INTENSIVE SURVEY OF
BARTON CREEK
SEGMENT 1430
May 20-24, 1985

Hydrology, Field Measurements,
Water Chemistry and Biology

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ABSTRACT

An intensive survey of Barton Creek (Segment 1430) was conducted May 20-24, 1985, by the Texas Department of Water Resources. The study area included the entire length of Barton Creek from its union with Town Lake in Austin to its headwaters in western Hays County. Water quality, hydraulic, and biological data were collected at 20 mainstream stations and two tributary streams. Stream widths of Barton Creek generally increased from upstream to downstream (range 5.2 - 22.9 m). Stream discharge increased from 0.0129 m^3/s (0.46 ft^3/s) near the headwaters to 0.3894 m^3/s (13.75 ft^3/s) at Lost Creek Boulevard, and then declined to 0.0372 m^3/s (1.32 ft^3/s) upstream of Barton Pool as the water flowed over the Edwards Aquifer recharge zone and infiltrated to the underground. Stream velocities were slow throughout the study area (range 0.04 - 0.07 m/s). Excepting one early morning measurement, dissolved oxygen levels remained above the 5 mg/L segment criterion. Nutrient and chlorophyll a levels were below or near the lower limits of detection throughout the segment. Stream $CBOD_5$ and $CBOD_{20}$ levels were low throughout Barton Creek. Chloride, sulfate, total dissolved solids, water temperature, and pH levels conformed to segment criteria. Benthic macroinvertebrate community structure reflected clean water and healthy environmental conditions throughout the creek.

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SEGMENT 1430

INTRODUCTION

DIRECTIVE

This intensive survey was accomplished in accordance with the Texas Water Quality Act, Section 26.127, as amended in 1977. The report is to be used in developing and maintaining the State Water Quality Strategy published in 40 CFR 35.1511-2 pursuant to Section 303(e) of the Federal Clean Water Act of 1977.

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 May 20-24, 1985, by the Texas Department of Water Resources Water Quality Assessment Unit and Modeling Unit personnel. Laboratory analyses of water samples were conducted by the Texas Department of Health Chemistry Laboratory in Austin, Texas. Bacteriological analyses were conducted by the Department's Water Quality Assessment Unit. Benthic macroinvertebrate samples were collected by Jack R. Davis at selected stations on May 22, 1985, 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

An intensive survey of Barton Creek (Segment 1430) was conducted by the Texas Department of Water Resources (TDWR) May 20-24, 1985. Barton Creek is a small central Texas stream approximately 80.6 kilometers (50.1 miles) in length from its headwaters in western Hays County near the community of Henly to its confluence with Town Lake on the Colorado River in Austin (Figure 1). Barton Creek drains portions of southwestern Travis County and northeastern Hays County. The entire Barton Creek watershed is undergoing rapid development by the spread of the Austin metropolitan area from the northeast. Presently, land near the headwaters of Barton Creek to US 71 is primarily rural where ranching activities dominate the economy. Downstream of US 71, the Barton Creek watershed is becoming much more urbanized by the continued expansion of large developments such as Lost Creek and Travis Country and construction of new ones (The Uplands, Barton Creek West, Rob Roy on the Creek).

During normal summertime low flow conditions stream flow is usually observable throughout Barton Creek with the exception of a 11.3 kilometer (7 mile) intermediate section near Camp Craft Road to Barton Pool in Zilker Park. In this area, Barton Creek flows over the Edwards Aquifer recharge zone and stream flow infiltrates to the subsurface. During prolonged dry periods, flow in Barton Creek upstream of the recharge zone may also become intermittent.

The Edwards Aquifer in the study area is bounded on the north by Town Lake, on the west by the limit of the Edwards Limestone outcrop, on the south by the drainage divide and groundwater divide between Onion Creek and the Blanco River, and on the east by a line that seperates freshwater and saline water. Within the study area the Edwards Aquifer consists of a water table and an artesian zone (Figure 2). The Edwards and associated limestone outcrops are exposed throughout much of the water table zone. Within the artesian zone, the Edwards Aquifer is covered by the low permeability Del Rio Clay. In the study area, the Edwards Aquifer is underlain by low permeability shales and limestones of the Walnut Formation. The Edwards and associated limestones, which crop out in the recharge zone of Barton Creek, are characterized by hard, massive limestones and dolomites (Brune and Duffin, 1983). The permeability of the Edwards in the area of Barton Creek has been established as exceptionally high, and it may transmit water as rapid as the surface stream (U. S. Corp of Engineers, 1969). The high permeability within the recharge zone along Barton Creek is a result of a network of steeply dipping faults, extensive fractures, and solution zones which are hydrologically interconnected. Due to the high permeability and rapid movement of water through the recharge zone, the Edwards Aquifer in the Austin area is very susceptible to pollution from natural and human sources during runoff (Andrews, Schertz, Slade, and Rawson, 1984).

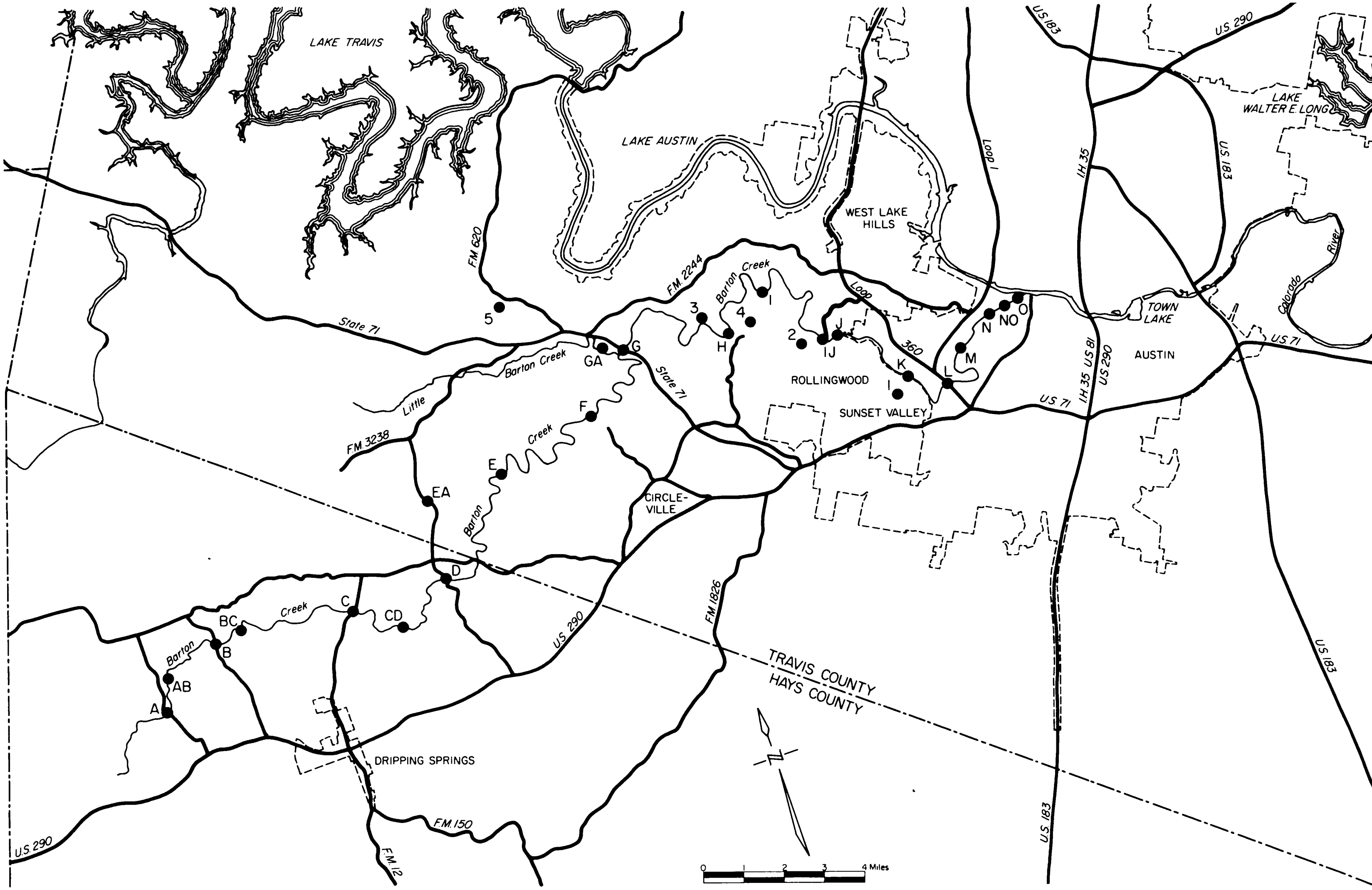

Figure 1
Map of Study Area

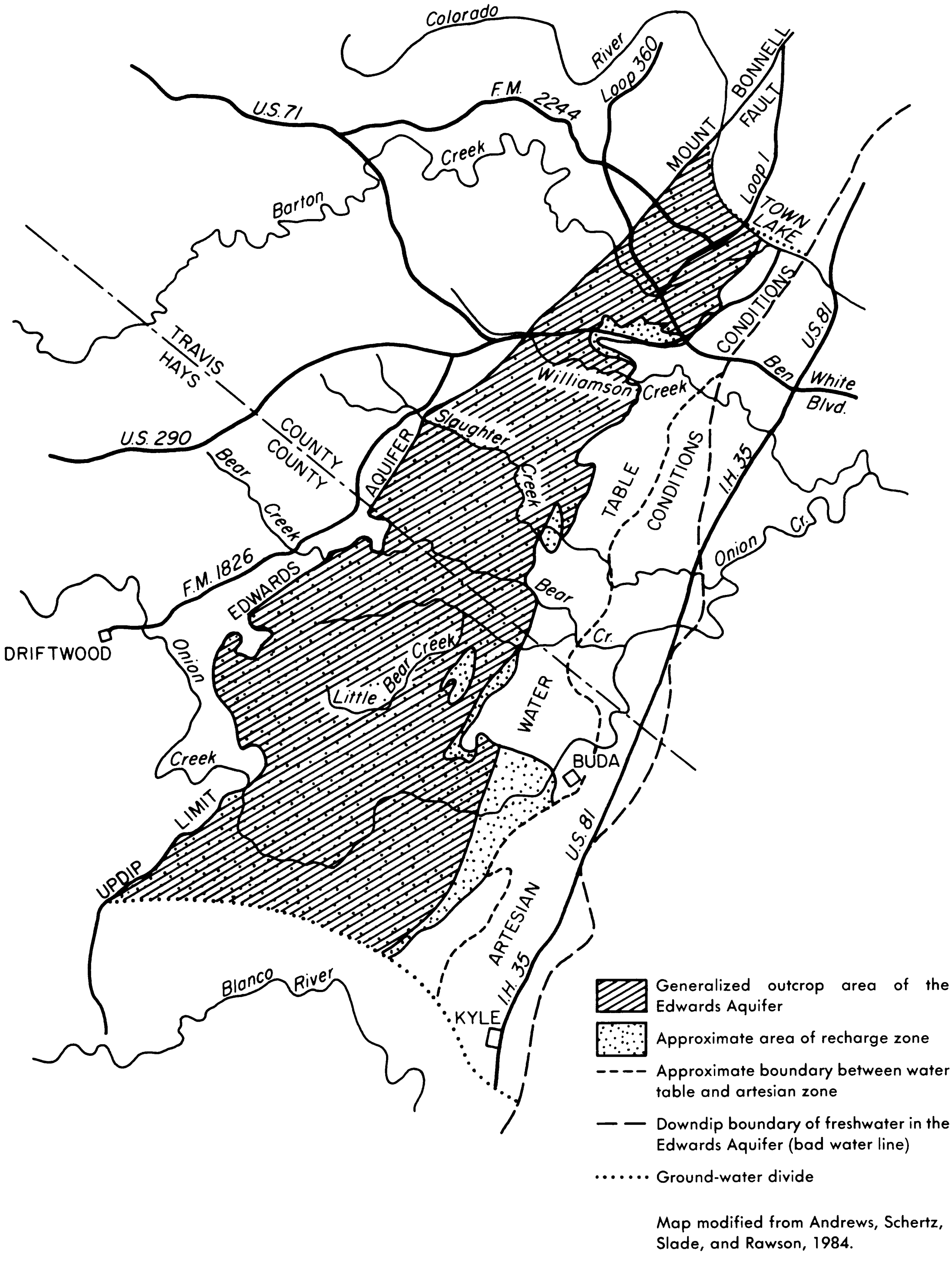

Figure 2
Map of Edwards Aquifer

Stream flow that infiltrates into the subsurface in the recharge zone of Barton Creek moves generally to the east-northeast and reappears in the lower portion of the basin as spring water. Several of the larger springs in the Zilker Park area of Austin are collectively called "Barton Springs". These springs are classified as large, and with an average annual flow of 1.42 m^3/s (50 ft^3/s), they are ranked as the fourth largest springs in Texas. Barton Springs reached their lowest recorded flow of 0.27 m^3/s (9.6 ft^3/s) on March 29, 1956 and their highest recorded flow of 4.7 m^3/s (166 ft^3/s) on May 10, 1941 (Brune, 1975).

Stream flow downstream of the springs has been impounded since the early 1880's to form Barton Pool, a large natural flow-through swimming pool. The present concrete dam structure was constructed in 1929 to replace earlier, less permanent ones made with boulders. In 1975 a storm water bypass was constructed to route Barton Creek water around the pool. The bypass will accommodate a stream flow of about 5.7 m^3/s (200 ft^3/s), so the pool remains open for public use following light to moderate rainfall. Barton Pool and Zilker Park serve as major recreational facilities.

Several studies indicate that significant recharge to Barton and associated springs results from Barton Creek stream loss and infiltration in the drainage basin (Guyton and Associates 1958 and 1964, Baker and Watson, 1974). Although infiltration and seepage of water from Barton Creek supplies a significant quantity to Barton Springs, the other streams that cross the recharge zone also contribute. Direct infiltration of precipitation that falls on the outcrop also contributes but to a lesser extent. A recent study by the United States Geological Survey (USGS) between July 1979 and December 1982 indicates that about 85 percent of the total recharge occurs along the main channels of six major streams in the recharge zone (Andrews, et al, 1984). Barton Creek contributed 28 percent of the total recharge contributed by watersheds of the six streams during the study; Williamson Creek contributed 6 percent, Slaughter Creek 12 percent, Bear Creek 10 percent, Little Bear Creek 10 percent, and Onion Creek 34 percent. The remaining 15 percent of total recharge to Barton Springs occurs along channels of tributaries and by direct precipitation. Although the rates and exact paths of water movement in the aquifer are unknown, the water quality of Barton Springs is partially governed by the surface water quality of the streams which cross the recharge zone.

An above average rainfall on the recharge zone is generally required to increase the flow of Barton Springs. This increase can come immediately after a rainfall or take longer than a week. Quick increases in spring flow result primarily from recharge to Barton Creek immediately upstream from Barton Springs. The slower increases in spring flow are believed to originate from recharge on Onion Creek, approximately 32 kilometers (20 miles) from the springs (Brune and Duffin, 1983).

Throughout its length Barton Creek is a scenic stream with crystal clear water. In the reach between US 71 and Zilker Park, Barton Creek meanders through the hill country just west of Austin. Here the stream is confined by steep rocky bluffs and canyons. The rough topography and rocky terrain offer scenic vistas but afford limited access to Barton Creek and makes development in the watershed difficult. The City of Austin has acquired land along Barton Creek from Zilker Park to Lost Creek Boulevard as a greenbelt to afford the public access and limit development adjacent to the creek. A developed hike and bike trail exists in the greenbelt from Zilker Park to Loop 360. From Loop 360 to Lost Creek Boulevard a primitive trail exists.

During periods when Barton Creek is flowing over the recharge zone, several large pools are formed in the streambed that are popular sites for swimming; Campbells Hole and Twin Falls are the best known. Following periods of heavy rainfall, Barton Creek is considered one of the finest waterways for white water recreation in Texas (TP&W, undated).

Twenty mainstream stations were established on Barton Creek for the survey. Sampling stations were also established on two tributaries that were flowing at the time of study (Little Barton Creek and Rocky Creek)(Table 1).

POPULATION

The estimated population for the Barton Creek watershed in 1980 was 9,400, with the vast majority residing in the Austin Metropolitan area (Parkhill, Smith and Cooper, 1985). Heavy development of the basin is projected during the next twenty years and the population is anticipated to be 35,090 in 1995 and 65,324 in 2010 (Turner, Collie and Braden, Inc., 1985). This expectation is due to the heavy growth rate of the Austin area (36.3 percent increase from 1970 to 1980), the desirability of the Barton Creek area, and the large amount of land available for development, even considering the density restrictions imposed under the Barton Creek Watershed Ordinance of the City of Austin. Excluding Austin, the cities of West Lake Hills, Rollingwood, and Dripping Springs are located along the Barton Creek basin. Their 1980 population figures are 1927, 1027, and 530, respectively.

CLIMATOLOGY

The climate of the Austin-Dripping Springs area may be characterized as warm, humid, and subtropical with hot summers and mild winters. Winters are generally mild, although cold weather occurs periodically every year. The mean minimum temperature for January is 4.9°C (40.8°F). Temperatures less than freezing (0°C/32°F) occur on an average of less than 25 days a year. In contrast, most summer afternoons are hot. The mean maximum temperature for July is 34.9°C (95°F).

Rainfall is generally evenly distributed throughout the year. The annual average precipitation recorded at the Austin Municipal Airport is 85.1 cm (33.5 in). The largest rainfall occurs in the spring, with May the wettest month (average 10.9 cm/4.3 in). Driest weather usually occurs during the summer, but the late winter/early spring periods are also typically dry. The driest month is August with an annual average of 5.6 cm (2.2 in). Most of the rainfall during the summer months usually results from thunderstorm activity. Surface winds come from the south throughout the year, although north winds and sudden temperature drops are frequent in the winter. The average length of the warm season is 273 days, with the average date of the first freeze in the fall being November 30 and the last freeze in the spring being March 1.

WATER QUALITY STANDARDS

Water quality standards specifying water uses deemed desirable and numerical criteria have recently been developed for Barton Creek. The current edition of the Texas Surface Water Quality Standards was adopted by the Texas Water Commission in October 1985 (TWC, 1985). 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 Barton Creek are contact recreation and high quality aquatic life habitat. The following are the numerical criteria established for Barton Creek (Segment 1430) 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
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 500 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, effluent dominated, 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 are required to determine the attainment of the fecal coliform criterion.

WATER QUALITY MONITORING STATIONS

The Texas Department of Water Resources has recently (September 1985) added three monitoring stations on Barton Creek. These stations are located at the pedestrian bridge in Zilker Park, Loop 360, and US 71. Field measurements, chemical measurements in water, and bacteriological analyses will be made at these stations on a semi-annual basis. The United States Geological Survey currently has three active monitoring stations on Barton Creek. Stream flow is gaged continuously at Barton Creek near Camp Craft Road and Loop 360. Field measurements and water quality data are periodically gathered by USGS at these two stations and from one immediately downstream of Barton Pool in Zilker Park (Table 2). In addition, continuous gaging of flow and periodic water quality sampling of Barton Springs in Zilker Park are conducted by the USGS. The USGS water quality data are published, but are also retrievable through the Commission's Stream Monitoring Program.

HISTORICAL WATER QUALITY

Historical water quality data from Barton Creek near Camp Craft Road, Loop 360, and just downstream of Barton Pool are presented in Table 3. In addition to periodic routine monitoring, the USGS has monitored water quality in Barton Creek during several storm events in 1980, 1981, and 1982. These data were not utilized in the computations presented in Table 3.

Surface water temperatures, pH measurements, and dissolved oxygen concentrations have been within the criteria (temperature maximum 32.1°C, pH range 6.5-9.0 units, dissolved oxygen minimum 5.0 mg/L) at the three monitoring stations over the past five years. Levels of chloride, sulfate, and total dissolved solids have not exceeded the respective criteria of 40, 40, and 500 mg/L (annual averages) for the past five years at the three stations. Only one fecal coliform level has exceeded the criterion (200/100 mL) over the past five years.

WASTEWATER DISCHARGERS

The Texas Department of Water Resources has issued permits to five domestic wastewater treatment plants (WWTP's) in Segment 1430 (Table 4). None of these permits allow a direct discharge of wastewater to Barton Creek. Travis Country Utility District irrigates its wastewater onto adjacent pastureland. Lost Creek Municipal Utility District irrigates its wastewater onto a golf course within the development. Lake Travis Independent School District utilizes subsurface irrigation to treat its wastewater. The Catholic High School for Austin, Inc. located in the Estates above Lost Creek has been issued a permit that allows irrigation. Due to the small size of the school, at the present time wastewater is retained in a large steel holding tank and trucked out of the development for treatment. The wastewater treatment facility at Barton Creek West Water Supply has not been constructed, but will utilize irrigation upon completion. Excepting the Lake Travis Independent School District, all of the wastewater treatment facilities are required to meet advanced secondary effluent limitations.

PREVIOUS WATER QUALITY STUDIES

The Texas Department of Water Resources has conducted a previous water quality study of Barton Creek and Barton Springs (Twidwell, 1976). Monthly bacteriological sampling of Barton Springs began September 1973 and continued through September 1974. Bacteriological and water quality sampling of Barton Creek at five locations continued from June 1975 until July 1976. Excepting one collection trip, all of the samples were collected during moderate to low flow conditions. Nutrient levels were low throughout the study and, on most sampling dates, chlorophyll a levels were below the detection limit (4 μg/L). The low nutrient levels, particularly phosphorus, were thought to be limiting the growth and proliferation of algae in Barton Creek. Chloride and sulfate levels averaged 10.8 and 17.9 mg/L, respectively, at the five stations during the year. Fecal coliform levels were below the criterion (200/100 mL) established for water utilized for contact recreation. Fecal coliform: fecal streptococci ratios indicate that the low bacterial levels observed in Barton Creek were of non-human animal origin.

Bacteriological sampling of Barton Springs indicated that the springs did not contain detectable levels of fecal coliform. The one sampling run made following a heavy spring rainfall revealed higher levels of suspended solids, nutrients, and bacteria and demonstrated the ability of runoff to wash pollutants into the creek.

INTENSIVE SURVEY DATA

Hydraulics

During dry summer conditions flow in Barton Creek becomes intermittent, particularly over the Edwards Aquifer recharge zone between Station J (Camp Craft Road) and Station N (Barton Pool). A flow regime was selected for this study in which there was flow throughout the segment, but with a minimum amount crossing the recharge zone.

No major rainfall events occurred in the watershed prior to the study as evidenced by precipitation data from the Austin Municipal Airport and Dripping Springs (Figure 3). Thunderstorms, which occurred in the area May 13 and 14, 1985, produced rainfall accumulations of 2 cm (0.8 in) in Austin and 3 cm (1.2 in) in Dripping Springs. Increases in Barton Creek stream flow near Camp Craft Road and Loop 360 were due to runoff from these storm events (Figure 4). Due to the dry conditions which preceeded these storm events and the light accumulations, stream flow in Barton Creek quickly receded. The light rains that occurred in the area on May 17, 1985 failed to produce increases in stream flow at the two gage sites. The hydrographs from these two locations show gradually declining stream flow rates throughout week of May 20-24, 1985, when this intensive survey was conducted (Figure 4). General thunderstorms occurred during the study in the predawn hours of May 21, 1985. This storm event produced rainfall accumulations of 1.2 cm (0.47 in) in Austin and 0.9 cm (0.39 in) in Dripping Springs. Although mean discharge rates from the two stream flow gages increased only slightly, instantaneous measurements made at eight locations on Barton Creek revealed gradual increases of 0.0283 m^3/s (1 ft^3/s) to 0.0566 m^3/s (2 ft^3/s)(Table 5).

Due to anticipated slow stream velocities during low flow conditions, Barton Creek was divided into three reaches in which collection of hydraulic data was concentrated. The upstream reach extended from Hays County Road 187 (Station A) to Hays County Road 185 (Station D),; the middle reach extended from the Paisano Ranch (Station F) to Crystal Creek Drive (Station I); and the lower reach extended from Lost Creek Boulevard (Station IJ) to Loop 360 (Station L). Stream widths of Barton Creek exhibited a downstream trend for generally increasing width (Table 6). The widest portion of the creek that was measured occurred upstream of the waterfall near Camp Craft Road, while the most narrow areas were in the extreme headwaters near Hays County Road 187.

Stream discharge in Barton Creek generally increased from the headwaters to Lost Creek Boulevard, and then declined as the water flowed over the Edwards Aquifer recharge zone and was lost to the aquifer (Table 5). The lowest discharge (0.01 m^3/s) (0.37 ft^3/s) was measured at Hays County Road 187 (Station A) and the high (0.41 m^3/s) (14.5 ft^3/s) occurred at Lost Creek Boulevard (Station IJ).

Approximately 0.35 m^3/s (12.4 ft^3/s) of water infiltrated to the underground aquifer in the reach between Lost Creek Boulevard and Barton Pool in Zilker Park (Station N). The increase in discharge between Loop 360 (Station L) and Barton Pool (Station N) suggests there are small active springs in the area. During the week following the study Barton Creek was dry at Loop 360 indicating all of the stream flow was infiltrating to the aquifer above that point. The rainfall that occurred throughout the study area in the early morning hours of May 21, 1985, produced variations in discharge that ranged from no increase at Station N immediately upstream of Barton Pool to 0.08 m^3/s (2.8 ft^3/s) at Crystal Creek Drive (Station I).

Stream velocities were generally slow throughout the segment but were slowest at opposite ends of the segment (Table 7). In the upstream reaches between Hays County Road 187 (Station A) and Hays County Road 185 (Station D) stream velocites were generally less than 0.0312 m/s (0.10 ft/s). In the downstream reach below Lost Creek Boulevard average stream velocity was 0.0338 m/s (0.11 ft/s) or less. Stream velocities were highest in the middle portion of Barton Creek where discharge rates were also the highest. Within the reach between the Paisano Ranch (Station F) and Crystal Creek Drive (Station I), stream velocities ranged from 0.044 m/s (0.15 ft/s) to 0.070 m/s (0.23 ft/s).

Field Measurements

The diel measurements indicate excellent water quality throughout most of Barton Creek. Excepting one early morning measurement (4.0 mg/L) at Station M, dissolved oxygen levels at all the stations remained above the 5 mg/L segment criterion (Table 8, Figure 5). Time weighted diel averages at all the stations were greater than the criterion.

The small diel ranges between dissolved oxygen minima and maxima among all the stations further indicates stability in water quality and reflects the low primary productivity of the stream. Although the temporal ranges were narrow for most of the stations, they demonstrate a downstream trend toward widening. This trend is particularly evident at stations between Camp Craft Road (Station J) and the pedestrian bridge in Zilker Park (Station O). At all six stations within this reach, the diel ranges of dissolved oxygen levels exceeded 2 mg/L. Upstream of Camp Craft Road to Hays County Road 187 (Station I-A) the dissolved oxygen temporal ranges were $<$ 2 mg/L at all but one of the nine stations.

Among the stations, the lowest dissolved oxygen levels were measured at Station M (Barton Hills Subdivision). The time weighted diel average at this station was approximately 2 mg/L lower than those of the two adjacent stations. The highest dissolved oxygen level (7.7 mg/L) at Station M was lower than the time weighted diel averages at all the other stations, and the early morning low (4.0 mg/L) was the only level measured during the study less than the segment criterion. Stream flow at this station was very sluggish and the macrophyte, alligator weed, (Alternanthera philoxeroides) had invaded the streambed. Decomposition of the macrophytes and periphyton, due to the receding water level, may partially explain the lower dissolved oxygen levels at this station.

Measurements of pH ranged between 7.2 and 8.5 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

The five day and twenty day carbonaceous biochemical oxygen demand (CBOD) tests are indirect measures of the amount of short and longer term degradable organic matter present and techniques for measuring the oxygen demand of stream water. $CBOD_5$ and $CBOD_{20}$ levels in Barton Creek were low at all 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. The highest $CBOD_5$ level (3.0 mg/L) occurred at Station K (Twin Falls).

Influence of surface runoff from the rainfall that occurred during the very early morning hours May 21, 1985 on $CBOD_5$ levels was minimal. There was little difference in $CBOD_5$ levels among discrete samples collected at Ranch Road 12 (Station C), US 71 (Station G), and Loop 360 (Station L) prior to and after the rainfall.

Nutrients and Chlorophyll a

No water quality criteria have been established for orthophosphorus (OP), ammonia (NH_3-N), nitrite (NO_2), or nitrate nitrogen (NO_3), but their involvement in nuisance aquatic plant growth warrants their consideration. In addition, high concentrations of ammonia nitrogen are toxic to aquatic organisms, deplete available oxygen through bacterial nitrification, and are frequently an indicator of recent sewage pollution. Abundance of orthophosphorus, a principle ingredient in household detergents, in the water is also an indicator of recent sewage pollution. Chlorophyll a analyses were utilized to provide an estimate of the relative planktonic algal standing crops that were present at the Barton Creek sampling stations.

Ammonia and nitrite nitrogen levels were very low throughout Barton Creek. Of 29 samples, only eight had detectable levels of ammonia nitrogen and none contained detectable levels of nitrite nitrogen (Table 9). Nitrate nitrogen occurred in low concentrations throughout most of the creek. The highest concentrations occurred in the extreme lower portions of the creek downstream of Loop 360. The two lower stations in Zilker Park were influenced by groundwater discharges from spring sources. The low levels of ammonia and absence of nitrite nitrogen throughout Barton Creek indicates that nitrification was not a factor to observed nitrate or dissolved oxygen levels.

Ortho and total phosphorus levels were also very low throughout Barton Creek. Of 29 samples, only eight had detectable levels of orthophosphorus and the highest concentration was only 0.02 mg/L. Such low levels suggest that the nutrient may be limiting to the aquatic plant communities in the stream.

Chlorophyll a levels were also low throughout Barton Creek. Chlorophyll a concentrations in 18 of 29 samples were less than the detection limit of 2 μg/L and the highest level recorded at Loop 360 (Station L) was only 6 μg/L (Table 9). These data indicate that planktonic algal productivity in Barton Creek during the study was low.

Influence of surface runoff from the rainfall that occurred during the very early morning hours of May 21, 1985 on nutrients was most pronounced in the lower portion of Barton Creek. The highest levels of ammonia and nitrate nitrogen and ortho and total phosphorus at Loop 360 (Station L) occurred in discrete samples collected following the rainfall. Concentrations of these parameters at least doubled following the rainfall and, while the levels are not considered elevated, similar trends among discrete samples collected before and after the rainfall at US 71 (Station G) and Ranch Road 12 (Station C) are not evident.

Chloride, Sulfate, Total Dissolved Solids, and Suspended Solids

All of the chloride, sulfate, and total dissolved solids levels at the mainstream Barton Creek stations were less than the respective segment criteria (40, 40, and 500 mg/L, annual averages). Instream concentrations for these parameters remained fairly consistent from station to station (Table 9). The influence of the rainfall on these conservative parameters was noticeable only at Loop 360 (Station L). Concentrations of chloride, sulfate, and total dissolved solids decreased slightly at the site after the rainfall due to dilution from the runoff.

Levels of total (TSS) and volatile suspended solids (VSS) were low throughout Barton Creek, but particularly in the upper half of the stream. Fifteen of 18 samples collected upstream of the Barton Creek West Subdivision (Station H), contained less than detectable levels of total suspended solids, an indication of the stream's clarity. Total suspended solids were generally detected in low concentrations at stations in the lower half of Barton Creek. The influence of rainfall on suspended solids was most noticeable at Loop 360 (Station L) where the highest concentration (34 mg/L) was measured in the discrete sample following the rainfall. In all of the suspended solids samples from Barton Creek the volatile or organic fractions were very low, indicating the solids detected were primarily inorganic.

Fecal Coliform Bacteria

Fecal coliform samples were collected at the Barton Creek stations in the morning of May 21, 1985, so they were influenced by the rainfall that occurred prior to sampling. Fecal coliform levels were highest in the extreme lower portion of Barton Creek at Stations M, N, and O where they exceeded 750/100 mL. These were the only samples that exceeded the 400/100 mL discrete sample criterion for contact recreation water (Table 10). From Loop 360 upstream, fecal coliform levels greater than 200/100 mL were measured at only two of 12 stations. While it is not possible to evaluate trends in bacterial quality on the basis of one sampling, the results of this study suggest that runoff from even a light rain on the watershed can produce elevated fecal coliform levels, particularly in the extreme lower portion of Barton Creek. Historical fecal coliform data collected at stations in this area during low flow conditions have generally been low in density (Table 3).

Benthic Macroinvertebrate Data

To assess existing biological health in the segment, benthic macroinvertebrates were collected at seven stations (Table 11). Eighty species were collected, a total comparable to numbers observed in other clean water central Texas streams. Macrobenthic density and diversity among stations generally reflected the amount and variety of organic matter available as food for invertebrate organisms. On the basis of macrobenthic community characteristics, the stream is divisible into three subreaches as discussed below.

The headwaters subreach, as represented by Station A, was characterized by a very narrow floodplain and dense riparian tree cover. Leaf litter was concentrated in the stream, and nutrients released from decaying detritus supported some periphytic diatom growth. In response to the abundant, varied food supply, the macrobenthic standing crop (2,158 individuals/m^2) was the highest in the study, and the number of species (32) was the second highest observed. In relative terms, the macrobenthic standing crop indicated a moderate level of secondary production. Community trophic structure, as indicated by the six most abundant species, was fairly well balanced, with four of the six functional feeding groups represented, and filterers of fine particulate organic matter (FPOM) predominant (48.3% of the community). Clean water indicative mayflies were well represented, with three species comprising 7.5% of the community. High diversity (3.66) and equitability (0.73) were well within ranges considered indicative of clean water and healthy environmental conditions.

The middle subreach, which encompassed most of the length of the segment, was represented by Stations D, G, J, and L. Leaf litter was less concentrated due to the wider floodplain, and food material for invertebrates was scarce, with an extreme scarcity of FPOM and periphytic algae. The lack of available food material limited species richness (13-24 species) and standing crop (381-691 individuals/m^2). In relative terms, the macrobenthic standing crop indicated very low levels of secondary production. Food material limitations were particularly evident in the upper portion of the subreach at Stations D and G, where diversity values (2.52, 2.22) were suppressed by low species richness (13 species at each station). Community trophic structure, as indicated by the six most abundant species, was fairly well balanced, with at least four functional feeding groups represented at each station. Filterers of suspended FPOM were predominant at Stations G, J, and L (76.9, 39.3, and 55.1%), while periphyton grazers and FPOM gatherers were codominant at Station D (26.1% each). Clean water indicative mayflies were well represented, with 2-5 species comprising from 1.5 to 56.4% of the community. Equitability was high at Stations D, J, and L (0.68, 0.68, 0.75), and moderate at Station G (0.60). Diversities were high at Stations J and L (3.11, 3.18), within the range generally associated with clean water.

Diversities at Stations D and G, as mentioned, were moderately low, but this is attributed to the limited food supply rather than degraded water quality. Overall macrobenthic community characteristics are considered indicative of clean water and healthy environmental conditions throughout the middle subreach.

The lower subreach, which extends from Station M to the mouth, was represented by Stations N and NO. It was characterized by plentiful invertebrate food supplies in the form of aquatic macrophytes and periphytic algae, the growth of which was promoted by nitrate nitrogen levels which were considerably higher than upstream. Nitrate nitrogen sources in the subreach appear to include natural inputs from springflow and nonpoint contributions from urban runoff. The plentiful food supply supported moderate-sized standing crops (1,928, 900 individuals/m^2) and relatively high species richness (35, 28 species), reflecting moderate levels of secondary production. Community trophic structure, as indicated by the six most abundant species, was well balanced, with five functional feeding groups represented and periphyton grazers slightly predominant (22.9, 20.1%) at each station. Clean water indicative mayflies were well represented, with five species comprising 12.5% of the community at Station N and two species comprising 8.3% of the community at Station NO. High diversities (4.05, 3.97) and equitabilities (0.79, 0.83) were in the upper end of ranges considered indicative of clean water and healthy environmental conditions.

Five species are representative of the existing macrobenthic assemblage in Barton Creek. The snail, Physa virgata, was present at all seven stations, while the mayflies, Baetis quilleri and Stenonema sp., and the caddisflies, Cheumatopsyche sp. and Chimarra sp., occurred at six stations. These species represent three functional feeding groups (periphyton grazers, sedimented FPOM gatherers, suspended FPOM filterers), which indicates that macrobenthic trophic structure is relatively well balanced at the present time.

The mayflies and caddisflies are relatively sensitive to environmental disturbance, and their widespread occurrence reflects healthy environmental conditions throughout the creek. The future status of these five species should be useful in monitoring gross environmental changes in Barton Creek.

In summary, macrobenthic community structure indicates that biological health is excellent throughout Barton Creek at the present time. Macrobenthic communities in the headwater subreach and lower subreach are very diverse, and secondary production is moderate. The middle subreach, which encompasses most of the length of the segment, is by nature very unproductive due to limited food supplies, which suppresses macrobenthic diversity by restricting the number of species present. However, from a water quality standpoint, this is a desirable condition that reflects the existence of excellent physicochemical quality. Compared to other area streams such as Slaughter and Bear creeks, Barton Creek has a much lower degree of primary and secondary production, indicating that nutrient and organic enrichment are not significant at the present time, and that Barton Creek remains in a comparatively pristine state.

Tributary Water Quality

Dissolved oxygen levels in Rocky Creek (Station EA) and Little Barton Creek (Station GA) remained above 6.0 mg/L throughout the diel sampling period. Levels of ammonia nitrogen (< 0.02 mg/L), nitrite nitrogen (< 0.01 mg/L), nitrate nitrogen ($\leq$ 0.04 mg/L), $CBOD_5$ (0.5 mg/L), chlorophyll *a* (3 μg/L), and total suspended solids (< 5 mg/L) were low. Water temperatures, and chloride, sulfate and total dissolved solids concentrations conformed to criteria established for Segment 1430.

CONCLUSIONS

Stream flow is usually observable throughout Barton Creek with the exception of an 11.3 kilometer intermediate section from near Camp Craft Road to Barton Pool in Zilker Park. Within this reach, Barton Creek flows over the Edwards Aquifer recharge zone, and under low flow conditions, its total stream flow infiltrates to the underground reservoir. A portion of this water reappears as spring water at Barton Springs in Zilker Park. This intensive survey was conducted at a time when there was minimal flow (0.0372 m^3/s) (1.31 ft^3/s) crossing the Edwards Aquifer recharge zone.

Previous studies have indicated that total infiltration of Barton Creek stream flow is not enough to account for the large volume of flow observed at Barton Springs. Onion Creek, Bear Creek, Little Bear Creek, Slaughter Creek, and Williamson Creek also cross the Edwards Aquifer recharge zone that supplies the underground aquifer. Although the rates and exact paths of water movement in the aquifer are not known, it is apparent that all the streams are hydrologically interconnected and, thus, influence the water quality of Barton Springs.

Population estimates for the next 25 years suggest rapid increases in the Barton Creek watershed. There presently are no sources of direct discharge of any type of wastewater to Barton Creek. Five permits have been issued by the Texas Water Commission for wastewater treatment facilities in Segment 1430. Of these five, two utilize land application, one uses subsurface irrigation, one trucks wastewater out of the basin, and one is under construction that will utilize land application. Water quality data collected during this study from Barton Creek upstream and downstream of each wastewater treatment facility indicate they are presently having no impacts.

The field and laboratory data collected during this study indicate excellent water quality throughout most of Barton Creek. Excepting one early morning measurement made near the Barton Hills Subdivision, dissolved oxygen levels remained above the segment 5 mg/L criterion. The narrow ranges between dissolved oxygen minima and maxima among the stations further indicates stability in water quality and reflects the low primary productivity of the stream. In most instances orthophosphorus concentrations were below or near the lower limit of detection (0.01 mg/L). Such low levels suggest that this nutrient may be limiting the productivity of aquatic plant communities in the stream. Chlorophyll *a* levels were less than the detection limit at more than half the stations on Barton Creek and the highest level was only 6 µg/L. Low levels of ammonia and absence of nitrite nitrogen indicate that nitrification was not a significant factor to the observed nitrate or dissolved oxygen levels. Stream $CBOD_5$ and $CBOD_{20}$ levels were low throughout and no areas of significant accumulation of or sources of oxygen demanding materials were found. Chloride, sulfate, total dissolved solids, water temperatures and pH levels conformed to segment criteria. Levels of total and volatile suspended solids were low throughout Barton Creek, but particularly in the upper half of the stream where most were less than 5 mg/L. Fecal coliform levels were elevated (>750/100 mL) in the lower portion of Barton Creek. Benthic macroinvertebrate community structure reflected low levels of secondary production and indicated clean water and healthy environmental conditions throughout the creek.

The influence of surface runoff from rainfall that occurred during the early morning hours of May 21, 1985, was most pronounced in the lower portion of Barton Creek. The highest levels of ammonia and nitrate nitrogen, ortho and total phosphorus, fecal coliform bacteria, total suspended solids, and chlorophyll a at Loop 360 occurred in discrete samples collected following the rainfall. Similar trends among discrete samples collected before and after the rainfall at US 71 and Ranch Road 12 north of Dripping Springs were not evident. While it is not possible to evaluate trends in water quality on the basis of one sampling, the results of the study suggest that runoff from even a light rain on the watershed adversely influences water quality, particularly in the extreme lower, more developed portion.

PRESENTATION OF DATA

TABLE 1

Barton Creek Survey Station Locations

Map Code	SMN Number	River Kilometer	Station Location
A	1430.1400	76.3	Barton Creek at Hays County Road 187
AB		74.9	Barton Creek on Private Property, 1.4 Km downstream of Hays County Road 187
B	1430.1300	71.1	Barton Creek at Hays County Road 169
BC		69.8	Barton Creek on Private Property, 1.3 Km downstream of Hays County Road 169
C	1430.1200	63.6	Barton Creek at Ranch Road 12
CD		60.7	Barton Creek on Private Property, 2.9 Km downstream of Ranch Road 12
D	1430.1100	57.1	Barton Creek at Hays County Road 185
E	1430.1000	49.5	Barton Creek on Shield Ranch, 7.6 Km downstream of Hays County Road 185
F	1430.0900	39.9	Barton Creek on the Paisano Ranch, 6 Km upstream of US 71
G	1430.0750	33.8	Barton Creek at US 71
H	1430.0700	26.2	Barton Creek at Barton Creek West Subdivision, 7.6 Km downstream of US 71
I	1430.0600	21.2	Barton Creek at Crystal Creek Drive
IJ		14.6	Barton Creek at Lost Creek Boulevard
J	1430.0500	12.5	Barton Creek near Camp Craft Road
K	1430.0400	10.1	Barton Creek at Twin Falls near Barton Creek Mall, 2.8 Km upstream of Loop 360
L	1430.0360	7.3	Barton Creek at Loop 360
M	1430.0250	3.4	Barton Creek Barton Hills Subdivision 2208 Forest Bend Drive, 3.9 Km downstream of Loop 360
N	1430.0100	1.2	Barton Creek 10 m upstream of Barton Pool
NO	1430.0075	0.8	Barton Creek 10 m downstream of Barton Pool
O	1430.0050	0.3	Barton Creek at Pedestrian Bridge in Zilker Park
GA	1400.2600	3.4/0.2	Little Barton Creek on Private Road near US 71
EA	1400.2650	49.9/3.3	Rocky Creek at Fitzhugh Road

TABLE 2

Active Water Quality Monitoring Stations on Barton Creek

Station	Map Code	Sampling Agency/ Station Number	Frequency Sampling/ Type of Record	Period of Record
Barton Creek at US 71	G	TWC - 1430.0750	3-FD, CH, BA	September 1985 to present
Barton Creek near Camp Craft Road	J	USGS - 08155260 (SMN 1430.0500)	2-CH, BC, PS 1-Dd	February 1983 to present September 1982 to present
Barton Creek at Loop 360	L	USGS - 08155300 TWC - 1430.0360	2-CH, BC, PS 1-Dd 3-FD, CH, BA	January 1979 to present February 1977 to present September 1985 to present
Barton Creek downstream of Barton Pool	NO	USGS - 08155505 (SMN 1430.0075)	2-CH, BC, PS 1-Dd	January 1975 to present January 1975 tp present
Barton Creek at the Pedestrian Bridge in Zilker Pool	O	TWC - 1430.0050	3-FD, CH, BA	September 1985 to present

Frequency of Sampling

1 Continuously
2 Periodically
3 Twice a year

Type of Record

FD Field Measurements in water
CH Chemical measurements in water
BC Biochemical measurements in water
PS Pesticide in water
Dd Stream discharge

TABLE 3

Historical Water Temperature, pH, Chloride, Sulfate, Total Dissolved Solids, and Fecal Coliform Data Collected by the United States Geological Survey at Three Locations on Barton Creek
January 1, 1980 - December 31, 1984

Monitoring Station SMN Number USGS Number	Map Code	Segment Critera →	Parameter: Water Temperature 32.1°C	pH Units 6.5-9.0	Dissolved Oxygen 5.0 mg/L	Chloride 40 mg/L	Sulfate 40 mg/L	TDS 500 mg/L	Fecal Coliform 200/100 mL
Barton Creek near	J	Number of Obs.	4	4	4	4	4	4	4
Camp Craft Road		Mean	15.0	---	10.1	16.5	29.5	239	40*
SMN 1430.0500		Range	13-19	7.8-8.2	9.5-11.6	14-19	18-32	230-252	5-770
USGS 08155260		Percent > Criterion	0	0	0	0	0	0	25
Barton Creek at	L	Number of Obs.	5	5	5	4	4	4	4
Loop 360		Mean	15.4	---	10.6	11.8	24.8	229	15*
SMN 1430.0360		Range	8.5-24	7.4-8.1	8.2-13.8	10-14	21-29	204-239	4-160
USGS 08155300		Percent > Criterion	0	0	0	0	0	0	0
Barton Creek	NO	Number of Obs.	6	6	6	6	6	6	6
downstream of		Mean	20.0	---	8.2	24.6	25.0	329	16*
Barton Pool		Range	19.5-22.5	6.9-7.6	7.4-10.6	17-34	20-31	287-359	3-130
SMN 1430.0075		Percent > Criterion	0	0	0	0	0	0	0
USGS									

* Geometric Mean

TABLE 4

Permitted Average Flow and Five-Day Biochemical Oxygen Demand (BOD_5)
For the Five Wastewater Treatment Plants in the Barton Creek Watershed

Wastewater Discharger	Map Code	Flow Daily Average m^3/s	Flow Daily Average MGD	BOD_5 Daily Average mg/L
Travis Country Utility District Permit No. 11294.01	1	0.0099	0.225	10
Lost Creek Municipal Utility District Permit No. 11319.01	2	0.0228	0.52	10
Barton Creek West Water Supply Permit No. 12786.01	3	0.0066	0.15	10
Catholic High School for Austin, Inc. Permit No. 12916.01	4	0.0006	0.013	10
Lake Travis Independent School District Permit No. 12920.01	5	0.0009	0.020	20

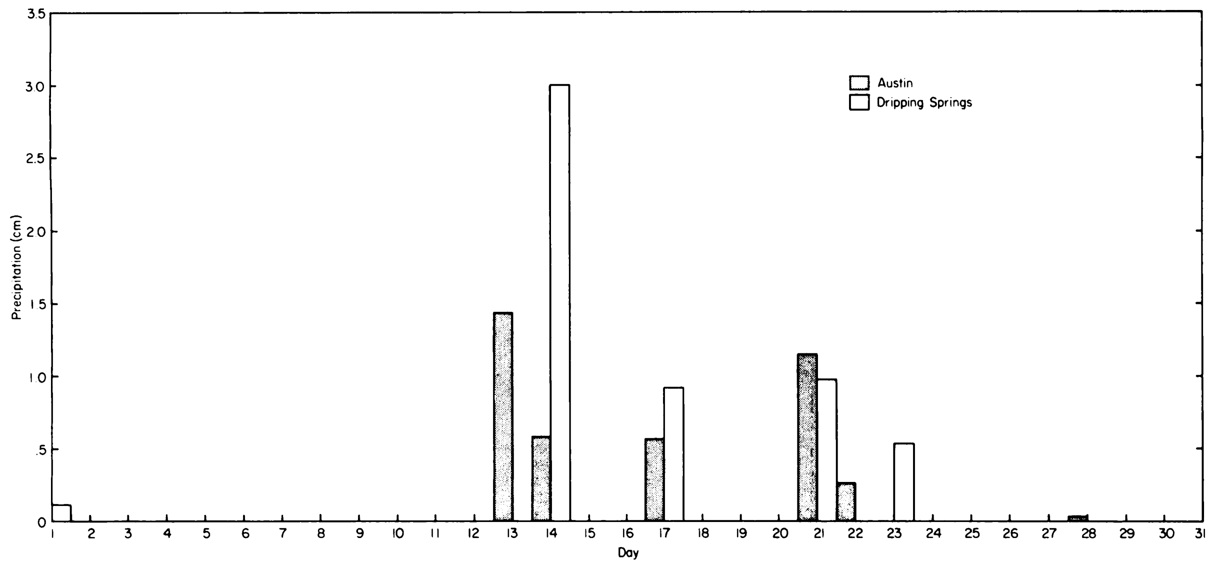

Figure 3

Daily Precipitation at Austin (Municipal Airport)
and Dripping Springs (George Bomar), May 1-31, 1985

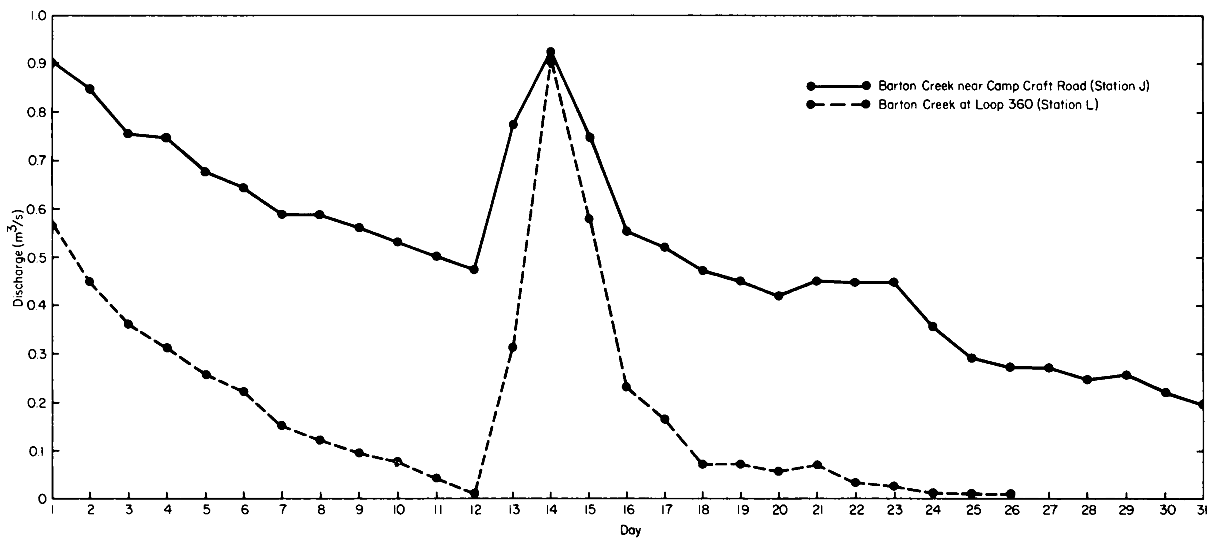

Figure 4

Mean Daily Discharge Rate From Barton Creek
Near Camp Craft Road and at Loop 360, May 1-31, 1985
Unpublished USGS Records, Subject to Revision

TABLE 5

Barton Creek Stream Discharge Data

Map Code	Station Location	Date	Time	Discharge m^3/s	Discharge ft^3/s	Method
A	Hays County Road 187	05/20/85	1205	0.0114	0.40	MM*
		05/21/85	1145	0.0224	0.79	MM
		05/22/85	0845	0.0105	0.37	MM
		05/23/85	0907	0.0073	0.26	MM
B	Hays County Road 169	05/21/85	1315	0.0291	1.03	MM
		05/23/85	0840	0.0179	0.63	MM
BC	Private Property	05/23/85	1400	0.0893	3.16	MM
C	Ranch to Market Road 12	05/20/85	1610	0.1078	3.81	MM
D	Hays County Road 185	05/20/85	1345	0.1798	6.35	MM
		05/20/85	1355	0.1773	6.26	MM
		05/21/85	0640	0.2028	7.16	MM
		05/22/85	0800	0.1868	6.60	MM
		05/23/85	1015	0.1895	6.69	MM
F	Paisano Ranch	05/20/85	1140	0.1532	5.41	MM
		05/21/85	1205	0.1797	6.35	MM
		05/22/85	1015	0.1733	6.12	MM
		05/23/85	1125	0.1615	5.70	MM
G	US 71	05/21/85	1040	0.3465	12.24	MM
H	Barton Creek West Subdivision	05/23/85	0925	0.3276	11.57	MM
		05/24/85	1430	0.2510	8.86	MM
I	Crystal Creek Drive	05/20/85	1610	0.3067	10.83	MM
		05/21/85	1855	0.3889	13.73	MM
		05/22/85	1930	0.4101	14.48	MM
		05/24/85	0945	0.3188	11.26	MM
IJ	Lost Creek Boulevard	05/20/85	1115	0.3588	12.67	MM
		05/21/85	0640	0.4115	14.53	MM
		05/22/85	0640	0.3869	13.66	MM
		05/23/85	0900	0.4007	14.15	MM
J	Camp Craft Road	05/20/85	1315	0.1906	6.73	MM
		05/21/85	1210	0.2410	8.51	MM

TABLE 5 CONTINUED

Map Code	Station Location	Date	Time	Discharge m^3/s	Discharge ft^3/s	Method
K	Twin Falls near Barton Creek Mall	05/20/85	1600	0.1728	6.10	MM
		05/21/85	1415	0.2356	8.32	MM
		05/22/85	1100	0.1637	5.78	MM
L	Loop 360	05/22/85	1150	0.0232	0.82	MM
		05/23/85	0825	0.0292	1.03	MM
N	10 m Upstream of Barton Pool	05/20/85	1025	0.0413	1.46	MM
		05/21/85	0715	0.0365	1.29	MM
		05/22/85	0725	0.0357	1.26	MM
		05/23/85	0945	0.0354	1.25	MM
EA	Rocky Creek at Hays County Road 185	05/21/85	1220	0.0354	1.25	MM
GA	Little Barton Creek near US 71	05/20/85	1420	0.0504	1.78	MM
		05/21/85	1935	0.0615	2.17	MM
		05/23/85	1245	0.0720	2.54	MM

* Discharge measured manually with electronic meter

TABLE 6

Barton Creek Stream Width Measurements

Stream Reach: From	Stream Reach: To	Number of Measurements	Range (m)	Mean (m)
Hays County Road 187 (A)	Hays County Road 169 (B)	73	0.3 - 20.6	5.2
Hays County Road 169 (B)	Ranch to Market Road 12 (C)	84	3.1 - 40.0	9.0
Ranch to Market Road 12 (C)	Hays County Road 185 (D)	78	3.2 - 24.5	10.3
Paisano Ranch (F)	US 71 (G)	43	4.9 - 22.0	13.0
US 71 (G)	Barton Creek West Subdivision (H)	44	6.8 - 26.0	15.9
Barton Creek West Subdivision (H)	Crystal Creek Drive (I)	41	5.2 - 24.0	12.6
Lost Creek Boulevard (IJ)	Camp Craft Road (J)	18	1.0 - 47.0	22.9
Camp Craft Road (J)	Twin Falls (K)	30	9.7 - 35.8	21.0
Twin Falls (K)	Loop 360 (L)	25	8.8 - 27.0	19.0

TABLE 7

Barton Creek Discharge and Velocity Measurements

From	To	Date	Discharge m³/s Upstream Sta./ Downstream Sta.	Distance km (mi.)	Travel Time (Hours)	Velocity m/s (ft/s)
Hays Co. Road 187 (A)	AB	05/20-21/85	0.4/---	1.4 (0.9)	24.83	0.0157 (0.05)
AB	Hays Co. Road 169 (B)	05/21-23/85	---/0.6	3.8 (2.4)	31.17	0.0339 (0.11)
Hays Co. Road 169 (B)	BC	05/21-22/85	1.0/3.2	1.3 (0.8)	21.25	0.0170 (0.06)
Ranch Road 12 (C)	CD	05/20-21/85	3.8/---	2.9 (1.8)	25.83	0.0312 (0.10)
Paisano Ranch (F)	US 71 (G)	05/20-22/85	5.4/12.2	6.1 (3.8)	38.30	0.0443 (0.15)
US 71 (G)	Barton Creek West Subdivision (H)	05/21-23/85	---/8.9	7.6 (4.7)	46.25	0.0456 (0.15)
Barton Creek West Subdivision (H)	Crystal Creek Drive (I)	05/23-24/85	11.6/11.3	5.0 (3.1)	19.78	0.0702 (0.23)
Lost Creek Boulevard (IJ)	Camp Craft Road (J)	05/20-21/85	12.7/8.5	2.1 (1.3)	17.25	0.0338 (0.11)
Camp Craft Road (J)	Twin Falls (K)	05/20/21/85	6.7/6.1	2.4 (1.5)	34.00	0.0196 (0.06)
Twin Falls (K)	Loop 360 (L)	05/21-23/85	8.3/1.0	2.8 (1.7)	35.92	0.0217 (0.07)

TABLE 8

Barton Creek Field Measurements

Map Code and Station Number	Time	Depth (m)	Water Temp. (°C)	Conductivity (µmhos/cm)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Sat)	pH (Units)
A 1430.1400	1025	0.3	22.7	570.	7.0	81.4	7.2
	1400	0.3	23.1	566.	7.3	85.6	7.7
	1755	0.3	24.9	564.	7.4	89.7	7.8
	0550	0.3	22.1	550.	7.1	81.6	7.8
	DIEL MEAN		23.3	561.	7.2	84.9	7.7
B 1430.1300	1059	0.3	22.3	564.	8.7	100.4	7.6
	1420	0.3	22.8	556.	8.5	99.1	7.8
	1806	0.3	23.3	561.	8.5	100.0	7.8
	0603	0.3	22.1	562.	7.8	89.7	7.8
	DIEL MEAN		22.6	561.	8.3	96.3	7.8
C 1430.1200	1125	0.3	23.0	484.	8.3	97.1	7.9
	1440	0.3	25.1	480.	8.2	99.8	8.0
	1823	0.3	26.0	478.	8.3	102.7	8.0
	0625	0.3	21.5	465.	7.4	84.1	8.0
	DIEL MEAN		23.8	475.	8.0	94.7	8.0
D 1430.1100	1146	0.3	23.2	484.	7.4	86.9	7.8
	1456	0.3	24.0	481.	7.8	93.0	7.9
	1837	0.3	25.2	482.	7.9	96.3	7.9
	0644	0.3	22.7	476.	7.4	86.1	7.9
	DIEL MEAN		23.8	480.	7.6	90.6	7.9
EA 1400.2650	1158	0.3	21.4	542.	6.9	78.3	7.7
	1515	0.3	22.4	538.	6.6	76.3	7.8
	1845	0.3	22.5	536.	6.3	73.0	7.8
	0708	0.3	20.2	534.	7.2	79.8	7.8
	DIEL MEAN		21.5	537.	6.8	76.8	7.8
E 1430.1000	1420	0.3	24.3	---	8.1	97.1	8.5
	1945	0.3	25.0	---	7.8	94.7	7.3
	0818	0.3	22.4	---	7.8	90.2	7.3
	DIEL MEAN		23.8	---	7.9	93.6	7.6

TABLE 8 CONTINUED

Map Code and Station Number	Time	Depth (m)	Water Temp. (°C)	Conductivity (µmhos/cm)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (mg/L)	pH (Units)
F 1430.0900	1105	0.3	23.9	---	5.9	70.2	7.3
	1705	0.3	25.3	---	8.9	108.7	7.3
	1800	0.3	25.3	---	9.0	109.9	7.4
	0628	0.3	23.4	---	7.2	84.9	7.8
	DIEL MEAN		24.3	---	7.7	92.1	7.5
GA 1400.2600	1247	0.3	24.0	---	7.7	91.8	7.8
	1615	0.3	25.6	---	8.6	105.6	7.3
	1834	0.3	26.0	---	8.6	106.4	7.3
	0755	0.3	23.1	---	6.7	78.5	7.3
	DIEL MEAN		24.5	---	7.7	93.2	7.4
G 1430.0750	1302	0.3	24.5	---	---	---	7.9
	1607	0.3	25.6	---	8.6	105.6	7.3
	1826	0.3	25.2	---	8.8	107.3	7.3
	0745	0.3	23.8	---	7.1	84.3	7.6
	DIEL MEAN		24.6	---	8.0	96.5	7.5
H 1430.0700	1223	0.3	24.6	---	7.5	90.4	7.8
	1542	0.3	25.4	---	7.9	96.7	7.3
	1915	0.3	25.2	---	8.2	100.0	7.3
	0902	0.3	24.4	---	7.3	87.7	7.3
	DIEL MEAN		24.9	---	7.7	93.8	7.4
I 1430.0600	1201	0.3	24.0	---	7.9	94.2	8.0
	1515	0.3	25.5	---	8.5	104.2	7.6
	1855	0.3	26.1	---	8.8	109.1	7.3
	0925	0.3	22.9	---	7.7	89.9	7.5
	DIEL MEAN		24.6	---	8.3	99.7	7.5
J 1430.0500	1225	0.3	24.7	461.	9.3	112.3	8.0
	1615	0.3	25.7	455.	7.9	97.2	8.1
	1940	0.3	25.8	457.	9.1	112.2	8.1
	0750	0.3	23.9	461.	6.9	82.1	8.0
	DIEL MEAN		24.9	459.	8.2	99.4	8.0

TABLE 8 CONTINUED

Map Code and Station Number	Time	Depth (m)	Water Temp. (°C)	Conductivity (μmhos/cm)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Sat)	pH (Units)
K 1430.0400	1155	0.3	24.0	505.	10.3	122.8	8.3
	1550	0.3	26.5	425.	8.0	99.9	8.3
	1905	0.3	26.3	429.	8.3	103.2	8.3
	0820	0.3	22.5	434.	7.5	86.9	8.2
	DIEL MEAN		24.6	442.	8.3	100.1	8.3
L 1430.0360	1100	0.3	25.0	415.	10.3	125.1	8.3
	1455	0.3	25.9	408.	8.5	105.0	8.3
	1840	0.3	26.6	410.	8.7	108.8	8.3
	0705	0.3	22.6	380.	7.1	82.4	8.1
	DIEL MEAN		24.9	400.	8.4	101.9	8.2
M 1430.0250	1045	0.3	21.3	584.	7.7	87.2	7.5
	1440	0.3	22.4	566.	6.2	71.7	7.4
	1825	0.3	23.8	568.	7.5	89.1	7.5
	0650	0.3	19.7	557.	4.0	43.9	7.3
	DIEL MEAN		21.8	567.	6.1	70.6	7.4
N 1430.0100	1025	0.3	22.3	557.	9.2	106.2	7.6
	1420	0.3	23.5	554.	8.1	95.7	7.6
	1808	0.3	25.6	551.	9.7	119.1	7.6
	0630	0.3	21.6	548.	6.3	71.7	7.4
	DIEL MEAN		23.4	551.	8.2	97.2	7.5
O 1430.0050	1000	0.3	21.3	625.	10.4	117.7	7.2
	1400	0.3	21.9	625.	8.2	93.9	7.2
	1750	0.3	22.4	620.	9.1	105.2	7.3
	0615	0.3	20.6	627.	6.4	71.5	7.2
	DIEL MEAN		21.5	624.	8.3	94.0	7.2

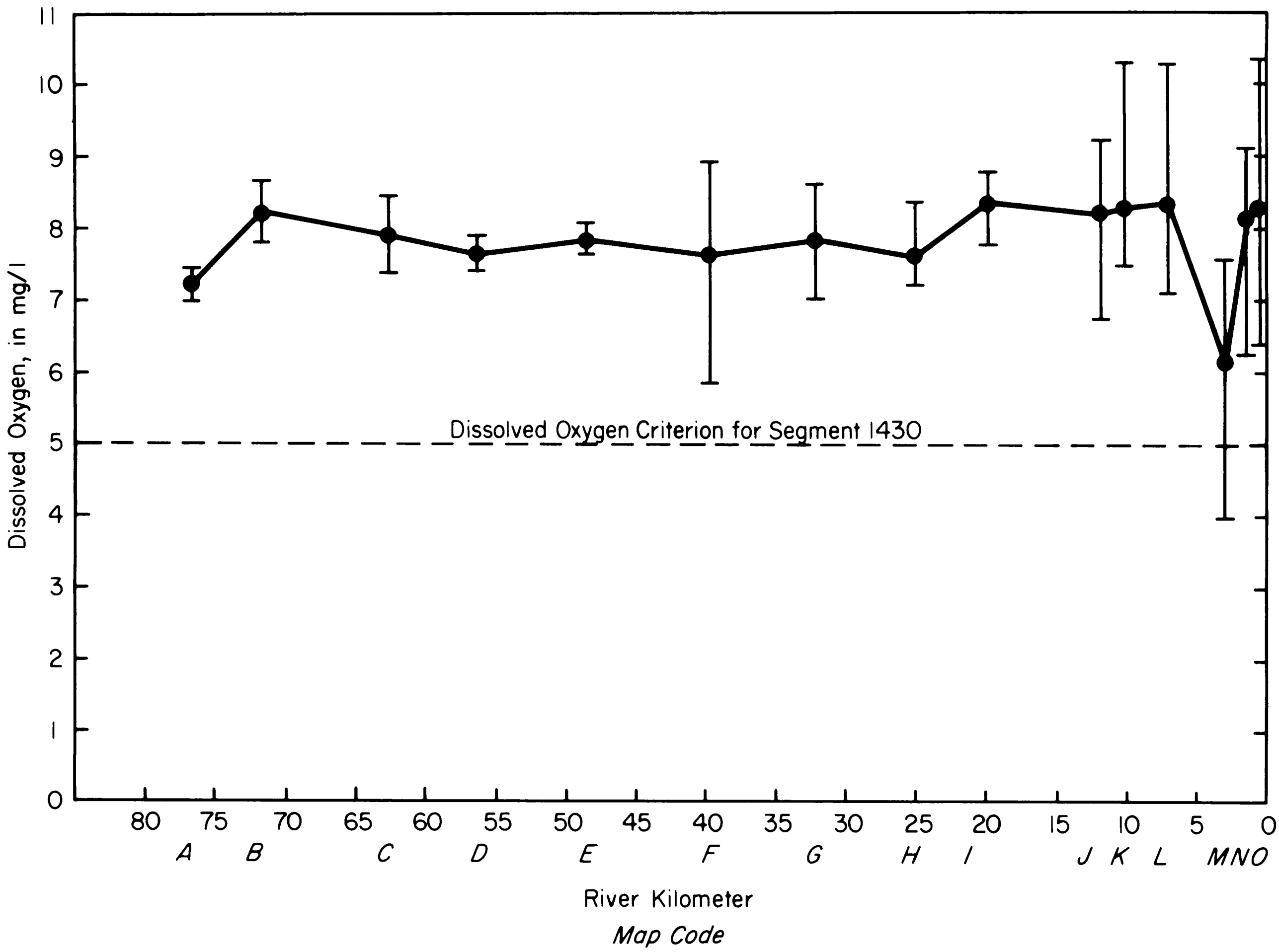

Figure 5

Mean and Range of Dissolved Oxygen Levels From Barton Creek by River Kilometer and Map Code, May 20-21, 1985

TABLE 9

Barton Creek Laboratory Water Analyses

Map Code	and Station Number	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_3-N mg/L	NO_2-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
A	1430.1400	COMP	0.3	1.0	1.0	2.0	2.0	2	0.50	0.03	<.01	0.01	0.02	0.03	<2	<2	20	27	5	2	304	251	616
B	1430.1300	COMP	0.3	0.5	0.5	1.5	1.5	2	0.30	<.02	<.01	0.03	<.01	0.02	<2	<2	18	23	<5	<5	292	255	608
C	1430.1200	COMP	0.3	<0.5	<0.5	0.5	0.5	1	0.30	<.02	<.01	0.08	<.01	0.02	3	<2	17	23	<5	<5	250	208	500
C	1430.1200	1125	0.3	<0.5	<0.5	<0.5	<0.5	1	0.20	<.02	<.01	0.07	<.01	0.01	<2	<2	18	24	<5	<5	254	211	508
C	1430.1200	1440	0.3	<0.5	<0.5	0.5	0.5	1	0.20	<.02	<.01	0.08	<.01	0.01	<2	<2	17	23	<5	<5	264	210	504
C	1430.1200	1823	0.3	<0.5	<0.5	1.0	1.0	1	0.10	<.02	<.01	0.08	<.01	0.01	<2	3	17	23	<5	<5	240	206	500
C	1430.1200	0625	0.3	0.5	<0.5	1.0	1.0	1	0.20	<.02	<.01	0.09	<.01	0.01	<2	<2	17	23	<5	<5	254	204	511
D	1430.1100	COMP	0.3	0.5	0.5	1.0	1.0	1	0.30	<.02	<.01	0.04	<.01	0.02	<2	<2	17	23	<5	<5	278	210	500
EA	1400.2650	COMP	0.3	0.5	0.5	1.0	1.0	1	0.20	0.03	<.01	0.04	<.01	0.01	<2	<2	14	28	<5	<5	282	243	572
E	1430.1000	COMP	0.3	1.0	0.5	1.5	1.0	1	0.20	<.02	<.01	0.04	<.01	0.02	3	<2	17	24	<5	<5	292	212	504
F	1430.0900	COMP	0.3	1.0	0.5	1.5	1.5	1	0.40	<.02	<.01	0.03	0.02	0.03	<2	<2	17	23	7	2	266	200	483
GA	1400.2600	COMP	0.3	0.5	0.5	1.0	1.0	1	0.30	<.02	<.01	0.03	<.01	0.02	<2	<2	17	22	<5	<5	236	197	483
G	1430.0750	COMP	0.3	1.0	0.5	1.5	1.0	1	0.30	<.02	<.01	0.02	<.01	0.02	<2	<2	16	23	<5	<5	252	197	476
G	1430.0750	1302	0.3	0.5	0.5	1.0	1.0	1	0.30	0.03	<.01	0.02	<.01	0.02	4	<2	17	22	<5	<5	240	200	480
G	1430.0750	1607	0.3	0.5	<0.5	1.0	1.0	1	0.20	<.02	<.01	0.02	<.01	0.01	<2	<2	16	23	<5	<5	244	197	473
G	1430.0750	1826	0.3	0.5	0.5	1.0	1.0	1	0.30	<.02	<.01	0.02	<.01	0.01	4	<2	16	22	<5	<5	238	195	473
G	1430.0750	0745	0.3	1.0	1.0	1.5	1.5	1	0.40	<.02	<.01	0.03	<.01	0.02	2	<2	16	22	5	2	248	195	473
H	1430.0700	COMP	0.3	0.5	1.0	1.5	1.0	1	0.30	0.03	<.01	0.03	<.01	0.02	<2	<2	17	23	<5	<5	254	194	473
I	1430.0600	COMP	0.3	1.0	1.0	1.5	1.5	1	0.30	<.02	<.01	0.04	<.01	0.02	<2	<2	16	23	5	1	246	193	469
J	1430.0500	COMP	0.3	1.0	0.5	1.5	1.0	2	0.60	0.05	<.01	0.04	0.01	0.04	<2	<2	17	24	7	3	260	192	473
K	1430.0400	COMP	0.3	3.0	1.5	5.0	3.0	2	0.80	0.04	<.01	0.03	<.01	0.09	4	5	21	25	15	4	260	178	462
L	1430.0360	COMP	0.3	1.5	1.0	2.5	1.5	2	0.40	<.02	<.01	0.06	<.01	0.06	3	<2	17	24	25	2	242	162	414
L	1430.0360	1100	0.3	1.0	1.0	2.0	1.5	2	0.40	<.02	<.01	0.02	<.01	0.04	2	<2	17	23	<5	<5	234	168	423
L	1430.0360	1455	0.3	1.0	0.5	2.0	1.5	2	0.40	<.02	<.01	0.01	<.01	0.02	6	<2	17	23	6	1	240	166	420
L	1430.0360	1840	0.3	1.5	1.0	2.0	2.0	2	0.40	0.02	<.01	0.01	0.01	0.02	<2	<2	17	23	5	3	226	166	420
L	1430.0360	0705	0.3	1.5	1.0	4.0	2.5	3	0.30	0.04	<.01	0.27	0.02	0.08	6	<2	13	21	34	4	196	137	350
M	1430.0250	COMP	0.3	1.0	0.5	1.5	1.0	2	0.30	<.02	<.01	0.38	<.01	0.02	<2	<2	16	25	8	2	284	253	588
N	1430.0100	COMP	0.3	1.0	0.5	1.5	1.0	2	0.30	<.02	<.01	0.77	0.01	0.02	4	<2	17	26	<5	<5	306	237	564
O	1430.0050	COMP	0.3	1.0	1.0	1.5	1.0	<1	0.30	<.02	<.01	1.21	0.02	0.03	<2	2	26	29	<5	<5	338	256	645

TABLE 10

Barton Creek Fecal Coliform Data

Map Code	Station Location	Fecal Coliform Density #/100 mL
A	Hays County Road 187	20
B	Hays County Road 169	80
C	Ranch Road 12	140
D	Hays County Road 185	170
E	Shield Ranch	290
F	Paisano Ranch	20
G	US 71	110
H	Barton Creek West Subdivision	20
I	Crystal Creek Drive	300
J	Camp Craft Road	10
K	Twin Falls	50
L	Loop 360	150
M	Forest Bend Drive	980
N	10 m Upstream of Barton Pool	960
O	Pedestrian Bridge in Zilker Park	780
GA	Little Barton Creek near US 71	70
EA	Rocky Creek at Fitzhugh Road	380

TABLE 11

Barton Creek Benthic Macroinvertebrate Data*

Station	A	D	G	J	L	N	NO
Number of Individuals/m^2	2,158	381	672	691	405	1,928	900
Number of Species	32	13	13	24	19	35	28
Diversity	3.66	2.52	2.22	3.11	3.18	4.05	3.97
Redundancy	0.32	0.49	0.51	0.48	0.43	0.26	0.25
Equitability	0.73	0.68	0.60	0.68	0.75	0.79	0.83
Taxon	**Number of Individuals/m^2**						
COELENTERATA							
Hydra sp.				5			5
TURBELLARIA							
Dugesia tigrina	54					5	124
NEMERTEA							
Prostoma rubrum	16		5	11		5	
NEMATODA	43						
HIRUDINEA							
Helobdella triserialis						129	11
Myzobdella lugubris						5	
Placobdella translucens				5			
OLIGOCHAETA							
Branchiura sowerbyi	54						
Chaetogaster diaphanus							5
Dero furcata							22
Limnodrilus sp.							5
Lumbricidae						5	
Nais variabilis							5
Pristina leidyi					5	5	
Pristina sima					5		
Slavina appendiculata			5		5	5	16
Sparganophilus tamesis		5	5	5	5		

TABLE 11 CONTINUED

Station	A	D	G	J	L	N	NO
Taxon	Number of Individuals/m²						
GASTROPODA							
Biomphalaria obstructus	43			5		11	
Physa virgata	124	5	32	5	16	172	5
Pyrgophorus coronatus				22		5	
AMPHIPODA							
Hyallela azteca							102
OSTRACODA							
Chlamydotheca arcuata						22	
HYDRACARINA							
Neoacarus sp.				5			
Sperchon sp.				11			
COLEOPTERA							
Berosus sp.	5					5	
Chelonariidae					5		
Deronectes sp.	70						
Enochrus sp.						5	
Neoelmis caesa				5			
Stenelmis bicarinata	16						
Stenelmis sexlineata	48						
Tropisternus sp.	5						
DIPTERA							
Ablabesmyia annulata			38				
Ablabesmyia sp.					5		
Rheotanytarsus sp.	344	16		253			
Conchapelopia sp.	11				5	43	5
Cricotopus bicinctus							16
Cricotopus sp.							48
Cryptochironomus fulvus gr.						43	
Dicrotendipes neomodestus						43	27
Dicrotendipes sp.	5						
Empididae		5					
Lauterborniella sp.						22	
Limnophora sp.						5	
Odontomyia sp.						5	
Orthocladius sp.	5						91
Parametriocnemus sp.							5
Pentaneura sp.		22	22		11	151	27

TABLE 11 CONTINUED

Station	A	D	G	J	L	N	NO
Taxon	Number of Individuals/m²						
DIPTERA CONTINUED							
Polypedilum convictum	43	16			22	129	5
Polypedilum illinoense	5		11				5
Polypedilum nr *scalaenum*	5						
Pseudochironomus sp.						108	65
Rheocricotopus sp.	5						
Simulium sp.				5			
Tanytarsus sp.						404	65
Thienemanniella fusca						22	27
Tribelos sp.	5						5
EPHEMEROPTERA							
Baetis quilleri	5	11	5	5		129	70
Caenis sp.	5						
Choroterpes mexicanus		5	5	11	11	32	
Dactylobaetis mexicanus					5		
Farrodes texanus				5			
Isonychia sicca manca				5	16	5	
Stenonema sp.	151	199		86	59	70	5
Tricorythodes albilineatus gr.					5	5	
HEMIPTERA							
Hebrus sp.							5
Microvelia sp.					5		
ODONATA							
Argia sp.	32	5		22	5	22	
Hetaerina sp.	48	38					
TRICHOPTERA							
Cheumatopsyche sp.	457	43	194	145	91	54	
Chimarra sp.	414	11	323	11	124	91	
Helicopsyche sp.	5						
Hydroptila sp.	22		5	11		156	124
Marilia sp.	5						
Mayatrichia ponta			22	43			
Nectopsyche gracilis						5	
Neotrichia sp.				5			
Ochrotrichia sp.	97			5			
Phryganeidae	11						
Polycentropus sp.						5	5

* two subsamples collected at each station using a Surber square foot sampler

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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

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

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)

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

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

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

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).

$$\text{Autotrophic Index} = \frac{\text{Biomass (g/m2)}}{\text{Chlorophyll } \underline{a} \text{ (g/m2)}}$$

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 flucrometers. 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 fcr 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:

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

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