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Project Summary

Operation of Water Distribution Systems to Improve Water Quality

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The quality of drinking water can change dramatically between the point of discharge from the treatment plant and the point of consumption. To study these changes in a systematic manner, EPA's Drinking Water Research Division in conjunction with the North Penn Water Authority (NPWA) in Lansdale, PA, developed and field tested contaminate propagation models over a 3-1/2 yr period.

Temporal and spatial variations in water quality were found to be much greater than expected. Steady-state predictive modeling of water quality provided insight into overall water quality variations and patterns within the distribution system, which received water from multiple sources. Point prediction of water quality was, however, limited. Dynamic modeling, though more difficult, provided better insights into system behavior and more accurately reflected changes in water quality.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The research summarized here explored the possibility of using operational modifications of the water distribution system (i.e., changes in pumping, valving, etc.), rather than additional treatment, to improve delivered quality water to the consumer. The NPWA uses multiple water sources, including a purchased, treated, surface water source and numerous wells. The purchased water has a significantly different chemical profile than does the well water, and water quality also varies among the wells. Water from different sources mixes and blends within the distribution system, changing with time. All of this results in variations in the quality of water delivered to the consumer.

This U.S. Environmental Protection Agency's Drinking Water Research Division has developed the Water Supply Simulation Model (WSSM), computer programs designed to create and maintain a data base of information concerning a water distribution system, so that a variety of models could be applied to that data base. The component of the WSSM known as the "Solver" algorithm was developed to predict mixing of water in a distribution system, based on steady-state assumptions and known hydraulic flow patterns. The WSSM had been applied on a theoretical basis, but had not been tested against field data. This study was designed to apply the predictive model of mixing to the NPWA system, field test the predictions, propose operational changes to modify the flow and mixing patterns, and test these modifications. During the study, after a short-term sampling program indicated the dynamic nature of quality variations, a dynamic water quality model (DWQM) was developed. Some operational modifications have been made in the NPWA system based on the data developed in this project.

The report details the significant use of computer modeling and the development of a number of generally applicable models. It also details the testing of two automated samplers that are capable of preserving volatile organics.

The North Penn Water Authority

The NPWA serves 14,500 customers in 19 municipalities in Montgomery County, north of Philadelphia. Water sources for the 5-mgd system include 1 mgd of treated surface water purchased from the Keystone Water Company and 4 mgd from 40 wells operated by NPWA. The system is largely contiguous; a few unconnected satellite systems were not modeled in this study. The system has five storage tanks and two pumping stations. Figure 1, a schematic representation of the 225 miles of pipe in the contiguous NPWA distribution system, shows the location of wells, the Keystone "tie-in," and the three pressure zones (Souderton Zone, Lansdale Low Zone, and Hillcrest Zone). Pipe sizes range from 3 to 24 inches but the majority of the pipe is cement-lined ductile iron or unlined cast iron.

Surface water enters the NPWA system at the Keystone tie-in. The rate of flow into the system is determined by the elevation of the tank in the Keystone system and by a throttling valve at the tie-in. Flow, which is monitored continuously, is relatively constant; the throttling valve is adjusted seasonally. Water flows into the Lansdale low pressure zone and from there enters the Lawn Avenue tank, from which it is pumped into the Souderton Zone. Additional water, solely derived from wells in the Hillcrest Pressure Zone, enters the Lansdale system at the Office Hillcrest transfer point. Except for unusual and extreme circumstances, such as fire or main breaks, water does not flow from the Souderton Zone in the Lansdale Low Zone, nor from the Lansdale Low Zone into the Hillcrest Zone. This study emphasized modeling water flow in the Lansdale Low Zone, which is the largest portion of the distribution system.

The well pumps operate on time clocks. Although some wells pump continuously, some are not pumped during the late evening and early morning hours. At these times, Keystone water moves further into the distribution system.

The chemical characteristics of Keystone water differ from those of the well waters. Keystone water contains total trihalomethanes (TTHM) at significantly higher levels than does the well water. Certain wells show the occurrence of trichloroethylene (TCE), or cis-1,2-dichloroethylene (cis-1-2-DCE), or both. Inorganic chemicals also vary from well to well and between the wells and Keystone water.

The NPWA distribution system is well instrumented, with detailed continuous records available on well pumpage, tank heights, and flow at various locations with the system. In addition, NPWA maintains a detailed water quality sampling program, both at sources and in the distribution system; thus, there is significant historical data available on system water quality.

Description of the Study

Steady-State Prediction of Mixing

With the use of WSSM, a steady-state prediction of mixing within the distribution system was obtained. This effort required the following steps: after establishing a WSSM data base for the NPWA distribution system and developing and parameterizing a hydraulic model of the NPWA distribution system as well as hydraulic "scenarios," hydraulic information obtained from selected scenarios was stored within the WSSM data base. Running the Solver module of the WSSM provided steady-state prediction of water mixing.

The steady-state algorithm as applied in this case did not take into account the concentration of Keystone water resident in the tanks. According to the late night scenario, at least some Keystone water will enter the tanks and then be discharged into the distribution system as another source of Keystone water. This is a more complex analysis, but, in the majority of the hydraulic scenarios selected in this study, tanks were filling, rather than discharging to the system.

The steady-state analysis inherently cannot take into account water already in the pipes of the distribution system. For example, the late night scenarios, in which wells are off, results in Keystone water flowing throughout the system. In fact, much of the water in the pipes at that time is well water; the pipes act as a reservoir for this water, even though the wells are off. Obviously, blending takes place, rather than water being either fully well water or fully Keystone water. volume of water in the pipes of the distribution system (as represented in the WSSM, i.e., neglecting smaller pipes) was calculated to be 2.8 million gallons, or over half of the average daily supply of 5 million gallons for the NPWA distribution system. The reservoir effect, which results when the wells are shut off at night and Keystone water enters pipes partially filled with well water, is likely to be significant and cannot be taken into account in traditional steady-state modeling. This further confirms the desirability of dynamic quality modeling.

Comparison of Steady-State Prediction with Historical Data

Solver module predictions were compared with water quality sampling data to assess the spatial variations in quality. Average values for specific water quality variables, at defined locations, were calculated. Because the TTHM formation of the purchased surface water was assumed to have achieved a steady-state relationship and the TTHM production for the other sources in the system was assumed to be zero, TTHMs were used as a predictor of mixing and blending of surface with well water. Solver predictions in general agree the analyzed historical data. "Point-prediction" capacity (the ability of the model to accurately estimate the level of a pollutant at a specific point in the distribution system) was, however, limited.

Short-Term Sampling Program

A short-term, pilot sampling program was undertaken to characterize more accurately the spatial (space) and temporal (time) variations of quality in the water distribution systems. Six sites throughout the distribution system were sampled at 4-hr intervals for a 36-hr period. This sampling program showed significant variations in TTHMs at the Keystone surface water source and obvious blending and mixing of the well and surface water in the distribution system and, as predicted by the steady-state modeling analysis, one location alternately fed by well water and by surface water.

The pilot sampling program clearly showed the dynamic nature of quality variation within the system and led to methods to predict dynamic quality. In addition, the difficulty in obtaining manual samples led to development of automated samplers.

Dynamic Quality Modeling Efforts

Sequential Steady-State Modeling

The initial attempt to model the dynamic quality variations found in the sampling study was based on successively applying the steady-state Solver technique to different demand patterns and boundary conditions. This technique was implemented in developing the quality model by designing different steady-state hydraulic scenarios, which were representative of different time periods within the sampling study, and successively predicting hydraulics and the associated water quality for each period. This technique, called sequential steady-state modeling, again yielded reasonable results in terms of overall patterns. Theoretically, however, this approach fails to take into account the water that is resident in the pipes of the distribution system which is obviously in a blended/mixed state, and is extremely cumbersome to handle logistically.

Development of Dynamic Water Quality Model/Flow Tracing Algorithm

A dynamic water quality model (DWQM) was developed that would better represent the variations observed in the water quality. DWQM is based on a routing technique that continually accounts for the quality of water in pipes within the distribution system. As with the steady-state model, the DWQM relies on externally available, detailed hydraulic information relating to flows in pipes and at nodes available for each time step in the quality simulation. The DWQM is based on flow tracing rather than on the simultaneous equation solution used in the Solver algorithm. When the DWQM was tested against the conditions of the sampling study, an extended-period hydraulic simulation was developed that showed good agreement between predicted and actual tank levels and the pressures in the system. This was then used to model the quality variations which again showed good agreement over the 36-hr sampling run.

Conclusions and Recommendations

Steady-State Predictive Modeling

Based on the results to date, steady-state predictive modeling appears to be a reasonable first step to characterize the distribution of water quality in multisource systems. Although point prediction capability is probably not accurate, and probably highly sensitive to hydraulic assumptions, general trends can be established, and then verified, through field sampling.

Steady-state prediction might be better suited to systems that are less dynamic in terms of operation, with fewer sources, than is the NPWA distribution system. Steady-state assumptions might be more consistent with a less dynamic system. Because of the manner in which the NPWA system was developed, by connecting of a number of separate systems, it is somewhat disjointed, a number of portions of the system are connected by a single pipe. Once the hydraulic solution establishes flow direction, the system is effectively partitioned, at least in certain areas, into zones of uniform concentration.

Dynamic Water Quality Model

Results of the pilot sampling study clearly showed the spatial and temporal variability of water quality in the NPWA distribution system. Because little information was available on short-term spatial/temporal variability for distribution systems (most monitoring strategies involve taking samples at daily, monthly, or quarterly intervals, at a selected number of sites) within-day quality variations were seldom noted.

Although steady-state prediction of quality does provide certain insights into system behavior, dynamic water quality models, though more demanding of input data describing the system, more accurately reflect changes in water quality.

The DWQM developed in this study is relatively simple to use and can easily be extended to more complex situations of nonconservative constituents. As applied to the NPWA pilot run, good agreement between predicted and actual results were found.

When using DWQMs, two major problems arise: the need to manage the large quantity of data that the models use and the need for improved methods of data analysis and display.

Dynamic water quality models both generate and use large quantities of data. Detailed descriptions of dynamic hydraulic behavior are required, and the models can generate extensive information on within-pipe and nodal water quality over time. Improvements in data handling, and development of techniques for analyzing and displaying data reflecting spatially varying, dynamic water quality, would contribute greatly to ease of using dynamic water quality models.

Monitoring Needs

A clear result from this research is the need to obtain more representative monitoring results than are normally acquired from distribution system sampling. Contaminant values can vary greatly over a relatively short time at a given point. There are also no doubt weekly and yearly cycles that, when combined with hydraulic and mixing variations, will have great effect on the contaminant levels at a given point in a distribution system. Existing compliance monitoring strategies probably fail to truly reflect population exposure because they are based on assumptions about quality behavior in distribution systems that imply essentially steady-state characteristics.

The use of automatic samplers, such as those developed and tested in this study, should prove to be of significant value in rapidly characterizing the degree of temporal/spatial variability of water quality in distribution systems. It is expected these samplers can, with minor modifications, be useful field instruments. Extension of the approach to bacteriological sampling would also prove very useful.

Having the tools to predict time-of-travel between points in a system and to estimate the quality of water provided to any point from any source would allow for realistic water quality monitoring strategies.

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The complete report, entitled "Operation of Water Distribution Systems to Improve Water Quality," (Order No. PB90-246 539/AS; Cost: $17.00, subject to change) will be available only from:

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