Total Maximum Daily Load For:
Lower Colorado River
for Nitrogen and Phosphorous

From Yuma Gage (USGS 09521100) to
Northern International Boundary (USGS 09522000)

January 1982

Open File Report 09-03

NOTE: Since initial publication the contact information has been updated. For more information please contact:

TMDL Unit Supervisor
602-771-4468
800-234-5677
TDD 602-771-4829

WQMS-371.013

RECOMMENDED NUTRIENT STANDARDS FOR THE LOWER COLORADO RIVER

From Yuma Gage (USGS No. 09521100) to Northern International Boundary (USGS No. 09522000)

FINAL REPORT
January 1992

By Perry Nixon

Point Source & Monitoring Unit
Water Assessment Section
Office of Water Quality
Arizona Department of Environmental Quality

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105

RECEIVED JUN 0 1 1992 26 MAY 1992

OFFICE OF THE
REGIONAL ADMINISTRATOR

Mr. Edward Z. Fox
Director
Arizona Department of Environmental Quality
P.O. Box 600
Phoenix, AZ 85001-0600

Dear ~~Mr. Fox~~ Ed:

I am pleased to inform you of the U.S. Environmental Protection Agency's partial approval of Arizona's rules on Water Quality Standards for Navigable Waters (Title 18, Chapter 11, Article 1). The Department of Environmental Quality adopted these rules on January 10, 1992 and the Arizona State Attorney General certified them on February 18, 1992.

This action pertains only to the portion of the adopted rules addressing numeric criteria for total nitrogen and total phosphorus for the Lower Colorado River between Yuma Gage and the Northern International Boundary. This letter represents EPA's assessment of State compliance with Section 303(c) of the Clean Water Act. Section 303(c) requires that new or revised State water quality standards protect a variety of water uses listed in the Section. We are approving the numeric criteria for nitrogen and phosphorous for the Lower Colorado River as being in full compliance with Section 303(c).

In addition, I am pleased to inform you of EPA's action on the Total Maximum Daily Loads (TMDLs) for nitrogen and phosphorus for the Lower Colorado River between Yuma Gage and the Northern International Boundary. The Department of Environmental Quality submitted these TMDLs for EPA's approval on January 31, 1992.

We are approving these TMDLs as being in full compliance with Section 303(d) of the Clean Water Act, which requires that TMDLs be established at levels necessary to implement the applicable water quality standards, taking into account seasonal variations and an adequate margin of safety.

We commend the considerable efforts on the part of the Department of Environmental Quality to develop numeric criteria and TMDLs for nitrogen and phosphorus for the Lower Colorado River. We also commend the Department for its efforts to make positive use of the TMDL process in its water quality management planning program. We look forward to assisting the Department in its future efforts to implement standards and the TMDL process to help address Arizona's most pressing water quality concerns. If you have any questions regarding this action, please ask your staff to call David Smith at (415) 744-2019.

Sincerely,

Dan McGovern

Daniel W. McGovern
Regional Administrator

cc: Brian Munson, ADEQ
Edwin Swanson, ADEQ

WQMS-371.013
HUC-1503108

FINAL REPORT

RECOMMENDED NUTRIENT STANDARDS FOR THE LOWER COLORADO RIVER

From Yuma Gage (USGS No. 09521100)
to Northerly International Boundary (USGS No. 09522000)

By

Perry Nixon

January 1992

Approved:

E.K. Swanson, Acting Manager
Water Assessment Section

Brian E. Munson, Assistant Director
Office of Water Quality

Point Source & Monitoring Unit
Water Assessment Section
Office of Water Quality
Arizona Department of Environmental Quality

FOREWORD

This report utilizes and refers to research conducted by federal, State and local agencies during the past 18 years. The cooperative water quality monitoring program conducted by the U.S. Geological Survey has produced a large database of surface water quality and discharge data beginning in 1972. These data were essential to this study. Both the City of Yuma and the U.S. Environmental Protection Agency (EPA) have been instrumental in providing the technical resources to support this project. Specific thanks are extended to the staff of John Carollo Engineers and Dr. James Duke, both consultants to the City of Yuma, for their efforts.

Comments regarding this report should be addressed to:

Arizona Department of Environmental Quality
c/o Edwin K. Swanson
PO Box 600
Phoenix, Arizona 850001-0600

I. INTRODUCTION AND SUMMARY OF RECOMMENDATIONS

A. Purpose and Contents of this Report

This report presents the assumptions and work that support nutrient standards for the Lower Colorado River (LCR) that were proposed in May 1991, by the Arizona Department of Environmental Quality (ADEQ). The study focuses on a reach of the Colorado River near Yuma, Arizona (Figure 1).

Section II presents a general description of the LCR study area and the history of nutrient standards regulations. Section III presents an analysis of the work that has been performed to develop ADEQ's recommended standards. Section IV discusses the study conclusions and documents the Total Maximum Daily Loads for nutrients. Section V contains conclusions and recommendations. All future references to total Nitrogen and total Phosphorous in this report will be expressed as elemental Nitrogen, as "N", and elemental Phosphorus, as "P". The terms "nutrient standards" and "standards for nutrients" are utilized in this report to describe numeric limits for concentrations of both N and P in surface water.

B. Report Recommendations

Numeric water quality standards for nutrients are recommended at two Control Point locations in the Lower Colorado River near Yuma. These recommendations are:

1. Colorado River at the Northerly International Boundary (NIB, USGS Gage No. 09522000) Control Point:

   Single Sample Maximum - No Limits
   90th Percentile - 2.50 mg/l Total N and 0.33 mg/L Total P
   Annual Mean - No Limits

   NOTE: These limits are recommended for incorporation in the state water quality standards review during 1991 and 1992.

2. Colorado River at the Yuma Gage (USGS Gage No. 09521100) Control Point:

   Single Sample Maximum - No Limits
   90th Percentile - 1.50 mg/l Total N and 0.13 mg/l Total P
   Annual Mean - No Limits

   NOTE: The upstream limits should be considered for the water quality standards update during the 1992 - 1994 timeframe.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

C. Justification

The evaluation of the recommended nutrient standards includes a wide range of concerns:

1. the protection of uses which are designated by State Water Quality Standards, A.A.C. Title 18, Chapter 11, Articles 1, 2 and 3;
2. correlations between various analytical techniques; and
3. practicability.

The evaluation of technical, management and economic factors shows the recommended limits are ecologically safe, administratively feasible and do not pose economic hardship.

II. BACKGROUND

A. Description of the Study Area

The LCR study area is located near Yuma, Arizona and includes a 6.4 mile segment of the Colorado River between the Yuma Gage and the Northerly International Boundary (Figure 1). The right bank of the river lies within Imperial County, California. The left bank lies within Yuma County, Arizona, part of which is within the incorporated limits of the City of Yuma. The Yuma Main Canal Wasteway discharges to the Colorado River from Imperial County approximately 1,000 feet upstream of the Yuma Gage, the most upstream location in the LCR study segment. During June 1990 the elevations of the Colorado River channel bottom at the Yuma Gage and Northerly International Boundary were 106.2 and 95.0 feet above Mean Sea Level, respectively.

The climate near the Colorado River is among the driest in the United States. Infrequent summer thunder storms and winter cyclonic storms are the principal sources of precipitation in the region. Usually these storms produce strong winds with very little rain. Average annual precipitation is 3.6 inches.

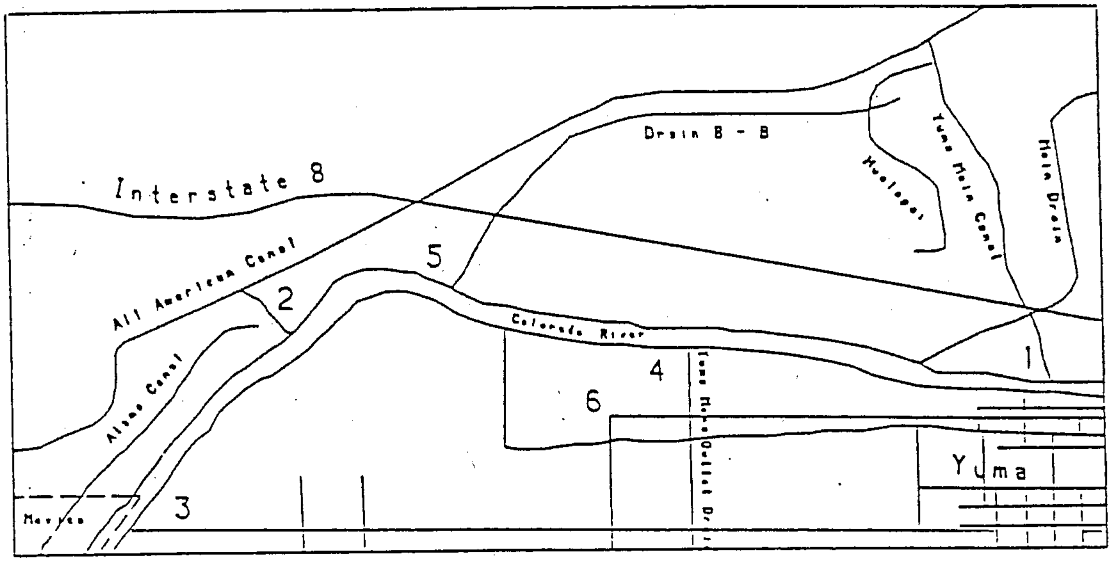
The Colorado River Valley consists of deep to very deep alluvial soils that are dominantly medium textured but range from coarse to fine textured. Soils are generally stratified, and subject to impacts from high water tables that may contain excessive amounts of salt. A "mesa" configuration, consisting of a gently rolling elevated delta-terrace, forms a transition area between the valley bottom and the mountains on each side of the River with deep, very sandy soils (loamy sands predominate). The geology of the Yuma sub-basin consists of two major subdivisions:

a) The lower strata includes marine and non-marine sedimentary rocks, volcanic rock, the Bouse formation and conglomerates.

b) The upper or "principal" strata includes a wedge zone (silts and clays to medium gravels), a coarse zone extends to a depth of 2500 feet and constitutes a significant part of the fresh water bearing deposits beneath the river valleys.

Recharge occurs from direct infiltration from the Colorado River and from irrigation.

Figure 1. Study Location



Legend

1 - Yuma Gaging Station

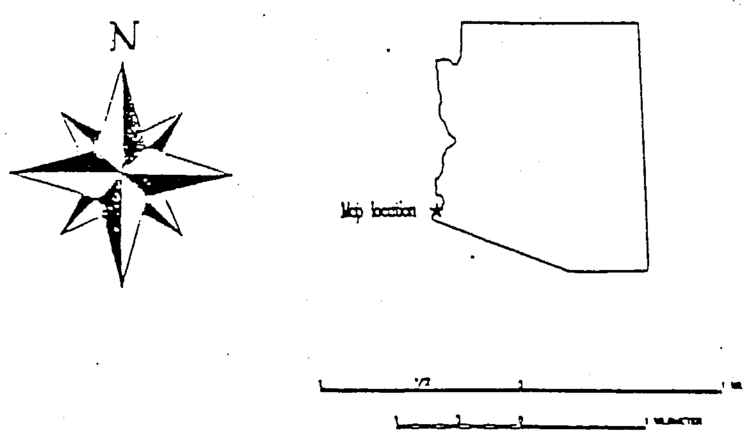
2 - Pilot Knob Gaging Station

3 - N.I.B Gaging Station

4 - Yuma Mesa Outlet Drain

5 - Drain 8 - B

6 - Yuma Wastewater Treatment Plant



ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY

BROWN 91

Surface water quality in the LCR study area is protected by State and Federal Water Quality Standards. Protected uses for the Colorado River include Aquatic and Wildlife (A&W), Domestic Water Source (DWS), Full Body Contact (FBC), Agricultural Irrigation (AgI) and Agricultural Livestock Watering (AgL). The principal game fish in the LCR study segment include channel catfish, flathead catfish, bullheads, large mouth bass, crappies, bluegill and sunfish.

The Lower Colorado River basin drainage area covers over 135,000 square miles and includes approximately 200 square miles within the LCR study area. Surface runoff resulting from precipitation is seldom. The Lower Colorado River study area contains many irrigation districts and diversions, including:

1. North Gila Valley Irrigation District
2. Welton-Mohawk Irrigation and Drainage District
3. Yuma Irrigation District
4. Yuma Mesa Irrigation and Drainage District
5. Unit "B" Irrigation and Drainage District
6. Yuma County Water User's Association
7. Cocopah Indian Reservation
8. City of Yuma
9. Diversions to California and to Mexico

Discharge in the Colorado River below Morelos Dam is vastly diminished from that entering the LCR study segment at the Yuma Gage. Stream-flow entering the segment is greatly affected by the diversion of water. Colorado River water is diverted into the All-American Canal at a location above Imperial Dam. This water is used for municipal, power generation and irrigation uses in the Yuma area, and irrigation in the Coachella and Imperial Valleys of California. This diversion is the largest in the study area (4,781,000 acre-feet in 1972). Approximately 155,750 acres were irrigated for agriculture in the Yuma area (1972). A treaty was signed by the United States and the Republic of Mexico in 1945 to provide for an annual delivery of 1,500,000 acre-feet of Colorado River water to the Northerly International Boundary (NIB). Hydroelectric power is generated within the study area at the Pilot Knob Hydroelectric Power Plant and Siphon Drop Power Plant. Both of these plants withdraw water from the All-American Canal and discharge to the Colorado River (ADHS, 1977).

B. <u>History of Water Quality Regulation on the Lower Colorado River</u>

Surface water quality standards are a key component of water quality management programs authorized by Congress in the federal Clean Water Act (CWA). Standards are implemented by water quality management plans, by discharge limitations in permits and by direct enforcement against sources that cause or contribute to violations of water quality standards. Water quality monitoring data are utilized to evaluate compliance with standards, prepare annual assessment reports, update discharge control strategies and provide information for other water quality program activities.

In 1976, the Environmental Protection Agency (EPA) promulgated nutrient standards for a number of waters in Arizona because the State had not adopted standards. EPA was concerned that elevated levels of nutrients in surface waters, combined with high summer temperatures and bright sunlight would produce excessive algal growth in the surface water and thereby interfere with or impair protected uses. The nutrient standards that EPA adopted for the Colorado River near Yuma were very restrictive and applied to the entire river segment from Imperial Dam to the Northerly International Boundary [40 CFR 131.31(a)].

During 1980, the Arizona Department of Health Services (ADHS), ADEQ's predecessor as the State Water Pollution Control Agency, and EPA jointly established a methodology for developing nutrient standards. This methodology, which is referred to as the "USEPA/ADHS Statistical Methodology", is discussed later in this report. In September 1985, ADHS staff completed a draft report that recommended nutrient standards for the LCR near Yuma using this methodology (ADHS, 1985). This report was presented to the Arizona Water Quality Control Council (AWQCC) for rulemaking. At that same meeting, the City of Yuma submitted a report recommending alternative N and P limits for the LCR. In July of 1986, the AWQCC-adopted nutrient standards at the concentrations recommended by the City of Yuma. These AWQCC adopted standards, which were at levels higher than those recommended by USEPA/ADHS Statistical Methodology, were then submitted to EPA for approval pursuant to CWA Section 303(c). EPA declined to approve the AWQCC-adopted nutrient standards because no environmental justification was provided to support the deviation from the accepted methodology. At this time the 1976 standards promulgated by EPA stand.

Additional water quality data and a predictive model were deemed necessary by EPA Region 9 to evaluate the potential for biostimulation in the LCR near Yuma. Further discussion among the City of Yuma, ADHS, U.S. Geological Survey (USGS) and EPA resulted in agreements to collect the additional data from the Colorado River and tributary discharges to the segment. During Water Years 1987 and 1988, ADEQ, as successor to ADHS, and the City of Yuma entered into cooperative agreements with the USGS to collect additional discharge and water quality data. During the period from 1988 through 1990, the City of Yuma conducted a supplemental data collection and modeling program to evaluate biostimulation in the LCR. The Yuma modeling study utilized the EPA QUAL2E model which was calibrated with data collected during the 1987 through 1990 timeframe (Duke, 1990a). During 1990, ADEQ evaluated the City of Yuma study and conducted a waste loading evaluation of the same reach of the LCR. Finally, ADEQ utilized the calibrated QUAL2E model to evaluate water quality during critical, low streamflow conditions in the LCR. This critical condition has been established for rivers and streams as the seven consecutive day low flow with a probability of occurrence once in ten years (7Q10) by EPA guidelines (EPA, 1985). At these low flow conditions the various nutrient sources will have the greatest expected impact on the net concentrations in the Colorado River. ADEQ recommends new nutrient standards for the LCR segment based upon this work. Table 1 summarizes nutrient standards that have been considered for the LCR since 1976.

TABLE 1. COMPARISON OF NUTRIENT STANDARDS RECOMMENDATIONS FOR THE COLORADO RIVER AT THE NORTHERLY INTERNATIONAL BOUNDARY

	Total Nitrogen as N, mg/l			Total Phosphorous as P, mg/l		
	Mean	90%	SSM*	Mean	90%	SSM*
Promulgation (1976)**	1.13	1.58	—	0.03	0.05	—
Staff Recommendations (Options C September 1985)	—	1.53	—	—	0.23	—
City of Yuma Recommendation (1986)	—	2.00	—	—	0.30	—
AWQCC Adopted Standards (July 1986)	—	2.00	—	—	0.30	—
City of Yuma Report (May 1990)	—	2.00	—	—	0.33	—
ADEQ Staff Recommendation (December 1990)						
USGS Gage 09521100 (Yuma Gage)****	—	1.50	—	—	0.13	—
USGS Gage 09522000 (NIB)	—	2.50	—	—	0.33	—

NOTES: All standards are for the Control Point at the NIB, except as noted.

* SSM - Single Sample Maximum.

** Colorado River from Imperial Dam to Morelos Dam.

**** Colorado River below Yuma Main Canal Wasteway, approximately 6.4 river miles above the NIB.

III. ANALYSIS

This section summarizes efforts to evaluate available water quality data and to propose nutrient standards in the LCR study segment (Colorado River, from Yuma Gage 09521100 to NIB 09522000). The first step is select data to establish statistical relationships. Then relationships will be used to predict expected water quality during critical, low flow conditions.

A. Data Sources

Four major sources of water quality data were used to develop ADEQ's proposed nutrient standards for the LCR:

1. United States Geological Survey (USGS). The USGS has gaged stream flow at two locations in the LCR segment for more than twenty five years. A wide range of chemical constituents has been monitored at one of these sites for more than twenty years. Data for Water Years 1972 through 1988 (USGS, 1972-1988) include discharge, nitrate/nitrite, ammonia nitrogen, organic nitrogen, total phosphorus, electroconductivity (EC), dissolved oxygen (DO) and total dissolved solids (TDS).

2. Lower Colorado River Nutrient Study for the City of Yuma by James H. Duke, Jr. (Duke, 1990a). This report describes the parameters, nutrient loading and biological factors required for the QUAL2E computer model analysis of the LCR. Parameters include discharge, electroconductivity, dissolved oxygen, biochemical oxygen demand (BOD), temperature, Chlorophyll a, organic nitrogen, ammonia nitrogen, nitrate and nitrite nitrogen, and dissolved and total phosphorus.

3. City of Yuma data for NPDES Permit No. AZ0020443. Municipal wastewater treatment plant discharge and quality data were used. Data for the period from October 1, 1986 through September 30, 1988 were analyzed for nitrates/nitrites, ammonia, organic nitrogen, phosphates and discharge.

4. City of Yuma preliminary database report (JCE, 1989). Water quality and discharge data at locations within the LCR study area were used.

B. Data Review and Analysis

The first step taken in the evaluation procedure was to review flow and water quality data to characterize river conditions and to identify normal and abnormal flow conditions. Data sets from published USGS records for flow/EC and flow/nutrients for the same sampling periods were evaluated using bivariate regression analyses to determine which years represented typical or abnormal water quality conditions in the LCR. Data for the Colorado River at the NIB were used because the site is strategically located and has the most complete, long term data set. Electroconductivity and flow data were used first for the characterization because:

1. EC is the numerical expression of the ability of an aqueous solution to carry an electric current and depends on many factors - the presence of ions, their total and relative concentrations, mobility, and valences (APHA, 1985). Generally, there is an inverse relationship between discharge and EC in natural water systems and this relationship can be established for specific waterbodies (Hem, 1970).

2. The published USGS data contained 660 observation sets of discharge and EC at the NIB for the years 1972 through 1988.

When years of typical discharge/EC were determined, nutrient/discharge relationship analyses were performed. Generally, the relationship for discharge/N and discharge/P are affected by factors which include flow, point and nonpoint pollution loads as well as other factors which are not fully understood. However, using the years of good discharge/EC correlations has proven useful for similar analyses. When the discharge/nutrient analyses were completed, background concentrations of total N and total P were statistically established for critical periods of low streamflow when the discharge of pollutants from point sources typically has the greatest impact on the receiving waterbody. These concentrations of total N and total P were used for calibration and as basic data for subsequent modeling efforts.

C. <u>Selection of Representative Data Sets</u>

Generally, the largest, most comprehensive data set with the highest correlation factor (r^2) will provide the most accurate characterization of water quality in a waterbody. Bivariate regression analyses of the data sets at the NIB for the years 1972 through 1988 were evaluated and the results summarized (Table 2).

TABLE 2. SUMMARY OF BIVARIATE REGRESSION ANALYSES FOR DISCHARGE AND LISTED PARAMETERS FOR USGS DATA, COLORADO RIVER AT NORTHERLY INTERNATIONAL BOUNDARY

	PARAMETER								
	CONDUCTIVITY			TOTAL NITROGEN			TOTAL PHOSPHOROUS		
DATA SETS	n	r^2	t	n	r^2	t	n	r^2	t
1972 - 1988	660	0.50	25.66**	174	0.00004	0.079ns	232	0.00848	1.4ns
1972, 1973, 1979 - 1981 and 1983 - 1987	331	0.46	16.85**	105	0.013	158ns	120	0.000003	0.022ns
1974 - 1978, 1982 and 1988	329	0.64	24.12**	69	0.124	3.06**	112	0.128	4.01**

NOTES: ** Significant at $p \le 0.01$
* Significant at $p \le 0.05$
ns Not significant at $p \le 0.05$

Discharge/EC results for all years with available data sets (1972-1988) were significant for $p \leq 0.01$. However, the same was not true for the discharge/nutrient sets during the same period. Data screening was necessary to select the years with useful nutrients data sets. Since the 7Q10 low flow conditions are most relevant to potential biostimulation problems within the LCR study segment, the screening focused on excluding incomplete data sets, periods of abnormally high flow and periods of abnormal water quality. The latter category of abnormality included discharge episodes from low yield watersheds and major wet cycle conditions on the upper Colorado River watershed.

Discharge at Morelos Dam, near the NIB, from 1972 through 1985 shows high flows during the years 1979 through 1981 and 1983 through 1985 (Figure 2). USGS records show high flow continued in the Colorado River at the NIB near Morelos Dam during 1986 and 1987. Simultaneous sampling of discharge/EC began in 1972. Simultaneous sampling of discharge/P and discharge/N started in 1973 and 1974, respectively (USGS, 1972-1988). As a result, data sets for 1972 and 1973 were screened. For the years 1979 through 1981, abnormal flows from the Gila River resulted in abnormally high flows in the LCR study segment and unusual correlations of discharge/EC. High snow melt and precipitation runoff in the upper Colorado River watershed during 1983 and 1984 resulted in abnormally high discharge at the NIB during 1983 through 1987. Regression plots for discharge/EC for all years, screened years and good (non-screened) years are shown in Figures 3,4 and 5, respectively.

Although the combined statistics for discharge/EC for the screened data sets (1972, 1973, 1979-1981 and 1983-1987) were significant at $p \leq 0.01$ (Table 2), the statistics for the nutrient data were not significant. When only the non-screened years (1974-1978, 1982 and 1988) were considered for the discharge/nutrient data sets, the r^2 values for both nutrients were significant at $p \leq 0.01$ (Table 2). The discharge/total N and discharge/total P correlation for the non-screened years are presented in Figures 6 and 7, respectively.

The screening steps of the discharge/nutrient sets have produced statistically significant correlations that will be used to predict current nutrient concentration values in the Colorado River at the NIB for critical low flow conditions. These predicted values will be utilized to evaluate the impact of future increased pollution discharges to the LCR study segment.

Figure 2. Discharge Flows at Morelos Dam

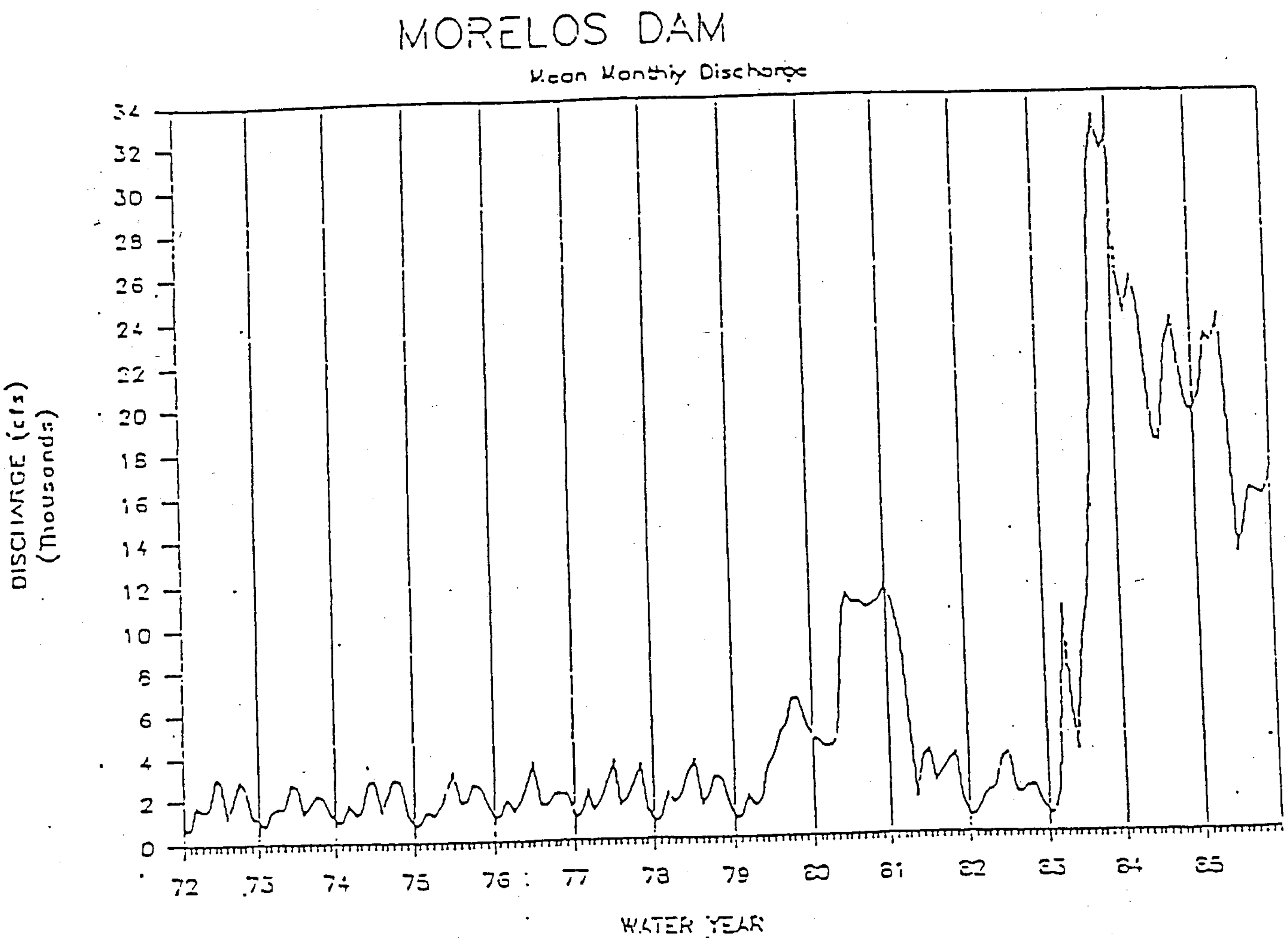
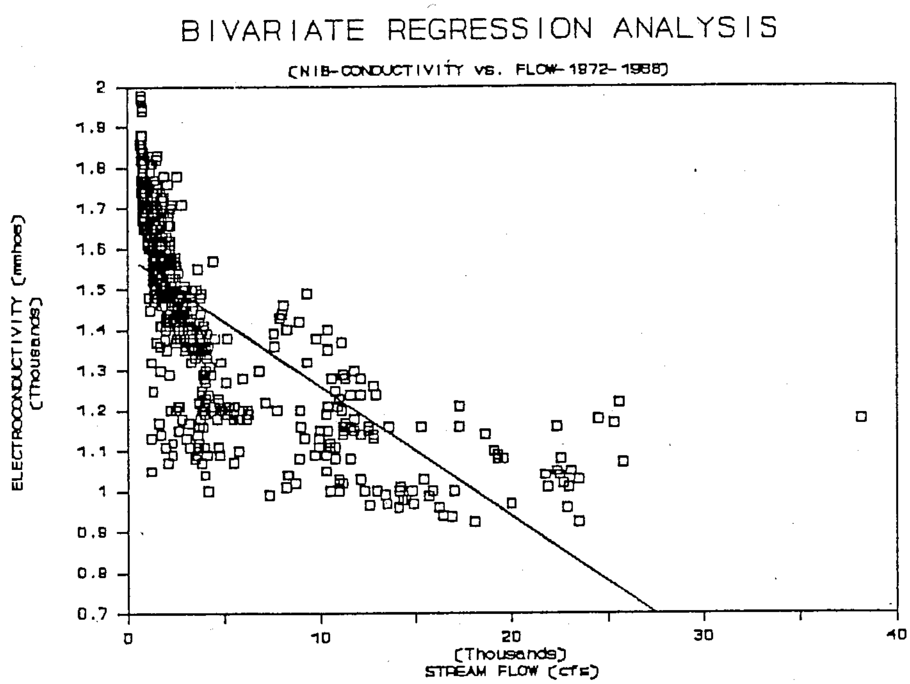


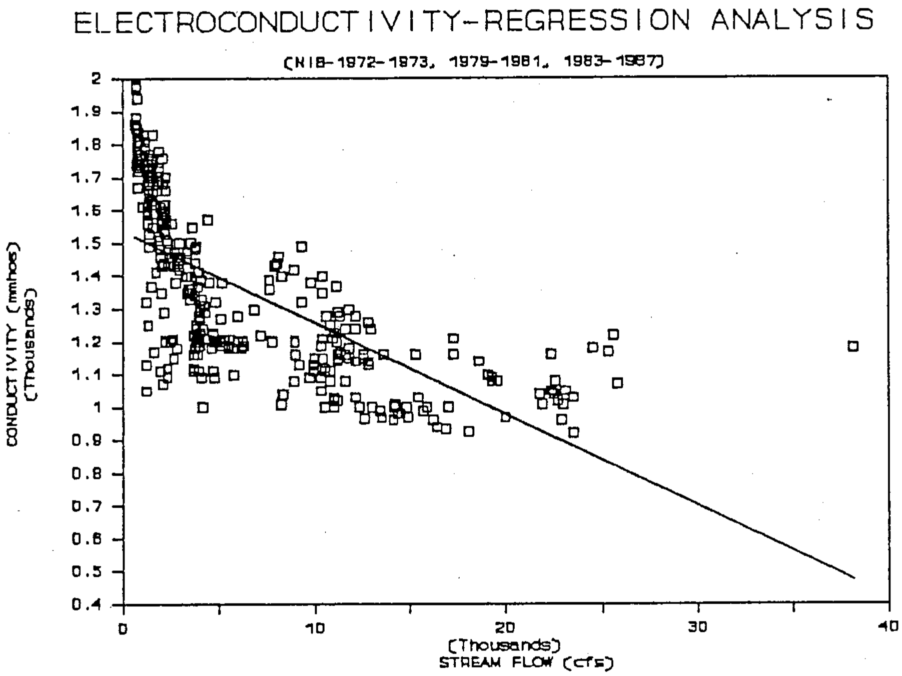
Figure 3. Regression Analysis-Electroconductivity, 1972 - 1988



Regression Output: CONDUCTIVITY

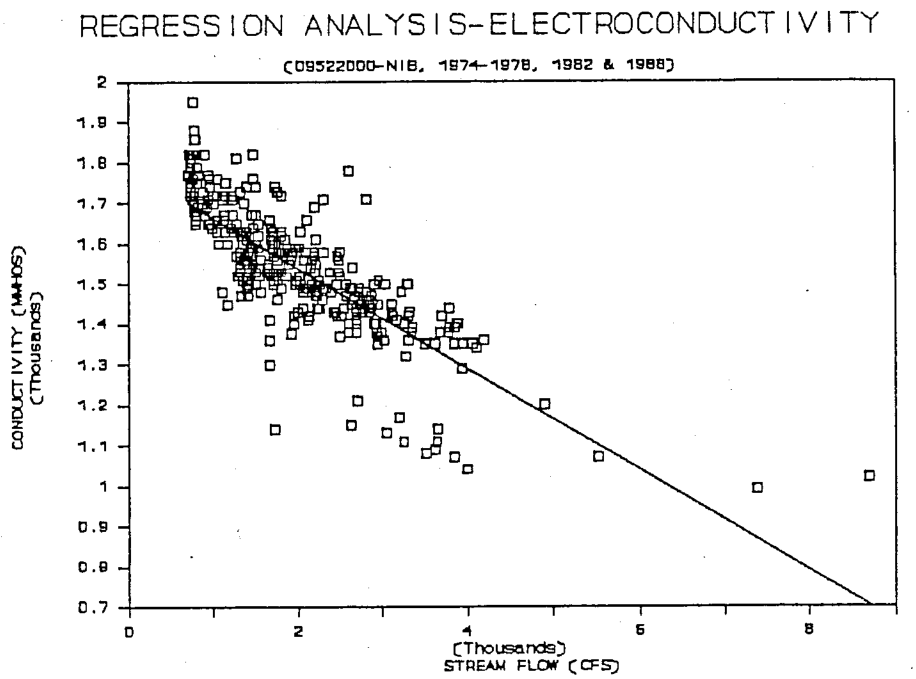
Constant	1581.495
Std Err of Y Est	166.6148
R Squared	0.505662
No. of Observations	660
Degrees of Freedom	658
X Coefficient(s)	-0.03205
Std Err of Coef.	0.001260

Figure 4. Regression Analysis-Electroconductivity 1972-1973,1979-1981,and 1983-1987



Regression Output:	CONDUCTIVITY
Constant	1535.823
Std Err of Y Est	191.1563
R Squared	0.464949
No. of Observations	331
Degrees of Freedom	329
X Coefficient (s)	-0.02781
Std Err of Coef.	0.001644

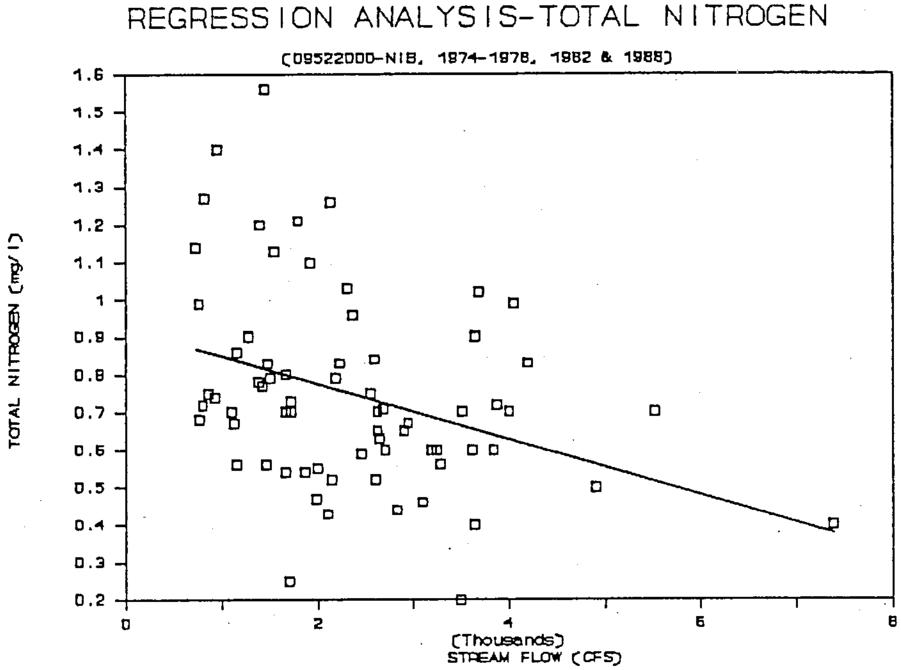
Figure 5. Regression Analysis-Electroconductivity 1974-1978, 1982 and 1988



Regression Output: CONDUCTIVITY

Constant	1787.293
Std Err of Y Est	95.12581
R Squared	0.635590
No. of Observations	329
Degrees of Freedom	327
X Coefficient(s)	-0.124652
Std Err of Coeff	0.0052195

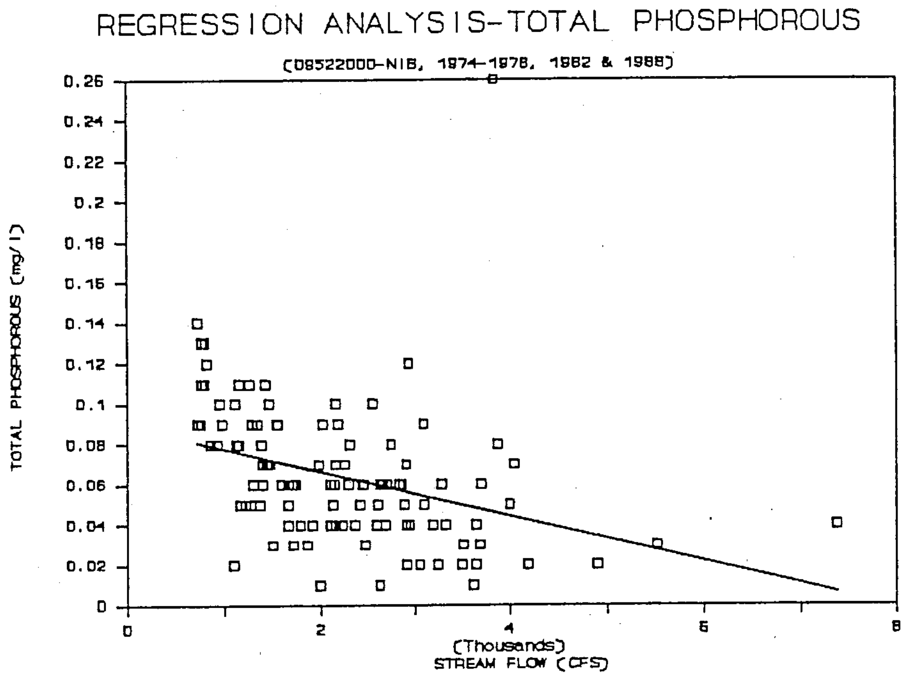
Figure 6. Regression Analysis - Total Nitrogen
1974-1978, 1982, and 1988



NITROGEN Regression Output:74-78/82 & 88

Constant	0.923410
Std Err of Y Est	0.245711
R Squared	0.124240
No. of Observations	69
Degrees of Freedom	67
X Coefficient(s)	-0.00007
Std Err of Coef.	0.000023

Figure 7. Regression Analysis - Total Phosphorous
1974-1978, 1982, and 1988



PHOSPHORUS Regression Output: 74-78/82 & 88

Constant	0.088734
Std Err of Y Est	0.032036
R Squared	0.128148
No. of Observations	112
Degrees of Freedom	110
X Coefficient(s)	-0.000014
Std Err of Coef.	0.000002

D. USEPA/ADHS Statistical Methodology for Nutrient Standards

The Statistical Methodology utilized for the LCR segment was based upon the USEPA/ADHS Methodology which was initially developed in 1980. This methodology requires that periods of representative flow and nutrient data be selected for statistical evaluation. When at least 100 observation sets are available, bivariate regression analyses are performed to statistically characterize flow and water quality in the river segment. The 7 consecutive day, low flow at the 10-year recurrence interval (7Q10), which is derived from EPA Guidelines for waste loading analyses, and annual mean flow values are determined by using at least 10 years of daily discharge records. Nutrient concentration values at these flows are determined using bivariate regression equations (see Figures 6 and 7, and Appendix A).

If the data are insufficient, the bivariate regression analysis is replaced by statistical analysis of the acceptable data set population for each averaging time. When using the USEPA/ADHS Statistical Methodology, water quality standards for a segment are generally calculated as follows:

1. Annual Mean - mean concentration values from the bivariate regression analyses plus 1.0 standard deviations. Depending on number of observations and data quality, 0.3 to 1.3 standard deviations may be added to the mean.

2. 90th Percentile - 7Q10 concentration value plus 2.0 standard deviations. Depending on the number of observations and data quality, up to 3.0 standard deviations could be added to the mean.

3. Single Sample Maximum (SSM) - maximum, non anomalous value observed, minimum of 100 acceptable observations.

ADHS, EPA and the Arizona Water Quality Control Council agreed in 1985 that only the 90th percentile control point limits would be adopted for nutrients at the NIB to serve as standards in the LCR segment.

E. Yuma Water Quality Modeling

Conventional statistical analysis of water quality data in the LCR segment was considered to be insufficient to predict and evaluate future conditions. Models have been developed to extend existing data. The EPA QUAL2E computer model is a model that is often used to predict and evaluate future water quality conditions. The discussion in this section describes and amplifies the work of Dr. James Duke for the City of Yuma.

The City of Yuma report (Duke, 1990a) presents QUAL2E water quality model simulations using data collected by the USGS and the City. The study evaluated the Colorado River between USGS Gage No. 09521100 (Yuma Gage, Colorado River below Yuma Main Canal Wasteway) and USGS Gage No. 09522000 (Colorado River at Northerly International Boundary). The model was calibrated using upstream inflow (USGS 09521100), five discharges to the segment and downstream outflow (USGS 09522000). These discharges are:

1. Yuma Mesa Outlet Drain (USGS 09530200)

2. City of Yuma Wastewater Treatment Plant (NPDES Permit No. AZ0020443)

3. Drain 8-B (USGS 09530500)

4. Pilot Knob Hydroelectric Power Plant (USGS 09527000)

5. Ungaged Inflow (nonpoint sources)

The QUAL2E model calibration was based upon current conditions within the segment, including the discharge of 7 MGD of secondary treated effluent from the City's wastewater treatment plant (WWTP). Nutrient concentrations and biostimulation were evaluated for the above sources over a 20+ year planning horizon using this model. These initial conditions that were used for model calibration are referred to as the "**BASE**" case in subsequent discussions. Simulated future conditions (at the end of the 20 year planning horizon) include an 18 MGD municipal WWTP discharge and are referred to as **"GROWTH"** cases in subsequent discussions. Four (4) subsets of the **GROWTH** case are evaluated in detail by ADEQ, using the City of Yuma's calibrated QUAL2E model. These are known as the **"GROWTH 1"**, **"GROWTH 2"**, **"GROWTH 3"** and **"GROWTH 4"** scenarios and are presented in Section G.

Fifteen data sets were used to calibrate the model (Duke, 1990a). Eleven of these sets were from published USGS data from the years 1987 and 1988. Four (4) data sets were from unpublished data collected by the City of Yuma during the year 1990. The calibrated model was run for the **BASE** and **GROWTH** scenarios at 7Q10 conditions using the water quality and hydrologic data presented in Tables 3 and 4. The 7Q10 flow was determined to be critical for purposes of biostimulation evaluation by both ADEQ and Dr. Duke.

TABLE 3. COMPARISON OF NUTRIENT CONCENTRATION VALUES USED IN THE CALIBRATED QUAL2E MODEL FOR 7Q10 ANALYSES AND CONCENTRATION VALUES FOR PUBLISHED USGS DATA AND CITY REPORTS

LOCATION	USGS GAGE No.	NITROGEN(mg/l)	PHOSPHOROUS(mg/l)
Yuma Gage	09521100	0.80* 0.70** 1.50***	0.04* 0.03** 0.13***
Yuma Mesa Outlet Drain	09530200	1.50* 1.85**	0.01* 0.03**
City of Yuma WWTP	NPDES No. AZ0020443	21.90* 21.90****	5.00* 5.00****
Drain 8 B (Araz)	09530500	0.50* 0.55**	0.13* 0.09**
Pilot Knob	09527000	0.40* 0.50**	0.02* 0.03**

NOTES:

* Values used by Dr. Duke for calibrated model.

** Arithmetic mean values for nitrogen and phosphorous data published by US Geological Survey.

*** Statistically determined concentration values for nitrogen and phosphorus data published by US Geological Survey. See Appendix A.

**** Arithmetic mean values for City from Yuma reports.

TABLE 4. FLOW VALUES USED IN THE CALIBRATED QUAL2E MODEL FOR 7Q10 ANALYSES FOR BASE AND GROWTH CASES

LOCATION	FLOW, CFS BASE	GROWTH
Headwater Inflow (09521100)	376.0	359.0
Yuma Mesa Outlet Drain	25.0	25.0
Yuma WWTP 1988 (7MGD)	10.9	---
Yuma WWTP 2010 (18 MGD)	---	27.9
Drain 8 - B	13.0	13.0
Pilot Knob	0.0	0.0
Ungaged Inflow (nonpoint sources)	223.1	223.1
DISCHARGE AT NIB(09522000)	648.0	648.0

Source: Duke, 1990a

The basic assumptions used by the City of Yuma for the 7Q10 analyses are discussed in detail below:

1. Low flow conditions at the outlet of the LCR study segment (USGS 09522000) are assumed to be unchanged because of water deliveries to the Republic of Mexico. The 7Q10 discharge was determined to be 648 CFS using the U.S. Army Corps of Engineers Statistical Program (Duke, 1990b).

2. Currently, (**BASE** case) the upstream 7Q10 inflow to the segment at the Yuma Gage (USGS 09521100) is calculated to be 376 CFS using the Army Corps of Engineers Statistical Program. The City of Yuma WWTP discharge is currently at 7 MGD. When the discharge increases to 18 MGD (for all **GROWTH** cases discussed herein) the upstream 7Q10 inflow value will be decreased to 359 CFS by streamflow regulation at Imperial Dam thereby maintaining the 648 CFS discharge to the Republic of Mexico during 7Q10 conditions. Nutrient concentration values at the Yuma Gage are shown in Table 3.

3. The City of Yuma WWTP discharge and nutrient concentrations data used in the calibrated model were obtained from the City of Yuma Database Report (JCE, 1989). The calculated arithmetic mean concentration values of 21.9 mg/l total N and 5.0 mg/l total P (Table 3) correspond to the average WWTP discharge of 7 MGD. This average WWTP discharge was established using data from the period of September 1986 through June 1988. Effluent from this plant is currently discharged to the Colorado River approximately 2 river-miles downstream of the head of the segment (USGS 09521100). In the future, this discharge is planned to increase to 18 MGD (Duke, 1990a). This flow is utilized for all **GROWTH** cases presented herein.

4. Two gaged agricultural return flows to the segment, the Yuma Mesa Outlet Drain (USGS 09530200) and the 8-B Drain (USGS 09530500), are measured by the USGS. Monthly mean discharge values are published by the USGS. For the model, each drain was assumed to have constant flow for each month. Table 3 shows that concentration values that were used in the calibrated model for the 8-B Drain and Yuma Mesa Outlet Drains.

5. The Pilot Knob Hydroelectric Plant (USGS 09527000) operates intermittently to generate electricity when water is available in the LCR study segment. When operating, this facility discharges water of relatively high quality from the All American Canal, which is diverted from the Colorado River near Imperial Dam. When the plant does not operate (such as during low flow conditions) river water at the NIB contains larger contributions from agricultural return flow discharges that originate below Imperial Dam. The **BASE** and **GROWTH** cases of the calibrated QUAL2E model at the 7Q10 flows were run using no discharge from Pilot Knob because that condition represented the worst case for potential impacts from pollution sources.

6. Ungaged Inflow was estimated for the LCR study area at 7Q10 conditions. Segment outflow at the NIB (USGS 09522000) was greater than the sum of gaged inflows at the Yuma Gage, Yuma Mesa Outlet Drain, City of Yuma WWTP, Drain 8-B and assumed flow from the Pilot Knob Hydroelectric Plant. The calculated difference (223.1 CFS) is represented as Ungaged Inflow in the calibrated QUAL2E model and was distributed by Dr. Duke to each reach as shown in Table 5. Nutrient concentrations for the Ungaged Inflow are calculated as the arithmetic mean of published USGS data for the period of October 1, 1986 through September 30, 1988 for the Yuma Mesa Outlet Drain and Drain 8-B (Duke, 1990a).

TABLE 5. QUAL2E MODEL ALLOCATION OF UNGAGED INFLOW BY REACH

REACH NUMBER	NUMBER OF ELEMENTS*	UNGAGED INFLOW % OF SEGMENT	UNGAGED INFLOW CFS
1	19	29.69	66.24
2	20	31.25	69.72
3	14	21.88	48.81
4	11	17.18	38.33
	64	100.00	223.10

NOTE:
* Computational elements within each reach of the calibrated QUAL2E model. Each element is equal to 0.1 miles for a total of 6.4 miles of the Lower Colorado River study segment.

F. Comparison of USEPA/ADHS Statistical Method and the Calibrated QUAL2E Model (City of Yuma)

Nitrogen and phosphorus concentrations in the Colorado River at the NIB during 7Q10 low flow were predicted using both the USEPA/ADEQ Statistical Methodology and the calibrated QUAL2E model for current (7 MGD) and future (18 MGD) discharge rates from the City of Yuma WWTP with all other sources at current concentration values. Both predictive techniques were used (Table 6).

TABLE 6. PREDICTED CONCENTRATIONS IN COLORADO RIVER AT NIB at 7Q10

Scenario	Statistical Method	Calibrated QUAL2E Model
BASE Case (7 MGD Municipal WWTP Discharge)		
Nitrogen	1.40 mg/l	1.31 mg/l
Phosphorus	0.16	0.13
GROWTH 1 Scenario (18 MGD Municipal WWTP Discharge)		
Nitrogen	1.95	1.88
Phosphorus	0.29	0.26

A comparison of these values shows a range of difference between 4 percent and 23 percent, averaging approximately 10 percent, with the calibrated QUAL2E model predicting the lower concentrations. The favorable comparison of results from these different techniques adds confidence to the results of both methods.

G. Detailed Evaluation of Water Quality Conditions Using the Calibrated QUAL2E Computer Model

Because the QUAL2E has been accepted by EPA for waste load analysis, it is assumed to be effective in evaluating Chlorophyll a concentrations and will be used to explore predicted Chlorophyll a concentrations in the LCR study segment for various environmental scenarios. This calibrated model (described in Section E above) was run to evaluate the resulting N, P and Chlorophyll a concentrations in the LCR segment at 7Q10 flow, the regime expected to be most sensitive to biostimulation. Chlorophyll a was selected to measure the combined influence of sunlight, water temperature and nutrients.

A criterion of 4.0 micrograms Chlorophyll a per liter (ug/l) was selected for initial evaluation, based upon a study by McGee (1983) who recommended 2 to 6 ug/l for oligo-mesotrophic conditions. This criterion was used on a provisional basis to evaluate the calibrated model's response to a range of environmental scenarios. Any departure from expected Chlorphyll a concentrations at the NIB evaluation point triggered a review of the resulting nutrient concentrations. Because the criterion was to be utilized on an iterative basis, the value was deemed the most satisfactory for initial evaluation. If the 4.0 ug/l Chlorophyll a criterion produced undesirable N and P loading limitations, it would be further scrutinized. However, useful results were obtained during this initial evaluation (no undesirable N and P loading impacts were predicted), therefore, no criterion refinement was considered to be necessary.

The environmental scenarios that were evaluated were chosen by varying input loads of nutrients for sources that were uncertain or likely to increase within the 20-year planning horizon of this study. Low flow output from the LCR study segment (648 CFS at the NIB) and input flows were held constant for **GROWTH** case assumptions (Table 4). Nutrient concentrations for all runs of the calibrated model (during low flow conditions) are unchanged for the **BASE** and **GROWTH** cases for the following sources that contribute flow to the LCR:

Yuma Mesa Outlet Drain
City of Yuma WWTP
Drain 8-B
Pilot Knob

The scenarios evaluated using the calibrated QUAL2E model are summarized in Tables 7 and 8. Upstream inflow is evaluated in detail because:

1. Upstream inflow is the largest single discharge to the LCR study segment; and

2. Upstream inflow is subject to the greatest uncertainty with respect to nutrient loadings from sources outside of the LCR study area.

The **GROWTH 4** scenario is considered to represent the outer boundary of the greatest expected nutrient loading for the LCR segment at the 7Q10 flow. Both the upstream flow (359 CFS) and the ungaged inflow (223.1 CFS), together represent 90 percent of the outflow at the NIB (648 CFS). Only the **GROWTH 4** scenario departed from the expected Chlorophyll a value. Thus, biostimulation is not expected to occur for virtually any of the scenarios evaluated.

Table 8 summarizes the nutrients source concentrations that were varied and the predicted constituent concentrations at the NIB outflow point during steady-state, low flow conditions.

TABLE 7. MODELED SCENARIOS FOR 7Q10 FLOW IN THE COLORADO RIVER

BASE	Existing conditions with City of Yuma WWTP discharge at 7 MGD.
GROWTH 1	Same as **BASE**, except the City of Yuma WWTP discharge is 18 MGD and upstream inflow (at Yuma Gage) was reduced by 11 MGD in accordance with treaty limits (648 CFS).
GROWTH 2	Same as **GROWTH 1**, except the nutrient concentrations at the Yuma Gage (upstream inflow for the LCR study segment) are established by statistical analysis of 48 observations during Water Years 1987 and 1988 (See Appendix A).
GROWTH 3	Same as **GROWTH 1**, except the nutrient concentrations at the Yuma Gage are three times the arithmetic mean values of the 48 observations during WYs 1987 and 1988.
GROWTH 4	Same as **GROWTH 3**, except the nutrient concentrations in Ungaged Inflow are three times the values used for the calibrated QUAL2E model in the **GROWTH 1** case. This is the extreme worst case, well outside the expected range of loads during the planning horizon.

TABLE 8. NUTRIENT SOURCE CONCENTRATIONS AND PREDICTED LCR OUTFLOW QUALITY FOR FIVE SCENARIOS

SCENARIO	WWTP Discharge (MGD)	NUTRIENT SOURCE: Nitrogen & Phosphorus Upstream Concentration 09521100 (mg/l) N	P	Nitrogen & Phosphorus Ungaged NPS Concentration (mg/l) N	P	PREDICTED QUALITY AT NIB USGS No 09522000 BY CALIBRATED QUAL2E: Chlorophyll a (ug/l)	N (mg/l)	P (mg/l)
BASE	7.	0.80	0.04	1.20	0.07	1.34	1.31	0.13
GROWTH 1	18.	0.80	0.04	1.20	0.07	1.37	1.88	0.26
GROWTH 2	18.	1.50	0.13	1.20	0.07	3.26	2.31	0.31
GROWTH 3	18.	2.40	0.12	1.20	0.07	3.91	2.75	0.31
GROWTH 4	18.	2.40	0.12	3.60	0.21	4.03	3.58	0.36

Notes: MGD - Million Gallons per Day
ug/l - micrograms per liter
mg/l - milligrams per liter
See Tables 3 and 4 for nutrient concentration and flow values for Nutrient Sources, respectively.
See Table 7 for Scenario descriptions.

IV. DISCUSSION

A. General

The bivariate regression analyses of the water quality constituents and flow resulted in the selection of data sets that characterized the quality of the Colorado River at the NIB during 7Q10 flow conditions. Statistical analyses of the discharge/total N and discharge/total P relationships for the years of useable data (1972-1978, 1982 and 1988) were significant at $p \leq 0.01$ (Table 2). The river system is expected to be most sensitive to biostimulation at the 7Q10 flow.

The USEPA/ADHS Statistical Methodology and calibrated QUAL2E Model satisfactorily predicted the nutrient concentrations at the NIB site at 7Q10 flow for the existing **BASE** conditions. Furthermore the statistical methodology and the calibrated model predicted comparable increases in nutrient concentrations associated with the **GROWTH 1** scenario. Because of its predictive capabilities and acceptance by USEPA, the QUAL2E model was utilized to explore a wide range of various nutrient loadings and environmental responses in the LCR study segment. While the scenarios of the future are the creation of the authors, they represent extrapolations of the larger, most uncertain sources of nutrients. Only future data collection and the evaluation of water pollution loads generated at those future times will produce actual information about those conditions. Extreme drought and over-allocation of Colorado River Basin water to upstream users may occur and produce future conditions that differ significantly from the evaluated scenarios. However, the United States commitment for the delivery of water to the Republic of Mexico will be maintained. Therefore, no change is expected to the key assumption of a 648 CFS discharge at the NIB during low flow conditions.

The Ungaged Inflow (UI), discussed in Section III.E.6, is somewhat higher than estimates by others. The UI was accepted for use in the calibrated QUAL2E model because it represented the maximum potential loading limit to the LCR study segment from unquantified sources. While there is uncertainty about the absolute value and specific sources of the nutrient loads from the UI contribution, it is best characterized as a nonpoint source (Richards, 1989). This load in the LCR study segment is expected to decline because agricultural land uses will be converted to urban use as the City of Yuma grows. Also Arizona's Ag BMP Program will result in nitrogen load reductions from the remaining agricultural activities. Fertilizer cost, weather, pest damages and market conditions will control agricultural production. Because the Ag BMP program is being implemented by education and other non-regulatory techniques, and nitrogen fertilizer feedstock costs are related to oil prices, the effectiveness of the program will be controlled by numerous, non-regulatory factors beyond the scope of this report. However, no major increase in UI nutrient loads are expected in the range of that evaluated by the **GROWTH 4** scenario.

At the head of the LCR segment, the discharge and nutrient concentration values at the Yuma Gage (09522000) are influenced by conditions upstream including flow regulation, agricultural return flows, permitted discharges under the federal CWA and seasonal runoff. At this time and in the foreseeable future, the Colorado River flow at the Yuma Gage represents a major source of nutrients and flow in the study segment during the 7Q10 condition. The loading from this source was increased for the **GROWTH 2, GROWTH 3,** and **GROWTH 4** scenarios (Table 8) because of uncertainty due to upstream sources, including point sources, the agricultural return flows, abnormal runoff events from tributaries such as the Bill Williams and Gila Rivers, and drought conditions. These sources are known to have a profound impact on water quality in the LCR study segment. The **GROWTH 2, GROWTH 3** and **GROWTH 4** scenarios represent a range of extreme conditions which could be encountered in the LCR study segment within the next 20 years.

For the **GROWTH 2** scenario, the N and P concentrations at the Yuma Gage were statistically derived by using the USEPA/ADHS Statistical Methodology because only 48 sets of observations were available (see Appendix A). For the **GROWTH 3** and **GROWTH 4** scenarios, the use of three times the arithmetic mean for the 48 sets of concentration observations at the Yuma Gage proved to be significantly more conservative in estimating upstream inflow loads to the LCR study segment during 7Q10 flow.

The modeled Chlorphyll a concentrations associated with these extreme conditions demonstrated with considerable confidence that the LCR study segment can receive significant increases in nutrient loads, and the designated uses can be protected by less stringent standards. The control point limits were judged by the authors to be an appropriate use of the data and the model to evaluate the LCR. Table 8 compares the predicted N, P and Chlorophyll a values for these scenarios (see Table 1 and text of Section II B. concerning the selection of Control Point nutrient standards).

A review of the QUAL2E results for each computational element showed no abnormal concentration values within the LCR segment, as compared to the outflow at the NIB. This supports the initial decision to adopt control point standards at the NIB. The complexities of hydraulic and pollutant loadings in the vicinity of the upstream end of the segment requires further study to select an upstream control point.

Recommended limits for nutrient standards in the LCR study segment need to satisfy several tests. First, the standards must result in adequate protection of designated uses. Second, the standards must have an adequate margin of safety taking into account the uncertainties of the predictive evaluation techniques utilized. Third, the standards must be practical and implementable. Fourth, a water quality surveillance program must be maintained to verify that the system behaves as predicted.

Scenario **GROWTH 2** protects against excessive algal production and is a generally conservative analysis. To satisfy the practicability/implementability test, Total Maximum Daily Loads (TMDL) and a limited economic evaluation must be performed. For purposes of the TMDL calculation, the **GROWTH 2** scenario is modified by rounding the total N and the total P values at the NIB to 2.50 and 0.33 mg/l, respectively (the values for the recommended standards). All input sources to the LCR segment for the TMDL calculation are unchanged from those used for the **GROWTH 2** analysis. For purposes of the following discussions, this scenario will be referred to as **MODIFIED GROWTH 2**.

B. Testing the **MODIFIED GROWTH 2** Scenario

The TMDL is generated by calculating the total N and total P loads that are allowed by proposed water quality standards at the outlet of the LCR study segment and then subtracting the sum of the input loads. If the remaining value is positive, the standards at the outlet (NIB Control Point) will be met and the remaining value is allocated to future sources not accounted for in the analysis. If the remaining value of this calculation is negative, reductions of controllable input loads (such as water quality based discharge limitations per CWA Section 304) must be made to achieve water quality standards at the segment outlet. Loads are calculated by multiplying the flow (CFS) and concentration (mg/l) and correcting for units to produce pounds/day. Tables 9 and 10 summarize the results of the TMDL evaluation for total N and total P, respectively, to achieve compliance with the recommended nutrient standards.

TABLE 9. LOWER COLORADO RIVER NITROGEN LOADS AT 7Q10 FLOW

	Discharge, CFS		Concentration of Total N, mg/l	Load of Total N, Lbs/Day	
Total Maximum Daily Load (TMDL) at NIB (USGS No. 09522000)		648.	2.50[2]		8,738.
Upstream Discharge at Yuma Gage (USGS No. 09521100)	359.		1.50[2]	2,905.	
Gaged Return Flows					
8-B Drain	13.		0.5	35.	
Yuma Mesa Outlet Drain	25.		1.5	202.	
Point Source Discharge for Municipal WWTP Facilities City of Yuma, 1988 (7 MGD)	10.9		21.9	1,288.[4]	
Reserved for **GROWTH** (11 MGD)	17.		21.9	2,008.[4]	
Ungaged Nonpoint Sources	223.1		1.2	1,444.	
Available for Load for Unspecified Future Sources	N/A		N/A	856.[4]	
TOTALS	648.	648.		8,738.	8,738.

NOTES:

1. Factor to correct for units = $5.3937 \frac{\text{lbs/day}}{\text{CFS-mg/l}}$

2. Recommended Water Quality Standards for 7Q10 for Total Nitrogen, 90 Percentile Limit:

USGS Gage No.	Recommended Standard
09522000	2.50 mg/l
09521100	1.50

3. N/A - Not Available.

4. Allocatable Load in Segment (Total of 4,152 pounds/day)

TABLE 10. LOWER COLORADO RIVER PHOSPHOROUS LOADS AT 7Q10 FLOW

	Discharge, CFS		Concentration of Total P, mg/l	Load of Total P, Lbs/Day	
Total Maximum Daily Load (TMDL) at NIB (USGS No. 09522000)		648.	0.33		1,153
Upstream Discharge at Yuma Gage (USGS No. 09521100)	359.		0.13	252.	
Gaged Return Flows					
8-B Drain	13.		0.13	9.	
Yuma Mesa Outlet Drain	25.		0.01	1.	
Point Source Discharge for Municipal WWTP Facilities City of Yuma, 1988 (7 MGD)	10.9		5.0	294.[4]	
Reserved for **GROWTH** (11 MGD)	17.		5.0	458.[4]	
Ungaged Nonpoint Sources	223.1		.07	84.	
Available for Load for Unspecified Future Sources	N/A		N/A	55.[4]	
TOTAL	648.	648.		1,153.	1,153.

NOTES:

1. Factor to correct for units = 5.3937 $\frac{\text{lbs/day}}{\text{CFS-mg/l}}$

2. Recommended Water Quality Standards for 7Q10 for Total Phosphorus, 90 Percentile Limit:

USGS Gage No.	Recommended Standard
09522000	0.33 mg/l
09521100	0.13

3. N/A - Not Available.

4. Allocatable Load in Segment (Total of 807 pounds/day).

The TMDL for total N at the NIB is 8,738 pounds per day. Of this amount, 856 pounds per day are available for unspecified future sources (Table 9). The TMDL at the NIB for total P is 1,153 pounds per day. Of this amount, 55 pounds per day are available for unspecified future sources (Table 10).

The economic evaluation is limited to comparing estimated annual costs for (a) controlling the City of Yuma discharge loads by tertiary treatment and re-fertilizing irrigation water deliveries to the Republic of Mexico with Nitrogen removed by the tertiary treatment plants and (b) the no cost alternative produced by amending Water Quality Standards as recommended. Estimated costs will be dependent on plant operating load and therefore two evaluations are presented - new 18MGD plant operating at 12 MGD and new 18 MGD plant operating at 18 MGD. Using estimates provided by John Carollo Engineers for an 18 MGD WWTP and making adjustments for nutrient removal rates, the **MODIFIED GROWTH 2** produces the following annual savings:

	Estimated Annual Costs ($ per year) At Average WWTP Loadings	
	12 MGD	18 MGD
Savings to the City of Yuma		
Capital Costs	616,800	616,800
O & M Costs	1,458,300	2,187,400
Savings to the Farmers		
Fertilizer Costs	41,700	130,700
TOTAL	$2,116,800/yr	$2,935,900/yr

It is concluded that the recommended limits for total N and total P at the NIB for **MODIFIED GROWTH 2** scenario results in the avoidance of significant annual costs that would accrue if the existing (antidegradation) surface water quality standards were maintained.

Other potential impacts of the recommended limits on downstream water users have been considered. Flows in the Colorado River at the NIB are diverted at Morales Dam for delivery to the Republic of Mexico. No specific data concerning water uses and water quality problems (other than salinity) have been obtained. However, several conclusions from the QUAL2E model runs can be made with respect to the presence of nutrients in water at the diversion point near the NIB:

1. The total N value equates to NO_3-N values that are well within USEPA MCL (10.0 mg/l) for public drinking water systems.

2. The predicted Chlorophyll a values during critical low flow conditions are within the range of those found at the intake to public drinking water system treatment plants in Arizona.

3. The total N and total P concentrations in irrigation water at the NIB (at the recommended limits) do not cause problems with system operation. In fact, agricultural users, for the most part, prefer elevated nitrogenous constituents in irrigation water because it contains "free fertilizer". Operating problems within irrigation delivery systems, however, are not evaluated by this study.

4. The recommended nutrient limits at the NIB support aquatic and wildlife and recreation limits within the LCR study segment and are expected to do the same in downstream waters with similar physical characteristics.

It is concluded that the total N and total P limits recommended at the NIB (based on the **MODIFIED GROWTH 2** scenario) result in no adverse water quality conditions for expected downstream uses.

Implementation of recommended nutrient standards at the NIB should be accompanied by development of TMDL and standards for upstream segments. Resources are currently not available to generate TMDLs for the segment upstream of the LCR study area. Also, the ADEQ rule-making process has not established nutrient standards for the outlet of the upstream segment (inlet to LCR study segment).

Based upon the analyses described in this report, no adverse water quality impacts are expected as a result of promulgation of the recommended nutrient standards. Furthermore, technology-based discharge limits currently being met by the Yuma WWTP will result in adequate water quality and reasonable treatment costs for those served by the discharge in the segment.

Total Maximum Daily Load (TMDL) development is described in the State's Continuing Planning Process (CPP) document. ADEQ is documenting TMDLs for the LCR from the Yuma Gage (09521100) to the Northerly International Boundary (09522000), based upon recommended nutrient standards presented in Section I. See Figure 1 for locations. Because ADEQ has recommended water quality standards which will not be violated by the predicted loads, no load allocation (LA) or waste load allocation (WLA) is necessary. The Colorado River near Yuma will cease to be a Water Quality Limited Segment (WQLS), once recommended Water Quality Standards are promulgated.

V. CONCLUSIONS AND RECOMMENDATIONS

The calibrated QUAL2E Model using the **MODIFIED GROWTH 2** scenario demonstrates that the recommended water quality standards are a feasible means to manage nutrients in the LCR study segment. Surface Water Quality Standards for the Colorado River at the NIB are therefore recommended at the limits for the 90th percentile averaging time. These limits are: 2.50 mg/l for total N and 0.33 mg/l for total P.

The proposed standards are designed to apply to the "control point" at the NIB (USGS 09522000). The limits to biostimulation resistance in the segment are undetermined. ADEQ must assure that the proposed nutrient standards at the NIB control point will be met into the future (a 20 year planning horizon). Therefore it is recommended that additional standards be considered for the reach upstream of the LCR study segment during the 1992-93 Water Quality Standards review. Because of the growth and development that has occurred along the Colorado River during the last five years, no action with regard to upstream standards is considered by the author as an unacceptable option. To provide a basis for managing future upstream sources, ADEQ should consider proposing the following 90th percentile limits as control point standards at the Yuma Gage, USGS Gage Number 09521100: 1.50 mg/l for total Nitrogen and 0.13 mg/l for total Phosphorus (Appendix A), unless further evaluation proves otherwise. These recommended values have been statistically calculated using the same methodology that EPA Region 9 and ADHS have agreed to utilize in the past when data and resources for more sophisticated studies were not available (ADHS, 1985). These upstream standards should be considered during the next triennial review.

In summary, this report recommends that 90th percentile nutrient standards of 2.50 mg/l total Nitrogen and 0.33 mg/l total Phosphorus be considered at the NIB control point. The report further recommends that 90th percentile nutrient standards of 1.50 mg/l total Nitrogen and 0.13 mg/l total Phosphorus be adopted at the Yuma Gage, USGS 09521100 during the next triennial review.

VI. REFERENCES

American Public Health Association (APHA, 1985). "Standard Methods for the Examination of Water and Wastewater", 16th Edition, pg 76.

Arizona Department of Health Services (ADHS, 1977). Water Quality Management Basin Plan: Colorado Mainstem River Basin, October, 1977

Arizona Department of Health Services (ADHS, 1985). Draft Staff Report: "Nutrient Standards for the Colorado River Near Yuma". September 1985.

Barnwell, Thomas O. Jr., Brown, Linfield C., Wiktor, Marek (1989). "Application of Expert Systems Technology in Water Quality Modeling." Wat. Sci. Tech. Vol 21, Brighton, pps. 1045-1056.

Betson, Roger P. and McMaster, William M. (1975). "Nonpoint Source Mineral Water Quality Model." Paper presented at the 47th Annual Conference of the Water Pollution Control Federation, Denver, Co. October 6-11, 1974.

Brown, Linfield C., and Thomas O. Barnwell, Jr. (1987). "The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual", EPA Report No. EPA/600/3-87/007, USEPA, Athens, Georgia.

Carollo, John, Engineers (JCE, 1989). "City of Yuma, Colorado River Preliminary Data Base". June, 1989.

Duke, James H. Jr., PhD., P.E. (Duke, 1990a). Report to the City of Yuma, "Lower Colorado River Nutrient Study". December, 1990.

Duke, James H. Jr., PhD., P.E. (Duke, 1990b). Personal communication. December 1990.

Edmiston, N.L., Myers, V.B. "Florida Lakes Assessment: Combining Macrophyte, Chlorophyll, Nutrient and Public Benefit Parameters into a Meaningful Lake Management Scheme." Bureau of Water Management, Florida Department of Environmental Regulation, Tallahassee, Fl. Lake and Reservoir Management.

Hem, John D. (1970). "Study and Interpretation of the Chemical Characteristics of Natural Water." Geological Survey Water-Supply Paper 1473. pp. 277-280.

Little, Keith W., Lauria, Donald T.(1989). "Water Quality Model Calibration. A Comparison of Input and Output Error Criteria," Water Resources Bulletin, 25, 4, pp. 755-764.

McGhee, R.F. (1983). "Experiences in Developing a Chlorophyll a Standard in the Southeast to Protect Lakes, Reservoirs and Estuaries." Lake Restoration, Protection and Management, pp. 163-165.

Richards, Peter (1989). "Evolution of Some Approaches to Estimating Non-Point Pollutant Loads for Unmonitored Areas." Water Resources Bulletin, 25, 4, pp. 891-904.

Steele, Timothy D. and Jennings, Marshall E. (1972). "Regional Analysis of Streamflow Chemical Quality in Texas." Water Resources Research, 8, 2, pp. 460-477.

United States Environmental Protection Agency (EPA, 1985). "Guidance for State Water Quality Monitoring and Waste Load Allocation Programs. EPA 440/4-85-031. Washington, D.C.

United States Geological Survey. (USGS 1972-1988). "USGS Water Resources Data for Arizona". Water Years 1972-1988. Reports for Department of the Interior, 1972-1974. Water Date Reports: AZ-75-1 through AZ-88-1.

APPENDIX A

During the period of October 1986 through September 1988, the U.S. Geological Survey performed a water quality characterization study for ADEQ at four locations in the Lower Colorado River to supplement the Primary Fixed Station Network monitoring site on the Colorado River at the Northerly International Boundary near Morelos Dam (USGS Gage No. 09522000). This characterization program focused on inflow rates and water quality at the beginning (must be upstream location) of the Lower Colorado River study segment, and at key, measurable sources.

Data collected at the upper end of the study segment showed upstream inflow to be the largest, nonpoint sources of pollution. Discharge, total nitrogen and total phosphorus data and the statistical results from analysis by LOTUS 1-2-3 are presented on the following page.

A:ESPEWQSL.DOC

LOWER COLORADO RIVER, YUMA GAGE-09521100
WY1986-1987 & WY1987-1988

DATE	FLOW	TN	PHOS
86/10/02	7390	0.5	0.03
86/10/15	3680	1	0.02
86/11/06	5260	0.6	0.04
86/11/20	7340	0.6	0.03
86/12/03	3840	0.7	0.005
86/12/17	8620	0.6	0.02
87/01/07	12000	0.8	0.31
87/01/21	11200	0.7	0.38
87/02/05	8260	0.7	0.08
87/02/19	3200	0.6	0.03
87/03/05	3190	1.1	0.04
87/03/19	1980	1	0.03
87/04/02	1830	0.8	0.02
87/04/15	1780	0.6	0.09
87/05/06	1770	0.6	0.03
87/05/21	1300	1	0.03
87/06/02	1190	0.9	0.03
87/06/18	1280	0.9	0.05
87/07/01	1310	0.9	0.08
87/07/20	1250	1.2	0.05
87/08/05	1280	1.2	0.05
87/08/19	1290	0.7	0.04
87/09/03	2250	0.4	0.1
87/09/16	2240	0.8	0.025
87/10/01	2650	0.8	0.02
87/10/14	2490	0.8	0.04
87/11/04	2480	0.9	0.03
87/11/18	1220	0.8	0.01
87/12/02	796	0.6	0.01
87/12/17	1520	0.6	0.05
88/01/07	1500	0.4	0.03
88/01/21	1610	0.8	0.04
88/02/04	1550	0.8	0.03
88/02/17	1430	0.8	0.03
88/03/02	1420	0.9	0.021
88/03/17	1090	0.6	0.01
88/04/07	1290	0.7	0.04
88/04/20	1540	0.6	0.04
88/05/05	646	0.7	0.02
88/05/19	1500	0.4	0.02
88/06/01	1050	0.4	0.02
88/06/15	1090	0.8	0.005
88/07/07	914	0.5	0.03
88/07/21	1150	0.9	0.02
88/08/03	1320	0.8	0.04
88/08/17	1250	0.6	0.02
88/09/06	2680	0.5	0.04
88/09/21	1570	0.7	0.04

DATA MANAGEMENT

Regression Output: Nitrogen	
Constant	0.758145
Std Err of Y Est	0.197041
R Squared	0.013163
No. of Observations	48
Degrees of Freedom	46
X Coefficient(s)	-0.00000
Std Err of Coef.	0.000010

Regression Output: Phosphorous	
Constant	0.017232
Std Err of Y Est	0.049490
R Squared	0.181921
No. of Observations	48
Degrees of Freedom	46
X Coefficient(s)	0.000008
Std Err of Coef.	0.000002

ADEQ

	FLOW	TN	PHOSPHOROUS
AVG	2707	0.735416	0.040541
SUM	129936	35.3	1.946
STD	2553.329	0.194175	0.053364

DUKE, 1990 QUAL2E MODEL

	FLOW	TN	PHOSPHOROUS
AVG	359	0.90	0.04

Estimated 90th Percentile at 359 CFS
Constant + 359 X Slope + 2(STD)

N= 0.758 + (-0.00000) X 359 + 2(0.194) = 1.15 mg/l (1.50 mg/l)

P= 0.017 + (0.000008) X 359 + 2(0.054) = 0.13 mg/l (0.13 mg/l)