Constructing Ecosystems and Determining their Connectivity to the Larger Ecological Landscape

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1 Introduction

Wetland construction is occurring throughout the world. Once the variety of ecological services provided by wetlands were elucidated,[1] many groups of people conceived the notion of constructing a wetland to perform a specific service in the hope of achieving a cost saving. Wetlands began to be constructed for treating sewage,[2] stabilizing shorelines,[3,4] controlling stormwater,[5] disposing of dredged material,[6] and treating acid mine drainage from coal mining operations.[7] Myriad case studies report a wide range of efficacy for these wetland construction efforts, but these projects benefit from the fact that the service to be provided by the construction is usually a stated goal of the project.

During much of the time that wetlands were being constructed for these specific functions, regulation of natural wetlands by the US Corps of Engineers (under Section 404 of the Clean Water Act of 1977) began to approve permits for wetland fills in exchange for constructed wetlands. Unlike most other 'single service' construction efforts, the goal here was replacement of the suite of services provided by the original wetland. By converting an upland site into a wetland that is structurally similar to the filled wetland, and preferably close to the filled wetland, all services would continue to be provided. Several recent reviews of

[1] J.H. Sather and R.D. Smith, 'Proceedings of the National Wetland Assessment Workshop', FWS/OBS-84-12, Fish and Wildlife Service, Washington, DC, 1984, p. 100.

[2] D.A. Hammer, 'Constructed Wetlands for Wastewater Treatment', Lewis Publishers, Chelsea, Michigan, 1989, p. 831.

[3] E.W. Garbisch, Jr., P.B. Woller, and R.J. McCallum, 'Salt Marsh Establishment and Development', US Army Corps of Engineers, Coastal Engineering Research Center, Ft. Belvior, Virginia, 1975, p. 110.

[4] E.D. Seneca, in 'Rehabilitation and Creation of Selected Coastal Habitats: Proceedings of a Workshop', FWS/OBS-80/27, ed. J.C. Lewis and E.W. Bunce, US Fish and Wildlife Service, Washington, DC, 1980, p. 58.

[5] L.W. Adams and L.E. Dove, 'Urban Wetlands for Stormwater Control and Wildlife Enhancement', National Institute for Urban Wildlife, Columbia, Maryland, 1984, p. 15.

[6] M.C. Landin and H.K. Smith, 'Beneficial Uses of Dredged Materials', Proceedings of the First Interagency Workshop, US Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, 1987.

[7] R.P. Brooks, D.E. Samuel, and J.B. Hill, 'Proceedings of a Conference: Wetlands and Water Management on Mined Lands', Pennsylvania State University, University Park, Pennsylvania, 1985, p. 393.

these 'compensatory' constructed wetlands suggest that the constructed wetlands are generally quite inferior to the predisturbance condition of the natural wetland, although some services may be adequately replaced.[8,9] Other studies have found that wetlands can be constructed as an alternative ecosystem in degraded or damaged lands.[10] This discussion focuses on the rationale for constructing wetlands for multiple services in order to enhance restoration of surface mined areas.

2 Post-mining Site Reclamation

Current reclamation practices may yield sites with a limited ability to perform ecological services. Specifically, services associated with wildlife utilization, water quality enhancement, and hydrologic modification are not maximized. Many post-mining land uses include minimal vegetative diversity that is often limited to non-native members of two families, *Fabaceae* (legumes) and *Poaceae* (grasses). Wildlife utilization potential may be limited by minimal habitat diversity and cover, and a lack of standing water. Many populations may be fragmented by wide reclaimed strips, due to an inability or unwillingness to cross these areas.

Severe water quality problems may also limit site ability to perform ecological services. Low pH and elevated metal concentrations are often associated with surface mining. Wetland treatment systems may be appropriate for such areas since many researchers have found significant treatment efficacy afforded by current technologies.[7] For any given pollutant, a wetland may act as transformer, filter, or sink at any given time.[11] However, the ecological services of wetlands are not all necessarily compatible. The potential for food chain mobilization and biological magnification of surface mine toxicants in wetlands have not been adequately considered in the literature. The burden of proof regarding these ecological risks should fall to those proposing wetland construction for both toxicant removal and wildlife usage. Therefore, wetland construction sites in this study received water within US Environmental Protection Agency water quality standards.

Off-site Impacts

Restoration of a damaged ecosystem should not be limited to approximating local preimpact conditions, but should also consider mitigating damage within the landscape. This would include minimizing off-site degradation caused by the reclaimed ecosystem. Increased sedimentation and exaggerated water flow can accompany the large scale disturbance associated with surface mining in

[8] M.S. Race, *Environ. Manage.*, 1985, **9**, 71.

[9] J.A. Kusler and M.E. Kentula, 'Wetland Creation and Restoration: The Status of the Science', Island Press, Washington, DC, 1990, p. 595.

[10] J. Cairns, Jr., *Min. Environ.*, 1983, **5**, 32.

[11] C.J. Richardson, in 'Freshwater Wetlands and Wildlife', DOE Symposium Series No. 61, ed. R. R. Sharitz and J. W. Gibbons, Office of Scientific and Technical Information, Oak Ridge, Tennessee, 1989, p. 25.

montane regions. Sediment run-off into streams and increased suspended solids have been identified as 'the most destructive features' in surface mined areas with widespread surface disturbance and/or disturbance in steep terrain. The primary cause is removal of vegetative cover, and the sediment deposition in stream channels has deleterious effects on stream biota. Sediment loss from mined watersheds can exceed that for unmined watersheds by a factor of 1000. Sediment reduces light penetration and alters temperature in streams, reduces fish production as food organisms are buried and spawning grounds are filled, and can choke streams and increase potential for flooding.[12]

US Regulatory Agencies, Standards, and Practices

Current reclamation practices have their origin in the Surface Mining Control and Reclamation Act of 1977 (SMCRA; P.L. 95-87) administered by the Office of Surface Mining Reclamation and Enforcement (OSMRE) within the US Department of the Interior. In Virginia, the Division of Mined Land Reclamation (DMLR) has promulgated regulations and assumed primacy, and OSMRE retains a supervisory role. These extensive regulations were phased in over several years and exerted a dramatic influence on reclamation. Among its components, the SMCRA called for the replacement of the approximate original contour (AOC) following mineral removal, extensive monitoring of water quality parameters, minimal standards for revegetation, and the use of sediment control structures (usually referred to as sediment ponds).

One of the effects of the 1977 law, although perhaps unintended, was the rapid dewatering of reclamation sites. The return to approximate original contour helped drain much of each reclamation site. Saturated soils at the foot of a fill were also undesirable due to concern for AOC fill stability, since the structural integrity of fills could be weakened by significant wetting of the material. Another reason to channel water away from reclaimed sites was the occasional exposure of pyritic material, which led to generation of acidic and concentrated iron and manganese discharges from operations that exposed significant volumes of pyritic material. Any part of a reclamation site with a discharge point would necessitate a water quality permit (National Pollution Discharge Elimination System). Since most of the reclamation site was well drained, the species planted to revegetate were primarily obligate upland species, *i.e.* species that occur in wetlands less than 1% of the time.[13] Not surprisingly, these species failed to colonize the poorly drained portions of reclamation sites. With considerable pressure to maintain well drained and densely vegetated conditions at reclamation sites, reclamation designs included moderate to steeply sloped contours and rock drains to confine the water to a channel and quickly remove it from a site. Thus, sediment ponds were the only areas designed to retain moisture, but regulations allow sediment pond removal within two years of the start of reclamation.

[12] R. D. Hill and E. C. Grim, in 'Recovery and Restoration of Damaged Ecosystems', ed. J. Cairns, Jr., K. L. Dickson, and E. E. Herricks, University Press of Virginia, Charlottesville, Virginia, 1975, p. 290.

[13] P. B. Reed, Jr., 'National List of Plant Species That Occur in Wetlands: National Summary', US Fish and Wildlife Service, Washington, DC, 1988.

3 Constructed Wetlands in Coal Mining Regions of Southwest Virginia

Even though reclamation practices evolved to exclude saturated soils, language in Virginia DMLR regulations allows inclusion of 'depressions' for the benefit of water retention for wildlife. Section 480-03-19.816.102, backfilling and grading paragraph (h), merely states that depressions may be left for wildlife, sediment retention, and flow amelioration. Although ecologically sound, the lack of engineering guidance regarding design specifications proved prohibitive. Coal company reclamation personnel lacked a definition of a depression and how to construct this feature on a reclamation site. Requirements for an ongoing OSMRE-funded study conducted by our University Center for Environmental and Hazardous Materials Studies included: (1) providing coal companies with design specifications and (2) providing DMLR with compliance monitoring criteria.

As with most restoration research, practical application is the primary goal, though theoretical advances are often associated with well-planned studies. Practical considerations in this case included the willingness of coal operators to include constructed wetlands in post-mining reclamation plans. Several concerns had to be addressed. The constructed wetlands could come under US Army Corps of Engineers (Corps) regulatory authority, which could require notification of wetland fills if land use changes occurred in the future. In this region of Southwest Virginia, the primary reason these constructed wetlands might be filled would be remining. In that instance, a Corps permit to fill the wetlands might be issued so long as constructed wetlands were again a component of the post-remining reclamation plan.

Both DMLR and the coal companies expressed concerns over liability associated with accidental drowning by swimmers and fishers. This necessitated design modifications, and an agreement of a maximum depth of 1.2 m was reached. A second liability and DMLR regulatory considerations were associated with the construction of dams. The solution for this concern was to limit dam height to no more than 0.6 m and achieve the 1.2 m maximum depth primarily by excavating the depression.

A third concern of coal companies dealt with acid mine drainage (discussed earlier and at greater length in other articles in this volume). Some mining operations expose acid generating strata and other toxicants may also be present [iron and manganese are often associated with the sulfuric acid that is generated from contact with pyritic strata, and the solution is referred to as acid mine drainage (AMD)]. Current regulations do not allow bond release for sites where AMD treatment is occurring, and wetlands receiving AMD are considered treatment facilities.

Landscape Compatibility

A principal consideration in constructed wetland design is landscape compatibility. Cove hardwoods, hemlocks (*Tsuga canadensis*), and *Rhododendron* spp. communities that are associated with mountain streams in the unglaciated Allegheny Plateau become fragmented by strip mining. Restoration of this community requires: (1) halting environmental degradation and (2) establishing a community that can perform ecological services and lead, through succession, to an approximation of the predisturbance community.

After mining, the coves are replaced by broad, flat areas crossed by intermittent, often braided streams. Small depressions could be designed to retain water in this area. The historical presence of beaver (*Castor canadensis*) provided a natural model for a regionally appropriate wetland type. Dam construction by beavers in the region leads to small (less than 1 hectare), palustrine, open-water wetlands that follow a successionary pathway that generally includes submergent, emergent (herbaceous), scrub–shrub, and then forested wetlands. This sequence has often been abbreviated in the southern Appalachians as a result of sedimentation, first from deforestation around the turn of the century and then from surface contour (or opencast) mining.

The potential for wetland establishment on surface mined lands is provided by wetlands that formed 'accidentally' following surface mining before recent legislation. Prior to SMCRA, contour surface mining left many depressions. These areas collected sediment from the often poorly revegetated adjacent areas, filled with water, were colonized by wetland plants, and were a source of water for both upland and wetland wildlife.[14,15] In addition to satisfying both the hydrology and vegetation criteria of the legal definition of wetlands, the hydric soil criterion has also been met by virtue of demonstrating both low chroma (below two) and oxidized rhizospheres.[16,17] These wetlands are classified as palustrine, emergent wetlands.[18] Microbes, macrophytes, invertebrates, fish, amphibians, reptiles, birds, and mammals have been catalogued for many accidental wetlands. Waterfowl surveys from 1956 to 1985 listed 59 species for coal surface-mined wetlands in Illinois, USA.[19]

A Model for Wetland Construction

Review of natural and accidental wetlands in the region has provided a model for wetland construction, which is being field validated. Wetlands are being constructed in a series of three, each approximately 10 × 50 m and up to 1.2 m deep. The first (upstream) wetland in each series is expected to accumulate sediment quickly as revegetation progresses and to limit sedimentation in the next two wetlands in the series. Accidental wetlands were used as donors for

[14] A. A. Arata, *J. Wildl. Manage.*, 1959, **23**, 177.

[15] R. Bell, *Ill. Acad. Sci. Trans.*, 1956, **48**, 85.

[16] Environmental Laboratory, 'Corps of Engineers Wetlands Delineation Manual', Technical Report Y-87-1, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1987.

[17] Federal Interagency Committee for Wetland Delineation, 'Federal Manual for Identifying and Delineating Jurisdictional Wetlands', Cooperative Technical Publication, US Army Corps of Engineers, US Environmental Protection Agency, US Fish and Wildlife Service, and USDA Soil Conservation Service, Washington, DC, 1989.

[18] L. M. Cowardin, V. Carter, F. C. Golet, and E. T. LaRoe, 'Classification of Wetlands and Deepwater Habitats of the United States', FWS/OBS-79/31, US Fish and Wildlife Service, Washington, DC, 1979, p. 103.

[19] J. R. Nawrot and W. D. Klimstra, in 'Animals in Primary Succession', ed. J. D. Majer, Cambridge University Press, Cambridge, England, 1989, p. 269.

hydric soils to provide both a seed source and a microbial community in order to hasten wetland establishment during the bond period. Soil amendments are only made to the second in each series since: (1) soil amendments to the first wetland probably would be buried by alluvium and (2) successful establishment in the second wetland should provide a source of propagules for the third wetland, thereby reducing construction costs and limiting disturbance to accidental wetlands.

Ecological Services

Wetlands are known to provide a diverse array of ecological services, many of which are closely linked with wetland functions. Included are wildlife habitat, water quality enhancement, and hydrologic modification. Maximizing performance of these three ecological services represents the goal for wetland construction on surface mined lands in our current study. Their potential relevance to the landscape is discussed below.

Wetlands provide a variety of benefits to wildlife. Many wetlands exhibit high primary productivity that supports wetland food webs and provides nesting sites for wetland fauna.[20] While these wildlife benefits derived from wetlands are recognized as being locally significant, wetlands constructed in natural drainageways on surface contour mined land may be positioned to perform additional services in a landscape and restoration context: (1) wetlands that connect unmined areas at elevations above and below the mined area may perform corridor services by providing an aquatic medium for some species and cover for others to pass through;[21] (2) wetlands may provide habitat amenities for wetland species and upland species in the region; (3) the attraction of both upland and wetland fauna to the constructed wetlands may lead to import of both upland and wetland propagules; (4) export of organic matter to aquatic communities downstream from constructed wetlands may be a more suitable substrate (and possess greater mass) than upland-derived allochthonous inputs.

The role of animals in restoration is understudied, but many researchers assign a great importance to animals in restoration.[22] One example is a study of turtles in freshwater wetlands.[23] Turtle productivity ranged from 7.3 $kg\,ha^{-1}\,yr^{-1}$ to 9.7 $kg\,ha^{-1}\,yr^{-1}$. Importance of turtles includes food for terrestrial species since roughly 40% of their productivity is egg production and since nest predation rates, *e.g.* by red fox (*Vulpes vulpes*) and raccoons (*Procyon lotor*) may exceed 95%. Turtles may recolonize disturbed sites because of their ability to move overland, which allows them to serve as vectors for wetland plants.[23] Majer[22] reviewed several faunal studies of surface mine restoration and concluded that certain plant species facilitate particular animal invasions, and those animals may alter sites to favor additional plant and animal immigrations. It seems likely, although difficult to quantify, that wetland corridors through a strip-mined area

[20] W. J. Mitsch and J. G. Gosselink, 'Wetlands', Van Nostrand Reinhold, New York, 1986, p. 539.
[21] R. T. T. Forman and M. Godron, *Bioscience*, 1981, **31**, 733.
[22] J. D. Majer, 'Animals in Primary Succession, The Role of Fauna in Reclaimed Land', Cambridge University Press, New York, 1989, p. 547.
[23] J. D. Cogdon and J. W. Gibbons, in 'Freshwater Wetlands and Wildlife', ed. R. R. Sharitz and J. W. Gibbons, US Department of Energy, Washington, DC, 1989, p. 583.

would increase floral and faunal establishment both in and adjacent to the wetlands.

The major pollutants from surface-mined coal sites are acid mine drainage and sediment. Although acid mine drainage is often not associated with surface mining, treatment of this pollutant is best performed by wetlands designed specifically for this function. Conversely, sediment removal processes may be compatible with wildlife services. Sedimentation rates should be highest during the earliest periods following reclamation and should slow as revegetation progresses in the watershed. The initially high sedimentation rates may improve constructed wetland development by providing a suitable substrate. Since soils in reclaimed sites are typically compacted by the heavy equipment, loose sediments in the constructed wetlands may facilitate aquatic macrophyte invasion and enhance vegetative cover and productivity.

Ecological services performed by constructed wetlands with regard to water quality may also exert positive effects at the landscape level. Since sediment ponds may be removed after two years following the start of reclamation, the wetlands may provide sediment retention services that would protect aquatic communities downstream. Standard reclamation measures may include nutrient applications, some of which could be transported through run-off and impact communities downstream. Wetlands have been shown to improve water quality by ameliorating excess nutrient inputs.[24]

Wetlands constructed on surface contour mined land have the potential to provide landscape level ecological services related to floodflow modification. The ability of wetlands to store flood water and to release that water slowly over time may provide two benefits. First, reduced flood peaks may limit disturbance of communities downstream. Second, slow release of water over time might help maintain hydric conditions by supplementing base flows.[25] The latter could facilitate faunal use further upstream, thus enhancing landscape connectivity.

Some data from accidental wetlands support the notion that constructed wetlands may perform these ecological services. To date, 94 plant species have been found associated with 14 accidental wetlands in our study. In June, the mean number of species per site was 17.77 ± 7.51, rising to 18.29 ± 7.49 in August. The presence of so many species that were not planted at sites of approximately fifteen years post-reclamation suggests that these areas may attract wildlife that bring more propagules, although causality has not been established. That is, we have no data to confirm whether most plant species were brought by animals or whether animals were attracted by the plant species diversity. Although somewhat circumstantial, evidence for corridor services is provided by the presence of several amphibian species within, and both upstream and downstream from, accidental wetlands. Upland and wetland, small and large mammal tracks were found in shoreline sediments. For example, evidence from

[24] R. P. Gambrell and W. H. Patrick, Jr., in 'Plant Life in Anaerobic Environments', ed. D. D. Hook and R. M. M. Crawford, Ann Arbor Science Publishers, Ann Arbor, Michigan, 1978, p. 375.

[25] G. G. Hollands, G. E. Hollis, and J. S. Larson, in 'Mitigating Freshwater Wetlands Alterations in the Glaciated Northeastern United States: An Assessment of the Science Base', ed. J. S. Larson and C. Neill, University of Massachusetts, Environmental Institute, Amherst, Massachusetts, 1986, p. 131.

tracks suggests that racoons exhibit nightly utilization of accidental wetlands as well as wetlands upstream and downstream.

Accidental wetlands appear to perform sediment accumulation and retention services. Preliminary results suggest that mean annual sediment accumulation rate is from 1 to 4 cm p.a., and greater during the first years after reclamation. No correlation has been detected between sedimentation rate and species richness in accidental wetlands; however, portions of accidental wetland sites with compacted soils, *e.g.* little or no accumulated sediment, exhibit low cover (preliminary biomass data also suggest lower biomass in portions of accidental wetlands having compacted soils). Accumulation rates may be lower in constructed wetlands due to better revegetation of adjacent upland areas in modern reclamation practices. However, recently reclaimed sites may comply with current revegetation standards and still exhibit significant soil loss, even after sediment ponds have been removed. Therefore, constructed wetlands may perform ecological services related to sediment trapping at both the local and landscape levels.

Evidence for hydrologic modification is perhaps less reliable. Standard deviation for mean water levels in accidental wetlands was low (3.4 cm), suggesting minimal water storage. However, accidental wetlands were located on fully revegetated mine sites with broad benches. Both factors could limit exposure of accidental wetlands to flood peaks and preclude opportunities to perform flood reduction services. Flood reduction services may be provided by constructed wetlands on newly reclaimed sites where these factors may be limited. The low standard deviation further suggests that accidental wetlands may exhibit fairly continuous discharge, which may help maintain flow in aquatic communities downstream.

Considerable temporal changes can be anticipated for both the constructed wetlands and the landscape in which they occur. Allochthonous materials (primarily sand, silt, and clay sediment deposits) are likely to comprise the bulk of the inputs through the first five years. Autochthonous inputs are likely to predominate during subsequent years as aquatic macrophyte cover and productivity increases. These abiotic and biotic processes have not been fully quantified for the accidental wetlands, and newer reclamation techniques limit the utility of accidental wetlands as a model for constructed wetland ontogeny; however, the likelihood that constructed wetlands will function as sinks for both inorganic and organic matter suggests that these systems will become shallower over time. Flood-intolerant species will slowly encroach around the margins and obligate wetland species (*e.g.* cattail, *Typha* spp.) may be out-competed by facultative species (*e.g.* wool grass, *Scirpus cyperinus*, and soft rush, *Juncus effusus*).[13] In addition to shifts in species composition, physiognamic changes in vegetation may lead to a change from emergent to scrub–shrub and/or forested wetlands.

Changes in the landscape can also be anticipated. Unpredictable human-induced disturbances, *e.g.* logging of adjacent areas, are quite possible in the region. Insufficient data on reclamation exist to predict successional direction for the strip-mined area. In addition, successional direction of constructed wetlands cannot be predicted from accidental wetlands with high accuracy due to the novel conditions present during constructed wetland development. As a result, the long-term need for ecological services, such as sediment trapping and hydrologic modification, cannot be anticipated. Ecological services related to habitat are likely to change as the landscape components change; however, the similarity to beaver pond ontogeny and position in the landscape suggest that habitat services should continue to be performed.

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