ESTABLISHING DYNAMIC EQUILIBRIUM IN AN URBAN STREAM

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Abstract. Channelization of urban streams has reduced infiltration and riparian habitat, increased flooding and isolated urban residents from natural processes. One possible way to restore environmental integrity of channeled streams is to re-establish dynamic equilibrium, where outflows of sediment and water are equal to those entering upstream. This paper describes a design methodology to guide re-establishment of dynamic equilibrium in channelized urban streams.

In a hypothetical landscape design, dynamic equilibrium is reestablished for a prominent Atlanta channeled urban stream. Three main aspects of dynamic equilibrium were considered in the design: 1) fluvial geomorphology, 2) riparian habitat and 3) human use of the stream.

This paper affirms that the principle of dynamic equilibrium can be used as a guide for establishing urban channel forms and associated riparian habitat zones. Human use and site specific exigencies can be integrated into the stream with restored form and function through landscape design.

INTRODUCTION

Many streams in urban environments have been degraded by disturbances such as channelization, increasing impermeable surfaces in the watershed, routing of storm water and sewage into streams, and direct human abuse (garbage dumping, compaction of soil, etc.). Stream channelization and other disturbances often result in loss of native riparian habitat, increased bank erosion, and flooding downstream. Combined, these factors result in loss of stream dynamic equilibrium and capability to respond to small perturbations occurring within the environment.

One such stream is Clear Creek, a tributary of Peachtree Creek, in Atlanta, Georgia. Clear Creek has a high percentage of impermeable surfaces in its watershed, and parts of the creek have been channeled into concrete flumes. A portion of the channeled section of this stream runs through Atlanta's Piedmont Park, where intense human use has resulted in stream degradation through pollution and soil compaction.

The City of Atlanta and local citizens' action groups have expressed an interest in returning the stream to a more natural form. These groups have collaborated in a grant application, which is currently being reviewed by the Army Corps of Engineers, for management of the entire Peachtree Creek watershed. Clear Creek would be used as a demonstration project to exhibit innovative ways in which storm water can be controlled in a metropolitan area. Stream restoration and wetland creation are two aspects of this grant application.

For these reasons, the portion of Clear Creek that runs though Piedmont Park invites a rehabilitation attempt. The purpose of this paper is to demonstrate that the principles of dynamic equilibrium can be used to design a rehabilitation of this portion of Clear Creek, producing a functioning ecosystem that can respond to perturbations occurring in the stream and surrounding environment. This paper is based on a study by Lucas (1994).

Dynamic Equilibrium

Dynamic equilibrium is a state in which inputs and outputs of a stream system are equal. "Equilibrium is statistical, not absolute; it exists within the context of constantly changing discharges and channel morphologies" (Ferguson, 1991). In this state, water moving through the stream channel has enough energy to carry sediment loads downstream equal to those entering upstream (Heede, 1986; Mackin, 1948). Erosion occurring at any point in the stream is accompanied by an equal amount of deposition (Dunne and Leopold, 1978). Although the channel may change form, if watershed parameters remain the same, cross sectional area may remain the same. The watershed of a stream in dynamic equilibrium can be characterized by a smooth transition between slopes, headwaters and the stream channel. The profile of the watershed is "smoothly concave; flow, width and velocity increase downstream while gradient and particle size decrease " (Ferguson, 1991, citing Dunne and Leopold, 1978, pg.89). "Changes in the watershed can trigger adjustments within streams and related biological and physical systems" (Nunnally, 1985). It must be recognized that a stream in dynamic equilibrium is also in equilibrium with other natural features around it, such as riparian vegetation (Heede, 1985). Any change to one feature will result in a corresponding change in another. This enables the stream ecosystem to withstand, and correct for, small perturbations occurring through the system by adjusting itself and related features to reach a new state of equilibrium. This describes a "healthy" stream and therefore can be used as a guiding principle in stream restoration.

The principle of equilibrium forms a basis for channel form in Clear Creek. It is not the objective of this paper to design a stream channel that simulates the form that Clear Creek had before any human disturbance. The watershed that Clear Creek occupies has been drastically altered by human development, and recreating the historic channel would not be appropriate to contemporary conditions or solve any problems the stream is currently experiencing. Although Clear Creek is not a pristine, natural stream, a dynamic equilibrium model can be used to estimate the channel form that Clear Creek would occupy in such a self evolved state, given its contemporary watershed parameters.

Rehabilitation Procedure

There are certain characteristics of streams in dynamic equilibrium that can be used to analyze stream ecosystems (Heede, 1980) and therefore are useful in the design of stream channels. The characteristics can be described in two categories: fluvial morphology and biotic habitat. Morphological indicators of equilibrium include meander wavelength, mean radius of curvature, gradient, width, sinuosity and meander belt (Gore, 1985). Biotic habitat indicators of equilibrium are pools, riffles, bed material, and riparian (streamside) vegetation (Beschta and Platts, 1986). Other biotic indicators may be identified by examining native flora and fauna habitat of the area in which the stream restoration will occur, and in similar areas elsewhere. In this paper, both geomorphic and habitat characteristics will be used to characterize proposed channel form.

In addition, because the stream is inside a city park, its relationship to human use cannot be ignored. The requirements of human use will further shape channel alignment and the appearance of the stream to enhance the aesthetic and recreational opportunities of Piedmont Park.

Also, to the degree possible within the above objectives and the constraints of the site, an attempt was made to control severe surges of storm water that may cause flooding downstream. Although this objective is not a facet of the restoration considered in isolation, it is part of the rehabilitation of Clear Creek and Peachtree Creek considered as a whole, in which every restored or treated reach must participate to the degree possible.

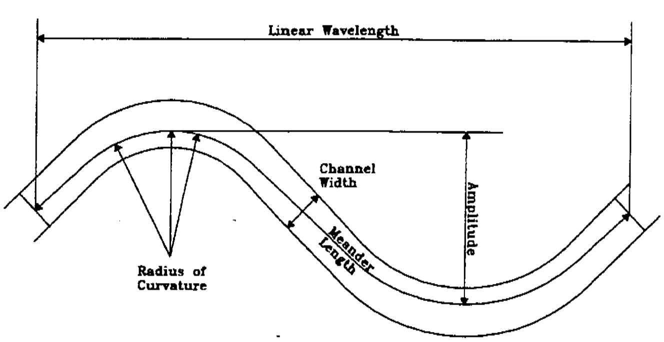

Figure 1. Meander Parameters

Fluvial Geomorphology

Streams naturally tend to form meanders. Even in straight reaches of channels, the thalweg (deepest part of the channel) tends to migrate back and forth from one side of the channel to the other (Leopold, 1964). The forces behind meandering contribute to the stream reaching a state of dynamic equilibrium. Measurable parameters of meanders useful in describing a stream channel in equilibrium and designing a channel for equilibrium are linear wavelength, width at inflection point, meander length, radius of curvature and meander belt width (amplitude) (Hasfurther in Gore, 1985 and Rosgen, 1994).

Biotic Habitat

Biotic habitat, in this paper, refers to a system which is composed of living and non-living material. The interactions between living and non-living elements determine the composition of individual components present in the system at any given time. Combined components form the habitat. Each component of the system is related to the next so that a change in one causes a corresponding change in another. Riparian habitats " have their greatest value as buffers between man's urban... development and his most vital resource - water" (Odum, 1978, pg. 3). After channel form has been established using principles of fluvial geomorphology, biotic habitat can be described within its context. Biotic habitat can be described in terms of four factors: pools, riffles, bed material and riparian vegetation.

Pools are formed by the convergence of flow in stream. Convergence occurs on the outside of bends and meanders, but can also occur around large roughness elements (logs) in the stream or deflection of flows by boulders (Beschta and Platts, 1986).

Riffles are shallow areas in streams composed of the largest material in the stream bed. Larger material is deposited as water flows out of pools and experiences decreased energy at the beginning of the riffle. Water accelerates as it moves through the riffle, increasing the energy gradient that is expended as scour at the next pool. Therefore, riffles have a slope greater than that of the overall channel slope. Riffles are commonly located at the inflection point between meander curves (Beschta and Platts, 1986).

Bed material can provide important habitat for some aquatic fauna as well as influence sediment transportation and channel dimensions (Beschta and Platts, 1986). Bed material also plays an important role in the armoring of the stream channel and providing habitat for aquatic fauna during periods of high flows.

Riparian vegetation consists of different micro-habitats. These micro-habitats can contain similar plant species, but have enough individual characteristics to occupy a particular niche in the environment. The piedmont riparian zone can be separated into six different micro-habitats (Schafale and Weakley, 1990): 1) Sand and Mud Bar, 2) Rocky Bar and Shore, 3) Levee, 4) Swamp Forest, 5) Bottomland Forest and 6) Floodplain Pool. The first two habitats may exist in the stream channel. All of these habitats do not necessarily exist together in any given section of a stream.

Design Procedure

This section explains the procedure used to design Clear Creek's rehabilitated channel and surrounding landscape. The design procedure can be broken down into several topical levels. The first is the establishment of channel dimensions and meander patterns. Once established, these patterns were aligned to fit Piedmont Park's specific site features, such as narrow valley walls. With alignment established, biotic habitat zones were designated and delineated in and around the channel. The final level of consideration is human use. An attempt was made for park visitors to have opportunities of direct contact with the stream in places that will cause the least amount of degradation to stream quality.

Establishment of Basic Channel Form

Manning's equation was used in the establishment of channel form. Manning's equation, widely applied, predicts rate of flow, channel dimensions, slope and roughness.

Leopold, Wolman and Miller (1964); and Dury (1973) established that the bank full flow for natural streams is the 1.5 year recurrence interval. In order to establish this flow for Clear Creek, data on storm flow events in nineteen urban watersheds in the Atlanta area were obtained from the United States Geologic Survey (USGS, 1994). Watersheds in the sample varied in size from .21 square miles to 19.10 square miles. No data were available for the 1.5 year flow, so data for the two year flow were used as a close approximation of bankfull stage. Data for two year flow were plotted against watershed area. Through interpolation of this graph, a two year recurrence interval (Q) for Clear Creek (watershed area = 5.13 mi^2) was derived to be 520 cfs.

Channel surveys of six of the streams used in the flow calculations were also obtained from the USGS (USGS, 1994). These were used to establish an average width-to-depth ratio for urban streams in Atlanta. The surveys reflect a wide variety of watershed sizes. The average depth-to-width ratio for these streams was calculated to be 0.18, ranging from 0.11 to 0.25. The value of 0.18 is assumed valid for Clear Creek's channel.

A procedure described by Arcement and Schneider (1989) was used to derive the roughness coefficient (n = .0713) for use in Manning's equation.

The slope of the existing channel was used as the slope factor (S) in Manning's equation. This will result in the least amount of soil disruption during construction.

Applying the above factors to Manning's equation, it was found that a width of 31 feet and a depth of 5.66 feet are the ideal channel dimensions for the two year storm of Clear Creek, including the required depth to width ratio of 0.18. With the width and depth of the channel established, Leopold, Wolman and Miller's relationships were used to establish meander parameters for the stream channel.

Leopold ,Wolman and Miller (1964) established several empirical relationships between bankfull channel width and meander parameters that can be used to guide design of stream channels. Linear wavelength (L) ranges from 7 to 10 times channel width. Meander length, measured along the channel thalweg, is 11 to 16 times channel width. Meander belt width ((A) or amplitude) can be expressed as $A=2.7w^{1.1}$. L is related to radius of curvature (r_m) by $L=4.7r_m^{0.98}$. Successive inflection points tend to occur at 5 to 7 times channel width. Leopold et al, (1964, p. 296), found these relationships to hold true "through a very large range of stream size, from laboratory streams a foot wide to the Mississippi river, a mile wide".

Modification of Alignment to Fit Site

With basic channel form calculated, the channel was modified to respond to topographic changes in Piedmont Park in such a way as to emulate a natural stream (Figure 2). An example of this would be a meander that reaches a valley wall and is forced to abruptly change direction. The stream was graded to have the appropriate overall slope for each area, but the bottom of the channel was graded to undulate in a pool and riffle pattern. In most areas, topography directly adjacent to the stream channel was also modified to return to grade or to create biotic habitat niches.

Proposed Biotic Habitat

With the channel alignment established, areas were zoned into habitat niches using natural habitats types found in and near natural piedmont streams as a guide. Pools and riffles were sited within the stream bed. Primary pools were sited like those that will naturally form at the outside of stream meanders, and are associated with sand bars on the opposite side of the channel. Riffles are typically located at the inflection point of the thalweg between meanders. Riffles were shaped in such a way as to direct the thalweg to the appropriate side of the channel and into the next pool.

After pools and riffles were established, in stream flora habitat niches were identified and designated with appropriate plant species. Out of bank habitats were also identified along the stream channel to include all areas of disturbance.

Establishment

It is suggested that all parts of the rehabilitated stream, except those that would require the demolition of the existing concrete channel, be built first. This would leave water flowing through the existing concrete channel for a portion of the construction time. The overlap areas should be left until the end of the construction sequence to allow time for stabilization and vegetational establishment of the proposed channel. Once the majority of the proposed channel is constructed, the connecting links though the concrete channel can be built and water can be diverted into the proposed channel. Establishment of vegetation in the biotic habitat zones should be accomplished through the use of biotechnical methods, including crib walls, erosion control fabric (vegetation establishment) and erosion control rolls (bank toe stabilization).

Human Use

Trail systems were designed to introduce park visitors to the stream in least erosive places. Park visitors will be directed away from the outside of bends, as these areas have the

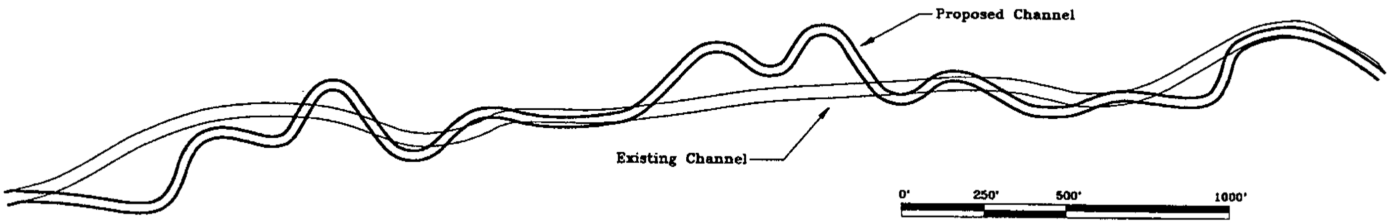

Figure 2: Channel Alignment

highest potential for erosion. Trails will cross the steam at several riffle points to allow controlled access to the stream bed. Trails will also cross each habitat zone to allow hikers to experience the different riparian habitats. Interpretation information are also suggested at prominent overlooks of the stream to educate park visitors.

CONCLUSIONS

This paper has attempted to demonstrate that characteristics of a stream in dynamic equilibrium can be used as a guide in designing an urban stream channel rehabilitation. Elements of fluvial geomorphology, biotic habitat and human use were combined to form the final stream channel and surrounding environment. It must be realized that streams are not static in nature. Especially in an urban environment, changes in the watershed will result in a corresponding change in the stream channel. The goal of this research is to design a stream channel that can respond to these changes while maintaining its ecological integrity. Although specific site factors will vary, the application of equilibrium principles will remain the same.

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LITERATURE CITED

Arcement, G.J., Jr. and V.R. Schneider. 1989. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains. USGS Water Supply Paper 2339, Washington D.C.

Beschta, R.L. and W.S. Platts. 1986. Morphological Features of Small Streams: Significance and Function. Water Resources Bulletin, American Water Resources Association. 22(3) 369-379.

Clear Creek and Peachtree Creek National Environmental Demonstration Project. 1993. Grant Application. Atlanta, Georgia.

Dunne, Thomas and L .B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company. New York.

Dury, G.H., 1973. Magnitude Frequency Analysis and Channel Morphology, in Fluvial Geomorphology. Marie Morisawa, Editor. A proceedings Volume of the Forth Annual Geomorphology Symposia Series held at Binghamton, New York. Sept. 27-28, 1973.

Ferguson, Bruce K. 1991. Urban Stream Reclamation. Journal of Soil and Water Conservation 46 (5):324-328.

Ferguson, Bruce K. 1992. The Concept of Landscape Health Journal of Environmental Management. vol. 40:129-137.

Gore, James A. 1985. The Restoration of Rivers and Streams: Theories and Experience. Butterworth Publishing. Stoneham, MA.

Leopold, L.B. , M.G. Wolman and J.P. Miller. 1964. Fluvial Processes in Geomorphology. W.H. Freeman and Company. San Francisco and London.

Heede, B.H., 1980. Stream Dynamics: An Overview for Land Managers. USDA Forest Service. General Technical Report RM-72. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Heede, B.H. Interactions Between Streamside Vegetation and Stream Dynamics. 1985. From: p. 54-58 of: Riparian Ecosytems and their Management Reconciling Conflicting Uses. First North American Riparian Conference, April 16-18, 1985, Tucson, Arizona, General Technical Report RM-120. Fort Collins: U.S. Forest Service.

Heede, B.H. 1986. Designing for Dynamic Equilibrium in Streams.

Water Resources Bulletin, American Water Resources Association. 22(3): 351-357.

Lucas, W.D. 1994. Re-establishment of Dynamic Equilibrium in an Urban Stream. Thesis, School of Environmental Design, University of Georgia. Athens, Georgia.Nunnally, N.R. 1985. Application of Fluvial Relationships to Planning and Design of Channel Modifications. Environmental Management. 9(5): 417-426.

Odum, E.P. 1978. Ecological Importance of the Riparian Zone. From p. 2-4 of: Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems, Proc. of Symp., Genral Technical Report WO-12, R.R. Johnson, and J.F. McCormick, Technical Coordinators, Washington: U.S. Forest Service.

Schafale, Michael P. and A.S. Weakley. 1990. Classification of the Natural Communities of North Carolina, Third Approximation. North Carolina Heritage Program. Division of Parks and Recreation. Department of Environment, Health and Natural Resources. Raleigh, North Carolina.

United States Geologic Survey. 1994. Written Communication