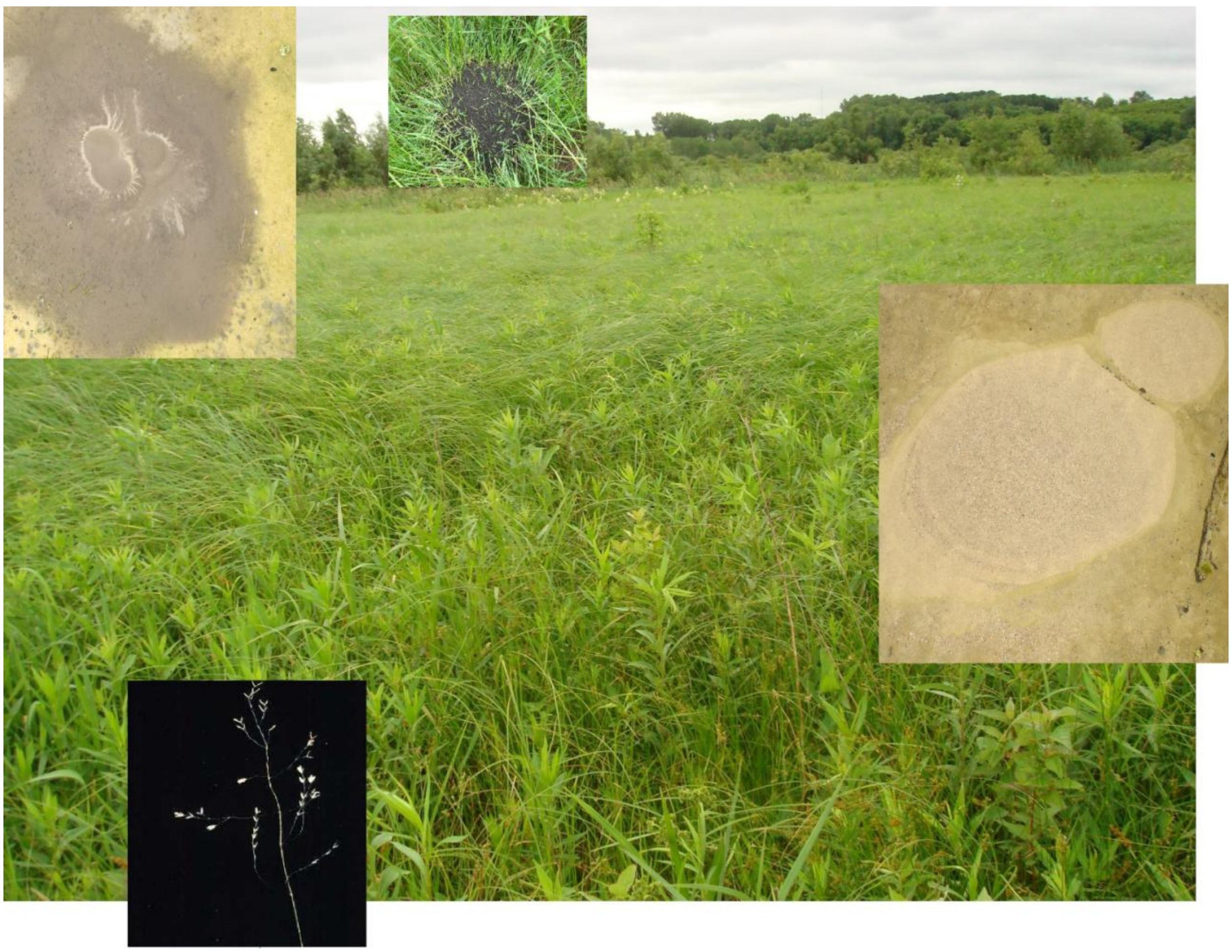
Aquatic Invasive Species Assessment and Management Plan for Recovery of Remnant Sedge Meadow and Associated Wetland Communities at Pheasant Branch Marsh, Dane County Unit



Integrated Restorations, LLC

Ecological Restoration & Land Management Services

Aquatic Invasive Species Assessment and Management Plan for Recovery of Remnant Sedge Meadow and Associated Wetland Communities at Pheasant Branch Marsh, Dane County Unit

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Summary

- Five herbaceous aquatic invasive species were detected within the project area: Reed canarygrass (*Phalaris arundinacea*), watercress (*Nasturtium officinale*), giant reed grass (*Phragmites australis*), narrow-leaved cattail (*Typha angustifolia*), and hybrid cattail (*Typha* x *glauca*).
- Vegetation surveys did not detect the presence of four additional high-impact invasive species within the project area: Purple loosestrife (*Lythrum salicaria*), tall manna grass (*Glyceria maxima*), water lettuce (*Pistia stratiotes*), or water hyacinth (*Eichhornia crassipes*), though additional scouting efforts should be carried out regularly.
- Soil phosphorus concentrations were high within the project area.
- There was evidence of sedimentation occurring within portions of the project area.
- Soil and water chemistry measurements demonstrated that the sediment retention ponds appear to be functioning, yet their performance could be enhanced by replacing existing vegetation stands with a diverse vegetation assemblage based on a resource-partitioning model.
- Long-term absence of a fire regime within the project area has resulted in litter accumulation and encroachment by shrubs and lowland trees.
- Despite a history of hydrological modifications to the Pheasant Branch Watershed, nutrient and sediment inputs, long-term absence of fire, and the presence of high-impact aquatic invasive species, the sedge meadow remnant in the project area is in highly recoverable condition.
- The strategic position of the Pheasant Branch Marsh within an urbanized landscape presents the opportunity for enhancing ecosystem services while providing the local community with public recreation and education opportunities.

Overall Assessment

The 62-acre northwest section of the Pheasant Branch Conservancy Marsh (hereafter referred to as the project area, Fig. 1) consists of a diverse mosaic of several wetland plant communities, including remnant sedge meadow grading into wet prairie, emergent marsh, shrub-carr with elements of lowland forest, shallow open water, and also calcareous fen communities surrounding spring outlet vents. The most conspicuous and extraordinary feature of the project area is Frederick Springs, a unique geologic feature that supports a small population of the rare conservative species yellow monkey-flower (*Mimulus guttatus*). Frederick Springs and the surrounding Conservancy draw thousands of visitors annually to this high-profile project area. A detailed hydrological assessment of the Pheasant Branch Watershed and Frederick Springs was performed by Hunt and Steuer (2000). The Pheasant Branch Watershed has undergone extensive hydrological modification since the 1880's, and the present watershed landscape consists of a mixture of agricultural and urban land-use patterns. Hydrological disturbances and nutrient inputs can predispose wetlands to species invasions, intensify the duration and magnitude of flooding in municipal areas, and diminish ecosystem service capacity. Several corrective actions have already been taken to mitigate these disturbances, including a ditch fill, stream re-routing, and installment of two artificial nutrient and sediment capture ponds to the northwest of the Frederick and north spring outlet vents. Pheasant Branch Marsh is primarily a groundwater-fed wetland that drains into the Lake Mendota system. Its strategic position within an urban landscape makes it an important provider of ecosystem services for the greater Madison metropolitan area, particularly in terms of flood prevention, nutrient and sediment capture, and also as part of the city of Middleton stormwater system. The marsh is the largest and highest quality wetland complex within the Pheasant Branch Watershed. Its proximity to a large metropolitan area provides the opportunity not only for providing ecosystem services but also to educate the public about the importance of wetland conservation.

The majority of the project area consists of high-quality remnant sedge meadow that is presently in highly recoverable condition. This remnant is dominated by the sedges *Carex stricta* (tussock sedge), *C. lacustris* (lake sedge), and *C. trichocarpa* (brown-fruited sedge), along with the cool-season grass *Calamagrostis canadensis* (Canada bluejoint grass). Members of the *Carex*, *Eupatorium*, *Aster*, *Scirpus*, and *Juncus* genera also well-represented, along with a diverse mixture of conservative and semi-conservative sedge meadow species. Non-aggressive native shrubs are also present, including *Salix bebbiana* (Bebb's willow), *Cornus alternifolia* (alternate-leaved dogwood), *Sambucus canadensis* (elderberry), *Alnus* spp. (alder), and *Prunus americanus* (American plum). Friends of Pheasant Branch (FOPB) Conservancy volunteer Tom Klein has compiled an extensive plant species inventory of the marsh and surrounding Conservancy (http://mainwest.zxq.net/flora_history/). Several indicators of sedge meadow system health are readily discernable within the project area. These include tall (in some cases up to ¾-meter) *Carex stricta* tussocks, several other forms of microtopographic heterogeneity (internal drainage channels, springs, and ephemeral pools), a diverse assemblage of herbaceous vegetation that is not overly-dominated by any single matrix species, and the probable presence of diverse and well-preserved native species propagule banks.

Five herbaceous aquatic invasive species are present within the project area in varying densities and distributions, and in the absence of a periodic fire regime, portions of the remnant are converting to shrub-carr dominated by red-osier dogwood (*Cornus stolonifera*). Fortunately, none of the invasive species detected in our assessment has yet reached an unmanageable density and all of the invasions can be reversed in a relatively short time period (although some level of scouting and management will be required indefinitely). Careful management (outlined in this management plan) should be able to reverse these invasions within four to six growing seasons, with noticeable improvements after only two or three growing seasons (provided management recommendations are carried out in detail).

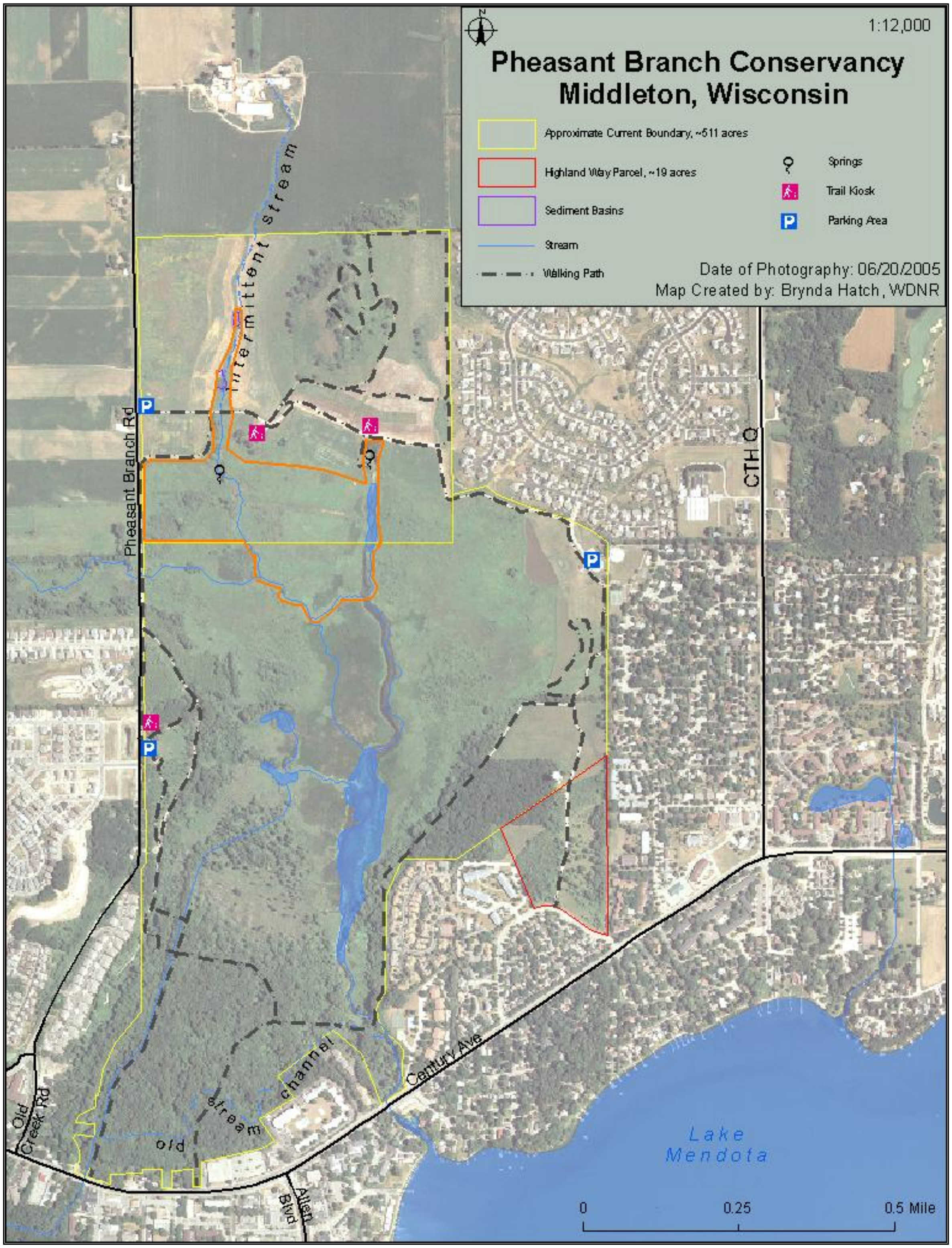
From a wetland conservation standpoint, restoration of the Pheasant Branch Marsh is highly desirable due to the rarity of high-quality remnant sedge meadows in southern Wisconsin, along with the unique geological features present at this site, its widespread use by the public, and its role in providing ecosystem services to the Lake Mendota system and surrounding municipal areas. Prior to Euro-American settlement, southern sedge meadow covered approximately one million acres of Wisconsin (Curtis 1959). Zedler and Potter (2008) reported that tussock meadows are in decline throughout the Midwest. At present, undisturbed southern sedge meadow that is free of high-impact invasive species is probably as rare as remnant prairie and savanna, although it is difficult to assess the present acreage of Wisconsin's southern sedge meadows because much of the acreage the Wisconsin DNR considers remnant sedge meadow exists in the wet meadow condition. Although often considered a distinct community type, the fresh or wet meadow (*sensu* Eggers and Reed 1997) represents an alternative disturbed state that arises when wet prairie or sedge meadow is disturbed by nutrient enrichment, artificial drainage (or other hydrological disturbance), or sedimentation, which leads to species invasions and replacement of the original vegetation structure with an alternative species mixture. Wet meadows are dominated by aggressive, nutrient-demanding perennial grasses and forbs, and may represent a transitional plant community between remnant sedge meadow and invasive species monoculture. This assertion is supported by the observation that tussocks are often present under wet meadow vegetation canopies (c.f. Annen2011). Most of the remaining sedge meadows in Wisconsin occur north of the Tension Zone, and sedge meadow losses may be as high as 75% in southern Wisconsin. Reasons for the decline in acreage of high-quality sedge meadow remnants include losses due to artificial drainage for agricultural purposes, species invasions, and fire suppression facilitating successional conversion into shrub-carr.

In our assessment, we documented the presence of a total of seven woody and five herbaceous aquatic invasive species within the project area. Listed in decreasing order of abundance, they are: Red-osier dogwood (*Cornus stolonifera*), reed canarygrass (*Phalaris arundinacea*), black willow (*Salix nigra*), watercress (*Nasturtium officinale*), common buckthorn (*Rhamnus cathartica*), honeysuckle (*Lonicera* x *bella*), giant reed (*Phragmites australis*), grey dogwood (*Cornus racemosa*), box elder (*Acer negundo*), cottonwood (*Populus deltoides*), narrow-leaved cattail (*Typha angustifolia*), and hybrid cattail (*Typha* x *glauca*).

We also scouted for the presence of four additional herbaceous invasive species within the project area, including water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*), purple loosestrife (*Lythrum salicaria*), and tall manna grass (*Glyceria maxima*), but fortunately did not observe these species at the present time. However, future monitoring for the presence of pioneer populations of these species should be conducted periodically since rapid responses to invasions are more cost-effective and likely to achieve success.

Reed canarygrass, red-osier dogwood, and watercress are presently the most prevalent invasive species within the project area. In the absence of management, it is likely that the aquatic invasive species present within the remnant will continue to expand in area and displace a growing proportion of high-quality remnant vegetation. Management intervention at this stage of invasion is critical to preventing the further spread of these invasive species. The longer management is delayed, the more difficult (and expensive) it will be to contain the spread and reverse the invasion. Once established, these species are capable of spreading into adjacent pristine areas.

Figure 1: Project area boundary (delineated in orange).



General Ecological Management Goals

- ✓ Restore remnant wetland plant communities to a reasonable facsimile of their presettlement condition, given the constraints of hydrological modifications that have occurred in this watershed since European settlement.
- ✓ Enhance ecological functioning of remnant sedge meadow and associated wetland communities to maximize their potential for contributing ecosystem services to the lower Pheasant Branch Watershed and Lake Mendota system (carbon storage, water retention and filtration, sediment and nutrient capture).
- ✓ Restore and maintain concurrent open-character habitat requirements for a multitude of native species across all trophic levels and enhance habitat quality to maximize species richness and diversity.
- ✓ Establish and maintain habitat structural elements (minor shrub component, basking logs, and bird perches) to benefit wildlife.
- ✓ Thin red-osier and grey dogwood by 75 – 80% to maintain the open character of the herbaceous marsh complex and facilitate management with periodic prescribed fire.
- ✓ Reintroduce periodic prescribed fire regimes to the Pheasant Branch Marsh wetland complex.
- ✓ Suppress or eradicate populations of high-impact invasive species, including reed canarygrass, watercress, *Phragmites*, hybrid and narrow-leaved cattail, buckthorn, and honeysuckle that threaten the biological and ecological integrity of the Pheasant Branch Marsh.
- ✓ Restore prairie and sedge meadow plant communities into buffer zones to connect adjacent vegetation communities along a wetland to upland continuum and maximize habitat (beta) diversity.
- ✓ Enhance habitat quality of remnant sedge meadow and associated wetland communities to increase the distribution and abundance of species of conservation concern and maintain these populations in a favorable conservation status (viable population sizes, metapopulations, and sufficient infraspecific genetic variability to avoid genetic bottlenecks).

Assessment Methods

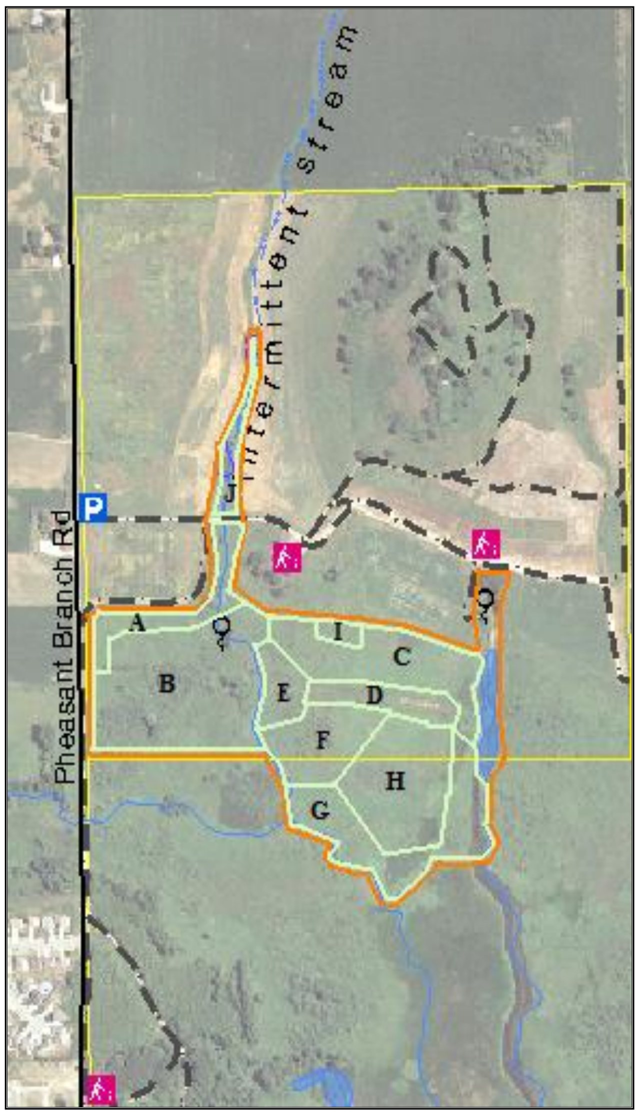
Decades of research into the ecology of aquatic invasive species has yielded a plethora of common themes, such as the relationship between disturbances and invasions, the role of nutrient enrichment and climate change in invasions, the diminished capacity for invaded wetlands to provide ecosystem services, and, of course, the ever-present inverse relationship between the presence and abundance of aquatic invasive species and biological diversity. Despite these generalities, each invaded wetland is unique in terms of its intrinsic characteristics (nutrient status, history and severity of hydrological disturbances, position in the watershed, existing vegetation composition), and every invasion thus proceeds by a somewhat unique mechanism. Each invasion mechanism results from interactions between the biology and ecology of the invasive species and preexisting site conditions. Site-specific baseline data are required to understand the specific factors responsible for each invasion (c.f. Schmieder et al. 2002) and properly address the unique opportunities and constraints each site offers in terms of reversing the invasion.

Vegetation Survey

For vegetation sampling purposes, we delineated the project area into ten vegetation phytosociological associations based on the most dominant herbaceous species present within each polygon (Fig. 2). Nomenclature follows Crow and Hellquist (2000) or Gleason and Cronquist (1991), unless otherwise noted. These associations were: *Phalaris*-dominated, *Carex-Juncus*, *Carex-Spartina*, *Carex-Typha-Phragmites*, *Carex trichocarpa-Calamagrostis*, *Carex stricta-Clamagrostis*, *Phalaris-Carex lacustris*, *Typha-Sagittaria-Caltha*, *Eriophorum*, and Sediment Pond Basin. We ignored the presence of shrub species when delineating associations, since this management plan recommends removal of much of the present shrub cover to facilitate sedge meadow recovery.

We used a stratified random sampling procedure to sample vegetation characteristics of the marsh. We superimposed a numbered grid over the vegetation association map and drew random numbers to generate n = 4 sampling points within each association. At each sampling point, we placed a 1-m^2 quadrat frame at the plant-soil interface and measured litter depth, the density of any invasive species present, height of tallest herbaceous vegetation, vegetation-height density of herbaceous cover, and herbaceous species presence. Species density (**S**) was calculated as the number of taxonomically distinct species per m^2. Litter depth and herbaceous vegetation height were estimated with a folding ruler. Herbaceous vegetation height-density was estimated with a Robel pole. Data from the four sampling quadrats were pooled to give a mean estimate for vegetation characteristics within each vegetation association. We then compared vegetation characteristics between invasive species-dominated and remnant plots. Data were tested for normality (χ^2 goodness-of-fit test) and homogeneity of variances (Bartlett's Test) (TOXSTAT software, version 3.0), and means were compared with pooled-variance parametric t-tests (SPSS software, version 14.0). Vegetation height-density data had to be square root-transformed to meet the assumption of homogeneity of variance, and were back-transformed for presentation in text and tables. We set the probability of Type I error at $\alpha = 0.10$ for statistical comparisons to compensate for the large variances encountered when comparing attributes of dissimilar vegetation associations. Effects sizes were calculated as $[(mean_1 - mean_2)/mean_1] \times 100$.

Figure 2: Vegetation associations used in vegetation sampling. A = *Phalaris*-dominated; B = *Carex-Juncus*; C = *Carex-Spartina*; D = *Carex-Typha-Phragmites*; E = *Carex trichocarpa-Calamagrostis*; F = *Carex stricta-Calamagrostis*; G = *Phalaris-Carex lacustris*; H = *Typha-Sagittaria-Caltha*; I = *Eriophorum*; J = Sediment Pond Basin.



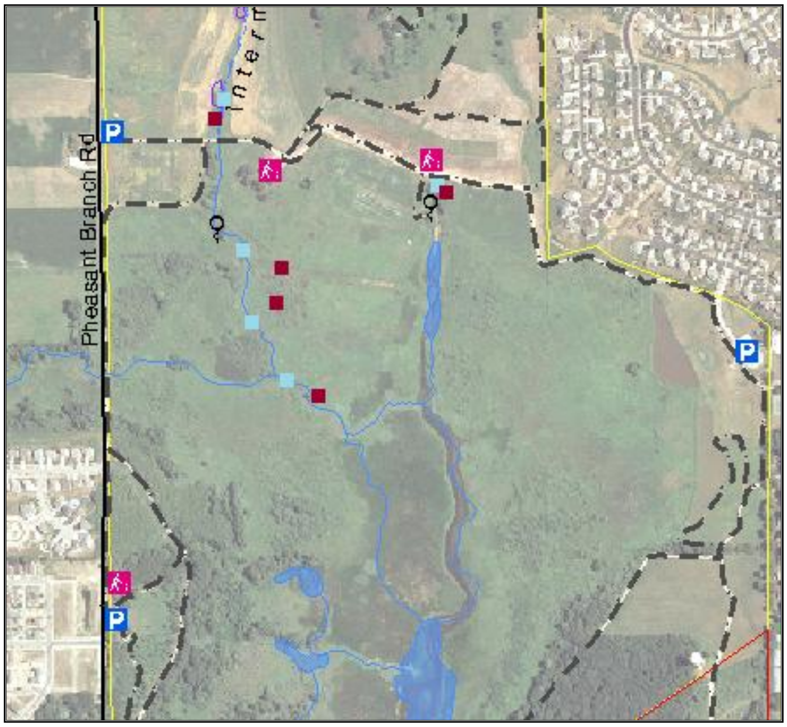
We also surveyed the entire project area for the presence and distribution of aquatic invasive species. Scouting was performed by having surveyors walk in a skirmish line approximately five meters apart across the project area. To increase the chances of detecting aquatic invasive species occurring at low densities, two such surveys were conducted, with the second survey performed in a direction perpendicular to the first. Vegetation characteristics were measured and herbaceous species surveys were conducted between 27 May and 5 July 2011.

Soils

Soils were sampled from five strategically-chosen locations within the marsh complex (Fig. 3). These locations were: Frederick Springs, near spring vent 2a (see Hunt and Steuer 2000 for a precise location of this vent), the western end of the ditch fill, the remnant sedge meadow (*Carex stricta-Calamagrostis* association) located to the south of the ditch fill, the *Phalaris-Carex lacustris* association located immediately to the north of the western fork of Pheasant Branch Creek, and from near the margin of the southern sediment capture pond. The Frederick Springs 2a vent was chosen because previous investigators (Hunt and Steuer 2000) measured high concentrations of nitrogen entering this wetland system through the western vents of this spring complex, which they attributed to nitrogen runoff and leaching into groundwater from agricultural activities in the upstream portions of the Pheasant Branch Watershed. The ditch fill location was chosen because the top layer of fill has been compacted and rests at an elevation approximately ¼-meter lower than the surrounding sedge meadow, and is also where small pioneer clones of *Phragmites*, narrow-leaved, and hybrid cattail occur. The remnant and *Phalaris*-impacted sedge meadow locations were chosen to compare soil nutrient concentrations under each vegetation type. Lastly, the sediment pond location was chosen to determine if soil nutrient concentrations were higher near the sediment pond than in the remnant portions of the project area.

At each sampling location, a composite sample of n = 4 subsamples were collected at random locations to a depth of 15 cm with an Oakfield® tube-type soil probe (with a 3-cm bore diameter). Sample locations were geo-referenced by recording GPS coordinates from the approximate center of each sampling cluster (see table 2). Litter was manually removed from the soil surface prior to sample collection, and the soil probe was thoroughly brushed clean between the different sampling locations. At each location, soil color was qualitatively estimated with a Munsell® Soil Color Chart. Soils were analyzed by the State of Wisconsin Hygiene Lab for total phosphorus, ammonia, and nitrate + nitrite, soil nutrient factors well known to be strongly correlated with *Phalaris*, *Typha*, and *Phragmites* invasions. Soil samples were collected on 24 June 2011, and submitted to the lab on the same date. Soil estimates were not subjected to statistical comparisons because our soil sampling procedure consisted of only a single replication.

Figure 3: Soil (brown) and water chemistry (light blue) sampling locations. Note: Sample locations are only approximate and are not orthorectified on this map. Refer to tables 2 & 3 for GPS coordinates of sample locations.



Water Chemistry

Water chemistry was sampled from five strategically-chosen locations within the marsh complex (Fig. 3); each sample location was GPS-referenced (see table 3). These locations were: Frederick Springs, within spring vent 2a, the small pond located to the south of the north spring vent, the western branch of Pheasant Branch Creek (approximately 50-m downstream from the pond), the west branch of Pheasant Branch Creek (approximately 50-m downstream from the previous creek sample), and from within the sediment capture and retention pond. The Frederick Springs 2a vent was chosen because previous investigators measured high concentrations of nitrogen entering this wetland system through the western vents of this spring complex. The sediment retention pond, the pond near the north spring vent and Pheasant Branch Creek were all sampled to determine if any nutrients from the sediment retention ponds were being transported downstream into the sedge meadow remnant. Water samples were analyzed by the State of Wisconsin Hygiene Lab for pH, dissolved ammonia, dissolved nitrate + nitrite-N, conductivity, alkalinity (as total $CaCO_3$), and total dissolved solids (TDS). Water column samples were collected on 24 June 2011 and submitted to the lab on the same date.

Widespread use of road salt in urban areas can salinify marsh soils, and has been implicated in contributing to *Phalaris*, *Typha*, and *Phragmites* invasions (Maeda et al. 2006, Stiles et al. 2008, Annen et al. 2008, Prasser and Zedler 2010). Therefore, we wanted to measure salinity in the waters of the project area. Salinity was estimated from the same locations and on the same date as the other water chemistry samples with an auto-ranging ExStik II EC400 salinity meter featuring automatic temperature compensation and 0.1 mg/L resolution. Similar to soil nutrient estimates, water chemistry estimates were not subjected to statistical comparisons because our sampling procedure consisted of only a single replication.

We measured stream velocity by marking off a 10-meter section of the western branch of the Pheasant Branch Creek and measuring the time required for a tennis ball to traverse this distance. Stream velocity measurements were taken in replicates of n = 3, then averaged to obtain an estimate of mean stream velocity. Seeds of *Phalaris*, *Phragmites*, and *Typha* float on water, and streams are highly effective dispersal corridors for their expansion. All three of these invasive species were distributed near the west branch of Pheasant Branch Creek within the project area. Coops and van der Velde (1995) examined hydrochory (water-borne seed dispersal) of several wetland plant species, including *Phalaris*, *Phragmites*, and *Typha*. These authors predicted the FT_{90} (90% seed float times) of these species. Combining this information with stream velocity measurements from the Pheasant Branch Creek enabled us to determine the distance seeds of these invasive species could migrate from their upstream locations to the downstream portions of the sedge meadow and throughout the lower Pheasant Branch Watershed and Lake Mendota system.

Results of Assessment

Vegetation Survey

Results of the vegetation survey are presented in table 1. Scouting revealed the presence of five herbaceous aquatic invasive species within the project area: Reed canarygrass, watercress, *Phragmites*, narrow-leaved cattail, and hybrid cattail. We did not observe water lettuce, water hyacinth, purple loosestrife, or tall manna grass within the project area. Notably, our vegetation surveys revealed the presence of two culms of Wisconsin-Threatened bog bluegrass (Fig. 4) within the project area (*Poa paludigena*, Fern. & Wiegand; nomenclature follows Flora of North America, volume 24 (2007)). This species was observed within the *Carex-Spartina* association near its border with the *Eriophorum* association. Fortunately, neither individual was located near any reed canarygrass at the time of the survey. Additionally, we observed a sedge wren in the project area during one of the site visits, and several scaffold ant mounds (*Formica* sp.) (Fig. 5) within the *Carex-Spartina* association.

Figure 4: *Poa paludigena.* Photo taken from UW-Stephens Point Herbarium website.

Figure 5: Scaffold ant mound.

Aquatic invasive species were present within 90% of sampling plots, although they occurred at widely varying densities (table 1). Reed canarygrass was present within 80% of vegetation sampling plots, and was only absent from plots dominated by either *Phragmites* or *Typha*. Mean reed canarygrass stem density was 129.9 culms/m^2 (SD = 177.1) across all sample plots, but ranged from 0.5 culms/m^2 in the *Carex trichocarpa-Calamagrostis* association to 402.0 culms/m^2 in the wetland-upland buffer areas, where it was clearly the dominant species and existed in near monoculture. The wide dispersion in variability of reed canarygrass density among sample plots can be attributed to its patchy distribution within the project area; reed canarygrass abundance ranged from near monoculture to only a few culms scattered within a native vegetation matrix. Dense clones of reed canarygrass, some as large as several meters in diameter, were also distributed throughout the project area. Reed canarygrass was most abundant in the wetland-upland buffer areas and along the Pheasant Branch and Spring Creek margins, and was less abundant within the diverse core remnant area (Fig. 6). *Phragmites*, along with narrow-leaved and hybrid cattail, were present in limited distribution within the project area, and both were restricted to locations near the ditch fill (Fig. 7). Two large clones of *Phragmites* located at (N43° 07.193' W89° 29.188') and (N43° 07.210' W89° 29.263') were discovered in this area by FOPB volunteer Tom Klein. Where it was present, *Phragmites* stem density averaged 84.3 stems/m^2 (SD = 60.8). Narrow-leaved and hybrid cattail were present in close proximity to the westernmost *Phragmites* clone (Fig. 7; N43° 07.210' W89° 29.283'), at a mean density of 24 culms/m^2 (SD = 6.5) (both cattail varieties pooled). The small clone of hybrid cattail was sympatric with the presence of both parent species (*Typha latifolia* and *T. angustifolia*), all of which occurred within the same general location. We did not observe any individuals of narrow-leaved or hybrid cattail in any other sections of the project area. Watercress was most abundant in the Frederick and north spring areas, and also within ephemeral pools within and near the ditch fill (Fig. 7). We did not record GPS locations of watercress because this species tends to move around to different locations within wetlands from year-to-year.

Figure 6: *Phalaris* distribution within the project area. Delineated areas only show the largest infestations. *Phalaris* is also distributed at lower densities throughout the remainder of the project area.

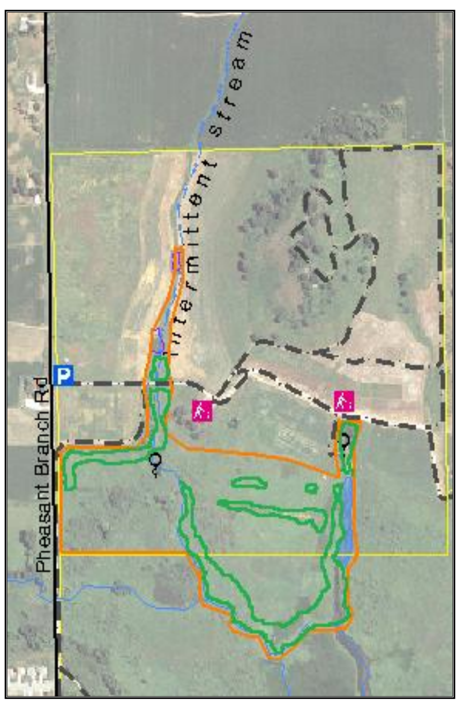
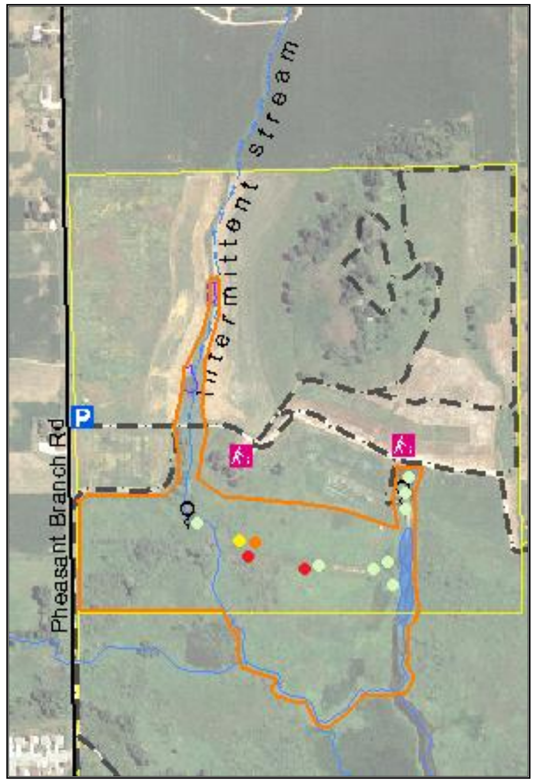


Figure 7: Watercress (green), *Typha angustifolia* (yellow), *Typha* x *glauca* (orange), and *Phragmites* (red) distributions within the project area. Note: Sample locations are only approximate and are not orthorectified on this map. Refer to text for GPS coordinates of sample locations.



On average, the study area supports 5.6 species/m^2 (SD = 4.3), ranging from 1.25 species/m^2 in the *Phalaris*-dominated wetland-upland buffer to 13.75 species/m^2 in the *Carex-Juncus* association. There was an inverse relationship between the presence and abundance of aquatic invasive species and species density. Species density was 183% higher in plots dominated by remnant vegetation (mean = 8.2 species/m^2) than plots dominated by invasive species (mean = 2.9 species/m^2) ($t_{(1,4)}$ = 2.42, p = 0.038). The negative relationship between reed canarygrass, *Phragmites*, and *Typha* dominance and species richness has been repeatedly documented in the literature (see Galatowitsch 1999 and Lavergne and Molofsky 2004 for reviews) and highlights the necessity for management intervention at Pheasant Branch Marsh.

Mean litter depth within the project area was 7.9 cm (SD = 3.7), and ranged from 2.9 cm in the *Carex stricta-Calamagrostis* association to 13.0 cm in the *Carex trichocarpa-Calamagrostis* association. Litter was twice as deep in associations where *Phalaris*, *Phragmites*, or *Typha* were abundant (mean = 10.0 cm) than plots dominated by remnant vegetation (mean = 5.8 cm) ($t_{(1,4)}$ = 2.09, p = 0.055). Moreover, the physical composition of the litter differed between the two types of plots; senescent culms and leaves were thinner and had numerous gaps allowing light penetration to the soil surface in plots dominated by remnant vegetation. Auclair et al. (1976) discussed the positive correlation between litter accumulation and herbaceous species invasions in *Carex*-dominated wetlands.

Mean herbaceous vegetation height within the project area was 98.8 cm (SD = 62.0), ranging from 31.3 cm in the *Carex-Juncus* association to 213.0 cm in the *Carex-Typha-Phragmites* association. The sediment pond basin technically had the lowest vegetation height, but much of the vegetation in this area was lodged. Mean vegetation height-density within the project area was 63.3 cm (SD = 64.4), ranging from 9.5 cm in the *Carex-Juncus* association to 203.3 cm in the *Carex-Typha-Phragmites* association. The wide range of estimates and standard deviations in these two characteristics indicates the high degree of canopy complexity and spatial heterogeneity within the project area. Excluding the sediment pond basin and *Phalaris-Carex lacustris* association (where much of the vegetation was in a lodged condition), plots dominated by invasive species were taller (mean = 175.1 cm compared with 76.7 cm) and had higher values of vegetation-height structure (mean = 125.5 cm compared with 45.1 cm) than plots dominated by relic vegetation ($t_{(1,3.3)} = 4.126$, $p = 0.015$ for vegetation height and $t_{(1,3.3)} = 2.087$, $p = 0.065$ for height-structure). In a previous study, Annen et al. (2008) recorded a similar pattern, and concluded that species invasions can affect habitat structural characteristics.

Soils

Results of the soil nutrient survey are presented in table 2. Soils from the Frederick Springs area, ditch fill, and *Carex stricta-Calamagrostis* association were dark (chroma of 1 or 2) mucky soils with thick dark surface hydric indicators. Soils from the *Phalaris-Carex lacustris* association and sediment retention pond were lighter-colored (chroma of 3 and 6) mineral soils, at least in their surface layers, which may be the result of sediment accumulation.

Soil nutrient chemistry was variable among the different sampling locations, but patterns were detectable that were consistent with explaining species invasions within the project area. Total phosphorus was detected at high concentrations in all samples, but was highest (detectable in parts per thousand) near the sediment retention pond and from soils of the *Phalaris-Carex lacustris* association and both areas are dominated by reed canarygrass at high density. These two sampling locations also had lighter soil color, indicating that both locations have experienced phosphorus-laden sediment deposition. Soil total phosphorus and ammonium concentrations were both high within the ditch fill where clones of reed canarygrass, watercress, *Phragmites*, and narrow-leaved and hybrid cattail occur, and near Frederick Springs, which supports dense populations of both reed canarygrass and watercress. Soil total phosphorus concentration was lowest (yet still high), as were concentrations of soil ammonium and nitrate + nitrite, within the *Carex stricta-Calamagrostis* association, an area with low reed canarygrass density and no other aquatic invasive species present. If we compare soil nutrient concentrations from the *Carex stricta-Calamagrostis* association with those from the *Phalaris-Carex lacustris* association, it is readily apparent that reed canarygrass is more abundant and species density is lower where nutrients are more readily available. A large body of empirical research (reviewed by Keddy 2002) suggests strong correlations between soil nutrient availability, species invasions, and loss of plant species diversity. This assertion is further supported by the observation that reed canarygrass stands in the *Phalaris-Carex lacustris* association had lodged. Lodging occurs in areas of high nutrient availability where light competition becomes important in determining the composition of vegetation stands (Hautier et al. 2009). Lodging occurs because reed canarygrass disproportionately allocates more resources to attaining height (to capture more light) at the expense of girth when nutrients are plentiful, and strong winds or heavy rains then blow down culms, creating a tangled mess of matted vegetation. In the Frederick Springs area, reed canarygrass appeared chlorotic (Fig. 8), possibly the result of potassium deficiency that can occur in fens where calcium occupies most of the cation exchange sites with soil clay matrices. However, we did not directly measure soil potassium concentrations in our assessment.

Figure 8: Chlorotic reed canarygrass growing near Frederick Springs.

Water Chemistry

Results of water chemistry analyses are presented in table 3. In terms of the parameters we estimated, the sediment retention pond had different water chemistry than other sample locations. Water chemistry estimates were similar among all other sampling locations, with the exception of nitrate and nitrite sampled from the water near vent 2a of Frederick Springs, which had the highest concentration of these ions. A previous assessment of Frederick Springs conducted by Hunt and Steuer (2000) reported a similar concentration of these ions from this same location (1.00 mmol/L compared to our estimate of 1.24 mmol/L, when converted to the same scale). Our estimate of specific conductivity from the 2a vent was likewise similar to Hunt and Steuer (2000) (839 µS/cm compared to 776 µS/cm). Hunt and Steuer (2000) also measured alkalinity from the 2a vent, as did we, but they estimated this parameter as carbonate anion whereas we estimated it as total $CaCO_3$; thus, a comparison of alkalinity between the two assessments was not appropriate. Alkalinity, specific conductance, nitrate + nitrite, total dissolved solids, and salinity were all lower in the sediment retention pond than from the other sample locations, and ammonia was two orders of magnitude higher than any other location. Salinity level is waters of the project area were moderate, and may be influencing species invasions along with other factors such as nutrient concentrations and sedimentation. It appears that the retention pond is functioning properly in capturing and retaining runoff originating from agricultural operations upstream and preventing it from accumulating in the project area.

Mean stream velocity of Pheasant Branch Creek was estimated at 0.224 m/s. Coops and van der Velde (1995) provided FT_{90} estimates for reed canarygrass (38.3 hours), *Typha angustifolia* (27.6 hours), and *Phragmites* (65.0 hours). From these estimates, we calculated that 90% of floating reed canarygrass seeds could be dispersed a distance of 30.9 km, *Typha* a distance of 22¼ km, and *Phragmites* a distance of 52.4 km from the marsh before becoming waterlogged and sinking. From this finding it is clear that propagules of all three of these aquatic invasive species have the potential to be dispersed throughout the lower Pheasant Branch Marsh and Lake Mendota system. Eradicating (or even suppressing) these species from the project area will protect ecological integrity of habitats downstream from Pheasant Branch Marsh.

Management Specifications

PRESCRIBED FIRE REGIMES

Similar to prairie grasslands, sedge meadows are disclimax communities maintained in part by periodic fire regimes. Although Curtis (1959) reports a fire interval of 1 – 3 years in both upland prairie and sedge meadows, fire in sedge meadow may have historically had a more irregular frequency than in upland prairies owing to periodically wetter site conditions, particularly prior to extensive hydrological modification of the landscape by European settlers. Superimposed on this frequency were longer-term variations in local climate that produced fluctuating wet and dry cycles. The effects of fire in sedge meadows are multi-scaled and often indirect because fire exhibits cross-scale effects on plant communities; it simultaneously acts as both a disturbance (in terms of biomass removal and nitrogen volitization) and a stabilizing factor (in terms of maintaining the open character of the community and preventing successional conversion into an alternative vegetation community). Fire is an essential tool for maintaining southern sedge meadow communities in Wisconsin. Although the following discussion focuses primarily on reed canarygrass (since it is the most abundant aquatic invasive species within the project area), much of these arguments also apply to *Typha* and *Phragmites*, herbaceous monocots with similar morphological attributes and invasion mechanisms (rhizomatous spread, high standing crop, dense litter, and respond well to nutrient additions) (Stüfer et al. 2002).

In the absence of fire, sedge meadow is relatively quickly invaded and displaced by shrub-carr dominated by red-osier and grey dogwood, honeysuckle, and buckthorn, with other native and non-native shrubs present at lower densities. Longer-term absence of fire eventually enables establishment of fire-intolerant lowland tree species such as box elder, willows, and cottonwood, resulting in a system collapse whereby an open sedge meadow is replaced by a mixed shrub-lowland forest community with little or no remaining herbaceous groundlayer.

Transition from sedge meadow to shrub-carr and lowland forest has multiple direct and indirect effects on the flora and fauna of the original sedge meadow community. These effects cascade through multiple trophic levels and create internal system feedbacks that reinforce not only the conversion but also make the site more vulnerable to ecological simplification in the form of species invasions. Initially, as shrubs encroach on the sedge meadow, the vegetation becomes less flammable because the fuel model changes, hindering future fire behavior and favoring additional shrub expansion. Concomitantly, conversion to shrub-carr increases vegetation height-structure, altering habitat conditions for birds and mammals. Mossman and Sample (1990) reported that several avian species were negatively affected by shrubby invasion of sedge meadows. Shrubs also directly displace and shade out relic sedge meadow vegetation, beginning with the most conservative species and continuing through the matrix species that determined the original fuel model and positive response of the system to fire. This reduces plant species richness and diversity, making the site less resilient and more susceptible to species invasions, while simultaneously diminishing the sedge meadow's ability to provide ecosystem services such as carbon storage, water filtration, and nutrient and sediment capture. Furthermore, fast-growing shrubs and lowland trees with high evapotranspiration rates can accelerate hydrological losses in sedge meadows, creating or enhancing an existing hydrological disturbance, which also makes the site more vulnerable to shifts in vegetation composition and species invasions. These shifts often begin with immigration of disturbance-tolerant aggressive native species (such as Canada goldenrod, *Solidago canadensis*) and progress to more serious species invasions by reed canarygrass. Indeed, Curtis (1959) documented the presence of reed canarygrass in eleven different plant community types, with maximum presence in unburned shrub-carr. Clearly there is an indirect link between absence of natural fire regimes and reed canarygrass invasions. Additional stresses imposed on the system in the form of nitrogen and phosphorus inputs from agricultural and urban land-use patterns in the adjacent landscape can accelerate degradation and loss of function and diversity of the original system. Once a threshold is reached in these disturbances, fire alone will no longer be sufficient to convert the system back to its original condition.

At present, approximately 15 acres of the project area already exists in this condition, and will continue to expand in area unless a fire regime is imposed on the site. For areas already impacted by heavy shrub cover, manual removal will be necessary to restore structure and function to the community, as well as enable future use of fire as a management tool. In the absence of a fire regime, additional brush removal will be required every 3 – 5 years to maintain the open character of the project area's sedge meadow remnant.

The use of prescribed fire will need to be an essential component of long-term management of the project area. Burning is an accessory treatment for invasive species suppression. Although not directly lethal to established invasives, prescribed fire augments and enhances suppression efforts, both ecologically and logistically, particularly if site conditions allow burns to be timed properly.

Phalaris, *Phragmites*, and *Typha* are among the most productive species in herbaceous wetlands, and their productivity is enhanced by widespread nonpoint nutrient inputs into wetland systems. Their litter has a mulching effect on competing species, yet these species can persist under their own litter by mobilizing their rhizome carbohydrate reserves when emerging in early spring. Immature tillers of these species (i.e., tillers that have not accumulated extensive rhizome networks) can also persist under dense litter by receiving intra-clonal carbohydrate subsidies within phytomer networks (Mittra and Wright 1966, Maurer and Zedler 2002). As these species increase in abundance and comprise a larger proportion of a site's standing crop, more litter accumulates each growing season, which further hinders emergence of competing species. Auclair et al. (1976) reported lower diversity at high litter levels resulting from low fire incidence in *Carex*-dominated wetlands. This internal feedback cycle reinforces these invasions and resists conversion back to the original undisturbed condition. This feedback cycle must be interrupted for mitigation to be successful (Annen 2011). Litter feedbacks can be relatively easily disrupted by implementing periodic prescribed fires.

During the initial two or three growing seasons of a reed canarygrass suppression effort, the entire project area should (ideally) be annually burned in early spring, prior to May 1st. After that, portions of the site should (ideally) be burned between April 15th and May 30th of each growing season, in a 1 – 3 year rotation that incorporates an element of randomness (e.g., burn the site every third year, then burn every two years, etc.). Random burn regimes more closely mimic historical patterns of fire in Wisconsin's southern sedge meadows. Unburned sections will serve as refugia for fire-sensitive species. Burns timed later in the spring can also be used to prevent panicle development in established (vernalized) tillers (Richard Henderson, WDNR, personal communication). Burning the site also improves site accessibility for contractors and limits the amount of herbicide spray wasted on the previous season's biomass litter, reducing costs related to implementation of suppression programs.

Burning too early (e.g., March) gives reed canarygrass a competitive advantage over native species because cool-season forbs and sedges emerge and attain maximum seasonal productivity later in the growing season (more than a month later for most of the common native wetland sedges) (Klopatek and Stearns 1978). Reed canarygrass emerges and attains maximum aboveground biomass production earlier in the spring than most native species, which is one reason it is able to successfully invade plant communities and displace other species. It does this by utilizing both rhizome carbohydrate reserves and photosynthetic carbohydrate assimilation during the entire period from emergence throughout the initial stages of anthesis and seed development (Begg and Wright 1962). In contrast, most native perennial species utilize reserves for emergence and development of first- and second-leaves only (Larcher 1995). An early burn gives reed canarygrass an even bigger head start on competing native species, enabling it to grow taller more quickly and shade out other species, particularly in nitrogen-enriched areas where competition for light is intense (Hautier et al. 2009). In contrast, a burn timed later in spring will set back established reed canarygrass plants by scalding its newly emerging (and somewhat fragile at this growth stage) crown buds while concomitantly removing litter and warming soil at a time when native species are just beginning to emerge. Follow-up applications of selective herbicides then further set back reed canarygrass. In combination, these paired management actions simultaneously enhance reed canarygrass suppression and competitive release of native species. Results from empirical research being conducted in the Pacific Northwest have documented a 40% increase in herbicide performance when herbicide applications were coupled to regular burning.

Furthermore, the primary germination window for reed canarygrass seeds occurs during March-April (Heide 1994), and a late burn can have directly lethal effects on newly-emerged reed canarygrass seedlings that have not had a chance to develop extensive rhizome networks and tillers. One perceived drawback to burning reed canarygrass stands (which is actually an advantage) is that litter removal can (and does) affect initial surges in seed germination from the active reed canarygrass seed bank. Reed canarygrass seedlings have low establishment vigor (Casler and Undersander 2006). Immature reed canarygrass seedlings (i.e., those plants that have not yet tillered) are more susceptible to postemergence systemic herbicides because they do not have rhizome carbohydrate reserves (etiolated regrowth potential) or dormant lateral rhizome buds from which to recover from herbicide treatments. Although the number of studies that have addressed the question of seed viability and seed bank longevity in reed canarygrass stands are regrettably few, existing data predicts that reed canarygrass seed viability is typically low in most stands and declines rapidly after only two or three years in saturated soil (Comes et al. 1978). If so, then coupling prescribed burning to herbicide applications may enable land managers to "flush out" any existing reed canarygrass seed bank within a short period of time. Therefore, during the first two growing seasons of reed canarygrass suppression, it is best to burn early in the spring (i.e., prior to May 1st) to flush out the reed canarygrass seed bank. Thereafter, burns should be timed later to suppress seedlings and reduce panicle development and seed production.

Notwithstanding the above arguments regarding the *idealized* timing of prescribed burns in reed canarygrass management, a point that bears emphasis is that <u>burning will augment reed canarygrass control efforts regardless of when the burn is conducted</u>. In an ideal world, we would be free to choose the optimal burn window for our management initiatives, but in the real world we often have to burn when conditions permit. The advantages of burning, in terms of litter removal and opening up the native seed bank to light outweigh the potential for shifting competitive advantages from desirable species to reed canarygrass through seedling recruitment. Several theoretical models of plant species competition (reviewed by Keddy 2002) show that litter processes are a better predictor of species replacements than competition.

BRUSH MANAGEMENT **(Contractor)**

Problem to be addressed: Long-term absence of a periodic fire regime has enabled shrubs and lowland trees to encroach on 15 acres of the remnant sedge meadow, altering habitat structure, fire behavior, and directly displacing native herbaceous species. Brush density is high enough to preclude use of fire alone as a management solution to this problem; direct intervention in the form of manual removal is required.

Location: Throughout the project area and also east of Spring Creek.

Action 1: Thin red-osier and grey dogwood cover by 80 – 90% to maintain the open character of the herbaceous marsh complex and facilitate management with periodic prescribed fire. Retain 10 – 20% of dogwood stands in a scattered but clumped distribution, since mosaics of different habitat structural elements will promote and maintain avian diversity within the project area (Mossman and Sample 1990). Although historical shrub densities in southern sedge meadows were much lower than this reserved density (only a few shrubs or tree saplings per acre) (Curtis 1959), this density will allow future fires to thin out shrub stands without eradicating this structural element from the site entirely.

Specifications: Apply a 50% (a.i.) mixture of water-soluble triclopyr/freezing point depressor/SPI dye to freshly cut stumps after the first killing frost and native herbaceous vegetation has senesced for the growing season. The treated area is to be posted with WPS signage during the restricted entry interval (REI) of water-soluble triclopyr (48 hours). Use herbicide BMPs to prevent collateral damage to non-target and/or at-risk species present and minimize the risk of environmental degradation. Pile and burn slash only after first killing frost and pending permission from local fire warden. Contractor must report to local fire warden on days when slash is being burned.

Action 2: Eradicate all buckthorn, honeysuckle, black willow, box elder, and cottonwood > 1 dm in height from the project area (future burns, if implemented, will eliminate shorter trees and shrubs).

Specifications: Apply a 50% (a.i.) mixture of water-soluble triclopyr/freezing point depressor/SPI dye to freshly cut stumps after the first killing frost and native herbaceous vegetation has senesced for the growing season. The treated area is to be posted with WPS signage during the restricted entry interval (REI) of water-soluble triclopyr (48 hours). Pile and burn slash only after first killing frost and pending permission from local fire warden. Contractor must report to local fire warden on days when slash is being burned. Frill-girdle larger cottonwood trees to create woodpecker snags. Apply a 17% (a.i.) mixture of oil-soluble triclopyr/diluent to frills. The treated area is to be posted with WPS signage during the restricted entry interval (REI) of oil-soluble triclopyr (12 hours). Use herbicide BMPs to prevent collateral damage to non-target and/or at-risk species present and minimize the risk of environmental degradation.

Action 3: Retain non-aggressive native shrubs (alternate-leaved dogwood, elderberry, and Bebb's willow) for wildlife use.

Things to consider: Reed canarygrass occupies gaps between shrub clusters throughout the heavy brush areas. It should be anticipated that reed canarygrass within the shrub area will expand following shrub removal which will increase light penetration. Also, if periodic fires are not imposed on the site, brush removal will be required every 3 – 5 years to maintain the project area in an open condition.

PHALARIS SUPPRESSION (Contractor)

Reed canarygrass is distributed at varying density throughout the entire project area, but is most abundant in the Frederick Springs area, within the ditch fill, in the margins of the sediment pond, at the interface between the remnant sedge meadow and upland prairie plantings, and along the banks of the western fork of the Pheasant Branch Creek (Fig. 6). With the exception of Frederick Springs, reed canarygrass is concentrated in portions of the project area with a history of disturbance, and the relationship between reed canarygrass invasion and disturbance is readily apparent in the project area. The soils of the ditch fill and sediment pond basin are high in nitrogen and phosphorus (table 2), the wetland-upland transition zone has a history of agriculture, and phosphorus-laden sediment deposition periodically occurs along the banks of the Pheasant Branch Creek. Fortunately, although this sedge meadow remnant is on a trajectory toward eventual reed canarygrass dominance, from an alternative states standpoint it is still in a pre-transitional condition and has not yet reached the degradation threshold beyond which restoration will no longer be feasible or cost-effective (see Annen et al. 2008). Much of the reed canarygrass present occurs within a mixed matrix of native species. Personal experience and several studies in the peer-reviewed literature suggest that reed canarygrass populations are particularly vulnerable to selective treatment strategies when occurring in mixed vegetation stands with well-established native species populations.

Selective Chemical Treatments

How an herbicide is used is as important to achieving end goals as herbicide choice. There are two general approaches to chemical control of invasive species. One approach is to use broad-spectrum (non-selective) herbicides, and the other is to use narrow-spectrum (selective) herbicides. When attempting to suppress invasive species in mixed vegetation stands, broad-spectrum herbicides (e.g. glyphosate) are superficially more effective on target species than selective herbicides; they result in more complete burn-down and suppress resurgence capacity for a longer time period. However, although they suppress resprouting and resurgence longer than selective herbicides, resurgence still occurs regardless of the herbicide or timing window used (Annen, in preparation). The principal drawback of using broad-spectrum herbicides in mixed vegetation stands is that they have the potential to eliminate non-target species, even when used properly and according to label directions. Moreover, non-selective herbicides also preclude the ability to reestablish replacement species when used over the course of multiple growing seasons. Broad-spectrum herbicides can achieve a measure of selective control when applied by various non-traditional methods and timing windows, such as with ropewick applicators, as cut surface treatments, or by applying them early in the growing season before the emergence of non-target species. However, these methods are labor-intensive, difficult to apply to larger project areas, and still do not guarantee effective control without collateral damage to potential replacement species. This is not to say that broad-spectrum herbicides are not without utility, particularly in highly degraded project areas. However, in high-quality remnant vegetation stands with intact native propagule banks such as the Pheasant Branch project area, selective herbicides are actually more effective in the long-term, despite their perceived short-term shortcomings. Applications of selective herbicides over the course of several growing seasons initiates a competitive release of desired endpoint vegetation, especially when a prescribed fire regime is imposed on the treatment area to remove litter and expose native propagule banks to light. Suppressing reed canarygrass early in the growing season enables native species to gain a space and height advantage, which acts to further suppresses reed canarygrass during its regrowth period since it is sensitive to the quality of light penetrating through native species vegetation canopies (refer to the subsequent discussion on revegetation for additional details). Additionally, the potential for secondary weed outbreaks is lower when using selective herbicides for reed canarygrass suppression because fewer canopy openings are created, although they can still occur.

Grass-selective herbicides from the cyclohexane-1,3-dione (CHD) chemical family (those with chemical names ending in *–dim*, e.g., sethoxydim, clethodim) are highly sensitive to physical decomposition from ultraviolet light; one study found that complete degradation of sethoxydim can occur within less than one hour under intense UV irradiation (Matysiak and Nalewaja 1999). High energy photons of UV radiation break chemical bonds, inactivating herbicide molecules and diminishing herbicide performance. The effect of UV on herbicide molecules depends on the molecular structure of the molecule, the intensity of UV radiation, and the presence and quality of herbicide additives in tank mixtures. Graminicide formulations from the aryloxyphenoxypropionic acid (APP) chemical family (those with chemical names ending in *–fop*, e.g., fluazifop) are resistant to ultraviolet degradation due to their molecular structure; these herbicides have a molecular backbone consisting of a phenolic ring with orbital resonance. UV photons do not have the energy to break this type of chemical bond. If ultraviolet degradation were the only constraint on herbicide choice, clearly APP formulations would be the better choice. However, APP formulations are less water-soluble and not as easily absorbed by the leaves and culms of the target plant as CHD formulations. APP formulations are also more persistent and more toxic to aquatic organisms than CHD formulations.

The problems associated with ultraviolet degradation and herbicide uptake can be addressed with herbicide additive systems (see Annen 2006). An organosilicone-based methylated seed oil + nonionic surfactant (MSO-NIS) blend (DYNE-AMIC®) can be added to tank mixtures at a rate of 1% (v/v). The seed oil component of this additive enhances herbicide penetration and accelerates uptake rates by dissolving waxy leaf cuticles that normally prevent exogenous substances from entering the plant, while the surfactant reduces surface tension of the spray mixture so applied herbicide spreads out more evenly and covers greater leaf surface area. The methyl groups that protrude from the hydrocarbon chains of the MSO surround herbicide molecules and help temporarily protect spray solutions from UV degradation, because some of the UV photons strike the protruding methyl group rather than the herbicide molecule. Organosilicone is biodegradable and will not dry on leaf surfaces as rapidly as silicone-based MSO additives. Organosilicone-based additives are considerably more expensive than soybean-based MSO formulations, but are less likely to gel (coagulate with insoluble calcium and magnesium precipitates found in hard water spray mixtures and jam sprayer components) in mixture. They also lubricate mechanical sprayer components. Lastly, we recommend using an organosilicone-based MSO/NIS blend rather than a petroleum- or crop oil-based blend since the latter can cause leaf spotting and curling on non-target species. These types of localized tissue damage are typically not lethal but can affect fecundity as more resources need to be allocated to recovery rather than flowering and seed production. Petroleum- and crop-based MSOs can also be moderately toxic to aquatic organisms. A water conditioning agent should also be added to tank mixtures of either CHD or APP herbicide formulations at a rate of 0.25% (v/v) to sequester any particulate material and hard water cations in the mix water. Herbicide molecules can adhere to particulate matter in mix water and become unavailable for uptake and translocation within target species because these colloids are physically too large to be actively loaded into phloem conducting tissues.

As an extra precaution, when applications are carried out adjacent to areas where standing water may be present, we recommend adding a chemical sticking agent to tank mixtures at a rate of 0.5%

(v/v). The product we recommend is Induce pH®. This additive is approved for use in aquatic areas and contains free fatty acids that cause herbicide spray to physically adhere to, and not wash off of, treated surfaces, even when treated vegetation is exposed to light rain or dew shortly after application. It also functions as a drift reducing agent and as a pH buffer (rates of uptake and physical and chemical decomposition of CHD herbicide formulations are accelerated at alkaline pH (Struve 1987)).

Timing of Herbicide Applications

Despite the widespread use of herbicides for reed canarygrass suppression, few empirical experiments have directly evaluated herbicide performance and treatment success along a gradient of different timing windows. Treatment windows reported in the literature can be partitioned into two categories: spring – early summer applications (early season applications) and late summer – early autumn applications (late season applications). Reinhardt-Adams and Galatowitsch (2006) compared early- and late-season applications and concluded that early season applications were "suboptimal" for reed canarygrass suppression. However, close examination of their results reveals that late season applications resulted in a mere 15% increase in stem density suppression over early season applications, while aboveground biomass was similar between the two timing windows. Moreover, reed canarygrass resurged to its pretreatment abundance when herbicide applications ceased, regardless of the timing window employed. Clearly, their conclusion was premature given our present level of understanding of this topic. A thorough review of the available literature on this topic shows that early season applications of grass-selective herbicides are more effective on cool-season perennial grasses than applications administered later in the growing season (Annen, in preparation). The reasons for this have to do with seasonal differences in the physiology of plant growth and herbicide uptake and translocation: Leaf growth and leaf surface area (and hence herbicide uptake potential) are maximal while rhizome carbohydrate reserves (and resurgence potential) are minimal during the early season window. Additionally, the early season timing window enables competitive release of native species that will shade out reed canarygrass during its recovery period, reducing its fitness, fecundity, and competitive ability. Therefore, reed canarygrass should be chemically treated at the four-leaf growth stage (plants will be approximately 8 – 12 inches tall).

<u>Frederick Springs Area</u> (Contractor and FOPB Volunteers)

Problem to be addressed: Suppress or eradicate reed canarygrass occurring within and around the Frederick Springs area without affecting water quality. Due to the unique geological and biological features present, and the fact that this spring complex is a major source of hydrological input to the Pheasant Branch Marsh, extreme caution should be exercised when applying herbicides in this area.

Action 1: Mow reed canarygrass to reduce its height and encourage leafy aftermath regrowth. Reed canarygrass has been selectively bred as a forage plant, and exhibits high aftermath vigor (Collins and Allinson 1995). Following this initial mowing, reed canarygrass regrowth will have a larger leaf surface area than if it were not mowed. The increased leaf surface area will not only enhance herbicide uptake and performance, it will also help prevent herbicide from making contact with soils and water in the spray area. Also, rhizome carbohydrate reserves will need to be mobilized for regrowth and recovery, which will contribute to depletion of rhizome reserves.

Specifications: FOPB volunteers should mow reed canarygrass in late April – early May and remove clippings from the site.

Action 2: Apply grass-selective herbicide to reed canarygrass regrowth.

Specifications: Contractors will apply a 0.5% (a.i.) mixture of clethodim (Intensity®) with 5% (v/v) sticking additive approved for use in aquatic applications (Induce pH®) to reed canarygrass at the four-leaf regrowth stage, following WDNR wet sock guidance and herbicide best management practices (BMPs) to avoid applying this herbicide to reed canarygrass over standing water. Herbicide applications should take place under DNR supervision. MSO-NIS will not be added to herbicide mixtures when treating reed canarygrass in Frederick Springs, since use of these products could pose risks to aquatic organisms in this treatment area. To discourage herbicide drift when applying herbicides in this area, small-capacity sprayers will be used at low pressure with cone-type nozzles adjusted for large spray droplet size. The treated area is to be posted with WDNR APM permit signage during the restricted entry interval (REI) of clethodim (24 hours). Additional herbicide applications will need to be carried out over several consecutive growing seasons to deplete reed canarygrass rhizome reserves and dampen resurgence from rhizomes and the active reed canarygrass seed bank.

Action 3: Remove by hand any untreated reed canarygrass rooted within standing water. This should be done after treated reed canarygrass begins to show signs of herbicide phytotoxicity (yellowing and/or browning of plants, beginning at leaf tips, margins, and intercalary meristems and then spreading to the remainder of the plant), approximately seven to ten days after the herbicide application date.

Specifications: FOPB volunteers should hand-pull any reed canarygrass rooted within standing water and remove plants from the site for destruction. This should be done at least seven to ten days after the herbicide application date. Some plants may disarticulate from rhizomes when hand pulling. To protect the integrity of the spring area substrate, do not use a shovel or other digging implement to dig up reed canarygrass rhizomes in this area. Expect rhizomes to resprout, and follow up with additional pulling. More than one pulling session will likely be required each growing season, especially for the first two or three years, and this procedure will require several growing seasons of consecutive effort to be effective.

Action 4: Revegetate the spring area with a diverse mixture of calcophilic native species characteristic of presettlement fen wetlands (Curtis 1959). For specific details regarding revegetation of this area, refer to the revegetating section of this report.

<u>*Phalaris*-Dominated Association (Wetland-Upland Transition Zone)</u> **(Contractor)**

Problem to be addressed: Dense *Phalaris* stands occur in the border between high-quality remnant sedge meadow and upland planted prairies. These stands are a source of invasion for both community types, and will continue to expand in the absence of management intervention.

Action: Suppress reed canarygrass and replace it with a diverse native prairie buffer. For specific details regarding revegetation of this area, refer to the revegetating section of this report.

Specifications: *Site preparation*: Apply a 5% (a.i.) mixture of glyphosate with 0.25% (v/v) water conditioning agent and 1% (v/v) MSO-NIS to the entire area in late summer. Repeat this procedure in spring and autumn of the subsequent year if necessary. Plant area to wet-mesic prairie after 2 – 3 iterations of this procedure, and burn as needed to remove litter and prepare the seedbed. Disking this area (if possible) will also augment reed canarygrass suppression efforts and seed bed preparation. *Continued management*-When planted species emerge, apply a 2% (a.i.) mixture of fluazifop-p-butyl (Fusilade DX®) with 1% (v/v) MSO-NIS to reemerging reed canarygrass to enable establishment of planted species. Following each application, treated areas are to be posted with WPS signage during the restricted entry interval (REI) of each herbicide applied (glyphosate-4 hours; fluazifop-12 hours).

<u>Sediment Retention Pond Basin</u> **(Contractor)**

Problem to be addressed: The basin of the sediment retention pond consists of a dense mixture of several invasive and undesirable species dominated by reed canarygrass, smooth brome grass, Queen Anne's lace, Canada thistle, Canada goldenrod, giant ragweed, and poison parsnip. High soil nutrient concentrations are exacerbating dominance of these species; nitrogen enhances growth and tillering of perennial species, and phosphorus enhances not only growth but also flowering and seed production (Larcher 1995). The retention pond is hydrologically connected with the sedge meadow remnant via the west branch of the Pheasant Branch Creek, and flooding events are transporting propagules of these species (and probably also phosphorus-laden sediment) into the Pheasant Branch Marsh, maintaining reed canarygrass populations and contributing to additional species invasions.

Action: Suppress reed canarygrass and other invasive species and replace the degraded species mixture with a diverse mixture of native, nutrient-absorbing species to curtail species invasions, provide habitat structural elements for wildlife, and enhance sediment and nutrient-retention capacity of the retention pond. Since this area is high in nutrients and reed canarygrass thrives under such conditions, the retention pond should be planted with species not easily displaced by reed canarygrass. For specific details regarding revegetation, refer to the revegetating section of this report.

Specifications: *Site preparation*-Apply a 0.5% (a.i.) mixture of clopyralid (Transline®) with 1% (v/v) MSO-NIS blend to Canada thistle in late May or early June of the first year. Apply a 5% (a.i.) mixture of glyphosate with 0.25% (v/v) water conditioning agent and 1% (v/v) MSO-NIS to the entire area approximately one week after treating Canada thistle, but prior to emergence of reed canarygrass panicles. Repeat this procedure in autumn of the first year if necessary. Details for revegetating the sediment pond basin are described in the revegetating section of this report. *Continued management*-When planted and plugged species emerge, apply a 2% (a.i.) mixture of fluazifop-p-butyl (Fusilade DX®) with 1% (v/v) MSO-NIS to reemerging reed canarygrass to enable establishment of planted and plugged species. Following each application, treated areas are to be posted with WPS signage during the restricted entry interval (REI) of each herbicide applied (clopyralid-1 hour; glyphosate-4 hours; fluazifop-12 hours).

Remainder of the Project Area **(Contractor)**

Problem to be addressed: Suppress reed canarygrass that is invading high-quality sedge meadow remnant without inflicting collateral damage to desirable non-target species. When applying herbicides to reed canarygrass within the *Carex-Spartina, Carex stricta-Calamagrostis* and *Carex trichocarpa-Calamagrostis* vegetation associations, extreme care should be taken to avoid inflicting collateral damage to culms of the desirable native grasses Canada bluejoint and prairie cordgrass, which are also susceptible to clethodim. Prior to inflorescence emergence, *Spartina* superficially resembles sedges. Canada bluejoint is morphologically and phenologically similar to reed canarygrass, and the two species have considerable overlap in niche breadth. Since Canada bluejoint occupies the same niche space as reed canarygrass, it is desirable to minimize or avoid any collateral damage due to misidentification. Only contractors who are proficient in discriminating between these species should be allowed to apply herbicides in this project area.

Action: Since *Phalaris* occurs within a mix of native species, suppression should consist of foliar spot-treatments with the systemic grass-selective herbicide clethodim with small-capacity sprayers. Tussock height and other microtopographic features within the project area will prevent the use larger capacity spray rigs for this portion of the abatement project. Additional herbicide applications will need to be carried out over several consecutive growing seasons to deplete reed canarygrass rhizome reserves and dampen resurgence from rhizomes and the active reed canarygrass seed bank.

Specifications: Apply a 0.5% (a.i.) mixture of clethodim (Intensity®) with 1% MSO-NIS and 0.5% sticking additive (as necessary when applying herbicides near areas of standing water) to reed canarygrass. The treated area is to be posted with WDNR APM permit signage during the restricted entry interval (REI) of clethodim (24 hours). For specific details regarding revegetation of these areas, refer to the revegetating section of this report.

TYPHA **SUPPRESSION** **(Contractor)**

Both narrow-leaved and hybrid cattail were detected within the project area during vegetation surveys (Fig. 9). Analyzing a time series of aerial photos of the Mukwonago Watershed, Boers and Zedler (2008) derived a linear regression model to predict the rate of spread of these aquatic invasive species. However, a followup survey conducted by Integrated Restorations in 2009 showed that this linear model underestimated the rate of spread. *Typha* populations were actually expanding at a finite rate of increase of λ = 0.507% per annum, nearly two orders of magnitude higher than predicted by the linear model. Narrow-leaved and hybrid cattail are capable of rapid spread, and it is essential to detect these species in the early stages of invasion and eradicate pioneer populations before they have a chance to expand and compromise the biological integrity of the project area.

Problem to be addressed: Eradicate *Typha angustifolia* and *T.* x *glauca* infestations in a high quality natural area without inflicting drastic collateral damage to non-target replacement species or disrupting the ecological integrity of the site. Invasive *Typha* are limited in their distribution and abundance within the project area and eradication of these pioneer populations has a high probability of success.

Location: Invasive cattails were restricted in distribution to the western end of the ditch fill (Fig. 7), where they occurred in low abundance.

Figure 9: *Typha angustifolia* (left) and *T.* x *glauca* (center and right) within the project area.

Action 1: Typically in this situation, the preferred (and tested) option is to mow *Typha* shoots and flood the site approximately 10 cm above cut shoots for at least two growing seasons. However, water levels within the Pheasant Branch Marsh cannot be directly manipulated with flood control gates, and mowing without flooding will only delay the problem for as long as it takes for the mowed *Typha* to resprout. Chemical treatment of cut shoots is another alternative, but there are no herbicides that will selectively control *Typha* without causing collateral damage to native sedge meadow species present. Nevertheless, if used judiciously and with proper additives and application techniques, non-selective herbicides can be a used eradicate *Typha* while minimizing the risk of inflicting collateral damage to non-target species. Aquatic formulations of glyphosate (such as Rodeo®) or the aquatic-approved herbicide imazapyr (Habitat®) are both effective on *Typha*. Each has its advantages relative to the other, mostly related to their persistence and potential for etiolated regrowth potential (i.e., post-treatment resurgence) of the target species. Glyphosate is less expensive and degrades more rapidly in aquatic systems than imazapyr. However, rhizomes of *Typha* phytomers possess elongated apical buds, appressed lateral buds covered by a cataphyll, and display a complete lack of rhizome branching, just as other species that experience rhizome apical dominance (Stüfer et al. 2002). If the concept of rhizome apical dominance as a mechanism for resurgence capacity (see Annen 2010) can be extrapolated to other rhizomatous monocots (such as *Typha* or *Phragmites*), we can predict that glyphosate will only provide one growing season worth of topkill, after which treated *Typha* will resprout from dormant lateral rhizome buds. Thus, treatment with glyphosate will not alleviate the problem for more than one

or (at most) two growing seasons, after which the *Typha* will resurge to its pretreatment density unless additional chemical treatments are applied. Although more expensive, the herbicide formulation imazapyr is more persistent within the plant, and offers the potential for better long-term control and suppression of regrowth. Unlike glyphosate, which rapidly degrades once the dominant apical bud is killed, imazapyr is still chemically active after apical bud necrosis, and is able to affect resprouting lateral buds once they have been released from apical dominance and begin to receive assimilate and nutrients from the main rhizome axis.

The disadvantage of imazapyr is that it creates a dead zone lasting two or three growing seasons, precluding the ability to establish replacement species, especially when applied with foliar application techniques. Land managers have been anecdotally experimenting with use of foam paint brushes to apply herbicides to cut surfaces. In our experience, there are two problems with the paint brush method: 1) the potential risk of spilling the herbicide container (which needs to remain open during applications to re-soak the brush), and 2) not enough herbicide gets on cut surfaces, resulting in loss of herbicide performance and diminished treatment effectiveness. Budyak et al. (in progress) are developing techniques for effective *Typha* suppression in the presence of high-quality non-target species.

Specifications: *Typha* aboveground stems should be trimmed approximately 10 cm from the plant/soil or plant/water interface with a sharp bypass shear after full leaf elongation. Apply imazapyr* to cut surfaces at a rate of 7.7% (a.i.) with a small-capacity compression sprayer. To prevent overspray, sprayer nozzles should be fitted with a polypropylene cone-shaped drip/drift guard attachment adjusted to the mean diameter of *Typha* shoots (Fig. 10). Since imazapyr is formulated as an isoproplyamine (IPA) salt, a water conditioning agent (ReQuest®) should be added to mix water at a rate of 0.25% (v/v). The active chemical moiety of imazapyr is the acid conjugate of the IPA salt. Divalent calcium cations present in mix water can bind to imazapyr and form coordinate covalent complexes through a Lewis acid-base reaction. This effectively inactivates the herbicide active ingredient, since calcium complexes are not loaded into phloem sieve tube elements and are thus not translocated within the plant. The reason for this is that the vacuolated appearance and solute conducting capability of phloem cells is a result of imposed calcium and boric acid deficiency within this type of specialized cell (Epstein 1973). Water conditioning agents should always be added to tank mixtures <u>before</u> herbicide, since their role is to sequester calcium cations before they can bind to herbicide active ingredients. A sticking agent approved for use in aquatic ecosystems (Induce pH®) should be added to imazapyr mixtures at a rate of 5% (v/v). This additive contains free fatty acids that cause applied herbicide to physically adhere to treated surfaces, prevents herbicide drift and runoff from treated surfaces, prevents herbicide wash-off during rewetting from morning dew or light rain during the uptake period, stabilizes tank mixture pH, and curtails evaporation of herbicide from treated surfaces. Chemical treatments should take place in June or July (depending on annual growing conditions), when *Typha* rhizome carbohydrate reserves are at a minimum due to drains for inflorescence development and flowering. At this growth stage, etiolated regrowth potential and resurgence capacity are minimal, as rhizome apical dominance is less pronounced that after seed development.

Figure 10: Small capacity compression sprayer modified with a drip/drift guard.

Action 2: Although we did not observe narrow-leaved or hybrid cattail in any other sections of the project area, additional scouting should be carried out on an annual basis to rapidly respond to possible future invasions. The ditch fill area is the perfect niche opportunity for *Typha* expansion, containing wet organic soils that are high in ammonium and phosphorus (van den Brink et al. 1995). Furthermore, proposed reed canarygrass and tree and shrub removal in the ditch fill will create open niche space for additional expansion.

****NOTE: Imazapyr can only be applied by licensed pesticide applicators certified in the WDATCP Aquatic & Mosquito Commercial Category (5.0).***

PHRAGMITES SUPPRESSION (Contractor)

Problem to be addressed: Eradicate *Phragmites* infestations in a high quality natural area without inflicting drastic collateral damage to non-target replacement species or disrupting the ecological integrity of the site. Since *Phragmites* is limited in its distribution and abundance within the project area, eradication of these pioneer populations has a high probability of success.

Location: *Phragmites* is presently restricted in distribution to the middle and western portions of the ditch fill (Fig. 7) (Fig. 11).

Figure 11: *Phragmites* located within the project area.

Action 1: Similar to *Typha* and *Phalaris*, *Phragmites* rhizomes possess elongated apical buds, appressed lateral buds covered by a cataphyll, and display a complete lack of rhizome branching, all indicators that a system of apical dominance is in place (Stüfer et al. 2002), which may contribute to this species' treatment recovery potential (Annen 2010). Effective *Phragmites* suppression necessitates use of the persistent, broad-spectrum herbicide imazapyr, for the same reasons discussed in the previous section on *Typha* suppression.

Specifications: Mow *Phragmites* to a height of 15 – 20 cm in early June and apply imazapyr* at a rate of 1.15% (a.i.) as a foliar spray with a small-capacity backpack sprayer once aftermath regrowth reaches the four-leaf growth stage (plants will be approximately 20 inches in height at this time). This relatively high stubble height will preserve high aftermath vigor, resulting in larger leaf surface area to intercept and absorb herbicide than un-mowed growth. A water conditioning agent (ReQuest®) should be added to tank mix water at a rate of 0.25% (v/v) to sequester hard water cations. A drift-reducing/sticking additive (Induce pH®) should be added to herbicide tank mixtures at a rate of 4% (v/v) to minimize the potential for inflicting collateral damage beyond the intended treatment area through drift and/or runoff of spray to treated surfaces. Chemical treatments of *Phragmites* should take place in late June or early July (depending on annual site and growing conditions), when rhizome carbohydrate reserves are at a minimum due to drains for inflorescence development and flowering. At this growth stage, etiolated regrowth potential and resurgence capacity are minimal, as rhizome apical dominance is less pronounced that after seed development.

Action 2: Although *Phragmites* was not observed in any other sections of the project area, additional scouting should be carried out on an annual basis to rapidly respond to possible future invasions. The ditch fill area is the perfect niche opportunity for *Phragmites* expansion, containing wet organic soils that are high in ammonium and phosphorus (van den Brink et al. 1995). Furthermore, proposed reed canarygrass and tree and shrub removal in the ditch fill will create open niche space for additional expansion.

****NOTE: Imazapyr can only be applied by licensed pesticide applicators certified in the WDATCP Aquatic & Mosquito Commercial Category (5.0).***

WATERCRESS SUPPRESSION **(FOPB Volunteers)**

Watercress (*Nasturtium officinale*) is an aggressive invader of springs, seeps, drainage channels, and streams (Fig. 12). This species can occupy surface space and adversely impact water flowage and discharge in small streams and can displace existing submersed aquatic vegetation in small ephemeral ponds used by reptiles and amphibians. Thick mats of watercress can also hinder amphibian thermoregulation (Dr. Josh Kapfer, UW-Whitewater, personal communication). Established populations of watercress are capable of spreading downstream along waterways, which can act as highly effective dispersal corridors for its propagules.

Figure 12: Watercress located within the project area.

Problem to be addressed: Eradicate watercress infestations in a high quality natural area without inflicting drastic collateral damage to non-target replacement species or disrupting the ecological integrity of the site. Expect watercress invasions to be a long-term occurrence within the project area, requiring some level of active management intervention on an annual basis.

Location: Watercress was found to be distributed in the Frederick and norths springs areas, and also in ephemeral pools and small ponds within and near the ditch fill (Fig.7).

Action: To protect water quality integrity, herbicides should not be used to control the watercress population at Pheasant Branch Marsh. An indirect consequence of applying herbicides to water is that decay of target plants reduces dissolved oxygen levels in the water column, adversely affecting aquatic organisms. Watercress should be harvested with a rake, bagged, and removed from the site for destruction. Any rooted stems should also be pulled out of the sediment and bagged. Due to the ability of this species to regenerate from fragments, Integrated Restorations has experimented with anchoring a fine mesh net (made of folded layers of cheesecloth) across the stream profile immediately downstream from raking points to trap fragments and prevent their downstream spread. However, we concluded that this method was somewhat cumbersome and only effective in the short-term, and that watercress quickly recolonized the sites in subsequent growing seasons whether the mesh netting method was used or not.

POTENTIAL FOR SECONDARY WEED OUTBREAKS

Management actions that reduce vegetative cover can act as a disturbance, and invasive species suppression efforts can produce a variety of unintended outcomes (Kellogg and Bridgham 2002, Odland and del Moral 2002, Suding et al. 2004). For instance, a targeted species may resurge, reinvading the treated area and necessitating additional treatment efforts over multiple years (Annen 2010). Another indirect consequence of successfully suppressing one invasive species is that there is the potential to open up niche space to other invasive species, resulting in a secondary weed outbreak. Often, a given invasive species suppresses not only desirable vegetation, but also other invasive species. For example, reed canarygrass has been documented to invade wetlands formerly dominated by purple loosestrife after management with biological control organisms (Rachich and Reader 1999, Morrison 2002).

During our vegetation survey, we detected *Phragmites* and invasive *Typha* in small densities with limited spatial distribution within the project area. Successful suppression of reed canarygrass could lead to an increase in *Phragmites* and invasive *Typha*. For this reason, all aquatic invasive species within the project area should be co-managed simultaneously to prevent a secondary weed outbreak from occurring. Otherwise, management of only reed canarygrass could result in a weed shift where the others end up expanding and dominating. The potential for secondary weed outbreaks also highlights the importance of active revegetation of areas denuded by herbicide applications. Variations of secondary week outbreaks are also possible if denuded treatment areas are recolonized by ruderal invasive species that thrive in disturbed areas (e.g. thistles), necessitating the use of additional herbicide formulations to deal with these secondary outbreaks. Within the Pheasant Branch Marsh project area, we observed two species that have high potential for secondary week outbreaks once aquatic invasive species are suppressed: Canada thistle, which occurs in abundance in the sediment pond basin and at lower abundance within the *Carex-Spartina* vegetation association, and leafy spurge (*Euphorbia esula*), which was observed in the *Phalaris*-dominated and near the northern boundary (border) of the *Carex-Juncus* associations. Both of these species should be scouted for and managed once aquatic invasive species suppression efforts are initiated.

REVEGETATING TREATMENT AREAS **(FOPB Volunteers)**

Reestablishing vegetation in areas where invasive species have been suppressed or removed is a critical, yet often overlooked, component of invasive species abatement. Management actions that reduce invasive species densities (e.g. tree and shrub removal and chemical herbiciding) can act as a disturbance, opening up niche space for subsequent reinvasion. An unfortunate indirect consequence of 150 years of agricultural and urban development is that fragmented present-day herbaceous plant communities are isolated from each other to such an extent that gene flow and propagule recruitment from adjacent natural areas (i.e., the efficient community-dispersal hypothesis) is often negligible. Proactive revegetation should be a component of any invasive species abatement effort to prevent treated areas from reverting back to their original invaded condition.

Competition from established native species augments and accelerates invasive species suppression efforts. In general, areas that are more diverse when suppression efforts are initiated respond more positively to grass-selective herbicide applications, and treatment effects persist longer, particularly when a prescribed fire regime is imposed on the site. Maurer et al. (2003) and the Wisconsin Reed Canary Grass Management Working Group (2009) have formulated guidelines and specific recommendations for successful reestablishment of native species once chemical suppression treatments of reed canarygrass have been initiated. These recommendations were put to the test in a case study by Annen (2011), who reported successful establishment of a diverse sedge meadow plant community in bareground space resulting from a ditch fill and scrape construction project with concomitant chemical suppression of reed canarygrass.

Reed canarygrass invasions are concordant with disturbances that create bareground spaces with high light availability. Management activities that create bareground space should be immediately reseeded to prevent reinvasion. When reestablishing native vegetation after wetland restoration, it is highly advisable to create a closed herbaceous species canopy as quickly as possible (Maurer et al. 2003). There is compelling empirical evidence that a closed, complex canopy will alter spectral quality within a vegetation stand, increasing the amount of far-red light reaching the soil surface. As transmission of far-red light increases (relative to blue light), reed canarygrass seed germination decreases (Lindig-Cisneros and Zedler 2001). Reed canarygrass displays low establishment rates and low seedling aggressiveness under light-limited conditions (Casler et al. 1999, Lindig-Cisneros 2002, Casler and Undersander 2006). The results of several experiments indicate that competing species (particularly broad-leaved forbs) change the concentration and quality of light reaching reed canarygrass leaves, reducing its fitness, fecundity, and competitive ability. The ideal endpoint planting is one that exhibits a complex, multi-layered, multi-species canopy that is vertically, serially (successionally), and phenologically layered (Wisconsin Reed Canary Grass Management Working Group 2009). A vegetation stand with a multi-layered canopy will intercept the most light, inhibiting reed canarygrass growth and seed germination. Lindig-Cisneros and Zedler (2002) further showed that diverse plant communities are, to an extent, resistant to reed canarygrass invasion. The best way to ensure establishment of a complex canopy is to plant a diverse mixture of morphologically variable species from different functional guilds (e.g., sedges, rushes, cool-and warm-season grasses, forbs, and shrubs). By themselves, sedges and grasses do not provide very much light competition for RCG, but forbs exhibit a diverse array of leaf morphology for intercepting light. Only 1% of incoming solar radiation reaches the soil surface under a dense forb canopy, whereas approximately 10% of incoming solar radiation reaches the soil surface in a grass or sedge monotype (Larcher 1995).

Treated areas should be seeded at high rates (7 – 10 pounds per acre, or 60 – 100 seeds/ft^2). Seeding in both spring and autumn (and over a couple of years) will allow you to hedge your bets against adverse environmental conditions that may have a negative impact on planting effectiveness. Another strategy is to collect species with maximum abundance along the entire soil moisture hydrosere, so that there will always be native species available in the active seed bank to provide canopy structure and enclosure during any moisture regime (as hydrological conditions in wetlands can be variable). I also recommend collecting seeds of both annual (mudflat), biennial, and perennial species. Avoid collecting seeds from aggressive native species (e.g., *Solidago canadensis* or *Helianthus grossesserratus*) or do so in limited amounts because these species could suppress more desirable native vegetation on site. Lastly, recent research has shown that *Carex* achenes have very limited storage life. Sow *Carex* seeds in the same growing season you collect them, or, if ordering seeds from a nursery, inquire about the collection date for the seed lot you are ordering.

It is also advisable to augment seeding with planting live plants, including plugs, bare root plants, rhizome fragments, rooted tubers, or even entire tussocks or sod transplants if a donor site is available and if financial resources permit. Typical plug planting densities range from 3 – 6 plugs/m^2 (low density) to 9 – 12 plugs/m^2 (high density). Planting live plants is a way to rapidly establish a closed canopy, and gives faster results for rare or conservative species whose seeds often require several years of stratification before they germinate. Huddleston and Young (2004) reported that a plug interplanting distance of 18 cm was sufficient to reduce competitive effects of highly aggressive perennial grasses. Prior to planting, soak live plant material for 12 – 24 hours in a 10% (v/v) solution of cytokinin (X-Cyte®) rooting hormone and water; do so out of direct sunlight but not in a dark location. Rooting hormone encourages cell division and enhances transplant success. Browsing exclosures should also be placed over plugs. Monitor and regularly water transplants during establishment (which may require a few months).

The five areas that need to be actively reseeded during aquatic invasive species suppression efforts are the *Phragmites* clones, the Frederick Springs area, the *Phalaris*-dominated buffer areas, the sediment pond basin, and the *Phalaris-Carex lacustris* association along the western branch of the Pheasant Branch Creek. All other areas contain reed canarygrass in low densities within a diverse matrix of native species; revegetation in these areas will occur naturally through seed rain and vegetative spread.

Phragmites Clones **(FOPB Volunteers)**

Despite the fact that imazapyr is approved for use in aquatic environments, the herbicide active ingredient has a field half-life of 25 - 142 days, depending on soil type. Its half-life is even longer (up to 24 months) in waterlogged soils (WSSA 1994). Imazapyr residues in soil are known to inhibit seed germination. For this reason, no attempt should be made to reseed *Phragmites*-treated areas for at least two growing seasons after the *Phragmites* clones have been eradicated. After this time period, collect a diverse mixture of seeds from the remnant sedge meadow community and frost-interseed them at high rates (the equivalent of ≥ 10 lbs/acre) for several growing seasons.

Frederick Springs Area **(FOPB Volunteers)**

The overall revegetation goal for the Frederick Springs area is to replace existing reed canarygrass with a diverse mixture of showy calcophilic native species characteristic of Wisconsin fen communities. Table 4 is a suggested list of fen species for revegetating Frederick Springs. Unable to find any historical records of the vegetation composition of spring areas, we chose a variety of species characteristic of fens listed in Curtis (1959). We limited species selections to showy, non-aggressive species with short stature. We recommend planting plugs of most or all of these species, since conditions within this area are not conducive to seed bed preparation and maintenance of the planting through burning and/or mowing. If plugs are not available from local nurseries, FOPB volunteers should consider purchasing seeds and then rearing their own plugs. This option would also be considerably less expensive than purchasing plugs from nurseries, and presents opportunities for community involvement and education.

Phalaris-Dominated Buffer Zones **(FOPB Volunteers)**

The *Phalaris*-dominated buffer zones along the wetland to upland transition should be restored to wet-mesic prairie once reed canarygrass has been sufficiently suppressed to allow planting. Annual burning will be necessary to prepare the seed bed and facilitate prairie establishment. Follow seed selection and planting guidelines prepared by the Wisconsin Reed Canary Grass Working Group (2009).

Sediment Retention Pond **(FOPB Volunteers)**

The overall revegetation goal for the sediment pond basin is to replace the existing degraded species mixture with a diverse mixture of native, nutrient-absorbing species to curtail species invasions, provide habitat structural elements for wildlife, improve visual aesthetics of the pond margins, and enhance sediment and nutrient-retention capacity of the retention pond. Since this area is high in nutrients and reed canarygrass thrives under such conditions, the retention pond should be planted with species not easily displaced by reed canarygrass. These goals can be accomplished by employing a resource-partitioning model in the species mix design (Krebs 1994). Resource-partitioning models assume that niche structure is hierarchical in natural plant communities, and in theory, a diverse vegetation stand structured along this model will capture and retain a greater proportion of nutrients and sediments due to more complete utilization of all available niche space throughout the growing season.

Table 5 is a species mix designed for this purpose. Species were chosen based on their competitive ability, high nutrient uptake potential and use in wastewater treatment wetlands in Europe, and characteristics known or suspected to be correlated with wildlife habitat and food sources (Gaudet and Keddy 1995, Keddy 2000, Fraser and Miletti 2008, Zmirek and Gawronski 2009). To construct this list, we partitioned desired endpoint species abundance into four categories: Matrix, subdominant, common, and rarefraction, with matrix corresponding to the most abundant species and rarefraction the least abundant. We then partitioned the number of species within each category along a stepwise distribution function, with five matrix species, ten subdominant species, fifteen common species, and twenty rarefraction species. This pattern is a simplified approximation of plant species distribution patterns in undisturbed plant communities, which follow a log-normal abundance curve ranging from a few matrix species comprising the majority of aboveground biomass to several rarefraction species with uncommon frequency within the community. We then modified Sugihara's Sequential Niche Breakage Hypothesis (Sugihara 1980) with a threshold abundance of 0.5 for each successive abundance category, such that:

$$\Sigma_{matrix} = \tfrac{1}{2}(\Sigma_{total})$$
$$\Sigma_{subdominant} = \tfrac{1}{2}(\Sigma_{matrix})$$
$$\Sigma_{common} = \tfrac{1}{2}(\Sigma_{subdominant}), \text{ and}$$
$$\Sigma_{rarefraction} = \tfrac{1}{2}(\Sigma_{common}),$$

where Σ represents the sum of species abundance within each abundance category.

The modified Sugihara model approximates a log-normal species abundance distribution because the abundances of individual species are variable while their sums are restricted by the abundance category to which a given species belongs. Within each abundance category, different species can vary in their abundances, so long as the sum of the abundances is no greater than 50% of the sum of species abundance in the next highest category.

To use the planting guidelines presented in table 5, first choose a total abundance level. For example, if plugs and seeds are used in the planting, the total abundance should be ≥ 7 pounds per acre to ensure a successful planting amidst competition pressure from invasive species. (Seed plug densities can be substituted for seed weight within this model, so long as the abundance measure (pounds of seed or seed density) is used consistently). There are five matrix species, all of which are known to exhibit high nutrient uptake and high competitive effect relative to reed canarygrass. The sum of the desired endpoint abundances of these five matrix species should be 50% of 7 pounds per acre, which is equal to 3.5 pounds per acre. Next, partition the five matrix species into roughly equal proportions such that their combined abundance is equal to 3.5 pounds per acre. The next abundance category is subdominant. The sum of species abundances in this category is 50% of the sum of the matrix category, or 0.5 x 3.5 pounds per acre, which is equal to 1.75 pounds per acre. Partition the ten subdominant species such that their cumulative abundance is equal to 1.75 pounds per acre. Repeat this procedure for the remaining abundance categories. Follow planting guidelines prepared by the Wisconsin Reed Canary Grass Management Working Group (2009).

It is highly advisable to plant both plugs and seeds when revegetating the sediment pond basin to ensure rapid revegetation of this area, and at a high plugging density of 9 – 12 plugs/m^2. If plugs are not available, FOPB volunteers should consider purchasing seeds and then rearing their own plugs. This option would also be considerably less expensive than purchasing plugs from a nursery. Chemical treatment of invasive species will destroy vegetative cover, which will diminish the pond's ability to capture and retain nutrients and sediments. The sediment pond basin should be mowed or (ideally) burned during vegetation establishment, initially to remove dead plant material and litter resulting from herbicide applications and subsequently to facilitate germination of seeds and expansion of plugs. Installment of semi-permanent firebreaks around the perimeter of the unit will help facilitate annual burns. Once replacement species are established, it is advisable to only burn the sediment pond basin infrequently (e.g. in a 3 – 4 year rotation). Although annual burns will volatize nitrogen and remove it from the system, they will also mobilize phosphorus which is stored in senescent biomass and litter. Following a burn, residual phosphorus accumulates in ash, which is easily transported to downstream areas of the system (Richard Henderson, WDNR, personal communication).

Remainder of the Project Area **(FOPB Volunteers)**

Assuming a periodic fire regime can be imposed on the site and diverse native propagule banks have been preserved, minimal reseeding will be required within the remainder of the project area, with the possible exception of the *Phalaris-Carex lacustris* vegetation association. Along the western branch of the Pheasant Branch Creek, the *Phalaris-Carex lacustris* association experiences periodic sediment deposition and phosphorus enrichment from flooding, and also propagule pressure from upstream reed canarygrass populations. In the absence of management, this area will continue to be dominated by reed canarygrass, which will expand further into the higher-quality portions of the sedge meadow remnant. FOPB volunteers should collect seeds from established native species already occurring within the sedge meadow remnant and frost-interseed them into any areas denuded by herbicide applications. Native species with high nutrient uptake potential and strong competitive ability, such as *Carex lacustris*, *Carex trichocarpa*, *Scirpus atrovirens*, *Rumex orbiculatus*, and *Silphium perfoliatum*, can be planted near the banks of the western branch of the Pheasant Branch Creek to buffer the remainder of the sedge meadow from phosphorus loading.

General Management Timeline

2012

FOPB volunteers:

January: Obtain AIS funding for the project through WDNR AIS Program (Tom Bernthal).
Late April – early May: Mow reed canarygrass in Frederick Springs area and remove clippings.
Late May – early June: Apply selective herbicide to Canada thistle growing within retention pond basin.
Mid-June: Hand-pull untreated reed canarygrass growing within standing water at Frederick Springs.
Growing season: Scout for and remove watercress from project area.
Growing season: Scout for presence and distribution of purple loosestrife, water lettuce, water hyacinth within the project area.
Autumn: Purchase and/or collect seeds and stratify for growing plugs for the spring 2014 sediment capture pond basin and Frederick Springs plantings.

Integrated Restorations, LLC:

March: Obtain 2012 Aquatic Plant Management (APM) Permit from WDNR.
Late May – early June: Apply herbicide to reed canarygrass in Frederick Springs area.
Late June – early July: Apply herbicide to narrow-leaved and hybrid cattail within the project area.
Late June – early July: Apply herbicide to *Phragmites* clones within the project area.
July: Scout for presence and distribution of additional narrow-leaved and hybrid cattail, *Glyceria maxima*, and *Phragmites* within the project area.
November – December: Begin tree and shrub removal.

2013

U.S. FWS:

April – May: Conduct a prescribed burn of the entire project area (except for Frederick Springs), pending site conditions and local approval.

FOPB volunteers:

Late April – early May: Mow reed canarygrass in Frederick Springs area and remove clippings.
May: Apply selective herbicide to Canada thistle growing within retention pond basin.
Mid-June: Hand-pull untreated reed canarygrass growing within standing water at Frederick Springs.
Autumn: Purchase and/or collect seeds for late autumn 2013 sediment capture pond basin planting.
Autumn: Burn sediment capture pond basin.
Late autumn: Prepare seed bed and plant seeds of forbs and cool-season sedges in the sediment pond basin.
Growing season: Scout for and remove watercress from project area.
Growing season: Scout for presence and distribution of purple loosestrife, water lettuce, water hyacinth within the project area.
All year: Grow plugs for spring 2014 planting within sediment pond basin and Frederick Springs.

Integrated Restorations, LLC:

March: Obtain 2013 Aquatic Plant Management (APM) Permit from WDNR.

April – early June: Apply herbicide to reed canarygrass in sedge meadow remnant portions of the project area.

Late May – early June: Apply herbicide to reed canarygrass in Frederick Springs area.

Early June: Apply herbicide to basin of sediment retention ponds and wet-mesic buffer areas.

Late June – early July: Follow-up chemical treatment of narrow-leaved and hybrid cattail within the project area (if needed).

Late June – early July: Follow-up chemical treatment of *Phragmites* clones within the project area (if needed).

July: Scout for presence and distribution of additional narrow-leaved and hybrid cattail, *Glyceria maxima*, and *Phragmites* within the project area.

August – September: Apply herbicide to basins of sediment retention ponds (if needed).

November – December: Continue with tree and shrub removal.

December: Evaluate progress and adjust management strategy and timeline accordingly.

2014

U.S. FWS:

April – May: Conduct a prescribed burn of the entire project area (except for Frederick Springs), pending site conditions and local approval.

FOPB volunteers:

Late April – early May: Mow reed canarygrass in Frederick Springs area and remove clippings.

May: Apply selective herbicide to Canada thistle growing within retention pond basin.

Mid-May: Plant plugs in sediment capture pond basin and Frederick Springs area. Install browsing exclosures and monitor/water plugs regularly throughout the growing season.

Mid-June: Hand-pull untreated reed canarygrass growing within standing water at Frederick Springs.

Growing season: Scout for and remove watercress from project area.

Growing season: Scout for presence and distribution of purple loosestrife, water lettuce, water hyacinth within the project area.

Autumn: Purchase or collect seeds for the autumn 2014 wet-mesic buffer planting; purchase or collect seeds of warm-season grasses to be used in the spring 2015 sediment pond basin planting.

Autumn: Burn buffer area planting site.

Late autumn: Prepare seed bed and plant seeds of forbs and cool-season sedges in the wet-mesic buffer.

Integrated Restorations, LLC:

March: Obtain 2014 Aquatic Plant Management (APM) Permit from WDNR.

April – early June: Apply herbicide to reed canarygrass in sedge meadow remnant portions of the project area.

Late May – early June: Apply herbicide to reed canarygrass in Frederick Springs area.

April: Apply herbicide to basin of sediment retention pond and wet-mesic buffer areas.

November – December: Conclude tree and shrub removal.

December: Evaluate progress and adjust management strategy and timeline accordingly.

2015

U.S. FWS:

May – June: Conduct a prescribed burn of approximately 2/3 project area, pending site conditions and local approval.

FOPB volunteers:

March: Burn basin of sediment retention ponds.
Early April: Prepare seed bed and plant seeds of warm-season grasses into sediment pond basin.
Late April – early May: Mow reed canarygrass in Frederick Springs area and remove clippings.
Late May – early June: Apply selective herbicide to Canada thistle growing within retention pond basin (if necessary).
Mid-June: Hand-pull untreated reed canarygrass growing within standing water at Frederick Springs.
Growing season: Scout for and remove watercress from project area.
Growing season: Scout for presence and distribution of purple loosestrife, water lettuce, water hyacinth within the project area.

Integrated Restorations, LLC:

March: Obtain 2015 Aquatic Plant Management (APM) Permit from WDNR.
April: Apply herbicide to basin of sediment retention pond and wet-mesic buffer areas.
April – early June: Apply herbicide to reed canarygrass in sedge meadow remnant portions of the project area.
Late May – early June: Apply herbicide to reed canarygrass in Frederick Springs area.
December: Evaluate progress and adjust management strategy and timeline accordingly.

Table 1: Vegetation characteristics within the Pheasant Branch Marsh project area (means +/- 1SD).

Vegetation Association	Litter depth (cm)	Height (cm)	Height-Density (cm)	AIS/m^2	S/m^2
***Phalaris*-dominated**	10.8 (0.9)	169.5 (7.3)	139.6 (12.3)	(*Phalaris*) 402 (74.8)	1.25 (0.5)
Carex-Juncus	4.0 (1.0)	31.3 (5.4)	9.5 (1.1)	(*Phalaris*) 13 (5.8)	13.75 (2.2)
Carex-Spartina	4.8 (0.6)	119.6 (8.8)	48.0 (13.9)	(*Phalaris*) 22 (17.7)	10.5 (3.4)
Carex-Typha-Phragmites	12.8 (2.5)	213.0 (7.5)	203.25 (6.8)	(*Phragmites*) 84.3 (60.8) (*Typha*) 24.0 (6.5)	1.75 (1.0)
Carex trichocarpa-Calamagrostis	13.0 (3.6)	103.1 (10.7)	87.4 (7.9)	(*Phalaris*) 0.5 (2.7)	2.5 (1.3)
Carex stricta-Clamagrostis	2.9 (1.7)	71.3 (12.5)	69.0 (9.1)	(*Phalaris*) 0.8 (1.0)	5.0 (1.8)
Phalaris-Carex lacustris	7.5 (2.0)	49.3* (7.4)	15.38* (9.5)	(*Phalaris*) 220.8 (62.1)	3 (0.8)
Typha-Sagittaria-Caltha	9.8 (0.5)	142.9 (13.9)	33.5 (15.7)	(*Phalaris*)‡	6.25 (2.5)
Eriophorum	4.4 (0.8)	58.3 (9.0)	11.5 (5.1)	(*Phalaris*) 1 (0.8)	9.25 (1.3)
Sediment Pond Basin	9.4 (4.1)	29.9*(3.0)	15.5* (3.5)	(*Phalaris*) 378.8 (139.8)	2.25 (1.3)
Overall Mean	**7.9 (3.7)**	**98.8 (62.0)**	**63.3 (64.4)**	**(*Phalaris*) 129.9 (177.1) (*Phragmites*) 84.3 (60.8) (*Typha*) 24.0 (6.5)**	**5.6 (4.3)**

*Vegetation was lodged at the time of sampling.
‡No AIS were sampled within quadrats, but reed canarygrass was present at low density within this vegetation association.

Table 2: Soil nutrient chemistry estimates for the Pheasant Branch Marsh project area.

Sample Location	GPS location	NH_4-N (mg/kg)	$NO_3 + NO_2$-N (mg/kg)	Total P (mg/kg)	Munsell color
Frederick Springs (vent 2a)	N43°07.271' W89°29.043'	31.1	7.5	900	10YR 4/1
Ditch Fill	N43°07.207' W89°29.273'	24.8	1.1	955	10YR 2/1
Carex stricta-Calamagrostis	N43°07.177' W89°29.284'	6.3	< 0.25	652	10YR 4/2
Phalaris-Carex lacustris	N43°07.068' W89°29.181'	13.5	3.5	1470	7.5YR 4/3
Sediment Pond	N43°07.358' W89°29.328'	2.6	12.7	1730	7.5YR 4/6

Table 3: Water Chemistry estimates for the Pheasant Branch Marsh project area.

Sample Location	GPS location	pH	Alkalinity (mg/L)	Conductivity (µS/cm)	NH3-N (mg/L)	$NO_3 + NO_2$-N (mg/L)	TDS (mg/L)	Salinity (mg/L)
Frederick Springs (vent 2a)	N43°07.271' W89°29.043'	7.42	307	839	< 0.015	17.50	496	370
Pond near north spring vent	N43°07.214' W89°29.299'	7.64	310	807	< 0.015	7.70	472	386
Pheasant Branch Creek – 1	N43°07.068' W89°29.184'	7.83	315	791	0.025	6.09	452	382
Pheasant Branch Creek – 2	N43°07.177' W89°29.294'	7.73	310	808	< 0.015	7.64	460	380
Sediment Pond	N43°07.366' W89°29.326'	7.66	221	571	2.52	< 0.019	418	282

Table 4: Recommended species for revegetation of the Frederick Springs basin.

Botanical Name	Common Name
Sedges and rushes	
Carex crinita	Fringed Sedge
Carex sartwellii	Running Marsh Sedge
Carex scoparia	Nodding Sedge
Carex stipata	Common Fox Sedge
Carex tuckermanii	Bladder Sedge
Carex sterilis	Fen Star Sedge
Carex stricta	Tussock Sedge
Juncus dudleyi	Dudley's Rush
Forbs	
Asclepias incarnata	Swamp Milkweed
Aster simplex	Panicled Aster
Aster umbellatus	Flat-Topped Aster
Caltha palustris	Marsh Marigold
Chelone glabra	Turtlehead
Eupatorium perfoliatum	Perfoliate Boneset
Gentiana crinita	Fringed Gentian
Gentiana andrewsii	Bottle-Brush Gentian
Iris virginica shrevei	Blue Flag Iris
Lycopus americanus	Water Horehound
Mentha arvensis	Water Mint
Pedicularis lanceolata	Marsh Betony
Solidago ohiensis	Ohio Goldenrod
Solidago riddellii	Riddell's Goldenrod

Table 5: Recommended species planting list for revegetation of the sediment pond basin.

Botanical Name	Common Name	Abundance Category	Comment(s):
Carex trichocarpa	Hairy-Fruited Sedge	**Matrix**	Rhizomatous; competitive
Panicum virgatum	Switch Grass	**Matrix**	High nutrient uptake
Scirpus atrovirens	Green Bulrush	**Matrix**	Adapts well to degraded conditions
Silphium perfoliatum	Cup Plant	**Matrix**	Competitive; avian habitat element
Eupatorium maculatum	Spotted Joe-Pye	**Matrix**	Competitive; prolific seeder
Carex vulpinoidea	Brown Fox Sedge	**Subdominant**	Prolific seed producer
Scirpus fluviatilis	River Bulrush	**Subdominant**	Competitive; high nutrient uptake; pond and stream margins
Asclepias incarnata	Swamp Milkweed	**Subdominant**	Butterfly plant; High nutrient uptake
Aster novae-anglae	New England Aster	**Subdominant**	Competitive
Bidens cernuus	Nodding Bur Marigold	**Subdominant**	Annual; cover crop
Bidens frondosa	Beggar's Ticks	**Subdominant**	Annual; cover crop
Helenium autumnale	Sneezeweed	**Subdominant**	Competitive
Helianthus laetiflorus	Showy Sunflower	**Subdominant**	Rhizomatous; competitive
Mimulus ringens	Monkeyflower	**Subdominant**	High nutrient uptake
Polygonum amphibium	Water Smartweed	**Subdominant**	Variable growth form, high nutrient uptake; waterfowl food
Scirpus cyperinus	Woolgrass	**Common**	High nutrient uptake
Carex stricta	Tussock Sedge	**Common**	Responds well to nitrogen
Asclepias syriaca	Common Milkweed	**Common**	Butterfly plant; high nutrient uptake
Aster punecius	Red-Stemmed Aster	**Common**	Adapts well to degraded conditions
Eupatorium perfoliatum	Perfoliate Boneset	**Common**	
Mondarda fistulosa	Wild Bergamont	**Common**	Self-seeder
Pycnanthemum virgin-ianum	Mountain Mint	**Common**	
Ratibida pinnata	Yellow Coneflower	**Common**	
Rudbeckia laciniata	Golden Glow	**Common**	Adapts well to degraded conditions
Rumex orbiculatus	Great Water Dock	**Common**	High competitive effect on RCG
Sagittaria latifolia	Arrowhead	**Common**	Pond Margins; waterfowl food
Solidago graminifolia	Grass-Leaved Goldenrod	**Common**	Rhizomatous
Solidago rigida	Rigid Goldenrod	**Common**	Adapts well to degraded conditions
Verbena hastata	Blue Vervain	**Common**	Establishes well

Botanical Name	Common Name	Abundance Category	Comment(s):
Veronia fasciculata	Ironweed	**Common**	High nutrient uptake
Eleocharis obtusa	Large Spike Rush	**Rarefraction**	High nutrient uptake
Scirpus pungens	Three-Square Rush	**Rarefraction**	Rhizomatous; high nutrient uptake
Scirpus validus	Soft-Stemmed Bulrush	**Rarefraction**	High nutrient uptake, pond margins
Alisma subcordatum	Water Plantain	**Rarefraction**	Pond margins
Aster pilosus	Frost Aster	**Rarefraction**	Tolerates disturbance
Aster simplex	Panicled Aster	**Rarefraction**	
Bidens connata	Purple-Stemmed Tickseed	**Rarefraction**	Annual; high nutrient uptake
Cacalia suavolens	Sweet Indian Plantain	**Rarefraction**	
Chelone glabra	Turtlehead	**Rarefraction**	
Hypericum pyramidatum	Great St. John's Wort	**Rarefraction**	Competitive
Iris virginica shrevei	Blue Flag Iris	**Rarefraction**	Pond margins
Lobelia siphilitica	Great Blue Lobelia	**Rarefraction**	
Oenothera biennis	Evening Primrose	**Rarefraction**	Tolerates disturbance; attracts moths
Rudbeckia hirta	Black-Eyed Susan	**Rarefraction**	Self-seeder
Rudbeckia subtomentosa	Sweet Blk-Eyed Susan	**Rarefraction**	
Rudbeckia triloba	Branching Blk-Eyed S.	**Rarefraction**	
Sparganium eurycarpum	Common Bur Reed	**Rarefraction**	Pond margins
Silphium integrifolium	Rosinweed	**Rarefraction**	Avian food source
Thalictrum dasycarpum	Tall Meadowrue	**Rarefraction**	Tolerates disturbance
Zizia aurea	Golden Alexander	**Rarefraction**	Responds well to nitrogen

References

Annen, C.A. (In preparation). When to spray? A literature review of timing windows for reed canarygrass (*Phalaris arundinacea* L.) control.

Annen, C.A. (2011). Manipulating internal system feedbacks to accelerate reed canarygrass (*Phalaris arundinacea*) control: From theory to practice. **Ecological Restoration** 29: 222-224.

Annen, C.A. (2010). Prospects for disrupting rhizome apical dominance prior to chemical treatment of *Phalaris arundinacea*. **Ecological Restoration** 28: 291-299.

Annen, C.A., R.W. Tyser, and E.M. Kirsch. (2008). Reed canarygrass invasions alter succession patterns and may reduce habitat quality in wet meadows. **Ecological Restoration** 26: 190-193.

Annen, C.A. (2006). Using sethoxydim to control reed canarygrass: Effects of additives and field conditions. **Ecological Restoration** 24:53.

Begg, J.E. and M.J. Wright. (1962). Growth and development of leaves from intercalary meristems of *Phalaris arundinacea* L. **Nature** 194: 1097-1098.

Boers, A.J. and J.B. Zedler. (2008). Stabilized water levels and *Typha* invasiveness. **Wetlands** 28: 676-685.

Budyak, A.J., C.A. Annen, and D. G. Cordray. (In progress). Effects of imazapyr on *Typha angustifolia* and *T.* x *glauca* in southern Wisconsin sedge meadow remnants.

Auclair, A.N.D., A. Bouchard, and J. Pajaczkowski. (1976). Productivity relations in a *Carex*-dominated ecosystem. **Oecologia** 26: 9-31.

Casler, M.D., D.C. West, and D.J. Undersander. (1999). Establishment of temperate pasture species into alfalfa by frost-seeding. **Agronomy Journal** 91: 916-921.

Casler, M.D. and D.J. Undersander. (2006). Selection for establishment capacity in reed canarygrass. **Crop Science** 46: 1277-1285.

Collins, S.A. and D.W. Allinson. (1995). Growth rate of herbage initially dominated by reed canarygrass or tall fescue. **Journal of Production Agriculture** 8: 227-232.

Comes, R.D., V.F. Burns, and A.D. Kelley. (1978). Longevity of certain weed and crop seeds in fresh water. **Weed Science** 26: 336-344.

Coops, H. and G. van der Velde. (1995). Seed dispersal, germination and seedling growth of six helophyte species in relation to water-level zonation. **Freshwater Biology** 34: 13-20.

Crow, G.E. and C. Barre Hellquist. (2000). *Aquatic and Wetland Plants of Northeastern North America.* University of Wisconsin Press.

Curtis, J.T. (1959). *The Vegetation of Wisconsin.* University of Wisconsin Press.

Eggers, S.D. and D. M. Reed. (1997). *Wetland Plants and Plant Communities of Minnesota and Wisconsin.* U.S. Army Corps of Engineers.

Epstein, E. (1973). Flow in the phloem and immobility of calcium and boron: A new hypothesis in support of an old one. **Experimentia** 29: 133-134.

Flora of North America Committee. (2007). *Flora of North America, Volume 24 Magnoliophyta: Commelinidae (in part): Poaceae, part 1.* Oxford University Press.

Fraser, L.H. and T.E. Miletti. (2008). Effect of minor water depth treatments on competitive effect and response of eight wetland plants. **Plant Ecology** 195: 33-41.

Galatowitsch, S.M., N.O. Anderson, and P.D. Ascher. (1999). Invasiveness in wetland plants in temperate North America. **Wetlands** 19: 733-755.

Gaudet, C.L. and P.A. Keddy. (1995). Competitive performance and species distribution in shoreline plant communities: A comparative approach. **Ecology** 76: 280-291.

Gleason, H.A. and A. Cronquist. (1991). *Manual of Vascular Plants of Northeastern United States and Adjacent Canada.* New York Botanical Garden.

Hautier, Y., P.A. Niklaus, and A. Hector. (2009). Competition for light causes plant biodiversity loss after eutrophication. **Science** 324: 636-638.

Heide, O.M. (1994). Control of flowering and reproduction in temperate grasses. **New Phytologist** 128: 347-362.

Huddleston, R.T. and T.P. Young. (2004). Spacing and competition between planted grass plugs and preexisting perennial grasses in a restoration site in Oregon. **Restoration Ecology** 12: 546-551.

Hunt, R.J. and J.J. Steuer. (2000). Simulation of the Recharge Area for Frederick Springs, Dane County, Wisconsin. U.S. Geological Survey Water-Resources Investigations Report 00-4172.

Keddy, P.A. (2002). *Wetland Ecology: Principles and Conservation.* Cambridge University Press.

Kellogg, C.H. and S.D. Bridgham. (2002). Colonization during early succession of restored freshwater marshes. **Canadian Journal of Botany** 80: 176-185.

Klopatek, J.M. and F.W. Stearns. (1978). Primary productivity of emergent macrophytes in a Wisconsin freshwater marsh system. **The American Midland Naturalist** 100: 320-332.

Krebs, C.J. (1994). *Ecology: The Experimental Analysis of Distribution and Abundance.* Harper-Collins.

Larcher, W. (1995). *Physiological Plant Ecology*. Springer-Verlag.

Lavergne, S. and J. Molofsky. (2004). Reed Canary Grass (*Phalaris arundinacea*) as a biological model in the study of plant invasions. **Critical Reviews in Plant Sciences** 23: 415-429.

Lindig-Cisneros, R. and J.B. Zedler. (2001). Effect of light on seed germination in *Phalaris arundinacea* L. (reed canarygrass). **Plant Ecology** 155: 75-78.

Lindig-Cisneros, R. and J.B. Zedler. (2002). *Phalaris arundinacea* seedling establishment: Effects of canopy complexity in fen, mesocosm, and restoration experiments. **Canadian Journal of Botany** 80: 617-624.

Maeda, Y., S. Hirano, M. Yoshiba, and T. Tadano. (2006). Variations in salt tolerance of reed canarygrass (*Phalaris arundinacea* L.) plants grown at sites with different degrees of cattle urine contamination. **Soil Science and Plant Nutrition** 52: 13-20.

Matysiak, R. and J.D. Nalewaja. (1999). Temperature, adjuvants, and UV light affect sethoxydim phytotoxicity. **Weed Technology** 13: 94-99.

Maurer, D.A. and J.B. Zedler. (2002). Differential invasion of a wetland grass explained by tests of nutrients and light availability on establishment and clonal growth. **Oecologia** 131: 279-288.

Maurer, D.A., R. Lindig-Cisneros, K.T. Werner, S. Kercher, R. Miller, and J.B. Zedler. (2003). The replacement of wetland vegetation by reed canarygrass (*Phalaris arundinacea* L.). **Ecological Restoration** 21: 116-119.

Mittra, M.K. and M.J. Wright. (1966). Intra-plant relationships in reed canarygrass. **Crop Science** 6: 393-395.

Mossman, M.J. and D.W. Sample. (1990). Birds of Wisconsin sedge meadows. **The Passenger Pigeon** 52: 39-55.

Morrison, J.A. (2002). Wetland vegetation before and after experimental purple loosestrife removal. **Wetlands** 22: 159-169.

Odland, A. and R. del Moral. (2002). Thirteen years of wetland vegetation succession following a permanent drawdown, Myrkdalen Lake, Norway. **Plant Ecology** 162: 185-198.

Prasser, N. and J.B. Zedler. (2010). Salt tolerance of invasive *Phalaris arundinacea* exceeds that of native *Carex stricta*. **Ecological Restoration** 28: 238-240.

Rachich, J. and R.J. Reader. (1999). An experimental study of wetland invasibility by purple loosestrife (*Lythrum salicaria*). **Canadian Journal of Botany** 77: 1499-1503.

Reinhardt-Adams, C. and S. Galatowitsch. (2006). Increasing the effectiveness of reed canary grass (*Phalaris arundinacea* L.) control in wet meadow restorations. **Restoration Ecology** 14: 440-450.

Schmieder, K., M. Dienst, and W. Ostendorp. (2002). Auswirkungen des Extremhochwassers 1999 auf die Flächendynamik und Bestandsstruktur der Uferröhrichte des Bodensees. **Limnologica** 32: 131-146.

Stiles, C.A., B. Bemis, and J.B. Zedler. (2008). Evaluating edaphic conditions favoring reed canary grass invasions in a restored native prairie. **Ecological Restoration** 26: 61-70.

Struve, I., B. Golle, and U. Luttage. (1987). Sethoxydim uptake by leaf slices of sethoxydim-resistant and sensitive grasses. **Zeitschrift für Naturforschung** 42: 279-282.

Stüfer, J.F., B. Erschbamer, H. Huber, and J.I. Suzuki. (2002). *Ecology and Evolutionary Biology of Clonal Plants*. Kluwer Academic Publishers.

Suding, K.N., K.L. Gross, and G.R. Houseman. (2004). Alternative states and positive feedbacks in restoration ecology. **Trends in Ecology and Evolution** 19: 46-53.

Sugihara, G. (1980). Minimal community structure: An explanation of species abundance patterns. **American Naturalist** 116: 770-787.

van den Brink, F.W.B., G. van der Velde, W.W. Bosman, and H. Coops. (1995). Effects of substrate parameters on growth responses of eight helophyte species in relation to flooding. **Aquatic Botany** 50: 79-97.

Weed Science Society of America. (1994). *Herbicide Handbook of the Weed Science Society of America, 7th edition.* WSSA.

Wisconsin Reed Canary Grass Management Working Group. (2009). Reed Canary Grass (*Phalaris arundinacea*) Management Guide: Recommendations for Landowners and Restoration Professionals. WDNR PUB-FR-428 2009.

Zedler, J.B. and K. Potter. (2008). Southern Wisconsin's Herbaceous Wetlands: Their Recent History and Precarious Fragility. Pages 193-210 in *The Vanishing Present*, edited by D. Waller and T. Rooney. University of Chicago Press.

Zmirek, M. and S. Gawronski. (2009). Survey of plant species present on constructed wetlands in Opalencia Municipality. **Annals of Warsaw University of Life Sciences** 41: 143-152.