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A Functional Assessment of Stream Restoration in Ohio

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Abstract

Stream restoration has become a multi-million dollar industry while the science and techniques are still relatively immature. A wave of early projects are now established and lend themselves to systematic appraisals. To increase our understanding of stream restorations throughout Ohio, 51 stream restoration projects, comprising primarily physical reconfiguration, were characterized and several elements of their ecological integrity evaluated. The stream restoration projects assessed were constructed primarily to mitigate channel impacts from land development (94%). The lengths of individual projects were limited (median 1117 ft). The streams affected tended to be very small headwaters (median drainage area 224 ac). They also tended to be low energy (median stream power, 14 lb_f/(s·ft) at 2 yr peak discharge), with some very low energy more naturally associated with wetlands (25% < 5 lb_f/(s·ft) at 2 yr peak discharge). A multi perspective evaluation of ecological integrity emphasized physical characteristics (morphology, hydraulic process, vegetation, soil and habitat) and their deviation from natural condition. The most striking deficiency in morphology was the lack of connectivity with a floodplain. Relative to natural conditions, floodplains were most often both narrow and high. Performance standards were evaluated based on their correlation with modeled floodplain connectivity. In-stream structures were almost all riffles but indeterminately constructed for habitat or grade control. The riffles were largely stable. However, they were often filled with fines and colonized by wetland vegetation. Soil investigations revealed soil quality of many sites similar to reference soils but a similar number of sites were considerably worse, dominated by subsoil with poor consistence and low organic matter, permeability or root density. Predicting the quality of soil characteristics ($R^2=0.69$, $P<<0.001$) was best achieved by weighing the amount of in-situ and depositional A horizon against the amount of in-situ and constructed C horizon. The headwater habitat evaluation index (HHEI) scores showed virtually no correlation with other characteristics of ecological integrity. The only significant correlation was a positive correlation with stream power. The success of the observed stream restoration projects, as measured by several aspects of physical condition, varied widely despite meeting required permit performance criteria. The results of this study demonstrate a need for physical standards for restoration projects that physically reconfigure streams.

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Introduction

The physical alteration of stream channels has been taking place in Ohio since the mid-1800s. Tens of thousands of miles of streams have been channelized (Pavelis 1987). This monumental effort was undertaken primarily to improve the use of the land through improved drainage or reduced flooding (Keller 1976, Brookes 1988, ODNR 2008 and ODNR 2009). Only recently has ecological integrity become a common goal for channel work. While streams continue to be modified for drainage and flood control, there is now the added expectation for many of these projects to minimize ecological impacts. In addition, a growing number of channel modification projects now are undertaken for the sole purpose of improving ecological condition (Shields et al 2003 and Bernhardt et al 2005).

No one term precisely encompasses the projects assessed in this report, so we will imperfectly refer to them all as restoration. What constitutes *stream restoration* has been debated at length (NRC 1992 and Shields et al 2003). Noting that restoring pre-settlement conditions is rarely obtainable, restoration has been proposed to mean restoring the biota and ecological processes and services (Shields et al 2003, 33 CFR 332.2). This partial restoration has alternatively been described with terms such as renovation and rehabilitation. Either way the idea implied is to improve the existing condition, which is not necessarily the case. For example, where land development impacts a quality stream, the goal is to minimize ecological impacts. Most projects have been constructed for reasons other than ecological improvement. By restoration, we mean only that, within site constraints, one of the project goals was to maximize ecological condition.

Typically, stream restoration projects have occurred for *mitigation*, defined by Shields et al (2003), as “an activity to compensate for or alleviate environmental damage. Mitigation may occur at the damaged site or elsewhere. It may also involve site restoration to an acceptable condition, but not necessarily to a natural condition”. Not included in this report are projects that provide stream preservation or stream bank stabilization for infrastructure protection which are sometimes confusingly lumped together with restoration.

Ecological restoration may at times consist of manipulation of the biota including planting trees, reintroduction of species or control of invasive species. However, for the purposes of this study, stream restoration projects are limited to those that involve *reconfiguration* with a substantial change in channel form.

In spite of having no concise definition, the types of projects reviewed in this report demonstrate an initial attempt at implementing a new norm for the physical alteration of stream channels. Enough projects have been constructed and are becoming established to allow for meaningful evaluation. Learning from these projects was *the goal of this assessment*, specifically better understanding which techniques are most appropriate for assessment, evaluation and measuring success, and identifying elements of standards and guidelines that will

lead more efficiently to successful projects. For stream reconfiguration projects, undertaken at least in part to benefit ecological integrity, this report will:

- describe the characteristics and types of streams being restored,
- evaluate restoration success based on an array of ecological functions,
- explore methods understood to be integral with the ecological function, specifically elements of physical condition influenced by reconfiguration projects that may serve as practical indicators of less tangible ecological functions.

Background

Stream Restoration Monitoring and Assessment

Although the terms stream mitigation, restoration, renovation, reclamation and rehabilitation have been used throughout the scientific literature for several decades; the science is still relatively immature (Tompkins and Kondolf 2007). Early on, Kondolf (1996) encouraged systematic studies to evaluate the success of stream mitigation projects attempting to restore ecological function. The lack of pre-project and post-project multi-disciplinary data was seen as a weakness in the scientific community's ability to collectively learn about each project's effectiveness. Kondolf recommended monitoring a broad array of stream characteristics to accumulate knowledge on successes and failures.

A database of 1,345 stream restorations constructed between 1970 and 2004 in the upper Midwest (Michigan, Ohio and Wisconsin), was compiled by Alexander and Allan (2006) as part of the National River Restoration Science Synthesis project to evaluate the effectiveness of commonly used stream restoration practices. Alexander and Allan emphasized the need for more detailed and standardized evaluation. The monitoring results that did exist were generally discouraging. Fewer than half of the 1,345 regionally completed projects evaluated by Alexander and Allan (2007) were described as ecologically successful. According to Alexander (2005) in her study of Michigan, Wisconsin and Ohio streams, the majority of the restoration projects were not sustainable and chemical parameters showed no change after restoration indicating that the stream's assimilative capacity had not increased. Rather than seeing improved watershed scale results, Alexander and Allan (2006) observed a trend toward increasing project costs and decreasing project lengths over time, indicating more money was being spent on smaller and more expensive projects. They also noted an increasing tendency to refer to channel stabilization projects as restorations. According to the National River Restoration Science Synthesis project, many projects were implemented to address the symptoms of an environmental concern without first understanding the larger scale processes underlying the observed environmental degradation (Tompkins and Kondolf 2007).

Two notable methods have been proposed specifically for ecological assessment of stream restoration. The first is the post project appraisal (PPA) protocol described by Downs and Kondolf (2002) which was an exhaustive list of physical assessments with streamflow data; conveyance data; channel roughness; channel cross sections; longitudinal profile; channel bed material; aquatic habitat mapping; mapping emergent, riparian and floodplain vegetation; floodplain deposition samples; and comparisons of historical aerial photos. Another assessment method proposed was more a list of guiding principles. Palmer et al (2005) suggested restoration: 1) be based on an image of a dynamic healthy river; 2) measurably improve ecological condition; 3) be self-sustaining and resilient to external perturbations; 4) cause no lasting harm; and 5) have pre and post-assessments completed and publicly available. These two very different restoration assessment methods are ecologically comprehensive. However, neither provides much specific guidance or definitive criteria for stream restoration regulation

or design. Well-founded stream restoration tools and assessment methods are not yet broadly established.

A third method is specifically a tool for the review of stream restoration proposals called RiverRAT for River Restoration Assessment Tool. It was developed by NOAA Fisheries and US Fish and Wildlife with an emphasis on west coast salmonid stream restorations. It starts with 16 questions regarding problem identification, the technical basis of the design and adequacy of assessment measurements. It goes on through links to a companion document, “Science Base and Tools for Evaluating Stream Engineering, Management and Restoration Proposals” to provide an in-depth resource suitable for large stream restoration challenges.

Ecological Integrity

Ohio’s stream mitigation/restoration programs have a sound conceptual foundation based on ecological integrity, defined by Karr and Dudley (1981) as the ability of a system to maintain and repair itself. Smith et al (1995) explained ecological integrity as the integration of nested ecological functions composed of a hierarchy of the all things a system does, starting with the individual processes such as nitrogen removal, flood control or support for a specific biotic community as simple functions nested in broader processes all the way to the most complex, ecological integrity, which is the maintenance of all the integrated functions (Figure 1). *This conceptual framework connects broad stream functions to measurable stream characteristics.* The denitrification process, for example, necessarily entails denitrifying bacteria and organic matter in anoxic conditions. Peak flow attenuation by the process of flood routing is determined by measurable floodplain form and quantifiable channel and floodplain roughness. Vegetation communities require light and soil with quantifiable characteristics.

Some components of ecological integrity are influenced by stream projects more than others. In this assessment, an attempt was made to evaluate component variables most sensitive to the physical modifications of stream reconfiguration.

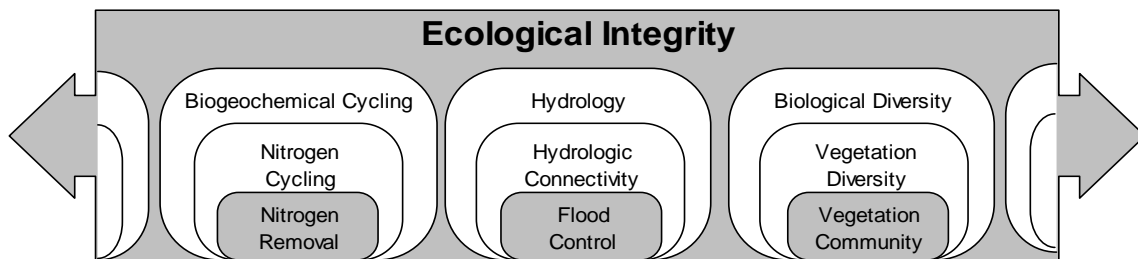


Figure 1 Ecological integrity is the integration of a hierarchy of many simpler functions down to individual ecological services (adapted from Fennessy, 2007 and Smith 1995). The simpler the function, the easier it is to describe by quantifiable structure and process variables.

Monitoring and Assessment in Ohio

An advantage when conducting monitoring and assessment studies in Ohio is that Ohio EPA’s Division of Surface Water has been a national leader in using biological indicators to assess overall stream ecological integrity. Ohio EPA has developed a widely used Index of Biotic

Integrity (IBI) tool for fish assessment, an Invertebrate Community Index (ICI) tool for macroinvertebrates, and the Qualitative Habitat Evaluation Index (QHEI) and Headwater Habitat Evaluation Index (HHEI) tools for habitat quality assessment.

Ohio EPA recently initiated a study of the effects of stream restoration on fish and macroinvertebrate communities. Two years of pre-restoration data have now been collected (Ohio EPA 2009b and 2010a). Post construction studies by Ohio EPA will document the effectiveness of the biological recovery. These Ohio EPA biotic studies are specifically on Clean Water Act Section 319 funded stream restoration projects and do not include Clean Water Act Sections 401/404 permitted stream mitigation projects which tend to be relocated channels on developed sites rather than streams selected for restoration.

The 401/404 projects are monitored by the permittee, generally for stability, habitat and any special permit conditions. The monitoring period is a minimum of five years post construction with annual reports submitted to Ohio EPA and the US Army Corps of Engineers, both of which make site visits in the third and fifth year.

Compared to Ohio's established stream monitoring programs that assess the overall condition of Ohio's streams, monitoring more applicable to stream reconfiguration projects is still developing. Generally, assessment of physical integrity is now limited to aspects of habitat.

By comparison, considerable monitoring work that includes key physical attributes has been completed for Ohio wetlands. Ohio EPA generated four studies on the effectiveness of wetland restoration (Fennessy and Roehrs 1997, Porej 2003, Kettlewell 2005 and Micacchion et al 2010) and one report on the ecological effectiveness of wetland mitigation banks (Mack and Micacchion 2006). Ohio EPA developed the Ohio Rapid Assessment Method (ORAM) screening tool to determine the integrity of wetlands and the likelihood a comparable wetland could be created elsewhere. Ohio EPA also requires that the functions of mitigated wetlands be assessed and compared to natural wetlands using one of several OEPA vegetation, macroinvertebrate or amphibian wetland assessment tools (Micacchion 2004, Mack 2007 and Ohio EPA 2004a). Ohio EPA has used the results and conclusions of these wetland studies to better clarify the physical, chemical and biological requirements for future mitigated wetlands to be created under Section 401 requirements.

Physical Integrity

Water quality is a compilation of physical, chemical and biological integrity as defined by the Clean Water Act, the cornerstone protection for surface water quality. Since 1972 and the promulgation of the Federal Water Pollution Control Amendments, including The Clean Water Act, projects that physically changed streams by moving the centerline or placing fill required a permit and mitigation activities for those impacts.

Even though there is a lack of broadly established stream restoration assessment tools, there appears to be agreement that morphology, or the study of form, is a logical part of stream

assessment. (This seems particularly apt for restoration involving stream reconfiguration.) Morphological assessments are based on direct measurements of the channel cross sectional dimension, longitudinal profile and meander pattern (Richards 1982). Stream form and process are inextricably coupled and thus an extension of direct measurement of stream form provides estimates of processes that take place at various flow rates. Vegetative roughness, velocity, shear stress and stream power are but a few of the process values routinely estimated as part of stream morphology assessment (Rosgen 1996).

Morphology assessment includes the entire area of the stream, not just the narrow strip typically wetted by daily flow but instead the entire width covered by high flows. Assessment of the floodplain is valuable because stream processes are largely episodic, during periods of high flow (Kondolf 2006). The flood pulse concept postulated by Junk, Bayley and Sparks (1989) described stream functions responsible for the productivity of river-floodplain systems as “batch processes” occurring at high flow. Palmer (1976) proposed the concept of a streamway to be inclusive of the portion of the valley that the dynamic meandering stream system occupies over time. The compound form that most natural channels exhibit with relatively broad floodplain and narrow channel allows streams to be self-maintaining through low flows and floods with a range of energy that crosses orders of magnitude (Leopold 1994). Thus, the forms that streams take at all flow rates are key to the evaluation of stream morphology.

A standard technique used in stream morphology is scaling proportional to the channel itself. The bankfull channel is consistently associated with those intermediate discharge rates that are both powerful enough and occur frequently enough to be most influential in the channel forming processes (Dunne and Leopold 1978). The bankfull channel dimensions commonly serve to normalize measured values and allow comparison of the characteristics of different size streams. For instance, floodplains can be described in terms of the number of times wider than the bankfull channel width. A floodplain 20 times wider than its bankfull channel is extensive whether it is a little headwater stream or a major river. Similarly, flood stages are expressed in multiples of the bankfull channel depth. For example, the width of flow at the stage two times the maximum bankfull channel depth defines the often-used term floodprone width (Rosgen 1994).

In addition to a stream’s form and processes, another physical aspect is the material of which it is composed, its subsurface lithology. Streams do not simply flow over an impermeable two-dimensional surface, but flow through banks, beds and floodplains laterally and vertically (Figure 2). Ground water and shallow hyporheic water flow through channel bed material and riparian soils. Van der Putten (2004) described the ecological services provided by natural floodplain soils including retention of nitrogen in biomass, physical stabilization, interception of runoff, moisture retention, evapo-transpiration and carbon sequestration. For these, he described the necessity of soil supporting soil organisms (bacteria, fungus, nematodes, protozoa, earthworms and isopods). The material composition of a streamway has an intricate role in its ecological functions and is certainly manipulated by restoration work.



Figure 2 Water movement through streams emphasizing pathways between channel and riparian area. (From the Committee on Riparian Zone Functioning and Strategies for Management, 2002. Reprinted with permission from the National Academies Press, Copyright 2002. National Academy of Science. Riparian Areas; Functions and Strategies for Management).

Headwater stream channels have been lowered over a large portion of Ohio (Figure 3), virtually without exception in low gradient landscapes, to facilitate drainage. Soil stratigraphy is of particular concern in riparian areas where channelization occurred, because deeper strata tend to be less conducive to stream functions. For example, an earlier assessment by Division of Soil and Water Resources (DSWR) compared deeper strata to the upper layers of natural soil for 34 previously channelized streams in Ohio showing an average of 24% reduction in available water capacity, 35% reduction in permeability and a 73% reduction in organic matter, based on data compiled from Ohio soil survey physical properties (Mecklenburg 2008).

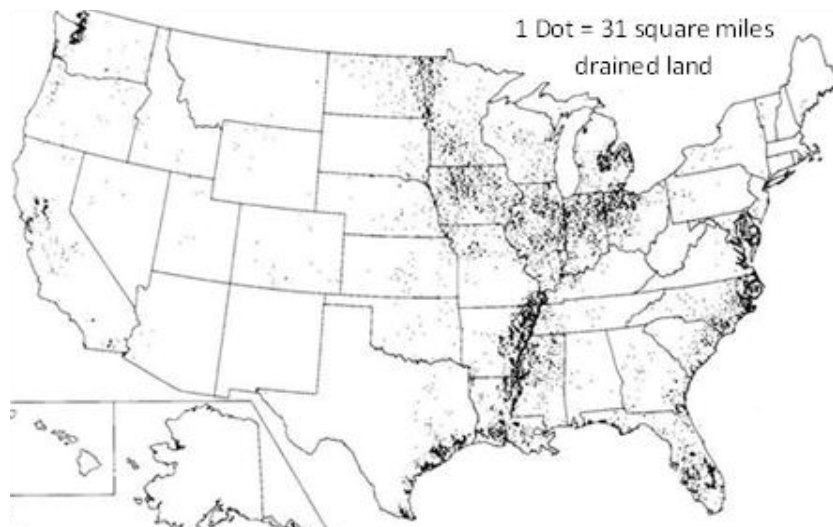


Figure 3 Distribution of drained lands in the United States (Pavelis 1987).

Methods

The physical condition of restored streams was investigated using multiple disciplines: morphology, vegetation, soils, and habitat. Characteristics were selected for their key functional roles in the nested scheme of ecological integrity.

Selection of Study Sites

For this study, 51 projects involving substantial channel modification were selected for monitoring from the total 518 permits issued in Ohio from 1996 to 2007. Permitted stream projects were those regulated by Ohio EPA Division of Surface Water's 401 Section, the United States Army Corps of Engineers' Nationwide permit 27 and 38, and Superfund cleanups (Figure 4).

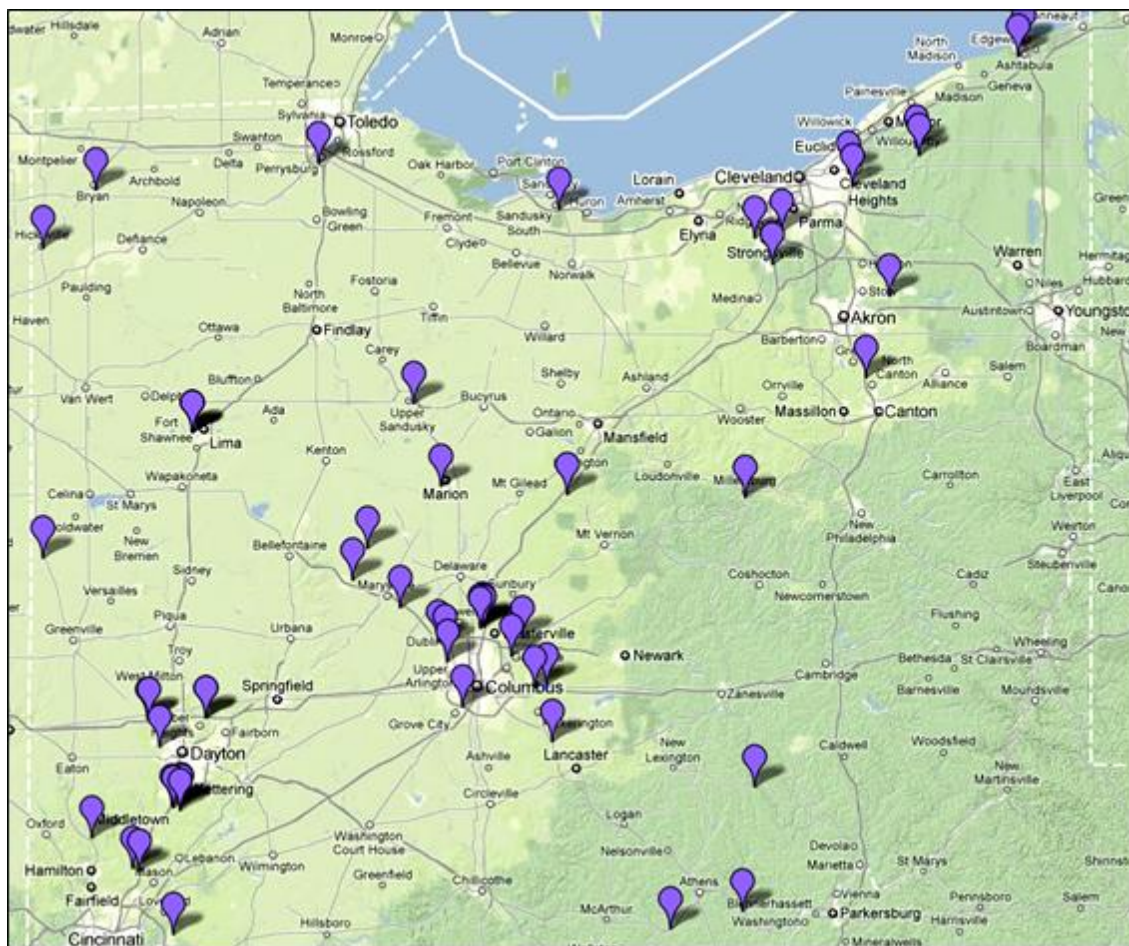


Figure 4 Assessed project site locations.

<http://maps.google.com/maps/ms?ie=UTF8&hl=en&msa=0&msid=107960685558029914341.000452b1247b2a72059da&ll=40.375844,-82.650146&spn=4.017137,6.696167&t=p&z=8>

The Ohio EPA's 401 Section provided DSWR a list of all projects that authorized stream impacts and required stream mitigation. Four hundred thirty six Section 401 projects were issued for stream impacts between 1996 and February 7, 2007. DSWR also obtained lists of 10 stream projects that were issued permits by the Army Corps of Engineers under Nationwide 38

