Formulation and Use of Practical River Quality Assessment Models

River-Quality Assessment of the Willamette River Basin, Oregon

GEOLOGICAL SURVEY CIRCULAR 715–B

Formulation and Use of Practical Models for River-Quality Assessment

By W. G. Hines, D. A. Rickert, S. W. McKenzie, and J. P. Bennett

RIVER-QUALITY ASSESSMENT OF THE WILLAMETTE RIVER BASIN, OREGON

GEOLOGICAL SURVEY CIRCULAR 715-B

1975

United States Department of the Interior

Geological Survey

V. E. McKelvey, *Director*

First printing 1975
Second printing 1980

Library of Congress Cataloging in Publication Data

Hines, Walter G.
Formulation and use of practical models for river-quality assessment. (River-quality assessment of the Willamette River Basin, Oregon)

(Geological Survey Circular 715-B)
Bibliography: p. B12-B13.
1. Water quality–Mathematical models. 2. Water quality–Willamette River watershed–Mathematical models. I. Hines, Walter G. II. Series. III. Series: United States. Geological Survey. Circular 715-B.
QE75.C5 No. 715-B [TD370] 628.1'61 75-28191

Free on application to the U.S. Geological Survey, National Center, Reston, Va. 22092

FOREWORD

The American public has identified the enhancement and protection of river quality as an important national goal, and recent laws have given this commitment considerable force. As a consequence, a considerable investment has been made in the past few years to improve the quality of the Nation's rivers. Further improvements will require substantial expenditures and the consumption of large amounts of energy. For these reasons, it is important that alternative plans for river-quality management be scientifically assessed in terms of their relative ability to produce environmental benefits. To aid this endeavor, this circular series presents a case history of an intensive river-quality assessment in the Willamette River basin, Oregon.

The series examines approaches to and results of critical aspects of river-quality assessment. The first several circulars describe approaches for providing technically sound, timely information for river-basin planning and management. Specific topics include practical approaches to mathematical modeling, analysis of river hydrology, analysis of earth resources–river quality relations, and development of data-collection programs for assessing specific problems. The later circulars describe the application of approaches to existing or potential river-quality problems in the Willamette River basin. Specific topics include maintenance of high-level dissolved oxygen in the river, effects of reservoir release patterns on downstream river quality, algal growth potential, distribution of toxic metals, and the significance of erosion potential to proposed future land and water uses.

Each circular is the product of a study devoted to developing resource information for general use. The circulars are written to be informative and useful to informed laymen, resource planners, and resource scientists. This design stems from the recognition that the ultimate success of river-quality assessment depends on the clarity and utility of approaches and results as well as their basic scientific validity.

Individual circulars will be published in an alphabetical sequence in the Geological Survey Circular 715 series entitled "River-Quality Assessment of the Willamette River Basin, Oregon."

J. S. Cragwall, Jr.
Chief Hydrologist

Cover: Willamette River as it winds through Portland, Oregon. Photograph taken by Hugh Ackroyd.

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Multiply	*By*	*To Obtain*
Feet (ft)	0.3048	Metres (m)
Miles (mi)	1.609	Kilometres (km)
Pounds (lb)	.4536	Kilograms (kg)
Cubic feet per second (ft^3/s)	.02832	Cubic metres per second (m^3/s)

Formulation And Use Of Practical Models For River-Quality Assessment

By W. G. Hines, D. A. Rickert, S. W. McKenzie, and J. P. Bennett

ABSTRACT

Complexities inherent in the study of large rivers and the need for quantitative description of river-quality have generated increasing interest in mathematical modeling. In concept, mathematical models have great potential as practical tools for predicting the impact of alternative planning proposals on river quality. However, many planners and decisionmakers have failed to accept models for river-quality assessment, and many actually view models with considerable mistrust. This situation can be partly traced to six major deficiencies common to applied modeling efforts: (1) application of a model to a variable or process that is too complex for formulation of a practical, applied model; (2) application of a sophisticated, general-case model without adequate understanding of the particular river in question; (3) failure to recognize the importance of basin hydrology in defining the critical planning and management decision periods for model simulation; (4) misapplication of model calibration and verification procedures; (5) use of a poor data base for interpretation, calibration, and verification; and (6) failure to format results for ease of user understanding. Overall, these deficiencies have caused an irrational progression of models from the conceptual to the applied states. With careful thought and interdisciplinary teamwork, these deficiencies can be corrected and conceptual models transformed into practical, useful tools for river-quality assessment.

INTRODUCTION

Environmental awareness and new laws such as Public Law 92–500 have established improved river quality as a major goal of comprehensive river-basin planning. River quality can be defined as the physical, chemical, and biological character of a river with regard to its suitability for a specified purpose. In this context, river quality concerns not only the observed quality of water in a river, but also involves the analysis of environmental factors on land, water, and in air that are responsibile for the observed quality.

To achieve improved river quality with a minimum of environmental, social, and economic cost, it is imperative that basin-planning decisions and the need for river-quality management facilities be based on scientific assessment rather than on arbitrary edicts and assumptions. Thus, the objective of river-quality assessment is to evaluate, before the fact, the beneficial or adverse environmental impacts of planning alternatives on the quality of the river. Once the environmental impacts have been examined, economic, social, and energy costs can be weighed and compared for each planning alternative.

The complexities inherent in the scientific study of large rivers, coupled with the need for quantitative description of river-quality behavior, have created great interest in mathematical models (referred to hereafter as river-quality models) as tools for simulating the response of river-quality variables to alternative basin-planning proposals. The study of dissolved oxygen-biochemical oxygen demand (DO-BOD) relationships by Streeter and Phelps (1925) is generally considered to be the pioneering effort at applied river-quality modeling. Although DO continues to be the subject of a majority of river-quality models, other variables and processes are receiving increasing attention. The subjects range in complexity from relatively simple variables such as temperature to highly complex long-term processes such as eutrophication (fig. 1).

In concept, river-quality models provide a great potential for problem-solving to resource planners and managers, pollution-control officers, and government decisionmakers. In general, however, these people have not only failed to accept river-quality models as a practical tool, but often view mathematical modeling with considerable mistrust. The authors have concluded that this failure to accept and trust models stems from the fact that many river-quality models have not been formulated on the basis of sound data nor effectively applied to planning and management situations.

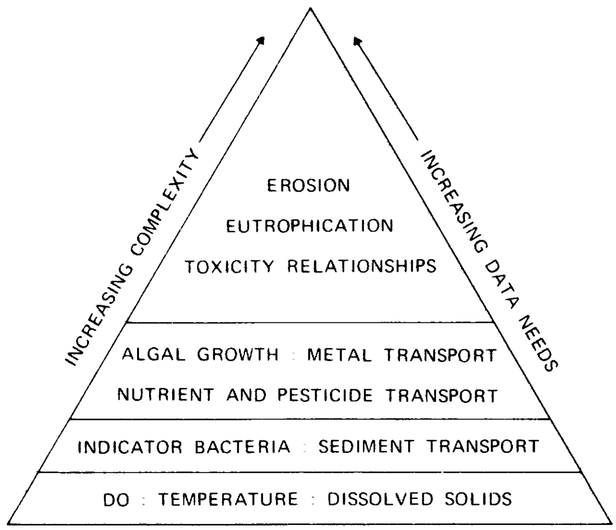

FIGURE 1.—Relative difficulty of applied modeling.

Similar conclusions have been cited by several other investigators, including Mar (1971), Lombardo (1973), Weber, Kisiel, and Duckstein (1973), and Velz (1970).

The objective of this circular is to describe considerations vital to the formulation and use of practical river-quality models intended for application to planning problems. The focus is on current deficiencies in modeling rationale and suggestions for improvement. The discussion is not meant to convey an indictment of models or modelers, nor is it intended solely as a critique of currently prevalent modeling approaches. Rather, the primary intent is to provide a basis for examining potential shortcomings in proposed river-quality models and to propose ideas and hypotheses useful for improving these models.

IMPORTANT CONSIDERATIONS IN APPLIED MODELING

To be an effective assessment and planning tool, a river-quality model must proceed from a conceptual state to an applied state. In the conceptual state, mathematical configuration, mathematical solution techniques, and computer adaption are of primary concern. In the applied state, a basic understanding of the particular river system is needed to formulate the model and quantify its parameters.

(A model parameter is an element of a mathematical model used to define a reaction rate, proportionality constant, or other process-describing characteristic. For example, in the basic DO reaeration equation of Streeter and Phelps (1925)

$$\frac{dD}{dt} = K_1 L - K_2 D,$$

where

D = the DO deficit with respect to the saturation value,

L = the stream BOD concentration, and

K_1 and K_2 are parameters defining the rate of biochemical oxidation (or deoxygenation) and the rate of stream reaeration, respectively.)

Irrational progression from the conceptual to the applied state is a major cause for the current poor utility of many applied river-quality models.

Table 1 summarizes major deficiencies that are prevalent in applied river-quality models, and presents suggestions for improvement. Each deficiency and suggestion is amplified in the discussion that follows. Where pertinent, examples are presented from a river-quality study of the Willamette River, Oreg.

MODELABILITY OF VARIABLE OR PROCESS

Mathematical equations have long been utilized for describing, at least in a conceptual sense, the behavior of certain river-quality variables and processes. In fact, most of the phenomena shown in figure 1 have been the subject of conceptual models. However, such models can be translated into applied river-quality models only when complemented by reasonable assumptions and quantified model parameters. These assumptions and model parameters are the driving force of all applied models because they describe the rates and relative importance of the factors that govern the behavior of river-quality phenomena. The quality of assumptions and model parameter values is based almost entirely on the level of understanding and empirical evidence concerning the variable, process, and river system in question. Measurement or determination of model parameters and assumptions increases in difficulty for each higher level in figure 1 and is a major reason that models become less quantitative at each higher level.

At present, many complex processes such as those appearing in the mid and upper levels of the triangle in figure 1 are difficult, if not impossible, to model in a practical, applied sense. This stems from the fact that appropriate assumptions and accurate model parameters are difficult to develop because of the poor state of knowledge about many river-quality processes and the effects of various environmental factors on process rates.

In the absence of reliable data and sound understanding of river phenomena, conceptual models have been used to make predictions of impacts related to planning and management alternatives. There can be little doubt that conceptual models are valuable for this and many other purposes, although their utility and validity compared with less sophisticated approaches have not been fully tested.

In lieu of modeling, particularly for the more complex river-quality variables and processes, semiquantitative descriptive studies may prove to be more useful. An example of such a case can be described for the Willamette River, Oreg.

In the Willamette River, a future potential for excessive algal growth exists because total nitrogen and phosphorus loads discharged to the river during summer low-flow conditions are increasing while BOD (carbon) loads have been dramatically reduced by new secondary waste-treatment plants (Gleeson, 1972). Jaworski, Lear, and Villa (1971) documented a severe algal-growth problem in the upper Potomac estuary under similar conditions. Concern about future algal growth in the Willamette led to a scrutiny of methods that could give predictive insight into the potential problem. Originally, a model to simulate algal growth was considered. However, a review of data indicated that only limited information was available for the Willamette on species and population of algae, the concentration of nutrients in the river and in waste-water discharges, and river DO, turbidity,

TABLE 1.—*Common deficiencies of applied river-quality models and suggestions for improvement*

[For discussion see text that follows]

Deficiencies	Suggestions for improvement
Application to a variable or process that is too complex for formulation of a practical applied model.	Model only those variables and processes for which major parameters and assumptions can be qualified or verified through field and laboratory study. Define model applications, limitations, biases, and predictive accuracy commensurate with the level of understanding surrounding the variable or process. Use semiquantitative descriptive studies when knowledge is inadequate to formulate a practical, applied model.
Application of a sophisticated, general-case model without adequate understanding of the particular river in question.	Conduct premodeling studies to develop a better understanding of river hydrology and important river-quality processes and tailor the model to reflect these determined characteristics. Consult with independent mathematicians and computer scientists concerning model configuration, solution techniques, and other technical model questions prior to selection or use of any particular model.
Failure to recognize the importance of basin hydrology in defining the critical planning and management decision periods for simulation by the model.	Conduct a detailed assessment of natural and man-influenced basin hydrology to determine the critical recurring conditions with respect to river quality. Establish recurrence probabilities for these conditions. Base production runs of the model (that is, predictions) wihthin the framework of these recurrence probabilities.
Misapplication of model calibration and verification procedures.	Use separate, independent sets of data for calibration and verification. Minimize reliance on mathematical "curve-fitting" techniques by independently establishing reasonable ranges for model parameters and assumptions through field and laboratory investigation.
Use of a poor data base for interpretation, model calibration, and model verification.	Collect a statistically reliable set of data specifically suited for analysis of the river-quality variable or process being modeled. Concentrate data-collection and analysis effort within periods when critical hydrologic and river-quality conditions occur.
Failure to format results for easy user understanding.	Consult continually with intended model users in order to update needs and instill familiarity with the model and its capabilities. Write user reports and products in nontechnical language. Include discussion of model limitations and applications. Display results of model production runs in graphical form whenever possible.

and light penetration. Thus it was apparent that a reliable algal-growth model would be most difficult to formulate and test within the 2½-year timespan of the study.

Instead of a model, a descriptive study was designed to assess the potential for algal problems. The study is composed of several elements:

1. Compilation and analysis of historical data from the Willamette (and other rivers) to relate present conditions in the river to past conditions, and to anticipate problems observed under similar conditions in other rivers.
2. A network of stations that are sampled frequently during summer low-flow, high-temperature conditions to determine species and populations of algae, river and algal-cell nutrient concentrations, DO concentration (instantaneous and diel), and physical conditions such as temperature and light penetration. The stations are also sampled periodically during other periods of the year.
3. Intensive studies involving algal primary productivity tests (light-and-dark-bottle BOD's) and enrichment bioassays.

Results of the study should allow better understanding of the algal system of the Willamette River and serve as a baseline from which trends can be established and predictions made using subsequent data sets for comparison. In contrast to a model, the study will not hide the fact that with current knowledge quantitative predictions are questionable at best.

The credibility of models can be improved through recognition of the fact that many river-quality phenomena are presently modelable only in a conceptual sense. Attempts to "sell" conceptual models as suitable for direct application to planning and management situations should be discouraged. All proposed river-quality models, whether conceptual or applied, should be accompanied by a statement of limitations, predictive accuracy, and suggested applications. Potential users could then exercise independent judgment as to whether a model or another technique should be applied to the river-quality problem in question.

MODEL CONFIGURATION

General applicability to any river is sometimes a stated objective of river-quality models (Pacific Northwest Laboratories, 1972; Texas Water Development Board, 1970a, b). Usually models with this objective are sophisticated in configuration because they must have dynamic mathematical components and model parameters to simulate any conceivable perturbation of the phenomena in question. For example, a general-case DO model must include mathematical equations and model parameters for simulating carbonaceous deoxygenation, reaeration, photosynthesis, respiration, nitrification, and benthal oxygen demand. In addition, the model must account for extremes in river discharge, hydraulic conditions, river temperature, and other environmental factors. The resulting sophisticated model configuration is seldom justified by conditions or needs for any particular basin.

Unfortunately, the proliferation of sophisticated, general-case river-quality models has caused a preoccupation with mathematical development, solution techniques, and computer programing. Although such technical model problems are important and deserve continuing attention, they tend to divert attention from analysis and understanding of river hydrology and the phenomena being modeled. In a publication describing the mismatch between data and models, Weber, Kisiel, and Duckstein (1973) stated: "* * * the increased availability of library computer programs tends to encourage analysis of data and generation of numbers without serious consideration of the assumptions on which these analyses are based." In light of this tendency, future efforts at applied modeling should minimize extraneous mathematical sophistication and maximize the understanding of river phenomena.

In cases where technical model problems persist or where there is uncertainty concerning the mathematical integrity of a particular model, users should consult with independent mathematicians or computer scientists.

Before the selection of a particular model or model configuration, many rivers can be assessed as to the required level of mathematical sophistication. The concept here is to fit the model to the river rather than the river to the model. The assessment can be partly based on a short premodeling data-collection and analysis program designed to determine such factors as mixing and waste-loading characteristics, streamflow patterns, expected ranges of model parameter values, and the presence or absence of benthal deposits. Insight into such factors before formulation of the model and the implementation of an intensive model data collection program will greatly enhance the compatibility of the model with actual river conditions.

In the Willamette River basin, a reconnaissance-level study was conducted on the river before a decision on the configuration of a DO model. The study indicated that several major changes had occurred since 1951 and 1960 when Velz (1951, 1961) studied the DO dynamics of the Willamette: BOD loading was much lower because of basinwide secondary treatment; waste-water discharges were less variable because of large aerated stabilization ponds at all pulp and paper mills; deoxygenation rates in the river and in waste water were much lower; significant benthal deposits were absent; algal photosynthesis and respiration were now active in many areas; and detention time and river channel geometry (and thus reaeration rates) had been affected by dredging. Conversely, several important river phenomena and conditions had not changed: the river was still well mixed in most reaches, DO concentration was lowest in the lower 55 miles (88 km) of the river, and streamflow during the late summer was still steady and low despite increased flow augmentation from reservoirs. Such findings led to the formulation of a model of simpler configuration than originally considered and allowed the design and implementation of a more efficient model-calibration and verification program. In other words, the premodeling study allowed more investigative effort to be placed on those factors having the largest effect on the DO system of the Willamette.

RECOGNITION OF CRITICAL PERIODS

The size and complexity of most river basins limit the capability for modeling all seasonal changes in a particular river-quality variable or process. There is a mystique, perhaps fostered by reliance on general-case river-quality models, that because seasonal changes in water quality do occur, a useful model must simulate all these changes. In reality, attempts to formulate perennial-simulation models may obscure important objectives and waste money and time.

In many river basins there exists a particular seasonal period, controlled by cyclical hydrologic processes, for which a river-quality model can be aimed. This is particularly true for the more commonly modeled variables—DO, temperature, and dissolved solids. For example, in the Willamette River, critically low DO conditions have historically been experienced only during the annually recurring low-flow high-temperature summer season (Gleeson, 1972). River-quality planning and management decisions in the Willamette Basin and many other basins have been predicated primarily on poor water-quality conditions that recur during the summer. Thus, river-quality models for DO can be highly useful for planning and management purposes, although intended to simulate only this specific condition.

The critical-condition rationale for model application also offers other advantages (table 2). First, critical conditions for many river-quality variables and processes (for example, DO, temperature, and dissolved solids) often occur during low-flow, steady-state hydrologic conditions. Therefore, the need for dynamic model components is drastically reduced. Steady, plug-flow conditions can usually be realistically assumed, and only small ranges in associated variables and processes need be considered. Second, because critical conditions are often governed by hydrology and commonly recur on a cyclical basis, it is often possible to statistically evaluate the recurrence probability

TABLE 2.—*Comparison of applied river-quality models*

Category	Applications	Mathematical sophistication	Model parameters	Data requirements
Perennial-condition	Perennial simulation. Real-time management. Assessment of planning alternatives. Impact prediction.	High, numerous dynamic elements necessary.	Numerous. Difficult to quantify.	Detailed year-round hydrologic and quality data. Continuous monitoring.
Critical-condition	Critical-condition simulation. Management during critical condition. Assessment of planning alternatives. Impact prediction.	Low to moderate, primarily steady-state elements.	Few. Easier to quantify.	Detailed hydrologic and quality data only during critical condition.

of the hydrologic event and to relate the results of model predictions to this probability. Third, data needs for calibration and verification of the river-quality model are reduced. Because sampling is needed only for a short period of the year, analysis is greatly simplified.

On the basis of extensive experience in a number of river basins, Velz (1970) described a detailed approach for analyzing low-flow hydrology to base formulation and application of river-quality models for DO, temperature, and several other variables.

Certain river-quality variables, especially those associated with erosion and sediment-transport phenomena, are most important during high-flow periods. Soils and transported sediment are repositories for pesticides, trace metals, and nutrients such as nitrogen and phosphorus. These materials often reach their concentration peaks in rivers during storm-runoff events, particularly in reaches below erodible areas or below agricultural and urban development.

The significance of river-quality problems associated with high flows depends primarily on the antecedent conditions of land surfaces in the basin and on the hydraulic regime of the river. For example, in an agricultural area, the first large runoff event of the year may transport a large quantity of sediment-associated nitrogen and phosphorus to the river. If streamflow and channel geometry are such that the sediment does not deposit in the river, the nutrients will be flushed from the basin. In this case, the inputs of nutrients will have little or no effect on subsequent algal growth within the river. However, if the sediment deposits in the river or behind a downstream dam, the attached nutrients may profoundly affect algal growth during spring and summer growth periods.

Obviously, the activities of man play a particularly important role in determining the magnitude of river-quality problems associated with high flows. Land-use activities affect the nature and quantity of materials transported to the river by runoff. River developments such as dams and navigation works change the hydraulic regime of the river and affect the fate and impact of transported materials.

Generally, mathematical models intended for simulatation of river-quality phenomena during high-flow periods are more difficult to formulate and apply than models intended for steady, low-flow periods. High-flow phenomena are so variable in time and space that they cannot presently be adequately studied and quantified for river-basin sized watersheds. Bennett (1974) described the chronic problems encountered in obtaining adequate data for formulating a quantitative watershed model for erosion and sediment transport. This situation is another example of the basic problem mentioned previously in the section, "Modelability of Variable or Process."

In summary, the failure to recognize critical periods for river-quality model application is usually attributable to a failure to recognize the overriding importance that river hydrology has in controlling river quality. To formulate a simulatory, predictive model and to define the periods of the year in which the model can be validly applied, river hydrology-quality interactions must be understood. Subsequent circulars in this series will deal with the quantification of certain hydrologic factors as a prerequisite to modeling and river-quality analysis.

CALIBRATION AND VERIFICATION REQUIREMENTS

Calibration is the procedure whereby model parameters are adjusted so that the model outputs (for a particular set of input data such as streamflow, temperature, and waste loads) approximate a set of observed river-quality data. The ranges within which model parameters can be realistically adjusted are important to the credibility of the calibration.

Unfortunately, modelers are often faced with poor data for calibration and have tended to rely heavily on mathematical optimization techniques to quantify model parameters. In simple terms, optimization involves two steps. First, a numerical range is established within which each model parameter can vary. The range, which is typically quite large, is usually obtained from a review of modeling literature. Second, numerous computer runs are conducted, and values for each parameter are simultaneously varied within the ranges previously established. During the computer runs, a least-squares procedure is used to obtain a "best fit" of model outputs to a set of observed river-quality data. The model parameter values resulting in the "best fit" are considered to be the optimum values. Often these values are not checked independently for accuracy within the river system being modeled.

When conducted in the manner described above, calibration in effect becomes little more than a computerized "curve-fitting" process instead of a "fine-tuning" process governed by scientific understanding.

Numerical ranges for most parameters can and should be established by independent field and laboratory study. For example, in the case of a DO model, a range of reasonable river deoxygenation rates can be established by a carefully conducted BOD sampling and analysis program. Similarly reaeration coefficients, though not directly measurable, can be approximated for any river reach for which detailed flow and channel geometry data are available (Bennett and Rathbun, 1972; Velz, 1970). It is also important that the major underlying assumptions are checked for reasonableness.

Verification is the essential step for substantiating the predictive capability of a river-quality model. The procedure involves the use of a calibrated model (that is, the same model parameter values developed during calibration) and a new set of observed data. Some of the new data establish the boundary conditions necessary to "start" and "run" the model. The rest of the data serve as an independent set of observations for comparison with model predictions (or outputs).

If the model predictions are "acceptably close" to the independent observations, the model is considered verified. If the predictions are not "acceptably close" or if model parameter values must be juggled to make the model "fit" the observations, the verification has failed. The "acceptably close" criterion can be established before verification and can, in part, be based on the "goodness of fit" obtained during calibration as defined by the standard error of estimate. Readers desiring criteria for judging the credibility of model calibration and verification should read Dawdy (1969).

Bella (1969) noted that model verification, by definition, implies the "proof of the truth of the model." He cautioned, however, that this definition does not describe the process of relating the model results to the real world and that a model cannot be truly verified—only its use justified for the situation in which it is used. The authors agree with this hypothesis.

Verification has been abused in many river-quality modeling efforts. As noted by Mar (1971), verification and calibration have often been based on the same set of observed data. In others, verification has not even been attempted. Such practices discredit the predictive capabilities of river-quality models.

The predictive capability of a river-quality model, and thus the integrity and utility of the model for assessing proposed planning alternatives, deserves careful scrutiny. A basic necessity is the collection and analysis of independent sets of statistically reliable data (see subsequent section, "Model Data Base") for calibration and for verification. In this regard, Dawdy (1969, p. D9) stated that in order to present a measure of utility of the model to a potential user, the data used in verification should *not* include any data used to calibrate the model or develop its parameters. It is also well to assume that the model will have to be recalibrated and reverified at a future date should drastic changes in the river system occur (for example, a change from primary to secondary waste treatment, extensive dredging or diversion of a large percentage of streamflow).

In some cases, the model's predictive ability can be further checked by comparing model predictions with results of past river-quality surveys. Care must be taken, however, to ensure that the old surveys were of high quality and accompanied by data on related factors such as waste loads, streamflow, river temperature, and channel geometry.

MODEL DATA BASE

In many basins, the existing river-quality data base has been compiled largely through pollution-monitoring and surveillance programs. Such programs are usually concerned with determining compliance with State and Federal water-quality standards or with detecting trends. Monitoring and surveillance programs usually involve routine grab sampling and rigid temporal and spatial guidelines. For example, in a particular river, 10 sites might be designated for sampling once or twice a month (commonly during daylight hours only) for temperature, DO, pH, specific conductance, alkalinity, turbidity, BOD, and coliform bacteria. Periodic samples may be collected for other selected constituents such as nitrogen and phosphorus. Continuous monitors for temperature or pH might also be operated at one or two sites.

Attempts are often made to use such data for calibration and verification of river-quality models, particularly DO models. Unfortunately, these data are almost always poorly suited for model calibration or verification. Several reasons can be cited for this poor suitability:

1. Limited samples at widely dispersed sites are not sufficient to give an indication of large diel or cross-sectional variations in quality that may be occurring. This is especially true for a nonconservative variable such as DO.
2. Correlative data on hydrology and waste discharges are seldom available to relate with sampling of the river. As a result, most monitoring and surveillance data give an indication only of an effect and do not permit much insight into causes of the effect.
3. The relation between streamflow and time of travel is seldom known or is overlooked when interpreting results. Therefore, results obtained from individual sites will represent a concurrent picture of the river only if samples happen to be collected during a long-term steady-state flow period and at the same time of day. This is rarely the case.
4. Inherent sampling and analysis errors for river-quality variables are relatively large. Consequently, a number of samples are usually necessary to define a statistically reliable mean and index of variability. Thus, single grab-sample values cannot be realistically utilized for modeling data.

In spite of these factors, much existing monitoring and surveillance data can be useful for designing definitive, intensive studies of river-quality phenomena and for providing checks on conclusions and predictions derived by a model. The value of existing data for these purposes (assuming the appropriate variables were sampled) is determined by several conditions: (1) the length of time during which the data were collected, (2) the frequency with which data were collected, (3) the location and number of sampling stations, and perhaps most importantly, (4) the compatibility of the data for segregation and collation on the basis of hydrology. Hydrologic segregation and collation are necessary to expunge the cyclical variability in river-quality conditions due to temporal and spatial changes in streamflow, water temperature, channel morphology, and other hydrologic conditions.

To overcome the deficiencies inherent in an inadequate model data base, a set of data specifically suited for analysis of the river-quality phenomena in question should be collected. The final data program should have as its goals (1) a quantitative description of the system being modeled, and (2) an independent evaluation and quantification of each model parameter and assumption. If these goals are met, the program should form a sound basis for analyzing the river system and permit suitable calibration and verification of a model.

WILLAMETTE RIVER DATA-COLLECTION PROGRAM

The data-collection program for the Willamette River DO model exemplifies the kinds of data required for applied river-quality models. The program was begun in summer, 1973.

1. General hydrologic characteristics of the river were determined from existing data on streamflow, water temperature, bed slope, bed material, and cross-sectional geometry. On the basis of similarity in hydraulic regime, the 187-mile (301-km) main stem of the river can be sectioned into three reaches. Figure 2 shows the location and elevation profiles of the three reaches, and table 3 includes descriptive data on each reach. (The locations of waste discharges and tributaries, in-reach time of travel, and availability of sampling sites

TABLE 3.—*Selected physical characteristics of the main stem Willamette River, Oreg.*

[Characteristics refer to summer low-flow conditions of 6×10^3 ft³/s at Salem]

Reach	Length (mi)	Approximate bed slope (ft/mi)	Bed material	Representative midchannel water depth (ft)	Velocity (mi/hr)	Approximate traveltime in reach (hrs)
Tidal Reach (1)	26.5	<0.1	Intermixed clay, sand, and gravel.	40	[1]0.11	240
Newberg Pool (2)	25.5	.12	Intermixed clay, sand, and gravel with some cobbles.	25	[1] .27	94
Upstream Reach (3)	135	2.8	Mostly cobbles and gravel.	7	[2]2.0	68

[1]Calculated by volume displacement method using channel cross-sectional data.
[2]Calculated from dye study conducted by U.S. Geological Survey (Harris, 1968).

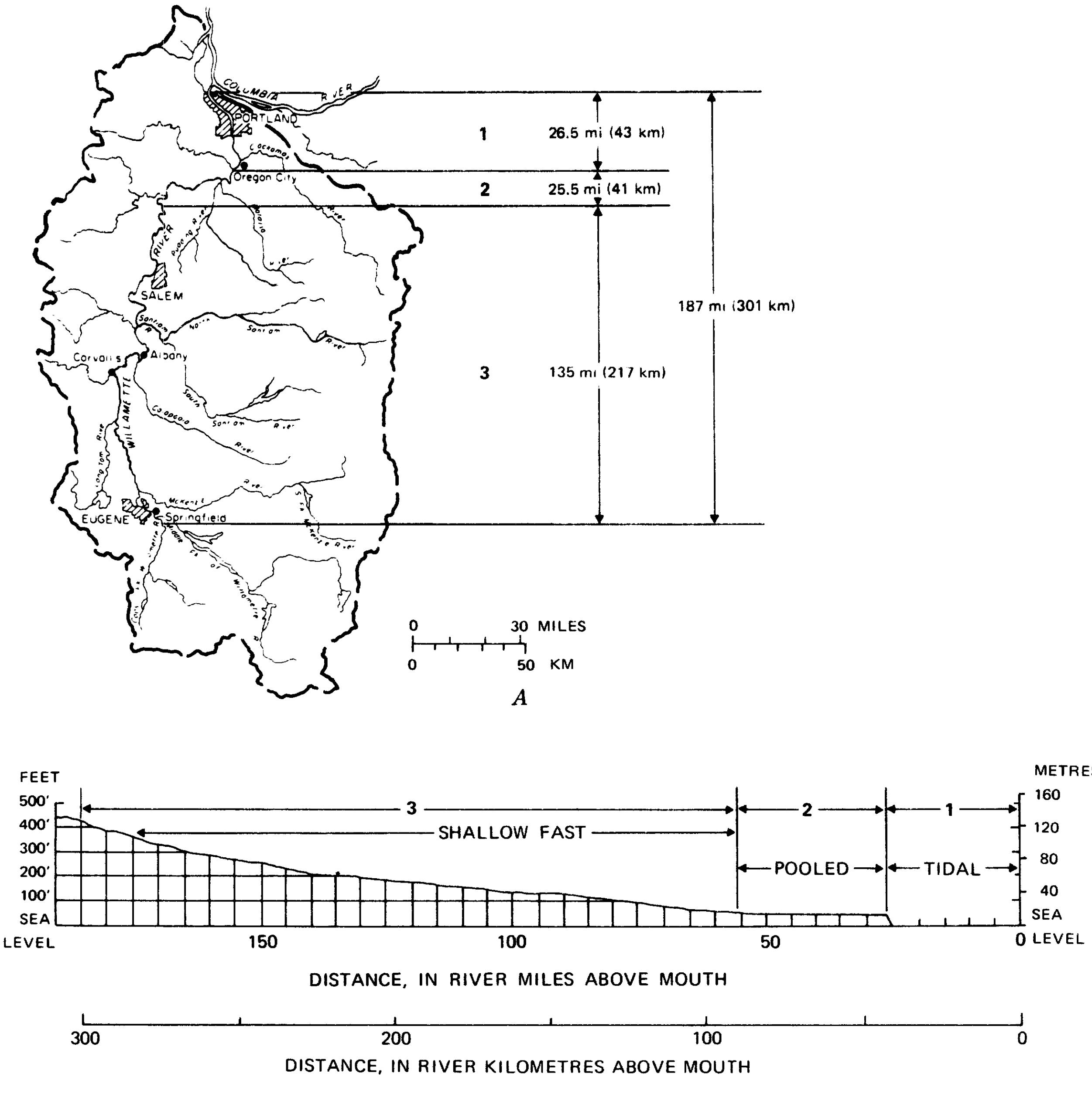

FIGURE 2.—Willamette River, Oreg. *A*, Distinctive hydrologic reaches. *B*, Elevation profile.

and stream gages necessitated minor changes in the reaches finally selected for sampling.)

2. Each reach was studied intensively during 72-hour periods within the July-August high-temperature, steady low-flow period (fig. 3). During the 72-hour studies, 5 to 10 stations were sampled in each reach from dawn until dusk. Every 2 hours, DO and water temperature were measured using a meter and field probe, and, where warranted, horizontal and vertical traverses were made. BOD samples of the river were collected every 2–4 hours. Samples to determine BOD loading were collected at least daily from tributaries and all municipal and industrial waste-treatment plants. Collection of BOD samples began 2–7 days before each 72-hour study, depending on time of travel through the reach.
3. During the 72-hour period, four recording monitors were operated continuously in

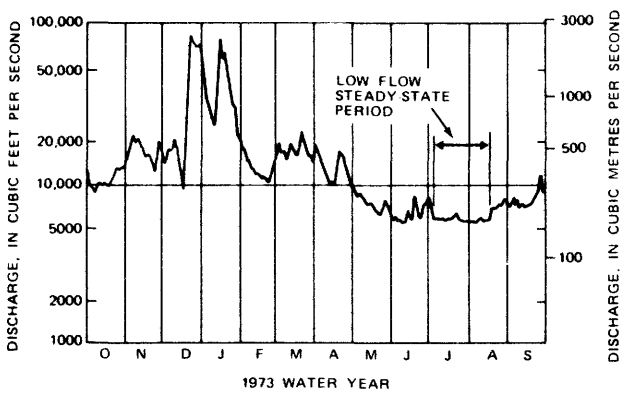

FIGURE 3.—Willamette River discharge at Salem, Oreg., 1973 water year.

each reach to record diel variations in temperature, DO, specific conductance, and pH. (Algal photo-synthesis and respiration were discernible at several sites from these data.)

4. All river- and waste-BOD samples were incubated for 20 days, and DO measurements were made at frequent intervals to determine BOD rate curves and ultimate BOD. The possibility of nitrification in the river was assessed by (a) running inhibited (Tuffey, 1973) and noninhibited BOD's and (b) analyzing Kjeldahl-N, ammonia-N, and nitrate-N samples of river water and waste water collected during several of the 72-hour studies.
5. The significance of benthal oxygen demand was evaluated by sampling bed material from areas that had historically contained benthal deposits and by examining results of vertical DO traverses at numerous cross sections.
6. Refined calculations of time-of-travel and reaeration rates were made for short subreaches of the river using detailed cross-sectional geometry data obtained from the U.S. Army Corps of Engineers. In reaches where there was reason to suspect recent changes from the Corps data, new cross-sectional data were obtained using a fathometer.
7. False-color infrared and black-and-white photographs of the main stem of the Willamette were obtained from the NASA Earth Resources Assessment Project and the U.S. Army Corps of Engineers. The photography was used, in conjunction with field observations, to examine river morphology and other physical factors.

COMMUNICATION AND APPLICATION OF MODEL OUTPUTS

The ultimate goal of an applied river-quality model is acceptance and use by planners and other decisionmakers for evaluating the impacts of planning alternatives on river quality. Typically, reports and products of modeling work are too technical for these users, many of whom have little background in mathematics or computers. Computer users' manuals and card decks, which commonly appear as final products, are useful for "running the model." However, they give users little guidance in applying the model to the river-quality planning and management questions at hand. This deficiency can be greatly improved if modelers and intended users consult frequently concerning the nature and progress of the model. Workshops, seminars, and "brainstorming sessions" can be invaluable for fostering communication and for establishing trust in the model.

User reports and products should be written in nontechnical language and specifically designed for application to the river-quality planning and management problems of the basin. Reports on model "production runs" are a key to the successful application of river-quality models.

"Production runs" produce the applied output of a calibrated-verified river-quality model. A different output is generated for each set of inputs. The inputs are based on future alternatives for waste-treatment plants, streamflow regulation, land-use zoning, etc. These alternatives, in turn, are functions of expected population growth, industrial development, water needs, new water-quality standards, and other social and environmental factors as identified by planners, managers, and the public. Information used as inputs for "production runs" should be carefully designed with intended model users to ensure the assessment of all reasonable river-quality planning and management alternatives.

An excellent technique for presenting results of "production runs" is the "control-curve" concept described by Velz (1970). Two "control curves" generated by an early DO model of the Willamette River (Velz, 1951) are shown in figures 4 and 5. Note that the curves are simple, user oriented, and permit assessment of multiple factors on one graph. Given a reliable river-quality model, the

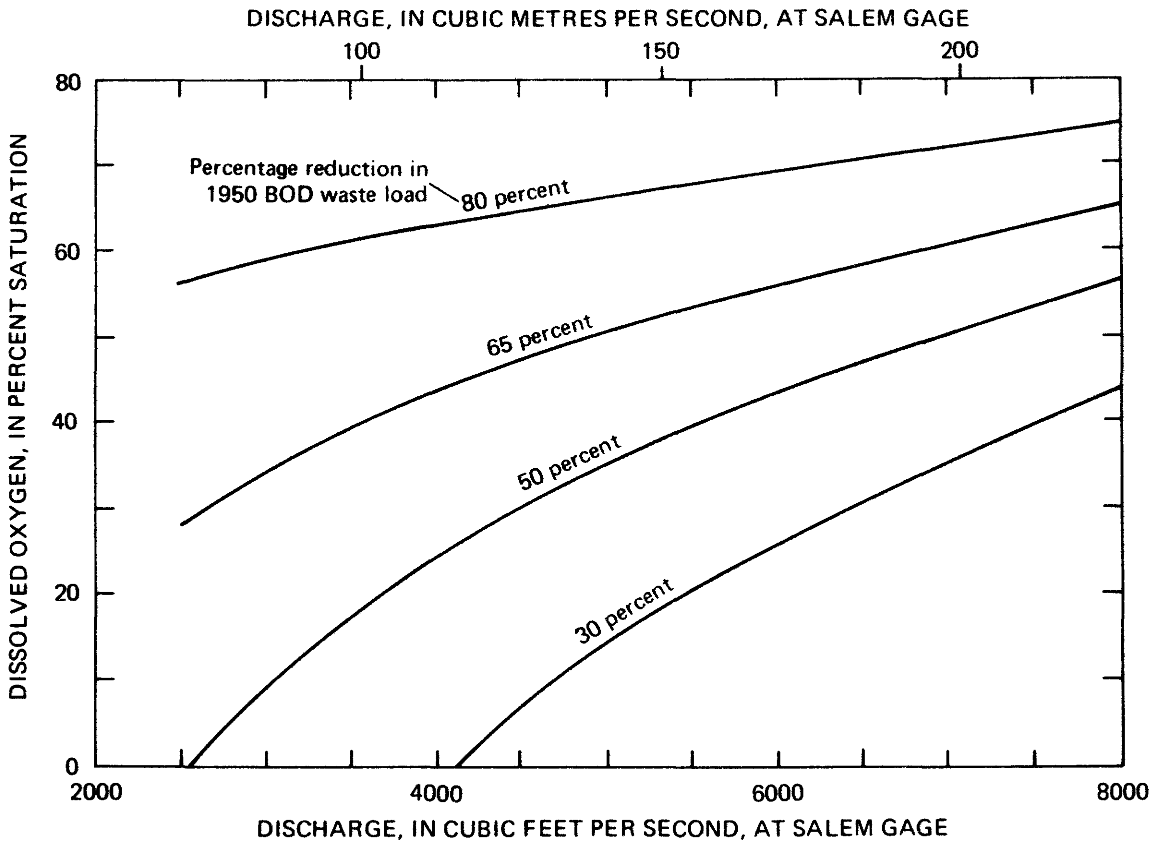

FIGURE 4.—Relation between DO and summer runoff for Willamette River, Oreg. (1950–51), at river mile 6. (See fig. 2.) Curves represent DO-runoff relations at different BOD waste-loading conditions. (Adapted from Velz, 1951, p. 68a.)

computer can easily produce a suite of curves for any given reach or station on the river. Such curves enable the simultaneous evaluation of numerous planning and management alternatives without separate production runs on the computer.

SUMMARY

A river-quality model can be a powerful predictive tool for river-basin planning and management provided that premises and limitations are recognized and that the model is properly calibrated and verified. These criteria can only be satisfied through a competent scientific appraisal of the environmental factors and processes affecting the river-quality phenomena being modeled. The ability to perform such an appraisal is related to the complexity of physical conditions within each river basin and to the background of available scientific knowledge concerning the relevant processes and variables. There are times when complex physical conditions or limited scientific understanding prevent formulation of a reliable, applied model. In such cases, semiquantitative descriptive studies are warranted in lieu of models to provide insight into river-quality processes and variables and to form a basis for future modeling work.

The analysis of river hydrology, particularly runoff and water-temperature patterns and channel morphology, is essential to the formulation of an applied river-quality model. River hydrology is the single most important factor governing the time-and-space variability in river quality. Knowledge of this time-and-space variability helps to identify critical time periods and reaches of the river for which a river-quality model can be most effectively applied.

Calibration and verification of river-quality models must be based on separate, statistically reliable sets of data for the variables and processes being modeled. Periodic grab-sample data com-

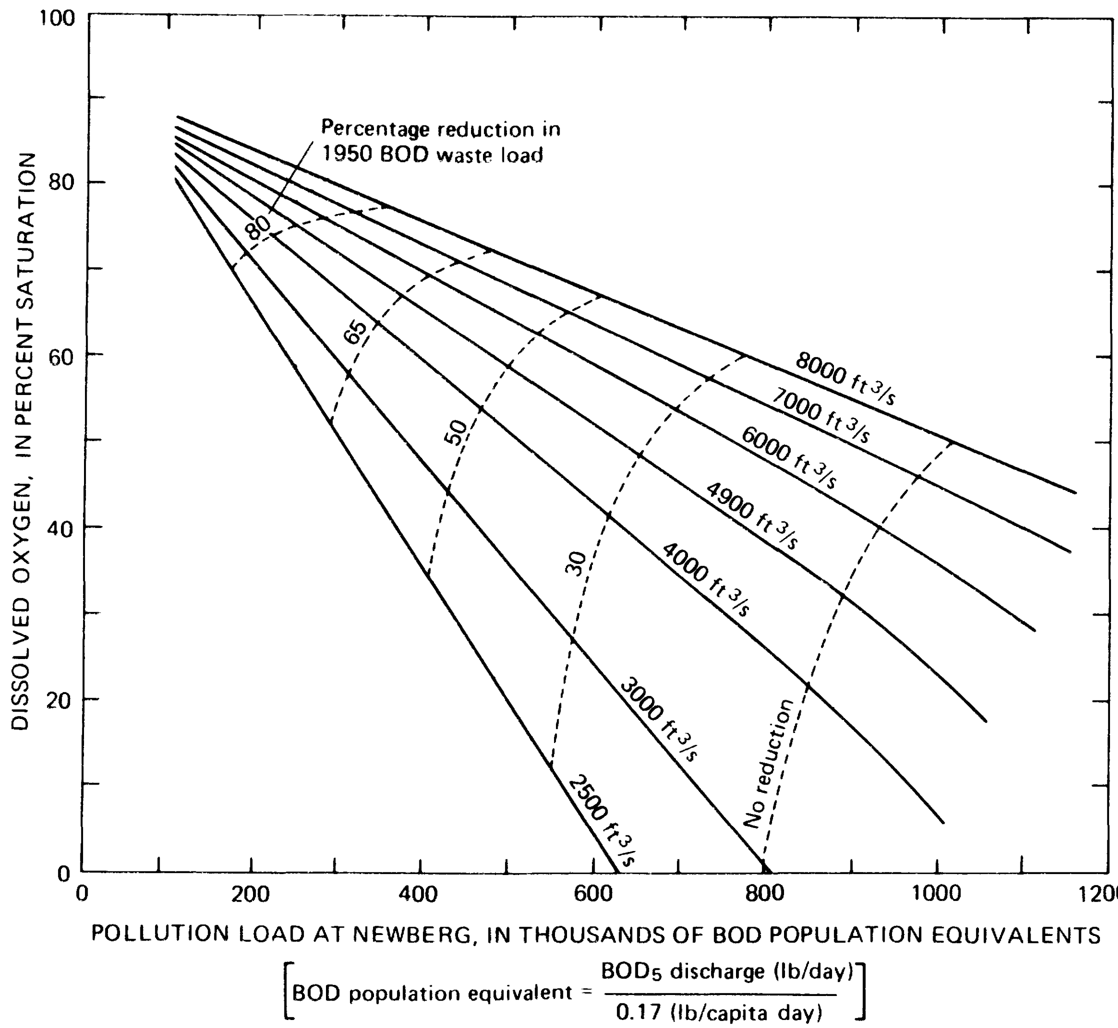

FIGURE 5.—Relation between DO and BOD waste loading for the Willamette River, Oreg. (1950–51), below river mile 50. (See fig. 2.) Curves represent DO–BOD load relations at various river discharges as measured at Salem (river mile 85). (Adapted from Velz, 1951, p. 75a.)

monly generated by pollution-monitoring and surveillance programs are almost never suitable for model calibration or verification.

Even those river-quality models with proven predictive capability will be of little value for planning and management purposes unless results of model production runs are translated into formats that are understandable to users. In this regard, constant communication and interplay among modelers and users are necessary to establish understanding and trust in the model and to ensure assessment of all important planning and management alternatives.

REFERENCES CITED

Bella, D. A., 1969, Modeling the eutrophication process: A further note on verification: Proc. workshop sponsored by Federal Water Quality Adm. and Univ. Florida, St. Petersburg, Fla., November 19–21, 1969, p. 21–25.

Bennett, J. P., 1974, Concepts of mathematical modeling of sediment yield: Water Resources Research, v. 10, no. 3, p. 485–492.

Bennett, J. P., and Rathbun, R. E., 1972, Reaeration in open-

channel flow: U.S. Geol. Survey Prof. Paper 737, 75 p.
Dawdy, D. R., 1969, Considerations involved in evaluating mathematical modeling of urban hydrologic systems: U.S. Geol. Survey Water-Supply Paper 1591-D, p. D1–D18.
Gleeson, G. W., 1972, The return of a river, the Willamette River, Oregon: Advisory Comm. on Environmental Sci. and Technology and the Water Resources Research Inst., Oregon State Univ., Corvallis, 103 p.
Harris, D. D., 1968, Travel rates of water for selected streams in the Wilamette River basin, Oregon: U.S. Geol. Survey Hydrol. Inv. Atlas HA–273.
Jaworski, N. T., Lear, D. W., Jr., and Villa, Orterio, Jr., 1971, Nutrient management in the Potomac Estuary: Environmental Protection Agency, Water Quality Office, Tech. Rept. 45, 61 p.
Lombardo, P. S., 1973, Critical review of currently available water-quality models: Consultants rept. to U.S. Dept. Interior, contract no. 14–31–0001–3571, 85 p.
Mar, B. W., 1971, Verification of models and basic data used in the management and control of water quality: Tech. Research Proj. Completion Rept., OWRR Proj. no. B023–WASH, 51 p.
Pacific Northwest Laboratories, 1972, Explore I: A river basin water quality model: Battelle Memorial Inst., Richland, Wash., 119 p.
Streeter, H. W., and Phelps, E. B., 1925, A study of the pollution and natural purification of the Ohio River: U.S. Public Health Service, Public Health Bull. 146, 75 p.
Texas Water Development Board, 1970a, Simulation of water quality in streams and canals: Texas Water Devel. Board, DOSAG–1, 51 p.
———1970b, Simulation of water quality in streams and canals: Texas Water Devel. Board, QUAL–1, 64 p.
Tuffey, T. J., 1973, The detection and study of nitrification in streams and estuaries: Ph.D. thesis, Rutgers Univ., New Brunswick, N.J., 180 p.
Velz, C. J., 1951, Report on natural purification capacities, Willamette River: Natl. Council for Stream Improvement of the Pulp, Paper, and Paperboard Industries, Inc., School of Public Health, Michigan Univ., Ann Arbor, Mich., 80 p.
———1961, Supplementary report on lower Willamette River waste assimilation capacity: Natl. Council for Stream Improvement of the Pulp, Paper, and Paperboard Industries, Inc., School of Public Health, Michigan Univ., Ann Arbor, Mich., 28 p.
———1970, Applied Stream sanitation: New York, John Wiley and Sons, Inc., 619 p.
Weber, J. E., Kisiel, C. C., and Duckstein, Lucien, 1973, On the mismatch between data and models of hydrologic and water resource systems: Water Resources Bull., v. 9, no. 6, p. 1075–1088.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1975-0-690-036/11