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UNIFICATION IN ESTIMATION OF CONFIDENCE INTERVALS

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Abstract

One area of future development needs in technology pertaining to surface runoff hydrology is the unification of techniques used by governmental agencies in the estimation of surface runoff quantities. Currently, the usual case is each governmental agency adopts its own methodology or hybridization. The policy as to which set of methods to be used are embodied in a *document called the hydrology manual.* With computerization, however, the various agencies become aware of differences in runoff predictions, due to methodology, and question why these differences occur and whether such differences are valid.

An important problem in urban hydrology is estimating the change in peak discharge due to urbanization of the catchment. It is also useful to be able to give confidence intervals which to some extent describe the uncertainty in this estimated increase in peak discharge. That is, an important problem to be solved is quantifying how the catchment peak flow rate will be affected by urbanization, and to what level of confidence is this estimate of change in peak flow rate. In this paper, a statistical model is developed to analyze the ratio between the pre-urbanized and post-urbanized catchment peak flow rates. Using this ratio of peak flow rates as *the criterion variable*, T-year return frequency estimates can be obtained, as well as lower one-sided confidence interval estimates, including 50-percent and 85-percent levels.

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Introduction

An important problem in urban hydrology is estimating the change in peak discharge due to urbanization of the catchment. One major reason for the problem's *significance is that some consequences* of this increase, for example the increased channel capacity necessary to carry this extra discharge, are now often paid for by those land developers whose planned projects constitute this future urbanization.

It is also useful to be able to give *confidence intervals which to some* extent describe the uncertainty in this estimated increase in peak discharge. There are of course numerous sources of uncertainty in hydrological estimation, and here we will focus on some uncertainty sources which are inherent in any typical runoff model and ignore the uncertainties in specifying the model and the uncertainties in the data used *in a runoff* model.

Problem formulation

By use of a prescribed policy or set of rules that dictate the hydrologic runoff model algorithms and parameters, hereafter referred to as the "hydrology manual" (i.e., the adopted flood control agency's criteria for estimating floodflows) for the region in question, present (natural condition) values *of peak discharge* Q and future discharge Qf can be obtained for several return periods T. These values, which are typically based on statistical averages for the region that are incorporated into the hydrology manual criteria, generally are such that the plots of logQ and logQf versus LogT can be easily approximated by curves of a simple form: often these plots of logQ *and logQf versus logT are approximately* linear:

$$X = \log Q = a + b \log T$$
$$Xf = \log Qf = a' + b' \log T \quad (1)$$

and therefore

$$Xf = \alpha + \beta X \quad (2)$$

with $\alpha = (a'b - b'a)/b$ and $\beta = b'/b$. Since X and Xf increase with T, b and b' are positive.

Note that the uncertainty in the rainfall-runoff model is neglected here, but will be considered in another paper.

Urbanization of a catchment generally decreases overall infiltration, depression storage, *and interception, and so in equations* (1) the line for X typically starts lower, but has a steeper slope, than the line for Xf, i.e., $0<\beta<1$. A minor anomoly in equations (1) is that for very large T, Xf is less than X, but such values of T do not occur in practice. (This above assumption of linearity in Eq. (2) is used now to develop the analysis, without complications. A weaker form of the assumption of Eq. (2) *is used* with a log Pearson III distribution in the later development.)

If X_T is the T-year value of X and Xf_T the T-year value of Xf, then from Eq. (2)

$$1-1/T = P(X \le X_T) = P(\alpha + \beta X \le \alpha + \beta X_T)$$

and $\alpha+\beta X_T$ is the T-year value for Xf; a result which follows from equation (2) but does not depend on the derivation of (2) from (1). Rewrite this as

$$\log(Qf_T/Q_T) = \alpha+(\beta-1)X_T \quad (3)$$

and set

$$\Delta = Xf_T - X_T = \log(Qf_T/Q_T) \quad (4)$$

Usually the value for X_T is estimated from data for the catchment and/or for the region. This process of estimation introduces a random element into the determination of X_T, and so it is more informative for design purposes to give a confidence interval for X_T, which reveals the extent of this random variation, than to give only a point estimate. If p is given, $0<p<1$, suppose that the one-sided interval

$$X_T \geq z_p \quad (5)$$

is a 100p-percent confidence interval for X_T, i.e. z_p is chosen so that if the sampling processes which gave the value for X_T were repeated a large number of times, thereby producing a large collection of X_T estimates, then approximately 100p-percent of the X_T values would satisfy inequality (5); in the limit, the inequality (5) holds with probability p. Then, since $\beta-1<0$, the inequality

$$\Delta = Xf_T - X_T \leq \alpha+(\beta-1)z_p \quad (6)$$

also holds with probability p. The one-sided confidence interval (6) which bounds Δ from above is the most useful confidence interval for hydrology.

Generalization of results

Note that assuming that the linear relation $X=a+b\log T$ holds (i.e., Eq. (1)) is really a simple assumption concerning the distribution of X: specifically that $\frac{X-a}{b}$ is an exponential distribution with parameter $\lambda=1$ [1]. This exponential distribution is the same as a log Pearson III distribution with a skew of 2, which is a large value for skew. In California, the values of skew obtained by applying the methods of [2] and estimating skew from regional data are often close to zero, i.e. the distributions are close to a log normal distribution.

The previous values of z_p obtained depend strongly on the value of the skew of the underlying distribution [1], and so a range of skews will be considered below. There is some conflict between the assumptions of equations (1) and the assumption that Q has a general log Pearson III distribution, but equations (1) are only used to derive equation (3) via equation (2).

Our basic assumption will be then that equation (3) holds, with α and β known, (i.e., there is a functional relationship between the natural and future condition flood frequency curves, as given by (3), for the range of T-values considered), and therefore equation (6) can be applied to any assumed distribution of Q, e.g. to a log Pearson III distribution. Note that it is not necessary to require that the value of Q for a given storm be related by equation (2) to the value of Qf for the same hypothetical storm over the now urbanized catchment; equation (3) is only a statement about the relation between the distribution of Q and the distribution of Qf.

The necessary values of z_p for a log Pearson III distribution, given in the table below for p=.50 and p=.15, which are needed in the computation of 50-percent and 85-percent confidence intervals, respectively, were obtained from the computer program discussed in [3]. (For an alternate method [4], see [5] and the restrictions discussed in [6].)

Table 1. Values z_p for equation (6), T=100 years, 40 data points

Skew =	-2.0	-.1.5	-1.0	-.5	0.0	.5	1.0	1.5	2.0
p=.15	.90	1.13	1.43	1.75	2.06	2.33	2.57	2.76	2.94
p=.50	1.04	1.31	1.62	1.98	2.36	2.73	3.10	3.46	3.82

The procedure for obtaining confidence intervals will be demonstrated by application to two examples (that represent typical flood frequency tendencies in Southern California). The data are assumed to come from a set of 40 values for annual peak discharge from the catchment, and the values in equations (1) are taken to be:

EXAMPLE 1. Q: a = 6.02, b = .28

Qf: a' = 7.12 b' = .10

from which

$$\alpha=4.97 \text{ and } \beta=.36.$$

Using equations (1), $Q_2=500$ and $Q_{100}=1495$, while $Qf_2=1325$ and $Qf_{100}=1960$, all in cfs. Also $E(\log Q)=a+b=6.30$ with $Var(\log Q)=b^2=(0.28)^2$ and $E(\log Qf)=7.22$ with $Var(\log Qf)=(0.10)^2$.

As a comparison, if logQ is taken to have a normal distribution, with mean a+b and standard deviation b, then $Q_2=e^{a+b}=545$ and $Q_{100}=e^{(a+b)+(2.32635)b}=1045$; and also according to the assumed basic equation (3) logQf is normal, with $Qf_2=1365$ and $Qf_{100}=1725$.

EXAMPLE 2. Q: a = 4.17, b = .66

Qf: a' = 7.12 b' = .10

from which

$$\alpha=6.49 \text{ and } \beta=.15.$$

Using equations (1) $Q_2=100$ and $Q_{100}=1350$, and $E(\log Q)=a+b=4.83$ with $Var(\log Q)=b^2=(.66)^2$; Qf is the same as in example 1.

The results from the above examples are summarized in the following Table 2, wherein the ratio of Qf_{100}/Q_{100} is computed for a range of skew values used in the log Pearson III distribution.

Table 2. One-Sided Confidence Intervals for the Ratio Qf_{100}/Q_{100}

	example 1		example 2	
	50%	85%	50%	85%
skew = -2.0	2.12	2.17	6.06	6.55
skew = -1.5	2.02	2.08	5.20	5.75
skew = -1.0	1.91	1.98	4.37	4.86
skew = -0.5	1.79	1.87	3.57	4.07
skew = 0.0	1.67	1.76	2.89	3.42
skew = 0.5	1.57	1.68	2.34	2.93
skew = 1.0	1.47	1.61	1.91	2.56
skew = 1.5	1.37	1.56	1.55	2.30
skew = 2.0	1.29	1.51	1.27	2.08

Consider example (1): An 85-percent confidence value for Qf_{100}/Q_{100} in the lognormal case (i.e., log Pearson III with zero skew) is 1.76. With Q_{100}=1045, $(Qf)_{100} \leq 1.76(1045)$=1840 cfs is an 85-percent confidence upper bound for the 100 year value of the future peak discharge Qf. Note that the corresponding factor is 1.51 for the case of a skew of 2, but the Q_{100} value is then 1495 so that the 85-percent confidence interval for this case is $(Qf)_{100} \leq 1.51(1495)$=2260 cfs.

Conclusions

The estimation of the increase in peak discharge in a catchment, due to urbanization, is an important problem in urban hydrology. In this paper, an analysis is developed to estimate one-sided confidence intervals on the ratio of peak discharge increase over current or natural conditions. Assuming log Pearson III type distributions, a range of skew values are considered. It is assumed, for analysis purposes, that the logarithm of the future flood frequency curve is linearly related to the logarithm of the existing flood frequency curve. It is estimated that for southern California case studies considered herein, full urbanization results in a near 100-percent increase in the 100-year return frequency peak discharge, at the 85-percent level of confidence.

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Hydrologic Modeling for Decision-Makers

by
Steve McKinley*

Abstract

All Properties within a community benefit from having an adequate system of storm drainage facilities and controls. Such benefits include: reduction of hazards to property and life resulting from excessive runoff due to urbanization, improvements in the general health and welfare through reductions of standing water; and mitigation of other undesirable conditions affecting water quality of local receiving waters.

Consequently, storm water management programs are being recognized by various levels of government as a means to enhance existing drainage systems, reduce the peaks and impacts of stormwater runoff related flooding, plan against potentially harmful land alterations, and control new development activities which may negatively impact the drainage system or its receiving waters. As a result of recent stormwater regulations promulgated by EPA, communities will also need to address water quality issues. The preeminent tool of a stormwater management program and the NPDES stormwater permit regulations is comprehensive, proactive computer modeling.

The focus of this paper is to show the benefits of developing community and agency support in the development and implementation of hydrologic models.

As a backdrop to these critical issues, experience with program development for the Louisville and Jefferson County Metropolitan Sewer District, as well as other water resource and stormwater projects, will be used in the discussion.

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