# AN EXPERT SYSTEM FOR CONTROL CURVE EVALUATION DURING DROUGHT

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**ABSTRACT**

This paper presents ongoing research into the automation of control curve generation and the development of an expert system for reservoir management for North West Water of Warrington, England. The paper begins with a brief introduction to the NWW and their use of control curve analysis for planning and operation. Next, a procedural computer program entitled SCREEN (Simulation Model for Control Curve Generation and Evaluation) is described that automates all phases of control curve analysis to increase the speed and ease with which control curves can be developed and evaluated. The paper then describes an expert system, ESCORT (Expert System Control Curve Analysis and Reservoir Tracking) that guides water managers through the development of operational strategies during droughts. A discussion of the knowledge acquisition process used to develop the expert system is also presented. The remainder of the paper addresses the incorporation of operational rules into the expert system and experience to date.

## Introduction

In the United Kingdom, the Water Act of 1973 consolidated approximately 1600 river authorities, town water commissions, and other public water supply and wastewater treatment systems into ten water authorities. North West Water (NWW - formerly the NorthWest Water Authority) is one of the largest of these. NWW provides water to the northwest portion of England, stretching from the Scottish border in the north to Chesire in the south. A total of approximately seven million consumers are served, spread over 14,500 square kilometers, and demanding approximately 2,500 megaliters of water per day (Ml/d). Numerous aqueducts connect the reservoirs and provide flexible solutions to water supply problems. Water sources include a number of upland impounding reservoirs as well as systems for pumped transfer of lake or river water, and extraction from boreholes. NWW operates approximately 120 reservoirs.

The project described in this paper serves as a feasibility study and prototype for the overall system. The current project deals with three reservoirs; Clowbridge, Cloughbottom, and Haslingden Grane, located in the Rossendale District, and built in the 1850's. These three sites supply water to Manchester and the surrounding area. The total active capacity of the three reservoirs is 3,910 Ml and they supply around 28 MI/d.

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**Control Curve Planning**

Like other water authorities in England, the NWW uses control curves as their primary approach to protect system reliability. NWW defines a reservoir control curve as a set of values of the storage required at the beginning of each month to meet a specified demand during a design drought without failure. Operational policy is then developed based upon the minimum and probabilistic inflow volumes from historical records. The derivation of the control curve ordinates can be divided into two steps. First, the inflows that might occur during the design drought are calculated from a probabilistic analysis. Second, these probabilistic inflows can be converted to values of storage required by simple continuity equations balancing inflow and release.

It is interesting to note that synthetic streamflow generation is not used as a planning tool. An important reason for this is the length of rainfall and inflow records available to use in probabilistic analysis. Instead, the minimum historic and probabilistic inflows (1, 2 5, 10, and 20%) for periods of 1 through 36 consecutive months starting in each month of the calendar year are calculated based on sixty-one years of data (1927 through 1987) for Stocks reservoir. These 432 sets of data are examined and fit to a 2-parameter log-normal distribution. Based on the continuity equation, the storage requirement at the beginning of each calendar month is calculated for the 2% reliability level to give the operational control curve.

Three simple operational rules are derived from these curves. If the storage level remains above the control curve for the target supply value, supplemental releases can be made. If the storage is below the control curve for the target supply value, only the target value can be released. If storage falls below the control curve evaluated at 85% of the target supply value, further analysis is usually undertaken to determine if drought actions are necessary.

**Automation of Control Curve Generation (SCREEN)**

Prior to the initiation of this research, the generation of all control curves and drought management analyses were performed on a main-frame computer run in a batch format. Interpretation of the control curves and the evaluation of simulation results was a time consuming and tedious process that required several distinct stages of analysis, some of which were performed on the computer and some with calculations and graphs created by hand. One individual was responsible for developing the control curves and projected storage of the system. During periods of low flow, when extended analysis of the situation is required, the requirements of this task exceed the available resources of one person.

One objective of this research, therefore, is to automate this process and augment the current procedure by providing extensive database and graphic functions to improve the planning environment. SCREEN (simulation Model for Control curve G and Evaluation), the system developed by researchers at University of Washington, to perform this function operates on IBM PC compatibles. The system is written in the C language and is currently 3000 lines in length. SCREEN is capable of processing information for three individual reservoirs; Clowbridge, Cloughbottom, and Haslingden Grane; and summarizes of all three reservoirs. The system currently has the following capabilities:

(1) Facilitate analysis with a Menus system and appropriate Help screens

(2) Graph existing rainfall and inflow data

(3) Calculate and present 432 sets of rainfall and streamflow data using 3-parameter log-normal distributions using quantile scheme

(4) Generate control curves based on minimum historic flows and the 1,2,5, 10, and 20% probabilistic inflows with various assumptions concerning default values

(5) Simulate and graph reservoir storage for any specified historic record or probabilistic inflows given initial storage, starting month, and demand

(7) Generate reservoir storage simulation summary tables, including the safe yield, critical period, minimum and maximum storage, spill and month of failure for various probability levels for all reservoirs

**Expert System for Operational Guidance (ESCORT)**

The development and interpretation of control curves and selection of the appropriate management response requires considerable expertise. This expertise is typically gained through several years of experience in evaluating control curves, discussing operational policy with managers and others with extended experience, and using simulation models of the water supply system. A second goal of this research is to develop an expert system that guides less experienced engineers through this process and allows managers to transfer the responsibility of developing initial drought plans to their subordinate engineers. ESCORT was developed to provide such guide through the interpretation of the results of SCREEN and to allow engineers to pursue analysis in an orderly and complete fashion.

Expert systems are computer programs that provide expert quality solutions or advice in a specific domain. Generally, the knowledge contained in expert systems is obtained from the experience and expertise of human experts. Expert systems differ from more conventional engineering programming in that they are more transparent, allowing the user to understand the logic of the program easily. Because expert systems separate the knowledge from the solution procedure, they are more easily modified.

ESCORT is a rule-based system primarily composed of IF/THEN type rules from which procedural and subjective paradigms used in drought decision making operational guidance are inferred. ESCORT was developed using VP-EXPERT, a relatively low-end expert system shell that is written in C.

**Knowledge Acquisition for ESCORT**

Knowledge acquisition (KA) is the process of gathering information and translating it into a format suitable for incorporation into an expert system. KA has often been cited as the major bottleneck in expert systems development. The authors have had similar experiences with other expert systems and were determined to perform this phase of research as efficiently and effectively as possible. The authors' experience suggests that no single technique for KA is "best' and that one must be familiar with a variety of methods to apply the one that is most appropriate. The following general categories were used in this project: structured interviews, unstructured interviews, interruption analysis, protocol/case study analysis, questionnaires, and documentation analysis. Each of these techniques was used in this project at various times.

The geographic distance between the researchers and the water supply managers and hydrologists in this project increased the normal problems of KA. This problem was overcome with the use of electronic mail, telephone calls, the FAX messages, and several in-person visits. The KA process in this project can be divided into four phases. Phase I included initial meetings between the principal investigators and the water supply managers to provide a general overview of the system. A number of documents written at North West Water also aided in providing the researchers an understanding of the system to be modeled and existing operational policy. In addition, second and third in-person interviews were made to define the parameters of the system to be developed. Phase II included a series of interviews conducted using Fax messages and telephone calls from the US to England. These interviews allowed a detailed understanding of the system to be obtained and a prototype expert system to be developed. Phase III included a third visit to England for in-depth interviews concerning operating procedures and a review of all software developed to that point. Phase IV, yet to be conducted, will include a final visit to NWW to ensure that all the concerns of the authority have been incorporated into the program.

**System Operation**

After the knowledge acquisition process, the rules obtained from NWW personnel were incorporated into ESCORT. Although the expert system is not yet complete, a prototype has been developed and software specifications and requirements have been established. The expert system will function in the following general manner: ESCORT begins by requesting fundamental operational data from the user such as the time of year, current reservoir storage, supply targets, compensation values, and desired probability levels to be used for the analysis. This information constitutes the basic components of the expert system rule base and is used to execute the portion of the SCREEN program that calculates basic control curve values. ESCORT then evaluates the results and determines whether or not a more detailed analysis is necessary. If the analysis suggests that storage will not fall below the rule curve for the desired probabilistic forecasts, ESCORT informs the user of this fact and the session is terminated. If the analysis suggests that storage could fall below the control curve at selected probability levels, ESCORT classifies the relative severity of the drought scenario and suggests that further analysis is required.

The relative severity of the drought scenario is used to determine both the extent to which further analysis is required and the type of analysis that is needed. Situations in which the drought potential is low requires only cursory review of system operation. For potentially more serious situations, more complete analysis is needed. It should be noted that such classification can save considerable time by preventing needless analysis and requiring analysis when it is appropriate. The severity is also used to determine the type of operational strategies that are available and their likelihood of success given the time of year, demands, and other considerations. Potential drought management strategies that the system can advise include balancing releases from primary reservoirs, obtaining water from alternatives (ie., more expensive) sources, pressure reductions, and hosepipe bans.

An extremely important aspect of this research that has not been completed is the validation and verification of the expert system. These phases are essential in the development of any successful expert system. They will be accomplished through a series of drought scenario games in which specific events are described, water managers are requested to suggest the type of analysis needed and the drought action that they would initiate. These results will then be compared to those generated by ESCORT.

**Summary and Conclusions**

This paper has described the development of two computer models to be used to automate and improve drought management planning for North West Water of Warrington, England. When used jointly, the models allow engineers to generate control curves for a variety of conditions, track reservoir operation using probabilistic inflow data, and to suggest drought management responses when appropriate.

**Acknowledgements**

The authors wish to acknowledge the funding support of North West Water, the Department of Civil Engineering of the University of Washington, and the Valle Scholarship and Scandiavian Exchange Program of the University of Washington. The authors also wish to acknowledge the research efforts of Dr. Paul Jowitt and David Howarth who have served as co-investigators in this research in the Department of Civil Engineering at Heriot-Watt University, Edinburgh, Scotland.