URBAN STREAM FLOOD CONTROL MANAGEMENT

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ABSTRACT

Urban stream flooding is of increasing frequency largely due to watershed development. Many cities are faced with providing flood protection for higher and more frequent flood flows. Generally, projects have provided improved channels along with levees and facilities to contain flood flows at desired frequency levels. However these proven solutions have been labeled as "structural" and are generally attacked by certain non-technical environmental planning groups which advocate non-structural or naturalist approaches for flood containment. The hydraulic engineering technology for controlling floods is well known and has long been successfully applied in the USA by the Army Corps of Engineers and other flood control agencies. The benefit/cost ratio of a project has been a standard reference for project approval, but this measure of tangibles seems to be ignored where certain environmental issues come into play. Yet the question remains as to how human life and property can be properly protected at a reasonable cost to the public at large and still satisfy all environmental desires. The aim of this paper is to examine the application of flood control alternatives for the conveyance of floods and to draw some conclusions as to their effects.

KEYWORDS: *Urban Streams, Flood Control, Alternatives, Studies, Project Evaluation.*

1 INTRODUCTION

Flood control alternatives in urban streams may be categorized as "Primary Flood Control: Structural", "Natural Flood Control: Non-Structural", "Bio-Engineering Flood Control: Semi-Structural", and "Subterranean Flood Control: Underground Structural" as discussed in following sections. Although each concept may be investigated in project studies, it is most economical to settle on the preferred alternative at the outset if possible. Studies start with the hydrologic determination of certain flood flows of concern at specified locations, including calculated flood flows for frequencies from one year up to 500 years. In many cases, the 100-yr frequency may be used as a design criterion with special protection for certain high risk areas. For watersheds in urban areas in the USA, various computer models are available including those widely used from the Army Corps of Engineers Hydrologic Engineering Center and the USA EPA. The effects of certain factors in these models are compared in following sections.

2 FLOOD PROTECTION PRIORITIES

In considering flood control alternative approaches, certain priorities must ultimately be considered as listed in order as follows:

2.1 PRIMARY PRIORITIES

1. Protection of human life

2. Protection of dwellings and private property

3. Protection of commercial and public property

2.2 SECONDARY PRIORITIES

1. Protection of fish and wildlife

2. Protection of biota and natural species

3. Aesthetic appearance

4. Enhancement of public and leisure facilities

5. Subterranean conveyance

3 FLOOD CONTROL ALTERNATIVES

3.1 PRIMARY FLOOD CONTROL: STRUCTURAL

Primary flood control may be considered the standard hydrologic engineering alternative wherein flood levels are controlled through upstream reservoir storage along with channel improvements. Reservoirs require dams, however in urban areas such sites are severely limited and may not be available for various reasons. Therefore, floods must be contained through channel improvements with a system of levees and/or flood walls, and in many cases with flood pump stations at the stream mouth where tributary to a river. Using an improved lined channel, this approach is generally the most hydraulically efficient system.

3.2 NATURAL FLOOD CONTROL: NON-STRUCTURAL

Natural flood control is a term used here as representing non-structural alternatives. It is generally advocated as leaving a stream largely in its natural state or trying to return it to its natural state with some channel and bank treatments of a vegetative type. The construction of levees and flood protection works is considered undesirable or non-aesthetic. With an application of this approach, flood flow reduction is advocated through land treatments including : flood-plain wetlands, upland wetlands or potholes, conservation reserve program lands, maximum infiltration, and detention structures. However these approaches are of limited value in reducing flood peaks. Wetlands have some small effect on floods for small frequent storms, but have less effect as the storm size increases as with major floods. Infiltration systems require large areas of land and are of little value in reducing floods when antecedent rainfall has saturated the area. In certain upstream vacant land watersheds, these are worthy considerations, but their limited effects on urban flood control must be recognized. Freeman, et al (1994) have carried out a scientific assessment of rivers in three mid-western USA rural watersheds and determined that maximum land treatments + detention storage reduced peak flood flows in the range of 5% to 15%. A strict application of this approach requires the acceptance of the inundation and flooding of riparian areas. It may further require that the project acquire property for flood flowage rights.

3.3 BIO-ENGINEERING FLOOD CONTROL

This approach is intended as an intermediate alternative utilizing some semi-structural channel improvements as required to contain floods. One bank of the channel is widened leaving the other as existing conditions. The channel material remains similar to existing conditions while the side-slopes are based on bio-engineering..

3.4 SUBTERRANEAN FLOOD CONTROL

Where urban stream corridors are extremely congested, subterranean flood control may be considered. This approach is generally comprised of tunnels, underground reservoirs and pump stations. It has been applied in some cities especially for the control of combined sewer overflows. However, for the control of major flood flows from a full watershed, this approach is generally prohibitive from a cost standpoint as compared with improved surface water channels.

4 FLOOD CONTROL STUDIES

The main objective of flood control studies is to set forth engineering plans for a comparison of existing conditions versus projected improvements. The studies require hydrologic investigations as discussed below.

4.1 FLOOD CONTROL HYDROLOGY

Flood flows, “Q”, at a respective station in an urban stream may be determined or projected from available flow records, i.e., 50 to 100 yr or more frequency flows depending on the degree of protection required. Where topographic sites are available, “Q” may be controlled to some extent with watershed storage systems in various forms, but mainly through the construction of dams and flood control reservoirs. Most USA municipalities require detention storage for any new development so as to not increase runoff from the site. Although these governmental regulations may require off-setting detention storage for buildings and site development, “Q” still typically increases with the associated infrastructure including public streets and facilities. Flood flows increase from the upper watershed in a downstream direction as they pick up tributary flows, storm water discharges, and non-point runoff, therefore “Q” changes from reach in the hydrologic analysis.

4.2 FLOOD CONTROL HYDRAULICS

Flood control studies are largely aimed at developing water surface profiles for a range of flood flows so that protection works can be designed. In the water surface profile calculations, a control or starting point must be established. This typically may be the mouth of the stream where the control point may be a variable level in a larger body of water such as a river or lake. Water surface profiles can then be computed using step-wise hydraulic methods such as with the Hydrologic Engineering Center computer program HEC-2. The water surface profiles establish the levels of flood flow at points in the channel for existing as well as projected conditions. Although the computational procedure is well provided in the HEC-2 computerized operations, certain analytical variables for controlling these flood flow levels must be judiciously selected. For uniform flow computations, the controllable variables are given in the Manning equation as follows:

$Q = A R^{2/3} S^{1/2}/n$ (S.I. system) or $Q = 1.49 AR^{2/3} S^{1/2}/n$ (technical English units)

"Q" = the selected flood flow for a respective frequency of occurrence, i.e., 1, 5, 10, 25, 50, 100, 200, 500-yr
"A" = the cross sectional area of the stream at progressive points of the stream, usually starting at the mouth.
"A" for existing conditions typically varies substantially from section to section and is used in calculations for establishing a basis for comparing project alternatives.
"A" for projected conditions typically is the area of an improved trapezoidal or rectangular channel, lined or unlined. Over-bank areas must also be included where applicable and may or not be of a prismatic shape.
"S" represents the channel bottom slope from section to section in calculations. Under existing natural stream conditions, "S" may vary substantially and undulate thereby affecting the channel resistance to flow. Under improved channel conditions, slopes are made more constant following the regime of the stream.
"R" is the hydraulic radius and is the channel area divided by the wetted perimeter: $R=A/P$
"n" must be selected for the respective conditions and is based on channel conditions, existing or projected as the case may be.
Channel transitions, obstructions, and bridges are handled individually in the HEC-2 computer program at respective stations in the channel.

4.3 CHANNEL SELECTION

For flood control purposes, usually trapezoidal or rectangular sections are selected depending on topography and area limitations. The best trapezoidal shape is that which approximates most closely to a semicircle with its center at the water surface. Where a rectangular channel is required, the best shape is that in which the width is twice the depth. Channel dimension selection is facilitated by utilizing the concept of channel "conveyance", indicated by the symbol "K" and defined as follows:

$Q = KS^{1/2}$ $K = A R^{2/3}/n$

Section Factor: $A R^{2/3} = n K$ and $A R^{2/3} = n Q/S^{1/2}$

Using the above Section Factor, variations in depth "y" can be calculated for a given case of n, Q, and S, in uniform flow.

For rectangular and trapezoidal channels, the following apply.

$Q = K' b^{8/3} S^{1/2}/n$ where b is the base width of the channel

$K' = (1 + my/b)^{5/3} (y/b)^{5/3}/[1 + 2(1 + m^2)(y/b)^{2/3}$

4.4 CHANNEL RESISTANCE

The channel roughness coefficient, n , is a most important factor in the design of a channel for flood control. Cowan (1956) has pointed out the most significant factors and has developed a procedure for calculating this coefficient as follows:

$n = (n_0 + n_1 + n_2 + n_3 + n_4)m_5$

where: n_0 is a basic n value for a straight, uniform, smooth channel in natural materials

n_1 is a value added to n to correct for the effect of surface irregularities
n_2 is a value for variations in shape and size of channel cross section
n_3 is a value for obstructions
n_4 is a value for vegetation and flow conditions
m_5 is a correction factor for a meandering channel

Typical values for estimating the above have been provided by Chow (1959).

As an illustration of the effects of n on flood flows, consider the following where A, R, and S are constant in the Manning equation. The subscript "1" represents existing "natural" conditions and subscript "2" represents improved conditions.

Q varies as 1/n….therefore $(Q_2)/Q_1)$ varies as $(n_1)/(n_2)$

Typical urban stream "natural" channel, winding with sluggish reaches, bank areas with brush and trees: n = 0.060 to 0.075

Typical "structural" improved channel with concrete bottom and gunite sides:

n = 0.025 to 0.030
$(Q_2)/(Q_1)$ varies as (0.060)/(0.025) = ~2.4 or (0.075)/(0.030) = ~2.5

This shows a "structural" improved channel may increase the passage of a flood flow by a factor in the range of ~2.4 to ~2.5, i.e., from 1,000 cu m/sec to 2,400 cu m/sec.

A further comparison is the effect of n on y where Q and S are held constant. For simplicity, use the case of a wide rectangular channel where R = ~y

y varies as $n^{5/3}$ for the wide channel case as used here for simple illustration

$(y_2)/(y_1)$ varies as $(0.025)^{5/3}/(0.060)^{5/3} = 0.23$
varies as $(0.030)^{5/3}/(0.075)^{5/3} = 0.22$

This comparison shows that the required depth for a "structural" improved channel, y_2 is approximately 0.23 to 0.22 of the y_1 for a "natural" channel, thereby reducing required depth by roughly 77% to 78% considering uniform flow.

Now consider a "bio-engineering" channel with widening of one bank leaving the other as existing conditions (high "n' values). The channel material is similar to existing conditions while side-slopes are based on bio-engineering.

Estimate n = 0.45 for "bio-engineering" channel versus
"natural" channel n = 0.060 to 0.075
$(Q_2)/(Q_1)$ varies as (0.060)/(0.045) = ~1.3 or (0.075)/(0.045) = ~1.7

The above shows that as compared with a "natural channel", a "bio-engineering" channel increases passage of flood flows by a factor of ~1.3 to ~1.7, but still significantly less than the more efficient "structural" channel which increases flood flows in the range of ~2.4 to ~2.5.

"Bio-engineering" channel depths as compared with a "natural" channel are calculated as follows:

$(y_2)/(y_1) = (0.045)^{5/3}/(0.060)^{5/3} = 0.62$ This reduces depth by ~ 38%
$= (0.045)^{5/3}/(0.075)^{5/3} = 0.43$ This reduces depth by ~ 57%

These depth reductions compare with the previous ~77% to ~78% depth reductions for the more efficient “structural” improved channel.

The above results illustrate the comparative effects for a more efficient “structural” channel and a less efficient “bio-engineering” channel versus “natural” conditions.. Using the applicable n values, water surface profile calculations are needed to show the required flood control facilities and to determine cost differences.

5 PROJECT EVALUATION

Ultimately, alternative projects need to be evaluated on an economic basis. The project benefit versus cost ratio (B/C) has long been the standard criterion in the selection and approval of flood control projects. It is developed from tangible benefits and costs in monetary terms. In flood control studies, benefits are evaluated in terms of flood damages avoided with each project alternative. Costs are totaled based on project construction. Intangible benefits and costs are usually not quantifiable in monetary terms and therefore are not included except that they become the basis for certain arguments “for” or “against”. It is to be recognized that certain of the secondary priorities may not be completely compatible with the most efficient channel hydraulics. For example, a meandering natural earth bottom channel with irregular vegetated banks may best provide for fish and certain species in the stream, but will severely reduce hydraulic efficiency and the degree of primary flood protection, as compared with a well engineered cement lined prismoidal channel. Other secondary priorities such as the enhancement of public and leisure facilities do not detract from the hydraulic efficiency of the system and may be added directly to the cost of the project, i.e., hiking trails, green-ways, sports and recreational areas, picnic tables, and other environmentally friendly facilities.

6 CONCLUSIONS

Flood control alternatives for urban streams have been categorized here as primary (structural), natural (non-structural), bio-engineering (semi-structural), and subterranean (underground structural). Well known hydrologic and hydraulic engineering methods are available for analyzing each project and its effects. These methods generally utilize the Manning equation as a basis in flood control studies. It includes the main hydrologic factors which affect flood levels in comparing unimproved versus improved channels. From the foregoing analysis of the effects of these factors, it can be seen that well engineered “structural” surface water channels may increase the allowable magnitude of flood flows by as much as 2.5 times over typical “natural” stream channel conditions. Flood depths under natural channel conditions may be reduced by as much as 78% with a “structural” improved channel. “Bio-engineering” channels are a less efficient compromise.

In evaluating flood control for streams in urban areas, the primary priorities must be of utmost consideration, including the protection of human life and property to a maximum affordable degree. Beyond this, secondary priorities largely of an environmental or aesthetic nature may be considered. The Benefit/Cost ratio still remains the most useful economic basis for project approval. Environmental and aesthetic embellishments certainly are desirable, but may be looked upon as luxury items in the final analysis.

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