CHANNEL PROTECTION

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INTRODUCTION

It is widely accepted that urbanization can alter the geometry and stability of stream channels. Both anecdotal evidence and field research support the notion that the larger and more frequent discharges that accompany watershed development cause downstream channels to enlarge, whether by widening, downcutting, or a combination of both (Figure 1). Channel enlargement severely degrades the quality of instream habitat structure and sharply increases the annual sediment yield from the watershed. These two factors, in turn, are often correlated with the sharp drop in aquatic diversity frequently observed in urban streams (U.S. EPA, 1997).

Despite the large body of research available, many questions about the channel enlargement process in urban and suburban streams remain to be answered. For example, how much development can occur before a stream response is observed? Exactly how much will a channel enlarge, and how many years will it take to do so? Finally, what stormwater management strategies can engineers use to mitigate the amount of future channel enlargement?

While it is not easy to predict the absolute degree of channel enlargement caused by watershed development, it is clear that enlargement will occur in the absence of stormwater controls (Figure 2). Therefore, the challenge facing the engineering community is to develop and adopt stormwater management criteria that will provide adequate channel protection to minimize the extent of future channel enlargement.

Figure 1. Examples of Channel Enlargement as a Consequence of Urbanization.

OPTIONS FOR CHANNEL PROTECTION CRITERIA

Historically, efforts to control channel erosion through stormwater management have been largely unsuccessful. The failure has, in part, been the result of an oversimplification of geomorphological processes. In the past, engineers reasoned that if natural channels are largely formed by "bankfull" storm events that occur on average once every one or two years (Leopold *et al.,* 1964), then stormwater ponds should detain the post-development peak discharge for the two-year storm to the predevelopment level (i.e., two-year storm control). There are two problems with this approach. First, while the magnitude of the peak discharge may not change from pre- to post-development with two-year control, the duration of erosive flows increases (Figure 3). This may actually exacerbate channel erosion since banks are exposed to a longer duration of erosive bankfull and subbankfull events (MacRae, 1993, 1996; McCuen and Moglen, 1988). Second, with increased development and associated increased runoff, the bankfull event often shifts to rainfall events smaller than the two-year return frequency. Consequently, the total

> *Channel enlargement in urbanizing streams can have significant economic and ecologic implications, from impacts to infrastructure*

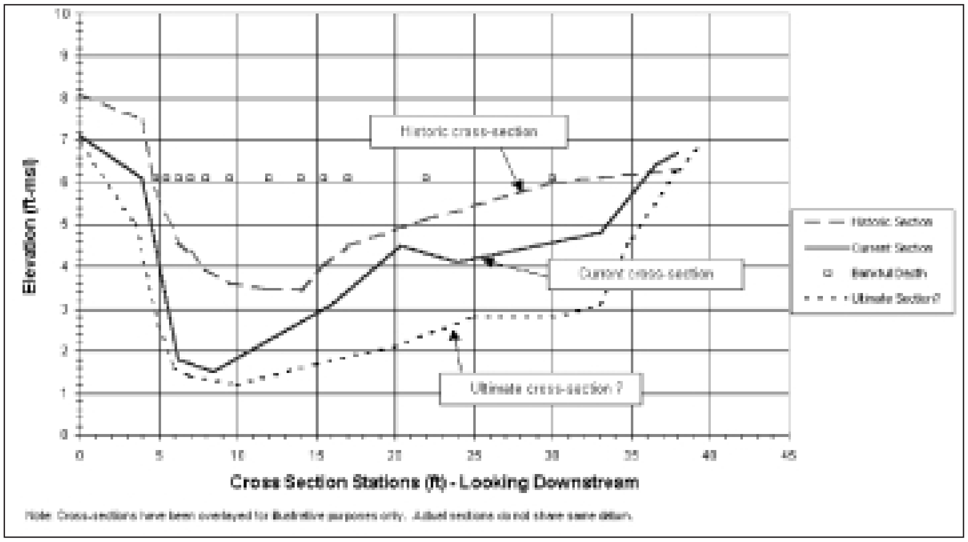

Figure 2. Illustration of Channel Cross Section Over Time (Brown and Claytor, 2001).

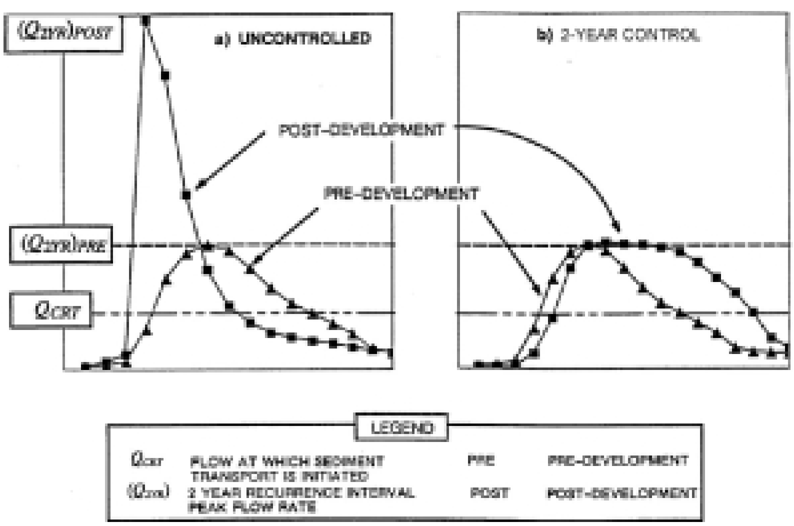

Figure 3. No Control vs. Two-Year Control (MacRae and Rowney, 1992).

energy available to transport bed materials can actually increase when two-year peak discharge control is used.

The choice of two-year storm control neglects the increased frequency of bankfull and sub-bankfull flows in urban watersheds. For example, Leopold (1994) observed that the average number of bankfull flow events in an urbanizing watershed near Washington, D.C., increased from two to seven times per year between 1958 and 1987.

Over time, practitioners have developed a better understanding of the key parameters to provide adequate downstream channel protection. With the advent of more sophisticated computer software, much of the analysis of channel geomorphology and protection criteria has been based on hydrologic and hydraulic modeling of streams. In addition, the limited field data that have been collected for some of the methodologies are favorable and support the use of these methodologies to protect channels from accelerated channel erosion. Generally speaking, the newer methodologies require more control (i.e., a larger required storage volume) than traditionally has been allocated to channel protection. One of the challenges of the more advanced channel protection approaches is to develop design methodologies that are relatively easy to apply. Three of the more promising approaches are described below briefly.

Two-Year Over-Control

This method (initially proposed by McCuen, 1979) is based on controlling the post-development peak flow rate to 50 percent or less of the predevelopment level. Another common numerical approach is to control the two-year post-development discharge rate to the one-year predevelopment rate, using the 24-hour storm event. Subsequent analysis by MacRae (1993), however, indicates that this design criterion is still not fully capable of protecting the stream channel from erosion. Modeling suggests that, depending on the bed and bank material, the channel may either degrade (downcut where soft boundary material is present) or aggrade (build up where firm boundary material is present) with over control.

Distributed Runoff Control (DRC)

This method was developed by MacRae (1993) and is proposed for adoption in Ontario, Canada (Aquafor Beech, 1999) and on a limited basis in the State of Vermont (VTANR, 2001). The DRC method involves detailed field assessments and hydraulic and hydrologic modeling to determine the hydraulic stress and erosion potential of bank materials. The methodology is based on the premise that channel erosion is minimized if the erosion potential of the channel bank materials remains the same as in predevelopment conditions over the range of flows at which sediment transport of bed or bank material begins (i.e., mid-bankfull to bankfull flow events). While the method holds great promise and has been applied and tested recently in Ontario, it requires some detailed field work at each site. The DRC hydrograph attempts to mimic the predevelopment hydrograph for the area above Q_{crt} (flow at which sediment transport is initiated) shown in Figure 4.

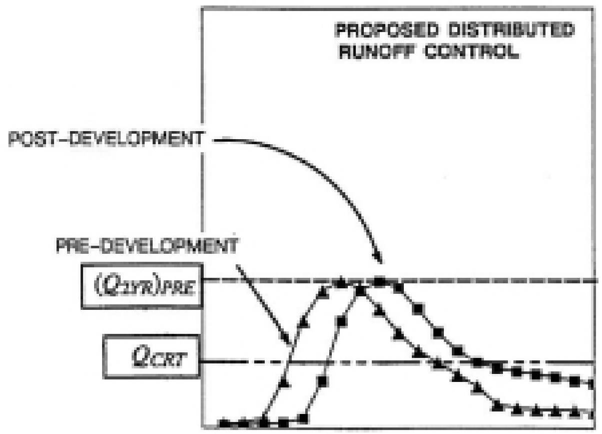

Figure 4. Distributed Runoff Control (DRC) vs. Predevelopment Hydrograph (MacRae and Rowney, 1992).

24-Hour Extended Detention of the One-Year Storm

This design method calls for holding the runoff volume generated by the one-year, 24-hour rainfall to be gradually released over a 24-hour period (MDE, 2000). The rainfall depth will vary depending on location and can be determined from intensity-duration-frequency [IDF] curves or other regional rainfall frequency analyses (e.g., NOAA Atlas 2 or TP 40). The premise of this approach is that runoff will be stored and released so gradually that critical erosive velocities will seldom be exceeded in downstream channels. Modeling based on a Maryland development site demonstrated that 24-hour extended detention approximated DRC well for storms less than the two-inch rainfall (Capuccitti and Page, 2000). The required storage volume needed for 24-hour detention of the one-year storm is not trivial; it is roughly comparable to the storage volume for ten-year peak discharge control.

It is of note that the 24-hour extended detention of the one-year storm event has been adopted in Maryland as the base channel protection criteria and is proposed for adoption in the states of New York, Vermont, and Georgia. The advantages of this approach over the DRC are that it is relatively easy to apply (in terms of computing the runoff volume and storage requirements), it is conducive to regional or statewide application, and it does not require extensive field measurements.

LIMITATIONS TO CHANNEL PROTECTION REQUIREMENT

From a programmatic and design standpoint, there are practical limitations on how broadly a channel protection criterion can be applied. Namely, there is a minimum site size at which the required orifice or weir sizes become too small to effectively operate and maintain. In addition, channel protection is generally not needed where sites discharge directly to a river (e.g., fourth order or greater), lake, reservoir, or estuary.

In addition, in streams where channel erosion is already occurring, it may be necessary to supplement the upstream channel protection storage with some form of in-stream channel protection controls. Representative practices range from robust bank protection measures such as imbricated riprap, boulder revetments, and root wads to grade control practices such as vortex weirs, cross veins, and step pools to "softer" bioengineering practices such as live fascines and coir fiber logs. A study by Brown (2000) indicates that most stream restoration practices work reasonably well in urban stream systems when sized, located, and installed correctly. The efficacy and longevity of these in-stream controls tends to improve when they are used in combination with upstream storage controls.

CONCLUSION

Channel enlargement in urbanizing streams can have significant economic and ecologic implications, from impacts to infrastructure such as culverts, sewers, bridges or pipelines to impacts on water quality and biology such as increased sediment loads, habitat loss and fish barrier creation. Consequently, there is a heightened need for stormwater engineers and managers to develop and assess stormwater design criteria that directly address the channel enlargement problem. While there are some promising approaches that are being applied in different regions of the country, more research is needed to determine how well these new criteria prevent or minimize the channel enlargement process.

LITERATURE CITED

Aquafor Beech Ltd., 1999. Final Stormwater Management Planning and Design Manual (Draft). Ontario Ministry of the Environment. *Available at* http://www.ene.gov.on.ca/envision/env_reg/ er/documents/stormwatermanual/index.htm.

Brown, E. and R. Claytor, 2001. Watts Branch Watershed Assessment Study. Prepared for City of Rockville, Maryland. Center for Watershed Protection. Ellicott City, Maryland.

Brown, K., 2000. Urban Stream Restoration Practices: An Initial Assessment. Center for Watershed Protection, Ellicott City, Maryland.

Capuccitti, D and W. Page, 2000. Stream Response to Stormwater Management Best Management Practices in Maryland. Maryland Department of the Environment, Final Deliverable for a U.S. EPA 319 Grant.

Leopold, L.B., 1994. A View of a River. Harvard University Press, Cambridge, Massachusetts.

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

MacRae, C., 1993. An Alternate Design Approach for the Control of Instream Erosion Potential in Urbanizing Watersheds. *In:* Proceedings of the Sixth International Conference on Urban Storm Drainage, Marsalek and Torno (Editors). Niagara Falls, Ontario, pp. 1086-1091.

MacRae, C., 1996. Experience From Morphological Research on Canadian Streams: Is Control of the Two-Year Frequency Runoff Event the Best Basis for Stream Channel Protection? *I In:* Effects of Watershed Development and Management on

Channel Protection . . . cont'd.

Aquatic Systems, Larry Roesner (Editor). Engineering Foundation Conference Proceedings, Snowbird, Utah, August 4-9, 1996, pp. 144-160.

MacRae C. and A. Rowney, 1992. The Role of Moderate Flow Events and Bank Structure in the Determination of Channel Response to Urbanization. 45th Annual Conference. Resolving Conflicts and Uncertainty in Water Management. Proceeding of the Canadian Water Resources Association, Kingston, Ontario.

MDE (Maryland Department of the Environment), 2000. Maryland Stormwater Design Manual. Baltimore, Maryland, Vol. 1.

McCuen, R., 1979. Downstream Effects of Stormwater Management Basins. Journal of the Hydraulics Division, American Society Civil Engineers 105(HY11).

McCuen R. and G. Moglen, 1988. Multicriterion Stormwater Management Methods. Journal of Water Resources Planning and Management (114)4.

U.S. EPA, 1997. Urbanization and Streams: Studies of Hydrologic Impacts. Office of Water, Washington, D.C., 841-R-97-009.

VTANR (Vermont Agency of Natural Resources), 2001. Vermont Stormwater Management Manual – Public Review Draft. Waterbury, Vermont.

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