RESEARCH SUMMARY

REGULATED FLOOD FREQUENCY ANALYSIS

by

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Introduction

Damages resulting from flooding in the U.S. have steadily increased with time, in spite of extensive work that has been performed in the area of ‘flood control.’ Annual flood related damages in the U.S. usually amount to several billion dollars. Population-adjusted death rates attributable to flooding have also increased since the beginning of this century, while the death rates caused by other natural hazards have dropped during the same time period.

A basic input for design of hydraulic engineering structures and flood protection facilities, as well as for nonstructural approaches to flood damage mitigation, is provided through flood frequency analysis (FFA). In the 20th century, a tremendous amount of effort has been devoted to development and improvement of FFA methods. Unfortunately, the majority of this work has ignored an important fact: the largest proportion of annual flood damage occurs along fairly sizable rivers, which are typically regulated by the construction of dams. Even Bulletin 17B, the FFA guidelines for the U.S., states that “…the procedures [presented in the bulletin] do not cover watersheds where floods are appreciably altered by reservoir regulation…” (IACWD, 1982). Unfortunately, Bulletin 17B does not define the term ‘appreciable alteration,’ nor does it provide guidance on what should be done if there is an ‘appreciable alteration.’ The inability to deal with regulated streams is a serious limitation of current FFA methods.

This research is the first step in an attempt to solve this problem. It focuses on two main areas. Primarily, it evaluates the existing data and the data requirements that are necessary for a solution to the regulated flood frequency (FF) estimation problem. The results of this part of the research should ultimately help to provide guidance for the design of necessary data collection programs. Secondarily, this research develops and examines a physically meaningful deterministic-stochastic framework for solution of the regulated FF problem. The deterministic part of the model accounts for the physical principles of conservation of mass and energy, while the stochastic part accounts for the variabilities in reservoir initial and boundary conditions, and reservoir inflows.

The remainder of this summary is organized as follows. The following section briefly discusses the data that are available for solution of the regulated FFA problem. Following that, the project results to date are presented. The summary finishes with conclusions and recommendations for future research.

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Data Availability Analysis

In a data availability survey, 41 individuals were contacted in more than 20 different governmental agencies, sub-agencies, and utility companies. The governmental agencies contacted included the U.S. Army Corps of Engineers (CoE), the U.S. Bureau of Reclamation (USBR), and the Tennessee Valley Authority (TVA). Besides governmental agencies that operate dams and reservoirs, agencies that collect data on floods, or influence the decision making process at dams were also contacted (U.S. Geological Survey (USGS), Federal Energy Regulatory Commission, and Federal Emergency Management Agency). Utility companies, including Southern Company, Alabama Power Company, and Georgia Power Company have also been contacted. Each of these agencies collects and/or distributes at least some data for reservoir inflows, outflows, and reservoir elevations.

The data availability survey has shown that for most large dams in the Southeastern U.S., data on inflow, outflow, and reservoir elevation are collected, in one form or another. Most of the data are stored digitally, but they are not always collected automatically. These data are usually reported at a frequency of one day. Daily data usually represent average daily values, as in the case of reservoir discharge, or a value of a parameter at a particular time of a day, as in the case of pool elevation. A summary of the data availability survey is given in Table 1. For more information about the survey, the reader is directed to Tomic and Burian (1997).

Table 1. Data Availability

<table>
<thead>
<tr>
<th>Agency</th>
<th>Outflow</th>
<th>Inflow</th>
<th>Water Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>global</td>
<td>by gate</td>
<td>indirect</td>
</tr>
<tr>
<td>U.S. Army CoE</td>
<td>D24/H1</td>
<td>D24</td>
<td>D24/H1</td>
</tr>
<tr>
<td>USBR</td>
<td>D24/H1</td>
<td>D24</td>
<td>D24/H1</td>
</tr>
<tr>
<td>USGS</td>
<td>D24</td>
<td></td>
<td>D24</td>
</tr>
<tr>
<td>TVA</td>
<td>D1</td>
<td>D1</td>
<td>D1</td>
</tr>
<tr>
<td>Southern Company</td>
<td>D24</td>
<td>H1</td>
<td>D24</td>
</tr>
<tr>
<td>Alabama Power</td>
<td>D24</td>
<td>H24</td>
<td>D24</td>
</tr>
<tr>
<td>Georgia Power</td>
<td>D1</td>
<td>H1</td>
<td>D1</td>
</tr>
</tbody>
</table>

D - digitally stored data; H - hard copy; D24 - collected daily; D1 - collected hourly
*

An issue believed to be significant is that while most agencies collect data on individual outlet gate settings and discharges, these data are usually maintained only in handwritten, hard copy form, and thus are not readily available for use in computer modeling. Only in a few cases are these data maintained in a digital form. The significance of these data lies mainly in the physics of the reservoir routing problem, and also in the fact that a desired outflow discharge from major dams may be obtained in any of a number of ways depending on the particular gate settings.

Results to Date

This research approaches the regulated FFA problem in a step-by-step fashion. It starts with a simple case, a detention pond with a single uncontrolled outlet, and builds up to the complex case of a large dam with multiple flood control gates that may change position during a flood event. This summary presents the results of the detention pond simulation.
The modeling framework used in the research is not discussed here due to space limitations. However, it generally consists of an integrated deterministic-stochastic approach based on Monte Carlo simulations (Durrans, 1994). Several parameters that influence a regulated FF distribution downstream of a detention pond have been examined. The pond volume and outlet size were used to represent the pond characteristics. A triangular hydrograph is assumed for the unregulated flood and it is represented by its time to peak. Initial pool elevation in the pond is represented by the probability of the pond being empty, average pool elevation and its variance. Due to space constraints results presented here concern only the correlation between the outlet structure size and the regulated FF distribution, under the assumption that the pond is always empty at the beginning of a flood event (‘dry’ pond).

![Graph showing influence of outlet structure size on regulated FF distribution](image)

**Figure 1. Influence of Outlet Structure Size on Regulated FF Distribution**

Figure 1 is an extreme value (Gumbel) probability plot. The horizontal axis is the flood recurrence interval, in years, and the vertical axis is relative peak flow, defined as the ratio of peak flow to the mean of the unregulated peak flow distribution. Shown on the plot are the unregulated peak flow distribution, and the regulated peak outflow distributions for several different outlet structure sizes. The outlet structure size is represented by $Q_{\text{ratio}}$, the ratio of mean unregulated peak flow to the outlet structure design discharge. A ‘dry pond’ is assumed for the initial reservoir condition. A striking feature of the regulated peak outflow distributions is that they exhibit a distinctive ‘break point’ coinciding with reservoir failure (where ‘failure’ is defined as overflow). Because of this characteristic, one cannot expect that any conventional probability distribution would be appropriate for modeling of a peak outflow distribution, and that one must therefore resort to