CONSIDERATIONS FOR DEVELOPING A MODEL FOR MEASURING AQUATIC ECOSYSTEM IMPROVEMENT FROM RESTORATION OF URBAN DEVELOPMENT

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Abstract. Many watershed improvement projects focus on reducing erosion potential and reducing storm flow peak discharges. The costs of these projects are easily determined, but quantification of benefits has been slower to develop. The benefits on instream aquatic habitat from these types of projects (i.e., storm water detention structures, constructed wetlands within the floodplain, natural channel restoration, stream bank and buffer improvements, etc.) are usually not considered (but should) as part of evaluating the benefits provided by each project. This paper will describe considerations that could be taken when developing a benefits model for aquatic ecosystem improvement from restoration projects. The steps of developing such a model include (Figure 1):

- Understanding how urbanization affects the flow regime and water quality of stream systems;
- Understanding what form urbanization is occurring;
- Understanding the biological response to urbanization; and
- Developing a benefits model that has measurable factors of impacts, defensible criteria, and quantitative or qualitative data to measure benefits.

INTRODUCTION

Most watershed implementation projects usually focus on reducing erosion potential and reducing storm flow peak discharges. The benefits on instream aquatic habitat from these types of projects (i.e., storm water detention structures, constructed wetlands in the floodplain, natural channel restoration, stream bank and buffer improvements, etc.) are usually not considered (but should be) as part of evaluating the benefits provided by each project. Very little research has been geared towards measuring the physical habitat changes as a response to geomorphic changes from landscape impacts. Most studies to date have focused on watershed changes (i.e. percent impervious area) and the effects on biological indicators (i.e. biotic integrity indices) that are indirect measurements of the impacts actually occurring in the stream. (Roesner and Bledsoe, 2003). How these direct impacts affect the biological community along with being able to link watershed impacts to physical and chemical shifts in the stream and then to the biological response needs to be understood in order to develop a model to measure improvements from projects aimed to improve stream conditions.

This paper will attempt to analyze how urbanization affects stream systems and how to develop a model to measure biological improvement from urban restoration (Figure 1). The first step is to understand how urbanization affects the flow regime and water quality of stream systems. The second step is to understand what form urbanization is occurring, because each has it's own level and type of impact on stream systems. These forms include the location in the watershed where the impacts are occurring, the timeframe of the disturbance, and whether the impact is direct of indirect. The third step is to understand the biological response to urbanization. All of these steps involve integration and reflecting on whether model components are adequately capturing the watershed impacts being studied. The final step is to develop a benefits model, and the elements of any benefits model include:

- Measurable factors of impacts for the areas you are trying to improve
- Defensible criteria that measure benefits related to the project objectives
- Quantitative data or qualitative data that can be justifiably be put into distinct categories

Stream assessments and restoration projects are becoming increasingly important to meet water quality standards and protect biological health. The purpose of this paper is to provide guidance on how to design stream assessment and restoration projects for collecting valuable data in the field. Collecting valuable data during the assessment stages is the backbone to providing effective restoration strategies.

BENEFIT MODEL COMPONENTS

How does Urbanization affect the flow regime and water quality?

Urbanization comes in many different forms but mostly fall into one of two categories – flow regime or water quality. Changing the pattern of how rainfall is transported across the landscape alters the flow regime. The change in duration, magnitude, and frequency of storm events are all factors of changing hydrology. The predictability of flows, or the flashiness of a stream, needs to be measured or modeled. Not only do volumes and peak discharges adversely impact streams, but the shorter duration and reduced infiltration of storm runoff decreases stream base flow. Maintaining adequate base flow is crucial to healthy biological communities (discussed in more detail below).

Water quality impacts mostly come in the form of sediment inputs into the stream. The altered flow regime indirect alters water quality by creating more shear stress in the stream channel, which increases erosion of the banks and streambed. Pollutants from the landscape enter streams as non-point sources, usually during the "first flush" or runoff from the first 1-1.2 inches of rainfall. Oils, chemicals, and other debris accumulate on the landscape and are collected by the first part of a storm's runoff and deposited in streams.

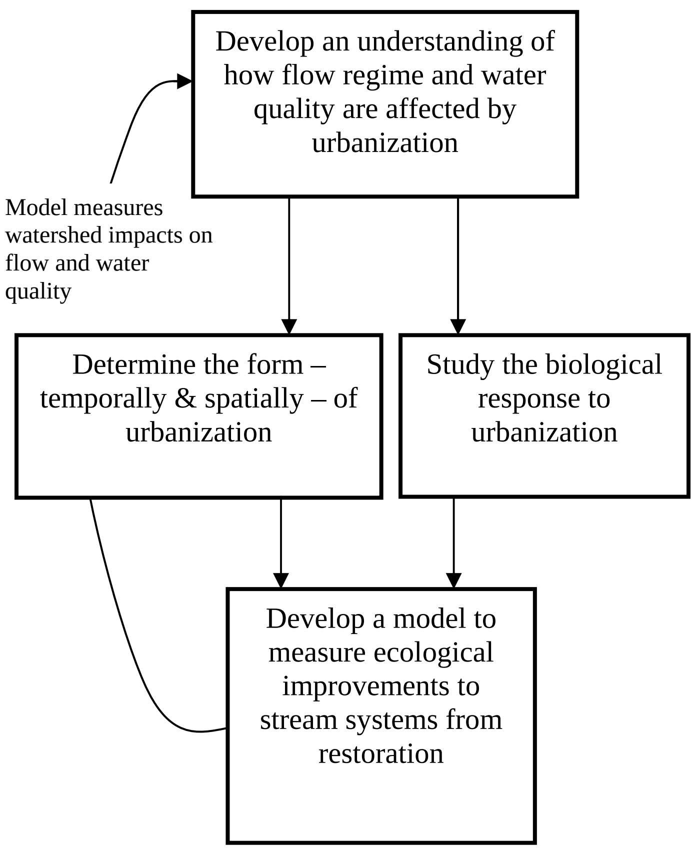

Figure 1. Benefit model components.

What form, temporally and spatially, of urbanization is occurring?

Impacts from urbanization occur in many different forms – widespread vs. localized, short-term vs. long-term, direct vs. indirect. In addition, the location of the watershed where the impacts are occurring is important to understand. Disturbances that occur in the headwaters impact smaller areas but can cumulatively become very detrimental to downstream locations in the watershed. Disturbances that occur further down in the watershed are often "diluted" by the contribution to the watershed upstream of the impact.

The timeframe that a disturbance occurs – how long and when - is important as well. Streams attempt to recover from disturbances, but the time it takes to recover can vary depending on the magnitude and type of disturbance. During the recovery period, additional disturbances often occur, causing it to be difficult to discern which impacts were caused by the various disturbances.

The amount of time a disturbance occurs, affects how a stream is altered. Shifts in land use that create more impervious areas permanently alter the hydrology of the system if proper best management practices (BMPs) are not installed. Stream erosion and morphological shifts of the channel will continue to occur via incision and widening until the stream is at equilibrium with the new hydrology. More temporary impacts, such as land disturbances that don't permanently alter the hydrology (i.e. forestry practices), will cause the morphology to begin to respond to any hydrological shifts, but the magnitude of the impact is less and the stream can recover more quickly. However, sediment inputs into the stream from the landscape are now part of the substrate and will be incorporated into the total load transported downstream.

How do you predict or measure the biological response to urbanization?

According to Karr (1992), the impact of human disturbances on stream systems affect the ecological integrity in five main areas - water quality, habitat structure, flow regime, energy source, and biotic interactions. These five areas are important components of any ecosystem for several reasons, including:

- **Water quality** – What components are potentially impacted by urbanization? What are you trying to improve?

- **Habitat** – What habitat has been altered from urbanization? How will habitat be improved from restoration? How do you effectively measure improvement?
- **Flow regime** – Biotic integrity is impact directly by changes in the flow and indirectly by morphological shifts from changes in the flow. What factors were impacted by flow shifts and how do you measure? Scale is important consideration with flow, because many of the changes are at a watershed scale whereas the restoration is at a reach scale.
- **Energy source** – How has this been altered and will restoration improve? Difficult to measure.
- **Biological interactions -** Before being able to determine what factors to measure, need to have full understanding of the disturbances presently occurring and how they affect the community plus understand how the interactions have been previously impacted.

All five of these areas are interconnected and involve many variables, many of which are closely related or difficult to measure. Accurately measuring how human impacts affect stream biological health is not a simple task. However, it is critical that the ecological responses to urban pressures and improvements from restoration projects be understood.

How do you develop a benefits model that has measurable factors of impacts, defensible criteria, and quantitative or qualitative data to measure the benefits and costs?

Determining the direct improvement from a restoration project can be simple – a new detention facility will control the hydrology by a measured amount or a stream restoration project will alter the channel morphology and add aquatic habitat. Measuring how the aquatic ecosystem improves can often be difficult. There is no set protocol for doing this, but key factors to consider when developing a model include:

- Develop defensible criteria that measure benefits related to the project objectives
- Measure quantitative data or qualitative data that can be justifiably be put into distinct categories
- Collect data at the correct scale and location
- Target the factor you are trying to improve.

For example, if erosion is a concern, directly measure erosion of the bank and bed. If habitat variety is key, then take cross-sectional measurements, substrate measurements, hydrologic regime (pool vs. riffle) percentages, woody debris amounts, riparian conditions, etc. Qualitative habitat scores are routinely used but are difficult to convert into useful metrics for a benefits model. These criteria are highly subjective and may be difficult to reproduce or compare to post-improvement scores. As stated above, be as quantitative as possible when developing the benefits model.

Considerations of Scale and Timing

When and how long does the impact occur? How far into the future do you want to consider when developing the model? When developing a model, match the level of data collected with the scale you are developing the model for – i.e. don't collect exact reach data if comparing options at the watershed scale or don't collect watershed level data if comparing reach specific projects.

Measuring Factors of Urbanization

It is important to understand when the impacts occurred and how the stream recovers, if at all, from the impact. Is the degradation actively occurring or is the degradation a result of historic impacts – what are you trying to fix?

Measuring Direct and Indirect Impacts

In many cases, even if the direct impacts are known they are difficult to accurately measure. Using a surrogate indirect measure closely correlated to the direct impact can be effectively used.

Use of Cost/Benefit Analysis Approach

It is beneficial to be able to measure the ecological improvements using a benefits model; however, many clients, both government and private, want to know the projects that have the most benefit for each unit of cost. The USACE uses an incremental analysis approach to systematically determine the project or group of projects that the benefits model shows having the most ecological improvement per unit of cost associated with the benefits.

EXAMPLE USES

Capital Improvements for Local Governments using the WRDA Section 206 Program

Under the Water Resources Development Act, Section 206, money is available under a cost sharing program with local governments with a goal to improve watershed conditions with site specific projects targeted to improve the flow regime and aquatic habitat. In one project in Cobb County, Georgia, projects were selected based on a watershed sediment loading model, a watershed hydrologic model, and field visits of selected sites. The benefits model for determining the largest habitat improvement for unit cost will be determined by directly measuring the aquatic habitat at the project location and modeling the predicted improvement of habitat based on the type of project type. The Georgia Department of Natural Resources (GaDNR) protocol was used to collect habitat information for each project site. The same criteria in the protocol are used to predict improvement from each project. For example, a Priority 1 (Rosgen-based) stream restoration will improve aquatic habitat by the maximum predicted amount, whereas a detention facility will only get a 0.3 factor of improvement due to only 3 of the 10 criteria being flow related. An incremental analysis will be performed on each project to determine which projects to construct.

Storm Water Master Planning for Municipal Governments

Many local governments develop a list of projects under a capital improvement program geared towards reducing storm water impacts on the watershed. In order to determine which projects are selected, it is necessary to outline goals on what the projects should be improving in the watershed. For example, Gwinnett County, Georgia has a goal to reduce sediment loading and improve aquatic habitat. The benefit model targets these two components by developing a watershed-based sediment-loading model using land cover, impervious area, and stream erosion data and measuring aquatic habitat condition throughout the watershed using the GaDNR approach. Results from several watersheds show that high TSS loading is closely correlated to the areas with poor habitat. Therefore, project lists were determined based on the TSS model, because the habitat data were difficult to apply to whole reaches of stream and determine improvement at specific project locations. Predicted improvements were calculated for sediment reductions for the projects based on scientific judgement and technical literature and compared to the project cost. Implementation considerations, such as property ownership and permitting considerations are completed when determining which projects from the ranked list to construct.

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