A STATISTICAL STUDY OF THE RELATIONSHIP BETWEEN INORGANIC QUALITY OF RIVER WATER AND STREAMFLOW

By

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1962

Submitted to the faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1969

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ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to the following persons and organizations:

Dr. D. F. Kincannon, his major adviser, who initiated this study and gave invaluable advice and guidance during the entire period of the research and thesis preparation.

Dr. A. F. Gaudy, Jr., and Professor Q. B. Graves, members of the Advisory Committee, for their attentive reading and valuable suggestions to this thesis.

Mrs. Margaret Morrison, who typed this manuscript carefully and accurately.

Mr. and Mrs. Cheng-ming Kao, his parents, whose help and encouragement made his study in the United States possible.

The office of Water Resources Research, Department of the Interior, for financial assistance in the form of a Research Assistantship provided by the grant (WRB-006-Okla.) with matching funds from the Oklahoma Water Resources Board.

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CHAPTER I

INTRODUCTION

General

Knowledge of the quality of river water is needed in planning the development, management, and use of the water resources of the area. The investigation of water quality at the various locations throughout the drainage basin will be useful to engineers locating reservoirs and dams, treatment plants, and water distribution facilities, because the chemical character of the water determines its suitability for domestic, irrigation, or industrial purposes. If raw water is not satisfactory for a specific use, the chemical analyses are necessary to determine the type or extent of treatment needed. Consideration of water quality with the hydrologic condition and water use will aid materially in the selection of water-quality criteria.

Chlorides, dissolved solids, hardness, and sulfates are four parameters of dissolved mineral constituents of river water involved in this research. For understanding their individual importance in the field of water resources engineering, a review of their general sources and significance based on the study of the Geological Survey, U. S. Department of the Interior (USGS) (8) (12) was made as follows.

Chloride is one of the principal anions present in water. It is usually dissolved from rocks and soils. It is also present in sewage and found in large amounts in ancient brines, sea water, and industrial brines. The chloride gives a salty taste to the drinking water, and in large quantities it increases the corrosiveness of water. According to the U. S. Public Health Service (1962) drinking-water standards, the concentration of chlorides should not exceed 250 ppm.

Dissolved solids are chiefly mineral constituents dissolved from rocks and soils. High concentration of dissolved solids may be closely associated with the corrosive property of a water, particularly if the chloride content is appreciable. With high concentration of magnesium chloride, water may be very corrosive, because hydrolysis of magnesium chloride yields hydrochloric acid. U. S. Public Health Service (1962) drinking-water standards recommend that waters containing more than 500 ppm dissolved solids should not be used if other less mineralized supplies are available. Water containing more than 1,000 ppm dissolved solids is unsuitable for many purposes.

In most waters nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness. Hardness is a property of water which receives great attention in evaluating an industrial water supply. This property is objectionable because it contributes to the formation of scale in pipes, radiators, boilers, and water heaters, a condition resulting in loss in heat transfer, loss of flow, and boiler failure. Waters of hardness as much as 60 ppm are considered soft; 61-120 ppm, moderately hard; 121-180 ppm, hard; more than 180 ppm, very hard.

Sulfate is one of the common anions found in water. It is dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. It is also commonly present in mine waters and in some industrial waters. Large amounts of sulfate, in combination with other ions, gives a bitter taste to water. Sulfate in water containing calcium forms hard scale in steam boilers. U. S. Public Health Service (1962) drinking water standards recommend that the concentration of sulfate should not exceed 250 ppm.

Purpose of This Research

The development of a method with satisfactory accuracy and convenience for understanding the quality-quantity relationship of river water would be helpful in determining the utilization of the water resource. In achieving that purpose, a statistical method is applicable if characteristics of water quality data and streamflow data are examined and treated properly to meet the requirements of each statistical technique used.

The report presents four linear regression models in logarithmic form for expressing the relationship between the different parameters of inorganic water quality and streamflow under different natural conditions. It attempts to express the monthly concentration of chlorides, dissolved solids, hardness, and sulfates in the stream as a function of either the current monthly streamflow or the current monthly streamflow and its antecedent flow. The results in this report will help engineers to make a reasonable estimate of dissolved mineral constituents in the stream for engineering purposes. In addition, the application of the regression method in this study provides a useful technique for further study in the investigation of other important factors affecting the variation of inorganic quality of river water.

Organization of the Research Report

In the course of conducting this investigation, four important steps were performed: (a) selecting the stations having long records of water quality and streamflow and having good geographic location to represent the variation of water quality in the studied area, (b) computing the monthly time-weighted averages of each parameter of water quality concerned and collecting the data of monthly streamflow, (c) developing regression models for relating the water quality and streamflow, and (d) making regression analysis and evaluating the regression models to determine their suitability. The succeeding chapters of this report present each of these aspects.

CHAPTER II

LITERATURE SURVEY

Glossary

In order to understand the meaning and characteristics contained in some important terms of this study, several explanations were made as follows:

Discharge

The rate of flow of a stream; includes dissolved solids and suspended sediment transported in the water (9).

Dissolved Solids

Approximate quantity of dissolved mineral matter in water. Quantity of dissolved solids usually determined by evaporating a given volume of water, drying residue at 180° C, and weighing dried residue (2).

Hardness

The property of water attributed to the presence of alkaline earths. It generally indicates the sum of the calcium and magnesium expressed as an equivalent amount of calcium carbonate ($CaCO_3$). Hardness is a physical-chemical characteristic, not a substance (13) (17).

The total hardness is often divided into carbonate and noncarbonate hardnesses. When the carbonate and bicarbonate alkalinity is equal to, or greater than, the total hardness, all the hardness is estimated as carbonate hardness. If the total hardness exceeds the carbonate and bicarbonate alkalinity, the excess is considered noncarbonate hardness. The principal anions associated with noncarbonate hardness are sulfate, chloride, and nitrate (13).

Parts Per Million (ppm)

A unit for expressing the concentration of dissolved chemical constituents by weight, usually as grams of constituents per million grams of solution (9).

Previous Studies in the Quality-Flow Relationships

The fact that the mineral quality of a stream varies with its streamflow has been known for many years. In 1953 Durum (6) found that chloride concentrations and flows in the Saline River in Kansas were related according to

$$Cl \times Q = K \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

with chlorides in ppm and streamflow, Q, in cfs and K was a constant.

Later, Ward (10) worked with monthly weighted averages for the Arkansas River near Tulsa, Oklahoma, and the Red River near Gainesville, Texas, and obtained a parabolic equation to relate the concentration of dissolved minerals and the streamflow. The equation was

$$C = K\,Q^{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.2)$$

in which C is the mineral concentration, Q denotes the streamflow, and K and b are regression constants.

Ledbetter and Gloyna (10) made another study by using the unregulated data for the Canadian River near Whitefield, Oklahoma, and for the

Red River near Gainesville, Texas, and reported that an improvement in the estimate of water quality in applying equation (2.2) may be made by holding K constant and allowing b to vary logarithmically with the streamflow according to

$$b = p\,Q^n \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.3)$$

in which p and n are regression constants. Furthermore, in determining the value of b, they found that b was also affected by the immediate past history of streamflow at the stations investigated and introduced an antecedent flow index, A_q, into the following equation to calculate b

$$b = f + g\log A_q + h\,Q^n \quad \ldots\ldots\ldots\ldots \quad (2.4)$$

in which n is the slope of the log b on log Q regression, f, g, and h are regression constants, and A_q was expressed by

$$A_{q_k} = \sum_{i=1}^{30} \frac{Q_i}{i} \quad \ldots\ldots\ldots\ldots\ldots \quad (2.5)$$

in which Q is the streamflow, and i denotes the number of days back from the kth day.

In discussing the work of Ledbetter and Gloyna, Hart et al. (7) presented an equation for relating the total quantity of inorganics and streamflow. The equation was expressed by

$$C = a_1(Q_g)^{b_1} + a_2(Q_i)^{b_2} + a_3(Q_s)^{b_3} \quad \ldots\ldots \quad (2.6)$$

in which C is the total load of the pollutant, Q_g, Q_i, and Q_s denote the respective contribution of ground water, intersurface flow, and surface runoff. In studying the relationship between water quality and quantity for the Russian River at Hopland, California, they found good correlation by considering the a's constant and assuming b's equal to unity.

In a study of streamflow and quality in the Columbia River Basin, Gunnerson (6) reported in 1967 that basically the relationship between the water quality and streamflow is a continuous annual cycle reflecting variations in rates at which minerals are weathered or leached from rocks or soils and in streamflow rates.

CHAPTER III

INVESTIGATIONS OF SAMPLING STATIONS

Data of Water Quality and Streamflow

The data of water quality and streamflow used in this study were all taken from the Water-Supply Papers published by the Geological Survey, U. S. Department of Interior (USGS). Kinds of water quality studied include concentration of chlorides, dissolved solids, hardness, and sulfates. Both the data of water quality and streamflow are monthly time-weighted averages with units in parts per million (ppm) and cubic feet per second (cfs), respectively.

In this study the water quality-quantity relationships involved essentially unregulated streamflow. Periods of essentially unregulated data for each station investigated will be given in related sections of this chapter.

Sources of Mineral Pollution

The principal mineral pollutants of surface waters and ground waters in the Arkansas River Basin are salt (sodium chloride) and gypsum (calcium sulfate) (1). Figure 1 indicates the salt and gypsum areas of the Arkansas River Basin.

Five major natural sources of mineral pollution in the Arkansas River Basin are indicated in Figure 2. These sources contribute about 11,000 tons daily or about 70 per cent of the total load carried past

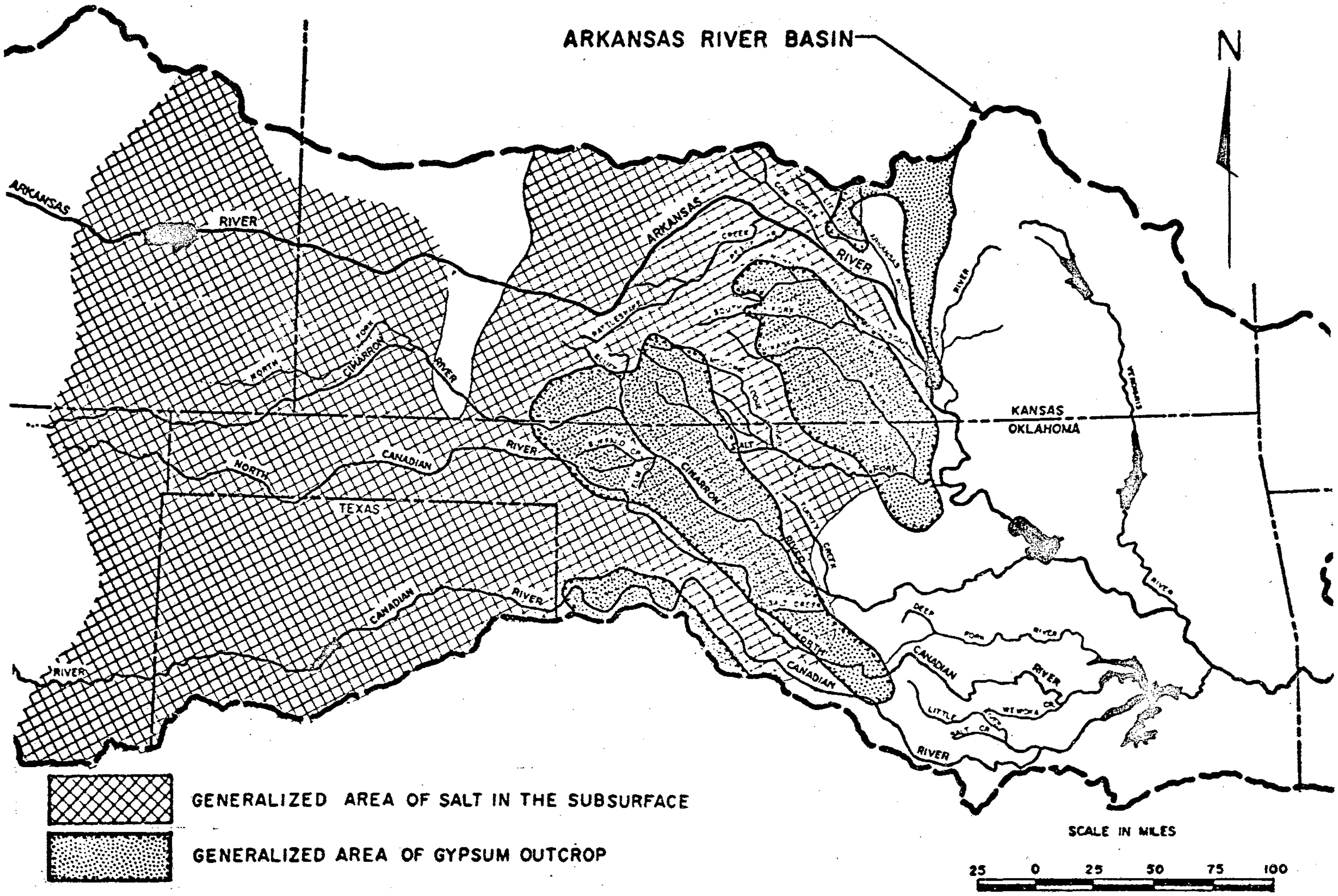

Figure 1. Salt and Gypsum Areas in Arkansas River Basin

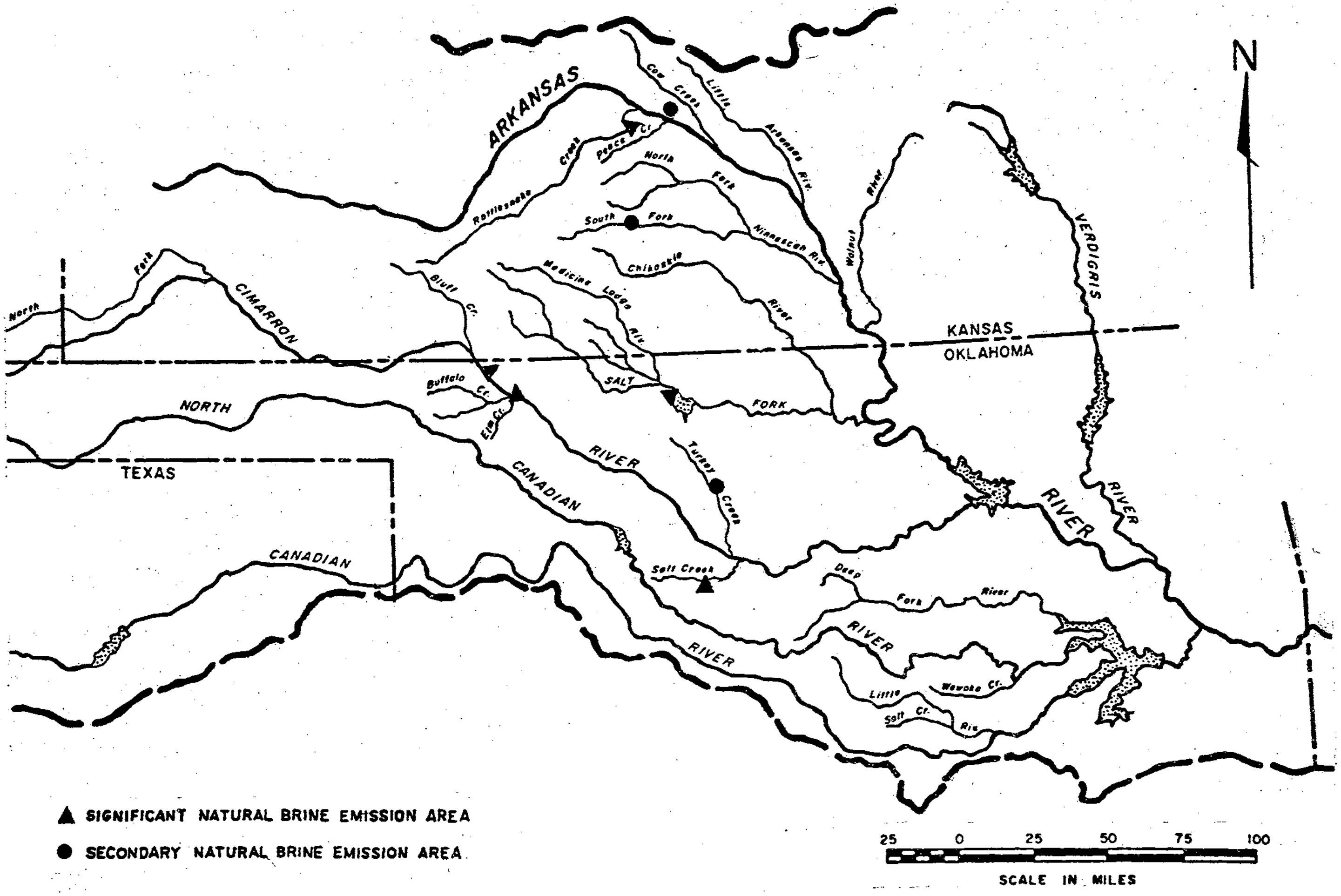

Figure 2. Location of Natural Brine Emissions in Arkansas River Basin

Tulsa, Oklahoma (3), and are identified as the primary causes of water quality deterioration with respect to minerals.

The state water pollution control agencies of Kansas, Oklahoma, and Texas indicated that over 95 per cent of the brines resulting from petroleum and natural gas extraction activities is reinjected into the producing strata for pollution control or secondary petroleum recovery (1).

Descriptions of Sampling Stations

Five sampling stations in the Arkansas River Basin were investigated. Figure 3 indicates the locations of the investigated stations. Information regarding each station related to this study is listed as follows:

Station 7-1465 (Arkansas River at Arkansas City, Kansas)

1. Drainage area: 43,713 square miles, of which 7,607 miles is probably noncontributing.
2. Records available:
   Water quality: October 1951 to September 1966
   Streamflow: September 1902 to September 1906 and September 1921 to September 1966.
3. Remarks: Upstream from this station, John Martin Reservoir was constructed at Caddoa, Colorado, in January 1943. The drainage area of that reservoir is 18,917 square miles, of which 785 square miles is probably noncontributing. Because that reservoir is located far upstream from this station and the drainage area of that reservoir is far less than that of this station, the records of this station from October 1951 to September 1966

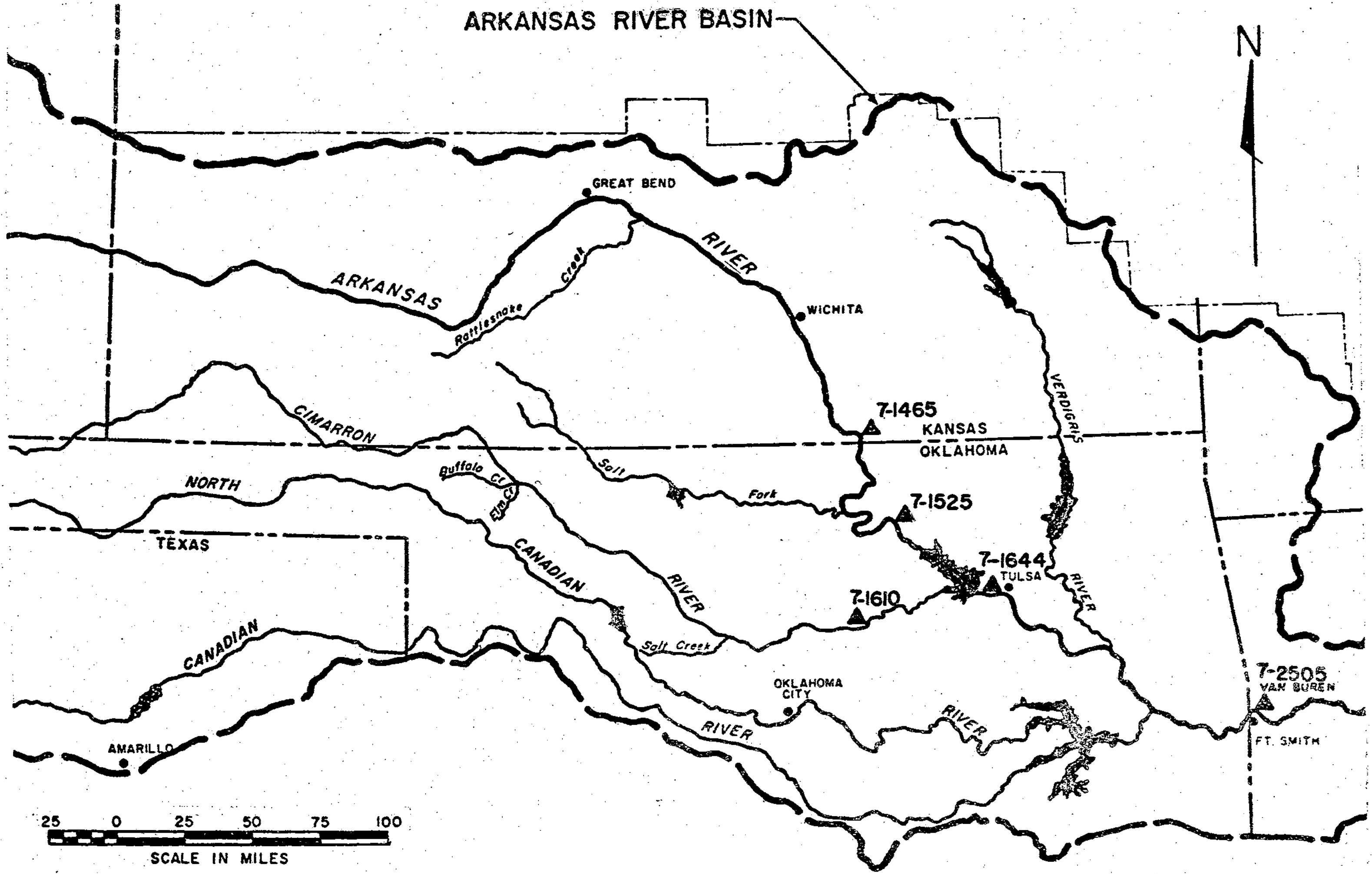

Figure 3. Location of Investigated Stations

are essentially unregulated.

Station 7-1525 (Arkansas River at Ralston, Oklahoma)

1. Drainage area: 54,465 square miles, of which 7,615 square miles is probably noncontributing.
2. Records available:

   Water quality: January 1950 to September 1963 and May 1965 to September 1966.

   Streamflow: October 1925 to September 1966.
3. Remarks: The Great Salt Plains Reservoir, having the catchment area of 3,200 square miles, was constructed near Jet, Oklahoma, in July 1941. By comparing the drainage area of these two stations, it can be seen that the regulating influence of the Great Salt Plains Reservoir to this station is negligible. In addition, based upon the same consideration made for station 7-1465, the regulating effect of John Martin Reservoir to this station is also limited. Owing to these two reasons, the records of this station are essentially unregulated.

Station 7-1610 (Cimarron River at Perkins, Oklahoma)

1. Drainage area: 17,852 square miles, of which 4,926 square miles is probably noncontributing.
2. Records available:

   Water quality: October 1952 to September 1963 and June 1965 to September 1966.

   Streamflow: June 1939 to September 1966.
3. Remarks: Data are unregulated.

Station 7-1644 (Arkansas River at Sand Springs Bridge, near Tulsa, Oklahoma)

1. Drainage area: 74,615 square miles, of which 12,541 square miles is probably noncontributing.
2. Records available:

   Water quality: October 1946 to September 1966.

   Streamflow: October 1925 to September 1966.
3. Remarks: (a) Streamflow records at this station are given for the Arkansas River at Tulsa (station 7-1645), Oklahoma. There was no appreciable inflow between this station and station 7-1645 except during periods of heavy local runoff.

   (b) Except for 109 square miles intervening area, flow has been completely regulated by Keystone Reservoir since September 1964. Prior minor regulation coming from John Martin Reservoir in Colorado and from Great Salt Plains Reservoir in Oklahoma is negligible, so that records before the completion of Keystone Reservoir are essentially unregulated.

Station 7-2505 (Arkansas River at Van Buren, Arkansas)

1. Drainage area: 150,483 square miles, of which 22,241 square miles is probably noncontributing.
2. Records available:

   Water quality: For concentration of chlorides, October 1945 to September 1959 and October 1960 to September 1966. For concentration of dissolved solids, hardness, and sulfates, October 1945 to September 1959, October 1960 to September 1961, and October 1963 to September 1966.

   Streamflow: October 1927 to September 1966.

3. Remarks: (a) Records of this station were regulated by several upstream reservoirs in Oklahoma under different degrees of influence and different periods of time. Table I which shows the reservoirs in Oklahoma that have a regulating effect on this station indicates that after the completion of Keystone Reservoir the sum of the drainage area of all reservoirs upstream from this station approximates 94 per cent of the total drainage area of this station.

   (b) Data prior to February 1963, when the closure for diversion was made for constructing the Eufaula Reservoir, are considered unregulated essentially in this study because during that period only the streamflow coming from about one tenth of the total drainage area was regulated.

Variation of Water Quality Among Stations Investigated

The water quality of the Arkansas River in Oklahoma varies markedly. Tables II to VII show the variation of water quality and quantity in the reach of the Arkansas River from the state line of Kansas-Oklahoma to that of Oklahoma-Arkansas. Records of station 7-1465 represent the quality of the incoming water of Oklahoma, which is rather poor. Because of the inflow of a tremendous amount of salts contributed by the Salt Fork of the Arkansas River and the Cimarron River, the mineral concentration of river water at station 7-1644 (near Tulsa) is much higher than that at other stations in the reach of the Arkansas River investigated in this study. Records of water quality at station 7-1610 (near Perkins) indicate the highly mineralized water of the Cimarron River in the reach downstream from the natural salt plain of western

TABLE I

RESERVOIRS IN OKLAHOMA UPSTREAM FROM STATION 7-2505

Station No.	Reservoir	Drainage Area sq. mi.	Beginning Date of Regulation
7-1645	Keystone*	73,506	Sept. 1964
7-1655	Heyburn	123	Sept. 1950
7-1714	Oologah	4,339	May 1963
7-1730	Hulah	736	Feb. 1950
7-1935	Fort Gibson	12,495	Sept. 1949
7-1980	Tenkiller Ferry	1,626	July 1952
7-2450	Eufaula	47,576	Feb. 1964
7-2485	Wister	993	Oct. 1949

*The regulation effect of reservoirs upstream from Keystone Reservoir is neglected.

TABLE II

MEANS AND EXTREMES OF MONTHLY STREAMFLOW AND WATER QUALITY AT STATIONS INVESTIGATED

	Streamflow, cfs			Chlorides, ppm			Dissolved Solids, ppm			Hardness, ppm			Sulfates, ppm		
Station	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
7-1465	1,787	11,890	32	409	1,163	85	1,174	2,497	391	511	1,032	165	193	607	59
7-1525	5,055	47,660	37	459	1,158	80	1,218	2,409	306	514	830	166	180	402	38
7-1610	1,204	17,800	2	2,686	5,900	728	5,279	10,905	1,627	1,067	1,903	460	372	668	155
7-1644	7,317	61,100	40	927	2,760	144	2,107	5,361	373	650	1,810	168	194	390	100
7-2505	27,585	218,800	492	292	825	55	754	1,777	237	300	701	99	69	164	23

TABLE III

MEANS AND EXTREMES OF MONTHLY STREAMFLOW AND WATER QUALITY STATION 7-1465 (ARKANSAS RIVER AT ARKANSAS CITY, KANSAS)

Calendar Month	Streamflow, cfs				Chlorides, ppm				Dissolved Solids, ppm				Hardness, ppm				Sulfates, ppm			
	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.
Jan.	15	757	2,043	127	15	466	723	336	15	1,390	1,751	1,102	13	636	784	402	15	233	464	161
Feb.	15	959	2,767	231	15	420	550	295	15	1,273	1,566	1,065	14	576	776	400	15	222	390	131
Mar.	15	1,165	6,394	377	15	400	633	225	15	1,255	1,723	838	14	560	1,032	366	15	227	607	149
Apr.	15	1,240	3,519	439	15	388	610	244	15	1,190	1,550	831	14	534	789	341	15	214	475	121
May	15	1,810	10,420	372	15	344	606	204	15	1,000	1,549	622	14	424	641	289	15	159	280	91
Jun.	15	1,780	11,890	248	15	286	687	110	15	892	1,640	391	15	378	621	165	15	149	308	59
Jul.	15	1,330	9,493	190	15	315	775	95	15	946	1,710	392	15	403	640	205	15	153	285	79
Aug.	15	810	4,978	67	15	380	965	180	15	1,070	2,210	624	14	461	770	240	15	157	297	87
Sept.	15	875	6,332	32	15	340	1,163	85	15	998	2,497	513	14	428	897	244	15	136	274	63
Oct.	15	1,002	7,744	65	15	352	848	177	15	1,045	1,917	661	14	455	692	299	15	149	383	93
Nov.	15	966	5,776	129	15	392	625	221	15	1,165	1,520	713	13	531	897	350	15	169	555	98
Dec.	15	775	1,839	146	15	446	625	336	15	1,310	1,503	1,011	13	575	783	364	15	200	449	137

Remark: N is the number of observations.

TABLE IV

MEANS AND EXTREMES OF MONTHLY STREAMFLOW AND WATER QUALITY STATION 7-1525 (ARKANSAS RIVER AT RALSTON, OKLA.)

Calendar Month	Streamflow, cfs				Chlorides, ppm				Dissolved Solids, ppm				Hardness, ppm				Sulfates, ppm			
	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.
Jan.	15	1,320	5,006	156	15	514	829	349	15	1,450	1,861	1,137	15	644	830	420	15	227	362	160
Feb.	15	1,640	7,477	233	15	478	720	251	15	1,360	1,702	901	15	618	820	422	15	218	342	151
Mar.	15	2,120	11,140	357	15	460	687	235	15	1,300	1,723	738	15	568	795	372	15	214	402	121
Apr.	15	2,420	9,566	460	15	425	705	243	15	1,190	1,640	581	15	508	704	323	15	184	331	86
May	16	4,580	33,340	431	16	355	935	80	16	995	2,000	306	16	405	635	166	16	139	263	38
Jun.	16	4,870	39,310	426	16	360	1,050	135	16	1,001	2,190	443	16	404	650	220	16	139	218	53
Jul.	16	4,400	47,660	281	16	330	895	124	16	925	1,885	515	16	382	620	209	16	129	218	74
Aug.	16	2,030	25,710	115	16	392	1,158	189	16	1,040	2,409	605	16	434	727	205	16	143	245	81
Sept.	16	2,020	16,360	37	16	365	1,043	163	16	990	2,174	521	16	398	717	269	16	131	201	71
Oct.	14	1,960	34,220	37	14	400	828	186	14	1,100	1,875	612	14	480	662	349	14	150	284	84
Nov.	14	1,560	22,530	123	14	441	754	171	14	1,230	1,706	590	14	552	800	337	14	169	414	68
Dec.	14	1,325	6,164	146	14	483	835	270	14	1,370	1,869	933	14	625	785	416	14	202	352	125

TABLE V

MEANS AND EXTREMES OF MONTHLY STREAMFLOW AND WATER QUALITY STATION 7-1610 (CIMARRON RIVER AT PERKINS, OKLA.)

Calendar Month	Streamflow, cfs				Chlorides, ppm				Dissolved Solids, ppm				Hardness, ppm				Sulfates, ppm			
	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.
Jan.	12	174	887	14	12	3,100	5,770	1,730	12	6,140	10,500	3,430	12	1,210	1,464	816	12	420	569	202
Feb.	12	263	2,632	26	12	3,420	5,900	1,905	12	6,740	10,700	3,931	12	1,200	1,545	875	12	435	538	286
Mar.	12	277	1,737	29	12	3,680	5,894	2,119	12	7,200	10,905	4,681	12	1,280	1,542	615	12	470	651	363
Apr.	12	380	3,501	82	12	3,060	4,800	1,802	12	5,970	9,100	4,088	12	1,140	1,631	664	12	430	572	339
May	12	922	17,800	106	12	2,210	3,650	962	12	4,520	6,950	2,117	12	960	1,344	636	12	370	460	242
Jun.	13	1,365	14,190	162	13	1,685	2,790	728	13	3,520	5,450	1,627	13	826	1,262	513	13	306	487	174
Jul.	13	672	2,994	22	13	1,890	3,900	969	13	3,840	7,400	2,157	13	867	1,675	461	13	306	465	212
Aug.	13	344	2,610	19	13	2,440	4,186	1,268	13	4,800	8,272	2,793	13	991	1,903	460	13	351	668	257
Sept.	13	692	4,370	14	13	1,900	3,260	897	13	2,780	5,900	1,953	13	820	1,355	536	13	278	425	155
Oct.	12	410	11,480	4	12	1,940	3,060	777	12	2,770	5,928	1,810	12	930	1,362	625	12	277	439	215
Nov.	12	179	3,385	2	12	2,370	3,739	1,154	12	3,240	7,695	2,555	12	1,070	1,474	712	12	325	488	180
Dec.	12	185	1,170	4	12	2,920	3,820	1,947	12	3,920	7,760	4,127	12	1,180	1,629	790	12	392	532	244

TABLE VI

MEANS AND EXTREMES OF MONTHLY STREAMFLOW AND WATER QUALITY STATION 7-1644 (ARKANSAS RIVER AT SAND SPRINGS BRIDGE, NEAR TULSA, OKLA.)

Calendar Month	Streamflow, cfs				Chlorides, ppm				Dissolved Solids, ppm				Hardness, ppm				Sulfates, ppm			
	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.
Jan.	18	1,790	12,630	214	18	1,300	2,107	734	18	2,820	4,100	1,884	18	835	1,489	600	18	248	319	162
Feb.	18	2,280	29,690	311	18	1,170	1,984	402	18	2,550	3,727	880	18	754	1,308	206	18	220	329	86
Mar.	18	3,160	14,320	407	18	1,100	1,749	640	18	2,380	3,501	1,660	18	690	1,093	374	18	227	336	159
Apr.	18	4,280	34,860	545	18	907	1,942	480	18	2,010	3,892	1,190	18	600	1,103	315	18	200	292	116
May	18	8,410	58,090	720	18	715	1,498	353	18	1,630	3,056	938	18	506	1,055	281	18	171	263	111
Jun.	18	8,700	61,100	897	18	616	1,550	272	18	1,450	3,120	700	18	445	834	186	18	161	223	70
Jul.	18	7,050	56,650	416	18	589	1,665	232	18	1,370	3,303	671	18	452	1,060	252	18	146	245	87
Aug.	18	3,440	32,880	196	18	786	2,252	403	18	1,755	4,494	1,020	18	548	1,349	260	18	170	314	114
Sept.	17	2,970	24,800	90	17	848	2,760	338	17	1,870	5,361	862	17	586	1,530	362	17	165	390	79
Oct.	16	2,500	56,740	125	16	864	2,151	280	16	1,915	4,111	758	16	640	1,448	367	16	161	247	89
Nov.	17	2,100	25,160	240	17	1,005	1,758	347	17	2,190	3,544	913	17	698	1,291	384	17	177	297	101
Dec.	17	1,760	8,833	210	17	1,175	2,336	595	17	2,540	4,421	1,550	17	801	1,639	586	17	221	364	154

TABLE VII

MEANS AND EXTREMES OF MONTHLY STREAMFLOW AND WATER QUALITY STATION 7-2505 (ARKANSAS RIVER AT VAN BUREN, ARK.)

Calendar Month	Streamflow, cfs				Chlorides, ppm				Dissolved Solids, ppm				Hardness, ppm				Sulfates, ppm			
	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.	N	Mean	Max.	Min.
Jan.	16	10,400	47,590	3,044	16	356	825	164	15	898	1,777	464	15	346	701	206	15	69	120	43
Feb.	16	16,400	111,700	4,388	16	266	708	69	15	735	1,491	237	15	276	567	112	15	60	120	29
Mar.	16	22,600	67,860	3,223	16	229	818	70	15	653	1,682	299	15	254	622	145	15	58	109	30
Apr.	15	26,600	120,100	3,185	15	232	769	93	15	630	1,649	305	15	251	561	149	15	56	79	31
May	16	51,500	195,400	8,915	16	173	469	55	15	505	1,089	249	15	208	428	99	15	47	94	23
Jun.	16	33,800	218,800	5,353	16	217	619	84	15	635	1,329	327	15	258	434	177	15	66	93	40
Jul.	16	28,600	176,000	3,509	16	169	454	62	15	575	1,074	279	15	242	481	123	15	60	122	36
Aug.	16	12,250	97,360	2,211	16	240	592	106	15	670	1,284	408	15	268	489	150	15	65	111	30
Sept.	16	10,500	71,400	742	16	258	530	72	15	726	1,207	295	15	288	443	151	15	66	101	33
Oct.	17	9,550	95,570	492	17	270	690	58	15	816	1,449	666	15	316	566	179	15	70	129	39
Nov.	17	9,550	75,140	1,262	17	280	741	62	15	864	1,687	415	15	336	603	151	15	70	106	43
Dec.	16	8,350	56,170	2,127	16	366	651	160	15	925	1,403	515	15	360	620	192	15	73	115	47

Oklahoma. In the reach of the Arkansas River from station 7-1644 (near Tulsa) to station 7-2505 (at Van Buren, Arkansas), the Canadian River is the only tributary which does not dilute or improve the quality of the Arkansas River water (4). Much of the Canadian River water flowing into the central and eastern plains from western Oklahoma already is highly mineralized. As a result of good-quality inflow from tributary streams with the exception of the Canadian River, the quality of water in the Arkansas River is better where it leaves Oklahoma than where it enters at the Kansas border.

CHAPTER IV

THEORETICAL CONSIDERATIONS

Water Quality and Streamflow

The quality of river water is variable. Under natural conditions changes in quality are caused by the variable quality of direct surface runoff and ground-water inflow that make up the flow in the stream.

Normally, an inverse relationship exists between chemical-quality parameters and streamflow. During extreme high-flow conditions, the concentration of dissolved constituents in a stream approximates that of the principal streamflow component, surface runoff, and is usually at a minimum. During extreme low-flow conditions, it approximates that of the ground-water inflow. Normally, concentrations are high during low-flow periods because the ground-water inflow, the water infiltrating to the zone of saturation below the surface of the earth and then percolating laterally toward the stream, usually contains more dissolved constituents than surface runoff, owing to longer duration of contact with soluble materials. Under natural conditions the dissolved constituents in the streamflow are a composite having the quality of both the ground-water inflow and the direct surface runoff and are regulated by the streamflow contributed by each.

In addition to the current streamflow, the antecedent flow was also considered in this study to account for the influence of prior leaching of the soluble materials in the basin. After being leached by prior surface runoff and ground-water flow, conditions of soluble materials in the soils or rocks, such as moisture condition, amount of soluble minerals remained, etc., can affect the degree of leaching by the succeeding surface runoff and ground-water flow.

Consideration in the Grouping of Data

For improving the reliability of the results from this study, the statistical characteristics of the data for streamflow and water quality were checked before the analytical work was conducted. Statistically, the monthly averages of streamflow and the concentration of dissolved constituents of different months were serially correlated and nonhomogeneous (14). If these monthly averages are used, the computed standard error of estimate for a regression equation would be an average of the standard errors of the individual month averages (14). In this study the monthly averages of streamflow and water quality coming from the same month were grouped together for statistical analysis. Each set of monthly averages approximates a set of homogeneous samples taken from a population and within each set each monthly average can be said to be independent of each other.

Applications of Regression and Correlation Analysis

Transformation of Data

Monthly averages of water quality and streamflow and other derived data used in this study were transformed into logarithmic values before the application of statistical methods. Advantages of transformation (14) are: (1) to linearize regression equations, (2) to achieve equal variance about the regression line, and (3) to introduce additivity to the models used and to achieve normality.

Premises of Using the Regression Method

There are four principal requirements in applying the regression method to this research work (14). The first is that the deviations of the dependent variable about the regression line be normally distributed with the same variance for each value of the independent variable. The second is that the independent variable be measured without error. The third is that the observed values of the dependent variable are uncorrelated random events. The fourth is that either the dependent variable or the independent variables are homogeneous; that is, all individual observations of a variable measure the same thing. Data are considered homogeneous if any subgroup to which certain of these data may be logically assigned has the same expected mean and variance as any other subgroup of the population. Neither the dependent variable nor the independent variable needs to have a probability distribution.

In considering the second requirement, it seems that the measured errors of independent variables used in this study are not enough to have any appreciable effect on the results. In meeting the first requirement, the condition of stable variance of deviations about the regression line can be obtained by a logarithmic transformation. The third and fourth requirements are not violated to any appreciable extent by using the monthly averages of dissolved constituents and streamflow.

Descriptions of Regression Models Selected

Four kinds of regression models were used in this study to test whether or not any significant relationships existed between water quality and streamflow at each of the five stations investigated. They are

$$\text{Model 1:} \quad \log C = a + b_1 \log Q \tag{4.1}$$

$$\text{Model 2:} \quad \log C = a + b_1 \log Q + b_2 (\log Q)^2 \tag{4.2}$$

$$\text{Model 3:} \quad \log C = a + b_1 \log Q + b_3 \log Q_a \tag{4.3}$$

$$\text{Model 4:} \quad \log C = a + b_1 \log Q + b_2 (\log Q)^2 + b_3 \log Q_a \tag{4.4}$$

in which C is the monthly concentration of chlorides, dissolved solids, hardness, and sulfates, respectively, in parts per million (ppm), Q denotes the current monthly streamflow in cubic feet per second (cfs), a is the intercept, b_1, b_2 and b_3 are regression coefficients, and Q_a denotes the antecedent flow index, which is

$$(Q_a)_k = \sum_{1}^{i} \frac{Q_i}{i} \quad (10) \tag{4.5}$$

in which Q is the monthly streamflow, and i represents the number of months back from the k^th month. Three is considerable precedent for this type of factor, which is known as the Zipf distribution, since an antecedent precipitation index has been used in hydrology.

For the convenience of expression and comparison, the same symbols of intercept and regression coefficients are used in equations (4.1), (4.2), (4.3), and (4.4), but actually the values of intercept and regression coefficients are different for each equation. This fact is a characteristic of the regression method which can be illustrated again by a general case made as follows:

Suppose

$$Y = a + b_1 X_1$$

the addition of another related independent variable to that equation will give

$$Y = a' + b_1' X_1 + b_2 X_2$$

where $a' \neq a$ and $b_1' \neq b_1$ (15)

Usually the independent variables in a regression equation are related to each other as well as to the dependent variable (11).

Equation (4.1) is a simple linear regression which is originally a parabolic equation

$$C = a_1 (Q)^{b_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.6)$$

in which $a = \log a_1$

Equation (4.3) is a multiple linear regression with three variables which can be expressed by the power equation

$$C = a_1 (Q)^{b_1} \cdot (Q_a)^{b_3} \quad \ldots\ldots\ldots\ldots\ldots \quad (4.7)$$

in which $a = \log a_1$

The term of $(\log Q)^2$ in equation (4.2) and (4.4) indicates a curved tendency in one direction. Equation (4.2) and (4.4) can be treated as multiple linear regression, respectively, by considering $(\log Q)^2$ as a new variable. These two equations can also be expressed as a power equation individually.

$$C = a_1 Q^{(b_1 + b_2 \log Q)} \quad \ldots\ldots\ldots\ldots\ldots \quad (4.8)$$

$$C = a_1 Q^{(b_1 + b_2 \log Q)} \cdot Q_a^{b_3} \quad \ldots\ldots\ldots \quad (4.9)$$

in which $a = \log a_1$

Analytical Methods for Determining Parameters of Linear Regression

The solution of the intercept and regression coefficient in the regression equation is based on the application of the least-square principle. An electronic computer was used to perform the operations in solving the regression problems of this study.

1. Simple Linear Regression (14)

   The typical equation of simple linear regression is

   $$Y = a + bX \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.10)$$

   Formulas for computing the regression coefficient, b, and the Y intercept, a, are

   $$b = \frac{\Sigma xy}{\Sigma x^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.11)$$

   in which
   $$\begin{aligned} \Sigma xy &= \Sigma(X - \overline{X})(Y - \overline{Y}) \\ &= \Sigma XY - N\,\overline{X}\,\overline{Y} \\ \Sigma x^2 &= \Sigma\,(X - \overline{X})^2 \\ &= \Sigma\,X^2 - N\,\overline{X}^2 \end{aligned}$$

   and
   $$a = \overline{Y} - b\,\overline{X} \quad \ldots\ldots\ldots\ldots \quad (4.12)$$

   $\overline{X}$ and $\overline{Y}$ are means of the independent variable, X, and the dependent variable, Y, respectively, and N is the number of paired observations.

2. Multiple linear regression (5) (14)

   The regression coefficients and intercept in a multiple linear regression are computed from normal equations. For the linear regression having two independent variables

$$Y = a_{y \cdot 12} + b_{y1 \cdot 2} X_1 + b_{y2 \cdot 1} X_2 \quad \ldots\ldots\ldots \quad (4.13)$$

the normal equations are

$$\Sigma(x_1^2)\, b_{y1 \cdot 2} + \Sigma(x_1 x_2)\, b_{y2 \cdot 1} = \Sigma(yx_1) \quad \ldots\ldots \quad (4.14)$$

$$\Sigma(x_1 x_2)\, b_{y1 \cdot 2} + \Sigma(x_2^2)\, b_{y2 \cdot 1} = \Sigma(yx_2) \quad \ldots\ldots \quad (4.15)$$

and the Y intercept is

$$a_{y \cdot 12} = \overline{Y} - b_{y1 \cdot 2} \overline{X}_1 - b_{y2 \cdot 1} \overline{X}_2 \quad \ldots\ldots\ldots\ldots \quad (4.16)$$

where Y and $\overline{Y}$ indicate a particular value and the mean of dependent variable, respectively, y represents $(Y - \overline{Y})$, the symbol $\overline{X}_i$ indicates the mean of the i^{th} independent variable, X_i represents a particular value of the i^{th} variable, and x_i represents $(X_i - \overline{X}_i)$, the deviation from the mean of that variable. The b's are termed partial regression coefficients (net regression coefficients). The constant $b_{y1 \cdot 2}$ is termed the partial regression of Y on X_1, holding X_2 constant, and $b_{y2 \cdot 1}$ termed the partial regression of Y on X_2, holding X_1 constant. All that means for $b_{y1 \cdot 2}$, for example, is "the average change observed in Y with unit changes in X_1, determined while simultaneously eliminating from Y any variation accompanying changes in X_2."

For the linear regression having three independent variables

$$Y = a_{y \cdot 123} + b_{y1 \cdot 23} X_1 + b_{y2 \cdot 13} X_2 + b_{y3 \cdot 12} X_3 \quad \ldots \quad (4.17)$$

the normal equations are

$$\Sigma(x_1^2)\ b_{y1\cdot23} + \Sigma(x_1x_2)\ b_{y2\cdot13} + \Sigma(x_1x_3)\ b_{y3\cdot12} = \Sigma(yx_1) \quad . . . . . . (4.18)$$

$$\Sigma(x_1x_2)\ b_{y1\cdot23} + \Sigma(x_2^2)\ b_{y2\cdot13} + \Sigma(x_2\ x_3)\ b_{y3\cdot12} = \Sigma(yx_2) \quad . . . . . (4.19)$$

$$\Sigma(x_1x_3)\ b_{y1\cdot23} + \Sigma(x_2x_3)\ b_{y2\cdot13} + \Sigma(x_3^2)\ b_{y3\cdot12} = \Sigma(yx_3) \quad . . . . . . (4.20)$$

and the Y intercept is

$$a_{y\cdot123} = \overline{Y} - b_{y1\cdot23}\ \overline{X}_1 - b_{y2\cdot13}\ \overline{X}_2 - b_{y3\cdot12}\ \overline{X}_3 \quad . . . . . . (4.21)$$

where the symbols are the same as before and the meaning for each of the b's can also be interpreted by the way mentioned before.

The normal equations are customarily solved by utilizing the Doolittle method (16), a simplified method of solving simultaneous equations having a certain symmetry.

Correlation Analysis

Correlation is a measure of the degree to which variables vary together or a measure of the intensity of association. The correlation coefficient is a mathematical definition of that association. However, distinctions between correlation and regression have been made by Dixon and Massey (14):

> "A regression problem considers the frequency distribution of one variable when another is held fixed at each of several levels. A correlation problem considers the joint variation of two measurements, neither of which is restricted by the experiment."

There are two principal requirements in applying the method of correlation analysis (14). One is that the data be obtained randomly from a bivariate normal distribution. Another is that both the dependent and independent variables be without measureable error. However, in 1957 McDonald (14) reported that experimental sampling studies showed that nonnormality effects are of inconsequential magnitude geophysically. In addition to that, the measured errors of data used in this study are obviously negligible. Based on these two reasons the method of correlation analysis is applicable in this study.

The analysis of correlation coefficient will be discussed in a later section.

Statistical Inference

1. Standard Error of Estimate

The reliability of a regression is measured by the standard error of estimate (also called standard deviation of residuals), which is the standard deviation of the distribution (assumed normal) of residuals about the regression equation. For the simple linear regression

$$\hat{Y} = a + bX \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.22)$$

the standard error of estimate is given by (16)

$$S_{y \cdot x} = \sqrt{\frac{\Sigma\,(Y-\hat{Y})^2}{N-2}} \quad \ldots\ldots\ldots \quad (4.23)$$

in which N is the sample size, Y is the observed value, and $\hat{Y}$ is the value determined from the straight regression line for a given X value.

For the multiple linear regression

$$\hat{Y} = a + b_{y1\cdot234\cdots k} X_1 + b_{y2\cdot134\cdots k} X_2 + \cdots$$
$$+ b_{yk\cdot123\cdots(k-1)} X_k \quad \ldots\ldots\ldots\ldots \quad (4.24)$$

the standard error of estimate is given by

$$S_{y\cdot123\cdots k} = \sqrt{\frac{\Sigma (Y - \hat{Y})^2}{N - k - 1}} \quad \ldots\ldots\ldots\ldots \quad (4.25)$$

in which k is the number of independent variables, Y is the observed value, and $\hat{Y}$ is the value estimated from equation (4.24).

The standard error of estimate for the simple linear regression is the simplest form of that multiple linear regression with k = 1.

The addition of a new independent variable X_{k+1} in a multiple linear regression will decrease the standard error of estimate if this variable influences the dependent variable Y (18). Whether this variable should be included in the multiple regression can be determined by examining how much the standard error of estimate is decreased and by checking results of the significance test for partial regression coefficients.

2. Significance Test for Regression

For a multiple linear regression with k independent variables, the reduction in sum of squares attributed to regression can be tested for significance by the statistic

$$F = \frac{\text{regression SS}/k}{\text{residual SS}/(N - k - 1)} \quad (11) \quad \ldots\ldots\ldots\ldots \quad (4.26)$$

with k and (N - k - 1) degrees of freedom.

The null hypothesis is written

$$H_0 : \beta_1 = \beta_2 = . . . \beta_k = 0$$

that is, we hypothesize that all true k partial regression coefficients, β_1, β_2, ..., and β_k, estimated by b_1, b_2, ... and b_k, are equal to zero. If the calculated F is larger than the tabulated F, it indicates the fact that not all the partial regression coefficients are significantly equal to zero, therefore H_0 has to be rejected. A significant result indicates that at least one independent variable used in the linear regression affects the mean of the dependent variable.

When k is equal to 1, the multiple linear regression becomes a simple linear regression and equation (4.26) becomes the statistic

$$F = \frac{\text{regression SS}/1}{\text{residual SS}/(N - 2)} \quad . . . . \quad (4.27)$$

with 1 and (N - 2) degree of freedom.

3. Significance Test for Partial Regression Coefficient

The statistic t is usually used in a significance test for the partial regression coefficient. In testing the hypothesis that a true partial regression coefficient β_i, estimated by b_i, is equal to zero, that is

$$H_0 : \beta_i = 0$$

the statistic t becomes

$$t = \frac{b_i}{S_{b_i}} \quad (11) \quad \ldots\ldots\ldots\ldots\ldots (4.28)$$

where b_i is a calculated regression coefficient and S_{b_i} is the standard error of estimate for b_i, given by

$$S_{b_i} = \sqrt{C_{ii} \cdot S^2_{y \cdot 12 \ldots k}} \quad \ldots\ldots\ldots (4.29)$$

in which C_{ii} is an element occupying the i^{th} row and the i^{th} column of the inverse of a k x k matrix, and $S_{y \cdot 12 \ldots k}$ is the standard error of estimate for the multiple linear regression. Several levels of significance, such as 0.1%, 1%, 5%, 10%, 20%, and 30%, were used in this study to test the significance of each partial regression coefficient calculated. If the calculated t from equation (4.28) is larger than the tabulated t at a certain significance level and with (N - k - 1) degrees of freedom, the hypothesis, $H_0 : \beta_i = 0$, should be rejected. That means that the partial regression coefficient tested is significantly different from zero.

When k = 1, the multiple linear regression becomes a simple linear regression and equation (4.28) becomes

$$t = \frac{b}{\sqrt{S^2_{y \cdot x} / \Sigma(X-\overline{X})^2}} \quad (11) \quad \ldots\ldots\ldots\ldots (4.30)$$

With (N - 2) degrees of freedom, in which X and $\overline{X}$ is a particular value and the mean of independent variable, respectively.

4. Simple Correlation Coefficient

The correlation coefficient, r, is defined as the square root of the ratio of the regression sum of squares to the total sum of squares.

$$r = \sqrt{\frac{\text{regression SS}}{\text{total SS}}} \quad (11) \quad \ldots\ldots\ldots\ldots \quad (4.31)$$

it can also be expressed by

$$r = \frac{\Sigma(X-\overline{X})\ (Y-\overline{Y})}{\sqrt{\Sigma(X-\overline{X})^2\ \Sigma(Y-\overline{Y})^2}} \quad (16) \quad \ldots\ldots\ldots \quad (4.32)$$

in which $\overline{X}$ and $\overline{Y}$ are the arithmetic means of the variable X and Y. Values of r from -1 to 1 indicate whether the estimated regression line has a positive or negative slope.

The simple correlation coefficient may be used as an index measuring the closeness of fit of the N observed points to the estimated line of regression; the larger the absolute value of r, the closer the points will fit the line.

5. Multiple Correlation Coefficient

The multiple correlation coefficient is also defined by equation (4.31), but it can only range from zero to one. It provides a measure of the degree to which the dependent variable Y is influenced by the k independent variables X_i.

6. Reliability of Correlation Coefficient

The reliability of the correlation coefficient depends on the size of sample, the magnitude of computed coefficient, and the number of independent variables (5). In general the confidence interval is quite wide for samples of 30 items or less, unless the correlation coefficient is very large (14). In this study, because the periods of available water quality records at investigated stations are less than 30 years, the intention of making the correlation analysis was only for comparing calculated correlation coefficients among stations and months.

CHAPTER V

RESULTS

All results included in this chapter resulted from applications of statistical methods described in Chapter IV. Selected regression models for different cases are summarized in Table VIII. Tables IX to XX show results of the regression analysis for each month. All models selected are significant in regression at the one per cent level. The regression coefficients of each model selected are shown with different symbols based on results of the significance test at the level of 0.1%, 1%, 5%, 10%, 20%, and 30%, respectively.

Because of the small sample size of available water quality data for each month, the level of significance adopted in this study to test the significance of regression effect was one per cent. Results of the significance test were used to justify whether a regression relationship between streamflow and inorganic quality of river water should be recognized or not.

Station 7-1465 (Arkansas River at Arkansas City, Kansas)

Streamflow and Chlorides

The concentration of chlorides has a highly significant regression relation with the streamflow. Obviously, an additional consideration of the antecedent flow with the current monthly streamflow makes a significant improvement in the reliability of the regression equation for the

TABLE VIII

SUMMARY OF REGRESSION MODELS FOR THE QUALITY AND QUANTITY OF RIVER WATER BY MONTHS

Station	Water Quality	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
7-1465	Chlorides	1	1	1	1	3	3	3	1	1	1	1	1
	Diss. Solids	-	-	3	3	1	3	3	3	3	1	-	-
	Hardness	-	-	-	-	-	3	3	3	1	-	-	-
	Sulfates	-	-	-	-	3	3	3	-	-	-	-	-
7-1525	Chlorides	1	4	1	3	-	1	1	1	3	3	1	1
	Diss. Solids	1	1	3	1	-	1	1	1	3	1	3	1
	Hardness	-	-	-	-	-	-	3	3	3	-	-	-
	Sulfates	-	-	-	3	-	-	3	-	3	-	-	-
7-1610	Chlorides	2	4	3	3	3	3	1	2	-	-	-	-
	Diss. Solids	2	4	3	3	3	3	1	2	-	-	-	-
	Hardness	-	-	-	-	-	-	3	-	-	-	-	-
	Sulfates	2	-	-	-	-	-	-	-	-	-	-	1
7-1644	Chlorides	-	2	3	3	3	1	1	1	3	1	1	1
	Diss. Solids	-	3	3	3	3	1	1	1	3	1	1	1
	Hardness	-	-	-	-	3	-	3	3	1	1	-	3
	Sulfates	-	-	-	-	-	-	-	-	3	-	-	-
7-2505	Chlorides	-	-	-	1	-	1	1	1	2	-	1	-
	Diss. Solids	-	3	-	4	-	1	1	1	2	-	3	-
	Hardness	-	-	-	3	-	1	1	-	3	-	3	3
	Sulfates	-	-	-	-	-	-	-	-	4	-	-	-

<u>Model 1</u>:
$\text{Log } C = a + b_1 \text{ Log } Q$

<u>Model 2</u>:
$\text{Log } C = a + b_1 \text{ Log } Q + b_2 (\text{Log } Q)^2$

<u>Model 3</u>:
$\text{Log } C = a + b_1 \text{ Log } Q + b_3 \text{ Log } Qa$

<u>Model 4</u>:
$\text{Log } C = a + b_1 \text{ Log } Q + b_2(\text{Log } Q)^2 + b_3 \text{ Log } Qa$

- :
No significant regression model has been found.

Remarks: 1. All models indicated are significant in regression at the 1% level.

2. C is monthly concentration of water quality, Q is current monthly streamflow, Qa denotes antecedent flow index, a is the intercept of regression equation, and b's are the coefficients of regression.

TABLE IX

RESULTS OF REGRESSION ANALYSIS OF JANUARY QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	log $\overline{C}$
7-1465	Chlorides	1	3.45866	-0.27460***			0.91255	0.04067	2.66804
	Diss. Solids	-							3.14273
	Hardness	-							2.80434
	Sulfates	-							2.36736
7-1525	Chlorides	1	3.44452	-0.23490***			0.90961	0.04624	2.71141
	Diss. Solids	1	3.53196	-0.11875***			0.79359	0.03924	3.16135
	Hardness	-							2.80915
	Sulfates	-							2.35567
7-1610	Chlorides	2	1.67839	1.87080***	-0.44700***		0.91869	0.07432	3.49192
	Diss. Solids	2	2.17290	1.63405***	-0.38458***		0.92484	0.06319	3.78808
	Hardness	-							3.08379
	Sulfates	2	1.55921	0.87351***	-0.16766***		0.96445	0.03859	2.62443
7-1644	Chlorides	-							3.11339
	Diss. Solids	-							3.45022
	Hardness	-							2.92239
	Sulfates	-							2.39411
7-2505	Chlorides	-							2.55078
	Diss. Solids	-							2.95326
	Hardness	-							2.53867
	Sulfates	-							1.83720

*** Significant at the 0.1% level.

** Significant at the 1% level.

* Significant at the 5% level.

† Significant at the 10% level.

ǂ Significant at the 20% level.

‡ Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\overline{C}$: Mean Concentration of Water Quality

TABLE X

RESULTS OF REGRESSION ANALYSIS OF FEBRUARY QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	log $\overline{C}$
7-1465	Chlorides	1	3.36293	-0.24845***			0.81125	0.05605	2.62221
	Diss. Solids	-							3.10458
	Hardness	-							2.75992
	Sulfates	-							2.34508
7-1525	Chlorides	4	1.52288	1.33659*	-0.20451*	-0.29132†	0.93182	0.05080	2.68038
	Diss. Solids	1	3.61027	-0.14782***			0.76664	0.05246	3.13518
	Hardness	-							2.79090
	Sulfates	-							2.33894
7-1610	Chlorides	4	1.62450	2.09367**	-0.38790***	-0.30988*	0.89564	0.08413	3.53389
	Diss. Solids	4	2.15080	1.81782**	-0.33437**	-0.26726*	0.88271	0.07630	3.82798
	Hardness	-							3.08076
	Sulfates	-							2.63828
7-1644	Chlorides	2	2.19105	0.80685†	-0.15916**		0.91441	0.07183	3.07066
	Diss. Solids	2	2.08871	1.01798**	-0.18265**		0.91739	0.06180	3.40728
	Hardness	-							2.87730
	Sulfates	-							2.34346
7-2505	Chlorides	-							2.42549
	Diss. Solids	3	4.19106	-0.52410**		0.20420ǂ	0.75365	0.16585	2.86567
	Hardness	-							2.44107
	Sulfates	-							1.77595

*** Significant at the 0.1% level.

** Significant at the 1% level.

* Significant at the 5% level.

† Significant at the 10% level.

‡ Significant at the 20% level.

ǂ Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\overline{C}$: Mean Concentration of Water Quality

TABLE XI

RESULTS OF REGRESSION ANALYSIS OF MARCH QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	log $\bar{C}$
7-1465	Chlorides	1	3.64550	-0.34066***			0.96051	0.03761	2.60092
	Diss. Solids	3	3.45446	-0.29761***		0.17332†	0.81888	0.05576	3.09764
	Hardness	-							3.08965
	Sulfates	-							2.35589
7-1525	Chlorides	1	3.73623	-0.32247***			0.92976	0.06194	2.66322
	Diss. Solids	3	3.71255	-0.32945***		0.14480*	0.91041	0.05296	3.11480
	Hardness	-							2.75543
	Sulfates	-							2.33126
7-1610	Chlorides	3	4.24075	-0.09938✠		-0.16405*	0.90789	0.06577	3.56600
	Diss. Solids	3	4.40509	-0.09034‡		-0.12429†	0.90453	0.05430	3.85711
	Hardness	-							3.10645
	Sulfates	-							2.67192
7-1644	Chlorides	3	3.95400	-0.11034‡		-0.14704†	0.82172	0.08487	3.04039
	Diss. Solids	3	4.10590	-0.13720*		-0.06936✠	0.85208	0.06138	3.37688
	Hardness	-							2.83897
	Sulfates	-							2.35578
7-2505	Chlorides	-							2.36003
	Diss. Solids	-							2.81446
	Hardness	-							2.40498
	Sulfates	-							1.76112

***
Significant at the 0.1% level.

**
Significant at the 1% level.

*
Significant at the 5% level.

†
Significant at the 10% level.

‡
Significant at the 20% level.

✠
Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\bar{C}$: Mean Concentration of Water Quality

TABLE XII

RESULTS OF REGRESSION ANALYSIS OF APRIL QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	$\log \bar{C}$
7-1465	Chlorides	1	3.65690	-0.34503***			0.91028	0.05070	2.58943
	Diss. Solids	3	3.49662	-0.29636***		0.15065*	0.82728	0.05077	3.07537
	Hardness	-							3.10366
	Sulfates	-							2.33153
7-1525	Chlorides	3	3.95247	-0.26828**		-0.11735‡	0.83670	0.10791	2.62845
	Diss. Solids	1	3.87277	-0.23532***			0.82634	0.07241	3.07623
	Hardness	-							2.70592
	Sulfates	3	2.60815	-0.33597**		0.22404*	0.73640	0.11938	2.26501
7-1610	Chlorides	3	4.38795	-0.10267†		-0.23706**	0.88645	0.07978	3.48522
	Diss. Solids	3	4.50225	-0.08752†		-0.18582**	0.83830	0.07969	3.77649
	Hardness	-							3.05635
	Sulfates	-							2.63798
7-1644	Chlorides	3	4.26913	-0.18357**		-0.17350**	0.87040	0.08867	2.95817
	Diss. Solids	3	4.35188	-0.17456**		-0.11120*	0.85443	0.07709	3.30299
	Hardness	-							2.77769
	Sulfates	-							2.30063
7-2505	Chlorides	1	4.61670	-0.50887***			0.87727	0.12845	2.36503
	Diss. Solids	4	11.01380	-3.74701*	0.38285†	0.17535✱	0.91126	0.09154	2.80030
	Hardness	1	3.78190	-0.31264***			0.81974	0.10078	2.39851
	Sulfates	-							1.75127

***
Significant at the 0.1% level.

**
Significant at the 1% level.

*
Significant at the 5% level.

†
Significant at the 10% level.

‡
Significant at the 20% level.

✱
Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\bar{C}$: Mean Concentration of Water Quality

TABLE XIII

RESULTS OF REGRESSION ANALYSIS OF MAY QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	log $\overline{C}$
7-1465	Chlorides	3	3.98479	-0.24380***		-0.19527**	0.94643	0.05158	2.53608
	Diss. Solids	1	3.81365	-0.24917***			0.88984	0.05237	3.00191
	Hardness	-							3.27773
	Sulfates	3	2.16499	-0.34512***		0.34659***	0.84702	0.07292	2.20223
7-1525	Chlorides	-							2.55060
	Diss. Solids	-							2.99815
	Hardness	-							2.60790
	Sulfates	-							2.14434
7-1610	Chlorides	3	4.37479	-0.12150*		-0.23617*	0.84051	0.11084	3.34405
	Diss. Solids	3	4.52934	-0.11523*		-0.18773*	0.83410	0.09764	3.65474
	Hardness	-							2.98154
	Sulfates	-							2.56761
7-1644	Chlorides	3	4.22005	-0.13601*		-0.21498**	0.82755	0.10375	2.85437
	Diss. Solids	3	4.33160	-0.13117*		-0.15613**	0.82944	0.08494	3.21259
	Hardness	3	3.56361	-0.14230*		-0.07775ǂ	0.71610	0.09926	2.70419
	Sulfates	-							2.23421
7-2505	Chlorides	-							2.23811
	Diss. Solids	-							2.70320
	Hardness	-							2.31888
	Sulfates	-							1.67327

***	Significant at the 0.1% level.
**	Significant at the 1% level.
*	Significant at the 5% level.
†	Significant at the 10% level.
‡	Significant at the 20% level.
ǂ	Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\overline{C}$: Mean Concentration of Water Quality

TABLE XIV

RESULTS OF REGRESSION ANALYSIS OF JUNE QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	log $\overline{C}$
7-1465	Chlorides	3	3.79356	-0.54487***		0.12485⹋	0.95027	0.08275	2.45707
	Diss. Solids	3	3.82147	-0.43418***		0.15523*	0.95823	0.05698	2.95031
	Hardness	3	2.79084	-0.32863***		0.24568*	0.81156	0.09373	2.57715
	Sulfates	3	2.45600	-0.42022***		0.31122*	0.81417	0.11883	2.17254
7-1525	Chlorides	1	4.01221	-0.39343***			0.76579	0.17474	2.56118
	Diss. Solids	1	4.09519	-0.29651***			0.76556	0.13179	3.00163
	Hardness	-							2.60567
	Sulfates	-							2.14421
7-1610	Chlorides	3	4.16983	-0.13413*		-0.16676*	0.88513	0.09826	3.22648
	Diss. Solids	3	4.38110	-0.12434*		-0.14175*	0.88487	0.08736	3.54686
	Hardness	-							2.91836
	Sulfates	-							2.48489
7-1644	Chlorides	1	4.34459	-0.39420***			0.82931	0.12123	2.79126
	Diss. Solids	1	4.35059	-0.30158***			0.80281	0.10223	3.16225
	Hardness	-							2.64789
	Sulfates	-							2.20831
7-2505	Chlorides	1	4.28447	-0.43013***			0.81044	0.13629	2.33643
	Diss. Solids	1	4.16633	-0.30168***			0.81534	0.09729	2.80187
	Hardness	1	3.58808	-0.26032***			0.76847	0.09844	2.41069
	Sulfates	-							1.82335

***
Significant at the 0.1% level.

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Significant at the 1% level.

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Significant at the 5% level.

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Significant at the 10% level.

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Significant at the 20% level.

⹋
Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\overline{C}$: Mean Concentration of Water Quality

TABLE XV

RESULTS OF REGRESSION ANALYSIS OF JULY QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	log $\bar{C}$
7-1465	Chlorides	3	3.36586	-0.61267***		0.29357*	0.95238	0.08751	2.48807
	Diss. Solids	3	3.37472	-0.45968***		0.29401**	0.94016	0.06785	2.97629
	Hardness	3	2.31781	-0.42991***		0.46225***	0.89218	0.07676	2.60601
	Sulfates	3	1.82298	-0.42580***		0.47931***	0.84113	0.09648	2.18422
7-1525	Chlorides	1	3.84722	-0.36449***			0.85258	0.14452	2.51931
	Diss. Solids	1	3.89277	-0.25419***			0.87151	0.09251	2.96672
	Hardness	3	2.68624	-0.31350***		0.26328**	0.85376	0.08346	2.58187
	Sulfates	3	2.22199	-0.29231**		0.24230*	0.74782	0.11358	2.11214
7-1610	Chlorides	1	3.89821	-0.22001***			0.88621	0.06982	3.27625
	Diss. Solids	1	4.14112	-0.19689***			0.88438	0.06308	3.58453
	Hardness	3	3.11157	-0.25921***		0.16697**	0.85165	0.08325	2.93757
	Sulfates	-							2.48488
7-1644	Chlorides	1	4.15775	-0.36076***			0.83696	0.14341	2.76955
	Diss. Solids	1	4.26022	-0.29181***			0.83030	0.11908	3.13733
	Hardness	3	3.20913	-0.32346***		0.16479†	0.82274	0.11331	2.65510
	Sulfates	-							2.16410
7-2505	Chlorides	1	4.29640	-0.44990***			0.87809	0.13357	2.29101
	Diss. Solids	1	4.16517	-0.31446***			0.89238	0.08947	2.75976
	Hardness	1	3.52366	-0.25506***			0.84931	0.08920	2.38375
	Sulfates	-							1.78122

***
Significant at the 0.1% level.

**
Significant at the 1% level.

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Significant at the 5% level.

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Significant at the 10% level.

‡
Significant at the 20% level.

ǂ
Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\bar{C}$: Mean Concentration of Water Quality

TABLE XVI

RESULTS OF REGRESSION ANALYSIS OF AUGUST QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	log $\overline{C}$
7-1465	Chlorides	1	3.68975	-0.38181***			0.94568	0.07651	2.57913
	Diss. Solids	3	3.63562	-0.33463***		0.10529*	0.95090	0.05502	3.03016
	Hardness	3	2.73472	-0.31369***		0.23817*	0.83979	0.08578	2.66363
	Sulfates	-							2.19483
7-1525	Chlorides	1	3.66882	-0.32528***			0.92020	0.09164	2.59275
	Diss. Solids	1	3.79694	-0.23603***			0.89251	0.07899	3.01610
	Hardness	3	2.71402	-0.28572***		0.21823**	0.82511	0.08668	2.63662
	Sulfates	-							2.15665
7-1610	Chlorides	2	3.06494	0.60263*	-0.17975*		0.90186	0.07777	3.38675
	Diss. Solids	2	3.41180	0.51738†	-0.15546*		0.86892	0.08112	3.68047
	Hardness	-							2.99624
	Sulfates	-							2.54474
7-1644	Chlorides	1	4.08394	-0.33591***			0.91757	0.08733	2.89611
	Diss. Solids	1	4.23955	-0.28155***			0.91161	0.07617	3.24359
	Hardness	3	3.33685	-0.37367***		0.17159*	0.89254	0.09080	2.73915
	Sulfates	-							2.23025
7-2505	Chlorides	1	3.81955	-0.35184**			0.73952	0.16209	2.38143
	Diss. Solids	1	3.81129	-0.24113**			0.73959	0.11525	2.82529
	Hardness	-							2.42818
	Sulfates	-							1.81482

***
Significant at the 0.1% level.

**
Significant at the 1% level.

*
Significant at the 5% level.

†
Significant at the 10% level.

‡
Significant at the 20% level.

✱
Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\overline{C}$: Mean Concentration of Water Quality

TABLE XVII

RESULTS OF REGRESSION ANALYSIS OF SEPTEMBER QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	log $\overline{C}$
7-1465	Chlorides	1	3.79928	-0.43054***			0.91132	0.13786	2.53243
	Diss. Solids	3	3.55772	-0.44804***		0.22497‡	0.92761	0.09116	2.99921
	Hardness	1	3.23038	-0.20325***			0.85012	0.09288	2.63224
	Sulfates	-							2.13338
7-1525	Chlorides	3	3.19705	-0.44693***		0.22046‡	0.91581	0.12418	2.56249
	Diss. Solids	3	3.39221	-0.34736***		0.19669*	0.93799	0.07703	2.99618
	Hardness	3	2.84214	-0.21256***		0.12047‡	0.84036	0.08134	2.60020
	Sulfates	3	2.10478	-0.25193**		0.22125*	0.77085	0.09912	2.11884
7-1610	Chlorides	-							3.27869
	Diss. Solids	-							2.44378
	Hardness	-							2.91378
	Sulfates	-							2.44378
7-1644	Chlorides	3	3.89197	-0.49549***		0.18571†	0.95433	0.09561	2.92842
	Diss. Solids	3	4.08067	-0.43846***		0.17474†	0.95773	0.08005	3.27053
	Hardness	1	3.78614	-0.29326***			0.87157	0.12518	2.76753
	Sulfates	3	2.05439	-0.34922***		0.33748*	0.78693	0.11322	2.21800
7-2505	Chlorides	2	-1.26230	2.30518**	-0.33901***		0.90631	0.11990	2.41125
	Diss. Solids	2	0.43211	1.51562***	-0.22249**		0.94013	0.06216	2.86087
	Hardness	2	1.38108	0.75363‡	-0.11862*		0.82734	0.08322	2.45892
	Sulfates	4	-1.61558	1.58000**	-0.22440**	0.16948‡	0.82508	0.08490	1.82293

***
Significant at the 0.1% level.

**
Significant at the 1% level.

*
Significant at the 5% level.

†
Significant at the 10% level.

‡
Significant at the 20% level.

⹋
Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\overline{C}$: Mean Concentration of Water Quality

TABLE XVIII

RESULTS OF REGRESSION ANALYSIS OF OCTOBER QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	log $\overline{C}$
7-1465	Chlorides	1	3.51023	-0.32102***			0.95162	0.06562	2.54676
	Diss. Solids	1	3.64768	-0.20958***			0.91292	0.05931	3.01868
	Hardness	-							3.01857
	Sulfates	-							2.17407
7-1525	Chlorides	3	3.48815	-0.18597**		-0.07351‡	0.92889	0.08257	2.60175
	Diss. Solids	1	3.59396	-0.16765***			0.89562	0.06849	3.04211
	Hardness	-							2.68139
	Sulfates	-							2.17745
7-1610	Chlorides	-							3.28786
	Diss. Solids	-							2.44258
	Hardness	-							2.96761
	Sulfates	-							2.44258
7-1644	Chlorides	1	3.98767	-0.30956***			0.88199	0.12380	2.93578
	Diss. Solids	1	4.13957	-0.25236***			0.88820	0.09771	3.28204
	Hardness	1	3.41803	-0.18004***			0.76742	0.11258	2.80625
	Sulfates	-							2.20669
7-2505	Chlorides	-							2.43100
	Diss. Solids	-							2.91229
	Hardness	-							2.50028
	Sulfates	-							1.84717

***
Significant at the 0.1% level.

**
Significant at the 1% level.

*
Significant at the 5% level.

†
Significant at the 10% level.

‡
Significant at the 20% level

ǂ
Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\overline{C}$: Mean Concentration of Water Quality

TABLE XIX

RESULTS OF REGRESSION ANALYSIS OF NOVEMBER QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	log $\overline{C}$
7-1465	Chlorides	1	3.35622	-0.25584***			0.90354	0.06052	2.59261
	Diss. Solids	-							3.06602
	Hardness	-							2.72508
	Sulfates	-							2.22799
7-1525	Chlorides	1	3.51303	-0.27214***			0.91406	0.07412	2.64405
	Diss. Solids	3	3.65495	-0.28324***		0.09289⧧	0.89483	0.06040	3.09043
	Hardness	-							2.74227
	Sulfates	-							2.22744
7-1610	Chlorides	-							3.37521
	Diss. Solids	-							2.51153
	Hardness	-							3.02826
	Sulfates	-							2.51153
7-1644	Chlorides	1	3.87949	-0.26429***			0.79226	0.11285	3.00171
	Diss. Solids	1	4.04751	-0.21268***			0.78305	0.09366	3.34107
	Hardness	-							2.84353
	Sulfates	-							2.24913
7-2505	Chlorides	1	4.36365	-0.47476***			0.79181	0.18006	2.47401
	Diss. Solids	3	3.87337	-0.36347**		0.11277‡	0.78367	0.11066	2.93561
	Hardness	3	3.46900	-0.37665**		0.12355⧧	0.78100	0.11466	2.52580
	Sulfates	-							1.84334

***
Significant at the 0.1% level.

**
Significant at the 1% level.

*
Significant at the 5% level.

†
Significant at the 10% level.

‡
Significant at the 20% level.

⧧
Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\overline{C}$: Mean Concentration of Water Quality

TABLE XX

RESULTS OF REGRESSION ANALYSIS OF DECEMBER QUALITY AND QUANTITY OF RIVER WATER

Station	Water Quality	Model	a	b_1	b_2	b_3	r	s	log $\overline{C}$
7-1465	Chlorides	1	3.31611	-0.23038***			0.87235	0.04427	2.65047
	Diss. Solids	-							3.11636
	Hardness	-							2.75913
	Sulfates	-							2.30125
7-1525	Chlorides	1	3.49244	-0.25883***			0.92170	0.05213	2.68443
	Diss. Solids	1	3.55679	-0.13467***			0.81527	0.04578	3.13638
	Hardness	-							2.79595
	Sulfates	-							2.30432
7-1610	Chlorides	-							3.46537
	Diss. Solids	-							2.59284
	Hardness	-							3.07363
	Sulfates	1	2.35266	0.10593**			0.70924	0.07999	2.59284
7-1644	Chlorides	1	3.90276	-0.25643***			0.77143	0.09710	3.07043
	Diss. Solids	1	3.98890	-0.17983***			0.73508	0.07614	3.40521
	Hardness	3	3.52055	-0.35645**		0.14798†	0.74327	0.08693	2.90928
	Sulfates	-							2.34525
7-2505	Chlorides	-							2.56376
	Diss. Solids	-							2.96634
	Hardness	3	3.58599	-0.41381**		0.13830‡	0.74772	0.10631	2.55594
	Sulfates	-							1.85992

***
Significant at the 0.1% level.

**
Significant at the 1% level.

*
Significant at the 5% level.

†
Significant at the 10% level.

‡
Significant at the 20% level.

✱
Significant at the 30% level.

a: Intercept

b's: Regression Coefficients

r: Correlation Coefficient

s: Standard Error of Estimate for Regression Equation

$\overline{C}$: Mean Concentration of Water Quality

months of May, June, and July. No significant influence of antecedent streamflow to the change of chloride concentration has been found from August to April.

The constants of the regression equation for each of the months from November to February are very close.

Streamflow and Dissolved Solids

For the months of the winter season, the regression relation between the concentration of dissolved solids and the streamflow is insignificant. But for the months from March to September with the exception of May the combined influence of current monthly flow and its antecedent flow to the concentration of dissolved solids is pronounced. This combined influence is especially obvious in June, July, and August.

Streamflow and Hardness

Only in the months from June to September was a significant relationship between the concentration of hardness and streamflow found. For the months of June, July, and August, consideration of the antecedent flow with its current monthly streamflow has made an improvement in the results of the study for hardness-streamflow relationship at this station.

Streamflow and Sulfates

No significant regression relationship has been found for the months from August to April. However, for the months of May, June, and July, the combined influence of current monthly streamflow and antecedent flow is significant to the change of sulfate concentration in river water.

Station 7-1525 (Arkansas River at Ralston, Oklahoma)

Streamflow and Chlorides

With the exception of May, there is a significant regression relationship between the concentration of chlorides and the streamflow on each month. Based on the calculated correlation coefficients and the standard errors of estimate, the regression equations derived for the months from August to March are more reliable than those derived for the months from April to July. For the months of February, April, September and October, an additional consideration of the antecedent flow to the preliminary regression model used, $\log C = a + b_1 \log Q$, has improved the results of the study of regression relationship. For February, the addition of a term $(\log Q)^2$, which indicates a curve tendency of one direction, to the regression model, $\log C = a + b_1 \log Q + b_3 \log Q_a$, has improved the reliability of the regression equation.

Streamflow and Dissolved Solids

The regression relationships between concentration of dissolved solids and streamflow are still significant in each month except May, but in general the reliability of regression equations is less than that for the concentration of chlorides and streamflow. The results also show that in the months of January, June, July, September, and December each regression model found for the concentration of dissolved solids and monthly streamflow is the same as each for the concentration of chlorides and monthly streamflow.

Streamflow and Hardness

Only during the months of July, August, and September was a significant regression equation found in which both the monthly streamflow and its antecedent streamflow are independent variables and the concentration of hardness is a dependent variable.

Streamflow and Sulfates

A common regression model, $\log C = a + b_1 \log Q + b_3 \log Q_a$, was found for expressing the relationship between concentration of sulfates and streamflow for the months of April, July, and September, in which both the current monthly streamflow and its antecedent flow influenced the variation of sulfate concentration in the stream.

Station 7-1610 (Cimarron River at Perkins, Oklahoma)

Streamflow and Chlorides

It was found that a regression relationship existed for chloride concentration and streamflow for the months of January to August. For the months of January, July, and August only the current monthly streamflow has significant influence to the change of chloride concentration in the stream, and for the months from March to June, an additional consideration of antecedent streamflow with its current monthly streamflow makes the regression relation more significant. The influence of antecedent flow is greater than that of current monthly streamflow for March and April and is equally important as that of current monthly streamflow for May and June. A regression equation with combined consideration of current monthly streamflow, antecedent flow, and a term indicating one direction curve tendency, $(\log Q)^2$, makes the regression relationship between chloride concentration and streamflow more significant for February. No significant regression equation in relating chloride concentration and streamflow was found for the months of September to December.

Streamflow and Dissolved Solids

During the months from January to August, the regression model found for dissolved solids and streamflow is consistent with that for chlorides and streamflow. It was found that no significant regression relationship existed for dissolved solids and streamflow for the months from September to December.

Streamflow and Hardness

Only in the month of July was a significant regression equation found in which both the monthly streamflow and its antecedent flow contribute influence to the change of hardness in the stream.

Streamflow and Sulfates

Significant regression equation for sulfates and streamflow was found only in the months of December and January. In December the current monthly streamflow is the only independent variable in the derived regression equation, but in the month of January the current monthly streamflow and an additional term indicating a one-direction curve tendency are the two independent variables in the regression equation.

Station 7-1644 (Arkansas River at Sand Springs Bridge, Near Tulsa, Oklahoma)

Streamflow and Chlorides

It was found that a regression relationship existed for chloride concentration and streamflow in each month except January. For the months of February, June, July, August, October, November, and December, only the current monthly streamflow has significant influence to the change of chloride concentration, and for the months of March, April, May, and September the combined consideration of current monthly streamflow and its antecedent flow has made a significant improvement in expressing the regression relationship between chloride concentration and streamflow.

Streamflow and Dissolved Solids

During the months from February to December a regression relationship between concentration of dissolved solids and streamflow existed, and in each of the months from March to December the model of regression equation for concentration of dissolved solids and streamflow is consistent with that for chloride concentration and streamflow.

Streamflow and Hardness

A regression relationship for concentration of hardness and streamflow was found only in the months of May, July, August, September, October, and December. In the months of September and October only the current monthly streamflow has significant influence to the change of hardness in the stream, but in the months of June, July, August, and December both the current monthly streamflow and its antecedent flow influence the concentration of hardness.

Streamflow and Sulfates

Only in September a regression equation for concentration of suffates and streamflow was found in which the current monthly streamflow and its antecedent flow influence the variation of sulfate concentration in the stream.

Station 7-2505 (Arkansas River at Van Buren, Arkansas)

Streamflow and Chlorides

Only in the months of April, June, July, August, September, and November was a regression relationship for chloride concentration and streamflow found in which the current monthly streamflow has significant influence to the variation of chloride concentration in the stream. For the month of September, an additional consideration of curve tendency, expressed by $(\log Q)^2$, made an improvement in the expression of the regression relationship for chloride concentration and streamflow.

Streamflow and Dissolved Solids

For the months of February, April, June, July, August, September, November, and December, a regression relationship for concentration of dissolved solids and streamflow was found. In the months from June to September, the model of regression equation for concentration of dissolved solids and streamflow is consistent with that for chloride concentration and streamflow. For the months of February, April, and November, the current monthly streamflow and its antecedent flow were considered as independent variables in the regression equation.

Streamflow and Hardness

It was found that only in the months of April, June, July, September, November, and December a regression relationship existed for concentration of hardness and streamflow. In the regression equation for the months of April, September, November, and December both the current monthly streamflow and its antecedent flow were considered as independent variables, whereas in the regression equation for the months of

June and July only the current monthly streamflow was considered as an independent variable.

Streamflow and Sulfates

Only in the month of September a regression equation for concentration of sulfates and streamflow was found, in which the independent variables are current monthly streamflow, antecedent flow, and a term for expressing a curve tendency of the regression equation.

CHAPTER VI

DISCUSSION

Evaluation of the Regression Relationship

General Evaluation

Normally, the concentrations of dissolved minerals in the stream varies inversely with the water discharges. But because of many factors, geological, meterologic, man-made, etc., involved in affecting the relationship between inorganic quality of river water and streamflow, there was no common regression model found in this study. However, four kinds of regression models used in this study have shown a good possibility in detecting the relationship between some parameter of inorganic water quality and streamflow by the application of the regression method. Table XXI shows an outline of the suitability of four regression models for chlorides, dissolved solids, hardness, and sulfates under a combined consideration of the five stations investigated. For relating chloride concentration and streamflow in regression form, model 1 is the most prevailing one with nearly 50 per cent frequency, model 3 is the next one with about 25 per cent frequency, and models 2 and 4 are negligible. For the concentration of dissolved solids and streamflow, the prevalence of model 1 and model 3 is the same with 33 per cent frequency for each. The suitability of models 2 and 4 is not pronounced. For hardness, the prevalence of four regression models used in relating its concentration with streamflow is not good with only 33 per cent frequency in which

TABLE XXI

FITNESS OF APPLIED REGRESSION MODELS FOR WATER QUALITY AND STREAMFLOW

Model		Chlorides	Dissolved Solids	Hardness	Sulfates
1	$\log C = a + b_1 \log Q$	28	20	5	1
2	$\log C = a + b_1 \log Q + b_2(\log Q)^2$	4	3	0	1
3	$\log C = a + b_1 \log Q + b_3 \log Qa$	14	20	15	7
4	$\log C = a + b_1 \log Q + b_2(\log Q)^2 + b_3 \log Qa$	2	2	0	1

Remarks: (1) This table was made by using the data of Table VIII.

(2) Each number listed includes five stations investigated.

(3) Maximum value indicating 100% frequency is 60.

model 3 is the most significant one with 25 per cent frequency. For the concentration of sulfates and streamflow, the frequency of having a significant expression in regression form by applying four models presented is only about 17 per cent, and it is obvious that the suitability of each model is poor.

Based on the results from the application of four regression models, the occurrence of regression relationship existing between each parameter of inorganic water quality and streamflow is compared in Table XXII. In the aspect of showing a regression relationship with streamflow, chloride is the most pronounced one among four parameters of inorganic water quality included in this study; its frequency of having a regression relationship is 80 per cent of total, 100 per cent for station 7-1465, 92 per cent for station 7-1525 and 7-1644, 67 per cent for station 7-1610, and 50 per cent for station 7-2505. The next most pronounced is dissolved solids, nearly as good as chlorides; its frequency is 75 per cent of total, 67 per cent for station 7-1465 and 7-1610, 92 per cent for station 7-1525 and 7-1644, and 60 per cent for station 7-2505. For hardness, the frequency of showing a regression relationship with streamflow is low in general, with 33 per cent of total, 33 per cent for station 7-1465, 25 per cent for station 7-1525, 8 per cent for station 7-1610, and 50 per cent for stations 7-1644 and 7-2505. Sulfate is the most insignificant one in showing a regression relationship with streamflow, with only 17 per cent of frequency for the total, 25 per cent for station 7-1465 and 7-1525, 17 per cent for station 7-1610, and 8 per cent for station 7-1644 and 7-2505.

Table XXII also shows that the stations are different in showing prevalence of the regression relationship between inorganic water

TABLE XXII

OCCURRENCE OF THE REGRESSION RELATIONSHIP FOR PARAMETERS OF WATER QUALITY AND STREAMFLOW

		Station				
Water Quality	Total	7-1465	7-1525	7-1610	7-1644	7-2505
Chlorides	48	12	11	8	11	6
Diss. Solids	45	8	11	8	11	7
Hardness	20	4	3	1	6	6
Sulfates	10	3	3	2	1	1

Remarks: (1) This table was made by using the data of Table VIII.

(2) Each number listed indicates the number of months showing regression relationship between water quality and streamflow.

(3) For each parameter of water quality, the maximum value with 100% of frequency in the column of total is 60, and that in the column of each individual station is 12.

(4) Each number indicated consists of all the relationships which can be expressed by any one of four regression models used.

quality and streamflow. Generally, stations 7-1465, 7-1525, and 7-1644 are better than stations 7-1610 and 7-2505 in the aspect of showing a quality-flow relationship. For stations 7-1465, 7-1525, and 7-1644, all located in the Arkansas River upstream from Tulsa, Oklahoma, the prevalence of a regression relationship is good or fair for either chloride or dissolved solids and streamflow, but poor for either hardness or sulfates and streamflow. Station 7-1610, located in the Cimarron River, has fair prevalence of relationship between either chloride or dissolved solids and streamflow, but poor between either hardness or sulfates and streamflow. For station 7-2505, which is located in the Arkansas River and has the largest drainage area, the prevalence of relationship between inorganic water quality and streamflow is the least one among the five stations investigated. The decrease of the suitability of applying four regression models at station 7-2505 seems due to the fact that the streamflow of this station is a composite of several waters with a great difference in the concentration of dissolved minerals. Three sources of that streamflow are (1) seriously degraded water of the Arkansas River near Tulsa, (2) good quality of water from eastern and northeastern parts of Oklahoma, and (3) water from the Canadian River. The expression of quality-flow relationship for station 7-2505 seems to need further development of a new equation in which sources of waters with different quality are also considered.

Judging from the results of the application of regression models, it is obvious that the prevalence of a quality-flow relationship also varies with different seasons. Table XXIII shows a seasonal variation in the prevalence of quality-flow relationship. For the concentration of chlorides and streamflow, the best prevalence of relationship was in

TABLE XXIII

SEASONAL VARIATION IN THE PREVALENCE OF REGRESSION RELATIONSHIP FOR WATER QUALITY AND STREAMFLOW

		Winter			Spring			Summer			Fall		
Water Quality	Total	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Chlorides	48	3	4	4	5	3	5	5	5	4	3	4	3
Diss. Solids	45	2	4	4	5	3	5	5	5	4	3	3	2
Hardness	20	0	0	0	1	1	2	5	3	4	1	1	2
Sulfates	10	1	0	0	1	1	1	2	0	3	0	0	1

Remarks: (1) This table was made by using the data of Table VIII.

(2) Each number indicated is the number of stations showing regression relationship between water quality and streamflow.

(3) For each parameter of water quality, the maximum value with 100% frequency in the column of total is 60, and that in the colum of month is 5.

(4) Each number listed consists of all the relationships which can be expressed by any one of four regression models used.

the summer, with 93 per cent frequency; the next was in the spring, which is still good with 87 per cent frequency; and then the winter and fall, which are fair with 73 per cent and 67 per cent frequency, respectively. Seasonal variation of the prevalence of regression relationship for concentration of dissolved solids and streamflow is nearly the same and as good as that for chloride concentration and streamflow. The order is: summer, 93 per cent frequency; spring, 87 per cent frequency; winter, 67 per cent frequency; and fall, 53 per cent frequency. For the concentration of hardness and streamflow, the relationship was prevailing in the summer with 80 per cent frequency. For the concentration of sulfates and streamflow, although the prevalence of regression relationship in the summer was the best one by comparing with those in the other three seasons, it is insignificant at all with only about 33 per cent frequency.

Station 7-1465 (Arkansas River at Arkansas City, Kansas)

Chlorides: In the aspect of regression relationship with streamflow, chloride is the most significant one among four parameters of inorganic water quality concerned. A regression relationship between chloride concentration and streamflow existed in each month. There were two regression models for two different periods during a year, model 1 for the months from August to April, and model 3 for the months from May to July. Judging from the significance test and from the calculated correlation coefficient, the reliability of the derived regression equation for chloride concentration and streamflow is good generally in each month.

Dissolved Solids: The derived regression equations for the months from March to October are also generally reliable. From comparing the calculated correlation coefficients, the reliability of equations for the months of June to September is higher than that for other months. In other words, the regression relationship between dissolved solids and streamflow for the summer season is better than that for other seasons.

Hardness: A regression relationship is significant only in the summer season, and the reliability of the regression equation derived is less than either that for chlorides and streamflow or that for dissolved solids and streamflow during the same period.

Sulfates: In regard to the total number of months exhibiting a regression relationship with streamflow, sulfate is the least one among four parameters of inorganic water quality considered in this study. The reliability of the derived equations for sulfates and streamflow is also less than either that for chlorides and streamflow or that for dissolved solids and streamflow in the same month.

Station 7-1525 (Arkansas River at Ralston, Oklahoma)

Chlorides: Among regression equations for the months from June to April in relating chloride concentration and streamflow, those for the months from August to March are more reliable than those for the other months. In eleven derived regression equations, seven of them are model 1, three are model 3, and one is model 4. This fact indicates that model 1 is the most prevailing one in expressing the relationship for chloride concentration and streamflow.

Dissolved Solids: It was found that the regression equations for the months from June to April are generally reliable. Among those eleven equations, eight of them are model 1 and three of them are model 3. Similar to the case for chloride concentration and streamflow, it is obvious that for most months model 1 is satisfactory in relating the concentration of dissolved solids and streamflow.

Hardness: Only in the summer season is a regression relationship for concentration of hardness and streamflow pronounced. Model 3 is the most satisfactory one in expressing that relationship. However, the reliability of regression equations derived is less than either that for chlorides and streamflow or that for dissolved solids and streamflow during the same months.

Sulfates: Although a regression relationship expressed by model 3 existed in the months of April, July, and September, the calculated values of the standard error of estimate and correlation coefficient indicate that the reliability of those regression equations is not substantially high.

Station 7-1610 (Cimarron River at Perkins, Oklahoma)

Chlorides: The regression equations derived for chloride concentration and streamflow in the months from January to August are substantially reliable. Among eight equations derived, four of them are model 3, two are model 2, one is model 1, and one is model 4. In models 3 and 4, both the current monthly streamflow and the antecedent flow are involved. The result of having most number of regression equations forming in models 3 and 4 indicates that the combined influence of the current monthly streamflow and the antecedent flow to the change of chloride concentration was more pronounced at this station than at the other four stations investigated.

Dissolved Solids: The number of months showing a regression relationship and model of regression equation for each month are the same as those for chlorides and streamflow. The reliability of regression equations is also nearly as good as that for chlorides and streamflow.

Besides, the combined influence of the current monthly streamflow and the antecedent flow to the variation of dissolved solids in the stream was pronounced.

Hardness: Based on the facts that only in July a regression equation was found for the concentration of hardness and streamflow and that the reliability of that equation for July is not substantially high, it is obvious that the regression relationship between hardness and streamflow is insignificant at station 7-1610.

Sulfates: No regression relationship can be emphasized for the sulfate concentration and streamflow. Although a regression relationship was found in January and December, the regression relationship was insignificant in the months from February to November.

Station 7-1644 (Arkansas River at Sand Springs Bridge, Near Tulsa, Oklahoma)

Chlorides: Judging from the fact that eleven regression equations were found in the months from February to December, it is obvious that the regression relationship between chloride concentration and streamflow is pronounced. Values of standard error of estimate and correlation coefficient indicate that regression equations for the months of February, August, and September are more reliable than those for other months. The number of each obtained regression model shows that model 1 is the most significant one, model 3 is the next, and model 2 is suitable for only one month.

Dissolved Solids: The regression relationship for dissolved solids and streamflow is as pronounced as that for chlorides and streamflow. Like the case for chlorides and streamflow, the reliability of regression equations for the concentration of dissolved solids and streamflow in the months of February, August, and September is higher than that in the other months. When comparing the number of months each regression model represented, the prevalence of model 1 and model 3 is nearly the same.

Hardness: The regression relationship was more pronounced in the months of the summer season than in other months. Judging from the values of standard error of estimate and correlation coefficient, regression equations for the months of August and September are more reliable than those for other months. By comparing the number of months each kind of regression model represented, the prevalence of model 3 is twice that of model 1. In addition, the reliability of regression relationship for hardness and streamflow is generally less than that for either chlorides and streamflow or that for dissolved solids and streamflow.

Sulfates: Judging from the facts that only in one month a regression relationship was found for sulfate concentration and streamflow and that the reliability of that unique equation is not substantially high, it is obvious that generally the regression relationship between sulfate concentration and streamflow is not significant.

Station 7-2505 (Arkansas River at Van Buren, Arkansas)

Chlorides: The number of months at this station showing regression relationship between chloride concentration and streamflow is the least among the five stations investigated. However, the regression relationship for chlorides and streamflow was pronounced in the summer season. Based on the values of standard error of estimate and correlation coefficient, the reliability of the regression equations for the months of April, July, and September is better than that for other months.

Among six months showing a regression relationship, five of them are model 1 and one is model 2. This fact indicates that at this station only the current streamflow has significant influence to the variation of chloride concentration in the stream.

Dissolved Solids: The prevalence of the regression relationship at this station is less than that at the other four stations. However, in the summer season, the regression relationship was pronounced. The phenomena of model 1 and model 2 prevailing in the months from June to September indicate that in the summer season only the current monthly streamflow has significant influence to the change of dissolved solids in the stream. As in the case of chloride concentration, the regression equations for the months of April, July, and September are more reliable than those for other months.

Hardness: Although the reliability of regression equations is not substantially high, the number of months having a regression relationship for concentration of hardness and streamflow is the greatest among the five stations investigated. By comparing the number of months each regression model represented, the prevalence of model 3 is twice that of model 1.

Sulfates: Because only one month showed a regression relationship between sulfate concentration and streamflow, and that unique regression equation was not substantially reliable, it is obvious that in substance the regression relationship for sulfate concentration and streamflow at this station is insignificant.

Conditions of Using Quality-Flow Relationship in Prediction

The regression equations presented in this report were determined by using past records. Although they represent phenomena that occurred in the past, they can be used to predict the dissolved constituents of river water for engineering purposes from assumed streamflows if the following conditions are obeyed: (1) Assumed streamflow should be essentially unregulated, because the regression equations in this study were developed by using the hydrologic data essentially unregulated. (2) The assumed streamflow beyond the observed range of past records should never be made, otherwise a large error of predicted water quality will occur.

CHAPTER VII

CONCLUSIONS

Based upon the results and discussion presented in this report, the following conclusions can be drawn:

1. For chlorides, dissolved solids, hardness, and sulfates, although their concentrations generally vary inversely with streamflow, the prevalence of their regression relationship with streamflow are different. For either chlorides or dissolved solids, the relationship is good to fair except at station 7-2505. However, for both hardness (except in the summer) and sulfates, the relationship is generally poor.

2. Prevalence of the regression relationship between either chlorides or dissolved solids and streamflow is different among the five stations investigated. It is good to fair at three stations of the Arkansas River upstream from Tulsa, Oklahoma, stations 7-1465, 7-1525, and 7-1644; fair at station 7-1610, a station on the Cimarron River; and only average at station 7-2505. Decrease of the prevalence of a regression relationship at station 7-2505 seems mainly due to the fact that streamflow at this station is a composite of waters coming from different parts of the basin with a significant difference in the inorganic water quality.

3. The quality-flow relationship changes with the seasons. For chlorides and dissolved solids, the prevalence of their relationship with streamflow shows the best results in the summer, good in the spring,

and fair in the winter and the fall. For hardness, the summer season is the only season in which the quality-flow relationship is significant.

4. In addition to the influence of the current monthly streamflow, the antecedent streamflow also has significant influence on the variation of inorganic quality of river water in many cases.

5. The regression method is applicable in investigating the factors affecting the variation of inorganic quality of river water. Among four regression models used, the suitability of models 1 and 3 is far better than that of models 2 and 4.

6. The derived regression equations can be used to predict the dissolved constituents of river water from assumed streamflow. The streamflows assumed should be within the range of original streamflow data.

CHAPTER VIII

SUGGESTIONS FOR FUTURE WORK

There are several suggestions for further studies in the area of relationships between the inorganic quality of river water and streamflow.

1. Study of a combined relationship between the inorganic water quality and the distinguishable parts of streamflow for the station with streamflow coming from various parts of a drainage basin with significantly different water quality.

2. Studies of flow-quality relationships under high-flow and low-flow conditions, respectively. From the former relation the influence of direct surface runoff to the variation of water quality can be understood, and from the latter relation the influence of ground-water flow to the variation of water quality can be detected. Maximum and minimum streamflows of each month or of each year can be used for such studies.

3. A study comparing the effects of antecedent flows to the variations of daily, monthly, and annual dissolved constituents of river water.

4. A study of the influence of reservoir regulation to the quality-flow relationships.

5. Using double-mass curves to check the consistency of streamflow records and of water quality records available before the beginning of future studies of quality-flow relationships.

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