Principles of Wetland Creation and Restoration: Reflections

Part 2: Technology Transfer, Cross-over of Disciplinary Approaches, and the 1988 Burlington County (NJ) Case Study

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This is the second in a series for articles prepared for WSP to address what, from my perspective, have become principles of wetland creation and restoration that have evolved after working in this field for more than 40 years. Before moving into the case study presented in this offering, I would like to address another fundamental principle that relates to planning and improving outcomes. This principle centers on the obvious, that wetlands are complex ecosystems, and these ecosystems are often driven by physical and chemical processes that in some circumstances supersede or override purely biological aspects of a particular site. Further, due to specialized training, education and experiences, in the past, practitioners and researchers may have been inclined to concentrate their efforts in much narrower problem-solving parameters (their *comfort zone*) rather than actively embracing multiple aspects of a much larger and interwoven web of functional drivers.

A colleague referred to "other" disciplines outside of his "parochial scientific training niche" as being separate "STEM disciplines" that form quasi-insular reservoirs of scientific knowledge and "arts" that he and others refer to as "technological silos." His premise in assuming this perspective is that persons working within these "silos" tend to resist interaction with the other insular disciplines, even though engaging them might greatly benefit their projects. This perspective is not new in complex fields and is also acknowledged in formal business training[2], but it is exceptionally noteworthy as a potential fatal flaw for practicing wetland science professionals engaged in restoration and creation projects.

To reinforce this perspective, consider some of the many biologically-based scientific skills that a wetland restoration/creation specialist might need in order to be successful. In general, designers and/or design teams will often employ or need to acquire detailed working-knowledge of basic biology, zoology, microbiology, marine biology, botany, plant physiology, plant taxonomy, plant ecology, plant propagation/horticulture, fundamentals of ecology, field ecology practices, aquatic ecology, restoration ecology, wildlife management, mammalogy, ornithology, ichthyology, limnology, entomology, mycology, various forestry disciplines, and soil sciences (soil microbiology, soil chemistry, soil fertility, agronomy), just to name a few. Other physical and chemical sciences likely to be needed include basic chemistry, biochemistry, biogeochemistry, organic chemistry, toxicology, quantitative analysis, hydraulics, basic physics, soil physics, hydrology, fluvial geomorphology, geology, geography, minerology, photogrammetry and remote sensing, and meteorology. Ancillary but often critical "other skills" extend to include land surveying, GIS/GPS technologies, hazardous materials management, regulatory compliance/permitting, erosion and sedimentation control, pesticide management, integrated pest management, general civil engineering and structural design disciplines, earthmoving and construction principles, construction inspection, risk management, statistical analysis, overall project management, and many other project-specific technical skills including field-installation/maintenance/replacement of scientific monitoring and data recording equipment, and many more. Consequently, this professional niche actually spans administrative and management expertise as well as purely scientific approaches.

Considering the above, it is important for us to evaluate critically and honestly our own competence in the listed technical disciplines. Sincere reflection will probably lead us to accept that most of us cannot be experts in everything, and we will therefore need to occasionally tap into one or more of those other insular "silos" to produce successful projects. An example applicable to a number of the case studies provided in this series of articles, including the first already presented for Wyandot County, Ohio[3], relates to the ability of a person trained primarily in biological/ecological sciences to be able to predict flooding frequency for a floodplain riparian corridor project site; and further, to identify the minimum 24-hour storm event (depth of precipitation) necessary to trigger overbank flooding. So, yes, there have been and continue to be times when planners will need to sharpen their own skills or approach one or more of those other disciplinary silos, and perhaps bring

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2 The term functional silo syndrome was coined in 1988 by Phil S. Ensor who worked in organizational development and employee relations for Goodyear Tire and Rubber Company, Eaton Corporation, and as a consultant. "Silo" and "stovepipe" (as in "stovepipe organization" and "stovepipe system") are now used interchangeably and applied broadly.

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in an engineer, a meteorologist, or someone with specialized hydraulics and/or fluvial-geomorphology training and expertise, or others.

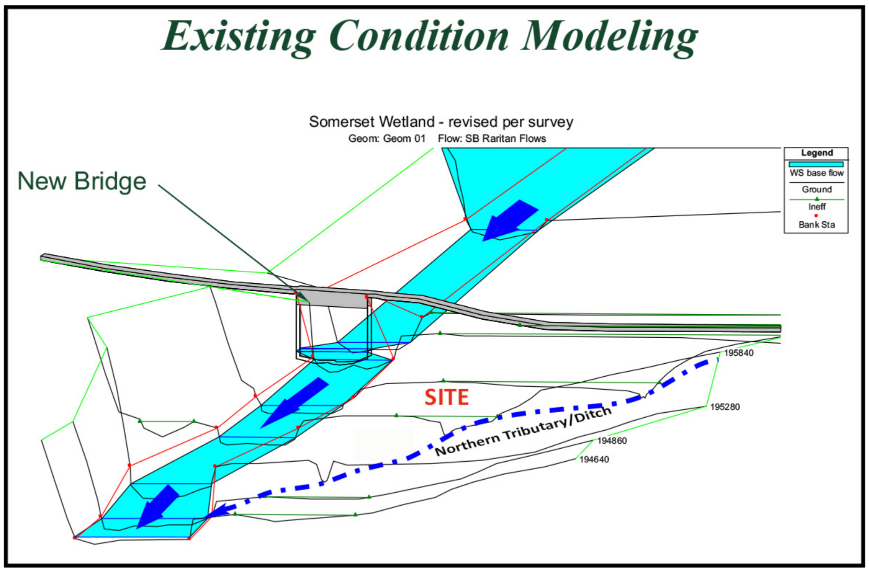
Over the last 40 years, the sophistication of the information we can glean from predictive models has evolved and accelerated exponentially with development of various equations and IT applications. For example, a collaboration of researchers from Virginia Tech, Old Dominion University, and University of Kentucky have tweaked and added to early predictive hydrograph models introduced by Gary Pierce circa 1993 (Pierce 1993, 2015). These early efforts were in turn modified shortly thereafter by Michael Rolband, founder of Wetland Studies and Solutions, Inc. (WSSI) of Gainesville, Virginia. Acknowledging Rolband's and Pierce's efforts, these present-day researchers have approached the challenge of preparing existing and predictive hydrograph models via a computer program they have developed and dubbed "Wetbud" (version 1.7.0.29, updated 7 Feb. 2018), which is short for "**Wet**land water **bud**get modeling software" (Stone 2017). This research effort is funded by two non-profit groups managed by WSSI. The Wetbud program (http://www.landrehab.org/WETBUD) integrates the USGS MODFLOW 3D numerical groundwater flow model (McDonald 2003) with streamlined computer algorithms and codes for basic hydrograph preparation. Wetbud allows for direct internet links to regional meteorological data, enhances prediction of groundwater inputs and losses, and has advanced and improved upon precursor approaches to predicting existing and candidate site hydrograph models.

In working with Wetbud, Lee Daniels (Virginia Tech) has noted another computational approach for groundwater modeling that may also prove useful in future wetland construction scenarios. Dr. Daniels suggests that the expanded HYDRUS software package for simulating water, heat, and solute movement in two- and three-dimensional variably saturated media (Šimůnek 2011) may have some promise as well. This Windows-based software package consists of a computational computer program and an interactive graphics-based user interface that could have value in modeling groundwater behavior in a number of constructed wetland project scenarios (http://www.groundwatersoftware.com/hydrus.htm).

An established example of applied-hydraulics modeling for streams, rivers and floodways is the collective and ever-evolving effort and program iterations of the U.S. Army

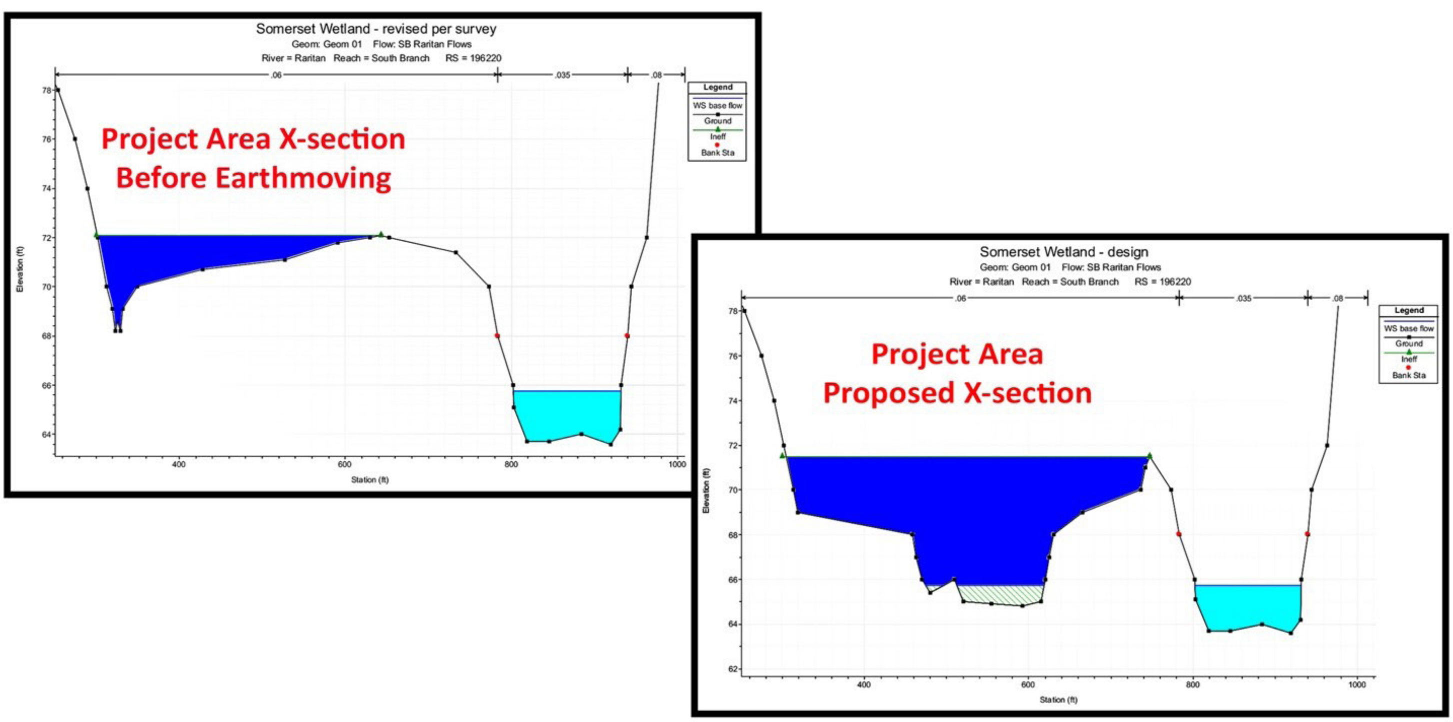
FIGURE 1. Aerial images of a floodplain mitigation site on the South Branch of the Raritan River in Neshanic, New Jersey. The vertical axis of each photo is North. No scale is provided, but the project area is ± 20-acres in size. The left image shows the Princeton Hydro site mentioned below as seen on May 5, 2003, prior to earthmoving, grading and replanting. Right image shows the site on August 27, 2016. A challenge for success of this project was prediction of periodic flooding from the adjacent small tributary along the northern limit of the project area as well as prediction of larger-scale flooding and backwater events driven by the whole of the riparian corridor watershed charging the main channel of the river.

FIGURE 2. Hydrologic modeling integrating the cross-sectional areas of the upstream watershed, physical structures, and site contours allowed planners to create visual illustrations of how water would be likely to behave on the project site before and following various storm events. This oblique illustration shows the approximate distribution of typical stream baseflow (the turquoise color) within the confines of the stream "bed and banks" before the effects of runoff and the flooding generated by various frequency storm events. The dark blue arrows indicate the direction of stream flow. The dashed blue line indicates the approximate location of the small tributary that flows along the northern boundary of the project site. Using present day HEC-RAS hydrologic modeling software similar images can be produced showing the incremental deepening of water within the channel and spreading of flood waters across the site for storm events of increasing intensity.



Corps Hydraulic Engineering Center (HEC) mentioned in the Wyandot case study presented in the Part 1 of these WSP articles. Since the mid-1960s, U.S. Army Corps engineers and technical staff working in the Hydraulics Engineering Center have incrementally improved upon and expanded their computational approaches to modeling flooding in and along the reaches of multiple stream-order riparian landscapes. At the time of the Wyandot project, the late 1980s and early 1990s, the Corps Hydraulic Engineering Center analyses employed to project overbank flooding were also being expanded and improved upon. The calculations used at that time were embedded in the "HEC-2 water surface profile computer program" (CEIWR-HEC 1990). These early modeling efforts were focused primarily on predictive analysis of "backwater flooding" in floodplains and floodways taking into account the size of the watershed and evaluation of multiple cross-sectional areas of the riparian corridor. However, fifty years later, the nuances and advances of "HEC-RAS" modeling projected from Version 1.0 released in 1995, to Version 5.0.3 released in

FIGURE 3. Before and proposed-after cross-sections of the central part of the site, illustrating the increased storm water storage capacity to be gained based on the depth of projected inundation before and after spoils removal and grading. The dark-blue color represents before and after flood storage potential before the site is completely inundated during an overbank flooding event.



September 2016 (Brunner 2016) collectively dwarf the first incremental efforts more than five decades ago.

Figures 2-5 that follow are printed with permission of Princeton Hydro, LLC of Ringoes, New Jersey. These figures illustrate how modern floodway modeling on one of Princeton Hydro's wetland mitigation project sites allowed the designers to visualize stream reaches in two and three dimensions and predict how and when a riparian corridor wetland creation and enhanced flood water storage project site would be incrementally inundated. These few figures are offered as just one example of the value-added when we engage persons with expertise in other disciplinary silos and also to illustrate how innovations and advances have improved predictable outcomes for contemporary projects.

CASE STUDY 2. RIPARIAN CORRIDOR WETLAND CONSTRUCTION, ASSISCUNK CREEK, BURLINGTON COUNTY, NJ – 1986-1988

Relevance of the Burlington County, New Jersey Case Study

Considering the wealth of information accumulated over the years, technical innovations, and improved present-day internet access to various technologies, the case study that follows serves primarily to highlight progress made in planning wetland construction and restoration since the mid to late-1980s. The Burlington County project was planned by biologists and ecologists with a sound understanding and appreciation of local wetland resources, and they managed to cobble together a plan to construct "mitigation wetlands" based on the skills they had available at the time. The intent was not simply to "dig a hole and let it fill with water." However, even in the late 1980s, a successful outreach to other "technological silos" might have benefitted the planning process. This observation is not a criticism, but rather it reflects the somewhat rudimentary "state-of-the-art" at the time. In any event, despite a somewhat narrow-disciplinary approach, this project has proven over time to have been a success. It was sited appropriately to prosper as a replacement wetland resource. The site selection process included anecdotal accounts of flooding and

FIGURE 4. This cross-sectional graphic shows how hydrologic modeling program allowed designers to predict inundation effects for various storm frequencies ranging from monthly to greater than 100-year events.

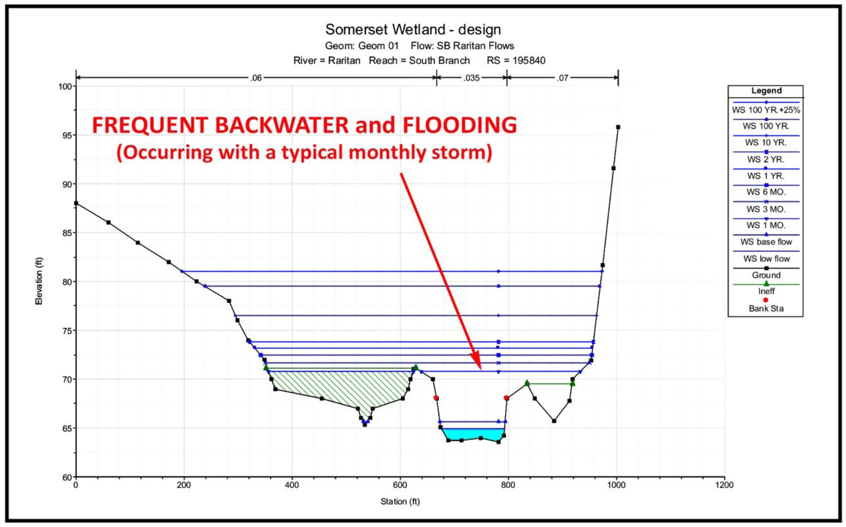


FIGURE 5. This plan-view perspective shows the extent of surface water inundation projected for a storm event likely to occur on a monthly basis. In this case, the project area floods first from water entering it from the small tributary on the northern edge of the site (initially from the northwest – red and yellow arrow). With more intense storms, additional water depth is again first added to the site footprint from the northern tributary and is augmented as water levels also rise in the main channel of the river. Subsequently, the river water and the waters within the project area footprint co-mingle as river water backs into the site from the confluence of the small tributary with the main river channel (double black and green arrow). With even more significant storms, the backwater inundation occurs first and is followed by complete overbank inundation as water depths rise in the river channel. As noted, this project example shows how active interaction with other technological "silos" with specialized tools can have significant value to wetland construction and restoration planners and designers. Ultimately, these integrated approaches enhance our ability to generate predictable outcomes for our projects.

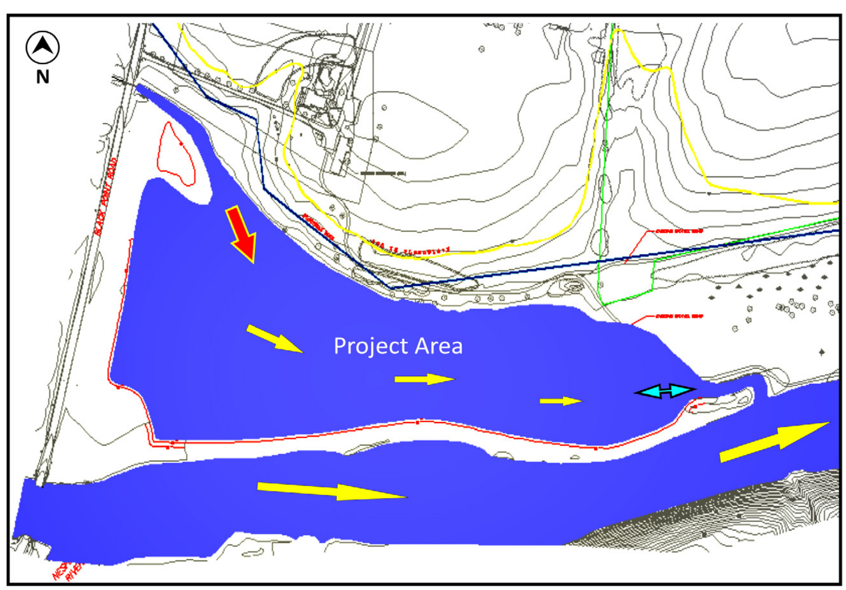
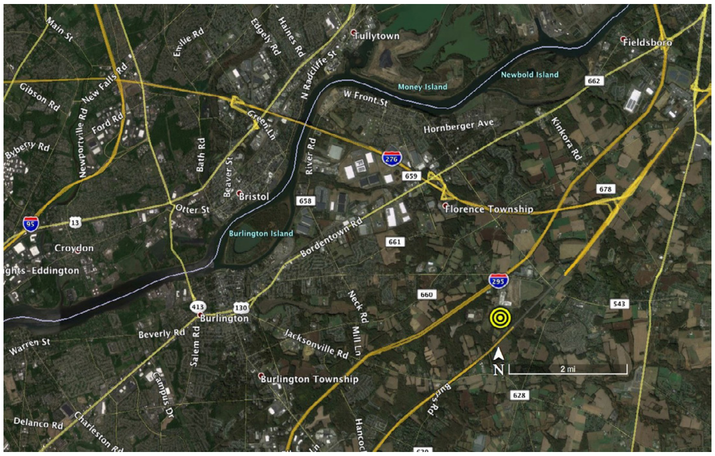


FIGURE 6. The circle symbol marks the site of the wetland construction project in Burlington Township (Burlington County, NJ).



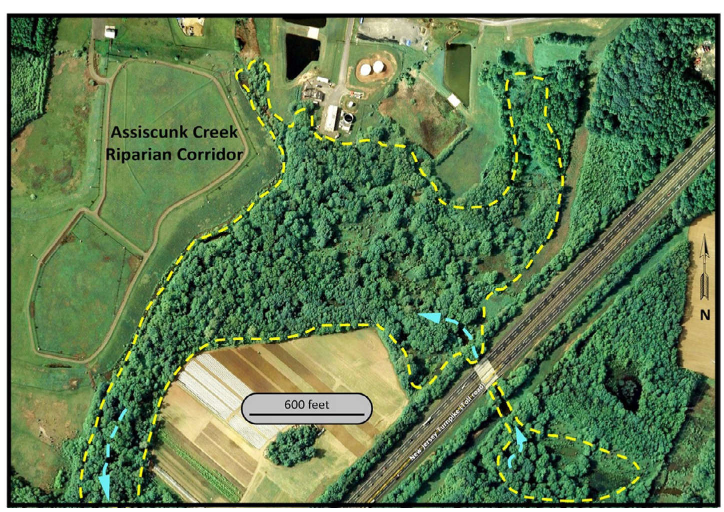
flooding frequency in the riparian corridor, soil investigations, on-site observations of scour and elevations of wrack deposits in the floodway (to confirm anecdotal reports of flooding and flooding depths used in the design), comparative inventories of local reference wetland types also occurring within the floodway corridor and consultation with regulatory agencies. Given the infancy of wetland mitigation, it should be noted that the quantity and variety of plant materials from commercial sources were limited at the time. Consequently, while the species planted in the constructed wetland cells were local natives, these plants were introduced primarily as "place-holders" that might allow *natural recruitment* of other riparian species that were not available as planting stock. In addition, upon completion of construction and planting, a few minor adjustments were made during the first several months of observation and monitoring (i.e., "proactive monitoring").

Since the time of construction, the wetland construction areas have settled nicely into the landscape. Thirty years later, largely due to natural selection and seed rain from intermittent flooding, the constructed wetland cells are difficult to distinguish from present-day *natural wetlands* found in the same riparian corridor. Consequently, this case study is an acknowledgement that although early in the development of wetland construction principles and protocols, when science-based approaches were applied, minor adjustments were made during post-construction monitoring, and appropriate siting and hydrology expression were considered, time and natural selection ultimately combined to facilitate project success – the establishment of a constructed wetland similar in form and function to nearby natural wetlands.

Location: Burlington Township, Burlington County, NJ (Figure 6).

Introduction: This site was proposed and constructed as mitigation for wetland impacts occurring in the footprint of an adjacent county operated landfill. Note that the wetlands were identified and delineated in the approximate timeframe of release of the 1987 U.S. Army Corps Delineation Manual. Wetland impacts were proposed to be mitigated by construction of replacement acreage at an approximate 2:1 ratio. Detailed functional analysis of the impact wetlands was not completed per se, but "general" primary wetland functions were documented and acknowledged, and nearby local replacement was considered to be most appropriate. The impact wetlands were located primarily in former agricultural areas in "upper-terrace" landscape positions, but they clearly drained to the adjoining Assiscunk Creek floodplain and riparian corridor. Consequently, the permittee and the oversight regulatory agencies agreed that the replacement wetlands would have benefit if constructed within and along the Assiscunk stream corridor that abuts landfill operations. Readily accessible records of the project planning process were difficult to find, but it is surmised that the total wetland impact acreage was limited, and the encroachments were therefore permitted under a USACE Nationwide permit.

FIGURE 7. June 2004 aerial view of the riparian corridor of Assiscunk Creek where a number of small wetlands were constructed in the late 1980s and early 1990s. Stream flow is from east to west, flowing under the New Jersey Turnpike and meandering within a gently undulating, primarily wooded, floodway floor. Anthropogenic modifications of the natural stream corridor floodway are inescapable in this setting. Nutrient loading from industrial, urban, and agricultural activities are also factors that affect functions being performed and composition of vegetation cover types. Candidate areas for wetland construction were investigated within the potential project area defined by the yellow-dashed lines. The wetlands constructed more than a decade earlier are visible in this image but are not necessarily obvious in this context (see Figure 8).



Project Sponsors: The Burlington County Landfill, a county-owned and operated facility at the time of the project.

Project Objectives: The primary objective of this project was to convert 1 to 2 acres of "upland" within and adjacent to the riparian corridor of Assiscunk Creek (tributary to the Delaware River) to areas of emergent, scrub/shrub, and forested bottomland wetlands. The suites of vegetation planted in each component area were chosen to reflect local flora and the landscape context to the maximum extent practical considering the availability of plant materials from commercial sources.

Planning and Design: This site was planned and designed by Mr. Mark Gallagher (at the time, employed by Princeton Aqua Science) and was constructed and planted between 1986 and 1988. The planting and some initial monitoring were accomplished by Dr. Gary Pierce through his company Southern Tier Consulting. Dr. Pierce also made planting suggestions and early modifications to the outlet weir elevation for Wetland Area B. Details of the original site design grading plans are not available. However, the project area has been used as a teaching site for continuing education courses since 1990 (Rutgers Office of Continuing Professional Education and others). Aspects of the successional development of the constructed wetland components have been observed and discussed annually in the field with students for nearly three decades.

From an anecdotal account provided by Mr. Gallagher, initial remote sensing and field surveys completed for the candidate replacement wetland cells also included use of the published USDA NRCS National Cooperative Soil Survey mapping from 1970. Careful reading of the profile descriptions of the Keyport soil series (where Wetland A was constructed by excavating and re-grading a terrace slope) suggested that a restrictive clay layer might be found at depth. If present, interception of this layer when excavating could result in exposure of a lateral ground water seepage area. In this case, the seepage area was actually exposed during construction and has subsequently provided additional water input to Wetland A nearly continuously since the wetland was constructed. The exposed seepage area also resulted in creation of a "ground water slope wetland" (Novitzki 1982, 1989) that in turn drains down-gradient into the depressional floor of the constructed wetland basin. Although somewhat serendipitous, this outcome could have been projected with careful reading of the soil survey descriptions. Nevertheless, the bonus of additional wetland acreage and supplemental hydrology could not be definitively factored in as part of the initial predicted "wetland footprint."

Considering these variables, project cells were designed primarily as shallow depressional basins mimicking other "meander scars" and depressions with higher linear mounded "natural levee" inclusions found within the Assiscunk riparian corridor. Obvious inlet and outlet "structures" placed to allow expected floodwaters to enter and exit each site were not specifically incorporated in designs. Vegetation zonation was projected to develop based on graded contour elevations and anticipated persistence of inundation and saturation. Fringes of the wetland cells were expected to be scrub-shrub cover types that would eventually support planted larger bottomland hardwood trees,

FIGURE 8. Closer view showing Wetlands A and B that were created in the areas indicated by the dashed yellow lines. Note: A few years after Wetlands A and B were constructed additional wetlands were created (circa 1990-1991, not shown in this photo) on the south side of the NJ Turnpike (southeast of the two areas shown here).

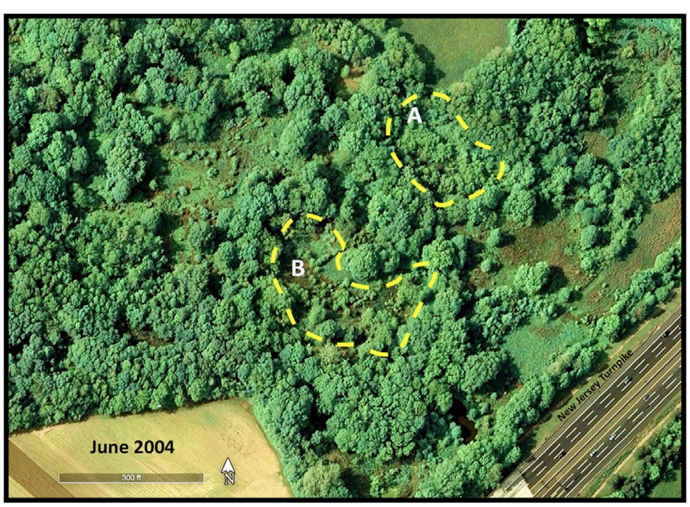
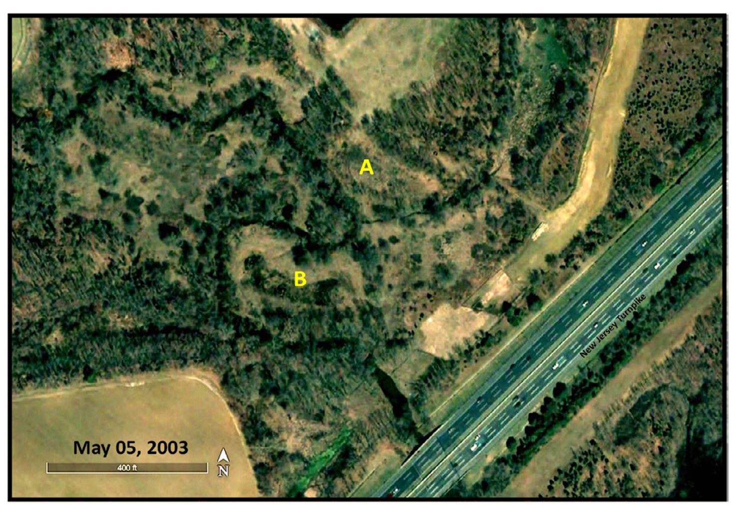


FIGURE 9. The constructed wetlands are seen more easily in this early spring 2003 aerial image.



as were other minimally and seasonally inundated areas within each wetland footprint. Initially, assuming minimal sediment accumulation following flooding events, semi-permanent emergent areas and refugium depressions within the wetland floor were expected to resist colonization by tree species due to persistence of shallow inundation. In any case, the successional development of plant community zonation was expected to progress from the initial plantings driven in concert with dynamic changes in the riparian corridor. Natural "seed rain" imported with flooding events was also expected to play a significant role in re-vegetation of the wetland cells. Pin oak, river birch, bur-reeds, pickerelweed, arrow-arum, tussock sedge, warm-season grasses, and cow lily were included in the suite of initial plantings.

FIGURE 10. Soil mapping of the project area circa 1970. Wetland Basin A was created by excavating a slope above the floodway dominated by Keyport soils (KIC) and then re-grading the area to elevations consistent with the active floodplain of Assiscunk Creek. Wetland Basin B was created by excavating and re-grading a mounded area of nonhydric alluvial soils (Ao) to create a concave depressional wetland within the stream meander.

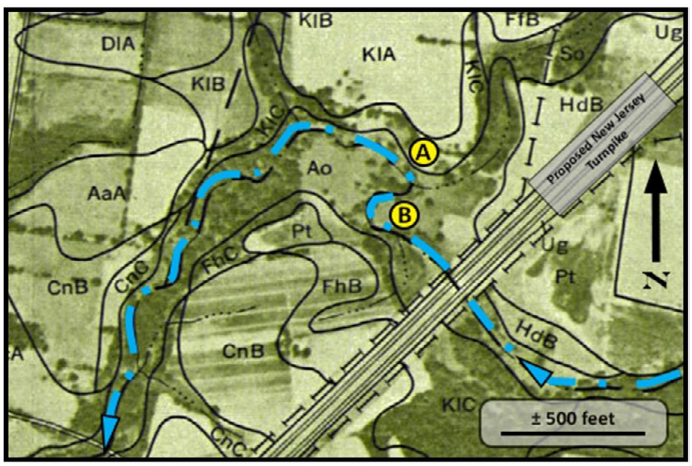


FIGURE 11. Fieldtrip students from Rutgers' freshwater wetlands construction course entering Area "A" approximately four years after planting. A seepage area was encountered when the hillside on which the students are walking was cut away to create the wetland floor. By keeping much of the substrate saturated throughout the growing season, this persistent groundwater discharge had a profound effect on the development of the wetland.

Site Hydrology: Potential hydrographs for each constructed wetland cell were not part of the 1980s planning process, but factors related to water inputs were definitely acknowledged. Inputs considered were frequency of overbank flooding from Assiscunk Creek, direct precipitation, potential for limited surface water runoff from adjacent slopes, and groundwater (interpreted from soils of the proposed wetland cells). Potential lateral seepage from the Keyport soil excavation area along the riparian corridor terrace slope was also acknowledged but was not part of the input estimates. Soil infiltration and evapotranspiration losses were not addressed specifically but were implicitly considered when evaluating on-site soils and local reference sites.

Construction: A simplified excavation and grading plan was prepared for the candidate cells and on-site construction inspection was provided by the design team. Excess earthen spoil material excavated from the cells was relocated to uplands outside of the riparian corridor, and stripped topsoils were reapplied to create the wetland substrate. As noted, groundwater seepage was confirmed in the excavated cut-slope of Wetland A. Following primary earthmoving and grading, the site was seeded with annual and warm-season (switch grass, *Panicum virgatum*) grasses and to protect it from erosion. Wetland hydrophyte plantings were delayed over winter while a qualified "wetland planting contractor" was being sought to complete springtime planting of selected species. The planting crew placed their introduced plant materials at elevations based on observa-

FIGURE 12. After observing the Wetland A slope seepage area and the emergent portion of the site (Figure 11), students are seen moving into and through the scrub-shrub fringe of Wetland A enroute to Wetland B.

tion of springtime hydrology, but shortly after planting, Dr. Pierce also installed an earthen outlet channel for Basin B to provide a more reliable fixed elevation to control maximum water depth (when not flooded) that would also allow more predictable vegetation zonation in the basin footprint.

Project Initiated: Circa 1987; wetland construction completed – June 1988.

Monitoring: Site monitoring was conducted intermittently during the first 2-3 years following site construction. This monitoring was required by permit conditions, but formal monitoring reports were very rudimentary at the time. The progress and successional development of the project site is detailed in the photo documentation that follows.

Lessons Learned: The following points are offered as lessons learned from this project.

- Although early in the regulatory context of wetland restoration/creation, this project once again emphasized the importance of coordination with regulatory stakeholders in developing an acceptable mitigation alternative.
- Persons with solid scientific training in biological disciplines were engaged in assessing the ecological context and biological nuances of impact wetlands and of candidate replacement sites. These persons also developed and prepared a list of primary functions the replacement sites were intended to perform over time. These "big picture" target functions centered on floodwater attenuation/storage and slower release, sediment retention, nutrient uptake, and provision of suites of general wildlife habitat niches. Although not emphasized on this project per-se, sequestration of organic materials generated on site as well as materials transported and deposited during significant flooding also relate to more contemporary concerns associated with carbon sequestration. As an aside, it is noteworthy that conscious efforts to target any one of these primary functions will tend to also benefit, facilitate, or enhance the others as ancillary products of an individual effort.
- This project highlights again the importance of having a reference context for the types of wetlands that were being targeted for construction and in using remote sensing and available soil data for initial identification of nearby candidate sites in appropriate landscape positions. Having this perspective improved the probability that the constructed wetlands would continue to be self-sustaining long after regulatory oversight (monitoring) had ended.
- Hydrology inputs and soils were addressed in the planning process, but, in particular, the depth, duration and timing of water inputs (and losses) might have been more clearly defined with more in-depth analysis. Additionally, the energy associated with flooding events might have been investigated more thoroughly from an engineering and erosion-control perspective, in particular assessing erosive overbank flooding and hydraulic shear stress. Yet, in retrospect and with deference to the designers, the cross-over and interaction of potentially "symbiotic" technical disciplines was not as well developed at the time of this project. In the present day, there is ample opportunity to improve our projects by actively seeking out other technical disciplines that have techniques

FIGURE 13. Another group of fieldtrip students entering Wetland A approximately sixteen years after planting. The transition from an emergent/scrub-shrub plant community to a young forested wetland was well underway for the entire project area as early as 2001.

FIGURE 14. Dense emergent growth dominated Wetland B for a decade after its initial planting. However, by 2004, planted river birch (*Betula nigra*), silky dogwood(*Cornus ammomum*), buttonbush (*Cephalanthus occidentalis*), and black willow (*Salix nigra*) had encroached and encircled the emergent center of the basin. Bur-reed (*Sparganium eurycarpum*), arrow arum (*Peltandra viginica*), duck potato (*Sagittaria latifolia*), smartweeds (*Persicaria* spp./*Polygonum* spp.), rice cutgrass (*Leersia oryzoides*), tussock sedge (*Carex stricta*), and an occasional cow-lily (*Nuphar luteum*) persist as emergent species in this 2004 photo.

and skills to generate data we can exploit to improve project outcomes. For this project, engaging a person or persons with training in fluvial geomorphology and/or open-channel flow (a branch of hydraulics and fluid mechanics) and erosive shear stresses, would have been helpful in first acknowledging the dynamics of the floodway and then in reinforcing the stability of the areas being constructed. In particular, assigning a fixed (and perhaps stone-lined weir) elevation within a channel strategically positioned for flood waters to back into the wetland cells and flow back out would have reinforced the durability and longevity of the wetlands, especially if these structures could have been installed at the time of earthmoving and construction. However, how much additional technical input we solicit for any given project will of course be dependent on the variables at play and the complexity of the design challenges. Sites with complex hydrology inputs/losses, difficult soils, challenging geomorphic landscapes, and/or complex ecosystem dynamics are more likely to benefit from seeking input from other specialty disciplines.

- During the 25-year span that this site had been followed by Rutgers trainees, a field discussion of the dynamic nature of floodplain and riparian corridor landscapes has surfaced repeatedly nearly every year since classes first visited the site in 1990. Students have noted the vulnerability of the Assiscunk Creek landscape and that gradual or sometimes catastrophic changes in the morphology of these higher energy flood-prone areas is inescapable. They have pointed out man-made infrastructure modifications, old meanders, natural streambank levees, oxbows, undercut streambanks and vulnerable larger trees, and have noted floodwater wrack and sediment deposits. They have also commented on the energy exerted on both the natural and constructed wetlands in the corridor, and the inexorable incremental changes being driven

FIGURE 15. Hydric soil morphology was documented in both constructed wetland basins within 3 years following establishment. The sample shown here was removed on fringes of Wetland B at a depth of approximately 10-15 cm from the soil surface and is from a horizon located immediately below a 1-2 cm thick surface fibric organic layer (an Oi horizon). It has a coarse sandy loam texture and easily meets Hydric Soil Indicator F3 (Depleted Matrix). The high percentage of the redoximorphic concentrations and oxidized rhizospheres is evidence of the alternating oxgenated and anoxic aquic conditions common in these frequently flooded soils.

FIGURE 16. Fieldtrip students entering the forested portion of constructed Wetland A nineteen-years after planting. Spicebush (*Lindera benzoin*), river birch, buttonbush, and black willow are the dominant woody plants. At this developmental stage, the site had clearly met the criteria for classification as a Palustrine Forested (PFO) wetland.

FIGURE 17. Under a closed canopy of river birch and black willow, Gary Pierce (red shirt) shares observations regarding transition of vegetation cover in Wetland A during the first twenty-years of development. Understory species include duck potato, halbred-leaved tearthumb (*Polygonum arifolium*), arrowleaf tearthumb (*P. sagittatum*), wood reedgrass (Cinna arundinacaea), rice cutgrass (*Leersia oryzoides*), remnant cattail (*Typha latifolia*), arrow arum, swamp rose-mallow (*Hibiscus moscheutos*), buttonbush, and sapling willows.

by recurring flood events. These observations along with ample evidence in contemporary and archival aerial photography suggest that phrases that include "permanent" or "in perpetuity" are either inappropriate or perhaps exuberantly optimistic when used in this landscape context. In general, regarding riparian corridor and floodplain projects, it appears that increased longevity and perhaps more stable expression of constructed wetlands over time can be anticipated where floodwater energies are spread widely, are more evenly dispersed, and the corridors have ample cross-sectional area over which the volumes of water can be distributed. The more energy associated with the floodway corridor, the more vulnerable a constructed wetland project is likely to be.

- Once again, the importance of looking beyond the project site to acknowledge surrounding land uses, potential future land use changes, and physiographic subtleties was an important factor in preparing the plan and design. To some extent, this awareness has allowed this site to be remain viable over time in its current but dynamic landscape position. Although somewhat simplistic, there was a deliberate effort to emulate floodplain meander/oxbow depression settings.
- It is important to have a plan for reestablishing and pushing vegetation in a preferred direction. In this case study example, there were limited plant material resources available to provide a strong suite of species to occupy each anticipated vegetation layer. Nevertheless, use of native species with affinity for site conditions being developed, in concert with natural "seed rain" and recruitment from repeated flooding, species competition, and successional development were factors that combined to generate tiered hydrophyte-dominated cover types that have been relatively free of non-native invasive species. In this case, the positive outcome may have been somewhat fortuitous, but the lesson once again is that we must be exceptionally thoughtful in developing planting plans, understanding the "needs" of targeted species, and in proper handling and installation of the plant materials.
- "Monitoring" is critical to success. Therefore, those responsible for this project component are encouraged to be "proactive" in their monitoring efforts and to monitor with the intent to detect potential problems and to facilitate, coordinate, or, if authorized by team and client consensus, to personally take corrective actions. This can also be viewed as "adaptive management," but in a regulatory context where a project is expected to meet specific milestones in a set period of time, being proactive and conscientious is essential. Individual monitors looking for small, incidental, or large adjustments that can be made early-on post construction can potentially salvage a project that is heading in the wrong direction.
- A recurring theme for all wetland construction is exemplified in this project. This is an awareness that *time* and *natural processes* are factors over which we ultimately have little control (Mitsch et. al. 2010). Yet, if an appropriate landscape position is chosen, a serviceable rooting medium is provided with potential to facilitate physical support of plant species,

FIGURE 18. Field trip students on the fringes of Wetland B in September 2015. At this stage, the constructed wetland had blended into the natural physiognomy of the riparian corridor to a point where it is difficult to distinguish it from natural wetland depressions. Photographer's vantage point was from atop a 3-foot wide, 2-foot tall tussock sedge.

FIGURE 19. Students leaving Wetland B in September 2015. Students at left are walking along the earthen outlet fashioned twenty-six years earlier circa 1989. This outlet "channel" also allows waters from the adjacent stream to back into and then flow out of the wetland depression more gently as flood waters rise and fall in the riparian corridor.

necessary nutrients are available, adequate hydrology inputs (versus losses) are included, and suites of plant species with affinity for the ecological niches expressed at the site are introduced, there is a very high probability that an upland project site can be converted to wetland. As scientists and wetland restoration/creation practitioners, it is our responsibility to do those things within our purview that will nudge our project site in a direction to express the physical appearance and functions we hope to achieve over time. We must, however, acknowledge and respect the fact that natural processes are always in play, and despite human intervention and our very best intentions, Nature is ultimately in charge. ■

FIGURE 20. The wetlands constructed in the Assiscunk riparian corridor do not have complex or complicated water control structures and fit well into the surrounding landscape. Having been in place for nearly 30 years and now supporting a predominance of native species common in the riparian corridor, the constructed wetlands are nearly impossible to distinguish from other "natural" wetland depressions found within and along the stream corridor floodplain. Yellow dots pin-point four areas of constructed wetlands built between 1988 and 1993; the two upper ones are the subject of this article.

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