# CHANNEL EVOLUTION IN URBAN WATERSHEDS: A CONCEPTUAL MODEL

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**Abstract** Stream channels in urban watersheds change their dimensions in response to multiple changes in watershed boundary conditions. The widely used incised Channel Evolution Model (Schumm et al, 1984) describes some but not all of the channel response. This paper describes how several channel evolution processes operate in tandem to cause changes in stream channel cross-section and profile in the urban watershed environment.

## INTRODUCTION

The channel evolution model (CEM) for incised channels was developed (Schumm et al, 1984) to describe the evolution of channel form in response to a lowered base level. It was developed in highly incised agricultural watersheds, where most incision was caused by upstream-advancing headcuts. Urban watersheds are often highly incised, but have several different incision mechanisms operating. Figures 1 and 2 show incised channels in urban watersheds. (In Figure 1, the channel has incised down to a sewer line, which is now acting as grade control. Incision has occurred on both the upstream and downstream sides of the sewer line, with slightly more incision downstream.) Urban channels frequently respond to lowered base levels but are also impacted by increased runoff from impervious surfaces. These processes work in conjunction to affect the cross-section and profile of urban channels. An important difference is that the headcutting process in the channel evolution model works from downstream to upstream, while the impacts of increased urban runoff are felt along the entire length of the channel. Figure 3 shows an agricultural watershed where incision is advancing upstream.

## IMPACTS OF URBANIZATION

Urban watersheds normally have the following impacts due to the increased amount of impervious surface:

- increased runoff from paved surfaces
- decreased time of concentration due to more effective conveyance system
- decreased sediment supply from a stabilized watershed.

It is common for urban watersheds to have reaches which have been channelized for flood control, resulting in a lowered base level at the upstream end of the channelized reach.

**Figure 1. Incised urban channel, with exposed sewer line acting as grade control. Flow is from left to right. Note that incision has occurred both upstream and downstream of the sewer line, with slightly more incision on the downstream side.**

**Figure 2. Incised channel in urban watershed**

**Figure 3. Upstream-advancing headcut in an agricultural watershed. The bridge culverts act as grade control. Note that there is no incision on the upstream side of the culverts, since the flow regime is not modified by urbanization.**

## INCISION MECHANISMS IN URBAN WATERSHEDS

The following mechanisms act together to cause incision in urban watersheds:

1. Headcutting due to lowered base levels
2. Channel enlargement in response to increased discharge
3. Channel incision caused by flattened equilibrium slope

These mechanisms are discussed below. It is important to note that all incision results from an imbalance in sediment continuity, in which sediment transport capacity exceeds sediment supply.

**Headcutting Due to Lowered Base Levels** A lowered base level will migrate upstream in a watershed until it reaches a point in the channel that will not erode. The lowered base level may be caused by channel straightening (for flood control or other purposes), dam removal, or other factors. The hard point which controls the channel grade may be a constructed grade control, or may be any other natural or man-made obstacle to erosion: bridge apron, culvert, dam for a stormwater management pond, bedrock outcrop, dumped rock, etc. It is important to note that an upstream-advancing headcut can be stopped with a single grade control structure.

**Channel Enlargement in Response to Increased Discharge**. The width and depth of an alluvial channel are adjusted to the flow regime which is often represented by the dominant or channel-forming discharge. (For alluvial channels in a forested watershed, the channel-forming

discharge is often in the range of the 1- to 2-year exceedence frequency flow.) As a watershed urbanizes, the increased impervious surface (along with a more efficient conveyance system) results in an overall increase in runoff. The magnitude of the channel-forming discharge increases, and the equilibrium channel width and depth increase as well. Therefore, one can expect a certain increase in channel depth (incision) related to the increase in channel-forming discharge as the upstream watershed urbanizes. Figures 4 and 5 show hydraulic geometry relations for width and depth. As shown in Figures 4 and 5, an increase in channel-forming discharge is related to increases in both channel width and depth. This is an evolution from one stable channel form to another, as the channel cross-section enlarges to accommodate a larger dominant discharge.

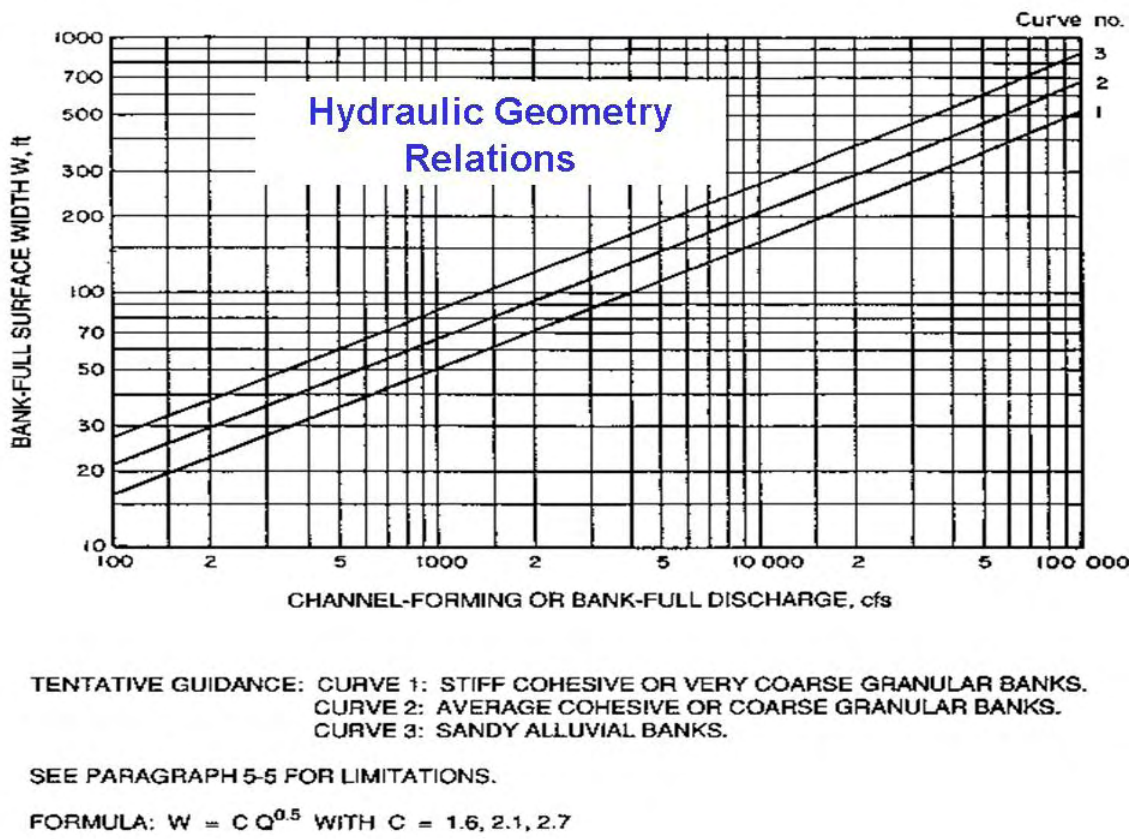
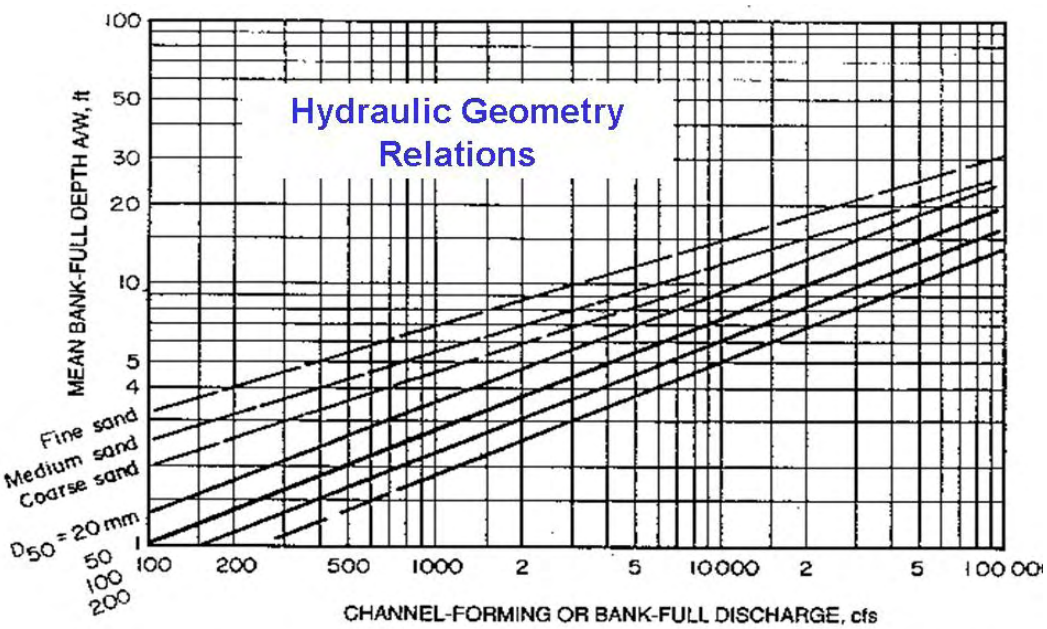


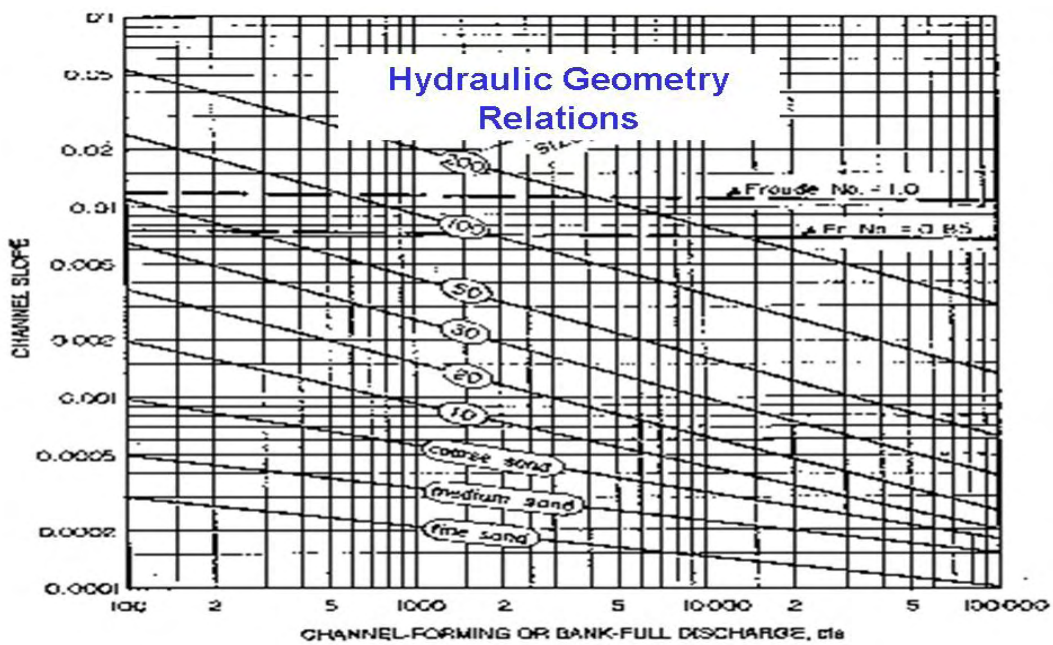

**Figure 4. Hydraulic geometry relations – width versus discharge (USACE, 1994)**




NOTE: FOR VERY APPROXIMATE GUIDANCE ONLY; DEPTHS SHOULD BE CHECKED BY UNIFORM-FLOW CALCULATION USING SELECTED WIDTH AND SLOPE (FIGURES 5-4 AND 5-5) AND ESTIMATED ROUGHNESS (SEE PARAGRAPH 4-7E).

APPLIES BASICALLY TO CHANNELS WITH LOW BED SEDIMENT TRANSPORT.

**Figure 5. Hydraulic geometry relations – depth versus discharge (USACE, 1994)**




NOTE: FOR LIMITATIONS SEE PARAGRAPH 5.5. CURVES ARE BASICALLY FOR SINGLE CHANNELS WITH FULLY ALLUVIAL BED BUT LOW BED SEDIMENT TRANSPORT. SLOPES MAY BE MUCH HIGHER WITH HIGH

**Figure 6. Hydraulic geometry relations – slope versus discharge (USACE, 1994)**

**Flattening of Channel Slope in Response to Increased Channel-Forming Discharge** As discussed above, urbanization typically results in an increased channel-forming discharge and a reduced sediment supply. Lane's relation (Lane, 1955) shows that both these changes cause the stable slope to be flatter.

$$\mathbf{QS \sim Q_s D_{50}} \qquad \textbf{(1)}$$

where
$Q$ = discharge, ft3/sec
$S$ = slope, ft/ft
$Qs$ = bed material discharge, tons/day
$D_{50}$ = median sediment size, ft

In other words, the increase in channel-forming discharge is related to a decrease in the stable slope, as shown in the hydraulic geometry relations for slope versus discharge (Figure 6). As the watershed urbanizes and runoff increases, the stable slope in the channel flattens. An example of slope flattening upstream of grade control structures is illustrated in Figure 7. As stated in EM 1110-2-1418, "Slopes vary inversely with discharges …and tend to reduce by degradation if flood discharges are increased," (USACE, 1994). This change may occur along the entire length of channel until it reaches a new equilibrium. Since this incision occurs along the entire length of the channel, it must be treated with a set of grade control measures, designed with a spacing that will keep incision to a pre-determined amount.

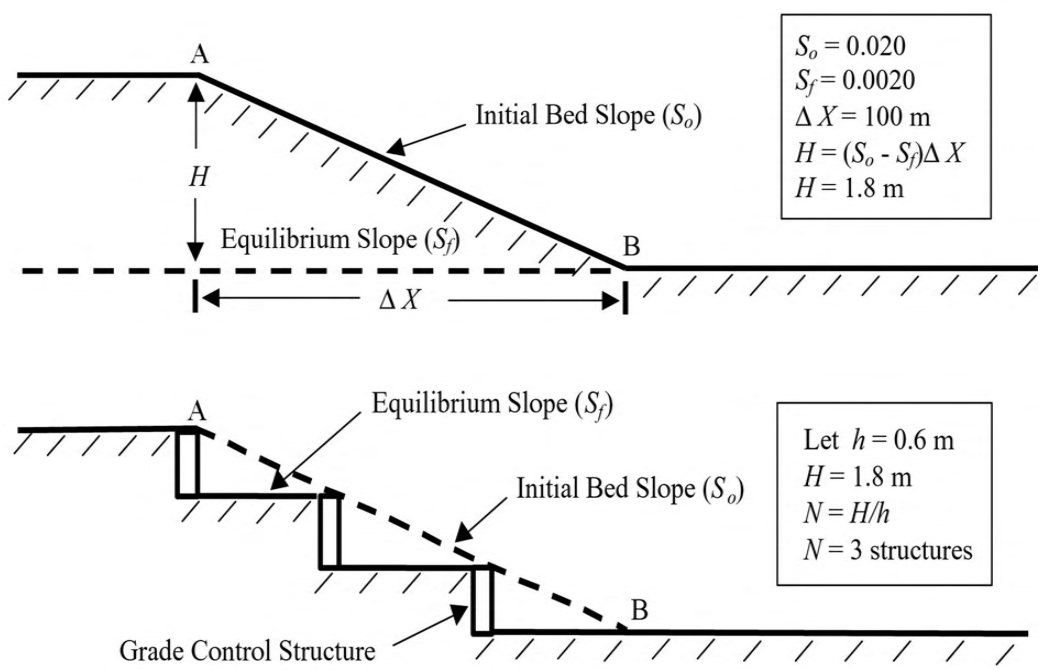



**Figure 7. Channel response to increased discharge. Flatter equilibrium slope results in incision between grade control structures.**

## SEDIMENT TRANSPORT ANALYSES

Channel equilibrium can be evaluated by comparing the bed material sediment transport capacity to the inflowing sediment load. These analyses can be performed using programs that compute sediment transport capacity, such as SIAM, SAM or the movable-bed sediment transport modeling component of HEC-RAS (Gibson and Little, 2006; Thomas et al, 2002; USACE, 2008).

## SUMMARY AND CONCLUSIONS

In agricultural watersheds, where the Channel Evolution Model was developed, incision is often caused by a base level lowering that migrates upstream. The upstream progression of this incision (into a reach that is not yet incised) can be stopped with a single grade control structure. In urban watersheds, the causes of incision are more complex. The impacts of increased runoff often cause incision along the entire length of the stream channel. In many cases, this is combined with upstream-migrating headcuts caused by channelization of certain reaches or by uneven development patterns. The mechanisms of incision must be identified and understood in order to design appropriate remedial measures. The identification and stabilization of any upstream-migrating headcuts in an urban watershed is a high priority because a single grade control structure can protect a significant length of channel upstream.

## REFERENCES

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