SIMULATION AND STATISTICAL QUALITY CONTROL FOR URBAN WATER MANAGEMENT

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ABSTRACT

As a tool in appraising the regional reliability, a set of statistical quality control charts was developed to relate the waste water treatment operations to the overall regional water quality reliability. Computer simulation was utilized in the stochastic nature of the system analysis. Field data from the San Antonio River Basin was evaluated to demonstrate the practicality of the developed model.

Introduction

In appraising the quality of water in streams or rivers, the concept of regional water system reliability provides an extra key in preserving the quality of urban life. Mainly, the water quality at any control point along a river depends upon: (a) the effluent quality from waste sources upstream, (b) the dilution effects of stream runoff, (c) the initial river quality, and (d) the decay rate, i.e. the rate of biological oxidation of non-conservative materials (biodegradable organic material).

The analysis of regional system reliability, plus the use of operating characteristic curves for each sewage treatment plant in a region would provide both the layman and decision-makers the capability to make best decisions in operational adjustments timely and correctly. The objective of this paper is to develop a set of statistical operating characteristic curves to relate the waste-water treatment operations to the overall regional system reliability.

The regional waste treatment system in the San Antonio River Basin near the city of San Antonio, Texas is selected as the demonstration site. There are three major waste treatment facilities in the region, serving the majority of the metropolitan area of San Antonio.

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The water quality of the basin must comply with the standards. For this particular section of the San Antonio River, above Elmendorf, the state required that water quality must contain five-day biochemical oxygen demand (BOD_5) of less than 10 mg/l. The average stream flows range between 27.0--188 MGD. Both BOD_5 and phosphate content are employed as primary characterization parameters for the regional water quality. It has been analyzed based on the condition that the phosphate level at quality control point must be less than or equal to 5 mg/l.

Model Formulation

By considering the effluent quality from waste sources, the dilution effects of stream runoff, and the biological decay functions, the water quality at the downstream control point was calculated by the formula:

$$L = \sum_{i=1}^{n} d_i \sum_{j=1}^{m_i} \frac{w_{ij}}{w_{ij} + f_{ij}} x_{ij}\, g(t_{ij}) \qquad (1)$$

$$i=1,2,\ldots\ldots,n$$
$$j=1,2,\ldots\ldots,m_i$$

where

- L=calculated water quality at control station
- f_{ij}=flow rate of ith stream upstream at the outfall of jth treated waste effluent
- d_i=dilution factor for the ith stream flow toward the flow at the control point
- w_{ij}=flow rate of the jth treated waste effluent on ith stream
- x_{ij}=effluent of jth facility along ith stream
- $g(t_{ij})$=decay function of jth treated waste effluent in ith stream, while t_{ij} is the travel time to the control point

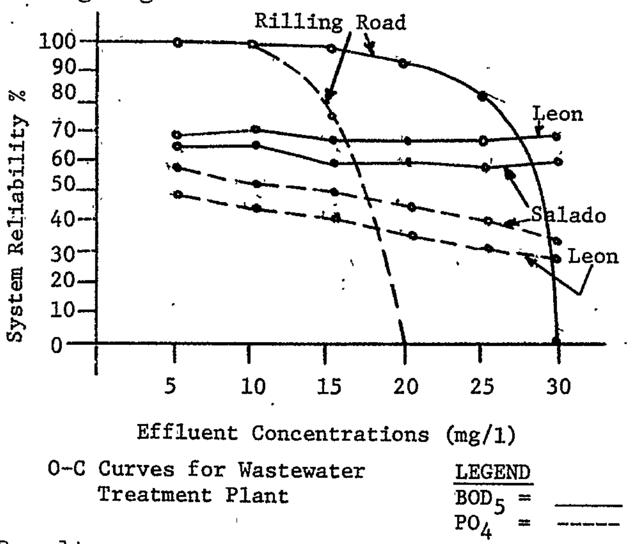
By combining the dilution factor, d_i, the decay function into stream mixing factor, α_i, the stochastic nature of the system were quantified by a chance-constraint,

$$P\{[\sum_{i=1}^{n-1} \alpha_i r_i y_i + \alpha_n r_n y_n] \le q\} \ge R \qquad (2)$$

where α_i $(i=1,2,\ldots,n)$ is the stream mixing factor for ith treatment plant.
$r_i y_i$ $(i=1,2,\ldots(n-1).)$ is the random variables representing the unregulated state of ith treatment plant.
$r_n y_n$ is the regulated state of the treatment plant where the effluent quality is assumed at the controlled state, i.e. the reliability r_n is equal to 1.0.
q is the water quality criterion at the regional system monitoring point.
R is the desired regional system reliability.

The frequency distributions which were developed from historical data were used as empirical distribution in random number generation. By specifying the BOD_5 at controlled values at specific plants, and generating the other effluent quantity based on empirical distributions, the simulation for the resultant water quality for desired system reliability were calculated. Equations (1) and (2) were used in computing the composition of statistical distributions. It must be noted that, for the case of phosphate, since it is a conservative pollutant, the decay function was simply a constant of 1.0.

The simulation programs were developed for IBM 360/65 system, and the execution time is around two minutes for 500 iterations. The operating characteristic curves for each major waste water treatment plant in San Antonio area for both BOD_5 and phosphate were obtained as shown in the following figure:



O-C Curves for Wastewater Treatment Plant

Results

The operating characteristic (O-C) curves for BOD_5 shows a steady trend between 65 to 70 per cent system reliability for both Salado and Leon plants, but for the Rilling Road plant, there is a sharp drop when the effluent level is above 20 mg/l. In case of phosphate, the O-C curve for Rilling Road plant shows a sharp drop when its quality level is above 15 mg/l whereas smooth curves were obtained for both Salado and Leon plants with system reliability varying from 30 to 60 per cent. This may confirm the classic conviction that the biggest polluter is also the most critical component in regional water quality management. It was also realized that if the BOD_5 effluent in Rilling Road can be controlled under 15 mg/l, the reliability of maintaining the regional water quality at monitoring point below the required standards is almost a hundred per cent. Meanwhile, the system reliability decreases sharply as the effluent BOD_5 in Rilling Road's effluent is 30 ppm or above. For Salado and Leon plants, due to their smaller capacities the worsening in effluent quality can be dampered by the dilution effects from stream fresh inflow.

In case of phosphate the systems reliability is found affected significantly by the effluent quality, even for both the smaller Salado Creek and Leon Creek plants. This may be attributed to the drastic difference between the phosphate in stream inflows and that in waste effluents. Again, because of the large capacity of Rilling Road plant, the system reliability will drop from one to zero when the phosphate concentration from this plant is varied between 5 to 20 mg/l.

Conclusions

Operating characteristic curves based on simulation and statistical control has added an extra dimension to the analysis in water pollution control. The complicated and unpredictable nature of streams has been recognized by many practitioners but ignored in current quality standards. Thus, the analytical method to relate the regional water quality system to the efficiency of individual waste treatment plants through the concept of reliability will provide an equitable guidelines in regulating the managerial policies for regional water pollution control. This systems approach in analyzing the regional water quality will furnish both the laymen and the managers a practical tool in their target setting for the individual treatment plant operations.

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