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Project Summary

Water Supply Simulation Model Volumes I, II, and III

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This three-volume report describes the development of a water supply simulation model (WSSM), a system of computer programs that allows for a systematic evaluation of the physical and economic characteristics of a water distribution system in a spatial framework.

The WSSM concept views a water utility as a network overlaid upon a spatial distribution of supply and demand. The model explicitly deals with the relationship of delivered water costs to the service requirements of spatially distributed demand. This spatial representation is based on a characterization of the water supply system as a link-node network. Water is assumed to enter and leave the system only at nodes, which represent treatment plants, junctions, demand locations and storage tanks. Water is carried between and among nodes through connecting links. Costs are allocated to the various facilities and system components based on flow in the system.

Once an adequate hydraulic simulation has been made, the model can be used to determine costs, travel time, and contaminant concentrations at various points in the network. Results from the model are particularly useful in establishing the cost of service to various spatially differentiated customers.

The model has been calibrated and tested on several water supply systems, including a small utility in New Vienna, Ohio, and the Kenton County Water District No. 1 in Kenton Couny, Kentucky. Volume 1 of this study describes the development of the model and its underlying principals. Volume 2 discusses some of the engineering and economic concepts used in developing the model. Volume 3 is a users manual for the model.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in three separate reports of the same title (see Project Report ordering information at back).

Introduction

Passage of the Safe Drinking Water Act has intensified interest in problems related to water supply and water utility management. Economic analysis of the regulations to be promulgated under the Act indicates that some water utilities may suffer adverse effects, which may be most pronounced in small utilities. An option often suggested for small systems is to join with another larger system to form a regional water supply utility. The economies of scale associated with a regional water system would supposedly benefit small system consumers.

Many utilities find that a tradeoff exists between the cost of building and operating facilities to meet demands for a product and the cost of transportation. High transportation costs and low facility costs imply decentralization; the reverse implies a few large, central facilities. These factors must be considered in planning, designing, constructing, and operating water supply systems.

The water supply system can be separated into two physical components: (1) acquisition and treatment facilities and (2) the delivery (transmission and distribution) system. Each of these components has a different cost function. The unit costs associated with treatment facilities are usually assumed to decrease as the quantity of service provided increases. But the delivery system is more directly affected by the characteristics of the area being served. The cost tradeoffs between the two components will determine the cost of delivering water to any portion of the service area.

Few analytical instruments are availble to study the economics of water supply systems. The U.S. Environmental Protection Agency (EPA) has therefore initiated a program to develop techniques and methods evaluating the regional economics for water supply. A water supply simulation model (WSSM) has been designed to aid such an evaluation. The model will also provide insights into other water-related economic issues such as spatial pricing and costing, conservation policies, operating improvements versus increased capital expenditure, user class subsidization, and fire protection capacity. In addition, the model can also be used to analyze mixing problems.

The WSSM incorporates a series of submodels to describe the various aspects of the economic, demographic, and hydraulic systems that make up a water utility. The logic used in developing the model is discussed in the following sections.

Model Structure

The WSSM is based on the concept of a water utility as a network overlaid on a spatial distribution of supply and demand. The model explicitly deals with the relationship of delivered water costs to satisfy the service requirements of spatially distributed demand. This spatial representation is based on a characterization of the water supply system as a link-node network. Water is assumed to enter and leave the system only at nodes, which represent treatment plants, junctions, demand locations, and storage tanks. Water is carried between and among nodes through connecting links. Costs are allocated to the various facilities and system components based on flow in the system.

The WSSM requires that the system be described as a network of pipes, storage tanks, treatment plants, demands, and other hydraulic elements. Information concerning the network is stored in a network data base, which also stores additional descriptive or calculated information about each element (such as size of pipe, geographic location of each demand, population associated with a demand, connectivity of pipes, etc.). Certain basic information *must* be stored for the system to operate, but other information is elective and is a function of the particular uses and analysis to which the WSSM is to be put. Other program modules communicate with the data base through standardized data base access methods, which consist of routines to extract or insert information into the network data base.

Figure 1 illustrates the way in which the WSSM operates. Data are entered into the data base (link and node files) through an establishment module. Once the data base is established, various program modules manipulate it. The general elements of the WSSM are the network data base, data base establishment and editing modules, data base access methods, hydraulic network analysis models, other physical and economic models, and display and reporting modules.

The original concepts and approaches of the model were tested in a pilot study of the Cincinnati, Ohio, Water Works system. A contour map of zonal costs for delivery of water to various locations within the service area (Figure 2) was developed from a pilot version of the WSSM. Further WSSM development was encouraged by the ability of such displays to synthesize easily the results of complex physical, policy, and economic situations. A revised, more general-purpose version uses the New Vienna, Ohio; Kenton County, Kentucky; and Tampa, Florida; water systems as testbeds. The New Vienna example is described in detail in this report.

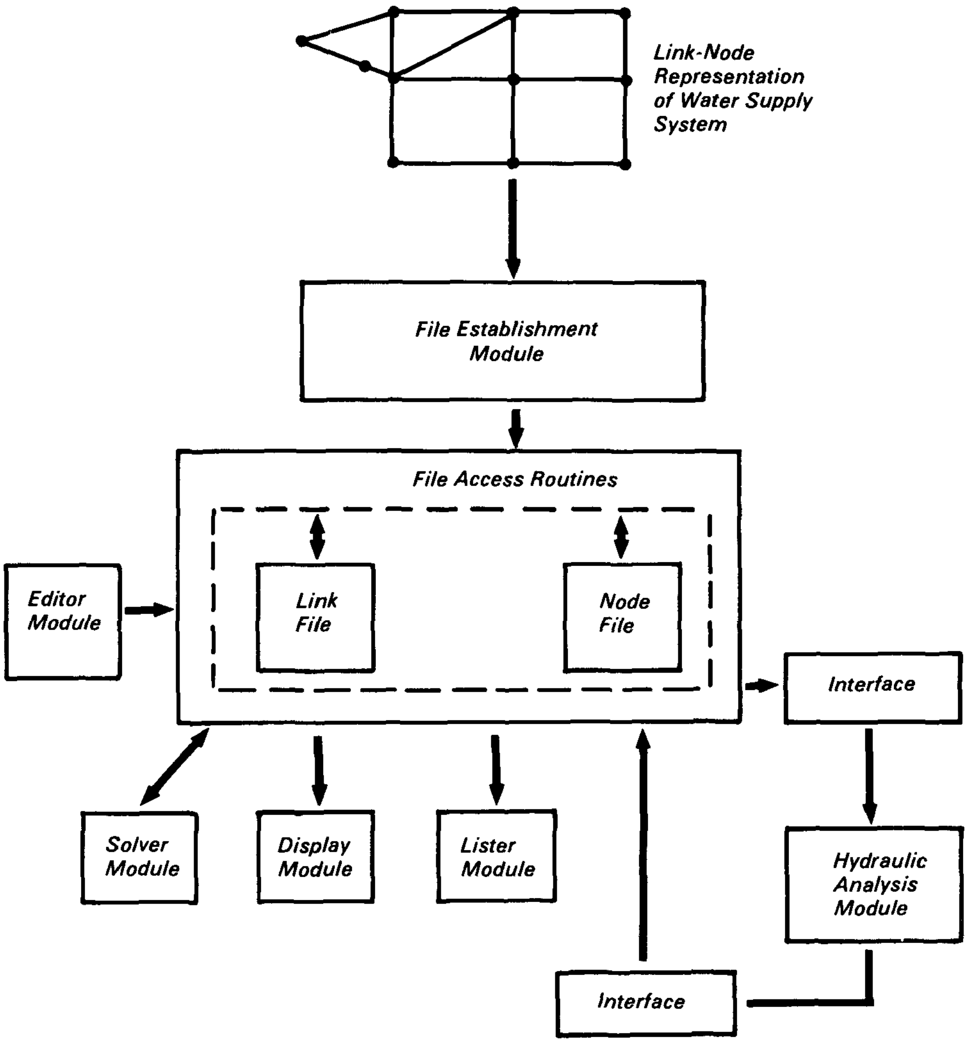
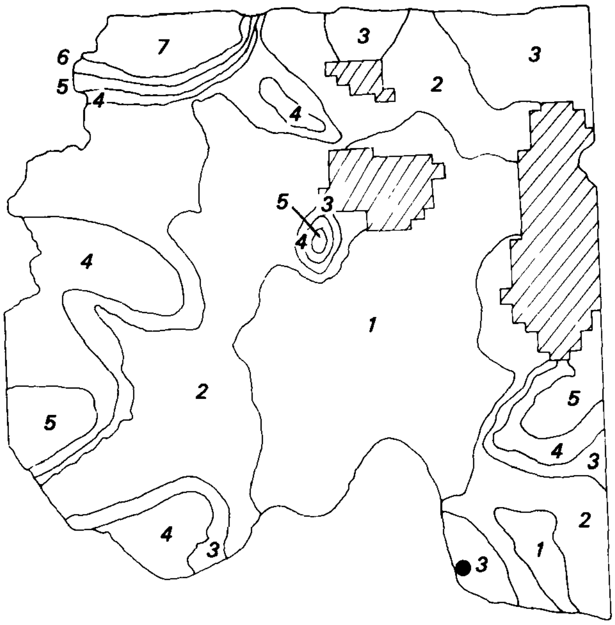


Figure 1. *Basic structure of the water supply simulation model.*



Zone	Cost ($/1000 gal)*
1	.15 - .20
2	.20 - .29
3	.29 - .38
4	.38 - .47
5	.47 - .57
6	.57 - .66
7	.66 - .76

*1973 Costs

▨ *Not included in service area*

●- *Treatment Plant*

Figure 2. *Cost contours for the Cincinnati Water Works area based on the WSSM. Source: Goddard, H. C., Stevie, R. G., and Trygg, G. D., "Planning Water Supply: Cost-Rate Differentials and Plumbing Permits," EPA-600/5-78-008, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978.*

All software modules of the WSSM are written in Fortran IV and adhere as closely as possible to ANSI Standard Fortran IV, thus increasing the ease with which the model can be transported from one computer to another. Hardware environments may exist, however, in which the system will require modifications. This problem has been minimized and localized by separating the file access routines into a separate module and preparing careful internal documentation of those parts of the code that are more susceptible to specific computer dependency.

The seven software modules used in the model include the establishment module, the editing module, the display module, the listing module, the hydraulic analysis module, the system solver module, and the (Input-Output) I/O module. The establishment of a data base for the WSSM requires the use of four of these modules. The establishment module prepares a list of possible errors that the user may make while creating the files; the input data are not corrected while the files are being created. The display and listing modules are then used to verify the contents of the files, and necessary corrections are made with the editing module. Because the integrity of the information is so important, all modules except those for key establishment and editing are designed to preclude destruction or distortion of these data.

Case Study

To display some of the features of the WSSM and to serve as a small, manageable system for testing various WSSM elements, the water supply system in the village of New Vienna, Ohio, was selected as an example. New Vienna is a village of approximately 1000 population (1980) located in Clinton County in Southwestern Ohio. The water supply system serves approximately 900 residents, with some 340 residential meters. In addition, light industry, laundromats, and schools are served from the system. Average metered use in the village is approximately 1.7 million gal per month.

Water is supplied to the system from two sources: a well field and treatment plant operated by the Village, and purchased water from Highland County. Because the Village is required to purchase a set amount of water each month from Highland County, it operates so as to purchase that amount and then switches over to its local sources. Typically, two-thirds of the water is purchased each month. The two sources do not operate simultaneously.

Development of the New Vienna Data Base consisted of the following steps:

a. Delineation of the system in link-node form,

b. Determination of physical system characteristics (pipe size, diameter, etc.) and spatial coordinates,

c. Development of demand data, and

d. Development of cost data.

Some interplay must occur among these efforts to ensure that the link-node representation does portray the important changes in physical system character.

Delineation of System in Link-Node Form

A link-node representation of the New Vienna water system was laid out on a gridded overlay to the 1 in. = 200 ft map. Nodes were located in continuous lengths of pipe, based on their serving as centers of aggregation of demand. Nodes were also located at pipe junctions and at changes in pipe diameter or type. The system was also laid out so that nodes were located at major changes of pipe direction, thus providing an accurate geometric and topologic map. Each link and node was numbered sequentially. The New Vienna link-node representation consists of approximately 50 links and 50 nodes (Figure 3).

Determination of Physical System and Spatial Characteristics

Pipe lengths, types, and diameters are available from the base map. This information was transferred to the link-node system and associated with each individual link number. Topological data in the form of the upstream and downstream node numbers for each link were also taken from the base map and recorded. This information sets the convention for flow throughout the WSSM and provides topologic connectivity. By convention, flow in the pipe from upstream to downstream node is positive, and flow into a node is positive.

The coordinate locations of each node were digitized through hand take-off from the gridded overlay and recorded. Elevations were obtained by placing the overlay on top of the base map and reading the elevation at each node from the contours on the base map. Contours on the base map are at 3-ft intervals. Data for both the links and nodes were encoded and prepared as input to the file establishment module of the WSSM.

Development of Demand Data

Metered information is available for the majority of the Village, but demand data were developed for other than industrial users by performing house counts within demand zones. These zones were drawn on the link-node overlay for an arbitrary association of demands with nodes. Each node has a demand zone, and it is assumed that any demands falling within that area are aggregated to the node.

Development of Cost Data

At its current state of development, the economic allocation procedures require a single annual cost representing the combination of amortized capital and operating and maintenance (O&M) costs for each node and link. For the case of New Vienna, actual construction costs were not available for most elements. Capital costs in general were estimated as current replacement costs and then revised to the actual year of installation through use of the three-digit Engineering News Record Construction Cost Index (CCI). The existing well and water treatment system costs were estimated with cost curves derived from EPA reference material. Bid data for replacement of the elevated storage tank were used to estimate its replacement cost. Pipe costs were developed based on unit prices in a construction bid for the area. All estimated costs were first calculated on a 1981 basis before being revised to year of installation. The base year of the CCI is 1913, thus all system elements known to be installed before that date were treated as if they had been installed in 1913.

Annual O&M costs are taken from Village records. Total 1981 O&M cost, including debt service and administrative costs, was projected to be $46,721. Costs were allocated as indicated above. Node and link cost summaries were calculated showing the 1981 construction cost, year of construction, CCI factor, original construction cost (computed), and 1981 O&M cost (Figure 4).

After the basic description of the link-node network and its physical characteristics were obtained, the data were encoded. These data were then used as input to the data base establishment programs, ESTBLINK and ESTBNODE. Program ERCHECK is run to test for topologic errors. At this point, it is frequently desirable to be able to visually inspect the data base and to be able to refer directly to the base map.

The full report was submitted in fulfillment of Contract No. 68-03-2941 by W. E. Gates and Associates, Inc., under the sponsorship of the U.S. Environmental Protection Agency.

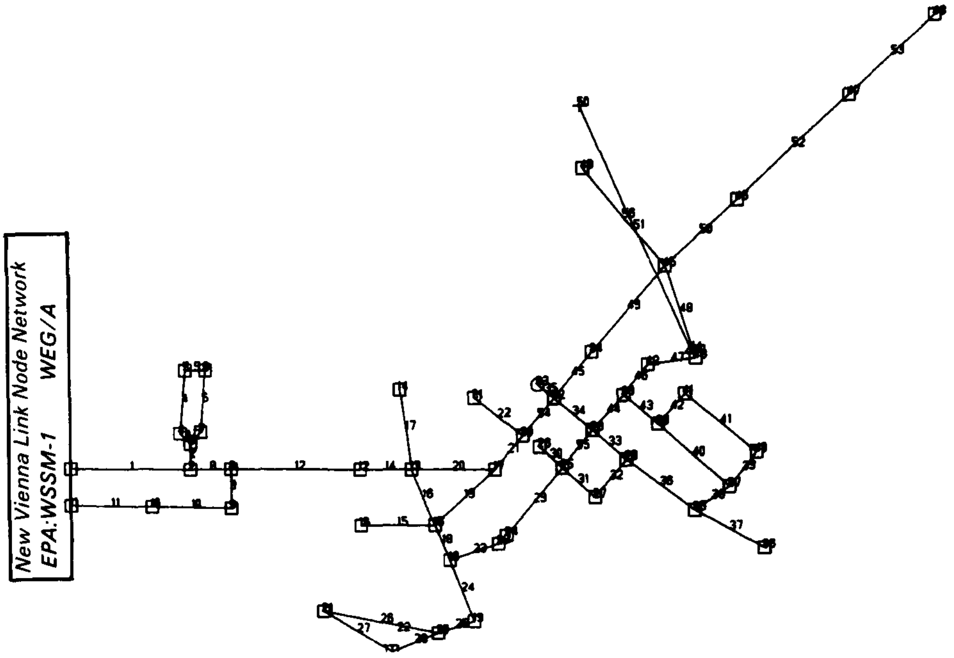


Figure 3. New Vienna link-node representation.

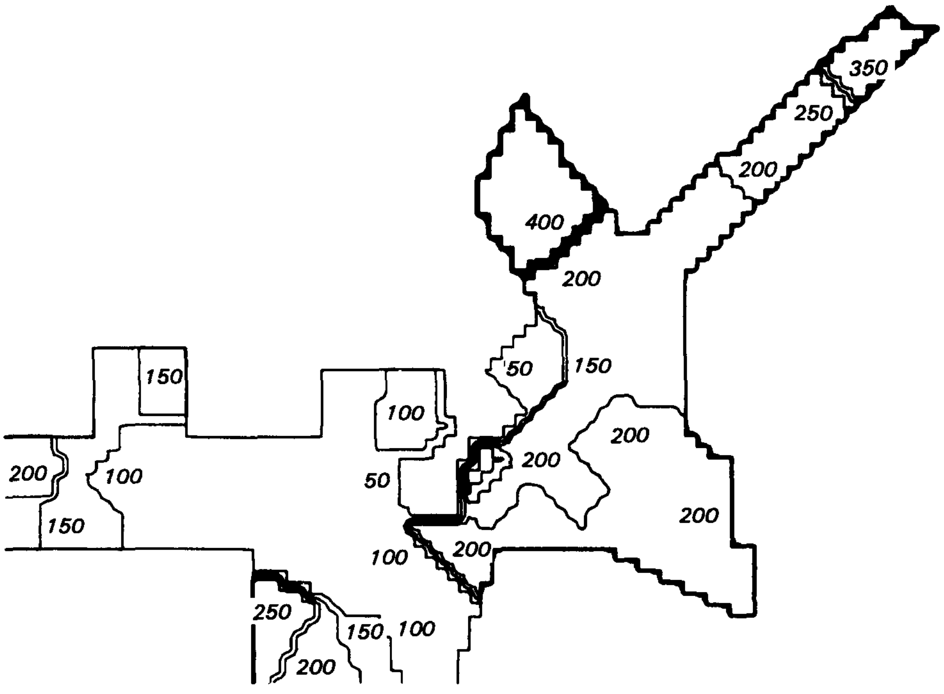


Figure 4. Cost contours (cents/1000 gals.) for New Vienna (Scenario 1).

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The complete report consists of three volumes, entitled "Water Supply Simulation Model," (Set Order No. PB 84-143 908; Cost: $32.00)

"Volume I. Model Development," (Order No. PB 84-143 916; Cost: $11.50

"Volume II. Literature Review and Background Research," (Order No. PB 84-143 924; Cost: $13.00)

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