INTENSIVE SURVEY OF

GUADALUPE RIVER

SEGMENT 1806

Hydrology, Field Measurements, Water Chemistry
and Benthic Macroinvertebrates

by

Stephen R. Twidwell

IS 87-02

Texas Water Commission

February 1987

Published and distributed
by the
Texas Water Commission
Post Office Box 13087
Austin, Texas 78711

ABSTRACT

An intensive survey of Guadalupe River Segment 1806 was conducted November 1-3, 1983, by the Texas Water Commission (Predecessor agency Texas Department of Water Resources). Segment 1806 of the Guadalupe River extends from the headwaters of Canyon Lake in Comal County to the confluence of the North and South Forks near Hunt in Kerr County, a distance of 168.2 km (104.5 mi). Water quality, hydraulic, and biological data were collected at 11 mainstream stations, three tributary streams, and the City of Kerrville wastewater treatment plant in the area upstream of SH 87 near Comfort to the upper segment boundary. Stream discharge was relatively stable (range 1.25-1.28 m^3/s) in the two reaches where measurements were made. Stream widths were variable (9-60 m) due to natural changes in topography and repeated mainstream impoundments located within the segment and stream velocities were moderate (0.078-0.12 m/s). Dissolved oxygen levels remained above the 5 mg/L stream criterion throughout the diurnal period at all mainstream stations. Levels of nitrogenous and carbonaceous oxygen demanding substances were low throughout the study area. Orthophosphorus and nitrate nitrogen levels were low enough to suggest that either would be limiting to aquatic plant growths in different areas of the stream. Chlorophyll *a* levels were less than 2 µg/L at most stations reflecting the low primary productivity of the stream. Chloride, sulfate, total dissolved solids, water temperature, pH and fecal coliform levels generally conformed to segment criteria. Benthic macroinvertebrate community structure reflected clean water and stable environmental conditions throughout the study reach. Highest levels of oxygen demanding substances, nutrients, chlorophyll *a*, chloride, sulfate, and total dissolved solids were observed at the upstream station on Third Creek, the tributary stream which receives periodic discharges from the City of Kerrville wastewater treatment plant.

TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

TABLES

INTENSIVE SURVEY OF
GUADALUPE RIVER
SEGMENT 1806

INTRODUCTION

DIRECTIVE

This intensive survey was accomplished in accordance with the Texas Water Quality Code, Section 26.127. The report is to be used for the purpose listed below.

PURPOSE

The purpose of this intensive survey was to provide the Texas Water Commission with a valid information source:

1. to determine quantitative cause and effect relationships of water quality;
2. to obtain data for updating water quality management plans, setting effluent limits, and where appropriate, verifying the classifications of segments;
3. to set priorities for establishing or improving pollution controls; and
4. to determine any additional water quality management actions required.

METHODS

Field and laboratory procedures used during this survey are described in Appendix A. The field measurements, water chemistry, hydraulic, and biological data were collected November 1-3, 1983, by the Texas Water Commission (predecessor agency, Texas Department of Water Resources), Water Quality Assessment Unit personnel with assistance from Texas Water Commission District 8 personnel in San Antonio. Laboratory analyses of water samples were conducted by the Texas Department of Health Chemistry Laboratory in Austin, Texas. Bacteriological analyses were conducted by the the Upper Guadalupe River Authority. Benthic macroinvertebrate samples were collected by Jack R. Davis at selected stations on November 2-3, 1983, and returned to the Water Quality Assessment Unit's laboratory for identification and enumeration. Parametric coverage, sampling frequencies and spatial relationships of sampling stations were consistent with the objectives of the survey and with known or suspected forms and variabilities of pollutants entering the stream.

RESULTS AND DISCUSSION

SITE DESCRIPTION

The Guadalupe River has its beginning in springs that form the North and South Forks in Kerr County west of Kerrville. These two forks join near the community of Hunt, and the mainstream flows eastward into Kendall and Comal counties where it turns and flows south to the Gulf of Mexico. Its total length is approximately 678.2 kilometers (421.4 miles). One major reservoir, Canyon Lake, and several smaller ones, Lake McQueeney, Lake Dunlap, Lake Placid, Lake Gonzales, Wood Lake, and Meadow Lake are located on the river. The Guadalupe River is very scenic, and sufficient stream flow for recreational use exists throughout its entire length, with the exception of the extreme headwaters.

Segment 1806 of the Guadalupe River extends 168.2 km (104.5 mi) from the confluence of the North and South Forks in Kerr County to the headwaters of Canyon Lake, 2.7 km (1.7 mi) downstream of Rebecca Creek Road in Comal County. The drainage area of the segment is located in the central Texas region known as the Edwards Plateau. Rolling hills covered by cedar and liveoak and underlain by thin soils and limestone outcrops are typical of the area. Within this region bald cypress trees line the banks of the Guadalupe River. The river water is usually crystal clear and swift flowing; thus, it is inviting for recreational uses. During September 1985-August 1986, 463,116 people utilized Kerrville State Park, located along the Guadalupe River near Kerrville, (TPW, 1986). The park is located adjacent to Flat Rock Lake a small mainstream impoundment formed by Flat Rock Dam. Farther downstream near Spring Branch, 231,426 people frequented Guadalupe River State Park during the same time period. The area near the park is one of the most scenic and popular white water areas for canoeing in Texas.

Stream flow within Segment 1806 alternates between riffle and pool areas and in most cases the cross section of the stream bed is broad and flat. The stream bottom is typically limestone bedrock or accumulations of gravel and limestone cobble; siltation is usually evident only in the pooled areas. The true character of the river channel has been altered by the construction of numerous impoundments which are used for recreation and/or water supply. The larger of these within the study area are Ingram Lake, Upper Guadalupe River Authority (UGRA) Lake, Flat Rock Lake and Center Point Lake. There are many intermittent tributaries and fewer perennial spring fed streams which provide inflow to the Guadalupe River in Segment 1806.

The small communities of Hunt, Ingram, Center Point, and Spring Branch and the larger City of Kerrville are drained by the Guadalupe River and its tributaries within Segment 1806. Kerrville is the county seat of Kerr County and one of the state's most popular health and recreational centers. More than a dozen boys and girls camps and several adult camps and dude ranches cater to tourists from throughout the United States. Besides tourism, ranching (sheep, cattle, goats) is extensively practiced in the area. Some wheat and oats are grown in the region, and income is also derived through the sale of cedar posts.

Eleven mainstream stations were established on Guadalupe River Segment 1806 for the intensive survey. Sampling stations were also established on Johnson Creek, Third Creek, and Cypress Creek and at the City of Kerrville Wastewater Treatment Plant (WWTP) (Table 1, Figure 1).

CLIMATOLOGY

The area near Kerrville has a warm-temperate, subtropical climate, characterized by dry winters and humid summers. Normal daily mean maximum temperatures range from 15.6°C (60°F) in January to a high of 34.7°C (94.6°F) in August. Average monthly rainfall is fairly consistent. The greatest percentage of precipitation occurs in only a few days. Mean annual rainfall is about 78.2 cm (30.8 in). There are two rainfall maxima, the first one in May, the second in September. Northerly winds prevail during most of the winter, while southeasterly winds from the Gulf of Mexico prevail during the summertime and may be experienced for long periods during the winter (NOAA, 1983).

POPULATION

Population for Segment 1806 of the Guadalupe River exceeds 32,000 (TWDB, 1986). The largest city in the segment is Kerrville with a population of 15,726 in 1980. Other communities along the segment include Comfort with a population of 1,460 and Ingram with a population of 1,235 (Kingston, 1985). Kerrville, including the immediately adjacent area, is projected to grow to approximately 29,000 by the year 2000. Based on a high growth scenario, population would be expected to increase to over 55,000 by the year 2000 for the entire segment (TWDB, 1986).

WATER QUALITY STANDARDS

Water quality standards specifying water uses deemed desirable and numerical criteria have recently been developed for Segment 1806 of the Guadalupe River. The current edition of the Texas Surface Water Quality Standards was adopted by the Texas Water Development Board in December 1984 (TWDB, 1984). This document was written pursuant to Section 26.023 of the Texas Water Code to meet 1983 goals in Section 303 of the Federal Clean Water Act, as amended. These goals require that, where attainable, water quality will support aquatic life and recreational uses. The water uses deemed desirable for Segment 1806 are contact recreation, high quality aquatic life habitat, and public water supply. The following are the numerical criteria established for Segment 1806 of the Guadalupe River and are intended to insure that water quality will be sufficient to maintain the desired uses:

Parameter	Criteria
Dissolved Oxygen	Not less than 5.0 mg/L
pH	Not less than 6.5 nor more than 9.0
Temperature	Not to exceed 32.1°C (95°F)
Chloride	Annual average not to exceed 40 mg/L
Sulfate	Annual average not to exceed 40 mg/L
Total Dissolved Solids	Annual average not to exceed 400 mg/L
Fecal Coliform	Thirty-day geometric mean not to exceed 200/100 mL

These numerical criteria are not applicable in mixing zones nor whenever the stream flow is intermittent or less than the low-flow criterion. At least four measurements are required to determine compliance for chloride, sulfate, and total dissolved solids criteria and at least five measurements, collected over not more than 30 days, are required to determine the attainment of the fecal coliform criterion.

For streams, or portions of streams, that are not designated by the Texas Water Commission as classified segments, the general criteria of the Texas Surface Water Quality Standards are applicable as a minimum. Higher uses, where existing, will be maintained. The goals of the Commission are to maintain a minimum of 3 mg/L of dissolved oxygen and a 2,000/100 mL fecal coliform density (thirty-day geometric mean) to protect minimum aquatic life and recreational uses for these streams. These general criteria, at a minimum, and others specified in Texas Surface Water Quality Standards, apply to the North and South Forks of the Guadalupe River upstream of their union and tributaries of the Guadalupe River along Segment 1806.

WATER QUALITY MONITORING STATIONS

The Texas Water Commission has established one monitoring station within Segment 1806 where routine water quality data are collected for the Stream Monitoring Network (SMN) (Table 2). This station is located at IH-10 near Comfort. The Upper Guadalupe River Authority (UGRA) also monitors water quality at this station and in addition monitors eight other stations. The United States Geological Survey (USGS) monitors stream discharge continuously at four sites. The water quality data collected by the TWC and UGRA are retrievable through the Commission's SMN Program.

HISTORICAL WATER QUALITY

Historical water quality data from nine stations located along Segment 1806 of the Guadalupe River are presented in Tables 3 and 4. Surface water temperatures, pH measurements, and dissolved oxygen levels have conformed to segment criteria (water temperature maximum 32.1°C, pH range 6.5-9.0 units, dissolved oxygen minimum 5.0 mg/L) at the nine stations over the past five years. Levels of chloride, sulfate, and total dissolved solids have occasionally (< 15 percent of samples) exceeded the respective criteria of 40, 40, and 400 mg/L (annual averages). Most of these exceedances occurred at two lower monitoring stations (US 87 and IH 10).

Fecal coliform levels have generally been less than the segment criterion at all nine sampling sites over the past five years. Fecal coliform levels greater than the criterion have occurred in only ten percent or less of the samples at eight of nine stations. The maximum fecal coliform levels were not excessively high (< 700/100 ml) and the geometric means at each station were substantially less than the criterion. These data indicate that the fecal coliform criterion is likely being attained through the segment.

WASTEWATER DISCHARGERS

The Texas Water Commission has issued permits to nine facilities in Segment 1806 (Table 5). All but two of these facilities retain and irrigate with their wastewaters and no discharges to segment are made. The City of Kerrville is served by one domestic wastewater treatment plant. Effluent from the plant is not discharged directly to Third Creek. The effluent is routed to a holding pond and is sprinkler irrigated onto adjacent pastureland. The tailwaters from the irrigated land are prevented from entering Third Creek by an earthen dike and are routed to a tailwater pond. Periodically when the pond fills, water is chlorinated and discharged to Third Creek. Such discharges are allowed by the permit as long as stream flow in the Guadalupe River exceeds 2.2 m^3/s (50 ft^3/s). When a discharge occurs the effluent must meet 20/20 (BOD_5/TSS) mg/L monthly limitations.

WATER QUALITY STUDIES

A limnological study to determine the influence of Canyon Reservoir on water quality of the Guadalupe River was conducted by Young (1971) November 1969 through January 1971. The study included one station within Segment 1806 at FM 311 near Spring Branch. Monthly dissolved oxygen levels at this station remained above 6 mg/L and near saturation throughout the study. The pH range at this station during the study was 8.0 to 8.4 units. Nutrient levels (orthophosphorus and nitrate nitrogen) were higher at the FM 311 station than those within the reservoir. On the basis of nitrogen: phosphorus ratios, phosphorus limitation was indicated at FM 311 in the summer months and nitrogen limitation was indicated in the winter months.

A more recent study to evaluate the impacts of a proposed continuous release of treated wastewater from the City of Kerrville's WWTP on algal growth in the Guadalupe River has been conducted by Short (1986a). The study involved placing clay pots, spiked with varying nutrient concentrations, in Guadalupe River at stations upstream of Ingram, near the Bear Creek confluence, and downstream of Flat Rock Dam. As the nutrients diffuse through the clay pots they stimulate growth of periphytic algae on the walls. Chlorophyll a levels extracted from periphyton scraped from the walls of the clay pots were used as a measure of algal growth. The study demonstrated that phosphorus was the nutrient that was most strongly limiting attached algal growth. Ambient levels of phosphorus were found to be low in the Guadalupe River except in the reach downstream of Flat Rock Lake. The phytoplankton bioassays were inconclusive; however, the results tended to indicate this area of the river was phosphorus enriched.

During the second year of the study, phosphorus limitation of attached algal growth was indicated three of four times measurements were made (Short, 1986b). Substantial variation in the degree of phosphorus limitation during each measurement set was attributed to differences in ambient phosphorus concentrations in the river. The phytoplankton bioassays indicate that nitrogen and phosphorus limit algal growth at different times of the year in the river.

Water quality data from Segment 1806 of the Guadalupe River were reviewed and stream water quality modeling analyses were conducted by Freese and Nichols, Inc. (1985) in their Regional Wastewater Treatment Plan conducted for the cities of Kerrville and Ingram and the UGRA. In addition an evaluation of the City of Kerrville's existing sewage collection and wastewater treatment systems and population, land use, and waste flow projections were made. The study recommended upgrading the existing Kerrville WWTP and construction of a new wastewater treatment plant near the Bear Creek confluence and a collector line upstream to Ingram. A portion of the Kerrville service area would be diverted to the new facility. Further, the study recommends the plants to be sized to treat estimated wastewater flows to the year 2000 and that construction, management, and financing be phased. On the basis of modeling studies a monthly average treatment level of 10/15/1/1 mg/L (BOD_5/TSS/NH_3-N/TP) was recommended for both the new plant and existing facility (Freese and Nichols, Inc., 1985).

The City of Kerrville plans to initially proceed with upgrading its existing wastewater treatment plant. The irrigation system and tailwater pond will be eliminated and all wastewater from the plant will be discharged to Third Creek. The discharge permit will be amended to reflect a monthly average flow of 0.15 m^3/s (3.5 MGD). Effluent quality limitations being requested during summer months for $CBOD_5$, TSS, ammonia nitrogen, and total phosphorus are 5, 5, 1, 0.5 mg/L, respectively. For winter months the requested respective limitations will be 5, 5, 2, 1 mg/L (Parkhill, Smith and Cooper, 1986).

CLASSIFICATION AND RANK

Due to excellent water quality and few water quality standards violations, Segment 1806 has been classified effluent limited and ranked 147 of 342 segments by the Commission (TWC, 1986). Segments are classified effluent limited if effluent limitations for point source dischargers required by Section 301(b)(1)(A) and Section 301(b)(1)(B) of Public Law 95-217 are stringent enough for the receiving waters to meet the appropriate water quality standards. Segments were ranked from 1 to 342 by the Commission with 1 indicating the highest need for stringent water quality controls and 342 indicating the least feasible necessity of stringent water quality controls other than for public health considerations.

INTENSIVE SURVEY DATA

Hydraulics

No major rainfall events occurred in the wastershed prior to the study as evidenced by precipitation data from the Kerrville observation station located 4.8 km (3 mi) northeast of Kerrville (NOAA, 1983). Thunderstorms occurred in the area on October 18 and 19 and produced rainfall accumulations of 0.10 cm (0.04 in) and 2.39 cm (0.94 in) on these two days. Prior to October 18, minor accumulations were also recorded on October 7 (0.10 cm, 0.04 in), October 9 (2.74 cm, 1.08 in), October 10 (0.61 cm, 0.24 in) and October 12 (0.25 cm, 0.10 in). Following October 19 there were 12 days of no precipitation prior to the start of the intensive survey.

Increases in Guadalupe River stream flow at SH 39, County Road near Bear Creek, IH 10, and RR 311 were due to runoff from the October 18 and 19 storm events (Figure 2). Due to the relatively dry conditions which preceded these storm events, and light accumulations, stream flow in the Guadalupe River quickly receded to near antecedent conditions. The hydrographs for each station indicate that steady-state flow conditions generally existed seven days prior to start of the study at SH 39 and County Road near Bear Creek stations, and three days at the IH 10 and RR 311 sites. The daily average stream flows on November 1, 1983 at SH 39 (0.93 m^3/s, 33 ft^3/s), County Road near Bear Creek (1.22 m^3/s, 43 ft^3/s), IH 10 (1.78 m^33/s, 63 ft^3/s) and RR 311 (2.6 m^3/s, 91 ft^3/s) exceeded their respective seven-day, two-year low flow values of 0.71 m^3/s (25.2 ft^3/s), 0.98 m^3/s (34.7 ft^3/s), 1.37 m^3/s (48.3 ft^3/s), and 1.89 m^3/s (66.9 ft^3/s).

Due to the highly variable morphometry of the stream channel, the Guadalupe River was divided into two reaches in which collection of hydraulic data was concentrated. The upstream reach extended from immediately downstream of the dam near SH 16 in Kerrville to a point 2.2 km (1.4 mi) downstream (Figure 3). The downstream reach extended from Flat Rock Dam to Wharton Road, a distance of 6.3 km (3.9 mi) (Figure 4).

Stream widths within these two reaches varied considerably (9-60 m). The widest portion of the stream was measured across a long pool upstream of G Street (Table 4). Stream discharge was relatively stable through the reaches ranging from 1.28 m^3/s (45.2 ft^3/s) at the site near SH 16 to 1.25 m^3/s (44.1 ft^3/s) at Wharton Road. Stream velocities were moderate through both areas with ranges from 0.078 m/s (0.26 ft/s) to 0.12 m/s (0.39 ft/s).

The Guadalupe River is impounded to form Flat Rock Lake immediately southeast of Kerrville. Treated wastewater which is occasionally discharged from the City of Kerrville enters Flat Rock Lake through Third Creek a tributary located on the north side of the Lake (Figures 1 and 5). The reservoir is approximately 3.9 km (2.4 mi) long and is 180 m (591 ft) wide near the damsite (Table 7). The maximum depth measured was 5.6 m (18.3 ft).

Field Measurements

The diurnal field measurements indicate excellent water quality through Segment 1806 of the Guadalupe River (Table 8). All of the dissolved oxygen levels exceeded the 5 mg/L criterion during the study. Excepting one early morning measurement (5.2 mg/L) at Old Medina Road (Station G) all of the dissolved oxygen levels remained above 6 mg/L throughout the diurnal period. The small diurnal ranges between dissolved oxygen minima and maxima among all the stations further indicate stability in water quality and reflects the low primary productivity of the river.

Measurements of pH ranged between 7.4 and 8.0 standard units and were within the minimum-maximum criteria range (6.5-9.0 standard units). All of the water temperatures measured were less than the criterion (32.1°C).

Carbonaceous Biochemical Oxygen Demand and Ammonia Nitrogen

The five-day and twenty-day carbonaceous biochemical oxygen demand (CBOD) tests are indirect measures of the amount of short and long term degradable organic matter present and are techniques for measuring the oxygen demand of wastewater effluents and stream water. Ammonia nitrogen is a common constituent of domestic sewage and stormwater runoff and elevated levels are toxic to aquatic life and deplete available oxygen through bacterial nitrification.

$CBOD_5$ and $CBOD_{20}$ levels in the Guadalupe River were low (< 2 mg/L) at all mainstream stations during the study period (Table 9). These low levels indicate that very little degradable organic matter was present in the water during the time of the study.

Ammonia and nitrite nitrogen levels were very low throughout the Guadalupe River. Of eleven mainstream stations, only one (County Road upstream of US 87) had a detectable level of ammonia nitrogen (0.03 mg/L) and nitrite nitrogen was not detected at any of them. These low levels indicate that nitrification did not contribute to observed nitrate nitrogen or dissolved oxygen levels at the time of the study.

Nutrients and Chlorophyll a

No water quality criteria have been established by the Commission for orthophosphorus (OP), ammonia nitrogen, nitrite nitrogen, or nitrate nitrogen (NO_3-N), but their involvement in aquatic plant growth warrants their consideration. An abundance of orthophosphorus, a principle ingredient of household detergents, in the water can be an indicator of recent sewage pollution. Chlorophyll a analyses may be utilized to provide an estimate of the relative planktonic algal standing crops that were present at the Guadalupe River sampling stations during the study period.

As mentioned previously ammonia and nitrite nitrogen levels were very low through Segment 1806. Nitrate nitrogen also occurred in low concentrations (< 0.25 mg/L) at the mainstream stations (Table 9). The source of nitrate nitrogen in the Guadalupe River may be spring sources from the Edwards Aquifer which has moderate levels (TWQB, 1977). Ortho and total phosphorus (TP) were also very low (< 0.04 mg/L) through the segment. These low levels suggest that nitrogen and phosphorus may be limiting to the aquatic plant communities in the river depending on the time of the year.

Chlorophyll a levels were also low (< 4 µg/L) through Segment 1806 (Table 9). Chlorophyll a levels were not detected in five of seven samples collected at the mainstream stations. These data indicate that planktonic algal productivity in the Guadalupe River during the study was low.

Chloride, Sulfate, and Total Dissolved Solids

All of the sulfate and total dissolved solids levels at the mainstream stations were less than the respective segment criteria (40 mg/L and 400 mg/L, annual averages) (Table 9). All but one chloride level (49 mg/L at Station J, downstream of Flat Rock Dam), were less than the 40 mg/L annual average criterion. Levels for all three parameters exhibited general downstream trend toward increasing concentrations.

Fecal Coliform Bacteria

Fecal coliform levels were generally low through Segment 1806 of the Guadalupe River (Table 10). Fecal coliform levels ranged from 6/100 mL downstream of Flat Rock Dam (Station J) to 142/100 mL at the county road upstream of SH 87. All of the levels were less than the 200/100 mL segment criterion.

Benthic Macroinvertebrates

To assess biological health in the study reach, benthic macroinvertebrates were collected at four riverine and three reservoir stations. A total of 114 species was collected, including 88 from the river and 39 from the reservoir (Table 11). The high total reflects the general prevalence of stable environmental conditions.

Near Station B, a riverine site located 0.2 m below Ingram Lake Dam, species richness was the highest in the study, and diversity and equitability values were well within ranges considered indicative of clean water. Sensitive mayflies were well represented (11 species; 9.6% of the community). The standing crop was large and reflected an abundant food supply. Filterers of fine particulate organic matter (FPOM) were the dominant functional feeding group (Table 12), indicating an abundance of suspended FPOM, probably mostly in the form of phytoplankton produced upstream in Ingram Lake. The three groups that utilize suspended or sedimented FPOM (gatherers, filterers, miners) cumulatively comprised 75.0 percent of the community, reflecting the importance of FPOM as the primary food material at the site.

At Old Medina Road in Kerrville, 1806.0237 (Station F), diversity and equitability were higher than upstream, and pollution-sensitive mayflies were fairly well represented (6 species; 11.7% of the community), indicating relatively stable environmental conditions. However, species richness and standing crop were appreciably lower than at any other riverine station, possibly due to the effects of siltation observed at the site. Urban runoff from Kerrville is the most likely contributor of silt, since there are no point source discharges upstream. Compared to upstream, filter feeders were less significant, while miners increased in importance, further reflecting increased sedimentation of FPOM. However, in absolute terms miners were not especially abundant, and all users of FPOM cumulatively decreased in significance, indicating that much of the silt was inorganic in nature, as might be expected if urban runoff were the major contributor.

The headwaters of Flat Rock Lake, 1806.0233 (Station G), exhibited extraordinarily high species richness, diversity, and equitability compared to previous studies on small Texas reservoirs, and mayflies were well represented (3 species; 39.5% of the community), indicating stable environmental conditions. FPOM feeders were predominant (76.8% of the community), as might be expected in a lentic, depositional habitat of this type.

Slightly less favorable environmental conditions were evident in Flat Rock Lake 200 m below Third Creek confluence, 1806.0228 (Station H), where species richness declined and sensitive mayflies were not as common (1 species; 12.3% of the community). However, diversity and equitability remained high and indicated generally stable environmental conditions. The standing crop was considerably smaller and FPOM feeders decreased in importance (61.5% of the community), indicating a longitudinal decrease in the amount of organic matter available as food material, and that no appreciable degree of organic enrichment results from Third Creek inflow.

Immediately above Flat Rock Dam, 1806.0227 (Station I), diversity and equitability were low due to the abundance of two predatory species (Chaoborus punctipennis, which feeds on zooplankton; Coelotanypus scapularis, which was probably feeding on Chaoborus). Mayflies were absent. However, species richness was comparable to the mid-lake station, and diversity and equitability were relatively high when Chaoborus and Coelotanypus were excluded from the calculations (2.87 and 0.83, respectively). Chaoborus and Coelotanypus are not normally associated with organic pollution, and their abundance and resultant depressed diversity were not considered indicative of water quality degradation. Also, there was no increase in the importance of pollution-tolerant species that feed on FPOM, and the standing crop was not elevated, in contrast to what would be expected in the presence of organic pollution.

Changes in species composition and community trophic structure observed through the reservoir were attributed to natural, longitudinal succession rather than the effects of artificial organic enrichment. Overall biological stability in the reservoir, as indicated by macrobenthic community structure, was judged to be good.

The river 200 m below Flat Rock Dam, 1806.0223 (Station J), exhibited the highest diversity and equitability and the second highest species richness in the study, and clean water mayflies were well represented (9 species; 14.1% of the community), indicating stable environmental conditions. Community structure resembled that below Ingram Lake Dam, in that both stations had large standing crops, with FPOM comprising the primary food material as indicated by community trophic structure. These common characteristics apparently result from influences of the small mainstream reservoirs immediately upstream from each station. However, decreased importance of filterers together with increased importance of gatherers indicated that a greater portion of the FPOM was in sedimented rather than suspended form below Flat Rock Dam. Also, grazers were considerably more important below Flat Rock Dam, indicating a greater prevalence of periphyton, perhaps due in part to nutrient inputs from the City of Kerrville.

The macrobenthic community at Wharton Road, 1806.0220 (Station K), was also stable as indicated by very high species richness, diversity, and equitability, and strong representation by mayflies (9 species; 14.6% of the community). A considerable shift in community trophic structure, with FPOM feeders decreasing and grazers increasing in importance, reflected a continuing longitudinal trend toward increasing prevalence of periphyton as the primary food source. This further suggests slightly elevated primary production, possibly as a result of periodic discharges of nutrients from Kerrville.

Tributary Water Quality

Dissolved oxygen was 8.1 mg/L in Johnson Creek (Station R) and 9.7 in Cypress Creek (Station V) when monitored (Table 8). All of the dissolved oxygen levels from the three stations on Third Creek (Stations S, T, and U) remained above 7.0 mg/L and the narrow ranges between minima and maximum levels indicates stability in water quality. Levels of pH at the three tributary streams were similar to those of the mainstream Guadalupe River stations and water temperature was less than 22°C.

$CBOD_5$ and $CBOD_{20}$ levels were very low in Johnson and Cypress Creeks ($\leq$ 1.0 mg/L), but were slightly elevated in Third Creek (Table 9). Levels for these two parameters were highest at the uppermost station on Third Creek (Station S). In fact they were the highest of any measured on the survey. Other parameters at this station that were also the highest measured on the survey include orthophosphorus (0.09 mg/L), total phosphorus (0.18

mg/L), chlorophyll a (29 µg/L, filtered total organic carbon (3.5 mg/L), chloride (81 mg/L), sulfate (42 mg/L), total dissolved solids (456 mg/L), and total suspended solids (33 mg/L). Concentrations for most of these parameters decreased downstream and at the lower station on Third Creek were comparable to those observed in Flat Rock Lake. Although the City of Kerrville's wastewater treatment plant was not discharging during the survey period, or for the entire months of October and November 1983, its effluent was the most likely source of the elevated levels. The sample collected at the City of Kerrville's wastewater treatment plant, from which discharges are periodically made, indicate levels of oxygen demanding substances and nutrient levels typical of secondary treated effluent (Station 1, Table 9).

CONCLUSIONS

The historical data and the results of this intensive survey indicate that water quality is excellent throughout Segment 1806 of the Guadalupe River. Diurnal dissolved oxygen levels remained above the 5 mg/L segment criterion at all stations within the study area. The narrow ranges between dissolved oxygen minima and maxima among the stations further indicate stability in water quality and reflects the low primary productivity of the stream. Nutrient levels were low through the river and suggest that either phosphorus and/or nitrogen may be limiting growth of aquatic plants during various seasons. The low levels of ammonia and absence of nitrite nitrogen indicate that nitrification was not a contributing factor affecting the observed nitrate and dissolved oxygen levels. Chloride, sulfate, total dissolved solids, water temperature, fecal coliform, and pH levels generally conformed to segment criteria. Benthic macroinvertebrate community structure reflected low levels of secondary production and indicated clean water and stable environmental conditions throughout the study area. Third Creek exhibited the poorest water quality in the study area due to periodic discharges from the City of Kerrville's wastewater treatment plant.

The water quality conditions of Guadalupe River Segment 1806 have been documented and are likely to continue as long as no continuous sources of wastewater enter the stream. The natural setting and excellent water quality provides residents of the area with a highly valued recreational and aesthetic resource. Partly as a result of this resource, the area is attractive to tourists and population in the Kerrville area is rapidly growing. As the population of the City of Kerrville continues to grow and effluent volumes increase, the likelihood of a continuous discharge from its wastewater treatment plant becomes more probable. The City of Kerrville has requested amendment to its existing permit to allow upgrading of the present facility to facilitate greater capacity and a continuous discharge to Third Creek. In addition the cities of Kerrville and Ingram and the Upper Guadalupe River Authority are jointly considering the option of building a regional wastewater treatment plant near the Bear Creek confluence, to meet future wastewater treatment needs of the area. Selection of the types of treatment facilities, locations of effluent discharge points, and effluent treatment levels for the proposed facilities will be essential to protecting existing water quality conditions in Segment 1806 of the Guadalupe River.

Another intensive survey of Segment 1806 has been scheduled by the Texas Water Commission. The survey will be conducted during low flow conditions when a discharge from the City of Kerrville's wastewater treatment plant is occurring. Data from the 1983 intensive survey and the proposed one will be utilized by the Commission, through mathematical modeling processes, to evaluate specific treatment levels for the City of Kerrville's wastewater treatment plant and to write a waste load evaluation for Segment 1806.

PRESENTATION OF DATA

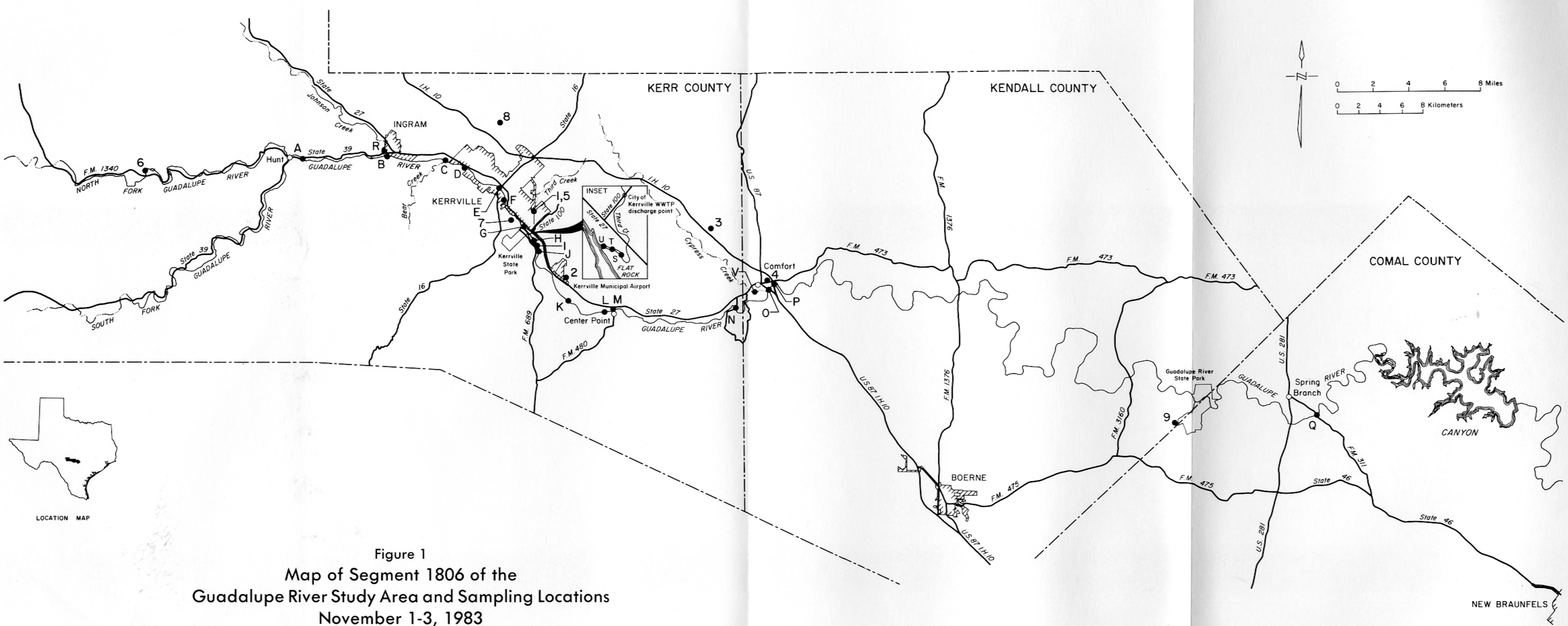

Figure 1
Map of Segment 1806 of the
Guadalupe River Study Area and Sampling Locations
November 1-3, 1983

TABLE 1

Guadalupe River Sampling Locations

Map Code	SMN Number	River Kilometer	River Mile	Location
A	1806.0300	677.2	420.8	Guadalupe River at SH 39
F	1806.0237	656.8	408.1	Guadalupe River at Old Medina Road in Kerrville
G	1806.0233	653.3	406.0	Guadalupe River at Kerrville State Park
H	1806.0228	652.0	405.2	Guadalupe River in Flat Rock Lake near Legion
I	1806.0227	651.5	404.8	Guadalupe River in Flat Rock Lake 0.1 km upstream of Flat Rock Dam
J	1806.0223	651.3	404.7	Guadalupe River at County Road downstream of Flat Rock Dam
K	1806.0221	645.0	400.8	Guadalupe River at Wharton Road near Kerrville Airport
M	1806.0219	640.3	397.9	Guadalupe River at FM 480 in Center Point
N	1806.0213	631.1	392.2	Guadalupe River at Lake Valley Road Southwest of Comfort
O	1806.0200	621.7	386.3	Guadalupe River at County Road upstream of SH 87 in Comfort
R	1800.0480	669.1/0.4	415.8/0.25	Johnson Creek at SH 39
S	1800.1406	652.6/0.5	405.5/0.31	Third Creek 0.5 km upstream of Guadalupe River
T	1800.1403	652.6/0.25	405.5/0.16	Third Creek 0.25 km upstream of Guadalupe River
U	1800.1402	652.6/0.03	405.5/0.05	Third Creek 0.05 km upstream of the Guadalupe River confluence
V	1800.0390	621.9/1.4	386.4/0.87	Cypress Creek at 7th Street in Comfort
1	1800.9010	652.6/2.0	405.5/1.2	City of Kerrville WWTP

* River kilometer at tributary confluence/distance up tributary to sampling site

TABLE 2

Active Water Quality Monitoring Stations in Segment 1806 of the Guadalupe River

Station Location	Map Code	Sampling Agency/ SMN Number	Frequency of Sampling/ Type of Record	Period of Record
SH 39 near Hunt	A	USGS 08165500 UGRA 1806.0300	1 Dd 2 FD,CH,BA	Oct. 1941-Present Nov. 1973-Present
Ingram Dam in Ingram	B	UGRA 1806.0260	2 FD,CH,BA	Sept. 1973-Present
County Road at Bear Creek	C	USGS 08166140	1 Dd	Apr. 1987-Present
UGRA Lake Dam	D	UGRA 1806.0242	2 FD,CH,BA	Feb. 1973-Present
SH 16 in Kerrville	E	UGRA 1806.0240	2 FD,CH,BA	Feb. 1972-Present
County Road Downstream of Flat Rock Dam	J	UGRA 1806.0223	2 FD,CH,BA	Feb. 1976-Present
Center Point Lake	L	UGRA 1806.0217	2 FD,CH,BA	June 1976-Present
County Road Southwest of Comfort	N	UGRA 1806.0210	2 FD,CH,BA	Feb. 1976-Present
US 87 at Lowwater Crossing Upstream of Bridge in Comfort	O	UGRA 1806.0200	2 FD,CH,BA	Feb. 1976-Present

TABLE 2 CONTINUED

Station Location	Map Code	Sampling Agency/ SMN Number	Frequency of Sampling/ Type of Record	Period of Record
IH 10 in Comfort	P	TWC 1806.0195	3 FD,CH,BA	Feb. 1976-Present
		UGRA 1806.0195	2 FD,CH,BA	
		USGS 08167000	1 Dd	May 1939-Present
Ranch Road 311 near Spring Branch	O	USGS 08167500	1Dd	June 1922-Present

Frequency of Sampling

1 Continuous
2 Monthly
3 Quarterly

Type of Record

FD Field Measurements in Water
CH Chemical Parameters in Water
BA Bacteriological Parameters in Water
Dd Stream Discharge

TABLE 3

Historical Water Temperature, pH, Chloride, Sulfate,
Total Dissolved Solids, and Fecal Coliform Bacteria
Data Collected by the Texas Water Commission and Upper Guadalupe
River Authority at Nine Locations on the Guadalupe River,
January 1, 1981 - December 31, 1985

Station/SMN Number	Map Code	Criteria →	Water Temperature 32.1°C	pH Units 6.5-9.0	Chloride 40 mg/L	Sulfate 40 mg/L	Total Dissolved Solids** 400 mg/L	Fecal Coliform 200/100 mL
SH 39 near Hunt	A	Number of Observations	10	11	1	8	14	57
		Mean	19.7	--	12	7	232	22*
		Range	7.8-26.0	7.9-8.4	--	5-9	198-304	2-200
SMN 1806.0300		Percent > Criterion	0	0	0	0	0	0
Ingram Dam in Ingram	B	Number of Observations	9	11		6	14	51
		Mean	20.8	--		7	239	11*
		Range	7.8-28.0	8.0-8.3		5-9	198-360	1-230
SMN 1806.0260		Percent > Criterion	0	0		0	0	0
UGRA Lake Dam	D	Number of Observations	5	10		5	14	36
		Mean	18.9	--		9	234	10*
		Range	7.0-27.0	8.0-8.4		5-11	186-280	1-183
SMN 1806.0242		Percent > Criterion	0	0		0	0	0
SH 16 in Kerrville	E	Number of Observations	8	10		5	15	53
		Mean	21.4	--		9	238	34*
		Range	7.0-29.0	8.0-8.4		5-15	186-291	1-382
SMN 1806.0240		Percent > Criterion	0	0		0	0	6
County Road Below Flat Rock Dam	J	Number of Observations	11	14	1	10	18	54
		Mean	21.4	--	49	10	264	9*
		Range	6.2-29.5	8.1-8.5	--	5-15	217-310	1-244
SMN 1806.0223		Percent > Criterion	0	0	100	0	0	2

TABLE 3 CONTINUED

Station/SMN Number	Map Code	Criteria →	Water Temperature 32.1°C	pH Units 6.5-9.0	Chloride 40 mg/L	Sulfate 40 mg/L	Total Dissolved Solids** 400 mg/L	Fecal Coliform 200/100 mL
Center Point Lake	L	Number of Observations	9	11		7	15	56
		Mean	20.2	--		11	263	21
		Range	6.0-28.0	8.1-8.6		6-16	186-304	1-420
SMN 1806.0217		Percent > Criterion	0	0		0	0	4
County Road	N	Number of Observations	10	9		6	13	55
Southwest of		Mean	20.7	--		17	270	26*
Comfort		Range	7.0-28.0	8.0-8.4		7-32	236-310	4-188
SMN 1806.0210		Percent > Criterion	0	0		0	0	0
US 87 at Lowwater	O	Number of Observations	27	27	14	22	28	69
Crossing Upstream of		Mean	20.2	--	31	23	298	48*
Bridge in Comfort		Range	7.0-28.0	7.1-8.9	8-200	9-120	227-614	3-480
SMN 1806.0200		Percent > Criterion	0	0	7	5	4	4
IH 10 in Comfort	P	Number of Observations	7	4	7	7	5	7
		Mean	21.6	--	34	23	296	93*
		Range	15.0-27.6	7.6-8.2	12-106	1-50	265-341	16-650
SMN 1806.0195		Percent > Criterion	0	0	14	14	0	29

* Geometric Mean
** Field Conductivity x 0.62

TABLE 4

Historical Dissolved Oxygen Data Collected by the
Texas Water Commission and Upper Guadalupe River Authority
at Nine Locations on the Guadaulpe River, January 1, 1981 - December 31, 1985

Station Location/ SMN Number	Map Code		Year				
			1981	1982	1983	1984	1985
SH 39 near Hunt	A	Number of Observations			1	4	7
		Mean, mg/L			8.5	8.2	8.4
		Range, mg/L			--	6.7-10.2	6.8-11.6
SMN 1806.0260		Percent < 5.0 mg/L			0	0	0
Ingram Dam in Ingram	B	Number of Observations				2	7
		Mean, mg/L				7.8	7.8
		Range, mg/L				7.4-8.3	5.2-9.8
SMN 1806.0260		Percent < 5.0 mg/L				0	0
UGRA Lake Dam	D	Number of Observations				2	3
		Mean, mg/L				7.7	8.9
		Range, mg/L				6.7-8.7	6.8-11.2
SMN 1806.0242		Percent < 5.0 mg/L				0	0
SH 16 in Kerrville	E	Number of Observations				2	6
		Mean, mg/L				7.7	7.6
		Range, mg/L				6.8-8.6	6.6-9.2
SMN 1806.0240		Percent < 5.0 mg/L				0	0
County Road Downstream of Flat Rock Lake	J	Number of Observations			4	3	6
		Mean, mg/L			8.4	7.7	8.6
		Range, mg/L			7.5-8.9	7.0-8.2	7.2-11.8
SMN 1806.0223		Percent < 5.0 mg/L			0	0	0

TABLE 4 CONTINUED

Station Location/ SMN Number	Map Code		Year 1981	1982	1983	1984	1985
Center Point Lake	L	Number of Observations				2	7
		Mean, mg/L				8.8	8.0
		Range, mg/L				8.0-9.7	5.4-12.2
SMN 2806.0217		Percent < 5.0 mg/L				0	0
County Road SW of Comfort	N	Number of Observations				4	8
		Mean, mg/L				8.9	8.1
		Range, mg/L				6.6-10.4	5.8-12.3
SMN 1806.0210		Percent < 5.0 mg/L				0	0
US 87 at Lowwater Crossing Upstream of	O	Number of Observations	5	4	7	3	8
Bridge in Comfort		Mean, mg/L	8.8	8.2	7.9	9.1	8.1
		Range, mg/L	7.5-10.8	7.0-9.1	6.6-8.6	7.8-10.6	5.8-12.3
SMN 1806.0200		Percent < 5.0 mg/L	0	0	0	0	0
IH 10 in Comfort	P	Number of Observations				4	3
		Mean, mg/L				8.1	8.5
		Range, mg/L				7.3-8.9	7.6-9.5
SMN 1806.0195		Percent < 5.0 mg/L				0	0

TABLE 5

Permitted Average Flow, Biochemical Oxygen Demand, and Total Suspended Solids for Nine Wastewater Treatment Facilities in Segment 1806 of the Guadalupe Rivers

Map Code	Permittee/ Permit Number	Flow		BOD_5 mg/L	TSS mg/L	Discharge Status
		m^3/s	MGD			
1	City of Kerrville 10576001	0.099	2.25	20	20	Discharge Occasionally
2	Mooney Aircraft Corp. 01340001	-----	----	--	--	Retained
3	Clyde Holencamp Dairy Farm 01884001	-----	----	--	--	Retained
4	Kendall County WCID 001 10414001	0.035	0.8	30	--	Retained
5	City of Kerrville 10576101	0.099	2.25	20	20	Stormwater Occasional Discharge
6	Presbyterian MO-Ranch Assembly 10768001	0.0002	0.005	20	20	Retained
7	City of Kerrville Subdivision Plant 11594001	0.013	0.3	10	15	Retained
8	James Avery Craftsman, Inc. 11834001	-----	----	--	--	Retained
9	Texas Parks and Wildlife Department Guadalupe River Park 12014001	0.001	0.032	30	--	Retained

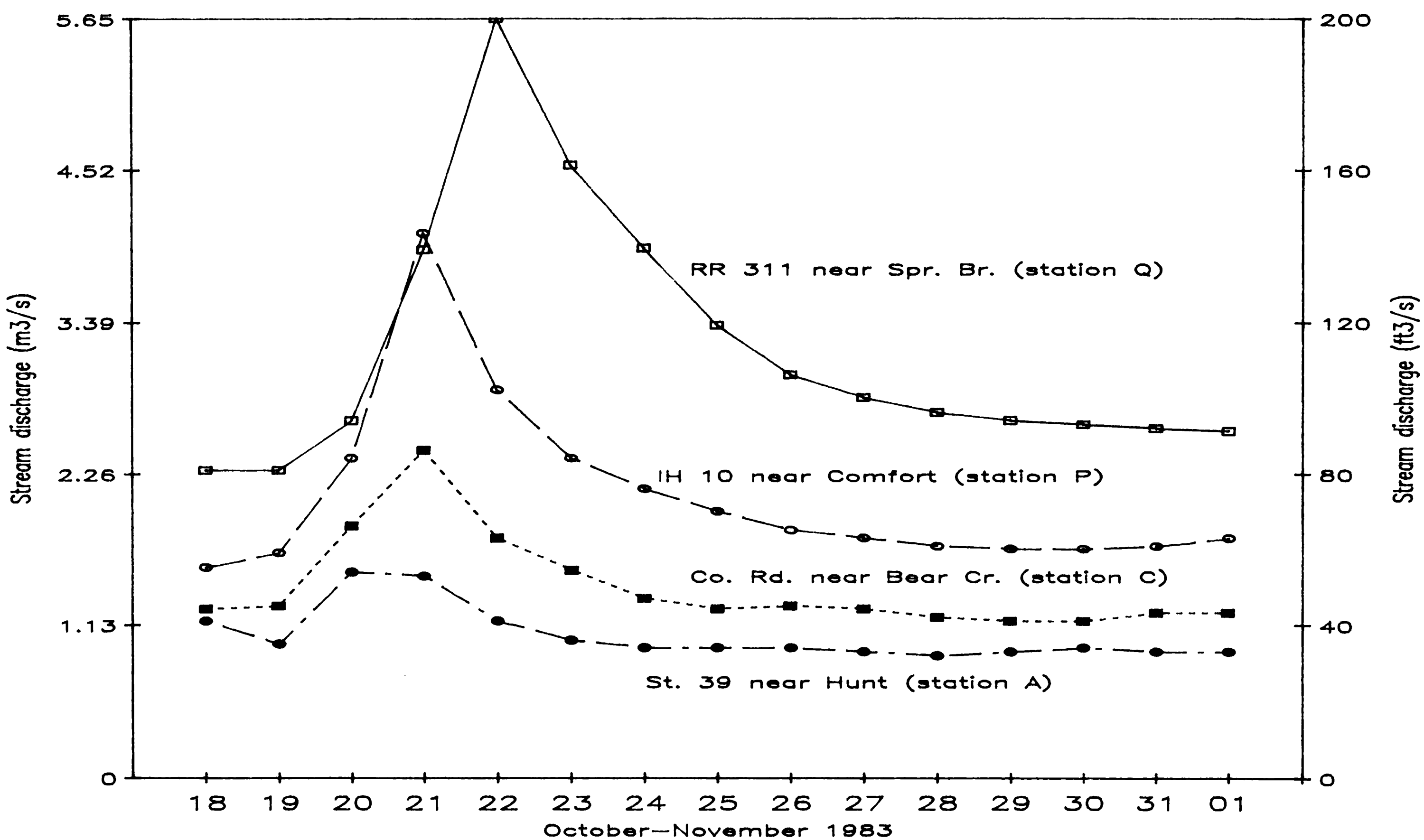

Figure 2

Mean Daily Discharge Rate at Four Locations on Segment 1806 of the Guadalupe River, October 18—November 1, 1986

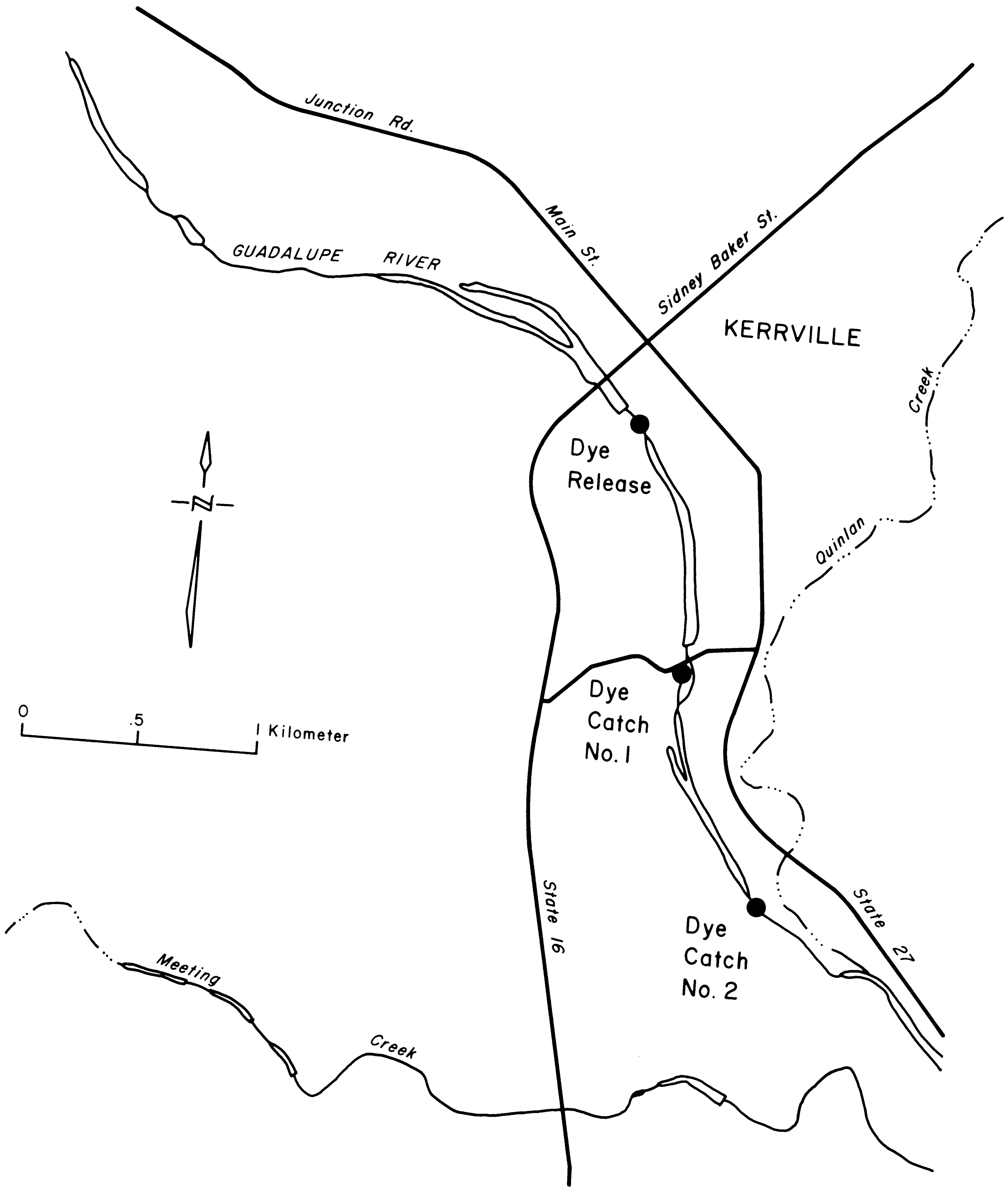

Figure 3
Location of Hydraulic Measurements Between State 16 and 2.2 Kilometers Downstream

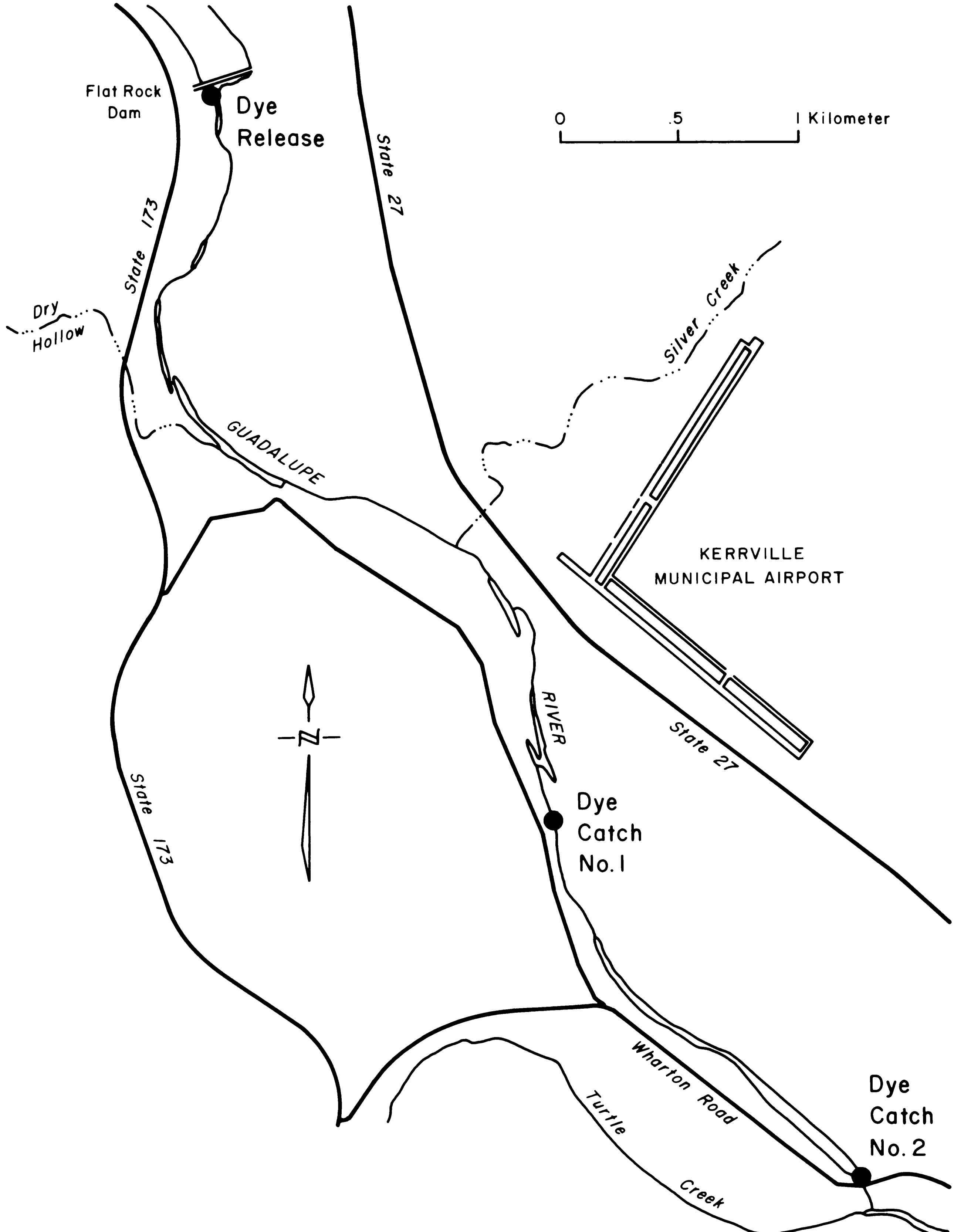

Figure 4
Location of Hydraulic Measurements Between Flatrock Dam and Wharton Road

TABLE 6

Guadalupe River Stream Width, Velocity, and Discharge Data

Stream Reach From:	To:	Date	Stream Widths (m) Number of Measurements	Range	Average	Distance (mi)	(km)	Travel Time (hrs.)	Velocity (ft/s)	(m/s)	Discharge (m^3/s) Upstream Sta./Downstream Sta.
Downstream of Dam at SH 16	G Street Bridge	11/01/83	3	57-60	58.3	0.68	1.1	3.57	0.28	0.086	--/1.28
G Street Bridge	Trailer House	11/01/83	6	9-20	13.0	0.68	1.1	3.25	0.31	0.094	1.28/--
Flat Rock Dam	Wharton Cemetary	10/31/83	5	12.2-33.0	24.4	2.4	3.9	8.92	0.39	0.122	1.20/--
Wharton Cemetary	Wharton Road	11/01/83	3	9.5-47.0	30.3	1.5	2.4	8.50	0.26	0.078	--/1.25

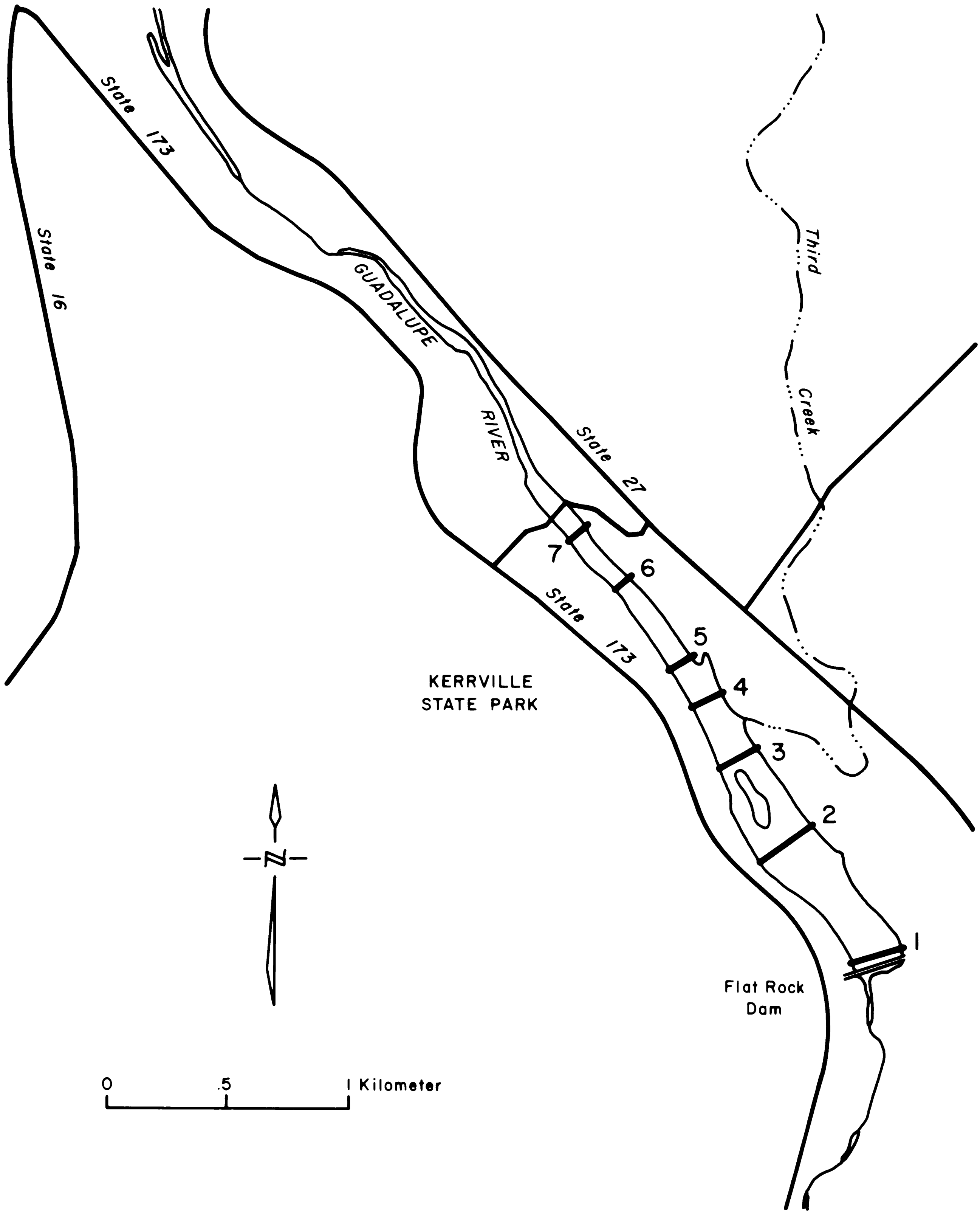

Figure 5
Location of Cross Sectional Measurements in Flatrock Lake

TABLE 7

Widths, Depths, and Cross Sectional Data
from Flat Rock Lake

Cross Section Number	Width m	Width ft	Depth Range m	Depth Range ft	Mean Depth m	Mean Depth ft	Cross-Sectional Area m^2	Cross-Sectional Area ft^2
1	180	591	0.6-4.6	2.0-15.0	2.7	8.9	494.8	5,324.1
2	175	574	0.3-5.6	1.0-18.3	2.8	9.2	488.4	5,255.2
3	280	919	0.6-4.6	2.0-15.2	2.0	6.6	563.2	6,060.0
4	200	656	1.2-3.8	4.0-12.5	2.1	6.9	427.4	4,598.8
5	175	574	0.8-2.5	2.5-8.3	1.6	5.2	284.3	3,059.1
6	100	328	1.4-2.9	4.5-9.5	2.2	7.2	224.5	2,415.6
7	99	325	1.4-2.7	4.7-9.0	2.2	7.2	214.0	2,302.6

TABLE 8

Guadalupe River Field Measurements

Map Code and Station Number	Date	Time	Depth (ft)	Water Temperature (°C)	Conductivity (µmhos/cm)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Sat.)	pH
A 1806.0300	11/01/83	1200	0.3	19.8	388	8.5	93.4	8.0
		DIEL MEAN		19.8	388	8.5	93.4	8.0
F 1806.0237	11/01/83	0515	0.3	19.6	386	5.2	56.9	7.5
	11/01/83	0900	0.3	20.6	395	8.1	90.5	7.7
	11/01/83	1320	0.3	22.1	392	9.5	109.2	8.0
	11/01/83	1705	0.3	22.0	391	9.6	110.2	8.0
		DIEL MEAN		21.0	390	7.9	89.0	7.8
G 1806.0233	11/01/83	0645	0.3	20.4	464	8.9	99.0	7.8
	11/01/83	0645	1.5	20.4	465	8.8	97.9	7.8
	11/01/83	1014	0.3	20.4	476	9.1	101.2	7.7
	11/01/83	1014	1.5	20.4	482	9.0	100.1	7.8
	11/01/83	1612	0.3	21.1	482	8.8	99.2	7.7
	11/01/83	1612	1.5	21.0	509	8.8	99.0	7.7
	11/01/83	1752	0.3	20.9	488	8.9	100.0	7.7
	11/01/83	1752	1.5	20.9	489	8.9	100.0	7.7
		DIEL MEAN		20.7	480	8.9	99.5	7.7
H 1806.0228	11/01/83	0745	0.3	20.2	504	8.8	97.5	7.7
	11/01/83	0745	1.5	20.1	503	8.6	95.1	7.7
	11/01/83	1054	0.3	20.2	510	8.9	98.6	7.7
	11/01/83	1054	1.5	20.2	524	8.6	95.3	7.7
	11/01/83	1550	0.3	21.0	492	9.5	106.9	7.9
	11/01/83	1550	1.5	20.9	494	9.4	105.6	7.9
	11/01/83	1816	0.3	20.9	494	9.5	106.7	7.9
	11/01/83	1816	1.5	20.8	500	9.2	103.1	7.9
		DIEL MEAN		20.5	502	9.0	100.8	7.8

TABLE 8 CONTINUED

Map Code and Station Number	Date	Time	Depth (ft)	Water Temperature (°C)	Conductivity (µmhos/cm)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Sat.)	pH
I 1806.0227	11/01/83	0755	0.3	19.8	492	9.0	98.9	7.8
	11/01/83	0755	1.5	19.8	491	9.0	98.9	7.9
	11/01/83	0755	2.8	19.5	495	8.1	88.5	7.8
	11/01/83	1107	0.3	20.2	488	8.6	95.3	7.8
	11/01/83	1107	1.5	20.0	488	8.4	92.7	7.8
	11/01/83	1107	3.1	19.6	495	7.9	86.5	7.8
	11/01/83	1107	4.6	19.3	499	7.4	80.5	7.8
	11/01/83	1603	0.3	20.7	491	9.0	100.7	7.8
	11/01/83	1603	1.5	20.6	491	9.2	102.7	7.8
	11/01/83	1603	3.1	19.8	494	8.0	87.9	7.8
	11/01/83	1603	4.6	19.4	494	7.9	86.1	7.8
	11/01/83	1822	0.3	20.6	495	9.0	100.5	7.8
	11/01/83	1822	1.5	20.5	495	8.8	98.1	7.8
	11/01/83	1822	3.1	20.1	494	8.3	91.8	7.8
	11/01/83	1822	4.6	19.8	495	8.0	87.9	7.8
		DIEL MEAN		20.0	493	8.5	93.9	7.8
J 1806.0223	11/01/83	0550	0.3	19.6	419	7.5	82.1	7.4
	11/01/83	0940	0.3	20.5	431	8.9	99.2	7.9
	11/01/83	1350	0.3	21.4	429	8.9	101.0	8.0
	11/01/83	1720	0.3	21.3	431	8.2	92.8	7.8
		DIEL MEAN		20.6	427	8.2	91.5	7.7
K 1806.0221	11/01/83	0610	0.3	19.7	416	8.6	93.5	7.4
	11/01/83	0950	0.3	20.3	437	7.3	81.0	7.8
	11/01/83	1405	0.3	21.1	435	8.2	92.5	7.9
	11/01/83	1735	0.3	21.3	434	8.8	99.6	7.5
		DIEL MEAN		20.6	429	8.4	93.3	7.6

Map Code and Station Number	Date	Time	Depth (m)	Water Temperature (°C)	Conductivity (µmhos/cm)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Sat.)	pH
M 1806.0219	11/01/83	0625	0.3	18.8	425	7.6	81.9	7.5
	11/01/83	1010	0.3	20.1	438	8.1	89.6	7.8
	11/01/83	1420	0.3	21.8	433	8.9	101.8	7.9
	11/01/83	1750	0.3	21.5	427	8.8	100.0	7.9
		DIEL MEAN		20.4	429	8.3	92.4	7.7
N 1806.0213	11/01/83	0650	0.3	18.8	431	7.7	82.9	---
	11/01/83	1020	0.3	20.3	434	8.4	93.2	8.0
	11/01/83	1430	0.3	22.0	434	9.2	105.6	8.0
	11/01/83	1800	0.3	21.6	436	8.8	100.2	7.8
		DIEL MEAN		20.5	434	8.4	94.1	7.9
O 1806.0200	11/01/83	0710	0.3	18.7	441	7.7	82.8	---
	11/01/83	1030	0.3	20.1	452	8.4	92.9	7.8
	11/01/83	1445	0.3	21.0	454	8.6	96.8	7.9
	11/01/83	1820	0.3	20.5	448	8.0	89.2	7.7
		DIEL MEAN		19.9	447	8.1	88.8	7.8
R 1800.0480	11/01/83	1220	0.3	20.8	435	8.1	90.8	7.8
		DIEL MEAN		20.8	435	8.1	90.8	7.8
S 1800.1406	11/01/83	0700	0.3	18.6	866	8.5	91.2	7.4
	11/01/83	1030	0.3	19.0	861	9.7	104.9	7.6
	11/01/83	1457	0.3	19.8	952	10.9	119.8	7.7
	11/01/83	1800	0.3	20.3	935	11.5	127.7	7.6
		DIEL MEAN		19.4	902	10.1	110.1	7.5

Map Code and Station Number	Date	Time	Depth (ft)	Water Temperature (°C)	Conductivity (µmhos/cm)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Sat.)	pH
T 1800.1403	11/01/83	0713	0.3	20.3	610	8.4	93.2	7.4
	11/01/83	0713	1.2	20.2	675	7.7	85.3	7.3
	11/01/83	1034	0.3	20.5	660	8.8	98.1	7.4
	11/01/83	1034	1.2	20.1	696	8.1	89.6	7.3
	11/01/83	1501	0.3	21.2	604	9.5	107.3	7.5
	11/01/83	1501	1.2	20.6	691	7.5	83.8	7.4
	11/01/83	1805	0.3	21.0	644	9.7	109.2	7.4
	11/01/83	1805	1.2	21.0	690	9.3	104.7	7.4
		DIEL MEAN		20.6	657	8.7	97.0	7.4
U 1800.1402	11/01/83	0730	0.3	20.2	508	8.6	95.3	7.7
	11/01/83	0730	1.5	20.3	688	8.2	91.0	7.5
	11/01/83	1044	0.3	20.4	508	8.5	94.5	7.6
	11/01/83	1044	1.5	20.4	523	8.4	93.4	7.6
	11/01/83	1518	0.3	20.9	509	9.0	101.1	7.7
	11/01/83	1518	1.5	20.9	511	8.8	98.9	7.7
	11/01/83	1810	0.3	20.9	508	9.1	102.2	7.8
	11/01/83	1810	1.5	20.9	512	9.0	101.1	7.8
		DIEL MEAN		20.6	541	8.7	97.2	7.7
V 1800.0390	11/01/83	1810	0.3	20.4	588	9.7	107.9	7.8
		DIEL MEAN		20.4	588	9.7	107.9	7.8
1 1800.9010	11/01/83	0530	0.3	22.8	1065	7.2	83.7	7.3
	11/01/83	0925	0.3	23.3	1068	6.8	80.0	7.3
	11/01/83	1335	0.3	24.2	1049	6.8	81.4	7.3
	11/01/83	1645	0.3	24.5	1086	6.2	74.6	7.3
		DIEL MEAN		23.7	1070	6.7	78.8	7.3

TABLE 9
Guadalupe River Laboratory Water Analyses

Map Code	and Station Number	Date	Time	Depth m	5day CBOD mg/L	Filt. 5day CBOD mg/L	20day CBOD mg/L	Filt. 20day CBOD mg/L	Filt. TOC mg/L	TKN mg/L	NH_3-N mg/L	NO_2-N mg/L	NO_3-N mg/L	Ortho P mg/L	Total P mg/L	Chl. a µg/L	Pheo. a µg/L	Cl^- mg/L	$SO_4^=$ mg/L	TSS mg/L	VSS mg/L	TDS mg/L	Total Alk. mg/L	Cond. µmhos/cm	pH
A	1806.0300	11/01/83	1200	0.3	<0.5	<0.5	1.0	1.0	2	0.20	<0.02	<0.01	0.23	0.02	0.02	<2	2	12	6	<10	<10	236	192	432	8.1
F	1806.0237	11/01/83	COMP	0.3	0.5	0.5	1.0	1.0	2	0.20	<0.02	<0.01	0.08	0.02	0.02	---	---	16	8	<10	<10	254	184	435	8.1
G	1806.0233	11/01/83	COMP	COMP	0.5	0.5	1.0	1.0	2	0.40	<0.02	<0.01	0.13	0.02	0.03	<2	2	19	10	<10	<10	242	191	462	8.1
H	1806.0228	11/01/83	COMP	COMP	1.0	1.0	1.5	1.5	2	0.30	<0.02	<0.01	0.09	0.02	0.02	---	---	22	11	27	2	257	192	477	8.2
I	1806.0227	11/01/83	COMP	COMP	<0.5	<0.5	1.5	1.0	2	0.30	<0.02	<0.01	0.08	0.03	0.03	2	3	22	10	16	2	250	194	477	8.2
J	1806.0223	11/01/83	COMP	0.3	<0.5	<0.5	1.0	1.0	2	0.30	<0.02	<0.01	0.08	0.02	0.02	3	3	49	15	<10	<10	340	190	564	8.1
K	1806.0221	11/01/83	COMP	0.3	<0.5	<0.5	1.0	1.0	2	0.30	<0.02	<0.01	0.09	0.03	0.03	<2	3	22	11	19	3	245	192	474	8.1
M	1806.0219	11/01/83	COMP	0.3	<0.5	<0.5	1.0	1.0	2	0.30	<0.02	<0.01	0.15	0.02	0.03	---	---	22	13	<10	<10	256	191	468	8.1
N	1806.0213	11/01/83	COMP	0.3	<0.5	<0.5	1.0	1.0	2	0.30	<0.02	<0.01	0.15	0.02	0.02	<2	<2	31	30	14	3	296	191	536	8.1
O	1806.0200	11/01/83	COMP	0.3	<0.5	<0.5	1.0	1.0	2	0.30	0.03	<0.01	0.24	0.02	0.02	<2	2	21	18	20	12	268	197	500	8.1
R	1800.0480	11/01/83	1220	0.3	<0.5	<0.5	1.0	0.5	1	0.20	<0.02	<0.01	0.21	0.02	0.02	<2	<2	28	11	<10	<10	278	192	486	8.1
S	1800.1406	11/01/83	COMP	COMP	2.5	1.0	6.5	3.5	2	0.80	<0.02	<0.01	0.05	0.09	0.18	29	7	81	42	33	9	456	270	894	8.1
T	1800.1403	11/01/83	COMP	COMP	1.5	0.5	2.5	1.0	2	0.50	<0.02	<0.01	0.13	0.03	0.06	12	3	46	18	11	2	344	222	650	7.9
U	1800.1402	11/01/83	COMP	COMP	0.5	0.5	1.0	1.0	2	0.20	<0.02	<0.01	0.12	0.02	0.02	2	<2	27	13	<10	<10	290	203	528	8.1
V	1800.0390	11/01/83	1810	0.3	<0.5	<0.5	1.0	0.5	1	0.20	<0.02	<0.01	0.46	0.02	0.02	<2	2	21	66	<10	<10	400	249	690	8.2
1	1800.9010	11/01/83	COMP	0.3	20.0	4.0	60.0	10.0	9	18.0	16.84	0.15	2.57	12.18	12.43	<2	<2	140	31	592	11	8	271	1232	7.8

TABLE 10

Guadalupe River Fecal Coliform Data

Map Code	Location	Fecal Coliform #/100 mL
F	Guadalupe River at Old Medina Road	62
G	Guadalupe River at Kerrville State Park	70
H	Guadalupe River in Flat Rock Lake near Legion	10
I	Guadalupe River 0.1 km upstream of Flat Rock Dam	14
J	Guadalupe River at County Road downstream of Flat Rock Dam	6
K	Guadalupe River at County Road near Airport	18
M	Guadalupe River at FM 480 in Center Point	28
N	Guadalupe River at County Road SW of Comfort	38
O	Guadalupe River at County Road upstream of SH 87 in Comfort	142
S	Third Creek 0.5 km upstream of Guadalupe River	34
T	Third Creek 0.2 km upstream of Guadalupe River	44
U	Third Creek 0.0 at the Guadalupe River Confluence	34

TABLE 11

Benthic Macroinvertebrate Data

Map Code	B	F	G	H	I	J	K
Station	1806.0260*	1806.0237*	1806.0233**	1806.0228**	1806.0227**	1806.0223*	1806.0220*
Number of Individuals/m²	5,675	979	3,272	1,984	3,700	7,020	2,047
Number of Species	56	37	25	15	13	51	51
Diversity	3.96	4.01	3.79	3.44	1.66	4.44	4.39
Redundancy	0.34	0.30	0.21	0.14	0.59	0.23	0.27
Equitability	0.68	0.77	0.82	0.88	0.45	0.78	0.77

Taxon	Number of Individuals/m²						
COELENTERATA							
Hydra sp.						4	
TURBELLARIA							
Dugesia tigrina	226					761	18
NEMERTEA							
Prostoma rubrum	36	43					11
NEMATODA							
unidentified spp.	4			57	7		11
HIRUNDINEA							
Helobdella elongata	43			57		32	
Helobdella fusca	144					11	
Helobdella stagnalis			22				
OLIGOCHAETA							
Aeolosoma sp.	4					75	4
Aulodrilus limnobius							4
Aulodrilus pigueti				57			
Branchiura sowerbyi		36	144				

TABLE 11 CONTINUED

Map Code Station	B 1806.0260*	F 1806.0237*	G 1806.0233**	H 1806.0228**	I 1806.0227**	J 1806.0223*	K 1806.0220*
Taxon	Number of Individuals/m²						
OLIGOCHAETA (cont.)							
Bratislavia unidentata				57			
Nais pardalis	4					14	14
Salvina appendiculata						75	4
Sparganophilus tamesis	29						4
GASTROPODA							
Cincinnatia comalensis	36						29
Gundlachia radiata	25						4
Helisoma anceps	29						4
Laevapex fuscus							11
Physa virgata	7	14					
PELECYPODA							
Corbicula fluminea	1,206	287	366	201	7	230	75
Eupera cubensis	14					133	
Pisidium casertanum	7		65	57			
Sphaerium transversum					14	610	
AMPHIPODA							
Hyallela azteca			100	57			4
OPEPODA							
Macrocyclops fuscus					115		
ISOPODA							
Asellus sp.	25						

TABLE 11 CONTINUED

Map Code Station	B 1806.0260*	F 1806.0237*	G 1806.0233**	H 1806.0228**	I 1806.0227**	J 1806.0223*	K 1806.0220*
Taxon	Number of Individuals/m^2						
OSTRACODA							
Stenocypris nr *malcolmsoni*			57				
COLEOPTERA							
Dubiraphia sp.	14		72		7		
Elsianus texanus						47	4
Hexacylloepus ferrugineus	36	11				176	39
Lutrochus luteus	7	7					
Microcylloepus pusillus	43	22				72	14
Neoelmis caesa	11					39	18
Psephenus texanus						54	
Stenelmis bicarinata						72	36
Stenelmis mexicanus							11
DIPTERA							
Ablabesmyia cinctipes			7		7	7	
Ablabesmyia mallochi			93				
Artherix variegata							4
Bezzia sp.			122				
Cardiocladius sp.						11	7
Chaoborus punctipennis var. b					2,461		
Cladotanytarsus sp.	158	75				7	57
Coelotanypus scapularis			79	423	710		
Conchapelopia sp.						11	
Cricotopus bicinctus		7				18	
Cricotpus cylindraceus gr.						183	
Cricotopus festivellus gr.	11	97					75
Cricotopus trifascia gr.						18	165
Cryptochironomus blarina			7				

TABLE 11 CONTINUED

Map Code Station	B 1806.0260*	F 1806.0237*	G 1806.0233**	H 1806.0228**	I 1806.0227**	J 1806.0223*	K 1806.0220*
Taxon	Number of Individuals/m²						
DIPTERA (cont.)							
Cryptochironomus fulvus					57		
Cryptochironomus sp. A				57			
Cryptochironomus sp. B							7
Dicrotendipes neomodestus	11			179			
Empididae	43	4					
Nanocladius sp.	54					25	
Omisus pica			172				
Orthocladius sp.			57				
Palpomyia tibialis		4					
Parachironomus abortivus gr.					136		
Paracladopelma sp.					65		
Pentaneura sp.							7
Phaenopsectra sp.			7				
Polypedilum convictum	11	4				291	
Procladius sp.					57		
Psectrocladius sp.		14					
Pseudochironemus sp. A			79	244			
Pseudochironomus sp. B		4	144	57			
Pseudochironomus sp. C	4	7				43	36
Simulium sp.	11					50	
Stictochironomus devinctus			7		57		
Stilobezzia sp.		4	57				
Tabanus sp.	4					4	7
Tanytarsus sp. A			57				
Tanytarsus sp. B		25					
Thienemanniella nr *fusca*						25	
Xenochironomus xenolabis	68						
EPHEMEROPTERA							
Baetis quilleri	11					104	
Baetis sp.	39					61	39

TABLE 11 CONTINUED

Map Code Station	B 1806.0260*	F 1806.0237*	G 1806.0233**	H 1806.0228**	I 1806.0227**	J 1806.0223*	K 1806.0220*
Taxon	Number of Individuals/m²						
EPHEMEROPTERA (cont.)							
Baetodes sp.						230	54
Brachycercus sp.			57				
Caenis sp.			309				
Choroterpes mexicanus	4						
Dactylobaetis mexicanus	29	25				147	4
Hexagenia limbata venusta			926	244			
Isonychia sicca manca	72	57				14	
Lepthohyphes packeri	11	4					11
Leptohyphes succinus	18					194	22
Pseudocloeon sp.	7					161	4
Thraulodes gonzalesi	36	11					39
Traverella presidiana	258	14				32	7
Tricorythodes albilineatus gr.	61	4				47	118
HEMIPTERA							
Ambrysus circumcinctus	22	14				118	22
LEPIDOPTERA							
Parargyractis sp.	251	29				86	25
MEGALOPTERA							
Corydalus cornutus	39	7				4	18
ODONATA							
Argia sp.	316	61				47	43
Didymops transversa				7			
TRICHOPTERA							
Cheumatopsyche sp. A	90						39
Cheumatopsyche sp. B	1,414	29				639	93

TABLE 11 CONTINUED

Map Code / Station	B	F	G	H	I	J	K
Station	1806.0260*	1806.0237*	1806.0233**	1806.0228**	1806.0227**	1806.0223*	1806.0220*
Taxon	Number of Individuals/m^2						
TRICHOPTERA (cont.)							
Chimarra sp.	68	4				79	7
Helicopsyche sp.						7	
Hydropsyche sp.	427	7				1,062	14
Hydroptila sp. A	108	7				7	298
Hydroptila sp. B	32					775	445
Ithytrichia sp.	4						
Neureclipsis sp.		4					
Ochrotrichia sp.	22	22				72	36
Oecetis sp.			115			14	
Oxyethira sp.	7						18
Polycentropus sp.			151	230			
Polyplectropus sp.	4	4					
Protoptila sp.		4					7
Smicridea sp.		7				22	

* riverine stations; three subsamples collected at each station using a Surber square foot sampler

** reservoir stations; six subsamples collected at each station using a 15.24 x 15.24 cm Ekman dredge

TABLE 12

Percentage Composition of Macrobenthic Functional Feeding Groups

Station	Functional Feeding Group***					
	Grazers	Gatherers	Filterers	Miners	Shredders	Predators
1806.0270*	11.2	8.6	63.9	2.5	1.1	13.0
1806.0237*	11.9	5.7	43.4	15.6	6.4	16.9
1806.0233**	1.8	47.9	15.3	13.6	6.4	15.0
1806.0228**	0.0	14.7	16.9	29.9	7.7	30.8
1806.0227**	0.1	8.1	0.6	0.5	0.6	90.1
1806.0223*	24.3	20.7	40.8	5.9	3.2	5.0
1806.0220*	49.3	15.3	12.9	10.5	6.2	5.8

* riverine stations

** reservoir stations

*** grazers: herbivores - periphyton scrapers; piercers of living vascular hydrophyte tissues or filamentous algal cells

gatherers: detritivores - collectors of sedimented fine particulate organic matter

filterers: omnivores - filterers of suspended fine particulate organic matter

miners: detritivores - burrowers in sedimented fine particulate organic matter

shredders: herbivores - chewers or miners of living vascular hydrophyte plant tissues; detritivores - chewers of decomposing coarse particulate organic matter

predators: carnivores - piercers, engulfers, and parasites of living animal tissues

LITERATURE CITED

Freese and Nichols, Inc. 1985. Regional Wastewater Treatment Plan. Freese and Nichols, Inc., Austin.

Kingston, M (Editor). 1985. Texas Almanac 1986-87. The Dallas Morning News, Dallas, 768 p.

National Oceanic and Atmospheric Administration. 1983. Climatological Data, Volume 88 (10 and 11). National Oceanic and Atmospheric Administration, Asheville, N.C.

Parkhill, Smith and Cooper. 1986. Letter to Edward Juenger, Texas Water Commission, from Tony Skeen relating to amendment to Permit No. 10576-01, City of Kerrville, Texas. Texas Water Commission Central Office Files, Austin.

Short, R.A. 1986a. Nutrient Limitation and Possible Influence of Wastewater Effluent on the Upper Guadalupe River. Southwest Texas State University, San Marcos, 23 p.

Short, R. A. 1986b. Preliminary Rsults of Nutrient Study, March 1-November 1, 1986. Letter to Upper Guadalupe River Authority, November 5, 1986. Southwest Texas State University, San Marcos.

Texas Parks and Wildlife Department. 1986. Annual State Park Visitations. Texas Parks and Wildlife Department, Austin.

Texas Water Commission. 1985. Texas Surface Water Quality Standards. Informational Draft Copy. Texas Water Commission, Austin.

Texas Water Commission. 1986. The State of Texas Water Quality Inventory, 8th Edition, Information Draft Copy, Texas Water Commission, Austin.

Texas Water Development Board. 1986. Census Data Report, 1980. Texas Water Development Board, Austin.

Texas Water Quality Board. 1977. The Edwards Aquifer, Texas. Texas Water Quality Board Staff Report, Texas Water Quality Board, Austin, 24 p.

Young, W. J. 1971. The Influence of Impoundment and Thermal Stratification in Canyon Reservoir on Physicochemical Limnology and Chlorophyll a of the Guadalupe River, Texas. Unpublished Masters Thesis, Southwest Texas State University, San Marcos, 85 p.

APPENDIX A

FIELD AND LABORATORY PROCEDURES

The following methods are utilized for field and laboratory determinations of specified physical and chemical parameters. Unless otherwise indicated composite water samples are collected at each sampling station and stored in polyethylene containers on ice until delivery to the laboratory. Sediment samples are collected with a dredge or coring device, decanted, mixed, placed in appropriate containers (glass for pesticides analyses and plastic for metals analyses), and stored on ice until delivery to the laboratory. Laboratory chemical analyses are conducted by the Water Chemistry Laboratory of the Texas Department of Health unless otherwise noted.

WATER ANALYSES

Field Measurements

Parameter	Unit of Measure	Method
Temperature	°C	Hand mercury thermometer, Hydrolab Model 60 Surveyor, or Hydrolab 4041.
Dissolved Oxygen (DO)	mg/l	Azide modification of Winkler titration method, Hydrolab Model 60 Surveyor, or Hydrolab 4041.
pH	Standard Units	Hydrolab Model 60 Surveyor, Hydrolab 4041 or Sargent-Welch portable pH meter.
Conductivity	µmhos/cm	Hydrolab Model 60 Surveyor, Hydrolab 4041, or Hydrolab TC-2 conductivity meter
Phenolphthalein Alkalinity (P-Alk)	mg/l as $CaCO_3$	Titration with sulfuric acid using phenolphthalein indicator(1).
Total Alkalinity (T-Alk)	mg/l as $CaCO_3$	Titration with sulfuric acid acid using phenolphthalein and methyl red/bromcresol green indicators(1).
Chlorine Residual	mg/l	N,N-diethyl-p-phenylene-diamine (DPD) Ferrous Tetrimetric method(1).
Transparency	m or cm	Secchi disc

Laboratory Analyses

Parameter	Unit of Measure	Method
Five Day, Nitrogen Suppressed, Biochemical Oxygen Demand (BOD_5, N-Supp.)	mg/l	Membrane electrode method(1). Nitrogen Suppression using 2-chloro-6-(trichloromethyl)-pyridine (TCMP) method(2).
Five Day, Filtered, Nitrogen Suppressed, Biochemical Oxygen Demand (BOD_5, Filt., N-Supp.)	mg/l	Samples filtered with glass fiber filter. Analysis conducted on filtrate. Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
Twenty Day, Nitrogen Suppressed, Biochemical Oxygen Demand (BOD_{20}, N-Supp.)	mg/l	Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
Twenty Day, Filtered, Nitrogen Suppressed, Biochemical Oxygen Demand (BOD_{20}, Filt., (N-Supp.)	mg/l	Samples filtered with glass fiber filter. Analyses conducted on filtrate. Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
One through Seven Day, Nitrogen-Suppressed, Biochemical Oxygen Demand (BOD_{1-7}, N-Supp.)	mg/l	Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
Total Suspended Solids (TSS)	mg/l	Gooch crucibles and glass fiber disc(1).
Volatile Suspended Solids (VSS)	mg/l	Gooch crucibles and glass fiber disc(1).
Kjeldahl Nitrogen (Kjel-N)	mg/l as N	Micro-Kjeldahl digestion and automated colorimetric phenate method(3).
Ammonia Nitrogen (NH_3-N)	mg/l as N	Distillation and automated colorimetric phenate method(3).
Nitrite Nitrogen (NO_2-N)	mg/l as N	Colorimetric method(1).
Nitrate Nitrogen (NO_3-N)	mg/l as N	Automated cadmium reduction method(3).

Laboratory Analyses - Continued

Parameter	Unit of Measure	Method
Total Phosphorus (T-P)	mg/l as P	Persulfate digestion followed by ascorbic acid method(1).
Orthophosphorus (O-P)	mg/l as P	Ascorbic acid method(1).
Sulfate (SO_4)	mg/l	Turbidimetric method(1).
Chloride (Cl)	mg/l	Automated thiocyanate method(3).
Total Dissolved Solids (TDS)	mg/l	Evaporation at 180°C(3).
Total Organic Carbon (TOC)	mg/l	Beckman TOC analyzer
Conductivity	µmhos/cm	Wheatstone bridge utilizing 0.01 cell constant(1).
Chlorophyll a	µg/l	Trichromatic method(1).
Pheophytin a	µg/l	Pheophytin correction method(1).

SEDIMENT ANALYSES

Field Measurements

Sediment Oxygen Demand

A benthic respirometer, constructed of clear plexiglass, is utilized on intensive surveys to measure benthal oxygen demand(14). A dissolved oxygen probe, paddle, solenoid valve and air diffuser are mounted inside the test chamber. The paddle issued to simulate stream velocity and produce circulation over the probe. The solenoid valve allows air to escape from the test chamber during aeration. The air diffuser is connected by plastic tubing to a 12-volt air compressor which is used to pump air into the test chamber if required.

The paddle, solenoid valve, and air compressor are actuated by switches on a control panel which is housed in an aluminum box. The control box also contains two 12-volt batteries, the air compressor, a stripchart recorder (for automatic recordings of dissolved oxygen meter readings), a battery charger, and a battery test meter.

Selection of a specific test site must be made in the field by the investigator with the depth, velocity, and benthic substrate taken into consideration. At the test site the dissolved oxygen meter, and strip-chart recorder are calibrated, the respirometer is dry tested by opening and closing switches and testing batteries; a stream velocity measurement is taken (for paddle calibration), and a water sample is collected just above the stream bottom near the sampling site. Portions of this water sample are poured into separate BOD bottles, one of which is opaque. The opaque bottle is placed on the respirometer and left for the remainder of the test. The initial dissolved oxygen value in the other bottle is measured when the test begins, while the dissolved oxygen in the opaque bottle is measured at the end of the benthic uptake test. The difference in the two dissolved oxygen values represents the oxygen demand of the water column.

The respirometer can be lowered from a boat or bridge, or can be placed by hand in shallow streams. Care is taken to insure that the sediment at the test location is not disturbed and that a good seal between the base of the instrument and bottom of the stream is made. After the respirometer has been placed in the stream, the dissolved oxygen is recorded. In shallow, clear streams the instrument is covered to prevent photosynthesis from occurring within the chamber. The test chamber is then closed and the paddle frequency adjusted. Recordings of dissolved oxygen are made until oxygen is depleted within the chamber or 6 hours has elapsed.

Paddle Frequency

$$f = 36\,v$$

where: f = Paddle frequency in revolutions per minute

v = Velocity to be simulated in m/s (measureed with current meter)

Benthic Oxygen Uptake

$$B^{T}DO_1\text{-}DO_2 = 196\,\frac{(DO_1\text{-}DO_2) - BOD_t}{\Delta t}$$

where: $B^{T}DO_1\text{-}DO_2$ = Oxygen uptake rate in $g/m^2/d$ corresponding to the sample temperature, T

DO_1 = Initial DO reading in mg/l

DO_2 = Final DO reading in mg/l

Δt = Time interval between DO_1 and DO_2

T = Temperature of sample in °C

BOD_t = Measured difference in DO between the two BOD bottles

Laboratory Analyses

Parameter	Unit of Measure	Method
Arsenic (As)	mg/kg	Silver diethylidithcocarbonate method(3).
Mercury (Hg)	mg/kg	Potassium permanganate digestion followed by atomic absorption(3,4).
All other metals	mg/kg	Atomic absorption(3,4).
Volatile Solids	mg/kg	Ignition in a muffle furnace(3).
Chemical Oxygen Demand (COD)	mg/kg	Dichromate reflux method(3).
Kjeldahl Nitrogen (Kjel-N)	mg/kg	Micro-Kjeldahl digestion and automated colorimetric method(3).
Total Phosphorus (T-P)	mg/kg as P	Ammonium molybdate(3).
Pesticides	µg/kg	Gas chromatographic method(4,5).
Oil and Grease	mg/kg	Soxhlet extraction method(3).

BACTERIOLOGICAL

Bacteriological samples are collected in sterilized bottles to which 0.5 ml of sodium thiosulfate is added to dechlorinate the sample. Following collection, the samples are stored on ice until delivery to a laboratory or until cultures are set up by survey personnel (within 6 hours of collection). Bacteriological analyses are conducted by survey personnel or a suitable laboratory in the survey area.

Parameter	Unit of Measure	Method
Total Coliform	Number/100 ml	Membrane filter method(1)
Fecal Coliform	Number/100 ml	Membrane filter method(1)
Fecal Streptococci	Number/100 ml	Membrane filter method(1)

BENTHIC MACROINVERTEBRATES

Benthic macroinvertebrates are collected with a Surber sampler (0.09 m^2) in riffles and an Ekman dredge (0.02 m^2) in pools. Samples are preserved in 5 percent formalin, stained with Rose Bengal, and sorted, identified, and enumerated in the laboratory.

Diversity ($\bar{d}$) is calculated according to Wilhm's(6) equation:

$$\bar{d} = -\sum_{1}^{s} (n_i/n) \log_2 (n_i/n)$$

where n is the total number of individuals in the sample, n_i is the number of individuals per taxon, and s is the number of taxa in the sample.

Redundancy ($\bar{r}$) is calculated according to the equations derived by Young et al.(7)

(1) $\bar{d}\ max = \log_2 s$

(2) $\bar{d}\ min = -\frac{s-1}{n} \log_2 \frac{1}{n} - \frac{n-(s-1)}{n} \log_2 \frac{n-(s-1)}{n}$

(3) $\bar{r} = \frac{\bar{d}\ max - \bar{d}}{\bar{d}\ max - \bar{d}\ min}$

where s is the number of taxa in the sample and n is the total number of individuals in the sample.

Equitability is (e) is calculated according to Pielow's(8) equation:

$$e = \frac{\bar{d}}{\log_2 s}$$

where $\bar{d}$ is the calculated diversity value and s is the number of taxa in the sample.

The number of individuals per square meter is determined by dividing the total number of individuals by the area sampled.

PERIPHYTON

Periphyton are collected from streams and reservoirs from natural substrates or from artificial substrates placed in the water. Standard size, frosted microscope slides are commonly used as artificial substrates and are held in place a few centimeters beneath the water surface at the sampling sites in floating periphytometers. Following a 25 to 30 day incubation period the accrued materials are analyzed for chlorophyll a, pheophytin a, and for identification and enumeration of the attached organisms.

In the field, following retrieval of the periphytometer, two slides are placed in a brown glass container containing 100 ml of 90 percent aqueous acetone. The material from these two slides is used for pigment measurements. Two slides are placed in another brown glass container containing 100 ml of 5 percent buffered formalin. The material from these two slides is used for biomass measurements. The remaining slides are also placed in buffered formalin and utilized for identification and enumeration of organisms according to procedures discussed for the phytoplankton. The brown glass jars containing the material for laboratory analyses (pigment and biomass measurements) are placed in a deep freeze and kept frozen prior to analysis.

The autotrophic index is calculated according to the equation given by Weber and McFarland(9).

$$\text{Autotrophic Index} = \frac{\text{Biomass } (g/m^2)}{\text{Chlorophyll } \underline{a} \ (g/m^2)}$$

Periphyton samples may also be collected from natural substrates by scraping areas from each type of substrate available at each sampling location. Scrapings are made from a range of depths from subsurface to the stream bottom, from bank to bank, and at points spanning the range in stream velocity. The scrapings from each sampling location are composited into a container, preserved with Lugols solution and returned to the laboratory for identification and enumeration following procedures discussed in the phytoplankton section. Diversity, redundancy, and equitability statistics are calculated as described previously.

PLANKTON

Phytoplankton

Stream phytoplankton are collected immediately beneath the water surface with a Van Dorn sampler or by immersing a sampling container. Phytoplankton samples are collected with a Van Dorn water sampler at depths evenly spaced throughout the water column of reservoirs.

Samples are stored in quart cubitainers on ice and transferred to the laboratory where aliquots of each sample are analyzed live to aid in taxonomic identification. Samples (950 ml) are then preserved with 50 ml of 95 percent buffered formalin or 9.5 ml of Lugols solution and stored in the dark until examination is completed. The phytoplankton are concentrated in sedimentation chambers, and identification and enumeration are conducted with an inverted microscope utilizing standard techniques. If diatoms are abundant in the samples, slide preparations are made using Hyrax mounting medium(10). The diatoms are identified at high magnification under oil until a minimum of 250 cells are tallied. Diversity, redundancy, and equitability statistics are calculated as described previously.

Zooplankton

Zooplankton are concentrated at the site by either filtering a known volumne of water through a number 20 mesh standard Wisconsin plankton net or vertically towing the net a known distance or time. Concentrated samples are preserved with Lugols solution or in a final concentration of 5 percent buffered formalin. The organisms are identified to the lowest taxonomic level possible, and counts are made utilizing a Sedgwick-Rafter cell. Diversity, redundancy, and equitability statistics are calculated as described previously.

NEKTON

Nekton samples are collected by the following methods(1):

Common-sense minnow seine	- 6 m x 1.8 m with 0.6 cm mesh
Otter trawl	- 3 m with 3 cm outer mesh and 1.3 cm stretch mesh liner
Chemical fishing	- rotenone
Experimental gill nets	- 38.1 m x 2.4 m (five 7.6 m sections ranging in mesh size from 1.9 to 6.4 cm).
Electrofishing	- backpack and boat units (both equipped with AC or DC selection). Boat unit is equipped with variable voltage pulsator.

Nekton are collected to determine: (1) species present, (2) relative and absolute abundance of each species, (3) species diversity (4) size distribution, (5) condition, (6) success of reproduction, (7) incidence of disease and parasitism, (8) palatability, and (9) presence or accumulations of toxins.

Nekton collected for palatability are iced or frozen immediately. Samples collected for heavy metals analyses are placed in leak-proof plastic bags and placed on ice. Samples collected for pesticides analyses are wrapped in alumnium foil, placed in a waterproof plastic bag, and placed on ice.

As special instances dictate, specimens necessary for positive identification or parasite examination are preserved in 10 percent formalin containing 3 borax and 50 ml glycerin per liter. Specimens over 15 cm in length are slit at least one-third of the length of the body to enhance preservation of the internal organs. As conditions dictate, other specimens are weighed and measured before being returned to the reservoir or stream.

ALGAL ASSAYS

The "Selenastrum capricornutum Printz Algal Assay Bottle Test" procedure(11) is utilized in assaying nutrient limitation in freshwater situations, whereas the "Marine Algal Assay Procedure Bottle Test"(12) is utilized in marine and estuarine situations. Selenastrum capricornutum is the freshwater assay organism and Dunaliella tertiolecta is the marine assay alga.

PHOTOSYNTHESIS AND RESPIRATION

In areas where restricted flow produces natural or artifical ponding of sufficient depth, standard light bottle-dark bottle techniques are used. In flowing water the diurnal curve analysis is utilized.

Light Bottle-Dark Bottle Analyses

The light and dark bottle technique is used to measure net production and respiration in the euphotic zone of a lentic environment. The depth of the euphotic zone is considered to be three times the Secchi disc transparency. This region is subdivided into three sections. Duplicate light bottles (300 ml BOD bottles) and dark bottles (300 ml BOD bottles covered with electrical tape, wrapped in aluminum foil, and enclosed in a plastic bag) are filled with water collected from the mid-point of each of the three vertical sections, placed on a horizontal metal rank, and suspended from a flotation platform to the mid-point of each vertical section. The platform is oriented in a north-south direction to minimize shading of the bottles. An additional BOD bottle is filled at each depth for determining initial dissolved oxygen concentrations (modified Winkler method). The bottles are allowed to incubate for a varying time interval, depending on the expected productivity of the waters. A minimum of 4 hours incubation is considered necessary.

The following equations are used to calculate respiration and photosynthesis:

(1) For plankton community respiration (R), expressed as mg/l O_2/hour,

$$R = \frac{DO_I - DO_{DB}}{\text{Hours incubated}}$$

where DO_I = initial dissolved oxygen concentration

and DO_{DB} = average dissolved oxygen concentration of the duplicate dark bottles

(2) For plankton net photosynthesis (P_N), expressed as mg/l O_2/hour,

$$P_N = \frac{DO_{LB} - DO_I}{\text{Hours incubated}}$$

where DO_{LB} = average dissolved oxygen concentration of duplicate light bottles

(3) For plankton gross photosynthesis (P_G), expressed as mg/l O_2/hour,

$$P_G = P_N + R$$

Conversion of respiration and phtotsynthesis volumetric values to an aerial basis may be accomplished by multiplying the depth of each of the three vertical zones (expressed in meters) by the measured dissolved oxygen levels expressed in g/m^3. These products are added and the result is expressed in g $O_2/m^2/d$ by multiplying by the photoperiod. Conversion from oxygen to carbon may be accomplished by multiplying grams O_2 by 0.32 [1 mole of O_2 (32 g) is released for each mole of carbon (12 g) fixed].

Diurnal Curve Analysis

In situations where the stream is flowing, relatively shallow, and may contain appreciable growths of macropytes or filamentous algae, the diurnal curve analysis is tuilized to determine productivity and respiration. The procedure is adopted from the United States Geological Survey(13). Both the dual station and single station analyses are utilized, depending upon the various controlling circumstances.

Dissolved oxygen and temperature data are collected utilizing the Hydrolab surface units, sondes, data scanners, and strip chart recorders. Diffusion rate constants are directly measured in those instances where atmospheric reaeration rate studies have been conducted. In situations where direct measurements are not made, either the diffusion dome method is utilized, or an appropriate alternative. These alternatives are: (1) calculations from raw data, (2) substitution into various published formulas for determination of K_2, and (3) arbitrary selection of a value from tables of measured diffusion rates for similar streams.

HYDROLOGICAL

Parameter	Unit of Measure	Method
Flow Measurement	m^3/s	Pygmy current meter (Weather Measure Corporation Model F583), Marsh-McBirney Model 201 electronic flow meter, Price current meter (Weather Measure Corporation Model F582), or gage height readings at USGS gaging stations.
Time-of-Travel	m/s	Tracing of Rhodamine WT dye using a Turner Model 110 or 111 fluorometer(15).
Stream Width	m	Measured with a range finder
Tidal Period	hours	Level recorder
Tidal Amplitude	m	Level recorder
Changes in Stream Surface Level	m	Level recorder

Stream Reaeration Measurements

The stream reaeration technique is utilized to measure the physical reaeration capacity of a desired stream segment(16). The method depends on the simultaneous release of three tracers in a single aqueous solution: a tracer for detecting dilution and dispersion (tritiated water molecules), a dissolved gaseous tracer for oxygen (krypton-85), and Rhodamine WT dye to indicate when to sample for the radiotracers in the field. The tracer release location is chosen to meet two requirements: (1) it must be upstream of the segment for which physical reaeration data are desired, and (2) it must be at least 0.6 m deep and where the most complete mixing takes place. Before the release, samples are collected at the release site and at designated sampling stations to determine background levels of radiation. The first samples are collected 15 to 60 m downstream from the release site in order to establish the initial ratio of drypton 85 to tritium. Sampling sites are located downstream to monitor the dye cloud every 4 to 6 hours over a total period of 35 to 40 hours. The Rhodamine WT dye is detected with Turner 111 flow-through fluorometers. Samples are collected in glass bottles (30 ml) equipped with polyseal caps which are sealed with black electrical tape. Samples are generally collected every 2 to 5 minutes during the passage of the dye cloud peak. The three samples collected nearest the peak are designated for analysis in the laboratory (three alternate samples collected near the peak are also designated). Extreme caution is exercised throughout the field and laboratory handling of samples to prevent entrainment of air.

Samples are transferred to the laboratory for analyses within 24 hours of the collection time. Triplicate counting vials are prepared from each primary sample. All counting vials are counted in a Tracor Analytic 6892 LSC Liquid Scintillation Counter which has been calibrated. For each vial, counting extends for a minimum of three 10-minute cycles. The data obtained are analyzed to determine the changes in the krypton-85 to tritium ratio as the tracers flow downstream.

The calculations utilized in determining the physical reaeration raes from a stream segment from the liquid scintillation counter data are included here. Krypton-85 transfer in a well-mixed water system is described by the expression:

$$\frac{dC_{kr}}{dt} = - K_{kr}(C_{kr},t) \qquad (1)$$

where: C_{kr},t = concentration of krypton-85 in the water at time(t)

K_{kr} = gas transfer rate coefficient for krypton-85

The concentration of krypton-85 present in the earth's atmosphere can be assumed zero for practical purposes. Therefore, any krypton-85 dissolved in water which is exposed to the atmosphere will be steadily lost from the water to the atmosphere according to equation 1.

The gas transfer rate coefficient for oxygen (K_{ox}) is related to K_{kr} by the equation:

$$\frac{K_{kr}}{K_{ox}} = 0.83 \pm 0.04 \qquad (2)$$

Equation 2 is the basis for using krypton-85 as a tracer for oxygen transfer in stream reaeration because the numerical constant (0.83) has been experimentally demonstrated to be independent of the degree of turbulent mixing, of the direction in which the two gases happen to be moving, and of temperature. The disperion or dilution tracer (tritiated water) is used simultaneously with the dissolved gas tracer (krypton-85) to correct for the effects of dispersion and dilution in the stream segment being studied.

A single homogeneous solution containing the dissolved krypton-85 gas, tritiated water, and dye is released at the upstream reach of the stream segment being studied. As the tracer mass moves downstream, multiple samples are collected as the peak concentration passes successive sampling stations. In the laboratory, peak concentration samples from each station are analyzed and the krypton-85/tritium concentration ratio (R) is established by the equation:

$$R = \frac{C_{kr}}{C_h} \qquad (3)$$

where: C_{kr} = concentration of krypton-85 in water at time of peak concentration

C_h = concentration of tritium in the water at time of peak concentration

Applying this ratio concept, equation 1 can be modified to:

$$\frac{dR}{dt} = - K_{kr} R \qquad (4)$$

with terms as previously defined

Equation 4 can be transformed to:

$$K_{kr} = \frac{n(R_d/R_u)}{- t_f} \qquad (5)$$

where: R_u and R_d = peak ratios of krypton-85 to tritium concentrations at an upstream and downstream station

t_f = travel time between the upstream and downstream station determined by dye peaks

The tracers are used to evaluate the actual krypton-85 transfer coefficient (K_{kr}), and the conversion to the oxygen transfer coefficient (K_{ox}) is from the established gas exchange ratio:

$$K_{ox} = \frac{K_{kr}}{0.83}$$

REFERENCES CITED

1. American Public Health Association. 1975. Standard Methods for the Examination of Water and Wastewater, 14th Ed. APHA, New York. 1134 pp.

2. Young, J.C. 1973. Chemical methods for nitrification control. J. Water Poll. Control Fed. 45: 637-646.

3. U. S. Environmental Protection Agency. 1979. Methods for Chemical Analyses of Water and Wastes. Report No. EPA-600/4-79-020, U.S.E.P.A., Washington, D. C. 298 pp.

4. U. S. Environmental Protection Agency. 1979. Interim Methods for the Sampling and Analysis of Priority Pollutants in Sediments and Fish Tissue. U.S.E.P.A., Washington, D.C.

5. U. S. Environmental Protection Agency. 1977. Analysis of Pesticide Residues in Human and Environmental Samples. U.S.E.P.A., Washington, D.C.

6. Wilhm, J.L. 1970. Range of diversity index in benthic macroinvertebrate populations. J. Water Poll. Control Fed. 42: R221-224.

7. Young, W.C., D.H. Kent, and B.G. Whiteside. 1976. The influence of a deep-storage reservoir on the species diversity of benthic macroinvertebrate communities of the Guadalupe River, Texas. Texas J. of Sci. 27:213-224.

8. Pielou, E.C. 1966. The measurements of diversity in different types of biological collections. J. Theoretical Biol. 13:131-144.

9. Weber, C.I., and B. McFarland. 1969. Periphyton biomass - chlorophyll ratio as an index of water quality. Presented at the 17th Annual Meeting, Midwest Benthological Society, Gilbertsville, Ky., April, 1969.

10. U.S. Environmental Protection Agency. 1973. Biological Field and Laboratory Methos for Measuring the Quality of Surface Waters and Effluents. Report No. EPA-670/4-73-001, U.S.E.P.A., Cincinnati.

11. Miller, W.E., J.C. Greene, and T. Shiroyama. 1978. The Selenastrum capricornutum Printz Algal Assay Bottle Test. Report No. EPA-600/9-78-018, U.S. Environmental Protection Agency, Corvallis. 126 pp.

12. U.S. Envoronmental Protection Agency. 1974. Marine Algal Assay Procedure: Bottle Test. U.S.E.P.A., Coravllis, Oregon. 43 pp.

13. U.S. Geological Survey. 1977. Methods for the Collection and Analysis of Aquatic Biological and Microbiological Samples. Bood 5, Chapter A4, U.S.G.S., Washington, D.C. 332 pp.

14. URS/Forrest and Cotton, Inc. 1979. Benthic respirometer users guide. URS/Forrest and Cotton, Austin. 14 p.

15. U.S. Geological Survey. 1970. Measurement of Time-of-Travel and Dispersion by Dye Tracing. In: Techniques of Water Resources Investigations of the United States, Book 3, U.S.G.S., Washington, D.C. 25 pp.

16. Neal, Larry A. 1979. Method for tracer measurement of reaeration in free-flowing Texas streams. Law Engineering and Testing Company, Atlanta, Georgia. 53 p.