 5 years compared to 6 – 30 years at Hebron, Fulton, Black Earth Creek, and Mt. Vernon (Leopold, Wolman, and Miller 1992 and Dunne and Leopold, 1996). Flood frequency intervals would tend to increase over time as a stream cuts further down into the exposed sediments, raising the elevation of the floodplain above the stream channel. At the older sites, streams have cut a smaller shelf into the side of the former pond area. These small strips are flooded more frequently the higher area covering most of the former pond bottom. The smaller shelves were observed at Mt. Vernon, Black Earth Creek, and a less well-developed shelf at Fulton.

The hydrograph for the Yahara River for June 1996 (Figure 11) shows that flood events overtopping the floodplain at Fulton do not last for very long. On June 18, 1996, the largest flood ever recorded in 20 years of record occurred, with an instantaneous peak reading of 3230 cfs. Despite the large amount of water flowing through the Yahara River, the amount of time that the flood exceeded 2700 cfs (the discharge required to flood the former pond area at Fulton) was only a few hours. Thus, the floodplain at the Fulton pond area was likely under water for only a few hours.

Figure 11: Hydrograph for the Yahara River near the gage at Fulton, June 1996.

(USGS, 1999)

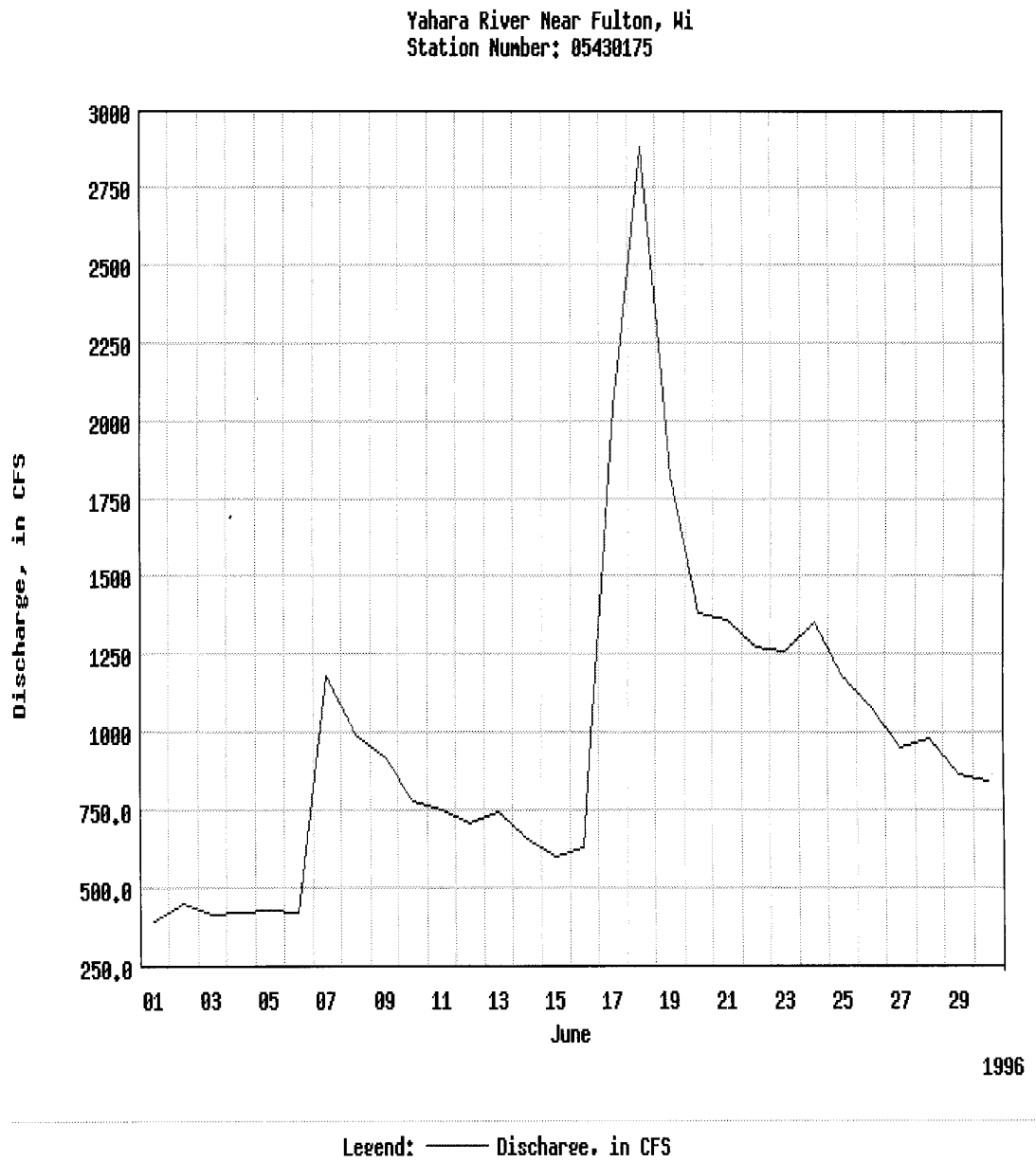
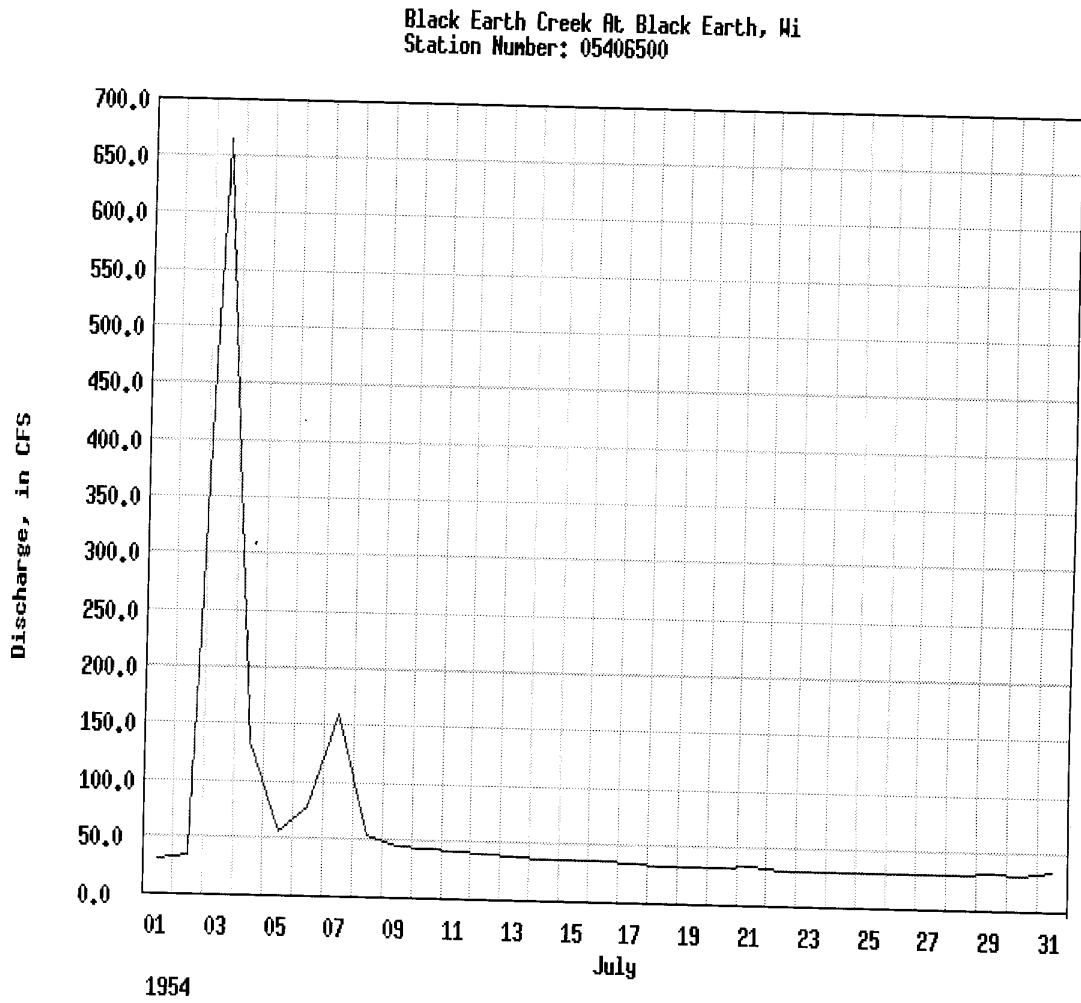


Figure 12: Hydrograph for Black Earth Creek at Black Earth, Wisconsin,
July 1954 (USGS, 1999)



Legend: — Discharge, in CFS
— Estimated Discharge, in CFS

Other peaks that exceeded the estimated pond flooding flow occurred in 1978 (2870 cfs), 1981 (3040 cfs) and 1994 (2730 cfs). The daily hydrograph records for these days do not even reach the recorded instantaneous peaks indicating that the peak flow must have only lasted for a period of minutes. On these smaller flood events, the river could have only potentially overtopped the floodplain for a period of one hour or less, the smallest time period measurable on the daily hydrographs.

At Black Earth Creek, the highest flow ever recorded in 45 years of gage records was July 3, 1954 at 1750 cfs (Figure 12). The daily hydrograph for this time period, shows a peak of around 660 cfs, indicating that the peak of 1750 cfs must have lasted very shortly, and probably overtopped the floodplain in the former pond area at Cross Plains for only a very short time .

The significance of these short flooding durations is that all of the sites except Waterloo appear not to get inundated by overbank flow for long time periods. Negative effects on bottomland tree species caused by inundation are usually measured in terms of days, not hours (Hosner, 1960). This implies that floods at these four sites may not inundate the floodplains long enough to have much limiting influence on the establishment and growth of trees.

SUMMARY OF FLOOD HYDROLOGY FINDINGS

- Four of the five sites have entrenched streams that rarely overtop their banks.

- The flood frequency of the former pond area varied from less than 2 years at Waterloo to greater than 30 years at Hebron.
- Duration of flood events was estimated to be very short at Black Earth Creek, Mt. Vernon, Fulton, and Hebron. Hydrographs reveal that flood duration would have been in the range of minutes to hours.

4.2.4 CHANNEL MORPHOLOGY

Although my research questions did not focus on channel morphology, channel cross sections and survey information did provide useful data that helped describe current conditions of channels at dam removal sites.

Location of Stream Channel in Relation to Historic Path

Soil cores in stream and floodplain areas showed that stream channels usually do not lie in the historic channel after dam removal. As a result many stream now run across historic floodplain soils. The Bark River at Hebron actually had tree stumps that were remnant of pre-dam logging rooted in the current channel. The fact that streams cut new paths following dam removal has several consequences:

- 1) The stream may lie on silt or other fine sediment instead of the sand or gravel bottom that is desirable for many fish species.
- 2) In some cases the new stream channel is extremely straight. The loss of meanders may have significance for the distribution of channel features such as pool and riffles and overhanging vegetation that may benefit fish populations.

Condition of Streambanks

Streams behind recently removed dams tended to have steep stream banks, frequently at angles of 90° or more. Sediment deposits are loosely aggregated after dam removal, making very unstable streambanks as the stream cuts vertically down. At sites removed up to five years ago, steep, unstable banks frequently slump into the stream (in chunks up to 2 x 4 feet), contributing large amounts of sediment to the channel. The older sites had more gradually sloping banks as the sharp edges of the banks were washed away by high flows. The banks at the older sites were vegetated with reed canary grass and other species while recently removed sites were more sparsely vegetated.

Channel Entrenchment

Many of the streams were deeply entrenched, with stream bottoms up to eight feet below the floodplain. A comparison of two cross sections taken at Mt. Vernon and Waterloo illustrates major differences in channel morphology between a site removed 3 years ago and one removed 45+ years ago (Figures 13 and 14). Although Waterloo and Mt. Vernon have similar mean annual discharges, Mt. Vernon's stream bottom lies over seven feet below the floodplain, while Waterloo lies about three feet below the floodplain.

Entrenchment may become greater over time as streams cut through the pond sediments.

Streams with greater amounts of deposited sediment, such as Mt. Vernon and Fulton tend to become more deeply entrenched than streams with less sediment, such as Waterloo, because these streams have further to downgrade to coarse material.

**Figure 13: Stream Cross Section at Mt. Vernon
Creek, WI
March 1999**

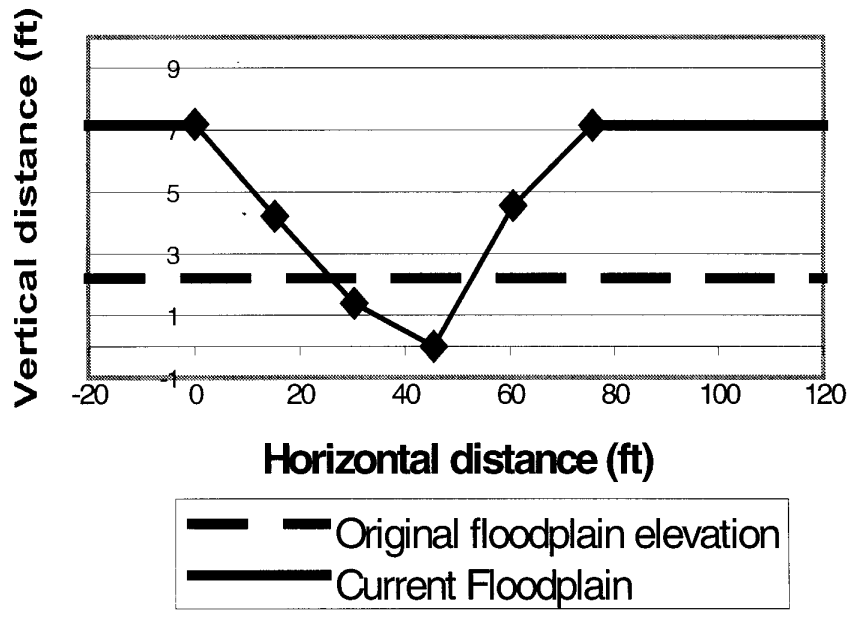
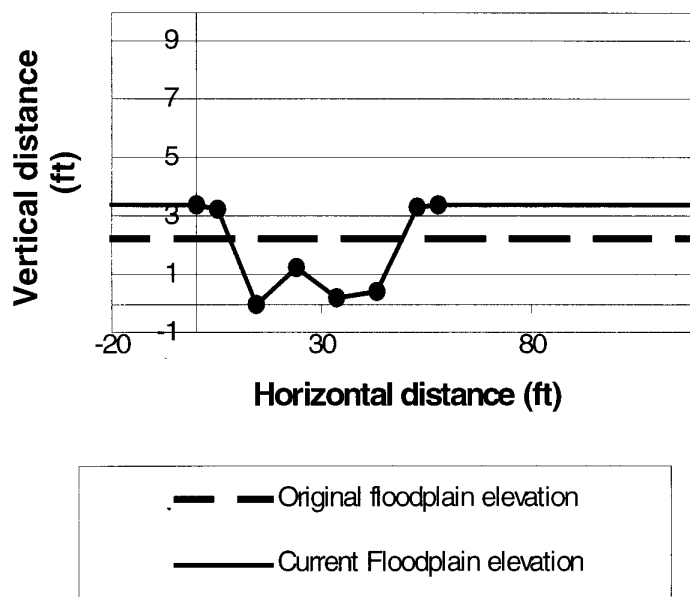


Figure 14: Maunesha River Cross Section, at Waterloo, February 1999



Depth of Stream Bottom Below Reservoir-Deposited Sediment

Streams at 8 of 10 cross-sections had cut beneath the pond-deposited sediment. At these locations the elevation of the stream bottom lay beneath the elevation of the pond-deposited sediment. The only site where the stream bottom still lied on the pond sediments was at Hebron, where the elevation of the stream bottom was 1-2 feet above the lower elevation of pond sediments. These two cross sections were taken about 400-600 yards from the old dam

which was removed 4 ½ years before the measurements were taken. Closer to the dam, the stream bottom had cut through the pond sediments and lay on top of the original flood-plain soils. The same pattern was observed at Waterloo, where both stream bottom elevations taken were lower than pond sediment elevations at about 200 yards from the former dam. Although no cross sections were taken in the vicinity, 600 yards and further upstream the stream channel appeared to be lying on top of the pond sediments still, lying at a depth of a foot or less below the current floodplain.

Water Surface Slope

The water surface slope was greater in the stream area running through the former impoundment than in unimpounded reaches at all sites except Mt. Vernon (Table 10).

Within the former reservoir area there were often areas of rapids at recently removed sites.

The rapids are somewhat unusual for these streams, because the Yahara, Bark and Maunsha River are all relatively low gradient streams (Table 10). These rapids probably exist because of these increased stream gradient in the former impoundment area (Tables 9 and 10). In the case of Fulton and Hebron, the slope in the former impoundment exceeded the main stem slope by 65% to over 100%.

The increased slope may be explained by the following. After dam removal the stream lies on a mound of sediment remaining from the reservoir and so it must cut downhill to reach the slope of the rest of the stream. The slope may drop precipitously in areas where the stream forms a headcut through the sediment. At Waterloo, the Maunsha River supports an

Table 10: Comparison of Channel Morphology in Former Pond Area Vs. Unimpounded Reaches

	BEC	Fulton	Hebron	Mt. Vernon	Waterloo
Mean annual flow*	17	371	100	10-15	No data
Main-stem channel slope**	6.9	2.14	3.8	18.5 - 23.3	5.8
Slope near study sites**	9.42	3.55 in lower Yahara	2.7 (over last 20 miles of river)	No data	No data
Slope of reach in former impoundment area	11.59	5.44	5.63	4.68	7.16
*USGS water resources data, 1954-1998					
**Reference: Krug, 1992, Day et al., 1995, Poff et al. 1968.					

unusually large headcut about 200 yards upstream from the former dam where the river drops 3-4 feet in a single plunge-pool. Mt. Vernon was an exception, with less of a slope in the former reservoir area than the rest of the river (4.68 feet per mile compared to 23.3 feet per mile for Mt. Vernon Creek mainstem). Aerial photos from the 1950's and 1960's reveal that a small pool remained in this area for years after the dam was removed. Apparently there has been an area of slackwater in this vicinity for several decades.

Sinuosity

Channels were noticeably straighter than would be expected in unchannelized streams at three sites. Black Earth Creek was particularly straight, lying in almost a perfectly straight line in the former reservoir (Figure 2a). Waterloo and Fulton also appeared extremely straight in the former reservoir (Figure 4a and 6a). In contrast, Hebron had a large meander

in the former reservoir area, forming at least a 180 degree turn, shaped like a “horseshoe” (Figure 5a). Preliminary measurements of sinuosity made from aerial photo showed that sinuosity was lower in the formerly impounded areas than un-impounded areas at four of five sites. Although some channels certainly appear straighter than would naturally be expected, the sinuosity data is insufficient to make any conclusions at this time

4.3 VEGETATION

4.3.1 General Plant Community Characteristics

The plant communities I sampled in the former reservoir areas have had from three to forty-nine years in which to develop since dam removal. All of the sites are similar in that they are all open communities covered mostly by herbaceous vegetation. In other words, none of the sites are heavily wooded. Fulton and Waterloo did have large areas of shrub coverage, consisting mostly of *Salix exigua* (sandbar willow). While all of the sites lie on floodplains, the plant species present ranged from obligate wetland species to plants characteristic of uplands. Pioneer and/or “weedy” species characteristic of disturbed soils, such as stinging nettle (*Urtica dioica*) and sandbar willow were abundant at all five locations, particularly where dams were recently removed.

Comparison of Drained Pond Communities to other Wisconsin Plant Communities

None of the plant communities I studied resembled naturally occurring Wisconsin plant community types described by Curtis (1959) or Eggers and Reed (1997) very closely. The older sites (Black Earth Creek and Mt. Vernon) were covered with many weeds and grasses

characteristic of “old-field” type communities. *Poa pratensis*, *Trifolium pratensis*, *Cirsium* sp., *Pastinaca sativa*, *Taraxacum officinale*, *Bromus inermis*, and *Phalaris arundinacea* were some of the most common species at these two sites (see Appendix C). These sites did have a strong resemblance to the weed communities that Curtis (1959) described which occur on disturbed soils. (Table 11 displays the percentage and number of species found at each site that were also listed on Curtis’s prevalent species list for that community type.) Thirteen species or 31.7% and 38.2% of species found in quadrat samples at Black Earth Creek and Mt. Vernon were also prevalent species in Curtis’s “Weed communities of Southern moist, nitrogen-rich soils” category.

Recently removed sites more resembled Curtis’s shrub carr, floodplain forest or Southern sedge meadow communities than Curtis’s weed communities (Table 11). Nine species or 23.1% of the total species found at Waterloo were also listed as prevalent in Curtis’s shrub carr community type. At Fulton the vegetation was divided among many of Curtis’s community types with four species found in four categories.

Table 11. Similarity of Vegetation in Drained Impoundments to Curtis (1959) Wisconsin Plant Community Types.

(The % of species found in 45 quadrat samples at each site that were also prevalent species in Curtis's plant community categories. The number of species in each category is listed in parenthesis.)

SITE	Black Earth Creek	Fulton	Hebron	Waterloo	Mt. Vernon
Most Similar community	Weed A* 31.7 % (13)	Floodplain forest 16% (4)	Shrub Carr 19.2% (5)	Shrub carr 23.1% (9)	Weed A 38.2% (13)
↓	Weed B** 29.3% (12)	Sedge meadow 16% (4)	Sedge Meadow 19.2% (5)	Sedge Meadow 17.9% (7)	Weed B 32.4% (11)
	Wet prairie 12.2% (5)	Weed A 16% (4)	Floodplain Forest 11.5% (3)	Weed A 12.8% (5)	Shrub carr 11.8% (4)
	Less Similar	Shrub carr 16% (4)	Emergent aquatics 11.5% (3)	Weed B 12.8% (5)	
* Weed A is Curtis' "Weed communities of Southern moist, nitrogen-rich soils" category. **Weed B is Curtis's Weed communities of southern heavy soils" category					

The four most cumulatively frequent species at the recently removed sites included stinging nettle (*Urtica dioica*), jewelweed (*Impatiens capensis*), reed canary grass (*Phalaris arundinacea*), and rice-cut grass (*Leersia oryzoides*). Most of Fulton and approximately 60% of Hebron was covered by stinging nettle stands that were nearly monocultures. Stinging nettle was found in 82% of quadrats at Fulton and 78% of quadrats at Hebron (See Appendix C). Jewelweed and rice-cut grass also covered large areas in nearly pure stands. Reed canary grass occurred primarily along streambanks. *Solidago sp.* (*canadensis* and *gigantea*), *Aster sp.*, *Cirsium sp.*, and *Salix exigua* were also frequently encountered species at recently removed sites. (For a discussion of life histories and plant species interactions see Chapter 6.)

It should be noted that Black Earth Creek and Mt. Vernon have been managed through mowing and hay harvest since dam removal. Therefore, comparison of species composition to the unmanaged sites may have limitations. For instance, it is likely that the mowing and haying operations have limited the development of woody vegetation. Along the streambanks of Mt. Vernon, numerous mature boxelder trees exist, suggesting that in the absence of active cultivation or management, the former pond area would support woody vegetation. It was assumed that the mowing and haying would not effect the relative amount of wetland species however. Mowing and plant harvest may affect species composition, but if the area is still wet, those species growing on the site must still be adapted to water-saturated conditions.

Summary of Plant Community Characteristics at Drained Impoundments

- The existing vegetation at these five sites does not clearly fit into any previously described Wisconsin plant community types
- The sites are all open communities covered mostly by herbaceous species, with the exception of small areas covered by sandbar willow
- Grasses and exotic weeds were more common at older dam removal sites
- Recently removed sites were dominated by one or more of the following individual species: stinging nettle (*Urtica dioica*), jewelweed (*I. capensis*), reed canary grass (*P. arundinacea*), rice-cut grass (*L. oryzoides*), and sandbar willow (*S. exigua*).

4.3.2 USFWS hydrophytic vegetation categorization

The Proportion of "Wetland" Versus "Upland" Species in Drained Impoundments

In general Fulton, Waterloo, and Hebron supported hydrophytic or "wetland" vegetation while less than one-quarter of species at Black Earth Creek and Mt. Vernon were hydrophytic, as defined by USFWS categories (Table 12). Wetland species were generally found only along streambanks at the older sites and on the outer edge of the pond near areas of groundwater discharge. Obligate wetland species were even more sparse at these two locations. Floating aquatic species - plants that require a nearly continuous supply of standing water, were sparse at all five locations. Floating aquatic species were only found in three quadrats at Hebron, the only site that had areas with water standing at the ground surface. Lesser duckweed (*Lemna minor*) was the only floating aquatic species found. Submerged aquatic plants were completely absent from all five sites.

Site	% of hydrophytic species *	% of obligate (OBL) wetland species	Weighted average and corresponding category
Black Earth Creek	16	6.3	7.62 (FACU)
Mt. Vernon	23	10.3	7.21 (FACU+)
Fulton	72	21.7	3.32 (FACW)
Hebron	90	61.5	2.86 (FACW)
Waterloo	84.4	32.4	1.57 (FACW+)
*Hydrophytic vegetation includes OBL, FACW+, FACW, FACW- species			

4.3.3 Plant Community Structure and Species Diversity

Species Diversity and Density

Generally the sites with dams removed 40+ years ago had greater species diversity than the younger sites. In 45 1m² quadrat samples, species diversity was found to be greatest at Black Earth Creek, with 42 species in the former pond area (Table 13). Fulton and Hebron had the least species, with 25 and 26. When species observed in walk-through samples are added, species diversity at Black Earth Creek totaled 60 species compared to 30 at Fulton and 38 at Hebron. A remnant area of sedge meadow and wet prairie exists between the former impoundment and a set of railroad tracks at Black Earth Creek. This area may have contributed plant colonizers to the former pond area at this site.

Black Earth Creek also had the greatest species density (species per 1m² quadrat) with 8.64 species per quadrat (Table 13). The recently removed sites had the lowest values, (Hebron 2.87 and Fulton 2.27) with the exception of Waterloo which had a score of 5.04. The colonization of the mudflats following dam removal is an example of primary succession. While pioneer species would be expected to dominate newly exposed soils initially, more species would be expected to colonize as the pioneer species alter the site conditions and microclimate through their growth and decay. However, the near monoculture growth of stinging nettle with its tall canopy may possibly inhibit the colonization of other species at Hebron and Fulton.

Table 13: Species Diversity and Exotic Species Data (In 45 1m² samples)

Site	Total species found in quadrat and walk through survey	Total species found in quadrat samples	Species Density (species per 1m ²)	% of species that are exotic	Years since dam removal
Black Earth Creek	59	41	8.64	47.6	38
Mt. Vernon	42	34	3.76	55.9	48
Fulton	30	25	2.27	24.0	5
Hebron	38	26	2.87	11.5	5
Waterloo	49	39	5.04	15.0	3

Exotic Plant Species

Exotic species, defined as species non-native to the United States, were most abundant at the older sites. At Mt. Vernon and Black Earth Creek exotics comprised 47.6% and 55.9%, respectively, of the total species at each site (Table 13). The younger sites had exotic percentages ranging from 11.5 - 24.0% of the total species. The most common exotic species was reed canary grass, which was found at all five sites. Purple loosestrife (*Lythrum salicaria*) was found at Hebron only, but appeared to be increasing between years four and five since dam removal. Garlic mustard (*Alliaria petiolata*) covered large areas in the adjacent floodplain forests at Fulton and was expanding into the former pond area there. At the older sites exotic species had the highest frequency scores, particularly *Poa pratensis*, *Daucus carota*, *Cirsium arvense*, *P. arundinacea* and *Pastinaca sativa*.

Functional Diversity

It has been suggested that the diversity of functional groups may be equally or more important for the maintenance of ecological processes than species diversity (Tilman et al, 1997). Functional diversity is supported by different life forms (e.g. woody or herbaceous) and/or different families which provide ecological functions such as nitrogen fixation as in the legume or fabaceae family. Some important functional groups include: woody species, legumes, C4 and C3 grasses, and forbs. (Note: functional groups may overlap with or exist as a subset of the family or life form classifications that are presented in Table 14.)

TABLE 14: Plant Community Structure (Frequency of plant families and life forms as the percentage of occurrence in 45 quadrats. The number of species in each group is listed in parenthesis.)					
Classification	Site				
	BEC	Fulton	Hebron	Mt. Vernon	Waterloo
Urticaceae	4.4 (2)	82.2 (2)	82.2 (3)	6.7 (1)	46.7 (2)
Gramineae	100 (4)	28.9 (2)	64.4 (2)	100 (6)	86.7 (5)
Balsaminaceae	11.1 (1)	37.8 (1)	22.2 (1)	2.22 (1)	53.3 (1)
Compositae	97.8 (10)	8.9 (5)	17.8 (5)	62.2 (6)	71.1 (9)
Cyperaceae	0	2.2 (1)	6.7 (3)	6.7 (3)	26.7 (2)
Salicaceae	0	13.3 (2)	0	0	28.9 (3)
Umbelliferae	95.6 (2)	0	0	8.9 (1)	2.2 (1)
Fabaceae	64.4 (5)	0	0	71.1 (3)	2.2 (1)
Brassicaceae	4.4 (1)	22.2 (2)	0	4.4 (2)	0
Other					
Life Forms					
Graminoids	100	28.9	64.4	100	86.7
Forbs	100	97.8	97.8	80	100
Vines	24.4	8.9	0	0	4.4
Trees	0	6.7	0	4.4	26.7
Shrubs	0	11.1	0	2.2	26.7

Graminoids

Because the sites were primarily open communities covered by herbaceous species, grasses are one of the more important plant groups occurring in drained impoundments. The graminoids, including the families Gramineae and Cyperaceae were comparatively more frequent at the older sites (Table 14). The grass family (Gramineae) occurred with 100% frequency at Mt. Vernon and Black Earth Creek, consisting of six and four grass species, respectively. At the younger sites, Hebron and Fulton both had only two grass species present, *L. oryzoides* and *P. arundinaceae*. Gramineae occurred in 64.4% and 29.9% of quadrats at these two sites. Large uniform stands of stinging nettle and other forb coverage may have limited grass coverage at these sites. Waterloo had five grass species occurring with a frequency of 86.7%. *L. oryzoides* was the most frequent graminoid at recently removed sites, while Kentucky Blue grass (*Poa pratensis*) and timothy (*Phleum pratensis*) were most common at the older sites.

Sedges (family Cyperaceae) including *Carex sp.* are one of the most important wetland plant species in Wisconsin wetlands (Eggers and Reed, 1997). Although sedges, particularly *Carex sp.*, are one of the most prevalent species in Wisconsin wetlands, they were mostly absent from the study sites, except Waterloo. *Carex stipata*, *Carex vulpinoidea*, and *Scirpus atrovirens* were the most common sedges, occurring with the greatest frequency at Waterloo (Table 14 and Appendix C).

Legumes

The legumes or Fabacea family were abundant at the older sites but not at the recently removed sites. Legumes are important species in prairie environments but occur less frequently in wetland areas (Curtis, 1959). Only one legume was found at the wetter, recently removed dam sites. However five legume species occurred with a cumulative frequency of 64.4% at Black Earth Creek and three legumes occurred in 71.1% of quadrats at Mt. Vernon (Table 14).

Vines

Vines, which are characteristic of floodplain forests, were most frequent at Fulton (8.9%) and Black Earth Creek (24.4%). The vines were mostly non-woody species, including bindweed (*Polygonum scandens*) and *Solanum dulcamara*.

Woody vegetation

The abundance of woody plants (e.g., trees and shrubs) is of particular interest because of the major ecological differences between wooded communities and open grasslands. Woody species were virtually non-existent at the older sites, while at younger sites they existed mostly as small seedlings. Both of these sites have been subject to mowing and haying, probably eliminating most woody species. Black Earth Creek had no woody species in quadrat samples, although some were present outside of samples. Mt. Vernon had a tree frequency of only 4.4% and 2.2% for shrubs.

The younger sites have undergone no mowing or burning and woody species were more abundant than at the older sites. Tree seedlings were present in small quantities at Fulton and Waterloo. These seedlings consisted mostly of plants less than one year old, although a few 2-3 year old seedlings were present at Fulton. Fulton, with a shrub frequency of 11.1% and a tree frequency of 6.7% and Waterloo with a frequency for both trees and shrubs of 26.7% had the highest frequency of woody plants (Appendix C). Sandbar willow (*Salix exigua*), a shrub, was the most frequently occurring species at sites with significant woody plant coverage. *S. exigua* was found in dense patches on slight rises, usually on sandy soils at Fulton and Waterloo. Boxelder (*Acer negundo*) was the most common tree species at Waterloo and seedlings were common at other sites, though not abundant in quadrat samples. Other common tree species were black willow (*Salix nigra*), cottonwood (*Populus deltoides*) and silver maple (*Acer saccharinum*).

Other Families

Urticaceae was the most frequent group at the family level at Fulton and at Hebron (both with frequency of 82.2%) (Table 14). Although what functional role Urticacea plays is uncertain, stinging nettle is known to be an efficient translocator of nutrients, moving them from the nutrient-rich pond soil to the plant's shoots (Srutek, 1995). These stands of stinging nettle may possibly serve to lower nutrient levels in drained pond soils after several years.

The Compositae family was abundant at all sites, but was most frequent at Black Earth Creek (97.8%). Composites actually had the largest number of species at all five sites. Black Earth Creek with ten and Waterloo with nine had the most species. Many composites play an

important role in supporting bird and insect populations. For instance, *Bidens cernua*, a common species at Hebron, is known to be a favorite source of food for waterfowl.

4.3.4 Vegetation in stream

Based on observations of stream vegetation, I found that submerged and floating aquatic vegetation was very sparse at recently removed sites and more abundant at the older sites. At recently removed sites, aquatic vegetation never exceeded approximately 5% coverage and was absent from much of the stream area running through the former impoundment. At Fulton, *Potamogeton crispus*, *Potamogeton pectinatus*, and *Elodea canadensis* were observed in sparse populations. At Waterloo, only Eurasian milfoil (*Myriophyllum spicatum*) was observed, an exotic species more commonly found in lakes or reservoirs. Hebron had also had sparse coverage with *M. spicatum* and *Potamogeton natans*. *M. spicatum* and *P. natans* are species that favor slack water and high nutrient levels. It is possible that these species existed in the reservoirs when the dam was still in place providing a source of colonizers that still remain today.

At the older sites submerged aquatic vegetation was abundant, particularly at Black Earth Creek, where coverage was estimated at 25-35%. Black Earth Creek was found to be a very productive stream for aquatic vegetation by Field and Graczyk, 1990. Apparently aquatic macrophytes have recolonized very successfully here since dam removal in 1960. *Rorriippa longistiros* and *Potamogeton pectinatus* were the most common species at Black Earth Creek. *P. crispus*, *Elodea canadensis*, *Callitriche sp.*, *Lemna minor* were present in less

abundance. Mt. Vernon had slightly less aquatic vegetation coverage, estimated at 15-25%.

R. longistiros and *P. pectinatus* were most abundant there.

Summary of Vegetation Findings

- All five sites are open sites covered mostly by herbaceous vegetation
- Hebron, Fulton, and Waterloo supported a majority of hydrophytic plant species
- Black Earth Creek and Mt. Vernon supported a majority of non-wetland plant species
- Grasses were more abundant at older sites than recently removed sites
- Sedges, particularly *Carex sp.* were sparse at all five sites
- Species with long life cycles (such as *Carex stricta*) were generally uncommon at the recently removed dam sites
- Exotic species were relatively more frequent at old dam removal sites.
- In-stream vegetation had very sparse coverage at recently removed sites but was very abundant at Black Earth Creek and Mt. Vernon

CHAPTER 5: CHANGES TO VEGETATION AND HYDROLOGY OVER TIME

5.1 SEDIMENT

As discussed earlier, considerable changes take place in the floodplain surface over time following dam removal. As the water is removed from a reservoir, the soil lies in a loose unconsolidated mound. The sediment may dry out over time considerably if the stream downgrades through the loose sediment and there is little groundwater discharge. At the older sites, the soil was strikingly more dense and the large fissures found at the recently exposed mudflats after dam removal were not present.

This investigation raises the question of what soil-forming processes may be occurring in the surface pond sediment over time. There are likely several processes going on, including:

- “De-watering” of soil may cause subsidence, which could cause a drop in ground elevation over time. In large sediment deposits, this may lead to a significant drop in elevation and subsequent increase in moisture.
- Organic matter, in the form of dead plant material, is accumulating on the soil surface
- Root growth and soil organisms may form conduits through the soil, tending to decrease density and increase water infiltration capacity

5.2 HYDROLOGY

The main hydrological changes that may occur over time after dam removal include:

- Increased depth to water table
- Reduced frequency of flooding on upper terrace.
- Changes to channel morphology

One of the main differences in channel morphology between recently removed sites and older sites is the slope and vegetative cover of streambanks. Over time the steep banks appear to get eroded away, forming more gradually sloped banks that are covered with vegetation, particularly reed canary grass. The area that was gauged out is lower in elevation and so is flooded more frequently than the upper terrace area. Knox (1977) observed similar patterns in streams located in southwestern Wisconsin. These stream systems had large amounts of sediment deposited in the late 1800's up until about 1950 before farming conservation practices became widely used. When the sediment supply was reduced, the streams began to downgrade, and cut through some of the sediment. Ruhlman and Nutter (1999) described a similar phenomenon in Georgia streams as well:

“Streams that once ran clear over small rocky channels with bed elevations similar to that of adjacent floodplains now run turbid through large entrenched channels over mostly sediment-covered bottoms. Floodplains that once had well-developed surface soils are now filled with thick deposits of modern sediment. The changes in channel geomorphology have likely influenced the flooding frequency of associated floodplains and riverine wetlands.”

With the exception of the description of rocky channels, the above description applies very well to the more heavily silted streams in my study. In the case of Georgia as well as Wisconsin, heavy sedimentation from anthropogenic sources left large amounts of sediment

on floodplain areas. After the source of sediment was reduced, streams adjusted by cutting down through the sediment leaving elevated terraces that are rarely flooded.

5.3 VEGETATION

5.3.1 Comparison of Current Plant Communities to Historic Plant Communities

The five locations in my study have undergone considerable change over the years. Starting as open rivers, they were impounded in the mid 1800's and existed as pond environments for 100 or more years. Today they are again open rivers, some still flowing across residual pond sediment. In some cases, relict cattails survived reservoir drainage and still grow in corners of Fulton and Waterloo.

Understanding pre-dam plant communities is important because they may serve as models for management, landscaping, or ecological restoration in former reservoir areas. If minimal sediment remains on the floodplains, it may be possible to restore a community similar to the pre-dam community. However, because the dams I studied were built between 1836 and 1857 little direct information was available on pre-dam communities.

To obtain information on pre-dam plant communities I did historical research and took soil cores. I found that most of the current plant communities do not resemble the pre-dam plant communities very closely (Table 15). The vegetation at Waterloo, the site least disturbed by pond-deposited sediment, did have some similarity. It currently supports a wet meadow with significant shrub coverage. Soil cores revealed a fibric peat composed

Table 15: Comparison of Current Vegetation to Pre-Dam plant Communities
(Based on historical land surveys, 1934 land-use maps, soil cores, and woody plant remains.)

SITE	Current Community Type	pre-dam plant community type***	Sources of historical information			
			1830's land survey	Bordner (1934)**	Soil cores	other
Cross Plains	Wet/wet-mesic prairie species with exotic weeds	Sedge meadow	Prairie surrounded by oak openings		✓	
Fulton	<i>U. dioica</i> monoculture, some tree seedlings	Shrub-carr and floodplain forest	"thin timber"	"Sedge marsh"	✓	
Hebron	1. <i>U. dioica</i> 2. <i>Leersia oryzoides</i> with emergent aquatics	Forested swamp With elm, ash and basswood	Marsh surrounded by mesic forest		✓	✓ ***
Mt. Vernon	Wet meadow with facultative upland species many exotic weeds	Sedge meadow	"marsh" in lowlands Burr Oak openings in upland	Sedge meadow bordering millpond	✓	
Waterloo	Wet meadow with willows invading from edge	Sedge meadow or shrub carr	Marsh common in between drumlins		✓	

**economic land inventory maps (Bordner, 1934)
 *** (Based on Eggers and Reed, 1997)
 *** Woody Plant Remains (see Appendix A)

of shrub material located on top of a clay layer. This indicates the site was probably a shrub-carr or sedge meadow with organic soil before dam construction. Structurally the site resembles a shrub-carr today except that there is 0-26 inches of mineral soil lying on top of the original floodplain soil. Species composition is likely quite different, however.

The other sites have changed more significantly. Mt. Vernon and Black Earth Creek were wetlands historically, much closer to the water table than they are today. Nearby communities bordering these streams are nearly all sedge meadows, often in seepage areas. Today both of these communities are covered with mostly facultative or facultative upland species, more closely resembling a prairie. Fulton, with an average of 78.7 inches of sandy sediment on top of the original floodplain, is covered primarily by stinging nettle (*Urtica dioica*) and sandbar willow (*Salix exigua*). The site was described as "thin timber" in the original land surveys done in the 1830's (Harrison, 1833). Combined with soil core evidence (fibric peat), it appears that areas of the site were probably shrub-carr. Adjacent floodplain forests that still exist today may have covered slightly higher areas. At Hebron, tree stumps remain in the former pond area that date to the pre-dam era (pre-1836). These woody remains were identified as elms, ash, and American basswood (See Appendix A). Based on woody remains, landscape position, and groundwater discharge patterns, the area was apparently a forested wetland in a seepage area. Currently there is an average of 51.6 inches of silty loam deposited on the original soil. It consists of *U. dioica* in drier areas and *L. oryzoides* mixed with emergent aquatics where the water table is near the surface.

SUMMARY

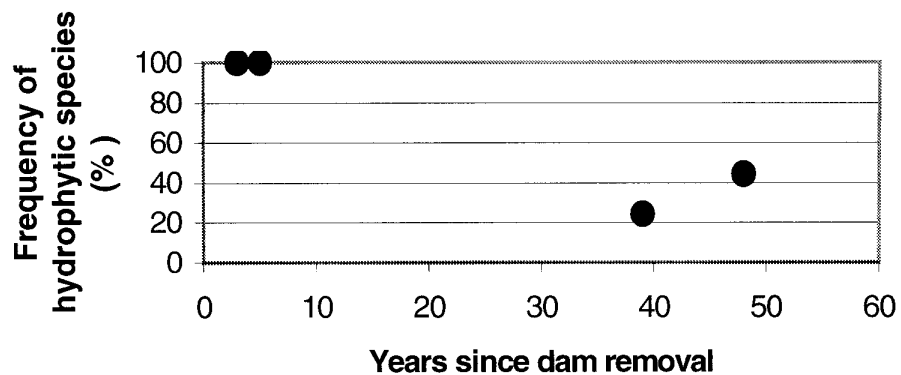
- Pre-dam plant communities (before 1836-1857), are very different from present-day communities with the possible exception of Waterloo (Table 15).

5.3.2 Displacement of Wetland Vegetation with Facultative and Facultative Upland Species Over Time Since Dam Removal

1. Percentage of "hydrophytic" species

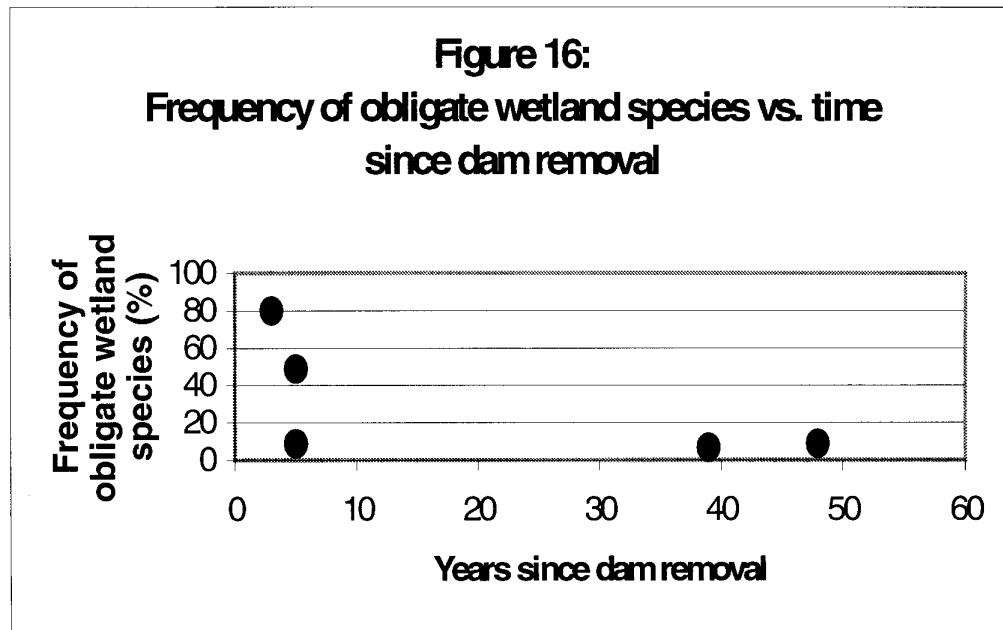
Categorization of plants using USFWS hydrophytic indicator scores (USFWS, 1998), showed quantitatively that the older sites supported less wetland vegetation and more facultative to upland species than the sites of recent dam removal (Figures 15-17). In contrast, the recently removed sites were dominated by wetland plants, both obligate (OBL) and facultative wetland (FACW) species (Table 12).

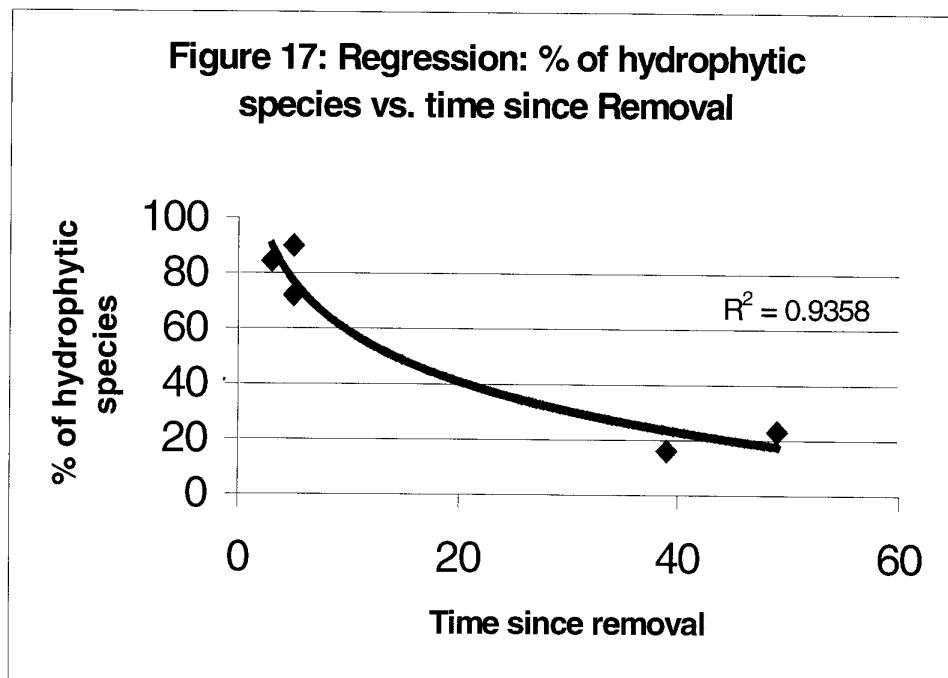
Figure 15: Frequency of hydrophytic species vs. time since dam removal



Obligate (OBL) wetland species are better indicators of saturated soil conditions than facultative wetland species (FACW) because obligate species are found in wetlands an estimated 99% of the time, compared to 67 - 99 % for facultative wetland species (Eggers and Reed, 1997 and Wisconsin Coastal Management Program, 1995). Obligate species,

which are defined as species found in wetlands 99% or more of the time, were common at the newer sites and very rare at the older sites (Figure 16). Obligate species represented only 6.3% of species found at Black Earth Creek and 10.3% of species found at Mt. Vernon. (Black Earth Creek had no obligate species if streambank samples are excluded.) At the younger sites, obligates accounted for 21.7-61.5% of the total species. (Table 12). Hebron had by far the highest percentage of obligate species with 61%, followed by Waterloo with 32.4%.





2. Weighted average indices

The weighted average index, a quantitative estimate of the hydrophytic status of an entire plant community also showed there was less wetland vegetation at the older sites (Table 12). The three recently removed sites had weighted scores of 1.57, 2.86 and 3.32, while the older sites had scores of 7.21 and 7.62. These scores correspond to hydrophytic indicators of facultative wetland plus (+) (FACW+) for Waterloo, facultative wetland (FACW) for Fulton and Hebron, facultative upland (FACU) for Black Earth Creek and facultative upland plus (+) -- (FACU+) for Mt. Vernon, respectively (Table 12). In summary the older sites had

lower frequencies of wetland species (Figures 15 and 16), less wetland species as a percentage of the total species (Figure 17), and higher weighted average indices than newer sites. (Table 12). As stream channels cut down through pond sediments, water tables would be expected to drop over time encouraging the colonization of facultative to facultative upland plants. The increasing depth to the water table that may occur over time would allow many upland or facultative upland species to invade the sites, so that the older sites do not support a majority of wetland vegetation.

CHAPTER 6: FACTORS AFFECTING PLANT COMMUNITY COMPOSITION IN FORMER IMPOUNDMENTS

To answer the question, “What factors most strongly affect plant community composition in former impoundments”, I compared soil and hydrological variables and time since dam removal at all five sites. Since there is so little information available on plant communities in drained ponds, one of the most basic questions that needs to be answered is what type of plant communities naturally develop in drained ponds. One of the strongest influences on plant community composition is the depth and character of sediment deposits in the former reservoir area.

6.1 DEPTH OF SILT AND CHARACTER OF POND - DEPOSITED SEDIMENT

6.1.1 Mineral Soils Overtop Organic Soils in Most Cases

The deposited sediment is different than the pre-dam soils in most cases, with mineral soils overtopping organic soils (peat and muck). The sediments are comprised of mostly silt, with sand abundant at Fulton and Waterloo (Table 4 and Appendix A). Pond sediments tend to be high in nutrients favoring weedy, fast growing species like stinging nettle (Srutek, 1995). Mineral soils also have different hydraulic properties than organic soils, tending to hold less water than organic peat soils. This contributes to the overall drying effect in the former pond area once the dam is removed. Sandy soils, such as the sandy loam soil found at Fulton, tend

to hold less water than the silt loams found at Black Earth Creek, Mt. Vernon, and Hebron due to the greater hydraulic conductivity of sand.

6.1.2 Exposed soils allow colonization of undesirable vegetation

Exposed soils favor colonization of pioneer species. Species such as stinging nettle and rice-cut grass have colonized and covered large areas of exposed mudflats. Significantly, the first plants to colonize a mudflat may persist for many years. A clonal species like stinging nettle may expand quickly and cover large areas of the pond area (See Chapter 7 for more detail on this potential problem).

6.2 THE AFFECT OF HYDROLOGIC FACTORS ON VEGETATION

6.2.1 Influence of Depth to Water table on vegetation

The degree of saturation or inundation in the upper soil horizons has a strong influence on plant species composition due to varying tolerances to inundation. Because of differences in hydraulic conductivity between soils, saturation in the capillary fringe may be a more accurate indicator of moisture experienced by plants in the root zone than depth to water table (Randall et al, 1999). However because the soils were very similar at all five sites, I considered depth to water table adequate for purposes of comparing soil moisture between sites in this study.

Using the 20 inch depth to water table guideline used in the Wisconsin Coastal Management Program's wetland delineation guidelines, most of the sites had sufficiently high water tables to support wetland vegetation (Wisconsin Coastal Management Program, 1995). However,

Black Earth Creek and Mt. Vernon did not in fact support wetland vegetation for the most part, with only 16 and 23% of hydrophytic vegetation. Most of the wetland vegetation at these sites occurred either on streambanks or near the edge of the pond where groundwater discharged near the surface. Waterloo, with the highest average water table (using the average depth of both wells on site), had 84.4% hydrophytic species. Hebron had the highest percentages of hydrophytic vegetation (90%) despite having a lower water table than Waterloo. However, about one-third of the former Hebron pond area had water standing at the surface year-round, although no wells were located in this area. Most of the plants in this area were obligate species, including emergent and floating aquatics such as *Sagittaria latifolia* and *Lemna minor*. Emergent species are generally found in areas with very high water tables, while floating aquatics are plants that require constant standing water. Floating aquatics were found at none of the other sites.

The affect of water table depth on plant species composition was apparent in comparing the distributions of rice-cut grass and stinging nettle, two species that dominated large areas of recently drained impoundments. Rice-cut grass favors high water tables, as it is an obligate (OBL) wetland species, related to rice (*Oryza sp.*), unlike *U. dioica* which is a facultative wetland species (FACW-). At Hebron, rice-cut grass grew in areas where the water table was at or near the surface. At sites of recent dam removal, rice-cut grass was the most frequent species where the mean water table was less than 20.5 inches from the ground surface. Rice-cut grass was not found in drier areas of Fulton and Hebron where the water table exceeded 28.85 inches below the ground surface. At depths greater than this stinging

nettle was the most frequent species. Stinging nettle was absent from areas where the water table was near the ground surface at Hebron.

Stinging nettle was more frequent in areas with a water table from 30.6 - 48.8 inches below the ground surface (in the vicinity of Hebron Well #2). At Fulton, where the water table was never closer to the ground surface than 14.36 inches, only one occurrence of rice-cut grass was recorded (frequency 2.2%). Rice-cut grass was also found to be one of the first colonizers in drained beaver impoundments in Tennessee (Houston et al, 1992). Houston et al. found that extensive mats of rice-cut grass suppressed tree seedling growth in the first growing season, though once tree canopy closure occurred rice-cut grass declined.

6.2.2 Effect of groundwater gradients on water table depth and vegetation

Strong upward groundwater gradients are usually correlated with high water tables (Randall et al, 1999). Even if sites are flooded infrequently, groundwater discharge may supply enough water to support wetland vegetation. In this study, there appeared to be no direct correlation between groundwater gradients and depth to water table however. Sediment deposits that have lowered water tables relative to the ground surface may be responsible for this. Unless groundwater discharge occurs in the top few feet of the sediment deposits, the water table may still be well beneath the ground. Apparently groundwater gradients contribute to the maintenance of wetland vegetation only if the discharge is close enough to saturate the root zone, where the plants are growing. For example at Hebron Well Nest #2 had the strongest mean upward gradient of any well location (+2.72 inches), but the water

table had a mean depth of 37.5 inches below the surface, the lowest average of all recorded water tables.

6.2.3 Influence of Flood Frequency on Woody Vegetation

Infrequent flood events with short duration characterize four of the five sites. This flood regime would seem to allow many tree species to establish in former pond area. However, trees were very infrequent at most of the sites. The most common trees found were one-year boxelder seedlings at Waterloo (Table 16). Several 2-4 years saplings were found at Fulton including one walnut and one green ash. Large mature boxelders also lined the Mt. Vernon streambanks, although none fell in the 1m² quadrats. Almost all of the woody species found were flood-tolerant species (Loucks, 1987). While flood frequencies at the sites varied from less than two to thirty-one years, apparently frequently enough to prevent flood-intolerant species from colonizing.

Flooding influences floodplain vegetation by physical disturbance, deposition of alluvial soils, and the creation of water saturated, anaerobic conditions. Flood frequency plays a strong role in determining whether a site will be dominated by woody or herbaceous vegetation. Gill (1970) found that continuous inundation for more than 40% of the growing season will prevent colonization of woody plants. Toner and Keady (1997) found that the timing, duration, and occurrence of multiple floods in the same growing season were the strongest determinants of woody plant cover. None of the sites I examined are likely to be continuously flooded for long periods of time, based on examination of daily hydrographs during flood events (Figures 11 and 12). As time progresses, dam removal sits are likely to

be even less frequently flooded. As the stream cuts down through the sediments, the stream becomes further from the floodplain and requires larger flows to overtop the streambanks (Table 8).

Species	Common Name	USFWS category	LOCATION				
			Waterloo	B.E.C.	Fulton	Hebron	Mt. Vernon
Shrubs							
<i>Salix exigua</i>	Sandbar willow	FACW+	26.67		11.1		
<i>Toxicodendron vernix</i>	Sumac	OBL					2.22
Trees							
<i>Acer negundo</i>	Boxelder	FACW-	20.00				4.44
<i>Acer saccharinum</i>	Silver maple	FACW	2.22				
<i>Fraxinus pennsylvanica</i>	Green ash	FACW			2.22		
<i>Juglans nigra</i>	Walnut	FACU			2.22		
<i>Populus deltoides</i>	Cottonwood	FAC+	4.44				
<i>Salix nigra</i>	Black willow	OBL	4.44		2.22		

I expected that as the pond–flooding recurrence interval increased the percentage of woody vegetation would increase. However, there no relationship was evident. At Black Earth Creek and Mt. Vernon, sites with intermediate and long flood recurrence intervals (6.2 and 15.2 years), mowing and haying operations have likely prevented the growth of woody species past the seedling stage. Black Earth Creek had no woody species and Mt. Vernon had a frequency of 2.2% for shrubs and 4.4% for trees in quadrat samples. At the more recently removed sites, Hebron had no woody plant coverage despite having the highest flood frequency (31.4 years). Waterloo and Fulton, sites with low to intermediate flood recurrence interval (<2 and 6.9 years) had the greatest amount of woody plant coverage (26.7%

frequency at Waterloo for trees and shrubs, and 6.7 and 11.1% tree and shrub frequency at Fulton) (Table 14). High water tables may also be responsible for inhibiting the colonization of woody species (Loucks, 1987) and may be a more important determinate of woody coverage than flood frequency at infrequently flooded sites, since few trees in Wisconsin can tolerate constant inundation of the root zone.

Flooding may provide significant amounts of groundwater recharge, however. In an Ohio river, floods overtopping the streambanks accounted for 65% of groundwater recharge computed in one floodplain over a five year period (Workman and Serrano, 1999).

At infrequently flooded sites (> 15 years) flooding may be expected to influence the composition of woody species, if not the coverage. Floods tend to eliminate flood-intolerant species, especially during the seedling stage because many trees are more tolerant as mature trees than as seedlings. If sites are flooded very infrequently, species that are intolerant in the seedling or sapling stage such as hackberry (*Celtis occidentalis*) or cottonwood (*Populus deltoides*), may survive if they reach maturity before another flood occurs.

Flood durations are probably not long enough to limit the growth of many tree species at my study sites (Table 9); (Hosner (1960). Hosner found that periods of inundation lasting five days or more were required to limit the growth of fifteen tree species that he studied.

However, the most common trees found in at my study sites were all flood tolerant species. Boxelder (*Acer negundo*), the most common tree species found cumulatively at all sites, is listed as intermediately tolerant by Loucks (1987) but was one of the most flood tolerant

species in the seedling stage examined by Hosner (1960). *Acer saccharinum*, *Salix nigra*, and *Fraxinus pennsylvanica* are described as flood tolerant by Loucks (1987). Black walnut (*Juglans nigra*) was the only flood-intolerant species found within the pond areas at any of the sites.

Sandbar willow (*Salix exigua*) was the most common shrub and covered large areas of Fulton and Waterloo. In both areas it colonized on sandy soils near the outer edge of the floodplain. This facultative wetland species (FACW+) characteristically colonizes freshly exposed soils as well as elevated sandbars in rivers (Eggers and Reed, 1997). Its clonal growth pattern allows it to spread quickly and cover large areas of suitable soils. At Fulton, it occurred with a frequency of 11.1% and at 26.7% of Waterloo quadrats.

6.3 INFLUENCE OF INDIVIDUAL PLANT SPECIES CHARACTERISTICS AND LIFE HISTORIES ON PLANT COMMUNITY COMPOSITION

Individual characteristics of plants colonizing the drained pond may strongly effect the overall plant community composition of a drained pond area. In general, species with long life cycles, such as *Carex stricta*, were absent from all five sites, especially at recently removed dam sites. Grasses, many of which require time to establish extensive root systems were more common at the older sites. At Fulton, Waterloo and Hebron large areas were covered by one of three species: Rice-cut grass (*L. oryzoides*), stinging nettle (*U. dioica*), and jewelweed. Reed canary grass (*Phalaris arundinacea*) was also common, but was largely

confined to streambanks and pond edges. An examination of the life histories of these and other plant species may explain some of these distribution patterns.

- Characteristics of stinging nettle

Urtica dioica covered large areas in nearly monotypic stands, occurring with a frequency of 82 % at Fulton and 77.8% at Hebron . Its rapid growth in nutrient-rich environments, clonal growth patterns, perennial life form, resistance to herbivory, as well as its rhizome and shoot architecture enable it to outgrow and shade out other species. It can rapidly cover large areas with a dense canopy, making it difficult for other species to establish (Srutek, 1995). In quadrat samples few species occurred with *U. dioica*. The average number of species occurring in quadrats with *U. dioica* was 2.54 per 1m² quadrat at Hebron and 2.1 species per quadrat at Fulton. Species commonly occurring with *U. dioica* were sandbar willow, reed canary grass, and floodplain vines.

The dense canopy of *U. dioica* (reaching estimated heights of seven feet or more) and litter accumulation may be a factor preventing establishment of wooded communities at Hebron and Fulton at this time, although sandbar willow appears to be a good competitor with the nettle. Although *U. dioica* is a pioneer species of disturbed soils, they were found to form long-lived communities on nutrient-rich, drained peat soils at the UW-Arboretum and in central Europe (Srutek, 1995).

- Characteristics of rice-cut grass

Rice-cut grass (*Leersia oryzoides*) is an annual grass that seeds prolifically. I found it to be one of the most common species on drained pond areas with water near the ground surface. It has several characteristics that would make it a strong competitor in recently exposed, moist soils (Houston, et al., 1992). 1) It forms dense mats that can exclude other plant species; 2) Because it is an annual it can establish quickly in exposed soils; 3) it has numerous dispersal mechanisms that facilitate widespread dispersal of seed.

- Characteristics of Carex species

Many *Carex* species have long life cycles and very particular seed germination requirements (van der Valk, et al., 1999). In natural sedge meadows, sedges tend to maintain themselves by clonal growth. In drained millponds, plants have to establish by seed initially, unless there is an established population adjacent to a drained pond area. Sedges were very sparse at all five sites, except Waterloo (Table 14) where *Carex vulpinoidea* was common. It may be that *Carex* species are slow to establish in drained millponds because they are outcompeted by fast growing species that thrive in nutrient-rich pond soils and have less particular germination requirements.

- Characteristics of exotic grasses vs. native prairie grasses

The greater abundance of Kentucky blue grass than native grasses at Black Earth Creek and Mt. Vernon may be due to two factors: 1) Kentucky blue grass begins growing earlier in the spring than native grasses and has a second growing period that lasts later in the fall, and, 2) Blue grass is favored by mowing, which was occurring at Black Earth Creek (Weaver, 1968).

High-nutrient conditions in the former pond sediments favor reed canary grass (*P. arundinacea*) over native grasses. Reed canary grass is known to thrive in high-nutrient conditions, particularly in areas of highly fluctuating water tables that other species cannot tolerate (Eggers and Reed, 1997). These conditions prevail on streambanks, where reed canary grass was most abundant in my study sites. Wet-prairie grasses such as Canada blue-joint grass (*Calamagrostis canadensis*), prairie cord-grass (*Spartina pectinata*), and big bluestem (*Andropogon gerardi*) do not compete well with reed canary grass in nutrient rich environments.

- *The affect of U. dioica and L. oryzoides growth patterns on woody vegetation*

It appears that pioneer species which establish after dam removal in drained ponds may persist for many years. The life histories, growth form and patterns of *U. dioica* and *L. oryzoides* may contribute to the suppression of woody plant growth in drained impoundments. Although abiotic conditions (depth to water table and flood frequency) at most sites would be suitable for tree colonization, there is little tree cover at most of these sites, at least up to 5 years after dam removal. The shrub *S. exigua* appears to be a better competitor with *U. dioica* and was the most frequently occurring woody species. Tree seedlings at Waterloo had a high frequency (26.7%) indicating that tree coverage may increase in the future.

6.3.2 Sources of plant propagules in drained millponds: adjacent plant communities

To answer the question “How do adjacent plant communities influence drained reservoir plant communities?”, I also took samples in plant communities adjacent to the former pond area. This investigation is really part of a larger question: “Where does the vegetation that colonizes drained millponds originate?” I believe that seedbanks at my study sites were insignificant sources of vegetation for several reasons. The original floodplain soil has been buried by sediment for over 100 years. Even if the seeds are still viable, in most cases they are buried under several feet of reservoir sediment. Therefore they are unlikely to contribute to the vegetation of reservoir areas after dam removal. The other sources of propagules include water, air, and animal transport of seeds. It is likely that many species such as reed canary grass are carried by water to the site from upstream areas. However adjacent areas may be one of the main sources of colonizing plants because of their proximity to the pond area.

Influence of Adjacent plant communities on drained pond vegetation.

Adjacent plant communities were sampled at the end of each pond transect (Figures 2-6), for a total of five quadrats per site (5 m² total). Diverse native plant communities adjacent to drained impoundments may be expected to increase species diversity in the pond area by providing sources of plant colonizers. The adjacent communities must contain vegetation capable of colonizing a moist floodplain in order to contribute pioneers. If the pond grades immediately into an upland area, it is unlikely that upland species such as red oak or sugar maple will be able to survive in a moist drained pond area. For example the dry oak forest bordering part of Fulton’s pond area may not contain any species capable of surviving on a

moist floodplain. If an intact wetland community borders the site there is much greater potential for colonization and thereby increased diversity in the pond area as occurred at Black Earth Creek. The degree to which plants from adjacent communities colonized the former pond area was estimated by comparing species composition in 45 pond samples to the 5 adjacent samples. Five quadrats from the pond area were randomly selected to facilitate the comparison.

Site	# of "overlapping" species found in both pond and adjacent area	% of species in pond area that overlapped	Total species in adjacent area (5 quadrats)	Total species found in 5 random quadrats from pond area
Black Earth Creek	7	16.7	27	24
Mt. Vernon	15	44.1	36	9
Fulton	3	12.0	24	7
Hebron	2	7.7	24	13
Waterloo	17	42.5	30	19

Adjacent communities were more diverse than the drained pond communities (Table 17). In all cases the five samples taken from the adjacent areas were more diverse than the five randomly selected quadrats from the pond area. There did appear to be a relationship between the number of overlapping species and species diversity in the pond area, at least at recently removed sites. Waterloo had the greatest diversity at recently removed sites (49) and the greatest number of species in common with the adjacent area (17). Fulton and Hebron only had 4 and 2 overlapping species and had lower diversities in the pond area, 30 and 38, respectively (Table 17).

Overlapping species

In general the most successful colonizers of former reservoir areas appeared to be one of three types; exotic cool season grasses such as *Bromus inermis*, *Poa pratensis* and *P. arundinaceae*, clonal species such as *Solidago canadensis*, *U. dioica*, and *S. exigua*, and fast growing annual species such as *L. oryzoides*.

At Black Earth Creek six of the seven overlapping species were exotic species, three of which were the cool season grasses, *Poa pratensis*, *P. arundinaceae*, and *Bromus inermis*. The only native species overlapping was jewelweed (*I. capensis*). The adjacent patch of wet prairie or sedge meadow in between the railroad tracks and the former pond area contained a multitude of native wetland plants that did not appear in the pond area including the following species *Onoclea sensibilis*, *Monarda fistulosa*, *Epilobium coloratum*, *Calamagrostis canadensis*, and *Chelone glabra*.

Mt. Vernon had similar overlapping species, consisting almost entirely of exotic species (11 of 15 overlapping were exotic). Reed canary grass and smooth brome grass (*B. inermis*) covered fairly large areas in both pond and non-pond areas. Some obligate wetland species overlapped in both areas, such as *Scirpus atrovirens* and jewelweed. These two species colonized only the wettest area of the pond, near the adjacent hillslope. At Waterloo one of the more successful colonizers from the adjacent area appears to be sandbar willow.

Although not one of the most abundant species in terms of frequency, sandbar willow covered a large swath of land bordering the edge of the pond. As at Black Earth Creek, cool-season grasses, in this case *P. arundinacea*, *P. pratensis*, and *Leersia orizoides* were overlapping species found in both areas. Several of the composites, such as *Solidago*

canadensis, *Aster lanceolatus*, and *Erigeron philadelphicus* were also found in both overlapping areas.

At Fulton, wood nettle (*Laportea canadensis*), silver maple (*A. saccharinum*), and *Smilax sp.* were the only overlapping species, while at Hebron only *P. arundinacea* and *Solidago canadensis* overlapped in quadrat samples. Fulton also had a number of tree saplings from two to five feet high that had colonized right next to the adjacent forest. These included walnut, ash sp., black willow, and one Ohio buckeye. The origin of these trees was unknown however. The shortage of overlapping species at Hebron can be attributed to the extreme disparity between the adjacent and former pond area vegetation. The former millpond area at Hebron is surrounded by a mesic forest consisting of basswood (*Tilia americana*), elm (*Ulmus sp.*), and maple (*Acer saccharinum* and *A. saccharum*) trees. Most of the pond ends abruptly in a one-two foot drop-off into the forest. As a result there is no gradient between upland and wetland and there are very few mesic forest species which can colonize in a wet floodplain area.

CHAPTER 7: MANAGEMENT and RESTORATION ISSUES

7.1 MANAGEMENT ISSUES

The floodplain area lying behind removed dams can serve as a “showcase” demonstrating the benefits of dam removal if a site is carefully managed and/or landscaped. For this reason, the identification of management issues in drained reservoir areas was one of the main objectives of my research. There is a shortage of information available to managers and owners of drained impoundments wishing to control sediment problems, manage fisheries or establish native plant communities. I identified several management concerns at recently removed sites that may be problems for at least several years after dam removal. These immediate concerns center around controlling further sediment washing downstream, preventing colonization of undesirable vegetation, and providing safe access to the former pond area. Some of the major management issues in drained pond areas are described below.

7.1.1 Sediment Issues

Timing of removal

The timing of removal may effect sediment transport. If the dam is removed during spring or late winter when flooding is most likely, large flows can wash a lot of sediment downstream and out of the floodplain, especially if the mudflats have not been stabilized by vegetation yet. The flushing of sediment during dam removal has both costs and benefits. Assuming there are no toxic substances present in the pond-sediments, flushing of sediment from the pond area may speed recovery of the former pond area by providing more favorable conditions for native vegetation in the floodplain and fish in the stream. However sediment flushing may have negative effects on downstream river ecosystems. Depending on whether

managers want to flush sediment downstream or retain it in the pond area (which is usually the goal), the time of year may be an important consideration.

Streambank erosion

On many streams (particularly the Yahara River at Fulton and the Bark River at Hebron) streambanks are very unstable and are depositing sediment into the stream area. At least up to five years after removal, I observed large pieces of soil, up to tens of cubic feet in size still slumping into the river. All of the recently removed sites (<5 years since removal) still have serious bank erosion occurring. Streambank stabilization and grading following removal may be necessary to prevent this. If banks could be graded back and seeded much of this erosion could be prevented. (See sections below on restoration alternatives.)

In-stream sediment

In stream sediment is an important management issue, in regard to fisheries habitat. Many fish require coarse sand or gravel for spawning, such as brook and brown trout in Wisconsin. Silt or other fine particle substratum may limit their ability to spawn in the stream. Excessive silt may also inhibit the colonization of some aquatic plant and/or invertebrate species, resulting in a lack of vegetation and the establishment of the lower levels of the food chain necessary to support a healthy ecosystem.

Although some sediment is washed out of newly formed stream channels during dam removal, much sediment may remain in the former pond area. Soil cores I took in the stream channels showed there were several feet of silt remaining in the streams at some sites where

dams had been gone for 3-5 years. Until a stream channel downgrades to the level of coarse substratum the stream bottom may lie on top of fine soil material. Flushing of in stream-silt may take a long time, however, depending on the ability of the stream to movement sediment. The potential long time periods required to flush silt deposits from stream ecosystems has been documented by several researchers (Knox, 1977 and Simons and Simons, 1991). Since it appears that pond sediment is scoured from the stream channel starting near the location of the old dam, sediment in the upstream end of the former reservoir may remain in place for even longer periods.

7.1.2 Vegetation Issues

Revegetation of Mudflats / Invasion of Weeds and Exotic Species

Following dam removal massive silt deposits often remain on the exposed floodplain. Exposed sediments usually become stabilized by vegetation quickly after dam removal (within a couple of months usually). In some rare cases, areas of the pond may be slow to re-colonize, as was the case in part of the Hebron pond. Plant species that colonize the pond initially can persist for years. Because of this, the timing of dam removal may significantly effect the vegetative cover of drained reservoirs in later years. If mudflats are exposed when a particular species is setting seed, that species may come to dominate the site. Therefore, the opportunity to establish desirable native species should be taken advantage of before undesirable species become established.

If the site is colonized early by undesirable species, such as stinging nettle, reed canary grass, purple loosestrife, or garlic mustard, the site may not be very biologically diverse nor useful

or enjoyable for human use. For example, stinging nettle now covers the majority of Fulton and Hebron pond areas, limiting the value of these sites in two ways. First, stinging nettle forms monocultures that seem to limit biological diversity. (Species diversity in quadrats that contained stinging nettle was much lower than quadrats not containing nettle at Fulton and Hebron). Secondly nettle coverage limits the potential use of the area by people. Dense growth of stinging nettle tends to deter recreational use of the site.

7.2 ECOLOGICAL RESTORATION AFTER DAM REMOVAL

7.2.1 Reasons for Doing Restoration

It is important to note that planting of native vegetation in the five sites I studied is not “restoration” in the strict sense of the word. The pre-dam plant communities would be very difficult to restore at my study sites because of the large amounts of sediment remaining after dam removal, as well as changes to the hydrologic regime caused by dam construction and removal. Because of this fact, “ecological restoration” activities in a broad sense should focus more on reestablishing ecological functionality and/or providing for recreational use. There are several reasons why landowners and/or managers may want to attempt restoration activities. Aside from improving access to the newly exposed river for fishing, canoeing, or other recreational activities, there are a number of ecological functions these areas may serve. Some of these roles include the following:

1. Flood storage

Floodplains serve to store floodwaters that may inundate or damage downstream areas.

Although storage is actually reduced by dam removal, these areas do still provide a good

deal of storage area for high water, particularly during large flood events. The upper terraces at four of the five sites in my research are not flooded during small two or three year floods. However, storage of water during these smaller flood events could be accomplished by dredging a small meander zone out of the pond sediments (see Recommendations, section 7.2.2). The meander zone would be lower in elevation than the upper terrace area and therefore would get flooded more frequently.

2. Habitat for birds, particularly great blue herons and Canada geese

Riparian wetlands often serve as stopover points for migratory waterfowl. Many of these sites are used heavily by Canada geese and several duck species. Great blue herons also use the Waterloo and Hebron pond areas.

3. Habitat for riverine reptiles and amphibians,

Riparian wetlands in Wisconsin are home to numerous threatened and endangered reptiles and amphibians (Addis et al., 1995). In some case removed dam sites can provide additional habitat for riverine reptiles and amphibians, as evidenced by abundant frog and turtle populations at Hebron. However, disconnection of floodplains from streams may limit the value of a floodplain area for some amphibian and reptile species (Reference - Wetlands, 1998 issue). For this, and other previously mentioned reasons, re-establishing a frequently flooded area may be desirable.

7.2.2 Recommendations for Restoration

7.2.2.1 INFORMATION NEEDED

If managers and/or landowners want to restore some of the previously mentioned functions, provide canoe access or walking trails, or reestablish vegetation more similar to native Wisconsin plant community types, some basic information is needed before proceeding with restoration and management, including:

- *Characterization or model of surface sediment deposit*

The depth and type of pond deposited sediment in the former pond area is important to know for two reasons. First, the depth of pond-deposited sediment needs to be known for calculating dredging costs if soil is going to be removed from the stream or floodplain area. Secondly, the depth of sediment may be an indicator of future conditions in the drained pond area. Ponds with deep sediment deposits are more likely to have deeply entrenched channels and infrequently flooded floodplains over time. In my research, I used 10 surface soil cores and 4-8 deeper cores into underlying horizons. For restoration work, a larger sample size would be desirable to more accurately model the sediment deposits in the former pond area.

- *Depth of water-restraining layers*

Soil horizons or layers with limiting hydraulic conductivity near the soil surface inhibit the downward flow of water, tending to maintain moisture on a site. Therefore it is important to know if there is a tight silt or clay layer within a few feet of the ground surface because the site will be more likely to maintain wetland vegetation over time.

- *Depth to water table and groundwater gradient*

It is important to have some idea of the depth of the water table and whether the site acts as a groundwater discharge or recharge zone. In my research I used two sets of wells at each site, located using a pre-determined sampling design. A better way to identify discharge zones would be to locate potential discharge zones before research begins and place additional wells in these areas. To better characterize fluctuations in water levels in the wells, a recording gage would be useful, but probably not necessary for most purposes.

- *Location of original stream channel*

It may be desirable to locate the original stream channel for two reasons. First, the original stream bottom may contain coarse material more suitable for fish spawning. Secondly, managers may want to recreate the sinuosity that was found in the original channel, particularly if the post-dam removal channel lacks meanders. To locate the original channel, extensive soil coring may be required. Sometimes hints as to the location of the original channel can be obtained from the original land survey notes and topographical clues such as constrictions in the valley where the path of stream is limited to one location.

- *Identify reference sites to serve as models for restoration*

To guide restoration activities, high-quality ecosystems may be useful as models. One problem with choosing models for these types of ecosystems is that there are often few undisturbed ecosystems around to serve as models. Secondly, it is very difficult to determine exactly what type of plant community existed in the former pond area before dam construction, making it difficult to determine what type of community should serve as a model in the first place. The use of evidence based on landscape position and soil cores from the original floodplain surface, combined with vegetation information from similar undisturbed floodplains is probably the best way to develop an ecosystem model or target.

7.2.2 ALTERNATIVE MANAGEMENT/RESTORATION STRATEGIES

Several strategies for restoration are presented below, ranging from minimal efforts to control sediment loss and exotic vegetation to extensive restoration of pre-dam ecosystems. When choosing a restoration and management strategy, there are several important considerations, once the goal for the site has been determined. The primary factor to realize is that conditions in drained ponds are very dynamic. Conditions in drain ponds appear to change considerably for at least 5-10 years. Planting done right after dam removal, may be wasted if conditions change too dramatically in the next few years. Therefore it may be wise to wait 10-15 years before attempting extensive planting of native vegetation. Activities in the first few years should focus on the major problems: stabilizing streambanks and controlling undesirable vegetation.

A. Strategy #1: Minimal Management Strategy

There are several steps that should be undertaken at any dam removal site, including:

- *Stabilization and/or grading of streambanks*
- *Seeding or planting of former pond area with native grass to prevent soil loss and invasion of undesirable vegetation*

It may be possible to control exotic invasion by seeding the site with a few native plant species. If feasible, it would be desirable to seed the sites immediately after removal to prevent invasion of undesirable species. Smartweeds (*Polygonum sp.*) were used as a cover crop in the removal of the Woolen Mills Dam in West Bend, Wisconsin. Rice-cut grass (*Leersia oryzoides*) may also be a good candidate for seeding drained ponds in this region of Wisconsin. I found it to be one of the most common species on drained pond areas with

water near the ground surface. It has several characteristics that would make it a good soil stabilizer or cover crop: 1) It forms dense mats that can help to exclude aggressive exotic species; 2) It is an annual and so may die back after the desired vegetation takes hold 3) It appears to be a strong competitor with other species in drained ponds, such as reed canary grass.

- *Clear at least one access point or trail to river*

As part of the most basic management plan, there should at least be one area cleared so that people have access to the river.

B. Strategy #2: Limited Dredging and Berm Construction

1. *Construction of Meander Belt*

A beltway ranging in size from tens to hundreds of feet would be dredged to recreate an active floodplain, the size of which would depend on the river's characteristics. The goal of this excavation is to reestablish connectivity with the floodplain so that the adjacent floodplain floods frequently (at least every one – two years). Connection is important because the interaction of stream and floodplain areas is vital for many ecological processes (Ward, 1989). The construction of the meander zone would include the following steps:

- The stream would have to be diverted into side-channel during construction
- The sediment from dredging could be piled onto berms on the outer edges of the old pond area.

The creation of berms, if done well, could become an asset to the site, providing elevated areas that could provide good access to the site and good views of the stream/floodplain area.

2. *Dredging of discharge zones*

Because springs and seepage areas often support unique flora (Eggers and Reed, 1997) and may provide year-round watering holes for animals, managers may want to dredge sediment from discharge zones. This approach may be most relevant to Hebron, which has extensive seepage areas.

C. Strategy #3: Total Restoration

If there is limited sediment in the former pond, or if an area has great potential for ecological restoration, managers may want to dredge out all residual sediment. This plan would include the following aspects:

- *All sediment would be dredged from the former pond area*

The most difficult task here is finding a place to locate the sediment. Ideally it would be placed back on farmer's fields, providing a nutrient rich topsoil. However, the cost of dredging and moving sediment is high enough that this option should probably not be attempted unless there is known to be an outstanding ecosystem or other unique resources lying under the pond sediment.

- *Original Stream channel would be found and the stream channel redirected into its' original path.*

This would restore stream meanders as well as the original stream bottom. The original bottom may contain coarse material more suitable for fish spawning and colonization of other aquatic species, such as mussels. Without this step the stream channel formed after dam removal may run across fine-particle pond sediments for decades.

- *Extensive planting of native wetland species*

Table 18 contains a species list of native plants that would be suitable for planting in drained pond areas after dam removal. Most of the species listed were observed thriving in drained millponds areas. The plant species chosen are native species found in plant sampling that thrive in high water table conditions prevalent shortly after removal. Facultative upland and upland species were excluded from the list because it is unlikely these species would survive in the wet conditions that exist shortly after dam removal. Undesirable natives such as stinging nettle were also excluded. This list applies only to ponds in the region of southern Wisconsin.

TABLE 18: LIST OF PLANT SPECIES SUITABLE FOR PLANTING AT DAM REMOVAL SITES IN SOUTHERN WISCONSIN		
GRASSES/SEDGES	Common name	Reason for selection
<i>Calamagrostis canadensis</i>	Blue-joint grass	Native grass that may compete with exotic grasses like reed canary grass
<i>Carex lacustris</i>	Lake sedge	**
<i>Carex stipata</i>	Stalk-grain sedge	*
<i>Carex trichocarpa</i>	sedge	**
<i>Carex vulpinoidea</i>	Fox sedge	*
<i>Echinochloa crusgalli</i>	Wild millet	Good waterfowl food source, native grass that may compete with exotic grasses
<i>Leersia oryzoides</i>	Rice-cut grass	*
<i>Muhlenbergia glomerata</i>	Muhly grass	**
<i>Panicum virgatum</i>	Switch grass	**
FORBS		
<i>Anemone canadensis</i>	Canada anemone	Observed in drier areas of drained ponds
<i>Asclepias incarnata</i>	Marsh milkweed	**
<i>Aster lanceolatus</i>	Lance-leaved aster	*

Aster puniceus	Red-stem aster	*
Bidens cernua	Beggar-ticks	*
Epilobium coloratum	Willow-herb	*
Eupatorium maculatum	Joe-pye weed	**
Impatiens capensis	Jewelweed	*
Iris versicolor	Blue-flag iris	Good for aesthetic purposes
Lycopus americanus	Water horehound	**
Mentha spicata	Mint	**
Polygonum lapathifolium	Smartweed	*
Polygonum pennsylvanicum	Pennsylvania smartweed	*
Sagittaria latifolia	Arrowhead	**
Solidago canadensis	Canada goldenrod	*
Solidago gigantea	Giant goldenrod	*
Sparganium eurycarpum	Bulreed	**
Stachys palustris	Hedge nettle	*
Verbena hastata	Blue vervain	*
TREES		
Acer saccharum	Silver maple	**
Fraxinus nigra	Black ash	**
Fraxinus pennsylvanica	Green ash	**
Platanus americana	Sycamore	Fast growing species in floodplains
Populus deltoides	Cottonwood	**
SHRUBS		
Cornus ammonum	Silky dogwood	Frequently planted for "wildlife" in wet areas
Salix exigua	Sandbar willow	*
Toxicodendron vernix	sumac	**
Notes: * Observed thriving in drained pond areas, **Present in pond areas		

7.3 SOCIAL ISSUES

1. River access and trail construction

The drained pond area is one of the main access sites to rivers at dam removal sites and the area most visibly influenced by dam removal. If management is not undertaken after dam removal, the site may become overgrown by nettles or other undesirable vegetation rendering

it unsuitable for human use. In these cases, the potential for recreation remains unrealized, a situation that can breed disillusionment with dam removal by the people who live near the old pond. Because one of the main benefits of dam removal is the emergence of newly exposed land with public access for fishing, canoeing, and/or walking, site access is vital for public support.

2. Safety

Drained ponds can be dangerous environments. The silt deposits are unconsolidated after removal, leaving dangerous sediment sinks. If there is groundwater upwelling, these areas can act like quicksand. I observed people sinking up to their chests within a few seconds in these areas. At the Hebron pond two people actually required rescue on separate occasions, once requiring the assistance of public a rescue squad (Kroll, personal communication, 1998). These hazards should be removed, or at least well marked, to avoid boating incidents.

Within the stream, dangerous nickpoints and incompletely removed dam structures may pose serious hazards to canoeists after removal. Canoeists are attracted to dam removal sites because of the rapids in these streams and the opportunity to explore new stretches of river. At Waterloo, a nick point in the stream near the former dam has left a plunge-pool in the stream with a drop of 3-5 feet. While at Hebron, a slab of concrete was left in the bottom of the stream that now lies beneath an area of rapids.

2. Memorials on the dam and site history.

Because millponds in Wisconsin were the centerpiece of many small towns, people who have lived near an old millpond town for a long time often have a hard time seeing the dam removed. Memorials and historical signs help remind people of the area's history and ease the transition towards dam removal, by allowing people to retain a piece of that history. For example, at Cross Plains, Wisconsin, a photo of the intact millpond from the 1920's was incased in glass and put into a wooden stand by the entrance to the park.

3. Funding for restoration

Management done on the sites after removal can greatly improve the value of these sites as natural and recreation areas. Although there is usually an attempt to stabilize the sediment deposits during dam removal, after this, there is often little done to improve these sites afterward. This is particularly a problem at privately owned sites. Private landowners may not have the resources, expertise, or inclination to manage problem areas. Mechanisms for funding management of dam removal sites need to be further researched to assist in management efforts following dam removal. Funding may be appropriate for a variety of purposes, especially:

- streambank stabilization/grading
- sediment excavation/stream restoration
- native plant landscaping/planting
- construction of trails and access sites
- historical displays on dam, memorials, signs, historical information

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Appendix A: Supplemental Analysis

1. *Plant macrofossil analysis (woody stump remains)*

At Hebron, stumps from trees dating before dam construction remain on the site today. Woody plant remains were gathered from stumps across the entire Hebron pond to determine the tree composition at the site prior to dam construction. I used this data to assist in the characterization of the pre-dam vegetation communities.

Methods

1. I gathered pieces of wood at least 4 x 2 inches in size from relict stumps in pond that dated back to pre-dam time period at Hebron
2. Remains were sent to the University of Wisconsin Forest Products Lab, Center for Wood Anatomy Research where botanist, Alex Wiedenhoef identified the tree families.

Results

Sample #	Genus/species	Common name
1	Ulmus sp.	Elm
2	Fraxinus sp.	Ash
3	Ulmus sp.	Elm
4	Ulmus sp.	Elm
5	Tilia sp. (americana)	Basswood
6	Ulmus sp.	Elm

The species identified above are characteristic of floodplain forests or forested lacustrine swamps as described by Eggers and Reed (1998). Using Curtis's classifications (1959), they are most similar to a southern lowland forest. Based on soil types (glacio-lacustrine

silt/clays) and hydrology (a seepage area) the pre-dam plant community resembles the forested lacustrine swamp community described by Eggers and Reed. However, the landscape position of the site is a floodplain. Considering both abiotic and biotic conditions, the site appears to have characteristics of both types of communities.

2. Soil Particle size analysis

Results of particle size analysis done by the University of Wisconsin-Madison Soils lab.

TABLE 6: Particle size analysis of pond sediments					
SITE	% sand	% silt	% clay	TEXTURE	% ORGANIC MATTER
Mt. Vernon	14	69	17	Silt Loam	4.2
Waterloo	49	38	13	Loam	5.3
Black Earth	30	58	12	Silt Loam	5.3
Fulton	62	32	6	Sandy Loam	7.2
Hebron	44	50	6	Silt Loam	10.9

APPENDIX B: FLOOD FREQUENCY DATA

Annual peak instantaneous flow recorded at USGS stream gages in cubic feet per second (cfs) (USGS, 1999)				
Gage Location				
year	Mt. Vernon on Mt. Vernon Creek	Black Earth on Black Earth Creek	Fulton on the Yahara River	Rome on the Bark River
1954		1750		
1955	471	654		
1956	230	408		
1957	164	1030		
1958	528	266		
1959	940	1120		
1960	900	1020		
1961	522	693		
1962	128	216		
1963	263	454		
1964	71	640		
1965	306	623		
1966		619		
1967		631		
1968		148		
1969		457		
1970		141		
1971		196		
1972		451		
1973		577		
1974		585		
1975		514		
1976	328	834		
1977	296	367		
1978	184	681	2870	
1979	138	260	1100	
1980	224	441	1050	210
1981	Discontinued	396	3040	280
1982		380	1810	443
1983		194	1070	258
1984		342	1250	256
1985		710	1650	325
1986		236	1220	399
1987		123	1070	402
1988		140	1300	222

APPENDIX B: FLOOD FREQUENCY DATA				
year	Mt. Vernon on Mt. Vernon Creek	Black Earth on Black Earth Creek	Fulton on the Yahara River	Rome on the Bark River
1989		433	1380	155
1990		401	1080	241
1991		312	1370	215
1992		243	1470	220
1993		1320	1820	479
1994		686	2730	249
1995		238	976	380
1996		503	3230	323
1997		412	2120	253
1998		661	1480	276

APPENDIX C: VEGETATION DATA

CUMULATIVE PLANT SPECIES LIST FOR ALL SITES						
SPECIES	FWS Rank	Frequency (% of occurrence in 45 quadrats)				
		Waterloo	BEC	Fulton	Hebron	Mt. Vernon
Graminoides						
<i>Grasses</i>						
<i>Bromus inermis</i>	UPL		53.33			11.11
<i>Bromus japonicus</i>	FACU					2.22
<i>Elymus canadensis</i>	FAC-		2.22			
<i>Leersia oryzoides</i>	OBL	75.56		2.22	26.67	
<i>Muhlenbergia glomerata</i>	FACW+	4.44				
<i>Panicum virgatum</i>	FAC+	2.22				
<i>Phalaris arundinacea</i>	FACW+	31.11	17.78	26.67	51.1	35.56
<i>Poa pratensis</i>	FAC-	4.44	88.89			24.44
<i>Setaria glauca</i>	FAC					2.22
<i>Phleum pratense</i>	FACU					68.89
<i>Sedges/Rushes</i>						
<i>Carex bebbii</i>	OBL				2.22	
<i>Carex sp.</i>	----			2.22		
<i>Carex trichocarpa</i>	OBL					2.22
<i>Carex tuckermanii</i>	OBL					2.22
<i>Carex vulpinoidea</i>	OBL	20.00				
<i>Eleocharis sp.</i>	OBL				2.22	
<i>Juncus nodosus</i>	OBL	4.44				
<i>Scirpus atrovirens</i>	OBL	17.78			2.22	2.22
Forbs						
<i>Abutilon theophrasti</i>	FACU-					4.44
<i>Alliaria petiolata</i>	FAC			13.33		2.22
<i>Amaranthus blitoides</i>	FACU		2.22			
<i>Amaranthus retroflexus</i>	FACU+					2.22
<i>Ambrosia trifida</i>	FAC+		4.44			
<i>Angelica atropurpurea</i>	OBL	2.22				
<i>Apocynum cannabinum</i>	FAC	2.22	28.89			
<i>Arctium minus</i>	NI		17.78			
<i>Arisaema tryphyllum</i>	FAC			2.22		
<i>Asclepias incarnata</i>	OBL				2.22	
<i>Asclepias syriaca</i>	NI		17.78	2.22		2.22

		Waterloo	BEC	Fulton	Hebron	Mt. Vernon
<i>Aster lanceolatus</i>	FACW	22.2				
<i>Aster puniceus</i>	OBL	4.44				
<i>Bidens cernua</i>	OBL	2.22		2.22	2.22	
<i>Boehrmia cylindrica</i>	OBL		2.22			
<i>Brassica nigra</i>	NI			8.89		
<i>Cirsium arvense</i>	FACU		15.56	2.22	13.33	24.44
<i>Cirsium vulgare</i>	FACU-	2.22	26.67	2.22		6.67
<i>Conyza canadensis</i>	FAC-	4.44	13.33			
<i>Daucus carota</i>	unlisted		71.00			
<i>Epilobium coloratum</i>	OBL	6.67				
<i>Erigeron annuus</i>			11.11			
<i>Erigeron philadelphicus</i>	FACW	4.44				
<i>Erigeron strigosus</i>	FAC-		46.67		2.22	
<i>Euphorbia esula</i>	unlisted		8.89			
<i>Galium triflorum</i>	FACU+	2.22				
<i>Geum canadense</i>	FAC		2.22			
<i>Glechoma hederacea</i>	FACU		24.44			
<i>Hypericum punctatum</i>	FAC+					2.22
<i>Impatiens capensis</i>	FACW+	53.3	11.11	37.78	22.2	2.22
<i>Kochia scoparia</i>	FACU-		17.78			
<i>Lactuca serriola</i>	FAC		6.67	2.22		8.89
<i>Laportea canadense</i>	FACW			2.22	6.67	
<i>Lemna minor</i>	OBL				2.22	
<i>Leonorus cardiaca</i>	unlisted	2.22				2.22
<i>Liatris pycnostachya</i>	FAC-		6.67			
<i>Lythrum salicaria</i>	OBL				13.33	
<i>Medicago sativa</i>	NI		13.33			31.11
<i>Melolitus officinalis</i>	FACU		15.56			
<i>Mentha spicata</i>	FACW+	2.22		2.22		
<i>Oxalis stricta</i>	FACU		8.89			2.22
<i>Pastinaca sativa</i>	unlisted		71.11			8.89
<i>Pilea fontana</i>	FACW	15.6			11.11	
<i>Plantago alisma-aquatica</i>	OBL				4.44	
<i>Plantago rugelii</i>	FAC		6.67			4.44
<i>Polygonum lapathifolium</i>	FACW+	13.3			4.44	
<i>Polygonum pennsylvanicum</i>	FACW+			2.22		
<i>Potentilla norvegica</i>	FACU					4.44

		Waterloo	BEC	Fulton	Hebron	Mt. Vernon
Rorrippa nasturtium-aquaticum	OBL		4.44			2.22
Rudbeckia hirta	FACU		2.22			
Rumex crispus	FAC+		4.44			13.33
Rumex orbiculatis	OBL	4.44			2.22	
Sagittaria latifolia	OBL				6.67	
Smilax sp.	unlisted				2.22	
Solidago canadensis	FACU	53.3	11.11	2.22	6.67	6.67
Solidago gigantea	FACW	8.89			2.22	2.22
Sonchus arvensis	FAC-		26.67			
Sparganium eurycarpum	OBL				2.22	
Stachys palustris	OBL				6.67	
Taraxacum officinale	FACU	11.1	71.11			15.56
Trifolium pratense	FAC	2.22	44.44			68.89
Typha angustifolia	OBL	2.22			6.67	
Typha latifolia	OBL	17.8		2.22		
Urtica dioica	FACW-	37.8	2.22	82.22	77.78	6.67
Verbena hastata	FACW+			2.22		
Verbena stricta	unlisted		2.22			
Verbena urticifolia	FAC+		4.44			
Vicia villosa	unlisted					2.22
Shrubs						
Salix exigua	FACW+	26.67		11.1		
Toxicodendron vernix	OBL					2.22
Trees						
Acer negundo	FACW-	20.00				4.44
Acer saccharinum	FACW	2.22				
Fraxinus pennsylvanica	FACW			2.22		
Juglans nigra	FACU			2.22		
Populus deltoides	FAC+	4.44				
Salix nigra	OBL	4.44		2.22		
Vines						
Apios americana	FACW		4.44			
Echinocystis lobata	FACW-			4.44		
Lathyrus palustris	FACW		2.22			
Polygonum scandens	FAC		15.56	4.44	2.22	
Solanum dulcamara	FAC	2.22	4.44			
Toxicodendrum radicans	FACU+	2.22				

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