A Function-Based Review of Stream Restoration Science

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INTRODUCTION

In 2008, the U.S. Army Corps of Engineers (Corps or USACE) and the U.S. Environmental Protection Agency (EPA) released regulations on compensatory mitigation under § 404 of the Clean Water Act (33 C.F.R. Parts 325 and 332; 40 C.F.R. Part 230 Subpart J). These regulations (the 2008 Rule or Rule) were intended to improve compensatory mitigation planning, implementation, and management by applying similar standards to all compensation projects and emphasizing a watershed approach to selecting project sites (USACE-EPA 2008). The Rule also clarified the agencies' interest in requiring compensation for impacts to streams. At the same time, stream compensation has been on the rise, as demonstrated by an increase in the percentage of mitigation banks and in-lieu fee programs that provide credits for impacts to streams. The Environmental Law Institute (ELI) reported that in 2005, 12 percent of all approved mitigation banks provided stream credits (Wilkinson and Thompson, 2006). By 2011, the Corps reported that 19 percent of all approved mitigation banks provided stream credits (Martin and Brumbaugh, 2011).

The science of stream restoration is also rapidly evolving (Wohl, 2015), as is the development of state and Corps policies governing stream assessment and compensation requirements. Thirteen states have formalized state stream mitigation programs, the majority of which were initiated after the Corps and EPA issued the 2008 Rule (ASWM, 2014), and at least 32 stream mitigation guidance documents and policies have been developed by states and Corps districts across the country. Even so, many decisions are still made on an ad hoc basis, depending on a regulator's own experience or expertise, and there are few resources available to guide the development of science-based policy on stream assessment and mitigation.

ELI, Stream Mechanics, and The Nature Conservancy have partnered to provide a wide-ranging view of the state of stream compensatory mitigation. In this series of white papers, we examine how stream compensatory mitigation has evolved in policy and practice in the more than seven years since the 2008 Rule, identifying trends as well as areas for improvement and best practices. We also examine how stream restoration science continues to evolve and what progress can still be made. Our goals are to improve understanding about how well stream compensatory mitigation policies are integrating best available science and how well practice aligns with these policies. Ultimately, we hope to inform the development of best practices and comprehensive, science-based stream assessment and mitigation programs. The white papers in this series include:

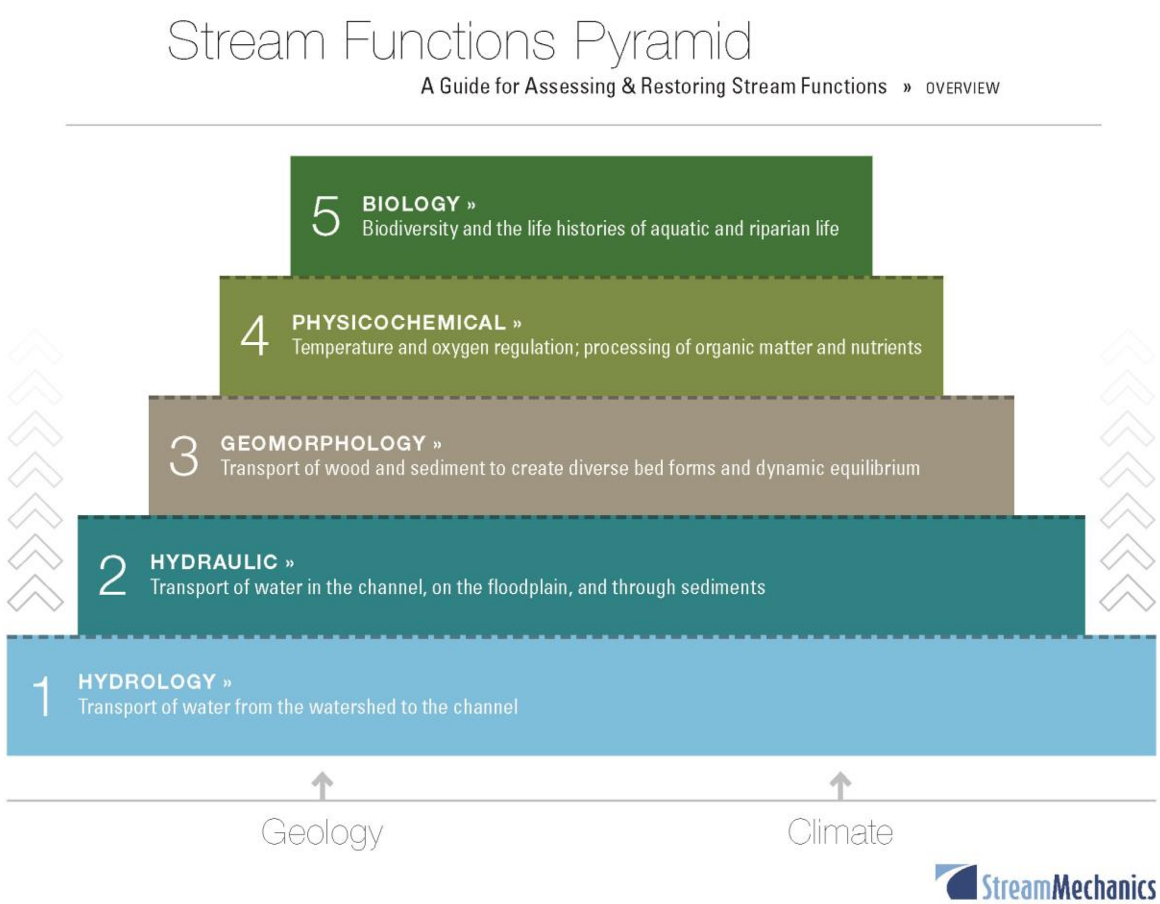
- Assessing Stream Mitigation Guidelines at the Corps district and State levels (Guidelines Paper). This paper includes a review of the credit determination methods, performance standards, and other program components currently being applied.
- Assessing stream mitigation practice (Practice Paper). This paper includes a review of the amounts of stream compensatory mitigation being required and the methods of compensation that are being used to meet permit requirements.
- A Function-Based Review of Stream Restoration Science (Science Paper).
- Aligning Stream Mitigation Policy with Science and Practice (Aligning Science, Policy, and Practice Paper). This paper integrates the first three white papers and evaluates how stream mitigation guidelines align with current mitigation practice and science.

We refer to the other white papers in this series using the abbreviations shown in parentheses.

A Function-Based Review of Stream Restoration Science

The purpose of this white paper is to review the scientific literature about stream restoration through a function-based approach. The literature review included an assessment of how well the scientific methods used in the research matched with practitioner goals and objectives. In addition, the literature reviewed identified the most common stream restoration approach used by designers and addressed whether external forces like watershed land use, project age, and length of monitoring effected the results.

The Stream Functions Pyramid Framework (SFPF) (Harman et al., 2012) was used to determine which functional categories and function-based parameters to include in the assessment. The SFPF was developed to assist stream restoration practitioners and agencies in communicating how stream restoration projects can provide functional lift. The framework includes a pyramid shape with lower level functions supporting higher level functions (See Figure 1). The framework includes a list of function-based parameters and measurement methods for each functional category. This list will be used in this paper to organize the results of the literature review. The list is provided below in the section, "Evaluating Stream Function Improvement."



To make the literature review manageable, the following criteria were established to determine which studies would be included in the review.

- Studies were collected from peer-reviewed journal articles and technical publications in order to analyze the best available scientific data.
- To ensure that the studies evaluated current stream restoration techniques, they had to be published after 2000 with all projects implemented after 1990.
- Restoration project design had to achieve a certain level of complexity, including the application of more than one technique. For example, projects that included changes to floodplain connectivity, bed form diversity, and lateral stability were included. Projects that implemented only riparian buffers or large woody debris were not included. There is a large body of research on the effectiveness of riparian vegetation/buffers and large woody debris and fewer reviews on stream restoration projects implementing multiple techniques.
- Finally, the research had to include actual measurements of stream condition or function; that is, no studies that used only surveys of practitioners or database searches were included within the review.

The literature review comprised 52 peer-reviewed publications that evaluated 172 projects meeting the above criteria. General characteristics of the studies and projects are included in Table 1. The majority of studies and projects were carried out in the United States, and the remainder occurred in Europe and Canada. Approximately one third of the projects evaluated were associated with compensatory mitigation. The review provides details found within the studies about the following topics and each is discussed in the following sections:

- Restoration Objectives Versus Research Objectives,
- Evaluating Stream Function Improvement,
- Watershed Land Use Analysis,
- Restoration Approaches,
- Project Age,
- Project Monitoring; and,
- Conclusions and Recommendations.

Table 1: Number of Papers and Projects Evaluated.

	Number of Projects (%)	**Number of Papers (%)**
Total	172	52
Project Location		
United States	114 (66)	40 (77)
Canada	5 (3)	2 (4)
Europe	53 (31)	10 (19)
Mitigation Projects		
Yes	62 (36)	5(10)
No	110 (64)	47 (90)

RESTORATION OBJECTIVES VERSUS RESEARCH OBJECTIVES

Clear restoration goals and objectives that are feasible to achieve are a key to implementing a successful restoration project. Goals are defined here as broad statements about why the project is being completed and the problem that will be addressed. An example goal is to reduce sediment supply from eroding streambanks in order to improve smallmouth bass habitat. This goal lets the reader know why there is a project (improve smallmouth bass habitat) and the functional problem that will be addressed (reduce sediment supply). Restoration objectives are more specific than goals and should explain how the goals will be addressed. For the example smallmouth bass goal above, objectives might include improving floodplain connectivity, bed form diversity, lateral stability, and riparian vegetation from a not functioning condition to a functioning condition. This tells the reader which function-based parameters will be manipulated during design and construction and qualitatively how much functional lift will occur (not functioning to functioning). Guidance for developing function-based goals and objectives as discussed in this paper and more examples are provided in *A Function-Based Framework for Stream Assessment and Restoration Projects* (Harman et al., 2012).

The projects reviewed typically did not distinguish between the terms goals and objectives. Therefore, for consistency, the term objective (rather than goals) is used to compare results. The literature review found that a specific restoration objective was stated for 70% of the projects. The most common included improving channel stability, in-stream habitat enhancement, and improvement to some aspect of biological function. Many papers discussed the long held assumption that increased habitat diversity and availability will lead to greater species diversity (Bernhardt et al., 2005; Fischenich, 2006). This assumption is based on well-established theory and stream ecology research (e.g. Hynes, 1970; Southwood, 1977; Allan and Castillo, 2007). However, the “Field of Dreams” approach that restoring habitat will automatically lead to restoring biota has been criticized for decades (NRC, 1992; Palmer et al., 1997; Hilderbrand et al., 2005). Additionally, there has been criticism in the literature that these objectives are rarely evaluated effectively, and that these objectives may not be appropriate or attainable for each project (e.g. Roni et al., 2002; Booth et al., 2004; Palmer et al., 2005; Bernhardt et al., 2005; Walsh et al., 2005b).

Thirty percent of the projects provided minimal or no information about project objectives. It was not clear in the literature review if researchers chose not to publish the objectives for a given restoration project, or if the information was not provided in project documents written by the designer. There was also a lack of information about the stream restoration techniques and practices that were implemented. For example, some research studies simply stated that a natural channel design project was evaluated. The paper did not explain if the existing condition was severely unstable and disconnected from the floodplain, and if the design reconnected the stream to the floodplain. The reader is therefore left to wonder if the existing stream was highly degraded and if the restoration techniques included reconnecting the stream to an original floodplain, excavating a new floodplain, or stabilizing the existing channel alignment. The absence of objectives, existing conditions, and techniques used made it difficult to know why the project was being undertaken, and why it was being evaluated.

Some studies included research objectives that did not match the stated project objectives. For example, physicochemical parameters (i.e., water quality, nutrients, organic carbon) were measured by the researcher to evaluate projects where the designer-stated objective was to improve channel stability (Klocker et al., 2009; Filoso and Palmer, 2011; Newcomer et al., 2012); or fish habitat (Kasahara and Hill, 2007). Note, improving fish habitat is not the same thing as improving fish biomass, so objectives should be clear about expectations. Some studies measured biological parameters to evaluate the success of stream restoration projects, even though biological improvement was not the stated objective (e.g. Baldigo et al., 2012; Ernst et al., 2012; Selego et al., 2012; Pierce et al., 2013). Studies that included parameters beyond the restoration objective contribute valuable information about the ability of stream restoration techniques to improve stream functions; however, conclusions about the success or failure of a specific project should be limited to evaluation of the specific restoration objectives of the project. Similarly, the programs and policies that guide or approve the development of restoration objectives must include appropriate parameters when drawing conclusions about the efficacy of stream restoration as a science.

Based on the results of the literature review, the following recommendations are provided for stream restoration researchers, practitioners, and policy makers.

Researchers

- In order to improve the science of stream restoration, more detail needs to be included in published studies about project goals and objectives, design approaches and construction methods. These details will help evaluate which stream restoration methods are most suitable to meet specific restoration objectives. These details should also be used when research objectives are chosen, ensuring the parameters measured target the stream restoration techniques and practices applied.
- The literature review found that 70% of the papers referred to the project's objective(s). This number should be 100%. All research papers that evaluate a stream restoration project should state the intended objective. If the practitioner did not provide a project objective, the researcher should contact the practitioner to obtain the information.
- The researcher should develop study methodologies and select metrics that first evaluate whether or not the project objectives were achieved. Additional metrics can be added to evaluate functional lift or loss beyond the objectives, but this additional analysis should be clearly communicated. The literature review showed that when the restoration objective was stated by the practitioner, only about two-thirds of the studies included variables that evaluated the specific project objectives. This led to discrepancies between the restoration objective and the research objective used to evaluate project success. If the researcher determines that important objectives or other opportunities for functional improvement were missed by the practitioner, these new objectives should be clearly stated and evaluated separately. This is especially important if conclusions are stated about the success or failure of the evaluated project, and if conclusions are then extrapolated about the overall success or failure of stream restoration as a general practice.

Practitioners

- Practitioners should provide function-based goals and objectives for every project as described in the first paragraph of this section. guidance can be found in 33 CFR §332.4(c)(2) where the Rule speaks of project objectives, Chapter 11 of *A Function-Based Framework for Stream Assessment and Restoration Projects,* Chapter 2 of the *National Engineering Handbook*, *Part 654*: Stream Restoration Design, and Chapters 6 and 7 of *Stream and Watershed Restoration:* A Guide to Restoring Riverine Processes and Habitats.
- Restoration goals and objectives should be project specific, clearly stated, and feasible to attain in the environment and location chosen for the project.
- Project reports should provide as much information as possible about the restoration approaches and techniques used to meet the project objectives. This makes it easier to categorize projects and match restoration techniques with the amount of functional lift achieved. Example approaches and techniques are provided in the *National Engineering Handbook*, *Part 654*: Stream Restoration Design and *Stream and Watershed Restoration*: A Guide to Restoring Riverine Processes and Habitats.

Policy Makers

- Stream mitigation guidelines should require practitioners to state programmatic goals and design goals and objectives (See 33 CFR §332.4(c)(2)). Programmatic goals refer to the funding driver for the project and could include mitigation, grants, etc. An example of a programmatic goal is: the goal of this project is to provide 1,000 mitigation credits. Design goals and objectives should be articulated as discussed in this section. Having clear goals and objectives will make it easier for Interagency Review Teams (IRTs) and other regulators to review stream mitigation projects.
- Mitigation plans should include a section on restoration potential, which describes the highest level of restoration that can be achieved based on watershed health, the reach condition, and constraints (See 33 CFR §332.3(d) and 33 CFR §332.4(c)(3)). Performance standards should then be developed that match the project's goals and objectives (See 33 CFR §332.5). This method will help prevent practitioners from overpromising restoration benefits and allow the IRT to align the monitoring and performance standards with the design goals and objectives.

EVALUATING STREAM FUNCTION IMPROVEMENT

Stream functions are the physical, chemical, and biological processes that occur in stream ecosystems (CWA, 2002; 2008 Mitigation Rule). The overall purpose of stream restoration is to improve degraded stream functions, to provide some level of functional improvement or lift. As the science of stream restoration has evolved, streams are no longer viewed as static, single thread corridors isolated from their floodplain. There has been a shift towards a more holistic approach to stream restoration, recognizing the dynamic structural and functional complexity of a natural stream system (e.g., Ward et al., 2001; Palmer et al., 2005; Wohl et al., 2005). Recommendations in the literature have encouraged more emphasis on a watershed scale rather than just a stream reach scale to improve stream functions and to better integrate processes that ensure a more functional stream corridor (Roni et al., 2002; Booth et al., 2004; Walsh, 2005a; Palmer et al., 2005; Sudduth et al., 2007).

In this literature review, efforts were made to identify Function-based Parameters that describe stream functions and to determine if these parameters were successfully improved through stream restoration. The SFPF was used to make the linkage between parameters assessed and stream function. The list of parameters is shown below in Table 2. A project was determined to show functional improvement or no functional improvement for each function-based parameter within each stream functional category. For example, bed form diversity (parameter) may be improved within the geomorphology functional category. A project can have both functional improvement and no functional improvement within a single functional category. For example, a project may have improved lateral stability but not bedform diversity within the geomorphology category. This project would be counted as both a functional improvement and a no functional improvement project.

Table 2: List of Function-based Parameters Provided in the Stream Functions Pyramid Framework (SFPF).

Functional Category	Function-Based Parameter
Level 1: Hydrology	Channel Forming Discharge Precipitation/Runoff Relationships Flow Duration
Level 2: Hydraulics	Floodplain Connectivity Flow dynamics Groundwater/Surface Water Interaction
Level 3: Geomorphology	Sediment Transport Competency and Capacity Large Woody Debris Channel Evolution Bank Migration / Lateral Stability Riparian Vegetation Bed Form Diversity Bed Material Characterization
Level 4: Physicochemical	Water Quality Nutrients Organic Carbon/Matter
Level 5: Biology	Microbial Communities Macrophyte Communities Benthic Macroinvertebrate Communities Fish Communities

Each study was evaluated to determine which functional categories and parameters were assessed.

The studies included in this literature review evaluated one or more of the stream functional categories with the most common being Geomorphology and Biology (Table 3). Only four studies measured parameters within the Hydrology category, and the reason is not clear within the literature.

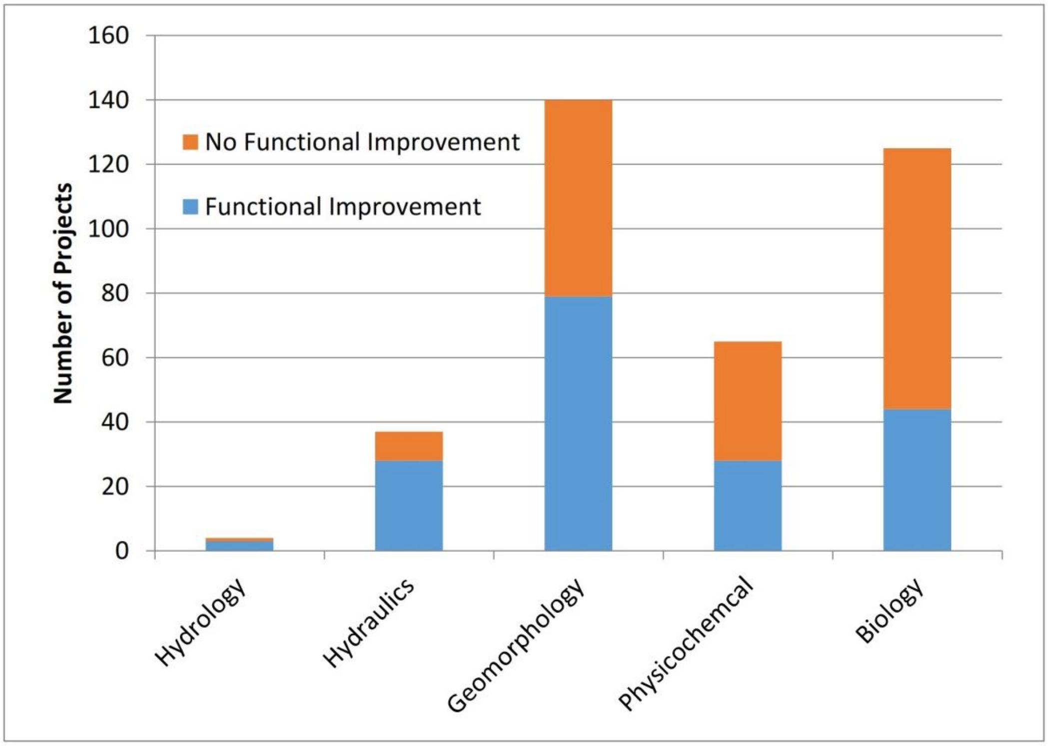
Table 3: Number of Projects and Studies Evaluating Each Functional Category.

Functional Category	Number (Percent) of Projects	Number (Percent) of Studies
Hydrology	4 (2)	4 (8)
Hydraulics	36 (21)	22 (42)
Geomorphology	137 (80)	35 (67)
Physicochemical	63 (37)	19 (37)
Biology	111 (65)	40 (77)

Note: projects may evaluate more than one functional category. The number of projects assessed per functional category is also shown on Figure 3 as the total score for each stacked column.

The number of projects showing functional improvement and/or no functional improvement per functional category is shown in Figure 2. Overall, more than half of the projects showed some improvement in Hydrology, Hydraulics, and Geomorphology, while less than half of the projects showed improvement in Physicochemical and Biology.

Figure 2: Functional Improvement and No Functional Improvement by Functional Category.



Notes: Some projects showed improvement and no improvement for the same category, e.g. improvement in bed form diversity and no improvement in lateral stability. The y-axis is number of projects from a total of 172 projects, so the total value for each stacked bar is the number of projects that assessed that functional category out of 172. For example, there were 137 projects out of 172 total projects that assessed Geomorphology. The percentages are shown in Table 3.

The results from Figure 2 were further analyzed based on the Function-Based Parameters measured for each functional category (Figure 3). The hydrology category was not assessed due to the low number of projects that evaluated hydrology parameters. For hydraulics, projects demonstrated functional improvement across all function-based parameters measured. Flow dynamics, like velocity, was assessed most often and included projects showing functional improvement and no improvement. Interestingly, floodplain connectivity was assessed the least often even though this is a known major contributor to functional improvement in higher level functions. Those projects that were assessed for floodplain connectivity did show improvement.

Within the geomorphology category, bed material characterization was assessed the most often and showed a fairly even split between improvement and no improvement. Information was generally not provided in the studies regarding the project's potential to show a change in bed material composition. Often, projects that have gravel beds and erosion from sandy banks are better candidates for showing a change in bed material. However, there was no way to determine the number of projects meeting these criteria. The next most common parameters assessed were lateral stability, bed form diversity, and then riparian vegetation. Large woody debris and sediment transport were the least assessed parameters. For all of these remaining parameters, there were more projects showing no improvement than improvement.

The reasons for less improvement in geomorphology functions are not clear from the studies. Potential causes may be related to the stream restoration approach and practices implemented for each project, the monitoring timeframe allowed, or due to the fact that these function-based parameters are measured more frequently than other parameters. In this literature review, the geomorphology results were disproportionately influenced by a few studies that included evaluation of multiple restoration projects, including 24 projects in Tullos et al. (2009), 16 projects in Miller and Kochel (2010), and 9 projects in Laub et al. (2012) that found no functional improvement in the geomorphology parameters measured. The methods in Miller and Kochel (2010) targeted projects with known stability problems resulting in a no improvement score for all projects. If these three papers are not considered in the analysis, there is overall functional improvement in the geomorphology category across all function-based parameters.

For physicochemical functions, the nutrient parameter demonstrated improvement in over half of the projects. The projects were not as successful improving water quality parameters, such as temperature and dissolved oxygen, and organic carbon parameters, such as course particulate organic matter and dissolved organic matter retention. The Tullos et al. (2009) paper may have influenced these results, with 24 projects showing no improvement in the organic carbon parameter.

For the biology functional category, benthic macroinvertebrate communities was the most common function-based parameter evaluated. Benthic macroinvertebrates have been an integral component of national stream restoration monitoring programs and rapid assessment methods for decades (Barbour et al., 1999), so it's not surprising that many researchers also used this parameter to evaluate stream restoration projects. Benthic macroinvertebrates have well established metrics, which combined with their functional diversity, limited migration patterns, complex life cycles over relatively short life spans, and their sensitivity to environmental stressors at different life stages, allows for documentation of community change over a relatively short time period following restoration. The results of the literature review demonstrated that only one fourth of the projects had functional improvement for benthic macroinvertebrate communities. These results were from a few papers that evaluated multiple restoration projects, including 25 projects in Sundermann et al. (2011), 16 projects in Tullos et al. (2009), and 12 projects in Jahnig et al. (2010) that found no improvement in the macroinvertebrate parameters measured. Overall, functional improvement was evident in slightly greater than half of the projects that evaluated macrophyte and fish community parameters. There was little improvement in the microbial community parameter, but only six percent of projects evaluated microbial metrics.

Figure 3: Functional Improvement and No Functional Improvement per Function-Based Parameter.

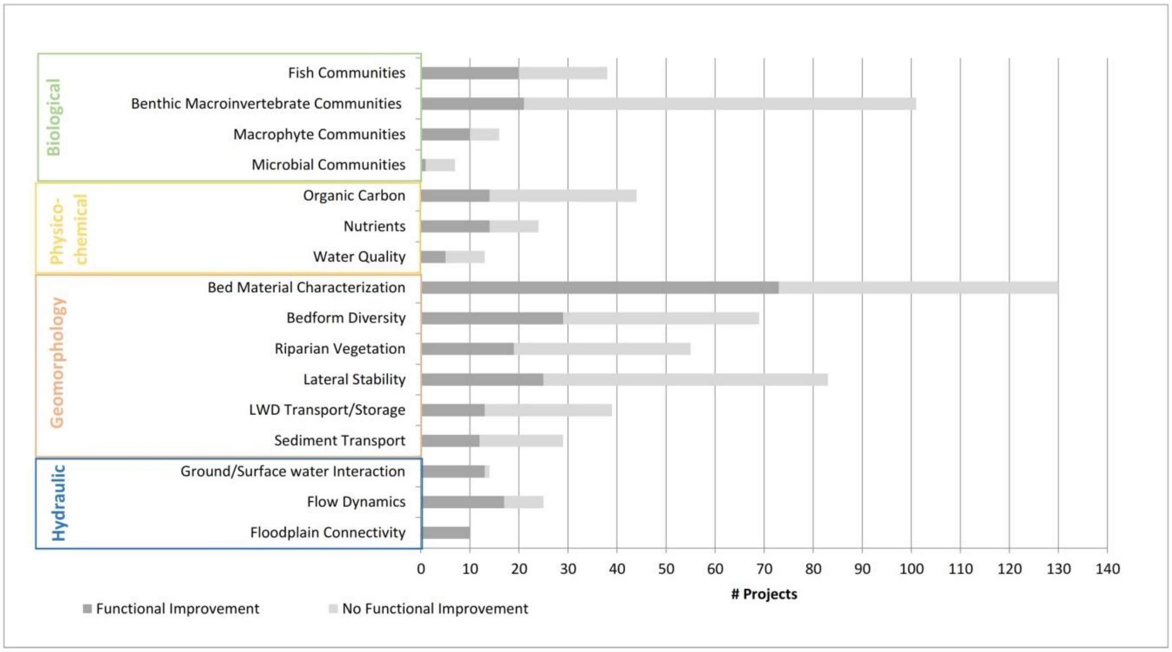


Figure 3 does not include Hydrology parameters, the Channel Evolution parameter within the Geomorphology category, and the Landscape Connectivity parameter within the Biology category due to the limited number of projects that included these parameters.

As discussed earlier, improving biological diversity is one of the most common objectives for stream restoration projects and the assumption is that if underlying functions are improved, then biological function will also be improved. This also assumes that the water quality entering the project reach will support biology. Criticism is prevalent in the literature concerning stream restoration practices and their tendency to focus on physical improvement of habitat, mostly through alteration of hydraulic and geomorphic functions. Many have criticized this approach, calling it the “Field of Dreams” scenario, summarized as “if you build it, they will come” (Palmer et al., 1997; Palmer et al., 2010). Palmer et al. (2010) reviewed 78 projects in the literature to determine if improvements in habitat heterogeneity lead to increases in invertebrate taxa richness. They found that most projects were indeed successful at habitat enhancement, but few of these projects were statistically successful at improving biodiversity. The conclusion was that there were other factors limiting biodiversity that were not addressed by stream restoration and that could not be overcome by habitat improvements alone. For our literature review, we found similar yet marginally better results. Both geomorphology and biology were evaluated in 94 projects, but improvement in both stream functions was documented in only 25.

Based on the literature review, it was unclear what caused the lack of improvement in biology function. Was it a lack of improvement in underlying stream functions, or due to flawed "Field of Dreams" thinking in the use of stream restoration approaches, or due to the metrics chosen to evaluate biological function? The reasons given within these studies were numerous and highly variable. In order to make accurate conclusions about why biology parameters were not improved, studies must effectively evaluate the supporting stream functions (supporting function means a function-based parameter from a lower-level functional category). As already discussed, few studies in our review evaluated hydrology. And none of the hydrology studies included biology parameters. And there were no projects with all five stream functional categories measured.

Of the 111 projects that measured biology function-based parameters, 15 projects had 3 underlying functions measured, 31 had 2 underlying functions measured, 48 had 1 underlying function measured, and 17 evaluated only biology function-based parameters.

Based on the results of the literature review, the following recommendations are provided for researchers, practitioners, and policy makers:

Researchers:

- Accurate and useful conclusions concerning stream restoration and its effects on biological function within the project reach should be based on assessment of underlying functions that support biology. Although it may not be feasible to measure all function-based parameters, better efforts need to be made to determine why biological function is or is not improved.
- Hydrology functions need more attention in stream restoration research. At a minimum, this should include some form of catchment assessment to determine if watershed hydrology is stable or changing. For example a watershed that is transitioning from rural to urban may negatively affect runoff to the project reach. This information can be included in a watershed health assessment to assist in determining restoration potential.
- Project sites should be stratified by restoration potential. Level 3 geomorphology or stability focused projects should be clearly identified and not penalized for showing a lack of functional improvement in Levels 4 and 5.

Practitioners:

- Refer to recommendations provided in the previous section. Clear goals and objectives make it easier to evaluate functional improvement. All projects should include well-articulated function-based goals and objectives and a description of the restoration potential, which will include a description of the catchment health and stressors, and project constraints.
- At a minimum, describe the functional lift that will occur in floodplain connectivity, bed form diversity, lateral stability, and riparian vegetation. Provide an explanation of parameters that will likely not change after restoration activities. Other function-based parameters should be included based on project condition and objectives.

Policy Makers:

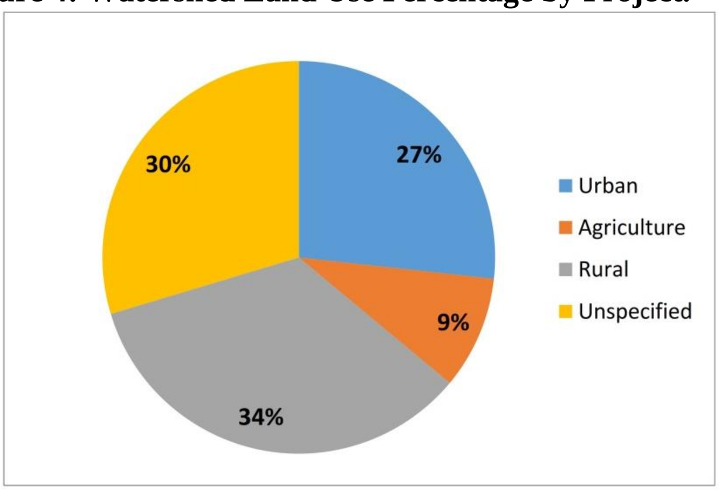
- Refer to recommendations provided in the previous section.

WATERSHED LAND USE ANALYSIS

The literature review included papers that evaluated projects implemented in watersheds with different land uses. Three land use categories were chosen for analysis based on information provided in the studies: urban, agriculture, and rural. The rural versus agricultural determination was used because some studies referred to the watershed as agricultural and others used the term rural. We assume that both categories include forms of agriculture; however, in rural watersheds, agriculture is not the predominant land use according to descriptions in the studies. The rural designation includes watersheds with majority forest cover and low density housing. The agricultural watersheds have more crop and pastureland than the rural designation.

Figure 4 shows the percentage of each land use for the projects. A third of the projects did not have a watershed land use specified. The unspecified projects were derived from only two papers (Miller and Kochel, 2010 and Sundermann et al., 2011), however, indicating that most papers (96%) included some level of information about the land use near the restoration project. When land use was specified, more than half of the projects were in rural and agricultural settings (62%), while the remainders were in urban settings. Determination of the watershed and floodplain land use provides valuable information for interpreting impacts on the success of the restoration project. Although most studies provided some information on land use, the amount of detail included was variable and not always thorough.

Figure 4: Watershed Land Use Percentage by Project.



Urban Land Use

For urban stream ecosystems, the predictable changes that occur are widespread and referred to as the 'urbanization cycle' (Leopold et al., 2005), or the 'urban stream syndrome' (Walsh et al., 2005a). Negative impacts increase with a corresponding increase in impervious cover within the watershed, described by the Impervious Cover Model (Schueller, 2004). Stormwater runoff increases through reduced infiltration and the "hyperconnectivity" created by stormwater infrastructure, leading to hydrology functions controlled by more frequent, larger stormflows. Urban streams often respond with channel instability and incision, losing geomorphology function along with connectivity to the floodplain and the groundwater table. Urban environments also contribute higher contaminant loads through stormwater runoff and larger sediment loads during watershed development and channel erosion, reducing physicochemical function. These changes to physical and chemical condition ultimately result in reduced biological function (Paul and Meyer, 2001; Meyer et al., 2005; Walsh et al., 2005).

The literature review showed that over half of the urban stream restoration projects showed no functional improvement. The lack of improvement was spread across the functional categories (Figure 5) and function-based parameters (Figure 6) assessed. Within hydraulics, restoration improved floodplain connectivity and groundwater/surface water interaction within the hyporheic zone, but results were not consistent for flow dynamics. This parameter is commonly evaluated through measurements of stream velocity, shear stress, and stream power, using direct measurements or hydraulic models. Lack of functional improvement in flow dynamics was most often blamed on inappropriate project design (e.g., Kondolf, 2001; Moerke and Lamberti, 2003; Smith and Prestegaard, 2005).

Geomorphology function showed little functional improvement across function-based parameters in urban projects.. Comments within the literature were variable. Some cited problems with riparian vegetation and large woody debris where existing vegetation is cleared during construction (e.g., Sudduth et al., 2011; Violin et al., 2011). Others cited problems with unaddressed high upstream sediment loads, which was detrimental to sediment transport and storage, bed material composition, and bedform diversity (e.g., Moerke and Lamberti, 2003; Miller and Kochel, 2010).

Physicochemical function also showed little functional improvement across function-based parameters evaluated, although about a third of the projects measured some functional improvement in nutrients. The studies attributed nutrient reductions to improvements in floodplain connectivity and ground/surface water interaction. However, reductions were not significant considering the overall high nutrient loading in these streams combined with the short restoration reach length (e.g., Kasahara and Hill, 2006; Kaushal et al., 2008; Klocker et al., 2009; Newcomer et al., 2012). In these studies, restoration did not appear to be as effective at improving water wuality and organic carbon parameters, although it was suggested that a longer period of monitoring would show improvement with increased riparian vegetation development and depth of hyporheic interaction. Richardson et al. (2011) did show significant reductions in nutrient concentrations and nutrient loading when stream restoration was coupled with a stormwater retention pond and riparian wetlands.

Figure 5: Functional Improvement and No Functional Improvement by Functional Category for Projects with Urban Land Use.

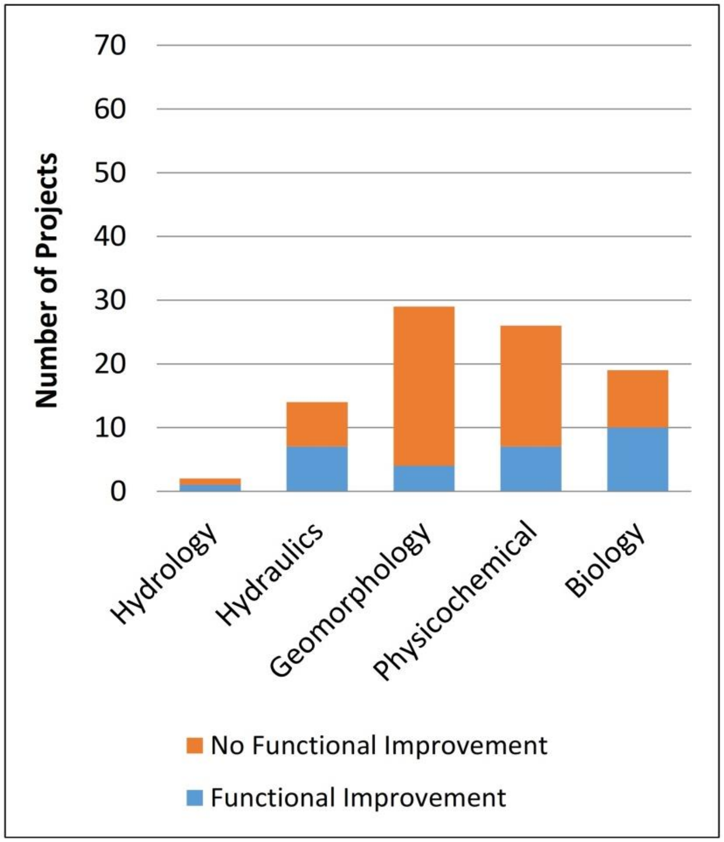
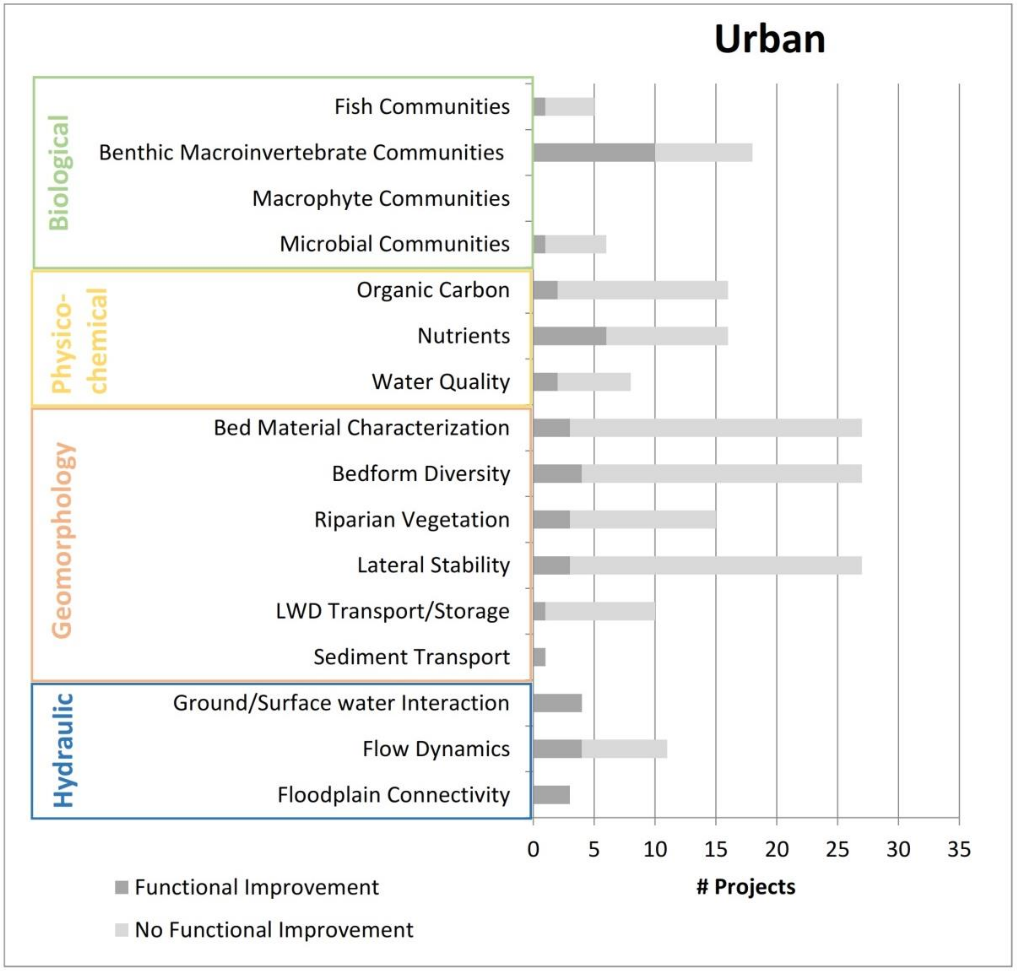


Figure 6: Functional Improvement and No Functional Improvement in Function-Based Parameters for Projects with Urban Land Use.



Results showed that about half of the projects measured functional improvement in biology, shown primarily in the benthic macroinvertebrate community parameter (Figure 5). Benthic macroinvertebrate studies typically quantified improvement in biodiversity through an increase in standard assessment methods, such as biomass and taxa richness. For some studies, results were dependent on only the measurement method chosen. Other studies compared metric results to the control reach chosen to derive conclusions about the benthic macroinvertebrate community. In general, restored urban reaches demonstrated some functional improvement when compared to upstream urban non-restored reaches (e.g., Purcell et al., 2002; Moerke and Lamberti, 2003; Moerke et al., 2004; Tullos et al., 2009). There was less functional improvement documented when the restored reach was compared to non-urban reference reaches (e.g., Violin et al., 2011; Stranko et al., 2012). Tullos et al. (2009) discussed the need for better metrics to evaluate biodiversity, particularly in urban settings. Although they found improvement in biodiversity metrics, the community comprised macroinvertebrates with similar functional traits, suggesting that other stressors in addition to the lack of habitat availability were inhibiting meaningful lift in biological function.

Many publications have criticized urban stream restoration projects for their lack of success in restoring biological functions. Another common criticism is the high project cost associated with urban environments, including high floodplain property values, expenses associated with population density and its supporting infrastructure near waterways (e.g. roads, utilities, floodplain development), and the stormwater runoff pollutant loads that must be treated. The National River Restoration Science Synthesis (NRRSS) project documented that for many regions of the United States, large amounts of restoration funding have been invested in a small number of urban stream projects. Based on results from this study, the expenditure has not resulted in significant ecological success (e.g. Hassett et al., 2007; Bernhardt et al., 2007; Sudduth et al., 2007). One reason cited for project failure is that current stream restoration practices have limited reach scale effects that do not address watershed scale problems associated with stormwater runoff and treatment in urban environments (Walsh et al., 2005b; Bernhardt and Palmer, 2007; Sudduth et al., 2011).

Suggestions to improve projects include better integration of interdisciplinary knowledge, improved identification of degradation cause and effect, and better assessment of the restoration potential of the project site (Booth et al., 2004; Walsh et al., 2005b; Bernhardt and Palmer, 2007). Many projects have an unrealistic objective to restore an urban stream to pre-disturbance conditions. Without fully identifying and addressing the causes of degradation, this objective may be impossible to meet regardless of the restoration techniques applied (Sudduth et al., 2011; Violin et al., 2011; Stranko et al., 2012). In urban environments especially, site selection may be as important as the reach-scale restoration for restoring biological function. An appropriate site must have the potential to alleviate watershed stressors that affect the underlying stream functions. And, source populations must be present upstream or in streams with close enough proximity to the restored reach for effective recruitment (Lake et al., 2007; Palmer et al., 2010; Sundermann et al., 2011; Stranko et al., 2012).

Agricultural Land Use

For agricultural watersheds, activities in the floodplain can degrade stream stability and water quality through land clearing and livestock access, while increasing nutrient and sediment loads through runoff (Line et al., 1998). In this literature review, stream restoration projects in agricultural settings showed functional improvement for each project; however, the improvement was not widespread across stream function categories or function-based parameters (Figures 7 and 8). Functional improvement did occur with several of the hydraulic function-based parameters, including flow dynamics and ground/surface water interaction. However, none of the studies evaluated floodplain connectivity in projects with agricultural land use.

There was little functional improvement across geomorphology parameters measured and about half of the projects showed functional improvement in physicochemical parameters. Water quality and nutrient parameters improved, but there was little functional improvement in the organic carbon parameter. The water quality and nutrient improvements were derived from only two studies (Kasahara and Hill, 2006 and 2007), however, where dissolved oxygen and nitrate were evaluated in the surface water and hyporheic zone. For biology, most studies evaluated benthic macroinvertebrate communities and there was little functional improvement. The studies that looked at fish communities and macrophyte communities, however, showed improvement.

Figure 7: Functional Improvement and No Functional Improvement by Functional Category for Projects with Agricultural Land Use.

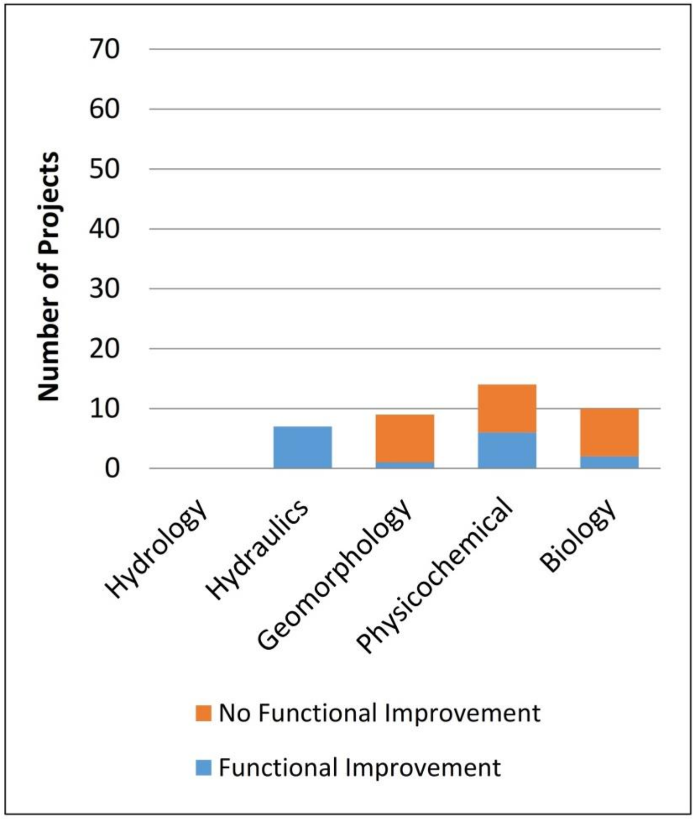
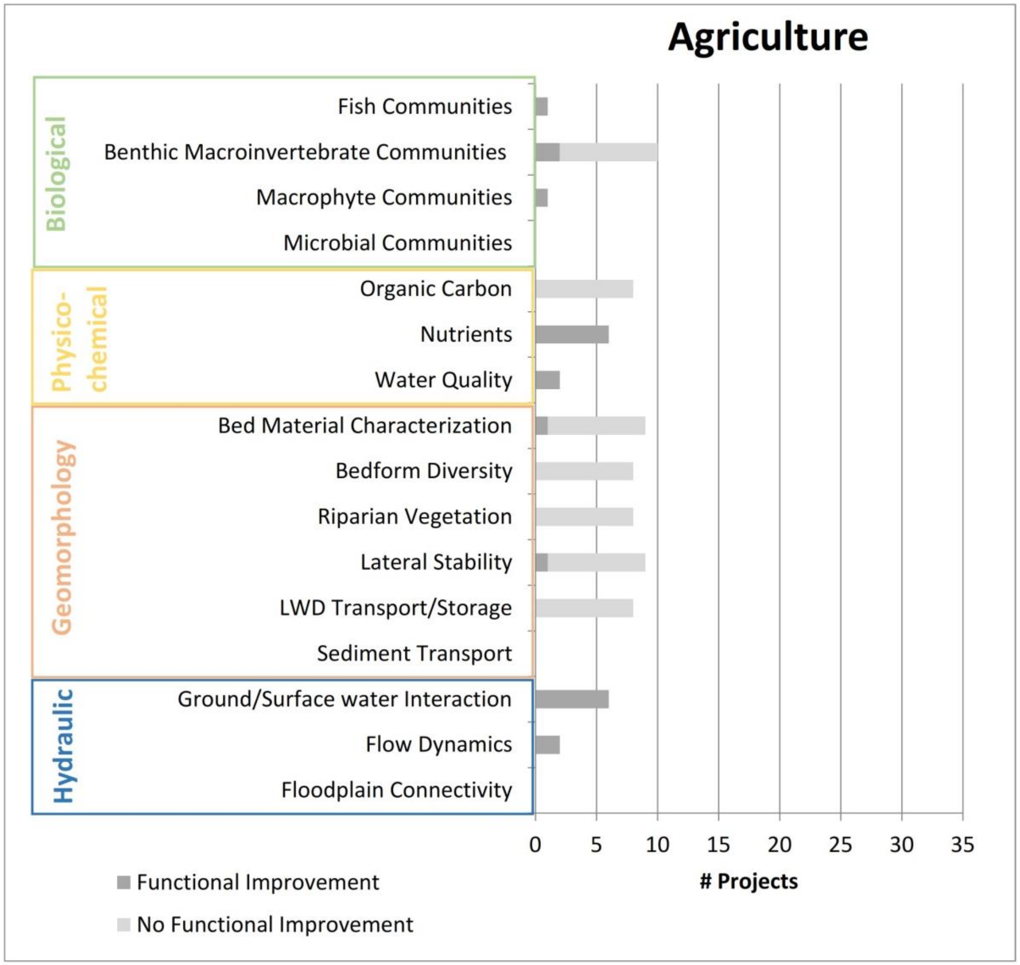


Figure 8: Functional Improvement and No Functional Improvement in Function-Based Parameters for Projects with Agricultural Land Use.



Based on the results of the literature review for agriculture streams, restoration has not adequately addressed stream stability through the function-based parameters assessed. The reasons given for lack of functional improvement in the studies were not particular to agriculture. Agricultural land use effects were not well discussed and provided limited opportunity to interpret the results. This literature review included a relatively small number of agriculture studies compared to the urban land use studies, so it's difficult to explain the reasons for the results. In general, it was observed that there is limited literature available evaluating stream restoration in agriculture watersheds.

Rural Land Use

Rural watersheds are considered those where the majority of land use is not urban or agriculture, and they are covered mostly by natural vegetation (i.e. forests, meadows). It is generally accepted that rural watersheds lack the stressors present in urban and agriculture dominated watersheds. The most common watershed impacts specified within the literature review studies for rural watersheds included past logging, mining, and conversion to agriculture, along with water impoundments. Based on land use, it was expected that restoration projects would be more successful at improving stream function in rural settings.

The literature review demonstrated that the majority of rural projects showed functional improvement across categories (Figure 9). Stream restoration was successful at improving hydraulics across all function-based parameters (Figures 9 and Figure 10). Geomorphology had functional improvement in over half of the projects across all function-based parameters, with the exception of riparian vegetation. Studies commented that the time frame after restoration had not been sufficient for riparian vegetation to mature. Physicochemical function was improved overall, with most functional improvement observed in the nutrient and organic carbon parameters. Within studies that evaluated water quality parameters, however, there was little functional improvement measured. Only about half of the stream restoration projects improved biology function, based mostly on the fish communities and macrophyte community results. The benthic macroinvertebrate community parameter did not respond as well to improvements in underlying stream functions. Overall, stream restoration projects within the rural setting were more successful at improving stream function than the urban and agricultural watersheds.

Figure 9: Functional Improvement and No Improvement by Functional Category for Projects with Rural Land Use.

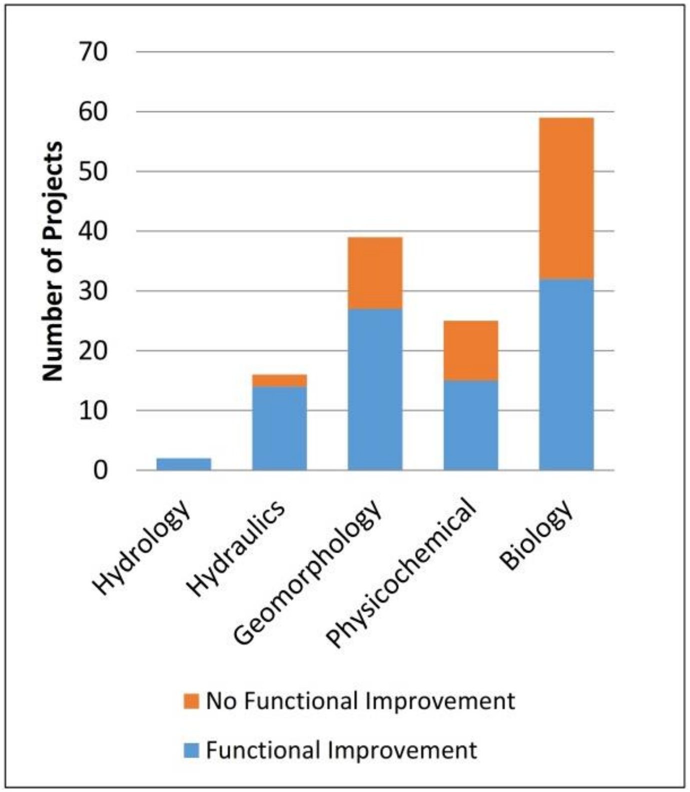
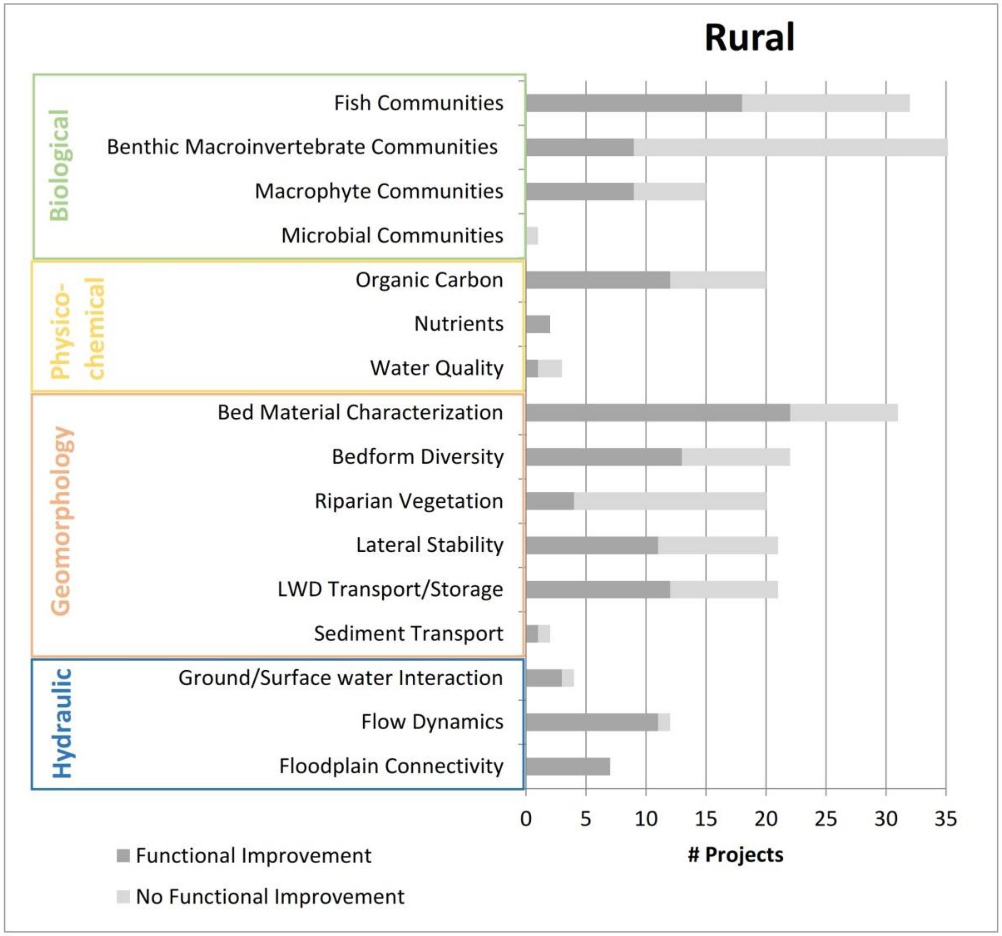


Figure 10: Functional Improvement and No Functional Improvement in Function-Based Parameters for Projects with Rural Land Use.



Based on our literature review and land use analysis, the following recommendations are made for researchers and practitioners:

<u>Researchers:</u>

- Studies should identify and discuss the watershed and floodplain land use to determine what impact this has on restoration potential and functional lift.

<u>Practitioners:</u>

- Site selection may be as important as reach-scale restoration for improving physicochemical and biological functions. For example, water quality from upstream sources must be able to support biological communities after the reach-scale improvements are made in order to see substantial improvements in reach-scale biology.

RESTORATION APPROACHES

The literature review also tried to determine if a specific restoration approach was used to design a restoration project, and to determine if functional improvement/ no improvement results could be stratified by restoration approach. Examples of stream restoration approaches searched for in the literature review included: natural channel design, process-based design, and regenerative design. The literature review found that multiple restoration approaches were used (Figure 11), with the most common being Natural Channel Design (NCD)(Rosgen, 1996; 1998; 2006). Other approaches were specified, including a European approach based on restoration of sport fishing habitat (Yrjana, 1998); various channel reconfiguration and channel geometry approaches (e.g., Jackson and Van Haveren, 1984; Riley, 1998); Valley Restoration, which is a stream-wetland complex approach (Filoso and Palmer, 2011); and an approach based on simulation of beaver dams (DeVries, 2012). The literature review found that 38% of projects did not specify a restoration approach, whether through a direct statement or through references included within the paper. Many of the unspecified stream restoration projects described had some manner of channel reconfiguration and channel dimension modification based on a designated storm event, usually bankfull. Some of these unspecified projects may have been based on NCD, but there were not enough details or references provided to confirm this approach.

Based on the literature review, many studies viewed stream restoration projects as a uniform, collective practice in itself, without analyzing effects of individual techniques or collection of techniques that comprise a specific approach. The following discussion includes the NCD approach only. There were only 13 projects within the "other" category; therefore, conclusions could not be drawn for these approaches and comparisons could not be made. Unspecified projects were also not included in the following discussion due to the lack of information.

Natural Channel Design is a stream restoration approach created by Rosgen (1996, 1998, 2006) and described in the USDA NRCS Engineering Handbook (USDA NRCS, 2007). It is the most commonly applied stream mitigation approach within the United States (Guidelines Paper, Practice Paper). The broad goal is to restore channel dimension, pattern, and profile so that the channel doesn't aggrade or degrade over time, with design based on the bankfull discharge and reference reach measurements. The approach has been extensively reviewed in the literature (e.g. Nagle, 2007; Lave, 2009), and has been criticized by those who feel that it does not effectively address the inherent complexity of fluvial systems (Doyle et al., 1999; Kondolf, 2006; Simon et al., 2007). These reviews suggest that NCD is a form-based approach relying on a classification system, and the approach does not address the process of alluvial streams adjusting to varying energy and material inputs (Juracek and Fitzpatrick, 2003; Kondolf, 2006; Simon et al., 2007). However, much of this criticism was published before the methodology was provided publically in the NRCS Engineering Handbook (USDA NRCS, 2007) and includes inaccurate assumptions, e.g., that natural channel design is equal to stream classification, that flood flows are not assessed, and that the design does not include hydrology and sediment transport processes. A review of the methodology shows that it does include watershed and reach-scale assessments, form- and process-based analyses, and passive and active forms of intervention, e.g., simple management changes (passive) to re-creating a new channel (active).

Based on this literature review, hydraulic functions were improved in about half of the NCD projects that evaluated these parameters (Figure 12), mostly attributable to improvements in the floodplain connectivity parameter (Figure 13). Figure 13 also shows that some projects had improvement in bed material characterization, bed form diversity, lateral stability, and sediment transport. However, more projects showed no improvement than improvement. The reasons given in the literature for lack of functional improvement were highly variable and inconclusive. The results for all function-based parameters were highly influenced by Tullos et al. (2009) due to the large number of projects (24) that found no improvement. It should be noted that Tullos et al. (2009) did not state that these projects were designed using the NCD Approach; however, documentation was readily available to conclude they were. Both physicochemical function and biology function also showed little success across function-based parameters, although more than half of the projects showed functional improvements in nutrients and fish communities when these parameters were assessed.

Figure 11: Percent of Projects for Each Restoration Approach.

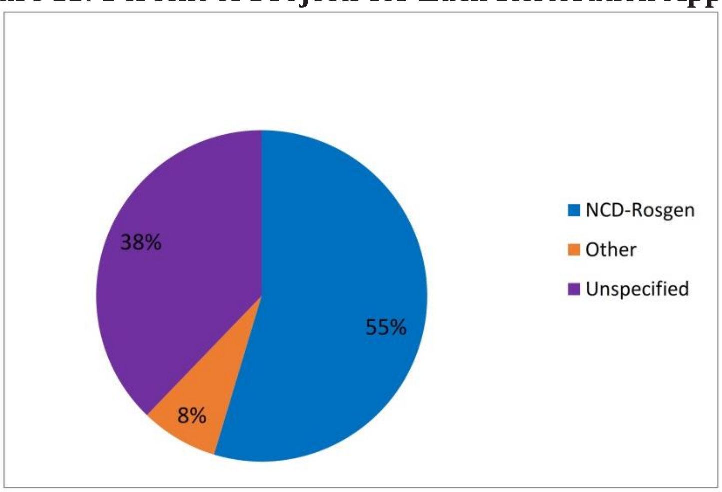


Figure 12: Functional Improvement and No Functional Improvement by Functional Category for Projects Carried Out Using the Natural Channel Design Approach.

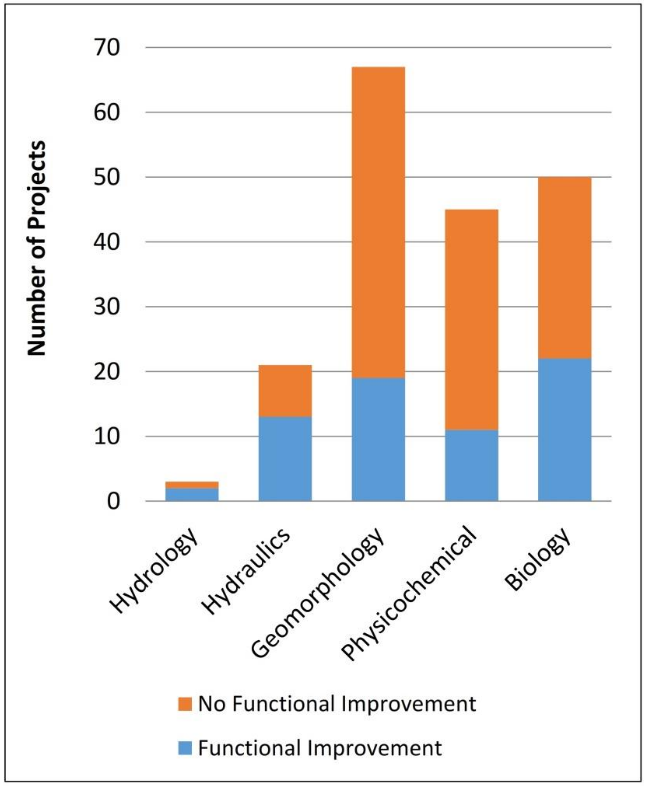
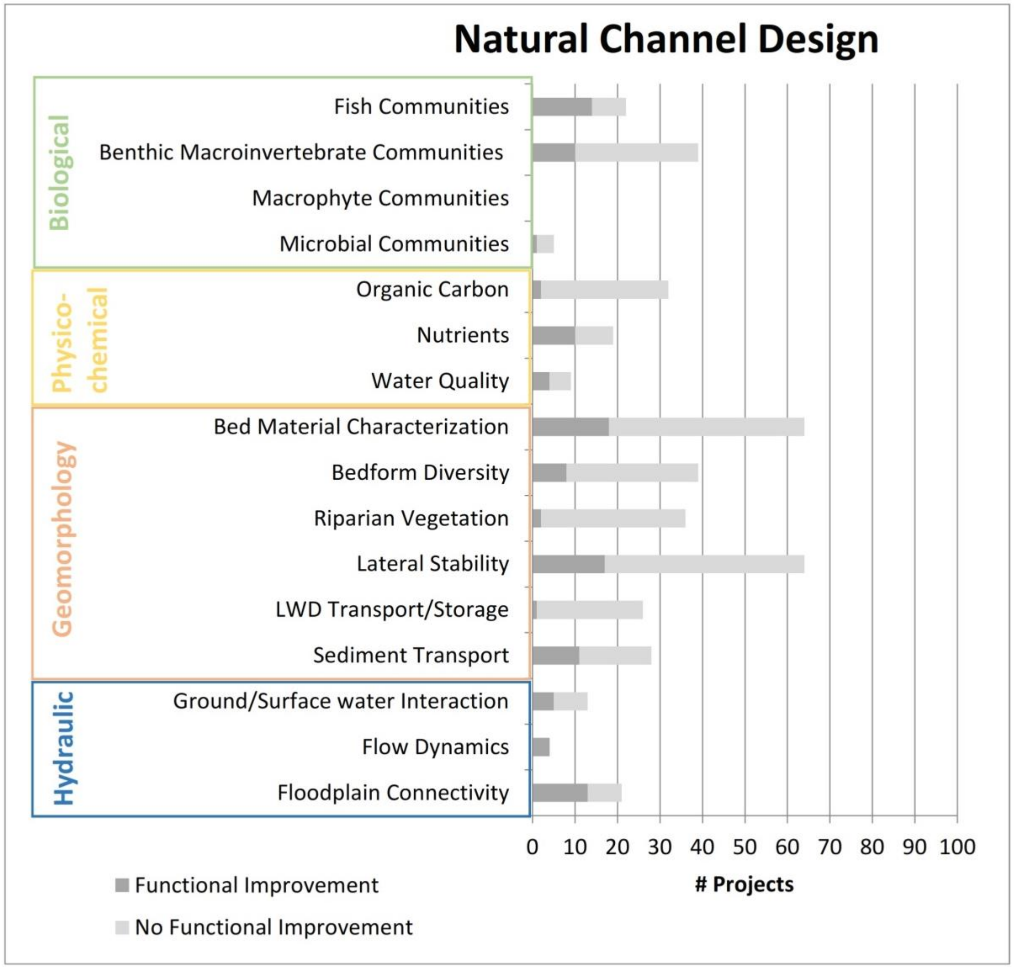


Figure 13: Functional Improvement and No Functional Improvement in Function-Based Parameters for Projects Carried Out Using the Natural Channel Design Approach.



Analysis of restoration approach led to the following recommendations for researchers and practitioners.

Researchers:

- Studies should identify the restoration approach and provide adequate details of techniques used within the design to help evaluate the approach and improve the science.
- Studies should seek to determine if the approach was appropriately used. This will allow evaluations to determine if project design or design approach is flawed or successful.

Practitioners:

- All design and mitigation reports should clearly state the restoration approach and techniques used.

Policy Makers:

- Mitigation guidelines should include a procedure for determining if restoration practitioners have the necessary training and experience for whatever approach they propose.

PROJECT AGE

As more projects are implemented and as better interdisciplinary approaches develop, it would stand to reason that there would be a greater success rate achieved over time in restoring stream functions. Pprojects were divided into two categories: those constructed between 1990 and 1999 and those constructed between 2000 and 2008. This division resulted in about two thirds of the projects being in the 2000 to 2008 category (Figure 14). It was expected that projects implemented after 2000 would show more functional improvement compared to those implemented after 2000. However, our results showed that there was no considerable difference in functional improvement based project age. We also found no positive trend over time when comparing functional categories and function-based parameters (Figure 15). The reasons for a lack of improvement could not be determined based on our review; therefore, further analysis is needed to determine if stream restoration practices are improving function over time.

Figure 14: Percent of Projects for Each Project Age Category.

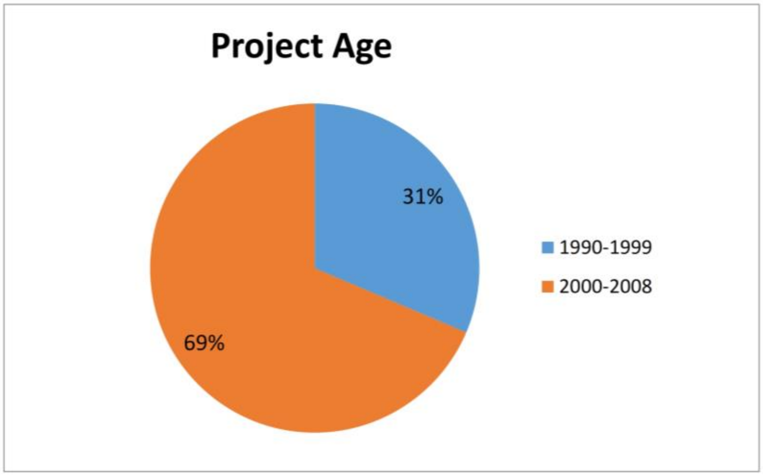
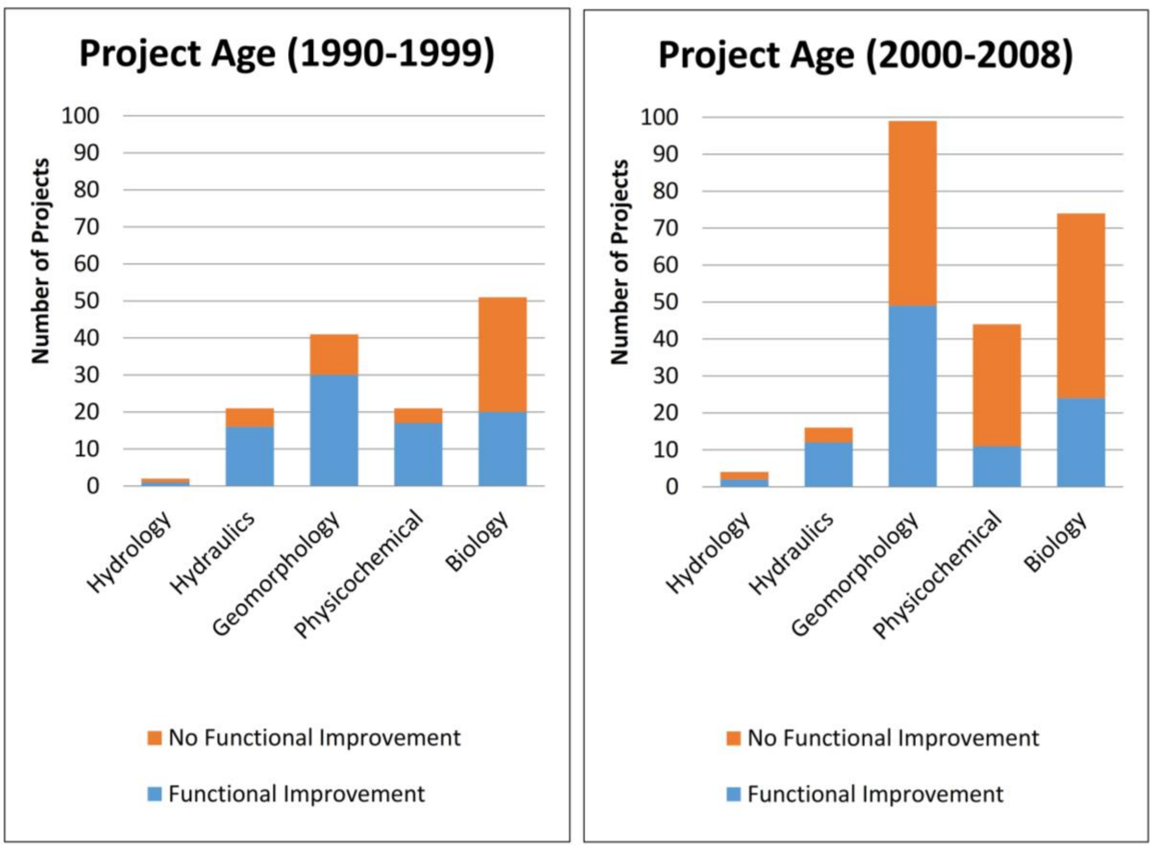


Figure 15: Functional Improvement and No Functional Improvement by Functional Category for Projects in Each Project Age Category.



PROJECT MONITORING

There has been much criticism in the literature concerning the insufficient quantity and quality of stream restoration project monitoring. Without this information, advances in the stream restoration science will be delayed, and many argue this has already occurred based on the increasing number of projects each year without a corresponding increase in project success (Roni et al., 2005; Bernhardt et al., 2005; Wohl et al., 2005; Bernhardt et al., 2007). A large national study of stream restoration called the National River Restoration Science Synthesis (NRRSS) project was carried out with the goals of documenting restoration practices and determining whether and how stream restoration success is being evaluated (Bernhardt et al., 2005; Bernhardt et al., 2007). The study found that although stream restoration practitioners mostly felt that their projects were successful, there was a lack of effective monitoring to verify these results and the monitoring that was carried out did not always support this response (Alexander and Allan, 2007; Berhardt et al., 2007; Hassett et al., 2007; Sudduth et al., 2007).

Most scientists and practitioners agree that stream restoration monitoring should include adequate measurements of parameters before and after project implementation within the project reach as well as within the most appropriate control reach used for comparison. Some studies refer to this monitoring plan as before-after control-impact or BACI (Underwood, 1994). There has been considerable discussion in the literature about what constitutes the most appropriate control or comparison reach. For example, the use of forested reference reaches to determine success of stream restoration projects in highly degraded systems will likely show that the project is unsuccessful (See Urban Land Use discussion; Booth et al., 2004; Bernhardt and Palmer, 2007).

Based on our literature review analysis, we found that about 20% of projects evaluated included pre-monitoring data in their assessment. . For projects with pre-monitoring data, about 60% showed functional improvement across all function-based parameters evaluated, compared to only 10% of projects without pre-monitoring data collection. The results demonstrate how important pre-monitoring data may be in verifying functional improvement attributed to stream restoration. The literature review also showed that upstream (or downstream) control reaches within the same stream was selected for comparison in approximately 70% of the projects. The remainder used stream data from other stream reaches with similar conditions and/or from reference reaches for comparison with the restored reach.

When control reaches were chosen outside the impact stream, 65% of these projects showed no functional improvement across all function-based parameters evaluated. Our results seem to show that using upstream and downstream reaches for comparison is a good way to show functional lift because it explicitly shows how the project reach changed values of the parameters assessed. However, using a reference condition (maybe in addition to upstream/downstream assessments) is a good way to determine the overall health of the project reach and provides a way to compare all projects in a given region to the same reference condition, e.g., it puts projects on the same scale. For example, an urban restoration project may improve a biological community from upstream to downstream of the project reach, which is functional lift. However, it may not restore the community back to a forested reference condition.

Another consideration for project monitoring is the length of time following project implementation that is required for effective evaluation. Streams are dynamic natural systems integrated into the landscape and they require adequate time periods to adjust to changes made within their watershed and to their physical condition. This concept has been well documented for watershed and in-stream disturbances by demonstrating the physical, chemical, and biological responses to these generally negative impacts (See urban land use discussion). This assumption must also be held for stream restoration, which has been shown to be a disturbance to the stream ecosystem (Muotka et al., 2002; Tullos et al., 2009; Sundermann et al., 2011). Disturbance caused by stream restoration is hopefully short term, and the goal is to achieve ultimate positive impacts to the stream ecosystem.

Long-term monitoring studies of stream restoration projects are rare within published literature; therefore, there is a significant lack of scientific knowledge on the long-term effectiveness of stream restoration approaches and practices. Reasons suggested in the literature for the deficiency in long-term studies include inadequate funding and resources for monitoring; lack of incentives and established methods for long-term monitoring; technical difficulties associated with sampling and quantifying responses in highly variable natural systems; statistical difficulties in isolating the impacts of restoration from other natural changes that occur throughout a study interval; and the difficulties associated with evaluating a new and rapidly evolving science (Palmer et al., 2005; Reeve et al., 2006; Klein et al., 2007). There is also significant lag time between study completion and publication of results. For example, our literature review included papers published through the beginning of 2014; however, the newest project evaluated was constructed in 2008.

The literature review analysis found that less than a third of the projects were evaluated at 5 or more years following construction, and many projects were only evaluated within the first two years after restoration (46%). Our results, however, did not show that post-monitoring years had a considerable effect on whether the project experienced functional improvement or no functional improvement. It was expected that more functional improvement would occur in projects that were monitored more than 5 years after implementation because these projects would have the longest time to adjust to the disturbances created by restoration activities. The reasons for lack of improvement over time were not clear within the longer term studies. Some studies suggested that the restoration approach or project design was flawed; therefore, lack of functional improvement was evident after large storm events with variable recurrence intervals (e.g. Kondolf, 2001; Densmore and Karle, 2009). Another reason may be that several studies with longer term monitoring involved measuring a greater number and variety of function-based parameters that increased the likelihood of one of these parameters not improving. This was observed with the Catskill Mountains, New York projects (Baldigo et al., 2010; Ernst et al., 2010; 2012); the Merced River, California project (Albertson et al., 2011; Harrison et al., 2011; Romanov et al., 2012; Utz et al., 2012; Albertson et al., 2013), and the Minebank Run, Maryland projects (Kaushal et al., 2008; Klocker et al., 2009; Newcomer et al., 2012; Stranko et al., 2012).

Based on the literature review analysis of project monitoring, the following recommendations are made for researchers and policy makers:

Researchers:

- Studies should include pre-monitoring data to determine whether a project has achieved functional improvement. Pre-monitoring data should come from upstream/downstream control reaches, where possible.
- Studies should also relate the functional capacity of the project reach to a reference condition.
- Studies should evaluate restoration projects over the long term to ensure recovery of the natural system and to ensure that a large storm event has occurred.

Policy Makers:

- Develop monitoring programs that focus on functional lift and not just channel stability.

CONCLUSIONS AND RECOMMENDATIONS

The literature review clearly shows that stream restoration projects show no improvement to stream functions more often than they show improvement. However, the reasons for this pattern are less clear. Based on the literature review, our experience with restoration practice, and information gained from interviews (Practice Paper), the following conclusions illustrate possible reasons. A final list of recommendations follows the conclusions to provide a roadmap for improving the science of evaluating stream restoration.

Conclusions about why more projects show no improvement than improvement to stream functions.

1. Practitioners often state project goals and objectives that are too broad. For example, common project goals are to improve habitat and water quality. There are many types of habitat so the goals should specify habitat for a particular organism, e.g., habitat for brook trout or smallmouth bass or native populations of fish found in an upstream reference reach. Note that habitat is not the same thing as biomass, so this goal is not stating that there will be more fish, just more habitat. The same holds for water quality. If water quality is a goal, the practitioner should clarify what will be improved, e.g., temperature, nitrogen loading, sediment supply reduction.

   The literature review showed that 30% of the projects studied did not state thegoals/objectives. This could be a leading reason why many projects showed no improvement because the researcher may have assessed parameters that were different than the goals. For example, perhaps the practitioner's goal was simply to reduce sediment supply from eroding streambanks, but the researcher evaluated changes in macroinvertebrate communities. If the macroinvertebrate community didn't improve, the researcher may conclude that there was no improvement, even if sediment supply was reduced by a large percentage.

2. The function-based parameters selected by researchers often do not correspond to restoration activities. The literature review showed that the most commonly evaluated parameter was bed material characterization, followed by benthic macroinvertebrate communities (See Figure 2). Yet, restoration activities would only change the bed material composition of certain conditions. Examples where this might occur are gravel bed streams with a large sand supply from bank erosion. If significant lengths of bank are stabilized, then the grain size distribution may coarsen, which would be an improvement. However, the research studies do not describe the restoration activity or composition of the bed and banks.

   Practitioners have less control over macroinvertebrate communities. To measure functional improvement for this function-based parameter, the watershed condition and the reach condition must be understood. This is accomplished by determining the restoration potential of the project reach. Projects that improve macroinvertebrate communities to a reference condition must have a healthy upstream watershed.

3. The literature review also showed that many projects did not improve lateral stability or bed form diversity. Unlike bed material composition and macroinvertebrate communities, practitioners have control over the improvement of these function-based parameters. It is unclear from the literature why the results are poor. Based on our experiences, the results for these parameters could reflect poor designs, young projects, or other unstudied factors. The literature review included projects that were constructed as early as 1990. The literature review also showed that Natural Channel Design is by far the most commonly used restoration approach. Natural Channel Design was a very new design methodology in the 90’s (the design manual was first published in the National Engineering Handbook 654 in 2007). Practitioners were learning as they implemented projects during this time frame. Many conference presentations by practitioners point to lessons learned during this timeframe.

   The literature review also showed that most projects were evaluated soon after construction (usually within two years) and without several years of follow up monitoring. Project monitoring from in-lieu fee programs like the NC Division of Mitigation Services show that lateral stability and bed form diversity improve over time as the streambank and riparian vegetation became established.

Final Recommendations based on literature review and conclusions.

For Researchers:

1. Develop project evaluation methods that are in alignment with project goals and objectives. Be very clear if the monitoring/evaluation go beyond the project goals and objectives.
2. Always provide information about what restoration approach and techniques were used to provide functional lift. Describe the approach and techniques in the paper. Try to determine if the design approach was properly applied. Always provide information about the watershed land use (e.g., urban, rural).

3. Evaluate the parameters that are likely to see functional lift and that were manipulated by the practitioner, e.g., floodplain connectivity, lateral stability, riparian vegetation, and bed form diversity. If parameters are included from the physicochemical and biological categories, link the assessment to the restoration potential. For example, the restoration potential should be Level 5, Biological in order to see improvement in biology to a reference condition.
4. Consider monitoring that shows functional lift and a comparison to reference condition. Many research studies only compare the biology of a restored stream to a forested reference condition. This is helpful information; however, knowing the before and after improvement is also helpful. For example, an urban stream restoration project may show considerable improvement to biological function-based parameters (e.g., macroinvertebrate communities); however, it will likely not be representative of a forested reference condition.

For Practitioners:

1. Develop function-based goals and objectives for every project. Refer to the section, “Restoration Objectives versus Research Objectives,” for more guidance.
2. Describe the restoration potential for every project. This requires information about the health of the watershed and constraints, in addition to the reach condition. Refer to the section, “Restoration Objectives versus Research Objectives,” for more guidance.
3. Describe the restoration approach used to develop the design (e.g. natural channel design) and the techniques used to create functional lift (floodplain connection by raising the channel or excavating the floodplain, bioengineering, riparian planting, large woody debris placement, riffle-pool construction, livestock exclusion).
4. At a minimum, discuss how improvements will be made to floodplain connectivity, bed form diversity, lateral stability, and the riparian vegetation. Many stream SOPs require changes to dimension, pattern, and profile in order to obtain restoration credit. If the geometry is changed, these parameters will be affected, and hopefully improved. Describing the changes in these parameters will better communicate functional lift than changes to dimension, pattern, and profile. Additional parameters can and should be added based on project conditions; these are just provided as a minimum.

Policy Makers:

1. Require practitioners to clearly state function-based goals and objectives. Refer to the section, “Restoration Objectives versus Research Objectives,” for more guidance.
2. Require practitioners to describe the restoration potential. Refer to the section, “Restoration Objectives versus Research Objectives,” for more guidance.
3. Develop debit and credit determination methods based on changes to function-based parameters rather than channel dimension, pattern, and profile. Examples include changes to floodplain connectivity, lateral stability, bed form diversity, and riparian vegetation.
4. Develop monitoring guidelines that focus on functional lift and not just channel stability.

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