Principles of Wetland Creation and Restoration: Reflections

Part 1: Introduction and Case Study #1 - Wyandot Project

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Through working for over 40 years as an applied wetland scientist on various projects for the U.S. Department of Agriculture, U.S. Army Corps of Engineers, U.S. Air Force, and for the private sector, I have learned much about wetland construction and restoration and wish to share some of my experiences with others through a series of articles in *Wetland Science & Practice*. This is the first of the series which addresses basic elements of planning and design and presents the first of five case studies of wetland construction projects. The series highlights key aspects of project planning and uses the case studies to show real world results. It is not intended to be a how-to treatise but hopefully provides readers with perspective on the challenges involved in this practice.

EARLY WETLAND CREATION AND RESTORATION PROJECTS

Wetland science has evolved during my career that began in the 1970s. Early efforts to create wetlands focused on impoundment and pond construction for agricultural purposes or waterfowl habitat as exemplified by the USDA's Water Bank Program and by the US Fish and Wildlife Service and state wildlife agencies. These projects involved diking of coastal and inland wetlands to create impoundments or building ponds and potholes through various means. In the late 1970s and early 1980s, I planned, designed and installed a number of projects that intentionally created "wetland components" in backwater and littoral fringe areas of man-made ponds with intent to function as transitional habitat for waterfowl, amphibians, fish, songbirds, and game and non-game mammals. Around 1988, I was asked to design and construct a replacement wetland to compensate for wetland impacts occurring on a project site in central Pennsylvania. Given my training and work on soil surveys, I first looked at soil surveys and chose a suitable place on the landscape that would likely receive sufficient hydrology to sustain the wetland. The target wetland type would be a very shallow USDA pond dominated by emergent vegetation. This was the common wetland creation approach by USDA and was also promoted by Donald A. Hammer in his 1992 publication - *Creating Freshwater Wetlands* (Hammer 1992, 1996).

FROM WATERFOWL IMPOUNDMENTS AND FARM PONDS TO VEGETATED WETLANDS

As wetland regulations expanded across the country[2] and mitigation to compensate for permitted losses became standard practice, "wetlands" became a focus for research and a recognized science and field of study for college students. Wetland mitigation has included wetland restoration, enhancement, and creation as well as monetary compensation and strengthening protection of existing wetlands through acquisition or perpetual easements. See *Compensating for Wetland Losses under the Clean Water Act* (Zedler et al. 2001) for details.

For mitigation, creation of in-kind wetlands (e.g., loss of forested wetland with a created forested wetland) began to receive more attention than creating a waterfowl or farm pond – a permanent or nearly permanent water body. This type of wetland creation required more analysis than simply excavating to a depth below the existing water table at a site or holding back water through in-stream impoundments, or impounding existing wetlands. For these new initiatives, knowledge of the temporal fluctuations of water levels and water tables and vegetative responses to such dynamics became essential in designing wetland creation and restoration projects.

THE IMPORTANCE OF HYDROGRAPHS

In the early 1990s, after numerous discussions with other wetland restoration/creation practitioners, I learned how to calculate and prepare site hydrographs from which the depth, duration, and timing of water pulses into and through a site could be predicted before a wetland was built. A "hydrograph" is a graphic representation of the current hydroperiod of a wetland, or the potential hydroperiod that might be achieved for a candidate site (see Chapter 2 in Tiner 2015 for examples for the diversity of wetlands found across the U.S.). Hydrographs are generally prepared to show variations of water volume available monthly and volumes that are likely to be retained or held within the wetland each month after losses due to evapotranspiration, infiltration, and outflow of surplus water are accounted

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[2] Wetland regulations played a major role in advancing wetland science especially in the areas of wetland identification and mitigation through research at the U.S. Army Corps of Engineers Waterways Experiment Station or funded by the Corps.

for. The typical hydrograph generated for wetland creation projects covers a 12-month temporal span, usually on a calendar year basis. However, the temporal span may be compressed or expanded depending on the needs of the individual application, perhaps covering just the typical growing season months, or expanding the temporal span to cover preceding and following years. The effect of calculating monthly volumes is to tamp down the "noise and scatter" that is often associated with attempting to plot individual storm events (that cannot be predicted with absolute accuracy for future years), or the effect of intense consecutive daily temperature anomalies that can skew attempts to quantify evapotranspiration losses. The resulting hydrograph generated in this assessment process allows a designer to see general trends that tend to repeat over successive years with similar patterns of precipitation and temperature variations. This allows the designer to anticipate site hydrology and devise means to mimic the conditions of the desired wetland type.

For comparison, "naturally occurring" wetlands in the locale serve as "reference sites" (Brinson 1996). The morphology, vegetation, resident and migratory animals, and functions of these reference sites are then assessed to assist in the physical design of the constructed or restored wetlands.

By the mid- to late 1990s, this approach for evaluating all candidate project sites for wetland construction and/or restoration was standard practice. This protocol involved preliminary data collection and assessment in order to address a series of fundamental questions. If this first step proved to be encouraging, a more rigorous investigation of a potential project site would follow.

BASIC QUESTIONS FOR SITE SELECTION

The preliminary questions that needed to be answered in evaluating potential sites for wetland creation or restoration often include the following:

- Is this site in an appropriate landscape position to persist as a wetland?
- Where is the water that will drive the proposed wetland coming from (e.g., groundwater, runoff, direct precipitation, or recurring flooding events)?
- How much water (volume) can be expected at this site? How will we deal with surpluses?
- When will the water arrive (e.g., seasonal timing vs. storm event driven pulses)?
- How long will the water persist after the wetland is fully "charged"?
- What range of water depths will be needed to promote the desired suites of vegetation (species zonation) and thereby the wetland appearance and functions? Can the depths be adjusted through grading, elevation changes, simple outlet/inlet weir placement, or not?
- How will water depths and persistence affect vegetation zonation and diversity? Can we predict the appearance (i.e., form, vegetation cover types, and species composition) of the wetland over time?
- What functions do we want the wetland to perform in 10 years, in 50 years?
- What are the soil properties within the project area (e.g., textures, coarse fragment content, relative homogeneity, aquitards, and hydraulic conductivity)? Can the soils be managed to accommodate the proposed use?
- Are surrounding land uses compatible with or potentially beneficial to the project area? Are surrounding land uses detrimental?
- Are there any encumbrances to the potential conversion to wetlands (e.g., public perceptions, potential hazards, existing covenants, deed restrictions, easements, and agreements)?

After considering these questions, a particular site would only be pursued further if the answers proved to support the potential for the site to be converted to functioning wetlands. Ancillary functional assessment techniques might also be applied as needed (e.g., WET II [Adamus et al. 1987], ORAM [Mack 2001], and HGM [Smith et al. 1995]).

LEARNING FROM EXISTING PROJECTS

Concurrent observation of wetlands constructed by others in several early permitting scenarios circa 1983-1990, revealed that projects could "fail to thrive", or might be much less functional with excess water just as easily as they might fail without adequate hydrology (e.g., Brown and Veneman 1988; McCoy, R.W. 1992). Even the best of planting schemes, strategies for soil amendment, and post-planting irrigation efforts could not be expected to overcome an inappropriate site hydrograph (hydroperiod). By studying and then calculating the hydrographs of natural local wetlands, a preferred hydrograph for the design area could then be prepared and presented. Once sites were deemed suitable for construction or restoration, other factors could be considered such as water chemistry (including salinity), nutrient loading, climate, solar aspect, surrounding land uses, potential for disturbance and herbivory, and the origin and nature of the wetland substrate soils. This hypothesis and documented results from multiple wetland construction projects continued to be reviewed and evaluated through continuing professional education courses, white papers, symposia, meetings, and in contracted work and writings for the U.S. Army Waterways Experiment Station. As a result, much of this information remained well out of the academic mainstream for several years after it was first applied and modified on various project sites.

Application of these fundamental approaches to planning, site selection, design/grading, construction, planting, and continued monitoring led progressively over the last four decades to much more predictable on-the-ground results and ever-increasing confidence that viable and functional wetland creation and restoration projects are entirely achievable. Despite published assertions to the contrary, several projects had already demonstrated that we have the tools and knowledge to design and predict initial outcomes on constructed wetland sites, and we can do much better than creation of manmade ponds. With resolve to share and apply available knowledge and acquired skills through seminars, professional education courses, expanded research, and careful documentation we can continue to improve and have greater confidence in our ability to achieve predictable outcomes.

WETLANDS ARE DYNAMIC ECOSYSTEMS

On occasion, an element that is overlooked by designers and the agencies charged to oversee wetland creation and restoration projects is an acknowledgement that wetlands, natural and created, are dynamic systems, and they will change over time in response to changing environmental conditions. Relatively minor or catastrophic events such as drought, disease, flooding, herbivory, infestations, landslides, fire, violent storms, petroleum or chemical spills, volcanic eruptions, adjacent land use changes (mainly urban development, road construction, land clearing, and installation of dams/dikes/levees), will generate both functional and long-term change in wetland systems. Although we may be able to predict with some degree of confidence the outcome of created or restored sites after 5 or 10 years of proactive monitoring (and often, with maintenance adjustments as necessary), we must recognize that successional development, competition, and adaptation will remain the processes by which all dynamic natural systems manage to persist and continue to function in the landscape. We cannot, therefore, figuratively expect to preserve wetland systems (natural or created) as though they might be "coated with urethane and be fixed in the landscape" forever. Rather, as living and truly functional systems, wetlands are not static. As practitioners and scientists, we must expect these unique resources to adapt and potentially to change their form and functions over time as wetland "causal factors" change (Keddy 2017). In light of predictions of climate change and recent disturbances such as massive flooding, drought, wildfires, mudslides, and melting of polar ice, we will certainly be in a position to observe, study, attempt remediation, and to document recovery and resilience or, perhaps sadly, the lack thereof on a grand scale.

In this forum, there is not sufficient opportunity to explain fully the maturation of concepts related to the importance of soils as a medium for rooting and growth of hydrophytes in constructed wetlands, nor the subtleties of carbon/nitrogen ratio, phosphorous release in newly anaerobic soil environments, carbon sequestration as a function of newly created wetland systems, the roles and importance of planting, seeding, and symbiotic soil microorganisms. Nor will I detail issues and lessons learned regarding organic amendments to wetland substrates, use of upland "topsoils" vs. borrowed "hydric" soils, expand on the techniques applied to generate site hydrographs, discuss construction nuances in great detail, or the need to design most created wetlands to be entirely "self-sustaining" (without complex water-control structures or typical dam/dike/levee structures). Rather, at the end of this series I will offer recommendations based on what I've learned.

CASE STUDIES

Five freshwater case study sites that have been followed during the course of the last four decades will be offered as documentation of the apparent effectiveness of the protocols espoused above. Hydrology sources for the case study sites vary and include overbank flooding, direct precipitation, surface water runoff, and ground water. The nuances of how the hydrographs were analyzed and balanced at each site to generate target vegetation zonation are not discussed in detail, but the preliminary site assessment questions presented above that were critical to siting, design, and construction of each project will be addressed. A set of images illustrate key aspects of the project with discussion points addressed in the captions.

CASE STUDY 1. FLOODPLAIN WETLAND RESTORATION, LITTLE TYMOCHTEE CREEK, WYANDOT COUNTY, OHIO - 1993

Location: Crawford, Wyandot County, Ohio (Figure 1).

Introduction: This site was proposed and constructed as mitigation for wetland impacts to relatively small and scattered emergent and scrub-shrub wetland inclusions occurring within farmed fields, along hedgerows, and ponded areas adjacent to existing borrow operations that would be removed as part of ongoing borrow excavation operations for a nearby residual waste landfill. Because the total wetland impact acreage was limited to under one acre, this action was permitted as a "Nationwide 26" permit action. Despite the impact areas being mostly in "upper-terrace" somewhat disturbed landscape positions (that drained down-gradient and into the adjoining floodplain and riparian corridor of Little Tymochtee Creek), a floodplain "lower-terrace" replacement site was ultimately chosen on the opposite side of the creek from landfill operations. The permittee and the oversight regulatory agencies reached agreement that replacement functions would have significant benefit if provided within and along this same riparian corridor that abuts the landfill operations. As a result, the site chosen was considered acceptable due to its proximity to the impact wetlands and its potential to provide significant functional replacement within the same watershed (Little Tymochtee Creek, Wyandot County, Ohio).

Project Sponsors: County Environmental of Wyandot, owned at the time by Envirite Corporation of Canton, Ohio.

Project Objectives: Primary objectives of this project were to restore a floodplain wetland by creating an emergent and scrub/shrub bottomland wetland approximately 4.0-acres in size[3] within the floodplain/floodway of Little Tymochtee Creek (Figure 1). These objectives were to be accomplished through "restoration" of a drained and actively farmed floodplain field and creation of deeper water refugium areas (less than 1.0-meter-deep at maximum water depth) within the wetland footprint to mimic sloughs and isolated (oxbow) stream meanders.

Planning and Design: Initial remote sensing and field surveys completed for candidate replacement sites in the locale intentionally targeted actively farmed fields with poorly drained and/or very poorly drained soils, often referred to as *prior converted cropland*.[4] In this case, areas with poorly drained Sloan silt loam soils became the focus. It is likely that the site chosen had been a forested wetland in the distant past. The project site was situated within the floodplain and riparian corridor of Little Tymochtee Creek on the opposite side of the creek from the landfill operations (Figure 2).

To emulate and improve upon some of the habitat features associated with the impacted wetlands, it was

FIGURE 1. Site of wetland restoration site in Crawford, Ohio (Wyandot County).

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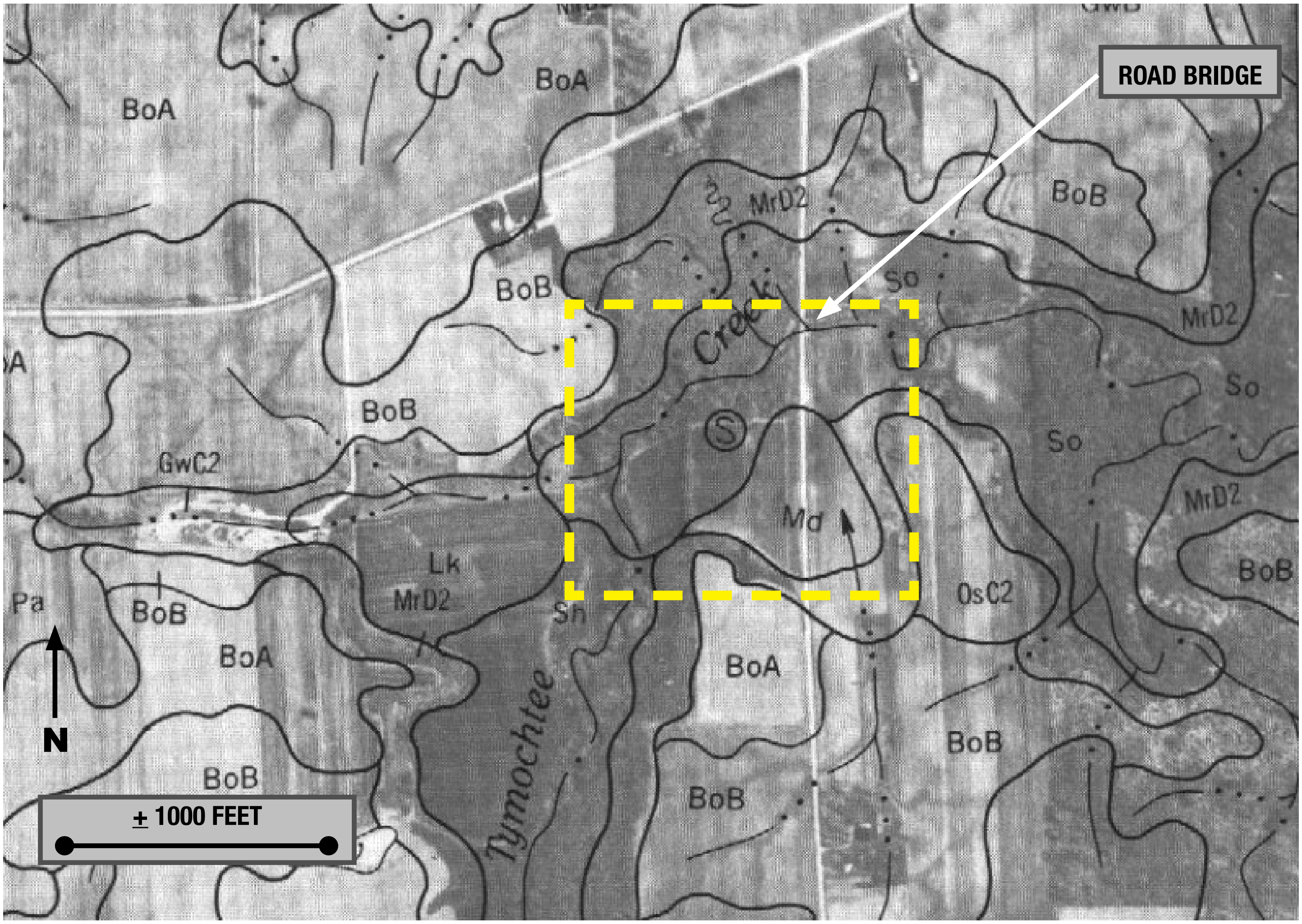
[3] The restored wetland ultimately exceeding 5-acres in size when constructed.

[4] At the time of this project and still being referenced today, "prior converted cropland" is defined, by the USDA Soil Conservation Service (in Section 512.15 of the National Food Security Act Manual, August 1988), as wetlands which were both manipulated (drained or otherwise physically altered to remove excess water from the land) and cropped before December 23, 1985, to the extent that they no longer exhibited important wetland values. Specifically, prior converted cropland can be inundated for no more than 14 consecutive days during the growing season. Prior converted cropland generally does not include pothole or playa wetlands. In addition, wetlands that are seasonally flooded or ponded for 15 or more consecutive days during the growing season are not considered prior converted cropland.

the design team's intent to convert the farmed candidate site to emergent and scrub-shrub vegetation cover types within a slough-like depression that would also include forested components over time. During site selection, nearby reference wetlands were largely lacking for this model because similar areas had also been cleared, graded, drained, and farmed. When examining historic Google™ Earth images of the general area, remnant "signatures" of old cut-off meanders and oxbows in actively farmed fields and in disjunct areas surrounded by stands of trees could be seen. Based on the poorly drained soils depicted in USDA NRCS National Cooperative Soil Survey mapping, the design team expected that the candidate site would have soils acceptable for restoration. This was confirmed with an initial site visit which noticed that the field had been tile drained. Further investigation with backhoe excavations revealed clay/clay loam soil horizon(s) at a depth of about 30 inches. This layer was several inches thick, was firm in place, and nearly massive in structure. Consequently, potential for excess hydrology losses from vertical infiltration were considered to be unlikely. Further examination of the upper soil horizons showed redox features starting at shallow depths, suggesting that prior to drainage, a high water-table occurred within inches of the soil surface and likely persisted for very long duration in most years (i.e., a mollic epipedon meeting contemporary F6 and/or A12 hydric soil indicators). These data reinforced the assumption that the deeper clay layers were in fact functioning as an aquitard to perch groundwater in the upper horizons (especially when evapotranspiration losses are minimal). Furthermore, saturation and a "free" water table were noted to essentially disappear by mid-summer in nearby forested sites with similar soils. Because the water table appeared to be perched rather than connected to a regional "true"

FIGURE 2. USDA Soils Mapping circa 1980 provides the local hydrogeomorphic setting of the candidate restoration site. This mapping was used to initially screen the area for candidate sites with good potential to be either restored or converted to functioning wetlands. The scale provided is approximate. The "circled S" symbol indicates the location of the "typical pedon/profile" description for the Sloan soil series (So) recorded for the Wyandot County, Ohio National Cooperative Soil Survey (Steiger and Hendershot 1982). This symbol also marks the approximate northern limit of the constructed wetland.



water table, it was judged to be a bit too nebulous/transient to exploit as a quantifiable input from ground water in the planning process. While the 1982 Soil Survey had described the water table in Sloan soils as being "apparent," they also noted its absence later in the growing season. It was also noted that the nearby stream channel of Little Tymochtee Creek was deeply incised with base flows perhaps 8-feet below the adjacent fields. Collectively, these observations and data suggested that readily available water perched above the clay loam horizon(s) would simply be depleted by evapotranspiration (ET) in most years, especially in the forested parts of the riparian corridor. Once the free water was depleted from the upper horizons, only the confined deeper water table (below the clay substratum) would be evident in the underlying alluvium. So, doing a simple analysis of the typical precipitation distribution affecting runoff and direct precipitation landing on the site itself as inputs, minus ET losses, and assuming that infiltration losses would be limited due to the spring "perched" water table above the deeper clay/clay loam horizon(s), a simplified water budget was sketched out. A rudimentary water budget was also prepared for a somewhat disturbed forested "reference site" about a mile downstream, but this site was not an especially good model for what the design team was inclined to accomplish on the candidate site, so it was mostly discounted and not expected to be "mirrored" per se. Nevertheless, preparing the candidate site hydrograph showed that the project site would be sufficiently wet in most years to meet the Corps' minimum wetland hydrology requirements even without anticipated overbank flooding. Also, as noted above, the project site had been extensively tile-drained, and it was thought that the springtime and early-summer water table could be raised again to within several inches of the soil surface simply by removing the tile drains. Looking at water inputs minus losses (primarily losses from Thornthwaite ET calculations), the reference site and project site appeared to be very similar. It was also noted, however, that the more mature trees in the "forested reference" area would be even more aggressive in pulling water out via ET and therefore more efficient in lowering the early growing season perched water table. Considering these variables, the project also included plans to create a depressional basin that would hold early growing season hydrology and then experience drawdown in most years as ET losses would accelerate with increasing daily temperatures. The "basin" floor was designed with flat to gently sloping edges around the outer limits of the footprint with deeper linear refugium depressions (mimicking "meander scars") and higher linear mounded "raised bed" inclusions fashioned parallel to the deeper depressions (to mimic "remnant stream bank natural levees") within the wetland floor. A simple stone-lined inlet and outlet channel was placed to allow expected floodwaters to back into the site and then flow out as floodwaters recede. Vegetation zonation was expected to develop based on graded contour elevations and anticipated persistence of inundation and saturation. A softened shrub-dominated transition zone was projected to develop along the fringes of the site and on interior raised beds. Parts of the scrub-shrub cover types were expected to eventually support larger bottomland hardwood trees as were other minimally and seasonally inundated areas within the wetland footprint. A significant percentage of the deeper water emergent area and refugium depressions within the wetland floor was expected to resist colonization by tree species due to persistent shallow inundation. Originally, this site was also intended to provide an opportunity to observe and document the successional development of plant community zonation where the site was intentionally allowed to re-vegetate from natural "seed rain" imported with flooding events. Only a few modest plantings of buttonbush (*Cephalanthus occidentalis*) as cuttings were introduced to the site in the first growing season following grading and application of an erosion control seeding of annual ryegrass and oats. Targeted wildlife use emphasized wading birds, amphibians, local and migratory songbirds, and waterfowl.

Site Hydrology: Hydrology sources acknowledged in hydrograph preparation for the candidate site were direct precipitation and runoff from an 11-acre localized drainage area. A HEC-RAS[5] analysis was done for the project area and upstream watershed. The original HEC-RAS calculations were completed by a consulting engineering firm from Toledo, Ohio. Although the HEC-RAS calculations suggested occasional overbank flooding from the adjacent creek, preliminary results suggested that a single significant 24-hour storm event between a 2-year and 5-year frequency probability (approximately a 2.5-inch storm event) could be expected to generate backwater flooding from the bridge just to the north of this site. However, because these events could not necessarily be anticipated to occur annually, this source was not used in the initial assessment of site hydrology. Also, no groundwater contribution was anticipated or factored into the development of the site hydrograph calculations. As noted above, water losses through infil-

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[5] HEC-RAS is a software package developed by the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center headquartered in Davis, California. The acronym is short for Hydrologic Engineering Center – River Analysis System. Calculations allow users to predict flooding events and high-water elevations that might be expected in floodplain and floodway landscape settings for different storm events. At the time this project was being planned, use of the HEC-RAS calculations often required multiple cross-sections of watershed floodplains to be physically surveyed in order to project water runoff volumes onto the floodplain cross-sectional areas. HEC-RAS has been used to prepare FEMA Flood Hazard Boundary Maps.

tration were projected as being negligible early in the growing season but perhaps increasing as the water table is depleted and drops due to ET losses after July 1. The hydrographs that follow show the projected average water depths in the basin over the course of a "typical" year chosen from meteorological data available prior to 1995 (Figures 3 and 4). The hydrographs can be adjusted to vary based on the depth of maximum water storage projected for the design grading plan and the size of the wetland footprint. Neither hydrograph accounts for occasional filling of the basin by overbank flooding, but the actual occurrences of HEC-RAS anticipated overbank flooding events are noted on the post construction hydrograph with a star. Remarkably, these events were rendered somewhat inconsequential, by the fact that the wetland would have already been filled or filling from precipitation and local runoff inputs at the time the flooding was predicted.

Construction: As noted, a grading plan was prepared for the candidate site and field reference surveying benchmarks were established by the excavation contractor. The excavation contractor established a grid of grade stakes marked with cut and fill instructions for the heavy equipment operators to follow. A site "grading supervisor/foreman" was on site with surveying equipment to monitor elevations and to ensure that all tile drains were removed as the grading plan was being implemented, substrate soils were being re-applied, and the stone lined inlet/outlet was being installed. The site sponsor provided stumps and woody debris for placement following grading. Touch-up grading was accomplished after stump placement, and the floor of the site was immediately seeded with a temporary erosion control seeding of oats and annual ryegrass. Outer disturbed upland areas were limed, fertilized, seeded (permanent seed mix) and mulched. Prior to the start of the 1994 growing season, Little Tymochtee Creek experienced the equivalent of a threshold flooding event (confirmed by the HEC-RAS calculations) and the replacement wetland was inundated for several consecutive hours before floodwaters receded. This event imported significant "seed rain" of hydrophyte species from upstream areas. A few days following this flooding event, approximately 50 *Cephalanthus occidentalis* dormant cuttings were installed along the linear raised beds in late April 1994. No additional planting/seeding followed as re-vegetation of this site was left entirely to natural seed rain colonization, competition,

FIGURE 3. Predictive hydrograph prepared for the Wyandot case study site. This rendition did not incorporate HEC-RAS analysis calculations suggesting overbank flooding for storms exceeding 2.5-inches in a 24-hour timespan. This presentation shows the monthly water storage depths for the predictive hydrograph if the candidate site was perfectly flat. Actual depths planned for the wetland floor grading plans varied from 0-inches to 36-inches, averaging ±10-inches for the entire wetland footprint. Arrows indicate drawdown and recovery.

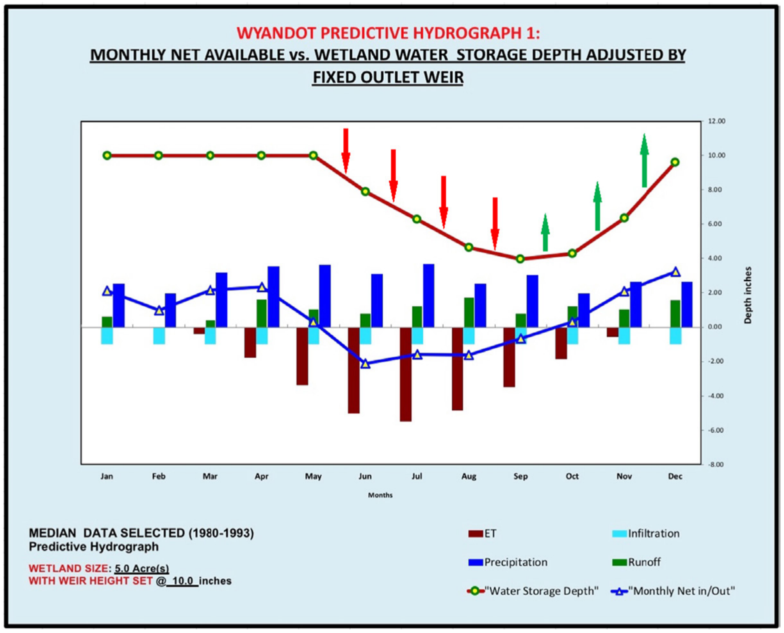
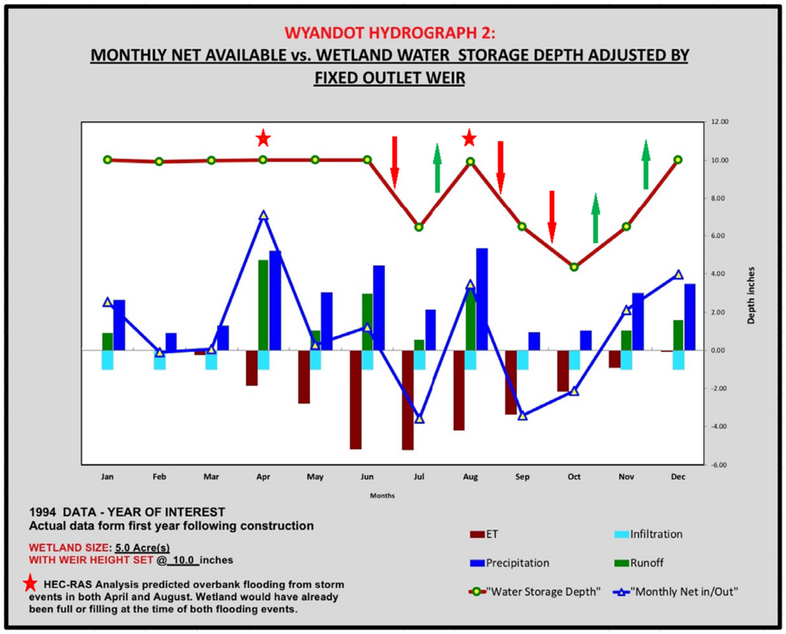


FIGURE 4. This hydrograph shows the water depth response to the actual precipitation events recorded and documented for the year immediately following construction. Ironically, two overbank flooding events predicted by the HEC-RAS analysis (illustrated by stars) occurred in this timespan, yet both events occurred either with the wetland already being "full" (April) or filling or nearly full (August). In any event, comparing the predictive hydrograph with the actual behavior of water provided by largely "unpredictable" natural events still shows the site as having adequate hydrology but also experiencing volume drawdowns driven by seasonal increases in ET losses.



and successional development. An academic researcher was sought to monitor, collect data, and report on this "natural recruitment" process, but none was found to have interest in the project.

Project Initiated: September 1993; wetland construction completed in November 1993.

Monitoring: Site monitoring was conducted intermittently during the first six years following site construction. This monitoring was required by permit conditions, but formal monitoring reports were only required at two-year intervals. Monitoring reports were required to be submitted to the USACE as a condition for issuance of the "Nationwide" permit action. The project area was released from additional monitoring requirements and was accepted as a jurisdictional wetland by the USACE on April 13, 2000. The progress of the project is detailed in the photo documentation that follows.

FIGURE 5. Reshaping and adjustment of the wetland floor to designed elevations. "Topsoil" materials were stockpiled and re-applied six to twelve inches deep to approximate the final finished elevations of the wetland floor and to act as the wetland "substrate" (the medium for plant growth and the microbial/invertebrate microbiome).

FIGURE 6. Following finish grading, stumps and other woody debris were placed to create escape cover for amphibians and singing/sentry platforms for various birds. The final task prior to onset of winter conditions was to protect the wetland from erosion. A combination of oats and annual ryegrass was seeded to provide rapid cover of the site. Effective as protective cover, these grasses did not compete with colonizing hydrophytes and soon succumbed to inundation. Yet, remnant stems and leaves acted to catch and hold "seed rain" from spring flooding in 1994 and to add detrital organic matter and nutrients to the soil substrate.

FIGURE 7. The inundated wetland floor seen at full springtime capacity in early April 1994.

FIGURE 9. Site in July 1996. In this instance, other than the permittee, the U.S. Army Corps of Engineers was the primary reviewing "stakeholder." The Corps agreed to allow the site to vegetate primarily via "seed rain" carried in with overbank flooding from the adjacent creek. Hydrologic analysis of the watershed and runoff calculations predicted late winter or springtime flooding of this location in eight out of ten years. With the amount of potential seed rain expected, the site received only token plantings of buttonbush (*Cephalanthus occidentalis*) cuttings. The "experimental design" for the site was to allow natural succession that would be documented over several years of observation. By the end of 1996, the dominant pioneering plant species was broad-leaf cattail (*Typha latifolia*) giving the appearance of a nearly monocultural stand. Although hidden in this view, significant dense patches of water plantain (*Alisma subcordatum*), broad-leaved arrowhead (*Sagittaria latifolia*), soft-stemmed bulrush (*Schoenoplectus tabernaemontani*), and giant bur-reed (*Sparganium eurycarpum*) were also noted within the expanse of cattail.

FIGURE 8. Black and white aerial image of site as seen on May 5, 1995. Constructed wetland is to left of road, between the road and Little Tymochtee Creek (dashed line indicates the direction of flow of the creek).

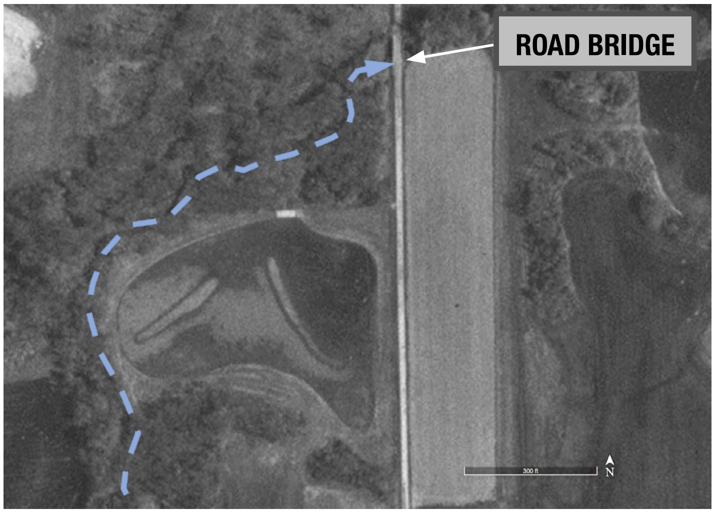


FIGURE 10. Site in August 2007 showing a shift in emergent vegetation from 1995 to 2007. During the fall and winter of 1996, muskrats (*Ondatra zibethicus*) colonized the wetland. These animals initiated a remarkable herbivory turnover of the wetland plant cover as they systematically removed more than 95% of the cattail biomass on the site. The wetland had transitioned from an early-successional, predominantly arenchymatous plant community to a sedge meadow with shrub components by 2000. Since then, the evolution of the site has continued to the condition shown here. Silky dogwood (*Cornus amomum*), buttonbush, and arrowwood (*Viburnum dentatum*) dominate the fringes of the site with burreed and occasional patches of duck-potato dominating the shallows in spring and early summer. Smartweeds (*Persicaria hydropiperoides* and *P. amphibia*) intermingle with burreed in mid-summer and grow to cover areas where shallow open water had been expressed eariler in the spring. The development of the site remains dynamic with sapling trees (green ash *Fraxinus pensylvanica*, cottonwood *Populus deltoides*, black willow *Salix nigra*, sycamore *Platanus occidentalis*, and red maple *Acer rubrum*) scattered throughout the wetland floor and its transitional "edge".

FIGURE 11. The developing shrub and sapling tree "soft edge" (photo foreground and background) of the site as seen in August 2007.

FIGURE 12. When the site experiences typical seasonal drawdowns surface water remains only in the deeper refugium areas of the wetland floor. The water depths anticipated for this site through calculation and preparation of hydrographs mirrored (or "approximated") the observed timing of water in wet, dry, and more typical "median" years.

FIGURE 13. Extreme late growing season drawdown is not always this well expressed. Occasional heavy thunderstorms and rapid rise of the water level in the adjacent stream often keep the wetland floor inundated or saturated throughout the summer months. Amphibians abound along with green and great blue herons, various probing/wading birds, as well as an occasional bald eagle.

FIGURE 14. Mussel gametes washed in during flooding events mature to support various foraging mammals. Raccoon have been seen feeding on mussels and frogs. Mink are suspected from telltale tracks in seasonally exposed mudflats.

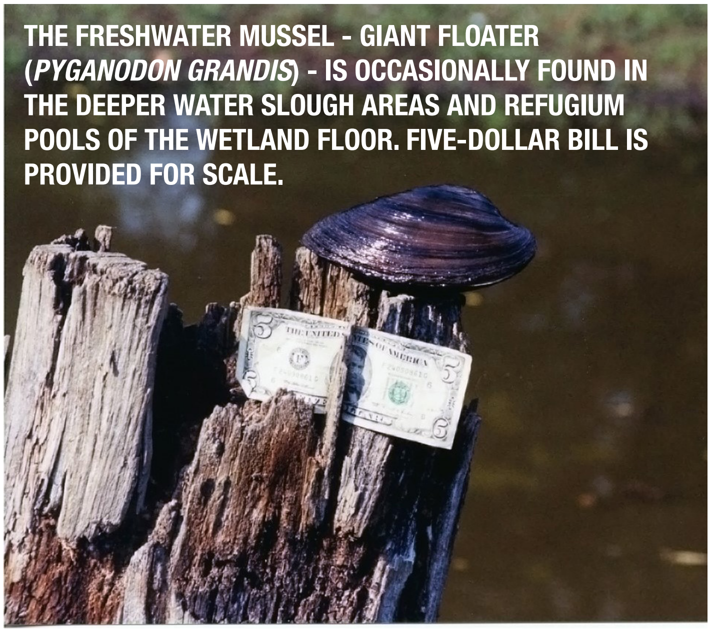
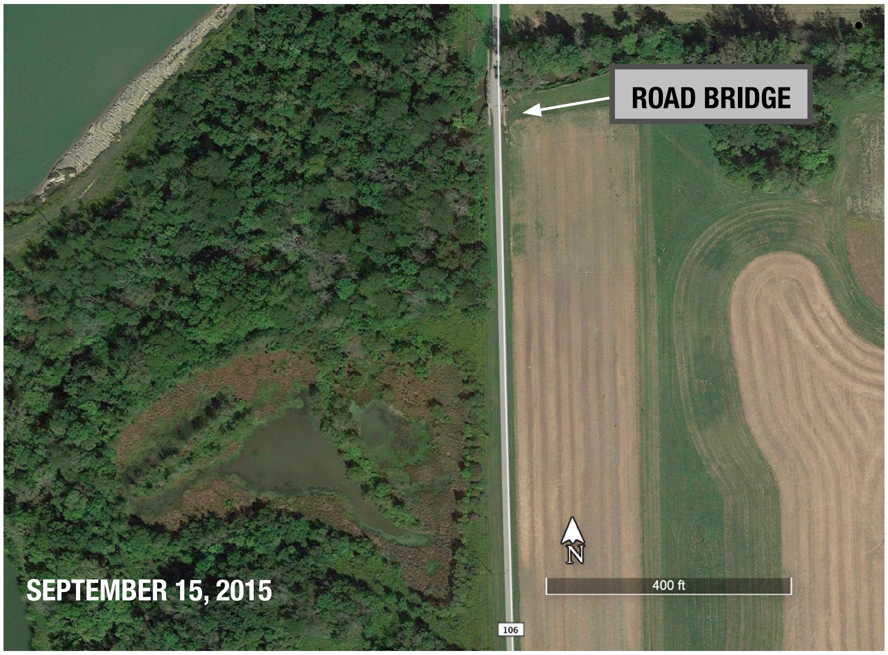


FIGURE 15. The seasonal dynamics of site vegetation dominance change throughout the growing season. Note the species and distribution in this springtime view as compared with the late season view shown in Figure 10.

FIGURE 16. September 2015 aerial image of site as seen with late season drawdown. Regardless of 25-years of progressive successional development, the site remains in a transitional stage, now moving towards 30% areal coverage by shrub and tree species. *Sparganium eurycarpum* remains as the dominant herbaceous species. Cattail colonization is still suppressed by muskrat herbivory. The wetland is clearly providing a number of significant and important physical, chemical and biological functions in its landscape setting. To a large extent, this site has been successful because it was sited in a landscape position where it was also able to profit from an anthropogenic modification. The roadway and bridge crossing of the floodway combine to alter natural "out-of-bank" flooding that would historically spread more uniformly within and along the riparian corridor floodway. The constriction of the cross-sectional flow path under the bridge in combination with the floodway damming-effect of the raised roadway, combine to create a predictable back-water flooding regime of the project area for much higher frequency storm events. These man-made stream corridor modifications were openly acknowledged and factored into the design of this site. Perhaps this approach was somewhat serendipitous with regard to what are now natural flooding regimes, but it acknowledges that roads, bridges, dams, dikes, levees and water control structures are very likely to remain in the landscape for many future generations.



Lessons Learned: Among the more important lessons learned from this project were the following.

- This project emphasized the importance of coordination with regulatory stakeholders in developing an acceptable mitigation alternative.
- This project highlighted the importance of remote sensing for initial identification of candidate sites.
- Thoroughly investigate candidate site hydrology and soils and prepare hydrographs to reinforce your assumption that the site will have adequate hydrology that is also timed to mirror the cycles apparent in other nearby wetland sites.
- Use reference sites even if they are not entirely consistent with the results you are seeking. For example, in this case the project site was planned to emulate a floodplain meander/oxbow depression. Although no such example was readily available along the reach of Little Tymochtee Creek, remnant sites that had been cleared, graded and drained for agriculture or that had simply been avoided by farmers were still available as points of reference to help project appropriate vegetation zones within the candidate site footprint.
- Prepare a detailed and properly engineered grading plan and insure that excavation and grading contours transferred to the field match those presented in the grading plans. This is facilitated by having a qualified excavation contractor who is capable of following grading plans and establishing critical elevations within the project area footprint.
- Have a plan for reestablishing and pushing vegetation in a preferred direction. This will start in nearly all cases by establishing a good erosion control seeding that will not compete with your preferred hydrophytes once site hydrology has been fully expressed. In this very unusual case study, natural seed rain, competition, herbivory, and successional development have all come together to support tiered hydrophyte-dominated cover types that are relatively free of invasive species. Despite this relative success and the ultimate form and function achieved for this site, development and implementation of an aggressive planting plan is still strongly recommended. Hydrophyte seeding can be accomplished with erosion control mixes,

but planting of cuttings, propagules, and containerized plants should occur only after or concurrent with observation of maximum site hydrology ("full" inundation of the site but not during short or longer-term flooding events).

- If intentionally placing larger stumps, logs or other woody materials in areas that are prone to flooding plan to anchor any of the larger pieces that you would prefer to keep on-site. This should be obvious, but it is sometimes overlooked and can have negative effects both on-site and in down-stream off-site properties.
- If a particular project has potential to generate an academic research paper, arrange in advance to acquire an interested principal investigator and student to support the effort. Consider modest funding to facilitate the research/data collection effort. This site had excellent potential to track and document natural successional development following "disturbance." Unfortunately, it was a missed opportunity.

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