Standards of Practice in Stream and River Restoration

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1. Stream restoration in the United States is big business, with annual expenditures in the billions of dollars and increasing every year.
2. Stream restoration, broadly defined, before 1980 typically involved basic reconnaissance and little or no engineering design or related standards of practice.
3. Perhaps the most important reasons for standards of practice is to help develop criteria for measuring project success. Failure to establish clear goals and objectives for projects makes establishing design criteria difficult or perfunctory.
4. Because of the variability of natural systems (e.g., streams), some have argued that standards for unique restoration projects are implausible or inappropriate, but the restoration engineering community has expressed a need for performance-based design criteria and guidelines to develop such criteria.
5. Standards of practices for the restoration in the Driftless Area are proposed in this paper.

Driftless Area | Goals | Objectives | Engineering | Design | Monitoring

Fig. 1. Restored Driftless Area stream with armoring of the bank toe. Credit: Dauwalter.

Historically, stream restoration projects in U.S. were designed and implemented by state or federal agencies, who completed assessment, design, and construction internally. The vast majority of trout stream habitat projects were small in size and were able to be done cheaply by government work crews. In the past 20 years, as funding has increased for stream restoration projects, average project size, complexity and cost have increased. In addition, our understanding of stream hydrologic and geomorphic processes has expanded greatly. Stream restoration is big business, with annual expenditures in the billions of dollars and increasing every year (1).

As Koonce (2) details, designing and implementing stream restoration techniques is a field of engineering and landscape architecture that has no generally agreed upon standards of practice. Many different approaches are used, some analytical and others experience based, which leads to confusion and disagreement among professionals and complicates adequate review of proposed and completed projects.

Restoration is defined as the action of returning something to its former condition. The Society for Ecological Restoration defines ecological restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. However, it is noted that stream restoration commonly refers to a wide range of project types and activities, including bank stabilization, channel reconstruction and fish habitat installation (Table 1). In this section, historical and current views on stream restoration standards of practice are outlined, and recommendations are made for applying standards of practice to projects in the Driftless Area.

Industry Development of Practice Standards

Stream restoration project implementation before 1980 typically involved basic reconnaissance and little or no engineering design or related standards of practice. Urban stabilization projects utilized and are often still utilizing threshold channel design standards or standard riprap calculations for basic hard armoring, threshold channel design being focused on little to no channel boundary movement at or below design flows (3, 4). The Natural Resource Conservation Service (NRCS) has developed some standards for channel and wetland restoration, but these sometimes involve hard armoring streambanks to a specified water surface elevation (e.g., 25-year return interval flow)(Fig. 1). More recent guideline documents integrate geomorphology, bioengineering, and hydraulic engineering in channel and bank stabilization design (5–10). From the evolution of these documents, it is evident that in the last 30 years, stream restoration practitioners have been slowly developing a

Statement of Interest

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Table 1. Restoration has been defined with a very specific definition, but it is also used as a term that encompasses a variety of other related terms and definitions. From Roni (18).

Term	Definition
Restoration	To return an aquatic system or habitat to its original, undisturbed state. It can be partitioned into passive (removal of human disturbance to allow recovery) or active (active manipulations to allow recovery). It is broadly used to include additional terms below.
Rehabilitation	To restore or improve some aspects of an ecosystem but not fully restore all components.
Enhancement or Improvement	To improve the quality of a habitat through direct manipulation (placement of structures, addition of nutrients).
Reclamation	To return an area to its previous habitat type but not necessarily fully restore all functions (e.g., removal of fill to expose historical floodplain).
Creation	Construction of new habitat or ecosystem where it did not previously exist (e.g., creation of off-channel pond).
Mitigation	Action taken to alleviate or compensate for potentially adverse effects on aquatic habitat that have been modified or lost through human activity (e.g., creation of new wetlands or replace those lost through land development).

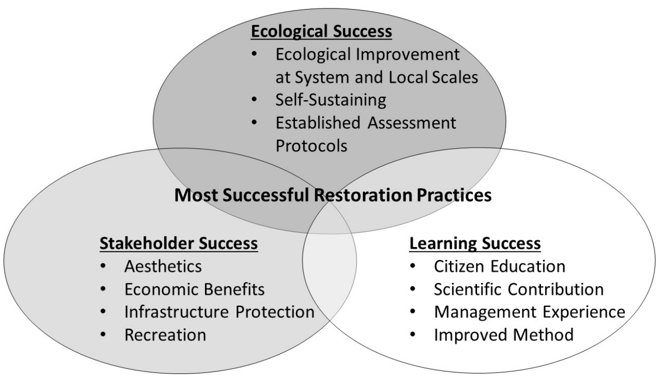

Fig. 2. The most effective river restoration projects lie at the intersection of the three primary axes of success. From Palmer, et al. (17).

collective standard of practice without formally documenting it or even being aware of the process.

Why Standards of Practice?. Perhaps the most important reason for developing standards of practice is to help develop criteria for measuring project success. Sustainable practices in the field of river restoration include the development of project design criteria, and a set of measurable goals for a project (11). Such criteria might specify the river flows under which a project will remain stable, or they might specify areas and volumes of restored habitat. These numeric criteria are measurable and can help determine if a project was successful or not.

Researchers have long stressed the relationship between goals and objectives and monitoring of project effectiveness (2, 5, 12–16). As Koonce (2) states, failure to establish clear goals and objectives also makes establishing design criteria difficult or perfunctory.

Prior to establishing numeric design criteria, it is recommended that project specific performance criteria be established. These answer the more general question, "what are we trying to achieve by doing this project?" and can be unspecific. In their review on the subject, Palmer, et al. (17) proposed five general criteria for measuring stream restoration project success from an ecological perspective:

- The design should be based on a specified guiding image of a more dynamic, healthy river that could exist at the site.
- The river's ecological condition must be measurably improved.
- The river system must be more self-sustaining and resilient to external perturbations so that only minimal follow-up maintenance is needed.
- During the construction phase, no lasting harm should be inflicted on the ecosystem.
- Both pre- and post-assessment must be completed and data made publicly available.

This list is a good starting point for developing performance criteria for Driftless Area projects. Other performance criteria may include such things as increased juvenile or adult cover, increased spawning habitat, improved habitat for turtles and other herptiles, increased bird habitat, or hydrologic improvements such as reduced peak flows and increased base flows. There is room in this process for the inclusion of other performance criterion that relate to recreation (angling) and agriculture, two obviously important regional considerations. Palmer, et al. (17) argues rightly that projects labelled restoration successes based on recreational or agricultural criteria should not be assumed to be ecological successes, and that projects initiated in whole or in part to restore a river or stream must also be judged on whether the restoration is an ecological success (Fig. 2).

Performance criteria and the subsequent numerical design criteria are established through consensus with the project funders, managers, and designers. The following list is an example of some of the potential numerical design criteria for an idealized channel meander restoration project:

- Design flows - The project shall be designed while considering baseflow (4.5 cubic feed per second [cfs]), bankfull (12.8 cfs), and flood flows (50 years for floodplain stability, 100-year return interval flow for bridge stability).
- Installed elements shall be designed to undergo minimal adjustment for the first eight years after establishment of vegetation. During this initial period, installed below bank project elements shall be stable up to but not in excess of the 10-year flood event, whereas floodplain

elements shall be stable up to but not in excess of the 25-flood event.

- The project will create 4.13 acres of new stream channel (sub-bankfull) including a 20% increase in pool habitat and spawning habitat over existing conditions, 14.5 acres of reconstructed floodplain, and 4.2 acres of off-channel vernal pool wetland habitat.
- Reconstructed road crossings shall be designed to pass flows up to the 50-year return interval flow. Crossings shall be designed to safely overtop without damage up to the 100-year return interval flow.

The above example list is a truncated set, but the criteria shown illustrate several important points. First, design criteria establish the project risk boundaries, inside which the designers must develop plans. The design flows are established, as are the areas and volumes of habitat to be created. The designer now has a set of recorded design targets from which to base the design.

Second, the above criteria include event-based performance, which is critical given the unpredictable nature of river flow. The above project could design all elements to withstand the 1,000-year flood event, but those solutions would likely be prohibitively expensive, involve structural armoring, and would not be conducive to improving trout populations, which is typically the main goal of Driftless Area projects. Project partners in this case have decided upon different flood flows for initial stability.

Third, the criteria include temporal limits on stability. This is a critical distinction in river restoration projects. Ideally, the least expensive and most ecologically sound projects would be those that establish a stream that is dynamically stable and self-maintaining in the future. Any stream restoration that involves hard armoring of any kind, particularly in alluvial systems, will eventually fail, because the natural tendency of rivers is to adjust both in cross-section and location within a valley, either slowly over a series of smaller events (e.g. sub bankfull) or dramatically during larger flood events. The above example establishes a period of non-deformability, which allows for stabilizing vegetation to establish. Beyond this initial period, the river is allowed to adjust. The alternative is to design a channel that is also non-deformable or static in the long term, which may be desirable if the goal is to protect infrastructure or cropland. The design life of a static project is then based on the longevity of the materials and the forces acting on those materials.

The standards of practice that assist in design criteria development then include, among others, adequate assessment of the geomorphology and ecology of the project area, prediction of the geomorphic response of the reach in question, accurate assessment of the hydrology of the region and the watershed, calculation of hydraulics of the reach, determination of the sediment transport affecting the project reach, and assessment of factors that will determine vegetation establishment (e.g. soils, climate)(Figs. 3, 4).

The Role of Engineering

In the 20th century, engineering of waterways was concentrated on either retaining water or removing water from urban/agricultural areas, resulting in damming, channelization and armoring of millions of miles of urban systems. This approach did not typically include consideration of ecological consequences. Conversely, habitat improvement or stream restoration focused on fisheries in rural areas with limited engineering considerations. Modern practitioners of river restoration are recognizing that the synthesis of multiple disciplines is required for successful restoration (2).

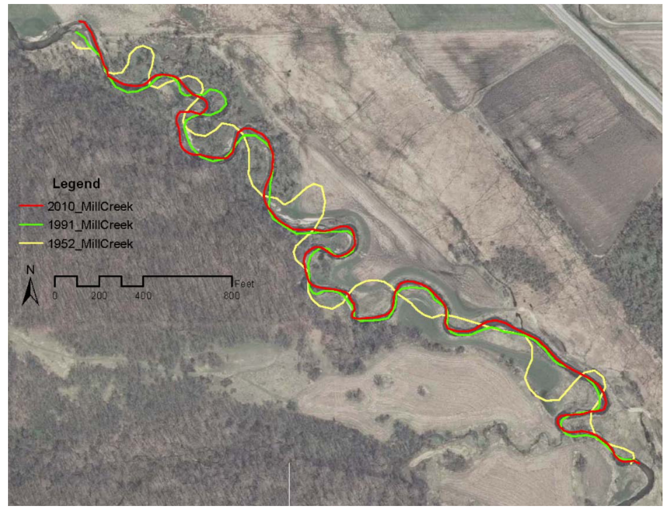

Fig. 3. Evaluation of the planform geometry of Mill Creek, Minnesota across three time periods. Credit: Inter-Fluve, Inc.

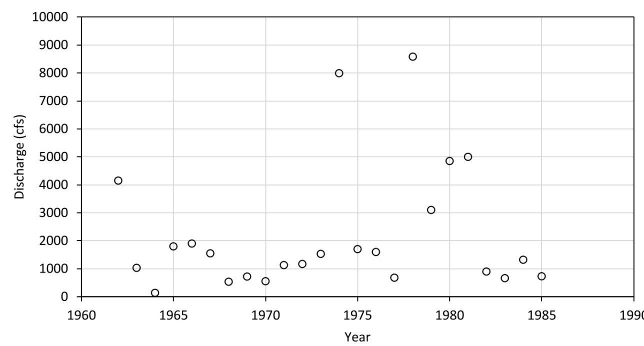

Fig. 4. Annual peak steamflow for Mill Creek, Minnesota from 1962 to 1985. Credit: Inter-Fluve, Inc.

As river restoration projects become larger and more complex, the risk associated with them increases. Projects involving channel relocation, floodplain grading, bank stabilization and road crossing modification or replacement can fail in a variety of ways. Failure of water projects can result in the loss of the taxpayer or private funding that paid for implementation, loss of future restoration funding, and damage to life and property. These risks and the definitions of engineering and landscape architecture in most states require that modern river restoration practice be subject to the rules governing those fields. The state of Wisconsin defines the practice of engineering as "any professional service requiring the application of engineering principles and data, in which the public welfare or the safeguarding of life, health or property is concerned and involved, such as consultation, investigation, evaluation, planning, design, or responsible supervision of construction, alteration, or operation, in connection with any public or private utilities, structures, projects, bridges, plants and buildings, machines, equipment, processes and works."

Landscape architecture is similarly defined by Wisconsin statutes as including, among other services, "the production of a graphic land area, grading, drainage, planting or land construction plan; and the planning of a road, bridge or other structure with respect to the aesthetic requirements of the area on which it will be constructed. . . "

Engineers and architects assume professional liability for the designs they produce. According to the American Society of Civil Engineers (ASCE), the purpose of licensure is to demonstrate competence in the field of engineering and to perform a design that safeguards the life, health, and welfare of the public and to comply with the principles of sustainable development (see ASCE Code of Ethics). As Slate, et al. (19) described, licensure and the affixing of an engineering seal to a design do not guarantee "success" of a project, but the seal indicates that the engineer has exercised his or her best professional judgment upholding the industry "standard of care" in the design process. Civil engineers and architects have many available design standards for myriad structures such as curbs, catch basins, stairs, doors, walls, bridges, streets, lighting, and so on. They design these structures based on industry standards and apply a factor of safety to ensure that the designs function as planned.

Engineering of Natural Systems

It is becoming more widely accepted that engineering and architectural professionals need to seal river restoration designs. Those that design river restoration projects without obtaining a professional seal need to be aware that they may be practicing engineering or landscape architecture without a license, which is illegal in every state in the United States. Simply practicing with an expired license can result in thousands of dollars of fines. Engineers and architects carry liability insurance that can, but not always, cover the work of the designer in the event of a failure under conditions not covered by the design criteria. For instance, if a fish passage culvert project is designed to be stable up to the 100-year event, and is washed away during a 50-year event, the design engineer may need to enlist his or her engineering liability insurance. This highlights the importance of developing solid design criteria to protect both the project owner and the designer. Design reports or technical memoranda should be developed for every project to clearly spell out the design criteria.

Because of the high level of risk involved, obtaining engineering liability insurance to cover river restoration may not be a simple process. Some pioneering firms have had to develop personalized insurance coverage specific to river restoration work, and premiums regularly exceed those for standard civil engineering (G. Koonce, pers. comm.). Engineering liability insurance for the design of recreational boating and kayak courses is so specialized and expensive that only a few firms in the country are able to practice.

River restoration using large wood (Fig. 5) introduces additional risk that is often poorly understood by novice or part-time practitioners and often requires significant engineering *due diligence*, that is, care that a reasonable person exercises to avoid harm to other persons or their property. Failure of large wood projects can occur due to inadequate assessment of buoyant and drag forces, trapping of debris, potential scour and erosion, torqueing, soil pumping and piping, and can lead to significant infrastructure failure due to downstream transport and racking on bridges, culverts and other infrastructure. Additional risks of large wood projects include occupational health and safety of installation contractors, attractive nuisance hazards, increased flooding, and the pinning and trapping of recreational boaters.

Fig. 5. Wood incorporated into a stream restoration project in southwestern Wisconsin. Credit: D. Dauwalter.

Every project requires a level of engineering due diligence to help minimize risk. The amount of engineering due diligence varies along a spectrum, with simple and inexpensive, low risk projects requiring less, and more complex larger projects requiring more. Skidmore, et al. (20) demonstrates this level of due diligence under the River Restoration Analysis Tool approach. The River RAT guidelines are an example of a system that directs practitioners to standards applicable for their required level of engineering due diligence.

River systems engineering differs somewhat from standard structural civil engineering in many ways, and these differences make it difficult to develop simple standards of practice:

1. Because of the many fields involved with river restoration, training and education in river restoration often must be gained from a variety of sources. Just the science of forensic fluvial geomorphology alone is complex, and accurate assessment requires many years of experience. Assessment of geomorphic stability and identification of potential problems is subjective and prone to error. Overestimation of bank erosion rates and channel adjustment are common and can lead to unnecessary or misapplied restoration projects. Civil engineers, even those with hydraulic engineering focus, are not necessarily trained in river restoration but are nevertheless designing and overseeing the construction of river restoration projects. Most civil engineers lack education and training in ecology, botany, and geomorphology. Conversely, many fisheries biologists and stream ecologists are practicing geomorphology and designing projects without geomorphology and engineering education, and only limited training related to those fields. It is thus critically important that people obtain cross-over education and training, and collaborate with other experts in the appropriate fields.

2. Natural materials vary in their shape, density, and longevity. Stone, soil, wood, and vegetation come in a variety of forms. Wood, for instance, can be green or dried, of variable diameter and length, have variable root and branch forms, and varying concentrations of resin, tannic acid, and lignin, all of which influence design life.

3. Multiple disciplines are needed to understand how project components fit together in a natural system. A project design typically needs to consider not only civil engineering and stormwater engineering, but also geology, geomorphology, hydrology, soils, hydraulics, sediment transport, botany, fisheries, stream ecology, horticulture, the social sciences, and occasionally environmental engineering when dealing with contaminated sediment.

4. River restoration projects have factors that revolve around streamflow, which is increasingly unpredictable. Baseflow for habitat varies during drought and wet years and with changes in landuse. Peak flows are highly variable and subject to changes in landuse, climate, and local weather patterns. Sediment movement is dependent on streamflow, and also on local perturbations such as riparian management, debris accumulations, local soil variability, and manmade structures.

5. Vegetation growth rates and the success of bioengineering solutions depends heavily on contractor warranties regarding watering, and also on streamflow and precipitation, which can very greatly.

6. Installed conditions can change greatly over time. Wetlands may convert to forested swamp, or a riparian grass community may convert to shrub scrub or forest over time, thus changing floodplain roughness and affecting both stream power and sediment movement. Conversely, forested riparian zones may be logged or converted to agricultural uses, and watersheds may experience increased impervious coverage with development. Geomorphic conditions such as channel base elevations, sediment movement, lateral channel migration, floodplain aggradation may increase or decrease during wet and dry periods.

7. Catastrophic or geomorphically significant floods may reset conditions on a watershed or reach basis and completely eliminate installed projects. The commonly understood equilibrium channel condition of streams can be wiped out, and channel locations can change dramatically during large floods (21, 22). Civil engineering projects are subject to extreme weather such as tornados, and earthquakes in tectonically active areas, but these impacts to civil projects are relatively rare. Extreme floods in the Driftless Area are becoming much more likely with increased global warming effects. Precipitation falling in 100-year storm events has increased by 37% in the Midwest, with as much as 50% of annual total precipitation falls during 10 days of the year in the western Great Lakes region. Accumulated precipitation during these 10 days has increased dramatically, with increases of 20-30% observed from 1971-2000 in many locations (23–25).

8. Although civil site areas, elevations, and soils can differ, standards can be developed more easily because building and structural components are typically the same. Buildings require customized foundations, but they are almost always concrete, the standards for which are established. In contrast, each subreach of a stream in the Driftless Area, or anywhere for that matter, is different from the next. Although some reference analog conditions may be similar to the project reach, there are almost always idiosyncrasies associated with a particular site. Floodplain morphology may differ, bank soils may differ, bedrock contacts are variable, floodplain encroachment and filling vary, roads and road crossings impact hydraulics during flooding, agricultural practices differ, watershed and valley morphology are unique, and riparian management varies (Fig. 6).

Fig. 6. Transition from open understory riparian vegetation to dense understory at Trout Run in southeast Minnesota. Credit: D. Dauwalter.

Standards of Practice for River Restoration

Because of the above variability, some have argued that standards for unique river restoration projects are implausible or inappropriate (11). The river restoration engineering community has expressed a need for performance-based design criteria and guidelines to develop such criteria (19). In many ways, standards have been developed over time and are continually being refined. Open channel design methods and channel design methodologies based on hydraulic and geotechnical principles have been around for decades and some are updated regularly (5, 6, 9, 26–28). New standards are being published based on increased levels of experience. For instance, the U.S. Bureau of Reclamation and Army Corps recently published the Large Wood Manual detailing practices used in the industry, and some states have published habitat restoration guidelines that guide the level of engineering for various projects (10, 12).

Some state agencies have placed special emphasis on the analog-empirical methodology offered by the Rosgen method, also called the reference reach method or natural channel design (29, 30). Some ecologists and fisheries biologists at state and federal agencies have invested heavily in this approach, which involves several weeks of short course training in data collection, analysis, and design. In general, the Rosgen approach emphasizes empirical relationships of valley and channel form and relates these to channel evolution through comparison of current and potential channel forms (31–34). The Rosgen approach is somewhat controversial, as described by Lave (35), and has been a source of debate among academics and practitioners for over twenty years (29, 34, 36–40).

The Rosgen approach is attractive to both engineers and non-engineers, and has been used successfully by many practitioners in the region. Short course training in geomorphology, ecology, and other disciplines is an excellent way for professionals to expand and progress toward a more complete understanding of the various disciplines. Reference reach or analog based design techniques can still be conducted without taking short courses or directly applying every aspect of the Rosgen methodology as published. Many practitioners educated and trained in fluvial geomorphology use analog and empirical data as part of a larger design process.

Hydraulic analysis is often part of the due diligence for stream restoration projects, and may be simple at-a-station calculations (e.g. Manning equation) or more complex computer models. Some situations require hydraulic modeling as part of due diligence. Projects in Federal Emergency Management Agency (FEMA) mapped areas must not cause a rise in the 100 year flood elevation compared to the modeled pre-project condition. Many design criteria detail stability requirements under various flows (such as the bridge safely overtopping during the 100-year return interval flow).

Standard practices for hydrologic and hydraulic modeling are changing rapidly as technology advances. As recently as 2000, geographic information systems (GIS) software were not advanced enough or readily available for application in the river restoration field, and hydraulic modeling software was expensive and time consuming. Advances in technology on many fronts have led to a synthesis of laser and GPS satellite-based surveying, powerful hydrologic models, computer aided drafting (CAD) software and both one- and two-dimensional hydraulic modeling (e.g. HEC-RAS). The programs used today make it much easier to assemble data and produce robust, predictive models incorporating hydrology, geomorphology, hydraulics, and sediment transport analysis where data allows.

The tools described above comprise a variety of standard practices. No single method or prescribed combination of methods can satisfy all of the engineering or architectural due diligence requirements, nor should they be expected to given the variability in river restoration as noted above. The amount of due diligence should not be dictated to the designer by a strict set of standards or a singular methodology. As Slate, et al. (19) asserts, "by gearing designs to satisfy specified, measurable criteria, engineers will be able to select the most appropriate design methods for a given project across a wide variety of boundary conditions and system processes." What is needed is a broader professional acceptance of multiple scientific design approaches for river restoration projects, a distinction between engineering and non-engineering practices, and quantifiable project goals to more easily evaluate success or failure.

Standards of Practice and Monitoring. Design criteria are documented in design reports, but are also reflected in specifications and plans. Many specifications have been standardized by state agencies, and thus are also a part of the industry practice standard. Design criteria, plans and specifications all form the basis for project success monitoring. Plans and as-built plans can be used to determine physical changes such as erosion, deposition, sediment movement, and changing channel dimensions, and ecological surveys can document changes in riparian vegetation, stream macroinvertebrate communities, and fish populations.

Setting realistic and achievable goals is an important part of design criteria development, and is supported by standards of practice. One of the first practice standards employed is the stakeholder meeting, the first of which is used to establish realistic project goals. Palmer, et al. (17) argue that rather than attempt to recreate unachievable or even unknown historical conditions, a more pragmatic approach is one in which the restoration goal should be to move the river towards the least degraded and most ecologically dynamic state possible, given the regional context (17, 41–43). For example, although a prairie dominated floodplain and riparian area may have been the historical condition for a particular reach, prairie restoration is extremely difficult to achieve and maintain, and may not be an achievable goal. Similarly, designing a project to increase Brook Trout *Salvelinus fontinalis* spawning may be desirable, but if piscivory by Brown Trout *Salmo trutta* is high, and the geology and geomorphology preclude meaningful installation and maintenance of Brook Trout spawning habitat, another performance criterion may be more appropriate.

As mentioned above, Palmer et al. imply that monitoring should be completed for every project. It is, however, unrealistic to expect every project to include the same level of monitoring. The degree of monitoring should be commensurate with the level of project risk, complexity, and cost. Simple projects may only need repeat photography or perhaps a site visit annually for the first few years post construction. Other projects may need a comprehensive monitoring plan based on assessment of design criteria. Some basic monitoring elements are listed below:

- **Stability** – Short term stability and long-term project change can be monitored by tracking physical changes both before and after construction, and for milestones proceeding ahead from Day 1 of post construction (site maturity). These have as their base, project surveys that include the following:
  - *Pre- and Post-Project Surveying* – Geomorphic or engineering-based surveys can be modified to include desired monitoring. For example, in addition to hydraulic or topographic sections shot for drafting purposes, permanent cross-sections or digital elevation models (DEMs) can be surveyed in greater detail and more permanently monumented for long term monitoring. GIS based surveying makes this process easier by reducing the need for multiple benchmarks.
  - *As Built Surveying* - Surveying of key structures or forms such as pools, riffle forms, bars, boulders and pocket water, large wood pieces, and other elements allows for monitoring of changes, and helps to document differences in project drawings versus what is actually constructed.
  - *Repeat Photography* - Photographs taken from established photo stations are an inexpensive way to monitor changes in vegetation communities and channel stability. Photogrammetry is now being

used whereby photographs from multiple perspectives are translated into actual topographic surface data. Drone photography allows for GIS located, low flying aerials to conduct repeat photography during both low and high-water events. Drone imagery can be extremely valuable in calibrating both pre- and post-construction flood modeling by accurately and safely documenting flood extents at known flow levels.

- **Fisheries** – Designing biological monitoring studies, including fisheries, is a complex science in and of itself (44, 45). Showing fisheries population changes that demonstrate changes related to large projects is difficult, and for small projects nearly impossible. Confounding variables such as attraction, production, climate, stream flow, temperature, turbidity, year class strength, angling and natural mortality must be quantified and controlled to the degree possible (46).

- **Macroinvertebrates** – Measuring the presence or absence of macroinvertebrates is relatively simple, but measuring population size changes related to restoration projects is challenging. Because of the inherent variability in macroinvertebrate populations, quantification of aquatic insect and macroinvertebrate populations typically requires a large number of samples and is cost prohibitive. A simpler approach is to employ studies that focus on the tolerance of species or families of invertebrates to water and habitat quality (indices of biotic integrity), or behavioral groups that reflect assemblages and can help monitor changes as a result of a project (e.g. functional feeding group assemblages). Qualitative studies such as biotic integrity comparisons, feeding group analysis, diversity indices and relative abundances require fewer samples and are less expensive. There are many references available to aid in macroinvertebrate monitoring (47–53).

- **Plants** – Plant success is critical to any river restoration project. Construction contractor warranties for plant health can be integrated into a long-term operations and management plan. Typically, contractors need to monitor and/or replace plants and seeding annually for 1-3 years, after which, project owners or partners need to take over monitoring of plant community success. Plans can include monitoring tree and shrub health, coverage of native species seeding or plug plantings, plant protection (cages, tree tubes etc.) maintenance and eventual removal, invasive species treatment, and plant watering. There are many Federal, state and local resources for native plant restoration and monitoring. State resources include local land and water conservation offices, University extension, and documents such as the Minnesota Board of Water and Soil Resources *Wetland Restoration Guide* that offer guidance related to plant management and monitoring (54).

Several authors have addressed the need for monitoring stream restoration projects, and have presented generalized outlines (14, 18, 45, 55–58). Guidelines for monitoring stream projects have been published by many state and federal agencies, and cover both physical and biological monitoring strategies (47, 59, 60).

Recommendations

In summary, standards of practice in river and stream restoration involve a variety of methods covering multiple disciplines (Fig. 7). The key to successful projects is to develop performance and design criteria that protect the project owner and designer from excessive liability, allow the engineer or designer to design a project that will meet multiple objectives while improving ecological health, and establish targets for monitoring success. The following recommendations are offered related to the application of design practice standards in the Driftless Area:

1. Channel design for stream restoration involves many sciences, and successful collaboration among people and fields of study is essential to project success.

2. Design standards of practice should be performance based, and centered around established performance criteria and published, project specific numerical design criteria.

3. Any development of a performance-based set of standards should consider multiple methods or design approaches involving multiple disciplines to achieve a common goal. No one methodology should be adopted as a standard of practice.

4. Engineers and landscape architects, if part of a design team, should work with other disciplines to ensure success.

5. Design goals should be clearly defined and based on general physical principles and channel processes, rather than solely referenced to an empirically defined equilibrium state. Urban and rural infrastructure influences, climate change impacts, changing landuse and potentially damaging flooding must be considered when determining the amount of engineering due diligence required.

6. Geomorphic assessment by qualified personnel should form the basis of any watershed or stream restoration program. Quantifying the geomorphic state of reaches, stages of channel evolution, channel stability, and future changes can help determine potential projects and both the spatial and temporal sequencing of those projects. Geomorphic based watershed assessments, combined with local management knowledge of angler and landowner goals, can better target available funding to have the most positive impact. Qualified personnel should have a combination of education, training, and demonstrated experience in evaluating stream geomorphology.

7. Stream restoration within a watershed should generally flow from headwaters to downstream to address hydrologic solutions for reducing peak flows and increasing base flows.

8. Stream restoration practitioners optimize the benefits of available design strategies, including analog, empirical and analytical approaches, and must ensure that the unique constraints and hydraulic characteristics of their project reach are quantified.

Fig. 7. Stream restoration project in southeast Minnesota.

9. Performance criteria and design criteria should consider both time and space considerations, short term, and long term deformability and successional changes.

10. Design criteria should form the basis of short and long term monitoring programs.

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