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BANKFULL CURVES FOR THE TEMPERATE RAINFORESTS IN THE SOUTHERN APPALACHIAN MOUNTAINS OF WESTERN NORTH CAROLINA

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Bankfull Curves for the Temperate Rainforests in the Southern Appalachian Mountains of Western North Carolina

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Bankfull Curves for the Temperate Rainforests in the Southern Appalachian Mountains of Western North Carolina. Bankfull hydraulic geometry relationships, also called regional curves, relate bankfull stream channel dimensions and discharge to watershed drainage area. This paper describes results of bankfull curve relationships developed for the temperate rainforests of the Southern Appalachian Mountains primarily on Western North Carolina Mountain streams in the Southeastern United States. Gauge stations for small and larger catchments were selected with a range of 10 to 50 years of continuous or peak discharge measurements, no major impoundments, no significant change in land use over the past 10 years, and impervious cover ranges of <20%. Cross-sectional and longitudinal surveys were measured at each study reach to determine channel dimension, pattern, and profile information. Log-Pearson Type III distributions were used to analyze annual peak discharge data for nine small watersheds sites gauged by the United States Department of Agriculture (USDA), Forest Service, Southern Research Station, Coweeta Hydrologic Laboratory and for eleven larger watersheds gauged by the United States Geological Survey (USGS). Power function relationships were developed using regression analyses for bankfull discharge, channel cross-sectional area, mean depth, and width as functions of watershed drainage area.

Keywords: Appalachian Mountains, Bankfull, Channel Morphology, Geomorphology, Southeastern United States, Storm Recurrence Intervals, Temperate Rainforests.

Curbe ale punctului de inundabilitate pentru pădurile temperate din sudul Munților Apalași ai Carolinei de Nord. Relațiile geometriei hidraulice ale punctului de inundabilitate, de asemenea numite și curbe regionale, fac referire la dimensiunile albiei și a punctului de inundabilitate, precum și la descărcarea din aria bazinului de recepție. Acest articol descrie rezultatele relațiilor curbei punctului de inundabilitate dezvoltate pentru pădurile temperate din sudul Munților Apalași, în principal în râurile montane din vestul Carolinei de Nord, din sud-estul Satelor Unite. Stațiile de măsurare selectate pentru bazine de recepție mici și mari, dețin o perioadă de măsurare a descărcărilor continue sau maxime de 10 până la 50 de ani, fără lacuri de retenție majore , fără schimbări majore ale utilizării terenurilor în ultimii 10 ani și având mai puțin de 20% din arie acoperită de suprafețe impermeabile. Au fost măsurate secțiuni transversale și longitudinale la fiecare studiu atins pentru a determina dimensiunile albiei, tiparul, și informația de profil. Au fost folosite distribuțiile Log-Peterson de tip III pentru a analiza datele privind descărcarea maximă anuală pentru nouă bazine de recepție mici măsurate de către Departamentul de Agricultură al Statelor Unite (USDA), Serviciul Forestier, Stațiunea Sudică de Cercetare, Laboratorul Hidrologic Coweeta și pentru unsprezece bazine de recepție mai mari măsurate de United States Geological Survey (USGS). Au fost dezvoltate relații de funcție putere utilizând analiza de regresie pentru descărcarea punctului de inundabilitate, aria secțiunii transversale a canalului, adâncimea și lățimea medie ca funcții ale bazinului de recepție.

Cuvinte cheie: Munții Appalachi, Bankfull, punct de inundabilitate, morfologia albiei, geomorfologie, sud-estul Statelor Unite, intervale de recurență a furtunilor, păduri temperate.

1. GENERAL STATEMENT

The shape of a stream channel is the result of many interrelated factors. Channel geometry describes the physical shape, size and characteristics of a stream and is related to debris loads (debris size, amount, lithology and debris forms) and to hydraulic factors (velocity, slope, roughness and flow frequency). For natural streams, the channel is self-formed and self-adjusted by the water and debris that moves through it [1].

Although the channel is formed and maintained in part by the flow it carries, it is never large enough to carry all discharges that occur. Some floods will overflow the channel banks and enter the floodplain, which is the area adjoining a channel constructed by the stream at times of high discharge. However, infrequent extreme flow events are not the main factors shaping the stream channel. Hydraulic geometry relationships are empirically derived and can be developed for streams in the same physiographic region with similar rainfall/runoff relationships [1]. Smaller events known as bankfull flows are primarily responsible for maintaining channel shape and dimensions. Bankfull hydraulic geometry relationships and regional curves relate bankfull channel dimensions to drainage area [2].

The ability to determine bankfull flow has practical value. Bankfull flows, in conjunction with other stream parameters, may be used to delineate the area inundated by floods and to establish the frequency of inundation. Bankfull level can be used as a predictor of other hydrologic parameters (channel morphology, bankfull discharge, and drainage basin area), which would provide inventory data for use with aquatic habitat or biological studies. When implementing flood prevention techniques to protect land and habitat, it is very important to locate the bankfull elevation so that the stream may be mitigated to original conditions.

Bankfull flow is a critical measurement in many stream classification systems. In many systems, both entrenchment (floodprone width divided by bankfull width) and stream width-depth ratios (bankfull width divided by mean bankfull depth) depend heavily on an accurate bankfull estimate. Meander, wavelength, and radius of curvature in streams are closely related to bankfull width.

The level of bankfull flow is relatively difficult to distinguish on small streams in the temperate rainforests of the Southern Appalachians in Western North Carolina. These streams are often high gradient channels in confined valleys or gorges with little or no floodplain. They have complex land-use histories and support diverse and vigorous vegetation communities. In many cases, flooding has caused major soil loss from the streambank. This soil is an important asset to the farm and food production; however, it is detrimental to fish habitat and particularly in spawning beds. Further, in most stream restoration projects a clear determination of bankfull is the first step in the mediation process.

2. STUDY AREAS

The highest, 100 inches (in.), and the lowest, 40 in., mean annual precipitation in the Eastern United States is recorded in the temperate rainforests of the Southern Appalachian Mountains in Western North Carolina. The steep mountain topography is another factor in stream morphology, with the highest peak east of the Rocky Mountains at Mt. Mitchell at 6,684 feet (ft). In general, watersheds are more than 50% forested. Land cover dominated by human influences is locally high, but is less than 40% overall.

It is easy to say, and admittedly, floods have a tremendous socio-economic impact. Its main effect is to retard development. A flood-stricken area must first be restored to normal before any development activity can be carried out. Restoration can take time. The social and emotional traumas inflicted on the people usually have a short-term inhibiting effect on the community's drive. Hence, a little time can elapse before any concerted move for normalization can take place.

According to the USGS [3], natural processes, such as hurricanes, weather systems, and snowmelt, can cause floods. Failure of levees and dams and inadequate drainage in urban areas can result in flooding. On average, floods in the United States kill about 140 people each year and cause $6 billion USD in property damage [3].

Although loss of life to floods during the past half-century has declined, mostly because of improved warning systems, economic losses have continued to rise due to increased urbanization. Flooding in the temperate rainforests of Western North Carolina is considered a major problem. In many cases, stormflow does not have access to wide floodplains therefore the storm discharge is dissipated by eroding streambanks. When these storms occur tons of sediment are removed from valuable farmland and distributed into streambeds. This additional sediment decreases fishery habitat, thus reducing the economic returns of the trout fishing industry in the region [4].

The analysis of small watersheds was conducted on eight experimental forested watersheds, ranging from 0.05 to 3.12 mi^2 in size, at the USDA Forest Service, Southeastern Research Station, Coweeta Hydrologic Laboratory in the temperate rainforests of the Southern Appalachian Mountains. These watersheds are located within the Blue Ridge Province of the Appalachian Mountain Physiographic Division. All but Watershed 1 are reference watersheds, i.e., they have not received any vegetation manipulation in more than 60 years (yr). Each watershed in this study is gauged by either a 90 degree, 120 degree V-notch, or a 12-ft Cippolletti sharp-crested weir, most with over 50 yr of continuous flow record [5].

Within the Coweeta basin, frequent precipitation (long-term records indicate an average of over 130 storms fairly evenly distributed throughout the year) sustains high evapotranspiration rates and humid climate. The Laboratory is located within one of the highest rainfall regions in the eastern United States, with annual rainfall varying from 70 in. at 2,201 ft to 100 in. at 5,000 ft [5]. Rainfall from convection storms predominates during the summer months, whereas precipitation during the dormant season is usually associated with frontal activity [5]. Elevations of the gaging stations for the small watersheds are all above 2,198 ft in elevation. Maximum elevations of the study watersheds range from about 3,251 ft to approximately 5,249 ft above sea level and mean channel gradients range from 18 to 37% [5]. Mean annual temperature is 12.0 degrees Celsius (ºC) and ranges from an average of 11.7 ºC in the winter to 21.6 ºC in the summer [5]. Soils are generally sandy loams formed from a base rock of mica gneiss, granite gneiss, and mica schist that have undergone metamorphosis [6]. The weathered solum on slopes at lower elevations is often 45 ft or more deep, whereas soils are immature and shallow at elevations greater than 4,494 ft. Soils which have developed under hardwood forests usually have infiltration rates exceeding the maximum rate of rainfall observed in the area; therefore, overland flow is uncommon and most water reaches streams by subsurface flow [7] [8]. The drainage pattern is dendritic and stream density is high, often 1.49 miles (mi) of streams per mi^2 of land area. Steep sloping mountains, deep soils, and humid climate all combine to give the Coweeta Hydrologic Laboratory relatively stable, year-round stream flows.

Larger watersheds analyzed in the Southern Appalachian Mountains were selected from USGS gauge stations that existed with at least 10 yr of continuous or peak discharge measurements, no major impoundments, no significant change in land use over the past 10 yr, and impervious cover ranges of <20%. A geographic information system was used to analyze Thematic Mapper (TM) 1996 data to select watersheds with less than 20% impervious cover.

3. MATERIAL AND METHODS

Accurate identification of the bankfull stage in the field can be difficult and subjective [9-12]. Numerous definitions exist of bankfull stage and methods for its identification in the field [13-17]. The identification of bankfull stage in the temperate rainforests of the Southern Appalachian Mountains is especially difficult because of dense understory vegetation and long history of channel modification and subsequent adjustment in channel morphology. It is generally accepted that bankfull stage corresponds with the discharge that fills a channel to the elevation of the active floodplain. The bankfull discharge is considered to be the channel-forming agent that maintains channel dimension and transports the bulk of sediment over time.

Visual indicator criteria were applied to mark bankfull depth on channel walls of all twenty channels, choosing sites that had uniform and undistorted flow during the bankfull stage. No significant flows joined the channel between the test section and the weir. The indicating criteria represent expected results of active channel shaping and maintaining processes. Most channels have a nearly vertical wall at normal water depth which changes as elevation increases to a sloped or flat floodplain. The elevation where the bank slope changes drastically may be the level of bankfull or channel-maintaining flow. On gently sloping banks, the level of channel-maintaining flows may be indicated by changes in sediment size. A point bar is a depositional feature of the stream where bedload material has been dropped during high flows [18]. Therefore, the top of the point bar may suggest the level of bankfull flow. Temporary vegetation may be present and/or permanent vegetation may be disturbed where the channel-maintaining flow has occurred. Roots and rocks will be exposed when high storm flows remove the finer particles from the bank [18]. The most consistent bankfull indicators for streams in the temperate rainforests of Western North Carolina are the highest scour line and the back of the point bar [19].

The following gauge station records were obtained from the USGS: 9-207 forms, stage/discharge rating tables, annual peak discharges, and established reference marks. Bankfull stage was flagged upstream and downstream of the gauge station using the field indicators listed above. Once a consistent indicator was found, a cross-sectional survey was completed at a riffle or run near the gauge plate. Temporary pins were installed in the left and right banks, looking downstream. The elevations from the survey were related to the elevation of a gauge station reference mark. Each cross section survey started at or beyond the top of the left bank. Moving left to right, morphological features were surveyed including top of bank, bankfull stage, lower bench or scour, edge of water, thalweg, and channel bottom [20]. From the survey data, bankfull hydraulic geometry was calculated.

For each reach, a longitudinal survey was completed over a stream length approximately equal to 20 bankfull widths [21]. Longitudinal stations were established at each bed feature (heads of riffles and pools, maximum pool depth, scour holes, etc.). The following channel features were surveyed at each station: thalweg, water surface, low bench or scour, bankfull stage, and top of the low bank. The longitudinal survey was carried through the gauge plate to obtain the bankfull stage. Using the current rating table and bankfull stage, the bankfull discharge was determined. Log-Pearson Type III distributions were used to analyze annual peak discharge data for the Coweeta and USGS gauge station sites. Procedures outlined in USGS Bulletin #17B Guidelines for Determining Flood Flow Frequency were followed [22].

4. RESULTS AND DISCUSSION

The regional curves for the temperate rainforests of Western North Carolina are shown in Figures 1, 2, 3, and 4. These relationships represent 9 USDA and 11 USGS gauge stations ranging in watershed area from 0.05 to 126.00 mi^2. The power function regression equations and corresponding coefficients of determination for bankfull discharge, cross sectional area, width, and mean depth are shown in Table 1.

Table 1: Power function regression equations for bankfull discharge and dimensions

Parameter	Power Function Equation	Coefficient of Determination R^2
Bankfull Discharge	$Q_{bkf} = 30.7A_w^{1.07}$	0.97
Bankfull Area	$A_{bkf} = 10.3A_w^{0.88}$	0.96
Bankfull Width	$W_{bkf} = 13.7A_w^{0.41}$	0.85
Bankfull Depth	$D_{bkf} = 0.7A_w^{0.45}$	0.95

Q_{bkf} = bankfull discharge (cfs), A_w = watershed drainage area (mi^2), A_{bkf} = bankfull cross sectional area (ft^2), W_{bkf} = bankfull width (ft) and D_{bkf} = bankfull mean depth (ft).

Coefficients of determination (R^2) for these equations were 0.97, 0.96, 0.85, and 0.95, respectively. The high correlation coefficient for the equation relating drainage-area size to bankfull discharge, channel cross-sectional area, and channel depth indicates that much of the variation in these variables is explained by the drainage-area size alone. The lower correlation coefficient for the equation that relate drainage-area size to bankfull channel width, however, indicate that other factors, such as slope and channel materials, could also affect these relations [21].

5. CONCLUSION

Bankfull hydraulic geometry relationships are valuable to natural resource managers, engineers, hydrologists, and biologists involved in flood prevention and mitigation. These relationships can be used to help evaluate the relative stability of a stream channel. Results of this study indicate good fit for regression equations of hydraulic geometry relationships in the temperate rainforests of the Southern Appalachian Mountains in Western North Carolina.

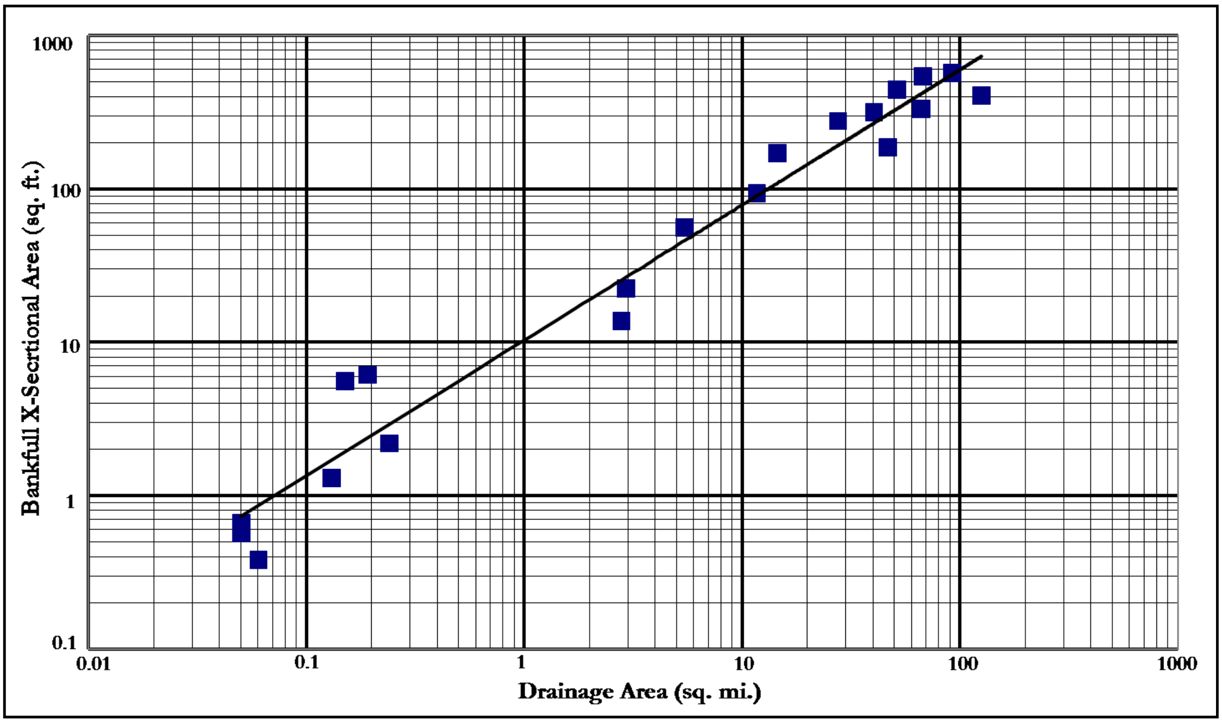

Figure 1. Bankfull cross-sectional area as a function of drainage area for streams and rivers in the temperate rainforests of the Southern Appalachian Mountains

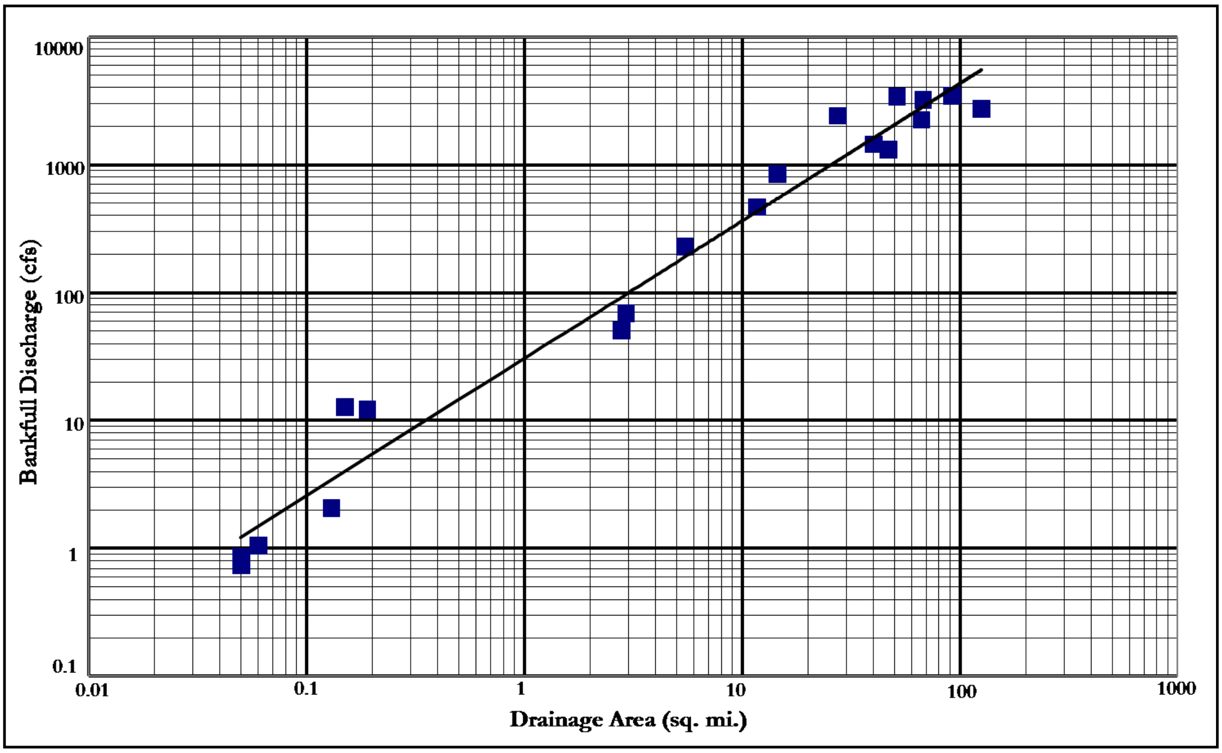

Figure 2. Bankfull discharge as a function of drainage area for streams and rivers in the temperate rainforests of the Southern Appalachian Mountains

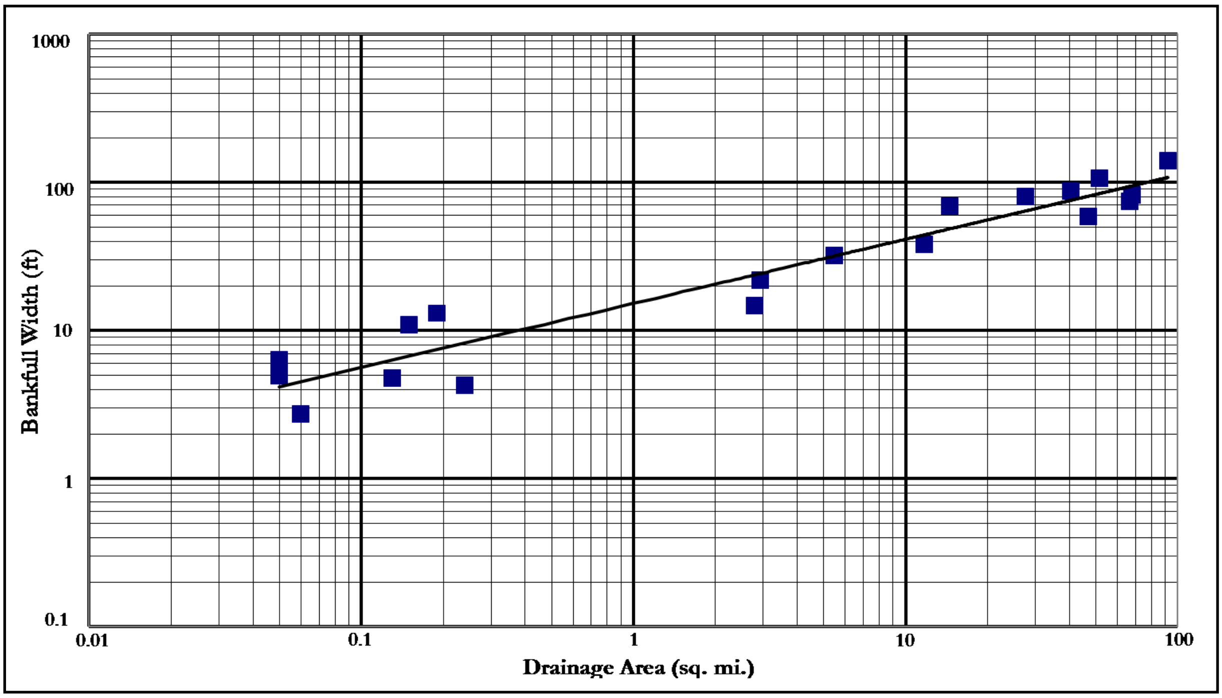

Figure 3. Bankfull width as a function of drainage area for streams and rivers in the temperate rainforests of the Southern Appalachian Mountains

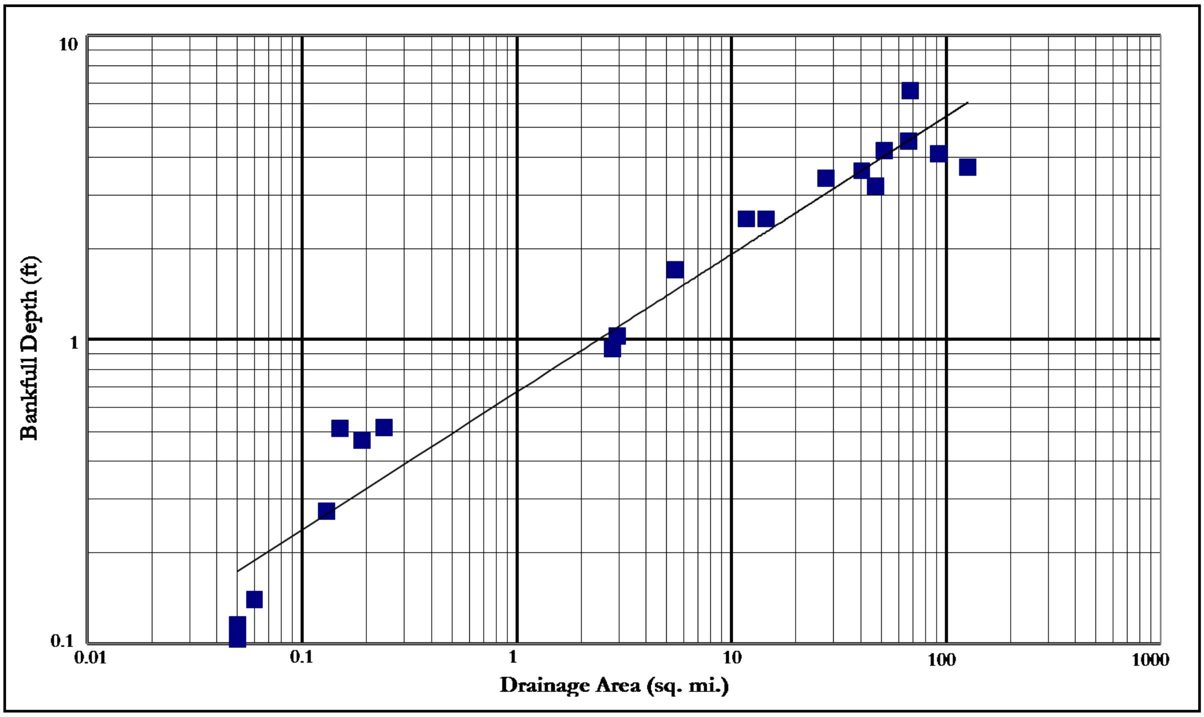

Figure 4. Bankfull depth as a function of drainage area for streams and rivers in the temperate rainforests of the southern appalachian mountains

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