A model for predicting ion concentrations in the Yellowstone River between Billings and Miles City, Montana : a management tool
by Richard William Karp

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Industrial and Management Engineering
Montana State University

Abstract:
Regression equations were developed for the individual common ions versus electrical conductivity (EC), and the individual common ions versus EC and flow (Q). These regression equations relate the instantaneous concentration of common ions in Meq/L to the instantaneous EC and Q in µmhos/ cm @ 25°c and cfs, respectively. The regression equations relating the common ion concentrations to EC produced relatively good results. A cation-anion balance was used to determine the quality of the simulated common ion concentrations.

Water quantity and quality models based upon the principle of conservation of matter and employing the macro-to-micro philosophy were developed on an annual basis. A methodology for obtaining the quality model from the quantity model was developed. The quantity model simulates the amounts of flow associated with the various flow components; and the quality model simulates the EC associated with the various flow components. The use of EC in the quality model provides the necessary parameter for the use of the regression equations involving the common ion concentrations.

Both the quantity and quality models provide reasonable results that would be expected on an annual basis.

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Date November 30, 1976

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Industrial and Management Engineering

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December, 1976

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the Montana State Department of Health and Environmental Sciences, Water Quality Bureau, the United States Environmental Protection Agency, and the Montana University Joint Water Resources Research Center at Montana State University for the financial support in the development of this thesis.

To Dr. Donald W. Boyd, Chairman of my graduate committee, and to the other members of my committee, I extend my thanks for the help they have provided.

Finally, to my wife Kathy, for spending many lonely nights and tolerating my anxiety when progress faltered, I give my sincerest thanks.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

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CHAPTER I

Introduction

The passage of the Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, exemplifies a major concern for the protection of water quality in the nation's waters. Congress stated that the goals of the Act were to restore and maintain the chemical, physical, and biological integrity of these waters (Ref. 1). Thus, the Act implied the need to describe natural variation in the chemical, physical, and biological behavior of the water ecosystem. These descriptions are needed in order that rational management decisions can be made with respect to water quality.

In response to P. L. 92-500, many governmental agencies that are concerned with water resource management have been collecting water quality data on the nation's waterways. As water quality data increases in amount, it is necessary to analyze the data for relationships which can be used to determine what the natural variations of the various factors are in the ecosystem. These relationships can also provide predictions needed in water quality management. Further, such relationships may identify those parameters for which more data is needed and those parameters for which data collection can be discontinued.

Recent concern for the water quality in the Yellowstone River Basin in Montana has increased due to the increase in coal and energy related developments in the middle portion of the basin. An intent of this study was to analyze the available data for relations that would aid in the water quality management of this area of the Yellowstone River Basin.

The inverse relationship between the concentration of dissolved constituents and flow (Q) has been well documented in the literature. This hyperbolic relationship has been pursued in a number of investigations on natural waters to determine regression equations. These regression equations are generally in terms of the logarithm of constituent concentration versus the logarithm of the flow (Ref. 7-11). Total dissolved solids (TDS) has received by far the most attention in its inverse relationship with Q (Ref. 8, 9). To date, these regression equations have involved the concentration of dissolved constituents in mass per volume units. In this study, however, the concentration of the common ions used in regression equations are in terms of milliequivalence per litre (Meq/L) which is a measure of the number of charged ion particles per volume. The regression equations are in terms of these concentrations for the common ions versus the measured electrical conductivity (ECM) and Q. In a recent investigation by Leonard Frost, Jr. (Ref. 5), linear regression analysis was performed on a number of dissolved constituents, including the common ions in mass per volume units of concentration, with ECM.

The majority of water quantity and quality models documented in the literature develop an extremely detailed model of a small incremental element of a basin. Often times, because of the extremely complex nature of the interacting components of a real world hydrologic system, the model is either unsolvable, or because of generalizations and approximations does not give realistic results. In this study, the macro-to-micro philosophy of modeling of large scale systems was employed. This approach provides a number of advantages. First of all, it provides a working model of the system from the very beginning. Even though the model at the most macro level may not produce usable results, it provides a stepping stone toward the micro level. The formulation of relationships at the macro level provide structure that can be built upon at the next level of modeling. Thus, a systematic development of working models is produced which allows for feedback of information. The next level of modeling, toward the micro, provides a check on the model at the previous level. Another advantage to this method of modeling is that in many instances usable results can be obtained from the first few levels (Ref. 2).

Scope and Objectives

The scope and objectives of this study were:

1. To develop a system of regression equations for predicting the level (concentration) of selected water quality parameters at specific points along the Yellowstone River and its major tributaries between Billings and Miles City, Montana. Relationships were sought between the common ions - calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), bicarbonate (HCO_3), carbonate (CO_3), sulfate (SO_4), and chloride (Cl) - and the measured electrical conductivity (ECM), and flow

(Q). The specific points on the Yellowstone River were the U. S. Geological Survey water quality and quantity stations at Billings and Miles City. The points on the major tributaries were the U. S. Geological Survey water quality and quantity stations on the Bighorn River near its confluence with the Yellowstone River at Bighorn, Montana, and on the Tongue River near its confluence with the Yellowstone River at Miles City.

2. To initialize an approach to the large scale modeling required to describe incremental changes in water quality parameters as a result of various water use categories in the Yellowstone River Basin. The Montana State Department of Natural Resources and Conservation's water planning model was calibrated on an annual basis for the Yellowstone River sub-basin 42KJA (Ref. 2, 3). The water planning model is a flow, hydrologic, or "quantity" model which has the potential of providing the flow component quantities required in modeling water quality. After the calibration of the water quantity model for sub-basin 42KJA on an annual basis, this model was employed in developing a water quality model.

Physical Description of the Study Area

Figure 1 shows a sketch map of the middle portion of the Yellowstone River Basin. This portion of the Yellowstone River Basin is on the western edge of the Great Plains. The basin is generally an area of rolling hills with gentle to moderate relief. The major surface water

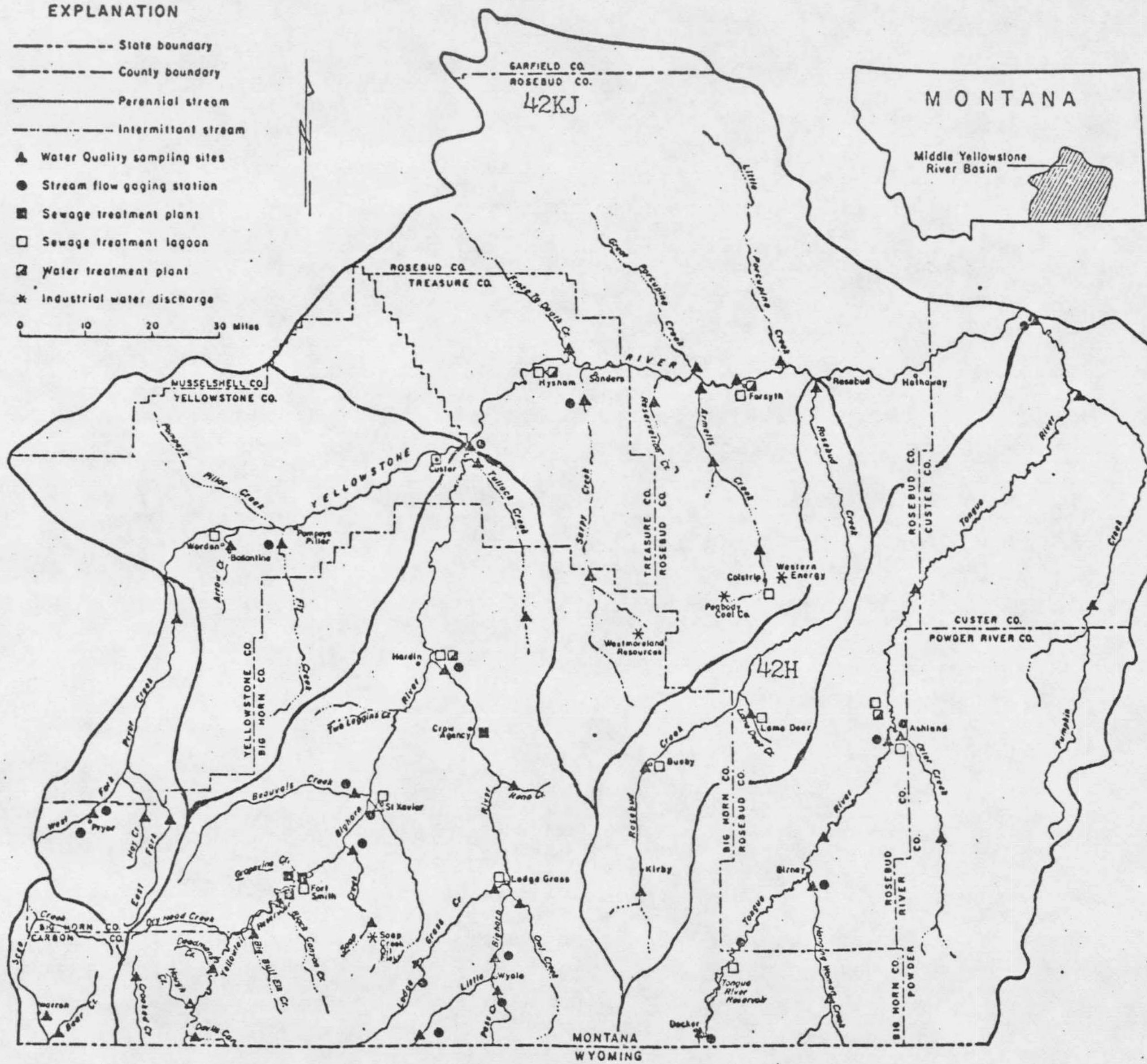

Figure 1 — Sketch map showing Middle Yellowstone River Basin
(Taken from Ref. 12)

inflows to the study area are the Yellowstone and Bighorn Rivers. The confluence of the Yellowstone and Tongue Rivers mark the eastern boundary of the study area. The Tongue River is not included as an inflow to sub-basin 42KJA.

Mountains to the west and southwest of the middle portion of the Yellowstone River Basin create a moisture shadow. Air masses moving toward the basin from these directions must rise to get over the mountains, and thus lose most of their moisture before reaching the basin. Average annual precipitation for the area ranges from 11 to 16 inches per year (Ref. 4).

About 75 percent of the land in the middle portion of the Yellowstone River Basin is used for pasture and range land in the production of livestock. Of the irrigated lands, about 70 percent is used in the production of hay, pasture and sugar beets. There is also a substantial amount of dryland farming for the production of grains. With the renewed interest in coal development, certain areas of this portion of the basin may, in the future, be supporting vast strip mines.

Agricultural irrigation is the primary water use in the basin. With the increase in coal and energy development expected to occur, the amount of water needed for industrial use will increase, but agricultural uses will probably still dominate because of existing water rights.