Plans and Recommendations for Abbey Lane Wetlands, Phase I of Miller Run Restoration

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Abstract

Miller Run at Bucknell University is a prime example of an ecosystem that has been radically altered by human intervention. For the first phase of restoration efforts funded by a Growing Greener Grant from the Pennsylvania Department of Environmental Protection, the headwater area where Miller Run first enters the University's property has been targeted as a site for wetland creation. It is hoped that these wetlands will increase water retention and storage capacity, thereby increasing base flow and improving overall stream ecology. Here, preliminary plans for the wetlands are presented and additional recommendations are made to guide the development of final plans and construction. Emphasis is placed on ensuring the site hydrology is correct and on mimicking natural "reference" wetlands.

Introduction

In order to sustain healthy ecosystems in today's world, it is becoming increasingly necessary to focus on restoring areas that are damaged. This represents a shift from historic experience; for the past 50 years, the primary strategy for protecting biodiversity and ecosystem services has been to preserve pristine areas. As the world population continues to expand, however, there are fewer opportunities for this kind of action and as a result, the ecological integrity of human-altered landscapes is becoming increasingly important. Through our desire to engineer and shape the environment to our liking, humans have fragmented, polluted, and destroyed many natural systems but with research, creativity, and holistic thinking, we also have the tools to repair the damage.

At Bucknell University, Miller Run is a prime example of an ecosystem that has been radically altered by human intervention. Major sections of this stream were straightened and channelized by the 1930s and historically, the University has treated the stream as little more than a large drainage ditch (Burke et al. 2009; El-Mogazi 2009). In recent years, this attitude has changed and there have been numerous efforts since 2008 to gather baseline data on Miller Run and initiate restoration efforts (Schaffer 2008; Burke et al. 2009, Meas and Crago 2010; HRG 2010). In January 2011, Bucknell University was awarded a $178,000 Growing Greener Grant through the Pennsylvania Department of Environmental Protection toward the restoration of Miller Run. While this will not fund the entire restoration, it provides the support needed to begin important first steps.

The headwater area where Miller Run first enters the University's property has been targeted for the first phase of restoration with the hopes that benefits will trickle downstream and the initial projects can serve as examples for future work (BUEC 2010). There is a general consensus that the creation of wetlands in the area near Abbey Lane would be a valuable component of this first phase of restoration since wetlands would address several major problems with Miller Run, namely low stormwater retention, high sediment influx, and low base flow (Cathy Myers, Ben Hayes, Warren Abrahamson, personal communication).

With the goals of this grant in mind, the objectives of this paper are to:

- Propose a preliminary design for wetlands in the Abbey lane headwaters of Miller Run based on existing knowledge of the watershed and studies of reference wetlands in central Pennsylvania
- Make recommendations regarding future studies that must take place before final design and construction can occur

Design Philosophy

Wetland restoration and creation is still a relatively young science that suffers from lack of successful examples and confusion regarding the overall design process. As a field that combines the efforts of biologists, geologists, engineers, and construction workers, much of the frustration stems from failure to clearly define goals and objectives. Before exploring site characteristics and design alternatives, it is essential that all parties have the same understanding of the overarching vision.

What is success?

With created wetlands, there is no clear answer to this question since achievement of "success" is so closely tied to individual site goals and monitoring programs. Depending on the project, success may be defined as compliance with a Section 404 permit, functional replacement of a "lost" wetland, or favorable comparison to natural "reference" wetlands (Mitsch and Wilson 1996; Kentula 2000). Once defined, success may then be measured by some combination of vegetative cover, soil chemistry, fauna presence, or hydrologic characteristics (Kentula 2000). Historically, most wetlands have not monitored any of these variables frequently enough to draw strong conclusions about their success (Mitsch and Wilson 1996). Of those that have, the majority have commonly focused on the presence of "wetland" vegetation and the abundance of species, even though these may not adequately capture the full range of functions in a wetland (Mitsch and Wilson 1996; Kentula 2000; Bedford 1996).

Perhaps the best approach to assessing wetland success utilizes the hydrogeomorphic (HGM) method of wetland classification and incorporates natural "reference" sites for comparison. The HGM method categorizes wetlands by hydrogeography, or the relative importance of surface water and groundwater flows to the site and the geological characteristics (e.g., topography, soil permeability) that control these flows (Bedford 1996). In the HGM method, the local climate (mainly precipitation and evaporation) is recognized as the primary driver of hydraulic processes and as a result, the definition of "wetland" can vary by landscape. Unlike vegetation or soil chemistry, the hydrogeography of a wetland is not dependent on time; if the hydrology of a created wetland is not designed correctly initially, the site will not be equivalent to the natural reference sites that serve as models for projects in a given area. Many of the secondary variables—vegetation, soil chemistry, wildlife—will follow based on duration, depth, and frequency of inundation or saturation. Appropriate hydrology, then, is the main criteria for success of created wetlands.

Why does failure occur?

Most of our experience with wetland creation and restoration results from the design of mitigation wetlands required by Section 404 of the 1972 Clean Water Act (Kentula 2000). Evaluations of these wetlands are not encouraging; some studies suggest as many as 50% of created wetlands are "failures" (Mitsch and Wilson 1996). Understanding failure is just as important as understanding success and, indeed, several trends can be identified by synthesizing these failures. In general, there are three key reasons for failure (Mitsch and Wilson 1996):

1. *Lack of understanding of wetland function.* Wetland creation is more of an art than a science (Kentula 2002); there is no certification program or curriculum for wetland managers and due to site-specific nature of problems, the process is relearned virtually every time a new wetland is built. Among those that have some experience, it is widely recognized that

wetland hydrology is the most important variable for wetland functions, but it this knowledge is not always realized in practice.

2. *Insufficient time for wetlands to develop*. "Long-term" monitoring typically involves five years of observation but there are indications that it takes closer to 15 or 20 years for wetlands to develop. Short-term trends in vegetation are not always indicative of long-term success, mainly because wetland hydrology—the most important determiner of function—is controlled by random hydrologic events. Ultimately, wetlands need to be designed to handle uncertainty and persist in the landscape (Kentula 2000) and we cannot fairly judge how well they accomplish this with only five years of data.
3. *Underappreciation for the self-design of wetland systems*. This is usually expressed by means of an overreliance on engineered structures like weirs, dams, and regular basins. Natural wetlands do not need these structures and if a wetland is presented with options in the form of hydraulic connections and a wide range of vegetative inputs, natural forces are fully capable of self-maintenance (Mitsch et. al 2005).

Design Philosophy for Miller Run

Based on these key ideas, there are several points to keep in mind when moving forward with the Miller Run restoration project. First, we must be very clear from the beginning what we hope to accomplish with this project. Thus far, several meetings have been held to ensure that all participants—the Bucknell Environmental Center, Facilities, PA DEP, and others—have the same vision for this restoration; this dialogue should continue. Second, we must give special attention to getting the hydrology right. This is also already a major focus of the restoration efforts and the preliminary designs proposed in this paper should reinforce this. Third, since the Abbey Lane site is a small area with little data and it has not been natural in quite some time, the design will need to rely heavily on studies of natural "reference" wetlands in order to create a system that has the best chance of persisting in this environment. Finally, once construction is complete there must be an adaptive approach to management and a long-term commitment to monitor this project indefinitely in order to accurately evaluate it and ensure success.

Site Description

Location

The Miller Run watershed consists of three subwatersheds: North Miller Run, South Miller Run, and Miller Run (Fig. 1). As previously described, the focus area for these wetlands is the area where South Miller Run enters Bucknell University's property at Abbey Lane.

Figure 1. Miller Run Watershed with proposed wetland site circled. Focus area for wetlands is at the headwaters of South Miller Run near Abbey Lane (adapted from HRG 2010).

History

The history of Miller Run as a permanent stream is questionable. A perennial stream appears on the 1893 United States Geological Survey (USGS) map and on the latest 2010 map; however, it is missing on the 1953 map. This may be due to changes in USGS criteria for perennial and intermittent streams or it may be a sign that Miller Run has experienced long spells when it was primarily dry (HRG 2010; Richard Crago, personal communication). The stream profile was straightened and channelized decades ago and is currently 75-100% channelized, 50% covered by rip-rap, and is the outlet for dozens of stormwater and underground pipes (Burke et al. 2009).

Geology

The area of interest for the proposed wetlands is primarily above Wills Creek shale and sandstone; the Abbey Lane site begins where Bloomsburg shale and sandstone transitions to this formation (Burke et al. 2009). The site soils are dominated by Calvin-Klinesville shaly silt loams with some Albrights silt loam close to Abbey Lane (Web Soil Survey 2004). Since these soils will produce a moderately high rate of stormwater runoff, previous studies have recommended creating retention ponds around the streams as a strategy to slow stormwater rather than relying on increased infiltration strategies (Schaffer 2008). Others have also expressed the belief that the site should be capable of retaining water at the surface but may not be favorable to infiltration (Duane Griffin, personal communication). Mounds of soil near Abbey Lane attest to the fact that the stream carries high sediment loads during peak flows.

Hydrology

Miller Run is a losing stream, that is, the water table does not intersect the stream and runoff does not properly recharge groundwater table (Burke et al. 2009). As a result, the stream frequently goes dry, particularly during summer months. Area land use and the resulting impervious surfaces have significant effects on stream hydrology via increased stormwater runoff, decreased infiltration, and reduced base flow. A clear sign of this altered hydrology is the double peak exhibited by the downstream section in Miller Run's hydrograph (Schaffer 2008; Burke et al. 2009). In natural streams, upstream sections experience peak discharge first and lower reaches peak later after this flow has traveled downstream. However, because of the dozens of stormwater discharge pipes connected to the downstream sections of Miller Run, water rushes to the lower reaches even faster than it can filter to the upstream sections during storm events (Burke et al. 2009). In the future, influxes of stormwater runoff are likely to increase in the Abbey Lane area due to a water easement that allows East Buffalo Township to construct a system to pipe stormwater from a nearby residence to the top edge of Bucknell's property (BUEC 2010). Currently, the upstream reach near Abbey Lane shows clear signs of high sediment loading and has several unnatural elbow bends in the stream profile (Fig. 2).

Figure 2. Section of Miller Run near Abbey Lane demonstrating one of several elbow turns and the debris deposited during high flows.

Based on how this section of the stream floods during storm events, there seems to be evidence that it would benefit from having a more functional floodplain and the opportunity to develop a multi-threaded path (Ben Hayes, personal communication). It is also important to note that shortly after entering Bucknell's property, Miller Run is diverted into pipes for a section underneath the driving range, which also inhibits most of the stream's functions.

Biota

All of Miller Run downstream of the Art Barn (near where North and South Miller Run meet) provides marginal to poor quality habitat for biota in addition to having impaired water quality and low biodiversity (Burke et al. 2009). Previous studies suggest that improving stream flow and water quality will increase biotic potential of stream . These studies also assert that flow permanence and improved flow volume are both essential to Miller Run's sustainability as fish habitat (Burke et al. 2009). While the proposed wetlands may not support fish, they should support amphibians, turtles, and other biota not currently present near the stream (Ben Hays, personal communication).

Proposed Design

Objectives

Given the problems in Miller Run demonstrated by these previous studies, the primary objective of the Abbey Lane wetlands is to increase water retention and storage capacity, thereby increasing base flow. Achieving this objective should begin to improve the hydrologic conditions for biota in addition to controlling stormwater runoff and flooding. Secondary objectives are numerous and include the reduction of sediments, encouragement of native vegetation and habitat, improvement of stream stability, and creation of an outdoor laboratory for academic research and learning.

Hydrology

As emphasized earlier, mimicking the hydrology of nearby reference wetlands is critically important to the success of these wetlands. Fortunately, over the past 15 years, numerous studies initiated by researchers at Riparia (formerly the Penn State Cooperative Wetlands Center) have investigated the hydrologic characteristics of wetlands in central Pennsylvania. Their work suggests that in the absence of long-term monitoring data, the hydrologic behavior of sites in the Ridge and Valley province can be predicted based on HGM subclass (Cole et al. 1997; Cole and Brooks 2000a, 2000b; Cole et al. 2008).

These studies have found that natural wetlands tend to be drier than their created counterparts in the central Pennsylvania area (Cole et al. 1997; Cole and Brooks 2000a, 2000b; Hoeltje and Cole 2007; Cole et al. 2008; Hoeltje and Cole 2009). Since the proposed wetlands are located along a stream of third-order or less whose dominant water source is stream flood flow (Burke et al 2009; HRG 2010), the Abbey Lane site can be considered a headwater wetland area (Cole et al. 2008). In natural headwater wetlands in central Pennsylvania, the median depth to water table is roughly -37 cm and the water table is below the root zones as frequently as it is within the root zone (Cole et al. 1997; Cole and Brooks 2000a, 2000b). The largest flows occur during spring floods but water typically drops out of the root zone quickly, within a few days or weeks of inundation (Cole et al. 1997).

With this in mind, the ubiquitous "ring-around-the-pool" wetlands with deep centers and rings of permanently inundated vegetation would clearly be inappropriate designs for this site. Instead, wetlands should be designed for short-term storage to handle stream overflow and runoff during storm events. For the wetlands at Abbey Lane, I suggest constructing several lowland wetlands at depths that ensure they are inundated several times a year by flooding; in this preliminary design, these are conceptualized as having maximum depths 1 ft above the base of the stream. Upland wetlands, conceptualized as having maximum depths 2.5 ft above the base of the stream, should be designed to handle overflow during the annual flood. Other aspects of the design should also keep in mind the periodic dry spells these wetlands will experience.

Location, Size, and Shape
A detailed schematic of the proposed design presented in Figure 3.

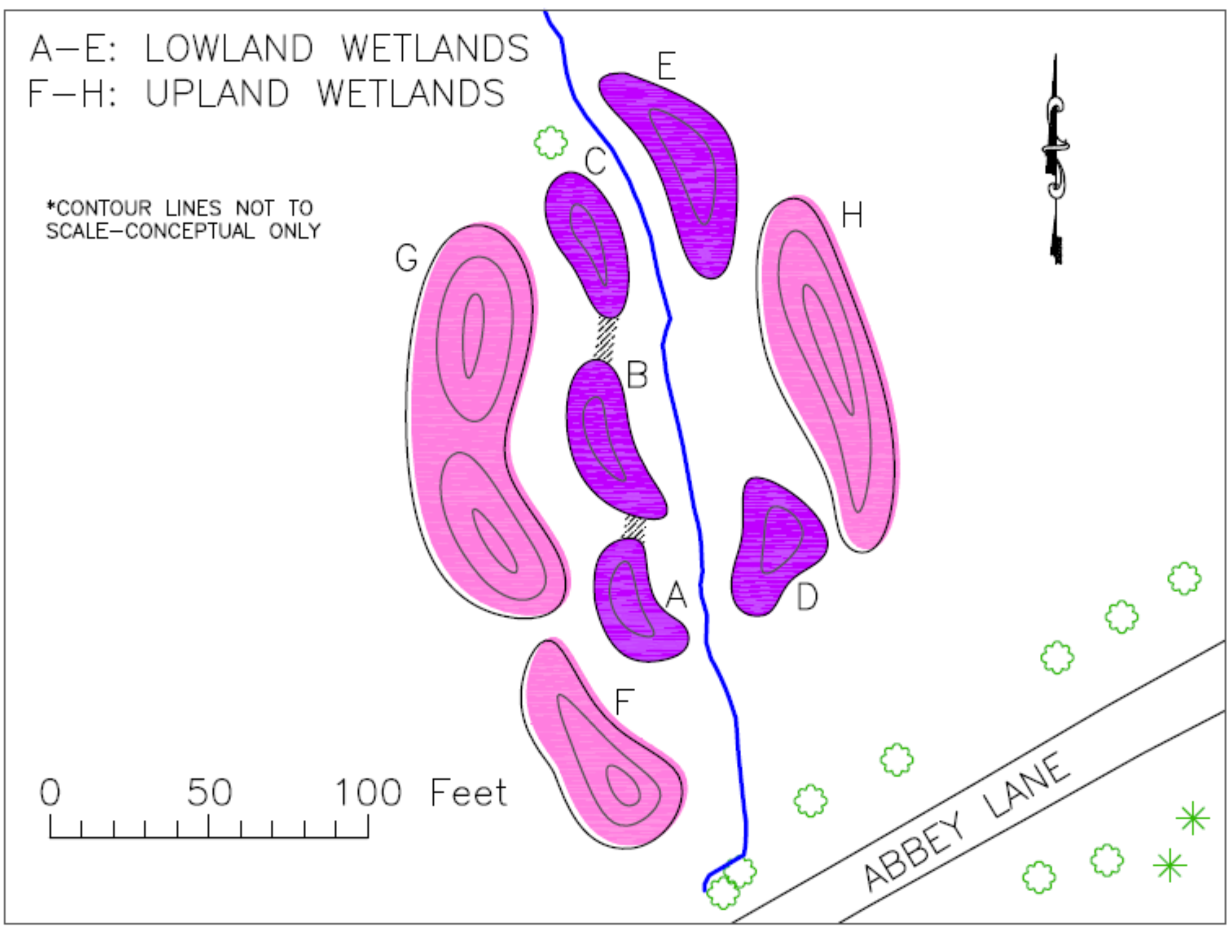

Figure 3. Preliminary design for wetlands at Abbey Lane. Shaded areas between wetlands A, B, and C indicate slight depressions to encourage connection between wetlands.

For the purposes of this paper, the design only extends to the large tree about 350 ft from the edge of Abbey Lane; however, the ideas in this design should be extended further downstream at least to Smoketown Road in order for real benefits to materialize. The total width of the area is about 150 ft and areas of individual wetlands range from 714 ft^2 to 4088 ft^2. All wetlands have irregular edges and are shaped to mimic the natural energies of the stream in an effort to encourage the self-design of the system. Lowland wetlands are placed at the elbow turns previously described in order to allow the stream to develop more natural paths; these wetlands are also connected by narrow depressions so that the stream may flow easily from one site to the next if flows are high enough. These connections provide a mechanism for the stream to develop a multi-threaded network over time. In large storm events (annual chance), the upland wetlands provide additional storage and connections between sites.

Topography

The proposed wetlands are designed to be depressional in order to encourage diversity of slopes and create storage areas for stream overflow (Fig. 3). Gentle slopes of less than 3% are generally preferred for wetlands in order to maximize the richness of vegetation (Admiraal et al. 1997; Gutrich et al. 2009). Work by Gutrich et al. indicates that natural wetlands may even have average slopes closer to 1%, so shallow slopes are highly recommended at the Abbey Lane site (2009).

Wetlands processes also thrive best when the microtopography, the depressions and ridges less than 6 inches in height or depth from the average land surface, are complex (Admiraal et al. 1997). I suggest that final design plans include plus and minus tolerances on the slopes (e.g, 1.5 ± 0.5%) and plan for an irregular soil surface in order to encourage this.

Vegetation and Wildlife

A very important question to resolve is to what degree these wetlands should rely on natural colonization. For the past 15 years, Mitsch and others at Ohio State University have been monitoring a long-term, large-scale experiment looking at the importance of wetland plant introduction on ecosystem function. After 10 years of data on two wetlands—one naturally colonized and the other planted—their findings indicated that the mode of plant introduction can affect plant diversity and productivity for years after wetland creation (Mitsch et al. 2005). In general, planted wetlands seem to be more diverse but less productive than those that have been naturally colonized; however, it is impossible to say which of these traits is "better" for ecosystem functioning (Mitsch et al. 2005). Based on their experience, Mitsch and Wilson advise against "designer" wetlands in which sites are formed with a gardening or landscape architecture mentality since this does not ensure function over longer time horizons and leaves wetlands vulnerable if initial plantings fail (1996; Mitsch and Gosselink 2000). Instead, they argue the best chances for success are when the wetland is provided with many vegetation options via multiple-seedings and transplantings as well as hydraulic connections with other seed sources.

Other studies support the practice of some form of human-assisted vegetation. Gutrich et al. have found that wetland projects with strong "initial effort"—defined as planting hydrophytes or transporting soil seed banks as well as contouring the site—result in vegetative communities that are more similar to natural reference sites (2009). Additionally, Stauffer and Brooks' investigation of the potential of salvaged marsh surface (hydric topsoil from destroyed wetlands) as a revegetation method indicates that while it should not be relied upon as the sole seed source, the addition of salvaged marsh surface may improve plant density and total cover at a site (1997). The simple addition of leaf litter to retain soil moisture and provide soil nutrients also appears to enhance vegetative success (Stauffer and Brooks 1997). Invasive species emerge regardless of vegetation method, but planting and transport of soil seed banks seems to reduce their emergence, at least initially (Stauffer and Brooks 1997; Mitsch and Wilson 2005; Gutrich et al. 2009).

Natural colonization has been successful at pilot wetlands at the nearby Montandon Marsh site, but given the more developed nature of the Abbey Lane site, I suggest slightly more involvement. I recommend a multipronged approach of planting a small variety of appropriate trees, shrubs, and hydrophytes and covering the rest of the site with a layer of leaf litter. Unless a wetland in the area is slated for destruction just prior to construction, it does not seem appropriate to introduce hydric topsoil from other sources, especially since experience at Montandon Marsh suggests that the soil at the Abbey Lane site will likely respond favorably once wetland conditions are created (Ben Hayes, personal communication).

As was previously alluded to, vegetation in these wetlands will be highly dependent on the hydrology and can be expected to experience seasonal variation in water levels. Target vegetation should be native species with inundation tolerances that range from 0-6 inches regular inundation to infrequent inundation. Appendix B of the Pennsylvania Stormwater Best Management Practices Manual provides a good list of species native to PA that fall within these categories, although I recommend that the advice of faculty and area experts guide these details of the design (PA DEP 2006). In addition to hydrophytes, shrubs and trees should be incorporated into the design and used to create shaded regions with cooler waters in which an abundance of organisms may thrive.

Due to its proximity to the golf course, a buffer zone may need to be established between the wetlands and the golfing facilities in order to minimize the impact of grass clippings and fertilizer run-off on water quality. The boundaries of this preliminary design run straight to the edge of the new driving range facilities; a zone of trees and shrubs may be appropriate here if future discussions with the golf course indicate these issues are real causes for concern.

Conclusions

This preliminary investigation has revealed a pressing need for more information on the Abbey Lane site before final design and construction can take place. In order to define slopes and elevations of the wetlands, detailed cross sections of Miller Run at this site should be obtained. More information about the annual chance storm and typical year-round flow for this section of the stream would also be helpful. Once the basic design is adjusted to reflect this new information, a detailed plan for vegetation should be created that addresses reliance on natural colonization or transplant of soil seed banks and specifies the type and amount of species to be planted.

It is also important to note that this project by itself will probably not have a significant impact on Miller Run as a whole unless these themes are continued downstream. Perhaps most importantly, the section of the stream that runs underneath the driving range will need to be daylighted in order for downstream to see the benefits of this first phase of restoration.

By initiating restoration efforts with this Growing Greener Grant, Bucknell has begun a long-term commitment to monitoring and managing the entire Miller Run ecosystem. If the talent of faculty, students, and staff are utilized to the fullest extent, these efforts are likely to be highly successful and the project will provide an incredible educational opportunity for the University.

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