ESTIMATING FLOOD FREQUENCY IN GAGED AND UNGAGED WATERSHEDS

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REFERENCE: Proceedings of the 1999 Georgia Water Resources Conference, held March 30-31, 1999, at The University of Georgia, Kathryn J. Hatcher, Editor, Institute of Ecology, The University of Georgia, Athens, Georgia

Abstract. Estimation of flood frequency is important in jurisdictional wetlands determination and functional assessment, stream classification and restoration, and in assessing urban and agricultural risk in flood prone areas. For example, in utilizing the hydrogeomorphic approach (HGM) for wetland functional assessment for riverine wetlands, the flood frequency variable is required in seven of the suite of fifteen functions. However, site-specific determination of flood frequency has been difficult, especially in ungaged watersheds. One promising method is development of regional dimensionless rating curves. The curves are derived from stage/discharge and channel geometric relationships associated with gaged watersheds. Once the curves are constructed and calibrated to a specific region, flood frequency and channel geometry can be estimated at any point within ungaged as well as gaged watersheds within that region. This method was employed to calibrate the flood frequency variable in the low gradient, riverine HGM guidebook applicable to Western Kentucky. Flood frequency and discharge were determined at several riverine reference wetlands for the purpose of assessing wetland function throughout the Western Kentucky Coalfield Physiographic Region.

INTRODUCTION

According to Brinson (1993), riverine wetlands comprise a specific class of wetlands under the Hydrogeomorphic Wetland Classification. These riverine wetlands occur on floodplains and riparian corridors in association with stream channels and are dominated by overbank flow from the channel, or by subsurface hydraulic connections between the stream channel and wetlands. The interaction of climatic and basin/watershed characteristics affect the magnitude, frequency and duration of water moving through the basin which subsequently affects where low gradient, riverine wetlands occur and how they function. Establishing reliable estimates of flood frequency poses a challenge to establishing wetland jurisdictional boundaries and assessing the ecological functions of riverine wetlands under Section 404 of the Clean Water Act and under the Food Securities Act. It also is important to agricultural interests (i.e., farmers and government agencies) for estimating the risk of utilizing land which is prone to flooding. Flood frequency estimation is also needed in stream restoration that physically reconfigure a stream channel to reestablish a characteristic flow regime. Several techniques exist to determine flood frequency (e.g., Weibull Method, Log Pearson Type III Method). However, few take into account the stage at which flooding occurs, and few are readily applicable in the field. Dunne and Leopold (1978) suggested that regional dimensionless rating curves could be developed to estimate flood depth and frequency on floodplains.

The objectives of this report are to discuss the significance of regional geomorphology to the hydrology of low gradient riverine wetlands in Western Kentucky and to present a regional dimensionless rating curve for estimating flood discharge and frequency at specific channel depths. These flows can then be used to determine the return interval of overbank events which inundate the wetland surface thus affecting wetland functions.

The study area occurs in the Interior Low Plateau, Shawnee Hills Section, of the Eastern Broadleaf Forest (Continental) Province ecoregion (McNab and Avers, 1994). The ecoregion is generally characterized as submaturely dissected alluvial plains with low to medium gradient streams, and channel beds comprised of Cenozoic sand, silt, and clay. Associated vegetation is oak-hickory, southern floodplain forest which occur on alfisols and ultisols soils. Topographic relief in the region ranges from approximately 24 - 101 m (80 - 330 ft) with precipitation ranging between 45 - 60 in and mean annual temperatures between 61-68°F (McNab and Bailey, 1994).

The predominant unaltered stream type which occurs adjacent to low gradient riverine wetlands in the Western Kentucky Coalfield can be classified as C6 (Rosgen, 1996). Generally these streams have gradients of less than

2%, are relatively sinuous and have bedform morphology indicative of a riffle/pool configuration. Streams classified as "C" streams are indicated by cross-sectional width/depth ratios generally greater than 12 and are slightly entrenched, meandering, and silt-clay dominated with a well developed floodplain. The floodplain, of which these low gradient riverine wetlands are a part, can be generally classified as a Class C floodplains formed by frequently recurring flow-events along a laterally stable, single threaded, low gradient channel (Nanson and Croke, 1992).

In contrast to unaltered stream reaches, the predominant altered stream class within the study area is "C" forming within an "F" featuring a deeply incised or entrenched channel (Rosgen, 1996). The stream channels are degraded and enlarged such that the stream has been decoupled from its historic floodplain. For this reason, bankfull and channelfull stages are defined as follows: 1) Bankfull stage corresponds to the discharge that on the long-term does the most channel work such as channel maintenance, moving sediment, forming or removing bars and forming or changing bends and meanders (Dunne and Leopold, 1978). In the southeast, the bankfull stage is represented by the top of the point bar or the active floodplain and has a recurrence interval of 1 to 2 years; and 2) Channelfull stage corresponds to the elevation required to flood the terrace or the historic (abandoned) floodplain.

METHODS

The regional dimensionless rating curve was developed from calibrated hydraulic curves at seven USGS gaging stations (Dunne and Leopold, 1978 and Leopold, 1994). The gaging stations were chosen in the study area based on a representative range of drainage area sizes, adequacy of hydrological record, availability of channel geometry (USGS 9-207 forms), and accessibility. Drainage areas ranged from approximately 15 mi^2 to 800 mi^2. A minimum of 10 years of the most recent hydrological record was utilized.

The annual maximum series for each gage station was ranked and the recurrence interval of each flow calculated using the Weibull flood frequency method (Ritter et al., 1995). Mean depths of the stream channel were estimated from cross-sectional areas and widths as reported in USGS gage summaries (form 9-207). The "K" factor was also calculated for each entry at each gaging station (Chow, 1964 and Henson et al., 1993). The "K" factor linearizes the relationship between flood frequency and discharge (Henson et al., 1993). Bankfull indicators were identified at representative cross sections at each of the seven USGS gaging stations. A subset of the sedimentary and boundary surfaces reported by Williams (1978) was utilized to establish bankfull dimensions. Indicators of boundary surfaces included the elevation of a change in textural particle size of recently deposited alluvium and the break in elevation between hydrophytic and perennial (upland) vegetation. The cross section was surveyed and bankfull indicators were compared against the elevation at which the width/depth ratio becomes a minimum (Knighton, 1984 and Williams, 1978). The elevation of bankfull indicators from the representative cross section was traversed across the USGS gage record (Harrelson et al., 1994) to correlate bankfull elevation with the corresponding stage/discharge relationship and estimated recurrence interval. Data from field measurements and from USGS records were used to plot mean depth at bankfull (D_{bkf}) vs. drainage area; bankfull discharge vs. drainage area; and a dimensionless rating curve depicting the ratio of channelfull discharge to bankfull discharge (Q_{chf}/Q_{bkf}) vs. mean depth at channelfull to mean depth at bankfull (D_{chf}/D_{bkf}).

Traditional surveying procedures were not precise enough to detect relatively subtle changes in the minimum width-depth ratio. Therefore, field indicators were relied upon to identify the bankfull depth.

RESULTS

Mean depth (D_{bkf}) at bankfull for each stream was calculated from the cross section, plotted against drainage area (Figure 1), and regressed against drainage area as follows:

$$D_{bkf} = 0.49\ A^{0.53} \qquad (1)$$

Once D_{bkf} and the corresponding gage height were determined, the USGS rating table was used to determine the discharge (Q_{bkf}) for each stream corresponding to the associated bankfull depth. This discharge was plotted against drainage area (Figure 2), and regressed against drainage area as follows:

$$Q_{bkf} = 1.46\ A^{1.34} \qquad (2)$$

The ratio of mean channel depth (D_{chf}) to D_{bkf} was plotted against the ratio of discharge at channelfull (Q_{chf}) to Q_{bkf} to formulate the dimensionless rating curve (Figure 3) (Multiple R = 0.97; $R^2 = 0.94$):

$$Q_{chf}/Q_{bkf} = -6.69 + 6.1\ D_{chf}/D_{bkf} \qquad (3)$$

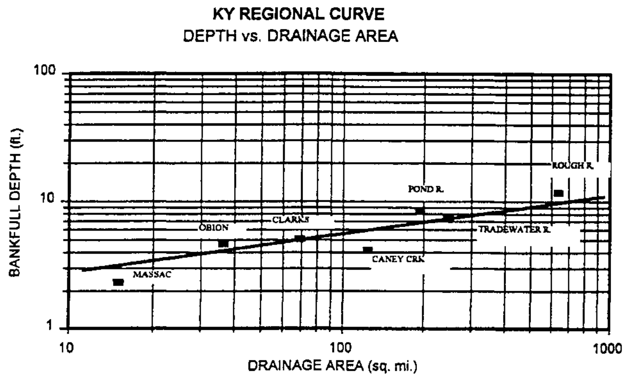

Figure 1. Bankfull depth (D_{bkf}) vs. drainage area (A) for seven streams in Western Kentucky.

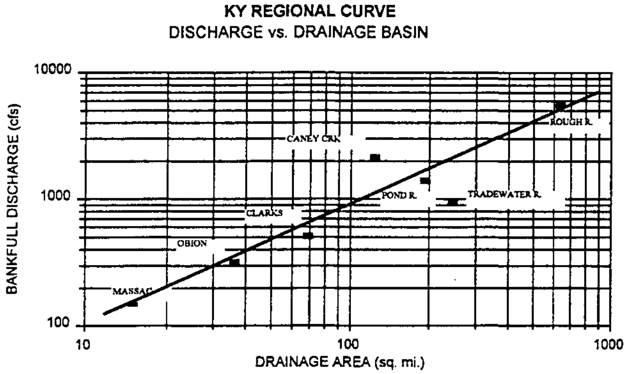

Figure 2. Bankfull discharge (Q_{bkf}) vs. drainage area (A) for seven streams in Western Kentucky.

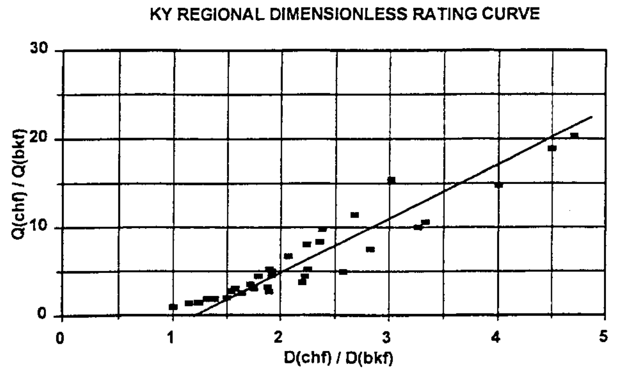

Figure 3. Dimensionless rating curve for Western Kentucky.

The channelfull discharge (Q_{chf}, the flow which overtops the stream banks) can be determined by rearranging equation (3):

$$Q_{chf} = [-6.69 + 6.1\ D_{chf}/D_{bkf}]\ Q_{bkf} \qquad (4)$$

Finally, recurrence interval (RI) can be estimated from the discharge at channelfull (Q_{chf}) as:

$$RI = 7E\text{-}8\ Q_{chf}^{2.03} \qquad (5)$$

DISCUSSION

The relationship between depth of flooding and discharge of streams is so similar in form that a dimensionless rating curve can be formulated for any given region (Leopold et al., 1964). For instance Knox (1993) utilized dimensionless rating curves to predict historic flood discharges associated with modest climate changes that occurred during the late Holocene in the Upper Mississippi River Valley. Dunne and Leopold (1978) suggested the use of dimensionless rating curves to map areas subject to flooding. Rosgen (1996) utilized dimensionless rating curves as a means of comparing flood depths to bankfull depths for streams of varying geomorphology. The objective of determining the frequency of flooding at a particular site is to ascertain how frequent channel capacity is reached or exceeded and flooding of the adjacent floodplain occurs.

Other methods of determining flood frequency (e.g., Weibull method (Ritter et al., 1995), Log Pearson Type III, HEC-1, and USGS flood frequency equations) only estimate the frequency of a given discharge over time. These methods cannot be utilized to determine site-specific depth/discharge relationships critical in estimating flood frequency on any surface (e.g., wetlands) above the stream channel.

The regional dimensionless rating curve provides estimates of channelfull discharges based upon measurements of channel depth at a wetland site of interest and the watershed position (drainage area) of the wetland. This curve has broad application in wetland delineation and functional assessment, as well as, in agricultural and urban floodplain planning and management. For instance, wetland jurisdictional determination (JD) requires the presence of wetland vegetation, soils, and hydrology. Along riverine floodplains, wetland hydrology is dominated, or significantly contributed to, by overbank flooding. The minimum threshold for meeting the hydrology criterion, according to the 1987 U.S. Army Corps of Engineers Wetlands Delineation Manual (Corps of Engineers, 1987) is inundation for five percent of the growing season in five out of ten years or at an annual recurrence interval. Often in channelized or enlarged stream channels evidence of flooding (e.g., water marks, sediment deposits, detrital dams, scour, water-stained leaves) is present on the floodplain. However, these indicators are evidence only that flood events have occurred sometime in the past. These indicators cannot be related accurately to flood frequency. Estimation of flood frequency using dimensionless rating curves would provide more definitive evidence of meeting the hydrology criterion.

In addition to wetland JD's, establishing flood frequency is important in assessing wetland functions. For instance, a flood frequency variable is required in six of eight of the low gradient riverine wetland functional models in Ainslie et al. (1998). Flood frequency is important in these functions as a source of water and as a vector between the channel and the wetland for sediment, contaminants, and aquatic organisms. Regional dimensionless curves allow site specific estimations of flood frequency at which the wetland surface is inundated with greater reliability and consistency than by using the hydrological indicators outlined in the U.S. Army Corps of Engineers Wetland Delineation Manual and other means of estimating flood frequency. The incorporation of channel depth at the site allows the wetland functional assessor to evaluate the effects of channelization and artificial levee construction on flooding of the adjacent wetland and impacts on wetland functions.

ACKNOWLEDGMENTS

The authors are greatly appreciative of the thorough reviews by Mr. Morris C. Flexner, Dr. Todd C. Rasmussen, Dr. Peter I. Kalla, and Mr. Chris D. Decker. Also, special thanks to Mr. Chris D. Decker for data entry and reduction.

LITERATURE CITED

Ainslie, W.B., R.D. Smith, B.A. Pruitt, T.H.Roberts,E.J. Sparks, L.West, G. Godshalk, and M.V. Miller. 1998. A regional guidebook for applying the hydrogeomorphic approach to riverine, low gradient wetlands in Western Kentucky. Technical Report in prep, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brinson, M.M. 1993. A hydrogeomorphic classification for wetlands. Tech. Report WRP-DE-4, U.S. Engineer Waterways Experiment Station, Vicksburg, MS.

Chow, V.T. 1964. Handbook of Applied Hydrology. McGraw Hill, New York

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman, San Francisco.

Harrelson, C.C., C.L. Rawlins, J.P. Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech. Rep. RM-245. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p.

Henson, M., L.W. Swift, Jr., and D. VanLear. 1993. Estimating the bankfull event in small watersheds of the southern Appalachian Mountains. Unpubl. Report.

Knighton, D. 1984. Fluvial forms and processes. Edward Arnold, New York. 218 pp.

Leopold, L.B. 1994. A View of the River. Harvard University Press. Cambridge MA. 298 pp.

Nanson, G.C. and Croke, J.C. 1992. A genetic classification of floodplains. In: G.R. Brakenridge and J. Hagedorn, eds. Floodplain Evolution. Geomorphology, 4:459-486.

McNab, W.H. and P.E. Avers. 1994. Ecological subregions of the United States: section descriptions. USDA Forest Service. WO-WSA-5. Washington, D.C.

McNab, W.H. and R.G. Bailey. 1994. Map unit descriptions of subregions (sections) of the United States: a table to supplement the map of ecosystems and subecoregions of the United States. USDA Forest Service.

Ritter, D.F., R.C. Kochel, and J.R. Miller. 1995. Process Geomorphology, 3rd ed. Wm C. Brown Publishers. Dubuque, IA. 546 pp.

Rosgen, D.L. 1996. Applied River Morphology.Wildland Hydrology. Pagosa Springs, CO.

Strahler, A.N. 1952. Dynamic basis of geomorphology. Geol. Soc. America Bull. 63:923-38.

Williams, G.P. 1978. Bank-full discharge of rivers. Water Resour. Res. 14(6): 1141-1154.