Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the San Marcos Springs/River Aquatic Ecosystem

FINAL 2001 ANNUAL REPORT

Prepared for:

Edwards Aquifer Authority
1615 N. St. Mary's Street
San Antonio, Texas 78215

Prepared by:

BIO-WEST, Inc
Austin Office
1406 Three Points Road, Suite A-200
Pflugerville, Texas 78660-3155

February 2002

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This annual summary report presents a synopsis of methodology used and an account of sampling activities including sampling conditions, locations and raw data obtained during all four quarterly sampling events (Comprehensive Monitoring Effort) conducted on the San Marcos Springs / River ecosystem in 2001. In addition, data obtained during the high-flow sampling event conducted on the San Marcos Springs / River ecosystem in December 2001 are presented. As with the annual report prepared for activities conducted in 2000, the data included here have not been subject to stringent data reduction techniques or statistical applications in order to prevent drawing premature conclusions from an incomplete data set. Once the complete range of data has been gathered, these techniques will be applied and presented in a final report to the Edwards Aquifer Authority.

The monitoring program was initiated in late summer 2000 when the flows in the San Marcos Springs / River ecosystem dropped below 120 cubic feet per second (cfs). This flow level triggered the Texas wild-rice (*Zizania texana*) physical observation sampling that was conducted in September 2000. When flows dropped to 106 cfs on October 5, 2000, a low-flow full event was initiated; however, significant rainfall over the weekend boosted the flows to 114 cfs and the low-flow sampling event was cancelled. Lower than average flows persisted in the San Marcos Springs / River ecosystem in the fall, and the fall 2000 quarterly sampling event was conducted at flows ranging from 117-151 cfs. Immediately following this event, a substantial amount of rainfall increased flows in the river and allowed the aquifer to recharge in late 2000. During 2001 the conditions in the San Marcos Springs / River ecosystem were representative of a wet winter and spring followed by the typical summertime decline. However, unlike summer 2000, a large rainfall event occurred in late summer (September 2001), and moderate-to-high rainfall conditions occurred throughout the remainder of the fall, including a major event in November 2001. No critical period samples were triggered by low-flow events in 2001, but one full sampling event (high flow) was conducted following the intense flooding in November 2001 (24-hour mean discharge reached levels that have occurred less than 0.1% of the time in the recorded hydrograph).

Overall, the San Marcos Springs / River ecosystem has experienced a wide range of environmental conditions including variable flows over the first 16 months of the study. Throughout this time period, the San Marcos Springs / River ecosystem can be characterized as an ecosystem with very high water quality for the chemical and physical variables that were measured. Thermistor data revealed a high degree of thermal uniformity (except the slough arm of Spring Lake, which was quite high, as has been observed before [Groeger, unpublished Hydrolab and thermistor data]) throughout the ecosystem despite the wide ranging conditions experienced throughout the study period. Though a preliminary judgement, there was no clear or dramatic change in any water quality variables that might raise concern when comparing data from all sampling dates.

Aquatic vegetation remained abundant throughout the study period and provided suitable habitat for biological communities. Sizable vegetation mats covered areas within the City Park Reach during winter and spring 2001 and the summers of both years. The seasonal maps also show that *Potamogeton*, *Hydrilla*, *Hygrophila*, and *Cabomba* responded rapidly to favorable conditions by expanding their coverage. There is also evidence of seasonal recreational use of the river with some decreasing *Hydrilla* coverage in the shallower sections of the City Park Reach. As in 2000 this effect of recreational impacts became more pronounced in the summer when an area of bare substrate stretched across the entire river on the shallowest route between the two banks. The vegetation maps (Appendix A) illustrate the potential recreational use effects on the aquatic vegetation community. The high-flow events also considerably impacted aquatic vegetation by removing or significantly thinning large areas of vegetation in the both reaches. There were also large areas where the substrate was displaced, leaving a much deeper channel, and other areas where sediment was deposited in large quantities. This is significant because of the importance of aquatic vegetation to fountain darters (*Etheostoma fonticola*), which became more concentrated in the remaining vegetation.

The most interesting observation from the Texas wild-rice data is the decrease in total coverage (~7%, >135 square meters [m^2]) that occurred between the summer and high-flow sampling events. The intensity of the flood event that occurred during November 2001 was significant enough to cause scouring in most areas within the river. The Texas wild-rice plants found in some areas were generally well protected by surrounding vegetation; however, many of the stands in the Sewell Park and I-35 areas were scoured such that large areas of bare substrate were left where Texas wild-rice had previously been. In addition, several small stands were completely removed. An examination of Texas Parks and Wildlife Department (TPWD) data confirms the effects of flooding on Texas wild-rice; a large percentage of Texas wild-rice were removed after the 1998 flood. Floating mats of vegetation appeared again in summer 2001 and covered patches of Texas wild-rice in some areas, but not to the degree experienced during summer 2000. Another observation was that the greatest emergence of Texas wild-rice (fall 2000) was most likely related to water level. Root exposure was another variable that was monitored, and data from certain reaches reveal that significant levels of root exposure may leave Texas wild-rice more vulnerable to scouring from high-flow events. However, data from other reaches indicate that the scouring effects of an intense high-flow event (such as occurred in November 2001) will remove vulnerable plants regardless of the level of root exposure.

Fountain darters were collected from each sampling reach during each sampling event. The overall size-class distribution is typical of a healthy fish assemblage although shifted towards larger fish than those observed in the Comal ecosystem. This is most likely a function of the habitat suitability of the two sampled reaches in the San Marcos Springs / River ecosystem. Adding the size-class distribution data from the high-quality habitat in Spring Lake would shift the peak of this distribution to a lower size class and yield a distribution that correlates well with that observed in the Comal ecosystem. As in the Comal ecosystem, differences in reproduction in individual reaches of the San Marcos Springs / River ecosystem yielded variable size-class distributions by season in some reaches. Large numbers of fountain darters were collected in the high quality habitat of Spring Lake, probably because of the cover provided at the substrate level and the high numbers of amphipods, which provide the fountain darters with an ample food supply. As in the Comal ecosystem, *Cabomba* (which grows in very silty substrate) revealed moderate densities of fountain darters. This association of a spring-adapted species with the lentic conditions and silty substrate is unusual and may indicate a greater tolerance of fountain darters to various habitat conditions compared with other spring-adapted species. Our visual observations (SCUBA surveys) continue to reinforce that Spring Lake is an integral component to the habitat of species found in the San Marcos Springs ecosystem and a sizable portion of the fountain darter population is found there.

By all indications, the densities of giant ramshorn snails (*Marisa cornuarietis*) observed in the San Marcos Springs / River ecosystem during the study period to date pose no serious threat to the aquatic vegetation. However, because of the impact that this exotic species can have under heavier densities, close monitoring of this species should continue. The gill parasite that has been reported infesting the fountain darter in the Comal ecosystem was not visually evident in fountain darters collected from the San Marcos Springs / River ecosystem.

Suitable habitat for the San Marcos salamander (*Eurycea nana*) was noted in Spring Lake and below Spring Lake Dam; San Marcos salamanders were observed in each area during each sampling event. Higher flows experienced below the dam in 2001 made the current sampling technique difficult, which may explain the slight reduction in San Marcos salamander numbers below the dam. The high-flow event (November 2001) also did extensive damage to the aquatic vegetation below the dam, which probably contributed to the reduction in San Marcos salamander numbers observed during sampling. The winter 2002 event will aid in evaluating the recovery potential of this area as flows stabilize and habitat returns. As documented via SCUBA surveys, the Spring Lake San Marcos salamander population has been thriving throughout the study period.

The high-flow event conducted in concert with quarterly sampling has provided an excellent opportunity to assess the recovery potential of the San Marcos Springs / River ecosystem. The recovery response of the ecosystem will be tracked, especially the parameters that exhibited the greatest degree of disturbance (aquatic vegetation, Texas wild-rice, San Marcos salamanders below Spring Lake dam). The high-flow event was the final sampling effort conducted in 2001; thus, the recovery potential will not be evaluated until the winter 2002 sampling effort.

As described above the data in this report are preliminary and, although they have been carefully evaluated to determine trends and observations of particular interest, stringent data reduction techniques and/or statistical applications have not yet been applied to this incomplete data set. More data from periods of low-flow (particularly from an extended period of low flow) are essential to fully evaluate the biological risks associated with future critical periods (high or low flow). Quarterly sampling will continue to be important to maintain an understanding of the current state of the ecosystem in order to be prepared for a period of low flow and to monitor conditions following such a period.

One conclusion that can be made is that this study is the most comprehensive biological evaluation that has ever been conducted on the San Marcos Springs / River ecosystem. The variable flow conditions encountered to date have provided an excellent confirmation that the study design is well suited to address the concerns of variable flow and water quality on the biological resources in the San Marcos Springs / River ecosystem. For a study to be scientifically valid in such a complex environment, several key procedures are essential for determining the dynamics dictating both the total population numbers and densities of endangered species under various environmental conditions. When feasible, a study should (1) directly evaluate the endangered species or combination of endangered species, (2) avoid conclusions based on one-time sampling events or limited sampling during particular seasons (understanding the condition of the ecosystem before a critical period [high or low flow] and tracking the recovery of that ecosystem after the critical period [high or low flow] are extremely important), and (3) use multiple collection techniques to evaluate as many components of the overall ecosystem as possible.

METHODS

A quarterly sampling event is typically divided into a 2-week effort and includes the components shown below.

Aquatic Vegetation Mapping

Water Quality
- Standard Parameters
- Thermistor Placement
- Thermistor Retrieval
- Habitat Quality Index
- Fixed Station Photography

Texas Wild-Rice Physical Observations

Fountain Darter Sampling
- Drop Nets
- Dip Nets

San Marcos Salamander Observations

Exotic / Predation Study

High-Flow Sampling

A period of intense rain on August 30, 2001, resulted in flooding within the Comal Springs ecosystem and led to a high-flow sampling event in that ecosystem; however, the increase in springflow was not as significant in the San Marcos Springs / River ecosystem, thus it was not sampled. A second high-flow event of even greater intensity occurred on November 15-16, 2001, and resulted in a significant increase in streamflow in both ecosystems, which triggered a second sampling effort on the Comal River in addition to a sampling event on the San Marcos River. The 24-hour mean discharge on the San Marcos River for this second event was 1,019 cfs on November 16. Over this time period, the San Marcos River flow peaked at 1,620 cfs, prior to a period of no recorded data, late on November 15 through early November 16 when the flows were reported at 1,560 cfs. Assuming 1,620 cfs was the peak and that flows stayed at 1,560 cfs until the gage started recording data the next day at 1,560 cfs, the daily averages exceeded our 0.5% occurrence trigger level for 5 straight days. Additionally, the 1,019 cfs daily average had less than a 0.1% chance of occurrence, and comparable flows have occurred only seven times in the recorded history. Sampling for this high-flow event was conducted after the ecosystem had been returned to normative conditions in order to evaluate the post-flooding effects, but not so soon that the sample would be influenced by immediate, ephemeral impacts occurring during the elevated flow conditions.

The high-flow sampling effort was designed to focus on those factors most likely to experience a shift in conditions following the natural disturbance. Aquatic vegetation mapping was conducted first to examine physical changes in vegetative distribution and abundance. The vegetation mapping included a complete survey of Texas wild-rice in the ecosystem because of concerns that the high-intensity flooding was sufficient to displace some stands. In addition to mapping all Texas wild-rice, physical measurements were taken of the stands that were recognized as being in vulnerable locations at the beginning of the study. Vegetation mapping is a vital component of all sampling activities because the presence of various species of vegetation affects the amount of habitat available to fountain darters and other species. Fountain darter sampling included standard drop net sampling in randomly selected sites, dip netting, and visual observations. San Marcos salamander observations and the predation study were conducted as during normal quarterly sampling.

The methodology for each component of the high-flow event was exactly the same as used in the quarterly (Comprehensive) sampling regime; however, the water quality component was not included in these samples. Water quality was undoubtedly influenced in the short-term (e.g., increased turbidity, potentially increased nutrients, potential for increased temperature from runoff inputs) during each high-flow period; however, we expect that a disturbance resulting from a high ratio of runoff to springflow inputs would have been quickly ameliorated when runoff subsided and normative flow conditions were restored.

Springflow

All discharge data were acquired from the U.S. Geological Survey (USGS) water resources division. The data are provisional as indicated in the disclaimer on the USGS website and, as such, may be subject to revision at a later date. According to the disclaimer, "recent data provided by the USGS in Texas — including stream discharge, water levels, precipitation, and components from water-quality monitors — are preliminary and have not received final approval" (USGS 2002). The discharge data for the San Marcos River were taken from USGS gage 08170500 at the University Drive Bridge. This site represents the cumulative discharge of the springs that form the San Marcos River ecosystem. In addition to the cumulative discharge measurements that were used to characterize this ecosystem during sampling, spot water velocity measurements were taken during each sampling event using a Marsh McBirney model 2000 portable flowmeter.

Water Quality

The water quality component of this study included measuring standard water quality parameters using a Hydrolab data sonde, gathering water samples for laboratory analyses, and deploying and retrieving thermistors at sites in the San Marcos Springs / River ecosystem (Figure 1). The objectives of the water quality analysis were: to delineate and track water chemistry throughout the ecosystem, monitor controlling variables (i.e., flow, temperature) with respect to the biology of each ecosystem, monitor any alterations in water chemistry that may be attributed to anthropogenic activities, and evaluate consistency with historical water quality information. Dr. Alan Groeger of Southwest Texas State University (SWT) supervised all aspects of the water quality component of this study, and the chemical analyses for each quarterly sampling event was conducted in Dr. Groeger's laboratory at SWT.

Hydrolab measurements included conventional in-situ physico-chemical parameters that were collected each time a water and/or biological station was occupied. The parameters included: water temperature, conductivity compensated to 25° C, pH, dissolved oxygen, water depth at sampling point, and observations of local conditions. These data were gathered at the surface, mid depth, and near the bottom at all biological stations when there was stratification, but only near the surface at water quality stations. In addition, to continuously monitor water temperature thermistors were placed in select water quality stations along the San Marcos River and downloaded at regular intervals. The thermistors were set to record temperature data every 5 minutes. The station locations will not be described in detail here in order to minimize the potential for unauthorized tampering with the field equipment.

Conventional water chemistry parameters of water samples taken at each of the water quality stations were also analyzed in the laboratory (Table 1). Water "grab" samples were taken in 1-liter polyethylene bottles with caps. Prior to sample collection, the bottles were soaked in Contrad 70 overnight, and rinsed repeatedly in DI water and once in Milli-Q water before being dried for 24 hours. At the

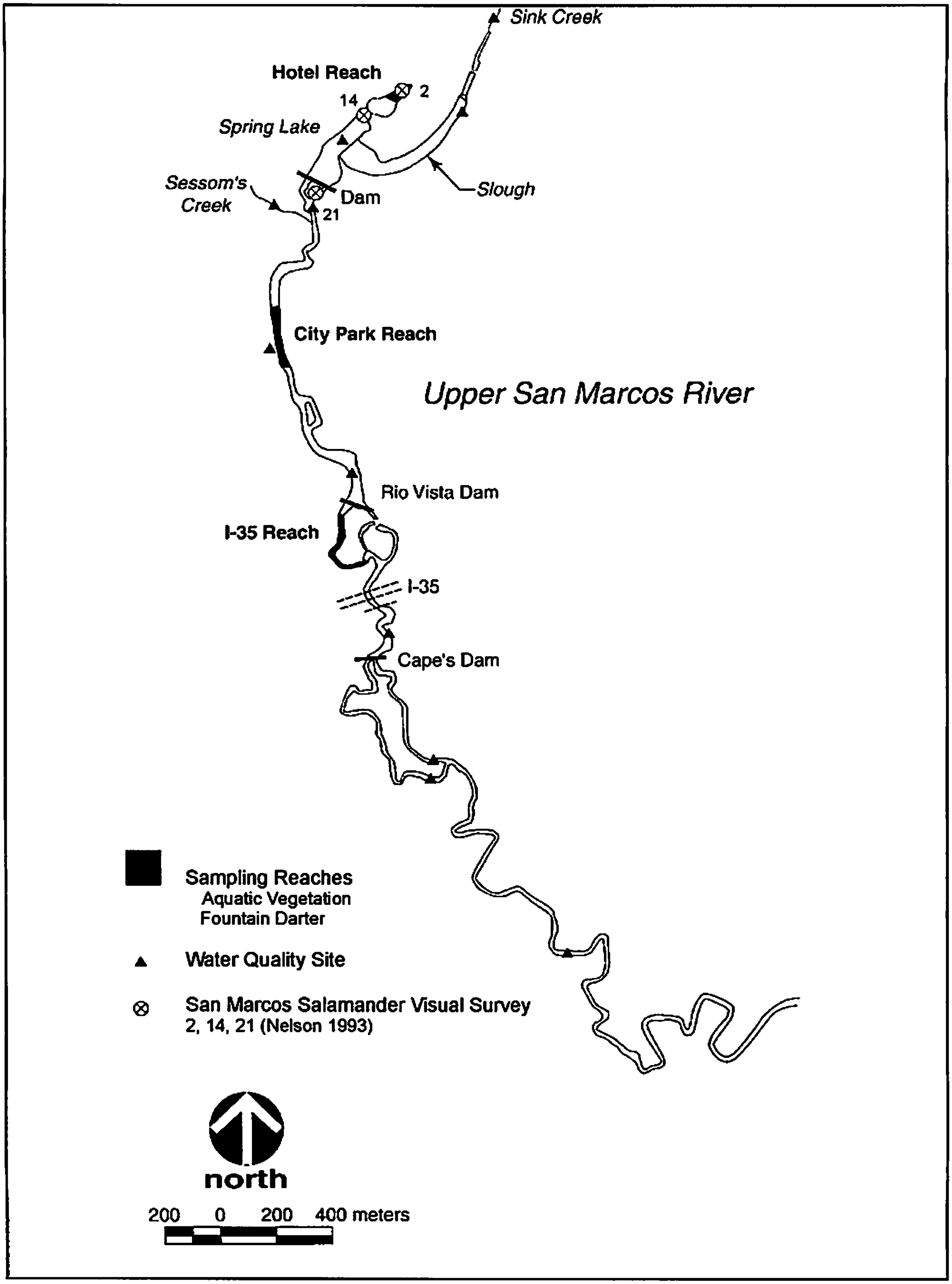


Figure 1. Upper San Marcos River water quality and biological sampling areas.

Table 1. Parameters, analytical methodology, minimum analytical levels, and minimum detection limits for water chemistry analyses conducted on water quality grab samples.

PARAMETER	METHOD	MINIMUM ANALYTICAL LEVELS (per liter)	MINIMUM DETECTION LIMITS (per liter)
Nitrate	UV Spectroscopy	≈10.0 µg*	≈3.0 µg
Total Nitrogen	UV Spectroscopy	10.0 µg	<5.0 µg
Ammonium	Fluorometric	7 µg	2 µg
Soluble Reactive Phosphorus	Spectroscopy	3 µg	0.5 µg
Total Phosphorus	Spectroscopy	5 µg	3 µg
Alkalinity	Potentiometric	Appropriate	
Total Suspended Solids	Gravimetric	Appropriate	

* micrograms

sampling site each bottle was rinsed with sample water prior to collection of the sample; all samples were collected from under the surface of the water to avoid surface-active particulates and floating debris. Samples were then stored in the dark, under ice, for the remainder of the collection period. Samples were transported to the laboratory within 4-6 hours and warmed to room temperature, at which point the samples were partitioned into fractions for the following analyses. Whole water samples were also frozen for a few weeks prior to some analysis; once frozen the samples are stable for many months.

Alkalinity, Turbidity, and Total Suspended Solids (TSS): All samples were immediately titrated to determine alkalinity, then sampled for nephelometric turbidity units and filtered onto prewashed and preweighed filters for determination of total suspended solids (TSS). Determination of TSS followed the methodology outlined in Standard Methods for the Examination of Water and Wastewater (APHA 1992).

Soluble Reactive Phosphorus (SRP): Soluble reactive phosphorus (SRP) and nitrate were usually analyzed within 48 hours. The SRP was measured following Strickland and Parson (1972) in which the filtered sample (0.45 µM) is allowed to react with a composite reagent containing molybdic acid (ammonium molybdate and sulfuric acid), ascorbic acid, and potassium antimonyl tartrate. The resulting complex heterpolic acid is reduced in situ to give a molybdenum blue solution, the extinction of which is measured at 885 nm and plotted on a standard curve.

Nitrate: Nitrate analysis was conducted via the method described by W.G. Crumpton (1992), in which the nitrate concentration is determined ultraviolet (UV) spectroscopy to measure the absorbance at 224-228 nm and a second derivative is calculated for that value. This derivative is linear to the concentration of nitrate ion in natural waters, assuming that the samples are reasonably clear. The second derivative function is calculated using a software package designed by Dr. Groeger.

Total Nitrogen and Total Phosphorus: Total nitrogen was analyzed using the same process as nitrate following a persulfate digestion and autoclave heating period of 30 minutes at 121° C and 15 PSI. Total phosphorus analysis was similar to the method for soluble reactive phosphorus (APHA 1992). The sample was first digested by the persulfate oxidation technique and then subjected to the ascorbic acid method for determination of the total phosphorus content.

Ammonium: The ammonium concentration was determined following the outline of Holmes et al. (1999). The method uses fluorescence of the sample minus background fluorescence and matrix effects against a standard curve. Protocol B was followed for systems with ammonium concentrations generally exceeding 0.5 μmol/L. The method uses a fluorometer equipped with a Turner designs optical kit 10-AU, near UV mercury vapor lamp, a 350 nm interference excitation filter with a 25 nm bandpass, a 410-600 nm combination emission filter, and a 1:75 attenuator plate.

In addition to the water quality collection effort, habitat evaluations were conducted using fixed station photography and a habitat quality index (HQI) developed specifically for this spring ecosystem. Fixed station photographs included an upstream, across-stream, and downstream picture at each water quality site depicted on Figure 1.

Aquatic Vegetation Mapping

The aquatic vegetation mapping effort consisted of mapping all of the vegetation in each of the two reaches (City Park and I-35; Appendix A). Mapping was conducted using a Trimble Pro-XRS global positioning system (GPS) unit with real-time differential correction capable of sub meter accuracy. The GPS unit was linked to a Fujitsu Stylistic 2300 laptop computer with Aspen software that displays field data as it is gathered and improves efficiency and accuracy. The GPS unit and computer were placed in a 3 meter Perception Swifty kayak with the GPS unit antenna mounted on the bow. The aquatic vegetation was identified and mapped by gathering coordinates while maneuvering the kayak around the perimeter of each vegetation type at the water's surface. Vegetation stands that measured between 0.5 and 1.0 meter in diameter were mapped by recording a single point. Vegetation stands less than 0.5 meter in diameter were not mapped.

In addition to mapping all of the vegetation found within the two study reaches, the 2001 summer sampling event included mapping all of the Texas wild-rice in the entire San Marcos River. An additional mapping effort of the Texas wild-rice throughout the river was conducted during the high-flow event in November.

Texas Wild-Rice Physical Observations

Surveys were conducted in the upper reach of the San Marcos River to identify, map, and record any stands of Texas wild-rice that were considered to be in vulnerable areas at the beginning of the study. Texas wild-rice stands were considered to be in vulnerable areas if they possessed one or more of the following characteristics: (1) occurred in shallow water, (2) revealed extreme root exposure because of substrate scouring, or (3) generally appeared to be in poor condition. For this study a stand of Texas wild-rice is defined as a contiguous group of plants that are growing no closer than 45 cm from any other stand(s) of Texas wild-rice. These monitoring efforts were designed following discussions with Dr. Robert Doyle, currently with Baylor University, and Ms. Paula Power of the U.S. Fish and Wildlife Service (USFWS) National Fish Hatchery and Technology Center.

After an evaluation of the general condition of all stands of Texas wild-rice along the San Marcos River from Spring Lake Dam to the confluence with the Blanco River in September 2000, 19 representative stands were selected for study. These included eight stands in the Sewell Park Reach, eight stands in the reach from Rio Vista Dam to I-35, and three stands between Cape's Dam and the City of San Marcos sewage treatment facility (one of the latter stands was lost between the winter and spring sampling trips).

During each quarterly and high-flow sampling effort, all stands of Texas wild-rice were measured for depth, maximum length, and maximum width. The length measurement was taken at the water surface parallel to streamflow and included the distance between the base of the roots to the tip of the longest leaf. The width was measured at the widest point perpendicular to the stream current (this usually did not include roots). The length and width measurements were used to calculate the area of each stand according to a method used by the TPWD (J. Poole, TPWD, pers. comm.) in which percent cover was estimated for the imaginary rectangle created from the maximum length and maximum width measurements. In addition to recording areal coverage with these methods, GPS with real-time differential correction was used to map each stand and provide improved precision on the location and a secondary means of estimating areal coverage.

Qualitative observations were also made on the condition of each Texas wild-rice stand. These qualitative measurements included the following categories: the percent of the stand that was emergent (and how much of that was in seed), the percent covered with vegetation mats or algae buildup, any evidence of foliage predation, and a categorical estimation of root exposure. Notes were also made regarding the observed (or presumed) impacts of recreational activities. Each category was assigned a number from 1 to 10 for each stand, with 10 representing the most significant impact.

Flow measurements were taken at the upstream edge of each Texas wild-rice stand, along with minimum and maximum water depth. A cross-section of the river was taken along the shallowest depth in which flow, depth, and substrate composition were measured at 1-meter intervals across the entire width of the river. To complement all of the measurements made during each survey, video images were taken using an underwater video camera during the summer and fall sampling trips. These images were gathered with the intent to create a visual record of changes in Texas wild-rice stands.

Fountain Darter Sampling

Drop Nets

A drop net is a type of sampling device previously used by the USFWS to sample fountain darters and other fish species. The design of the net is such that it encloses a known area (2 m^2) and allows thorough sampling by preventing escape of fishes occupying that area. A large dip net (1 m^2) is used within the drop net and is swept along the length of the river substrate 15 times to ensure complete enumeration of all fish trapped within the net. For sampling during this study, a drop net was placed in randomly selected sites within specific aquatic vegetation types. The vegetation types used in each reach were defined at the beginning of the study as the dominant species found in that reach. Sampling sites were randomly selected per dominant vegetation type for each quarterly event from a grid overlain on the most recent map (created with GPS the previous week) of that reach.

At each location the vegetation type, height, and areal coverage were recorded, along with substrate type, mean column velocity, velocity at 15 cm above the bottom, water temperature, conductivity, pH, and dissolved oxygen. In addition, vegetation type, height, and areal coverage, along with substrate type, were noted for all adjacent 3 m cell areas. Fountain darters were identified, enumerated, measured for standard length, and returned to the river at the point of collection. The same measurements were taken for all other fish species, except abundant species for which only the first 25 were measured; a total count was recorded for a drop net sample beyond the first 25 individuals in such instances. Fish species not readily identifiable in the field were preserved for identification in the laboratory. All live giant ramshorn snails were counted, measured, and destroyed, while a categorical abundance was recorded (i.e., none, slight, moderate, or heavy) for the exotic Asian snails (*Melanoides tuberculata* and

Thiara granifera) and the Asian clam (*Corbicula* sp.). A total count of crayfish (*Procambarus* sp.) and grass shrimp (*Palaemontes* sp.) was also recorded for each dip net sweep.

Dip Nets

In addition to drop net sampling for fountain darters, a less quantitative, though potentially more thorough, method of sampling was used. A dip net of approximately 40 cm x 40 cm (1.6-mm mesh) was used to sample all habitat types within each reach. Collecting was generally done while moving upstream through a reach. An attempt was made to sample all habitat types within a reach. Habitats thought to contain fountain darters, such as along or in clumps of certain types of aquatic vegetation, were targeted and received the most effort. Areas deeper than 1.4 m were not sampled. Fountain darters collected by this means were identified, measured, recorded as number per dip net sweep, and returned to the river at the point of collection (except for those retained for refugia purposes under the guidance of Dr. Thomas Brandt, USFWS National Fish Hatchery and Technology Center). The abundance of exotic snails was also estimated and recorded per sweep.

To balance the effort expended across sampling events, a predetermined time constraint was used for each reach (Hotel Reach – 0.5 hour, City Park Reach – 1.0 hour, I-35 Reach – 1.0 hour). The areas of fountain darter collection were marked on a base map of the reach. Though information relating the number of fountain darters by vegetation type was not gathered by this method (as in the drop net sampling) it did permit a more thorough exploration of various habitats within the reach. Also, spending a comparable length of time sampling the entirety of each reach allowed comparisons to be made between the data gathered during each sampling event.

San Marcos Salamander Visual Observations

Visual observations were made in areas previously described as habitat for San Marcos salamanders (Nelson 1993) during each 2001 quarterly and high-flow sampling effort. All surveys were conducted at the head of the San Marcos River and included two areas in Spring Lake and one area below Spring Lake Dam adjacent to Clear Springs Apartments. The upstream-most area in the lake was adjacent to the old hotel (known as the Hotel Reach) and was identified as site 2 in Nelson (1993). The other site in Spring Lake was deeper (~6 m) and located directly across from the Aquarena Springs boat dock. This site was identified as site 14 in Nelson (1993). The final sampling area was located just below Spring Lake Dam in the eastern spillway (site 21, Nelson 1993) and was subdivided into four smaller areas for a greater coverage of suitable habitat. San Marcos salamander densities in the four subdivisions were averaged as one.

SCUBA gear was used to sample habitats in Spring Lake, while a mask and snorkel were used in the site below Spring Lake Dam. For each sample an area of macrophyte-free rock was outlined using flagging tape, and three timed surveys (5 minutes each) were conducted by turning over rocks >5 cm wide and noting the number of San Marcos salamanders observed underneath. Following each timed search, the total number of rocks surveyed was noted in order to estimate the number of San Marcos salamanders per rock in the area searched. The three surveys were averaged to yield the number of San Marcos salamanders per rock.

The density of suitably sized rocks at each sampling site was determined by using a square frame constructed out of steel rod to take random samples within the sampling area. Three random samples were taken in each area by blindly throwing the 0.25 m^2 frame into the sampling area and counting the number of appropriately sized rocks. The three samples were then averaged to yield a density estimate of the rocks in the sampling area.

The area of each sampling site was determined after sampling by using two sets of rope connected 60 cm apart by steel rods. The rods were positioned along marks placed every 60 cm on each rope so that a grid with squares of 60 cm x 60 cm was created over the sampling area. To count the total number of squares in the sampling area, one rod and rope set was placed lengthwise across the sampling area while the other set was placed perpendicular to the first. While the first set of rods and rope remained stationary lengthwise, the second set was moved along the 60-cm intervals. For each placement of the rods and rope along a 60-cm interval, the number of complete squares created by the set of ropes perpendicular to the stationary reference was counted. In addition, a percentage of any incomplete square was noted. This method effectively allowed for a grid of 60 cm x 60 cm squares to be established across the sampling site in order to determine the total area.

In addition to mapping the sampling areas with the grid system, a GPS with real-time differential correction was used in the later surveys to outline the sampling area and determine the surface area. This was accomplished by attaching the unit to a kayak and towing it around the flagged sampling area. A comparison of the results of the two methods revealed similar estimates, and the GPS system was adopted for shallower sites where it was more time efficient.

An important note about these San Marcos salamander density estimates is that extrapolating beyond the area sampled into surrounding habitats would not necessarily yield accurate values, particularly in the Hotel Reach. This is because the area sampled was selected based on the presence of silt-free rocks and limited algal coverage during each survey. Much of the habitat surrounding the sampling areas is typically covered with algae and provides a three-dimensional habitat structure that may harbor a different population size. The estimates created from this work are valuable for comparing between trips, but any estimates of a total population size derived from this work should be viewed with caution.

Exotics / Predation Study

A 150-foot experimental gill net with mesh sizes ranging from 0.75 to 3 inches was placed in Spring Lake to collect predatory fish of various species and sizes during each quarterly and high-flow sampling effort. This sampling was conducted to attempt to determine the density of various exotic fish species in Spring Lake and to perform stomach content analyses with particular emphasis on potential predation on those endangered species. The gill net was placed in the area previously identified through SCUBA surveys as supporting fountain darters and San Marcos salamanders. All fish collected in the gill net were identified, enumerated, weighed, and measured. The original intention was to retain a few representative individuals of each species within different size classes; however, sample sizes were smaller than anticipated so all fishes were used in the stomach analysis. Fish collected in the field were stored on crushed ice until transferred to the SWT Aquatic Center or the BIO-WEST Nekton Laboratory where the stomachs were removed and contents examined. Although the focus was on fountain darter and/or San Marcos salamander predation by the various species and size classes, all stomach contents were recorded.

Because of the limited sample sizes obtained during winter and spring quarterly sampling, rod-and-reel sampling was employed to target larger sunfish and small- to intermediate-sized bass, which are the most likely piscine predators on the fountain darters and San Marcos salamanders. In addition, fish trapped in the gill net posed problems unique to that method of capture. Those fish are often partially decomposed if entangled soon after the net is placed; the fish have also been known to regurgitate food items upon entanglement and will continue to digest any remaining food items as long as they are trapped. As a result of incorporating rod-and-reel sampling, sample sizes were much larger and many of the problems with gill net sampling were avoided. Both techniques will continue to be used in future quarterly and critical period sampling on the Spring Lake ecosystem.

OBSERVATIONS

The BIO-WEST project team conducted the 2001 sampling components as shown in Table 2.

Table 2. Components of 2001 sampling events.

EVENT	DATES	EVENT	DATES
Winter Sampling		**Fall Sampling**	
Water Quality Sampling	Mar 5	Water Quality Sampling	Oct 24
Vegetation Mapping	Feb 27-Mar 1	Vegetation Mapping	Oct 18-19
Texas Wild-rice Physical Observations	Mar 9	Texas Wild-rice Physical Observations	Oct 22
Fountain Darter Sampling	Mar 5-8	Fountain Darter Sampling	Oct 25-26
San Marcos Salamander Observations	Mar 7	San Marcos Salamander Observations	Nov 2
Exotic / Predation Study	Mar 7-8	Exotic / Predation Study	Oct 23-24
Spring Sampling		**High-Flow Sampling**	
Water Quality Sampling	May 7	Vegetation Mapping	Dec 3-7
Vegetation Mapping	Apr 30-May 1	Texas Wild-rice Physical Observations	Dec 5
Texas Wild-rice Physical Observations	May 2	Fountain Darter Sampling	Dec 6-7
Fountain Darter Sampling	May 7-8	San Marcos Salamander Observations	Dec 4
San Marcos Salamander Observations	May 9-10	Exotic / Predation Study	Dec 4-5
Exotic / Predation Study	May 9-10		
Summer Sampling			
Water Quality Sampling	Aug 13		
Vegetation Mapping	Jul 30-Aug 3		
Texas Wild-rice Physical Observations	Aug 9		
Fountain Darter Sampling	Aug 13-14		
San Marcos Salamander Observations	Aug 15		
Exotic / Predation Study	Aug 15-16		

High-Flow Sampling

High-flow sampling produced interesting data for each included sampling component. The results and conclusions for each will be discussed in the representative sections.

Springflow

Daily 2001 springflow averages were generally higher than in 2000; for instance, discharge in the San Marcos Springs / River ecosystem barely dropped to below 170 cfs in 2001, while it had decreased to below 110 cfs in 2000 (Figure 2). As a result the quarterly 2001 sampling events were conducted during

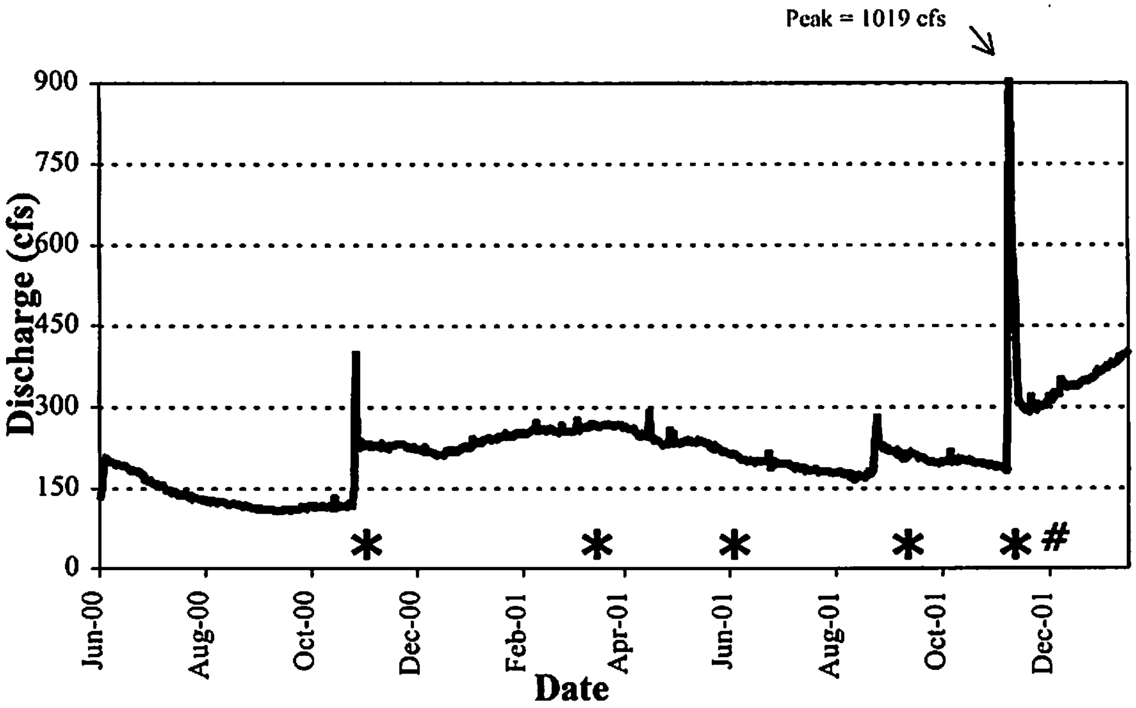


Figure 2. Mean daily discharge in the San Marcos River during the study period; approximate dates for quarterly (*) and high-flow sampling efforts (#) are indicated.

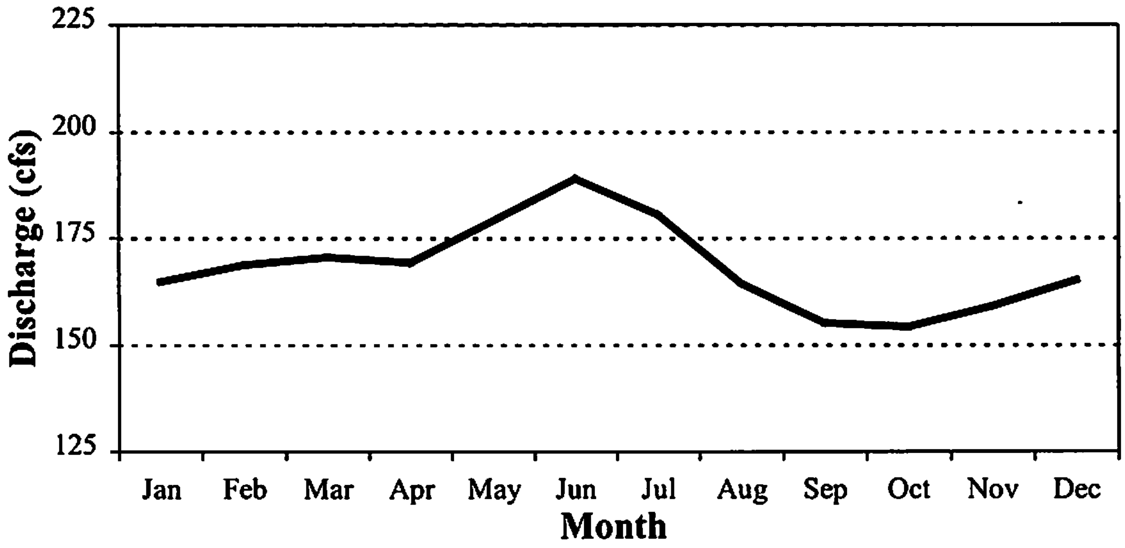


Figure 3. Mean monthly discharge in the San Marcos River during the 1956-2000 period of record.

higher springflows than the one conducted in 2000. Each 2001 quarterly sampling event occurred during higher-than-average springflow conditions for those times of year because of wetter-than-normal conditions and several high-intensity rain events (Figure 3). However, the summer was typical with periods of little to no rainfall between June and mid August, which dropped the springflow levels to slightly above average for that time of year. The higher flows experienced overall in 2001 meant that no critical period low-flow sampling events were triggered.

WATER QUALITY

Hydrolab profiles and water quality samples were taken at all nine sites in the San Marcos Springs / River ecosystem. The sites were as follows:

Chute (located directly downstream of the chute at Joe's Crab Shack);
Dam (located just downstream of the true dam on Spring Lake);
Sessoms Creek (beside Freeman Aquatic Biology building, before confluence with the San Marcos River);
Lions Club (located within the City Park/Lions Club Reach);
Rio Vista Park (located near the far channel at Rio Vista);
I-35 (located just upstream of the I-35 highway crossing);
Thompson's Island artificial (located upstream of the falls on artificial channel);
Thompson's Island natural (located upstream of state fish hatchery outflow); and
Animal Shelter (located directly behind the San Marcos animal shelter).

Spring Lake was also sampled during each quarterly event, but on a separate date from the others (March 6, 2001; May 14, 2001; August 15, 2001; and October 30, 2001). Sink Creek, which enters in the slough arm of the lake was also sampled on April 2, 2001, following a spate (this site ceases to flow during dry periods so it was not always sampled). Placement of a remote Hydrolab unit also occurred in various locations within the lake for 1 week to 9 days at a time. The sampling sites for Spring Lake were chosen based on historical locations that have been used during basic limnological sampling conducted at SWT. The sites were as follows:

Site A was located directly in front of the hotel on Spring Lake in a deep hole,
Site B was located in front of the "submarine" area,
Site C was located across from "The Landing,"
Site D was just upstream from the chute at Joe's Crab Shack,
Site E was located just upstream of the dam,
Site F was chosen to represent the site of mixing of the slough arm and the spring arm,
Site G was located behind the softball fields and under a powerline in the slough, and
Site H was located downstream of the road crossing.

A summary of the water quality data for this project is presented in Tables 3 and 4; graphs of thermistor data for important/representative reaches are presented in Figures 4 and 5. A more detailed list of data for each sample, along with all thermistor graphs can be found in Appendix B.

The period covered by this analysis is less than 2 years, in which the first year (2000) was an extremely dry year and the second year was a very wet year, although closer to a statistical median or "average" year. Therefore, the discussion of this water quality data using any sort of trend analysis is not feasible at this time. The San Marcos River ecosystem, like the Comal ecosystem, exhibited exceedingly high water quality in general. There are some distinct differences in the water between the two ecosystems: San Marcos spring flows are roughly 1° C cooler, NO3-N is lower ($\approx$1.5 mg/L), and the specific conductance and alkalinity content is higher. As in the Comal ecosystem, the thermal environment in the San Marcos River was quite constant, with variability increasing with distance from the springs. Presumably because of the cease in flow through the chute arm of Spring Lake during the summer and fall, when the dam was being repaired, temperature, turbidity, and variability increased at this site (Table

Table 3. Summary of physical parameters in the San Marcos River ecosystem from 2000-2001.

SITE	DEPTH			TEMPERATURE			pH			DISSOLVED OXYGEN			CONDUCTIVITY			TURBIDITY			ALKALINITY		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Animal Shelter	0.56	0.30	0.90	22.30	21.74	22.73	7.69	7.41	7.88	8.81	7.75	10.39	578	559	593	3.12	2.50	4.60	4.55	2.50	4.60
Thompson's Island, Artificial	1.93	0.50	2.50	22.23	21.68	22.81	7.70	7.60	7.91	8.57	6.63	11.47	578	559	596	2.73	1.90	3.80	4.63	1.90	3.80
Thompson's Island, Natural	0.77	0.46	1.50	22.39	21.81	22.95	7.79	7.72	7.89	8.95	7.99	9.80	579	560	596	2.50	1.90	3.70	4.67	1.90	3.70
I-35	0.86	0.50	1.50	22.61	21.98	23.24	7.69	7.61	7.78	9.17	8.21	10.88	579	560	596	1.86	1.60	2.30	4.74	1.60	2.30
Rio Vista Park	1.85	1.50	2.10	22.73	22.13	23.28	7.56	7.46	7.62	9.87	8.81	11.68	579	559	596	1.88	1.40	2.20	4.67	1.40	2.20
Lion's Club	1.59	1.00	2.15	22.78	22.31	23.28	7.51	7.42	7.66	9.2	8.25	11.60	578	560	595	1.60	1.20	2.00	4.80	1.20	2.00
Sessoms Creek	0.10	0.10	0.11	22.88	21.82	23.7	7.48	7.42	7.53	7.38	6.77	8.63	605	588	611	1.72	1.10	2.20	4.62	1.10	2.20
Dam	0.79	0.50	1.20	22.66	22.23	23.34	7.43	7.29	7.52	8.47	7.20	10.91	579	562	598	1.18	0.90	1.40	4.60	0.90	1.40
Chute	1.08	0.91	1.20	22.59	22.30	23.01	7.35	7.04	7.47	8.60	7.75	10.61	580	561	596	2.88	1.00	8.20	4.75	1.00	8.20

Table 4. Summary of chemical parameters in the San Marcos River ecosystem from 2000-2001.

SITE	SOLUBLE REACTIVE PHOSPHORUS (µgP/l)			TOTAL PHOSPHORUS (µg/l)			AMMONIUM (µg/l)			NITRATE (mg/l)			TOTAL NITROGEN (mg/l)			TOTAL SUSPENDED SOLIDS (mg/l)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Animal Shelter	14.43	1.57	30.83	18.13	1.57	33.99	33.6	12.0	56.9	1.35	1.20	1.65	1.61	1.39	1.96	0.029	0.002	0.121
Thompson's Island, Artificial	7.59	3.83	17.24	11.41	3.83	14.26	52.7	36.0	89.0	1.23	0.67	1.89	1.43	0.99	2.35	0.019	0.004	0.09
Thompson's Island, Natural	6.38	1.74	16.89	12.49	1.74	18.52	51.5	14.0	81.0	1.37	1.05	1.62	1.59	1.38	1.71	0.031	0.004	0.136
I-35	7.29	1.22	19.85	15.58	1.22	31.62	49.1	16.0	127.3	1.54	1.33	1.79	1.66	1.12	2.26	0.022	0.002	0.091
Rio Vista Park	5.87	0.70	16.54	11.20	0.70	18.36	93.8	7.0	127.3	1.60	1.22	2.12	2.07	1.63	2.82	0.014	0.001	0.059
Lion's Club	12.99	4.96	21.07	23.92	4.96	29.90	64.2	18.0	115.9	1.49	1.24	1.68	1.72	1.53	1.9	0.021	0.002	0.094
Sessoms Creek	7.68	4.44	11.49	17.54	4.44	21.77	23.5	2.0	104.6	1.72	1.26	2.26	1.82	1.09	2.71	0.005	0.002	0.015
Dam	9.77	4.09	15.67	14.56	4.09	19.58	80.2	31.9	118.0	1.49	1.20	1.76	1.92	1.63	2.33	0.015	0.001	0.064
Chute	8.99	4.79	11.15	16.64	4.79	32.24	27.1	19.0	43.3	1.23	0.51	1.90	1.45	0.8	2.2	0.017	0.000	0.080

3). Thermal variability in the slough arm of Spring Lake was quite high, as has been observed before (Groeger, unpublished Hydrolab and thermistor data). Though this is a preliminary judgement, there is no clear or dramatic change in these variables when comparing the low-flow fall 2000 data with the following, higher-flow period data.

Aquatic Vegetation Mapping

Maps of the aquatic vegetation during each sampling effort can be found in Appendix A. The maps are organized by individual reach with successive sampling trips (quarterly and high flow) ordered chronologically. It is difficult to make sweeping generalizations about seasonal and other trip-to-trip characteristics, since most changes occurred in fine detail; however, some of the more interesting observations are described below.

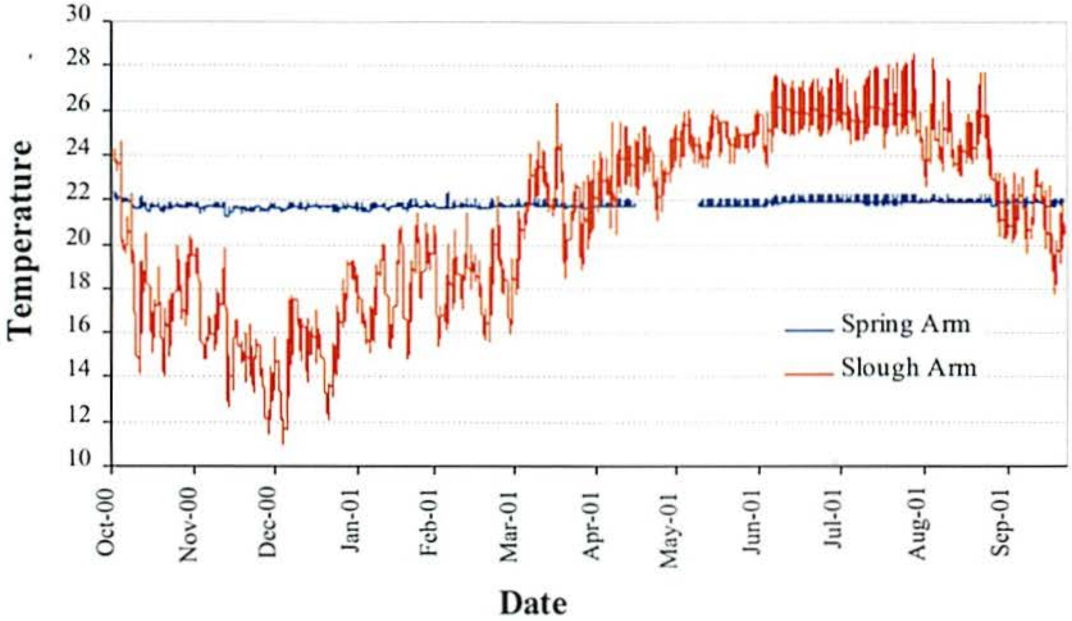


Figure 4. Thermistor data from the slough and spring (Hotel Reach) arms of Spring Lake.

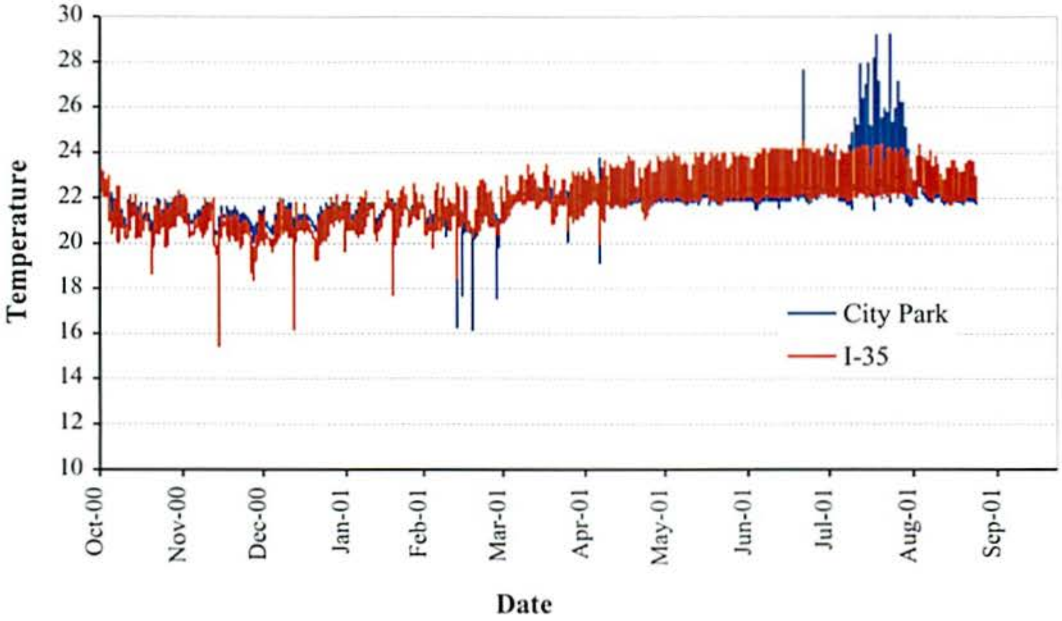


Figure 5. Thermistor data from the City Park and I-35 Reaches.

City Park Reach

The City Park Reach experienced some seasonal fluctuation in certain vegetation types. The fall 2000 map of this area reveals a reduced *Hydrilla* coverage relative to the other mapping efforts. Potential recreational impact in this area will be discussed below. These areas were quickly filled in with a dense stand of vegetation in the following months. By the winter sampling effort (late February 2001), most of the areas were completely covered with vegetation; there was relatively little bare at that time. It also appeared that a few Texas wild-rice plants were able to take hold in areas within the*Potamogeton/Hydrilla* complex; several Texas wild-rice plants appeared between the two sampling efforts. It should be noted that in the winter, spring, and summer sizable vegetation mats covered areas within this reach, and some Texas wild-rice plants appear on some maps but not because they were obscured by vegetation.

In the spring almost the entire northern quarter of the map (Appendix A) is filled in with vegetation (*Potamogeton, Hydrilla, Hygrophila*, and *Sagittaria*). Further downstream there is evidence of seasonal recreational use of the river with some decreasing *Hydrilla* coverage in the shallower sections. As in 2000 the effect of recreational impacts became more visible on the summer map (Appendix A), which shows an area of bare substrate stretching across the entire river on the shallowest route between the two banks. Though *Hydrilla* is an undesirable exotic species, these maps illustrate the potential effects of recreational use on the aquatic vegetation community.

The downstream half of this reach remained relatively unchanged in the spring (Appendix A) and throughout all sampling events. This area is deeper and probably experiences little impact from recreation or flooding. The entire stream bottom is covered with vegetation *(Hydrilla, Potamogeton, Hygrophila*, and various mixtures of these three), the estimate of which changes slightly during each trip because of difficulty observing exact distinctions between vegetation complexes in deeper water. Several smaller Texas wild-rice plants "appear" in the *Potamogeton/Hygrophila* stand in the spring and summer, but most likely these plants were obscured by the dense growth of *Potamogeton* and *Hygrophila* around them.

The effect of the high-flow event on this ecosystem in fall 2001 is evident in the post-flood map (Appendix A). Large areas were scoured in the dense *Potamogeton/Hygrophila* stand in the upstream portion of the reach, and even large scoured areas are evident in the *Hydrilla*. In addition to the bare areas seen on the map, many large areas of reduced coverage were observed (i.e., 20-50% *Potamogeton* and 20-50% *Hydrilla*) but not indicated separately on this map. Even the downstream portion of this reach, where very little change had occurred previously, revealed significant areas of newly scoured bare substrate.

Interestingly, the areal coverage of Texas wild-rice was shown to increase slightly between the fall effort and the post-flood mapping (most of the stands were slightly larger). It is possible that some growth occurred during this time, but the more probable explanation is that the vegetation surrounding the Texas wild-rice stands was reduced, and more of each stand became visible to the mapping crew. In addition, the reduction of surrounding vegetation would allow the Texas wild-rice plants more freedom of movement with the current and result in a larger surface area for the mapping crew to outline for each. Regardless, the map clearly indicates that the Texas wild-rice in this reach is not as likely to be displaced during intense flooding events as in other areas where the Texas wild-rice stands grow in the absence of other vegetation types. None of the stands "disappeared" between the fall and high-flow maps, and one small piece even appeared to have been washed in from an upstream location and deposited in a scoured-out area of bare substrate.

I-35 Reach

The I-35 Reach was particularly difficult to map during most sampling efforts because of the dense canopy that reduced the efficacy of the GPS receiver; therefore, small discrepancies are apparent in the exact location of individual stands between sampling events. In addition, some estimates of total coverage may be less precise than in other reaches. During the Texas wild-rice survey conducted in the summer (when the canopy was most dense), an extra amount of time was devoted to gathering the most precise data possible for each Texas wild-rice stand.

One observation is the growth of *Cabomba* in the upstream half of this reach between fall 2000 and spring 2001. The *Cabomba* even displaced some of the other vegetation types in this preferable habitat type (e.g., lentic backwaters, deep silty substrates). During the summer sampling event it appeared that *Cabomba* had receded along that western shoreline, but it was actually a factor of GPS reception quality at that time; much of that stand fell outside of the boundary. Other vegetation types were also expanding on the outer edge of the *Cabomba* where more streamflow was available (*Sagittaria, Ludwigia*, and *Zizania*). There was relatively little change in any other area/vegetation type within this reach until the high-flow event.

The high-flow event in November 2001 had a particularly distinct impact on this reach. Much of this reach is constricted to a narrow channel with a dense riparian corridor and, in some places, steep banks. This resulted in a very intense scouring effect from the flood event that wiped out much of the vegetation and overhanging trees/branches. There were also large areas where the substrate was displaced, leaving a much deeper channel and other areas where sediment was deposited in large quantities. Much of the *Cabomba* was scoured out and thinned to a small percent coverage. The *Hydrilla* in the upstream-most areas was eliminated or reduced in coverage (the latter is not evident on map). One small patch of Texas wild-rice was removed in the upstream-most area (from within a patch of *Justicia*) and, just downstream, some scouring was evident in several other small patches.

Continuing downstream past the large bend in this reach, the effects were most pronounced. This is where the substrate was scoured and most of the vegetation (other than Texas wild-rice) was completely removed. Only one patch of *Sagittaria* (which is a low-profile species), one patch of *Hygrophila* immediately adjacent to the shoreline, and some *Heteranthera* in deeper water remained in this reach. The Texas wild-rice was also significantly reduced in the reach, but it managed to retain enough substrate with its root structure so as not to be entirely displaced. However, most of the remaining plants had roots that were largely exposed. In the last portion of the reach the *Cabomba* was almost completely removed, and the *Hydrilla* in deeper water was either scoured or covered with deposited gravel. The large Texas wild-rice stand in this smaller bend in the river was also heavily scoured and reduced to several smaller, individual stands. The overall reduction of Texas wild-rice in this reach was about 50 m^2 of the 124 m^2 observed during the previous trip.

Texas Wild-Rice Surveys

Maps generated from the summer and high-flow surveys of the entire San Marcos River (downstream of Spring Lake) can be found in Appendix A. The maps reveal certain trends that were observed in Texas wild-rice coverage, and the effects of an intense high-flow event. For comparison, the data gathered by TPWD and R. Doyle (Baylor University, pers. comm.) on total coverage of Texas wild-rice in the San Marcos River are displayed alongside our findings in Table 5. The most recent 2001 data was gathered by the TPWD just days prior to the summer sampling effort and provided nearly identical numbers to those obtained in this study.

Table 5. Total coverage of Texas wild-rice (m^2) in the San Marcos River as measured by the TPWD for 1994-2001.

YEAR/EVENT	1994	1995	1996	1997	1998	1999	2000	2001	Summer	High-Flow
COVERAGE·	1,456.3	1,624.0	1,652.1	1,584.2	1,949.0	1,644.9	1,791.1	1,895.6	1,901.2	1,765.9

·Total coverage values obtained in this study are included for the summer and high-flow events in 2001.

The most interesting observation resulting from these data is the decrease in total coverage (~7%) that occurred between the summer and high-flow sampling efforts (despite the fact that several deeper stands were found in the fall between the two pedestrian bridges in Sewell Park that had been overlooked in the summer, as well as one small stand just upstream of Aquarena Springs Drive). The intensity of the fall 2001 flood event was significant enough to cause scouring in most areas. The only area where little impact occurred as a result of that flooding was in the reach that runs from the City Park area to below the MOPAC railroad bridge (Appendix A, Texas wild-rice Map 2); there was actually a slight increase in this area. As discussed above, the Texas wild-rice plants found in this reach were generally well protected by surrounding vegetation and, although scouring of other vegetation types occurred in this reach, no scouring of Texas wild-rice occurred.

In other areas, however, the Texas wild-rice plants were not so well protected. Many of the stands in the Sewell Park and I-35 Reaches were so scoured that large bare substrate areas were left where Texas wild-rice had been. The downstream-most areas (Appendix A, Texas wild-rice Maps 5-7) were where the greatest loss by percent coverage occurred. Several small stands were removed completely, and most others experienced some level of scouring. These areas appeared to be most vulnerable to the high-flow events (TPWD 2001); pre-1998 flood maps of Texas wild-rice revealed a greater number of stands in these lower reaches.

Texas Wild-Rice Physical Observations

Several of the Texas wild-rice stands grew together to form larger, individual stands between the fall 2000 quarterly and winter 2001 sampling efforts (Table 6). This was most evident in the Sewell Park Reach, but two of the stands in the I-35 Reach were combined for winter the 2001 sampling event only. Trends in areal coverage of the stands, as well as for each of the qualitative categories, are discussed below for each of the reaches.

The Sewell Park, I-35, and Thompson's Island (Natural) Reaches displayed the greatest percent Texas wild-rice emergence during the fall 2000 sampling effort (Appendix B); this was also the only time the depth at any stand was measured below 0.5 foot (in Sewell Park and I-35, but not Thompson's Island; Appendix B). The significant emergence during that sampling event appears to be related to water level. After the intense high-flow event occurring in fall 2001, the Texas wild-rice emergence was given the lowest index values to date; the values were also low during following a period of increased flows between the fall 2000 and winter 2001 sampling efforts. A preliminary explanation for these observations is that periods of low-flow stimulate emergence and the amount is dramatically reduced as flows reach higher levels. One hypothesis is that the exposure of leaves to the air/water interface and reduced movement of the leaves (reduced force resulting from decreased streamflow) stimulate growth of a seed stalk. Increased water flows likely cover the emergent parts and/or increase the force of water flow acting on that portion of the plant, causing the plant to cut back on the resources devoted to maintaining a seed stalk.

Table 6. Texas wild-rice areal coverage for each stand by sampling period.

REACH-STAND NO.[a]	FALL 2000	WINTER 2001	SPRING 2001	SUMMER 2001	FALL 2001	HIGH-FLOW
Sewell Park-1	1.65	8.84	13.18	15.48	13.10	12.47
Sewell Park-2	4.43					
Sewell Park-3	45.94	63.81	62.11	63.44	59.49	60.73
Sewell Park-4	1.24	13.77	10.02	9.60	9.21	13.12
Sewell Park-5	3.61					
Sewell Park-6	52.08	417.36	448.01	472.97	399.37	368.20
Sewell Park-7	43.65					
Sewell Park-8	4.36					
Total Area	**156.97**	**503.78**	**533.32**	**561.48**	**481.17**	**454.51**
I-35-1	0.02	0.03	0.74	0.22	0.21	0.27
I-35-2	0.02	1.02	3.02	1.48	1.39	0.59
I-35-3	0.02	1.37	1.81	0.96	1.00	1.23
I-35-4	0.13	0.10	0.24	0.26	0.24	0.18
I-35-5	72.96	63.54	74.73	66.91	70.26	38.50
I-35-6	2.30	20.40	5.10	5.55	6.733	5.12
I-35-7	5.51		25.38	20.41	14.69	19.16
I-35-8	90.51	149.48	120.51	147.88	142.85	142.56
Total Area	**171.46**	**235.94**	**231.52**	**243.67**	**237.36**	**207.60**
Thompson's Island, Natural-1	6.37[b]	Gone	Gone	Gone	Gone	Gone
Thompson's Island, Natural-2	1.12	1.78	2.48	6.18	4.37	4.99
Thompson's Island, Natural-3	0.02	0.15	0.15	0.64	0.32	0.81
Total Area	**1.15**	**1.93**	**2.63**	**6.82**	**4.70**	**5.80**

[a] Many stands grew together to form individual stands after the first sampling period (SP-1, SP-2; SP-4, SP-5; SP-6, SP-7, SP-8; I-35-6, I-35-7 [winter 2001]).

[b] Not calculated.

Sewell Park Reach

The average areal coverage of Texas wild-rice considered to be in vulnerable locations in this reach was 449 m^2, but it ranged from 157 m^2 in fall 2000 to 562 m^2 in summer 2001 (Table 6). The first field effort (fall 2000) was conducted during a low-flow period with shallow water levels and sparse Texas wild-rice stands. Because of the merging of stands prior to the following surveys, several stands were combined and treated as one contiguous stand; this appears to have contributed to the significant increase in coverage that was observed during these later sampling efforts. One of the most significant results of this stand merging was a very large patch of Texas wild-rice that was not included in the first sampling effort joining to one of the vulnerable stands and remaining throughout 2001.

Despite the discrepancy between fall 2000 and winter 2001, during which additional areas were included in the calculations, an increase in the coverage was observed in this reach during each sampling effort throughout summer 2001. Following summer sampling, a period of increased flow occurred in the ecosystem (corresponding to the first Comal River high flow), but it was not sampled separately. The results were apparent during the fall sampling effort when the first decrease in areal coverage of Texas wild-rice occurred (~14.3%). A second decrease occurred following the second high-flow event (~5.5%).

Root exposure in this reach was highest during periods of lowest flow (fall 2000 and summer 2001, Appendix B), although exposure was also high following the second high-flow event. Root exposure may not necessarily translate into any significant impact to the plants; however, it should be noted that the greatest decrease in plant coverage occurred following a high-flow event (September 2001) before which the roots exhibited the greatest exposure (see results for the I-35 Reach section below). Less reduction in Texas wild-rice coverage was observed following the greater high-flow event, when root exposure was much lower. Therefore, it appears that significant levels of root exposure may leave the plants more vulnerable to scouring.

I-35 Reach

The average areal coverage of Texas wild-rice considered to be in vulnerable areas in this reach was 221 m^2, but it ranged from 171 m^2 in fall 2000 to 244 m^2 in summer 2001 (Table 6). All study stands within this reach remained as individual stands with the exception of two stands that merged during winter 2001. Like in the Sewell Park Reach, total coverage increased dramatically between the fall 2000 and winter 2001 sampling events (~38%), but there was less variation in subsequent sampling in this reach. A slight decrease was observed during the spring sampling effort (~2%,) and an increase had occurred by the summer sampling effort (~5%). Similar to the Sewell Park Reach, a decrease was observed following the periods of greater flow, the fall and high-flow events (~2.5% and 12.6%, respectively), but the greater decrease followed the greater high-flow event.

Root exposure in this reach decreased steadily between winter 2001 and fall 2001 sampling efforts (a slight increase occurred in spring) to the lowest point just prior to the high-flow event (Appendix B). Unlike in the Sewell Park Reach, where root exposure was highest just prior to the greatest decrease in Texas wild-rice coverage, the root exposure here was nearly the lowest. This suggests that the scouring effects of an intense high-flow event will remove vulnerable plants regardless of the level of root exposure.

Thompson's Island Reach (Natural)

Three individual Texas wild-rice stands that were considered to be in vulnerable areas were initially identified within this reach. However, as noted during the second sampling effort in winter 2001, one entire stand had disappeared from its original location and it was removed from the calculations. The remaining two stands within this reach had increased dramatically by the following sampling event (1.15 - 1.93 m^2) and continued to increase to a maximum of 6.8 m^2 by the summer sampling event. Both stands decreased in size dramatically after the first high-flow event (~30.8%), but they actually increased after the second high-flow event (~23.4%). The latter result is perplexing and cannot really be explained in terms of the effects of streamflow on the plants. It is possible that favorable weather conditions allowed the stands to increase in size and the hydraulics of the second high-flow limited the force of the water in the immediate area of these two stands (on the inside of a river bend).

Regardless of the explanation for the increase in the Texas wild-rice stands within this reach following the more intense high-flow event, root exposure did not appear to be a factor. Root exposure was low during both the summer and fall 2001 sampling efforts (before and after the only significant decrease), but it was high following the more intense high-flow event (Appendix B). Apparently the latter high-flow event was not intense enough to remove the stands, but it did cause some scouring around the root area.

Another interesting observation in the Thompson's Island Reach (Natural) was that this area appeared to be least effected by predation/herbivory; after fall 2000 no signs of predation/herbivory were evident (Appendix B). In the other reaches, the two fall seasons (2000 and 2001) exhibited the greatest evidence of predation/herbivory. The low impact in the Thompson's Island Reach may be attributed to its remote location.

Fountain Darter Sampling

Drop Nets

The number of drop net sites and vegetation types sampled per reach is presented in Table 7.

Table 7. Drop net sites and vegetation types sampled per reach.

CITY PARK REACH	I-35 REACH
Open (2)	Open (2)
Hygrophila (2)	Hygrophila (2)
Hydrilla (2)	Hydrilla (2)
Potamogeton/Hygrophila (2)	Cabomba (2)
Total (8)	**Total (8)**

The drop net site locations are depicted on the aquatic vegetation maps (Appendix A) for the respective reaches per sampling event. The data sheets for the drop net sampling are presented in the tables section of Appendix C (bound separately) by reach and specific site, respectively.

The size-class distribution for fountain darters collected by drop nets from the San Marcos Springs / River ecosystem is presented in Figure 6. The overall distribution is typical of a healthy fish assemblage, although shifted towards fish larger than those observed in the Comal ecosystem. This is most likely a function of the habitat suitability of the two sampled reaches. As discussed in the dipnet section, adding the size-class distribution data from the high-quality habitat in Spring Lake would shift the peak of this distribution to a lower size class and yield a distribution that correlates well with that observed in the Comal ecosystem.

Figure 7 describes the number of fountain darters collected in the San Marcos Springs / River ecosystem by sampling event. In general, the number of fountain darters per net in the San Marcos River was much lower than in the Comal River. Again, this is likely related to the quality of habitat sampled in each ecosystem. Compared with the Comal ecosystem, trends in fountain darter abundance in the San Marcos Springs / River ecosystem appear to lag behind by one event. For instance, the lowest numbers appear during the winter period (vs. fall for the Comal ecosystem) and the highest numbers are reported in the summer (vs. spring for the Comal ecosystem). It is interesting to note that the fall 2000 sampling

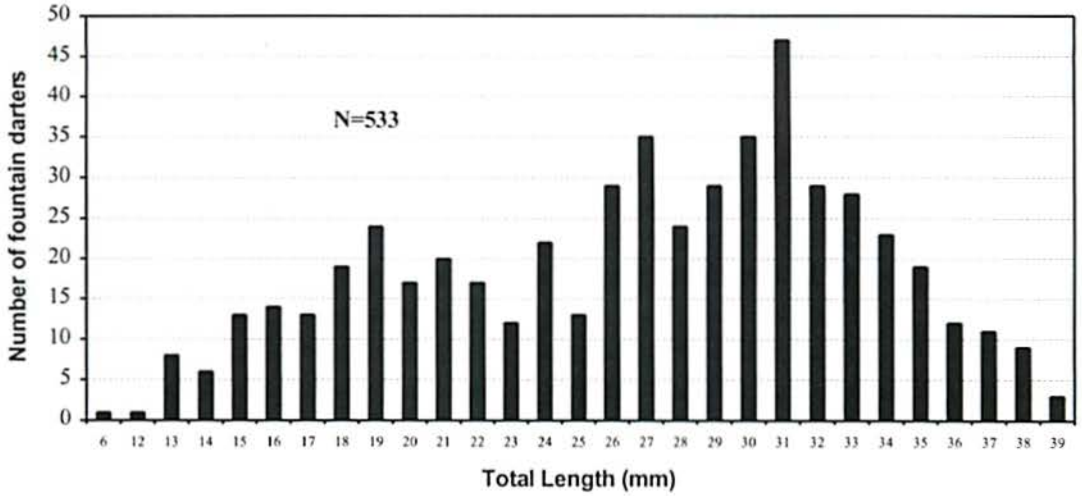


Figure 6. Fountain darter size class distribution among all drop net sampling events.

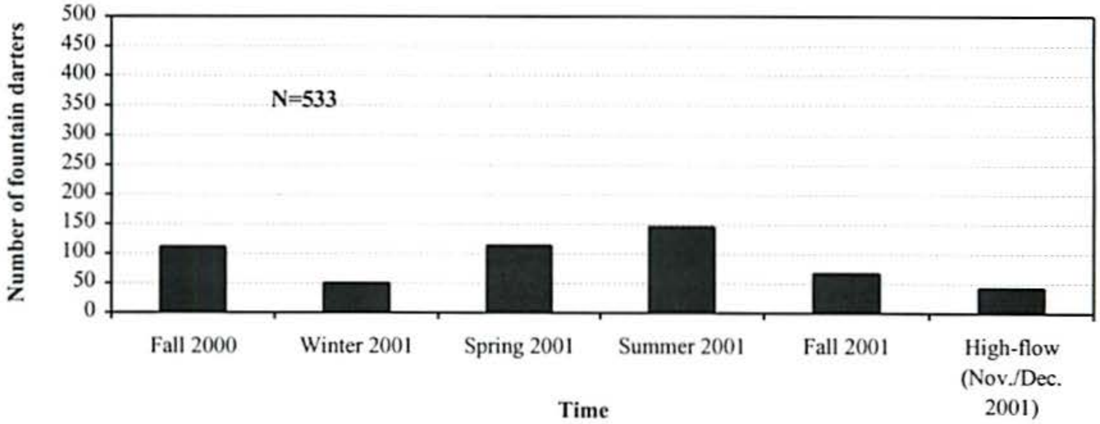


Figure 7. Number of fountain darters collected by drop net sampling event.

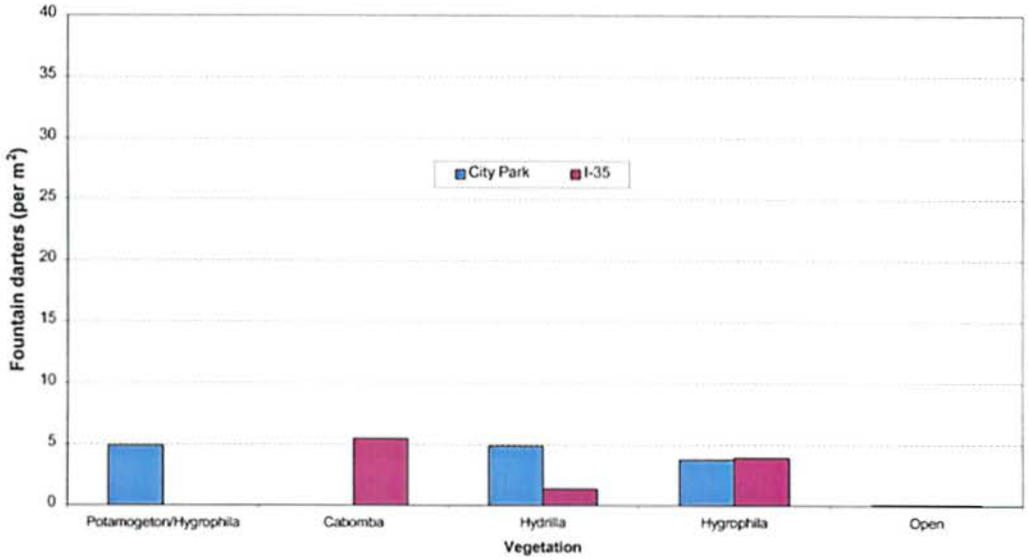


Figure 8. Density of fountain darters collected by vegetation type.

event was conducted during a period of low flow and the fall 2001 sampling event followed a period of considerably higher flow, yet the number of fountain darters collected during the fall 2000 sampling event was much higher.

At first glance the high-flow event dip net and drop net results for the I-35 Reach appear to present contradictory results; fewer fountain darters were collected in drop nets and more fountain darters were collected in dip nets after the high-flow event. As described in the dip net section, the overall habitat was greatly reduced and this was reflected in the drop net results; however, one inundated patch of vegetation sampled with a dip net but not with a drop net revealed a clumping (concentration) effect of fountain darters within certain patches of remaining habitat. The results of this particular sampling effort were enough to skew the data set and provide the apparently contradictory results between the two methods. This re-emphasizes the importance of detailed examination of an ecosystem via multiple collection techniques rather than a one-time sampling event or limited sampling during particular seasons using only one technique.

A breakdown of fountain darter density per vegetation type is presented in Figure 8. All vegetative habitat in the City Park Reach contained a density approaching five fountain darters per m^2; in the I-35 Reach, fountain darter density in *Cabomba* was also approximately five per m^2. *Hydrilla* and *Hygrophila* also supported fountain darter populations but at lesser densities. As in the Comal ecosystem, *Cabomba* sites yielded fountain darters despite the apparently unfavorable conditions generally associated with these sites (silty substrate, minimal flow, presence of competitors/predators). This association with silty substrate is interesting for a spring-adapted species and may indicate a greater tolerance level for the fountain darter compared with other spring-adapted species. All sampling conducted over bare substrate yielded zero fountain darters. As in previous studies, vegetation is a key factor in the abundance of fountain darters within any area.

Table 8 lists the fish species collected during the 2001 drop net sampling event on the San Marcos Springs / River ecosystem. In all, 23 species of fish totaling 4,304 individuals were collected. Of the 23 species, seven are considered introduced (exotic) to the San Marcos Springs / River ecosystem.

Another exotic species, the giant ramshorn snail, was also recorded and measured at each drop net location. Only 19 total specimens have been collected to date from a total of 112 drop net locations. Therefore, the densities of giant ramshorn snails currently found in the San Marcos Springs / River ecosystem (including the 2000 fall event) pose no serious threat to aquatic vegetation. However, because of the impact that this exotic species can have under heavier densities, close monitoring should continue.

Dip Nets

The boundaries for each section of the dip net collection efforts are depicted on Figure 9. Section numbers are included to be consistent with the USFWS classification system for the San Marcos River. Data gathered using dip nets for all sections are graphically represented in Appendix B. Using dip nets, fountain darters were collected from every section during every sampling event.

Among the three reaches sampled on the San Marcos Springs / River ecosystem, the Hotel Reach (Figure 10) exhibited reproduction occurring during sampling events and a very stable size-class distribution. This description holds true for the fall 2000 sampling event that was conducted under low-flow conditions. For this analysis, reproduction is considered to be occurring if fish 5-15 mm in length are being collected. Relative to the growth curves for fountain darters established by Brandt et al.

Table 8. Fish species and the number of each collected during 2001 drop net sampling.

COMMON NAME	SCIENTIFIC NAME	STATUS	TOTAL NUMBER
Rock bass	*Ambloplites rupestris*	Introduced	46
Yellow bullhead	*Amelurus natalis*	Native	9
Mexican tetra	*Astyanax mexicanus*	Introduced	1
Rio Grande perch	*Cichlasoma cyanoguttatum*	Introduced	4
Blacktail shiner	*Cyprinella venusta*	Native	6
Roundnose minnow	*Dionda episcopa*	Native	2
Minnow species	*Dionda* sp.	Native	3
Fountain darter	*Etheostoma fonticola*	Native	421
Gambusia	*Gambusia* sp.	Native	3,521
Suckermouth catfish	*Hypostomus plecostomus*	Introduced	5
Redbreast sunfish	*Lepomis auritus*	Introduced	16
Green sunfish	*Lepomis cyanellus*	Native	1
Warmouth	*Lepomis gulosus*	Native	6
Bluegill	*Lepomis macrochirus*	Native	27
Longear sunfish	*Lepomis megalotis*	Native	3
Spotted sunfish	*Lepomis punctatus*	Native	101
Sunfish	*Lepomis* sp.	Native	24
Largemouth bass	*Micropterus salmoides*	Native	15
Gray redhorse	*Moxostoma congestum*	Native	1
Texas shiner	*Notropis amabilis*	Native	11
Iron color shiner	*Notropis chalybaeus*	Native	8
Shiner species	*Notropis* sp.	Native	2
Dusky darter	*Percina sciera*	Native	2
Sailfin molly	*Poecilia latipinna*	Introduced	67
Tilapia	*Tilapia* sp.	Introduced	2

(1993), our size category of 5-15 mm represents fountain darters <58 days old. Evident reproduction occurred in the remaining two sample reaches (City Park and I-35) during two sampling events; the spring sampling event was the only time reproduction was evident in both reaches.

According to project team observations, the algae present in the Spring Lake Hotel Reach provides high-quality habitat for the fountain darter with excellent cover and an abundance of food. This has been observed during every San Marcos salamander SCUBA survey conducted in the Hotel Reach. The City Park and I-35 Reaches both maintain less quality habitat, and thus the number of fountain darters collected in each reach was less than in Spring Lake, despite greater collection times. Another interesting finding was that there were no fountain darters >35 mm in length collected in Spring Lake, whereas six of the seven sampling events in the City Park Reach and all sampling events in the I-35 Reach yielded fountain darters >35 mm in length. The correlation between habitat quality and fountain darter size is an interesting observation that will be explored in greater detail as more data are gathered in 2002.

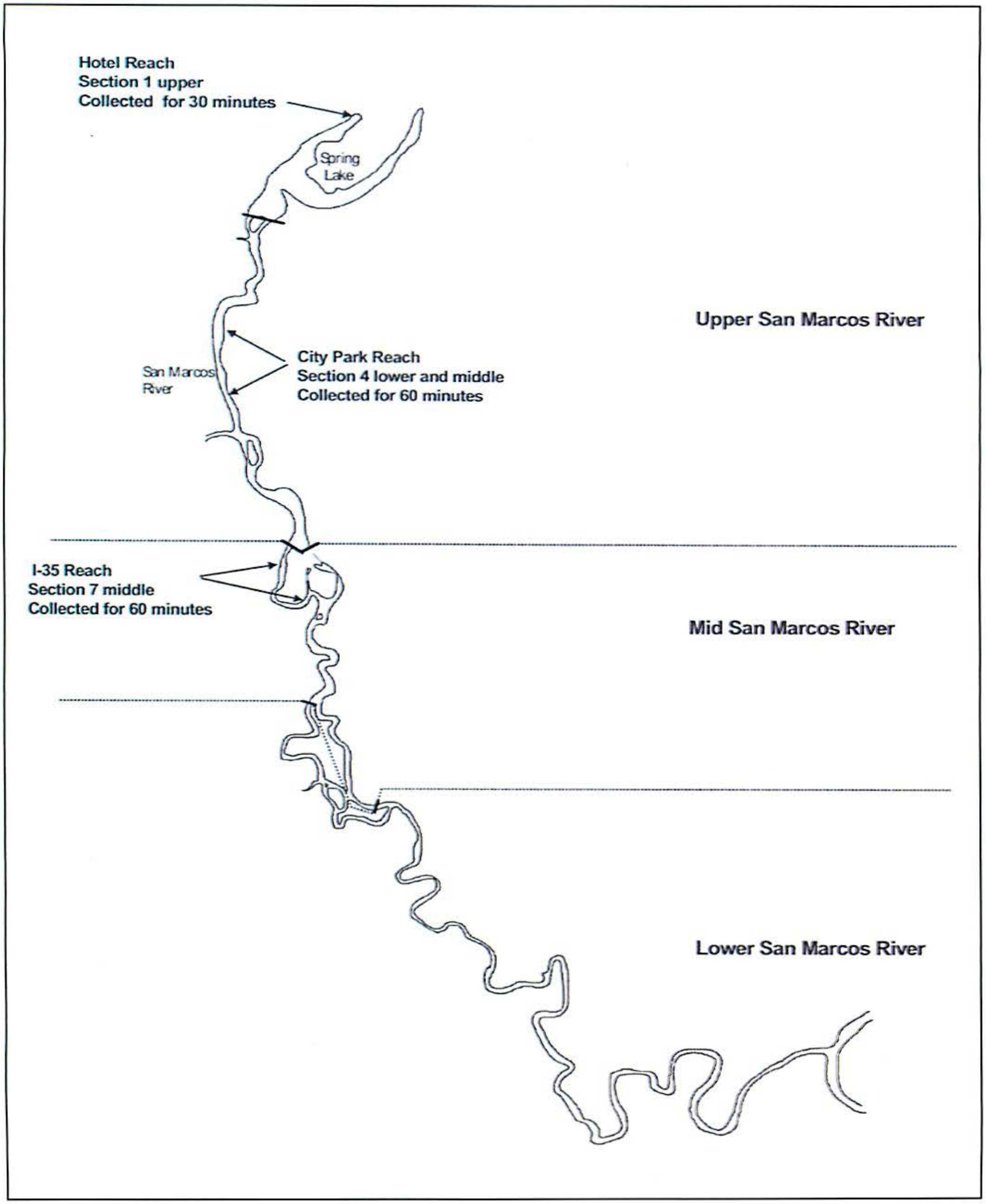


Figure 9. Areas where fountain darters were collected with dip nets, measured, and released in the San Marcos River.

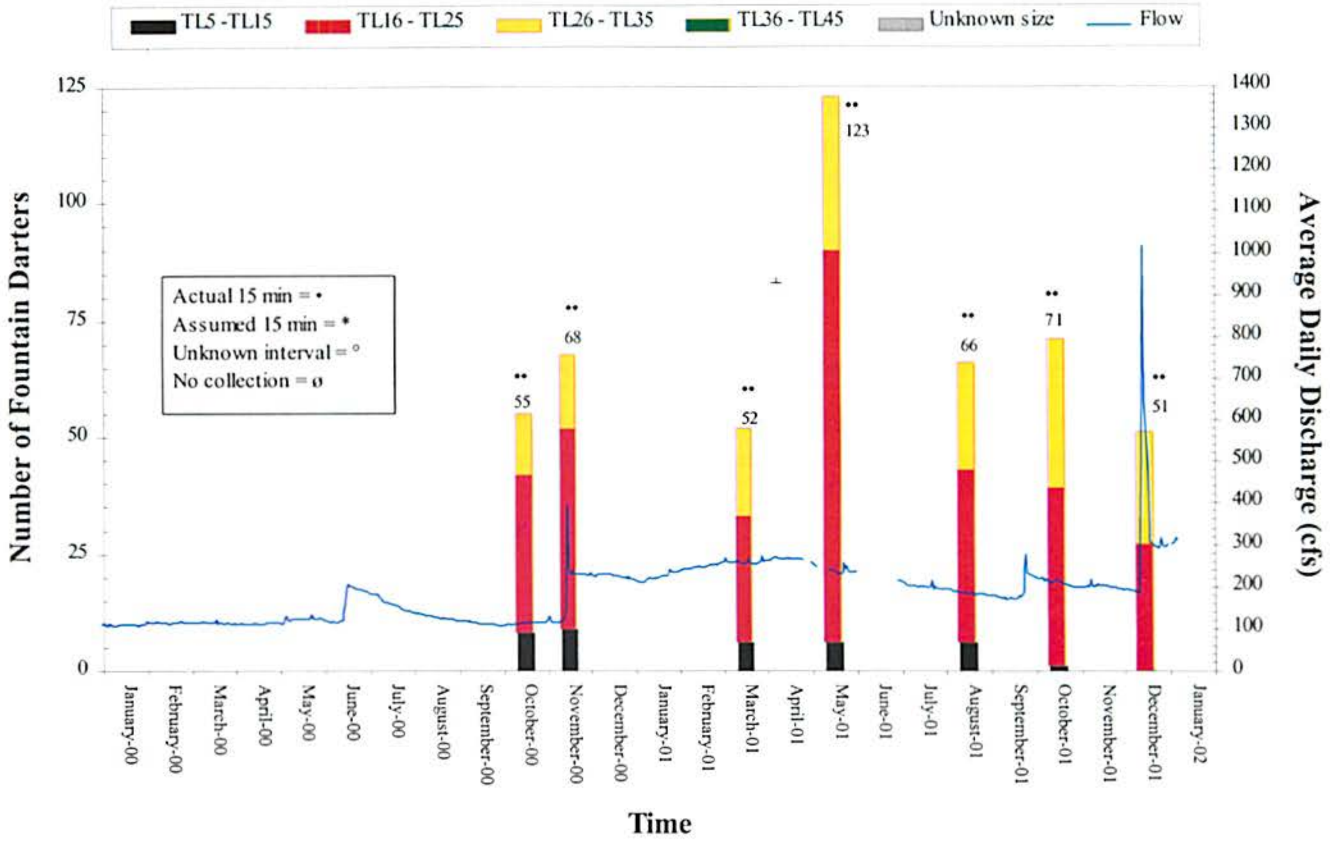


Figure 10. Number of fountain darters collected from the Hotel Reach (section 1 upper) using dip nets.

The greatest number of fountain darters observed in the I-35 Reach was during the high-flow event in December 2001. The high-flow event caused extensive vegetation scouring in the I-35 Reach, as evidenced in the aquatic vegetation maps described above (Appendix A). This reduction in vegetation, coupled with additional backwater areas that were inundated from higher water levels, led to what likely was a clumping (concentration) effect on the fountain darter population. As seen in the Comal ecosystem, greater densities observed in vegetation sampled following acute disturbances typically do not equate to an increased overall population size because a large amount of suitable vegetation is removed from the ecosystem.

Overall, these findings generally coincide with the findings of the drop net sampling. However, it is still premature to try and correlate these data directly with overall flow conditions in the San Marcos Springs / River ecosystem.

San Marcos Salamander Visual Observations

Sampling sites 2 (Hotel Reach) and 14 (Figure 1) experienced significant fluctuations in habitat characteristics between seasons; beginning during the winter 2001 sampling event and continuing into fall 2001, algae and other aquatic vegetation covered the area in thick mats. This potentially affected the results because the area had to be cleared prior to sampling activities during these times, and a smaller area was sampled than during periods in which the algae was less dense. It is possible that a significant portion of the San Marcos salamander population that would have been found under rocks were instead occupying the algae on top of the rocks during these times. Indeed, many San Marcos salamanders were observed when clearing the area. In addition, the disturbance associated with cleaning the area may have alerted the San Marcos salamanders to the impending search and impelled some individuals to retreat to deeper cavities within the rocks. Winter 2001 quarterly sampling was not performed at sampling site 14, and the sampling area was greatly reduced at this site during spring quarterly sampling because of excessive algae growth. Sampling site 11 was omitted after the initial fall 2000 survey because of heavy sedimentation, which prevented adequate surveying.

San Marcos salamander densities (m^2) that were observed at each survey site during each sampling period are presented in Table 9.

Table 9. San Marcos salamander density per square meter (m^2).

SAMPLING PERIOD	SAMPLING AREA 2	SAMPLING AREA 14	SAMPLING AREA 21
Fall 2000	19.4	3.4	5.2
Winter 2001	8.7	Omitted	2.6
Spring 2001	9.4	13.9	0.4
Summer 2001	16.6	11.1	1.5
Fall 2001	10.0	6.7	3.2
High-flow 2001	9.7	8.6	1.0

As shown in Table 9, San Marcos salamanders were observed during each sampling event. The greatest densities of San Marcos salamanders observed for sampling sites 2 and 21 occurred during the fall 2000 sampling event, a period of low-flow. As described above, the site 2 sampling area did not require a great deal of cleaning prior to surveying in fall 2000, whereas it did in subsequent trips. As noted, many San Marcos salamanders were observed in the algae upon removal. However, the survey technique required by USFWS to be comparable with Nelson (1993) simply is ineffective if the area is covered with algae and associated detritus; thus, removal is mandatory prior to surveying. Overall, a thriving San Marcos salamander population in sampling site 2 was observed throughout the study to date.

During this study, sampling site 14 has maintained a fairly stable population. The area experienced a massive algal growth in late winter 2001 that extended through the spring 2001 sampling event. Although difficult to sample during those periods, San Marcos salamanders have remained abundant in the area.

As mentioned above, sampling site 21 is located immediately below Spring Lake dam. During the fall 2000 sampling event when the ecosystem was experiencing lower flows, the San Marcos salamander population was abundant in this reach. However, it is likely that this relatively high density has a lot to do with the ease of sampling during lower flow conditions. Because this area is located in the river, the sampling technique was much more difficult under higher flow conditions that occurred during the rest of the study. At this time there is no explanation for the density reduction observed during the spring sampling event. The flows were high but not dissimilar to those that occurred during winter sampling. Repair of the Spring Lake Dam western spillway area during summer necessitated diverting the majority of water to the eastern spillway (sampling site 21). Therefore, much greater flows were witnessed in the eastern spillway during summer 2001 than reported at the stream gage. Subsequently, when flows stabilized after the western spillway reopened, it was not surprising that San Marcos salamander density increased during fall 2001 sampling. The reduction after the high-flow event was likely a combination of sampling difficulty and excessive disturbance in the habitat resulting from higher flows.

Exotics / Predation Study

A summary of the number of individuals of each species collected and the contents of their stomachs can be found in Tables 10 and 11 in the San Marcos and Comal ecosystems, respectively; a more detailed account of the data by sampling period is presented in Appendix B. Very few fountain darters and only a single salamander (in 2000) were found within the stomachs of potential predators. This is despite the increase in sample size that was accompanied by introducing rod-and-reel

Table 10. Predator diet summary for gill net and rod-and-reel surveyed fish in the San Marcos ecosystem.

TAXA	NUMBER	MEAN LENGTH (mm)	MEAN WEIGHT (g)	STOMACH CONTENTS· (% OF PREY ITEM)							
				Empty	Algae	Fountain Darters	Other Fish•	Salamanders	Crayfish and grass shrimp	Aquatic Invertebrates	Other·
C. cyanoguttatum	3	221.3	156.0	100.0	-	-	-	-	-	-	-
L. oculatus	14	689.9	1,418.2	57.1	-	-	35.7	-	-	-	7.1
L. auritus	5	174.0	116.1	-	-	-	-	-	-	80.0	40.0
L. gulosus	11	191.7	167.6	54.5	-	9.1	-	-	45.5	-	-
L. machrochirus	14	139.9	69.6	21.4	7.1	-	-	-	7.1	78.6	21.4
L. megalotis	11	183.5	134.1	36.4	-	-	-	-	9.1	54.5	-
L. microlophus	4	170.8	122.5	75.0	-	-	-	-	-	25.0	-
L. punctatus	22	124.2	50.8	36.4	-	-	-	-	-	59.1	4.5
M. salmoides	27	279.6	343.1	18.5	-	-	25.9	3.7	22.2	3.7	29.6

·If multiple items were found in the stomach, then all items were included in calculations.
•Includes unidentifiable fish remains, thus, fountain darter numbers could be higher than indicated.
·Terrestrial insects, unidentifiable material, etc.

Table 11. Predator diet summary for gill net and rod-and-reel surveyed fish in the Comal ecosystem.

TAXA	NUMBER	MEAN LENGTH (mm)	MEAN WEIGHT (g)	STOMACH CONTENTS· (% OF PREY ITEM)							
				Empty	Algae	Fountain Darters	Other Fish•	Salamanders	Crayfish and grass shrimp	Aquatic Invertebrates	Other·
C. cyanoguttatum	23	153.1	106.9	34.8	39.1	-	-	-	13.0	30.4	-
L. auritus	9	137.7	45.9	22.2	-	-	11.1	-	11.1	77.8	-
L. cyanellus	1	105.0	57.0	-	-	-	-	-	-	100.0	-
L. gulosus	4	102.5	25.3	25.0	-	-	-	-	-	50.0	25.0
L. megalotis	17	128.3	58.8	29.4	-	-	-	-	17.6	58.8	11.8
L. punctatus	42	125.8	52.6	26.2	2.4	-	-	-	11.9	52.4	7.1
M. salmoides	29	290.1	445.0	27.6	-	6.9	24.1	-	51.7	3.4	3.4
H. plecostomas	1	440.0	1,106.0	100.0	-	-	-	-	-	-	-
T. aurea	40	367.2	959.3	35.5	54.8	-	-	-	-	25.8	-

·If multiple items were found in the stomach, then all items were included in calculations.
•Includes unidentifiable fish remains, thus, fountain darter numbers could be higher than indicated.
·Terrestrial insects, unidentifiable material, etc.

sampling methods.

The largemouth bass (*Micropterus salmoides*) and warmouth (*Lepomis gulosus*) were the two predator species observed to feed on fountain darters. Other fish prey were found in the stomachs of the largemouth bass. However, no other fish prey were found in any warmouth; they fed primarily on crayfish in the San Marcos River and other aquatic invertebrates in the Comal River. Fish and crayfish were the most common items in the diet of the largemouth bass, although there was one instance of a San Marcos salamander in the stomach of a San Marcos largemouth bass. Fish were found in about 25% of all largemouth bass stomachs, while crayfish were abundant in the diet of Comal individuals (52%) but less common in the San Marcos largemouth bass diet (22%). From this data set, it appears that the fountain darter may be an incidental prey item for the largemouth bass, which tends to be an opportunistic species. The warmouth may, however, be more suited to target the fountain darters as a prey species, given the larger size of the mouth relative to other sunfish and the tendency to focus on benthic fauna (unlike the bass). Nonetheless, the occurrence of fountain darters in the warmouth diet is limited to just the one instance. A greater sample size of this species will determine whether that observation was an anomaly or if warmouth do prey on fountain darter when the opportunity arises.

Spotted gars (*Lepisosteus oculatus*) are another San Marcos River predator with fish as a common food item; however, no fountain darter was found in the diet of that species. Rio Grande cichlids (*Cichlasoma cyanoguttatum*) were also sampled in both ecosystems, but both individuals from the San Marcos had empty stomachs and the primary food item in the stomachs of the Comal fish was algae. The remainder of the fish sampled were sunfish species (*Lepomis*), which fed primarily on aquatic invertebrates.

REFERENCES

Brandt, T. M., K. G. Graves, C. S. Berkhouse, T. P. Simon, and B. G. Whiteside. 1993. Laboratory spawning and rearing of the endangered fountain darter. Progressive Fish-Culturist 55: 149-156.

Crumpton, W.G. T.M. Isenhart, P.D. Mitchell. 1992. Nitrate and organic n analyses with second-derivative spectroscopy. Limnol. Oceanogr. 37(4): 907-913

Doyle, R. 2002. Botanist, Baylor University, Department of Biology. Personal communication with Ed Oborny of BIO-WEST, Inc., Pflugerville, Texas, regarding Texas wild-rice annual coverages – San Marcos system. 01/2002.

Holmes, R.M., A. Aminot, R Kerovel, B.A. Hooker, and B.J. Peterson. 1999. A simple and precise method for measuring ammonium in marine and freshwater ecosystems. Can. J. Fish. Aquat. Sci. 56(10): 1801-1808

Nelson, J. 1993. Population size, distribution, and life history of *Eurycea nana* in the San Marcos River. Thesis, Master of Science, Southwest Texas State University. 43 pp.

Poole, J. 2000. Botanist, Texas Parks and Wildlife Department. Personal communication with Marty Heaney, PBS&J, Inc., Houston, Texas, regarding Texas wild-rice physical observations – San Marcos system. 09/2000.

American Public Health Association (APHA). 1992. standard methods for the examination of water and wastewater, 18th edition. American Public Health Association, Washington D.C.

Strickland, J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis, 2nd edition. Fisheries Research Board of Canada, Ottawa.

Texas Parks and Wildlife Department (TPWD). 2001. An evaluation of spring flows to support the Upper San Marcos River Spring Ecosystem, Hays County, Texas. Resource Protection Division, Texas Parks and Wildlife Department, Austin, Texas.

U.S. Geological Survey (USGS). 01/2000. Provisional data for Texas. Location: http://tx.waterdata.usgs.gov/niwis/help/provisional.

APPENDIX A: MAPS

San Marcos River
Aquatic Vegetation
City Park - Fall

October 30, 2000

Shore and Islands
River
Study Area (5,850.6 m^2)
Bare Substrate
Colocasia
Drop Net Sample Sites

	Meters^2		
Hydrilla	1,137.0	*Hydrilla / Potamogeton*	427.6
Hygrophila	446.2	*Hydrilla / Sagittaria*	8.1
Ludwigia	1.8	*Hygrophila / Chara*	1.1
Potamogeton	7.2	*Hygrophila / Potamogeton*	1,536.4
Sagittaria	49.1	*Hygrophila / Sagittaria*	15.6
Vallisneria	21.7	*Potamogeton / Sagittaria*	16.2
Zizania	21.5	*Hydrilla / Hygrophila / Potamogeton*	0.9
Hydrilla / Hygrophila	1.2	*Hygrophila / Potamogeton / Sagittaria*	76.6

EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

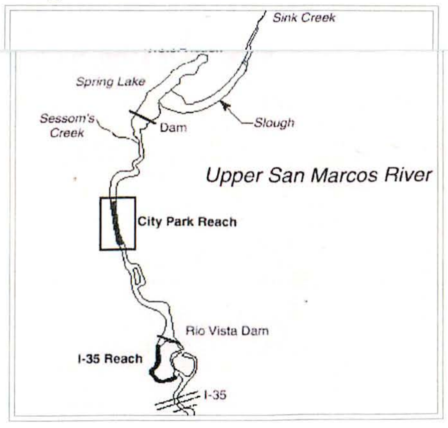
PBS&J

San Marcos River Aquatic Vegetation

City Park - Winter

February 28, 2001

Project Location



- ▨ Shore and Islands
- ☐ River
- ☐ Study Area (5,850.6 m^2)
- ▨ Bare Substrate
- *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters^2
Hydrilla	1,823.9
Hygrophila	270.5
Ludwigia	1.4
Potamogeton	238.6
Sagittaria	93.9
Vallisneria	8.5
Zizania	40.3
Hydrilla / Potamogeton	471.7
Hygrophila / Potamogeton	1,580.5
Hydrilla / Hygrophila / Potamogeton	70.4

Scale: 1"=70'

Meters 10 0 10 20 30 40

EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

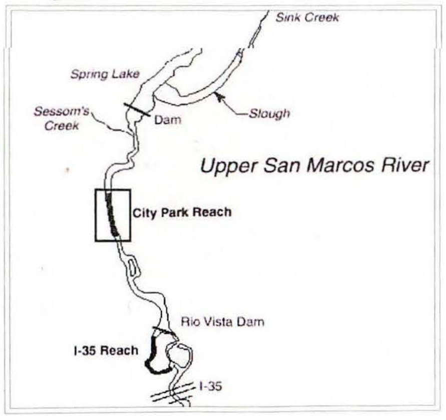
PBS&J

San Marcos River Aquatic Vegetation

City Park - Spring

April 30, 2001

Project Location



- ▨ Shore and Islands
- ▢ River
- 🟥 Study Area (5,850.6 m^2)
- ▢ Bare Substrate
- *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters^2
🟩 *Hydrilla*	1,584.9
🟨 *Hygrophila*	201.2
🟧 *Ludwigia*	0.9
🟩 *Sagittaria*	24.5
▢ *Vallisneria*	5.2
🟥 *Zizania*	58.4
▨ *Hydrilla / Potamogeton*	842.2

▨ *Hygrophila / Potamogeton*	1,624.7
▨ *Hygrophila / Sagittaria*	53.9
▨ *Potamogeton / Sagittaria*	89.1

Scale: 1"=70'

Meters 10 0 10 20 30 40

EDWARDS AQUIFER AUTHORITY

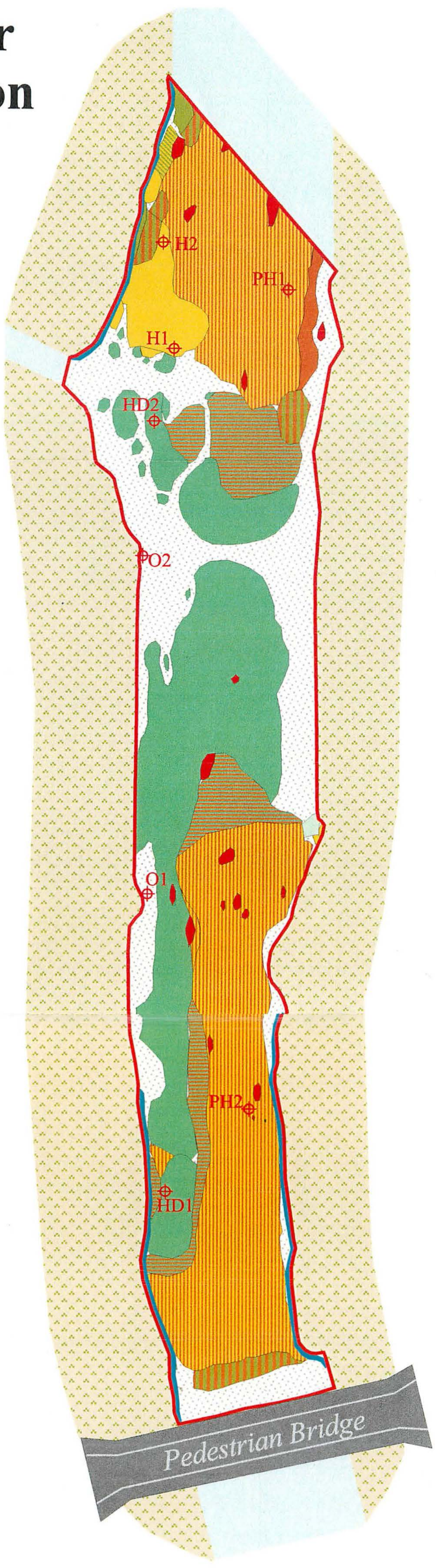
BIO-WEST, Inc.

PBSJ

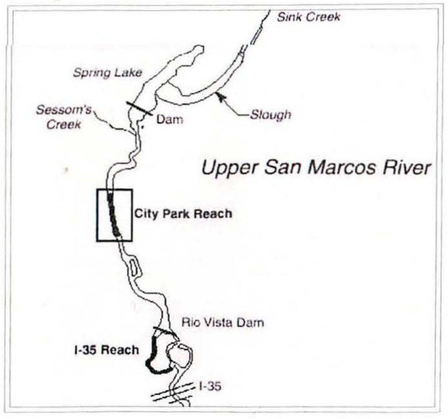
San Marcos River Aquatic Vegetation

City Park - Summer

July 31, 2001



Project Location



▨ Shore and Islands
⬜ River
▭ Study Area (5,850.6 m^2)
⬜ Bare Substrate
Colocasia
⊕ Drop Net Sample Sites

Scale: 1"=70'

Meters 10 0 10 20 30 40

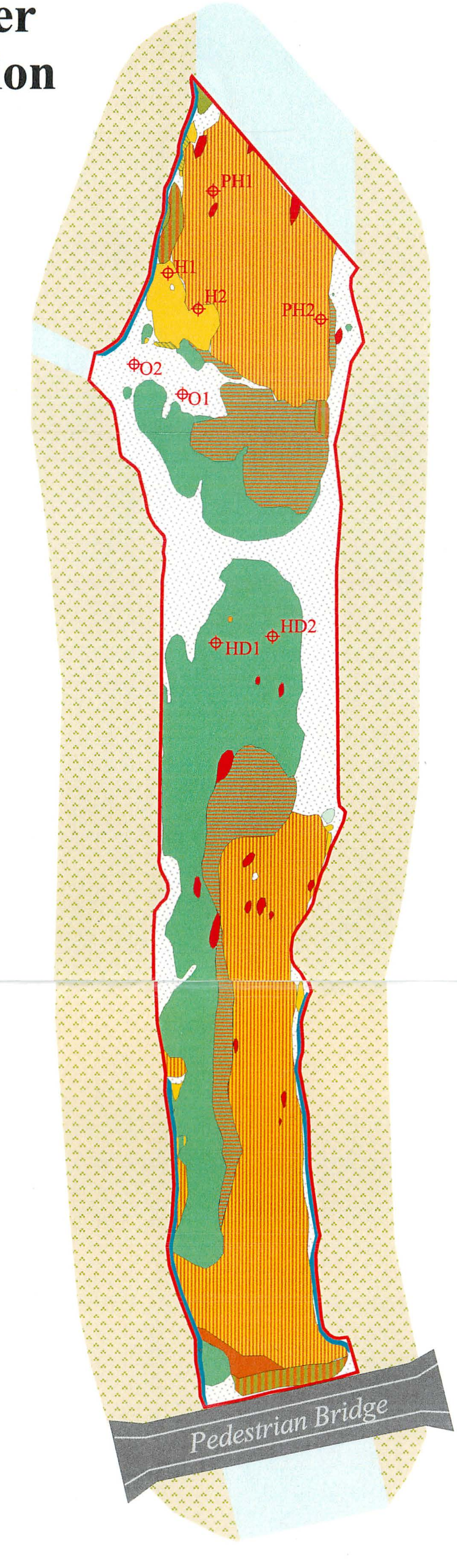
		Meters^2
🟩	*Hydrilla*	1,421.9
🟨	*Hygrophila*	190.1
🟧	*Potamogeton*	45.0
🟩	*Sagittaria*	30.6
⬜	*Vallisneria*	7.9
🟥	*Zizania*	52.3
▨	*Hydrilla / Potamogeton*	492.1
▨	*Hygrophila / Potamogeton*	1,994.4
▨	*Hygrophila / Sagittaria*	17.9
▨	*Potamogeton / Sagittaria*	133.0

EDWARDS AQUIFER AUTHORITY
BIO-WEST, Inc.
PBSJ

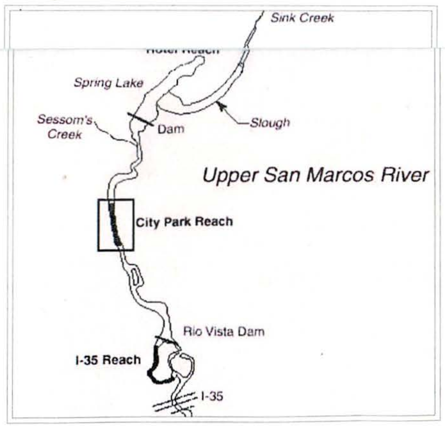
San Marcos River Aquatic Vegetation

City Park - Fall

October 18, 2001



Project Location



- ▨ Shore and Islands
- ▭ River
- 🟥 Study Area (5,850.6 m^2)
- ▨ Bare Substrate
- ⋀ *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters^2
🟩 *Hydrilla*	1,487.1
🟨 *Hygrophila*	121.7
🟧 *Ludwigia*	0.5
🟧 *Potamogeton*	35.3
🟩 *Sagittaria*	12.9
▭ *Vallisneria*	3.618
🟥 *Zizania*	51.6
▥ *Hydrilla / Hygrophila*	4.3

▤ *Hydrilla / Potamogeton*	642.4
▥ *Hygrophila / Potamogeton*	2,100.5
▨ *Hygrophila / Sagittaria*	8.3
▥ *Potamogeton / Sagittaria*	96.6

Scale: 1"=70'

Meters 10 0 10 20 30 40

EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

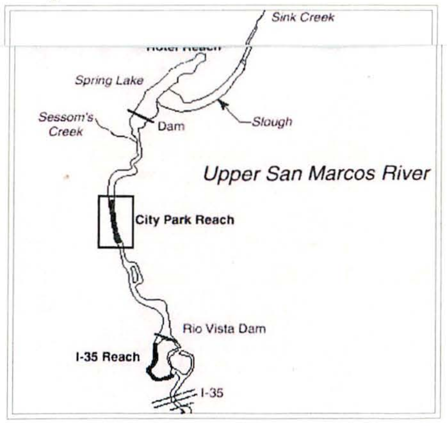
PBS&J

San Marcos River Aquatic Vegetation

City Park - High Flow 2

December 3, 2001

Project Location



- ▨ Shore and Islands
- ▭ River
- 🟥 Study Area (5,850.6 m^2)
- ▭ Bare Substrate
- ∧∕ *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters^2		
🟩 *Hydrilla*	1,539.0		
🟨 *Hygrophila*	121.8		
🟧 *Ludwigia*	0.6		
🟧 *Potamogeton*	207.2		
🟩 *Sagittaria*	20.5	▥ *Hygrophila / Potamogeton*	1,668.2
▭ *Vallisneria*	8.8	▨ *Hygrophila / Sagittaria*	18.4
🟥 *Zizania*	63.9	▥ *Potamogeton / Sagittaria*	75.3
▤ *Hydrilla / Potamogeton*	576.8	▦ *Hygrophila / Potamogeton / Sagittaria*	75.9

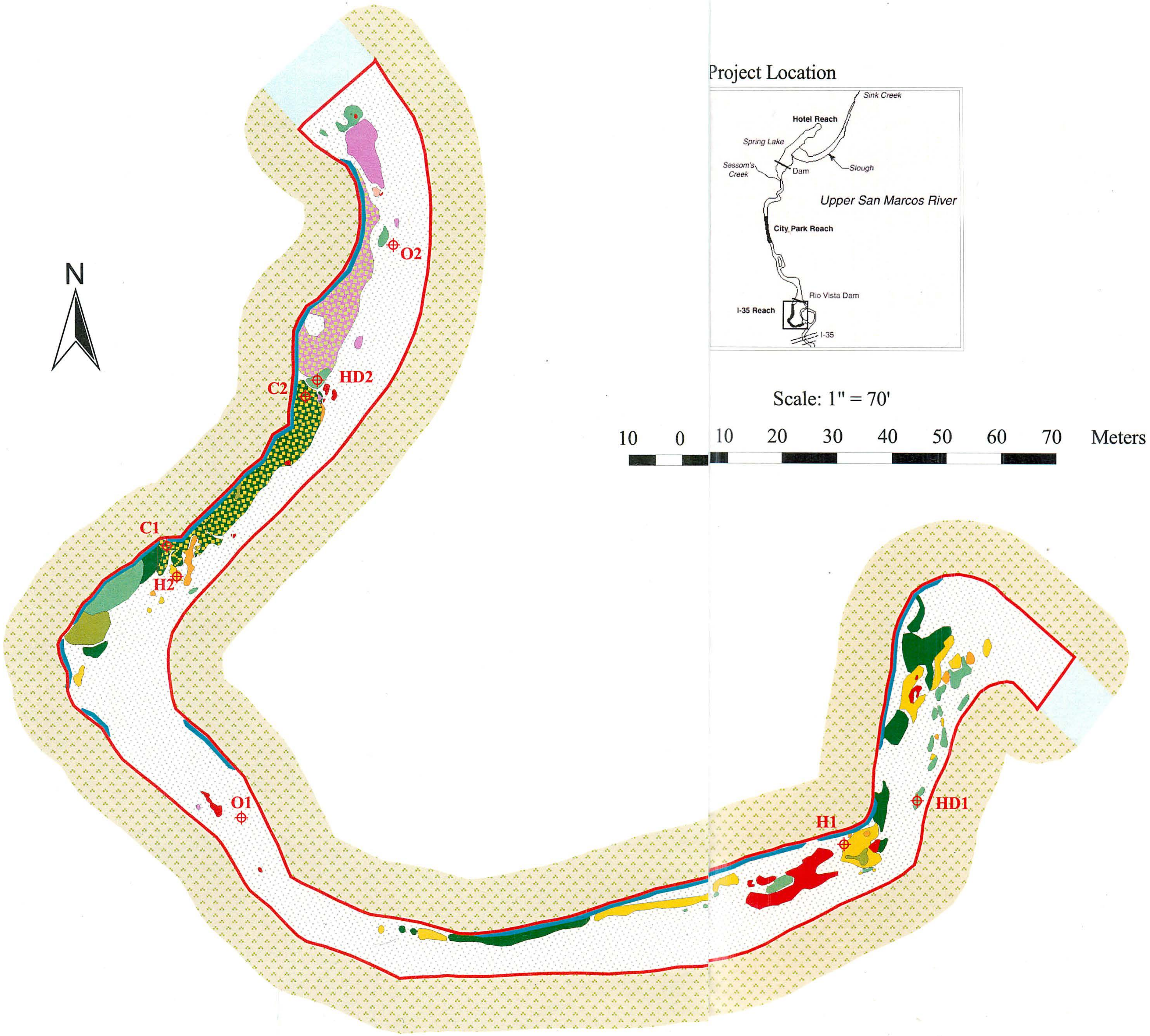
Scale: 1"=70'

Meters 10 0 10 20 30 40

EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



San Marcos River Aquatic Vegetation

I-35 Reach - Fall

October 31, 2000

- ▨ Shore and Islands
- ▨ River
- ☐ Study Area (4,627.0 m^2)
- ▨ Bare Substrate
- *Colocasia*
- ⌖ Drop Net Sample Sites

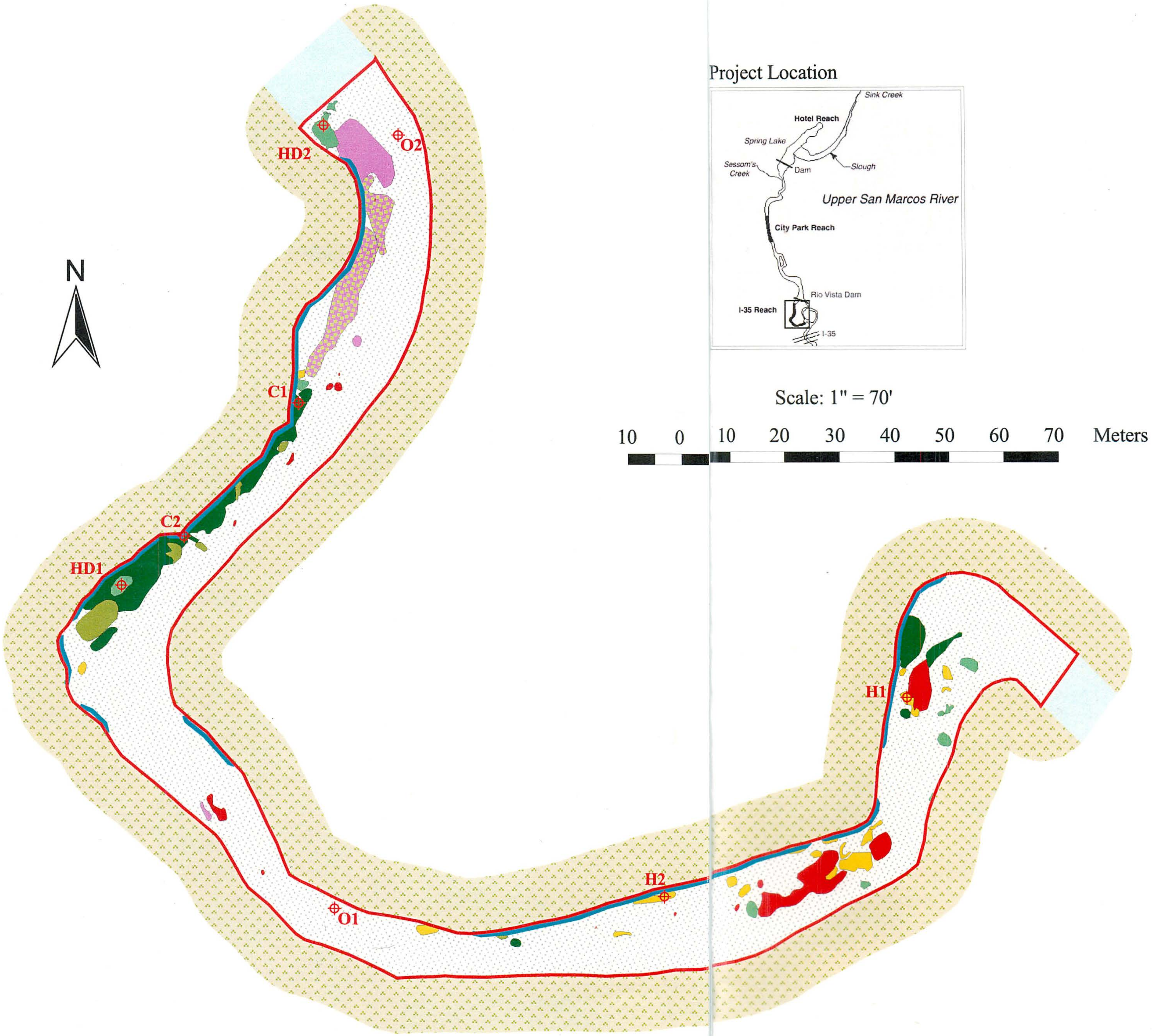
	Meters^2
🟩 *Cabomba*	169.6
▨ *Heteranthera*	1.6
🟩 *Hydrilla*	124.0
🟨 *Hygrophila*	134.4
🟪 *Justicia*	51.3
🟧 *Ludwigia*	19.1
🟩 *Sagittaria*	44.4
🟥 *Zizania*	80.8
▨ *Hygrophila / Sagittaria*	0.6
▨ *Cabomba / Ceratopteris / Hygrophila*	181.0
▨ *Cabomba / Heteranthera / Justicia*	1.5
▨ *Cabomba / Hygrophila / Sagittaria*	7.9
▨ *Justicia / Nuphar / Rorippa*	186.6

EDWARDS AQUIFER AUTHORITY
BIO-WEST, Inc.
PBS&J

San Marcos River Aquatic Vegetation

I-35 Reach - Winter

March 1, 2001



▨ Shore and Islands

▢ River

▭ Study Area (4,627.0 m^2)

▢ Bare Substrate

Colocasia

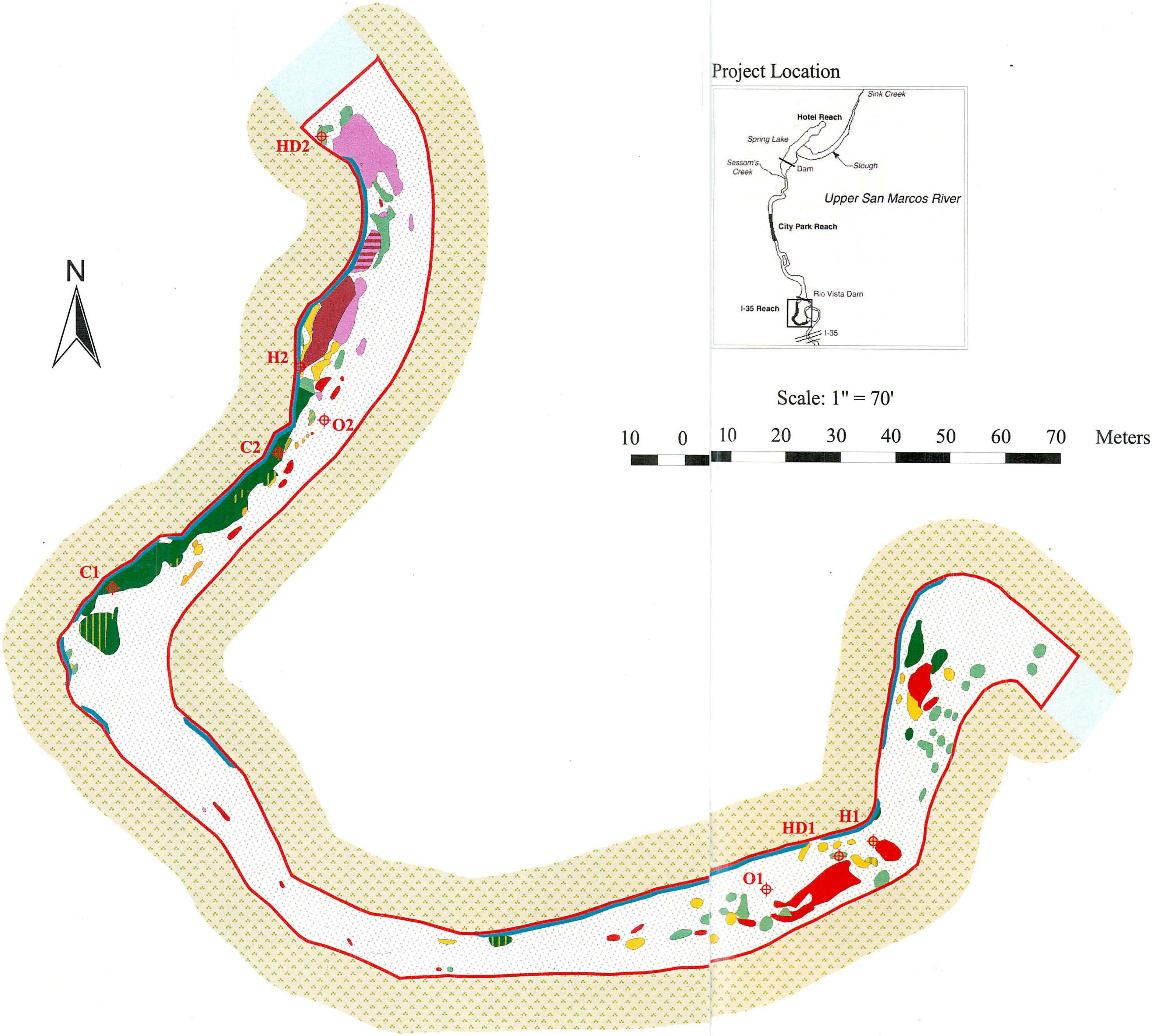
⊕ Drop Net Sample Sites

	Meters^2
🟩 *Cabomba*	256.6
🟩 *Hydrilla*	53.0
🟨 *Hygrophila*	75.8
🟪 *Justicia*	83.8
🟩 *Sagittaria*	54.1
🟥 *Zizania*	121.7
▨ *Justicia / Nuphar / Rorippa*	145.1

EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



San Marcos River Aquatic Vegetation

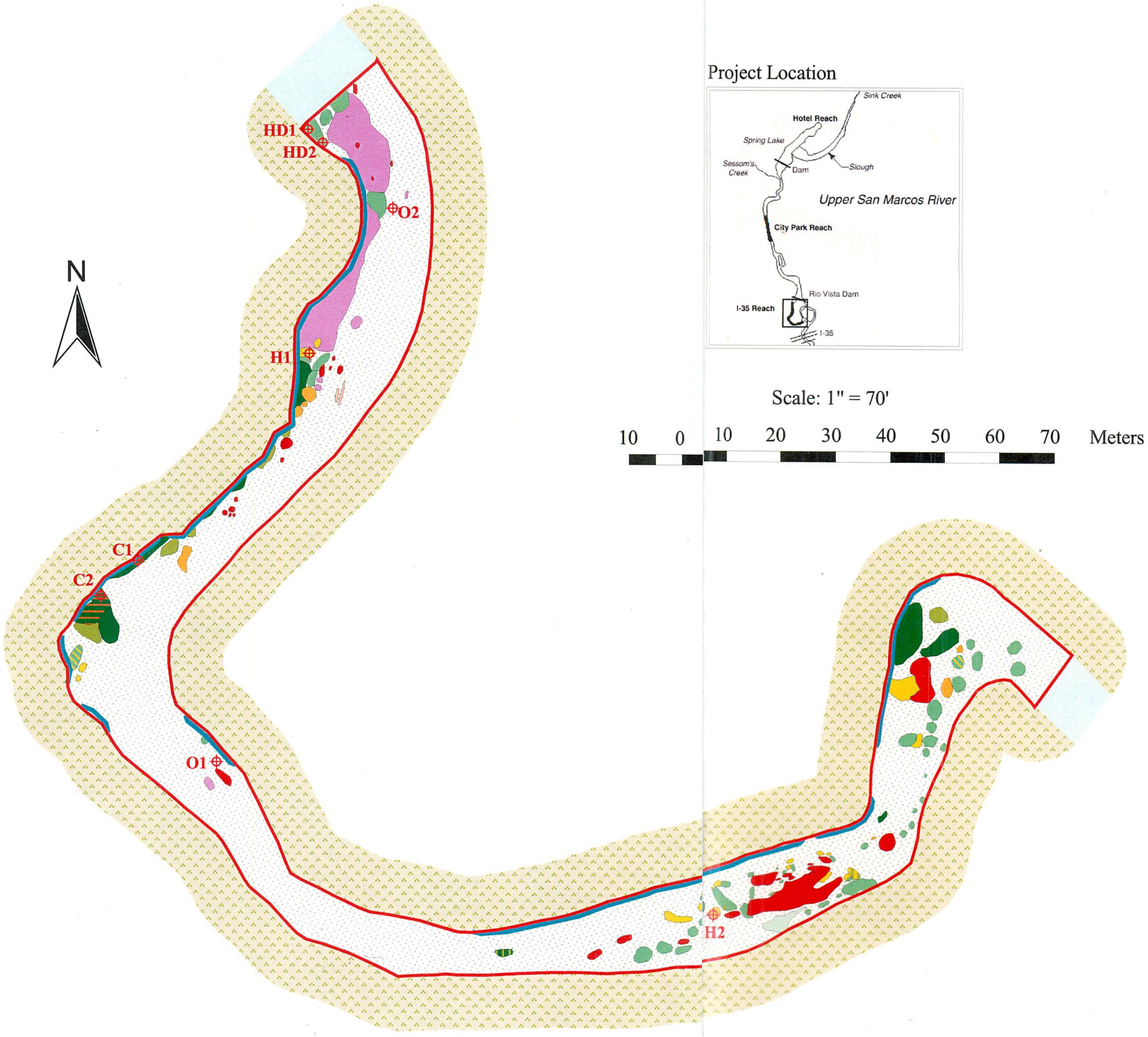
I-35 Reach - Spring

May 1, 2001

▨ Shore and Islands
▭ River
▭ Study Area (4,627.0 m^2)
▨ Bare Substrate
Colocasia
⊕ Drop Net Sample Sites

	Meters^2
■ *Cabomba*	228.5
■ *Hydrilla*	129.8
■ *Hygrophila*	74.6
■ *Justicia*	128.1
■ *Ludwigia*	6.8
■ *Rorripa*	66.0
■ *Sagittaria*	1.6
■ *Zizania*	127.8
▥ *Cabomba / Ludwiggia*	0.6
▥ *Cabomba / Sagittaria*	45.6
▨ *Hydrilla / Ludwigia*	2.4
▥ *Hygrophila / Sagittaria*	2.6
▤ *Justicia / Rorippa*	23.6

EDWARDS AQUIFER AUTHORITY
BIO-WEST, Inc.
PBS&J



San Marcos River Aquatic Vegetation

I-35 Reach - Summer

August 1, 2001

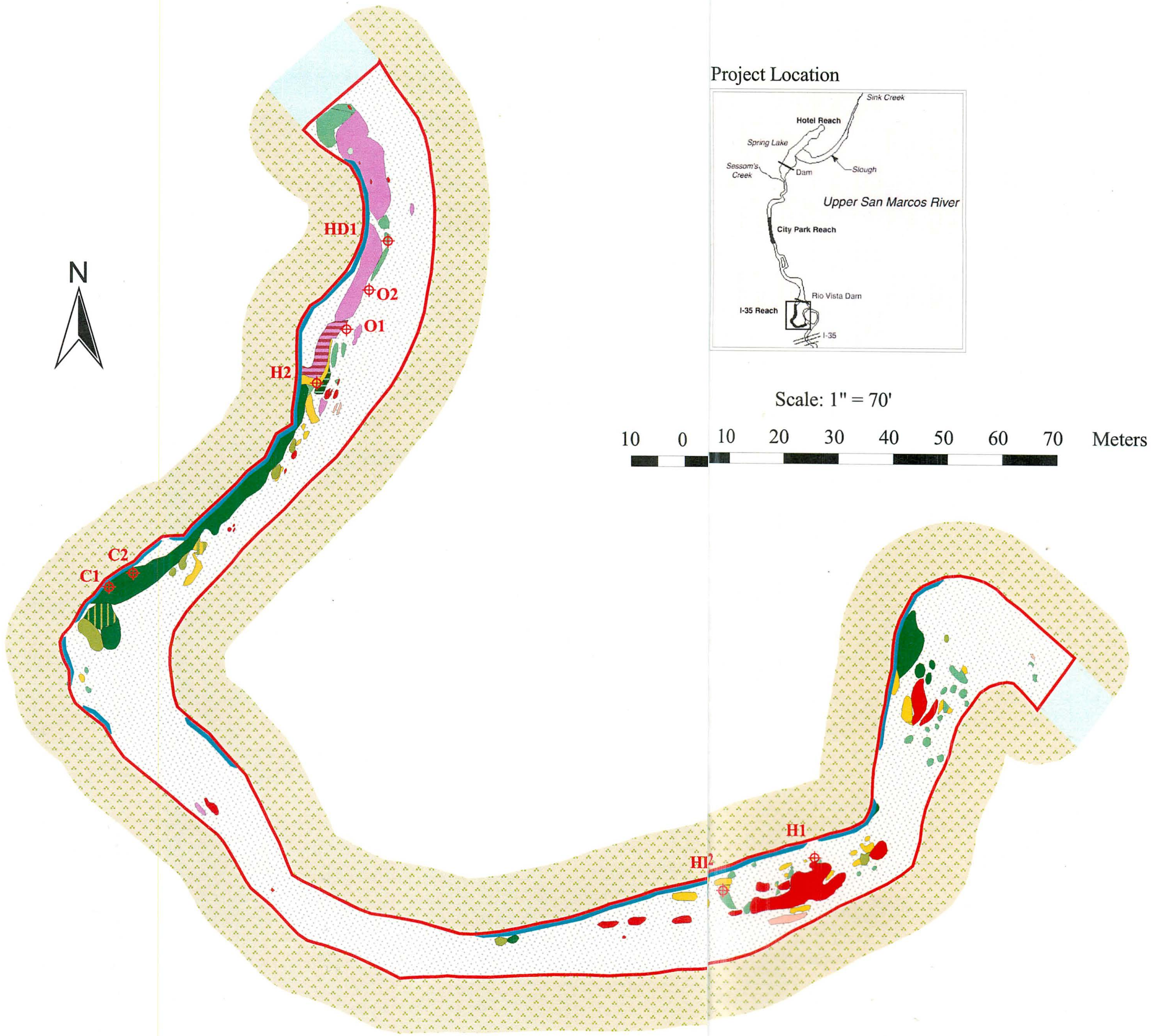
Shore and Islands
River
Study Area (4,627.0 m^2)
Bare Substrate
Colocasia
Drop Net Sample Sites

	Meters^2
Cabomba	142.1
Heteranthera	2.7
Hydrilla	164.3
Hygrophila	50.4
Justicia	243.4
Ludwigia	25.4
Sagittaria	40.2
Vallisneria	13.2
Zizania	141.5
Cabomba / Potamogeton	24.9
Cabomba / Sagittaria	3.5
Hydrilla / Hygrophila	12.3
Hygrophila / Sagittaria	3.2

EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



San Marcos River Aquatic Vegetation

I-35 Reach - Fall

October 19, 2001

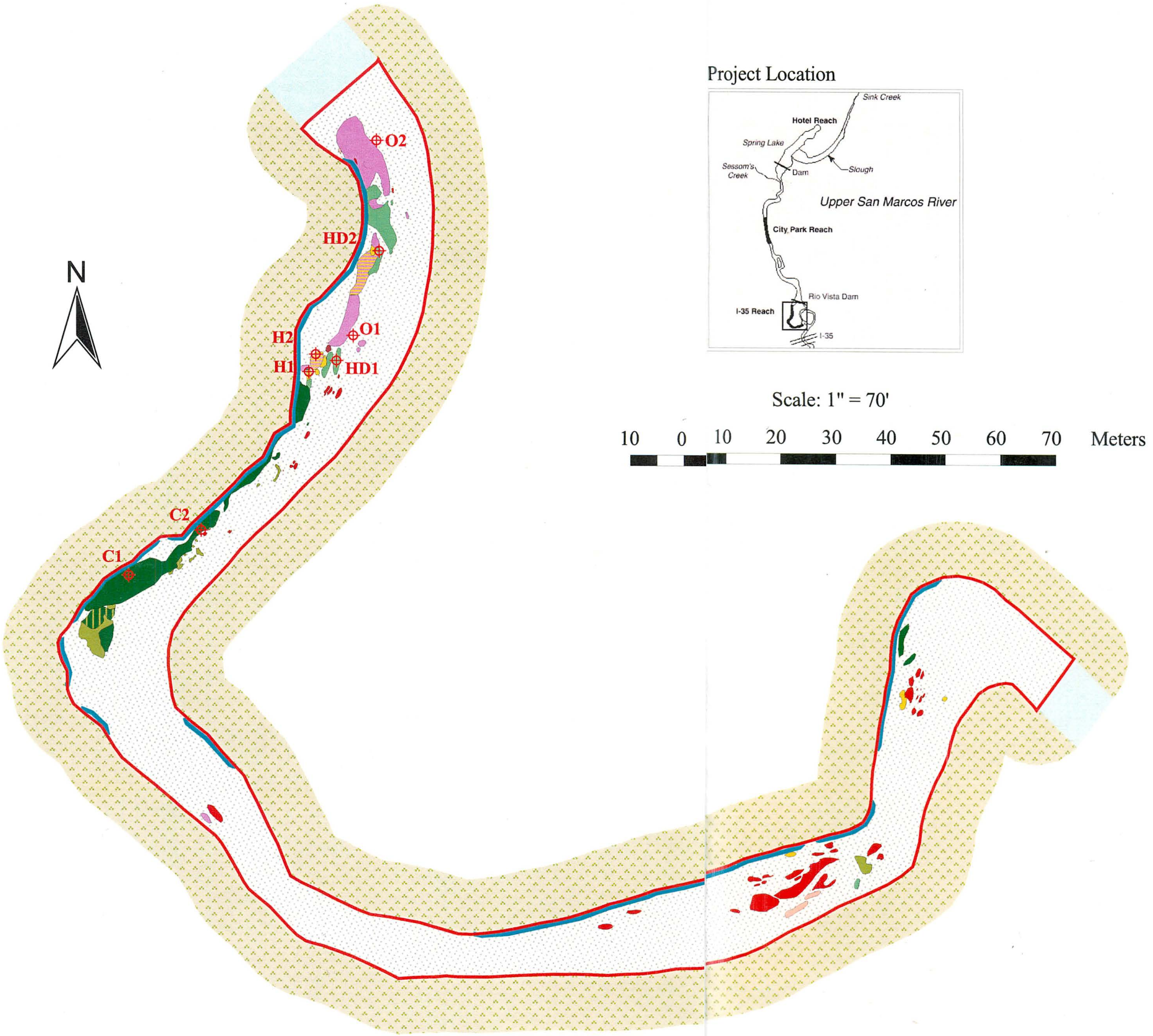
- ▨ Shore and Islands
- ▭ River
- ▭ Study Area (4,627.0 m^2)
- ▭ Bare Substrate
- ∧ *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters^2
🟩 *Cabomba*	233.5
▭ *Heteranthera*	9.7
🟩 *Hydrilla*	85.1
🟨 *Hygrophila*	72.4
🟪 *Justicia*	157.5
🟩 *Sagittaria*	32.1
▭ *Vallisneria*	1.0
🟥 *Zizania*	129.8
▤ *Algae / Hydrilla*	5.1
▥ *Cabomba / Sagittaria*	19.6
▨ *Hydrilla / Hygrophila*	0.5
▥ *Hygrophila / Sagittaria*	4.5
▤ *Justicia / Rorippa*	30.1

EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



San Marcos River Aquatic Vegetation

I-35 Reach - High Flow 2

December 5, 2001

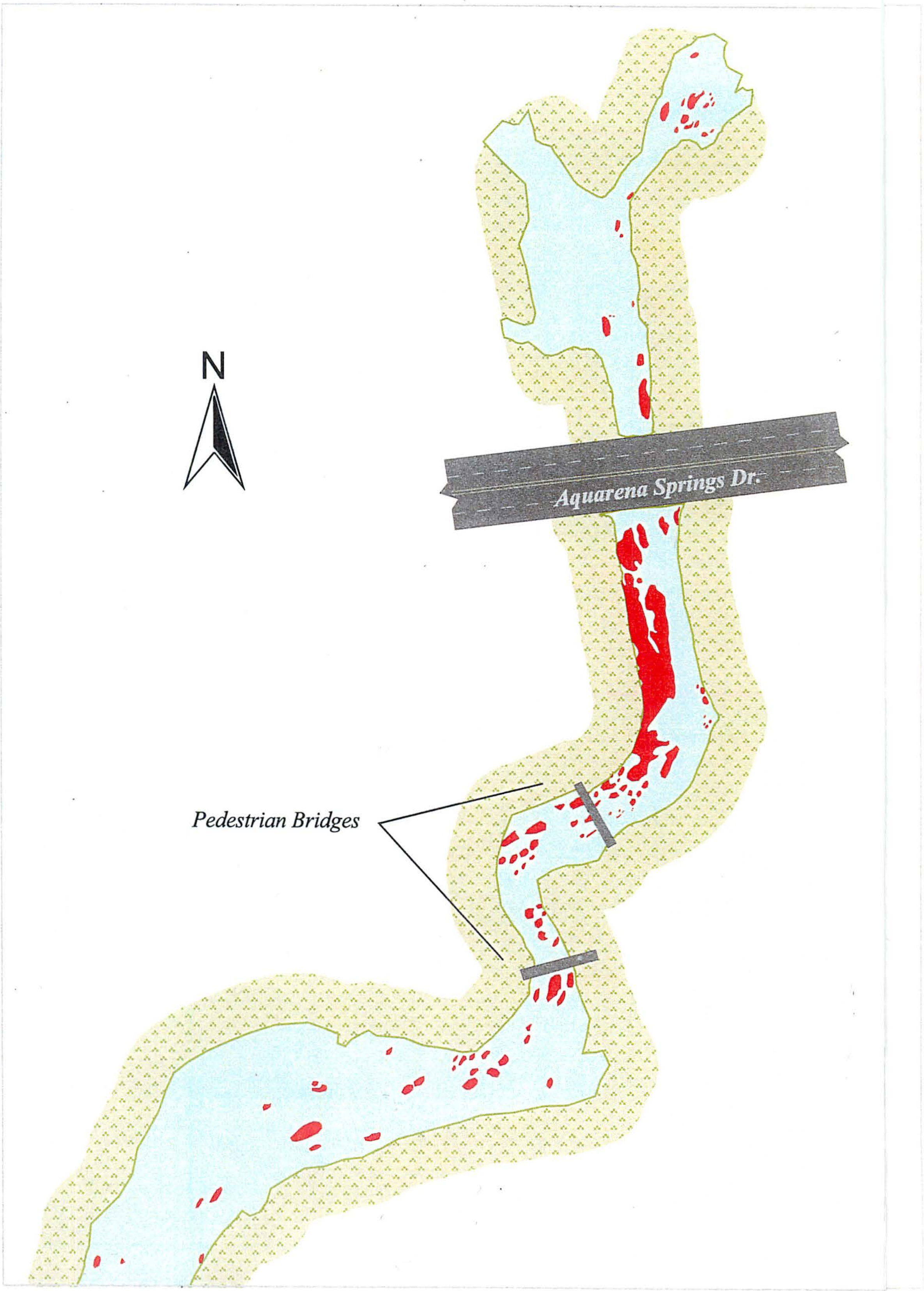
- ▨ Shore and Islands
- ▭ River
- ☐ Study Area (4,627.0 m^2)
- ░ Bare Substrate
- ∧ *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters^2
🟩 *Cabomba*	150.9
▨ *Heteranthera*	6.7
🟩 *Hydrilla*	49.9
🟨 *Hygrophila*	9.9
🟪 *Justicia*	102.1
🟦 *Limnophila*	0.2
🟥 *Rorripa*	0.9
🟩 *Sagittaria*	31.8
🟥 *Zizania*	74.1
▥ *Cabomba / Sagittaria*	13.5
▤ *Hygrophila / Justicia*	23.9

EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



San Marcos River
Texas wild-rice

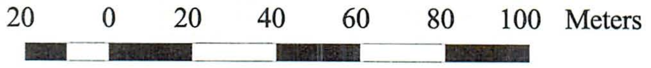
(Zizania texana)

Summer - Map 1 of 7

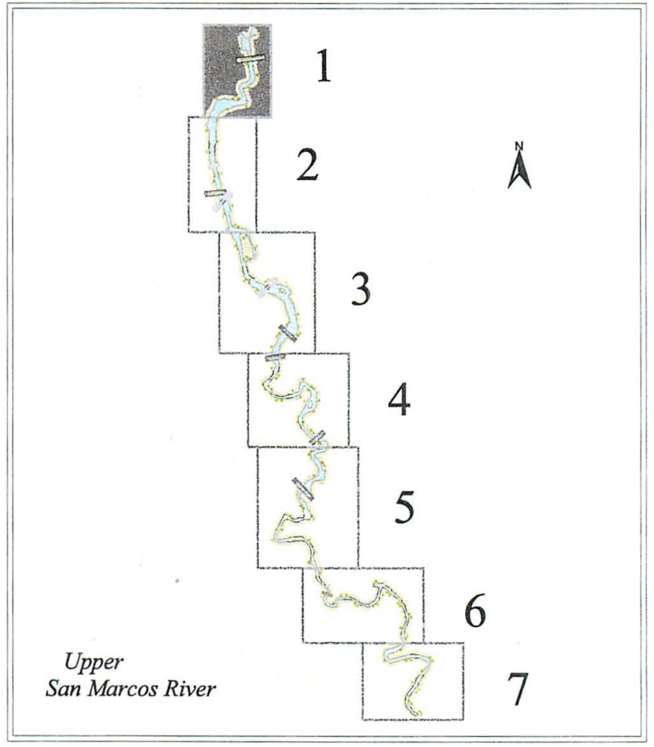
August 2001

		Map 1 (m^2)	Total Population (m^2)
🟥	*Zizania*	1,005.5	1,901.2

Scale: 1"=150'



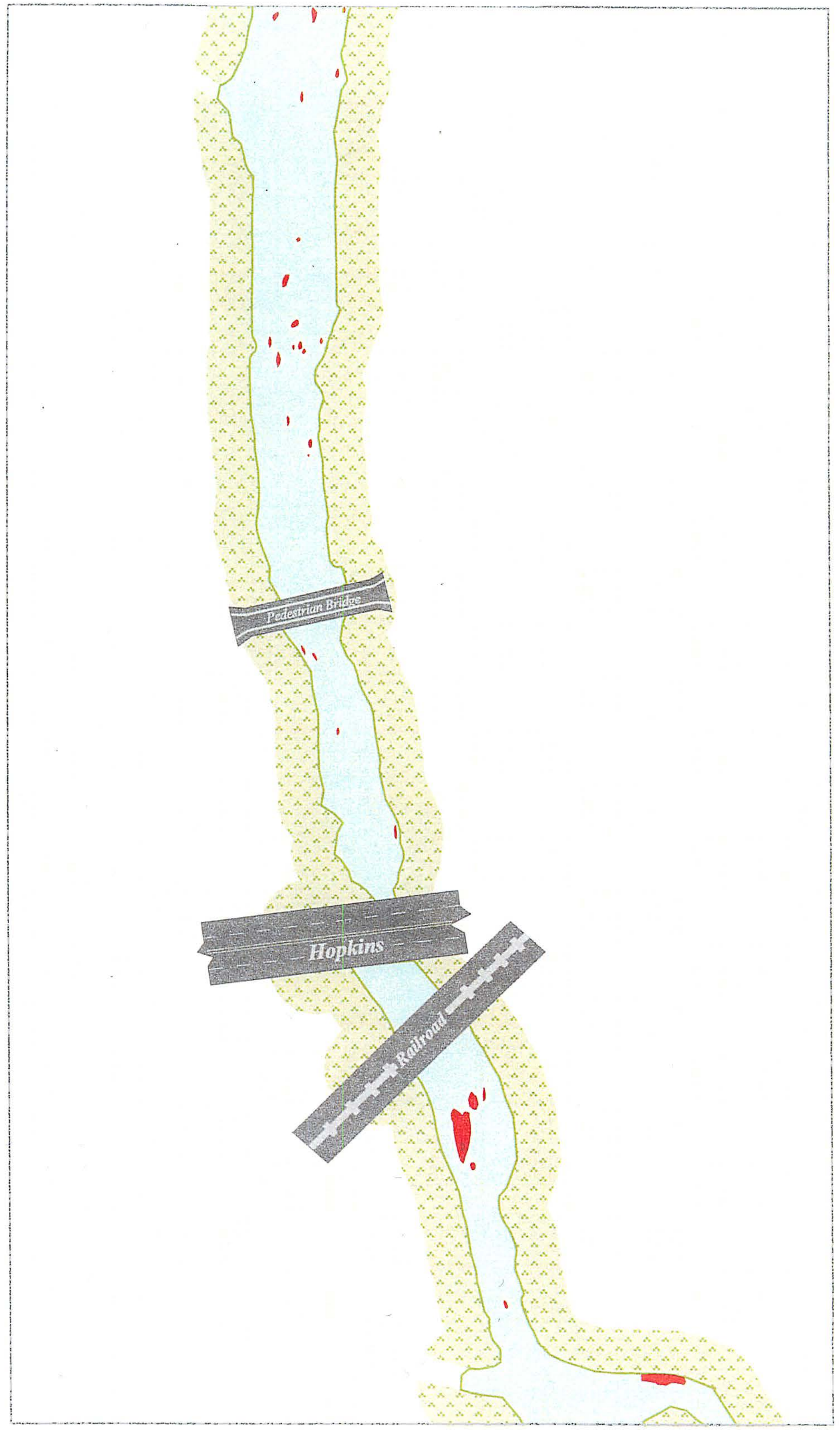
Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



San Marcos River
Texas wild-rice
(Zizania texana)
Summer - Map 2 of 7
August 2001

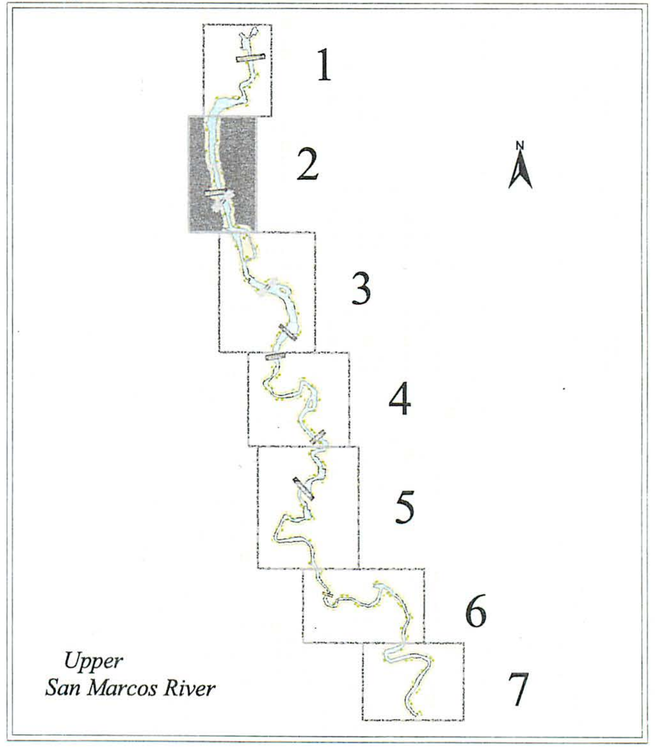
		Map 2 (m^2)	Total Population (m^2)
🟥	*Zizania*	203.3	1,901.2

N

Scale: 1"=190'

20 0 20 40 60 80 100 120 140 160 Meters

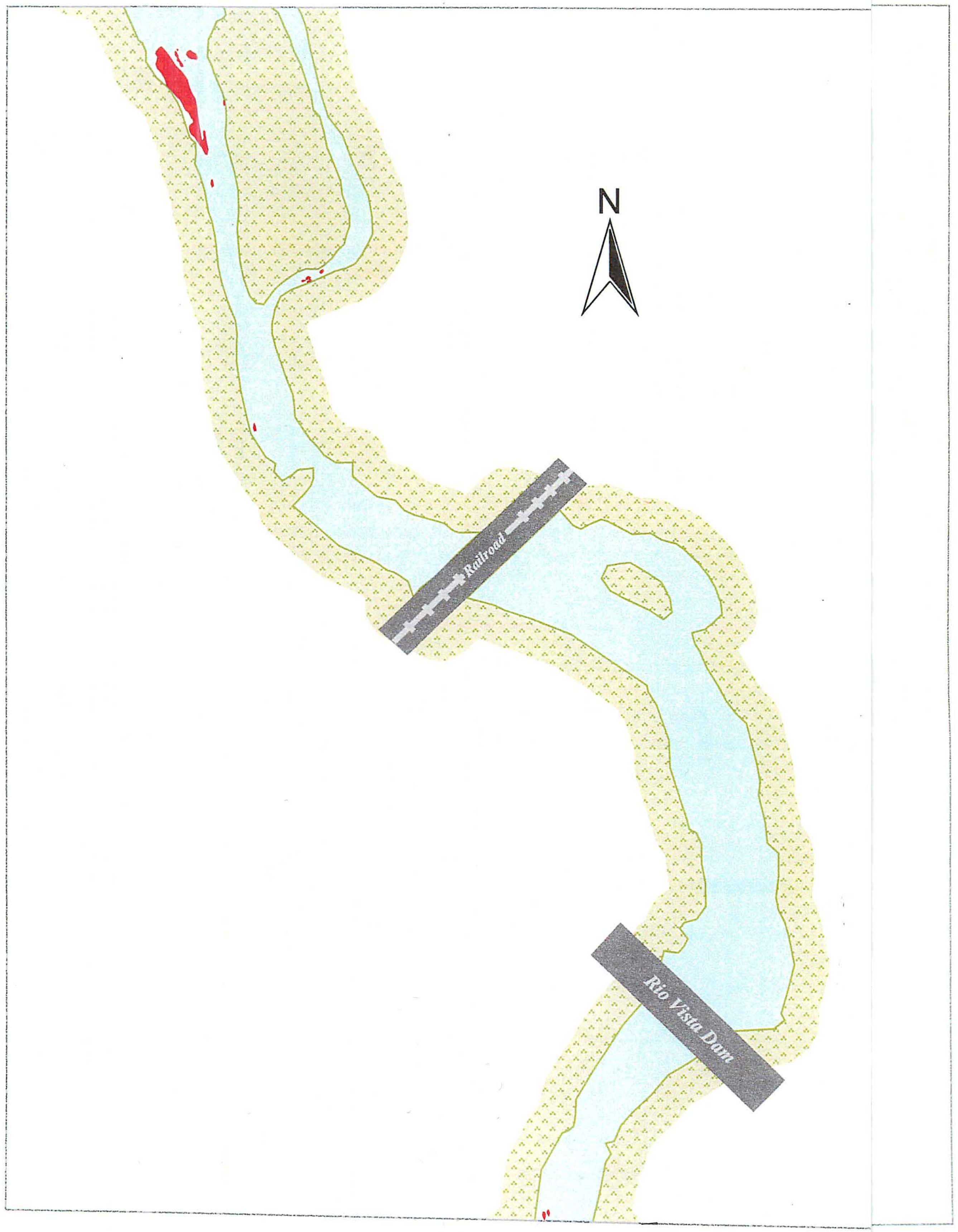
Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



San Marcos River
Texas wild-rice

(Zizania texana)

Summer - Map 3 of 7

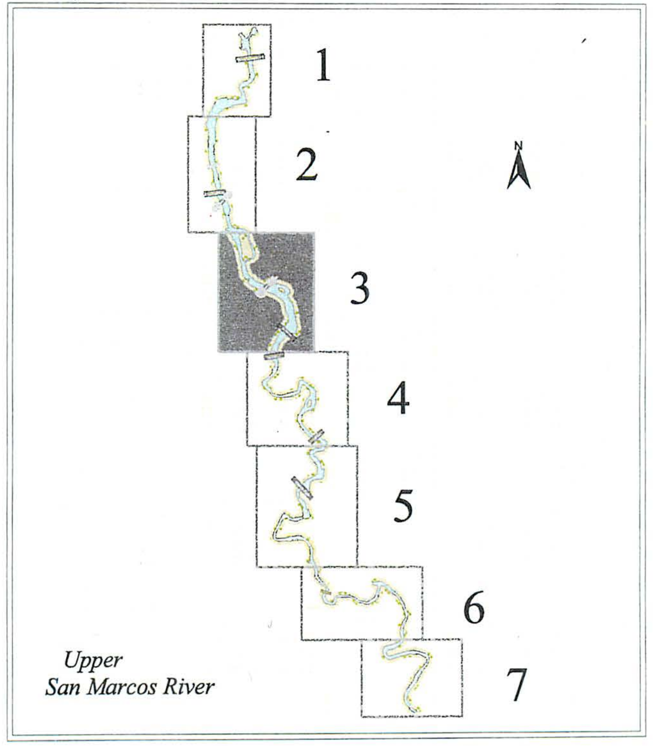
August 2001

		Map 3 (m^2)	Total Population (m^2)
🟥	*Zizania*	296.0	1,901.2

Scale: 1"=190'

20 0 20 40 60 80 100 Meters

Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

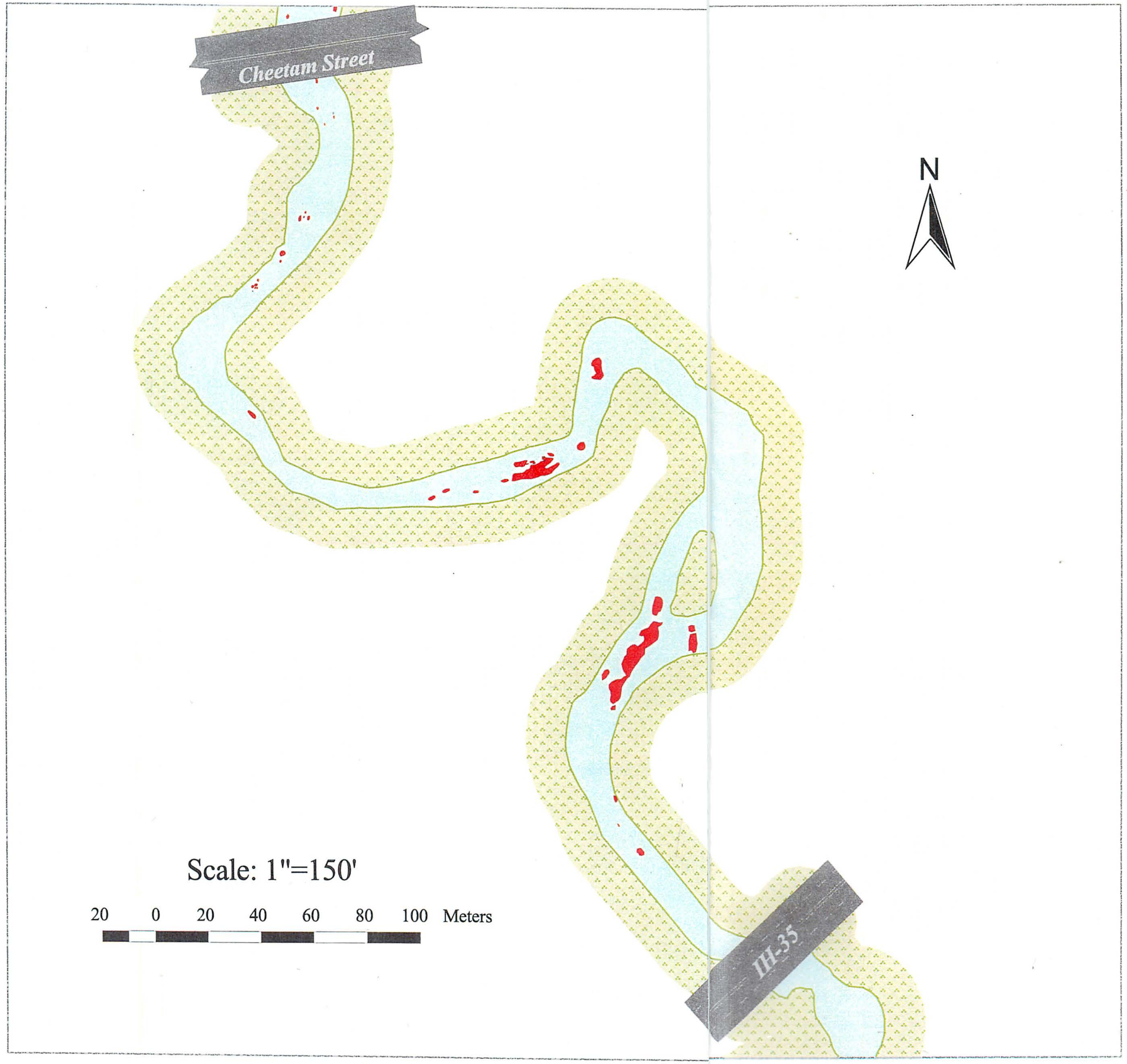
PBS&J

San Marcos River
Texas wild-rice

(Zizania texana)

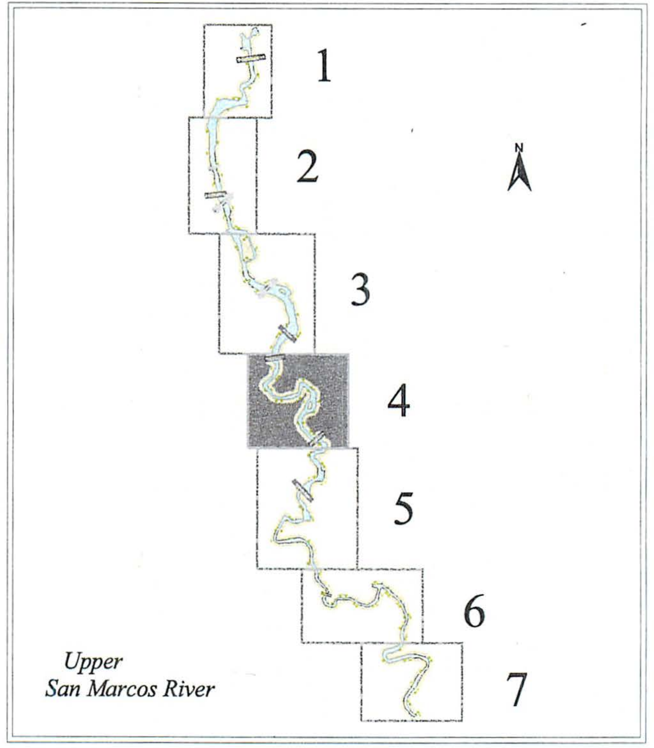
Summer - Map 4 of 7

August 2001



		Map 4 (m^2)	Total Population (m^2)
🟥	*Zizania*	359.3	1,901.2

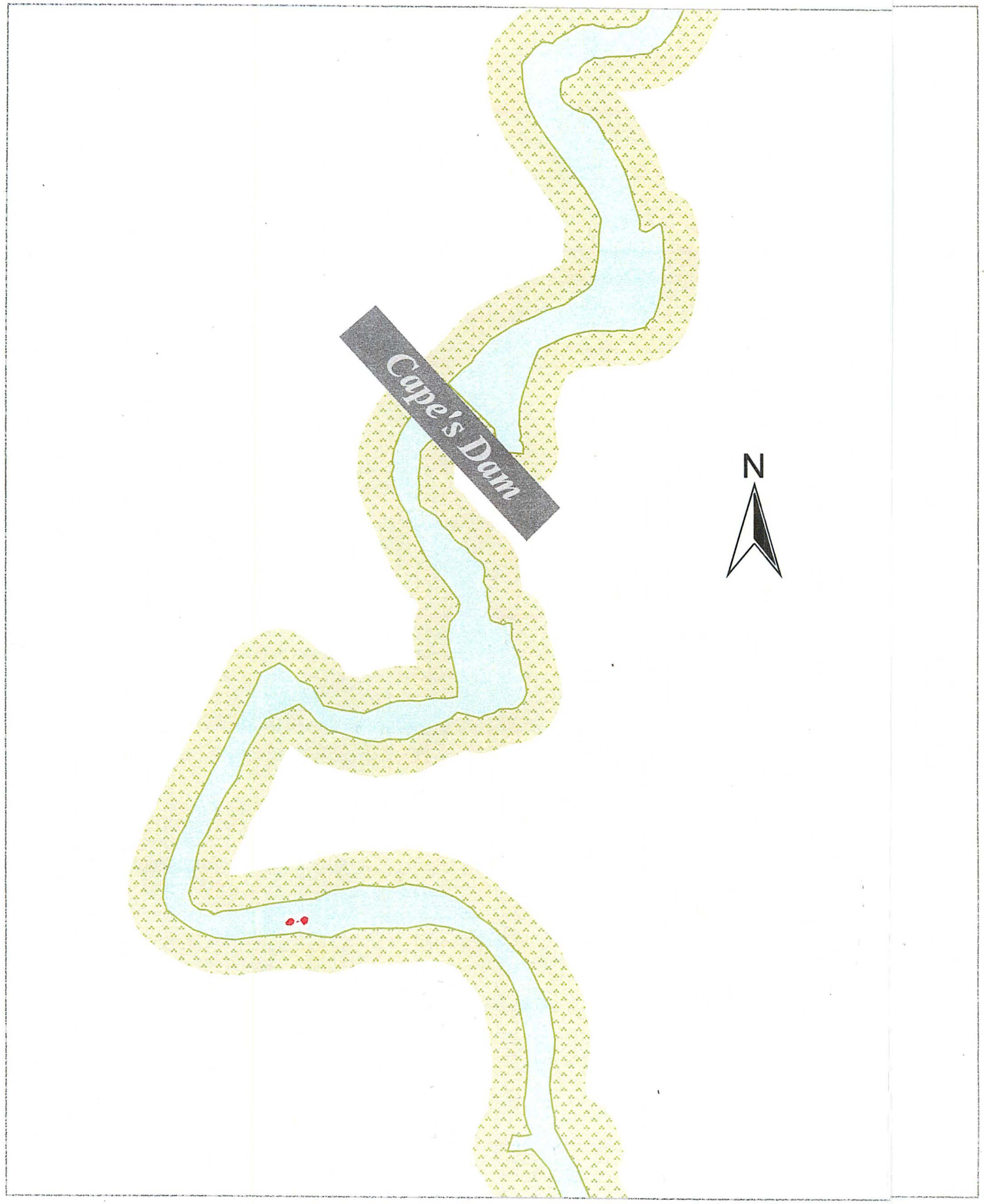
Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



San Marcos River
Texas wild-rice

(Zizania texana)

Summer - Map 5 of 7

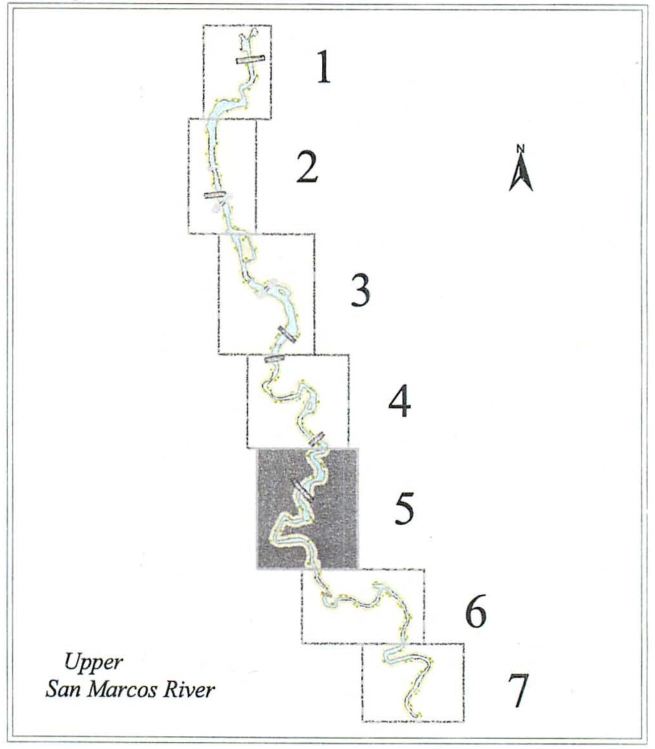
August 2001

		Map 5 (m^2)	Total Population (m^2)
🟥	*Zizania*	16.0	1,901.2

Scale: 1"=190'

20 0 20 40 60 80 100 Meters

Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

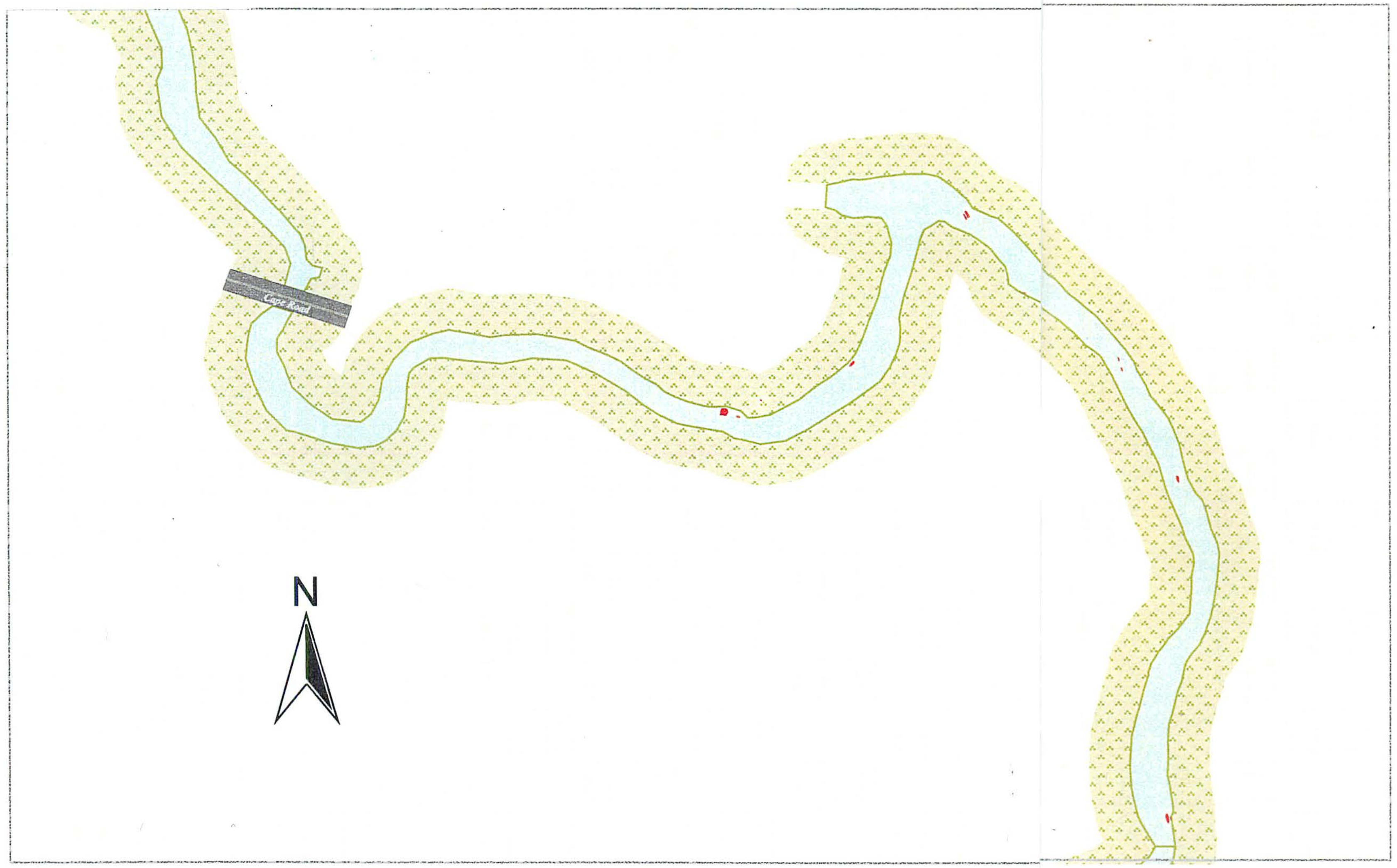
San Marcos River
Texas wild-rice

(Zizania texana)

Summer - Map 6 of 7

August 2001

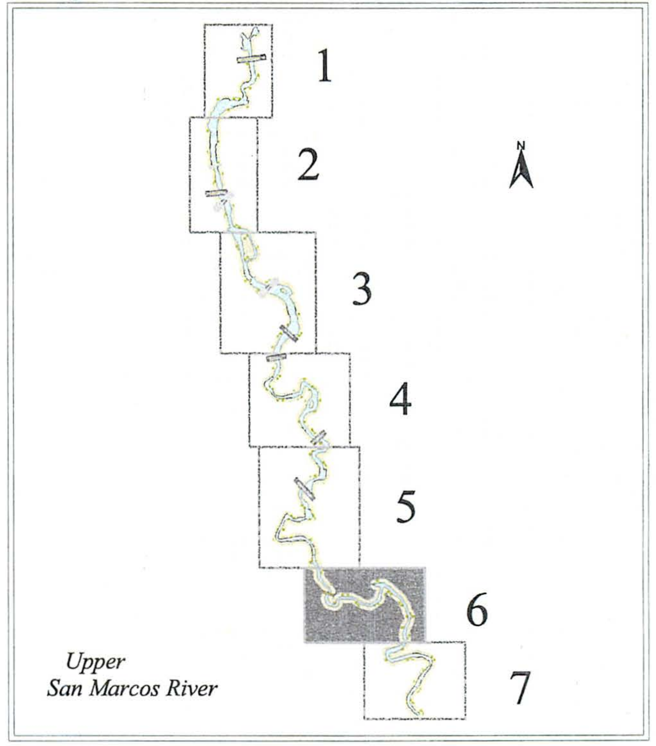
		Map 6 (m^2)	Total Population (m^2)
🟥	*Zizania*	17.8	1,901.2



Scale: 1"=190'

20 0 20 40 60 80 100 Meters

Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

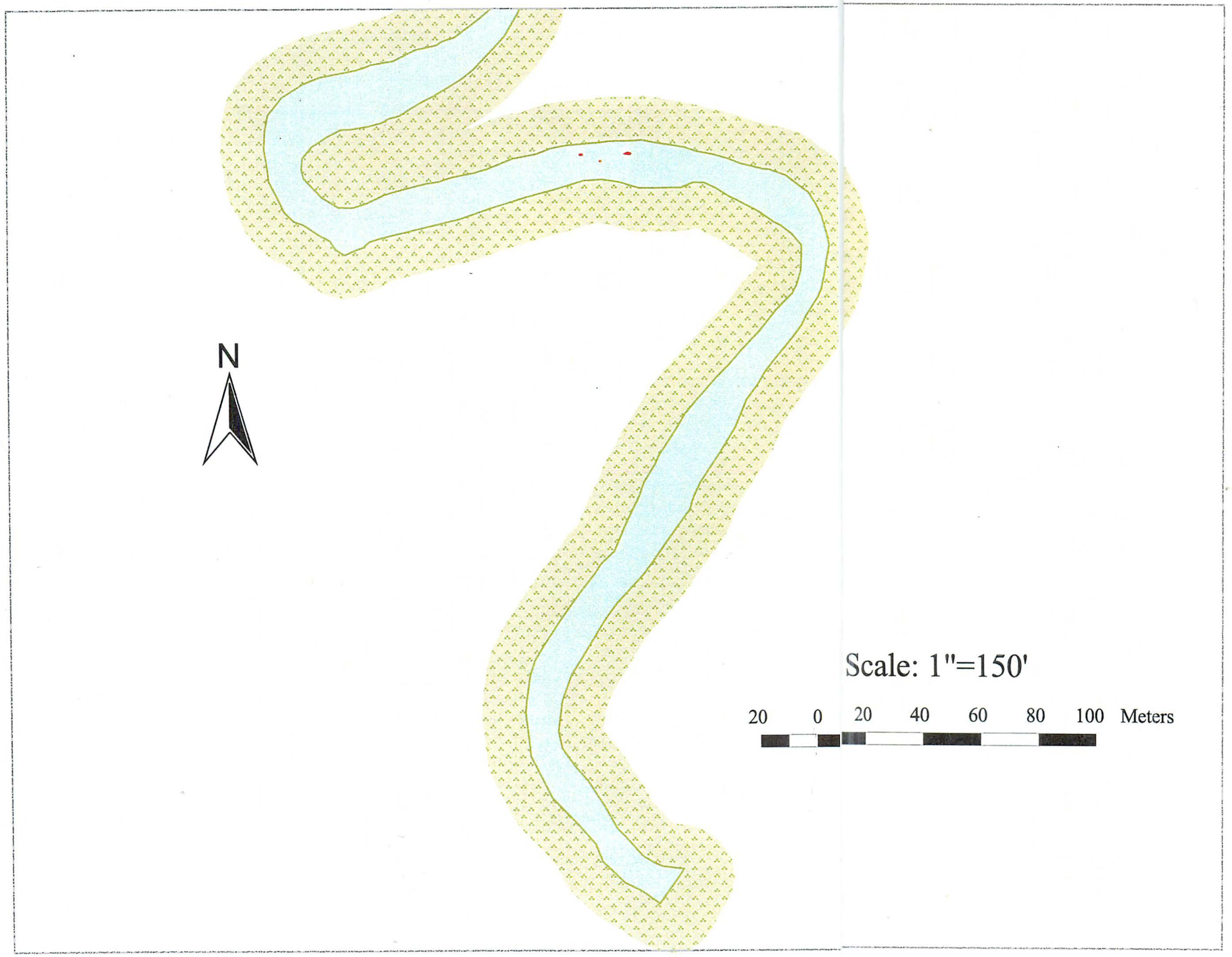
San Marcos River
Texas wild-rice

(Zizania texana)

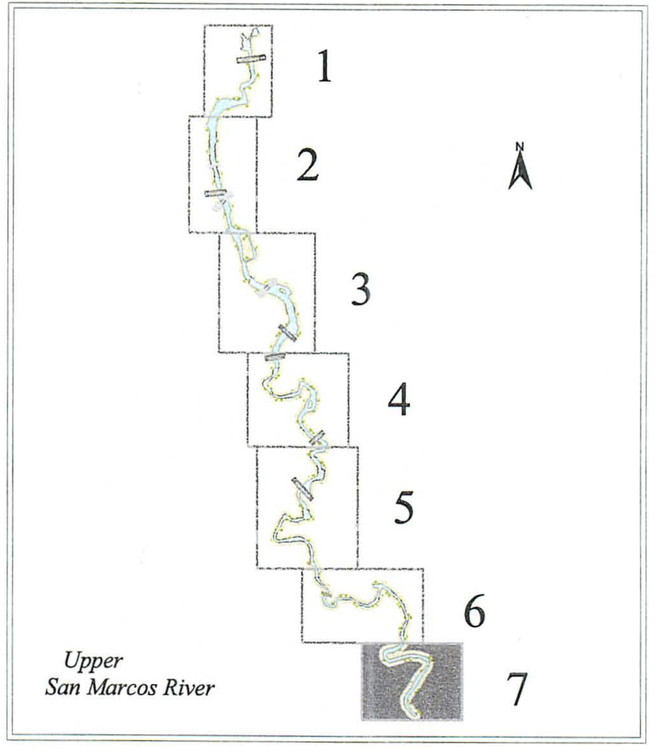
Summer - Map 7 of 7

August 2001

		Map 7 (m^2)	Total Population (m^2)
🟥	*Zizania*	3.3	1,901.2



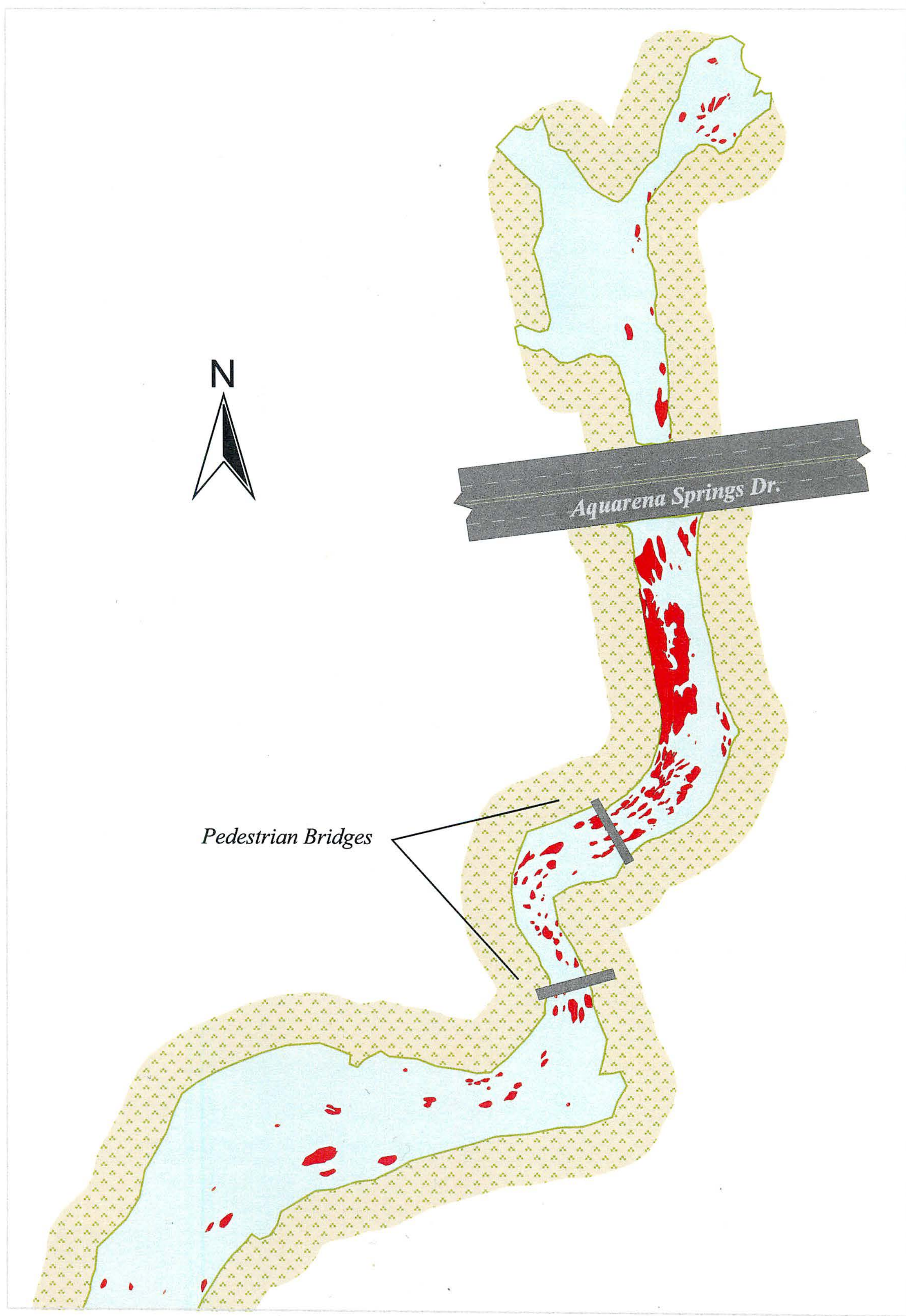
Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



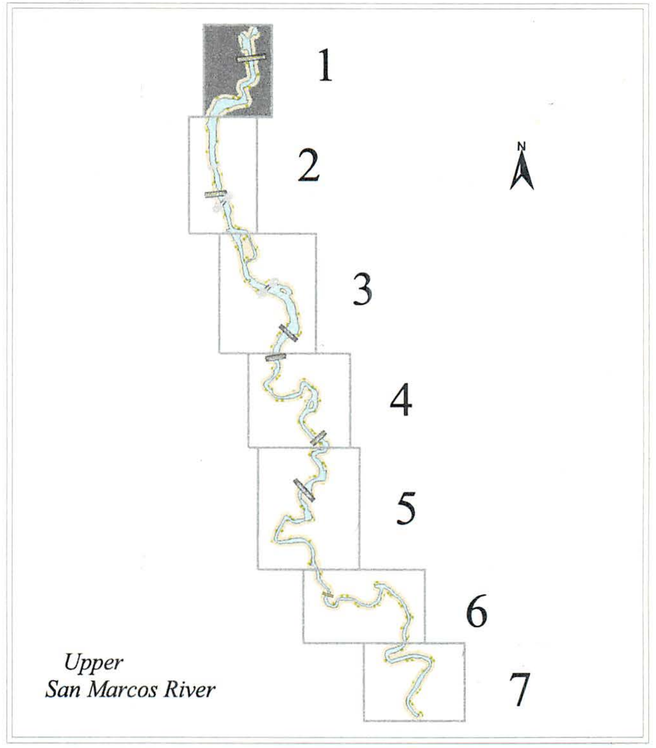
San Marcos River
Texas wild-rice
(Zizania texana)
High Flow 2 - Map 1 of 7
December 2001

		Map 1 (m^2)	Total Population (m^2)
🟥	*Zizania*	945.4	1,765.9

Scale: 1"=150'

20 0 20 40 60 80 100 Meters

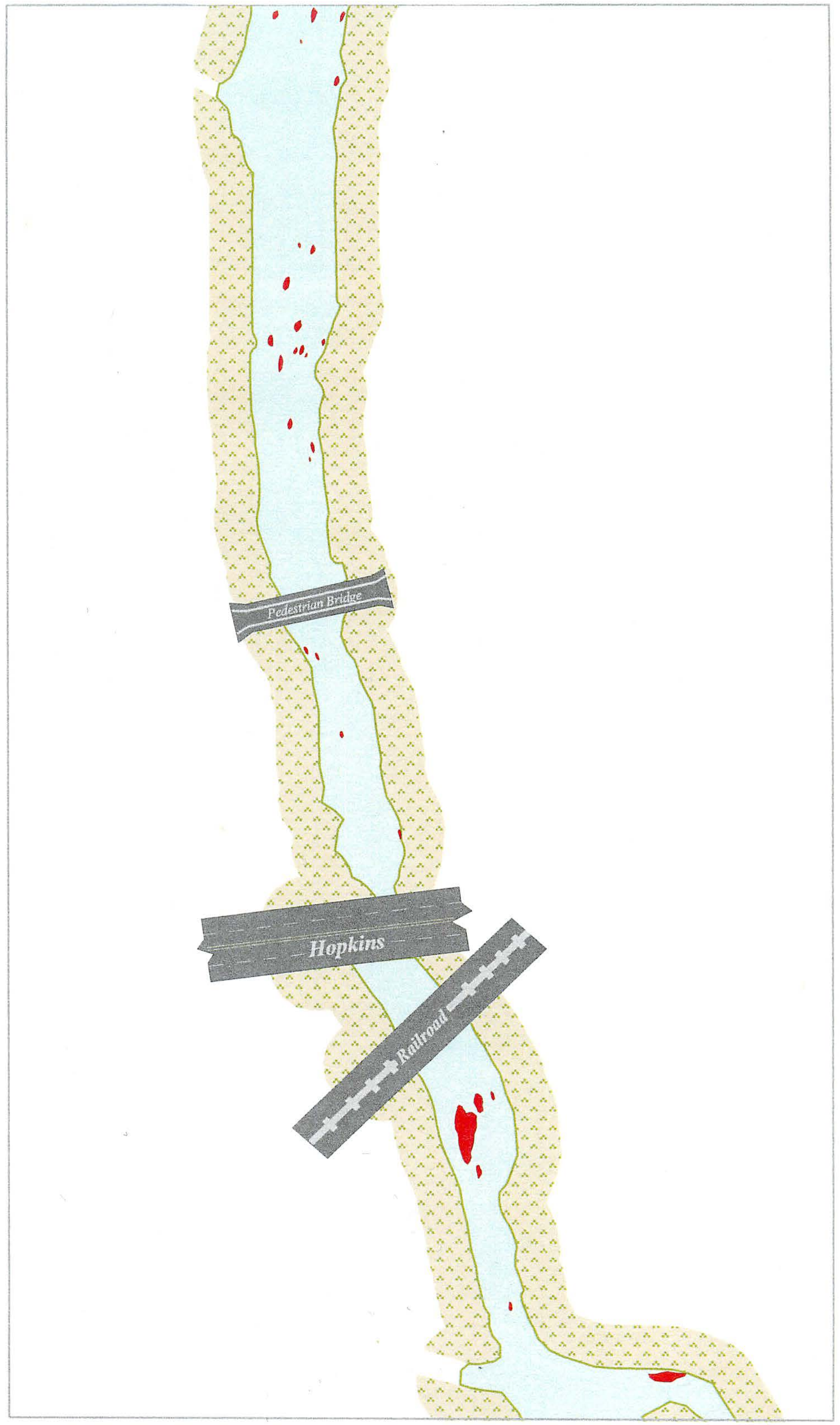
Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



San Marcos River
Texas wild-rice

(Zizania texana)

High Flow 2 - Map 2 of 7

December 2001

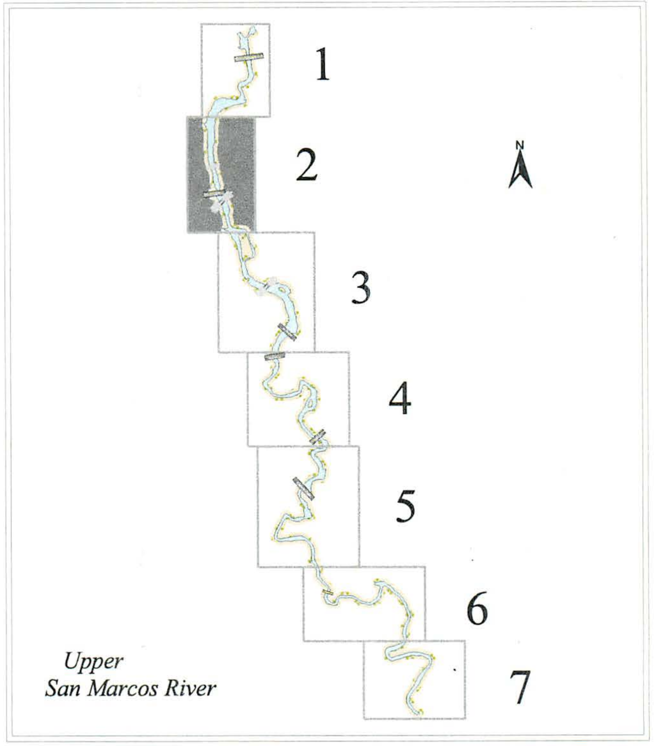
		Map 2 (m^2)	Total Population (m^2)
🟥	*Zizania*	223.2	1,765.9

N

Scale: 1"=190'

20 0 20 40 60 80 100 120 140 160 Meters

Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

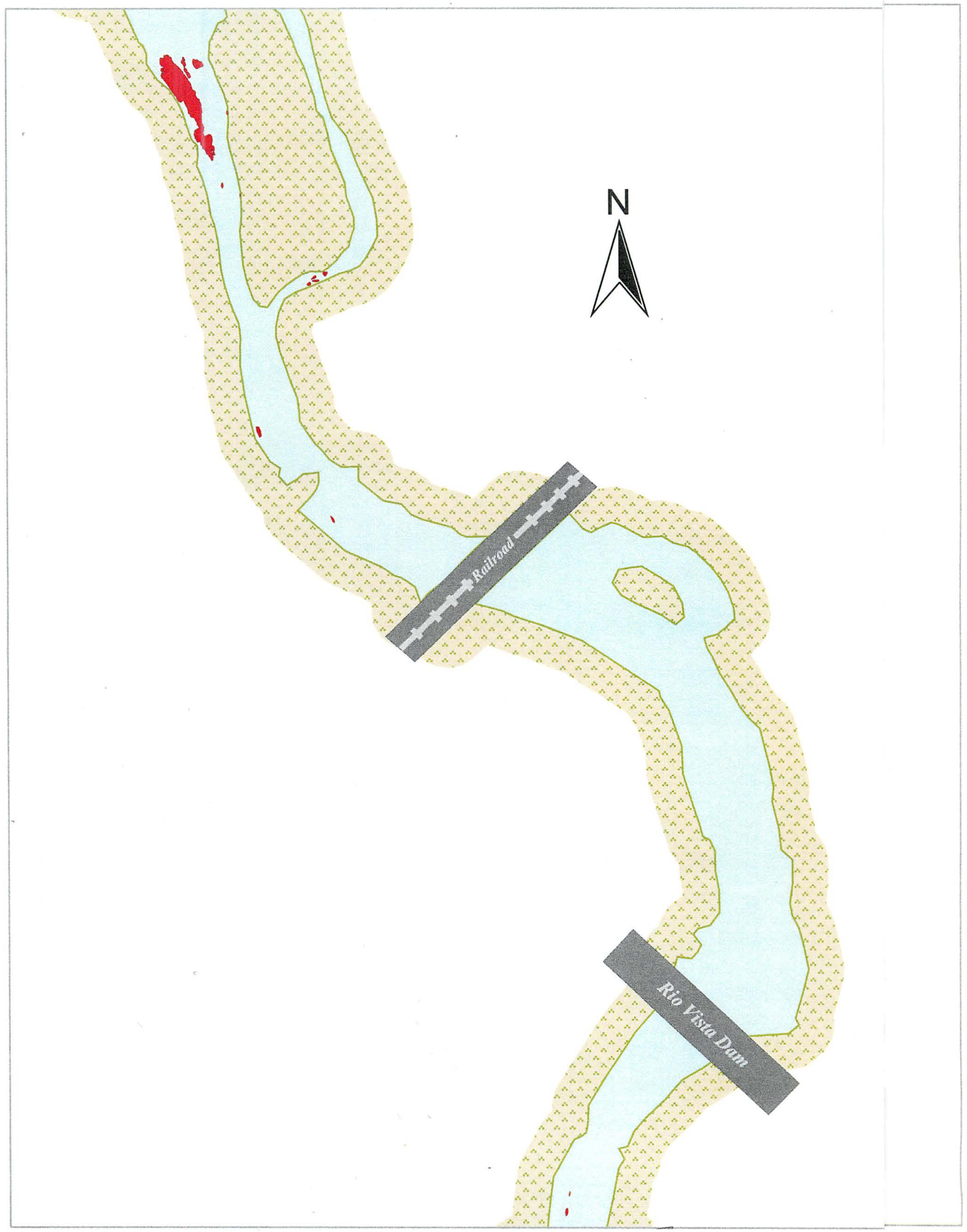
San Marcos River
Texas wild-rice

(Zizania texana)

High Flow 2 - Map 3 of 7

December 2001

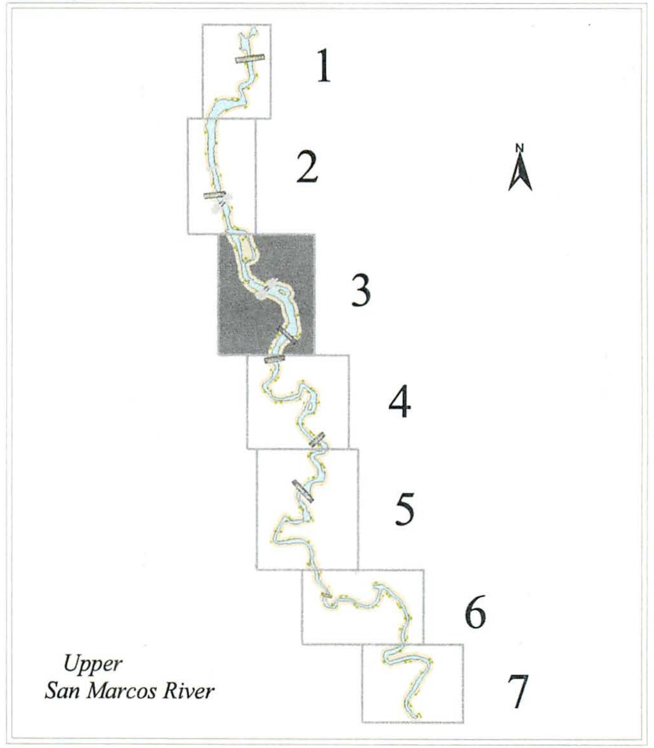
		Map 3 (m^2)	Total Population (m^2)
🟥	*Zizania*	301.9	1,765.9



Scale: 1"=190'

20 0 20 40 60 80 100 Meters

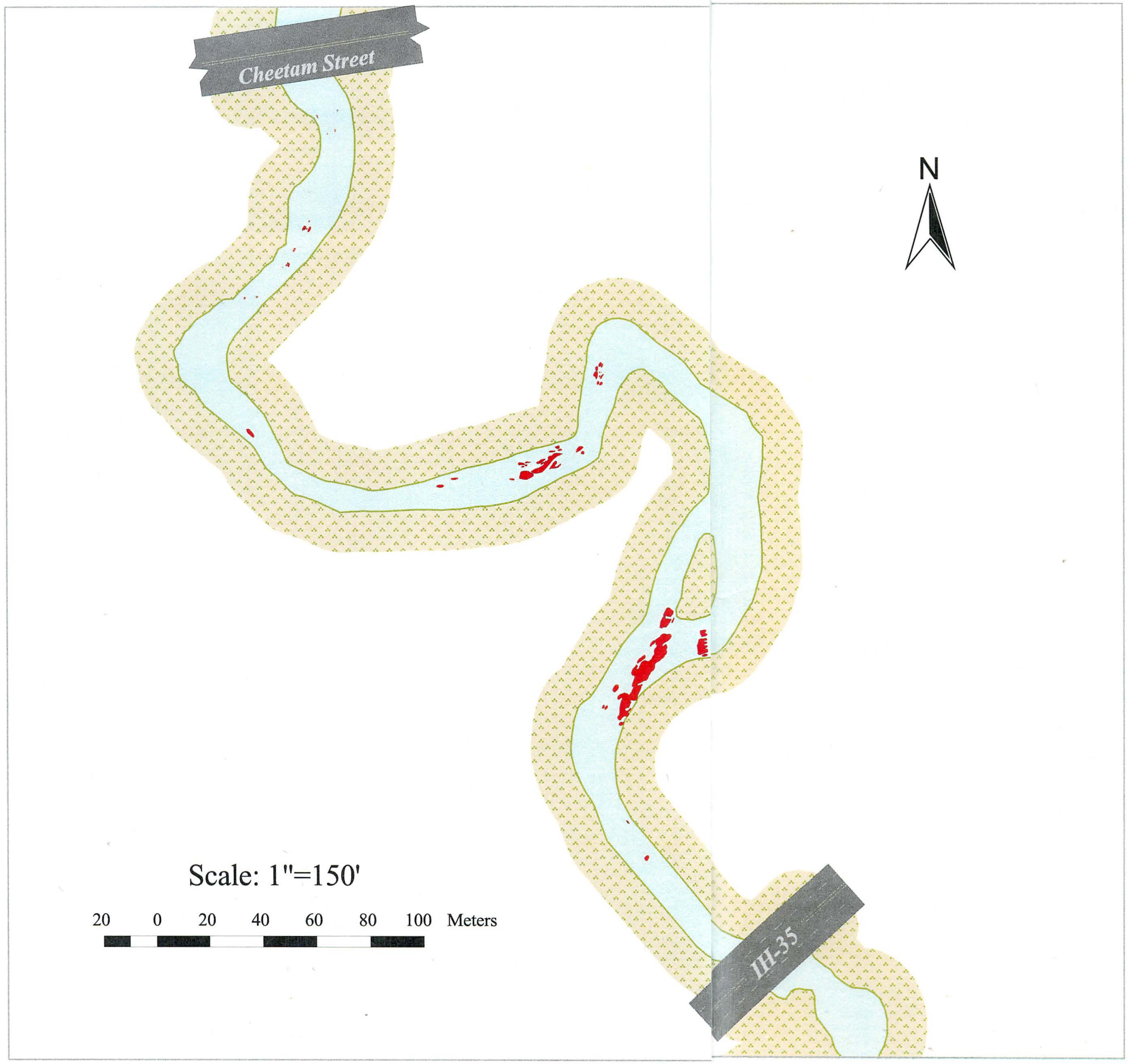
Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



San Marcos River Texas wild-rice

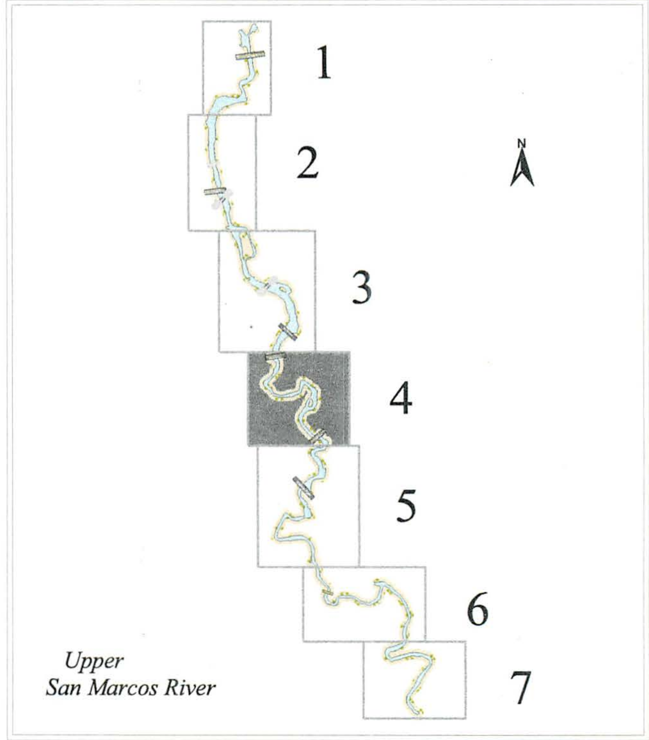
(Zizania texana)

High Flow 2 - Map 4 of 7

December 2001

		Map 4 (m^2)	Total Population (m^2)
🟥	*Zizania*	279.0	1,765.9

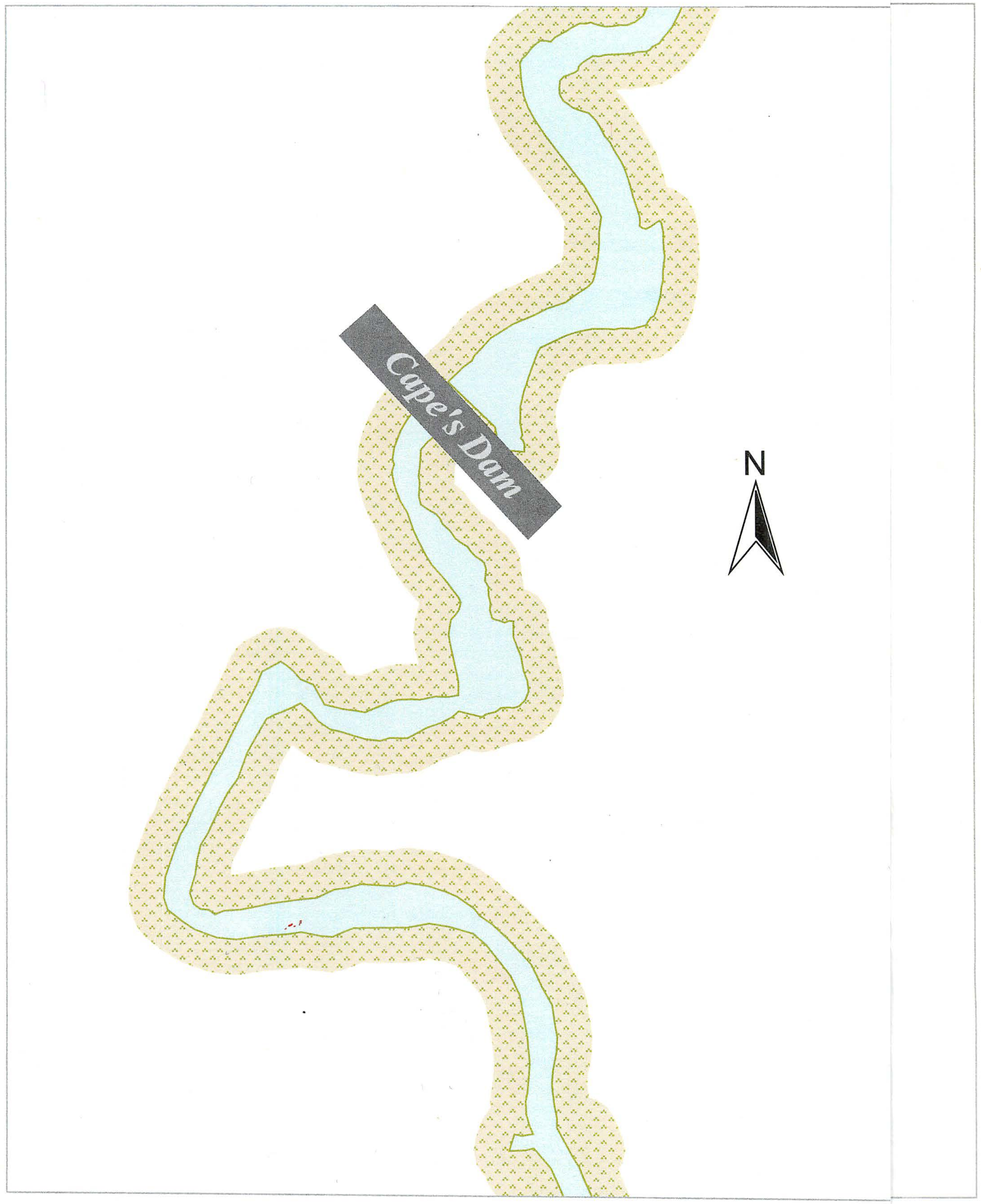
Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J



San Marcos River
Texas wild-rice

(Zizania texana)

High Flow 2 - Map 5 of 7

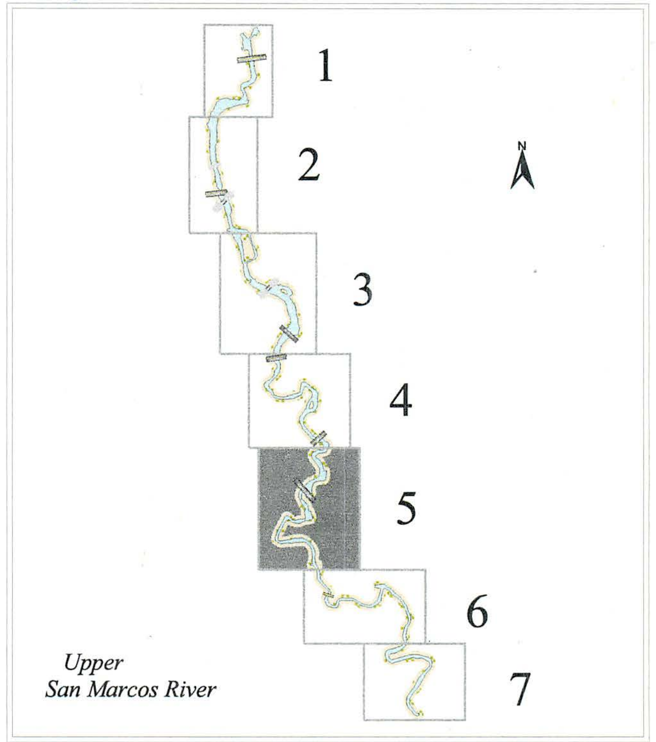
December 2001

		Map 5 (m^2)	Total Population (m^2)
🟥	*Zizania*	2.1	1,765.9

Scale: 1"=190'

20 0 20 40 60 80 100 Meters

Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

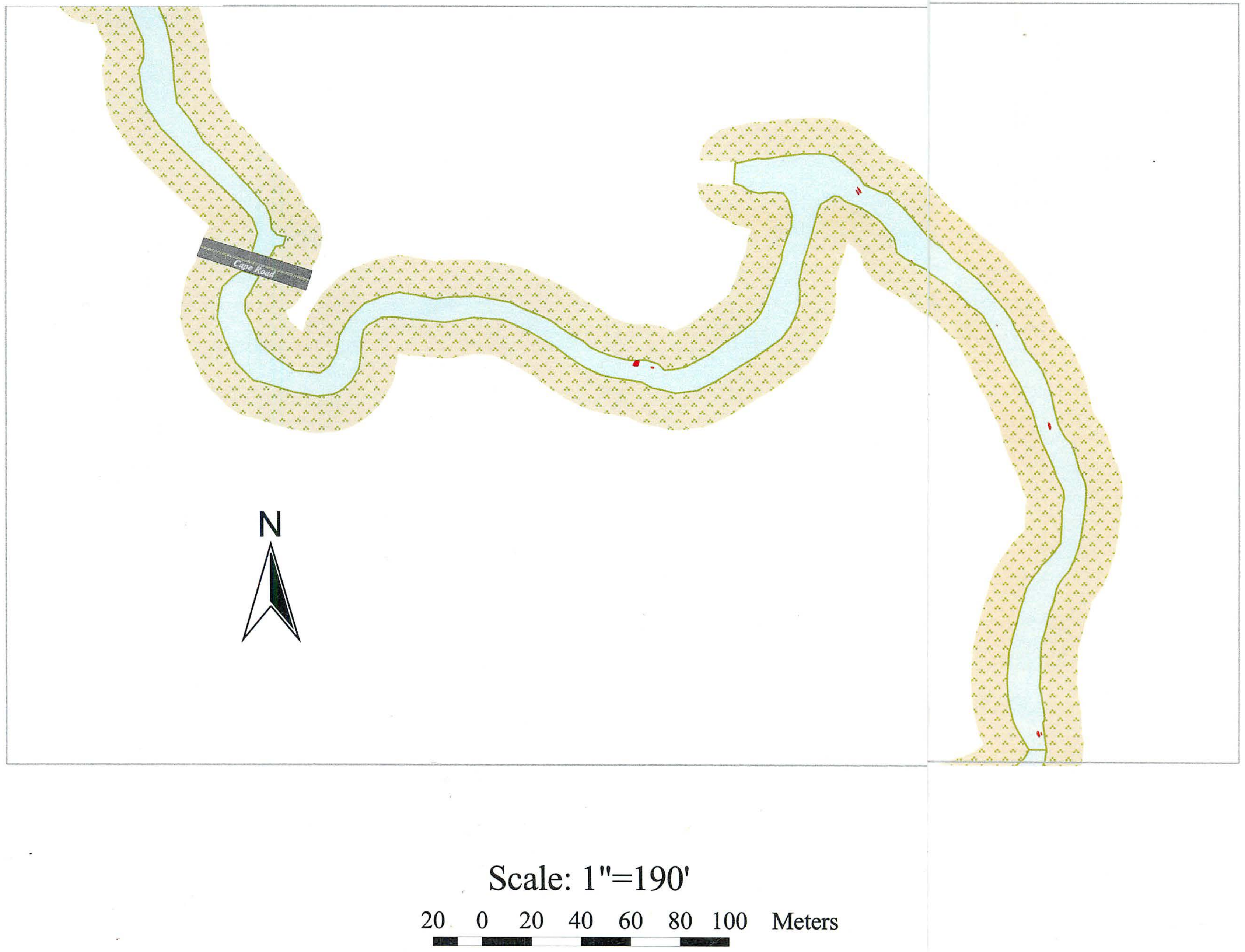
PBS&J

San Marcos River
Texas wild-rice

(Zizania texana)

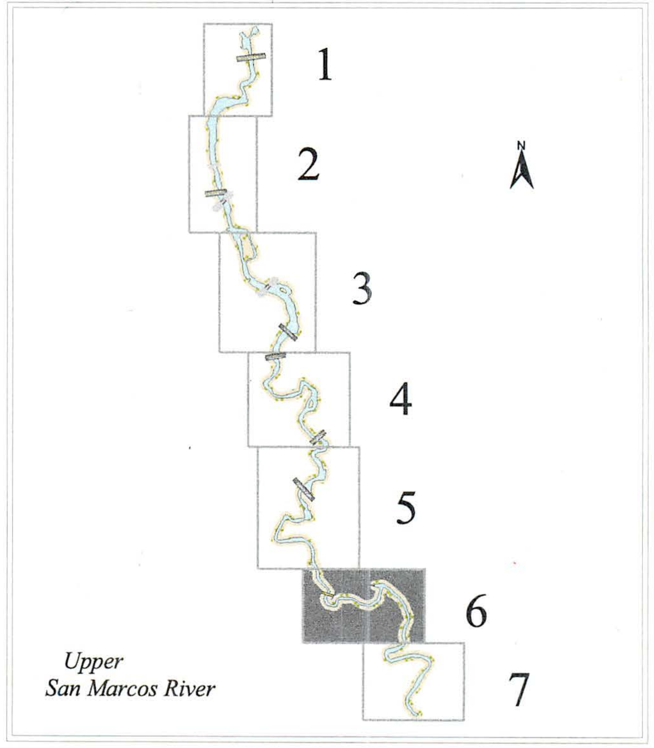
High Flow 2 - Map 6 of 7

December 2001



		Map 6 (m^2)	Total Population (m^2)
🟥	*Zizania*	13.6	1,765.9

Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

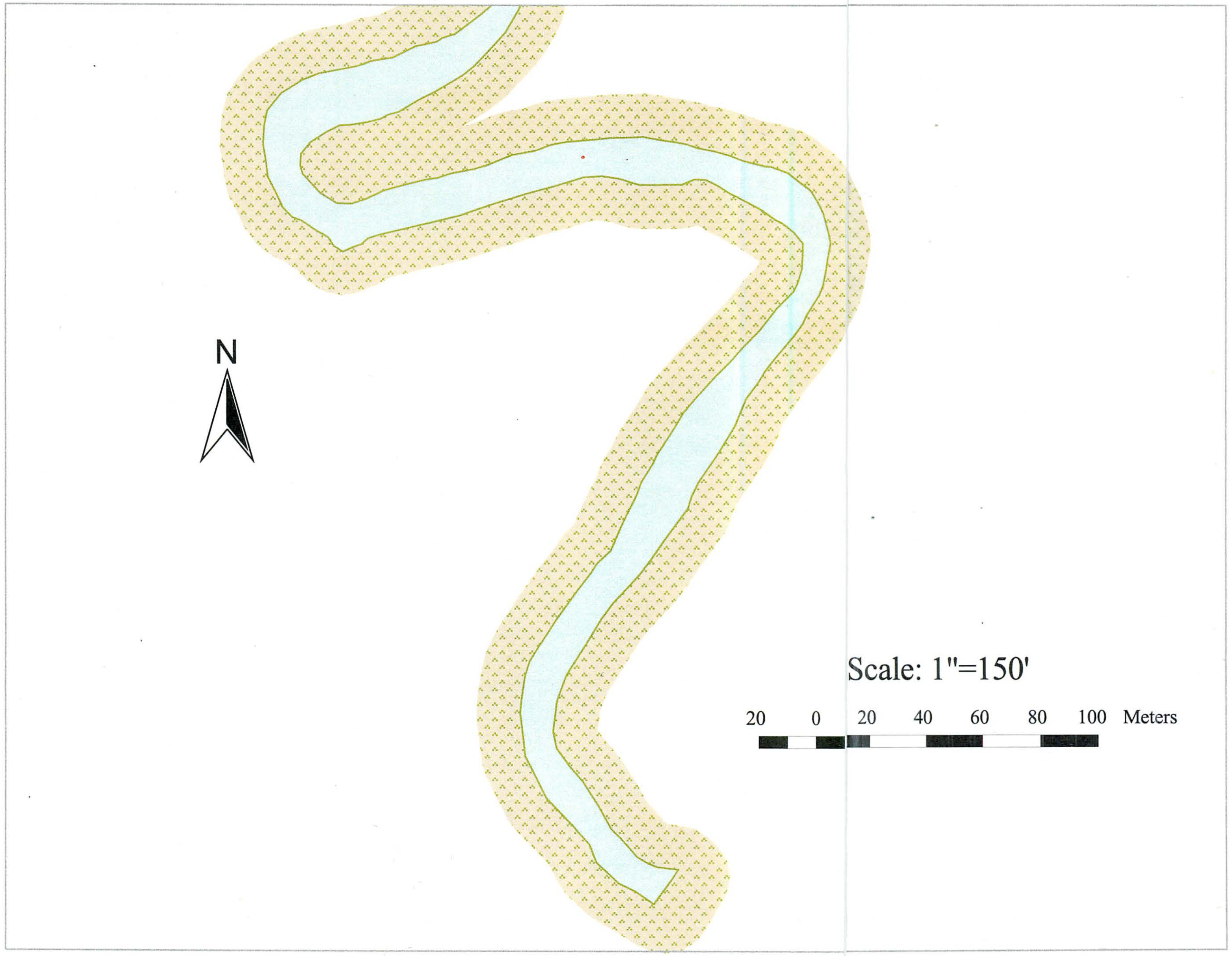
San Marcos River
Texas wild-rice

(Zizania texana)

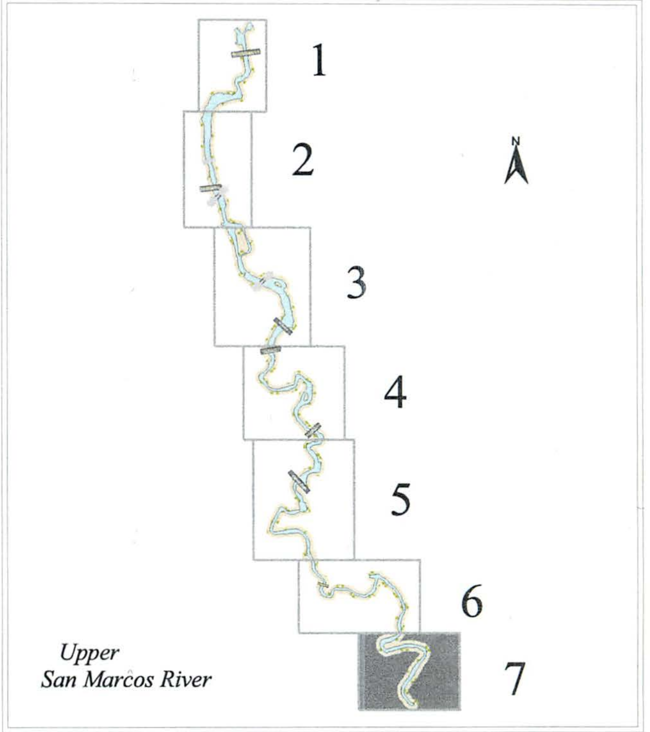
High Flow 2 - Map 7 of 7

December 2001

		Map 7 (m^2)	Total Population (m^2)
🟥	*Zizania*	0.7	1,765.9



Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

APPENDIX B: DATA AND GRAPHS

Water Quality Data

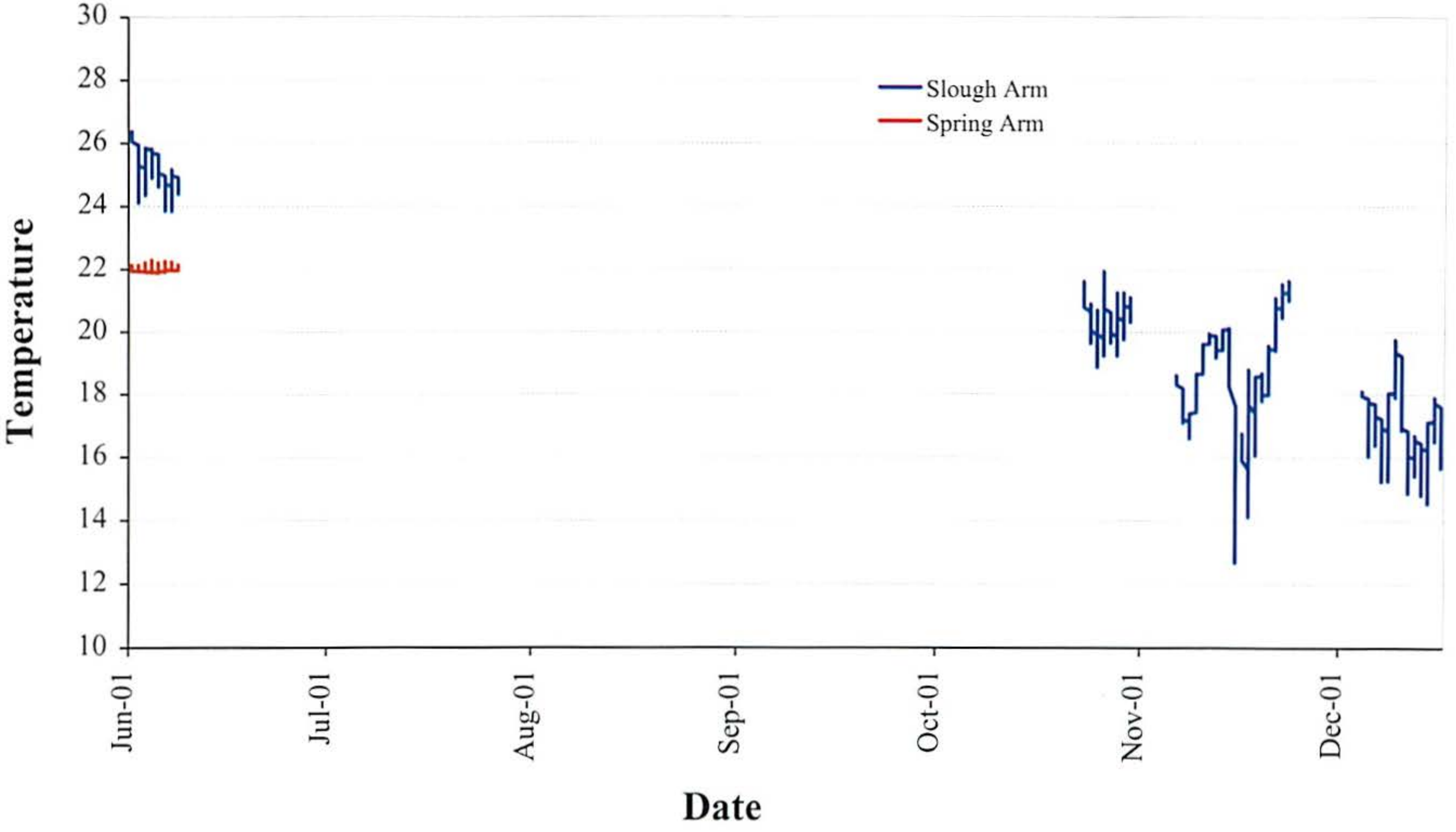
Standard parameters and nutrient values for each sample trip in the San Marcos River system.

Site	Date	Depth	Temp	pH	D.O.	Cond	Turb.	Alkalinity	SRP ugP/l	TP ug/l	NH4-N(ug/L)	N03-N(mg/L)	TN-N(mg/L)	TSS (mg/L)
Animal Shelter	11/1/2000	0.3	22.62	7.78	10.4	575	4.6	4.364	4.615	18.517	56.9	1.2	1.6	0.008
Animal Shelter	3/6/2001	0.9	21.85	7.88	9.45	582	2.5	4.836	20.724	15.069	30	1.3	1.7	0.002
Animal Shelter	5/8/2001	0.6	21.74	7.73	7.9	559	2.5	4.598	108.496	115.76	43	1.2	1.43	0.121
Animal Shelter	8/14/2001	0.5	22.55	7.66	7.75	593	3.1	4.598	30.825	33.985	26	1.65	1.96	0.008
Animal Shelter	10/25/2001	0.5	22.73	7.41	8.54	579	2.9	4.333	1.567	4.958	12	1.37	1.39	0.006
	MEAN	0.56	22.3	7.69	8.81	578	3.12	4.546	33.245	37.658	33.58	1.35	1.61	0.029
	MAX	0.9	22.73	7.88	10.4	593	4.6	4.836	108.496	115.76	56.9	1.65	1.96	0.121
	MIN	0.3	21.74	7.41	7.75	559	2.5	4.333	1.567	4.958	12	1.2	1.39	0.002
Thompson's Island, Artifical	11/1/2000	2.4	22.57	7.67	8.37	580	3.8	4.609	4.441	9.207	45.68	1.01	1.15	0.004
Thompson's Island, Artifical	11/1/2000						3.3	4.666	3.895	9.552	45.55	1.13	1.19	0.004
Thompson's Island, Artifical	3/6/2001	2.5	21.68	7.91	11.5	578	1.9	4.741	17.241	9.552	89	1.89	2.35	0.006
Thompson's Island, Artifical	5/8/2001	0.5	21.69	7.64	7.59	559	2	4.652	127.304	130.86	36	0.67	0.99	0.09
Thompson's Island, Artifical	8/14/2001	2.3	22.39	7.6	6.63	596	2.9	4.664	3.831	12.279	45	1.46	1.61	0.008
Thompson's Island, Artifical	10/25/2001		22.81	7.67	8.78	579	2.5	4.433	5.399	14.256	55	1.25	1.3	0.005
	MEAN	1.93	22.23	7.7	8.57	578	2.73	4.628	27.019	30.951	52.71	1.23	1.43	0.019
	MAX	2.5	22.81	7.91	11.5	596	3.8	4.741	127.304	130.86	89	1.89	2.35	0.09
	MIN	0.5	21.68	7.6	6.63	559	1.9	4.433	3.831	9.207	36	0.67	0.99	0.004
Thompson's Island, Natural	11/1/2000	0.46	22.5	7.74	9.8	579	3.7	4.647	3.918	11.621	20.58	1.05	1.38	0.004
Thompson's Island, Natural	3/6/2001	0.9	22.19	7.89	9.28	581	2	4.798	16.893	18.517	81	1.28	1.63	0.004
Thompson's Island, Natural	5/8/2001	1.5	21.81	7.73	7.99	560	1.9	4.698	124.518	154.04	14	1.41	1.6	0.136
Thompson's Island, Natural	8/14/2001	0.5	22.51	7.72	7..68	596	2.5	4.648	1.742	9.853	62	1.62	1.71	0.007
Thompson's Island, Natural	10/25/2001	0.5	22.95	7.85	8.74	579	2.4	4.532	2.961	9.958	80	1.51	1.63	0.006
	MEAN	0.77	22.39	7.79	8.95	579	2.5	4.665	30.006	40.797	51.52	1.37	1.59	0.031
	MAX	1.5	22.95	7.89	9.8	596	3.7	4.798	124.518	154.04	81	1.62	1.71	0.136
	MIN	0.46	21.81	7.72	7.99	560	1.9	4.532	1.742	9.853	14	1.05	1.38	0.004
I.H. 35	11/1/2000	0.61	22.64	7.67	10.9	576	2.3	4.496	5.486	10.931	127.27	1.45	1.12	0.002
I.H. 35	3/6/2001	1.5	22.58	7.78	9.58	583	1.7	4.741	19.853	31.621	16	1.64	2.26	0.007
I.H. 35	5/8/2001	0.5	21.98	7.65	8.22	560	1.9	4.948	136.012	139.9	30	1.33	1.46	0.091
I.H. 35	8/14/2001	1.2	22.61	7.61	8.21	596	1.8	5.028	1.219	10.129	23	1.79	1.96	0.006
I.H. 35	10/25/2001	0.5	23.24	7.74	8.95	578	1.6	4.466	2.612	9.658	N.D.	1.5	1.51	0.004
	MEAN	0.86	22.61	7.69	9.17	579	1.86	4.736	33.036	40.447	49.07	1.54	1.66	0.022
	MAX	1.5	23.24	7.78	10.9	596	2.3	5.028	136.012	139.9	127.27	1.79	2.26	0.091
	MIN	0.5	21.98	7.61	8.21	560	1.6	4.466	1.219	9.658	16	1.33	1.12	0.002
Rio Vista Park two	11/1/2000						1.9	4.768	4.226	9.897	156.78	1.42	2.41	0.001

Standard parameters and nutrient values for each sample trip in the San Marcos River system (continued).

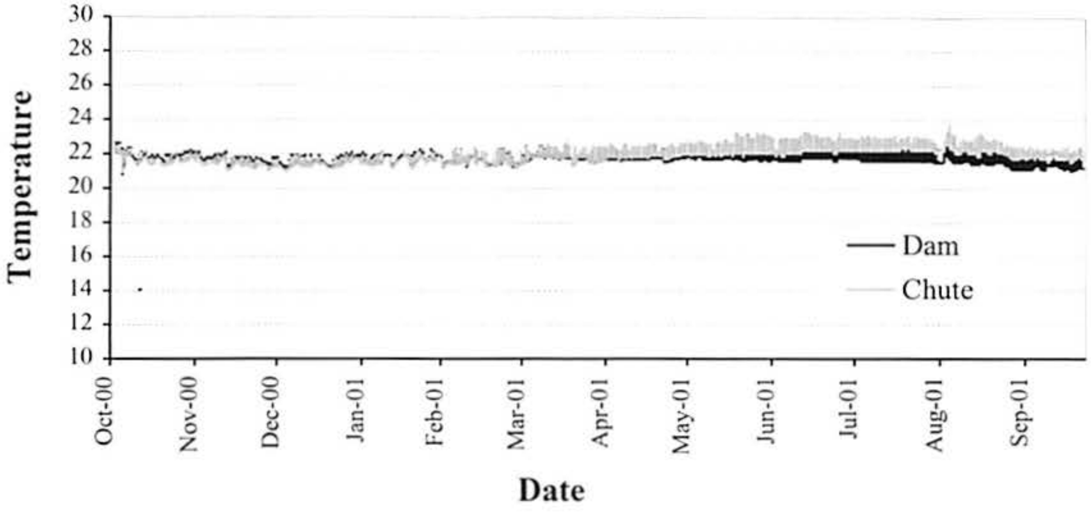
Site	Date	Depth	Temp	pH	D.O.	Cond	Turb.	Alkalinity	SRP ugP/l	TP ug/l	NH4-N(ug/L)	N03-N(mg/L)	TN-N(mg/L)	TSS (mg/L)
Rio Vista Park	11/1/2000	2	22.85	7.57	11.7	579	2.1	4.573	3.966	9.552	127.27	1.39	2.82	0.001
Rio Vista Park	3/6/2001	1.8	22.64	7.62	10.2	581	2.2	4.723	16.544	18.361	7	1.22	1.63	0.002
Rio Vista Park	5/8/2001	2.1	22.13	7.54	8.81	559	2.2	4.785	124.518	152.31	114	2.12	2.36	0.059
Rio Vista Park	8/14/2001	1.5	22.76	7.46	8.92	596	1.5	4.83	2.264	13.927	0	1.77	1.9	0.004
Rio Vista Park	10/25/2001		23.28	7.6	9.79	579	1.4	4.433	0.697	2.969	127	1.49	1.63	0.004
	MEAN	1.85	22.73	7.56	9.87	579	1.88	4.669	29.598	39.424	93.82	1.6	2.07	0.014
	MAX	2.1	23.28	7.62	11.7	596	2.2	4.83	124.518	152.31	127.27	2.12	2.82	0.059
	MIN	1.5	22.13	7.46	8.81	559	1.4	4.433	0.697	2.969	7	1.22	1.63	0.001
Lion's Club	11/1/2000	1.5	23.28	7.66	11.6	575	1.9	5.251	4.963	12.31	115.92	1.24	1.53	0.002
Lion's Club	3/16/2001	2.15	22.5	7.49	8.9	583	2	4.899	15.998	24.152	99	1.4	1.9	0.002
Lion's Club	5/8/2001	2.1	22.31	7.45	8.45	560		4.761	144.197	163	24	1.5	1.75	0.094
Lion's Club	8/14/2001	1.2	22.76	7.42	8.25	595	1.3	4.681	21.072	29.332	18	1.68	1.8	0.005
Lion's Club	10/25/2001	1	23.06	7.53	8.81	579	1.2	4.383	9.927	29.895	N.D.	1.61	1.63	0.004
	MEAN	1.59	22.78	7.51	9.2	578	1.6	4.795	39.231	51.738	64.23	1.49	1.72	0.021
	MAX	2.15	23.28	7.66	11.6	595	2	5.251	144.197	163	115.92	1.68	1.9	0.094
	MIN	1	22.31	7.42	8.25	560	1.2	4.383	4.963	12.31	18	1.24	1.53	0.002
Sessoms Creek	11/1/2000	0.11	23.33	7.42	8.63	607	2.2	4.609	4.441	18.172	104.57	1.35	1.09	0.002
Sessoms Creek	3/6/2001	0.1	21.82	7.53	7.53	609	2.1	4.723	11.494	13.345	2	2.26	2.71	0.004
Sessoms Creek	5/8/2001	0.1	22.62	7.48	6.9	588	2	4.689	118.945	136.13	2.1	1.26	1.35	0.015
Sessoms Creek	8/14/2001	0.1	23.7	7.5	7.08	611	1.2	4.631	8.011	16.859	2	2.1	2.3	0.003
Sessoms Creek	10/25/2001	0.1	22.93	7.48	6.77	610	1.1	4.433	6.792	21.765	7	1.61	1.63	0.003
	MEAN	0.1	22.88	7.48	7.38	605	1.72	4.617	29.937	41.253	23.53	1.72	1.82	0.005
	MAX	0.11	23.7	7.53	8.63	611	2.2	4.723	118.945	136.13	104.57	2.26	2.71	0.015
	MIN	0.1	21.82	7.42	6.77	588	1.1	4.433	4.441	13.345	2	1.26	1.09	0.002
Dam Side	11/1/2000	0.76	23.34	7.52	10.9	574	1.3	4.76	4.093	3.345	31.93	1.2	2.33	0.001
Dam Side	3/6/2001	1.2	22.23	7.44	8.09	581	1.2	4.571	15.674	16.187	82	1.35	1.8	0.004
Dam Side	5/8/2001		22.32	7.43	8.2	562	1.4	4.569	111.282	129.55	84	1.39	1.63	0.064
Dam Side	8/14/2001	0.5	22.68	7.29	7.2	598	1.1	4.669	13.584	19.583	85	1.76	1.98	0.002
Dam Side	10/25/2001	0.7	22.71	7.46	7.95	580	0.9	4.433	5.747	19.129	118	1.73	1.86	0.002
	MEAN	0.79	22.66	7.43	8.47	579	1.18	4.6	30.076	37.559	80.19	1.49	1.92	0.015
	MAX	1.2	23.34	7.52	10.9	598	1.4	4.76	111.282	129.55	118	1.76	2.33	0.064
	MIN	0.5	22.23	7.29	7.2	562	0.9	4.433	4.093	3.345	31.93	1.2	1.63	0.001
Chute Side	11/1/2000	0.91	23.01	7.47	10.6	578	1.1	5.212	4.789	7.828	43.28	1.16	1.18	0
Chute Side	3/6/2001	1.2	22.3	7.4	8.35	584	1.9	4.741	11.146	10.241	21	1.24	1.66	0.002
Chute Side	5/8/2001	1.2	22.37	7.43	7.95	561	2.2	4.741	137.251	173.35	25	0.51	0.8	0.08
Chute Side	8/14/2001	1	22.73	7.39	7.75	596	8.2	4.601	9.752	16.259	19	1.9	2.2	0.003
Chute Side	10/25/2001	1.1	22.55	7.04	8.35	580	1	4.466	10.275	32.236	N.D.	1.36	1.4	0.002
	MEAN	1.08	22.59	7.35	8.6	580	2.88	4.752	34.643	47.982	27.07	1.23	1.45	0.017
	MAX	1.2	23.01	7.47	10.6	596	8.2	5.212	137.251	173.35	43.28	1.9	2.2	0.08
	MIN	0.91	22.3	7.04	7.75	561	1	4.466	4.789	7.828	19	0.51	0.8	0

Hydrolab data from Spring Lake

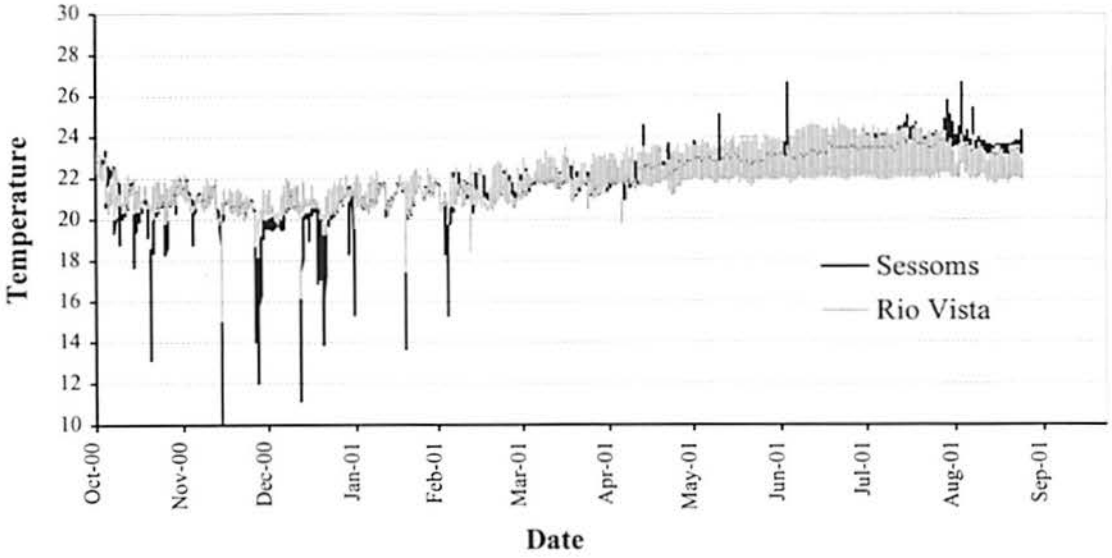


Thermistor Graphs

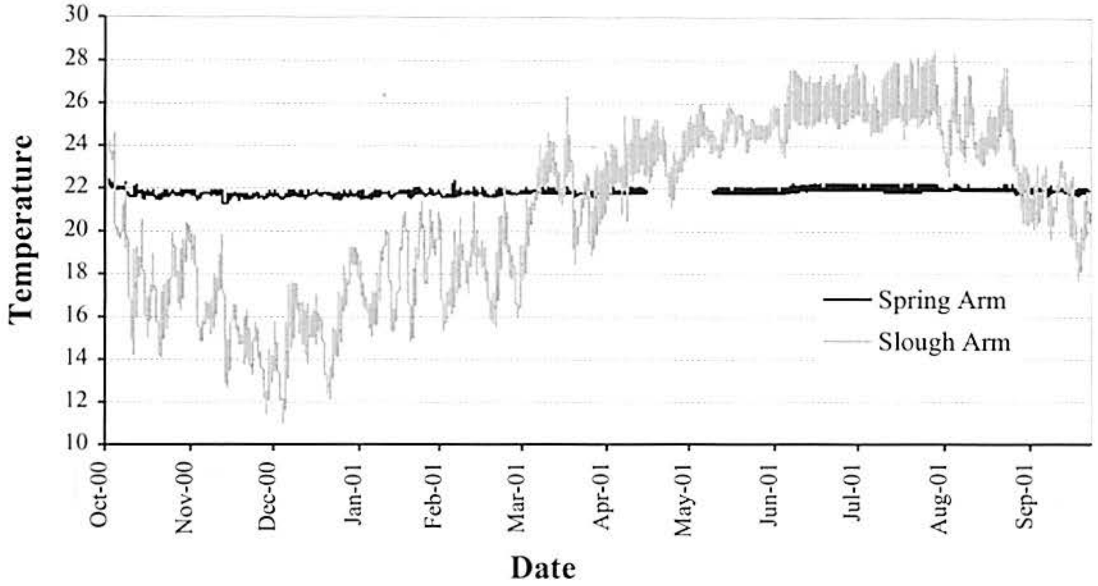
Thermistor Data: Dam and Chute Below Spring Lake



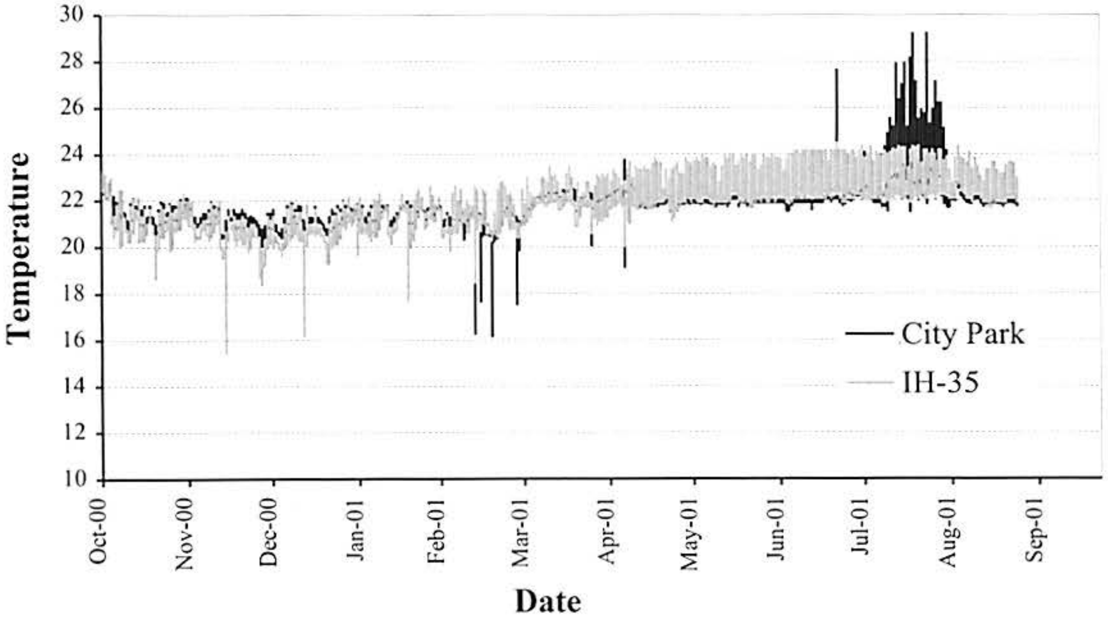
Thermistor Data: Sessoms Creek and Rio Vista Dam



Thermistor Data: Spring Lake Sites

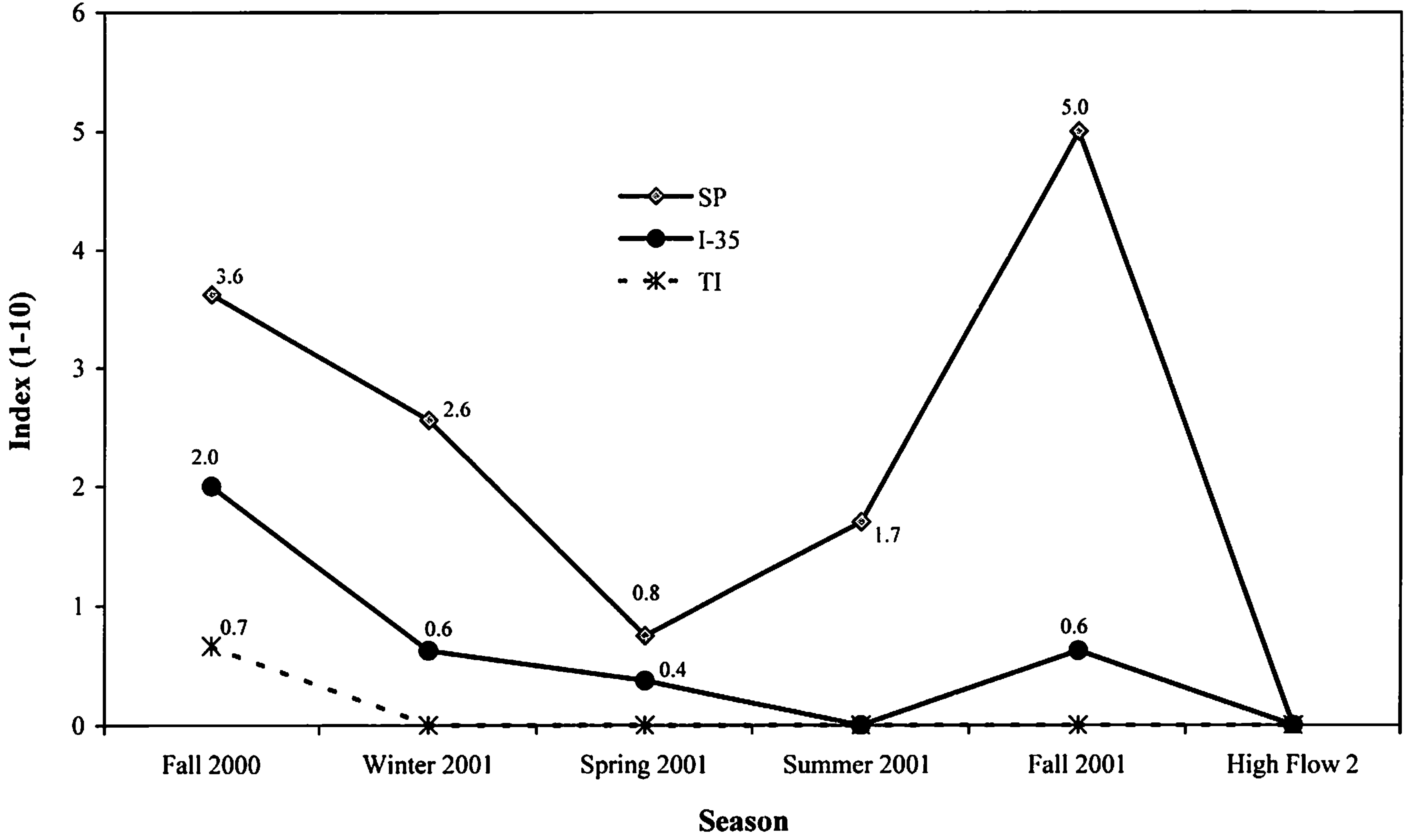


Thermistor Data: City Park & IH-35

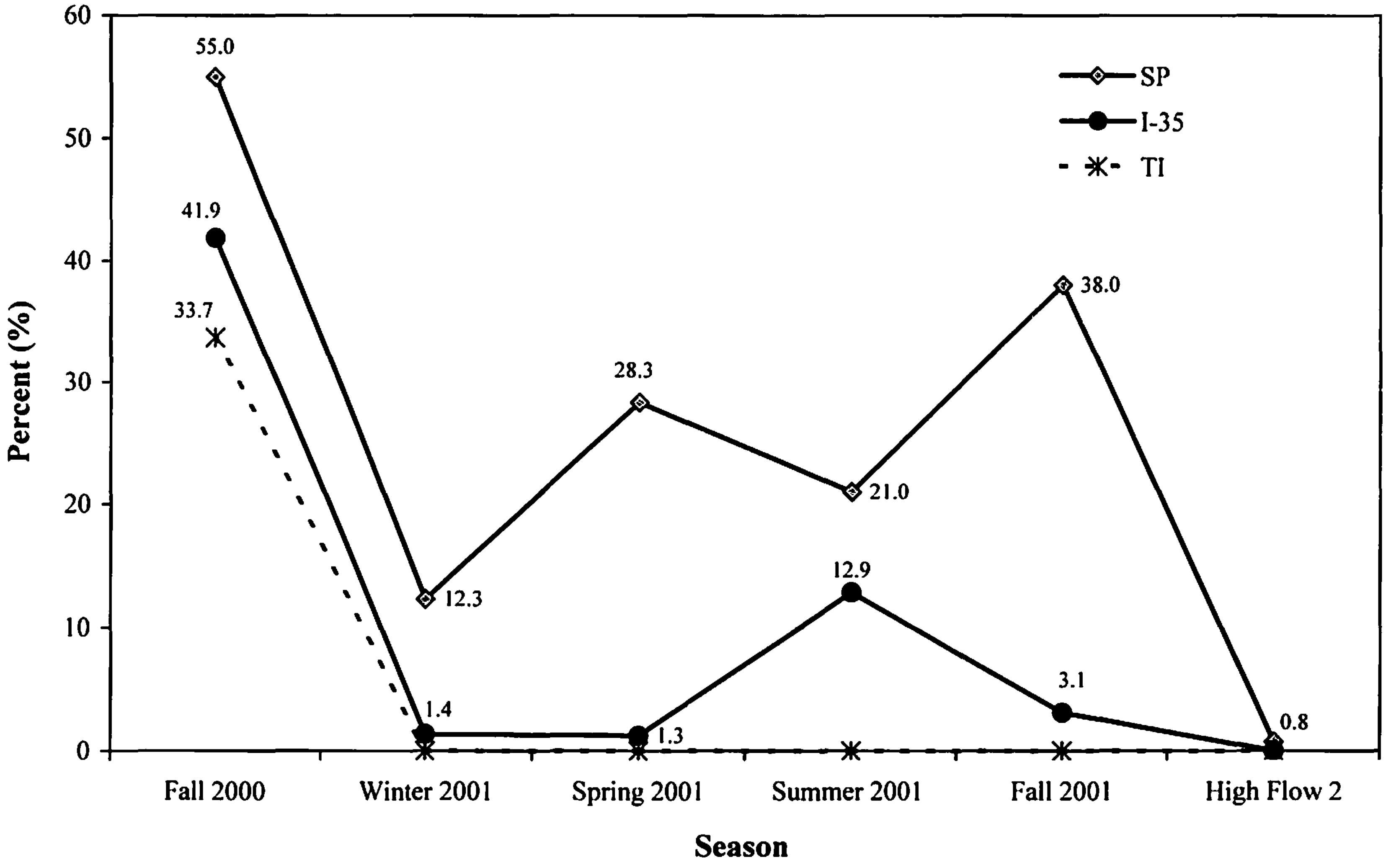


Texas Wild-Rice Observation Data

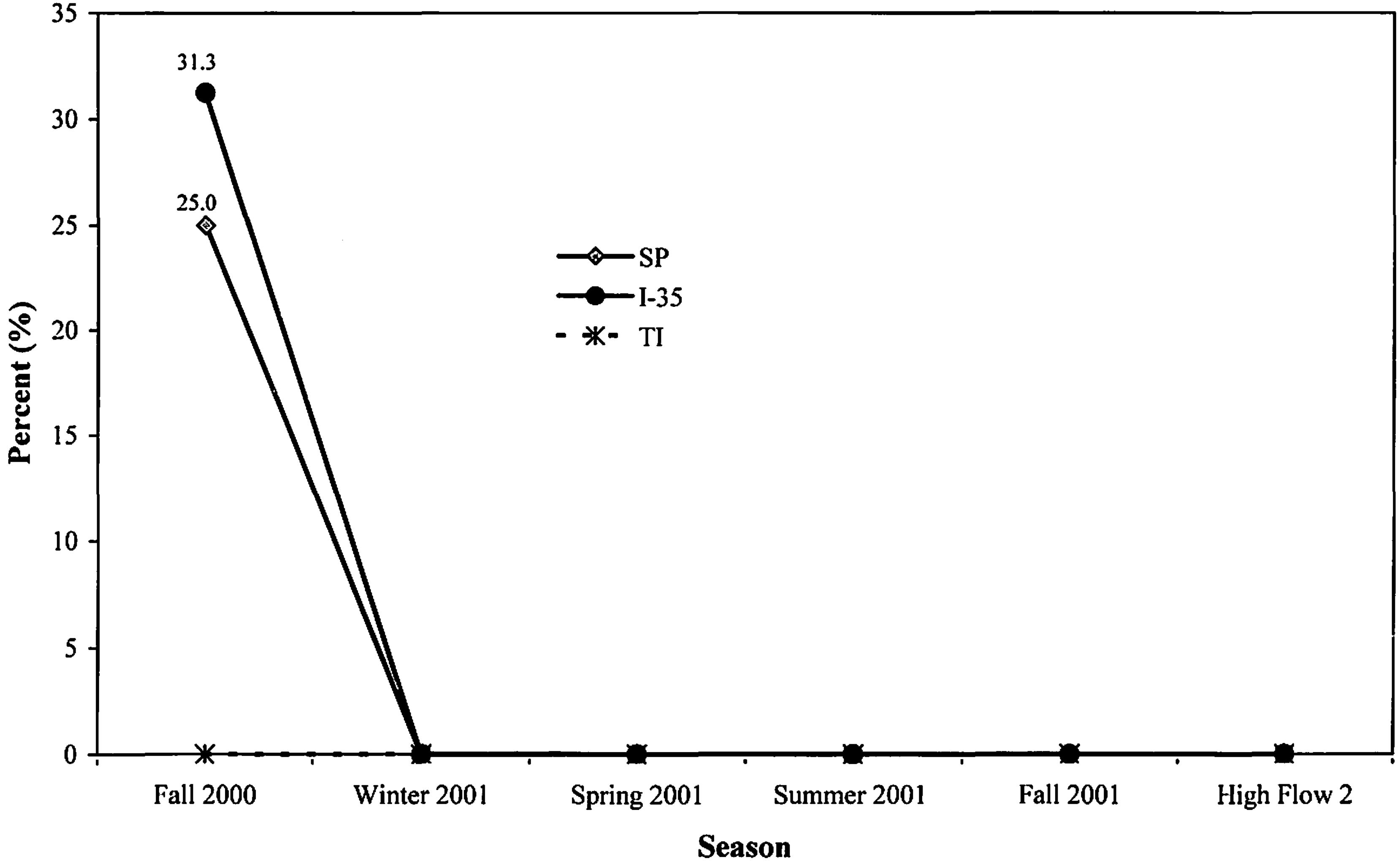
Index of Herbivory for TWR Stands



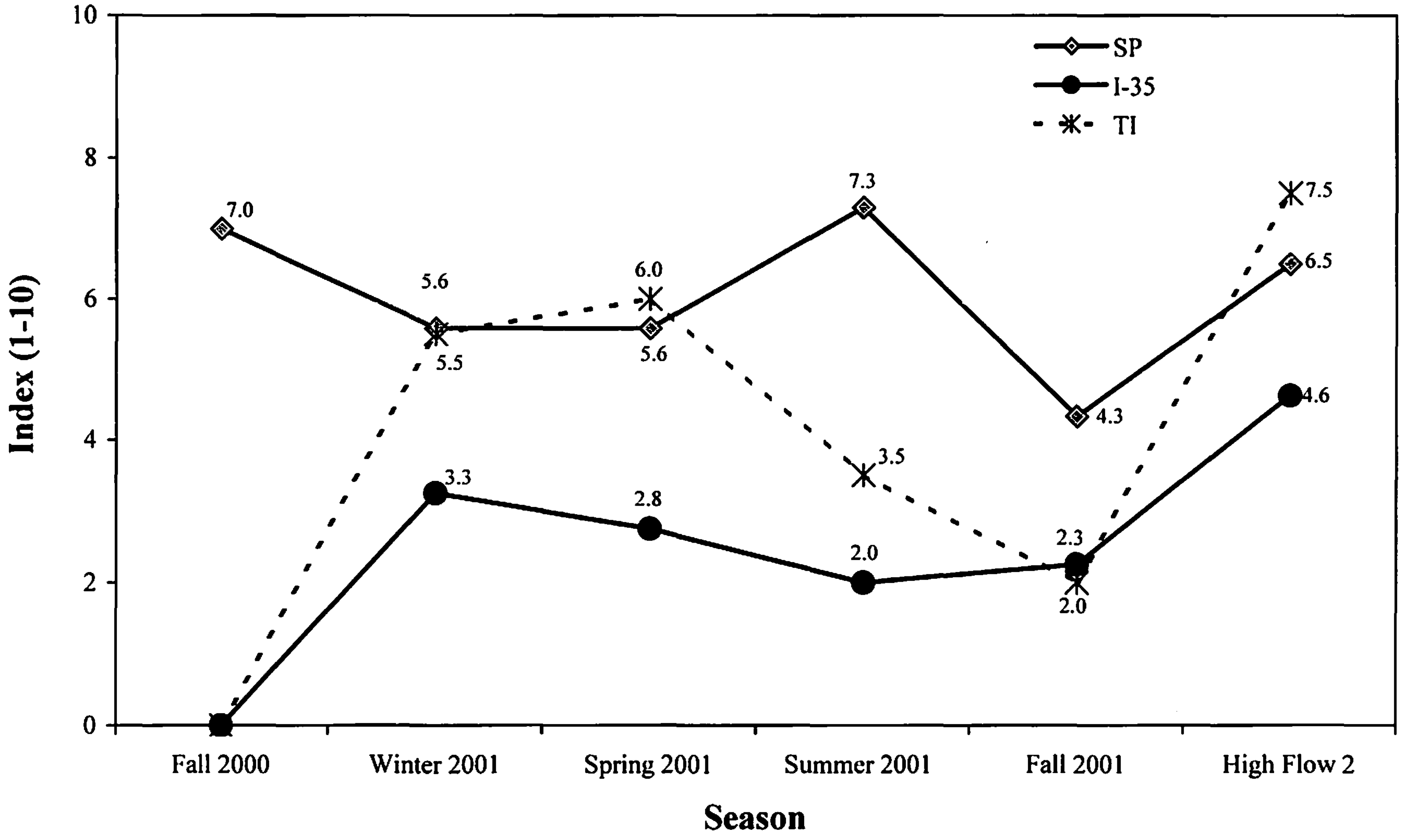
Percent Emergent TWR



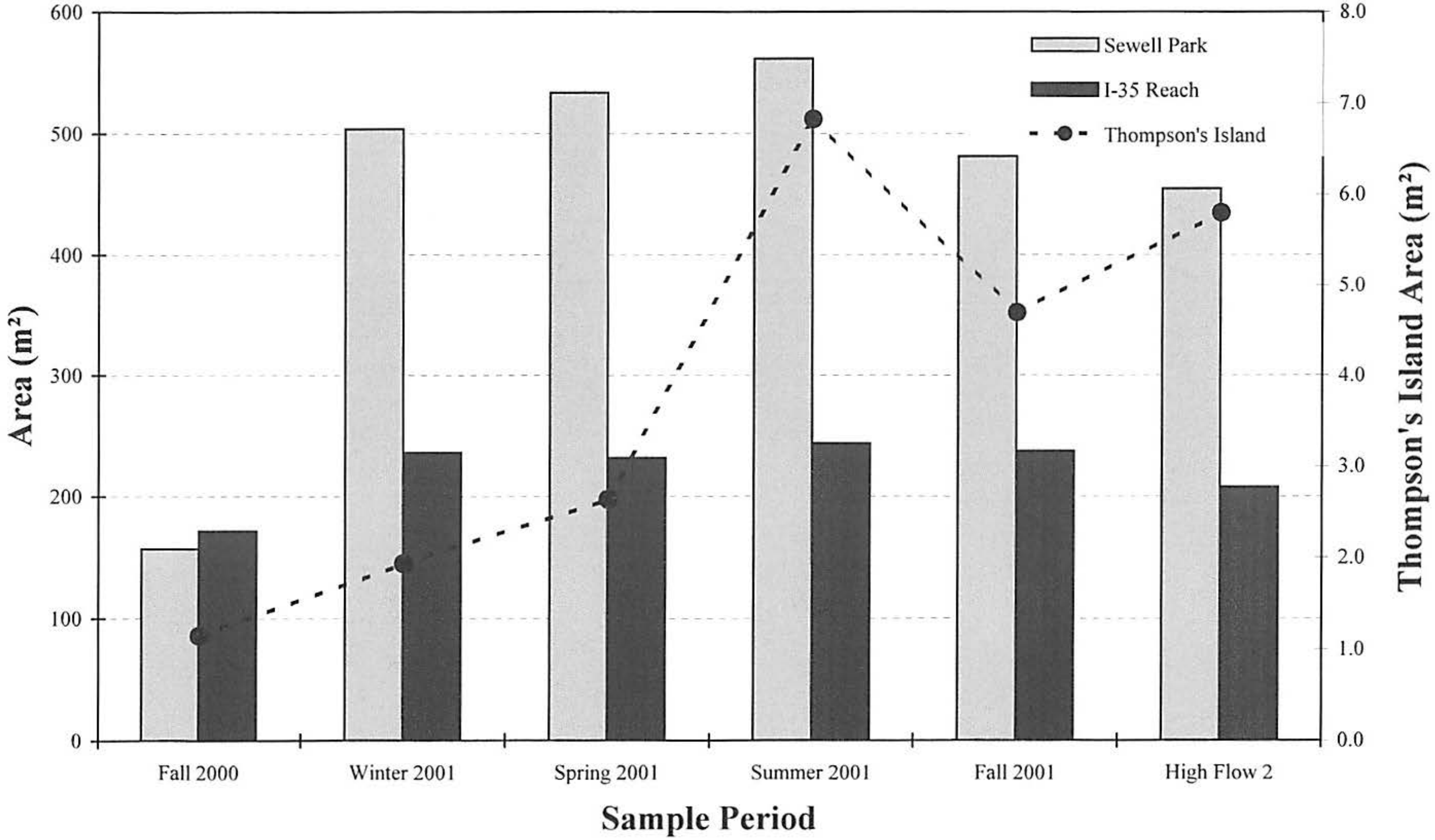
Percent of TWR Stands < 0.5 Feet



Index of Root Exposure for TWR Stands

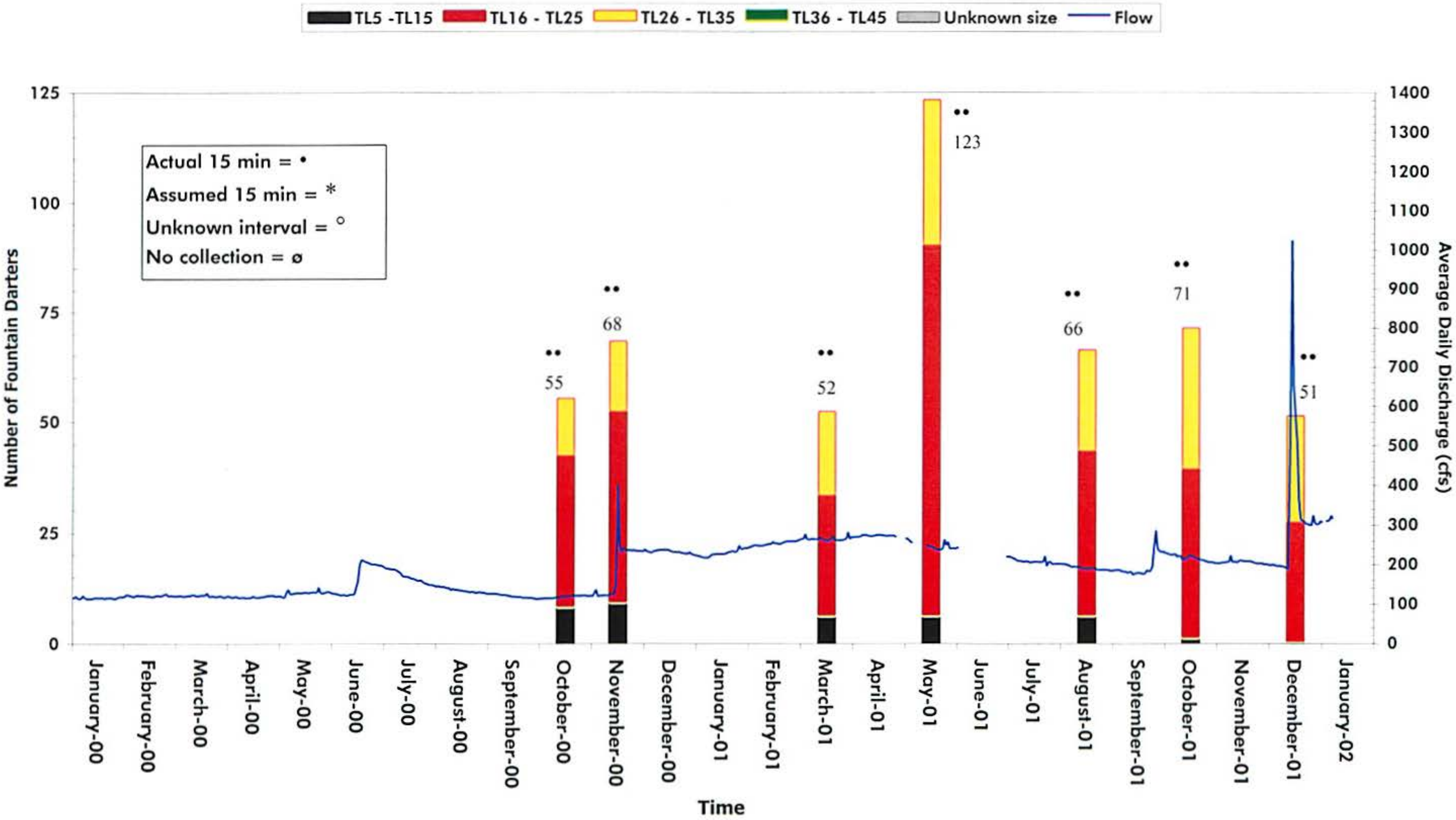


TWR Area by Season

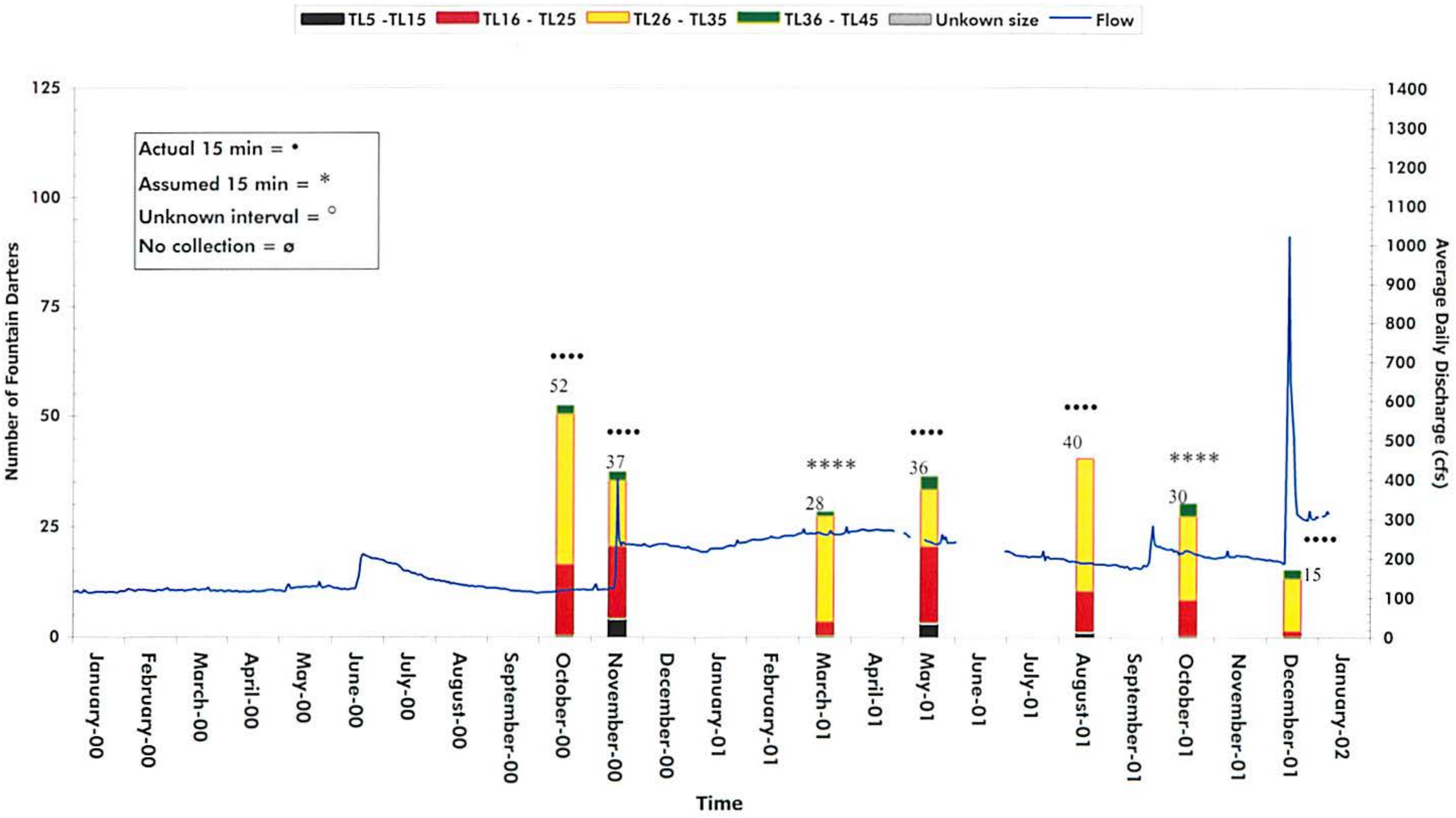


Dip Net Graphs

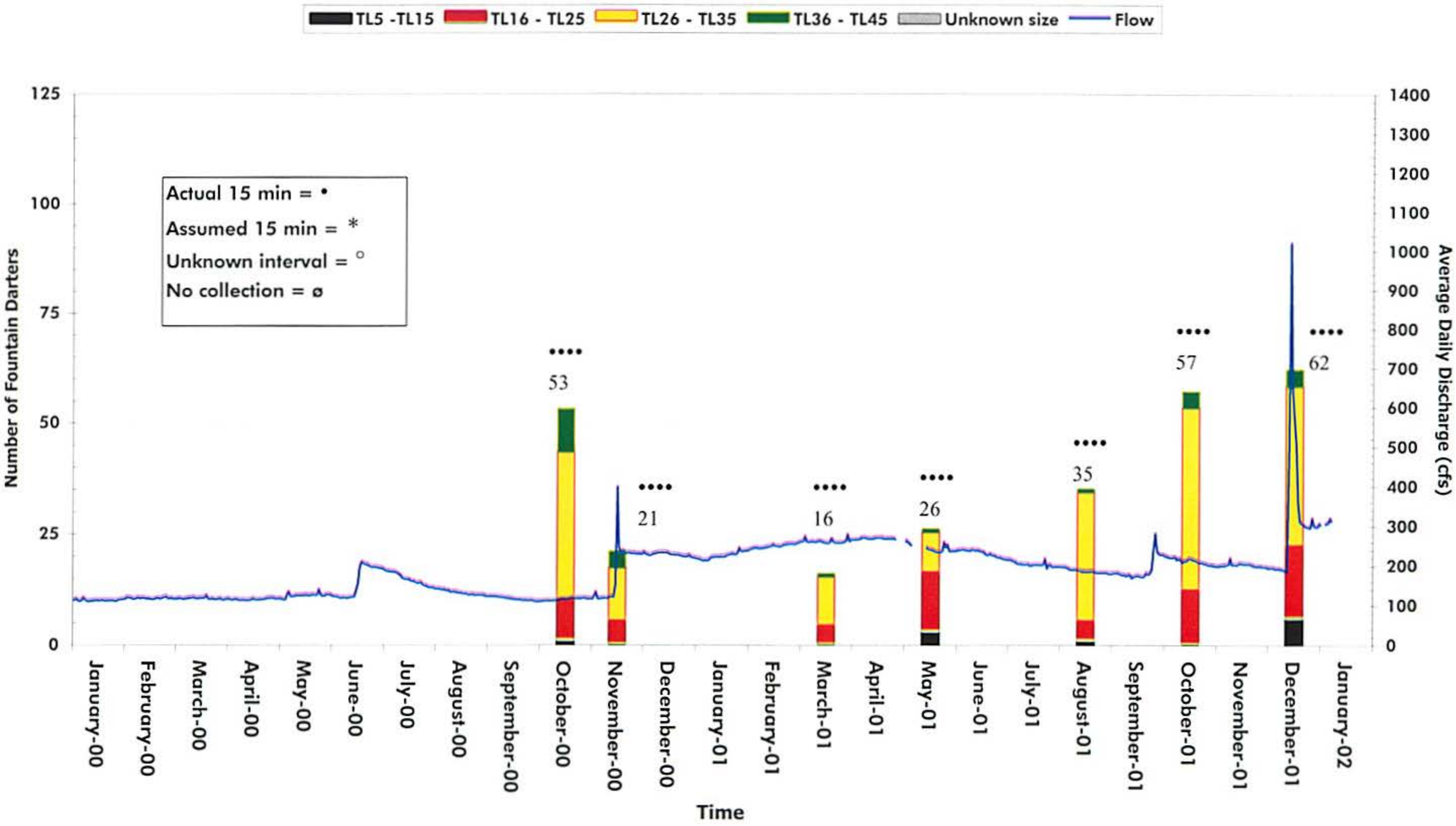
Fountain Darters Collected from Hotel Reach (Section 1U)
Dip Net Results - San Marcos River



Fountain Darters Collected from City Park Reach (Section 4L-M)
Dip Net Results - San Marcos River



Fountain Darters Collected from I-35 Reach (Section 7-M)
Dip Net Results - San Marcos River



Exotics / Predation Study

SPRING LAKE GILL NET DATA
SAN MARCOS RIVER - WINTER QUARTERLY SAMPLING

Species	Total Length (mm)	Total Weight (gr)	Stomach Contents
Lepisosteus oculatus	593	700	empty
	696	1350	1 *Lepomis sp.*
	731	1925	unidentified fish remains
	741	1700	empty
Lepomis auritus	173	105	odonate larvae, chironomid
	202	195	unidentified material
	206	140	diptera larvae, amphipods, chironomids, 1 Elmid larvae and 1 Elmid adult, snails
Lepomis gulosus	220	250	crayfish remains
	220	260	empty
	233	280	empty
Lepomis megalotis	142	50	empty
	152	60	adult diptera, 1 hydra corinidae, amphipods
	170	110	snails, 1 copepod, 2 eggs, amphipods
	176	110	unident. insect parts, 1 mayfly, amphipod
	176	105	larval chironomids, amphipods
	193	150	empty
	195	190	empty
	205	195	adult chironomid
Cichlasoma cyanoguttam	264	360	empty
Lepomis microlophus	153	90	coiled snail, chironomid adults and larvae, amphipods
	207	190	empty
	220	190	empty
Lepomis punctatus	94	20	chironomid larvae, amphipods
	117	40	amphipods
	126	75	coiled snail, adult diptera, amphipods, chironomid
	130	50	empty
	135	60	coiled snail
Micropterus salmoides	281	290	crayfish remains
	283	305	empty
	319	395	Unident. fish remains
	330	450	2 unident. fish remains
	398	800	2 minnow remains
	442	820	unident. fish remains
	444	1190	1 crayfish

SPRING LAKE GILL NET DATA
SAN MARCOS RIVER - SPRING QUARTERLY SAMPLING

Species	Total Length (mm)	Total Weight (oz)	Stomach Contents
Lepomis gulosus	170	108	crayfish
Lepomis macrochirus	150	57	terrestrial beetle; amphipods; corixidae; chironomids; diptera adults; baetidae; tricorithidae; ephemeroptera; water mite
	140	57	unident. Insect parts
	130	51	water mites; cladocera; amphipods; adult diptera; filamentous algae; crayfish
	105	28	empty
	100	23	amphipods; chironomids; ephemeroptera
	100	28	amphipods; chironomids; unident. Insect parts
Micropterus salmoides	170	57	empty
	230	142	1 *Astayanax mexicanus*; 1 prawn
	305	340	1 prawn

SPRING LAKE GILL NET DATA
SAN MARCOS RIVER - SUMMER QUARTERLY SAMPLING

Species	Total Length (mm)	Total Weight (gr)	Stomach Contents
Lepisosteus oculatus	735	1928	1 *Lepomis sp.*
Lepomis gulosus	145	57	1 prawn
	170	113	empty
	189	170	1 *E. fonticola*, 2 crayfish
Lepomis macrochirus	142	85	6 bosmina, amphipod, chironomids, diptera adults
	189	113	1 chironomid, amphipods
	198	170	2 flying terrestrial insects, diptera, amphipods
Lepomis punctatus	97	28	diptera adult, amphipods
	119	57	mayfly (?), chironomid, amphipods
	121	57	chironomid, amphipod, snail
	122	57	empty
	124	57	amphipods, chironomid
	124	57	amphipods
	128	57	amphipods
	130	57	amphipods
	131	57	diptera adult, caddisfly, amphipods

SPRING LAKE GILL NET DATA
SAN MARCOS RIVER - FALL QUARTERLY SAMPLING

Species	Total Length (mm)	Total Weight (gr)	Stomach Contents
Lepisosteus oculatus	593	700	empty
	696	1350	1 *Lepomis sp.*
	731	1925	unidentified fish remains
	741	1700	empty
Lepomis auritus	173	105	odonate larvae, chironomid
	202	195	unidentified material
	206	140	diptera larvae, amphipods, chironomids, 1 Elmid larvae and 1 Elmid adult, snails
Lepomis gulosus	220	250	crayfish remains
	220	260	empty
	233	280	empty
Lepomis megalotis	142	50	empty
	152	60	adult diptera, 1 hydra corinidae, amphipods
	170	110	snails, 1 copepod, 2 eggs, amphipods
	176	110	unident. insect parts, 1 mayfly, amphipod
	176	105	larval chironomids, amphipods
	193	150	empty
	195	190	empty
	205	195	adult chironomid
Cichlasoma cyanoguttam	264	360	empty
Lepomis microlophus	153	90	coiled snail, chironomid adults and larvae, amphipods
	207	190	empty
	220	190	empty
Lepomis punctatus	94	20	chironomid larvae, amphipods
	117	40	amphipods
	126	75	coiled snail, adult diptera, amphipods, chironomid
	130	50	empty
	135	60	coiled snail
Micropterus salmoides	281	290	crayfish remains
	283	305	empty
	319	395	Unident. fish remains
	330	450	2 unident. fish remains
	398	800	2 minnow remains
	442	820	unident. fish remains
	444	1190	1 crayfish