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# The Formulation and Application of A Generalized Water Quality Index Based on Multivariate Factor Analysis of Water Quality Data From Agricultural Irrigation Return Flows

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Houng-ming Joung

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Dissertation Committee:

Professor Watkins W. Miller, Chairman
Professor John W. Bird
Professor Thomas E. Hoffer
Professor Lawrence T. Larson
Professor Clare N. Mahannah
Professor Baldev K. Vig

The dissertation of Houng-ming Joung is approved:

Dissertation Advisor

Department Chairman

Dean, Graduate School

University of Nevada

Reno

February 1978

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Houng-Ming Joung

ABSTRACT OF DISSERTATION

The Formulation and Application of A Generalized Water Quality Index Based on Multivariate Factor Analysis of Water Quality Data from Agricultural Irrigation Return Flows

Water quality indexes permit an evaluation of water quality conditions in comparative terms. Such indexes are empirical expressions which integrate significant physical, chemical and biological parameters of water quality into a single number. This dissertation presents a method for calculation of a generalized water quality index based on multivariate factor analysis of data from agricultural irrigation return flows and examines the geographical applicability of the proposed index.

Physical, chemical and biological water quality parameters of irrigation water and surface return flows were measured in the Carson Valley area of Nevada during the 1974, 1975 and 1976 irrigation seasons. Ten pollutant parameters of 895 water samples provided the basis for two indexes: a) WQITN = f(Temp., BOD, TP, EC, DODP); and b) WQIPN = f(Temp., BOD, $PO_4$-P, EC, DODP). Regression analysis of the two indexes as functions of water quality variables from river basins of Nevada indicated WQITN to be the better index (F-test 99%, $R^2$ = 0.9098). WQITN was then applied to the Kansas River Basin to compare it with a water quality index developed in the Kansas Study (WQIKS) which was an extensive water quality index study conducted by the Environmental Protection Agency (EPA). Greater range and sensitivity of WQITN than WQIKS was illustrated by comparing the high and low index values. WQITN also provided a better pollution assessment than WQIKS for presenting overall quality variation as a function of river distance. Further,

WQITN was compared with index values suggested by water quality experts (WQIE). Regression coefficients were determined for WQIE and WQITN as functions of water quality data from selected locations throughout the United States. The proposed WQITN appeared the most geographically acceptable index (F-test 99%, $R^2 = 0.9754$).

The WQITN formulation estimated by factor analysis was shown to have good potential as a generalized water quality index. Such an index should enable the systematic identification of problem areas and associated pollutants; potentially leading to the establishment of appropriate water quality standards for the respective locales. Standardization of the proposed index in terms of a specific use and range of acceptability, e.g., light, moderate, or severe pollution is suggested for further investigation.

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# Chapter 1. General Introduction

Economic and social indicators such as the index of wholesale prices and the cost of living index have been utilized by governmental decision makers and the general public for years. More recently, environmental related indexes have been developed to assess the quality of our air, water and land resources (13, 26, 37, 38, 65). Responsible decision making depends on the availability of reliable information. If we are to achieve effective management of our environment, we will need comprehensive data about the status and changes in the air, water and land. Optimally, these data could be organized in terms of indexes that summarize relevant data. Presently, our measures of indexes are inadequate because of their lack of objectivity (26, 38, 63, 65). We thus need better and more reliable indexes to understand the effects of man's activities on the environment and to determine what actions might eliminate or mitigate the adverse effects.

Indeed, the demand for an objective water quality index which effectively characterizes the water pollution problem has been frequently expressed by numerous investigators (13, 18, 26, 47, 65, 72). As early as 1965, the Environmental Pollution Panel of the President's Science Advisory Committee proposed (72) ". . . that the Federal Government stimulate development of a method for assigning a numerical index of chemical pollution to water samples. Such an index will allow us to follow many important changes in general water quality." Addressing the 1973 National Conference on managing the environment, Russell E. Train (47), the former Administrator of the Environmental Protection

Agency (EPA), recommended ". . . For top management and general public policy development, monitoring data must be shaped into easy-to-understand indices that aggregate data into understandable forms. I am convinced that much more effort must be placed on the development of better monitoring systems and indices than we have in the past. Failure to do so will result in sub-optimum achievement of goals at much greater expense." Because environmental quality is complex and comprehensive in nature, an objective index describing the quality of trends and identifying the pollution source would appear useful.

The sources of water quality pollution involve point and nonpoint sources (71, 76). The term nonpoint source is descriptive of the manner in which pollution enters water, a source lacking a high degree of discreteness (67). A point source is any discernable confined conveyance, including but not limited to any pipe, ditch, conduit, well, container, concentrated animal feeding operation, or floating craft from which pollutants are or may be discharged. The full significance of agricultural waste water has finally been identified long after municipal and industrial waste water, especially that portion entering water from nonpoint sources. Federal Water Pollution Control Act Amendments of 1972, PL 92-500 (69), have stressed the need to control pollution from agriculture, much of which will enter ground and surface water from nonpoint sources. Significantly, through the 1972 amendments, the U. S. Federal Government explicitly recognized for the first time that the nation had to deal with nonpoint sources of pollution if it were to achieve the goals of fishable and swimmable aquatic environments by 1983.

The problems encountered in management of nonpoint sources are enormous, mainly because of difficulty in identifying the characteristics and sources of nonpoint pollution. Since nonpoint source discharges enter the water in a diffuse manner and at intermittent intervals, the pollutants may arise over an extensive area of land and be in transit long before they enter water bodies. Yet, elimination or control of these pollutants must be directed at specific sites. Further, the extent of nonpoint source pollution is related at least in part to certain uncontrollable climatic events, as well as geographic and geologic conditions, and may differ greatly from place to place. Generally, control of nonpoint source pollution will rely heavily on the identification of specific sources.

The purpose of the research reported in this dissertation was as follows: a) to develop a generalized water quality index (WQI) formulation based on factor analysis; b) to apply the WQI to different river basins and respective water quality control point standards; c) to determine, then compare values from the proposed WQI with index values previously reported from a Kansas River Basin Study; and d) to compare the proposed index with an index suggested by a panel of water quality experts. Chapter 2 of this dissertation presents the water quality monitoring data from Carson Valley, Nevada, which provides the basic material for development of the index model. In Chapter 3, two different WQI formulations were statistically tested and polynomial regression analysis was conducted. To test applicability of the proposed WQI model, Chapter 4 investigates the use of the selected index formulation in the State of Nevada and the Kansas River Basin. A step forward multiple regression analysis is presented in Chapter 5. The analysis indicates a high reliability of the originally proposed WQI formulation. Modified rating equations are also presented in Chapter 5. Finally, Chapter 6 considers the index use potential and recommendations for further research.

# Chapter 2. Water Quality Monitoring in the Carson Valley, Nevada

## 2.1. Introduction

In this study, quality and quantity of irrigation water and surface return flow were measured at selected agricultural fields in the Carson Valley, Nevada (Figure 1). Physical characteristics and general hydrogeology of the study area are presented in the following sections.

### 2.1.1. Physical Characteristics

Carson Valley is located in Western Nevada approximately five miles south of Eagle Valley. This irregular oval shaped valley is bounded on the west and south by the Sierra Nevadas and on the east by the Pine Nut Mountains (Figure 1). The valley floor extends over an area approximately 20 miles long by 8 miles wide. The elevation ranges from about 5,200 feet at the inlet of the southern top to about 4,600 feet at the northern outlet of Carson Valley. With the exception of a few creeks, sloughs and ditches, the principal channels within the valley are the East Fork and West Fork of Carson River. These two forks flow north to their intersection in the vicinity of Genoa near the west central part of the valley, and the joined Carson River exits from the Carson Valley through a narrow canyon between the Pine Nut Mountains and Prison Hill (Figure 2).

Originally, much of the plain area was native grass meadow watered principally by overbank flow of stream channels during the yearly snowmelt freshet. Initial agricultural development in the valley occurred around the year 1850. By 1900, most of the land that is

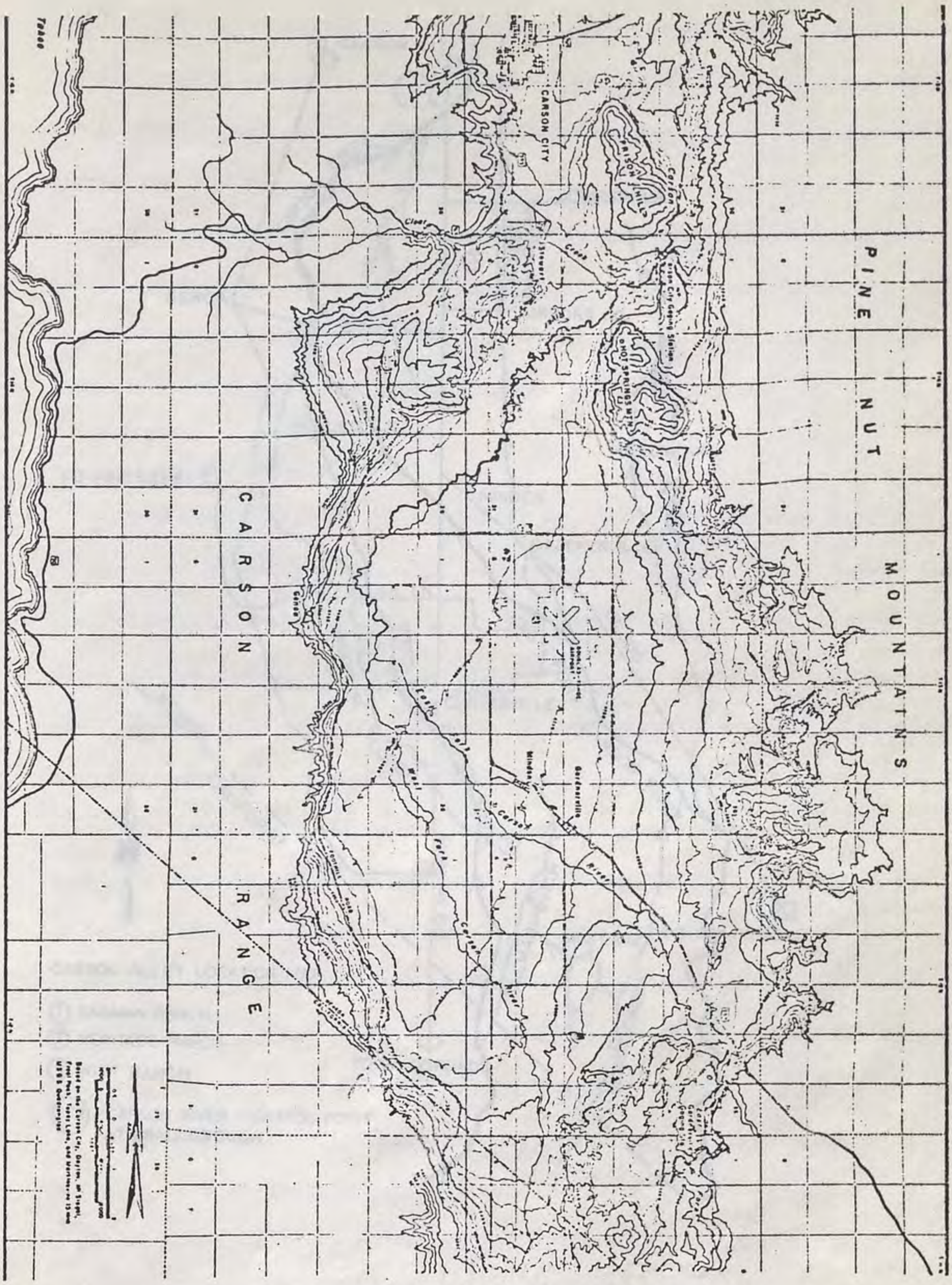



Figure 1. Location map of Carson Valley, Nevada showing topographical and hydrographical boundaries

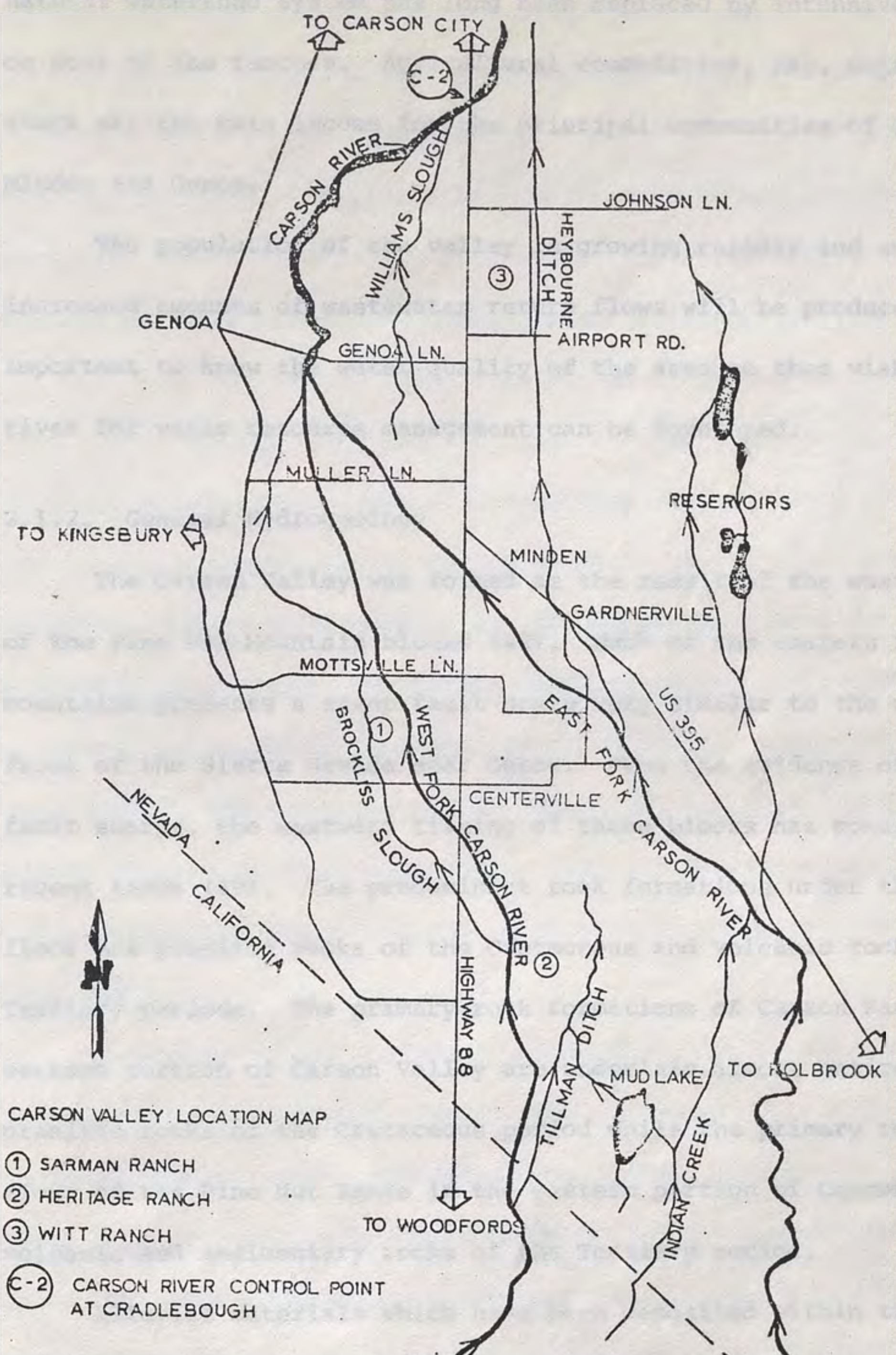



Figure 2. Locations of selected study sites and control point of Carson River

presently being farmed had been developed (68). The original overbank natural watershed system has long been replaced by intensive irrigation on most of the ranches. Agricultural commodities, hay, dairy and livestock are the main income for the principal communities of Gardnerville, Minden and Genoa.

The population of the valley is growing rapidly and subsequent increased amounts of wastewater return flows will be produced. It is important to know the water quality of the area so that viable alternatives for water resource management can be developed.

2.1.2. General Hydrogeology

The Carson Valley was formed as the result of the west tilting of the Pine Nut Mountain blocks (42). Much of the eastern front of the mountains presents a steep fault scarp very similar to the western front of the Sierra Nevada near Genoa. From the evidence of recent fault scarps, the westward tilting of these blocks has continued to very recent times (49). The predominant rock formations under the valley floor are granitic rocks of the Cretaceous and volcanic rocks of the Tertiary periods. The primary rock formations of Carson Range in the western portion of Carson Valley are underlain almost entirely by granitic rocks of the Cretaceous period while the primary rock formations of the Pine Nut Range in the eastern portion of Carson Valley are volcanic and sedimentary rocks of the Tertiary period.

Alluvial materials which have been deposited within the Carson Valley have been derived mainly from erosion of the drainage basin of the East and West Forks of the Carson River above Carson Valley (39, 49). Two typical alluvial deposits, younger and older, are present within the drainage floor. The major portion of the basin drainage area consists of younger alluvial deposits which have been laid down by recent stream activity and contain mixtures of sand, gravel and boulders in a consolidated or semi-consolidated state. The older alluvial deposits consist predominantly of fanglomerate, pediment gravels and late Pleistocene lakebed deposits. Such deposits provide only fair ground-water aquifers in the zone of coarser materials.

Well log information (59), together with the geological conditions within Carson Valley, indicate that ground water recharge to the deeper strata occurs from the mouths of the canyons of both Forks of Carson River in the southern portion of the valley. The external hydraulic boundaries of the drainage basin are formed by the consolidated rocks surrounding the valley. The ground water movements are eastward from the foot of Carson Range and westward from Pine Nut Mountains to the Carson River. The water table information of well logs and faults also indicate an area of natural discharge from the deeper confined strata in the vicinity of Genoa. Natural discharge in this area enters the Carson River.

The climate of Carson Valley (leeward of the Sierra Nevadas) is characterized by short warm summers and long moderately cold winters. This hydrometeorological characteristic causes considerable precipitation during the wintertime on the Carson Range along the west side of the valley, with little precipitation on the valley floor and the Pine Nut Mountains to the east. Average annual precipitation including mostly snowfall and some rainfall for the weather station at Minden, central Carson Valley, is approximately 8 inches. Carson Range and the Pine Nut Mountains, covered by desert vegetation and forest, provide regulating storage for runoff.

2.2. Methods

Improved management practices may reduce water pollution from irrigated agricultural areas (17, 69). With the aid of water quality data, research dealing with land-water management offers a greater promise for water quality control. Dependable water quality data are based on the selection of sampling sites and uniform sampling procedures.

2.2.1. Sampling Site Selection

Water quality is influenced by natural factors and by man's activities. The natural factors include climate, vegetation, mineralogy, geomorphology, etc. When water finally discharges as surface and subsurface irrigation return flow, organic and inorganic constituents may be reflective of man's management activities.

In Carson Valley, these factors could be particularly important for downstream areas where irrigation return flow is reused and animal waste and agricultural fertilizers are prevalent.

The present study was primarily concerned with determining the pollution potential of four study sites in Carson Valley, Nevada (Figure 2). The sampling site selections (23) were based on a) geomorphologic location, b) cropping patterns and practices, c) livestock management, d) soils, e) depth to water table, f) irrigation water source, g) irrigation stream flow (cfs), h) number of irrigations, and i) disposition of return flow. Four study sites at three locations (Heritage, Sarman, Witt Alfalfa and Witt Pasture Ranches) were chosen to represent different agricultural characteristics in the Carson Valley.

Characteristics of each study site are summarized in Table I and are more specifically described as follows:

Sarman Ranch--Sixty acres of lowlands are located west of the Carson River's West Fork. The ranch produced grass for hay and pasture and was grazed by beef cattle after the irrigation season. The soils are of medium to fine texture (39) with water tables ranging from 0.2 to 3 feet from the ground surface during the irrigation season. Because most of the water diverted from West Fork and minor amounts from irrigation return flows of adjacent fields, the ground water of Sarman Ranch was affected by the variations of water tables in the West Fork of Carson River. The flow rates ranged from .1 to 11.2 cfs over a total of 18 irrigations. During 1974, 1975 and 1976 irrigation seasons, this study site was leaching 55 to 77 percent of irrigation water into the subsurface. The surface return flow eventually discharged westward into Brockliss Slough and eastward back into the West Fork. Periodic upward movements of ground water have caused difficulty in the evaluation of infiltrated irrigation water and water-table water utilization by the crop (24, 54).

Heritage Ranch--Fifty-three acres below and west of the Tillman Ditch and south of Dresslerville Lane, a geographic benchland position near the Upper West Fork was also selected for study. This ranch produced alfalfa-grass hay mixture for cash income and grass for grazing. Grazing was restricted to before and after the irrigation season. With a deep coarse textured soil, the water table rose to 4 feet during irrigation and fell below 20 feet from the ground surface after the irrigation season. Since the sources of water were from up stream of Carson River's West Fork and from Mud Lake, the flow rates ranged up to

Table I. Characteristics and irrigation parameters of study sites during 1974, 1975 and 1976 irrigation seasons

| Site Name | Site Acreage and Land Use | Geographic Position and Soil Texture | Total No. of Irrigations | Water Sources | Water Table (feet) | Flow Rate (cfs) | Total Water Applied (feet) | Surface Return Flow (%) |
|---|---|---|---|---|---|---|---|---|
| Sarman | 60 acres of hay and pasture | Lowland with texture of medium to fine soil | 18 | Lower West Fork of Carson River | 0.2 to 3.0 | 0.1 to 11.2 | 3.8 to 4.5 | 23 to 45 |
| Heritage | 53 acres of alfalfa-grass mixture and limited grazing | Benchland with texture of coarse soil | 14 | Upper West Fork of Carson River and Mud Lake | 4.0 to 20.0 | 0.1 to 40.0 | 5.2 to 14.8 | 21 to 35 |
| Witt--Alfalfa | 21.3 acres of alfalfa for hay | Flood plain with texture of medium to fine soil | 28 | Heybourne Ditch and irrigation well | 4.0 to 7.0 | 0.1 to 14.0 | 5.6 to 8.1 | 37 to 54 |
| Witt--Pasture | 40 acres of grasses for pasture | Flood plain with texture of medium to fine soil | 39 | Heybourne Ditch and irrigation well | 4.0 to 7.0 | 0.1 to 14.0 | 5.7 to 6.8 | 48 to 54 |

40 cfs over a total of 14 irrigations within 1974, 1975 and 1976 irrigation seasons. An initially deep water table and a coarse textured soil allowed 65 to 79 percent deep percolation which was the highest in the three study locations. In general, this study site had the best water quality because of the purest source of water.

Witt Ranch--Two adjacent study sites, 40 acres of alfalfa and 21.3 acres of pasture, were located near the Heybourne Ditch between Airport Road and Johnson Lane as shows in Figure 2. The alfalfa was cut for hay and grazed after the hay season, and the pasture was grazed without interruption by replacement dairy livestock or horses. The soils were of medium to fine texture with a fairly stable water table at 4 to 7 feet below the surface. Periodically, dairy wastewater and a fair amount of ground water were used as irrigation water. However, the major water source was diverted from upstream surface return flow that resulted in poor initial water quality at this ranch. The pasture was irrigated 39 times and alfalfa 28 times with flow rates varying from .1 to 14 cfs during the three-year study period. The fairly stable water table and medium and fine soil texture land caused the lowest deep seepage which ranged from 46 to 63 percent and 46 to 52 percent in pasture and alfalfa respectively.

2.2.2. Sampling and Analysis

A uniform procedure (34) for field sampling and laboratory analysis to meet the requirements of the Environmental Protection Agency have been proposed. The proposed procedures describe the analytical methods selected for use in the report "Quality Monitoring of Irrigation Water and Return Flows" (23, 24). Methods from "Standard Methods of the

Examination of Water and Wastewater" (1), "Water and Atmospheric Analysis" (2), "Methods for Chemical Analysis of Water and Wastes" (70), instrument manual (30), factory bulletin (6), and other literature (35, 67) were carefully selected for analytical procedures. The methods were used to measure a desired chemical constituent with sufficient accuracy even in the presence of interferences normally encountered in polluted water. When necessary, methods were modified and used to meet the physical characteristics of the polluted water and the capabilities of the Nevada Soil and Water Laboratory, Plant, Soil and Water Science Division, Univeristy of Nevada, Reno. Instrumental methods of analysis were selected for special chemical constituents for speed and accuracy.

2.2.2.1. Quantity Measurements

Parshall Flumes, Flow Stage Recorder and a Rectangular Weir were installed by field technicians at measurement stations to measure cumulative flow in acre feet (af) of applied irrigation water and surface return flow. Flow rates in cubic feet per second (cfs) were measured at 12-hour intervals during the irrigation. Exceptions were made at Witt Pasture Ranch in which flow rates were measured at 6-hour sampling frequency for 1975 and 1976 irrigation seasons because of the short irrigation duration observed during the 1974 irrigation season.

2.2.2.2. Water Quality Measurement

Standard procedures (34) were followed for the laboratory analysis of field samples. At the time of flow rate measurement, a one-gallon water sample was taken into a cubitainer for a number of laboratory analyses. The water samples were kept under refrigeration to minimize biological and chemical reactions during transportation to the laboratory. Records included the date, hour, water temperature and location of the water sample source.

A 300-ml BOD bottle was filled with water sample to which oxygen was fixed immediately in the field. The BOD bottle was kept in a refrigerator during transportation and was returned to the laboratory for measurement of dissolved oxygen (DO) by the Winkler method (1, 2). A sampling attachment (34) was invented to minimize the flow turbulence during the collection of the water sample for DO measurement.

Regardless of the initial nature of the water sample, complete stability for every constituent is not always possible. Addition of preservatives to the water samples is not recommended because of the many chemical constituents to be analyzed. Water samples were analyzed as soon as possible.

2.2.3. Data Processing

Data processing included tabulation of data and graphical illustration. The tabulated data were calculated by computer programs and the graphical illustrations were plotted by Hewlett-Packard Plotter.

2.2.3.1. Tabulation of Data

The large quantity of basic data and computed results have been categorized and tabulated by three Fortran programs. Results included: a) quality of the water samples; b) measured water flow and computed water quality loads; and c) temperature, DOS, DO and DOD relationships (23, 24, 48). The logic flow charts are shown in Appendix 1A, 1B and 1C. Representative results are also presented in Tables II, III and IV.

Table II shows basic chemical and physical water quality of the water samples. Irrigation time, head or tail, and date of cutting were

Table II. Water Quality at The Heritage Ranch (53 acres)

| SAMPLE NUMBER | SAMPLING DATE | TIME HOUR | LOCAT. H--T[1] | TEMP. C | DO MG/L | BOD MG/L | P MG/L | PO4-P MG/L | N MG/L | NO3-N MG/L | TURB. MG/L | EC UMH/CM | PH | CA+MG MEQ/L | NA MEQ/L | HCO3 MEQ/L | CL MEQ/L | SO4 MG/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/19-5/23 | | | | | | | | FIRST IRRIGATION | | | | | | | | | | |
| H1 | 5/19 | 14:30P | H | 11.5 | 7.12 | .97 | .10 | < .10 | .60 | < .10 | 4.9 | 59. | 7.4 | .38 | .11 | .38 | .012 | 5.0 |
| H2 | 5/20 | 2:30A | H | 3.0 | 8.26 | 1.14 | .20 | < .10 | .43 | .17 | 12.8 | 48. | 7.3 | .31 | .06 | .33 | .031 | 7.8 |
| H3 | 5/20 | 3:05A | T | 1.0 | 7.82 | 5.09 | .34 | .23 | .60 | .17 | 6.0 | 107. | 7.2 | .74 | .29 | .70 | .043 | 13.5 |
| H4 | 5/20 | 14:15P | H | 6.0 | 7.12 | .62 | < .10 | < .10 | .25 | < .10 | 5.4 | 60. | 7.4 | .43 | .08 | .47 | .016 | 9.5 |
| H5 | 5/20 | 14:30P | T | 9.0 | 5.89 | 5.54 | .37 | .30 | 1.29 | .80 | 2.4 | 80. | 7.1 | .54 | .10 | .61 | .027 | 2.0 |
| H6 | 5/21 | 2:35A | H | 3.5 | 7.21 | 1.32 | < .10 | < .10 | .63 | < .10 | 3.8 | 132. | 7.4 | .89 | .41 | .89 | .019 | 15.0 |
| H7 | 5/21 | 14:20P | H | 9.0 | 7.29 | 1.05 | < .10 | < .10 | .25 | < .10 | 5.4 | 72. | 7.5 | .54 | .13 | .61 | .029 | 6.5 |
| H8 | 5/21 | 14:45P | T | 17.0 | 4.65 | 14.86 | .40 | .36 | 1.15 | .80 | 2.8 | 132. | 7.3 | .89 | .24 | .99 | .062 | 15.0 |
| H9 | 5/22 | 2:30A | H | 6.0 | 7.12 | 1.14 | < .10 | < .10 | .25 | .11 | 3.8 | 80. | 7.3 | .56 | .11 | .56 | .025 | 2.6 |
| H10 | 5/22 | 2:35A | T | 5.5 | 7.03 | 1.93 | .26 | .10 | .31 | < .10 | 2.8 | 111. | 7.4 | .82 | .27 | .85 | .058 | 10.8 |
| H11 | 5/22 | 14:20P | H | 14.5 | 6.50 | 1.14 | .14 | < .10 | .33 | .13 | 3.6 | 71. | 7.5 | .54 | .10 | .56 | .025 | 1.5 |
| H12 | 5/22 | 2:40P | T | 19.5 | 4.39 | 3.48 | .27 | .22 | .72 | .43 | 2.8 | 119. | 7.5 | .84 | .26 | .99 | .060 | 8.0 |
| H13 | 5/23 | 2:35A | H | 7.0 | 7.12 | 1.49 | .11 | < .10 | .22 | < .10 | 5.1 | 72. | 7.4 | .59 | .13 | .56 | .030 | 5.5 |
| H14 | 5/23 | 3:00A | T | 6.5 | 6.42 | 2.28 | .13 | < .10 | .31 | .11 | 3.0 | 78. | 7.4 | .59 | .14 | .66 | .033 | 10.0 |
| 6/10-6/13 | | | | | | | | SECOND IRRIGATION | | | | | | | | | | |
| H15 | 6/10 | 8:00A | H | 8.5 | 7.12 | 2.20 | < .10 | < .10 | .17 | < .10 | 2.8 | 68. | 7.5 | .64 | .09 | .47 | .028 | 5.1 |
| H16 | 6/10 | 19:45P | H | 14.5 | 6.15 | .79 | < .10 | < .10 | .11 | < .10 | 3.0 | 66. | 7.3 | .56 | .11 | .47 | .024 | 3.6 |
| H17 | 6/10 | 20:00P | T | 16.0 | 4.66 | 2.87 | .11 | .10 | .43 | .11 | 3.1 | 76. | 7.2 | .66 | .12 | .61 | .033 | 3.2 |
| H18 | 6/11 | 7:45A | H | 10.0 | 6.79 | .44 | .10 | < .10 | .37 | .11 | 2.2 | 65. | 7.2 | .54 | .07 | .33 | .025 | 4.7 |
| H19 | 6/11 | 7:30A | T | 12.5 | 6.45 | 4.48 | .26 | .23 | .61 | .24 | 2.1 | 87. | 7.1 | .71 | .13 | .61 | .056 | 3.1 |
| H20 | 6/11 | 19:45P | H | 15.5 | 6.89 | .97 | .10 | < .10 | .25 | < .10 | 3.1 | 67. | 7.3 | .51 | .12 | .47 | .030 | 5.1 |

## Table III. Measured Water Flow and Computed Water Quality at The Heritage Ranch

| SAMPLE NUMBER | SAMPLING DATE | TIME HOUR | FLOW RATE CFS | FLOW VOLUME AF | TDS LBS[1] | TDS --&LBS-- | BOD LBS | BOD --&LBS-- | N LBS | N --&LBS-- | NO3-N LBS | NO3-N --&LBS-- | P LBS | P --&LBS-- | PO4-P LBS | PO4-P --&LBS-- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/19-5/23 | | | | | | | FIRST IRRIGATION | | | | | | | | | |
| HEAD | | | | | | | | | | | | | | | | |
| START | 5/19 | 14:30P | -0 | -0 | | | | | | | | | | | | |
| H1 | 5/19 | 14:30P | 9.1 | -0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| H2 | 5/20 | 2:30A | 10.9 | 15.69 | 1461.3 | 1461.3 | 45.02 | 45.02 | 21.98 | 21.98 | 5.76 | 5.76 | 6.40 | 6.40 | 3.20[2] | 3.20 |
| H4 | 5/20 | 14:15P | 5.6 | 10.80 | 1071.6 | 2532.9 | 25.85 | 70.87 | 9.99 | 31.97 | 3.23 | 8.99 | 3.67 | 10.07 | 1.47 | 4.67 |
| H6 | 5/21 | 2:35A | 8.3 | 10.96 | 1316.5 | 3849.4 | 28.92 | 99.79 | 13.12 | 45.08 | 1.49 | 10.48 | 1.49 | 11.56 | 1.49 | 6.16 |
| H7 | 5/21 | 14:20P | 25.7 | 8.89 | 1114.3 | 4963.6 | 28.65 | 128.45 | 10.64 | 55.72 | 1.21 | 11.69 | 1.21 | 12.77 | 1.21 | 7.37 |
| H9 | 5/22 | 2:30A | 25.7 | 24.34 | 3220.2 | 8183.8 | 72.49 | 200.94 | 16.55 | 72.27 | 5.30 | 16.99 | 3.31 | 16.08 | 3.31 | 10.66 |
| H11 | 5/22 | 14:20P | 24.3 | 27.28 | 3585.4 | 11769.2 | 84.59 | 285.53 | 21.52 | 93.79 | 8.90 | 25.89 | 7.05 | 23.13 | 3.71 | 14.39 |
| H13 | 5/23 | 2:35A | 15.4 | 17.88 | 2225.5 | 13994.7 | 63.95 | 349.48 | 13.37 | 107.17 | 4.38 | 30.27 | 6.08 | 29.21 | 2.43 | 16.82 |
| STOP | 5/23 | 20:15A | -0 | 7.84 | 982.6 | 14977.3 | 31.77 | 381.26 | 4.69 | 111.86 | 1.07 | 31.34 | 2.35 | 31.56 | 1.07 | 17.89 |
| TAIL | | | | | | | | | | | | | | | | |
| START | 5/20 | 3:05A | 29.0 | -0 | | | | | | | | | | | | |
| H3 | 5/20 | 3:05A | 29.0 | -0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| H5 | 5/20 | 14:30P | -0 | 4.58 | 745.5 | 745.5 | 66.21 | 66.21 | 11.77 | 11.77 | 6.04 | 6.04 | 4.42 | 4.42 | 3.30 | 3.30 |

Table IV. Temperature, DOS, DO, and DOD Relationships at The Heritage Ranch

| SAMPLING NUMBER | | SAMPLING TIME | | TEMPERATURE C | | DOS[1] MG/L | | DO MG/L | | DOD MG/L | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HEAD | TAIL | DATE | HOUR | HEAD | TAIL | HEAD | TAIL | HEAD | TAIL | HEAD | TAIL |
| 5/19-5/23 | | | | FIRST IRRIGATION | | | | | | | |
| H1 | | 5/19 | 14:30P | 11.5 | | 9.25 | | 7.12 | | 2.13 | |
| H2 | | 5/20 | 2:30A | 3.0 | | 11.28 | | 8.26 | | 3.02 | |
| | H3 | 5/20 | 3:05A | | 1.0 | | 11.91 | | 7.82 | | 4.09 |
| H4 | | 5/20 | 14:15P | 6.0 | | 10.51 | | 7.12 | | 3.39 | |
| | H5 | 5/20 | 14:30P | | 9.0 | | 9.76 | | 5.89 | | 3.87 |
| H6 | | 5/21 | 2:35A | 3.5 | | 11.20 | | 7.21 | | 3.99 | |
| H7 | | 5/21 | 14:20P | 9.0 | | 9.84 | | 7.29 | | 2.55 | |
| | H8 | 5/21 | 14:45P | | 17.0 | | 8.33 | | 4.65 | | 3.68 |
| H9 | | 5/22 | 2:30A | 6.0 | | 10.57 | | 7.12 | | 3.45 | |
| | H10 | 5/22 | 2:35A | | 5.5 | | 10.71 | | 7.03 | | 3.68 |
| H11 | | 5/22 | 14:20P | 14.5 | | 8.77 | | 6.50 | | 2.27 | |
| | H12 | 5/22 | 2:40A | | 19.5 | | 7.88 | | 4.39 | | 3.49 |
| H13 | | 5/23 | 2:35A | 7.0 | | 10.34 | | 7.12 | | 3.22 | |
| | H14 | 5/23 | 3:00A | | 6.5 | | 10.48 | | 6.42 | | 4.06 |
| 6/10-6/13 | | | | SECOND IRRIGATION | | | | | | | |
| H15 | | 6/10 | 8:00A | 8.5 | | 10.02 | | 7.12 | | 2.90 | |
| H16 | | 6/10 | 19:45P | 14.5 | | 8.69 | | 6.15 | | 2.54 | |
| | H17 | 6/10 | 20:00P | | 16.0 | | 8.43 | | 4.66 | | 3.77 |
| H18 | | 6/11 | 7:45A | 10.0 | | 9.63 | | 6.79 | | 2.84 | |

also included in the computer output. Sample numbers have been included for easy cross reference among tables.

The data from Table II combined with water flow volume produced the load of specific chemical constituents in pounds and cumulative pounds per sampling intervals as presented in Table III. Table III also shows sources of water and date of cutting to check if they had any effect on quality changes. When the concentration of water quality constituents is reported, for example, as less than X mg/l, the total load is calculated by using (0 + X)/2 mg/l, i.e., assuming the average from zero to X mg/l within the sampling period.

With the relationships of water temperature, barometric pressure, salinity and relative humidity, the computer program for Table IV calculated the theoretical saturated dissolved oxygen (DOS) for field conditions. The difference between saturated dissolved oxygen (DOS) and measured dissolved oxygen (DO) is presented as the deficit dissolved oxygen (DOD). Occasionally, DO is larger than DOS. In such cases, the DOD is set to be zero in the computation (Table IV).

2.2.3.2. Graphical Illustration

The Hewlett-Packard 9820A Calculator and 11220A Peripheral Control I Plotter (31) were used to plot graphs for concentration and total load of pollutants. The plotter units can plot graphs from calculator programs or from stored data on magnetic cards.

The representative results are graphically presented in Figure 3 and Figure 4. Figure 3 shows the electrical conductivity (EC) per irrigation sequence and irrigation time at the Heritage Ranch. Figure 4 presents the cumulative total dissolved solids (TDS) per irrigation vs. irrigation sequence and irrigation time at the Heritage Ranch.

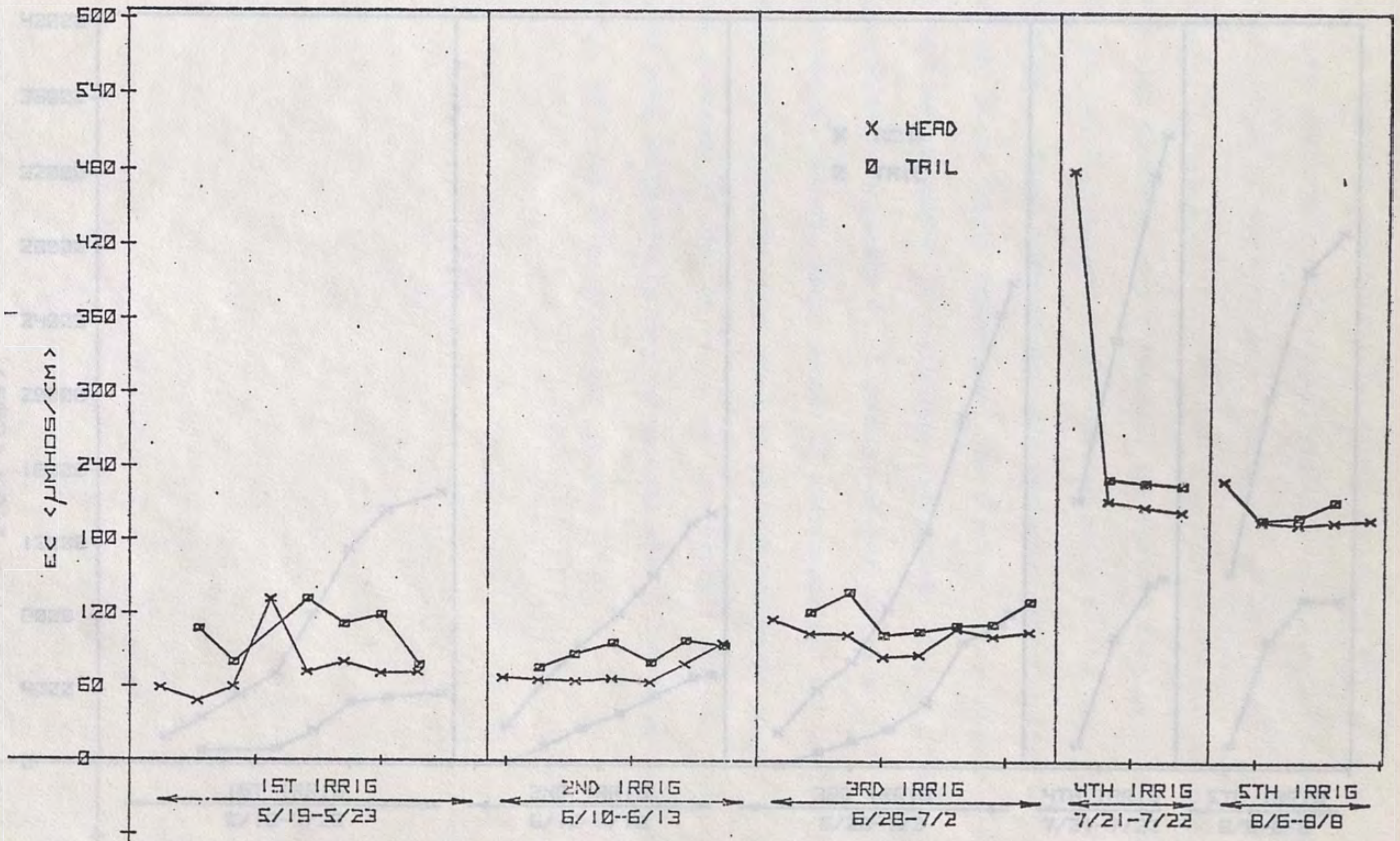



FIG. 3. EC VS. IRRIGATION SEQUENCE AND SAMPLING TIME AT THE HERITAGE RANCH

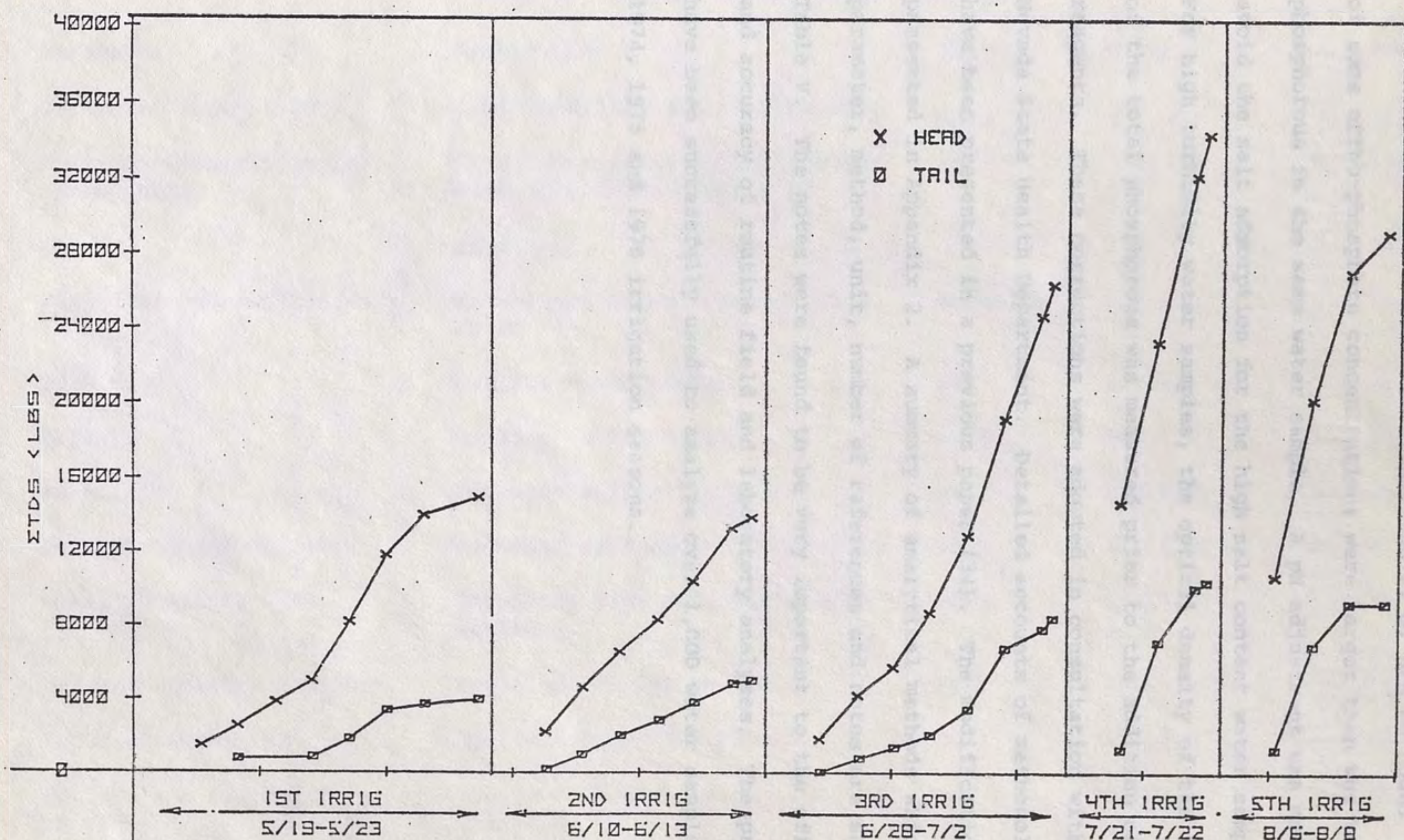



FIG. 4 CUMULATIVE TDS PER IRRIGATION VS. IRRIGATION SEQUENCE AND IRRIGATION TIME AT THE HERITAGE RANCH

2.3. Comments

Problems were identified within the U. S. EPA methods. Results of some ortho-phosphate concentrations were larger than the total phosphorous in the same water sample. A pH adjustment was made to avoid the salt adsorption for the high salt content water samples. For high turbidity water samples, the optical density of the turbidity of the total phosphorous was measured prior to the addition of combined reagents. These corrections were adopted in consultation with the Nevada State Health Department. Detailed accounts of methodologies have been presented in a previous paper (34). The modifications are presented in Appendix 2. A summary of analytical methods which include parameter, method, unit, number of references and notes are shown in Table V. The notes were found to be very important to the efficiency and accuracy of routine field and laboratory analyses. The procedures have been successfully used to analyze over 1,000 water samples during 1974, 1975 and 1976 irrigation seasons.

Table V. Summary of Analytical Methods

| Parameter | Method Used | Unit | Notes | References |
|---|---|---|---|---|
| Dissolved oxygen (DO) | Azide modification of Winkler | mg/l | 1,2,3,4 | 1,2,35,70 |
| 5-day biochemical oxygen demand (BOD) | Dilution seeding in conjunction with Winkler method for DO | mg/l | 3,4,5,6 | 1,2,17,70 |
| pH | pH meter | -- | 7,8 | 1,2,70 |
| Electric conductivity (EC) | Wheatstone bridge conductivity meter | $\mu$mhos/cm | 8,9 | 1,2,70 |
| Turbidity | Hellige turbidimeter | JTU | 10,11 | 1,2,30,70 |
| Sulfate | Hellige turbidimeter | mg/l | 10,11,17 | 1,2,30,70 |
| Alkalinity | Phenolphthaline titration | meq/l | 12,13,14 | 1,2,35,70 |
| Orthophosphate ($PO_4$-P) | Ascorbic acid method | mg/l | 14,15,16,17 | 67,70 |
| Total phosphate (TP) | Digestion with ascorbic acid method | mg/l | 15,17,18 | 1,2,35,70 |
| Nitrate nitrogen ($NO_3$-N) | Modified brucine method | mg/l | 14,15,18 | 1,2,35,70 |
| Total nitrogen (TN) | Kjeldahl digestion method | mg/l | 15,19,20 | 1,2,35,70 |
| Calcium and magnesium (Ca+Mg) | Ethylene-diamine tetractate titration | meq/l | 21,22 | 1,2,35,70 |
| Sodium | Flame photometer | meq/l | 23,24 | 1,2,6,70 |
| Chloride (Cl) | Silver nitrate with automatic pH meter titration | meq/l | 25,26 | 1,2,35,70 |

# Chapter 3. Development of a Water Quality Index

## 3.1. Introduction

As indicated from previous discussion, development of a practical water quality index (WQI) (see Table VI for meaning of acronyms) might offer a feasible solution for broad water quality control strategies (11, 12, 14, 18). By definition, WQI is a single numerical expression which reflects the composite influence of significant physical, chemical and microbiological parameters of water quality. Such an index would provide an opportunity to evaluate water quality conditions in relative terms.

Horton (10) presented an index based on eight rated and two unrated parameters. Rated parameters included dissolved oxygen (DO), pH, coliform density, specific conductance, carbon chloroform extract (CCE), alkalinity, chloride and level of sewage treatment (i.e., primary or secondary treatment). Unrated parameters, temperature and "obvious pollutants" were combined as weighted multipliers. Index values ranged from 0 to 100, the worse to the best possible, respectively. Usefulness of the index was limited, however, since the choice of parameters and their ratings represented preliminary subjective judgements.

Brown et al. (13) proposed an arithmetic water quality index (WQIA) which was similar to that of Horton, but was formulated from the collective opinion of a panel of 125 water quality experts. The mean values of the experts' water quality indexes were referred to as WQIE. Brown, et al. (11), McClelland (47) and Landwehr (37) later presented three additional non-statistical methods: a) the multiplicative water

Table VI. Table of Selected Acronyms

| Acronyms | Unit | Meaning of Acronyms |
|---|---|---|
| Temp. | °C | Temperature |
| BOD | mg/l | Biochemical oxygen demand (5-day) |
| TP | mg/l | Total phosphate |
| $PO_4$-P | mg/l | Phosphate-phosphorus |
| TN | mg/l | Total nitrogen |
| $NO_3$-N | mg/l | Nitrate-nitrogen |
| EC | µmhos/cm | Electric conductivity |
| Turb. | JTU | Turbidity |
| pH | -- | pH |
| DODP | % | Dissolved oxygen deficit percentage |
| WQI | -- | Water quality index |
| WQIE | -- | Water quality index of experts |
| WQITN | -- | Water quality index of total nutrient |
| WQIPN | -- | Water quality index of partial nutrient |
| WQIA | -- | Arithmetic water quality index |
| WQIM | -- | Multiplicative water quality index |
| WQIAU | -- | Unweighted arithmetic water quality index |
| WQIMU | -- | Unweighted multiplicative water quality index |
| WQISN | -- | Water quality index of nonparametric statistical method |

quality index (WQIM); b) the unweighted arithmetic water quality index (WQIAU); and c) the unweighted multiplicative water quality index (WQIMU). Landwehr (37) tested the correlation of index values obtained from the above methods with those suggested by water quality experts (WQIE). Because of the high correlation obtained between WQIMU and WQIE values, Landwehr concluded that the WQIMU method was a viable and unbiased method.

Harkins (26), citing the index developed by Brown et al. (12) as not objective because ". . . panels of experts often give different weights to the same parameters," presented a statistical method for an objective water quality index (WQISN) based on nonparametric multivariate ranking procedure. However, Landwehr and Deininger (38) in statistically analyzing the various indexes, stated that the Harkins index agreed least with that of the experts. Further, they concluded (38) that WQISN had to be recalculated every time new data became available.

Factor analysis, a technique developed by psychometrists and others for the purpose of determining for each of a set of variables the proportions of their factor loadings, is a method that takes the information contained in the correlation matrix and rearranges the data to present it in a manner that better explains the structure of the underlying system that produced the data. Through manipulation of the correlation coefficient matrix, the factor analysis identifies and quantifies underlying patterns of variation in a data set (27). The analysis allows the researcher to build column vector indexes that explain variation in the data set in fewer than the original number of column vectors. This technique has been successfully used in the development of dependent variables for index building (20, 25, 57). Hagood (25), in 1952, constructed farm-operator level of living indexes of various counties in the United States based on factor analysis from correlation matrix. Factor analysis was also applied by Dawdy, et al. (20) to results of chemical analyses of 103 water samples from wells in Mojave River Valley, California. Three principal chemical types of water, calcium bicarbonate, sodium sulfate and sodium chloride, as well as many mixtures of the three were identified. Shoji, et al. (57) applied factor analysis to identify four principal factors from 20 original water quality parameters in Yodo River System, Japan. Deleting 2 water quality parameters, a composite pollution index equation was constructed from 18 water quality parameters for the evaluation of the degree of gross stream pollution ranging from -2 to +2. The applicability of such an equation was limited, however, since water quality data rarely reported all 18 water quality parameters. No statistical comparison was made to test the reliability of the composite pollution index, yet, the methodology did offer a good foundation for water quality evaluation.

Since complex and not always obvious dependent interrelationships exist among various water quality parameters, development of an objective water quality index should be based upon a multivariate factor analysis. Further, to avoid a subjective bias common to indexes based solely on the opinion of water quality experts, factor analysis can be utilized to select the parameters of major significance and to develop a suitable weighting scale.

Acknowledged is the fact that water may be used for many purposes, i.e., domestic, recreation, irrigation, fish and wildlife, industrial, etc. Indeed, each specific use naturally concerns a specific set of water quality criteria. However, as a "first-step" towards getting a handle on water quality status suitable for water quality control programs, Section 208 of P.L. 92-500 (areawide water quality and waste treatment management) has emphasized the need to first identify overall water quality status of problem areas for immediate input into the planning process. The use of a generalized water quality index for water quality planning is, thus, a subject of recent interest.

Additional support for the concept of such a "generalized" index is found in a report by Landwehr (37) where she reviews the construction of two specific use indexes by O'Connor (52), i.e., a fish and wildlife index and a public water supply index. These two indexes were found to be highly correlated with the generalized water quality index developed by Brown, et al. (3). Landwehr concluded that one index to describe overall water quality would be best (at least for the time being) for purposes of communicating the status of water quality situations to the general public. Hence, the proposed indexes reported herein, do not intend to represent specific usage of water. Rather, the intent is to present a methodology, exemplified by the construction of a generalized water quality index, the technique of which could then be applied to the individual development of a specific use.

## 3.2 Methods

Physical and chemical water quality constituents of irrigation water and surface return flows were measured in the Carson Valley area of Nevada. A total of 895 samples were taken from four study sites at three locations (23, 24, 48) during the 1974, 1975 and 1976 irrigation seasons (W. W. Miller, unpublished data). Ten water quality variables were considered in the development of the water quality index: temperature, bio-chemical oxygen demand (BOD), total phosphate (TP), orthophosphate ($PO_4$-P), total nitrogen (TN), nitrate-nitrogen ($NO_3$-N), electrical conductivity (EC), turbidity, pH and dissolved oxygen deficit percentage (DODP). The DODP of irrigation and surface return flow water was computed by:

$$DODP = (DOS-DO)/DOS \times 100 \qquad (1)$$

where DOS is theoretically saturated dissolved oxygen as a function of water temperature, site elevation and salinity, and DO is dissolved oxygen at the time of sampling. Rating scales for water quality parameters were chosen so that each could be assigned a relative value from 0 to 100, the worse to the most ideal water quality criteria (11, 23, 26), respectively. Principal component analysis was used to transform the set of ten variables into a new set of principal components not correlated to one another (27).

Because factor analysis may be unfamiliar to some readers, a short review of methodology is given. Factor analysis takes the explained variance in the correlation matrix and redistributes it among a set of factors (27). The factors reveal underlying linear combinations of the original variables. Each factor is made up of various proportions of the individual constituents.

$$F_i = a_{i1}x_1 + a_{i2}x_2 + - - - + a_{in}x_n \qquad (2)$$

where $F_i$ is the ith factor, $x_j$ is the jth variable and the $a_{ij}$ are constants. These factors themselves are variables that can only be estimated in terms of the original variables.

The first step in factor analysis is to find the principal components (eigenvectors) of the correlation matrix. The principals are similar to the factors in that they are linear combinations of the variables.

$$P_i = c_{i1}x_1 + c_{i2}x_2 + - - - + c_{in}x_n \quad (3)$$

The first principal component ($P_1$) is defined as that combination of the constants $c_{ij}$ and variables $x_j$ that explains the greatest possible amount of the variances and covariances in the correlation matrix. The second principal component ($P_2$) is chosen as an independent combination of the $x_j$'s, which then explains to the extent possible the remaining covariance, and so forth. Each principal component is by definition independent of (orthogonal to) all other principal components. That is:

$$\sum_{i=1}^{n} \sum_{j=1}^{k} c_i c_j = 0 \quad (4)$$

for all i and j where $i \neq j$. Therefore, if the principal components are considered as new variables, they represent a set of uncorrelated (independent) variables. For more detail in index development, readers are referred to Appendix 3 for specific presentation of the mathematical approach (75) to the derivation.

The first principal factor extracted represented the best linear combination of variables which explain the greatest variance. The second principal factor identified the second best linear combination of variables uncorrelated to the first, and so on.

Eight of the ten water quality parameters were identified as most significant to a water quality index. By examination of a correlation matrix, the relative importance of each parameter was estimated and a weighting scale was derived by analytical solution process (27, 32). Two index equations were developed: WQITN = f (Temp., BOD, TP, TN, EC and DODP) and WQIPN = f (Temp., BOD, $PO_4$-P, $NO_3$-N, EC and DODP). Multiple regression analysis was then applied relating both indexes to original water quality variables. Regression coefficients were estimated for WQIPN and WQITN values as functions of water quality data. Values of DO%, $NO_3$-N, $PO_4$-P and TDS were calculated from DO% = 1-DODP, $NO_3$-N = 0.423 (TN) - 0.246 (from simple regression), $PO_4$-P = 0.662 (TP) - 0.251 (from simple regression), and TDS = 0.64 (EC), for purposes of index comparison.

## 3.3. Results and Discussion

Table VII tabulates a simple correlation matrix, means and standard deviations. The mean values and standard deviations were used to standardize each variable for principal component analysis. A factor matrix, Eigenvalues and the cumulative percentage of three principal factors are presented in Table VIII. The first factor shows high loadings on phosphorous, nitrogen, BOD, DODP, parameters; the second factor for electrical conductivity; and the third factor for temperature. Since principal components are linear relationships of the original water quality parameters, principal components can be used to formulate a water quality index. The coefficients for each component are computed mathematically so as to maximize its variance subject to the restraint that it be uncorrelated with scores from other components. Eight major water quality parameters were thus selected using a critical value of 0.55. Eigenvalues and cumulative percentage indicates

Table VII. Simple Correlation Coefficient (r), Mean (M), and Standard Deviation (S) for Temp., BOD, TP, $PO_4$-P, TN, $NO_3$-N, EC, Turb., pH, and DOD/DOS % (DODP) of 895 water samples from Carson Valley, Nevada.

| | Temp. | BOD | TP | $PO_4$-P | TN | $NO_3$-N | EC | Turb. | pH | DODP |
|---|---|---|---|---|---|---|---|---|---|---|
| Temp. | 1.00 | 0.17 | 0.11 | 0.12 | 0.12 | 0.02 | 0.21 | 0.01 | -0.08 | 0.24 |
| BOD | | 1.00 | 0.61 | 0.65 | 0.71 | 0.57 | 0.25 | 0.16 | -0.38 | 0.43 |
| TP | | | 1.00 | 0.87 | 0.76 | 0.71 | 0.34 | 0.14 | -0.31 | 0.37 |
| $PO_4$-P | | | | 1.00 | 0.66 | 0.58 | 0.36 | 0.13 | -0.33 | 0.45 |
| TN | | | | | 1.00 | 0.78 | 0.23 | 0.16 | -0.31 | 0.36 |
| $NO_3$-N | | | | | | 1.00 | 0.08 | 0.21 | -0.35 | 0.20 |
| EC | | | | | | | 1.00 | -0.16 | 0.25 | 0.40 |
| Turb. | | | | | | | | 1.00 | -0.15 | -0.02 |
| pH | | | | | | | | | 1.00 | -0.30 |
| DODP | | | | | | | | | | 1.00 |
| Mean (M) | 16.85 | 7.80 | 0.55 | 0.31 | 0.93 | 0.31 | 245.35 | 11.74 | 7.39 | 49.52 |
| Standard Deviation (S) | 5.00 | 9.90 | 0.51 | 0.30 | 0.86 | 0.31 | 95.83 | 19.42 | 0.21 | 23.55 |

Table VIII. Factor Matrix, Eigenvalues and Cumulative Percentage of Ten Water Quality Parameters

| Parameter | F1 | F2 | F3 |
|---|---|---|---|
| Temperature ($X_1$) | 0.216 | 0.394 | 0.649 |
| BOD | 0.819 | -0.028 | 0.070 |
| TP | 0.895 | 0.007 | -0.213 |
| $PO_4$-P | 0.874 | 0.078 | -0.111 |
| TN | 0.874 | -0.102 | -0.162 |
| $NO_3$-N | 0.786 | -0.304 | -0.231 |
| EC | 0.358 | 0.790 | -0.218 |
| Turbidity | 0.204 | -0.511 | 0.129 |
| pH | -0.461 | 0.462 | -0.539 |
| DODP ($X_{10}$) | 0.558 | 0.403 | 0.388 |
| Eigenvalues | 4.360 | 1.527 | 1.068 |
| Cumulative Percentage | 43.60 | 58.87 | 69.55 |

that these three principal components represent 69.55% of the water quality parameters of greatest significance to irrigation and surface return flows. These eight parameters were then used for development of a weighting scale. Since $PO_4$-P and $NO_3$-N are partial nutrient components of TP and TN, two index equations were constructed, i.e., one considering totals (WQITN = f (temperature ($V_1$), BOD ($V_2$), TN ($V_3$), TP ($V_4$), EC ($V_5$) and DODP ($V_6$)) and one considering partial components (WQIPN = f (temperature ($V_1$), BOD ($V_2$), $NO_3$-N ($V_3$), $PO_4$-P ($V_4$), EC ($V_5$) and DODP ($V_6$)).

The respective weighting scales were solved by substituting correlations into equation (13) (see Appendix 3). The water quality indexes were estimated to be:

$$WQITN = 0.195V_1 + 0.493V_2 + 0.470V_3 + 0.506V_4 + 0.321V_5 + 0.350V_6 \quad (5)$$

and

$$WQIPN = 0.196V_1 + 0.500V_2 + 0.519V_3 + 0.404V_4 + 0.328V_5 + 0.414V_6 \quad (6)$$

respectively. Both equations are conceptually simple as well as easy to compute.

Regression analyses for indexes WQITN and WQIPN are presented in Table IX. The F-statistics for both equations were significant at the 99% level of confidence. However, the coefficient of determination ($R^2$) for WQITN was greater than for WQIPN, 0.9351 and 0.6759, respectively. Hence, WQITN was considered the better index.

Table IX. Simple correlations, (r), multiple coefficients of determinations ($R^2$), and multiple regression for temp., BOD, TP, $PO_4$-P, TN, $NO_3$-N, EC, DOD/DOS% (DODP), WQITN and WQIPN of 895 water samples from Carson Valley, Nevada

| | Temp. | BOD | TP | $PO_4$-P | TN | $NO_3$-N | EC | DODP | WQITN | WQIPN |
|---|---|---|---|---|---|---|---|---|---|---|
| WQITN[#] | -0.38 | -0.92 | -0.52 | -0.61 | -0.19 | -0.18 | 0.32 | -0.15 | 1 | |
| WQIPN[#] | -0.43 | -0.87 | -0.74 | -0.74 | -0.25 | 0.20 | 0.37 | -0.26 | 0.93 | 1 |

WQITN[§] = 439.35 + 3.37 (Temp.) + 6.06 (BOD) + 4.46 (TP) - 4.54 ($PO_4$-p) + 0.25 (TN) + 0.97 ($NO_3$-N) - 8.20 (EC) + 8.54 (DODP)

$R^2$ = .9351 F = 1596.13** (at df = 8,894)

WQIPN[§] = 1238.76 + 3.18 (Temp.) + 3.13 (BOD) + 29.49 (TP) + 3.27 ($PO_4$-P) + 0.05 (TN) + 0.02 ($NO_3$-N) - 27.25 (EC) + 28.52 (DODP)

$R^2$ = 0.6759 F = 230.92** (at df = 8,894)

[#]WQITN and WQIPN values were calculated from WQITN = f (Temp., BOD, TP, TN, EC, DODP), and WQIPN = f (Temp., BOD, $PO_4$-P, $NO_3$-N, EC, DODP), respectively. Multiple regression analysis was then applied to the original (i.e., all 8) water quality parameters.

[§]WQITN and WQIPN index regression equations.

**The regression coefficient is significant at the 99% level.

# Chapter 4. Index Application: State of Nevada, Kansas River Basin

## 4.1 Introduction

A concerted effort to enhance habitability of our plant is unlikely to succeed unless we know "where we are" and "what we should do". To answer these questions, we first must consider exactly what we include in the term "environment". If we restrict our consideration to overly simplified definitions, such as the pollutant amount of total dissolved solids (TDS), we have very little difficulty in measuring water quality (63). However, as we broaden our definition to include most physical, chemical and biological components, environment becomes exponentially difficult to describe (12, 26, 67).

Researchers and agencies collect vast amounts of objective data in attempts to explain what is meant by water quality (4, 11, 15, 16, 40, 46, 50, 62, 64, 77, 80). The masses of numbers describing a system are vague, complex and insufficient (12, 33, 37). We have no universally recognized methods for combining our quantitative measures with our qualitative concepts of water resources. It is therefore the purpose of the generalized water quality index presented in this investigation to reflect in one number the quality level of a water resource body as measured by several different parameters. Thus, a water quality index becomes an invaluable tool for water quality management systems because it effectively summarizes large amounts of information (37). One number, rather than several different values, is sufficient to describe the relative situation of the system.

A critical question of current water pollution control regulations is whether or not the regulated quality standard has met historical water quality trends. To help alleviate this problem, the water quality index is used as an estimator. By analyzing the historical water quality data and the current levels of water quality standards, reliability of the standards can be appraised by comparing the indexes of historical data and current quality standards.

Further, the WQI should provide an ideal method for presenting overall quality variations as a function of time and distance. Seasonal precipitation provides dilution effect for water resources which will stimulate higher quality water (17). Therefore, the WQI should be able to detect the overall quality variations as a seasonal function of time. Within a river basin as the water travels through downstream agricultural, municipal and industrial operations, accumulated waste materials increase. Hence, WQI should also be able to detect the overall quality variations as a function of river distance. Further, a dependable WQI should be applicable to different geographical areas with high reliability.

The purposes of this portion of the investigation were: a) to test the suitability of the water quality standards by applying the proposed WQI formulation to river basins within the State of Nevada; b) to examine the ability of the proposed WQI formulation to evaluate the overall quality variations as a function of time and distance; and c) to analyze the geographical reliability of the proposed index by comparing determined index values with the index developed in the Kansas River Basin.

4.2. Methods

Four designated river basins within the state of Nevada--Colorado, Walker, Humboldt and Snake Rivers--were selected primarily because these basins had more historical water quality data available for index analysis. Water quality control point standards for the river basins have been proposed by the Department of Human Resources, Bureau of Environmental Health, State of Nevada (60). A control point is a location on a stream or river segment where numerical water quality criteria are specified. The criteria so specified apply to all surface waters in the watershed upstream from the control point, or to the next upstream control point, or to the next specifically named or classified water.

When the water quality data was reported as $NO_3$-N, $PO_4$-P and EC; TN, TP and TDS were calculated from simple correlations of TN = 2.364 ($NO_3$-N) + 0.582, TP = 1.511 ($PO_4$-P) + 0.379, EC = TDS x ($^1/0.64$) for purpose of index construction. These calculations were operated by program of input data standardization ("XA" Program - Appendix 4). However, if more than one of TN, TP and TDS was missing in a water sample, the sample was deleted to maintain a high realistic acceptability. Six water quality parameters--DODP, BOD, TN, TP, EC and temperature--were entered into water quality index and statistical analysis program ("WQISDA" Program - Appendix 5) for calculation of WQITN and the associated statistical results. The statistical results include mean, standard deviation, standard error of mean and coefficient of variability. The detailed statements of "XA" and "WQISDA" programs are shown in Appendix 4 and Appendix 5, respectively.

The summary statistics, mean, standard deviation, standard error of the mean and coefficient of variability of WQI were analyzed for the four designated river basins within the State of Nevada. Of the four river basins analyzed, two river basins, Walker and Snake River Basins, had more water quality data for each control point showing yearly trends. Also, these two river basins, one located in the north central portion of Nevada (Snake River Basin) and the other located in the western portion of Nevada (Walker River Basin), offered a good geographical distribution within the State of Nevada. Hence, WQI of water samples and water quality standard (SQS) for each control point of the Snake and Walker River Basins were plotted to illustrate the suitability of the administrative water quality standards and to discuss the chronological time function.

An extensive WQI study sponsored by the Environmental Protection Agency (EPA) was conducted in the Kansas River Basin (47). Twenty-six sampling stations between Junction City and Kansas City, 14 on the main stem and 12 on major tributaries, were sampled for the WQI study of the Kansas River Basin (WQIKS). Three representative WQIKS samples, minimum, medium and maximum, from each station were selected for WQITN analysis. The WQITN of the selected water samples were calculated by "XA" and "WQISDA" programs.

High (maximum) and low (minimum) values of WQIKS and WQITN were plotted to examine the overall water quality variation as a function of distance. Sampling stations from main stems and tributaries were separately plotted to determine the pollution effects of agricultural and industrial wastes.

## 4.3 Results and Discussion

WQITN was calculated for all sampling stations for four river basins of Nevada State and Kansas River Basin. Index values of water samples and water quality standards (SQS) for each control point of two river basins in Nevada State were graphically compared to test the overall water quality variations as a function of time. High and low values of WQIKS and WQITN were plotted to examine the overall water quality variation as a function of river distance.

### 4.3.1. State of Nevada

Table X presents the summary statistics for four river basins within the State of Nevada. In discussing the data from this study, variations of ±5 WQI were considered significant in accordance with the literature (47). The mean WQI decreased from 85.50 in northern Nevada at the Snake River Basin to 73.23 in southern Nevada at the Colorado River Basin. It was apparent that water quality in the river basins of Nevada showed a significant geographical variation (12.27 units of WQI).

Colorado River Basin had the least WQI range (a minimum of 63.19 to a maximum of 83.96) and the least standard deviation (4.98). Walker River Basin had the highest WQI range (40.96 to 91.30), highest standard deviation and highest coefficient in comparison to the other three river basins. Surprisingly, the lowest WQI (40.96) ever detected was not in the Colorado River Basin, but rather in the Walker River Basin. Snake River Basin had the highest WQI (94.33) because of the pristine water source.

The Humboldt River Basin had a lower mean WQI, but not significantly different, in comparison to the Walker River Basin located

Table X. Summary Statistics of WQITN for River Basins in State of Nevada

| Name of River Basin | | Colorado | Walker | Humboldt | Snake |
|---|---|---|---|---|---|
| No. of Samples | | 30 | 92 | 30 | 94 |
| Mean of WQITN | | 73.23 | 82.43 | 82.32 | 85.50 |
| Standard Deviation | | 4.98 | 8.53 | 5.90 | 6.14 |
| Standard Error of Mean | | 0.91 | 0.89 | 1.08 | 0.63 |
| Coefficient of Variability % | | 6.80 | 10.35 | 7.16 | 7.18 |
| Range | Minimum | 63.19 | 40.96 | 64.21 | 61.84 |
| | Maximum | 83.96 | 91.30 | 88.38 | 94.33 |
| No. of Control Points* | | --** | 4 | 5 | 9 |

*Water quality standard proposed by Department of Human Resources, Bureau of Environmental Health, Nevada.

**No data available.

several hundred miles to the south. This particular basin comprises an area of about 17,000 square miles or about 15 percent of the State of Nevada. The river meanders over 300 miles in a westerly direction before the water finally enters the Humboldt Sink, where evapotranspiration consumes virtually the entire amount of the remaining water. It may be reasonable to assume that both factors of the large discharge area and the slow, long meandering river with evapotranspiration sink do contribute to the relatively low mean WQI value observed along the Humboldt River Basin.

Table XI shows the location (longitude and latitude) for the water quality control points of Walker and Snake River Basins, Nevada. The geographical areas are presented in Figures 5 and 6. WQI values of water samples and state quality standard (SQS) at the control points of Walker and Snake River Basins were graphically plotted as shown in Figures 7 to 19. The index values of proposed state quality standard (SQS) by the Bureau of Environmental Health, State of Nevada, was plotted in SQS line, while the WQI of water samples were plotted in chronological sequence.

As shown in the plotted graphs, most of the water samples had met the proposed state quality standard in Walker and Snake River Basins. From Figure 7, the WQI at the control point of below diversion to Topaz Lake, Walker River were all meeting state quality standards from January 1975 to April 1977. The WQI variations from sample to sample were always less than ±5 which showed a non-significant change for the entire period.

There were two water samples that violated the proposed state water quality standard[1] at the control point of south of Yerington above

Table XI. Proposed water quality control point locations (longitude/latitude) for Walker and Snake River Basins

| River Basin | Name of the Control Point | Longitude | Latitude | Figure Number |
|---|---|---|---|---|
| Walker | Diversion to Topaz Lake (W1) | 38°38'30" | 119°30'30" | 7 |
| " | Nordyke Road at East Walker (W2) | 38°53'25" | 119°10'00" | 8 |
| " | Yerington above Confluence (W3) | 38°55'07" | 119°11'22" | 9 |
| " | J. J. Ranch (W4) | 39°09'11" | 119°05'30" | 10 |
| Snake | Petan Access Road (S1) | 41°47'31" | 116°24'50" | 11 |
| " | Nevada-Idaho State Line (S2) | 41°59'47" | 116°08'55" | 12 |
| " | Owyhee at New China Dam (S3) | 41°55'32" | 116°05'35" | 13 |
| " | Mill Creek at Ranger Station (S4) | 41°48'40" | 115°57'15" | 14 |
| " | Diamond "A" Road (S5) | 41°44'55" | 115°34'40" | 15 |
| " | Upstream from Jarbidge (S6) | 41°52'02" | 115°25'50" | 16 |
| " | Downstream from Jarbidge (S7) | 41°52'50" | 115°25'50" | 17 |
| " | Highway 93 South of Jackpot (S8) | 41°56'40" | 114°41'10" | 18 |
| " | Jackpot to Delaplain Road (S9) | 41°57'32" | 114°44'20" | 19 |

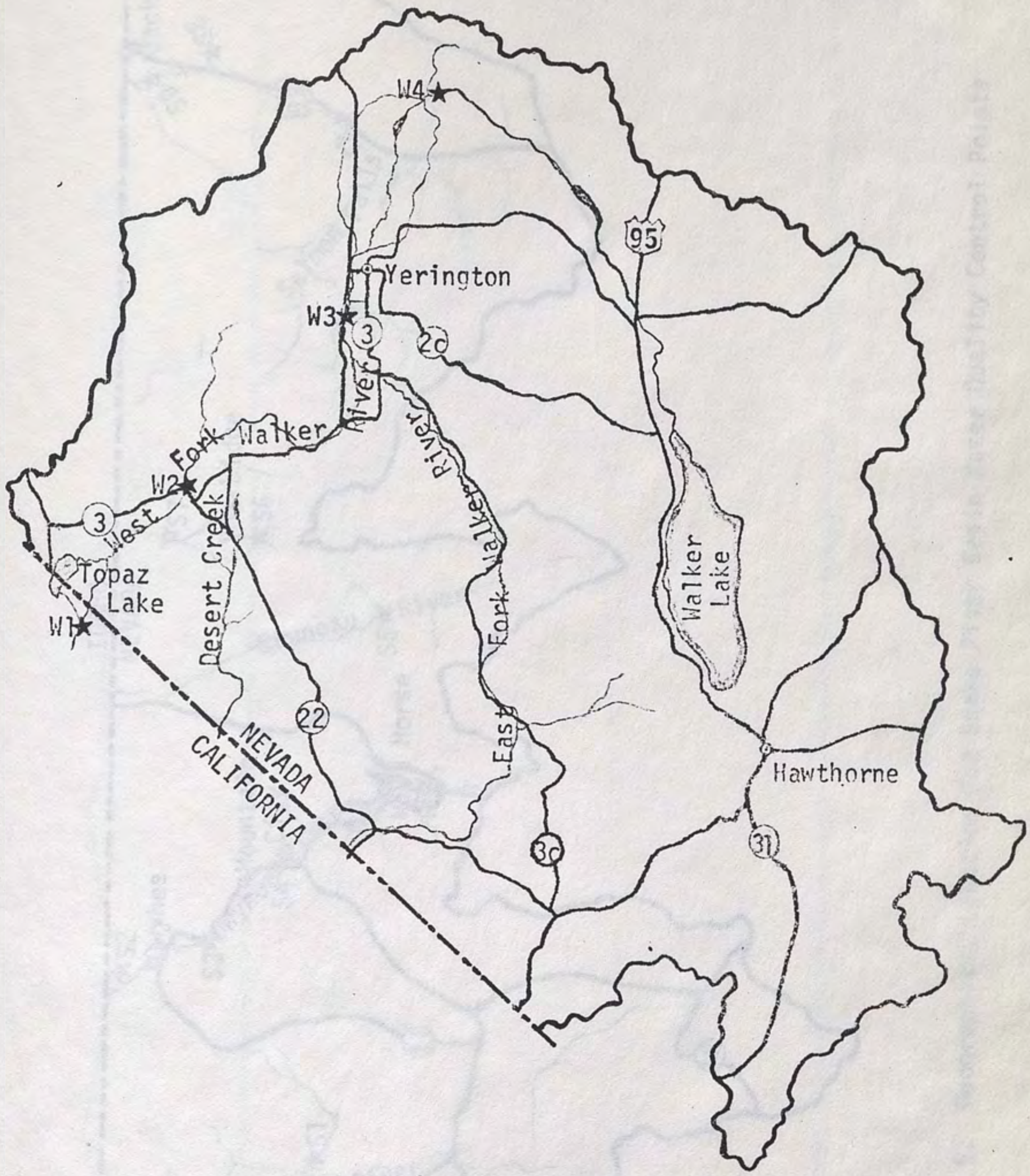



Figure 5. Geographical Location for Walker River Basin Water Quality Control Points

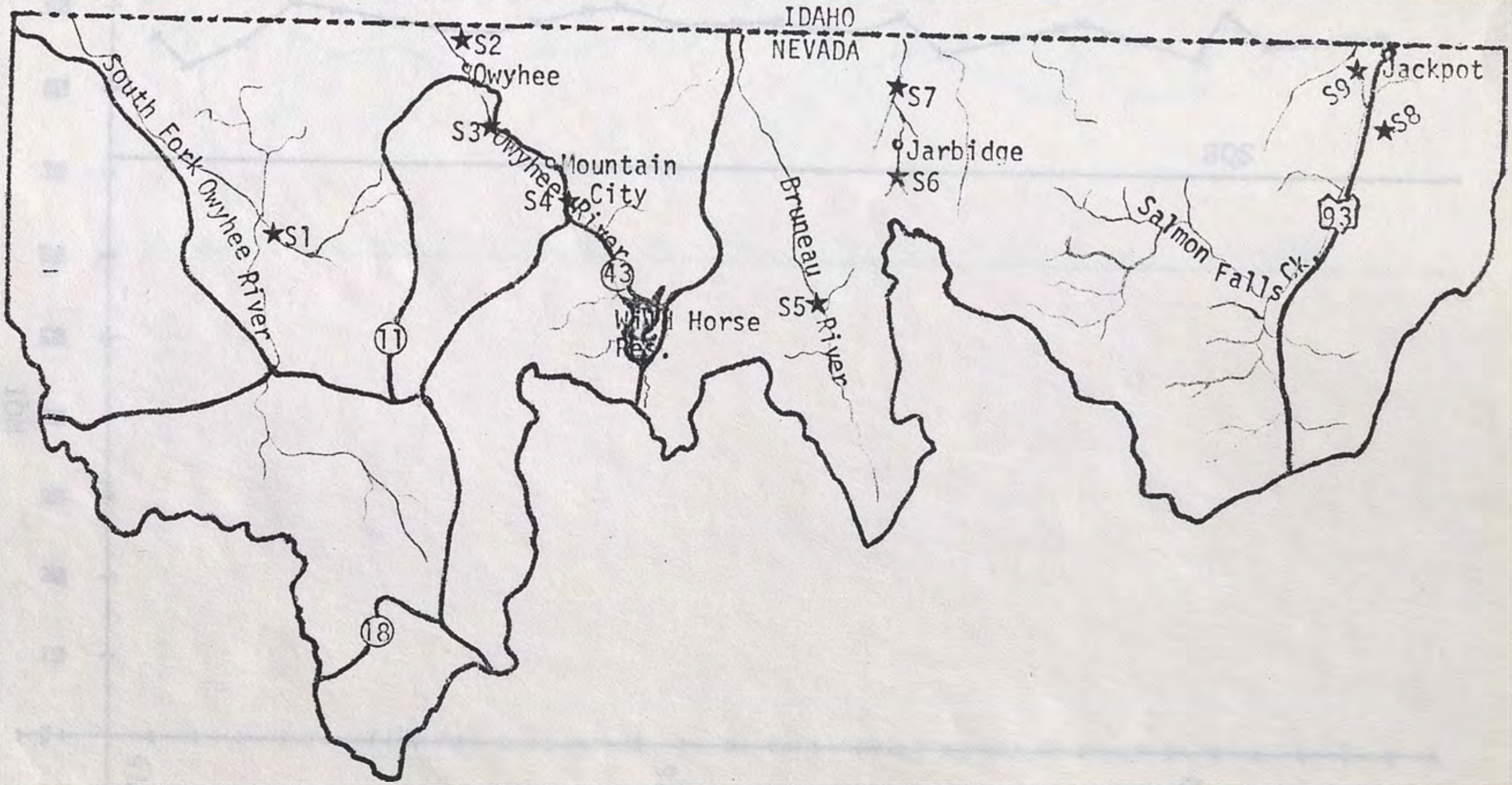



Figure 6. Geographical Location for Snake River Basin Water Quality Control Points

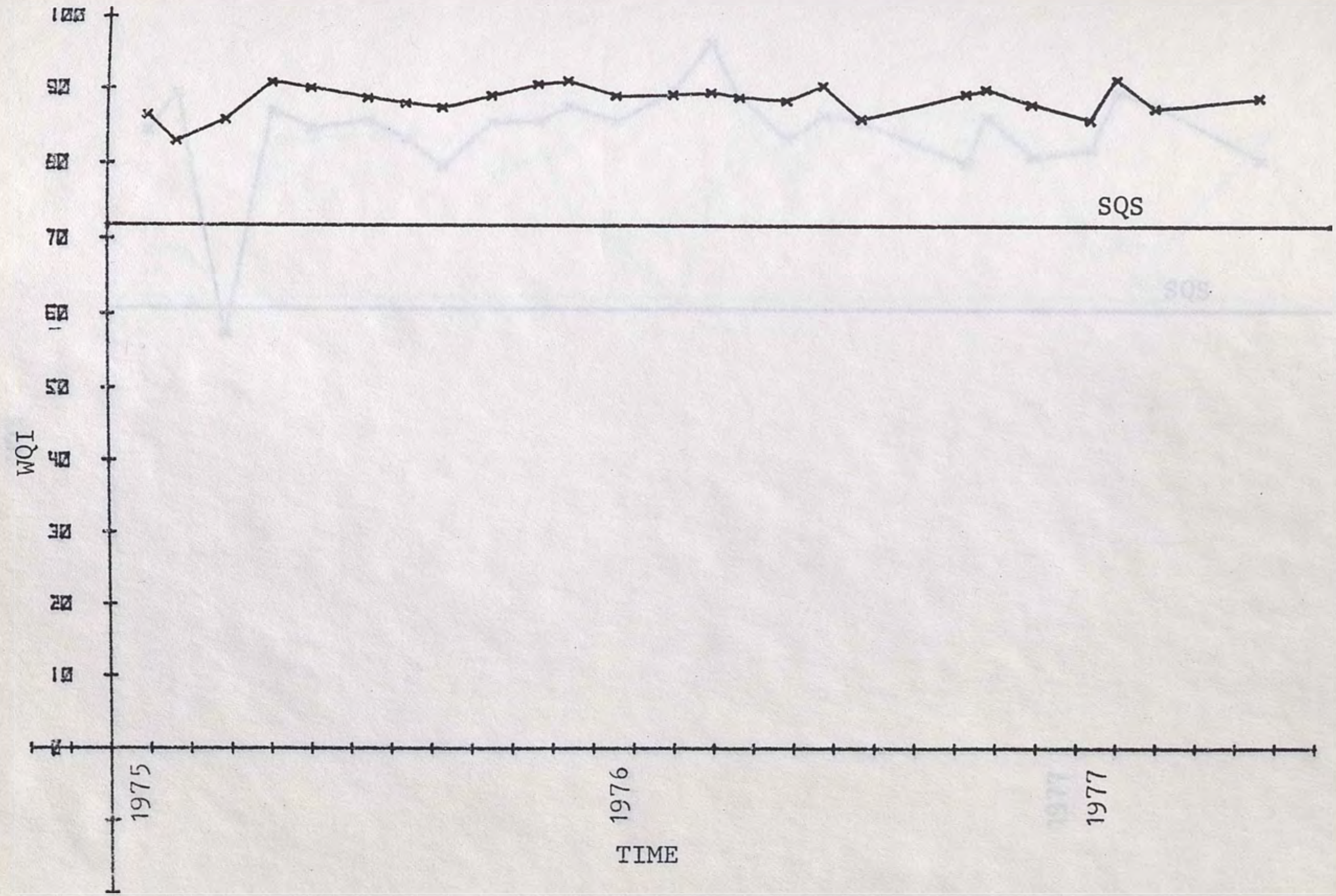



Figure 7. WQI of water samples and state quality standard (SQS) at control point of below diversion to Topaz Lake, Walker River

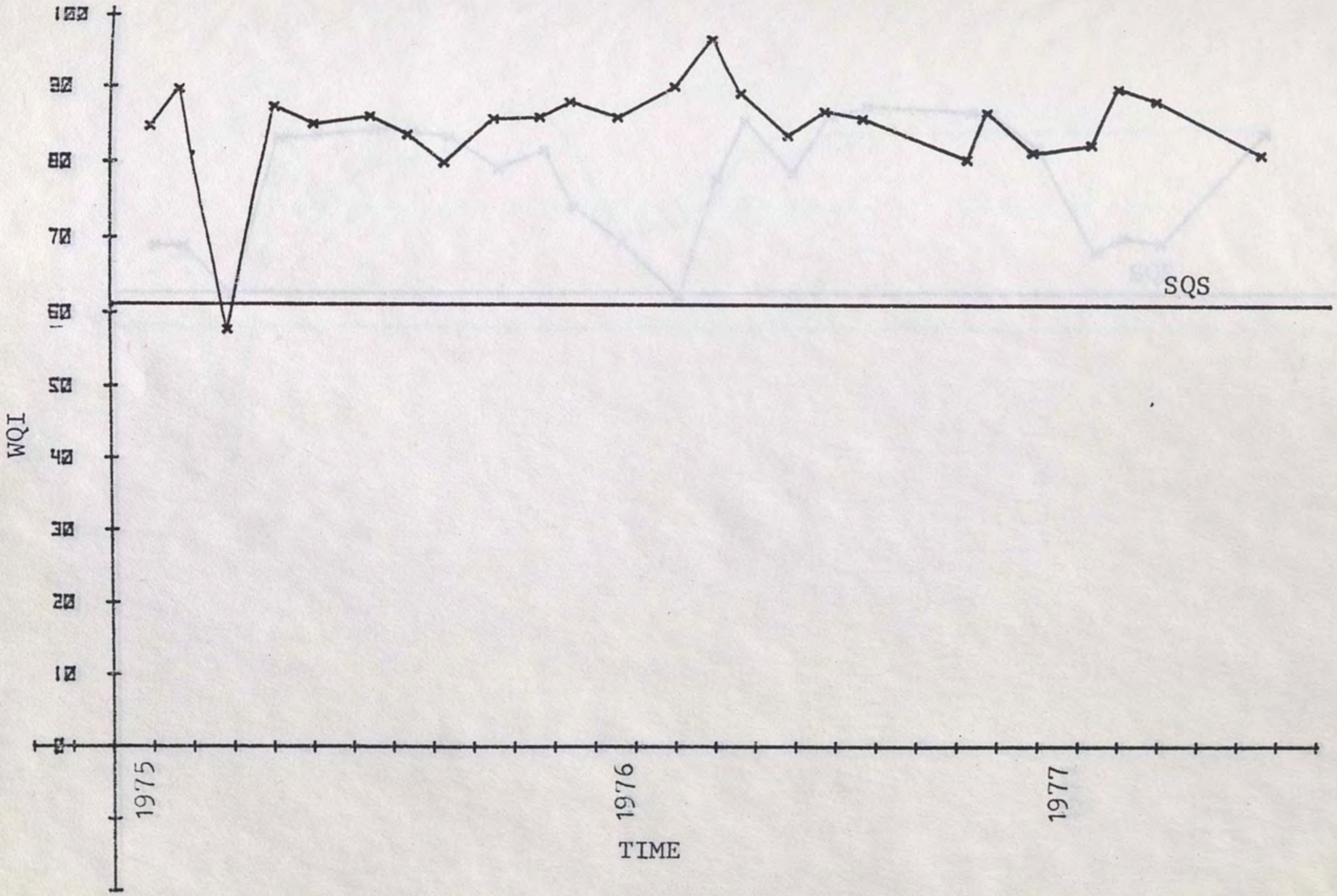



Figure 8. WQI of water samples and state quality standard (SQS) at control point above confluence with East Walker (Nordyke Road), Walker River

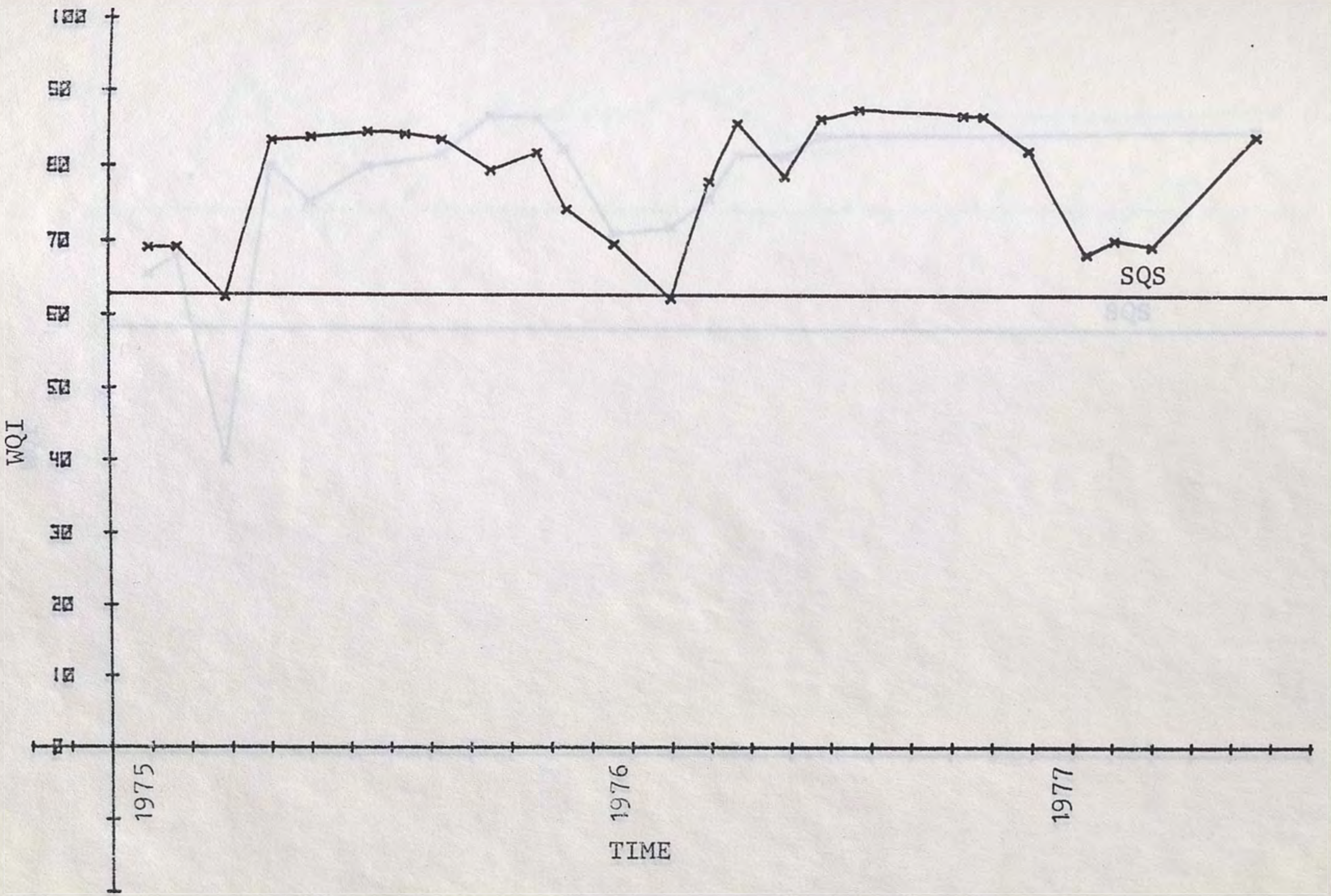



Figure 9. WQI of water samples and state quality standard (SQS) at control point of south of Yerington above confluence, Walker River

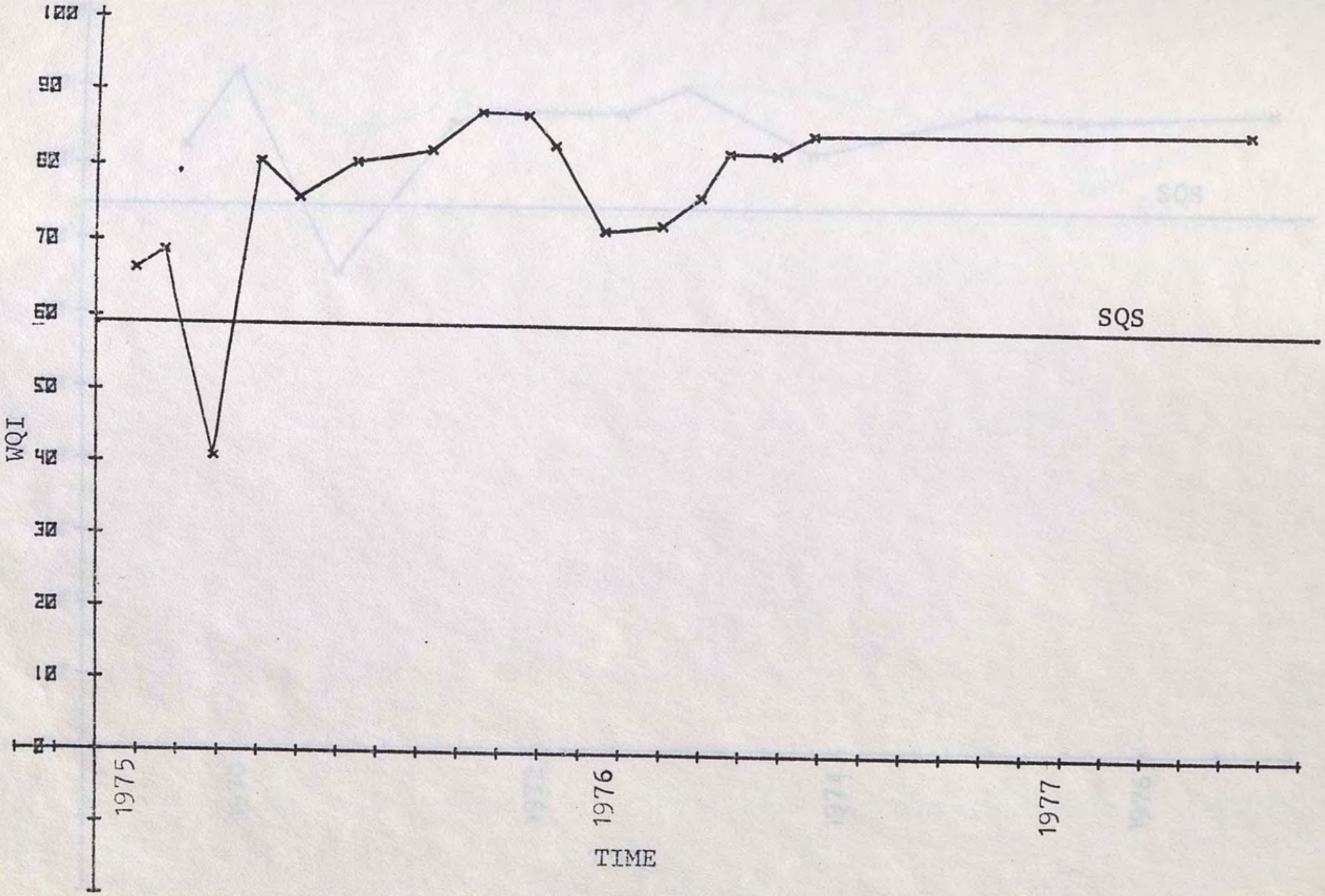



Figure 10. WQI of water samples and state quality standard (SQS) at control point of J. J. Ranch, Walker River

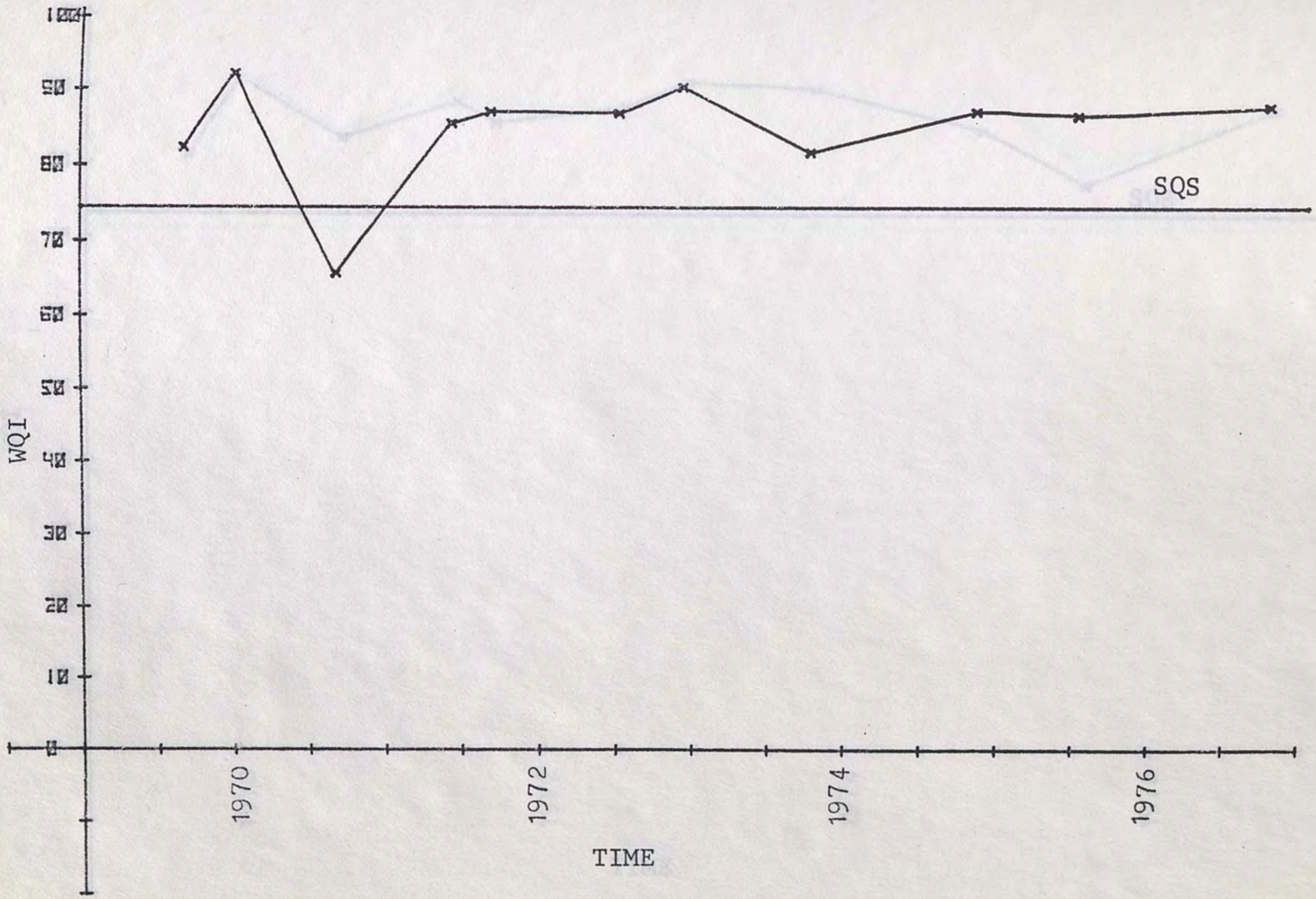



Figure 11. WQI of water samples and state quality standard (SQS) at control point of Petan Access Road, Snake River

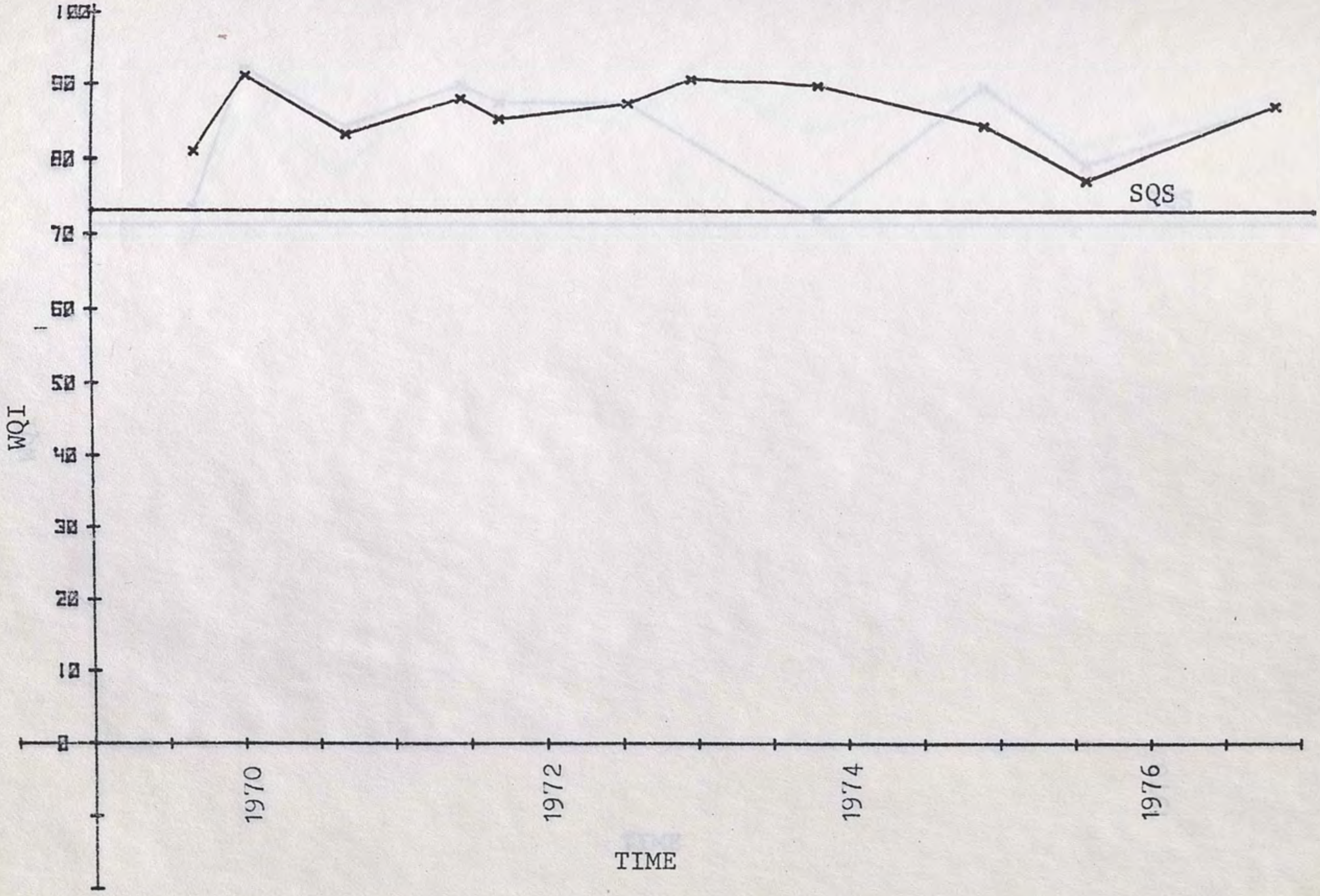



Figure 12. WQI of water samples and state quality standard (SQS) at control point of Nevada-Idaho State Line, Snake River

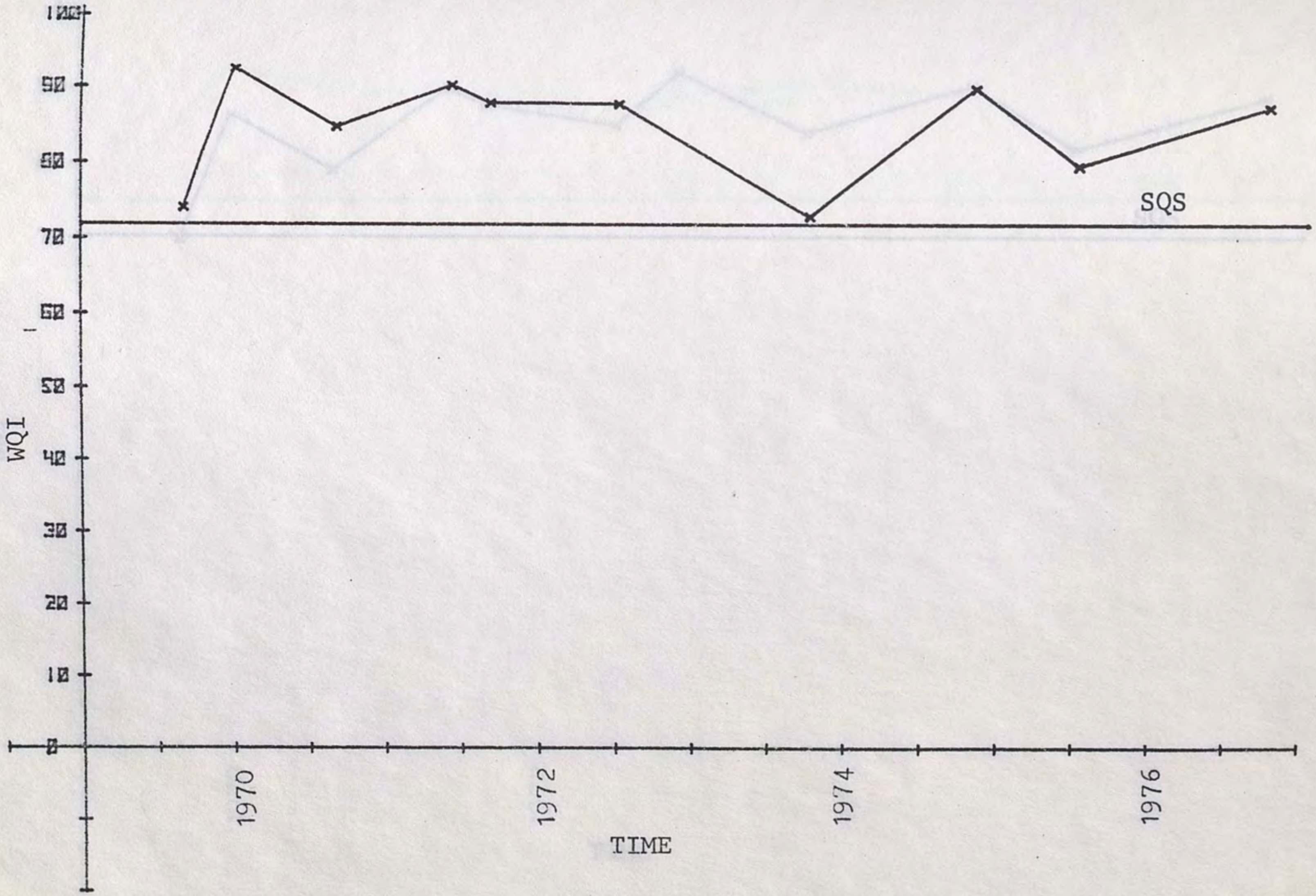



Figure 13. WQI of water samples and state quality standard (SQS) at control point of south of Owyhee at New China Dam, Snake River

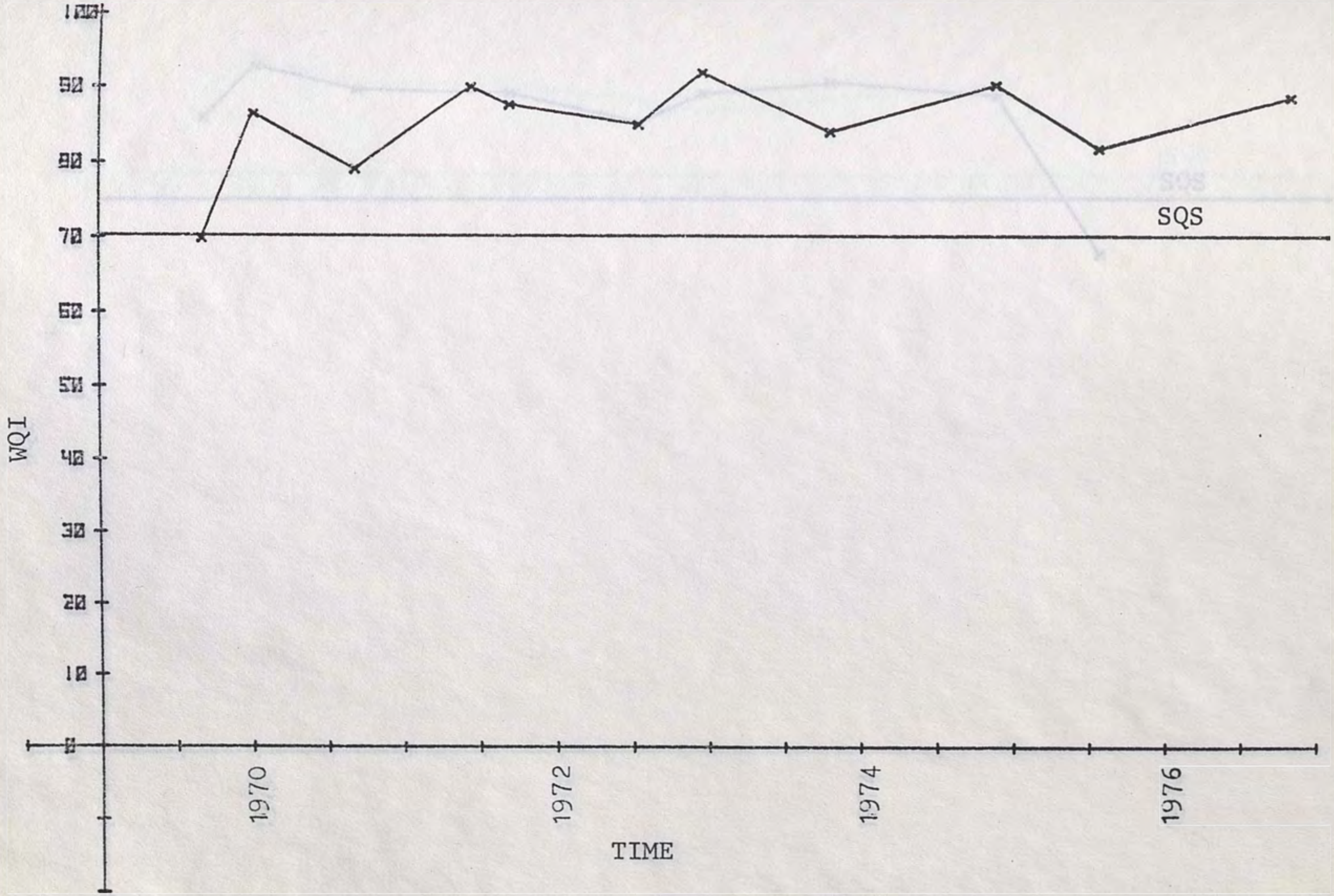



Figure 14. WQI of water samples and state quality standard (SQS) at control point of above Mill Creek at Ranger Station, Snake River

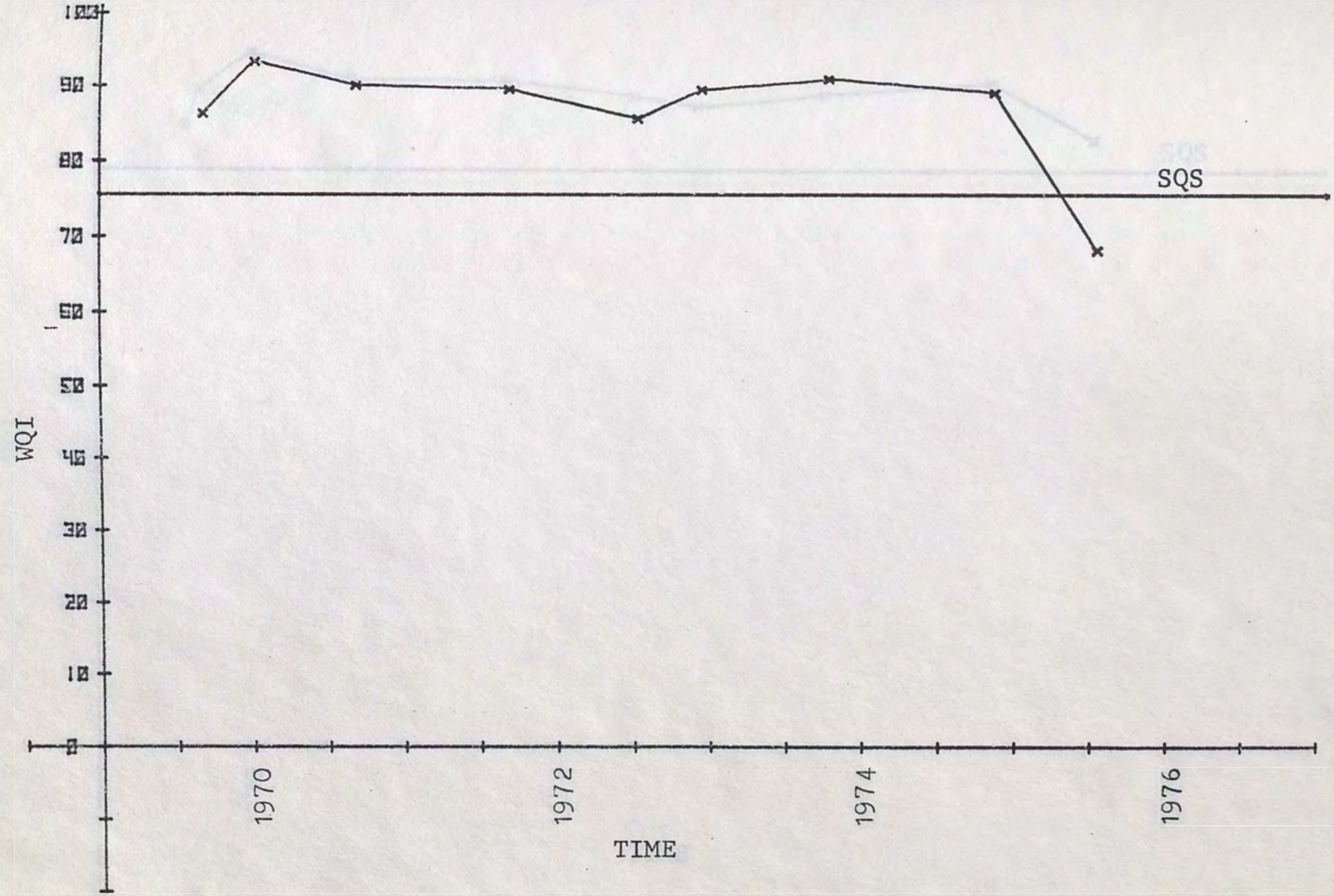



Figure 15. WQI of water samples and state quality standard (SQS) at control point of Diamond "A" Road, Snake River

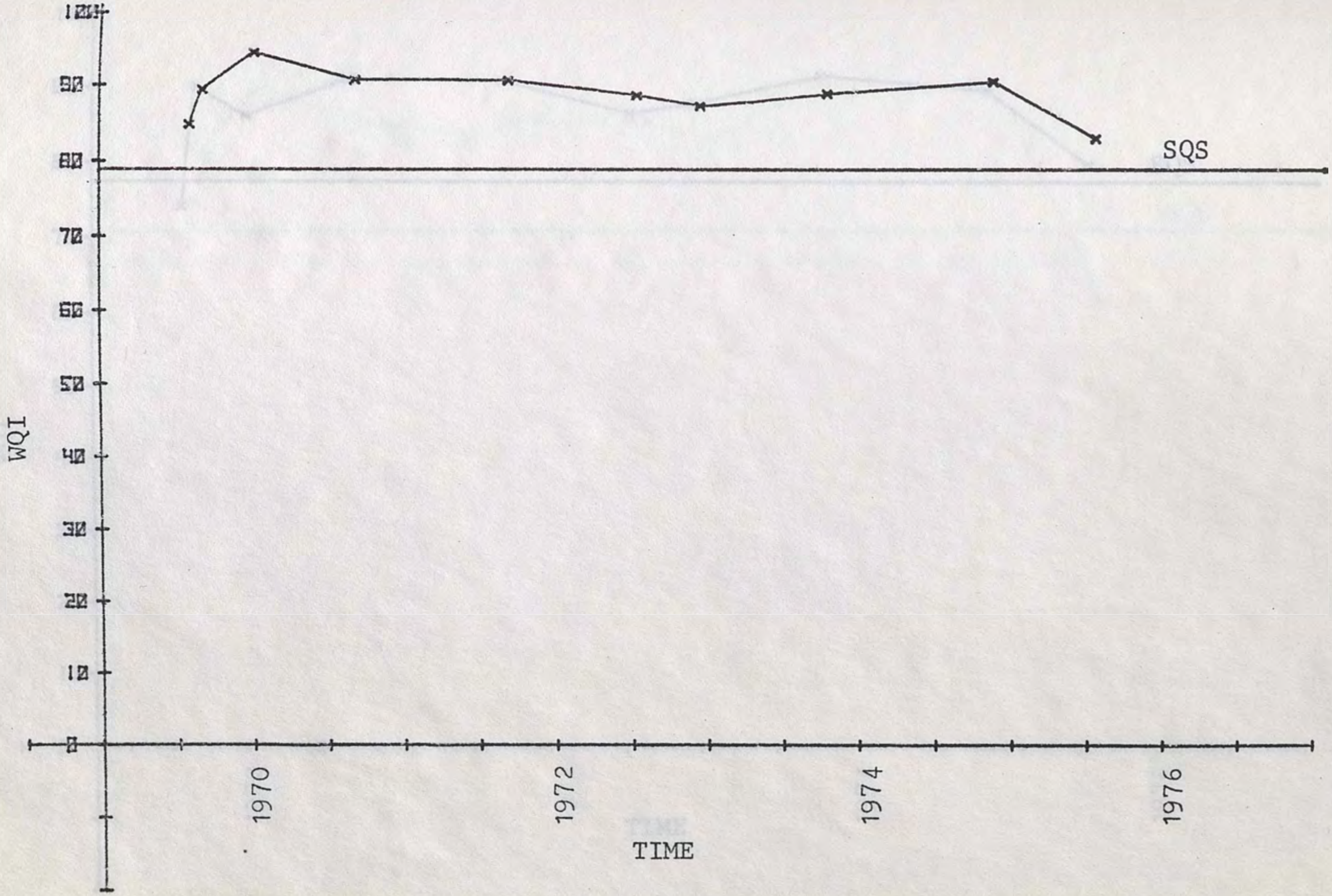



Figure 10. WQI of water samples and state quality standard (SQS) at control point upstream from Jarbidge, Snake River

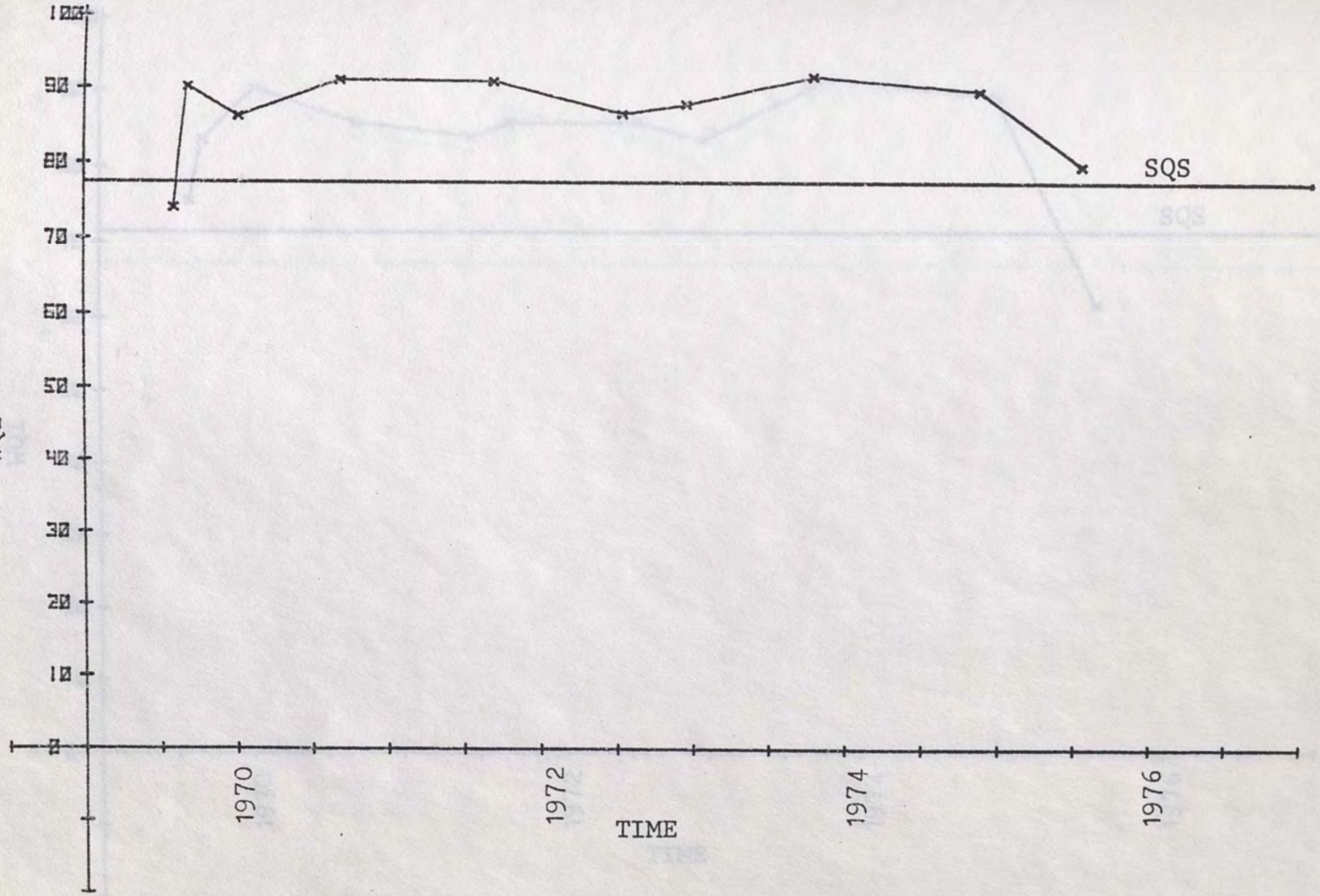



Figure 17. WQI of water samples and state quality standard (SQS) at control point of downstream from Jarbidge, Snake River

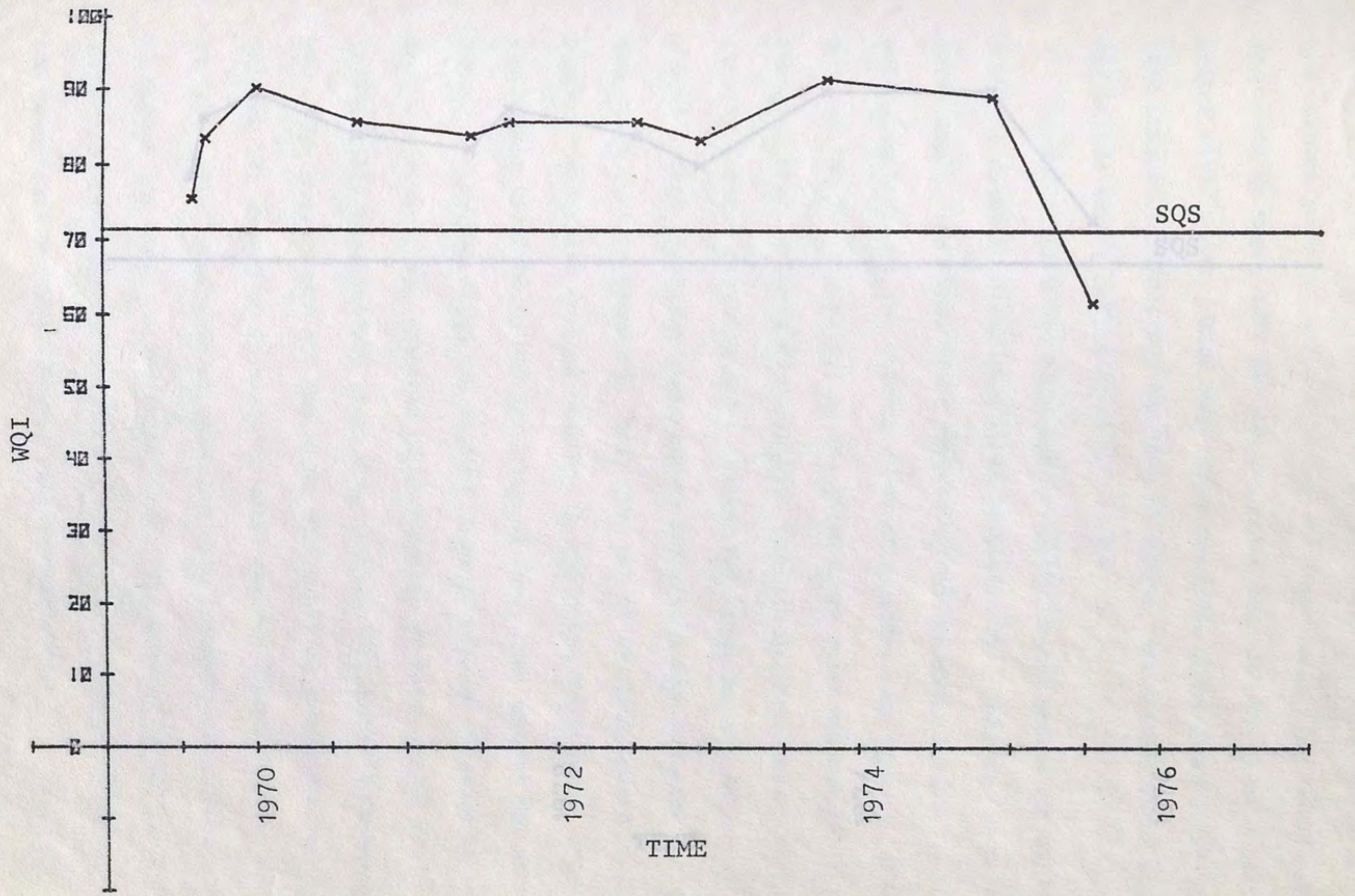



Figure 18. WQI of water samples and state quality standard (SQS) at control point of Highway 93 south of Jackpot, Snake River

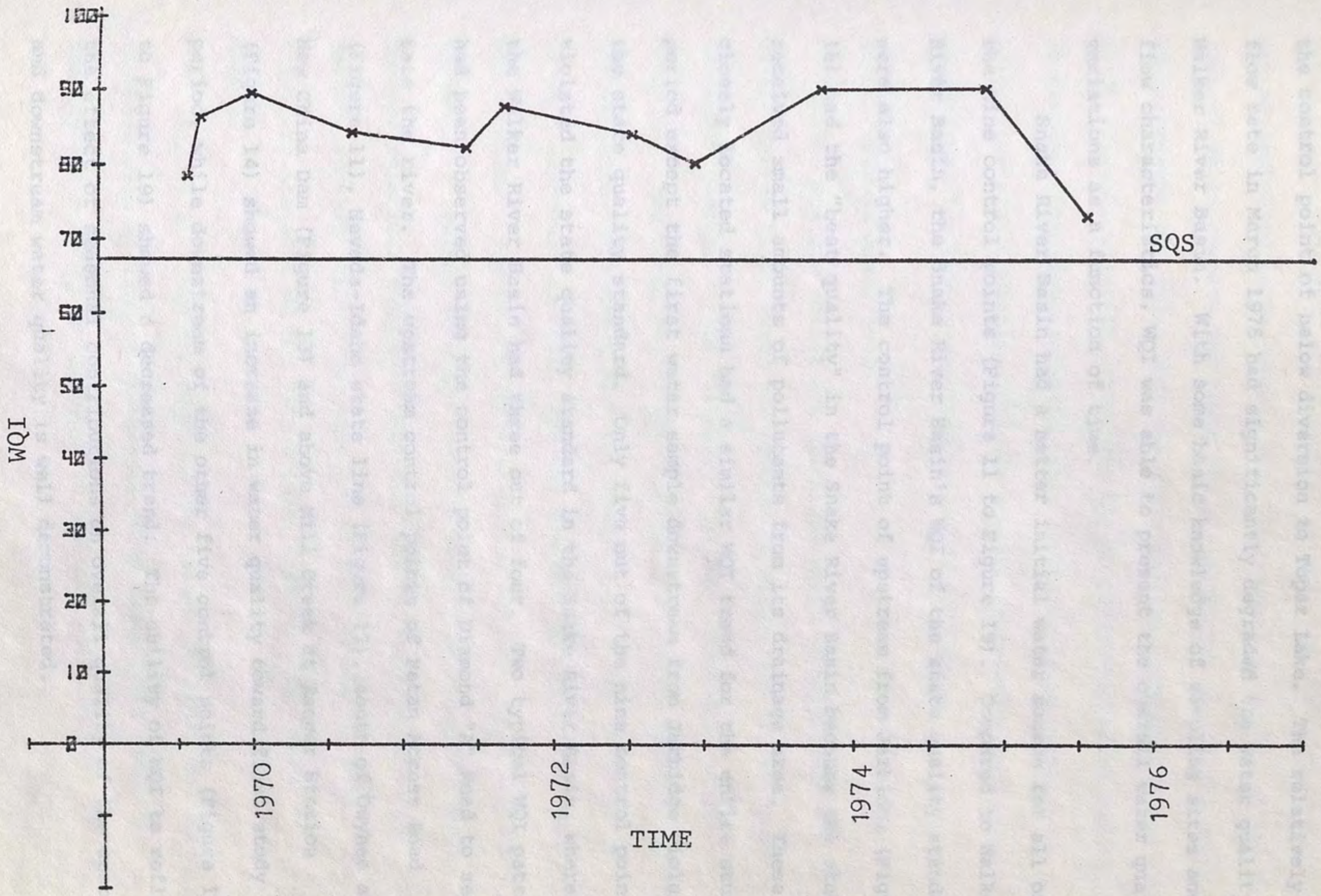



Figure 19. WQI of water samples and state quality standard (SQS) at control point of Jackpot to Delaplain Road, Snake River

confluence of Walker River (Figure 10). In Walker River Basin, all WQI of March 1975 did not meet the proposed state quality standard except the control point of below diversion to Topaz Lake. The relatively low flow rate in March 1975 had significantly degraded the water quality at Walker River Basin. With some basic knowledge of sampling sites and flow characteristics, WQI was able to present the overall water quality variations as a function of time.

Snake River Basin had a better initial water source for all of the nine control points (Figure 11 to Figure 19). Compared to Walker River Basin, the Snake River Basin's WQI of the state quality standards were also higher. The control point of upstream from Jarbidge (Figure 16) had the "best quality" in the Snake River Basin because the station received small amounts of pollutants from its drainage area. These two closely located stations had a similar WQI trend for the entire study period except the first water sample downstream from Jarbidge violated the state quality standard. Only five out of the nine control points violated the state quality standard in the Snake River Basin, whereas the Walker River Basin had three out of four. Two typical WQI patterns had been observed using the control point of Diamond "A" Road to separate the river. The upstream control points of Petan Access Road (Figure 11), Nevada-Idaho state line (Figure 12), south of Owyhee at New China Dam (Figure 13) and above Mill Creek at Ranger Station (Figure 14) showed an increase in water quality toward final study period, while downstream of the other five control points (Figure 15 to Figure 19) showed a decreased trend. The ability of WQI to reflect the effect of seasonal contributions on overall quality of the upstream and downstream water quality is well demonstrated.

From the summary statistics (Table X) and WQI time profile (Figure 7 to Figure 19), it is apparent that water quality in different river basins does vary among control points, and that these variations can be expressed as an overall WQI. By comparing the WQI of the historical water samples and state quality standards of control point, the administrator can infer that the state quality standards at Snake River Basin are appropriately set by the Bureau of Environmental Health, State of Nevada. The high violation ratio at Walker River Basin means that either the state quality standards are too restrictive or the water quality has too many unexpected pollutant sources.

4.3.2. Kansas River Basin

High and low values for WQIKS and WQITN at each tributary station of the Kansas River Basin are plotted in Figure 20. It is apparent that the water quality at the tributary stations showed only slight variations over the study period when expressed as either WQIKS or WQITN with the exception of station #8. The lowest quality was observed in station #2 when expressed as WQIKS, but was observed in station #1 when expressed as WQITN. The best tributary quality for both WQIKS and WQITN was recorded at station #4 which received water from reservoir supply (47). Because reservoir retention provides time for self purification, the quality at this station was expected to be consistently high. These 12 tributary stations do not have a large variation from upstream to downstream.

Figure 21 shows the high and low values for WQIKS and WQITN at the main stem station of the Kansas River Basin. The highest water quality for both WQIKS and WQITN is the same (station #8); however,

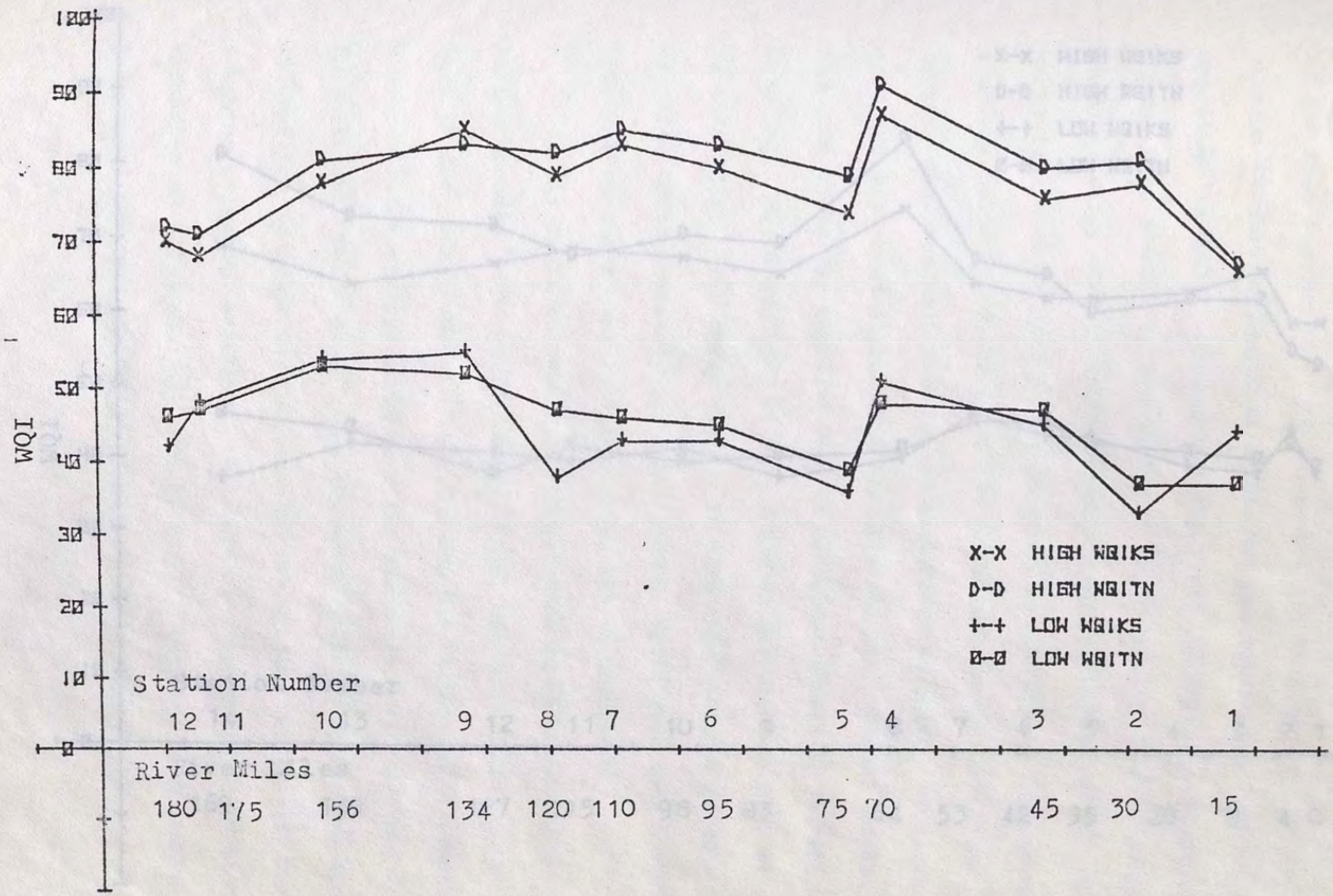



Figure 20. High and low values for WQIKS and WQITN at tributary stations of Kansas River Basin

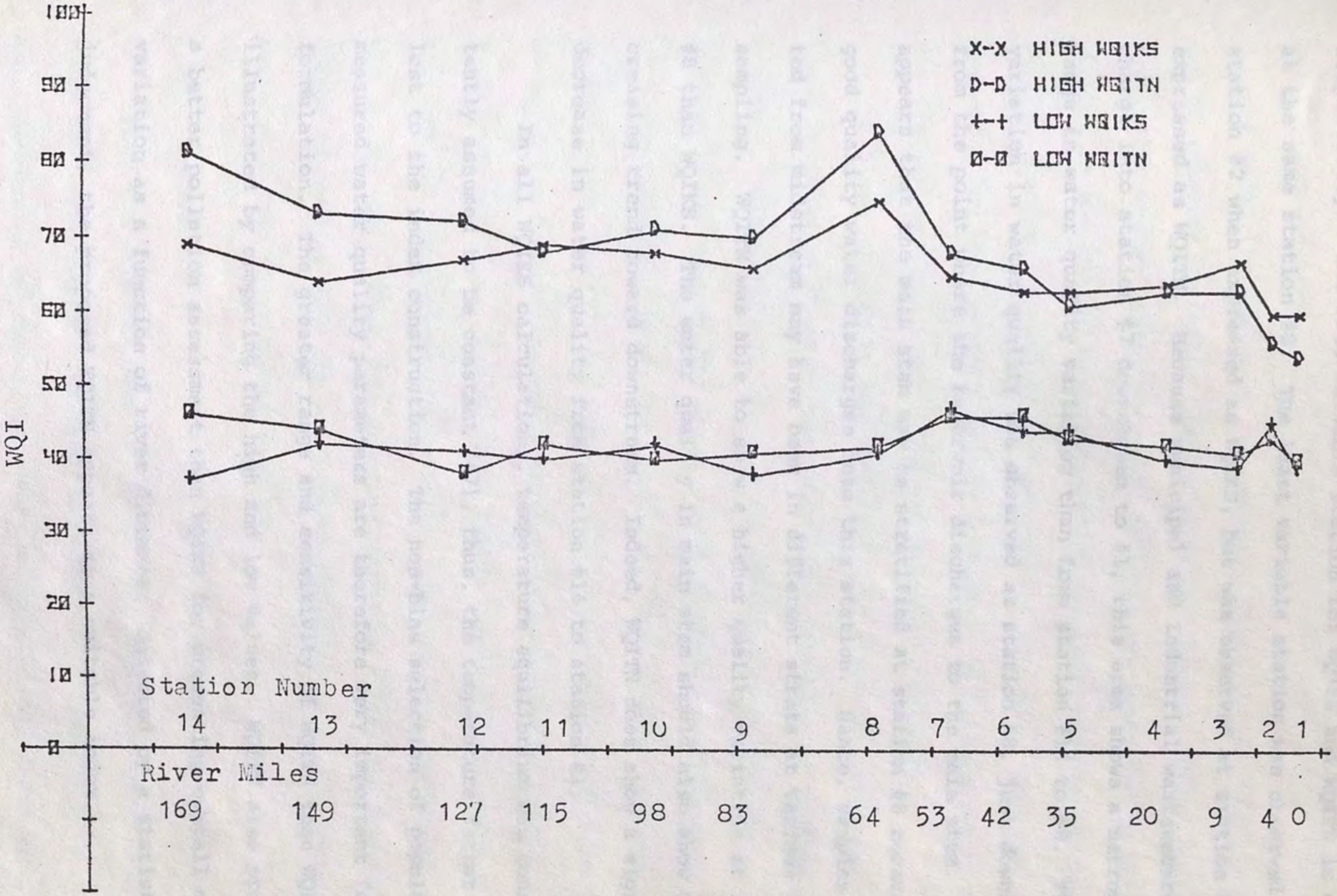



Figure 21. High and low values for WQIKS and WQITN at main stem stations of Kansas River Basin

the lowest water quality stations for WQIKS and WQITN are #14 and #12, respectively. The most variable station for WQIKS and WQITN is detected at the same station #8. The least variable station was observed at station #2 when expressed as WQIKS, but was observed at station #1 when expressed as WQITN. Because municipal and industrial wastewaters discharge into station #7 downstream to #1, this area shows a narrower range in water quality variation than from station #14 to #8. The most variation in water quality was observed at station #8, just downstream from the point where the reservoir discharges to the main stem. It appears that the main stem may be stratified at station #8 because the good quality water discharges into this station. Hence, samples collected from midstream may have been in different strata at various times of sampling. WQITN was able to show a higher quality variation at station #8 than WQIKS. The water quality in main stem should also show a decreasing trend toward downstream. Indeed, WQITN does show a significant decrease in water quality from station #14 to station #1.

In all WQIKS calculations, temperature equilibrium was consistently assumed to be constant (47), thus, the temperature factor was lost to the index construction. The non-bias selection of popular measured water quality parameters are therefore very important for WQITN formulation. The greater range and sensitivity of WQITN than WQIKS is illustrated by comparing the high and low values. WQITN also provides a better pollution assessment than WQIKS for presenting overall quality variation as a function of river distance. Selected by a statistical judgement, the proposed WQITN appears as a suitable index.

# Chapter 5. Index Modification

## 5.1. Introduction

A major limitation of the preceding index is how reliable is the set of selected variables identified by multivariate factor analysis. A step-forward multiple regression analysis was conducted to confirm whether or not the selected independent variables were indeed most suitable to predict dependent index variables (27, 61). This analysis technique has been applied by many scientists to discriminantly select the regression among independent and dependent variables.

A basic problem in the development of linear discriminant functions is deciding which of the explanatory variables to include in the function. Alternatively, given a set of explanatory variables, the problem is one of choosing which subset of these variables provides the best discrimination among the groupings. This problem is encountered in regression analysis and several other statistical results have been advanced for determining which explanatory variables to include in a regression equation. The approach yields consistent estimates of the variance and may provide the basis for a t-test when the sample size is very large (61). Thus, the stepwise procedure allows the researcher a degree of control over the statistical significance of the variables included in the discriminant function.

## 5.2. Methods

From the existing data (3, 8, 11, 12), the rated water quality index corresponding to different water quality parameters were collected. Because of the non-linear relationships between rated water quality index values and the water quality parameters, rating equations for water quality parameters were statistically developed by polynomial regression analysis (Table XII). The rating equations were then used to compute the overall water quality index based on first principal factor. A step-forward multiple regression was conducted to identify the most important variables by comparing the ten basic water quality parameters as independent variables to the overall water quality index as a dependent variable. Compared to the variables selected by principal analysis, the statistical results of step-forward multiple regression analysis were used to subjectively confirm or deny the selection of most important water quality parameters for the construction of two simplified water quality index formulations. By examination of a correlation matrix, the relative importance of each parameter was estimated and a weighting scale was derived by analytical solution process. Two simplified index equations were developed: WQITN = f (Temp., BOD, TP, EC and DODP) and WQIPN = f (Temp., BOD, $PO_4$-P, EC and DODP).

Because the index equations were developed from data of Carson Valley, Nevada, two of Nevada's river basins, Snake and Colorado River Basins, were used to test acceptability of the modified WQITN and WQIPN equations. By comparison of the correlation results, one formulation was selected. To test the applicability of the proposed WQI formulation, water quality data at different geographical regions (38, 58) were considered.

## 5.3. Results and Discussion

The step-forward multiple regression analysis (Table XIII) established relative importance sequence of TP, BOD, DODP, $PO_4$-P, EC, Temp.,

Table XII. Rating Equation of Temp. ($X_1$), BOD ($X_2$), TP ($X_3$), $PO_4$-P ($X_4$, TN ($X_5$), $NO_3$-N ($X_6$), EC ($X_7$), Turb. ($X_8$), pH ($X_9$), and DODP ($X_{10}$) for Rating Water Quality ($Y_i$)

$$Y_1 = 86.840 - 10.181\ X_1 + 0.330\ X_1^2$$

$$Y_2 = 94.595 - 7.336\ X_2 + 0.149\ X_2^2$$

$$Y_3 = 98.378 - 66.296\ X_3 + 13.188\ X_3^2$$

$$Y_4 = 93.687 - 44.982\ X_4 + 5.779\ X_4^2$$

$$Y_5 = 96.334 - 2.272\ X_5 + 0.0159\ X_5^2$$

$$Y_6 = 91.723 - 3.689\ X_6 + 0.0425\ X_6^2$$

$$Y_7 = 99.044 + 0.019\ X_7 - 0.0011\ X_7^2$$

$$Y_8 = 97.143 - 1.638\ X_8 + 0.0087\ X_8^2$$

$$Y_9 = 93.372 - 54.521\ X_9 + 7.888\ X_9^2 \quad \text{(when pH} \leq 7.00\text{)}$$

$$Y_9 = 343.951 - 42.942\ X_9 + 1.158\ X_9^2 \quad \text{(when pH > 7.00)}$$

$$Y_{10} = 94.963 - 0.821\ X_{10} - 0.0016\ X_{10}^2$$

Table XIII. Step forward multiple regression analysis for rating WQI of temp. ($X_1$), BOD ($X_2$), TP ($X_3$), $PO_4$-P ($X_4$), TN ($X_5$), $NO_3$-N ($X_6$), EC ($X_7$), Turb. ($X_8$), pH ($X_9$), DODP ($X_{10}$) versus dependent variable of water quality index

| Step | Variable Entered ($X_i$) | Name of Variable | Cumulative Multiple Coefficient of Determination ($R^2$) | F-Value for ANOVA | Regression Coefficient | Standard Error of Regression Coefficient | Computed T-Value |
|---|---|---|---|---|---|---|---|
| 1 | 3 | TP | 0.867 | 2.703E+3 | 0.179 | 1.229E-5 | 1.464E+4 |
| 2 | 2 | BOD | 0.956 | 4.707E+3 | 0.160 | 4.933E-6 | 3.243E+4 |
| 3 | 10 | DODP | 0.987 | 1.107E+4 | 0.110 | 5.612E-6 | 1.960E+4 |
| 4 | 4 | $PO_4$-P | 0.991 | 1.230E+4 | 0.169 | 1.855E-5 | 9.163E+3 |
| 5 | 7 | EC | 0.994 | 1.532E+4 | 0.069 | 6.301E-6 | 1.111E+5 |
| 6 | 1 | Temp. | 0.997 | 2.726E+4 | 0.004 | 4.666E-6 | 8.573E+3 |
| 7 | 8 | Turb. | 0.999 | 5.900E+4 | 0.004 | 6.708E-6 | 5.963E+3 |
| 8 | 9 | pH | 0.999 | 1.311E+5 | -0.009 | 2.469E-5 | -3.644E+3 |
| 9 | 5 | TN | 0.999 | 1.473E+6 | 0.170 | 9.860E-5 | 1.724E+3 |
| 10 | 6 | $NO_3$-N | 1.000 | 1.209E+9 | 0.150 | 1.671E-4 | 8.977E+2 |

Turb., pH, TN, to $NO_3$-N. F-values and computed T-value were highly significant for the regression test. Factor analysis (Chapter 3) selected TP, $PO_4$-P, BOD, DODP, TN, $NO_3$-N, EC and Temp. as important variables for index evaluation. The majority of the selected variables were matched by comparing the results of step-forward multiple regression analysis and factor analysis.

TN and $NO_3$-N were rejected in the overall selection of parameters. This is explained by re-examining the results of factor analysis. First factor which obtained 43.60% of the total variance was negatively correlated with pH. The second factor, strongly loaded on EC, was negatively correlated with turbidity, both nitrogen forms and BOD. Third factor, the temperature factor, was negatively loaded with pH, both nitrogen forms, both phosphate forms and EC. Although TN and $NO_3$-N were strongly correlated to first factor, the negative correlation in both second and third factors indicates their rejection in the overall step-forward analysis selection of parameters.

The high correlation between phosphate and nitrogen forms in water bodies are well documented (7, 13, 48, 62). In most polluted waters, high phosphate content would also have a high nitrogen content. From a biological pollution aspect, phosphate and nitrogen forms were macronutrients. However, phosphate forms appear to be a most limiting factor in organism growth (17) rather than the nitrogen forms. Statistically, the step-forward multiple regression analysis (Table XIII) confirmed that TN and $NO_3$-N should be rejected.

Deleting the TN and $NO_3$-N in the three principal factors, six major variables, temperature, BOD, TP, $PO_4$-P, EC and DODP, were then used for development of a weighting scale. Since $PO_4$-P is a partial nutrient component of TP, two index equations were again constructed, i.e., one considering totals (WQITN = f (temperature ($V_1$), BOD ($V_2$), TP ($V_3$), EC ($V_4$) and DODP ($V_5$)) and one considering partial components (WQIPN = f (temperature ($V_1$), BOD ($V_2$), $PO_4$-P ($V_3$), EC ($V_4$) and DODP ($V_5$)).

Respective weighting scales were again solved by substituting correlations into equation (13) (see Appendix). With a Lagrange multiplier (g) of 2.385 for WQITN and 1.801 for WQIPN, the water quality indexes were estimated to be:

$$WQITN = 0.118\ V_1 + 0.230\ V_2 + 0.242\ V_3 + 0.186\ V_4 + 0.224\ V_5 \qquad (7)$$

and

$$WQIPN = 0.121\ V_1 + 0.231\ V_2 + 0.236\ V_3 + 0.190\ V_4 + 0.222\ V_5 \qquad (8)$$

respectively. Both modified formulations of WQITN and WQIPN are once again conceptually simple as well as easy to compute.

WQITN and WQIPN formulations were used to statistically analyze data from the Snake and Colorado River Basins, Nevada. Regression analyses for indexes WQITN and WQIPN are presented in Table XIV. The F-test statistics for both equations were significant at the 99% level of confidence. However, the coefficient of determination ($R^2$) for WQITN was greater than for WQIPN, 0.9098 and 0.7287, respectively. Hence, WQITN was considered the better index.

To further test applicability of the proposed WQITN as modified to different geological areas, a second regression analysis of water quality data from 20 locations throughout the United States was conduc-

Table XIV. Simple correlations (r), multiple coefficients of determinations ($R^2$), and multiple regression for DOD /DOS % (DODP), BOD, $PO_4$-P, temperature, EC, WQITN, and WQIPN of 124 water samples from Snake River Basin and Colorado River Basin, Nevada

| | DODP | BOD | $PO_4$-P | Temp. | EC | WQITN | WQIPN |
|---|---|---|---|---|---|---|---|
| WQITN+ | -0.50 | -0.30 | -0.08 | -0.34 | -0.86 | 1 | |
| WQIPN+ | -0.42 | -0.34 | 0.08 | -0.34 | -0.78 | 0.91 | 1 |

$$WQITN^{\S} = 92.42 - 0.22\ (DODP) - 2.10\ (BOD) - 15.88\ (PO_4\text{-}P) - 0.29\ (Temp.) - 2.59\ (EC)$$

$$R^2 = 0.9098 \qquad F^{**} = 237.92\ (\text{at df} = 5{,}118)$$

$$WQIPN^{\S} = 91.03 - 0.16\ (DODP) - 2.48\ (BOD) - 5.20\ (PO_4\text{-}P) - 0.35\ (Temp.) - 2.07\ (EC)$$

$$R^2 = 0.7287 \qquad F^{**} = 63.38\ (\text{at df} = 5{,}118)$$

+WQITN and WQIPN values were calculated from WQITN = f(DODP, BOD, TP, Temp., EC), and WQIPN = f(DODP, BOD, $PO_4$-P, Temp., EC), respectively.

§WQITN and WQIPN index regression equations.

**The regression coefficient is significant at the 99.0% level.

ted to determine the level of agreement with WQIE (index estimates by water quality experts) as reported in the literature (12, 13). Simple correlation (r), coefficients of determination ($R^2$) and multiple regression equations are presented in Table XV. The F-test for WQITN'' significant to 99%, whereas for WQIE'' the F-test was significant only to 95%. The coefficient of determination ($R^2$) for WQITN'' was also higher than for WQIE'', 0.9754 and 0.7976, respectively.

It should be noted that the two indexes, WQITN and WQIPN, do not represent the set of all possible index formulations. The author is aware that in using the water quality index as derived one runs the risk of a "specification bias" problem. Specifically, the index is a function of some of the water quality variables, and when regressed is subsequently related to all water quality variables observed. Thus, on both sides of the regression equations, both sets of variables are considered. This is considered by some to be in direct violation of the least squares assumption that the independent variables in the regression equation are non-stochastic. That is, if the left hand side (e.g., WQITN) is a function of some of the water quality variables that also appear on the right hand side of the progression equation, this assumption of non-stochastic independent variables appears to be violated. To the extent that this assumption is violated, the author runs the risk of specification bias. The step-forward multiple regression analysis, however, does provide supporting evidence for the variables selected. And because of the high correlations that exist between the selected water quality variables and the dependent WQI variable, the step-forward multiple regression analysis thus reduces the risk of analysis bias. Further, the methodology does reveal that

Table XV. Simple correlation (r), multiple coefficients of determination ($R^2$), and multiple regression coefficient for DO%, BOD, $PO_4$-P, Temperature, TDS, WQIE, and WQITN of 20 representative water samples from rivers of U.S.

| | DO % | BOD | $PO_4$-P | Temp. | TDS | WQIE | WQITN |
|---|---|---|---|---|---|---|---|
| WQIE+ | 0.22 | 0.28 | -0.10 | 0.63 | 0.81 | 1.00 | |
| WQITN+ | 0.23 | 0.54 | 0.31 | 0.71 | 0.67 | 0.68 | 1.00 |

$$WQIE'' = 53.811 + 9.97\ (DO\%) + 0.045\ (BOD) - 0.114\ (PO_4\text{-}P) + 0.347\ (Temp.) + 0.411\ (TDS)$$

$R^2 = 0.7976$ $F = 7.037$* (at df = 5, 19)

$$WQITN'' = 3.309 + 4.294\ (DO\%) + 0.257\ (BOD) - 0.237\ (PO_4\text{-}P) + 0.203\ (Temp.) + 0.217\ (TDS)$$

$R^2 = 0.9754$ $F = 111.200$** (at df = 5, 19)

+Values of DO%, $PO_4$-P, and TDS were calculated from DO% = 1 - DODP, $PO_4$-P = 0.662 (TP) - 0.251, and TDS = 0.64 x EC for purposes of index comparison.

"WQIE and WQITN index regression equations.

*The regression coefficient is significant at 95% level.

**The regression coefficient is significant at 99% level.

the modified WQITN formulation has a good potential for comparative evaluation of water quality pollution, and appears worthy of further investigation.

## Chapter 6. Conclusion and Summary

Researchers and agencies collect vast amounts of numerical data in attempts to explain what is meant by environmental quality. Still, we have no universally recognized methods for combining our quantitative measures with our qualitative concepts of environment. The ability to assess the quality of water in quantitative terms according to a nonbiased and reproducible method becomes imperative as concern for pollution abatement grows. Water quality indexes are tools which give administrators, scientists and planners the ability to assess a quantitative water quality term for pollution abatement. With them, the success and the impact of a water quality control project can be measured, and large amounts of raw data may be summarized in a quickly understandable form.

Since 1970, several chemical water quality indexes have been suggested. However, the majority of these indexes have been presented more as examples of possible approaches and applied to limited data sets. There were three basic problems in developing a generalized nonbiased and reproducible WQI model. First was the selection of the most important water quality parameters from the many chemical, physical and biological parameters. Second was the decision of weighting scales of each selected water quality parameter which reflected an overall importance in WQI construction. Third, recognized as a minor problem by most WQI model researchers, was the choice of rating scales which ranged from 0 (the worse) to 100 (the best possible).

To solve the first problem, the WQI formulation developed and analyzed in this investigation utilized the principal components of factor analysis to statistically select the major factors. The major water quality parameters were selected by setting a critical value for factor matrix. The second problem was solved by applying a mathematic model developed by Waugh (72) as shown in Appendix 3. By maximizing variance of index, an objective equation was obtained by partial differentiation with respect to factors of weighting scales ($W_j$) and Lagrange multiplier (g). The weighting scales were calculated by iterating the objective question with the substitution of simple correlation coefficients. The third problem was resolved by polynomial regression analysis. A relation between two variables might be approximately linear when studied over a limited range. However, a non-linear curve was required to describe the relation over the entire range. The vast water quality data accumulated in this study provided a good scientific foundation for statistical analysis. A significant non-linear curve fitting indicated that the additional increment of polynomial degree was not constant by changes progressively (59). Thus, the rating scale analyzed by regression analysis would overcome the "eye-balled" bias characterized by the researchers' judgement.

In this investigation, the first and second problems were successfully solved by factor analysis which conquered the weakness of WQI analysis by the use of mean parameter quality rating method developed by Horton (33) and generalized by Brown, McClelland, Deininger and Landwehr (12, 37, 38, 47). The weighting scales developed and analyzed in the WQI formulation applied the scientific statistical method rather than the subjective judgement of the experts. In addition, the principal component factors provided the ability to choose the major important water quality parameters. The WQITN formulation developed by solving the first and second problems were statistically determined to be a good method for the evaluation of water quality at different geographical river basins.

The modified index formulation applied step-forward multiple regression analysis to support the original index formulation developed by factor analysis. The results showed significant agreement on the selection of variables. Further, the step-forward multiple regression analysis provided a basic rule for the construction of simplified index formulations and the regression results showed that the simplified index formulation did not loose its sensitivity.

There exists many possible relationships on which to base such a generalized water quality index. Consequently, a comparison of water quality data from one area to another requires the selection of variables that are of broad general interest. The ten variables considered in this analysis were found to be of significant concern to most water quality investigations (9, 23, 37, 47, 48).

Since a water quality index is not strictly an analytical and measureable entity, an acceptable criteria for evaluation must be established. The model which best satisfies these criteria may be concluded the most appropriate index characterization of water quality. Two criteria were considered. First, because the index is intended as a tool for summarizing large amounts of water quality data for the general public and agency personnel, the index should be conceptually simple as well as easy to compute. Secondly, the index should be significantly influenced by all of the considered water quality parameters, and it should be applicable to different geographical areas. That is, water samples from different locations and sampling times should yield a comparative set of index values. The index derived in this investigation would appear to satisfy both criteria.

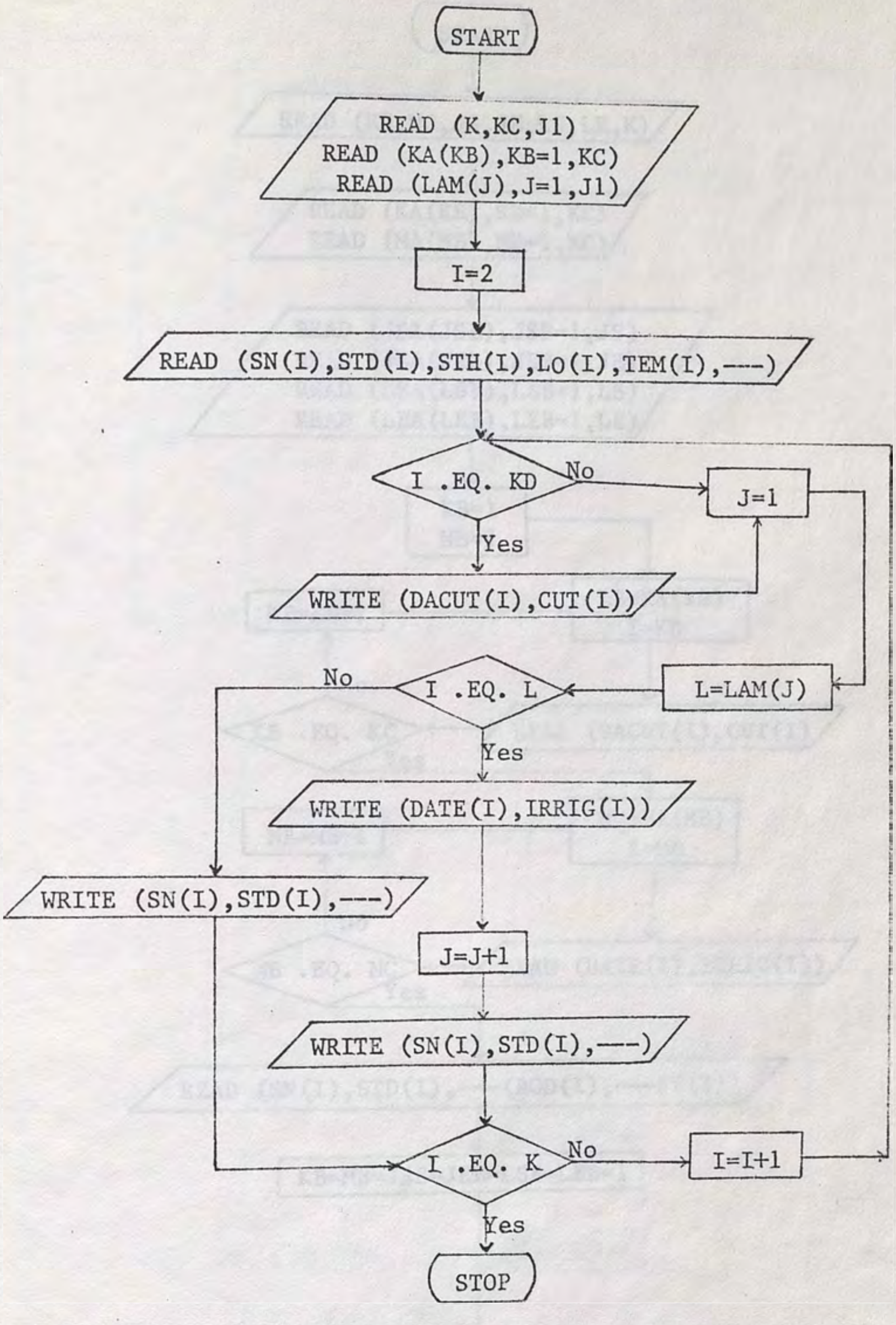
As stated, the proposed indexes did not include all possible water quality parameters of concern for specific uses. Indeed, factor analysis did indicate only 70% of the important water quality parameters to be represented. Also, the author must acknowledge the omission of certain water quality parameters which, to date, are not commonly reported except in very specific water quality studies. However, the methodology of index development is of key importance. As more comprehensive water quality data become available, a more comprehensive index can be developed using the proposed methodology.

The index, as presented, would have application in characterizing relative overall levels of water pollution from irrigation return flows with respect to seasonal and geographic trends. Variability of individual parameter concentrations from time to time would be of lesser concern to such a general pollution index. Obviously, as more data is accumulated and experience gained, improvements and refinements of the indexing model can be expected to continue. Thus, an increasingly meaningful link between the sources and amounts of water pollution and their effect on the receiving environment is provided. This should enable a more systematic identification of problem areas and associated pollutants, potentially leading to the establishment of appropriate water quality standards for the respective locales.

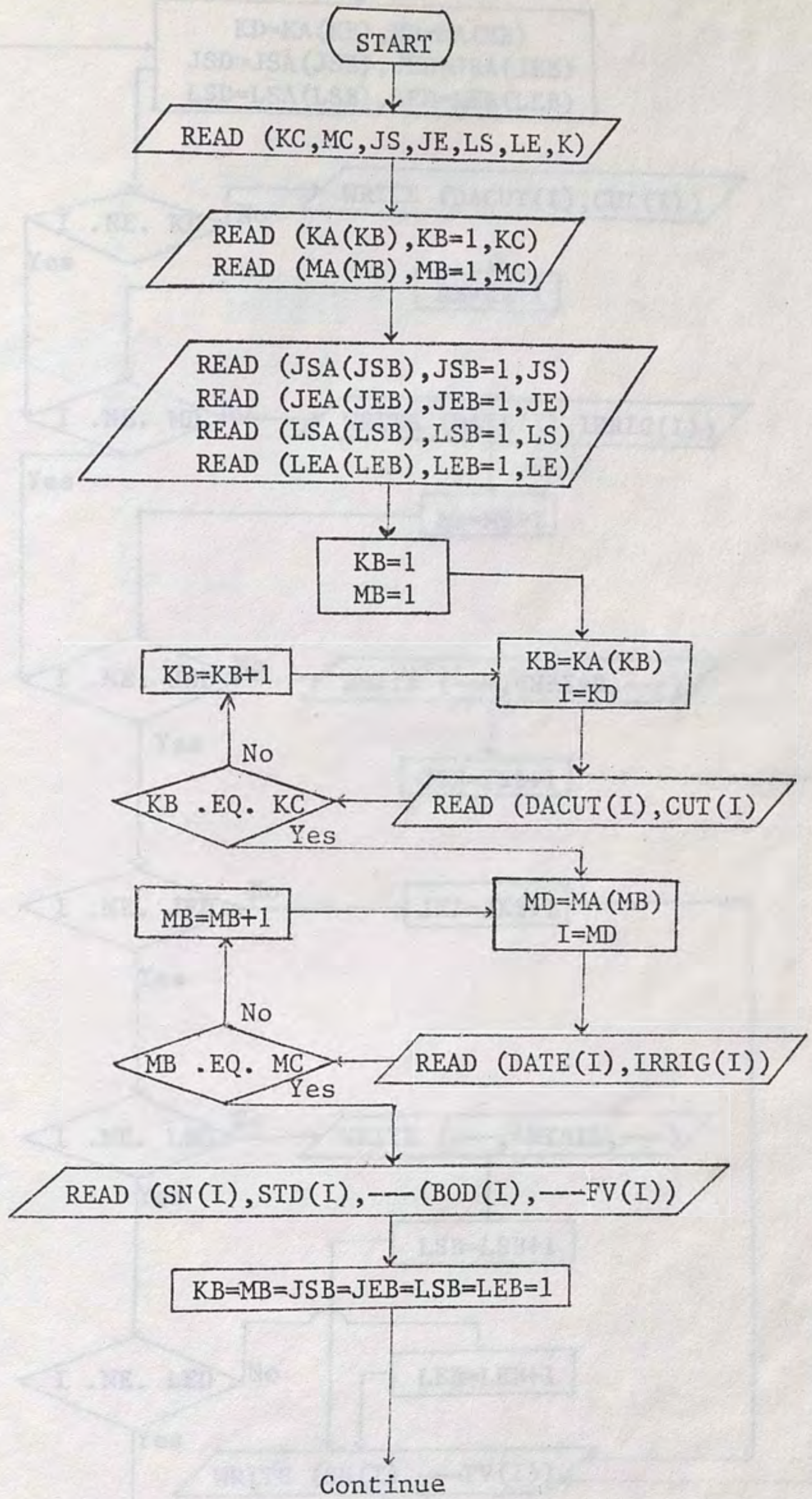
An additional limitation of the proposed indexes concerns evaluation of the range and degree of sensitivity. These have not been quantified. Once the sensitivity of such an index can be explicitly defined (i.e., where levels of acceptability can be identified), then the polluted level at which a change in any given parameter significantly reduces the WQI value below the normal range can be identified as the lowest acceptable level for that water quality parameter. Indeed, the WQI levels must be keyed to specific uses for the above relationships to be developed. One must take the necessary parameters for a specific use, develop an index, determine index values for recommended standards for the particular use, and then test the sensitivity in terms of maximum and minimum values.

A remaining question then hinges on what level of overall water pollution is acceptable for a given location or intended use. Any proposed index ranging from 0 to 100 must be standardized in terms of a specific use and range of acceptability, e.g., light, moderate, or severe pollution. This, too, must be the subject of further investigation.

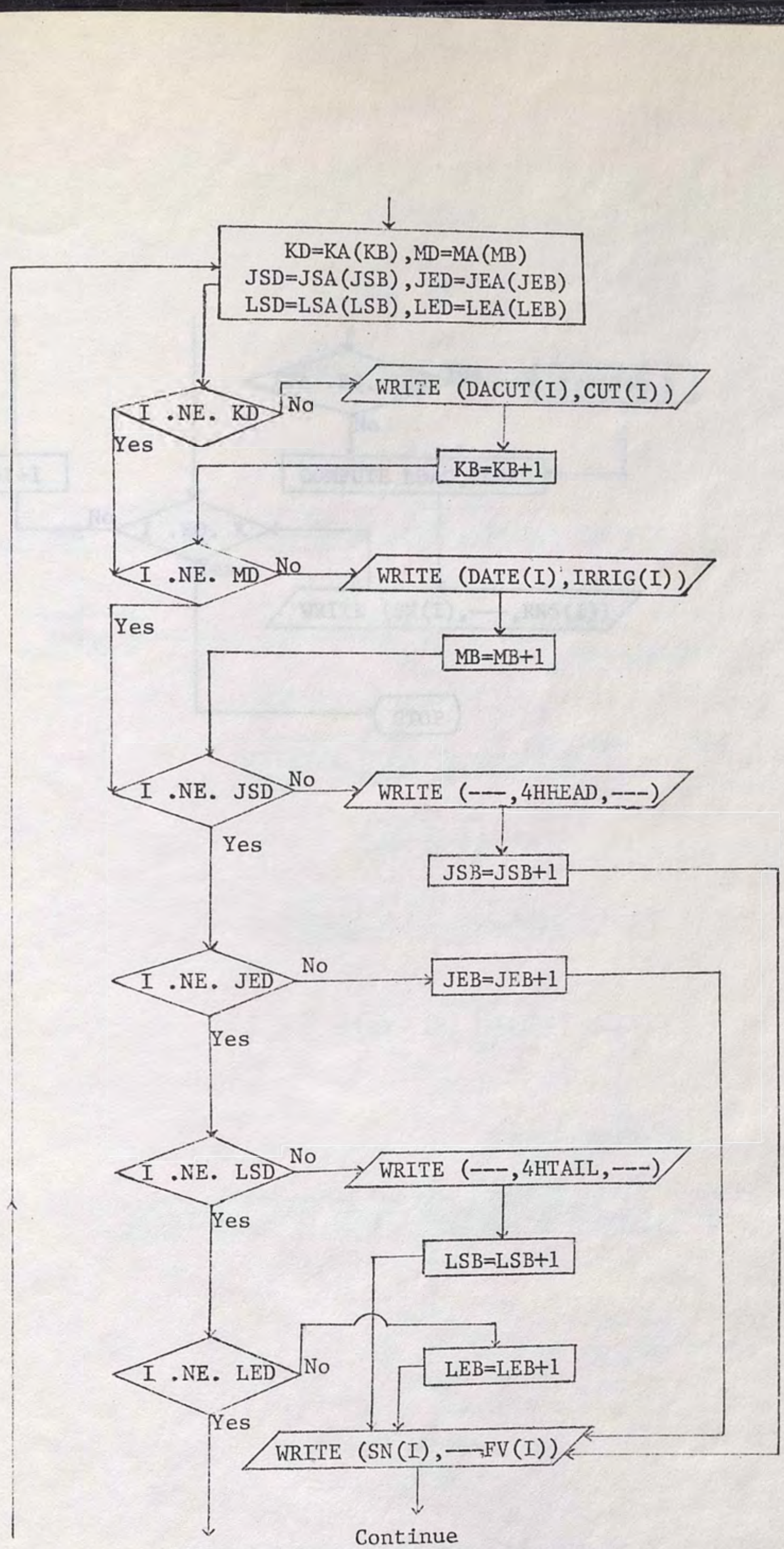
# APPENDIX 1: Flow Diagrams for Computer Programs



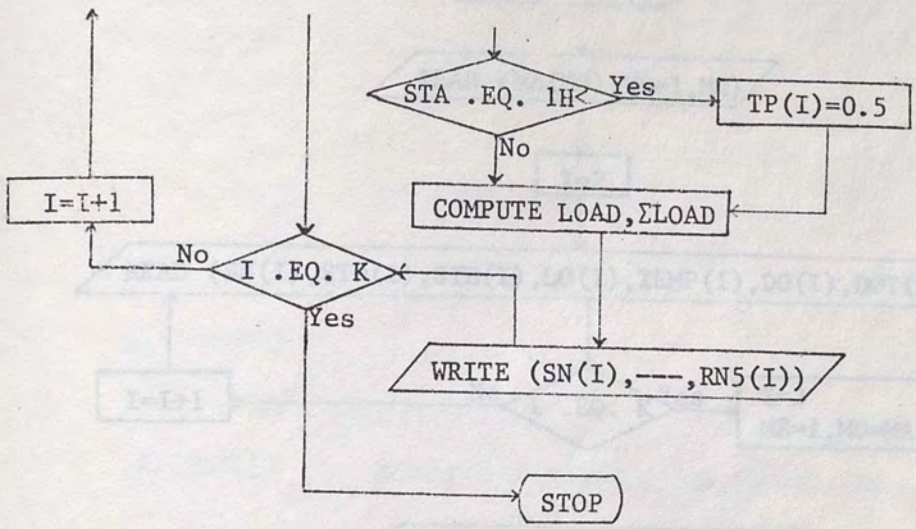

Appendix 1A: Flow Chart for Table II

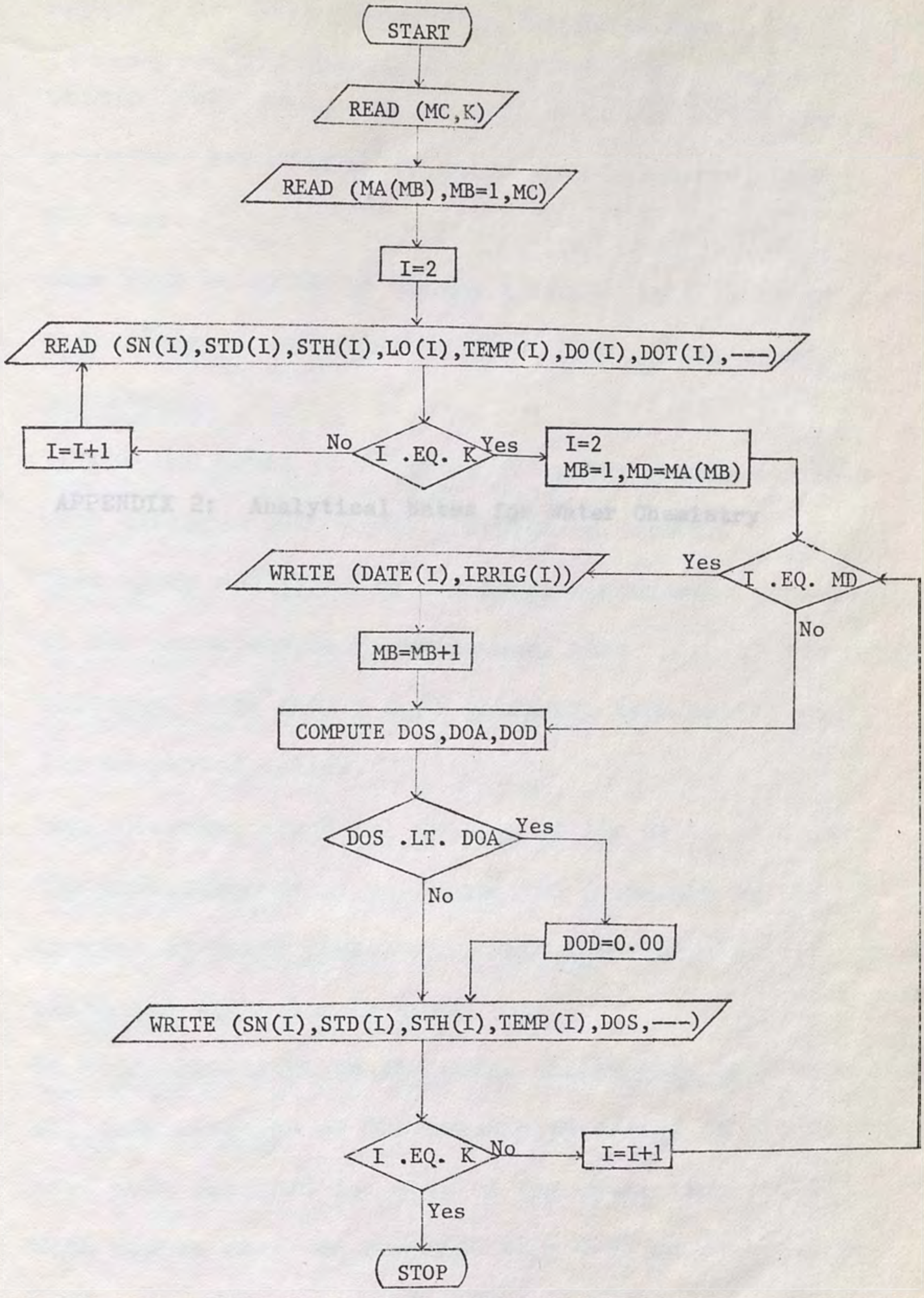



Appendix 1B: Flow Chart for Table III



KD=KA(KB),MD=MA(MB)
JSD=JSA(JSB),JED=JEA(JEB)
LSD=LSA(LSB),LED=LEA(LEB)
I .NE. KD
No
Yes
WRITE (DACUT(I),CUT(I))
KB=KB+1
I .NE. MD
No
Yes
WRITE (DATE(I),IRRIG(I))
MB=MB+1
I .NE. JSD
No
Yes
WRITE (---,4HHEAD,---)
JSB=JSB+1
I .NE. JED
No
Yes
JEB=JEB+1
I .NE. LSD
No
Yes
WRITE (---,4HTAIL,---)
LSB=LSB+1
I .NE. LED
No
Yes
LEB=LEB+1
WRITE (SN(I),---FV(I))
Continue


STA .EQ. 1H
Yes
TP(I)=0.5
No
COMPUTE LOAD,ΣLOAD
I=I+1
No
I .EQ. K
Yes
WRITE (SN(I),---,RN5(I))
STOP




Appendix 1C. Flow Chart for Table IV.

# APPENDIX 2: Analytical Notes for Water Chemistry

Appendix 2: Analytical Notes for Water Chemistry

1. Obtain fresh manganese sulfate solution, alkali-azide solution, and distilled water from laboratory once per week.
2. Care must be taken to obtain a sample that is truly representative of existing conditions during field procedures.
3. If the end point is overrun, the water sample may be back titrated with 0.025 N biniodate solution.
4. This azide modification method is recommended especially if the water sample contains more that 50 ug/l of nitrate nitrogen, less than 5 mg/l of ferric iron salts, and low suspended solids.
5. Periodically, check the quality of the dilution water, the effectiveness of seed, and the technique of the analyst by using glucose-glutamic acid solution for which the BOD value is known.
6. No neutralizations of the water sample have been made for the determination of BOD because pH values of around 7.0 have been detected for most of the water samples.
7. With proper care, an accuracy of $\pm$ 0.05 pH unit can be achieved. However, a $\pm$ 0.1 pH unit is reported in this study.

8. The analyst should constantly be on the alert of possible erratic results arising from the mechanical or electrical failures of the pH meter, and conductivity bridge.
9. Prepare fresh solutions of standard buffer solutions and standard 0.01 M potassium chloride if there are any mold growth or contamination.
10. Refer to the scale on the length of turbidimeter tube, filter of the light, and dilution of the water sample, and determine the concentration of turbidity and sulfate directly from the appropriate calibration curve.
11. For accurate determinations of turbidity and sulfate, redisperse the precipitation with the rubber-tipped glass stirring rod and take a second or third reading.
12. If the pH value is 8.3 or greater, the water sample should measure the phenolphthalein alkalinity.
13. To prevent high chlorine residue, the addition of one drop 0.1 N. sodium thiosulfates will eliminate the bleaching action of chlorine.
14. Run at least one blank and two standards with each series of samples, and treat them the same as the procedure for the water sample analysis. If the number of water samples is more than 30, prepare an extra blank.

15. If the standards do not agree within 2% of the tree value, check reagents and procedure. Repeat procedures again.
16. For one set of standards and samples, the same cuvette should be used to measure both standards and water samples to avoid error of optical density.
17. Measuring cup was used to increase laboratory efficiency.
18. To prevent changing volume, always wash the spectrophotometer cuvette with distilled water but not with sample water.
19. The distillation apparatus should be pre-steamed until the aparatus is free of ammonia.
20. If a red phenolphthalein color does not appear in kjeldahl flask, more distillation reagent should be added until a red alkaline solution is formed.
21. After the addition of buffer solution, do not extend titration duration beyond 5 minutes.
22. To prevent the color interference at and point, daylight or a daylight fluorescent lamp is highly recommended.
23. For those water samples which have high turbidity, filter the water samples through a quantitative filter paper to prevent clogging the burner.

24. Do not keep samples in glass sample cups and beakers longer than necessary if large amounts of sodium are being determined.

25. A smaller volume of standard silver nitrate titrant should be added at longer intervals toward the end point of titration.

26. If the potential of silver-electrode is not within -18 to -25 mv at the 20-30$^{o}$c, the silver-electrode should be recoated.

# APPENDIX 3: Factor Analysis Formulation by Waugh

## Appendix 3: Factor Analysis Formulation by Waugh

A theoretical approach to index formulation based on "factor" or "Component analysis" was presented by Waugh (75) in 1962. For purposes of explanation with respect to this investigation, the theory may be briefly summarized as follows.

If I is the index, it can be written

$$I = K + \sum_{j=1}^{k} b_j X_j \qquad (9)$$

where K and $b_j$ are constants, and $X_j$ are respective water quality variables. If lower case letters are used to indicate deviations from average pollutant levels and the values are standarized by dividing each by its standard deviation, equation (9) can be rewritten

$$i = \sum_{j=1}^{k} W_j V_j \qquad (10)$$

where $W_j$ are respective weighting coefficients to standardized variables $V_j$. Values for $W_j$ should be assigned in such as way as to provide variation so that the index will discriminate between waters of high, medium and low pollution.

Variance of the index (var. i) is

$$\text{var. } i = \frac{1}{n} \Sigma i^2 = \Sigma W_j^2 + 2(r_{12} W_1 W_2 + r_{13} W_1 W_3 + r_{23} W_2 W_3) \qquad (11)$$

for j = 1,2,3 and where $r_{12}$, $r_{13}$ and $r_{23}$ are zero order correlation coefficients. This variance, however, has no maximum, i.e., it could be increased indefinitely by multiplying all $W_j$ by constants greater than 1. To avoid this arbitrary result, variance of i must be maximized. In order to maximize equation (11) subject to the restraint that the sum of the squared weights is unity, we can maximize a function (F)

$$F = \text{var. } i - g(W_1^2 + W_2^2 + W_3^2 - 1) \qquad (12)$$

The function F is maximized by partial differentiation with respect $W_j$ (j = 1, 2, 3) and g, and setting all the derivatives equal to zero. The resultant equations,

$$\begin{aligned}
(1-g)W_1 - r_{12}W_2 + r_{13}W_3 &= 0 \\
r_{12}W_1 + (1-g)W_2 + r_{23}W_3 &= 0 \\
r_{13}W_1 + r_{23}W_2 + (1-g)W_3 &= 0 \\
W_1^2 + W_2^2 + W_3^2 &= 1
\end{aligned}$$

however, are not sufficient in their restraints. For a maximum $d^2F$ must be negatively definited, thus the following conditions must hold

$$\bar{H}_2 = \begin{vmatrix} 1-g & r_{12} & -W_1 \\ r_{12} & 1-g & W_2 \\ -W & -W & 0 \end{vmatrix} > 0; \quad \bar{H}_3 = \begin{vmatrix} 1-g & r_{12} & r_{13} & -W_1 \\ r_{12} & 1-g & r_{23} & -W_2 \\ r_{13} & r_{23} & 1-g & -W_3 \\ -W_1 & -W_2 & -W_3 & 0 \end{vmatrix} > 0 \qquad (14)$$

Equation (13) are then solved for $W_j$ (j = 1, 2, 3) and checked against the conditions of equation (14).

# APPENDIX 4: Program of Input Data Standardization--

## "XA" Program

Appendix 4; Program of Input Data Standardization--

"XA" Program

```
READY.
LIST

 77/07/18. 11.35.30.
PROGRAM XA

00100 PROGRAM W2(TAPE1,OUTPUT,TAPE2=OUTPUT,TAPE5)
00110 DIMENSION SN(900),TEMP(900),DO(900),BOD(900),
00120+TP(900),RN(900),TDS(900),TN(900),DODP(900),
00130+EC(900),EL(900),RP(900)
00140 K=6
00150 TMB=0.0
00160 BOB=0.0
00170 TPB=0.0
00180 TNB=0.0
00190 ECB=0.0
00200 DOB=0.0
00210CEL=1000
00220 DO 50 I=1,K
00230 GO TO 2032
00240 READ(1,) SN(I),TEMP(I),DO(I),BOD(I),TP(I),RN(I),TDS(I)
00250CEL(I)=1000.0
00260 GO TO 2022
00270 2032 READ(1,)SN(I),TEMP(I),DO(I),BOD(I),RP(I),RN(I),TDS(I)
00280CGO TO 2022
00290 TP(I)=(RP(I)*2.0)-.02
00300 2022 TN(I)=(RN(I)*3.598)-.171
00310 EC(I)=TDS(I)/.64
00320 TEM=TEMP(I)
00330 IF (TEM .GT. 5.0) GO TO 20
00340 DOT=14.62-(.36*(TEM))
00350 20 IF (TEM .GT. 10.0) GO TO 21
00360 DOT=12.48-(.29*(TEM-5.0))
00370 GO TO 30
00380 21 IF (TEM .GT. 15.0) GO TO 22
00390 DOT=11.08-(.24*(TEM-10.0))
00400 GO TO 30
00410 22 IF (TEM .GT. 20.0) GO TO 23
00420 DOT=9.95-(.20*(TEM-15.0))
00430 GO TO 30
00440 23 IF (TEM .GT. 25.0) GO TO 24
00450 DOT=8.99-(.17*(TEM-20.0))
00460 GO TO 30
00470 24 IF (TEM .GT. 30.0) GO TO 25
00480 DOT=8.22-(.15*(TEM-25.0))
00490 GO TO 30
00500 25 IF (TEM .GT. 35.0) GO TO 50
```

```
DOT=7.51-(.14*(TEM-30.0))
30 ELA=EL(I)/100
ELPS=1-(.00344*ELA)
TMA=TEMP(I)
BOA=BOD(I)
TPA=TP(I)
TNA=TN(I)
ECA=EC(I)
DOS=DOT*ELPS
IF (DOS .LE. DO(I)) GO TO 35
DODP(I)=((DOS-DO(I))/DOS)*100
GO TO 40
35 DODP(I)=0.0
40 GO TO 45
 WRITE (2,100) SN(I),TEMP(I),BOD(I),TP(I),TN(I),EC(I),
+DODP(I),DOS
100 FORMAT (A5,2X,2(F5.1,1X),2(F5.2,1X),F5.0,1X,F6.2,F6.2)
45 IF (TMA .LT. TMB) GO TO 65
TMB=TMA
65 IF (BOA .LT. BOB) GO TO 67
BOB=BOA
67 IF (TPA .LT. TPB) GO TO 69
TPB=TPA
69 IF (TNA .LT. TNB) GO TO 70
TNB=TNA
70 IF (ECA .LT. ECB) GO TO 155
ECB=ECA
CGO TO 80
155 IF (TN(I) .LT. 0.03) GO TO 153
IF (TP(I) .LT. 0.03) GO TO 153
GO TO 72
153 TN(I)=0.03
TP(I)=0.03
72 WRITE (5,110) SN(I),TEMP(I),BOD(I),TP(I),TN(I),EC(I)
110 FORMAT (A5,2X,2(F5.1,1X),2(F6.2,1X),F7.1,1X,F6.2)
GO TO 50
80 WRITE(5,112) TEMP(I),BOD(I),TP(I),TN(I),EC(I),DODP(I)
112 FORMAT(2F6.1,2F7.2,F6.0,F6.2)
50 CONTINUE
WRITE (2,115)
115 FORMAT(12HMAXTEM MXBOD,12H MX TP MX TN,6H MX EC)
WRITE (2,150)TMB,BOB,TPB,TNB,ECB
150 FORMAT(2F6.1,2F6.2,F6.0)
STOP
END
READY.
OLD,WQISDA

READY.
RES
```

APPENDIX 5: Program of Water Quality Index and Standard Deviation Analysis--"WQISDA" Program

## Appendix 5: Program of Water Quality Index and Standard Deviation Analysis--"WQISDA" Program

```
FORT,OLD,WQISDA

READY.
LIST

 77/07/18. 11.37.58.
PROGRAM WQISDA

 PROGRAM WQA(TAPE1,OUTPUT,TAPE2=OUTPUT,TAPE3)
 DIMENSION SN(900),TEMP(900),DODP(900),TP(900),TN(900),
+BOD(900),
+WQD(900)
 K=30
 AA=0
 BB=0
 WQMX=0.0
 WQMI=0.0
 WQA=0.0
 WQSQM=0.0
 WQST=0.0
 CC=0
 WCK=100.0
 DD=0
 EE=0
 FF=0
 WRITE(2,5)
 5 FORMAT(8HSAM. NO.,8H     WQI,8H   PWBOD,8H   PW TN,
+8H  PWTEMP,8H  PWDODP,8H   PWTDS)
 DO 50 I=1,K
CGO TO 2026
 READ(1,) SN(I),TEMP(I),BOD(I),TP(I),TN(I),EC(I),DODP(I)
 GO TO 2045
 2026 READ(1,) TEMP(I),BOD(I),TP(I),TN(I),EC(I),DODP(I)
 2045 WDOR=(100-DODP(I))*.98
 IF (BOD(I) .LT. 30) GO TO 11
 WBOD=8
 GO TO 12
 11 WBOD=((30-BOD(I))*3.07)+8
 12 IF (TN(I) .GE. 14) GO TO 21
 WRN=((10-TN(I))*9.604)+2
 GO TO 25
 21 WRN=2
 25 IF (TP(I) .GE. 7) GO TO 31
 WRP=((5-TP(I))*18.41)+4
 GO TO 32
 31 WRP=6
 32 IF (TEMP(I) .GE. 30) GO TO 41
 WTEMP=((30-TEMP(I))*2.8)+10
 GO TO 42
```

```
41 WTEMP=10
42 TDS=EC(I)*.64
IF (TDS .GE. 1500) GO TO 1000
WTDS=((1500-TDS)*.036)+30
GO TO 1001
1000 WTDS=30
GO TO 1001
2035 WTDS=-.0001*(EC(I)**2)-.012*(EC(I))+79.663
IF (WTDS .LT. 0.0) GO TO 2037
GO TO 2038
2037 WTDS=0.0
2038 WTEMP=-.003*(TEMP(I)**3)+.105*(TEMP(I)**2)-1.393
WBOD=.013*(BOD(I)**2)-1.3*(BOD(I))+82.54
WRP=2.72*(TP(I)**2)-23.301*(TP(I))+86.494
WRN=.871*(TN(I)**2)-14.318*(TN(I))+87.098
WDOR=-.0023*(DODP(I)**2)-.099*(DODP(I))+87.111
IF (WBOD .GT. WCK) GO TO 2255
IF (WRP .GT. WCK) GO TO 2255
GO TO 1001
2255 WBOD=WCK
WRP=WCK
1001 A=WBOD*.21
B=WRN*.22
C=WRP*.20
D=WTEMP*.08
E=WDOR*.15
F=WTDS*.14
GO TO 2005
1016 A=WBOD*.074
B=WRN*1.922
C=WRP*2.552
D=WTEMP*.057
E=WDOR*.026
F=WTDS*.004
2005 WQD(I)=A+B+C+D+E+F
WQ1=WQD(I)
IF (WQ1 .LT. WQMX) GO TO 62
WQMX=WQ1
62 IF (I .EQ. 1) GO TO 63
IF (WQ1 .GT. WQMI) GO TO 65
63 WQMI=WQ1
65 WQA=WQA+WQ1
WQSQ=WQ1*WQ1
TN2=TN(I)*TN(I)
EC2=EC(I)*EC(I)
EC3=EC2*EC(I)
DODP2=DODP(I)*DODP(I)
WQSQM=WQSQM+WQSQ
GO TO 1015
TEMP2=TEMP(I)*TEMP(I)
```

```
TEMP3=TEMP2*TEMP(I)
BOD2=BOD(I)*BOD(I)
TP2=TP(I)*TP(I)
GO TO 1015
GO TO 1007
GO TO 1006
GO TO 1005
WRITE(2,210) SN(I),WQD(I),A,B,C,D,E,F
210 FORMAT(3X,A5,7F8.2)
WRITE(3,101) I,SN(I),WQD(I),A,B,C,D,E,F
101 FORMAT(I4,2X,A5,7F8.2)
1005 WRITE(3,180)WQD(I),TEMP2,TEMP(I),BOD2,BOD(I),TP2,TP(I)
180 FORMAT(7F8.2)
1006 WRITE(3,181) WQD(I),TN2,TN(I),EC2,EC(I),DODP2,DODP(I)
181 FORMAT(3F8.2,3F10.1,F8.2)
1007 WRITE(3,182) WQD(I),TEMP3,TEMP2,TEMP(I),EC3,EC2,EC(I)
182 FORMAT(F6.2,F10.1,F8.1,F7.1,F12.1,F10.1,F8.1)
1015 WRITE (2,183) SN(I),WQD(I)
183 FORMAT (A5,F7.2)
55 AA=AA+A
BB=BB+B
CC=CC+C
DD=DD+D
EE=EE+E
FF=FF+F
50 CONTINUE
WRITE(2,105)
105 FORMAT(2/,32H         MEAN WATER QUALITY INDEX)
WRITE(2,115)
115 FORMAT(8X,22H(FOR INPUT PARAMETERS))
WRITE(2,116)
116 FORMAT(5X,8H     WQI,8H  ID BOD,8H   ID TN,8H   ID TP,
+8H ID TEMP,8H ID DODP,,8H   ID EC)
WQA1=WQA/K
AA1=AA/K
BB1=BB/K
CC1=CC/K
DD1=DD/K
EE1=EE/K
FF1=FF/K
WRITE(2,200) WQA1,AA1,BB1,CC1,DD1,EE1,FF1
200 FORMAT(5X,7F8.2,2/)
2028 WQASQ=WQA*WQA
WQA1=WQA/K
WQSUB=WQASQ/K
SS=WQSQM-WQSUB
VAR=SS/(K-1)
SD=SQRT(VAR)
VARN=VAR/K
SDER=SQRT(VARN)
```

```
01510 CV=(100*SD)/WQA1
01520 WRITE (2,72)
01530 72 FORMAT(6X,8HNUMBER  ,8X,9HSTANDARD , 1X,9HSTANDARD ,
01540+13H COEFFICIENT ,16H     RANGE        )
01550 WRITE(2,73)
01560 73 FORMAT(6X,8H   OF   ,8H  MEAN  ,9X,9H  ERROR  ,
01570+13H     OF      )
01580 WRITE(2,74)
01590 74 FORMAT(6X,8HSAMPLES ,8X,9HDEVIATION,9H OF MEAN ,
01600+13H VARIABILITY ,16H MINIMUM MAXIMUM)
01610 WRITE(2,77)
01620 77 FORMAT(8X,3(1H-),4X,5(1H-),5X,5(1H-),
01630+4X,5(1H-),5X,5(1H-),7X,5(1H-),3X,5(1H-))
01640 WRITE(2,76) K,WQA1,SD,SDER,CV,WQMI,WQMX
01650 76 FORMAT(8X,I3,2X,F7.2,2X,2(F8.2,1X),4X,F5.2,4X,2F8.2,3/)
01660 STOP
01670 END
READY.
```

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