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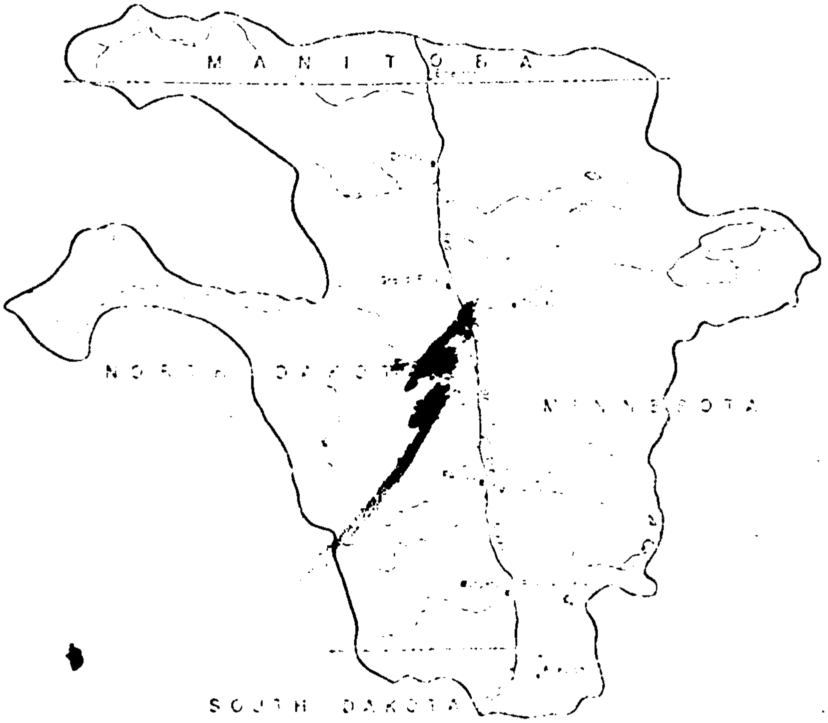
FITTING THE
RED RIVER OF THE NORTH BASIN
TO THE
GENERAL RIVER BASIN SIMULATION PROGRAM



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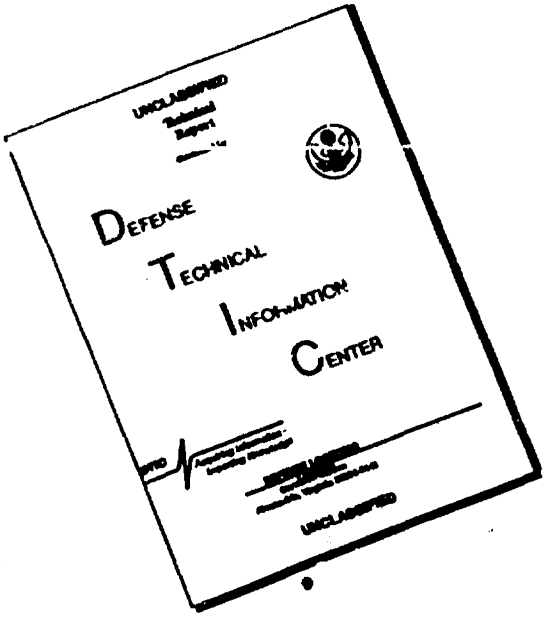

SUMMARY

A mathematical model of the Red River of the North Basin, Minnesota and North Dakota, can be used as a water quality planning management tool to simulate time and spatial variations of flow and concentrations of total dissolved solids throughout the Basin. Other parameters of water quality can be included in the model with little effort. The model incorporates hydrologic and water quality data and the Fiering-Pisano mathematical model described in the report "River Basin Simulation Program" issued by the Office of Comprehensive Planning and Programs, March 1967.

Given (1) the River Basin Simulation Program, (2) this report, and (3) tape of operational hydrology, other investigators can study various combinations of water quality management schemes.

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INTRODUCTION

Purpose and Scope of Report

This report describes the application of the Fiering-Pisano mathematical model to the Red River of the North Basin. The report describes pertinent hydrologic factors, waste loadings to the river system, and methods of applying the model to determine effects of water management practices in the Basin. The report presents the model in a form that is applicable to other river basin systems for which appropriate data are available.

Need to Model the Red River of the North

The Red River of the North and its tributaries are the major water supplies for over 160,000 people and several industries in North Dakota and Minnesota. In return, treated and untreated wastes from municipalities and industries are added to these streams at various points in the Basin. Many of the streams frequently contain excessive concentrations of dissolved salts from natural sources. Even higher concentrations of salts will be added to Sheyenne River and Red River as a result of inflow of planned irrigation return flows and flushed saline waters from the Devil's Lake Basin.

As a result of wastes currently added to the system, the Red River of the North is polluted. Because of the pollution and because the Red River of the North is an interstate and international stream, a pollution abatement enforcement action has been held and the river is under study by FWPCA and the I.J.C. (International Joint Commission).[5]

As an interstate and an international stream, the Red River of the North carries the wastes of dwellers in South Dakota, North Dakota, Minnesota, and Canada. At the same time it represents a potential of many other beneficial uses for the residents in the Basin. Water quality standards, currently being established for the river, must be a compromise of the desirable conditions sought by the users of the river and the practical limits that can be achieved by the best water management practices. Determination of the values representing this compromise can be accomplished by use of the model with greater speed and validity than by trial and error or by other time-consuming detailed evaluations. The principal purpose of the model is to explore the impact of proposed water and related land resource developments on water quality and to demonstrate the advantages of water quality management in realizing maximum accommodations of conflicting interests and desires.

WHAT THE MODEL CAN DO

Attaining Water Quality Goals

The feasibility of attaining some set of instream water quality goals can be investigated in the following fashion.

Given:

1. a set of water quality goals that may vary spatially and seasonally throughout a system.
2. a configuration of economic activity which is translatable into a set of waste loadings.
3. a tool that (a) preserves the essential characteristics of the river basin under study and (b) is capable of quickly determining the consequences of imposing the above loadings on the river basin.

Question: Will the intended goals be achieved with a low probability of uneventful failures? If not, what blend of preventive and curative pollution control measures must be initiated such that the frequency and magnitude of violations will be acceptable?

Preventive measures may require either a curtailment of some desired activity or the installation of treatment devices. One curative measure that could be applied would be to allow pollution to occur and then to correct the problem by either scheduling the transport of waste such that maximum advantage is taken of natural dilution or, alternatively, by scheduling dilution water.

Clearly the process is iterative. A change in goals or the introduction of a new blend of economic activity can be evaluated to determine whether or not the goals will be met without pollution control devices or to determine what measures must be taken to maintain the goals. The different sets of alternatives may then be arrayed, condensed, and subsequently reported to management.

Management then can determine what water resources management practices should be impelemented that would allow North Dakota to develop irrigation and flush Devil's Lake as quickly as possible while minimizing the number and degree of violations of any proposed water quality TDS (total dissolved solids) standard.

Scheduling of Waste Discharges

The consequences of imposing any seasonal distribution of waste loadings at ten different sites in the Basin can be easily evaluated. Although the model is limited at present to the consideration of total dissolved solids and instream flow requirements, other elements can be programmed with little difficulty. Maintenance of a desired level of D.O. (Dissolved Oxygen), for example, is commonly expressed as a certain flow that must be maintained. Earlier studies1/, in turn, have determined what minimum flows need to be maintained by supplementing natural flow with reservoir releases. Other elements can be reduced to comparable terms and evaluated.

Flushing of Devil's Lake

The Bureau of Reclamation's plan is to use irrigation return flows together with direct import of Garrison Reservoir water to raise the levels of the two lakes, thereby diluting the salt concentration of the lakes to an acceptable limit for the placement of game fish. The time horizon necessary to accomplish this task can be evaluated by considering the effect of different rates of import from the two major sources. An additional consideration may be that of storing dilution waters in the Lonetree Reservoir for maintenance of water quality in the Sheyenne. Alternatively or jointly different operational release schemes for the existing reservoirs serving the Red River of the North may be tested with the model.

Management of Existing Storage

Parameters for specifying the operating rules of rule curves of existing and proposed reservoirs are data input to the model. These rules define reservoir operation during any simulation run. Thus, if irrigation return flows together with overflows from the Devil's Lake cause serious water quality problems, one course of the investigation would be to see if existing reservoirs could be operated, within the bounds of their existing functions and in a slightly different fashion to reduce the number of violations to some set of water quality goals.

DESCRIPTION

Geography

The Red River of the North, located in north central United States and south central Canada, begins as drainage from South Dakota, North Dakota, and Minnesota at the junction of the Bois de Sioux and Ottertail Rivers at Wahpeton, N. Dak., and Breckenridge, Minn. It courses 400 miles northward between North Dakota and Minnesota through the broad flat plain bed of the glacial lake, Lake Agassiz, past the cities of Fargo-Moorhead and Grand Forks-East Grand Forks, and enters Canada just north of Pembina, the oldest town in North Dakota.

The Basin of the Red River of the North is relatively flat. East and west of the river valley, elevations in some hilly sections may approach 1,000 feet above the river level, particularly near Pembina, but these areas are not extensive. Low rolling hills are prominent in the southeastern part of the Basin in Minnesota, and higher hills occur in the northeastern and western sections. The remainder of the Basin, particularly the flood plain that is the bed of the glacial lake, illustrates insignificant relief. The fall of the river, as a result, is about a half foot per mile in the United States reach.

Hydrology

Water is not abundant in the Basin. Average annual precipitation varies from a maximum of about 25 inches in the eastern part of the Basin to a minimum of about 16 inches in the western part of the Basin. High evaporation rates further reduce the available supply of water in the Basin to the extent that during low flows less than 0.001 cfsm^{2} (cubic feet per second per square mile) drains from the [illegible] square miles of drainage area at the international boundary. The maximum flood of record (1912-1960) in 1950 for example, at 95,500 cfs near the boundary, represents only about 2.4 cfsm^2 runoff -- considerably lower than the 10 or more cfsm^2 runoff common to the more humid regions of the eastern United States.

Highest flows commonly occur during the spring, in March and April, from snow and ice melt. High flows occur also during the nonwinter months as a result of storms. Flooding, common in the lower reaches as a result of these high flows, is compounded during the spring periods by the progressively northward thawing of snow and ice as the winter ends. The lower, northern reach of the river, blocked with winter ice is incapable of conveying, without flooding, the large flows resulting from melts of the earlier thawing southern sections of the Basin.

Low flows occur frequently in the Basin each year, generally during late fall and during the winter. Some small streams, unless augmented by reservoir releases, cease to flow during the winter months. A description of flow characteristics, including relationships between flow and TDS concentrations, is provided for several streams in the section describing the mathematical model of the Basin.

Thirty percent of the average flow in the Red River of the North at Emerson, Canada, passes through control structures of reservoirs on major tributaries. Five reservoirs on tributaries in the Basin, with a total capacity of over 2 million acre-feet, provide some flood relief. Consideration of water quality in the operation of these reservoirs could make them effective tools for management of water quality in the river. Table I provides information on these reservoirs.

TABLE 1

Storage and Operation of Five Reservoirs in the Red River of the North Basin

RESERVOIR	USABLE STORAGE (AF)	STORAGE TIME (YRS)
ORWELL OTTERTAIL R.	20,400	0.1
LAKE TRAVERSE BOIS DE SIOUX R.	137,000	2.5
LAKE ASHTABULA SHEYENNE R.	69,100	0.9
RED LAKES RED LAKE R.	1,905,000	6.6
HOMME SO. BR. PARK R.	3,550	0.2

OPERATING RULES

	ORWELL	TRAVERSE	ASHTABULA	RED LAKES	HOMME (cfs)
OCT	0.691	0.412	0.595	0.549	300
NOV	.635	.412	.580	.545	300
DEC	.550	.412	.560	.540	300
JAN	.450	.412	.540	.534	300
FEB	.300	.412	.510	.528	300
MAR	.200	.436	.500	.522	300
APR	.156	.900	.595	.545	180
MAY	.200	.500	.595	.510	180
JUN	.230	.440	.600	.567	180
JUL	.280	.420	.600	.564	180
AUG	.420	.412	.600	.557	180
SEP	.530	.412	.600	.554	180

NOTE: Figures are proportion of total capacity to be maintained, except those for Homme Reservoir, which are monthly drafts, in cubic feet per second.

Although many tributaries contribute to the flow of the Red River of the North, those from Minnesota have a greater impact on the flow of the river than those from North Dakota. Information on major tributaries is provided in the section describing the model of the Basin. Other surface water features of the Basin include many small lakes in the southeastern section of the Basin that drain to tributaries of the Red River, several small lakes and "pot holes" that offer no direct surface water contribution to the river system, and the closed Devil's Lake Basin that, at present is not continuous with the river system. Planned water resource and land development in which irrigation return flows will be routed through the Devil's Lake Basin into the Sheyenne River will have a major impact on water quality of the Red River.

The planned process of routing water through the Devil's Lake Basin will be accomplished by diverting about 750,000 acre-feet of water per year from the Missouri River to irrigable lands north of the Basin. Return flows from this irrigation, although expectedly high in mineral content, will be considerably lower in concentrations of dissolved solids than water in the Devil's Lake Basin (concentrations of TDS generally exceed 30,000 ppm), and are expected to "freshen" the water in the Basin lakes. By controlled releases of the freshened lake waters and Garrison Reservoir water into Sheyenne River while continually adding water to the lake system, the lakes are expected to be "freshened" to the point of providing a beneficial habitat for fish and wildlife without seriously impairing water quality in the Sheyenne, and eventually the Red River of the North.

Water quality problems are not limited to the Devil's Lake area in the Red River Basin. Concentrations of TDS and specific ions such as chloride and sulfate frequently exceed desirable limits in several streams in the Basin. High concentrations of salts in the streams are attributable primarily to the mineral composition of the glacial drifts and sandstone through which the streams pass or from which they receive groundwater flow. This is compounded by high evaporation rates and the addition of municipal and industrial wastes to the streams.

Water Use

Approximately 23 mgd (million gallons per day) of water was used for municipal supplies in the Red River of the North Basin in 1964.[2] Of this, about 15 mgd was obtained from surface water sources; the remainder was obtained from wells. Water for industrial use amounts to about 18 mgd and is obtained from wells and municipal supplies. An additional amount of water, about 40 mgd, is withdrawn from streams and used for cooling purposes by several thermo-electric plants.

Pollution

Red River of the North and many of its tributaries are polluted. Wastes from four large sugar beet mills, several potato processing plants, other industries, and many municipalities have impaired several existing and potential uses of these water sources. Because of these wastes, the water sources frequently are low in dissolved oxygen, and contain excessive amounts of dissolved and suspended solids, slimes, and pathogenic organisms. As a result, the water must receive above normal treatment before it is used for municipal supplies to assure adequate safeguards to health. Also because of the pollution, some stream reaches are devoid of fish and the water constitutes a health hazard to persons participating in water contact sports.

One complication of waste disposal in the Red River of the North system is the long winter period in which ice covers the streams. Wastes generally are held in lagoons during this period and released during the high runoff period of the spring thaw. Although flows are high at this time, the water often contains high concentrations of dissolved solids. The snow, in melting, picks up and transports saline residues from the land surface and stream banks to the receiving streams.

At the request of the Governor of Minnesota, FWPCA began a pollution study of the Red River of the North in 1964. Efforts are being made to improve water quality conditions in accordance with recommendations of the conferences. (Reference to Conferences, In the Matter of Pollution of Interstate Waters of the Red River of the North, Sept. 14, 1965.)

THE MODEL

Background

A very general and flexible package entitled, "River Basin Simulation Program"[1/] was used in this study. It is a series of programs which accept certain kinds of data. The package and the data attempt to capture the pertinent underlying behavior or characteristics of the process(es) being investigated. This package, and data for another river basin would again become the model of that basin.

Briefly, the informational requirements for the Red River of the North model include data on (1) historical flows at gaging stations; (2) geometric location of reservoirs, waste water inputs, and water users; (3) background water quality relationships; (4) evaporation at damsites; (5) magnitudes of water use, waste input, and reservoir volumes, and (6) waste scheduling and reservoir management practices.

Objective

The objective of this report is to develop a model which preserves the statistical characteristics of monthly streamflow and monthly concentrations of total dissolved solids throughout the United States portion of the Red River of the North system comprised of 3,000 miles of river draining 40,000 square miles. The model must consider (1) natural streamflows, (2) existing reservoirs and their current management practices, and (3) existing withdrawals and waste return flows.

Strategy

A. Hydrologic

1. General

The hydrologic model was defined by the monthly flow data at twelve gages located throughout the Basin. Ten of the gages are located at points where there has been no flow regulation; the other two gages, at Ottertail River below Orwell Dam, near Fergus Falls, Minnesota, and at Park River near Grafton, North Dakota, are affected by regulation. Backrouting was performed on the data from the latter two gages to restore them to the natural regime.

It is our assumption that the system is sufficiently described by (1) using the twelve gages to define the Basin-wide hydrology, and (2) superimposing on this all flow regulations consisting of (a) existing reservoirs, (b) existing municipal and industrial diversions and return flows.

2. Gages

Shown on Figure 1 are twelve gages considered to be (1) sufficiently representative of the various distributions of runoff characteristic in the Basin; and (2) adequately widespread as to capture the attendant regional spatial correlations that exist. Shown also on Figure 1 are the areas of ungaged portions of the Basin that were represented by areal transforms (adjusted in some instances by known yield information). Roughly 65 percent of the total area was not gaged.

LOCATION OF GAGING STATIONS

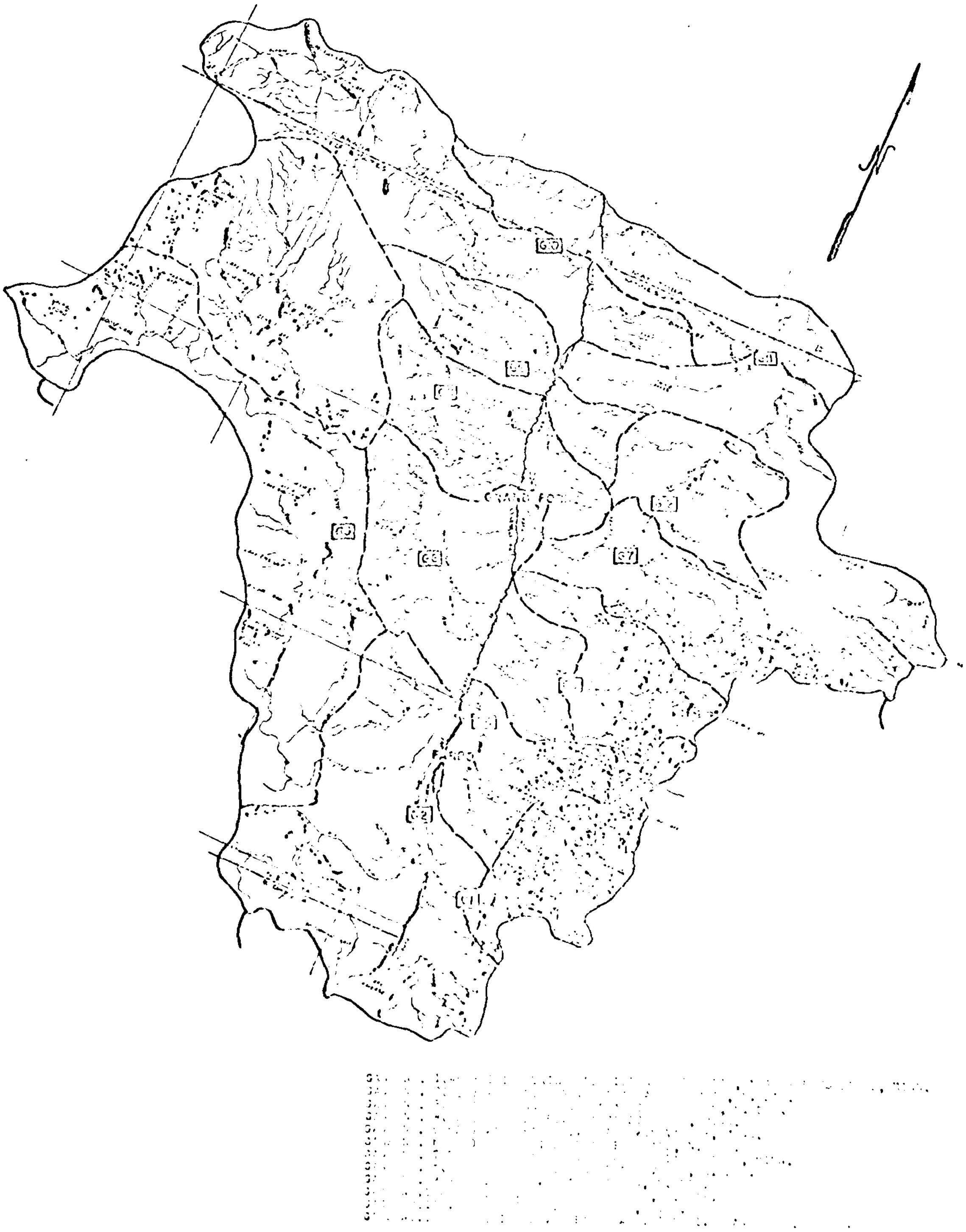


FIGURE 1

Record length between years 1941-1960 was chosen to (1) reduce the effort and the associated errors, inherent in record extension and backrouting of regulated flows; (2) be representative of wet and arid periods, and (3) provide a period when each of the twelve gages, save one, recorded information. The data gap, located at Cooperstown, North Dakota was filled in with graphical analysis of an adjacent point. The mean monthly discharges and standard deviations for each gage are shown on Figure 2.

Using statistical parameters derived from the monthly historical flows at the twelve gages, a tape of two thousand years of operational hydrology was prepared for future use. Pertinent input and output data are available on request. A brief description of the technique is provided in the Appendix.

3. System

Shown in Figure 3 is the system of components used in the analysis. Note also the inset table which describes: (1) each coordinate, (2) the supporting drainage area, (3) the gage used to define the inflow into this coordinate, and (4) the factor used to scale the flow at the gage. It should be clear that the 50 coordinates shown were more than enough to define the system. It would be possible, at a later time, to expand the current system to incorporate more waste sites, test points, and damsites. At present, tremendous flexibility is inherent in the system.

MEAN MONTHLY DISCHARGES AND STANDARD DEVIATION W. Y. 1941 - 1960

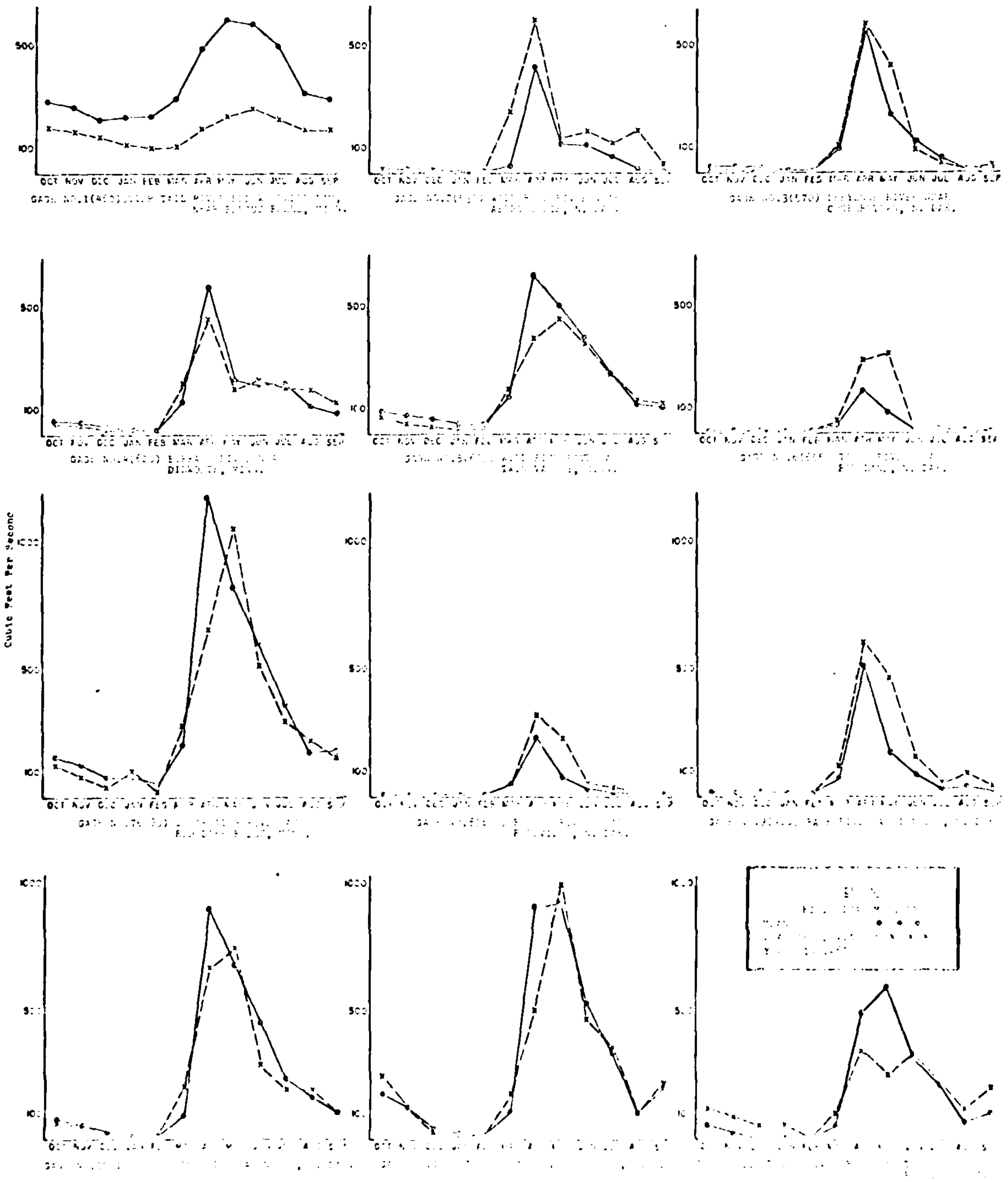
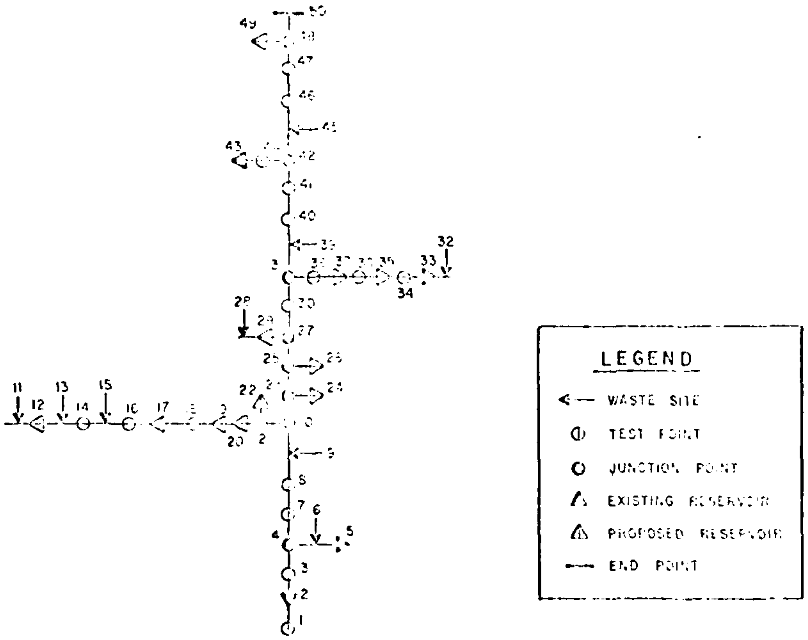


FIGURE 2

SYSTEM REPRESENTATION
RED RIVER OF THE NORTH



[illegible]	[illegible]	DRAINAGE AREA (SQUARE MILES)	GAGE [illegible]	[illegible]
1	[illegible]	50	1	[illegible]
2	[illegible]	[illegible]	2	[illegible]
3	[illegible]	810	2	[illegible]
4	[illegible]	0	[illegible]	0.
5	[illegible]	1530	1	[illegible]
6	[illegible]	213	2	[illegible]
7	[illegible]	[illegible]	2	[illegible]
8	[illegible]	340	4	[illegible]
9	[illegible]	0	2	0.
10	[illegible]	150	2	[illegible]
11	[illegible]	243	3	[illegible]
12	[illegible]	0	3	0.
13	[illegible]	606	3	0.4772
14	[illegible]	0	3	0.
15	[illegible]	0	3	0.
16	[illegible]	415	3	[illegible]
17	[illegible]	0	3	0.
18	[illegible]	[illegible]	3	[illegible]
19	[illegible]	[illegible]	3	[illegible]
20	[illegible]	[illegible]	3	[illegible]
21	[illegible]	[illegible]	2	[illegible]
22	[illegible]	[illegible]	3	[illegible]
23	[illegible]	[illegible]	4	[illegible]
24	[illegible]	[illegible]	4	[illegible]
25	[illegible]	[illegible]	6	[illegible]
26	[illegible]	[illegible]	5	[illegible]
27	[illegible]	[illegible]	6	[illegible]
28	[illegible]	0	6	0.
29	[illegible]	407	6	[illegible]
30	[illegible]	[illegible]	5	[illegible]
31	[illegible]	[illegible]	6	[illegible]
32	[illegible]	[illegible]	11	[illegible]
33	[illegible]	[illegible]	7	[illegible]
34	[illegible]	[illegible]	[illegible]	[illegible]
35	[illegible]	[illegible]	[illegible]	[illegible]
36	[illegible]	[illegible]	7	[illegible]
37	[illegible]	1470	7	[illegible]
38	[illegible]	200	7	[illegible]
39	[illegible]	0	7	0.
40	[illegible]	0	7	0.
41	[illegible]	[illegible]	8	[illegible]
42	[illegible]	[illegible]	9	[illegible]
43	[illegible]	[illegible]	9	[illegible]
44	[illegible]	[illegible]	9	[illegible]
45	[illegible]	[illegible]	[illegible]	[illegible]
46	[illegible]	[illegible]	11	[illegible]
47	[illegible]	[illegible]	[illegible]	[illegible]
48	[illegible]	[illegible]	[illegible]	[illegible]
49	[illegible]	[illegible]	10	[illegible]
50	[illegible]	0	[illegible]	0.

FIGURE 3

4. Reservoirs and Rule Curves

Table 1 gives pertinent information for the five existing reservoirs in the system including the five sets of reservoir operating rules used in the analysis. The seasonal rules either maintain a certain pool level (expressed as percentage of capacity) or alternatively stipulate a certain draft to be made during that time period. This information was furnished in U. S. Army Corps of Engineers report.[3/] [4/]

5. Verification of the Hydraulic Routing

The model translates and routes monthly flows from the twelve gages through the intervening dams and confluences to various downstream points. Given two concurrent sets of flow data for upstream and downstream points, the routing and translation assumptions can be verified. The model is used on the upstream data to estimate the downstream data. The estimated downstream data are compared with the observed downstream data to verify the model in the following examples.

Example 1 - (1941-1950) During this period, the only dam in the system was at Red Lake. Figure 4 shows the comparison of the observed mean monthly flows, ± (plus or minus) one standard deviation, and those produced by the model for the Emerson, Canada, and Grand Forks, and Fargo, North Dakota gages.

COMPARISON - OBSERVED AND COMPUTED MEAN MONTHLY DISCHARGES AND STANDARD DEVIATIONS W.Y. 1941 - 1950

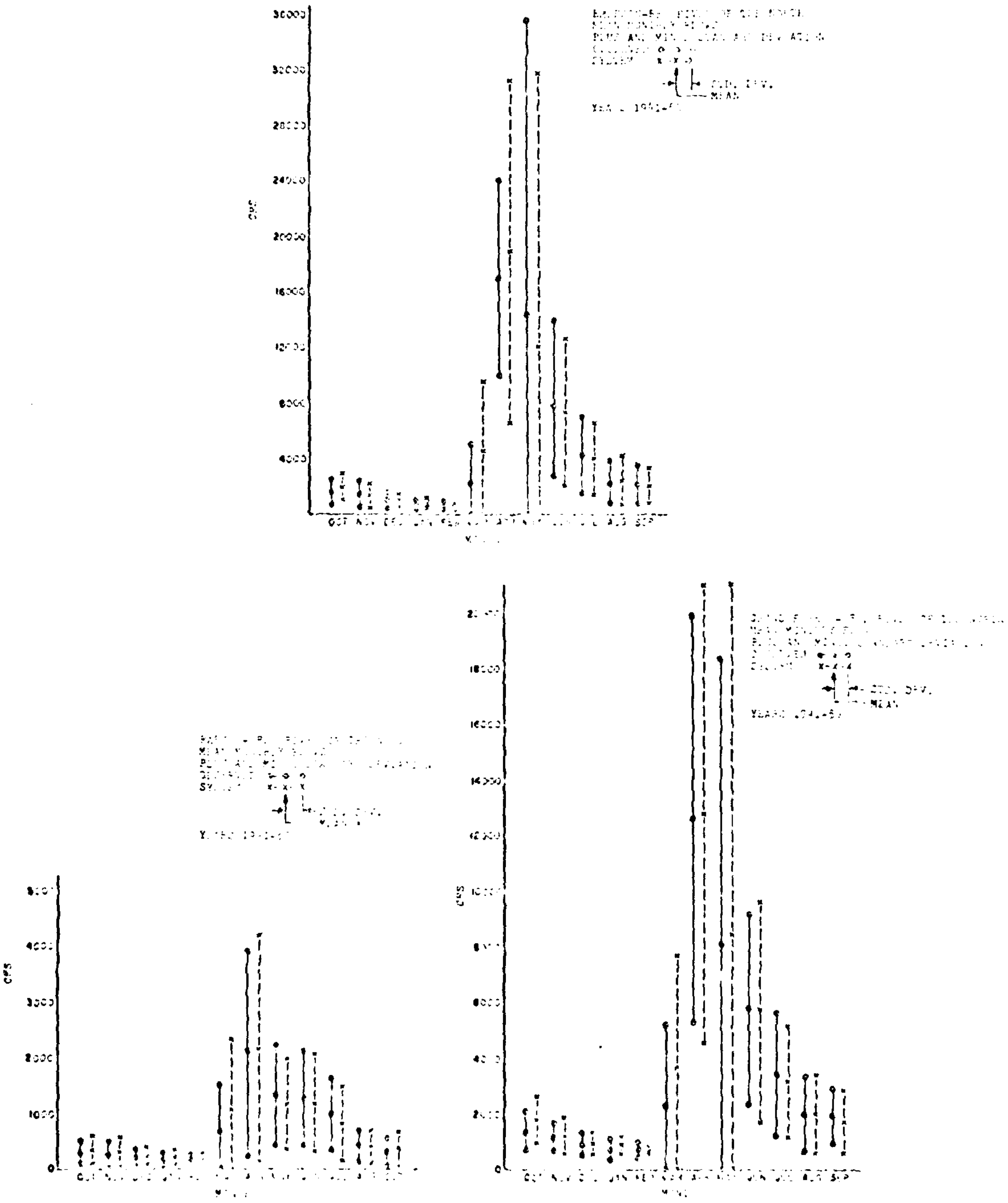


FIGURE 4

Example 2 - (1951-1960) All reservoirs were in operation during this period. Shown in Figures 5 and 6 are the comparisons of the observed monthly flows at the Grand Forks and Emerson gages with those from the model at the same locations and for the same time periods.

Figure 7 presents the observed mean monthly flows (1951-1960), ± one standard deviation, and their respective model counterparts for the gages at Emerson, Grand Forks, and Fargo. The drainage area gaged by the three stations is respectively 40,200, 30,100, and 6,800 square miles. Table 11 shows a comparison of the observed average discharge for the period of record with that produced by the model for a number of strategic points in the system.

6. Conclusion

The agreement between estimated and observed flow data implies that the translation and routing assumptions are valid.

COMPARISON - OBSERVED AND COMPUTED MEAN MONTHLY DISCHARGES
W. Y. 1951 - 1960

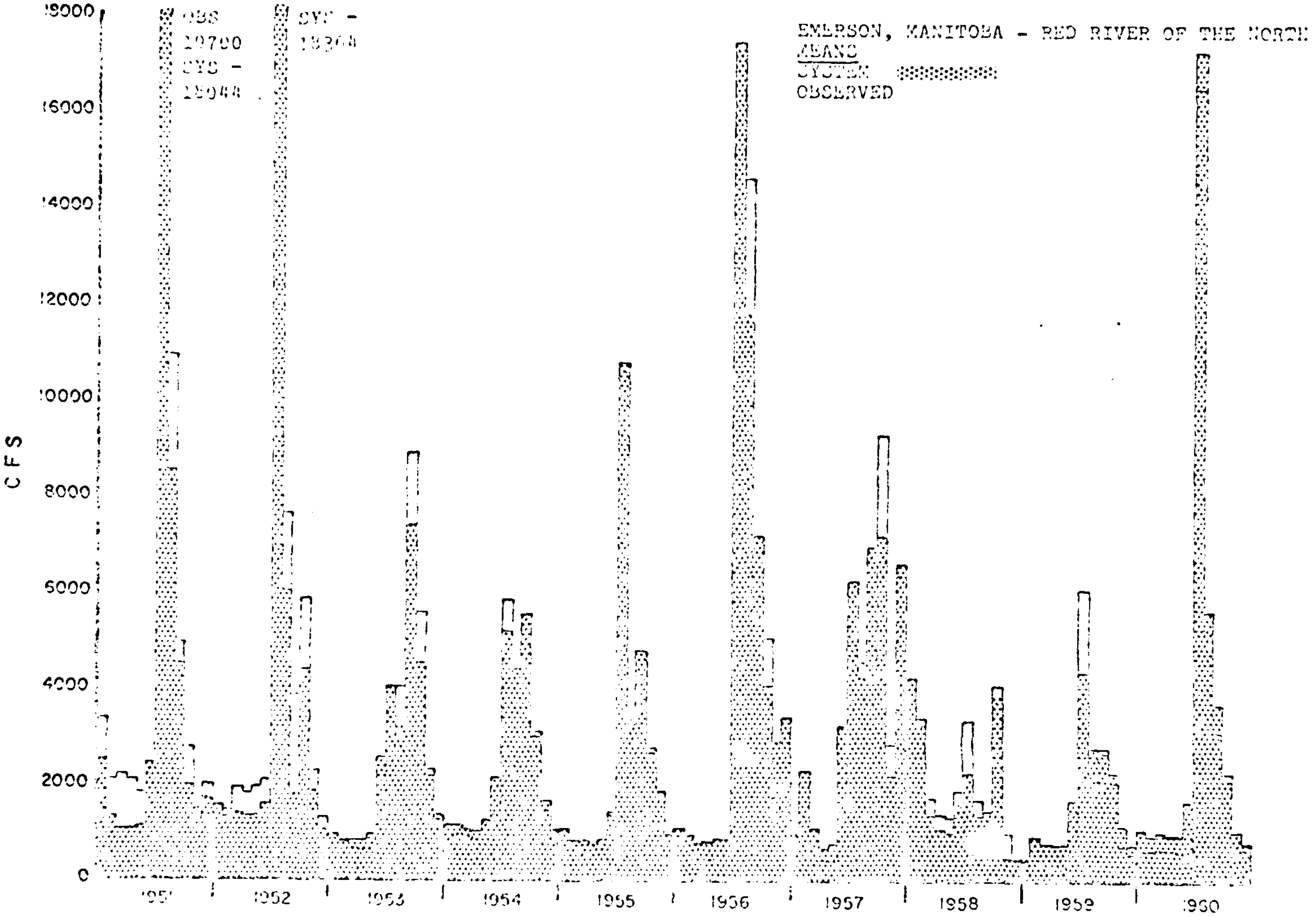


FIGURE 5

COMPARISON - OBSERVED AND COMPUTED MEAN MONTHLY DISCHARGES
W. Y. 1951 - 1960

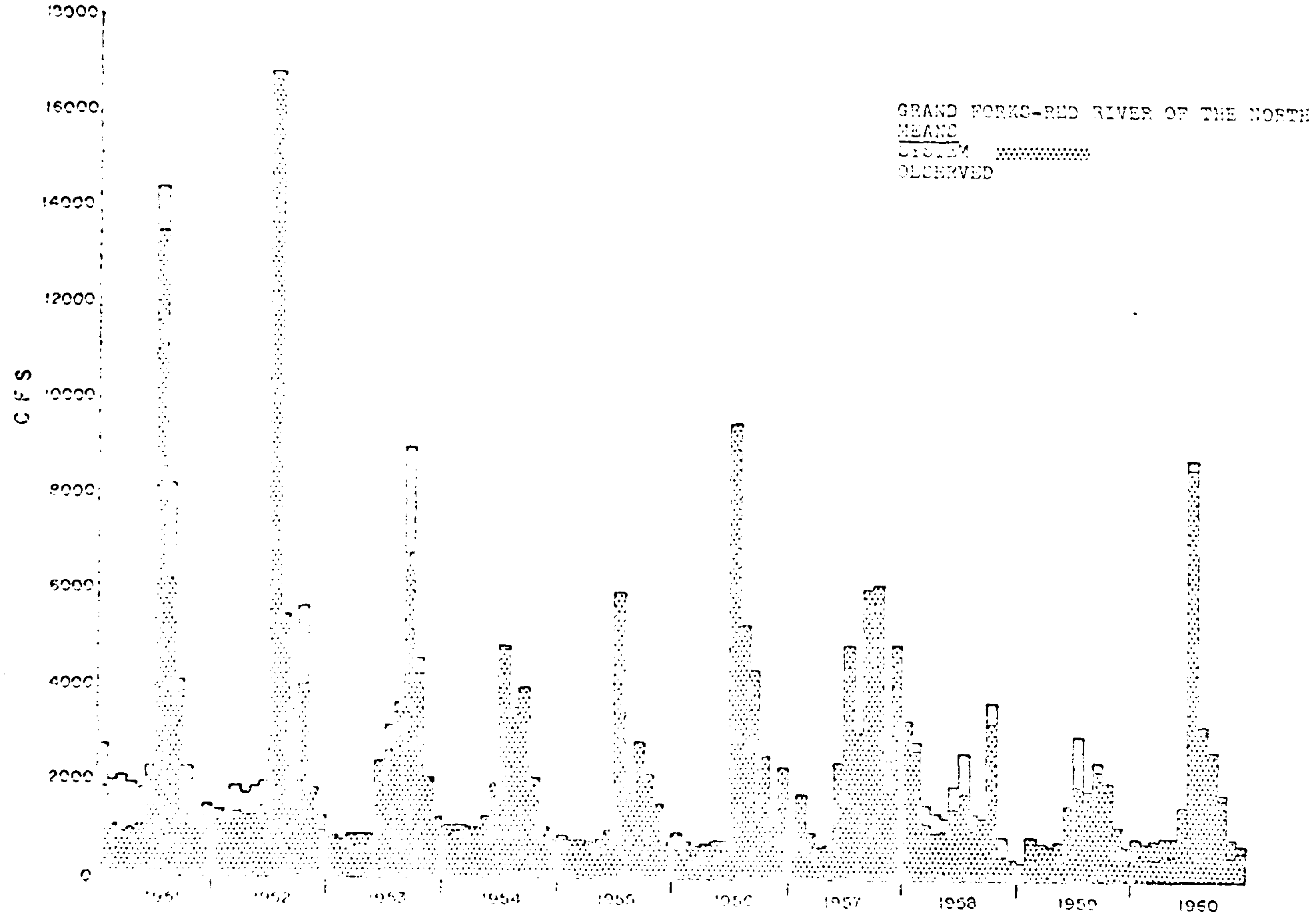


FIGURE 6

COMPARISON - OBSERVED AND COMPUTED MEAN MONTHLY DISCHARGES AND STANDARD DEVIATIONS
W. Y. 1951 - 1960

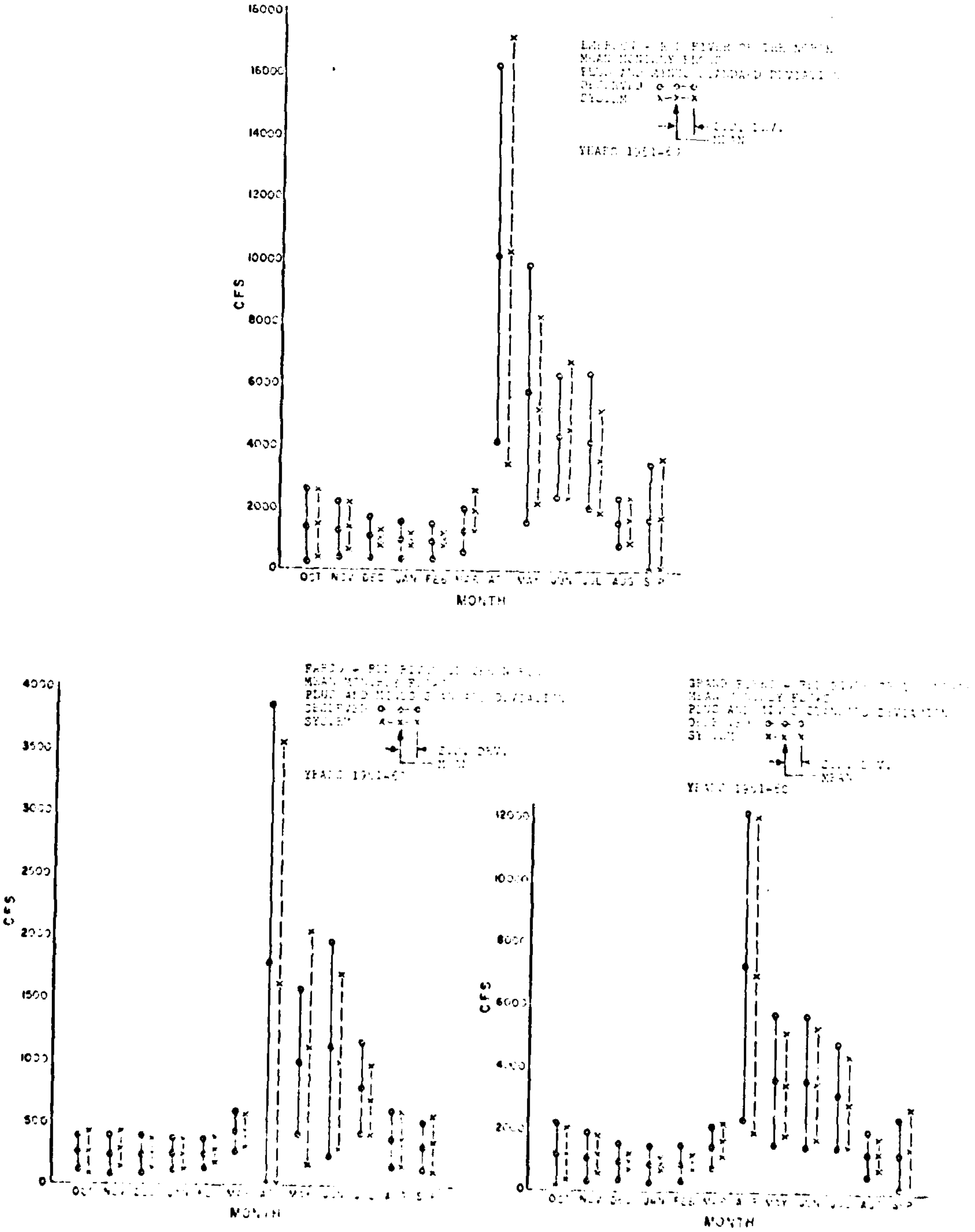


FIGURE 7

B. Quality - Total Dissolved Solids

1. Natural - Background

Presented in Figure 8 are the locations of six water quality monitoring stations from which data were obtained to define average monthly concentration -- discharge relationships. Shown also are the areas which are assumed to exhibit similar leaching and discharge behavior. The pertinent coefficients for these relationships are shown in Table III.

2. Existing waste loadings

Present municipal and industrial (potato and sugar beet) diversions, waste return flows and loadings for the Wahpeton, Fargo, and Grand Forks complexes are shown in Table IV. The pollutional contribution from the new sugar beet processing plant at Drayton was not considered.

3. Verifying Quality

For the years 1956-1960, quality (as TDS) measurements were recorded at Lisbon, Fargo, and Grand Forks, North Dakota. The model was operated for the same period of record. Shown in Figure 9 are the observed time -- weighted monthly means, ± one standard deviation, and the system counterparts for Lisbon, Fargo, and Grand Forks. In Figure 10 the accumulative probability curves for the three locations are given.

TABLE II

Comparison of the Observed and Computed Mean Discharge for Period, Water Years 1941-1960, at Selected Gages

STREAM AND LOCATION	MEAN DISCHARGE Observed (cfs)	MEAN DISCHARGE Computed (cfs)	Difference (percent)
Red River of the North at Wahpeton, N. Dak.	480	471	-1.9
Red River of the North at Fargo, N. Dak.	590	578	-2.0
Red Lake River at Crookston, Minn.	937	928	-1.0
Red River of the North at Grand Forks, N.Dak.	2,193	2,187	-0.3
Red River of the North at Emerson, Manitoba	2,863	2,887	+0.8

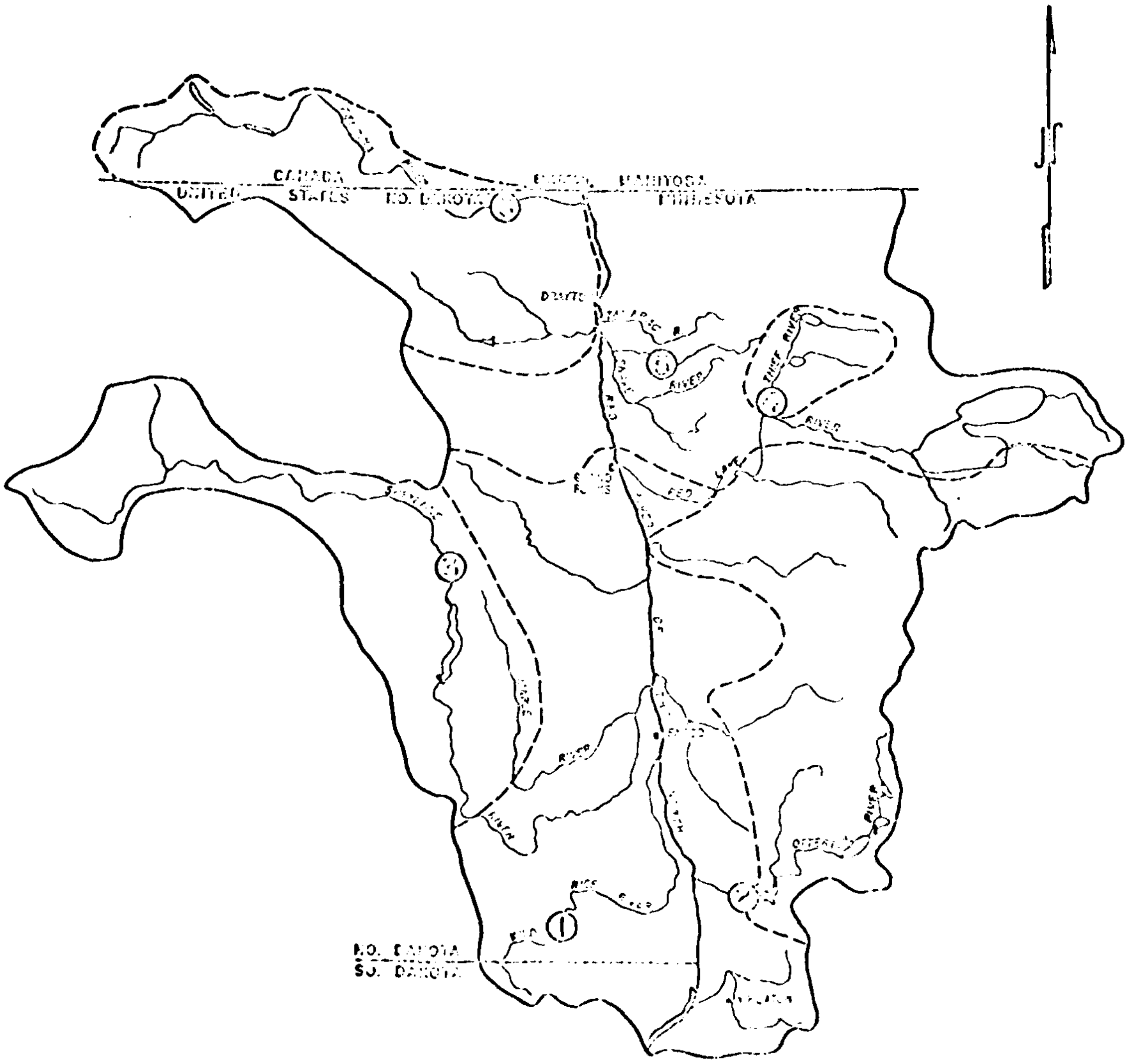
TABLE III

Coefficients for Relationships of Mean Monthly Concentration and Discharge for Six Monitoring Stations

($L > C = aQ^b > T$, where C=concentration of total dissolved solids, in ppm, Q=discharge, in cfs. L=upper limit of concentration and T=lower limit of concentration.)

Station	a	b	L	T	Sample Size
Breckenridge	700	-.1780	600	200	50
Cayuga	1240	-.2015	2250	300	42
Cooperstown	985	-.2155	800	200	44
Thief R. Falls	950	-.200	1250	250	10
Composite Snake, Tamarac and Two Rivers	590	-.170	600	160	97
Walhalla	890	-.148	760	275	77

LOCATION MAP
WATER QUALITY MONITORING STATIONS



WATER QUALITY MONITORING STATIONS

1. Wild Rice River near Cayuga
2. Ottertail River at Breckenridge
3. Sheyenne River at Cooperstown
4. Thief River at Thief River Falls
5. Composite Snake, Tamarac, and Two Rivers
6. Pembina River at Walhalla

FIGURE 8

TABLE IV

Existing Municipal and Industrial Monthly Diversions, Waste Return Flows, and Loadings for Wahpeton, Fargo, and Grand Forks, N.Dak.

	WAHPETON			FARGO			GRAND FORKS		
Month	Diversion (cfs)	Return Flow (cfs)	Concentration (mg/l)	Diversion (cfs)	Return Flow (cfs)	Concentration (mg/l)	Diversion (cfs)	Return Flow (cfs)	Concentration (mg/l)
Oct.	6.5	4.5	800	15	9	1000	17	15	1000
Nov.	6.5	4.5	800	15	9	1000	17	15	1000
Dec.	3.0	1.5	800	15	4.5	1000	17	15	1000
Jan.	3.0	1.5	800	15	4.5	1000	17	15	1000
Feb.	3.0	1.5	800	15	4.5	1000	5	5	1000
Mar.	3.0	1.5	800	9	4.5	1000	5	5	1000
Apr.	3.0	9.5	800	9	30.0	1000	5	5	1000
May	3.0	9.5	800	9	30.0	1000	5	5	1000
June	3.0	3.0	800	9	9	1000	3	3	1000
July	3.0	3.0	800	9	9	1000	3	3	1000
Aug.	6.5	4.5	800	9	9	1000	3	3	1000
Sept.	6.5	4.5	800	9	9	1000	3	3	1000

NOTE: An estimated 525 tons/year of lime (sugar beet) is discharged into the Red River of the North, assumed distributed as follows:

Month	Tons	Percent	Month	Tons	Percent	Month	Tons	Percent
Oct.	68.2	13.0	Feb.	0	0	June	105	20
Nov.	18.4	3.5	Mar.	105	20	July	0	0
Dec.	18.4	3.5	Apr.	105	20	Aug.	0	0
Jan.	0	0	May	105	20	Sept.	0	0

COMPARISON - OBSERVED AND COMPUTED MEAN MONTHLY CONCENTRATION OF TOTAL DISSOLVED SOLIDS AND STANDARD DEVIATIONS - W. Y. 1956-1960

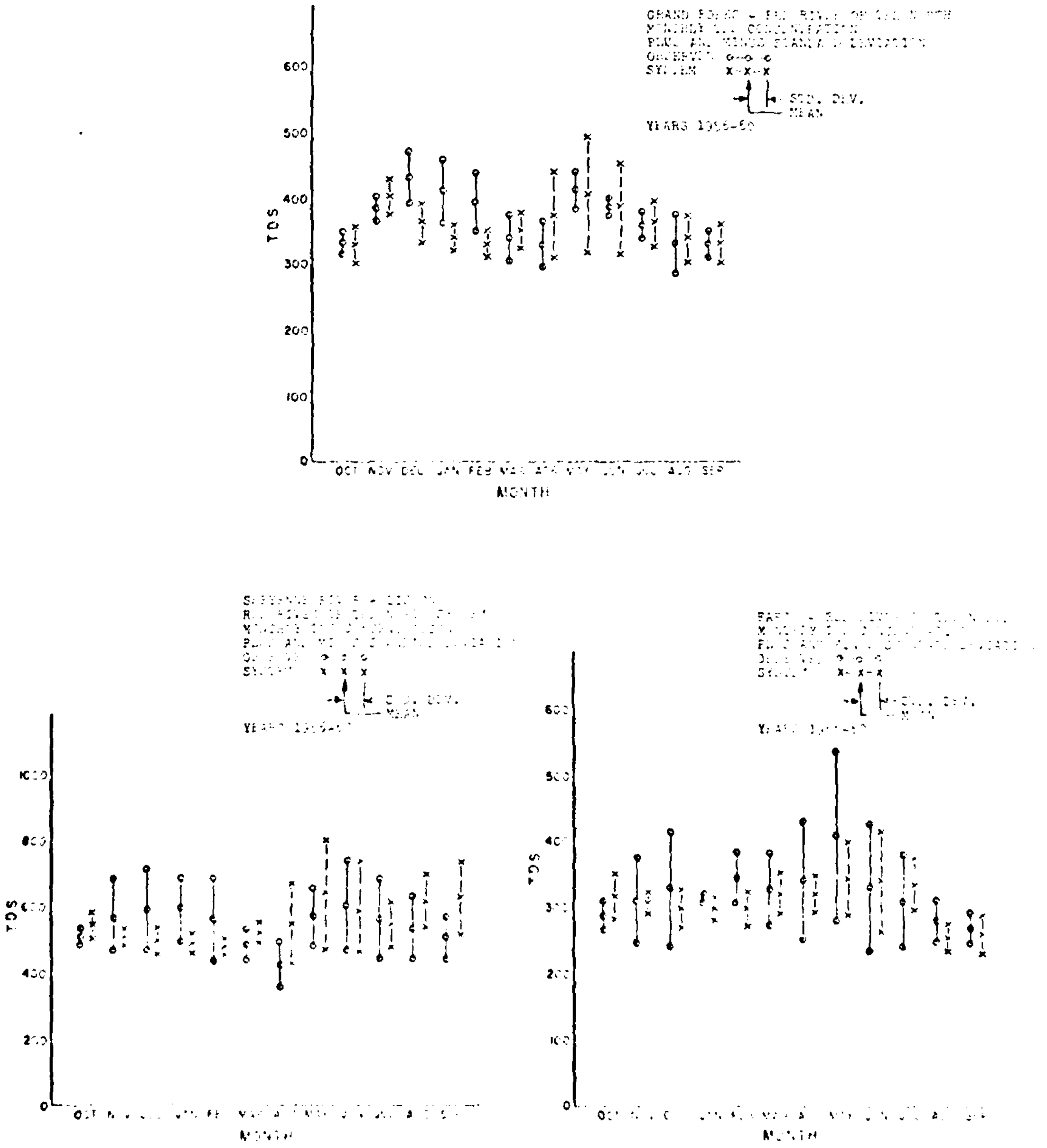


FIGURE 9

COMPARISON - OBSERVED AND COMPUTED FREQUENCY CURVES OF CONCENTRATION OF TOTAL DISSOLVED SOLIDS W. Y. 1956 - 1960

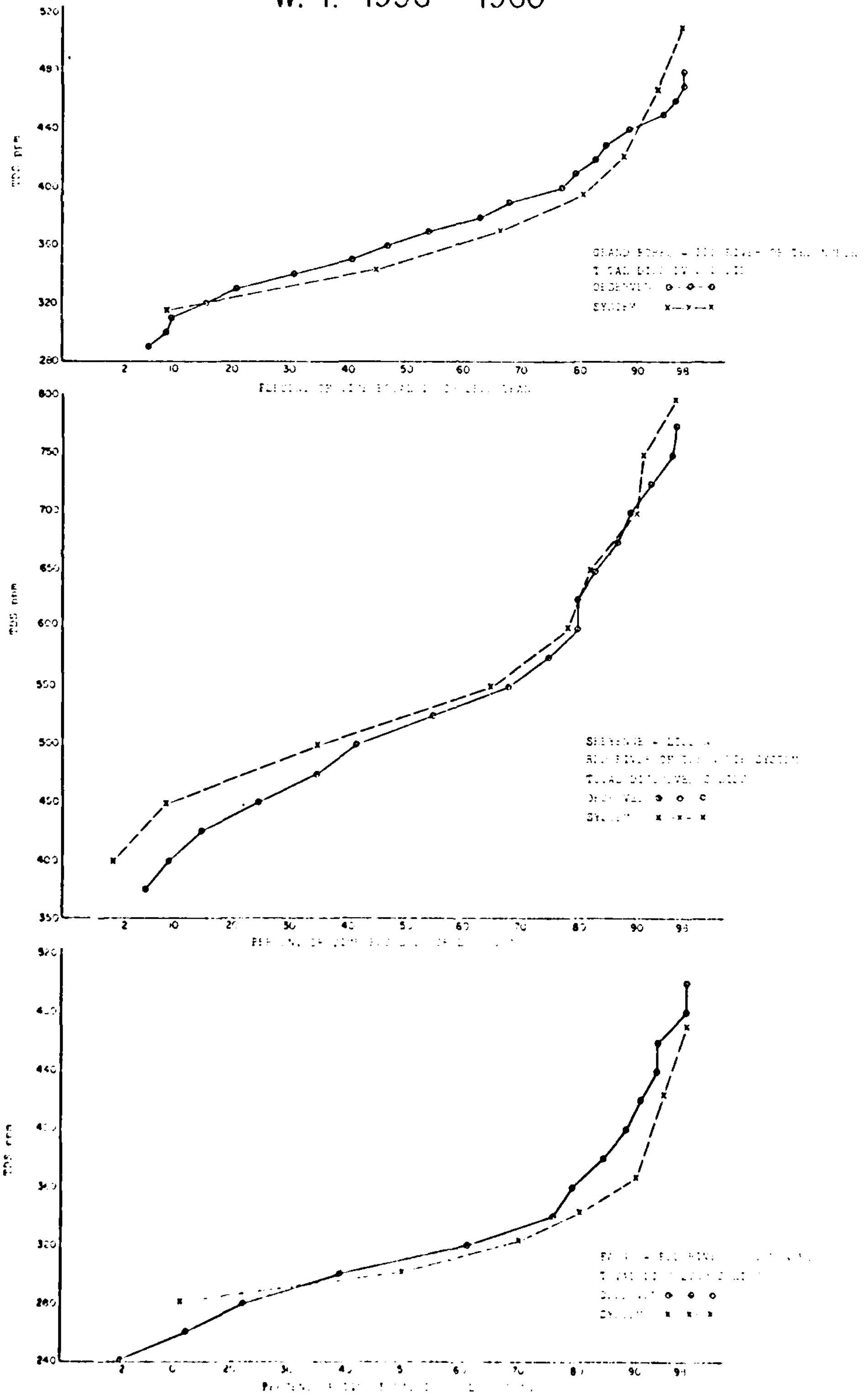


FIGURE 10

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APPENDIX

Mathematical Model of Streamflow in a River Basin

One scheme for a mathematical model of streamflow in a river basin is used in a FWPCA computer program, "River Basin Simulation Program." The program produces synthetic discharges that duplicate specific characteristics of historical streamflow data. A long synthetic record can provide a large variety of possible combinations, sequences of events, extremes, and conditions not yet documented. The long record enables the user to define a wider spectrum of discharge events than the historical data provide, to test a design, plan a facility, schedule an operational pattern, or otherwise consider the possible range of conditions at selected locations.

In addition to the sample provided by the historical record, additional samples can be synthesized thereby permitting the user to better gage the reliabilities of various alternative courses of action. In other words, one can (1) measure various consequences for the same course of action, (2) study the distribution or occurrence frequencies of the consequences, and then (3) decide on the desirability of the course of action.

Three specific characteristics of historical streamflow data are used in this model for each gaging station and for each time interval. The time interval (season) can be whatever is compatible with the particular study -- monthly, bimonthly, trimonthly, semiannual, or annual. Calendar months are usually used in river basin studies.

The first parameter is the arithmetic mean, in any units, for each season for the period of historical record common to all records in the basin. Thus, for each gaged point, a set of twelve mean discharges represents the central value of the distribution for each calendar month.

The second parameter is the standard deviation, in the same units as the mean, for each season which is taken to be the square root of the mean of the squares of deviations from the mean of all discharges for each season. This parameter provides a numerical index of dispersion of discharge magnitudes representing each of the twelve months.

The third parameter is the lag correlation coefficient. Because each monthly discharge is dependent to some extent, however small, on the discharge during the preceding month, the discharges are not completely random. The lag correlation coefficient relates the serial interdependence between each month and the month immediately preceding. Thus, a set of 12 lag correlation coefficients for each gaging station record measures the temporal (sequential) relationships of the historical data.

The hydrology of a large river basin varies with location. Some influences causing the variation are obvious, others are subtle. The transition from place to place may be sudden or gradual. Each gaging station within a whole basin is a sampling point of streamflow components of the hydrology of part of the basin. Gages close to each other tend to exhibit similar characteristics and are therefore not completely independent among themselves. To consider this tendency, the model estimates and uses a table (matrix) of correlations of each gage with each of the other gages for each of the twelve months. These 12 tables measure the spatial relationships among the gaged discharges with their variation from month to month.

The temporal and spatial parameters derived from the historical data are used to generate a multivariate distribution function which in turn is used to generate synthetic discharges for each gaged point in the basin. Any of three distributions -- normal, log normal, or gamma -- can be selected. The computer then generates a large number of synthetic discharges (operational hydrology) based on the assumed distribution and having the same parametric characteristics (mean, standard deviation, lag correlation, and spatial correlation) as the historical data. The parameters of the synthetic record are computed to provide a comparison with those of the historical data to insure proper replication.