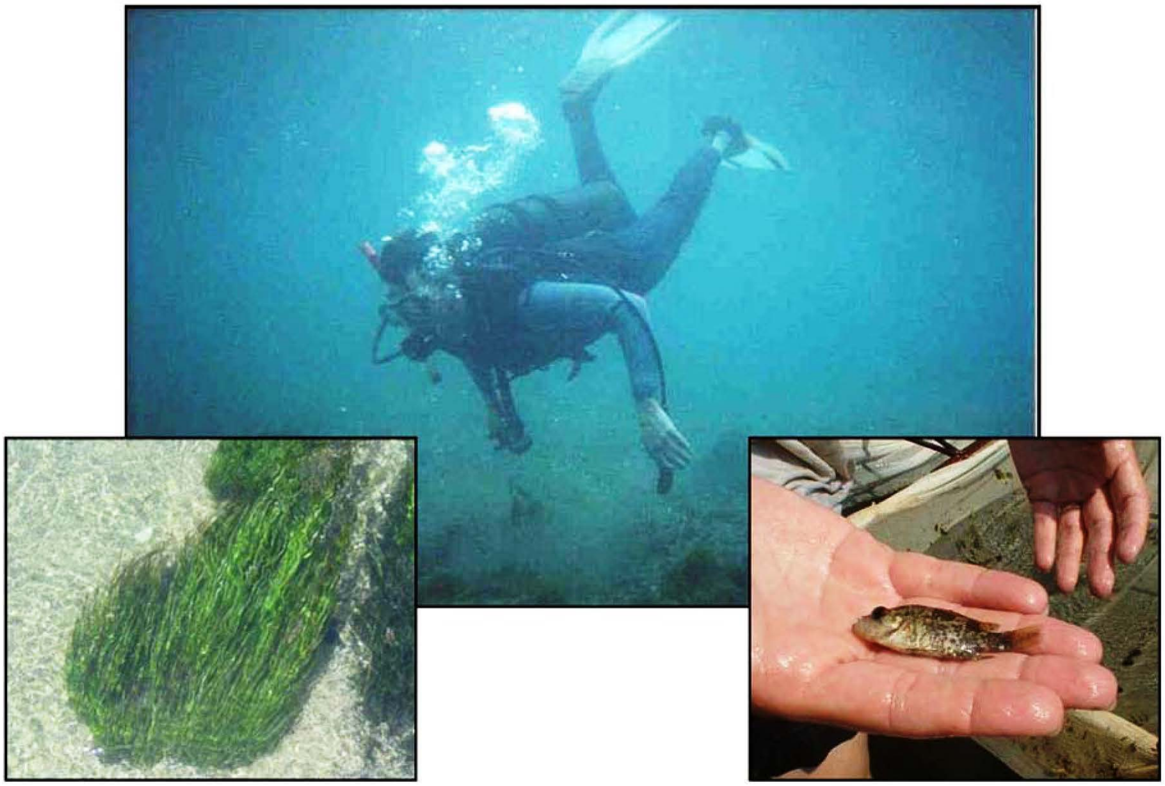
Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow On Biological Resources in the San Marcos Springs/River Aquatic Ecosystem

Final 2006 ANNUAL REPORT



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EXECUTIVE SUMMARY

This annual summary report presents a synopsis of methodology used and an account of sampling activities including sampling conditions, locations, and data obtained during two quarterly sampling events (Comprehensive Monitoring Effort) and two Critical Period events conducted on the San Marcos Springs/River ecosystem in 2006. Limited recharge was experienced in 2006, and as a result Critical Period sampling events were triggered when total discharge in the San Marcos River decreased to near 100 cubic feet per second (cfs) in July, and below 95 cfs in September. During each Critical Period sampling event, the sampling regime included all methods conducted during a Comprehensive monitoring effort (drop netting, vegetation mapping, etc.), however, predation surveys, water quality samples, and mapping of all Texas wild-rice (*Zizania texana*) were also performed.

Discharge continued to decline in the San Marcos River through 2006 due to a lack of significant rainfall. The lowest discharge occurred in September (90 cfs), and average monthly discharge in the river was below the historic average for the entire year. Discharge in 2006 also failed to top 200 cfs for the first time since this study was implemented (Fall 2000) and all four sampling events were conducted at lower discharge conditions than any other sampling period since the inception of this study. During these conditions, thermistor data continued to show a high degree of thermal uniformity in 2006. Temperatures were most consistent within Spring Lake and at the dam sites because they are nearest to spring inputs, while the Animal Shelter site showed the most variation in water temperature as it is the farthest downstream measurement.

Water Quality grab samples were collected at multiple sites in Spring Lake and the San Marcos River to evaluate select parameters during the two Critical Period sampling events. Conductivity and Total Dissolved Solids (TDS) were similar to or below the average from 2000-2002 at all sites. As to be expected, dissolved oxygen (DO) was extremely low within the stagnant water of the slough locations and sink creek during both Critical Period sampling events in Spring Lake. Of the river sites, only the Sessom's creek site fell below 6.0 milligrams per liter (mg/L) during the first Critical Period sampling event. Total Suspended Solids (TSS) were low at all sites in Spring Lake, and showed an increasing trend in the San Marcos River between Critical Period events. Nitrate values at the Spring Lake and San Marcos River sites were higher than the average from 2000-2002 for Critical Period 1 with the source of these nitrates most likely water coming out of the springs.

For the fountain darter (*Etheostoma fonticola*), habitat use is largely influenced by aquatic vegetation, and assessments of habitat availability were conducted by mapping this vegetation during each sampling event. A general trend of decreasing vegetation area was observed at the Spring Lake Dam site in 2006. At the mouth of Sessom's Creek a large "island" developed as a result of large sediment loads carried by this flashy stream. This "new" bank was mapped and resulted in a loss of available area for vegetation growth in the Spring Lake Dam Reach. By the first Critical Period event, much of the vegetation had decreased in the vicinity of this "island". Another considerable loss of vegetation occurred in this reach in September, when approximately 234 m^2 of Texas wild-rice was manually pulled out along the eastern shore of the Spring Lake Dam Reach. Rootwads of these plants were still present in several areas, but the leaves had been completely removed. During this time, man-made rock structures were also constructed in the eastern arm of the reach immediately downstream of Spring Lake Dam. Some of these structures caused the river to be channelized allowing less flow to several Texas wild-rice plants. It is clear that both the Texas wild-rice removal and rock art were caused directly by humans. By

November, the Texas wild-rice in this area had begun to recover, but was still severely fragmented as a result of the mechanical destruction.

Such dramatic aquatic vegetation changes were not observed in 2006 at the City Park or I-35 reaches. Total vegetation area began to decrease by the first Critical Period sampling event due to the combination of less wetted area and increased recreation during the hot summer months. This was evidenced by a large area in the middle of the City Park Reach (immediately adjacent to the cement wall in City Park) that became extremely shallow. This allowed a larger number of people to enter the water and walk around disturbing vegetation and also increasing turbidity. Most of the decrease in vegetation was exhibited by a loss in *Hydrilla* plants present in this increasingly shallow area. In the downstream half of the City Park Reach, the water remained deep and the vegetation well established. As a result, little change was exhibited in the vegetation in that area. The bank on the river right side at the top of the I-35 Reach expanded during 2006, decreasing the amount of wetted habitat area available to aquatic organisms. Construction of the new Rio Vista Dam just upstream of this reach contributed to high turbidity during the spring sample and likely to the bank expansion. Texas wild-rice changed little from 2005 to 2006 in the City Park Reach while increasing in the I-35 Reach.

Of all the biological communities monitored in the San Marcos River in 2006, Texas wild-rice in the upper most reaches of the San Marcos River (Spring Lake Dam Reach through Sewell Park) seemed to be affected most by the lower discharge conditions in 2006. Overall, by the first Critical Period event (July), total area of Texas wild-rice in the San Marcos River had actually increased to 3,335.7 m^2. The lower spring time discharge conditions seemed to spur new growth causing individual plants to grow together. However, by the second Critical Period event in September, direct and indirect effects of the lower than average discharge caused declines in overall Texas wild-rice area to 3,000.4 m^2. A large portion of this was the recreational impacts (234 m^2 physically removed) described in the Spring Lake Dam Reach. However, impacts of the lower discharge conditions were evident in the Sewell Park Reach as well. In this reach, thick, heavy vegetation mats covered large areas of Texas wild-rice plants. This led to pale, yellow leaves from lack of sunlight. It also contributed to shredding of leaves and fragmentation of stands when the mats moved downstream. These heavy vegetation mats also covered up reproductive culms that typically emerge from the water column during the summer months. In addition, a large, shallow area (due to excessive sedimentation in this reach and lower discharge conditions) that was previously occupied by a large Texas wild-rice stand became exposed and was taken over by other emergent plants. The intrusion of other aquatic vegetation in these shallow areas led to large-scale fragmentation of larger Texas wild-rice stands in the Sewell Park Reach. The shallow water also contributed to increased herbivory rates because more plants were accessible to waterfowl and nutria. The shallow water (again due to the lower discharge conditions coupled with the increased sedimentation over the last decade) also had the indirect effect of making this area more accessible to recreation. A wading path developed in this part of Sewell Park where the water was shallow. This led to further fragmentation of the Texas wild-rice in this reach. Total area of wild-rice in the Sewell Park Reach decreased from 777.5 m^2 in April to 558.8 m^2 in November.

With the exception of Texas wild-rice in the Spring Lake Dam and Sewell Park reaches (described above), Texas wild-rice areas increased in the downstream reaches. One plant was lost just upstream of Cheatham Street due to the Rio Vista Dam construction, but another was gained just downstream. Plants in the I-35 Reach continued to grow, and many were emergent in the summer. Several flowers and reproductive culms were observed in the large plants immediately upstream of I-35. In the lower reaches of the San Marcos River, Texas wild-rice coverage continued to expand throughout 2006.

Direct sampling of the fountain darter occurred in the same reaches as mapped for aquatic vegetation, with the most recent mapping determining the stratified random sample locations. The suitability of the various vegetation types (as measured by fountain darter density) is considerably lower in the San Marcos River when compared with the Comal River. Densities of darters in 2006 were highest in *Cabomba* and *Potamogeton*/*Hygrophila* as in previous years. Dip net data and visual observations (SCUBA) from Spring Lake confirmed high numbers of fountain darters throughout 2006 and again demonstrated that small darters are present throughout the year indicating year round reproduction. A wide range of size classes were collected in the I-35 reach in late summer and fall, which is indicative that habitat degradation to the point of affecting population dynamics was not occurring. As there is little variation in the average density of fountain darters found among vegetation types in the San Marcos River, changes in vegetation coverage do not have dramatic impacts on fountain darter abundance in the San Marcos River and population estimates are less variable between samples than in the Comal Springs/River ecosystem.

Exotic species continue to inhabit the San Marcos River, but did not appear to have any noticeable impacts during the lower discharge conditions of 2006. The sheer number and varying sizes of suckermouth catfish (*Hypostomus sp.*) that were removed by the U.S. Fish and Wildlife Service (USFWS) biologists during the reconstruction of Rio Vista Dam is cause for concern and close future observation of this exotic species. The rock bass (*Ambloplites rupestris*) and sailfin molly (*Poecilia latipinna*) were the most abundant exotic species collected in routine sampling. The giant ramshorn snail (*Marisa cornuarietis*) can have severe detrimental impacts on vegetation, but only 15 live specimens have been caught from 2004 to 2006 in drop trap sampling. The gill parasite that has been reported to infect the fountain darter in the Comal system is present in the San Marcos River but gill flaring was rarely observed on collected fountain darters in 2006.

During 2006, the San Marcos Salamander remained most abundant in Spring Lake, with densities in the lake and river comparable to previous years. As part of the Critical Period sampling, a predation survey was implemented at Spring Lake to determine if any fish were predating on fountain darters. Largemouth bass (*Micropterus salmoides*) and redbreast sunfish (*Lepomis auritus*) stomachs were excised to determine what they were eating. Many different food items were found, but there was no definitive evidence that these fish were preying on fountain darters.

The extended period of limited recharge leading up to and extending throughout 2006 caused discharge in the San Marcos River to decline to levels not experienced since 1996. When reviewing the annual discharge in the San Marcos River since the installation of the USGS gage in fall 1956, the 2006 average annual discharge of 112 cfs was the eighth lowest on record. This period of limited recharge and lower than average discharge provided an excellent opportunity to observe biological conditions and direct and indirect impacts associated with these discharge levels. A discussion of these Critical Period observations and impacts on the surface dwelling threatened and endangered species (fountain darter, San Marcos salamander, and Texas wild-rice) is presented in greater detail in the Critical Period Observations section on page 50.

In summary, increased recreational access during 2006 created the greatest effects on the threatened and endangered species in the San Marcos Springs/River ecosystem. These effects included destruction of Texas wild-rice and habitat modification for the San Marcos salamander (humans physically moving rocks below Spring Lake Dam) and fountain darter (increased foot traffic through commonly deeper areas). Direct effects of the lower discharge conditions were not evident for the San Marcos salamander at the discharge levels measured in 2006. Direct effects on the fountain darter may have been experienced with some compensatory reproduction occurring as a result of lower discharge conditions, however, this is not an absolute, nor did the response have any measurable impact on the fountain darter population in the San Marcos River in 2006. Finally, the greatest direct impact associated with the lower discharges experienced in 2006 was to Texas wild-rice with an overall reduction in coverage (~3% entire river and ~21% in vulnerable areas.)

The data collected in 2006 will be extremely valuable in initiating discussions with the Edwards Aquifer Authority, Technical Advisory Group, and state and federal agencies relative to the condition of the San Marcos Springs/River ecosystem during lower discharge conditions. It is important to remember that these data must be evaluated in context, which is a one-time event with an extended duration, preceded by an extended period of good biological conditions. Caution should be taken when speculating how these results might transfer to longer durations of low discharge, lower than observed discharge, or similar discharge preceded by poor ecological condition. The established database and comprehensive and critical period monitoring through the Authority's Variable Flow Study continues to provide an excellent measure of ecosystem condition and after 2006, some very strong insight into biological responses to low discharge conditions. However, since direct impacts measured in 2006 were relatively minor, additional field data at lower discharge conditions are necessary to fully assess conditions that might jeopardize the existence of one or several of these species in the wild. As we hope the occurrence of these extreme conditions are rare, interim efforts to evaluate response mechanisms of the threatened and endangered species to low discharge conditions either via laboratory investigation (as conducted in previous years under this program) or via field (*in situ*) experiments as proposed with the "intensive management areas" concept could provide valuable information for management decisions.

METHODS

During 2006, four full sampling efforts were conducted in the San Marcos River system. Two corresponded to the regular comprehensive sampling events (spring and fall), and two were conducted because low-flow triggers were surpassed during mid and late summer. The first trigger occurred at the end of July when total discharge in the San Marcos River declined to 100 cubic feet per second (cfs), and the second in mid-September when discharge dropped to 95 cfs. In addition, Texas wild-rice cross-section data were collected on two additional dates (6/27/06 and 8/15/06), first initiated by discharge less than 120 cfs. The 2006 sampling schedule included the following components four times in 2006 unless otherwise noted:

- Aquatic Vegetation Mapping
  - Texas wild-rice annual survey (Critical Periods only)
- Water Quality
  - Thermistor Placement
  - Thermistor Retrieval
  - Fixed Station Photography
  - Grab samples (Critical Periods only)
- Predation Survey
  - (Critical Periods only)
- Texas Wild-Rice Physical Observations
  - Cross-section data
  - Physical measurements
- Fountain Darter Sampling
  - Drop Nets
  - Dip Nets
- San Marcos Salamander Observations

Low-Flow Sampling

Two Critical Period sampling events were triggered by low-flows beginning on July 18 and September 7, 2006. The first event coincided with the annual Texas wild-rice mapping period. The minimum 24-hour mean discharges during the first and second critical period sampling events were 102 cfs on August 5th and 90 cfs on September 8th, respectively. Though the initial low-flow trigger is 100 cfs, uncorrected gage data in late July indicated that flows had reached 100 cfs and a sampling event was initiated. The 2006 conditions included the lowest reported flows in the San Marcos River since the inception of this study in 2000. In addition, Texas wild-rice cross section data and physical measurements were collected on June 27 and August 15, 2006 to better evaluate Texas wild-rice stands located in vulnerable locations in the river.

The Critical Period sampling event was designed to focus on those factors most likely to experience a shift in conditions following some type of disturbance, in this case drought. Aquatic vegetation mapping was conducted first to examine physical changes in vegetative distribution and abundance. The vegetation mapping for both events included a complete survey of Texas wild-rice in the system in order to better understand the effects of sustained lower discharge conditions on this endangered species. 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 also conducted during both Critical Period sampling events. Comprehensive water quality measurements, including grab samples, were collected at numerous sites within the San Marcos River in order to monitor changes in water chemistry as a result of decreased flows.

The methodology for each component of the Critical Period sampling events was exactly the same as used in the semi-annual (Comprehensive Monitoring Effort) sampling regime as described in this report.

High-Flow Sampling

There were no high-flow sampling events in 2006.

Springflow

All discharge data were acquired from the U.S. Geologic 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 2006). 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 system. In addition to the cumulative discharge measurements that were used to characterize this ecosystem during sampling, spot measurements of water velocity were taken during each sampling event using a Marsh McBirney model 2000 portable flowmeter.

Water Quality

The objectives of the water quality analysis are: delineating and tracking water chemistry throughout the ecosystem; monitoring controlling variables (i.e., flow, temperature) with respect to the biology of each ecosystem; monitoring any alterations in water chemistry that may be attributed to anthropogenic activities; and evaluating consistency with historical water quality information. The initial water quality component of this study was conducted during one sampling event in 2000, four sampling events in 2001, and the first three 2002 sampling events, which included one high flow event (Fall 2002). That data resulted in a baseline water quality assessment that is described in detail in the 2002 annual report (BIO-WEST 2003) and summarized in the Observations section of this document. This water quality component was reduced in 2003, but the two components necessary for maintenance of long-term baseline data, temperature loggers (thermistors) and fixed station photography, have been conducted throughout the project (2000-2006). Due to Critical Period triggers being reached in the San Marcos River during the summer of 2006, two full water quality sampling events were again conducted to characterize all previously sampled water quality components. In addition, conventional *in situ* physico-chemical parameters (water temperature, conductivity compensated to 25°C, pH, dissolved oxygen, water depth at sampling point, and observations of local conditions) were taken at the surface and near the bottom in all drop-net sampling sites using a Hydrolab Quanta.

Water quality was evaluated in the headwaters of the San Marcos River in Spring Lake, as well as in the Upper San Marcos River, north of the City of San Marcos wastewater treatment outfall. A total of nine sites were used to characterize water quality conditions in Spring Lake and the same number of sites chosen to represent water quality conditions in the San Marcos River (Figure 1). At each sample site, standard water quality parameters including temperature, conductivity compensated to 25°C, pH, and dissolved oxygen (DO) levels were collected *in situ* using a Hydrolab datasonde. These measurements were made at the surface of the water column at all water quality sampling sites. Water depth at all sampling points and observations of local conditions were noted.

In addition to the standard water quality parameters, surface water grab samples were collected at all sample sites to evaluate conventional water chemistry parameters. Sample collection and water chemistry analyses conducted during the 2000-2002 sampling events are described in the 2002 annual report (BIO-WEST 2003). Following the same protocol, water quality analysis was conducted during two Critical Period sampling events in 2006 at the same sites within Spring Lake and the San Marcos River. During the 2006 sample collection, two 500-mL surface water samples were collected at each site. One of the two samples was left unpreserved for nitrate, soluble reactive phosphorus (SRP), alkalinity and total suspended solid (TSS) analyses, and the other sample was acidified with sulfuric acid for ammonia, total nitrogen (TN), and total phosphorus (TP) analyses. Turbidity was not determined for water samples in 2006. Chemical analyses of surface water samples for the 2006 sampling events were conducted by the AnalySys, Inc. laboratory in Austin, Texas, where water chemistry parameters were determined utilizing EPA standard methods (Table 1) and are described in more detail below.

Nitrate Nitrogen and Soluble Reactive Phosphorus: Following standard EPA Method 300.1, the concentrations of anions in a 10-µL sample are determined using an ion chromatography system equipped with a conductivity detector.

Total Nitrogen: Following standard EPA Method 351.2, the sample is heated in the presence of sulfuric acid, potassium sulfate, and mercuric sulfate for two and one half hours. The resulting residue is cooled, diluted to 25mL and determined by spectroscopy.

Ammonium: Following standard EPA Method 350.2, the sample is buffered at alkaline pH with borate buffer to decrease hydrolysis of cyanates and organic nitrogen compounds, distilled into a solution of boric acid and then determined by spectroscopy.

Total Phosphorus: Following standard EPA Method 365.2, the sample is pretreated to select the phosphorus forms of interest; the forms are then converted to orthophosphate. Ammonium molybdate and antimony potassium tartrate react in an acid medium with dilute solutions of phosphorus to form an antimony-phospho-molybdate complex, which is reduced with ascorbic acid to form an intense blue-colored complex. The absorbance of the complex is measured by spectroscopy, and is proportional to the orthophosphate concentration.

Alkalinity: Following standard EPA Method 310.1, an unaltered sample is titrated to an electrometrically determined end point of pH 4.5.

Total Suspended Solids: Following standard EPA Method 160.2, a well-mixed sample is filtered through a glass fiber filter, and the residue retained on the filter is dried to a constant weight at 103-105°C.

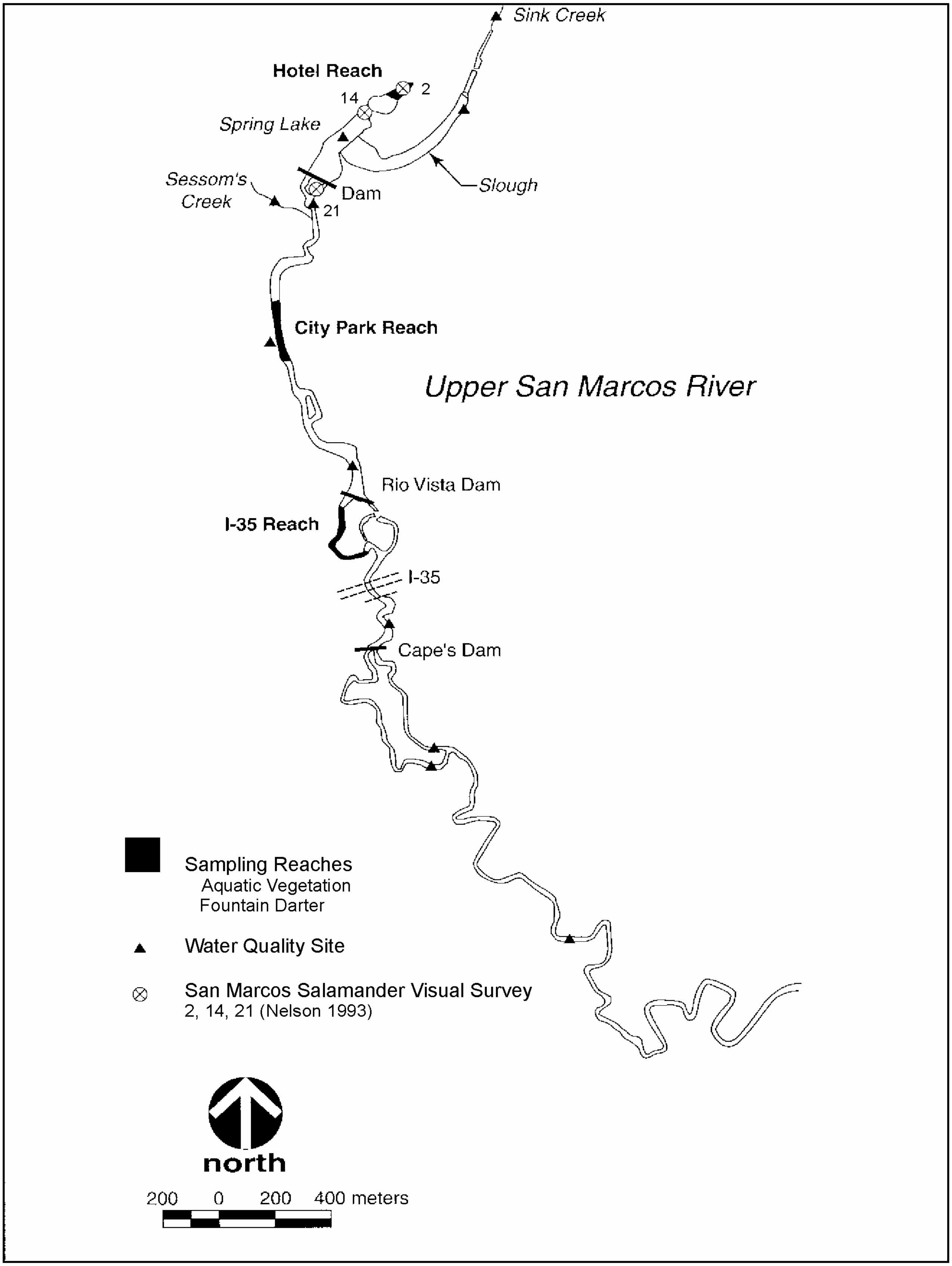

Figure 1. Upper San Marcos River water quality and biological sampling areas.

Table 1. Parameters, analytical method and technique, minimum analytical levels, and minimum detection limits for water chemistry analyses conducted on surface water grab samples from 2006.

PARAMETER	EPA METHOD	TECHNIQUE (2006)	MINIMUM ANALYTIC LEVELS (per liter)
Total Suspended Solids	160.2	Gravimetric	Appropriate
Alkalinity	310.1	Titration	10 mg
Nitrate Nitrogen	300.1	Ion Chromatography	50 µg[a]
Ammonium	350.2	Spectroscopy	10 µg
Total Nitrogen	351.2	Spectroscopy	0.5 mg
Soluble Reactive Phosphorous	300.1	Ion Chromatography	50 µg
Total Phosphorous	365.2	Spectroscopy	10 µg

[a] micrograms.

In addition to the water quality collection effort, a long term record of habitat has been maintained with fixed station photography. Fixed station photographs allowed for temporal habitat evaluations and included an upstream, a cross-stream, and a downstream picture; these were taken at each water quality site depicted on Figure 1. Thermistors were placed in select water quality stations along the San Marcos River and downloaded at regular intervals to provide continuous monitoring of water temperatures in these areas. The thermistors were placed using SCUBA gear in deeper locations within the ecosystem and set to record temperature data every 10 minutes. The thermistor locations are purposely not described in detail to minimize the potential for tampering with field equipment.

Aquatic Vegetation Mapping

The aquatic vegetation mapping effort consisted of mapping all of the vegetation in each of three reaches (Spring Lake Dam, City Park, and I-35; Appendix A). Mapping was conducted using a Trimble Pro-XH global positioning system (GPS) unit with real-time differential correction capable of submeter accuracy. The Pro XH receiver was linked to a Trimble Recon Windows CE device with TerraSync software that displays field data as it is gathered and improves efficiency and accuracy. The GPS unit was placed in a 10-meter (m) Perception Swifty kayak with the GPS 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 m in diameter were mapped by recording a single point. Vegetation stands less than 0.5 m in diameter were not mapped**.**

GPS and kayak setup used during aquatic vegetation mapping

Critical period sampling events were triggered twice in 2006, and as a result, four aquatic vegetation mapping efforts were conducted at the three reaches. In addition, all Texas wild-rice stands in the San Marcos River were mapped during the two Critical Period sampling events.

Texas Wild-Rice Physical Observations

The aerial coverage of Texas wild-rice stands in vulnerable locations were determined by GPS mapping (described above), but some smaller stands were measured using 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 Texas Parks and Wildlife Department (J. Poole, TPWD, pers. comm.) in which percent cover was estimated for the imaginary rectangle created from the maximum length and maximum width measurements.

Texas wild-rice stand in the IH-35 reach

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 and depth was measured at the shallowest point in the stand. Data on velocity, depth, and substrate composition were collected at 1-m intervals along cross-sections in the river in each area where Texas wild-rice plants are monitored. To complement all of the measurements made during each survey, several photo sets were made for each of the Comprehensive and Critical sampling events in 2006.

Fountain Darter Sampling

Drop Nets

A drop net is a type of sampling device previously used by the U.S. Fish and Wildlife Service (USFWS) to sample fountain darters and other fish species in the Comal and San Marcos Springs/River ecosystems. The design of the net is such that it encloses a known area (2 square meters [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 Comprehensive and Critical Period event from a grid overlain on the most recent map (created using GPS-collected data during the previous week) of that reach.

Typical drop net setup

Endangered fountain darter

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 (*Marisa cornuarietis*) 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.

Drop Net Data Analysis

The fisheries data collected with drop nets were analyzed in several ways. Calculations of fountain darter density in the various vegetation types during 2000-2006 provide valuable data on species/habitat relationships. These average density values were also used with aquatic vegetation mapping data on total coverage of each vegetation type by sampling effort to create estimates of the population abundance in each reach (fountain darter density within a vegetation type x total coverage of that vegetation type in the given reach). Because there were generally only two drop net samples in each vegetation type within each reach, density estimates between sampling efforts had great variation and population estimates based on those densities would be greatly influenced by this variation. Part of the variation would be due to changes in environmental conditions (discharge, temperature, etc.) that had occurred since the last sample, but part was due to natural variation between samples. Without adding samples (the total number is limited by federal permit and time constraints) it is impossible to tell how much of the variation is attributed to each source within a given sampling effort. Using the average density of fountain darters across all samples for a given vegetation type does not account for changes in density across samples (differences associated with changes in environmental conditions), but the increased sample size substantially reduces the high natural variability. This type of comparison between samples, where density values are held constant across all samples, is based entirely upon changes in vegetation composition and abundance between sampling efforts. Because these abundance estimates use the same density values across sites and seasons, and do not include estimates of fountain darters found in vegetation types that are not sampled with drop nets, the absolute numbers generated with this method have some uncertainty associated with them. Thus, the estimates are presented as relative comparisons by normalizing the data to the maximum estimate (the absolute value of all samples are converted to a percentage of the maximum value).

Dip Nets

In addition to drop net sampling for fountain darters, a dip net of approximately 40 cm x 40 cm (1.6-millimeter [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 presence of native and exotic snails was 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.

Dip Net Data Analysis

Dip net data were used to identify periods of fountain darter reproductive activity since this method was more likely to sample small fountain darters (<15 mm) along shoreline habitats. This size-class is indicative of recent reproduction since fountain darters of this size should be <60 days old (Brandt et al. 1993). The dip net data were also useful for identifying trends in edge habitat use by fountain darters since this method focused on that habitat type. In some instances, changes that were observed in fountain darter distribution and abundance in the main channel were not observed in the edge habitat. In that way, the dip net data provided a valuable second method of sampling fountain darters in the same sample reaches as drop netting, which allowed a more complete characterization of fountain darter dynamics in a sample reach. The dip net data were analyzed by visually evaluating graphs of length-frequency distribution for each sample reach.

Dip Net Techniques Evaluation

Last year an effort was made to establish a rapid method for assessing changes in fountain darter population abundance between sample efforts, especially during critical periods (high- and low-flow events). While drop netting provides quantitative data of fountain darter populations, it is somewhat labor-intensive and destructive to vegetation that is valuable habitat especially in low-flow periods. Dip netting, as it is currently used, provides information on the relative abundance of fountain darters between samples. However, sample sites are selected in high quality channel edge habitat and are not distributed among available vegetation types. In addition, this method yields one data point (a single timed survey) for a given reach. Therefore, it does not result in data that may be used to determine a statistical difference among samples, or account for possible habitat shifts and clumping under low-flow conditions. Objectives of this portion of the study were to assess the viability of an alternative dip netting method designed to gather presence/absence data at multiple sites within each reach and thereby increase the number of data points that may be collected, reduce the time necessary to collect data at all sites, and reduce habitat disturbance. Although presence/absence data provides no means of calculating fountain darter abundance, repeated sampling does provide a quick and less labor intensive way to monitor trends in the fountain darter population. This technique was thoroughly evaluated on the Comal River in 2005 (BIO-WEST 2006) and determined to be a repeatable way to examine trends in the fountain darter population between sites.

In 2006, presence/absence dip netting was conducted on the San Marcos River during the spring sampling event (April 24), the fall sampling event (November 20), and during both Critical Period sampling efforts (July 26 and September 7). During each sample, fifty sites were distributed among the four sample reaches based on total area, diversity of vegetation, previous fountain darter abundance estimates, and overall biological importance of each reach (Table 2). In most cases, sites were randomly selected from a grid overlain on the most recent vegetation map of that reach. However, occasionally, where certain vegetation types exhibited limited coverage, sites were chosen to fall within the proper vegetation type. After each dip, presence or absence of fountain darters was noted and the entire contents of the net were placed into a plastic tub with river water to avoid recapturing organisms. After all dips were completed at a site, all organisms were released and time of day was recorded.

Table2. Distribution of 50 dip net sites among three reaches and three vegetation types.

SPRING LAKE DAM REACH	CITY PARK REACH	I - 35 REACH
Hygrophila (2)	*Hygrophila* (2)	*Hygrophila* (2)
Hydrilla (6)	*Hydrilla* (10)	*Hydrilla* (6)
Potamogeton/Hygrophila (6)	*Potamogeton/Hygrophila* (10)	*Potamogeton/Hygrophila* (6)
Total (14)	**Total (22)**	**Total (14)**

San Marcos Salamander Visual Observations

Visual observations were made in areas previously described as habitat for San Marcos salamanders (Nelson 1993). 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 the 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 below Spring Lake Dam 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 suitable sized rocks at each sampling site was determined by using a square frame constructed out of steel rod to take random samples within the 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 area was determined with a grid measurement on a GPS with real-time differential correction. This was accomplished by attaching the unit to a kayak and towing it around the flagged sampling area.

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 relatively low algal coverage (compared to adjacent areas) during each survey. Much of the habitat surrounding the sampling areas is usually densely covered with algae and provides a three-dimensional habitat structure that support different densities of San Marcos salamanders. 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.

Predation Study

As a result of the lower discharges observed on the San Marcos Springs/River ecosystem in 2006, the predation component of the monitoring plan was implemented to examine potential effects of predation on endangered species during the Critical Period sampling events. Previous sampling conducted in 2001-2002 on both systems examined the effects of predation during average discharge conditions. After two years of quarterly evaluations with limited predation observed, the decision was made to only include predation sampling during Critical Period low-flow events beginning in 2003.

Previous sampling for the predation component of the monitoring plan was conducted with gill nets as well as hook-and-line methods. In order to minimize impacts to the system only hook-and-line sampling was conducted in 2006. During each Critical Period sampling event in 2006, 10 predator fish were collected from the upper reaches of the San Marcos River. These fish were placed on ice and taken to the Texas State University fish lab where the contents of their alimentary tracts were removed and examined using a dissecting microscope. All contents were identified to the lowest practical taxon and enumerated.

OBSERVATIONS

The BIO-WEST project team conducted the 2006 sampling components as shown in Table 3.

Table 3. Components of 2006 sampling events.

EVENT	DATES	EVENT	DATES
Spring Sampling		**Fall Sampling**	
Vegetation Mapping	Apr 17 - 19	Vegetation Mapping	Nov 2 - 3
Texas wild-rice Physical Observations	Apr 24, June 27	Texas wild-rice Physical Observations	Nov 14
Fountain Darter Sampling	Apr 13, 24 - 26	Fountain Darter Sampling	Nov 7, 20 - 21
San Marcos Salamander Observations	Apr 12		
Critical Period 1 Sampling		**Critical Period 2 Sampling**	
Vegetation Mapping	July 25 - 28	Vegetation Mapping	Sept 22 – 27, Oct 3
Texas wild-rice Annual Survey	July 27 – Aug 5	Texas wild-rice Survey	Sept 20 – Oct 3
Texas wild-rice Physical Observations	July 24, Aug 15	Texas wild-rice Physical Observations	Sept 8
Fountain Darter Sampling	July 18, 26 - 28	Fountain Darter Sampling	Sept 7, 19 - 21
San Marcos Salamander Observations	Aug 2	San Marcos Salamander Observations	Sept 22
Predation Survey	Aug 3	Predation Survey	Sept 22
Water Quality Sampling	July 25	Water Quality Sampling	Sept 14

Low-Flow Sampling

Critical Period low-flow sampling results and conclusions for each component will be discussed in the representative sections.

Springflow

Springflow continued to decline from 2005 and through much of 2006 (Figure 2). Discharge was considerably below average historic levels for the entire year due to below average rainfall (Figure 3). The lowest discharge occurred in the month of September (Table 4) dropping to 90 cfs, with small rain events increasing springflow in the following months. Discharge in the San Marcos River has not been below 90 cfs since December 1996. The highest mean daily flow (145 cfs) was reached in the first days of 2006, and was only slightly higher than the minimum mean daily flow of 2005 (136 cfs). Discharge in 2006 also failed to top 200 cfs for the first time since this study was implemented in 2000. As a result, each sampling event (including both Critical Period events) was carried out at lower discharges than any sampling period since the inception of this study (Table 5). A more detailed comparison of 2006 discharge conditions to historical occurrence is provided in the Critical Periods Observations section (Page 50).

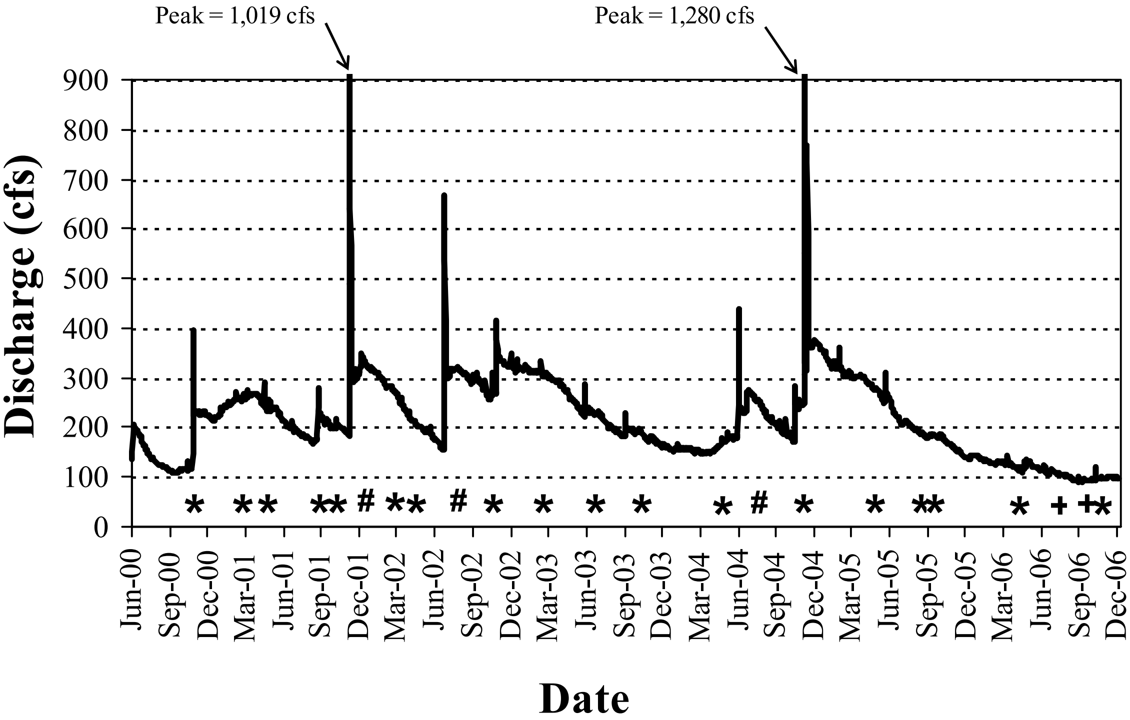

Figure 2. Mean daily discharge in the San Marcos River during the study period; approximate dates for quarterly (*), high-flow (#), and low-flow sampling efforts (+) are indicated.

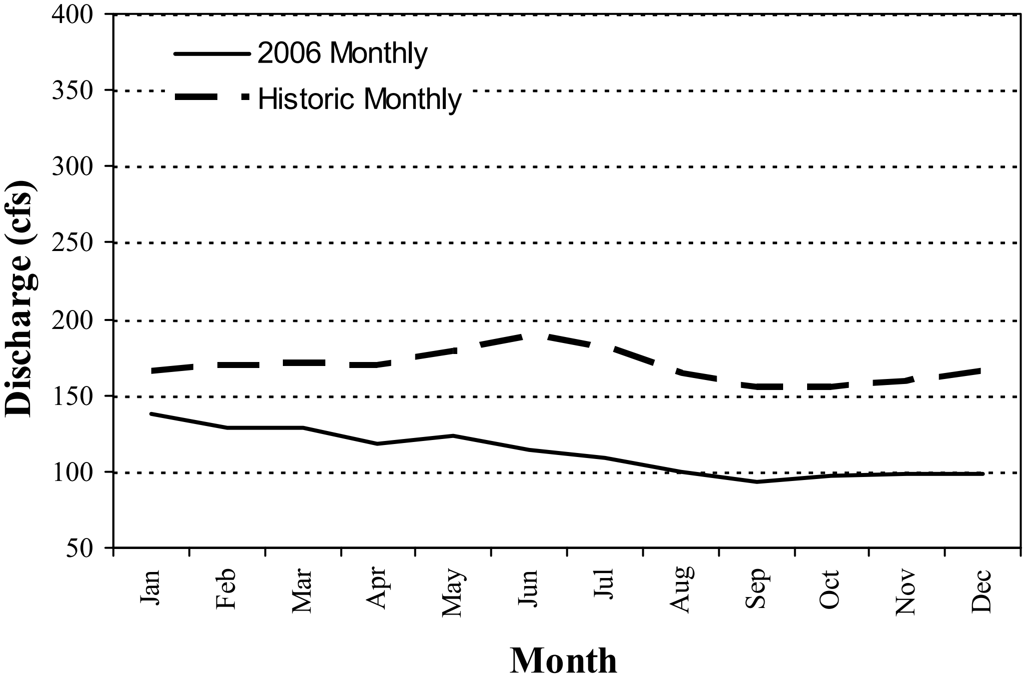

Figure 3. Mean monthly discharge in the San Marcos River during the 1956-2006 period of record.

Table 4. Lowest discharge (cfs) during each year of the study and the date on which it occurred.

Year	Discharge	Date
2000	108	Sept. 18
2001	167	Aug. 19
2002	157	Jun. 28
2003	156	Dec. 29
2004	146	Mar. 8
2005	136	Dec. 17
2006	90	Sept. 8

Table 5. Mean daily discharge (cfs) of the San Marcos River during Comprehensive sampling events.

		Sampling Event	
Year	Spring	Summer	Fall
2000	-	-	120.5
2001	237.6	178.8	199.8
2002	200.0	318.3[a]	272.5
2003	283.2	198.9	176.6
2004	157.0	251.4	180.3
2005	288.9	196.5	181.0
2006	115.7	103.6[b]	98.2

[a] **Occurred during a high-flow event (July 22 – August 5, 2002).**

[b] **Occurred during a low-flow event (July 18 – August 15, 2006).**

WATER QUALITY

Spring Lake

The original sampling sites (2000-2002) for Spring Lake were chosen based on historical locations that have been used during basic limnological sampling conducted at Texas State University. Those same nine water quality sampling sites were sampled during both Critical Period sampling events in 2006. The site locations 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 mixing of the slough and spring arms,
Site G was located behind the softball fields and under a powerline in the slough,
Site H was located downstream of the road crossing, and
Site S was in Sink Creek.

The Spring Lake water quality sampling sites can be grouped into Spring Arm, Slough Arm, and Sink Creek sites. Spring Arm sites include A through E. Site A is closest to the headwaters and E is closest to the dam. Slough Arm sites include F through H. Site F is closest to the dam while H is closest to the Sink Creek. Site S is located in Sink Creek, which often goes dry during the late summer months.

Information on standard water quality parameter point measurements for each water quality site in Spring Lake is presented in Table 6. Average values from seven sampling events during 2000-2002 (Average 2000-2002; this mean does not include the high-flow event), values from the 2002 high-flow event (High Flow), and values from the two low-flow Critical Period events in 2006 (Critical Period 1 and Critical Period 2) are displayed to compare between varying discharge conditions. Similarly, information on water chemistry measurements for each site in Spring Lake is presented in Table 7.

Temperatures within the Spring Arm (Sites A through E) are very similar, while temperatures at the Slough Arm sites generally have larger mean and maximum values and lower minimum values than the Spring Arm sites (Appendix B). Temperatures measured during the two 2006 low-flow Critical Period sampling events were similar to the mean of temperatures measured during 2000-2002, with the exception of Sites G, H, and S in the Slough Arm and Sink Creek itself (Table 6). At these sites, higher maximum temperatures were recorded during the low-flow Critical Period sampling events than during previous sampling events (Appendix B).

Conductivity did not vary among sites within the lake for the period of the study. A conductivity-to-TDS conversion of 0.65 was used so that a comparison could be made with the TDS water quality standard. During the August 2002 sampling event TDS values at each of the Slough Arm sites approached or met the water quality standard value of 400 milligrams per liter (mg/l), which equals 615 micromhos per centimeter (umhos/cm). During the first Critical Period sampling event, conductivity values were lower than the average during 2000-2002 at all sites, while conductivity values during Critical Period 2 were similar to the average (Table 6).

Table 6. Standard water quality parameters of surface water at sampling sites in Spring Lake.

Sampling Period	Site								
	A	B	C	D	E	F	G	H	S
Temperature (°C)									
Mean*	21.73	21.97	22.18	22.54	22.56	23.83	22.85	22.49	20.61
High Flow[b]	21.56	21.63	22.00	22.28	22.44	25.49	26.16	24.79	23.59
Low Flow 1[c]	21.70	23.17	22.73	23.14	23.57	22.78	28.54	24.77	24.83
Low Flow 2[d]	22.02	22.27	22.99	22.53	22.05	22.43	25.48	23.01	23.21
Conductivity (µS/cm)[a]									
Mean*	563	558	560	561	560	545	541	562	642
High Flow[b]	577	574	562	564	568	600	607	615	610
Low Flow 1[c]	517	530	526	545	536	537	486	502	509
Low Flow 2[d]	566	572	567	581	575	571	545	544	559
pH									
Mean*	7.11	7.14	7.13	7.17	7.24	7.35	7.49	7.61	7.51
High Flow[b]	6.80	6.83	6.81	6.83	6.87	7.13	7.20	7.11	7.17
Low Flow 1[c]	7.13	7.18	7.22	7.13	7.18	7.16	7.26	7.2	7.19
Low Flow 2[d]	7.11	7.11	7.20	7.09	7.20	7.15	7.31	7.13	7.13
DO (mg/l)									
Mean*	5.54	6.23	6.45	8.45	8.60	9.58	8.07	10.07	6.64
High Flow[b]	4.81	4.74	5.66	6.39	6.68	6.24	6.38	4.60	5.98
Low Flow 1[c]	4.51	6.06	7.90	7.05	6.94	7.51	1.90	2.32	2.18
Low Flow 2[d]	6.24	5.90	6.60	5.94	6.04	5.68	5.40	0.83	2.86

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high flow sampling event in Fall 2002.

[a] microSiemens per centimeter; equivalent to µmohs/cm

[b] Critical Period event conducted on August 5, 2002

[c] Critical Period event conducted on July 25, 2006

[d] Critical Period event conducted on September 14, 2006

As during previous sampling events, dissolved oxygen (DO) concentrations measured during the 2006 Critical Period sampling events at sites A and B (nearest the springs) and at the Slough Arm sites did not always meet the Texas Commission on Environmental Quality (TCEQ) “high” water quality standard of 6.0 mg/l for DO for the Upper San Marcos River Segment No. 1814 (Appendix B). After prolonged lower discharge conditions, DO levels were lower during Critical Period 2 at six of the nine sites relative to those measured during Critical Period 1. Lower DO concentrations at the headwaters may occur due to aquifer water naturally having lower DO concentrations. Low DO concentrations in the Slough Arm occurred due to the higher water temperatures in the summer and decomposition of the abundant plant material, which requires oxygen.

Total suspended solids (TSS) values were low at all sites in Spring Lake (Table 7). Unfortunately, the TSS analysis conducted during 2006 was less sensitive than during the initial characterization, but several comparisons can still be made between the sampling events. The highest values were recorded in the Slough Arm during the 2006 Critical Period sampling events (Table 7). As during the

2000-2002 sampling events, Sink Creek had the highest TSS values, which was probably due to the extremely high plant and algae growth that occurs in this creek. Alkalinity was fairly constant throughout Spring Lake for the duration of the study (Table 7, Appendix B).

Nitrate values exceeded the TCEQ water quality standards screening level of 1.0 mg/l in most cases, both during the 2000-2002 and the 2006 Critical Period events (Appendix B). However, nitrate concentrations were lower in Spring Lake overall during Critical Period sampling events in 2006. Ammonium values were well below the TCEQ screening level of 1.0 mg/l during all sampling events (Appendix B). Similar to the 2000-2002 sampling events, TN concentrations in Spring Lake during the 2006 Critical Period sampling events consisted of a high percentage of nitrate and a low percentage of ammonium. However, TN concentrations were higher than average during these two events (Table 7). As discussed below for the San Marcos River, the high nitrate values found in the San Marcos River and Spring Lake were not the result of anthropogenic inputs to the immediate surface waters. Spring flow is the most likely source of high nitrate values found at all sites in the San Marcos River and Spring Lake. The median concentration of nitrate in the Edward's Aquifer ranges from 1.4 to 1.7 mg/l (Bush et al. 1998). Nitrate values at the Spring Arm sites are fairly constant among these sites and throughout the year (Appendix B). Whereas, nitrate concentrations at the Slough Arm sites and Sink Creek fluctuate throughout the year, they are actually much lower than the Spring Arm sites for most sampling events (Table 7). These lower concentrations are due to uptake of nitrate by the abundant plants and algae in the Slough Arm and Sink Creek.

Soluble Reactive Phosphorus concentrations (SRP) and Total Phosphorous (TP) concentrations in Spring Lake during all sampling periods were well below the TCEQ's screening values of 0.1 and 0.2 mg/l, respectively. The SRP and TP values fluctuated from season to season and site to site throughout the 2000-2002 sampling period. During this period, the Slough Arm sites and Sink Creek generally had higher concentrations of SRP than the Spring Arm sites (Appendix B). The higher SRP concentrations probably occurred due to recycling of SRP (as plant material decayed) and inputs of phosphorus from the immediate watershed. Due to the use of different analytical methods for these two analytes in 2006, the detection limit was not as sensitive, but SRP and TP levels during the two low-flow Critical Periods were determined to be less than 0.01 mg/l (Table 7).

Table 7. Water chemistry parameters of surface water at sampling sites in Spring Lake.

Sampling Period	Site								
	A	B	C	D	E	F	G	H	S
Alkalinity (mEq/l)									
Mean*	4.64	4.65	4.88	4.89	4.83	4.97	4.80	4.93	5.56
High Flow[b]	5.26	5.22	5.22	5.14	5.14	5.30	5.14	5.34	5.42
Low Flow 1[c]	5.20	5.00	5.20	5.20	5.20	5.20	3.80	4.40	4.40
Low Flow 2[d]	5.20	5.20	5.20	5.40	5.40	5.20	4.60	4.80	4.80
TSS (mg/l)									
Mean*	0.002	0.003	0.002	0.005	0.017	0.003	0.008	0.085	0.204
High Flow[b]	0.427	0.343	0.2	0.343	0.014	0.068	0.324	0.125	0.173
Low Flow 1[c]	1	2	1	1	1	<1	7	2	6
Low Flow 2[d]	<1	<1	1	3	<1	<1	7	<1	11
Nitrate Nitrogen (mg/l)									
Mean*	1.261	1.327	1.512	1.621	1.717	0.890	0.680	0.559	0.195
High Flow[b]	2.621	1.608	1.813	1.659	1.532	1.431	1.174	1.251	1.404
Low Flow 1[c]	1.630	1.310	1.380	1.610	1.420	1.180	<0.05	<0.05	0.167
Low Flow 2[d]	1.010	1.100	0.936	1.110	1.020	1.060	0.332	<0.05	<0.05
Ammonium (mg/l)									
Mean*	0.040	0.036	0.018	0.048	0.023	0.051	0.049	0.044	0.043
High Flow[b]	0.032	0.017	0.039	0.035	0.043	0.035	0.048	0.046	0.043
Low Flow 1[c]	0.042	0.056	0.066	0.084	0.072	0.075	0.079	0.082	0.075
Low Flow 2[d]	0.036	0.046	0.054	0.047	0.081	0.046	0.091	0.118	0.062
Total Nitrogen (mg/l)									
Mean*	1.497	1.634	1.889	2.055	2.002	1.126	0.910	0.885	0.938
High Flow[b]	2.458	2.218	2.325	2.109	1.952	1.813	1.598	1.692	1.894
Low Flow 1[c]	3.990	2.430	4.250	2.520	2.340	2.140	1.050	1.010	2.730
Low Flow 2[d]	3.070	2.400	3.920	2.040	1.890	2.080	1.380	1.120	1.990
Soluble Reactive Phosphorus (µg/l)									
Mean*	15.65	18.22	13.93	16.14	14.58	18.49	24.29	19.15	38.77
High Flow[b]	9.88	13.11	8.00	6.81	8.68	8.51	10.39	8.34	19.07
Low Flow 1[c]	<10	<10	<10	<10	<10	<10	<10	<10	<10
Low Flow 2[d]	<10	<10	<10	<10	<10	<10	<10	<10	<10
Total Phosphorus (µg/l)									
Mean*	21.05	48.10	17.01	27.17	37.11	22.67	47.85	24.10	72.65
High Flow[b]	4.72	21.97	18.17	27.83	43.35	27.83	64.72	27.14	58.52
Low Flow 1[c]	<10	<10	<10	<10	<10	<10	<10	<10	<10
Low Flow 2[d]	<10	<10	<10	<10	<10	<10	<10	<10	<10

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high flow sampling event in Fall 2002.

[b] Critical Period event conducted on August 5, 2002

[c] Critical Period event conducted on July 25, 2006

[d] Critical Period event conducted on September 14, 2006

San Marcos River

The nine water quality sampling sites in the San Marcos River were the same in 2006 as the sites sampled during the initial water quality assessment in 2000-2002. The sites were as follows:

Site 1 was located directly downstream of the chute at Joe's Crab Shack.
Site 2 was located just downstream of Spring Lake Dam.
Site 3 was located in Sessom's Creek at the Texas State University Aquatic Biology building, before the confluence with the San Marcos River.
Site 4 was located within the City Park/Lions Club Reach.
Site 5 was located in the far channel at Rio Vista Park.
Site 6 was located just upstream of the I-35 highway crossing.
Site 7 was located upstream of the falls within the artificial channel near the state fish hatchery.
Site 8 was located upstream of state fish hatchery outflow.
Site 9 was located directly behind the San Marcos animal shelter.

Information on standard water quality parameter point measurements for each water quality site in the San Marcos River is presented in Table 8. Average values from seven sampling events during 2000-2002 (Average 2000-2002; this mean does not include the high-flow event), values from the 2002 high-flow event (High Flow), and values from the two low-flow Critical Period sampling events in 2006 (Critical Period 1 and Critical Period 2) are displayed to compare between varying discharge conditions. Similarly, information on water chemistry measurements for each site in the San Marcos River is presented in Table 9.

The lowest water temperatures occurred during winter at Sessom's Creek and the sites furthest downstream of the springs (Thompson's Island Artificial Canal and Animal Shelter Sites); winter minimum temperatures occasionally dropped as low as 10° C at the downstream sites (Appendix B). These sites are least influenced by the constant temperatures of spring water. Point temperature measurements made during the Critical Periods sampling events in 2006 were similar to average point temperatures (Table 8). Significant water temperature decreases in the San Marcos River coincided with lower air temperatures. Springflow kept temperatures fairly constant in the upper reaches of the river system, compared with conditions that would occur in a stream without significant spring flow.

The continuously sampled temperature data provide a more valuable data set than the temperature data collected with the water quality grab samples. The water quality grab data does not capture the full range of water temperatures, daily fluctuation, or extreme values that are present in the continuous thermistor data. Water quality grab sample temperatures recorded for the comprehensive and critical period sampling events do not exceed the TCEQ water quality standards value (Appendix B).

Table 8. Standard water quality parameters of surface water at sampling sites in the San Marcos River during normal conditions (Mean), a high-flow event in Fall 2002 (High Flow), and two Critical Period events in 2006 (Low Flow 1 and 2).

Sampling Period	Site								
	1	2	3	4	5	6	7	8	9
Temperature (°C)									
Mean*	22.53	22.55	22.75	22.67	22.64	22.47	22.00	22.22	22.08
High Flow[b]	22.78	22.76	22.90	22.83	23.17	23.12	22.71	22.97	22.65
Low Flow 1[c]	22.74	23.20	23.62	22.78	22.95	22.68	22.85	22.81	23.10
Low Flow 2[d]	22.21	22.02	22.74	21.92	21.79	21.68	21.80	21.74	22.02
Conductivity (µS/cm)[a]									
Mean*	571	570	593	570	570	570	570	570	568
High Flow[b]	580	584	598	583	582	582	583	582	581
Low Flow 1[c]	538	535	563	544	540	543	540	542	531
Low Flow 2[d]	578	575	598	575	577	576	576	576	566
pH									
Mean*	7.28	7.36	7.42	7.43	7.49	7.62	7.62	7.71	7.62
High Flow[b]	7.01	7.03	7.07	7.03	7.14	7.26	7.27	7.37	7.38
Low Flow 1[c]	7.34	7.39	7.37	7.40	7.50	7.56	7.52	7.66	7.79
Low Flow 2[d]	7.37	7.37	7.29	7.38	7.41	7.56	7.53	7.68	7.73
DO (mg/l)									
Mean*	8.59	8.54	7.48	9.28	10.30	9.46	8.66	9.04	8.99
High Flow[b]	10.61	9.10	8.17	10.91	11.50	10.48	10.00	9.83	9.46
Low Flow 1[c]	8.36	7.94	6.18	8.29	8.81	7.63	6.69	7.58	7.45
Low Flow 2[d]	7.77	7.75	5.76	9.68	6.64	8.00	6.53	7.65	8.07

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high flow sampling event in Fall 2002.

[a] microSiemens per centimeter; equivalent to µmohs/cm

[b] Critical Period event conducted on August 5, 2002

[c] Critical Period event conducted on July 25, 2006

[d] Critical Period event conducted on September 14, 2006

The thermistor data for the City Park and I-35 reaches are presented in Figure 4, additional graphs can be found in Appendix B. The continuously sampled water temperature data provide a significant amount of information regarding fluctuations due to atmospheric conditions and springflow influences in the San Marcos River. In many places the temperature remained nearly constant due to nearby spring inputs, while other locations (typically further away from spring influences) are more substantially affected by atmospheric conditions. At times, it appears that precipitation can have acute impacts (typically very cold rainfall) in some locations, but these are generally short-lived and the overall relationship at these sites is more directly associated with air temperature (also, air temperatures strongly influence precipitation temperatures).

Temperatures at two sites exceeded the TCEQ water quality standards value (26.67 ˚C) in 2006. This occurred at Sessom's Creek, which is a flashy stream draining an urban area where fountain darters are not found. This also occurred in the artificial channel at Thompson's Island, where flow is substantially less than the main river channel, and temperatures are more responsive to ambient air temperatures. The lowest temperatures were at the Animal Shelter site in winter, and were likely the response of rain events briefly dropping the temperature of the water. This site is well downstream of any spring inputs and is more susceptible to changes in the surrounding environment.

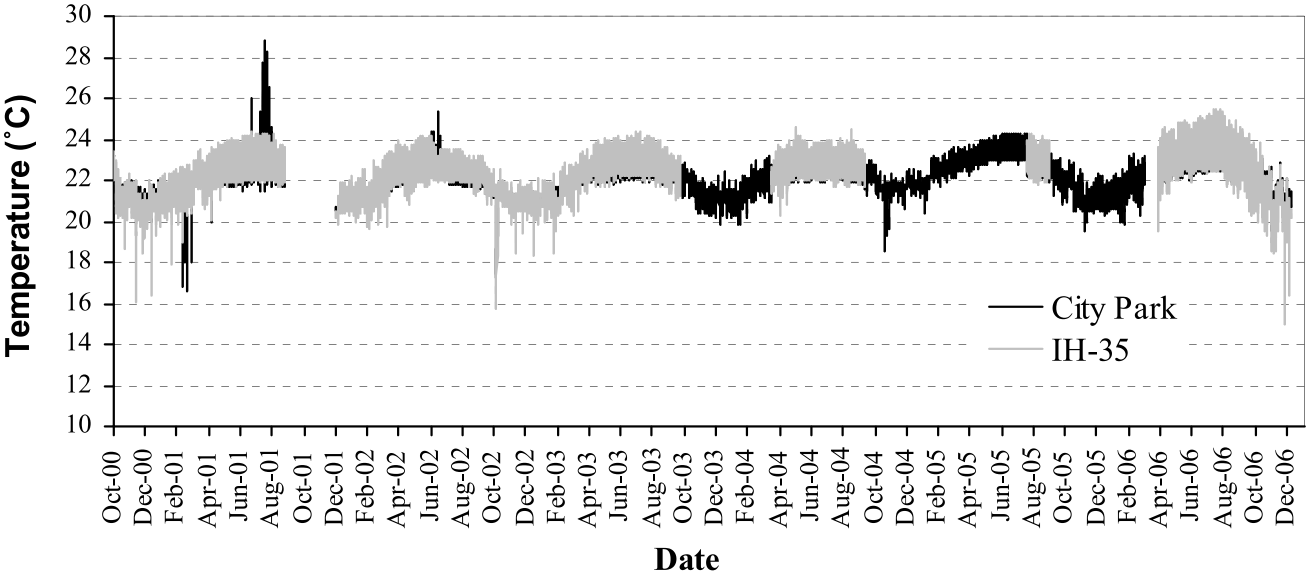

Figure 4. Thermistor data from the City Park and I-35 Reaches.

Generally, an upstream-to-downstream pattern in water quality values other than temperature and pH has not been observed during the study. Values remain fairly constant throughout the system or they fluctuate minimally among sites. There does not appear to be much influence on water quality from surface water inflow to the river. The spring water quality conditions generally prevail within the study reaches of the San Marcos River system.

Conductivity did not vary among sites within the river system during the period of the study (Appendix B). A conductivity-to-TDS conversion of 0.65 was used so that a comparison could be made with the TDS standards for each system. The TDS values at each San Marcos River site during the August 2001 sampling event and two other sampling events on Sessom's Creek exceeded the TCEQ water quality standard value of 400 mg/l. The high TDS values recorded in August 2001 were thought to have been due to relatively low-flow conditions in the river at the time. However, average and below-average conductivity values measured during the two 2006 Critical Period sampling events do not support this assumption (Table 8). No previous mention of exceedences has been indicated by the TCEQ, which suggests that this water quality parameter is not a concern.

Dissolved oxygen concentrations met the TCEQ “high” water quality standard of 6.0 mg/l for DO in all samples from the San Marcos River throughout the period of the study, with one exception at Site 3 (Sessom’s Creek) during Critical Period 2 (Appendix B). Dissolved oxygen values were, on average, higher in the San Marcos River than in Spring Lake. In general, there was not an upstream-downstream gradient in DO, but concentrations were lower during the Critical Period sampling events than the high-flow Critical Period in 2002 or the average quarterly sampling periods in 2000-2002 (Figure 5).

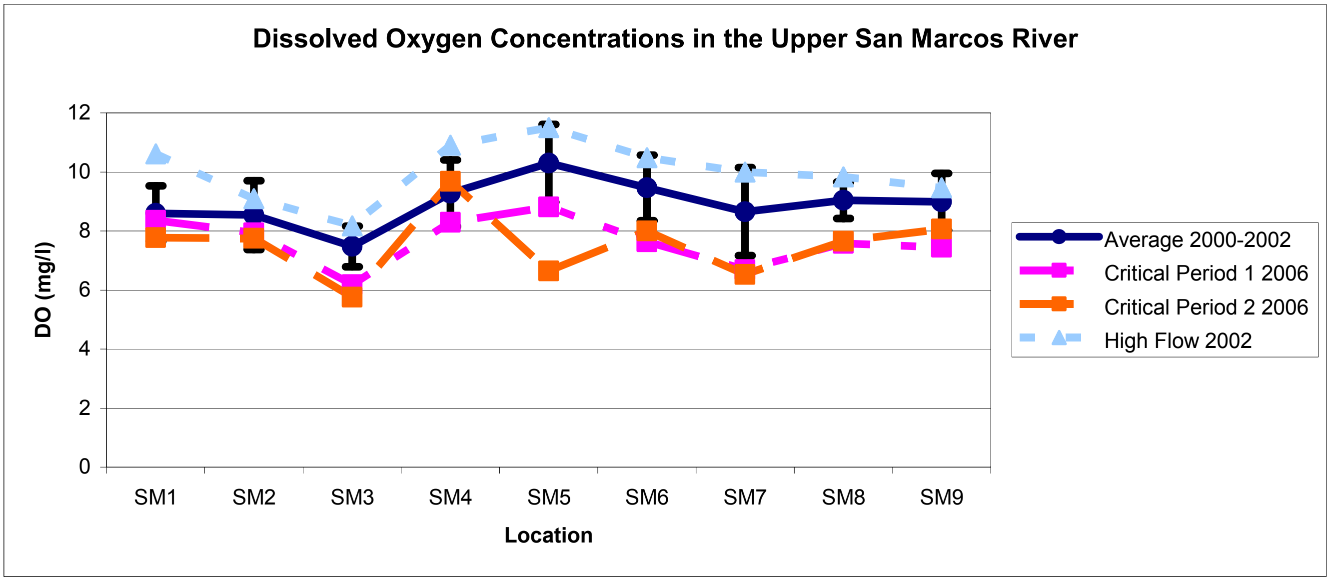

Figure 5. Dissolved oxygen concentrations across nine sites in the San Marcos River, presented as the mean (± standard deviation) of seven sampling events during 2000-2002 (not including the high-flow sampling event in 2002) and actual data from two low-flow Critical Period sampling events in 2006 (Critical Period 1 and 2) and the high-flow sampling event in 2002 (High Flow 2002).

As previously mentioned, the TSS analysis conducted during 2006 was less sensitive than during the initial characterization, therefore one should be cautious when making comparisons to previous years. Alkalinity was constant throughout the river during all sampling events, with values similar to those in Spring Lake (Appendix B).

Nitrate values exceeded the TCEQ water quality standard screening level of 1.0 mg/l in most cases throughout the study, whereas ammonium values were well below the screening level of 1.0 mg/l at all sites throughout the study (Appendix B). The TN values for the San Marcos River are influenced by high nitrate concentrations. These high values are likely not the result of anthropogenic inputs to the immediate surface waters, but rather springflow. The median concentration of nitrate in the Edward’s Aquifer ranges from 1.4 to 1.7 mg/l (Bush et al. 1998). Nitrate values in the San Marcos River are fairly constant throughout the river and throughout the year (Appendix B), except during the lower discharge conditions in 2006, when nitrate concentrations decreased between the first and second Critical Period sampling events (Table 9). In contrast, ammonium concentrations vary throughout the sampling period and among sites and the values are very low (Appendix B).

The SRP and TP concentrations on the San Marcos River were well below the TCEQ's screening values of 0.1 and 0.2 mg/l, respectively (Appendix B). Due to the use of different analytical methods for these two analytes in 2006, the detection limit was not as sensitive. However, these analyses did determine that during the Critical Period sampling events in 2006, all but two sampling sites had SRP and TP levels less than 0.01 mg/l (Table 9). The two downstream-most sites (Thompson's Island Natural Canal and Animal Shelter) had slightly elevated levels of SRP and TP. These higher SRP values in the river could be caused by point or non-point source loads within the immediate watershed. The only permitted discharge upstream of the last sampling site is the TPWD fish hatchery. The City of San Marcos wastewater treatment plant is located downstream of the last sampling site. Non-point source discharges include the San Marcos urban area as well as agricultural areas. Although values are higher at these sites, it should be stressed that these SRP values are well below TCEQ's screening levels for surface waters.

Table 9. Water chemistry parameters of surface water at sampling sites in the San Marcos River.

Sampling Period	Site								
	1	2	3	4	5	6	7	8	9
Alkalinity (mEq/l)									
Mean*	4.77	4.65	4.63	4.78	4.71	4.75	4.64	4.72	4.52
High Flow	5.18	5.18	5.18	5.18	5.24	5.26	5.18	5.22	5.18
Low Flow 1	5.40	5.20	5.40	5.40	5.20	5.40	5.40	5.20	5.20
Low Flow 2	5.40	5.20	5.40	5.40	5.20	5.40	5.20	5.40	5.20
TSS (mg/l)									
Mean*	0.013	0.011	0.004	0.016	0.011	0.016	0.017	0.024	0.023
High Flow	0.008	0.008	0.004	0.006	0.007	0.006	0.022	0.006	0.007
Low Flow 1	2	<1	3	3	1	<1	3	4	7
Low Flow 2	3	2	2	5	3	5	5	10	9
Nitrate Nitrogen (mg/l)									
Mean*	1.284	1.439	1.631	1.453	1.531	1.421	1.331	1.318	1.278
High Flow	1.661	1.169	1.598	1.116	1.218	1.218	1.577	1.207	1.217
Low Flow 1	1.72	1.460	1.740	1.650	1.600	1.610	1.560	1.560	1.510
Low Flow 2	1.19	1.030	0.995	1.110	1.060	1.090	1.040	1.060	0.990
Ammonium (mg/l)									
Mean*	0.032	0.066	0.041	0.080	0.088	0.069	0.026	0.048	0.041
High Flow	0.03	0.043	0.023	0.018	0.030	0.028	0.068	0.036	0.071
Low Flow 1	0.039	0.085	0.076	0.070	0.052	0.061	0.062	0.055	0.087
Low Flow 2	0.036	0.049	0.070	0.058	0.048	0.054	0.077	0.056	0.060
Total Nitrogen (mg/l)									
Mean*	1.477	1.798	1.766	1.664	1.983	1.560	1.550	1.528	1.506
High Flow	2.019	1.396	1.719	1.299	1.410	1.658	1.948	1.616	1.542
Low Flow 1	2.7	3.130	2.760	2.650	3.190	2.620	3.710	2.630	3.620
Low Flow 2	2.09	2.930	2.100	2.110	2.290	2.170	3.080	2.160	3.650
Soluble Reactive Phosphorus (µg/l)									
Mean*	7.600	8.041	6.595	10.371	5.411	6.665	6.736	5.735	11.264
High Flow	6.269	5.573	10.101	7.837	8.535	8.011	49.459	8.882	6.269
Low Flow 1	<10	<10	<10	<10	<10	<10	<10	<50	<50
Low Flow 2	<10	<10	<10	<10	<10	<10	<10	<10	<10
Total Phosphorus (µg/l)									
Mean*	13.750	12.424	16.259	21.003	12.277	14.450	11.015	12.372	18.335
High Flow	10.112	9.562	15.273	14.903	16.173	14.305	52.493	14.362	15.989
Low Flow 1	<10	<10	<10	<10	<10	<10	<10	25.600	46.200
Low Flow 2	<10	<10	<10	<10	<10	<10	<10	<10	<10

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high flow sampling event in Fall 2002.

[b] Critical Period event conducted on August 5, 2002

[c] Critical Period event conducted on July 25, 2006

[d] Critical Period event conducted on September 14, 2006

Aquatic Vegetation Mapping

Maps of the aquatic vegetation observed during each sample effort can be found in the Appendix A map pockets. The maps are organized by individual reach with successive sampling trips in order by date of occurrence. It is difficult to make sweeping generalizations about seasonal and other trip-to-trip characteristics since most changes occur in such fine detail; however, some of the more interesting observations are described below.

Spring Lake Dam Reach

Significant changes in vegetation occurred in the Spring Lake Dam Reach in 2006 mostly due to recreational impacts in late summer. Total vegetation area increased from fall 2005 to spring 2006 (1,224.4 and 1,360.2 m^2, respectively) with much of the vegetation growth in the middle and upper part of the reach directly below the dam. Large patches of thick vegetation mats covered areas previously occupied by a mix of *Potamogeton* and *Hydrilla*. With lower discharge conditions, *Colocasia* plants along the eastern side of the reach (river left) grew outward from the bank covering up areas previously occupied by various vegetation types. Smaller patches of *Hygrophila* were able to gain a foothold at the mouth of Sessom's Creek because there were few significant rain events to scour them out of the mouth of this stream.

Sessom's Creek is a flashy stream that drains an urban area that is part of the Texas State University Campus. As a result, large rain events can carry copious amounts of sediment into the San Marcos River within the Spring Lake Dam Reach. Over several years this has resulted in a large area of trapped sediment that has formed an area known as BobDog Island. The location of this "island" is directly downstream of the mouth of Sessom's Creek and has diverted flow in a manner that it will flow upstream before joining the flow of the San Marcos River. The "island" is characterized by sand and gravelly substrates with several species of plants with a firm foothold in the substrate. A new boundary was created on the aquatic vegetation maps (Spring Lake Dam Reach, Critical Period 1, Appendix A) to depict this area. The development of this island has decreased the amount of wetted area available for aquatic vegetation in this reach.

The first Critical Period mapping event for the Spring Lake Dam Reach occurred on July 28th. Total vegetation area decreased from April to July (1,360.2 and 1,250.1 m^2, respectively) with most of this decrease occurring along the edge of BobDog Island. *Potamogeton* increased nearly five times in area because the large vegetation mats covering these areas had been removed and *Hydrilla* that is normally associated with these *Potamogeton* patches was not present. A small area in the middle of the reach that was previously bare substrate is now occupied by a *Potamogeton*/*Hydrilla* mix. In addition, patches of *Hydrocotyle* and *Hydrilla* near the dam were absent. During the first Critical Period sampling event, the lower than average discharge conditions appeared to have little effect on the vegetation in the Spring Lake Dam Reach.

An extended period of limited recharge resulting in a continued decrease in discharge led to the second Critical Period mapping event, which occurred on September 27th. Total vegetation area decreased by 200 m^2 between the two Critical Period events. Much of this can be attributed to the significant loss of Texas wild-rice which is discussed below. *Potamogeton* continued to increase in area with a new patch appearing close to the western spillway of Spring Lake Dam. Continued lower than average discharge led to a large increase in the amount of *Colocasia* along the banks of the reach. This encroachment of *Colocasia* was especially apparent along the river left bank.

The amount of vegetation changed little from September to November with an increase of total vegetation area of only 10.9 m^2. Some areas that were dominated by *Potamogeton* were infiltrated by small areas of *Hydrilla*. In addition, the *Hygrophila* patches present all year at the mouth of Sessom's Creek were conspicuously absent during the fall mapping event. There was a rain event on October 18th that may have led to these plants being scoured.

Texas wild-rice underwent significant changes in the Spring Lake Dam reach in 2006. From fall 2005 to spring 2006 wild-rice increased substantially (257.1 to 321.0 m^2) resulting in a 25% increase (Table 10). Conditions present over winter resulted in smaller individual plants growing together and forming larger plants. By the Critical Period 1 sampling event, discharge in the San Marcos River had declined to near 100 cfs, but this appeared to have little effect on Texas wild-rice plants, resulting in only a slight decrease in total area (Table 10). In early September, the BIO-WEST team discovered that large areas of Texas wild-rice were missing from the Spring Lake Dam Reach especially in the east arm of the river. Upon closer examination it appeared that the leaves of the plants had been ripped out, but the root wads of many of the plants were still in place. This mechanical destruction of Texas wild-rice plants resulted in numerous small plants (often with only 1 or 2 leaves) where larger plants had been. While much of this was relegated to the eastern arm of the reach there was also significant damage to plants downstream resulting in fragmentation of larger plants. Again, in these downstream areas it appeared that the leaves had been ripped out, but many of the root wads were still present. At this time it was also discovered that severe channelization of the river in the eastern arm had resulted from humans placing large rocks to form dams and chutes immediately upstream of several old wooden pillars (Figures 6 and 7). This area was just upstream of many of the large Texas wild-rice plants that had been ripped out.

Table 10. Changes in total area of Texas wild-rice (*Zizania texana*) in the Spring Lake Dam Reach for 2005 – 2006.

Sampling Period	Total Area (m^2)	Percent Change
August 2005	281.3	-
September 2005	257.1	- 8.6
April 2006	321.0	+ 24.9
August 2006*	320.0	- 0.8
September 2006*	85.9	- 73.2
November 2006	107.2	+ 24.8

*Critical Period events.

As a result of many Texas wild-rice plants being removed from the reach, Texas wild-rice decreased over 73% from July to September in this reach (Table 10). Therefore, only 85.9m^2 of this plant remained in the Spring Lake Dam Reach by the end of September. Texas wild-rice plants that were too small to map accurately were denoted with a single point on the map (Appendix A). By November 2006 some of the individual rice plants began to grow together, but this area was still severely denuded from the human disturbance in September. Total area of wild-rice increased by nearly 25% to 107.2 m^2 (Table 10) although total San Marcos discharge remained below 95cfs. This area will continue to be closely monitored to determine how quickly the Texas wild-rice recovers after a major disturbance.

Figure 6. Channelization from human disturbance in the eastern arm of the Spring Lake Dam Reach in the San Marcos River (photo taken October 13th, 2006).

Figure 7. A dam resulting from human disturbance in the eastern arm of the Spring Lake Dam Reach of the San Marcos River (photo taken October 13th, 2006).

City Park Reach

As discharge continued to decline over winter from 2005 to 2006, total vegetation area in the City Park Reach increased by 303.0 m^2. This increase may largely be a result of decreased recreational use during this colder time of year. A decrease in the number of people in the water results in plants being able to colonize previously bare areas. In addition, *Hydrilla* plants began to colonize the area where a large tree was removed in 2005 located along the river right side of the reach near the outfall of a culvert. While pure stands of *Hydrilla* decreased between fall and spring, this species was able to mix into areas that were previously dominated by a *Potamogeton*/*Hygrophila* mix. Individual stands of Texas wild-rice merged with other stands to increase the total area of this species by 50.1 m^2. A few new Texas wild-rice plants also colonized the area where the tree was removed adding to this total.

Increased recreational use and shallow depths due to reduced discharge in this reach led to a slight decrease in total vegetation area between Spring 2006 and Critical Period 1 (July 25) in the City Park Reach (4,620.1 and 4,407.0 m^2, respectively). As discharge continued to decrease and temperatures rose, the number of people using the river increased dramatically. Due to shallower water, areas that were previously too deep for people to walk were now easily reached. As a result the "path" in the middle of the reach became larger and displaced vegetation. Most notable were patches of *Hydrilla* and *Potamogeton*. However, both of these plants were able to become established in other parts of the reach where the water was a little deeper. Texas wild-rice decreased slightly due to large, thick vegetation mats that were not easily moved with the lack of flushing events. In these areas, the Texas wild-rice plants were discolored, achlorotic, and fragmented. With large mats sitting on these plants, the leaves are unable to receive any sunlight; in addition, when these mats are moved (by higher flows or people) they often pull out the leaves causing larger plants to fragment.

The trend of lower than average discharge and increased recreation continued into the late summer and early fall. By the second Critical Period event (September 22) total vegetation area in this reach decreased an additional 209.9 m^2. Again, this is indirectly caused by lower discharge increasing areas of shallow water, consequently increasing the number of people using these shallow areas. This was most prevalent along the cement wall on the river left side and the "path" in the middle of the reach. Though this path often emerges in summer, it has not expanded to the extent it did in summer 2006. In addition, large shallow areas began to emerge at the outfall of the culvert on the river right side of the reach. As a result, *Hydrilla* was reduced along with the *Potamogeton*/*Hydrilla* mixed vegetation patches. In the lower end of the reach, the *Hygrophila*/*Potamogeton* mix increased in areas that were predominantly a *Potamogeton*/*Hydrilla* mix. Total vegetation area also decreased because of a large increase in the amount of *Colocasia* along both banks of the river. Texas wild-rice increased slightly due to a new plant that appeared near the bottom of the reach and a few other individual plants growing together.

During discharges ranging from 97 to 100 cfs in the San Marcos River in November, temperatures had decreased and recreation impacts appeared to subside. Total vegetation area decreased slightly by 26.5 m^2, however, some areas that were previously bare began to be colonized by *Hydrilla* plants. *Hydrilla* also infiltrated areas that were previously dominated by a *Potamogeton*/*Hygrophila* mix. Texas wild-rice plants continued to grow together increasing the total area of the endangered plant in the City Park Reach.

I-35 Reach

This reach presents difficulties in obtaining accurate GPS coordinates when the canopy is dense (i.e., spring and summer); therefore, small discrepancies are apparent in the exact location of individual stands between samples. In addition, some estimates of total coverage may be less precise than in other reaches.

Conditions experienced during 2006 contributed to an increase in total vegetation area even though some of the changes led to a decrease in available habitat. Lower discharges over winter allowed the river right bank at the top of the site to expand, leading to less available wetted habitat. Another major event in 2006 led to increased sedimentation in the I-35 Reach. Immediately upstream of the Cheatham Street bridge construction to stabilize the existing Rio Vista Dam was conducted. This transformed the original concrete structure it into a series of rapids. This construction took place during the spring sample and led to increased turbidity in the I-35 Reach. Though most of this reach is shallow and plants are easily seen, the lower end has a deep spot at an eddy in the river and some plants were concealed due to increased turbidity. This disturbance also led to the continued expansion of the river right bank at the top of this site.

During 2006, algal growth was spurred and mixed with stands of *Hydrilla*. *Hygrophila* increased slightly from 2005 to 2006 (57.6 and 63.8 m^2, respectively). *Cabomba* occurs in this reach because of suitable conditions along the outside bends in the river (lentic backwaters, deep silty substrates). This vegetation type is important because it provides the highest-quality fountain darter habitat (of those sampled quantitatively) in the San Marcos River, but it is also highly susceptible to flood events. Without any major flushing flows over winter, total area of *Cabomba* changed very little. Texas wild-rice decreased as several larger plants in the middle of the reach became fragmented.

Overall, total vegetation area in the I-35 Reach continued to increase from the spring to Critical Period 1 sampling event. Total area of *Cabomba* nearly doubled in three months with much of the growth in the upper part of the reach (114.7 to 221.6 m^2). *Hygrophila* decreased by 17.5 m^2 as plants in the lower end of the reach fragmented. Texas wild-rice plants also continued to fragment in the middle and lower parts of the reach decreasing to only 83.1 m^2 by the first Critical Period sample. The *Hydrilla*/Algae mix continued to expand as green algae grew quickly in the shallower water.

A notable increase in *Hydrilla* occurred by the second Critical Period sampling event in the I-35 reach, but much of this is attributed to green algae dying off in the fall, and former mixed stands becoming pure *Hydrilla* stands. Both *Hygrophila* and *Cabomba* increased slightly from July to October with much of the growth occurring in the upper part of the reach. Texas wild-rice began to recover with two new plants becoming established in the upper and middle parts of the reach. With individual stands beginning to grow together in the middle of the reach, total area of Texas wild-rice increased from 83.1 m^2 to 121.4 m^2, while total discharge remained at approximately 98 cfs.

By the fall sampling period, discharge continued to decline in the river, but vegetation areas changed little. Large areas of the bank that were submerged in 2005 continued to be exposed in fall 2006. Total area of *Cabomba* decreased slightly, while *Hygrophila* and *Ludwigia* increased marginally. Texas wild-rice plants decreased by 1.3 m^2 in total area with a plant that had appeared in October no longer present in the middle of the reach. Because this reach is further downstream from most recreational impacts the changes in vegetation area were less notable than in the upper reaches even as discharge continued to decline.

Texas Wild-Rice Surveys

Maps generated from the two Critical Period surveys of the San Marcos River (downstream of Spring Lake) can be found in Appendix A. The total coverage calculated by the BIO-WEST project team differed somewhat from the total area measured by the TPWD (Table 11) in 2006. This variation is due to differences in mapping techniques and procedures, primarily in decisions to map Texas wild-rice plants as individual plants or as combined stands. BIO-WEST maps plants individually when open area is present between plants, whereas the TPWD methodology often lumps plants into stands and measures the entire perimeter. The important aspect at this point is consistency within sample methodology with both methods providing a valuable double check for the other. An increase in Texas wild-rice total area for the first Critical Period event may be attributed to the lower than average discharge conditions present the first six months of 2006. Decreased flows allowed individual plants to expand into previously deep areas. In addition, scouring of sediment at the leading edge of plants was diminished because there were few high-flow events.

A large increase in coverage of Texas wild-rice was recorded in the section where Texas wild-rice had been planted in 2003 (Appendix A, Map 7). Discharge conditions allowed plants to grow into each other, where individual plants previously existed. In addition, a new plant established itself just upstream of this section by the second Critical Period sampling event. Another section that exhibited significant increases in Texas wild-rice area by summer 2006 was Sewell Park. Several plants immediately downstream of the University Drive bridge grew together by summer 2006 (Appendix A, Map 1). This trend continued for the upstream plants in this reach by the second Critical Period sampling event, but this was not the case for a large stand just downstream in Sewell Park (discussed in detail in the next section).

Table 11. Total coverage of Texas wild-rice (m^2) in the San Marcos River as measured by the TPWD for 1996-2006 and BIO-WEST in 2001-2006.

YEAR/EVENT	1998	1999	2000	2001[a]	High-Flow[a]	2002	2003	2004	2005	2006[b]	Low-Flow[c]
TPWD	1,949.0	1,644.9	1,791.1	1,895.6		1,916.3	2,776.0	3,390.0	3,992.7	4161.1	
BIO-WEST				1,901.2	1,765.9	1,913.2	2,560.7	3,145.3	2,949.7	3,335.7	3,000.4

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

[b] Total coverage values obtained during a Critical Period low-flow event (July 27 – August 5, 2006).

[c] Total coverage values obtained during a second Critical Period low-flow event (September 20 – October 3, 2006).

As discharge continued to decline to the lowest levels recorded in ten years, areas that were previously very shallow became exposed in the Sewell Park reach. As dry land became more prevalent in this section, large Texas wild-rice plants became fragmented. Other grasses began to replace habitat that had previously been dominated by Texas wild-rice. The shallow water also encouraged more people to walk around in this sensitive area creating paths and further fragmenting large Texas wild-rice plants. People were frequently seen parking boats (canoes, kayaks) on top of plants because the water was shallow enough for them to easily get out of their boats. In addition, a canoe class was held in this area one day, where students were expected to maneuver boats around floats. A few of these floats were located near Texas wild-rice plants; as a result many boats and paddles came into close contact with several of these plants.

Lack of flushing flow events also led to large, thick vegetation mats covering large areas of plants. This is especially prevalent in shallow areas, like Sewell Park, where many of the plants have emergent blades that catch floating vegetation coming out of Spring Lake. These floating vegetation mats can prohibit photosynthesis as evidenced by discoloring of leaves when these mats are cleared off. In addition, as vegetation floats over the Texas wild-rice, it can pull out or shred the leaves. In the Sewell Park/Spring Lake Dam reach, total area of Texas wild-rice decreased 384.1 m^2, an 18% decrease in coverage in 2006. As discussed earlier, much of this decrease occurred in the Spring Lake Dam reach where a large area of Texas wild-rice was manually removed in early September. When this section was mapped in late September these plants had little time to recover, therefore, the mapping effort represented an accurate depiction of this extensive loss of plants.

Though shallow water depths, recreational impacts, and vegetation mats led to a large decrease in Texas wild-rice in the upper reaches, plants were able to expand farther downstream (Appendix A, Map 4). Mechanical disturbance due to the creation of the new Rio Vista Dam led to the loss of a small Texas wild-rice plant approximately 25 m downstream of the dam. In the I-35 reach, individual Texas wild-rice plants grew into other ones creating much larger plants. Although, the two large Texas wild-rice plants immediately upstream of the I-35 overpass were located in extremely shallow sections of the river, recreational impacts here were minimal because it is located farther away from population centers like City Park and the university. In addition, tubers rarely make it this far downstream and are much less likely to disturb the plants. Little change was observed downstream (Appendix A, Maps 5-7) with Texas wild-rice plants increasing slightly in overall area. Though these plants are more vulnerable because they lack other vegetation to protect them, there were no major rain events to scour them out.

Texas Wild-Rice Physical Observations

Total coverage of Texas wild-rice observed during 2006 in each "vulnerable" stand is presented in Table 12, and observations on trends in areal coverage are discussed by reach below. More detailed graphs on observations of root exposure, herbivory, emergence, etc. are found in Appendix B. Physical observations were conducted six times at each of the vulnerable stands in 2006.

Table 12. Texas wild-rice areal coverage (m^2) for each stand by sampling period (2006 only).

REACH-STAND NO.[a]	Spring 2006 [b]	Critical Period 1	Critical Period 2	Fall 2006 [b]
Sewell Park-1	267.2	217.9	217.5	217.7
Sewell Park-2				
Sewell Park-3				
Sewell Park-4	54.2	47.8	46.9	46.9
Sewell Park-5				
Sewell Park-6	35.7	69.2	28.3	28.2
Sewell Park-7	420.4	342.6	292.3	266.0
Sewell Park-8				
Total Area	**777.5**	**677.5**	**585.0**	**558.8**
I-35-1	-	-	0.4	0.4
I-35-2	1.4	1.2	1.0	0.9
I-35-3	0.6	0.7	0.9	0.8
I-35-4	0.7	0.3	0.2	0.3
I-35-5	5.4	8.3	12.3	12.4
I-35-6	38.2	36.4	36.7	32.7
I-35-7				
I-35-8	149.3	161.2	160.5	162.6
Total Area	**195.6**	**208.1**	**212.1**	**210.1**
Thompson's Island - 1	-	-	-	0.3
Thompson's Island - 2	5.5	3.9	3.0	2.0
Thompson's Island - 3	2.1	1.3	1.4	1.7
Total Area	**7.6**	**5.3**	**4.4**	**4.0**

[a] Many stands grew together to form individual stands after the first sampling period. [b] Areas reflect results of cross-section measurements and not GPS mapping at Thompson's Island.

Sewell Park Reach

Of the three reaches sampled, Sewell Park demonstrated the most dramatic changes in 2006. Total area of Texas wild-rice displayed a steady decline that resulted in a loss of 218.7 m^2 between the first and last sampling periods of 2006. In this reach, discharge conditions resulted in increases in the amount of floating vegetation mats and the area of extremely shallow water. During the spring comprehensive sampling event, only 15% of the Texas wild-rice in this section was found in water less than 0.5 feet, and the vegetation mats covered a smaller percentage of the stands (Appendix B). As discharge declined in late spring and summer 2006, the water near these vulnerable stands became shallower and mechanical disturbances resulted in greater impacts. By June 2006, 25% of the Texas wild-rice stands measured were below 0.5 ft, and herbivory had reached its highest percentage since the study began. Herbivory was high this time of year because stands were in very shallow water and emergence of these plants began to increase leaving significant portions of the plant exposed to feeding by waterfowl and

Nutria. Though emergence was beginning to increase, it remained low compared to other sampling periods in 2006. In June, vegetation mats covered 60% of the Texas wild-rice in this reach because the floating vegetation was easily caught on Texas wild-rice leaves in these shallow areas. Thick vegetation mats covering plants in vulnerable areas can have detrimental effects (Figure 8), as they can lead to reproductive failure due to the mats limiting emergence of culms, and reduce photosynthesis by blocking sunlight resulting in achlorotic leaves (Power 1996).

Beginning in July, the amount of vegetation mats became reduced, and emergence of plants began to increase. Culms emerge and produce panicles during spring, summer and fall months (Power 1997). With the vegetation mats decreased (likely through physical removal by agency and city personnel), Texas wild-rice plants were able to produce culms that could emerge out of the water column for reproductive purposes. Though signs of herbivory continued to be higher than previous years, they actually decreased starting in July as emergence increased in the Sewell Park reach. Recreation continued to have a significant impact by fragmenting Texas wild-rice in this area. As the water became shallower, paths developed in areas that were previously dominated by Texas wild-rice stands.

By the Critical Period 2 and the fall sampling events, indirect effects of low discharge and direct effects of recreation had impacted Texas wild-rice in the Sewell Park reach. Total area had decreased from 775 m^2 in the spring to 558 m^2 by November, the lowest total area since summer 2005. By September, increased fragmentation of Texas wild-rice in this reach was clearly evident. Flowering reached its peak in 2006 in the fall as this species continued to reproduce through most of the year. In addition, vegetation mats were fewer at this time enabling culms to emerge from the water column. Root exposure in 2006 was relatively high compared to recent years, but changed little as discharge declined (Appendix B).

Figure 8. Vegetation mats covering Texas wild-rice in the Sewell Park Reach.

I-35 Reach

Average areal coverage of Texas wild-rice "vulnerable" stands in the I-35 reach decreased from 2005 (205.7 m^2) to 2006 (195.6 m^2), but remained relatively constant over the remainder of 2006. A small Texas wild-rice plant in the upper section of the reach disappeared by spring 2006, but a new one reappeared in the same area by the Critical Period 2 sampling event in September. Plants in this reach were relatively unaffected by recreation because this reach is farther away from recreational areas (City Park, Sewell Park). As a result of less comparative recreation in this reach, Texas wild-rice plants were much less fragmented by mechanical disturbance. Emergence in this reach was highest in spring because vegetation mats were less numerous at this time of year. Subsequently, emergence decreased in the summer months as the coverage of vegetation mats increased. Most of the emergent plants were plants 6, 7, and 8 (Table 12) because they are in a very shallow area of the reach. Though the percent of Texas wild-rice found in shallow (< 0.5 ft.) water fluctuated widely in 2006, plant 6 remained in shallow water the entire year. The fluctuations are due to averaging of plants found in deeper water with plants that are consistently located in shallow areas.

Herbivory also fluctuated throughout 2006, but most of it was concentrated in plants 6, 7, and 8 because these are found in shallow waters. Flowering culms were not prevalent in the Texas wild-rice in the I-35 reach possibly due to an increase in vegetation mats during the summer months when the culms typically emerge. By November, the area of vegetation mats was significantly reduced, but flowering was nearly completed. Root exposure peaked by the Critical Period 2 sampling event, but was relatively low throughout the rest of the year. With few rain events in 2006, the sediment near the roots remained intact with limited scouring recorded.

Thompson's Island Reach (Natural)

The average coverage of Texas wild-rice in "vulnerable" areas within this reach increased from fall 2005 (6.2 m^2) to spring 2006 (7.6 m^2), but decreased through the rest of the year. In the fall 2006 sample a new plant was discovered in this reach and assigned the number 1, and will continue to be measured in future sampling events. Emergence of these plants was significantly higher than previous years and emergence directly corresponded with an increase in plants found in water less than 0.5 ft. As a result, herbivory also increased in this area because so many plants were exposed in this shallow water. The amount of flowering area was higher than previous years, but this also resulted in increased herbivory. Total areal coverage of plants was lowest in the fall 2006 sample (4.0 m^2) even with the addition of another plant.

Fountain Darter Sampling

Drop Nets

The number of drop net sites and vegetation types sampled per reach is presented in Table 13. The drop net site locations are depicted on the aquatic vegetation maps (Appendix A) for the respective reaches per sampling event and resulting data sheets are found in Appendix C.

Table 13. Drop net sites and vegetation types sampled per reach.

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

Numerous vegetation types in the San Marcos River provide fountain darter habitat with a range of suitability. The suitability of the various vegetation types (as measured by fountain darter density) is considerably lower in the San Marcos River when compared with the Comal River. For example, in the Comal Springs/River ecosystem *Cabomba* and *Hygrophila* exhibit fountain darter densities of 11.0/m^2 and 6.5/m^2, respectively. In the San Marcos River, these same vegetation types yield fountain darter densities of 5.1/m^2 (*Cabomba*) and 3.7/m^2 (*Hygrophila*) (Figure 9). Although densities are generally lower in the San Marcos River there are similarities between the two systems. Densities of fountain darters tend to be highest in native vegetation types. In the San Marcos River, exotics such as *Hydrilla* and *Hygrophila* exhibit lower suitability than native plants such as *Potamogeton* and *Cabomba*. Similarly, in the Comal River native plants such as filamentous algae, bryophytes, *Ludwigia*, and *Cabomba* exhibit the highest densities (Figure 6, BIO-WEST 2007). In both systems bare substrates contain very few, if any, fountain darters showing the overall importance of aquatic vegetation as fountain darter habitat.

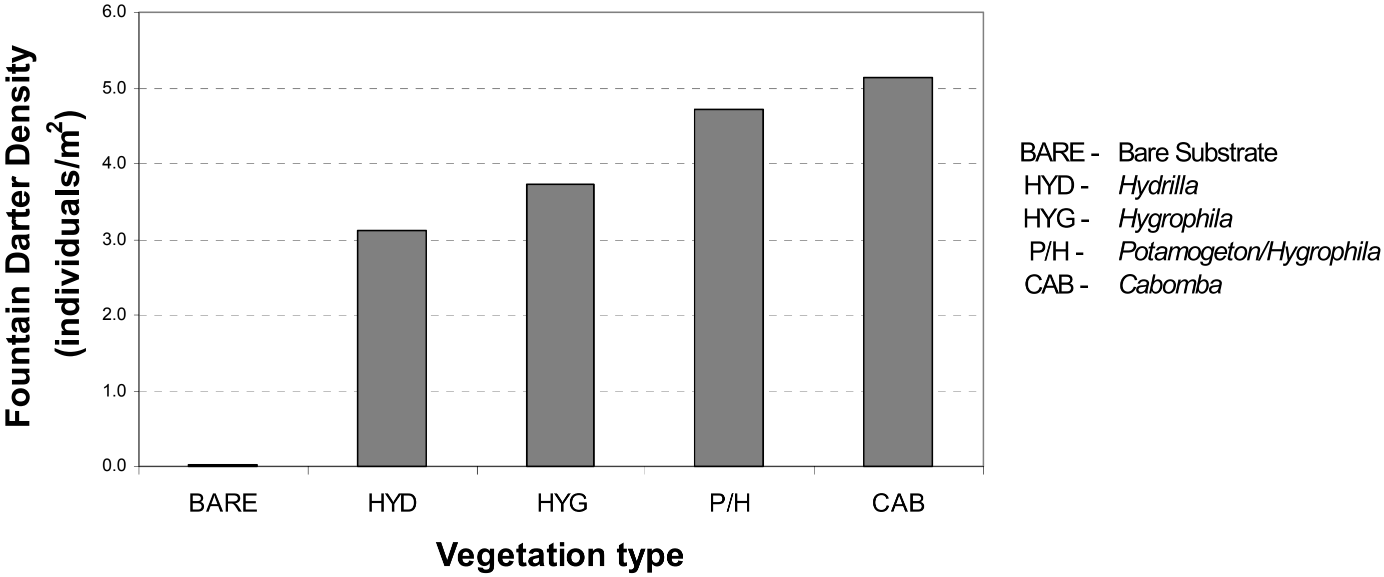

Figure 9. Density of fountain darters collected by vegetation type in the San Marcos Springs/River ecosystem (2000-2006).

The size-class distribution for fountain darters collected by drop net from the San Marcos Springs/River ecosystem during all sampling events combined in 2006 is presented in Appendix B. The distribution is similar to the distribution observed throughout the project and is typical of a healthy fish assemblage. Presence of fewer small fountain darters in the San Marcos River collections when compared to the Comal River collections is most likely a function of differences in vegetation types and current velocities in the two systems. Less suitable vegetation types as well as stronger currents limit the availability and quality of habitat in the San Marcos River. However, smaller individuals are abundant in dip net data from Spring Lake suggesting year-round reproduction there.

When examined by reach and sample (Figures 10 and 11) the size-class distributions reveal trends similar to those observed in the Comal Springs/River ecosystem. Fall samples from both reaches are dominated by larger individuals while juvenile fountain darters are most abundant in spring samples suggesting a spring reproductive peak. A wider range of size classes were collected in the I-35 reach in late summer and fall, which is indicative of the more suitable habitats (*Cabomba*) found within this reach.

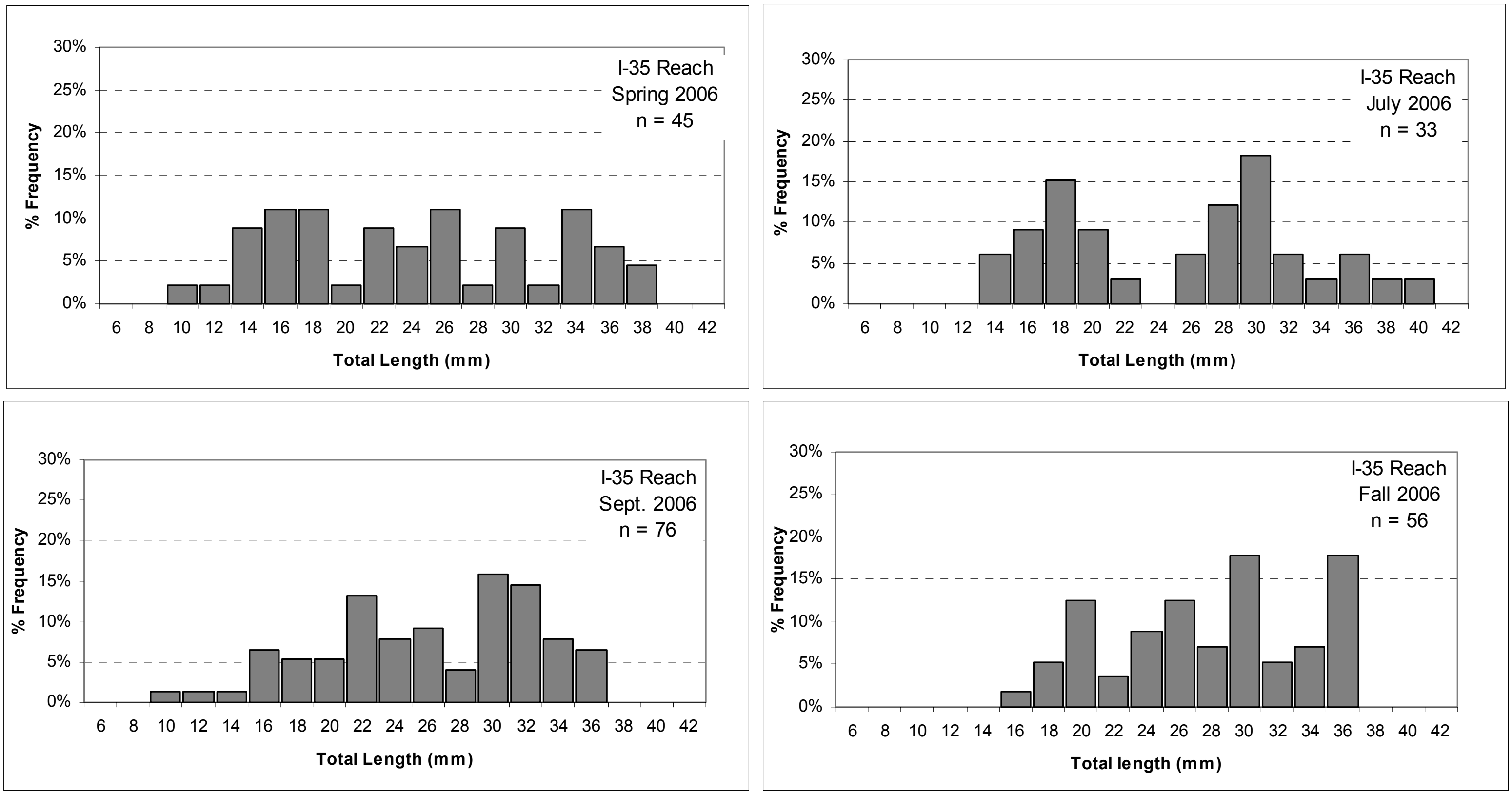

Figure 10. Length frequency distributions of fountain darters collected in each sample from the I-35 Reach in 2006.

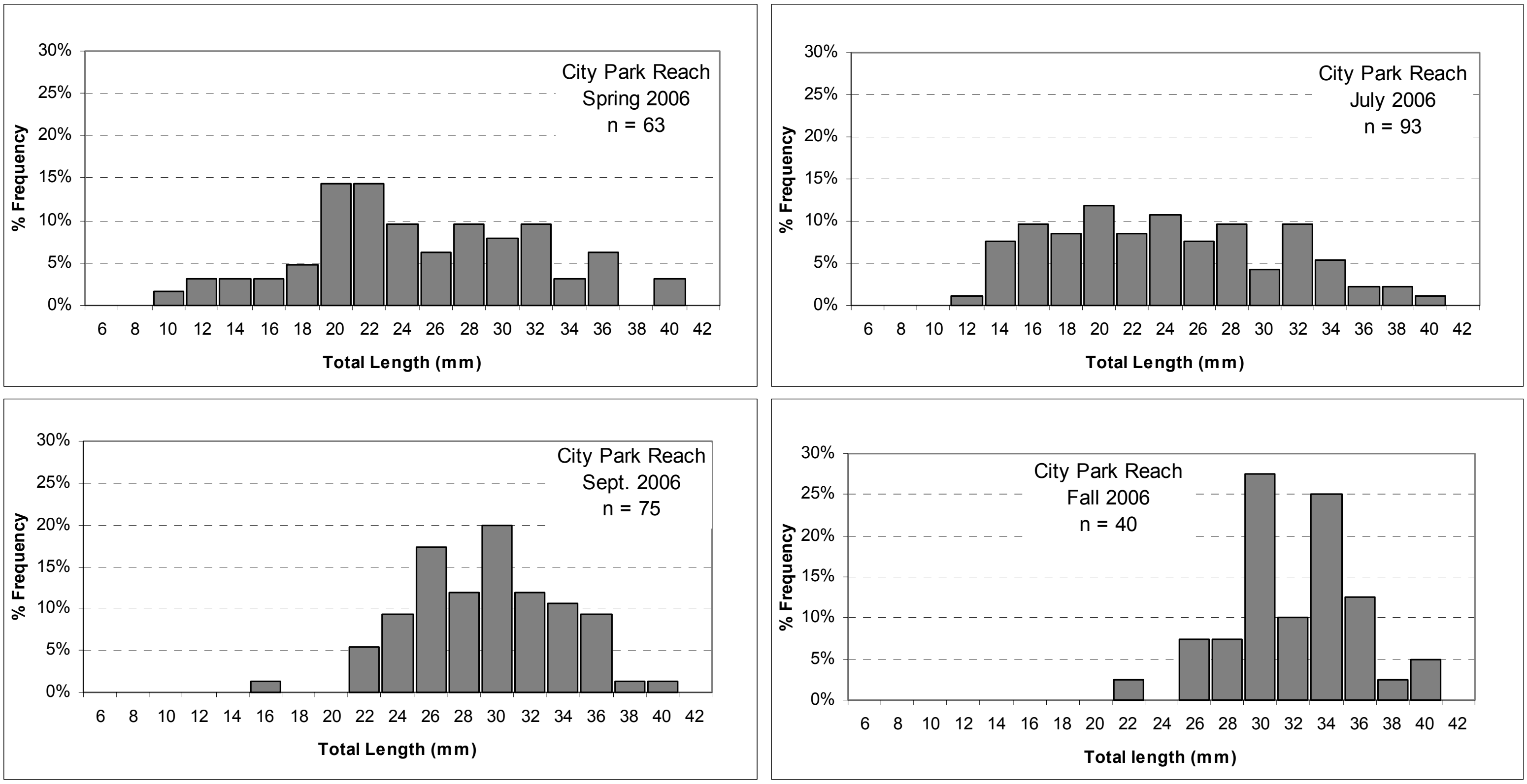

Figure 11. Length frequency distributions of fountain darters collected in each sample from the City Park Reach in 2006.

Estimates of fountain darter population abundance were based on the changes in vegetation composition and abundance and the average density of fountain darters found in each, as described in the methods section. Data from the Spring Lake Dam Reach were not included in these estimates because drop net sampling was not conducted there. There is little variation in the average density of fountain darters found among vegetation types in the San Marcos River; therefore, changes in vegetation coverage do not have dramatic impacts on fountain darter abundance and population estimates are less variable between samples than in the Comal Springs/River ecosystem (Figure 12). As in the Comal River, high-flows resulted in decreased amounts of vegetation and thus, lower population estimates. Population estimates actually increased during lower discharge conditions in 2006. This could indicate clumping of fountain darters into high quality habitat under lower discharges, or could simply represent variation inherent in a random sampling design. Continued monitoring of fountain darter densities and vegetation coverage will allow further insight into any trends in the population.

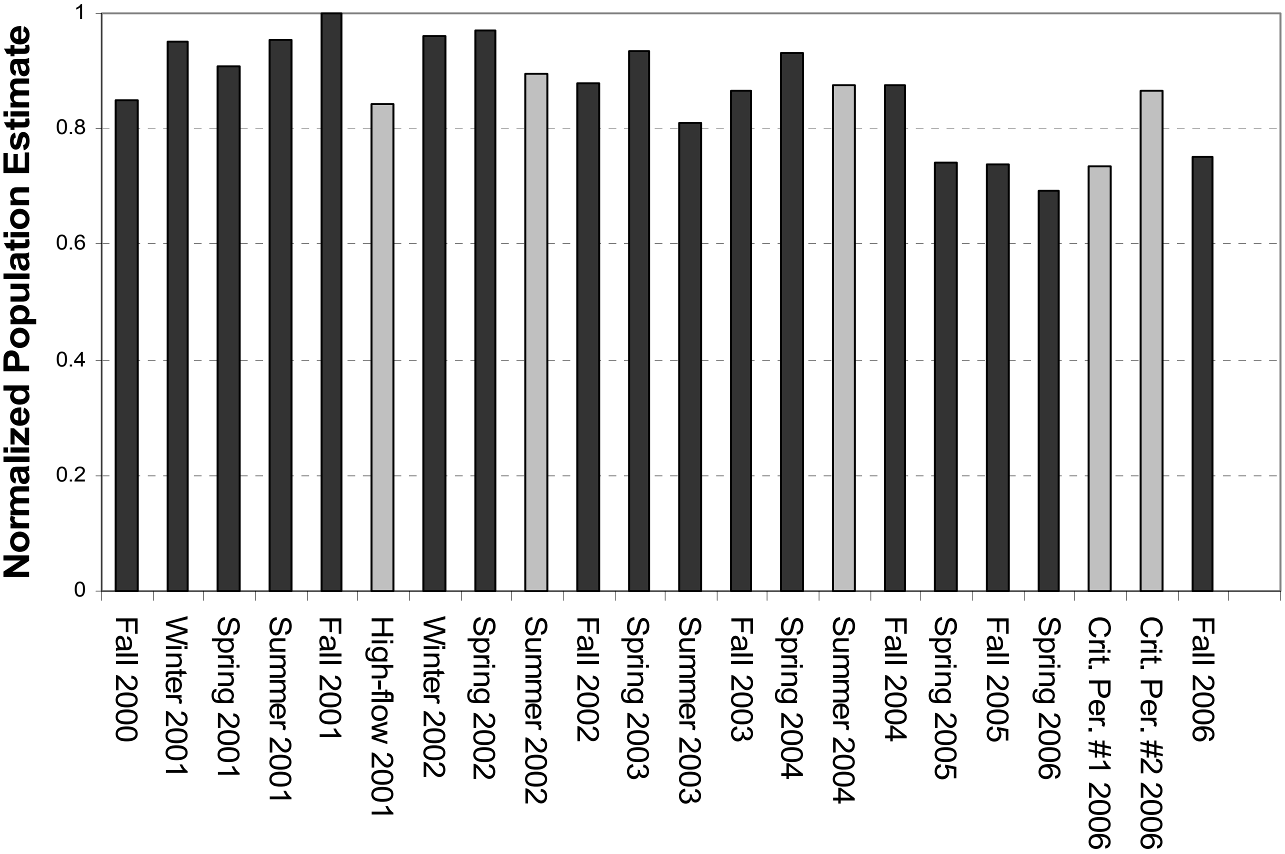

Figure 12. Population estimates of fountain darters in the San Marcos River; values are normalized to a proportion of the maximum observed in any single sample. Light-colored bars represent Critical Period sampling events.

In addition to fountain darters, there have been 18,206 fishes representing 26 other taxa collected by drop netting since 2001 (Table 14). Of these, 7 species are considered introduced or exotic to the San Marcos Springs/River ecosystem. The most abundant exotic or introduced species in the system include the rock bass (*Ambloplites rupestris*) and the sailfin molly (*Poecilia latipinna*). Another exotic species of particular concern is the suckermouth catfish (*Hypostomus sp.*). Although these fish are rarely captured in drop nets, based on visual observations they are extremely abundant in the system. This species has the potential to drastically affect the vegetation community and thus impact critical fountain darter habitats and food supplies. The sheer number and varying sizes of suckermouth catfish that were removed by the U.S. Fish and Wildlife Service biologists during the reconstruction of Rio Vista Dam (Figure 13) is cause for concern and close future observation of this exotic species.

Table 14. Fish species and the number of each collected during drop-net sampling in the San Marcos Springs/River ecosystem.

			NUMBER COLLECTED	
COMMON NAME	SCIENTIFIC NAME	STATUS	2006	2001-2006
Rock bass	*Ambloplites rupestris*	Introduced	42	301
Black bullhead	*Ameiurus melas*	Native	0	2
Yellow bullhead	*Ameiurus natalis*	Native	12	64
Mexican tetra	*Astyanax mexicanus*	Introduced	1	14
Rio Grande cichlid	*Cichlasoma cyanoguttatum*	Introduced	23	34
Guadalupe roundnose minnow	*Dionda nigrotaeniata*	Native	7	26
Fountain darter	*Etheostoma fonticola*	Native	477	1610
Greenthroat darter	*Etheostoma lepidum*	Native	1	1
Gambusia	*Gambusia sp.*	Native	9881	16675
Suckermouth catfish	*Hypostomus plecostomus*	Exotic	5	19
Redbreast sunfish	*Lepomis auritus*	Introduced	3	38
Green sunfish	*Lepomis cyanellus*	Native	0	5
Warmouth	*Lepomis gulosus*	Native	2	22
Bluegill	*Lepomis macrochirus*	Native	2	65
Longear sunfish	*Lepomis megalotis*	Native	0	3
Spotted sunfish	*Lepomis punctatus*	Native	130	566
Sunfish	*Lepomis sp.*	Native/Introduced	15	110
Largemouth bass	*Micropterus salmoides*	Native	3	34
Gray redhorse	*Moxostoma congestum*	Native	0	3
Blacktail shiner	*Cyprinella venusta*	Native	0	6
Texas shiner	*Notropis amabilis*	Native	4	17
Ironcolor shiner	*Notropis chalybaeus*	Native	21	52
Unknown shiner	*Notropis sp.*	Native	0	4
Tadpole madtom	*Noturus gyrinus*	Native	0	4
Logperch	*Percina caprodes*	Native	0	2
Dusky darter	*Percina sciera*	Native	0	13
Sailfin molly	*Poecilia latipinna*	Introduced	7	92
Unknown molly	*Poecilia sp.*	Native/Introduced	0	30
Tilapia	*Tilapia sp.*	Exotic	0	4

Figure13. Suckermouth catfish captured in the San Marcos River near Rio Vista Dam. Photo courtesy of the U.S. Fish and Wildlife Service.

Among exotic species, the giant ramshorn snail also elicits concern because of its recent impacts (early 1990s) on aquatic vegetation in the Comal River. In the fall 2000 sample, 19 giant ramshorn snails were sampled in the San Marcos Springs/River ecosystem, but none were collected during 2001-2003. In 2004-2006, there were a total of 15 giant ramshorn snails collected in drop net sampling. Although data suggests that giant ramshorn snail numbers are extremely low, close monitoring should continue because of the impact that this exotic species can have on the vegetation community under heavier densities.

Dip Nets

The boundary for each section where dip net collections were conducted is depicted on Figure 14. Section numbers are included to be consistent with the USFWS classification system for the San Marcos River. Data gathered from the Hotel Reach are presented in Figure 15, and data from all other sections are graphically represented in Appendix B. The overall number of fountain darters collected in the Hotel Reach by dip nets is much greater than that found in the other two reaches. Filamentous algae present in this area provide the highest quality habitat found in the San Marcos Springs/River ecosystem. The majority of samples collected from the Hotel Reach during the study period contained individuals in the smallest size class (5-15mm). This size class represents fountain darters <58 days old (Brandt et al. 1993) and their presence in all seasons indicate year-round reproduction.

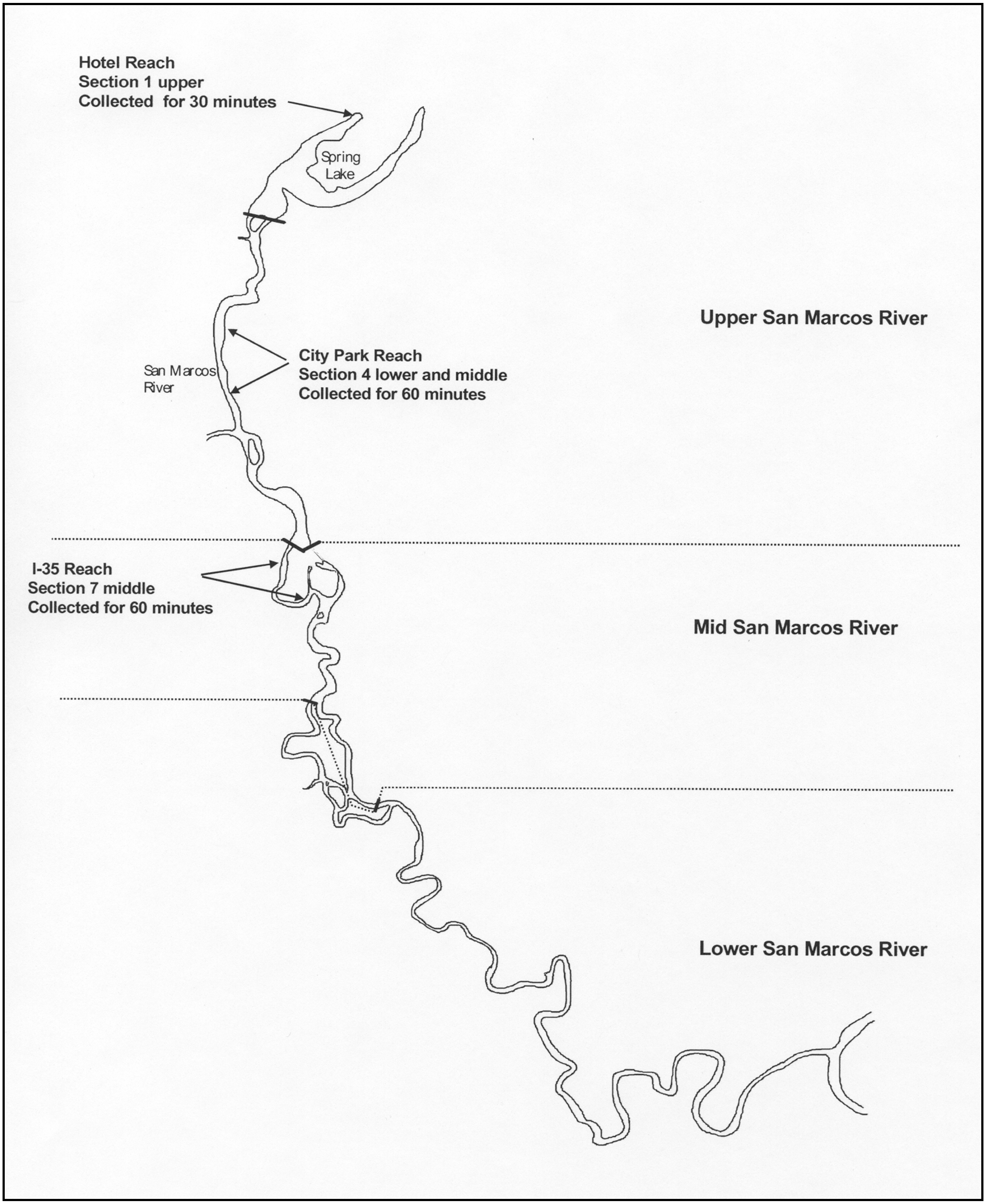

Figure 14. Areas where fountain darters were collected with dip nets, measured, and released in the San Marcos River.

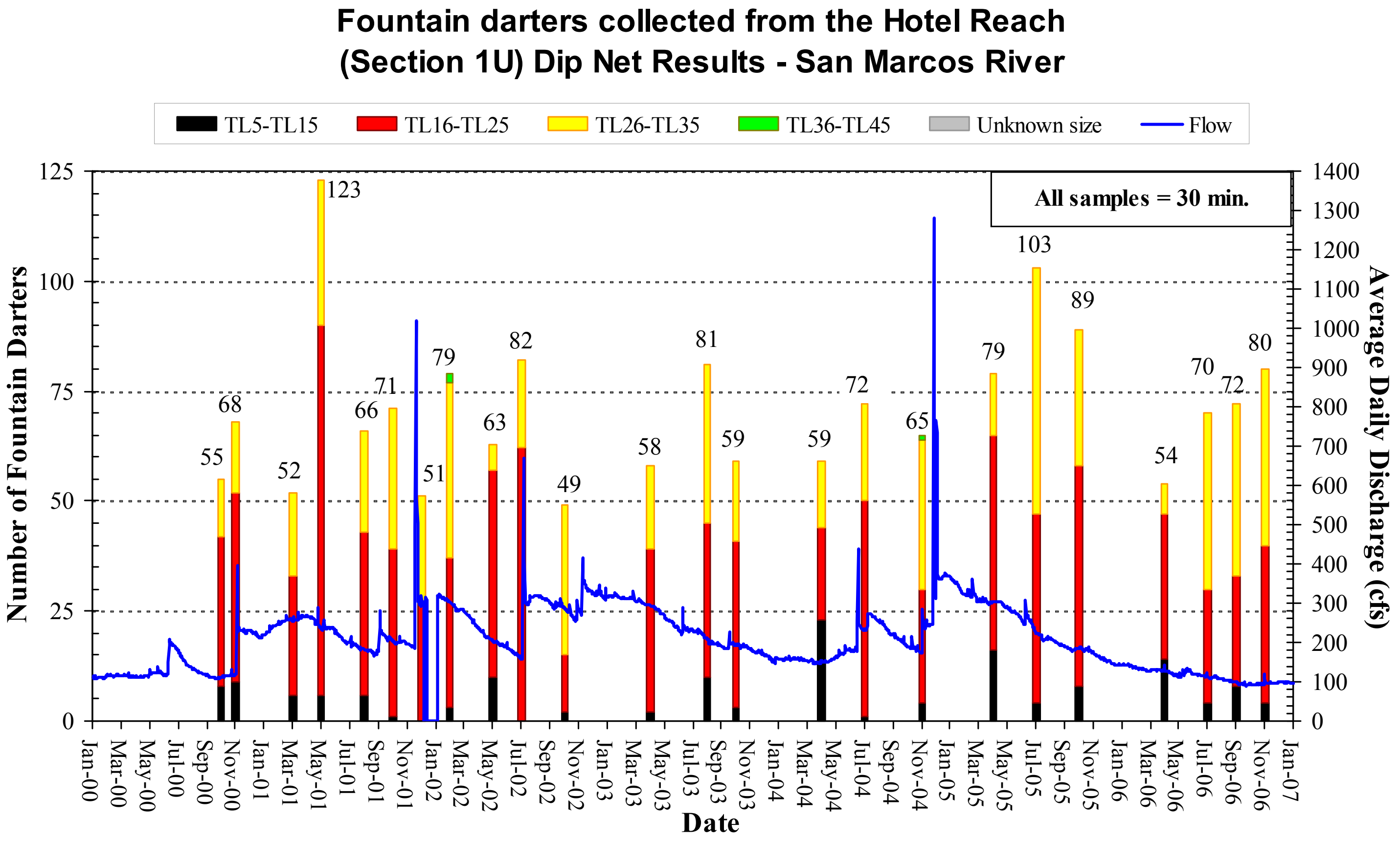

Figure 15. Number of fountain darters collected from the Hotel Reach (section 1 upper) of the San Marcos Springs/River ecosystem using dip nets.

In summer 2006, small darters were collected from the City Park and I-35 reaches during both Critical Period sampling events. This is in contrast to previous years in which reproduction in these reaches has primarily been noted only in spring samples (Appendix B). Reproduction is thought to occur more seasonally in these reaches because of the lower quality habitat. Reproduction observed in summer 2006 may have been a compensatory response to the observed lower discharge conditions.

Dip Net Techniques Evaluation

Across all vegetation types, fountain darters were present at 40% of sites during the May sample, at 50% of sites in July, at 48% of sites in September, and at 44% of sites in November (Figure 16). Since this technique was not previously conducted on the San Marcos River, future data will aid in determining the importance of the variation observed in 2006.

Fountain darters were most common in *Cabomba* (92% of sites), and were much less common in *Hygrophila* (42%), *Hydrilla* (39%), and *Potamogeton*/*Hygrophila* (39%) (Figure 17). This corresponds directly with drop net data from the San Marcos River which shows *Cabomba* to have the highest density of all vegetation types sampled by that technique.

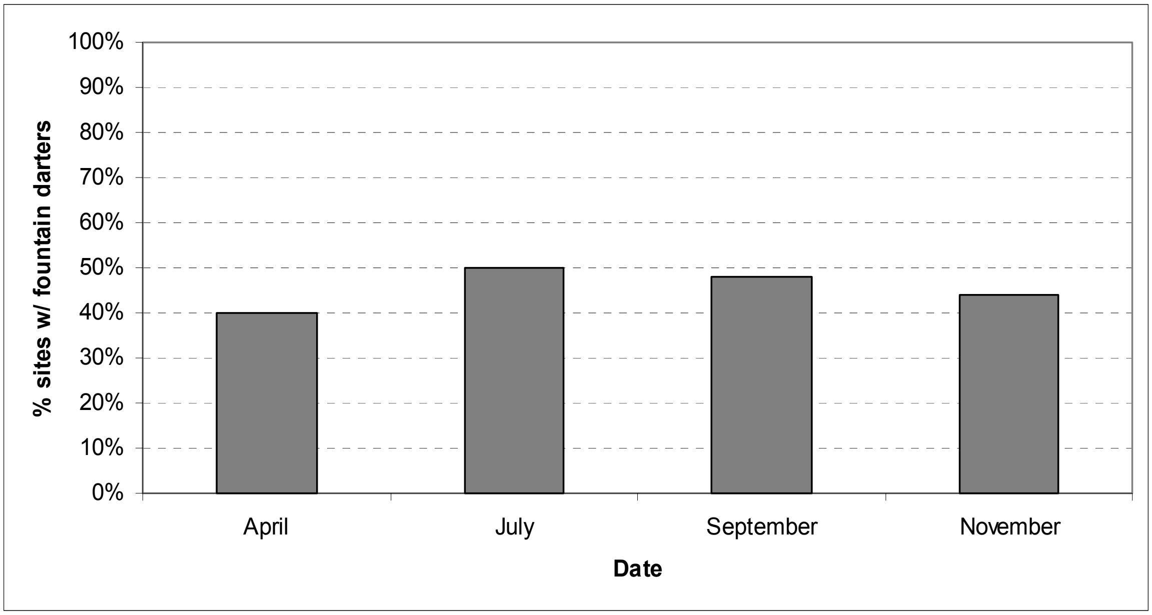

Figure 16. Percent of sites (n = 50) with fountain darters present in each presence/absence dip net sample conducted on the San Marcos Springs/River ecosystem in 2006.

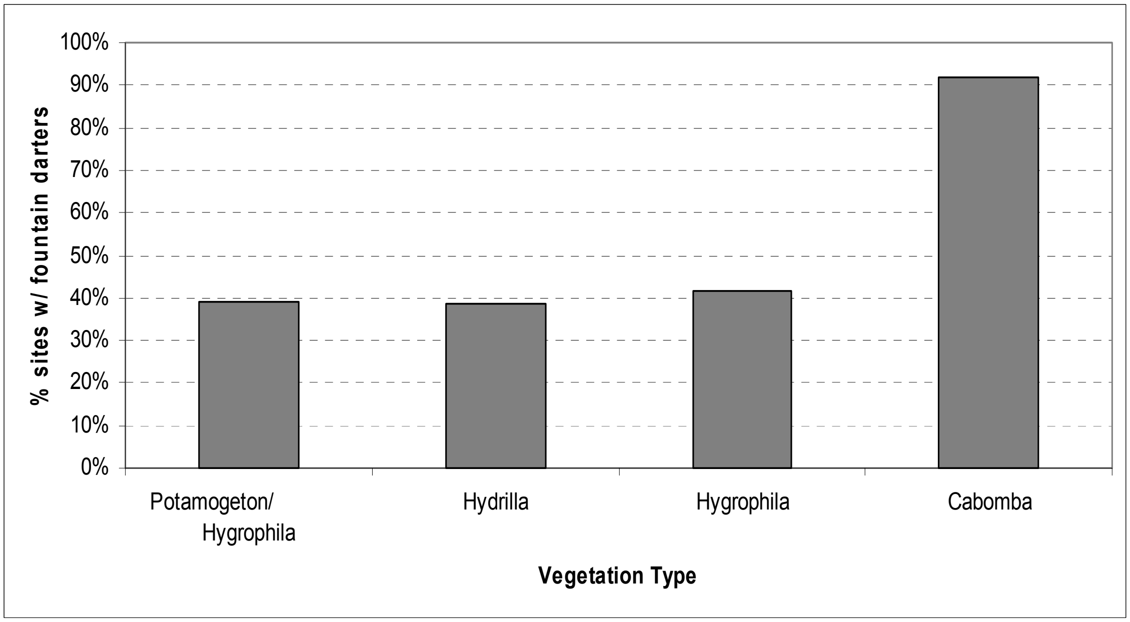

Figure 17. Percent of sites within each vegetation type with fountain darters present.

San Marcos Salamander Visual Observations

As in previous years filamentous algae covered sample sites 2 (Hotel Reach) and 14 with thick mats and coverage was abundant throughout 2006. The abundance of algae potentially affected density estimates of San Marcos salamanders in these habitats because the area had to be cleared prior to sampling activities (i.e., disturbance may have startled salamanders and caused them to move) and a smaller area was sampled relative to periods in which the algae was less dense. It is also possible that a significant portion of the San Marcos salamander population that would have been found under rocks was instead occupying the algae over top of the rocks during these times. Many 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 presence of the divers and impelled some individuals to retreat into deeper cavities within the rocks. Although this methodology inflects some uncertainty, it is consistent each year and allows valid comparisons among sites and seasons.

Salamanders were abundant at each sample area, and appeared to be unaffected by the lower than average discharge conditions prevalent in 2006 (Table 15). Salamander numbers in sample areas 14 and 21 decreased from Fall 2005 to Spring 2006, while salamander density increased at sample area 2. Though the density of salamanders decreased at sample area 21 by spring 2006, there were still more present in 2006 than previous years (excluding 2005). In addition, 19.2 salamanders per m^2 was the highest density at sample area 14 since the inception of the study. Overall, a thriving San Marcos salamander population has been observed in sample site 2 throughout the study to date and salamanders continue to be abundant under rocks. In addition, the presence of algae covering many of the rocks potentially provide increased three-dimensional habitat for salamanders to disperse into.

Table 15. San Marcos salamander density per square meter (m^2).

SAMPLING PERIOD	SAMPLE AREA 2	SAMPLE AREA 14	SAMPLE 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
Winter 2002	6.1	6.5	0.9
Spring 2002	20.2	8.5	0.6
Summer/High Flow 2002	17.7	4.2	0.7
Fall 2002	16.8	8.7	3.0
Spring 2003	7.9	11.9	1.0
Summer 2003	20.1	6.8	2.0
Fall 2003	11.3	9.5	2.7
Spring 2004	14.6	9.9	7.1
Summer 2004	10.9	9.2	7.0
Fall 2004	11.7	13.7	4.5
Spring 2005	18.2	7.8	3.5
Fall 2005	11.6	12.6	12.1
Spring 2006	15.5	7.7	7.1
Critical Period 1 2006	17.4	8.4	7.9
Critical Period 2 2006	16.1	19.2	7.5

The higher than average numbers below Spring Lake dam are in part due to the lower discharge conditions in 2006. Since sample site 21 is located in the river, the sampling technique is much easier when flows are lower, and velocities are reduced. In addition, in this reach there is an increase in suitable habitat for salamanders that results from lower discharge conditions. Overall, the estimated population densities of the San Marcos salamander in 2006 were consistent with previous years.

Predation Study

Ten predatory fish were collected by hook-and-line from Spring Lake during each Critical Period sampling event (8/3/06 and 9/22/06) in 2006. Collections resulted in the capture of 15 largemouth bass (*Micropterus salmoides*) and 5 redbreast sunfish (*Lepomis auritus*). Percent occurrence of the various food items identified from the stomachs of these fish is presented in Table 16. Food items identified included algae, numerous aquatic and terrestrial insects, crayfish, fish, snails, and detritus. No endangered species were identified in 2006 samples. However, evidence of unidentified small fish that was noted in several stomachs could possibly represent fountain darters. Continued sampling during critical periods will aid in understanding the effect of predation during low discharge conditions.

Table 16. Percent occurrence of various food items in the diet of fish collected from Spring Lake during Critical Period sampling events in 2006.

Species	Number	Mean Length (mm)	Food Items							
			Empty	Algae	Aquatic Insects	Crayfish	Salamanders	Fountain Darters	Unidentifiable Fish	Other
M. salmoides (<300 mm)	6	221	0%	17%	17%	33%	0%	0%	67%	17%
M. salmoides (>300 mm)	9	384	22%	11%	22%	33%	0%	0%	44%	33%
L. auritus	5	230	0%	20%	60%	0%	0%	0%	20%	60%

Critical Period Observations

The extended period of limited recharge leading up to and extending throughout 2006 caused discharge in the San Marcos River to decline to levels not experienced since 1996. Total discharge in the San Marcos River declined below 140 cfs in early January and remained below this level for the remainder of the year. As discussed above, the lowest recorded average daily discharge in 2006 was 90 cfs in early September. Table 17 shows various discharge levels and total and consecutive days below those respective levels experienced in 2006.

Table 17. Days below select discharge levels in the San Marcos River in 2006.

	Days		
Discharge (cfs)	Total	Consecutive	Start Date
140	356	355	1/7/2007
130	309	232	2/6/2007
120	241	181	4/10/2007
110	180	172	5/20/2007
100	115	90	8/20/2007
95	47	29	8/26/2007

When reviewing the annual discharge in the San Marcos River since the installation of the USGS gage in fall 1956, the 2006 average annual discharge of 112 cfs was the eighth lowest on record. This period of limited recharge and lower than average discharge provided an excellent opportunity to observe biological conditions and direct and indirect impacts associated with these discharge levels. A summary of these observations and impacts on the surface dwelling threatened and endangered species (fountain darter, San Marcos salamander, and Texas wild-rice) are presented below.

The overall fountain darter population did not exhibit any major changes during the experienced discharge conditions. In fact, population estimates of darters actually increased during the critical period sampling events. It has been hypothesized that this would occur during lower discharge conditions as a function of clumping associated with reductions in aquatic vegetation (i.e. available habitat). However, as described throughout this report, large reductions in available habitat were not measured in 2006. Therefore, this increase in population may simply represent biological variation inherent in this type of sampling. One interesting note was the observance of reproduction of fountain darters during the early and late summer months in the drop trap sampling from the City Park and I35 reaches. Reproduction during this time period in these reaches has not been reported with this technique during this study. This coupled with the increased reproduction documented by the dip net samples during this time period suggests that this might represent a biological response that was triggered by the onset of lower discharges and slight reductions in available habitat. Alternatively, this may simply reflect inherent biological variation in this complex system. This phenomenon will be closely monitored during future low discharge conditions as a potential predictor of stress related biological response.

Overall there was no observed impact of the measured discharges on the population of San Marcos salamanders. The densities reported in 2006 were very similar to previous years and available habitat within Spring Lake was also very comparable with no signs of increased siltation or excessive vegetation growth around spring outlets. The shallower water depths below Spring Lake Dam as a result of the low discharge conditions in late summer did cause some indirect effects on San Marcos salamander habitat via increased recreational activity. Recreation in the immediate areas below the dam seemed to increase during this period with a lot of rocks being physically moved by people to create structures, dams, and artificial channels. Although not captured in the snorkel surveys, the physical perturbation associated with this recreation as well as the habitat modification likely had some impacts on the resident salamander population.

The most notable impacts to a species were the direct and indirect effects of the measured discharge on Texas wild-rice. The declining discharge coupled with the dramatic increase in sedimentation over the past 10 years led to areas of river bottom becoming completely exposed during the late summer months. The Sewell Park reach was the best example of this condition. A small island was actually created in the middle of what had previously been a large expanse of Texas wild-rice. On this island, other plants established themselves resulting in fragmentation of the Texas wild-rice. In addition, larger portions of Texas wild-rice in this reach were emergent and thus, more prone to herbivory by waterfowl and *Nutria* than in previous years. Also, because these plants were in such shallow areas, thick vegetation mats from cuttings in Spring Lake often got caught on these plants and covered them for extended periods of time. This led to achlorotic leaves, and suppression of reproductive culms because the Texas wild-rice could not push through these heavy mats.

The greatest impacts observed during 2006 were the indirect effects of the lower discharge conditions on Texas wild-rice. The most prominent indirect effect was an increase in recreation in these newly created shallow areas. For example, in the Sewell Park reach, “paths” developed in the shallow areas where

Texas wild-rice was located because it was easier for people to wade in these areas during lower discharge conditions. This led to extensive fragmentation both within the Sewell Park and Spring Lake Dam Reaches. Recreators were observed walking in these areas and parking their boats on top of plants, both leading to plants being pulled out or damaged. The greatest single impact was observed in the Spring Lake Dam reach adjacent to the Clear Springs Apartments where a 73% decrease in total Texas wild-rice area was observed in late summer 2006. It was evident that large patches of Texas wild-rice had been physically pulled out with only solitary leaves and root-wads to indicate where these plants had been. Further evidence of manipulation of the river by people was present immediately downstream of Spring Lake Dam. Artificially created walls of rocks emerging from the water column served to further channelize this area blocking flow to several Texas wild-rice plants.

To put this into perspective, the overall coverage of Texas wild-rice in the San Marcos River actually increased by 50.7 m^2 from Summer 2005 to the second Critical Period sampling in late Summer 2006. From spring 2006 to the second Critical Period sampling, the overall Texas wild-rice coverage declined by 335.3 m^2 or approximately 11%. If you subtract the 234 m^2 that was clearly physical disturbance, this leaves an overall 2006 decline (101 m^2/approx. 3%) that might be directly attributable to lower discharges. If you look just at the Texas wild-rice deemed to be in the most vulnerable locations there was a reduction from 980.7 m^2 in spring 2006 to 772.9 m^2 in fall 2006 or approximately a 21% decline. As this is greater than the overall coverage change, as expected, it also points out that Texas wild-rice not located in vulnerable areas actually increased throughout the lower discharge conditions in 2006. A follow-up consideration is that if the excessive sedimentation in the San Marcos River over the last 10 years had not occurred creating these vulnerable areas, Texas wild-rice likely would have continued to expand even during the eighth lowest average annual discharge on record.

In summary, increased recreational access during 2006 created the greatest effects on the threatened and endangered species in the San Marcos Springs/River ecosystem. These effects included destruction of Texas wild-rice and habitat modification for the San Marcos salamander (humans physically moving rocks below Spring Lake Dam) and fountain darter (increased foot traffic through commonly deeper areas). Direct effects of the lower discharge conditions were not evident for the San Marcos salamander at the discharge levels measured in 2006. Direct effects on the fountain darter may have been experienced with a compensatory reproduction occurring as a result of lower discharge conditions, however, this is not an absolute, nor did the response have any measurable impact on the fountain darter population in the San Marcos River in 2006. Finally, the greatest direct impact associated with the lower discharges experienced in 2006 was to Texas wild-rice with an overall reduction in coverage (~3% entire river and ~21% in vulnerable areas.)

The data collected in 2006 will be extremely valuable in initiating discussions with the Edwards Aquifer Authority, Technical Advisory Group, and state and federal agencies relative to the condition of the San Marcos Springs/River ecosystem during lower discharge conditions. It is important to remember that these data must be evaluated in context, which is a one-time event with an extended duration, preceded by an extended period of good biological conditions. Caution should be taken when speculating how these results might transfer to longer durations of low discharge, lower than observed discharge, or similar discharge preceded by poor ecological condition. The established database and comprehensive and critical period monitoring through the Authority's Variable Flow Study continues to provide an excellent measure of ecosystem condition and after 2006, some very strong insight into biological responses to low discharge conditions. However, since direct impacts measured in 2006 were relatively minor, additional field data at lower discharge conditions are necessary to fully assess conditions that might jeopardize the existence of one or several of these species in the wild. As we hope the occurrence of these extreme conditions are rare, interim efforts to evaluate response mechanisms of the threatened and endangered species to low discharge conditions either via laboratory investigation (as conducted in previous years under this program) or via field (in situ) experiments as proposed with the "intensive management areas" concept would provide valuable information for management decisions.

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APPENDIX A:
AQUATIC VEGETATION MAPS

(separate file)

APPENDIX B:
DATA AND GRAPHS

Water Quality Data
and
Thermistor Graphs

Water quality conditions at sites 1-9 on the San Marcos River during normal flows (10/2000-5/2002), a high-flow event (8/5/2002), and low-flow events (7/25/2006 and 9/14/2006).

Sampling Date	Temp	pH	Cond	D.O.	Turbidity (NTU)	TSS (mg/L)	Alkalinity (mEq/L)	NH_3-N (mg/L)	$N0_3$-N (mg/L)	TN-N (mg/L)	SRP (ugP/L)	TP (ug/L)
Site 1												
10/31/2000	23.01	7.47	578	10.61	1.1	0.0000	5.212	0.043	1.160	1.180	4.789	7.828
3/5/2001	22.30	7.40	584	8.35	1.9	0.0020	4.741	0.021	1.240	1.660	11.146	10.241
5/7/2001	22.37	7.43	561	7.95	2.2	0.0800	4.741	0.025	0.510	0.800		
8/13/2001	22.73	7.39	596	7.75	8.2	0.0030	4.601	0.019	1.900	2.200	9.752	16.259
10/24/2001	22.55	7.04	580	8.35	1.0	0.0020	4.466		1.360	1.400	10.275	32.236
2/13/2002	22	7.15	560	8.63	1.3	0.0010	4.764	0.046	1.257	1.395	4.978	6.489
5/8/2002	22.74	7.13	538	8.5	1	0.0011	4.869	0.039	1.561	1.701	4.652	9.449
Average (10/2000-5/2002)	**22.53**	**7.29**	**571.00**	**8.59**	**2.39**	**0.01**	**4.77**	**0.03**	**1.28**	**1.48**	**7.60**	**13.75**
8/5/2002 (High Flow)	22.78	7.01	580	10.61	1.5	0.0080	5.180	0.030	1.661	2.019	6.269	10.112
7/25/2006 (Low Flow CP1)	22.74	7.34	538	8.36		2	5.40	0.0388	1.72	2.7	<50	<10
9/14/2006 (Low Flow CP 2)	22.21	7.37	578	7.77		3	5.40	0.0362	1.19	2.09	<50	<10
Overall Average	**22.54**	**7.27**	**569.30**	**8.69**	**2.28**	**0.51**	**4.94**	**0.03**	**1.36**	**1.71**	**7.41**	**13.23**
Overall Minimum	**22.00**	**7.01**	**538.00**	**7.75**	**1.00**	**0.00**	**4.47**	**0.02**	**0.51**	**0.80**	**4.65**	**6.49**
Overall Maximum	**23.01**	**7.47**	**596.00**	**10.61**	**8.20**	**3.00**	**5.40**	**0.05**	**1.90**	**2.70**	**11.15**	**32.24**
Site 2												
10/31/2000	23.34	7.52	574	10.91	1.3	0.0010	4.760	0.032	1.200	2.330	4.093	3.345
3/5/2001	22.23	7.44	581	8.09	1.2	0.0040	4.571	0.082	1.350	1.800	15.674	16.187
5/7/2001	22.32	7.43	562	8.20	1.4	0.0640	4.569	0.084	1.390	1.630		
8/13/2001	22.68	7.29	598	7.20	1.1	0.0020	4.669	0.085	1.760	1.980	13.584	19.583
10/24/2001	22.71	7.46	580	7.95	0.9	0.0020	4.433	0.118	1.730	1.860	5.747	19.129
2/13/2002	21.75	7.23	559	8.73	1.1	0.0021	4.730	0.039	1.32	1.521	4.725	7.189
5/8/2002	22.83	7.15	537	8.69	1.1	0.0016	4.837	0.021	1.325	1.463	4.425	9.110
Average (10/2000-5/2002)	**22.55**	**7.36**	**570.14**	**8.54**	**1.16**	**0.01**	**4.65**	**0.07**	**1.44**	**1.80**	**8.04**	**12.42**
8/5/2002 (High Flow)	22.76	7.03	584	9.1	1.4	0.0080	5.180	0.043	1.169	1.396	5.573	9.562
7/25/2006 (Low Flow CP1)	23.20	7.39	535	7.94		0	5.20	0.0848	1.46	3.13	<50	<10
9/14/2006 (Low Flow CP 2)	22.02	7.37	575	7.75		2	5.20	0.0490	1.03	2.93	<50	<10
Overall Average	**22.58**	**7.33**	**568.50**	**8.46**	**1.19**	**0.21**	**4.81**	**0.06**	**1.37**	**2.00**	**7.69**	**12.02**
Overall Minimum	**21.75**	**7.03**	**535.00**	**7.20**	**0.90**	**0.00**	**4.43**	**0.02**	**1.03**	**1.40**	**4.09**	**3.35**
Overall Maximum	**23.34**	**7.52**	**598.00**	**10.91**	**1.40**	**2.00**	**5.20**	**0.12**	**1.76**	**3.13**	**15.67**	**19.58**

Water quality conditions at sites 1-9 on the San Marcos River during normal flows (10/2000-5/2002), a high-flow event (8/5/2002), and low-flow events (7/25/2006 and 9/14/2006).

Sampling Date	Temp	pH	Cond	D.O.	Turbidity (NTU)	TSS (mg/L)	Alkalinity (mEq/L)	NH_3-N (mg/L)	$N0_3$-N (mg/L)	TN-N (mg/L)	SRP (ugP/L)	TP (ug/L)
Site 3												
10/31/2000	23.33	7.42	607	8.63	2.2	0.0020	4.609	0.105	1.350	1.090	4.441	18.172
3/5/2001	21.82	7.53	609	7.53	2.1	0.0040	4.723	0.002	2.260	2.710	11.494	13.345
5/7/2001	22.62	7.48	588	6.90	2.0	0.0150	4.689	0.002	1.260	1.350		
8/13/2001	23.70	7.50	611	7.08	1.2	0.0030	4.631	0.002	2.100	2.300	8.011	16.859
10/24/2001	22.93	7.48	610	6.77	1.1	0.0030	4.433	0.007	1.610	1.630	6.792	21.765
2/13/2002	21.78	7.29	571	8.17	2	0.0023	4.664	0.096	1.439	1.635	4.609	12.659
5/8/2002	23.06	7.22	553	7.26	0.9	0.0019	4.631	0.072	1.395	1.647	4.225	14.752
Average (10/2000-5/2002)	**22.75**	**7.42**	**592.71**	**7.48**	**1.64**	**0.00**	**4.63**	**0.04**	**1.63**	**1.77**	**6.60**	**16.26**
8/5/2002 (High Flow)	22.9	7.07	598	8.17	1.4	0.004	5.18	0.023	1.598	1.719	10.101	15.273
7/25/2006 (Low Flow CP1)	23.62	7.37	563	6.18		3	5.40	0.0764	1.74	2.76	<50	<10
9/14/2006 (Low Flow CP 2)	22.74	7.29	598	5.76		2	5.40	0.0700	1.00	2.10	<50	<10
Overall Average	**22.85**	**7.37**	**590.80**	**7.25**	**1.61**	**0.50**	**4.84**	**0.05**	**1.57**	**1.89**	**7.10**	**16.12**
Overall Minimum	**21.78**	**7.07**	**553.00**	**5.76**	**0.90**	**0.00**	**4.43**	**0.00**	**1.00**	**1.09**	**4.23**	**12.66**
Overall Maximum	**23.70**	**7.53**	**611.00**	**8.63**	**2.20**	**3.00**	**5.40**	**0.10**	**2.26**	**2.76**	**11.49**	**21.77**
Site 4												
10/31/2000	23.28	7.66	575	11.60	1.9	0.0020	5.251	0.116	1.240	1.530	4.963	12.310
3/15/2001	22.50	7.49	583	8.90	2.0	0.0020	4.899	0.099	1.400	1.900	15.998	24.152
5/7/2001	22.31	7.45	560	8.45		0.0940	4.761	0.024	1.500	1.750		
8/13/2001	22.76	7.42	595	8.25	1.3	0.0050	4.681	0.018	1.680	1.800	21.072	29.332
10/24/2001	23.06	7.53	579	8.81	1.2	0.0040	4.383		1.610	1.630	9.927	29.895
2/13/2002	21.84	7.26	559	9.68	1.3	0.0016	4.73	0.120	1.328	1.449	5.251	15.215
5/8/2002	22.92	7.17	538	9.27	1.1	0.0025	4.764	0.106	1.415	1.592	5.015	15.115
Average (10/2000-5/2002)	**22.67**	**7.43**	**569.86**	**9.28**	**1.47**	**0.02**	**4.78**	**0.08**	**1.45**	**1.66**	**10.37**	**21.00**
8/5/2002 (High Flow)	22.83	7.03	583	10.91	1.6	0.0060	5.18	0.018	1.116	1.299	7.837	14.903
7/25/2006 (Low Flow CP1)	22.78	7.40	544	8.29		3	5.40	0.0703	1.65	2.65	<50	<10
9/14/2006 (Low Flow CP 2)	21.92	7.38	575	9.68		5	5.40	0.0583	1.11	2.11	<50	<10
Overall Average	**22.62**	**7.38**	**569.10**	**9.38**	**1.49**	**0.81**	**4.94**	**0.07**	**1.40**	**1.77**	**10.01**	**20.13**
Overall Minimum	**21.84**	**7.03**	**538.00**	**8.25**	**1.10**	**0.00**	**4.38**	**0.02**	**1.11**	**1.30**	**4.96**	**12.31**
Overall Maximum	**23.28**	**7.66**	**595.00**	**11.60**	**2.00**	**5.00**	**5.40**	**0.12**	**1.68**	**2.65**	**21.07**	**29.90**

Water quality conditions at sites 1-9 on the San Marcos River during normal flows (10/2000-5/2002), a high-flow event (8/5/2002), and low-flow events (7/25/2006 and 9/14/2006).

Sampling Date	Temp	pH	Cond	D.O.	Turbidity (NTU)	TSS (mg/L)	Alkalinity (mEq/L)	NH$_3$-N (mg/L)	N0$_3$-N (mg/L)	TN-N (mg/L)	SRP (ugP/L)	TP (ug/L)
Site 5												
10/31/2000	22.85	7.57	579	11.68	2.1	0.0010	4.573	0.127	1.390	2.820	3.966	9.552
3/5/2001	22.64	7.62	581	10.15	2.2	0.0020	4.723	0.007	1.220	1.630	16.544	18.361
5/7/2001	22.13	7.54	559	8.81	2.2	0.0590	4.785	0.114	2.120	2.360		
8/13/2001	22.76	7.46	596	8.92	1.5	0.0040	4.830	0.000	1.770	1.900	2.264	13.927
10/24/2001	23.28	7.60	579	9.79	1.4	0.0040	4.433	0.127	1.490	1.630	0.697	2.969
2/13/2002	21.66	7.29	560	12.32	1.4	0.0023	4.71	0.123	1.306	1.763	4.008	12.986
5/8/2002	23.18	7.33	537	10.4	1.3	0.0023	4.919	0.121	1.422	1.776	4.985	15.869
Average (10/2000-5/2002)	**22.64**	**7.49**	**570.14**	**10.30**	**1.73**	**0.01**	**4.71**	**0.09**	**1.53**	**1.98**	**5.41**	**12.28**
8/5/2002 (High Flow)	23.17	7.14	582	11.5	1.6	0.007	5.24	0.03	1.218	1.41	8.535	16.173
7/25/2006 (Low Flow CP1)	22.95	7.50	540	8.81		1	5.20	0.0521	1.60	3.19	<50	<10
9/14/2006 (Low Flow CP 2)	21.79	7.41	577	6.64		3	5.20	0.0478	1.06	2.29	<50	<10
Overall Average	**22.64**	**7.45**	**569.00**	**9.90**	**1.71**	**0.41**	**4.86**	**0.07**	**1.46**	**2.08**	**5.86**	**12.83**
Overall Minimum	**21.66**	**7.14**	**537.00**	**6.64**	**1.30**	**0.00**	**4.43**	**0.00**	**1.06**	**1.41**	**0.70**	**2.97**
Overall Maximum	**23.28**	**7.62**	**596.00**	**12.32**	**2.20**	**3.00**	**5.24**	**0.13**	**2.12**	**3.19**	**16.54**	**18.36**
Site 6												
10/31/2000	22.64	7.67	576	10.88	2.3	0.0020	4.496	0.127	1.450	1.120	5.486	10.931
3/5/2001	22.58	7.78	583	9.58	1.7	0.0070	4.741	0.016	1.640	2.260	19.853	31.621
5/7/2001	21.98	7.65	560	8.22	1.9	0.0910	4.948	0.030	1.330	1.460		
8/13/2001	22.61	7.61	596	8.21	1.8	0.0060	5.028	0.023	1.790	1.960	1.219	10.129
10/24/2001	23.24	7.74	578	8.95	1.6	0.0040	4.466		1.500	1.510	2.612	9.658
2/13/2002	21.04	7.41	559	10.88	1.5	0.0026	4.764	0.116	1.121	1.215	5.696	10.125
5/8/2002	23.19	7.45	537	9.5	1.3	0.0022	4.774	0.099	1.119	1.396	5.125	14.235
Average (10/2000-5/2002)	**22.47**	**7.62**	**569.86**	**9.46**	**1.73**	**0.02**	**4.75**	**0.07**	**1.42**	**1.56**	**6.67**	**14.45**
8/5/2002 (High Flow)	23.12	7.26	582	10.48	1.9	0.006	5.26	0.028	1.218	1.658	8.011	14.305
7/25/2006 (Low Flow CP1)	22.68	7.56	543	7.63		0	5.40	0.0606	1.61	2.62	<50	<10
9/14/2006 (Low Flow CP 2)	21.68	7.56	576	8.00		5	5.40	0.0536	1.09	2.17	<50	<10
Overall Average	**22.48**	**7.57**	**569.00**	**9.23**	**1.75**	**0.51**	**4.93**	**0.06**	**1.39**	**1.74**	**6.86**	**14.43**
Overall Minimum	**21.04**	**7.26**	**537.00**	**7.63**	**1.30**	**0.00**	**4.47**	**0.02**	**1.09**	**1.12**	**1.22**	**9.66**
Overall Maximum	**23.24**	**7.78**	**596.00**	**10.88**	**2.30**	**5.00**	**5.40**	**0.13**	**1.79**	**2.62**	**19.85**	**31.62**

Water quality conditions at sites 1-9 on the San Marcos River during normal flows (10/2000-5/2002), a high-flow event (8/5/2002), and low-flow events (7/25/2006 and 9/14/2006).

Sampling Date	Temp	pH	Cond	D.O.	Turbidity (NTU)	TSS (mg/L)	Alkalinity (mEq/L)	NH_3-N (mg/L)	$N0_3$-N (mg/L)	TN-N (mg/L)	SRP (ugP/L)	TP (ug/L)
Site 7												
10/31/2000	22.57	7.67	580	8.37	3.8	0.0040	4.609	0.005	1.010	1.150	4.441	9.207
3/5/2001	21.68	7.91	578	11.47	1.9	0.0060	4.741	0.005	1.890	2.350	17.241	9.552
5/7/2001	21.69	7.64	559	7.59	2.0	0.0900	4.652	0.005	0.670	0.990		
8/13/2001	22.39	7.60	596	6.63	2.9	0.0080	4.664	0.005	1.460	1.610	3.831	12.279
10/24/2001	22.81	7.67	579	8.78	2.5	0.0050	4.433	0.004	1.250	1.300	5.399	14.256
2/13/2002	20.09	7.43	558	8.70	1.3	0.0043	4.680	0.077	1.662	1.950	4.810	9.600
5/8/2002	22.76	7.39	537	9.05	1.2	0.0042	4.695	0.079	1.376	1.502	4.696	11.195
Average (10/2000-5/2002)	**22.00**	**7.62**	**569.57**	**8.66**	**2.23**	**0.02**	**4.64**	**0.03**	**1.33**	**1.55**	**6.74**	**11.01**
8/5/2002 (High Flow)	22.71	7.27	583	10.00	2.1	0.0220	5.180	0.068	1.577	1.948	49.459	52.493
7/25/2006 (Low Flow CP1)	22.85	7.52	540	6.69		3	5.40	0.0618	1.56	3.71	<50	<10
9/14/2006 (Low Flow CP 2)	21.80	7.53	576	6.53		5	5.20	0.0770	1.04	3.08	<50	<10
Overall Average	**22.14**	**7.56**	**568.60**	**8.38**	**2.21**	**0.81**	**4.83**	**0.04**	**1.35**	**1.96**	**12.84**	**16.94**
Overall Minimum	**20.09**	**7.27**	**537.00**	**6.53**	**1.20**	**0.00**	**4.43**	**0.00**	**0.67**	**0.99**	**3.83**	**9.21**
Overall Maximum	**22.85**	**7.91**	**596.00**	**11.47**	**3.80**	**5.00**	**5.40**	**0.08**	**1.89**	**3.71**	**49.46**	**52.49**
Site 8												
10/31/2000	22.50	7.74	579	9.80	3.7	0.0040	4.647	0.021	1.050	1.380	3.918	11.621
3/5/2001	22.19	7.89	581	9.28	2.0	0.0040	4.798	0.081	1.280	1.630	16.893	18.517
5/7/2001	21.81	7.73	560	7.99	1.9	0.1360	4.698	0.014	1.410	1.600		
8/13/2001	22.51	7.72	596	7..68	2.5	0.0070	4.648	0.062	1.620	1.710	1.742	9.853
10/24/2001	22.95	7.85	579	8.74	2.4	0.0060	4.532	0.080	1.510	1.630	2.961	9.958
2/13/2002	20.60	7.51	558	9.35	1.9	0.0045	4.730	0.036	1.105	1.347	3.998	11.625
5/8/2002	22.97	7.55	537	9.07	1.5	0.0046	4.996	0.042	1.252	1.401	4.895	12.658
Average (10/2000-5/2002)	**22.22**	**7.71**	**570.00**	**9.04**	**2.27**	**0.02**	**4.72**	**0.05**	**1.32**	**1.53**	**5.73**	**12.37**
8/5/2002 (High Flow)	22.97	7.37	582	9.83	1.9	0.0060	5.22	0.036	1.207	1.616	8.882	14.362
7/25/2006 (Low Flow CP1)	22.81	7.66	542	7.58		4	5.20	0.0545	1.56	2.63	<50	25.60
9/14/2006 (Low Flow CP 2)	21.74	7.68	576	7.65		10	5.40	0.0560	1.06	2.16	<50	<10
Overall Average	**22.31**	**7.67**	**569.00**	**8.81**	**2.23**	**1.42**	**4.89**	**0.05**	**1.31**	**1.71**	**6.18**	**14.27**
Overall Minimum	**20.60**	**7.37**	**537.00**	**7.58**	**1.50**	**0.00**	**4.53**	**0.01**	**1.05**	**1.35**	**1.74**	**9.85**
Overall Maximum	**22.97**	**7.89**	**596.00**	**9.83**	**3.70**	**10.00**	**5.40**	**0.08**	**1.62**	**2.63**	**16.89**	**25.60**

Water quality conditions at sites 1-9 on the San Marcos River during normal flows (10/2000-5/2002), a high-flow event (8/5/2002), and low-flow events (7/25/2006 and 9/14/2006).

Sampling Date	Temp	pH	Cond	D.O.	Turbidity (NTU)	TSS (mg/L)	Alkalinity (mEq/L)	NH_3-N (mg/L)	$N0_3$-N (mg/L)	TN-N (mg/L)	SRP (ugP/L)	TP (ug/L)
Site 9												
10/31/2000	22.62	7.78	575	10.39	4.6	0.0080	4.364	0.057	1.200	1.600	4.615	18.517
3/5/2001	21.85	7.88	582	9.45	2.5	0.0020	4.836	0.030	1.300	1.700	20.724	15.069
5/7/2001	21.74	7.73	559	7.90	2.5	0.1210	4.598	0.043	1.200	1.430		
8/13/2001	22.55	7.66	593	7.75	3.1	0.0080	4.598	0.026	1.650	1.960	30.825	33.985
10/24/2001	22.73	7.41	579	8.54	2.9	0.0060	4.333	0.012	1.370	1.390	1.567	4.958
2/13/2002	20.24	7.49	557	9.58	2.1	0.0084	4.367	0.056	1.012	1.095	5.252	19.521
5/8/2002	22.80	7.36	531	9.29	1.7	0.0078	4.565	0.065	1.215	1.364	4.598	17.958
Average (10/2000-5/2002)	**22.08**	**7.62**	**568.00**	**8.99**	**2.77**	**0.02**	**4.52**	**0.04**	**1.28**	**1.51**	**11.26**	**18.33**
8/5/2002 (High Flow)	22.65	7.38	581	9.46	2.2	0.0070	5.180	0.071	1.217	1.542	6.269	15.989
7/25/2006 (Low Flow CP1)	23.10	7.79	531	7.45		7	5.20	0.0873	1.51	3.62	<50	46.20
9/14/2006 (Low Flow CP 2)	22.02	7.73	566	8.07		9	5.20	0.0595	0.99	3.65	<50	<10
Overall Average	**22.23**	**7.62**	**565.40**	**8.79**	**2.70**	**1.62**	**4.72**	**0.05**	**1.27**	**1.94**	**10.55**	**21.52**
Overall Minimum	**20.24**	**7.36**	**531.00**	**7.45**	**1.70**	**0.00**	**4.33**	**0.01**	**0.99**	**1.10**	**1.57**	**4.96**
Overall Maximum	**23.10**	**7.88**	**593.00**	**10.39**	**4.60**	**9.00**	**5.20**	**0.09**	**1.65**	**3.65**	**30.83**	**46.20**

Water quality conditions at sites A-S in Spring Lake during normal flows (10/2000-5/2002), a high-flow event (8/5/2002), and low-flow events (7/25/2006 and 9/14/2006).

Sampling Date	Temp	pH	Cond	D.O.	Turbidity (NTU)	TSS (mg/L)	Alkalinity (mEq/L)	NH$_3$-N (mg/L)	N0$_3$-N (mg/L)	TN-N (mg/L)	SRP (ugP/L)	TP (ug/L)
Site A												
10/31/2000	22.36	7.24	566	6.33	1.3	0.0004	4.8736	0.048	1.4066	0.83	54.248	2.6552
3/6/2001	21.49	7.17	596	4.5	0.9	0.0004	5.087	0.03	1.0393	1.196	11.146	36.963
5/14/2001	21.52	7.23	567	4.9	1.4	0.0018	3.986	0.004	1.0956	2.293	13.792	36.945
8/15/2001	22.1	7.26	*566*	6.8	1.4	0.002	4.664	0.025	1.2275	1.295	3.235	10.129
10/30/2001	21.6	7.15	546	5.44	1	0.004	4.201	0.139	0.9298	1.251	2.724	16.421
2/14/2002	21.46	6.91	568	4.58	1.1	0.0004	4.764	0.032	1.913	2.145	11.416	17.925
5/22/2002	21.55	6.82	530	6.24	1	0.0019	4.917	0.005	1.216	1.469	12.973	26.285
Average (10/2000-5/2002)	**21.73**	**7.11**	**562.71**	**5.54**	**1.16**	**0.00**	**4.64**	**0.04**	**1.26**	**1.50**	**15.65**	**21.05**
8/7/2002 (High Flow)	21.56	6.8	577	4.81	1.1	0.427	5.258	0.032	2.621	2.458	9.875	4.724
7/25/2006 (Low Flow CP1)	21.70	7.13	517	4.51		1	5.20	0.0424	1.63	3.99	<50	<10
9/14/2006 (Low Flow CP 2)	22.02	7.11	566	6.24		0	5.20	0.0362	1.01	3.07	<50	<10
Overall Average	**21.74**	**7.08**	**559.90**	**5.44**	**1.15**	**0.14**	**4.82**	**0.04**	**1.41**	**2.00**	**14.93**	**19.01**
Overall Minimum	**21.46**	**6.80**	**517.00**	**4.50**	**0.90**	**0.00**	**3.99**	**0.00**	**0.93**	**0.83**	**2.72**	**2.66**
Overall Maximum	**22.36**	**7.26**	**596.00**	**6.80**	**1.40**	**1.00**	**5.26**	**0.14**	**2.62**	**3.99**	**54.25**	**36.96**
Site B												
10/31/2000	22.44	7.26	564	8.15	1.2	0.001	4.8358	0.098	1.2779	0.9571	45.54	N/A
3/6/2001	21.73	7.22	584	5.61	0.9	0.0003	4.853	0.009	1.4241	1.633	13.932	171.97
5/14/2001	21.84	7.24	566	5.69	1.4	0.0012	3.986	0.008	1.542	3.129	10.897	29.495
8/15/2001	22.25	7.25	*567*	5.82	1.4	0.01	4.995	0.071	1.2363	1.312	30.648	35.468
10/30/2001	22.1	7.23	541	6.33	0.9	0.009	4.3	0.039	0.9289	1.105	2.213	9.125
2/14/2002	21.52	6.94	562	5.13	1	0.0005	4.598	0.019	1.431	1.679	12.392	14.959
5/22/2002	21.91	6.85	524	6.9	0.9	0.0016	4.977	0.011	1.451	1.623	11.898	27.615
Average (10/2000-5/2002)	**21.97**	**7.14**	**558.29**	**6.23**	**1.10**	**0.00**	**4.65**	**0.04**	**1.33**	**1.63**	**18.22**	**48.10**
8/7/2002 (High Flow)	21.63	6.83	574	4.74	1.2	0.343	5.218	0.017	1.608	2.218	13.111	21.965
7/25/2006 (Low Flow CP1)	23.17	7.18	530	6.06		2	5.00	0.0558	1.31	2.43	<50	<10
9/14/2006 (Low Flow CP 2)	22.27	7.11	572	5.90		0	5.20	0.0455	1.10	2.40	<50	<10
Overall Average	**22.09**	**7.11**	**558.40**	**6.03**	**1.11**	**0.24**	**4.80**	**0.04**	**1.33**	**1.85**	**17.58**	**44.37**
Overall Minimum	**21.52**	**6.83**	**524.00**	**4.74**	**0.90**	**0.00**	**3.99**	**0.01**	**0.93**	**0.96**	**2.21**	**9.13**
Overall Maximum	**23.17**	**7.26**	**584.00**	**8.15**	**1.40**	**2.00**	**5.22**	**0.10**	**1.61**	**3.13**	**45.54**	**171.97**

Water quality conditions at sites A-S in Spring Lake during normal flows (10/2000-5/2002), a high-flow event (8/5/2002), and low-flow events (7/25/2006 and 9/14/2006).

Sampling Date	Temp	pH	Cond	D.O.	Turbidity (NTU)	TSS (mg/L)	Alkalinity (mEq/L)	NH_3-N (mg/L)	$N0_3$-N (mg/L)	TN-N (mg/L)	SRP (ugP/L)	TP (ug/L)
Site C												
10/31/2000	22.42	7.17	576	7.07	1.2	0.0008	5.2703	0.061	1.4784	1.3109	36.833	6.1034
3/6/2001	22.01	7.22	581	6.18	1	0.0005	4.989	0.001	1.4881	1.798	15.674	29.552
5/14/2001	22.06	7.22	562	6.09	1.6	0.001	4.168	0.001	1.526	3.069	9.365	18.095
8/15/2001	22.73	7.28	*566*	7.34	1.6	0.003	5.657	0.025	1.2276	1.265	9.705	21.639
10/30/2001	22.1	7.19	550	5.87	1	0.005	4.4	0.032	1.7579	2.197	2.895	10.126
2/14/2002	21.85	6.94	555	5.84	1.1	0.0004	4.697	0.0014	1.581	1.656	12.657	13.215
5/22/2002	22.11	6.86	527	6.79	1.1	0.0012	4.997	0.0012	1.525	1.928	10.346	20.329
Average (10/2000-5/2002)	**22.18**	**7.13**	**559.57**	**6.45**	**1.23**	**0.00**	**4.88**	**0.02**	**1.51**	**1.89**	**13.93**	**17.01**
8/7/2002 (High Flow)	22	6.81	562	5.66	1.2	0.2	5.218	0.039	1.813	2.325	8.003	18.172
7/25/2006 (Low Flow CP1)	22.73	7.22	526	7.90		1	5.20	0.0655	1.38	4.25	<50	<10
9/14/2006 (Low Flow CP 2)	22.99	7.20	567	6.60		1	5.20	0.0536	0.94	3.92	<50	<10
Overall Average	**22.30**	**7.11**	**557.20**	**6.53**	**1.23**	**0.22**	**4.98**	**0.03**	**1.47**	**2.37**	**13.18**	**17.15**
Overall Minimum	**21.85**	**6.81**	**526.00**	**5.66**	**1.00**	**0.00**	**4.17**	**0.00**	**0.94**	**1.27**	**2.90**	**6.10**
Overall Maximum	**22.99**	**7.28**	**581.00**	**7.90**	**1.60**	**1.00**	**5.66**	**0.07**	**1.81**	**4.25**	**36.83**	**29.55**
Site D												
10/31/2000	22.79	7.21	578	8.38	1.2	0.001	5.3459	0.025	1.6596	1.6445	48.327	9.2064
3/6/2001	22.09	7.26	582	6.92	1.1	0.0019	4.931	0.001	1.6759	1.936	13.235	76.103
5/14/2001	22.46	7.24	561	7.38	1.6	0.0008	4.052	0.001	1.892	3.895	9.024	18.196
8/15/2001	23.96	7.33	*569*	12.01	1.6	0.013	5.987	0.227	1.1239	1.361	16.346	33.459
10/30/2001	22.32	7.22	554	6.84	1	0.016	4.201	0.08	1.314	1.525	3.576	15.936
2/14/2002	21.78	7.05	556	8.16	0.9	0.002	4.664	0.001	1.756	1.921	13.335	18.658
5/22/2002	22.4	6.9	527	9.46	1	0.0009	5.058	0.0011	1.925	2.105	9.136	18.628
Average (10/2000-5/2002)	**22.54**	**7.17**	**561.00**	**8.45**	**1.20**	**0.01**	**4.89**	**0.05**	**1.62**	**2.06**	**16.14**	**27.17**
8/7/2002 (High Flow)	22.28	6.83	564	6.39	1.2	0.343	5.138	0.035	1.659	2.109	6.811	27.828
7/25/2006 (Low Flow CP1)	23.14	7.13	545	7.05		1	5.20	0.0836	1.61	2.52	<50	<10
9/14/2006 (Low Flow CP 2)	22.53	7.09	581	5.94		3	5.40	0.0466	1.11	2.04	<50	<10
Overall Average	**22.58**	**7.13**	**561.70**	**7.85**	**1.20**	**0.44**	**5.00**	**0.05**	**1.57**	**2.11**	**14.97**	**27.25**
Overall Minimum	**21.78**	**6.83**	**527.00**	**5.94**	**0.90**	**0.00**	**4.05**	**0.00**	**1.11**	**1.36**	**3.58**	**9.21**
Overall Maximum	**23.96**	**7.33**	**582.00**	**12.01**	**1.60**	**3.00**	**5.99**	**0.23**	**1.93**	**3.90**	**48.33**	**76.10**

Water quality conditions at sites A-S in Spring Lake during normal flows (10/2000-5/2002), a high-flow event (8/5/2002), and low-flow events (7/25/2006 and 9/14/2006).

Sampling Date	**Temp**	**pH**	**Cond**	**D.O.**	**Turbidity (NTU)**	**TSS (mg/L)**	**Alkalinity (mEq/L)**	**NH_3-N (mg/L)**	**$N0_3$-N (mg/L)**	**TN-N (mg/L)**	**SRP (ugP/L)**	**TP (ug/L)**
Site E												
10/31/2000	23.11	7.56	573	9.96	1.3	0.0006	5.0247	0.095	1.556	1.1247	49.894	8.1724
3/6/2001	22.01	7.35	583	8.86	1	0.0004	4.911	0.002	2.291	2.459	10.971	155.41
5/14/2001	22.72	7.28	562	8.18	1.4	0.104	3.391	0.003	1.591	3.279	9.194	24.965
8/15/2001	23.07	7.22	*574*	8.18	1.4	0.003	6.318	0.032	1.5208	1.562	9.875	22.495
10/30/2001	22.48	7.29	546	8.33	1.1	0.006	4.4	0.023	1.2889	1.462	1.703	12.198
2/14/2002	21.92	7.06	556	8.08	1.1	0.0006	4.697	0.0021	2.115	2.314	11.097	15.128
5/22/2002	22.6	6.95	526	8.61	1.1	0.0015	5.098	0.0034	1.657	1.812	9.298	21.429
Average (10/2000-5/2002)	**22.56**	**7.24**	**560.00**	**8.60**	**1.20**	**0.02**	**4.83**	**0.02**	**1.72**	**2.00**	**14.58**	**37.11**
8/7/2002 (High Flow)	22.44	6.87	568	6.68	1.2	0.014	5.138	0.043	1.532	1.952	8.684	43.345
7/25/2006 (Low Flow CP1)	23.57	7.18	536	6.94		1	5.20	0.0715	1.42	2.34	<50	<10
9/14/2006 (Low Flow CP 2)	22.05	7.20	575	6.04		0	5.40	0.0805	1.02	1.89	<50	<10
Overall Average	**22.60**	**7.20**	**559.90**	**7.99**	**1.20**	**0.11**	**4.96**	**0.04**	**1.60**	**2.02**	**13.84**	**37.89**
Overall Minimum	**21.92**	**6.87**	**526.00**	**6.04**	**1.00**	**0.00**	**3.39**	**0.00**	**1.02**	**1.12**	**1.70**	**8.17**
Overall Maximum	**23.57**	**7.56**	**583.00**	**9.96**	**1.40**	**1.00**	**6.32**	**0.10**	**2.29**	**3.28**	**49.89**	**155.41**
Site F												
10/31/2000	23.93	7.43	564	10.68	1.7	0.001	4.6923	0.050	0.8868	1.0168	40.316	7.8276
3/6/2001	22.48	7.61	574	13.8	0.9	0.001	4.892	0.036	0.8629	1.1106	13.584	6.7931
5/14/2001	24.06	7.29	507	2.86	1.9	0.002	4.118	0.019	0.5629	1.265	18.729	39.564
8/15/2001	26.89	7.37	*560*	7.98	1.9	0.004	6.98	0.166	0.2482	0.0512	23.667	39.498
10/30/2001	23.04	7.34	539	8.23	1.1	0.009	4.4	0.043	1.2582	1.399	2.554	11.109
2/14/2002	22.12	7.12	554	10.26	1.3	0.0012	4.73	0.039	1.195	1.459	13.584	19.584
5/22/2002	24.28	7.27	517	13.26	1.2	0.0035	5.001	0.0023	1.215	1.583	16.982	34.294
Average (10/2000-5/2002)	**23.83**	**7.35**	**545.00**	**9.58**	**1.43**	**0.00**	**4.97**	**0.05**	**0.89**	**1.13**	**18.49**	**22.67**
8/7/2002 (High Flow)	25.49	7.13	600	6.24	1.6	0.068	5.298	0.035	1.431	1.813	8.513	27.828
7/25/2006 (Low Flow CP1)	22.78	7.16	537	7.51		0	5.20	0.0752	1.18	2.14	<50	<10
9/14/2006 (Low Flow CP 2)	22.43	7.15	571	5.68		0	5.20	0.0455	1.06	2.08	<50	<10
Overall Average	**23.75**	**7.29**	**552.30**	**8.65**	**1.45**	**0.01**	**5.05**	**0.05**	**0.99**	**1.39**	**17.24**	**23.31**
Overall Minimum	**22.12**	**7.12**	**507.00**	**2.86**	**0.90**	**0.00**	**4.12**	**0.00**	**0.25**	**0.05**	**2.55**	**6.79**
Overall Maximum	**26.89**	**7.61**	**600.00**	**13.80**	**1.90**	**0.07**	**6.98**	**0.17**	**1.43**	**2.14**	**40.32**	**39.56**

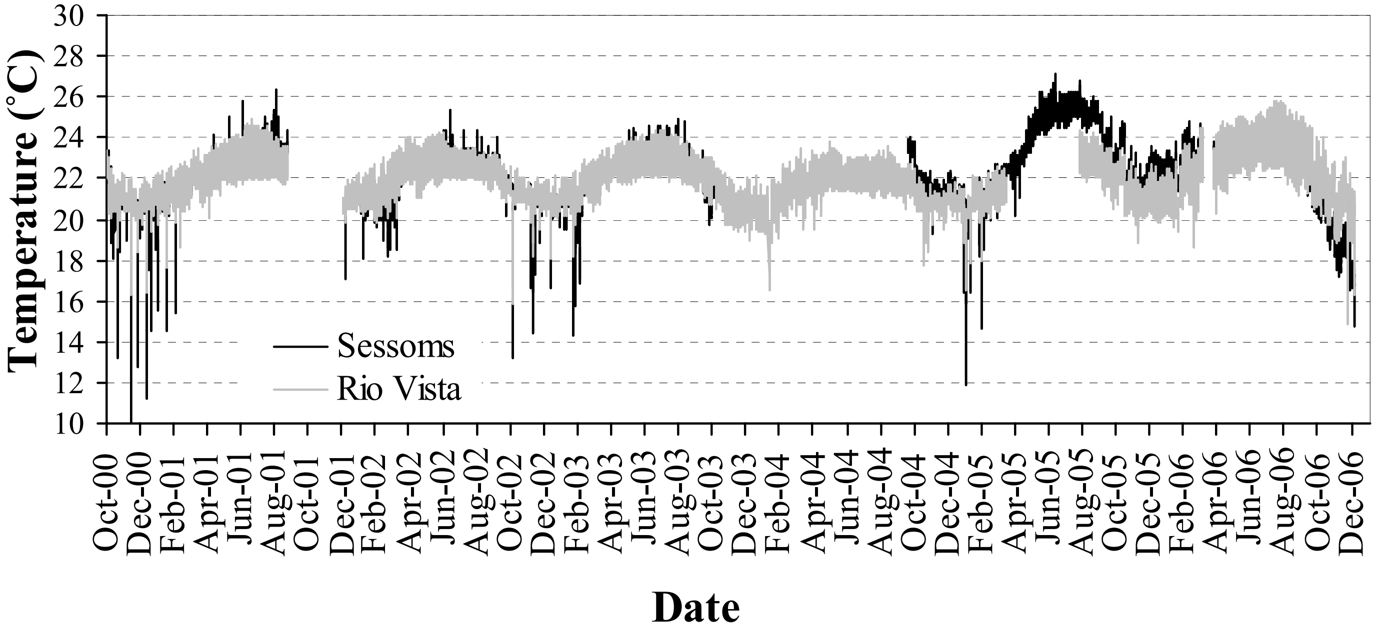
Water quality conditions at sites A-S in Spring Lake during normal flows (10/2000-5/2002), a high-flow event (8/5/2002), and low-flow events (7/25/2006 and 9/14/2006).

Sampling Date	Temp	pH	Cond	D.O.	Turbidity (NTU)	TSS (mg/L)	Alkalinity (mEq/L)	NH_3-N (mg/L)	$N0_3$-N (mg/L)	TN-N (mg/L)	SRP (ugP/L)	TP (ug/L)
Site G												
10/31/2000	24.16	7.4	546	5.18	1.8	0.012	4.817	0.025	0.6094	0.5828	34.046	13
3/6/2001	18.45	8	577	11.99	1.2	0.015	4.892	0.059	0.5997	1.1009	17.763	87.483
5/14/2001	25.55	7.46	517	6.04	2.2	0.006	3.341	0.051	0.6104	1.326	48.526	117.96
8/15/2001	26.35	7.27	*571*	4.44	2.2	0.005	7.311	0.102	0.2667	0.0495	32.351	44.349
10/30/2001	20.67	7.71	536	11.68	1.1	0.009	4.267	0.043	0.5727	0.895	0.17	9.985
2/14/2002	20.47	7.18	553	7.8	1.9	0.0019	4.73	0.056	1.094	1.215	17.623	22.989
5/22/2002	24.29	7.44	489	9.37	1.2	0.0065	4.255	0.0039	1.009	1.198	19.546	39.197
Average (10/2000-5/2002)	**22.85**	**7.49**	**541.29**	**8.07**	**1.66**	**0.01**	**4.80**	**0.05**	**0.68**	**0.91**	**24.29**	**47.85**
8/7/2002 (High Flow)	26.16	7.2	607	6.38	1.9	0.324	5.138	0.048	1.174	1.598	10.386	64.724
7/25/2006 (Low Flow CP1)	28.54	7.26	486	1.90		7	3.80	0.0788	0	1.05	<50	<10
9/14/2006 (Low Flow CP 2)	25.48	7.31	545	5.40		7	4.60	0.0910	0.33	1.38	<50	<10
Overall Average	**24.01**	**7.42**	**542.70**	**7.02**	**1.69**	**1.44**	**4.72**	**0.06**	**0.63**	**1.04**	**22.55**	**49.96**
Overall Minimum	**18.45**	**7.18**	**486.00**	**1.90**	**1.10**	**0.00**	**3.34**	**0.00**	**0.00**	**0.05**	**0.17**	**9.99**
Overall Maximum	**28.54**	**8.00**	**607.00**	**11.99**	**2.20**	**7.00**	**7.31**	**0.10**	**1.17**	**1.60**	**48.53**	**117.96**
Site H												
10/31/2000	24.51	7.74	528	7.88	1.8	0.182	4.4769	0.098	0.2712	1.1057	39.445	10.931
3/6/2001	19.61	8.25	586	18.72	1.6	0.295	4.911	0.012	0.6104	1.1029	16.893	6.1034
5/14/2001	23.69	7.28	575	4.22	1.9	0.006	4.003	0.009	0.6593	1.354	28.605	56.498
8/15/2001	28.73	7.42	*581*	4.95	1.9	0.008	7.641	0.116	0.1521	0.0326	3.746	18.934
10/30/2001	20.65	7.53	563	9.2	1.7	0.095	4.201	0.036	0.2073	0.3651	1.192	12.528
2/14/2002	16.68	7.49	580	14.21	2.6	0.0025	4.764	0.032	0.9985	1.105	17.974	21.542
5/22/2002	23.54	7.59	519	11.31	1.4	0.0074	4.536	0.008	1.015	1.128	26.212	42.158
Average (10/2000-5/2002)	**22.49**	**7.61**	**561.71**	**10.07**	**1.84**	**0.09**	**4.93**	**0.04**	**0.56**	**0.88**	**19.15**	**24.10**
8/7/2002 (High Flow)	24.79	7.11	615	4.6	1.9	0.125	5.339	0.046	1.251	1.692	8.343	27.138
7/25/2006 (Low Flow CP1)	24.77	7.20	502	2.32		2	4.40	0.0824	0	1.01	<50	<10
9/14/2006 (Low Flow CP 2)	23.01	7.13	544	0.83		0	4.80	0.1180	0	1.12	<50	<10
Overall Average	**23.00**	**7.47**	**559.30**	**7.82**	**1.85**	**0.27**	**4.91**	**0.06**	**0.52**	**1.00**	**17.80**	**24.48**
Overall Minimum	**16.68**	**7.11**	**502.00**	**0.83**	**1.40**	**0.00**	**4.00**	**0.01**	**0.00**	**0.03**	**1.19**	**6.10**
Overall Maximum	**28.73**	**8.25**	**615.00**	**18.72**	**2.60**	**2.00**	**7.64**	**0.12**	**1.25**	**1.69**	**39.45**	**56.50**

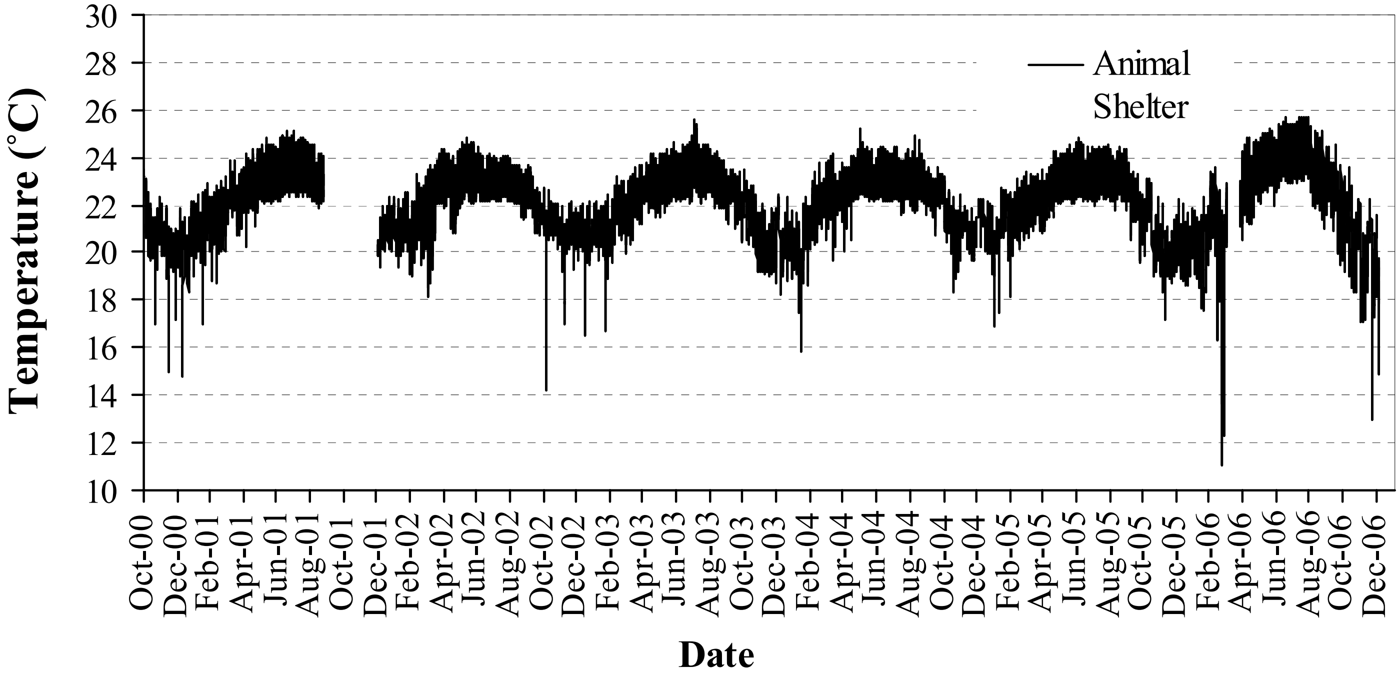
Water quality conditions at sites A-S in Spring Lake during normal flows (10/2000-5/2002), a high-flow event (8/5/2002), and low-flow events (7/25/2006 and 9/14/2006).

Sampling Date	Temp	pH	Cond	D.O.	Turbidity (NTU)	TSS (mg/L)	Alkalinity (mEq/L)	NH_3-N (mg/L)	$N0_3$-N (mg/L)	TN-N (mg/L)	SRP (ugP/L)	TP (ug/L)
Site S												
10/31/2000												
4/2/2001	21.28	7.72	689	7.86	2.7	0.196	5.769	0.068	0.3442	1.151	55.38	117.64
5/14/2001	23.07	7.56	587	4.53	5.1	0.409	4.615	0.059	0.4296	1.236	88.709	129.86
8/15/2001												
10/30/2001	20.7	7.58	773	3.45	7.7	0.41	6.9635	0.027	0.0477	0.0985	11.578	32.195
2/14/2002	15.6	7.83	564	15.05	3.3	0.0039	4.929	0.059	0.0654	1.119	22.497	29.258
5/22/2002	22.42	6.84	599	2.3	1.7	0.0035	5.519	0.0034	0.0895	1.085	15.695	54.295
Average (10/2000-5/2002)	**20.61**	**7.51**	**642.40**	**6.64**	**4.10**	**0.20**	**5.56**	**0.04**	**0.20**	**0.94**	**38.77**	**72.65**
8/7/2002 (High Flow)	23.59	7.17	610	5.98	2.1	0.173	5.419	0.043	1.404	1.894	19.07	58.517
7/25/2006 (Low Flow CP1)	24.83	7.19	509	2.18		6	4.40	0.0752	0.167	2.73	<50	<10
9/14/2006 (Low Flow CP 2)	23.21	7.13	559	2.86		11	4.80	0.0618	0	1.99	<50	<10
Overall Average	**21.84**	**7.38**	**611.25**	**5.53**	**3.77**	**2.27**	**5.30**	**0.05**	**0.32**	**1.41**	**35.49**	**70.29**
Overall Minimum	**15.6**	**6.84**	**509**	**2.18**	**1.7**	**0.0035**	**4.4**	**0.0034**	**0**	**0.0985**	**11.578**	**29.258**
Overall Maximum	**24.83**	**7.83**	**773**	**15.05**	**7.7**	**11**	**6.9635**	**0.0752**	**1.404**	**2.73**	**88.709**	**129.86**

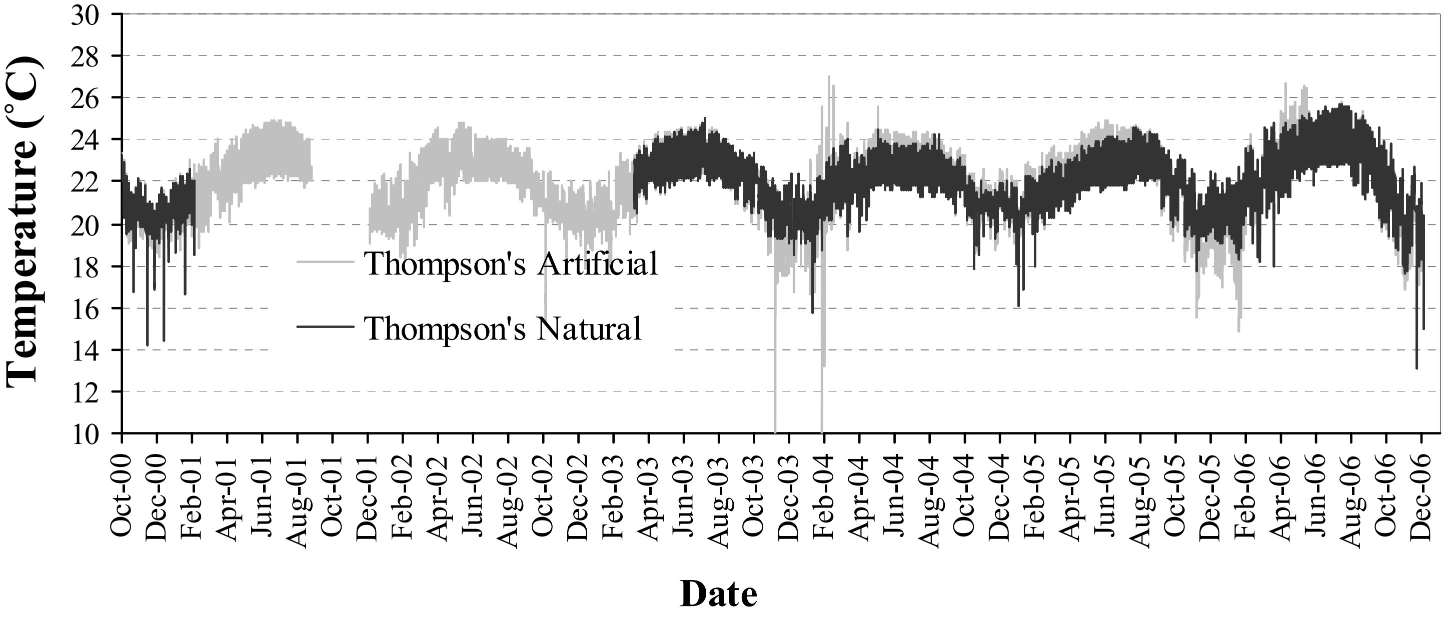
Thermistor Data: Sessoms Creek and Rio Vista Dam



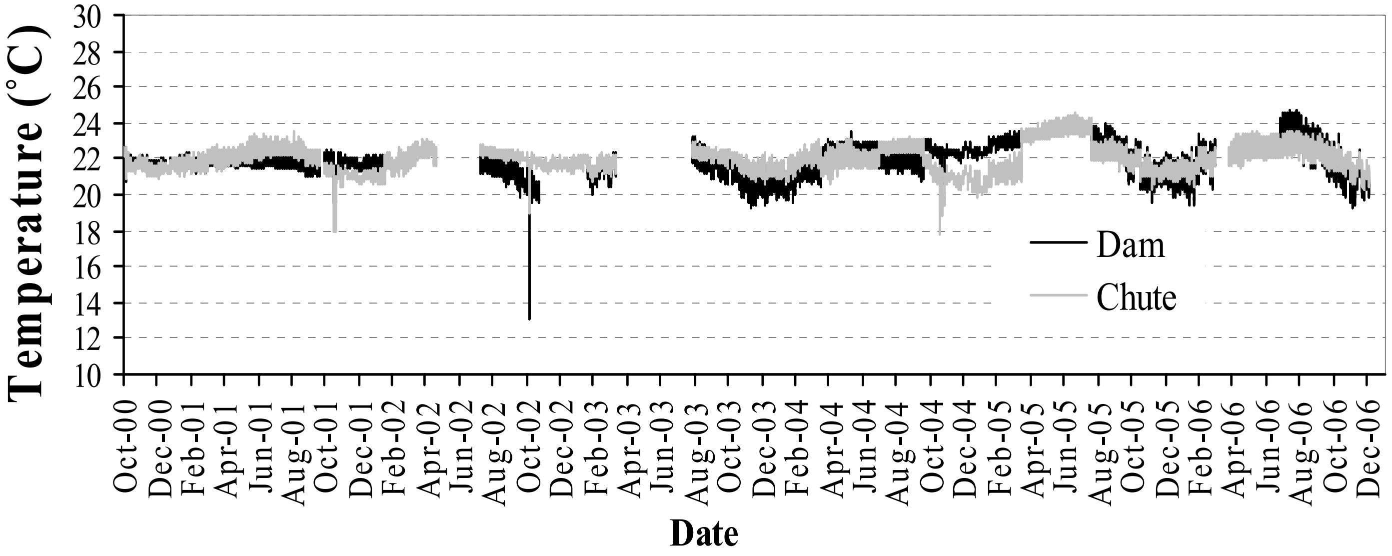
Thermistor Data: Animal Shelter



Thermistor Data: Thompson's Island Artificial and Natural Canal Sites

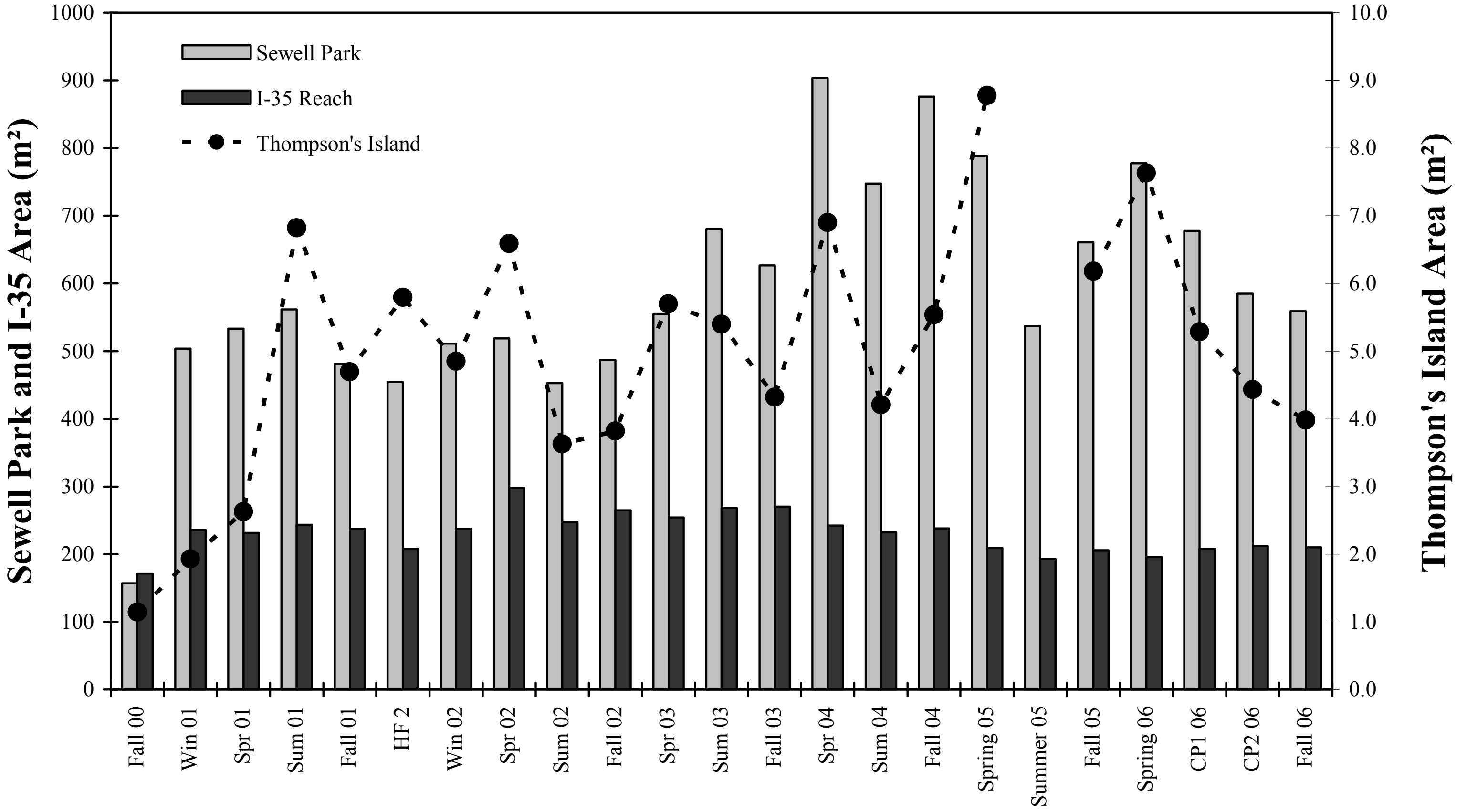


Thermistor Data: Dam and Chute Tailraces

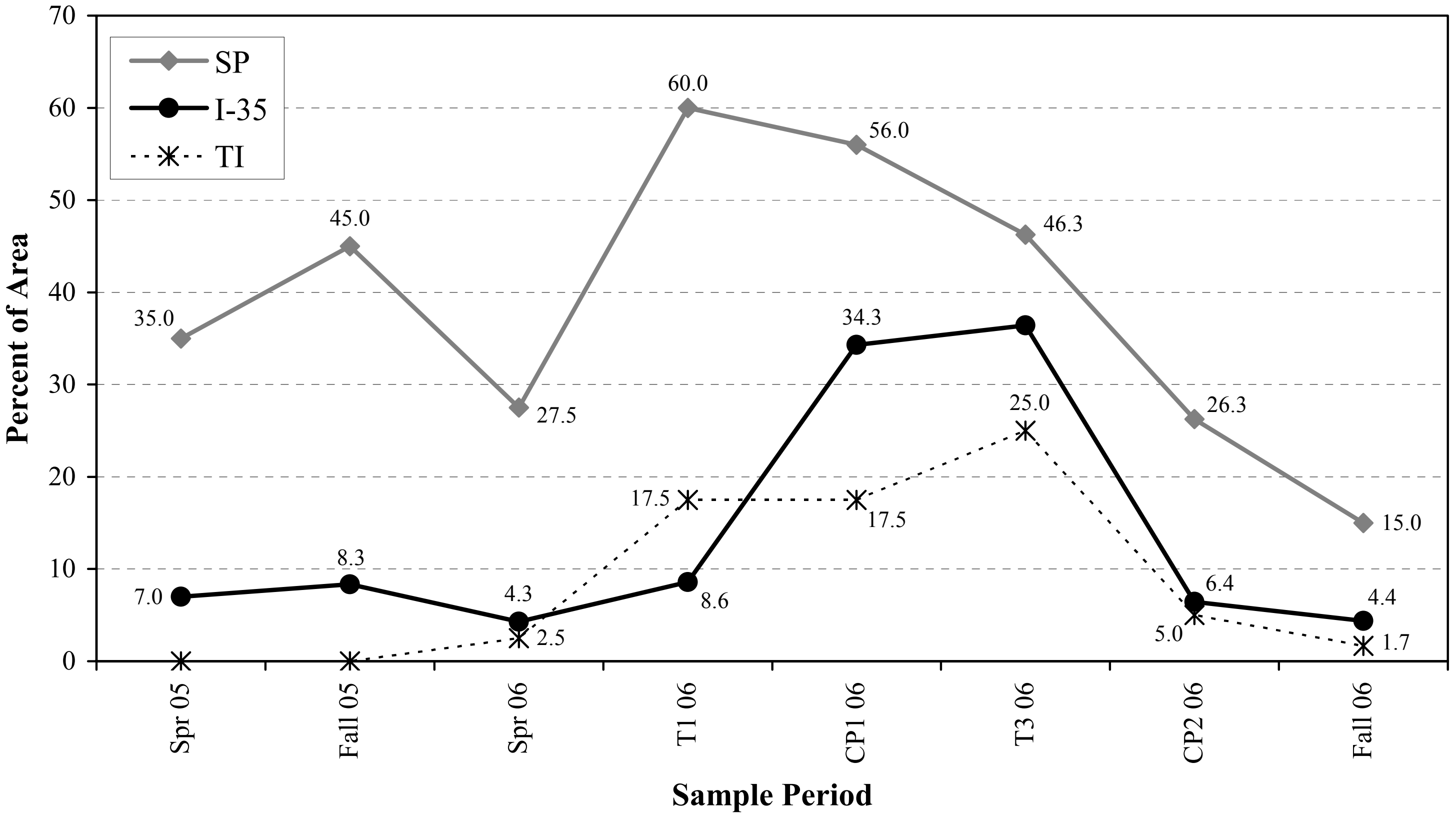


Texas Wild-Rice Observation Data

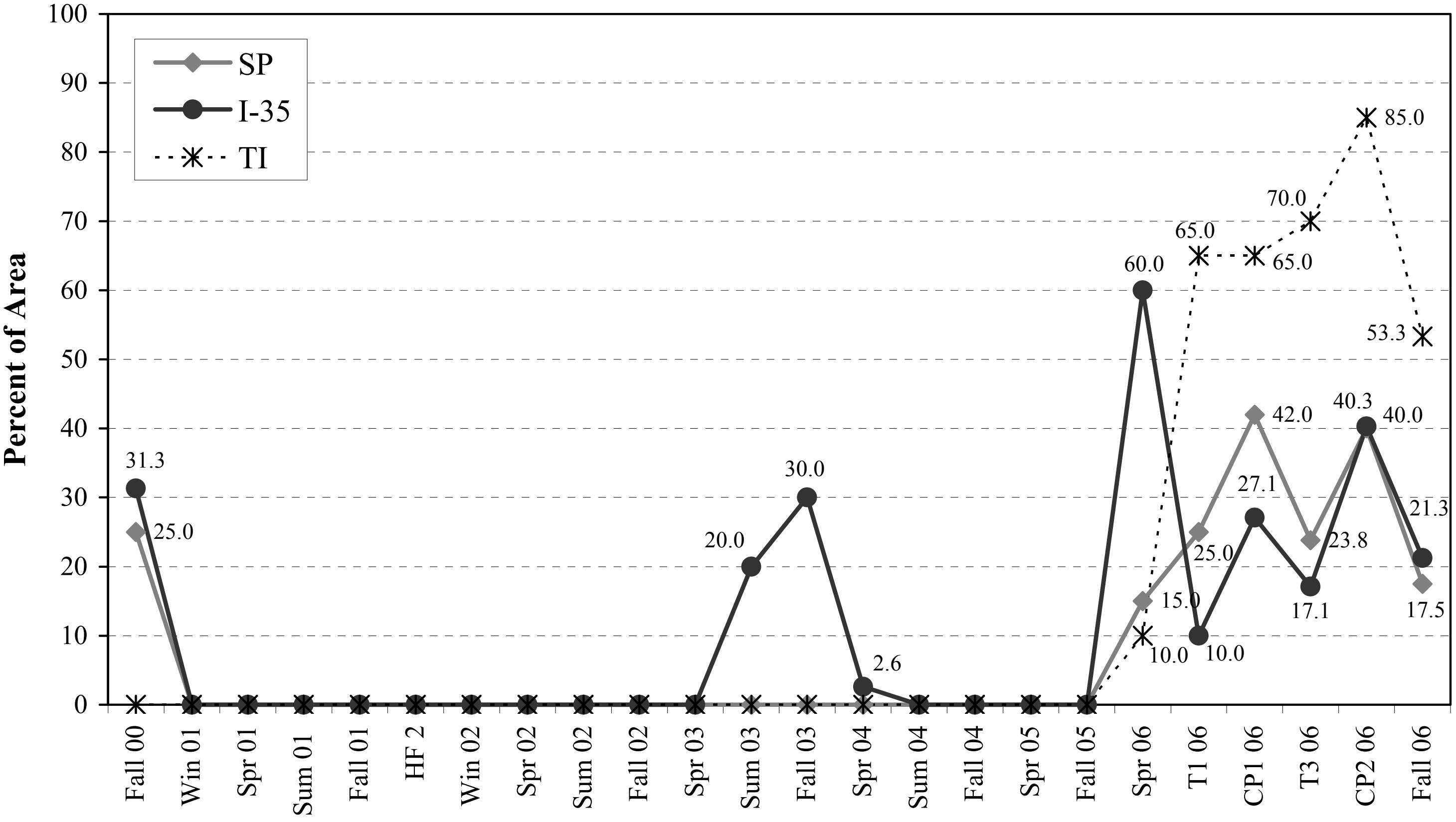
TWR Area by Season



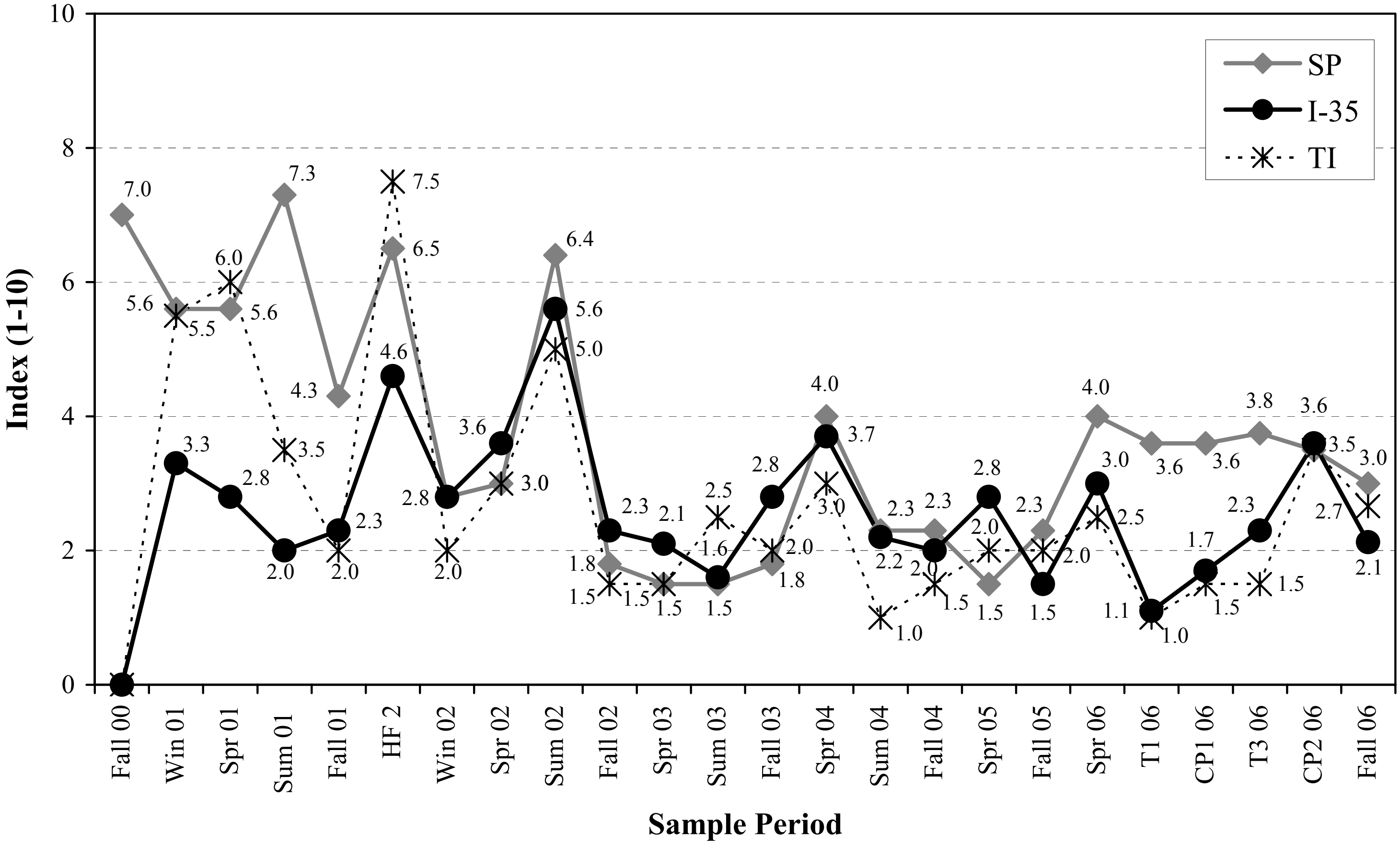
Percent of TWR Covered by Vegetation Mats



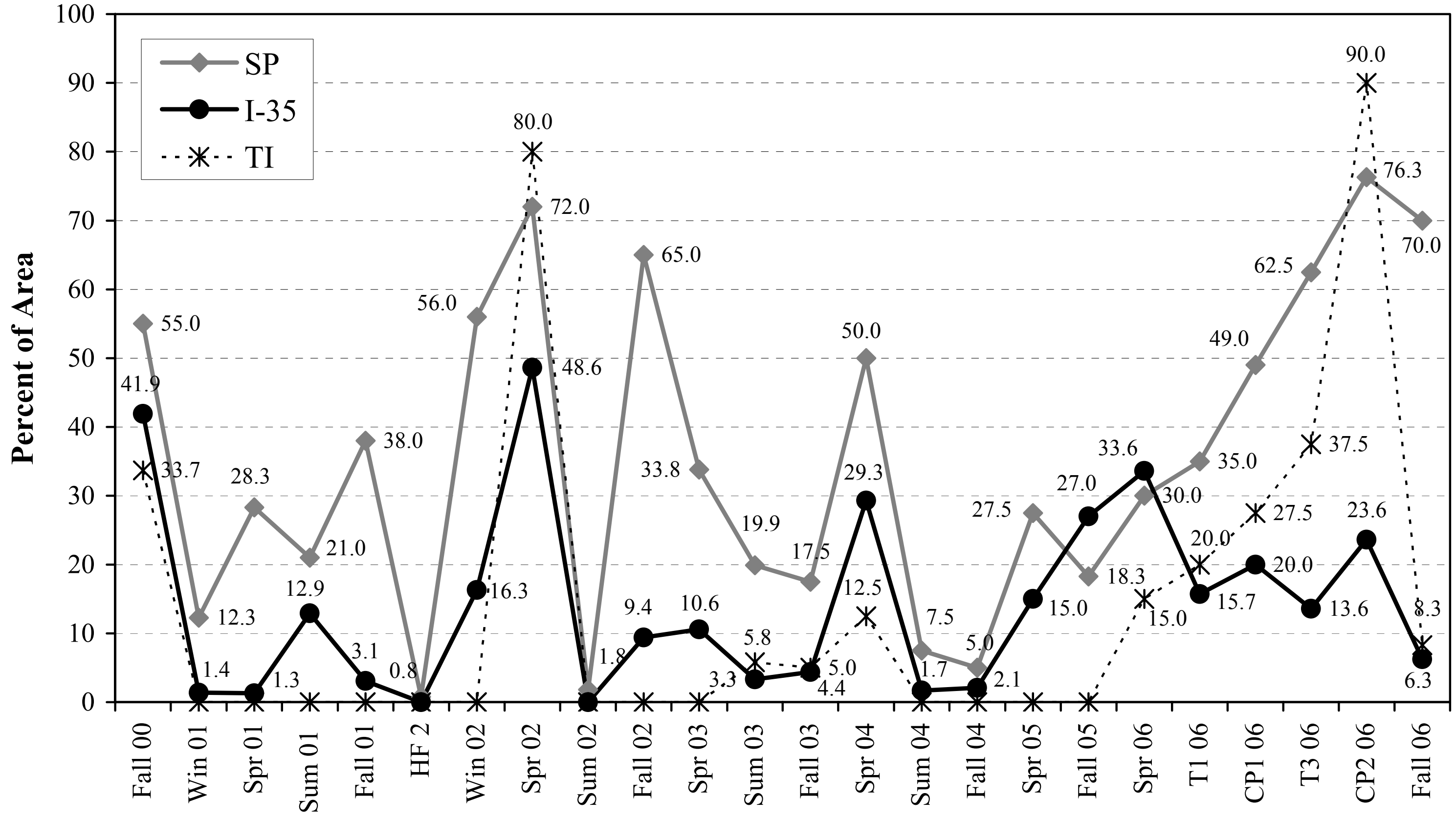
Percent of TWR Stands < 0.5 Feet



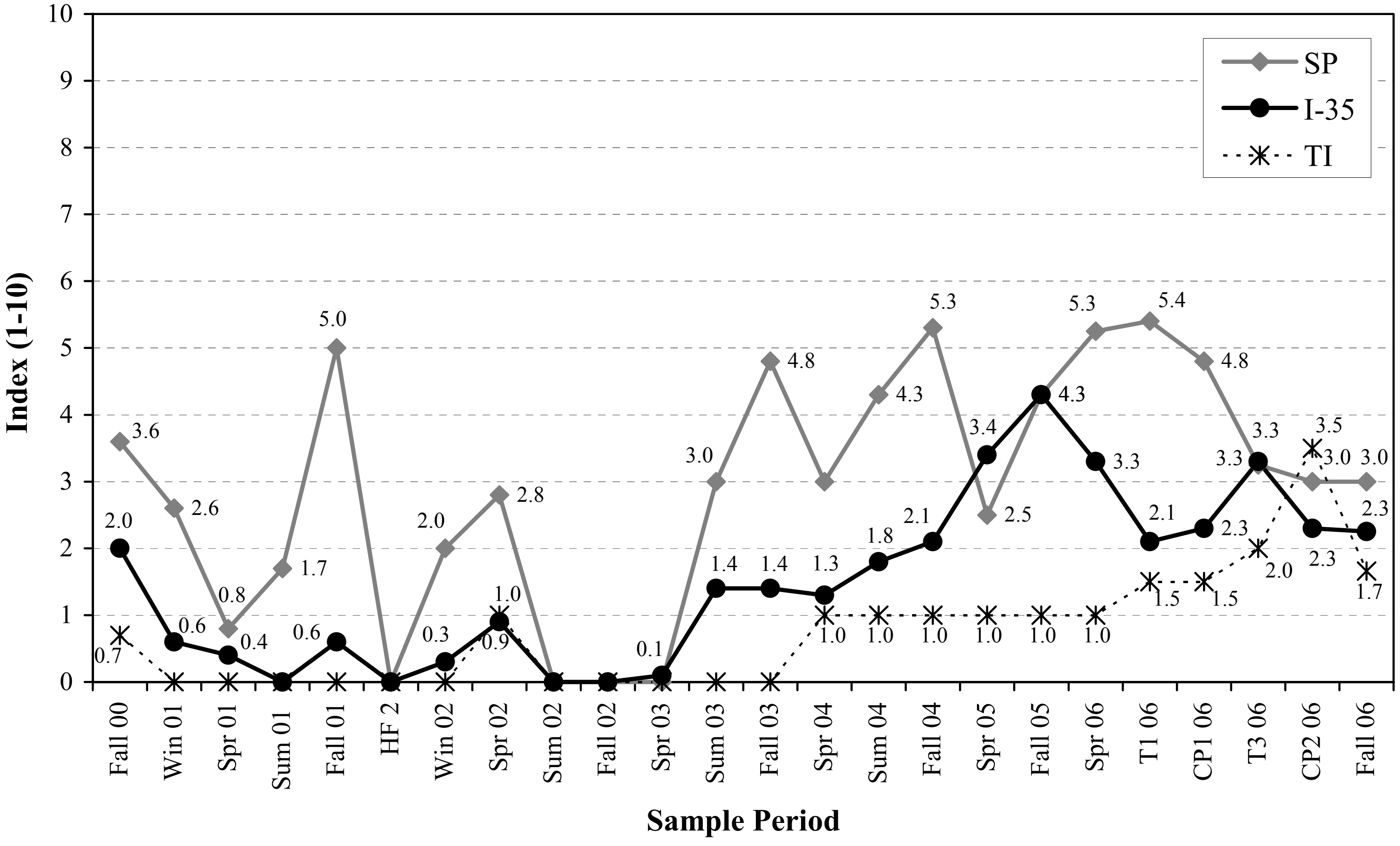
Index of Root Exposure for TWR Stands



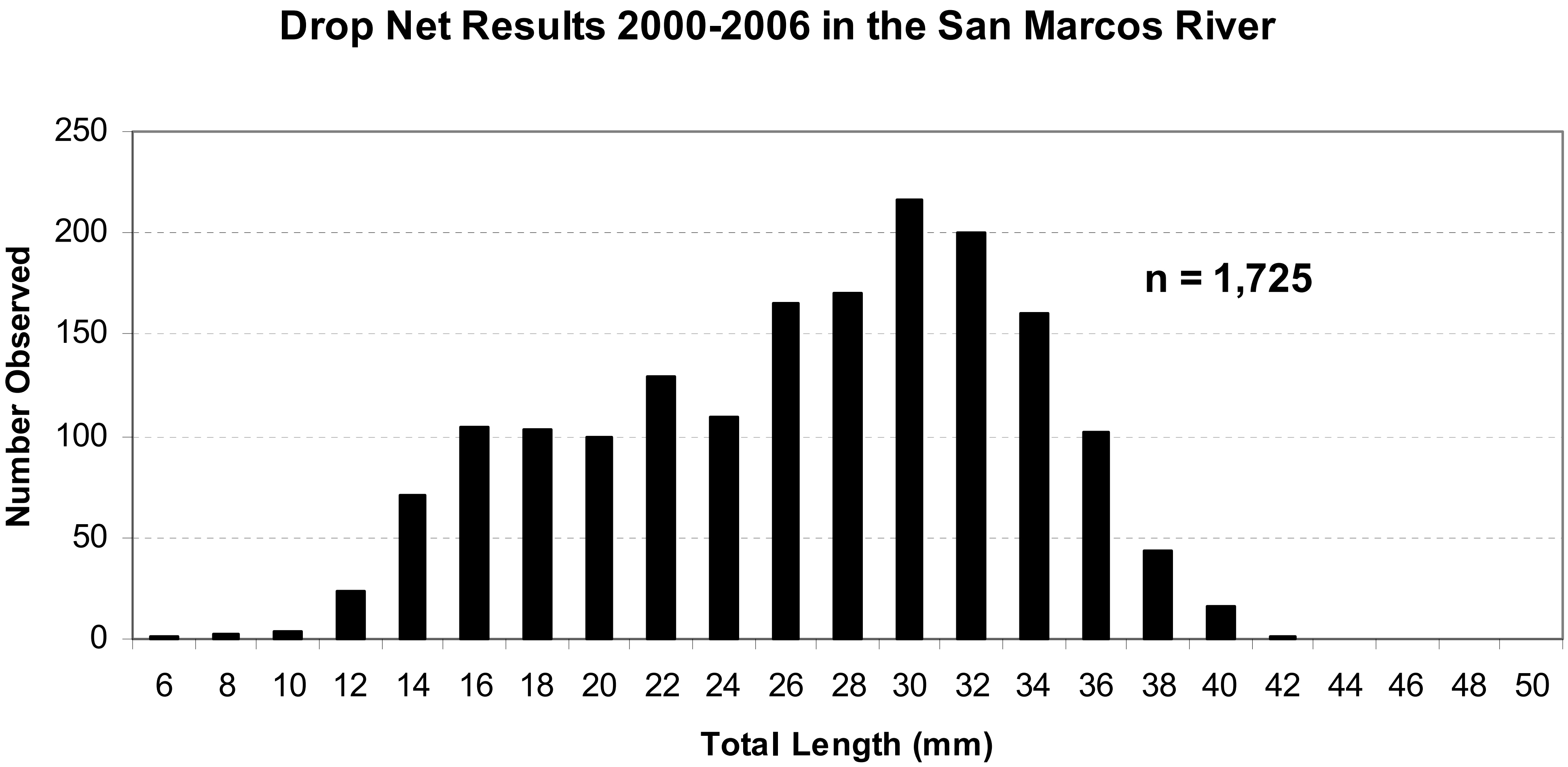
Percent Emergent TWR



Index of Herbivory for TWR Stands



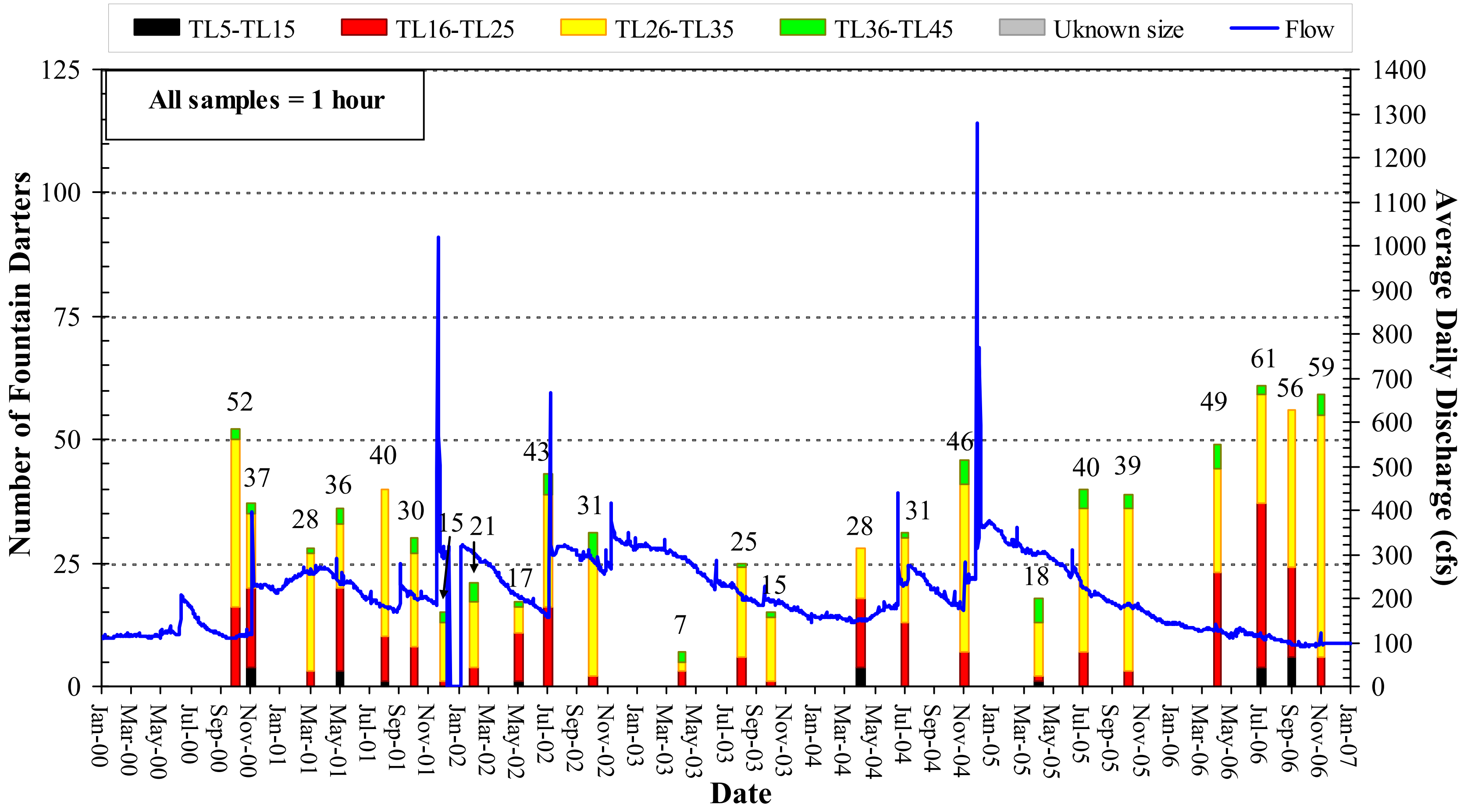
Drop Net Graph



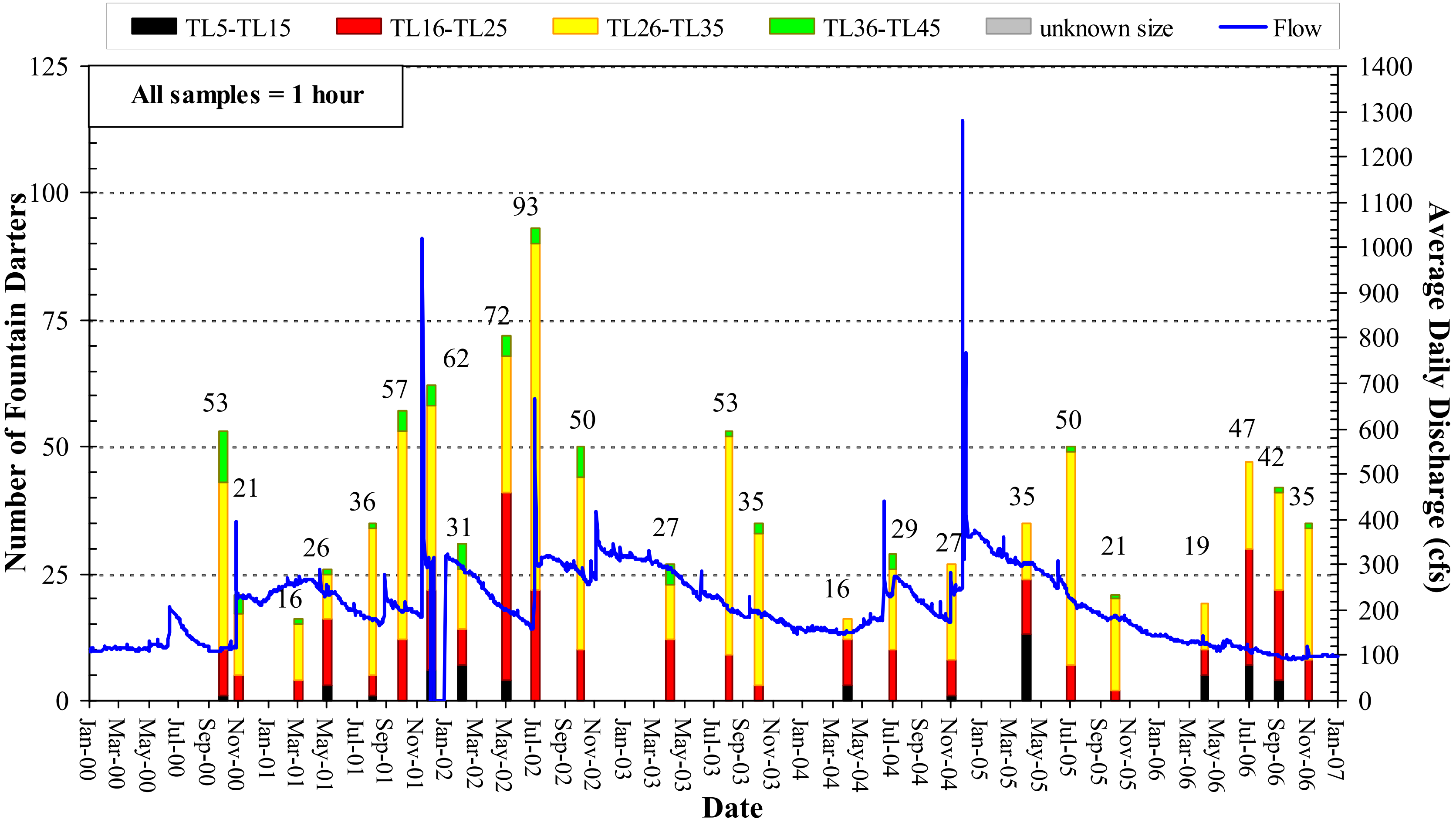
Drop Net Results 2000-2006 in the San Marcos River

Dip Net Graphs

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



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



APPENDIX C:
DROP NET RAW DATA

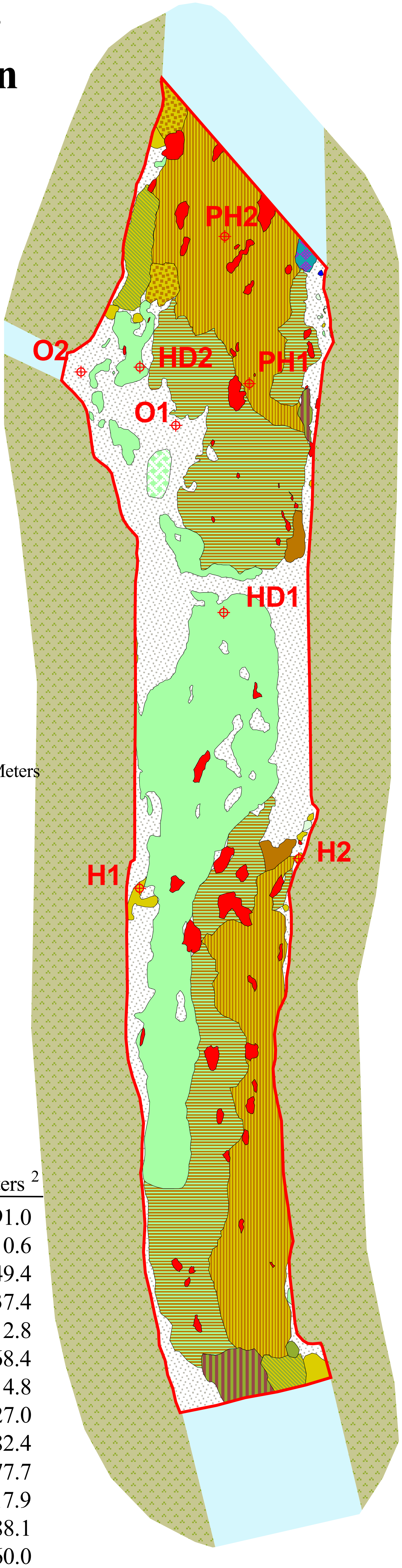
(not available online)

City Park Reach

San Marcos River Aquatic Vegetation

City Park - Spring

April 17, 2006



Scale: 1" = 60'

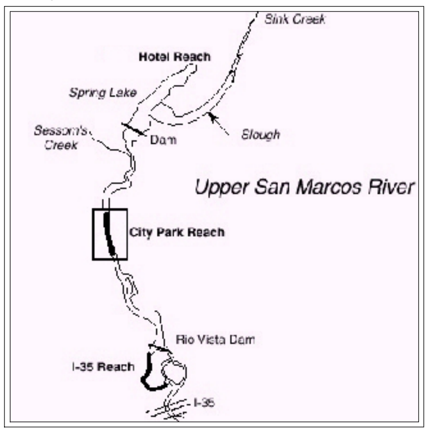
10 0 10 20 30 40 Meters

N

- Shore and Islands
- River
- Study Area (5,991.8 m^2)
- Bare Substrate
- *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters ^{2}
Hydrilla	1,291.0
Hydrocotle	0.6
Hygrophila	49.4
Potamogeton	37.4
Vallisneria	2.8
Zizania	168.4
Sagittaria	4.8
Hydrilla 50%	27.0
Hydrilla / Potamogeton	1,382.4
Hygrophila / Potamogeton	1,377.7
Hygrophila / Sagittaria	117.9
Potamogeton / Sagittaria	88.1
Hygrophila / Potamogeton / Sagittaria	60.0
Hydrilla / Potamogeton / Hydrocotle	12.9

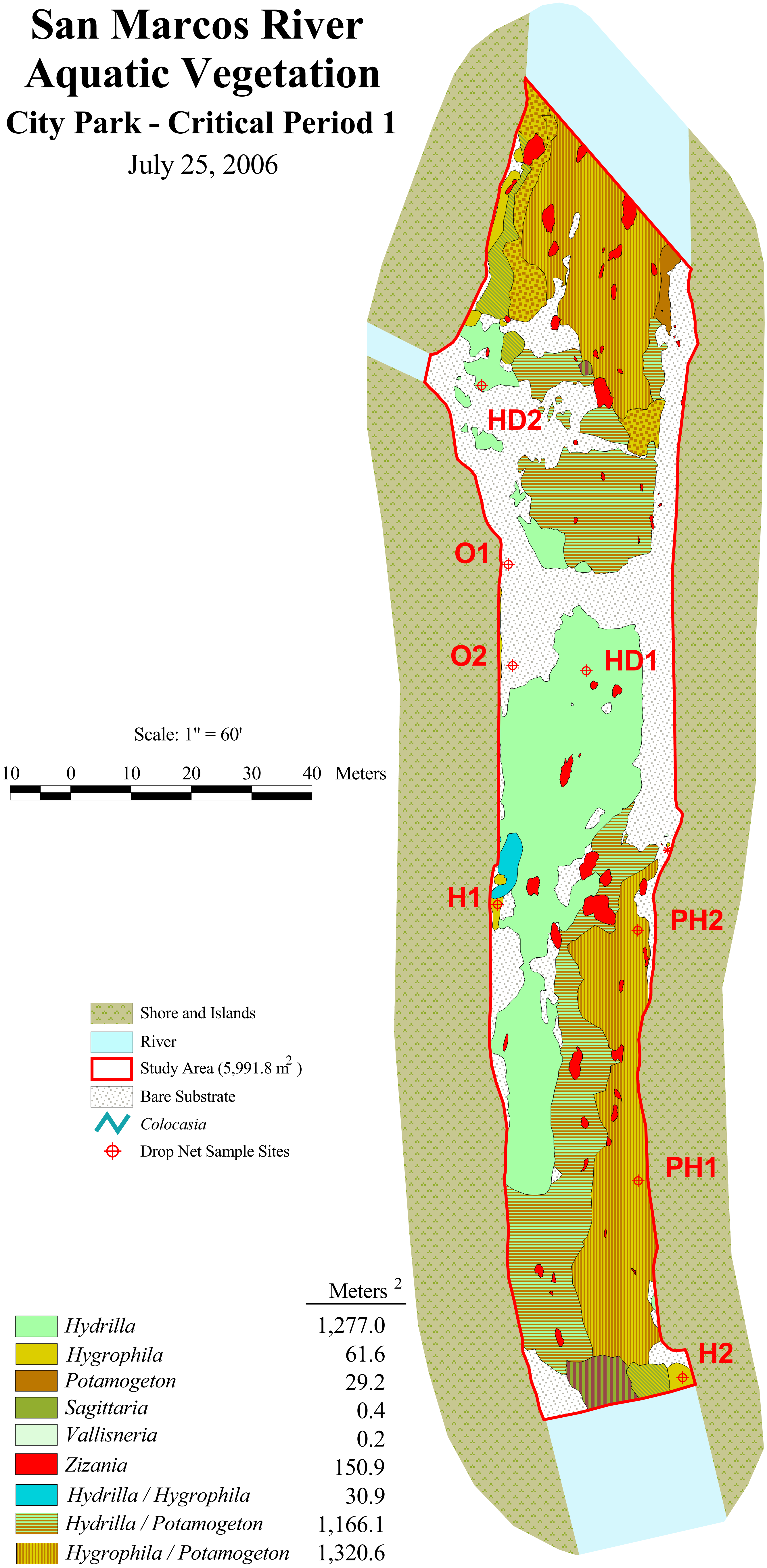
Project Location



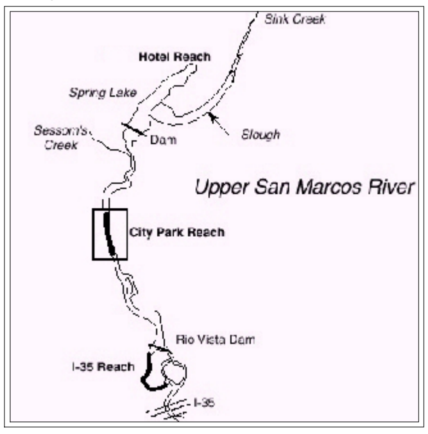
BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River
Aquatic Vegetation
City Park - Critical Period 1
July 25, 2006



Project Location



	Meters^2
Hydrilla	1,277.0
Hygrophila	61.6
Potamogeton	29.2
Sagittaria	0.4
Vallisneria	0.2
Zizania	150.9
Hydrilla / Hygrophila	30.9
Hydrilla / Potamogeton	1,166.1
Hygrophila / Potamogeton	1,320.6
Hygrophila / Sagittaria	118.6
Potamogeton / Sagittaria	78.2
Potamogeton / Hygrophila / Sagittaria	173.3

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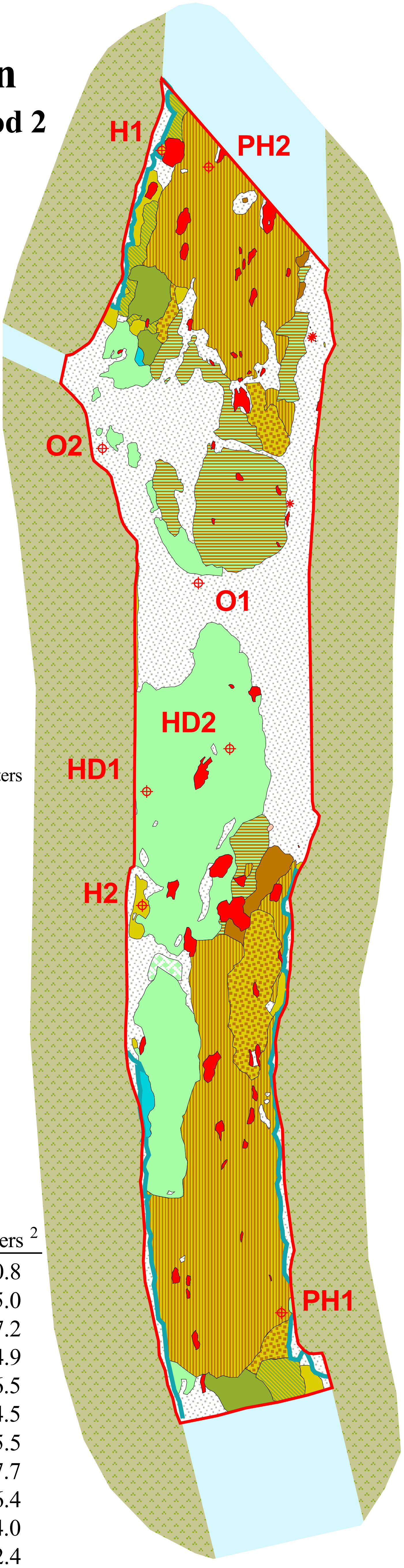
EDWARDS AQUIFER AUTHORITY

San Marcos River Aquatic Vegetation

City Park - Critical Period 2

September 22, 2006



Scale: 1" = 60'

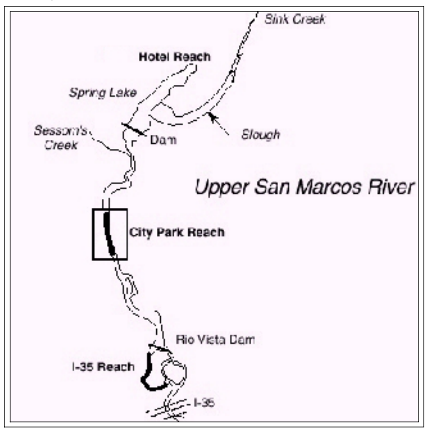
10 0 10 20 30 40 Meters

N

- Shore and Islands
- River
- Study Area (5,991.8 m^2)
- Bare Substrate
- *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters ^{2}
Heteranthera	0.8
Hydrilla	1,215.0
Hygrophila	97.2
Potamogeton	54.9
Sagittaria	116.5
Zizania	154.5
Hydrilla 50%	15.5
Hydrilla / Potamogeton	507.7
Hygrophila / Potamogeton	1,666.4
Hygrophila / Sagittaria	104.0
Hygrophila / Hydrilla	22.4
Hygrophila / Potamogeton / Sagittaria	242.2

Project Location



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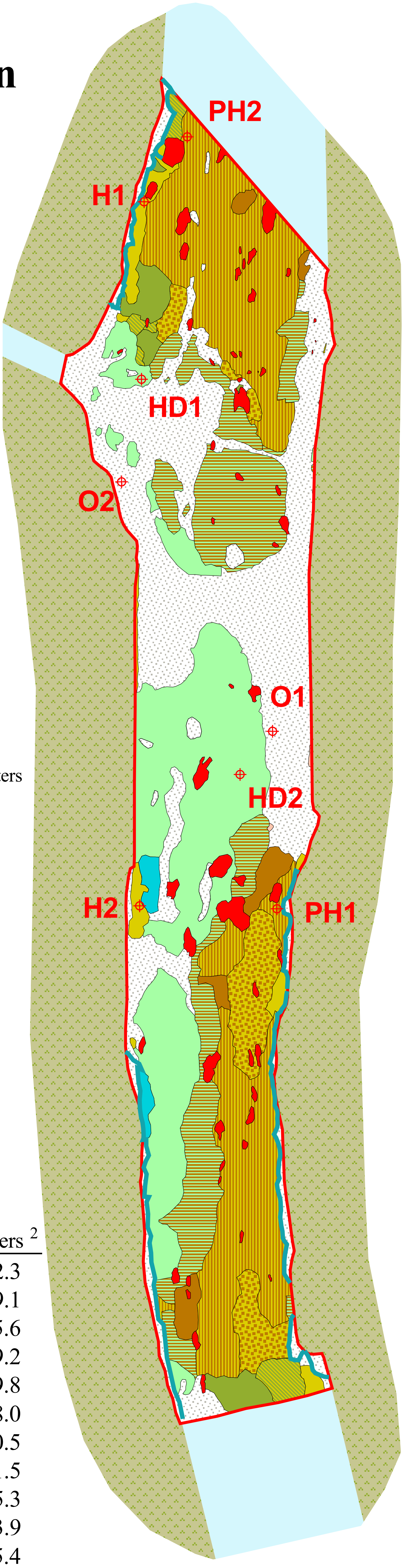
EDWARDS AQUIFER AUTHORITY

San Marcos River Aquatic Vegetation

City Park - Fall

November 2, 2006



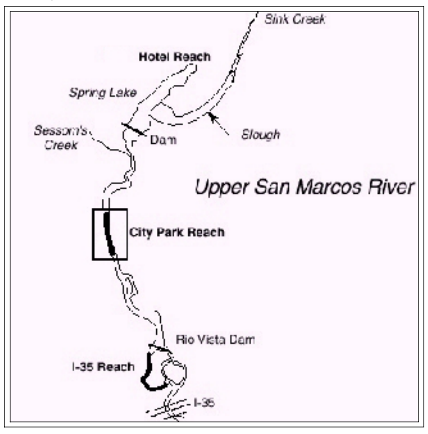
Scale: 1" = 60'

10 0 10 20 30 40 Meters

- ▨ Shore and Islands
- ▭ River
- ▭ Study Area (5,991.8 m^2)
- ░ Bare Substrate
- ∿ *Colocasia*
- ⊕ Drop Net Sample Sites

		Meters^2
■	*Heteranthera*	2.3
■	*Hydrilla*	1,169.1
■	*Hygrophila*	125.6
■	*Potamogeton*	109.2
■	*Sagittaria*	119.8
■	*Zizania*	168.0
▤	*Hydrilla / Potamogeton*	790.5
▥	*Hygrophila / Potamogeton*	1,281.5
▧	*Hygrophila / Sagittaria*	75.3
■	*Hygrophila / Hydrilla*	43.9
▩	*Hygrophila / Potamogeton / Sagittaria*	285.4

Project Location



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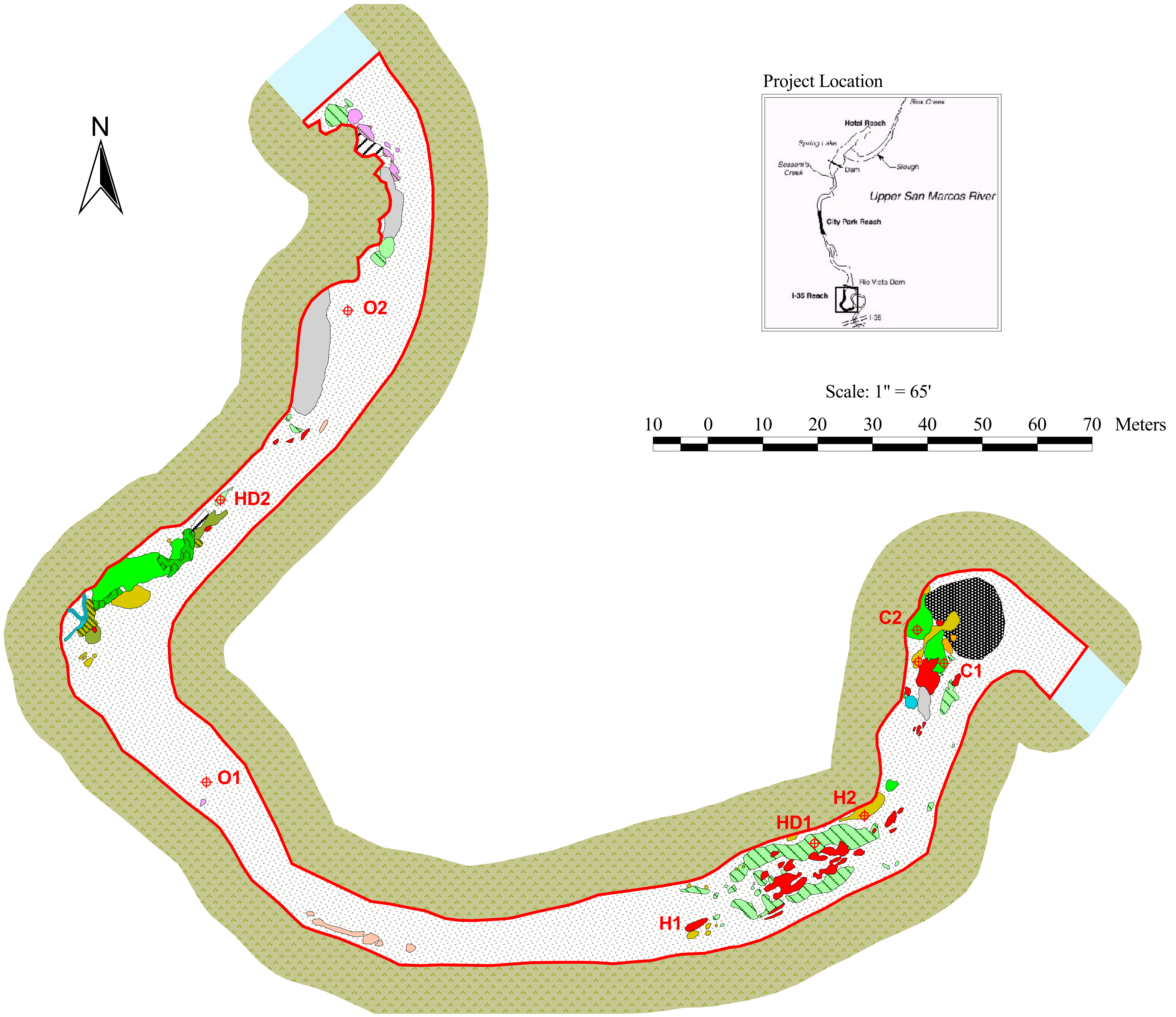
EDWARDS AQUIFER AUTHORITY

IH-35 Reach



San Marcos River Aquatic Vegetation

I-35 Reach - Spring

April 18, 2006

- ▨ Shore and Islands
- ▨ River
- ☐ Study Area (4,616.3 m^2)
- ▨ Bare Substrate
- *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters^2
🟩 *Cabomba*	114.7
▨ *Heteranthera*	18.3
▨ *Hydrilla*	14.9
▨ *Hygrophila*	63.8
▨ *Justicia*	7.5
▨ *Ludwigia*	4.5
▨ *Sagittaria*	16.8
🟥 *Zizania*	88.7
▨ *Algae*	149.8
▨ *Floating Vegetation Mat*	19.8
▨ *Too deep / turbid to map*	144.4
▨ *Hygrophila / Hydrilla*	7.3
▨ *Hygrophila / Sagittaria*	13.7
▨ *Sagittaria / Cabomba*	29.4
▨ *Hydrilla / Algae*	177.4
▨ *Justicia / Algae*	12.0

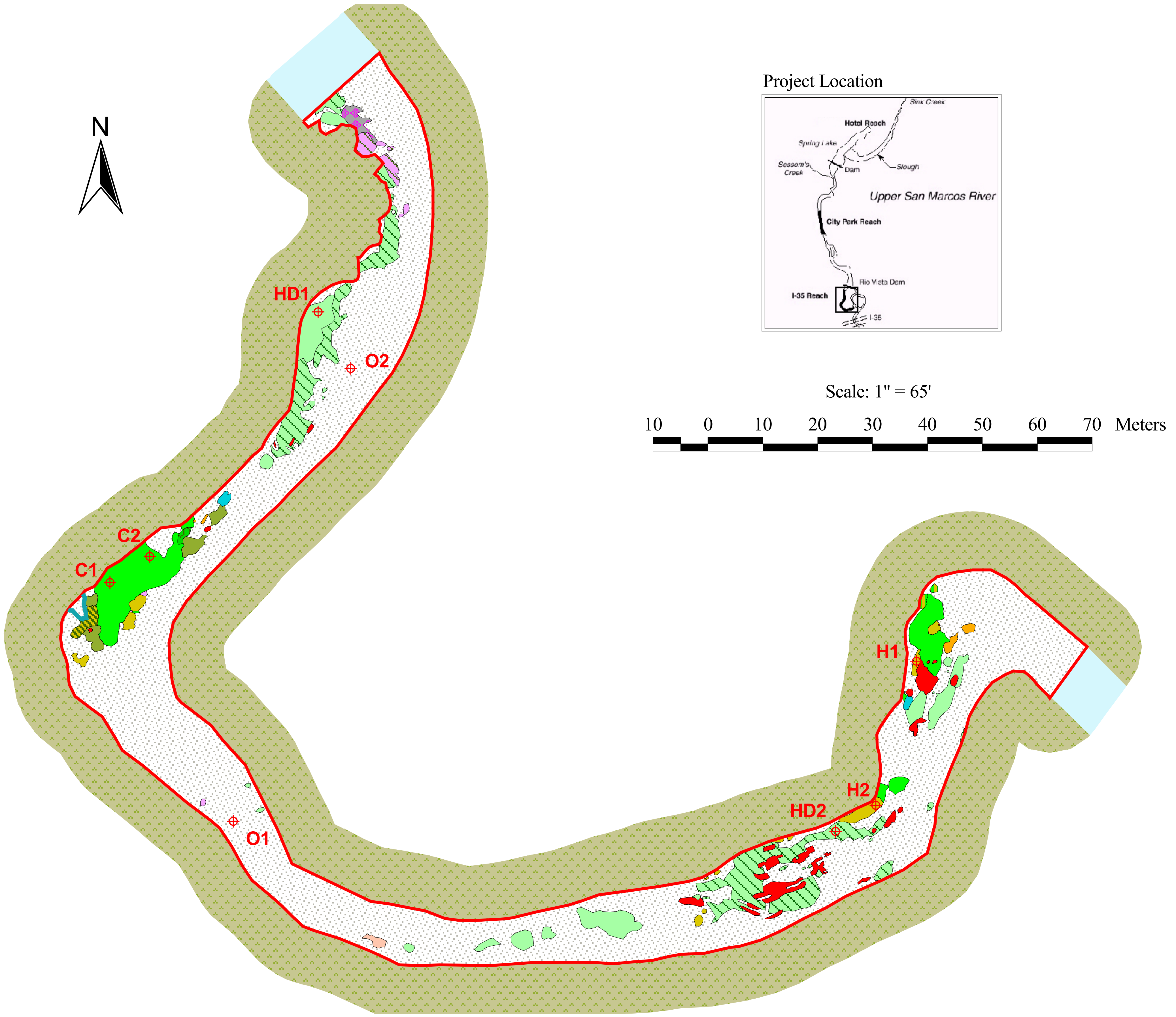
BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River Aquatic Vegetation

I-35 Reach - Critical Period 1

July 25, 2006



▨ Shore and Islands
🟦 River
▭ Study Area (4,616.3 m^2)
░ Bare Substrate
∧ *Colocasia*
⊕ Drop Net Sample Sites

	Meters^2
🟩 *Cabomba*	221.6
🟧 *Heteranthera*	5.3
🟩 *Hydrilla*	173.1
🟨 *Hygrophila*	46.3
🟪 *Justicia*	4.1
🟧 *Ludwigia*	9.2
🟩 *Sagittaria*	32.9
🟥 *Zizania*	83.1
▨ *Hygrophila / Sagittaria*	14.1
▥ *Hygrophila / Cabomba*	4.6
🟦 *Hygrophila / Hydrilla*	7.5
▨ *Hydrilla / Algae*	325.1
▨ *Justicia / Algae*	23.9
▦ *Sagittaria / Cabomba*	3.9
▦ *Justicia / Algae / Hydrilla*	16.9

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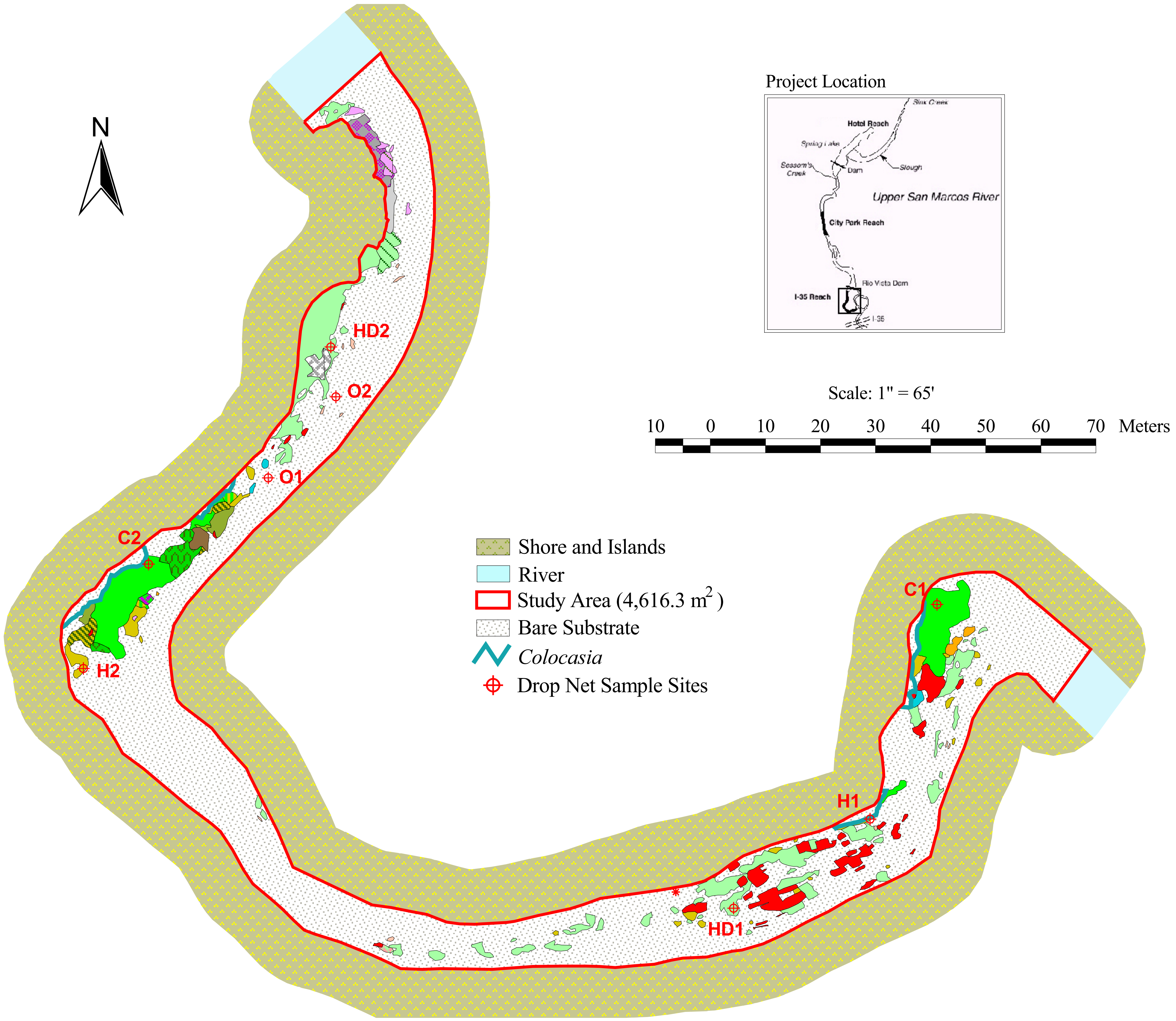
EDWARDS AQUIFER AUTHORITY

San Marcos River Aquatic Vegetation

I-35 Reach - Critical Period 2

October 3, 2006



▨ Shore and Islands
🟦 River
▭ Study Area (4,616.3 m^2)
▨ Bare Substrate
⋀ *Colocasia*
⊕ Drop Net Sample Sites

	Meters^2
🟩 *Cabomba*	227.4
🟧 *Heteranthera*	5.2
🟩 *Hydrilla*	352.0
🟨 *Hygrophila*	58.8
🟪 *Justicia*	8.3
🟧 *Ludwigia*	8.7
🟩 *Sagittaria*	19.9
🟥 *Zizania*	121.4
⬜ *Algae*	13.5
▨ *Algae 50%*	15.1
▨ *Hygrophila / Sagittaria*	20.4
🟦 *Hygrophila / Hydrilla*	7.3
▨ *Hygrophila / Cabomba*	6.2
▨ *Hydrilla / Algae*	20.6
🟫 *Hydrilla / Sagittaria*	10.9
▨ *Hydrilla / Heteranthera*	2.2
▨ *Cabomba / Sagittaria*	35.0
▨ *Cabomba / Justicia*	3.5
🟩 *Cabomba / Ludwigia*	1.6
▨ *Justicia / Algae*	7.4
▨ *Hydrilla / Justicia / Algae*	30.4

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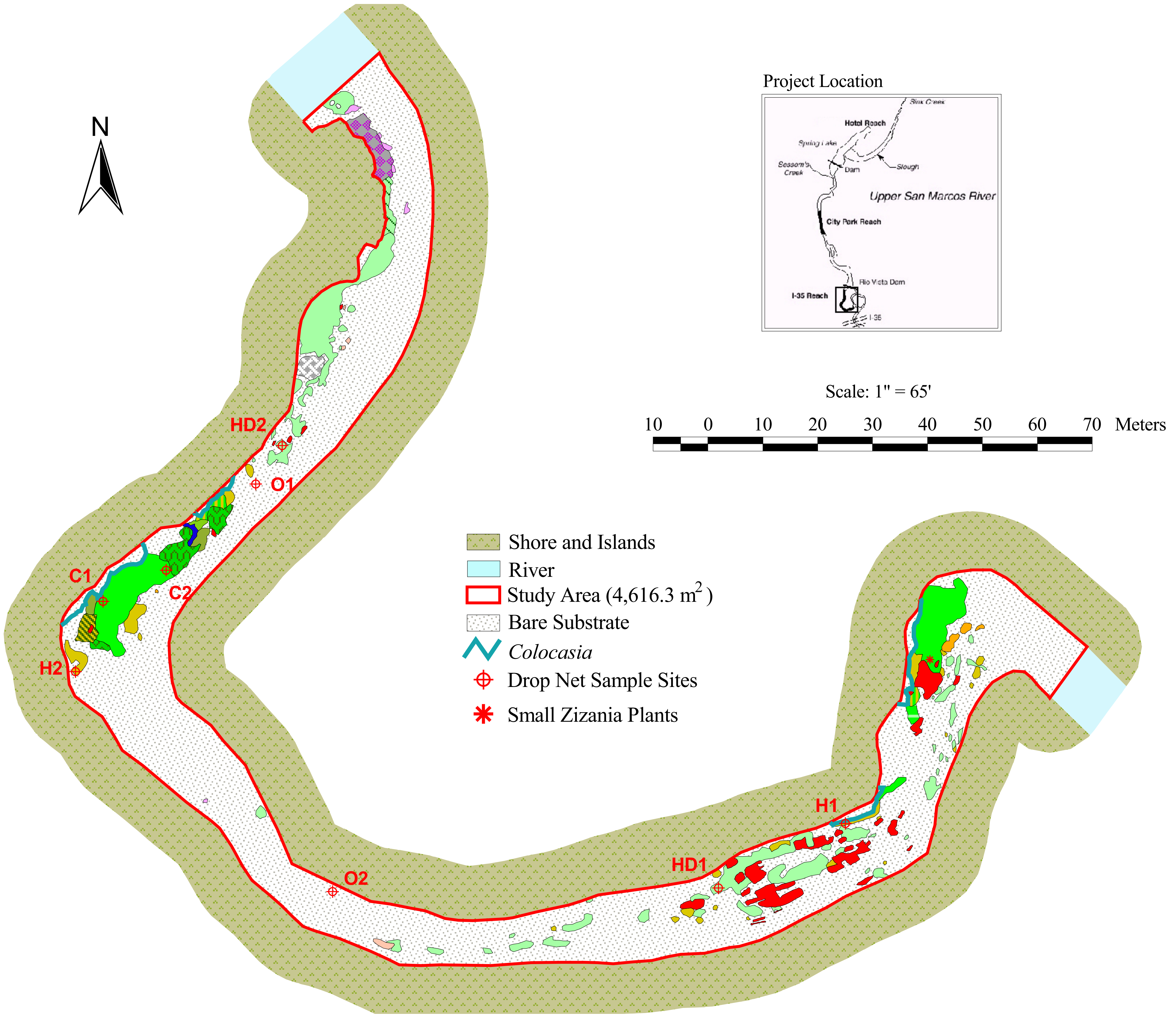
EDWARDS AQUIFER AUTHORITY



San Marcos River Aquatic Vegetation

I-35 Reach - Fall

November 2, 2006

		Meters^2
🟩	*Cabomba*	214.6
🟧	*Heteranthera*	5.2
🟩	*Hydrilla*	332.6
🟨	*Hygrophila*	70.2
🟪	*Justicia*	7.6
🟧	*Ludwigia*	9.8
🟩	*Sagittaria*	14.6
🟥	*Zizania*	120.1
▨	*Algae 50%*	17.0
▥	*Hygrophila / Cabomba*	14.1
▨	*Cabomba / Sagittaria*	50.3
🟩	*Cabomba / Hydrilla*	6.0
🟩	*Cabomba / Ludwigia*	3.6
▨	*Hydrilla / Algae*	14.9
🟦	*Sagittaria / Cabomba / Hydrilla*	4.5
▨	*Hydrilla / Justicia / Algae*	39.7

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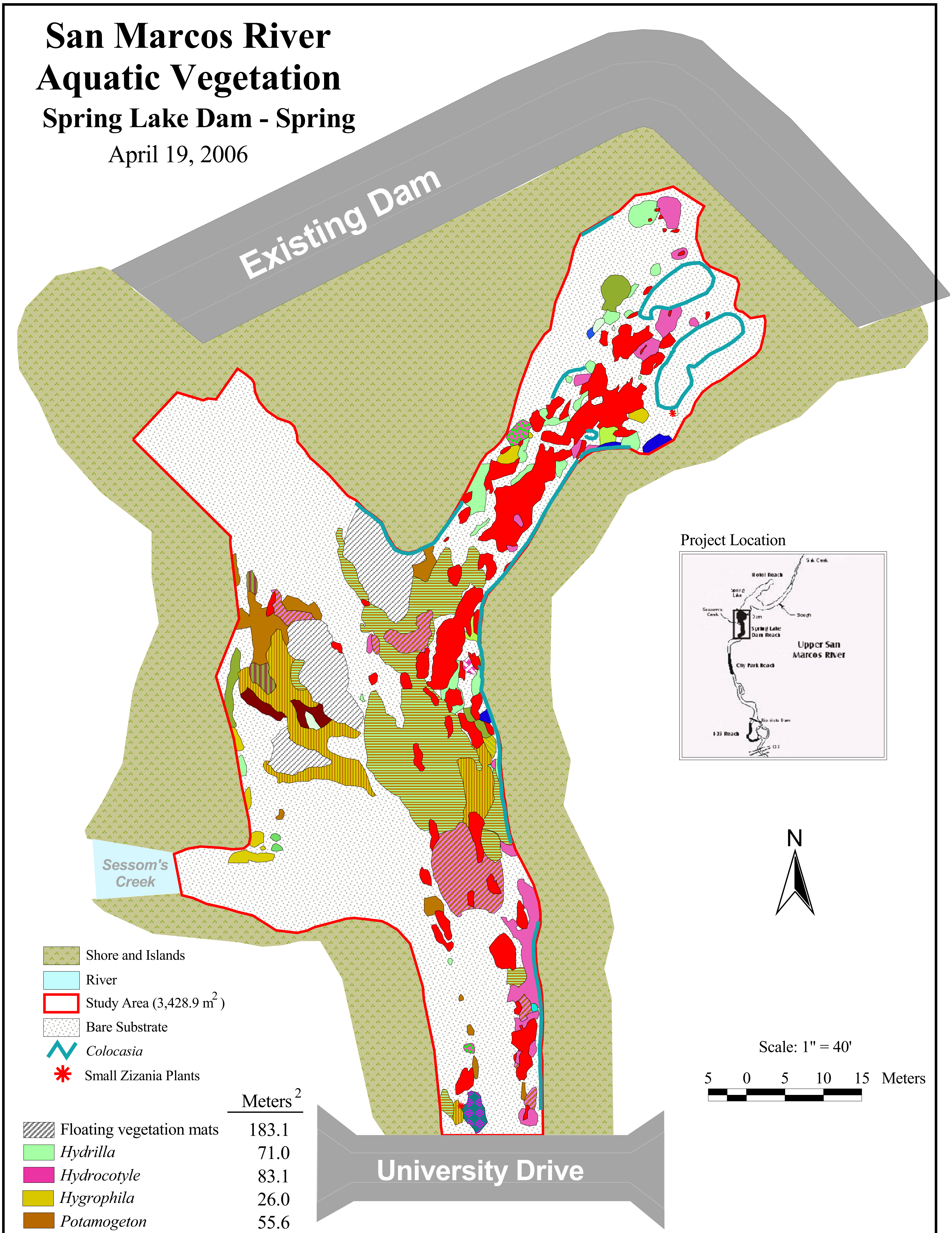
EDWARDS AQUIFER AUTHORITY

Spring Lake Dam Reach

San Marcos River Aquatic Vegetation

Spring Lake Dam - Spring

April 19, 2006



▨ Shore and Islands
▭ River
▭ Study Area (3,428.9 m ^{2})
▨ Bare Substrate
⋀ *Colocasia*
✱ Small Zizania Plants

	Meters ^{2}
▨ Floating vegetation mats	183.1
🟩 *Hydrilla*	71.0
🟪 *Hydrocotyle*	83.1
🟨 *Hygrophila*	26.0
🟫 *Potamogeton*	55.6
🟩 *Sagittaria*	28.1
🟩 *Vallisneria*	5.0
🟥 *Zizania*	321.0
🟦 *Hyacinth*	9.3
▨ *Hydrocotyle 50%*	2.5
▨ *Hygrophila / Sagittaria*	3.1
🟩 *Hygrophila / Hydrocotyle*	6.7
▤ *Potamogeton / Hydrilla*	108.5
▨ *Potamogeton / Hydrocotyle*	335.9
▥ *Potamogeton / Hygrophila*	127.2

	Meters ^{2}
▥ *Potamogeton / Sagittaria*	12.3
🟫 *Potamogeton / Vallisneria*	17.4
🟦 *Hydrocotyle / Sagittaria*	0.8
▨ *Hydrocotyle / Hydrilla*	8.2
▨ *Sagittaria / Vallisneria*	0.9
▨ *Potamogeton / Hydrocotyle / Hydrilla*	11.4
🟨 *Potamogeton / Hydrocotyle / Hygrophila*	3.7

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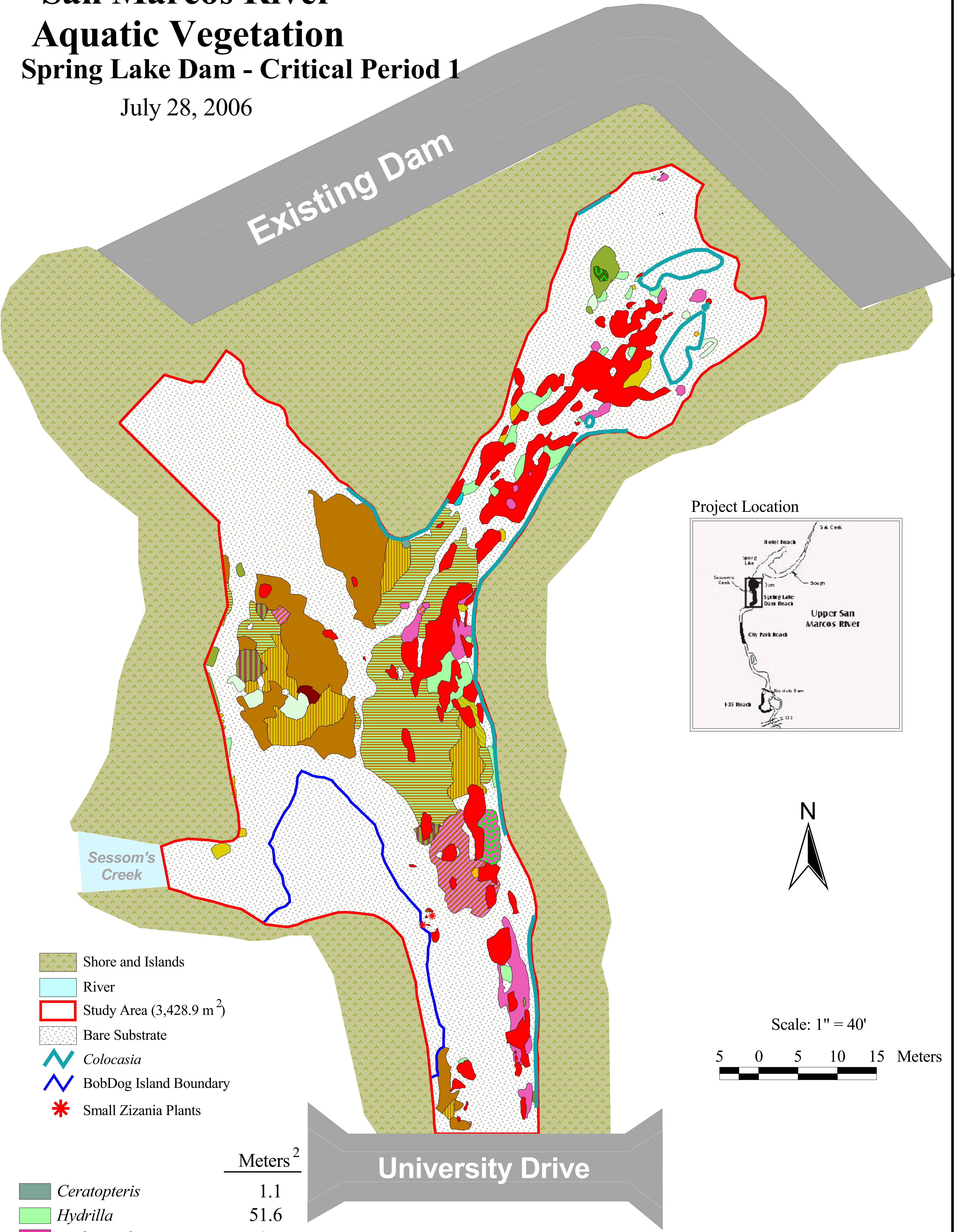
EDWARDS AQUIFER AUTHORITY

San Marcos River
Aquatic Vegetation
Spring Lake Dam - Critical Period 1

July 28, 2006



		Meters^2
■	*Ceratopteris*	1.1
■	*Hydrilla*	51.6
■	*Hydrocotyle*	59.5
■	*Hygrophila*	18.0
■	*Ludwigia*	1.2
■	*Potamogeton*	248.9
■	*Sagittaria*	20.6
■	*Vallisneria*	21.0
■	*Zizania*	323.3
▤	*Potamogeton / Hydrilla*	287.4
▨	*Potamogeton / Hydrocotyle*	59.4
▥	*Potamogeton / Hygrophila*	110.1

		Meters^2
▥	*Potamogeton / Sagittaria*	18.2
■	*Potamogeton / Vallisneria*	3.8
■	*Hygrophila / Hydrilla*	1.1
▦	*Hydrocotyle / Hydrilla*	14.6
▧	*Hygrophila / Sagittaria*	6.2
■	*Potamogeton / Hygrophila / Hydrilla*	1.8
▩	*Sagittaria / Cabomba*	2.3

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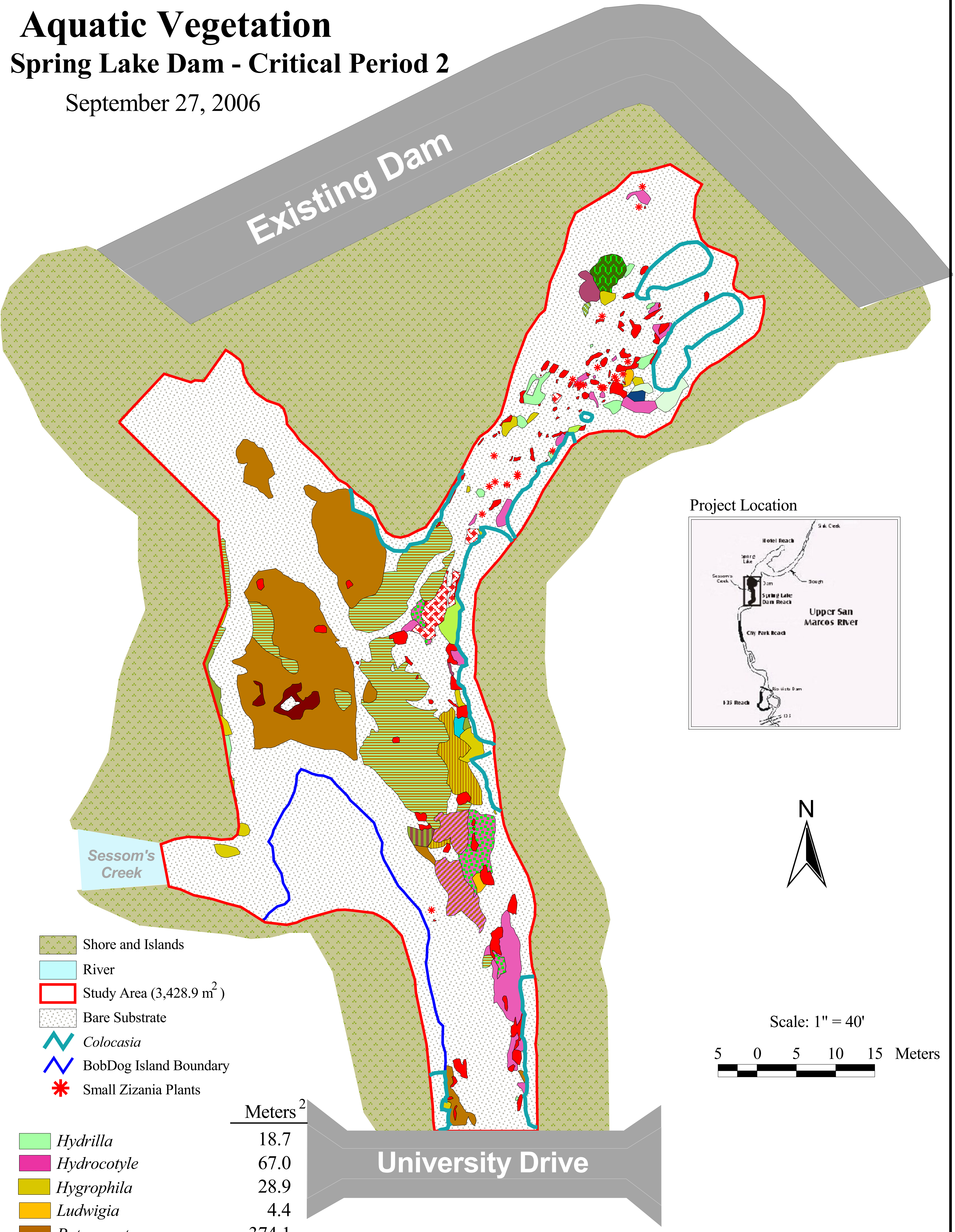
EDWARDS AQUIFER AUTHORITY

San Marcos River
Aquatic Vegetation
Spring Lake Dam - Critical Period 2

September 27, 2006



Scale: 1" = 40'

- ▨ Shore and Islands
- ▭ River
- ▭ Study Area (3,428.9 m^2)
- ▨ Bare Substrate
- *Colocasia*
- BobDog Island Boundary
- ✱ Small Zizania Plants

		Meters ^{2}
🟩	*Hydrilla*	18.7
🟪	*Hydrocotyle*	67.0
🟨	*Hygrophila*	28.9
🟧	*Ludwigia*	4.4
🟫	*Potamogeton*	374.1
🟩	*Sagittaria*	7.0
🟩	*Vallisneria*	10.6
🟥	*Zizania*	74.4
▨	*Zizania 50%*	23.8
▨	*Potamogeton / Hydrocotyle*	45.9
▨	*Potamogeton / Hydrilla*	266.7
▨	*Potamogeton / Hygrophila*	32.2
▨	*Potamogeton / Sagittaria*	6.4
🟥	*Potamogeton / Vallisneria*	14.5

		Meters ^{2}
🟩	*Hydrocotyle / Hygrophila*	11.4
▨	*Hydrocotyle / Hydrilla*	34.6
▨	*Vallisneria / Sagittaria*	1.1
🟦	*Vallisneria / Hydrilla*	2.5
🟦	*Hygrophila / Hydrilla*	2.8
▨	*Sagittaria / Cabomba*	15.0
🟪	*Sagittaria / Hydrilla*	8.2

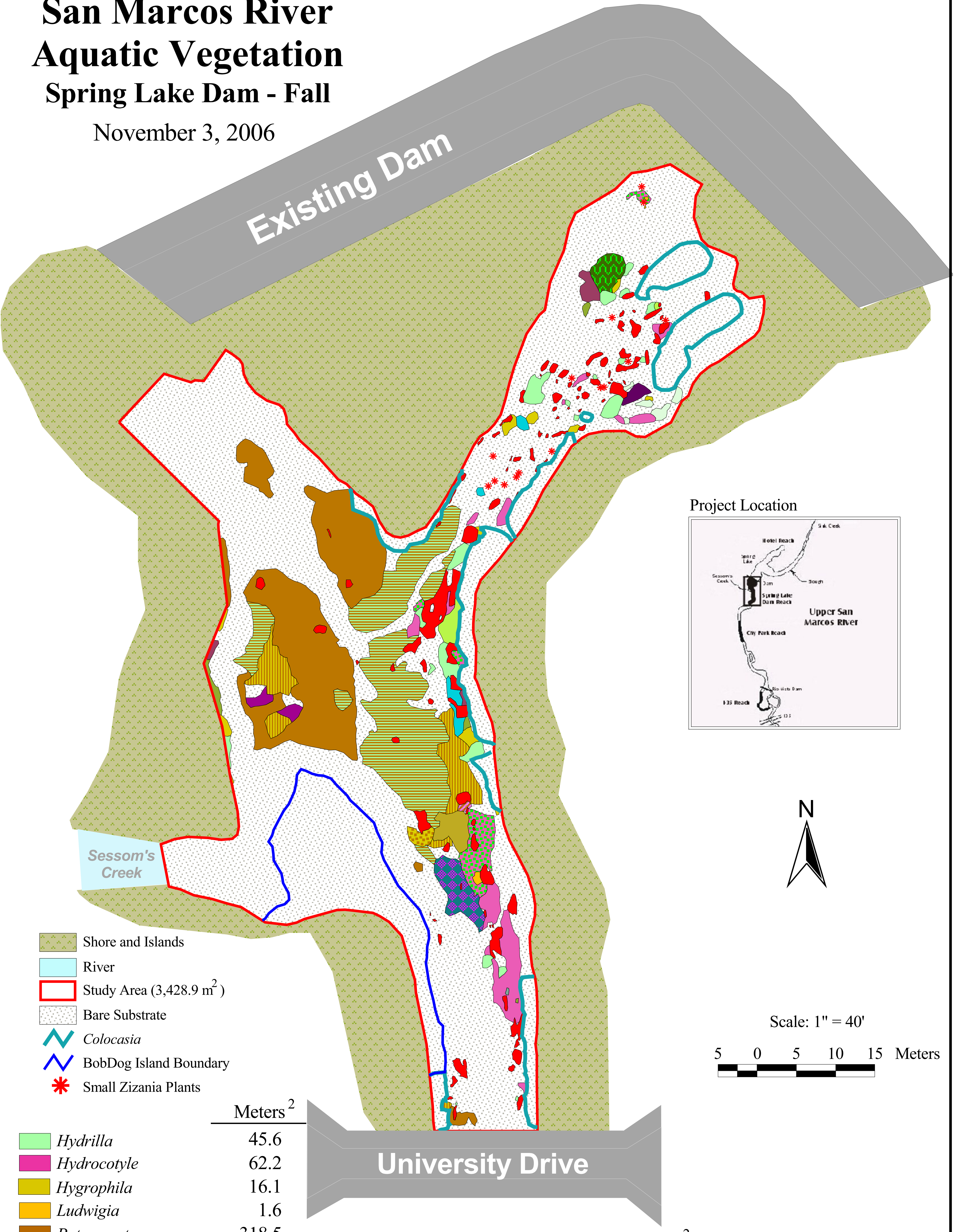
BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River Aquatic Vegetation

Spring Lake Dam - Fall

November 3, 2006



▨ Shore and Islands
■ River
☐ Study Area (3,428.9 m^2)
░ Bare Substrate
∿ *Colocasia*
∿ BobDog Island Boundary
✱ Small Zizania Plants

		Meters^2
■	*Hydrilla*	45.6
■	*Hydrocotyle*	62.2
■	*Hygrophila*	16.1
■	*Ludwigia*	1.6
■	*Potamogeton*	318.5
■	*Sagittaria*	7.2
■	*Vallisneria*	7.6
■	*Zizania*	107.2
■	*Ceratopteris*	0.3
▨	*Potamogeton / Hydrocotyle*	1.5
▤	*Potamogeton / Hydrilla*	276.7
▥	*Potamogeton / Hygrophila*	69.0
■	*Potamogeton / Vallisneria*	8.6
▩	*Sagittaria / Cabomba*	15.6

		Meters^2
■	*Hygrophila / Ludwigia*	5.0
■	*Hygrophila / Hydrilla*	10.2
■	*Hygrophila / Hydrocotyle*	10.4
▩	*Hydrilla / Hydrocotyle*	34.9
■	*Hydrilla / Sagittaria*	10.1
▩	*Potamogeton / Hydrocotyle / Hydrilla*	29.7
▩	*Potamogeton / Hygrophila / Sagittaria*	6.1
■	*Potamogeton / Hygrophila / Hydrocotyle*	17.0

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EDWARDS AQUIFER AUTHORITY

Texas Wild-Rice

San Marcos River
Texas wild-rice

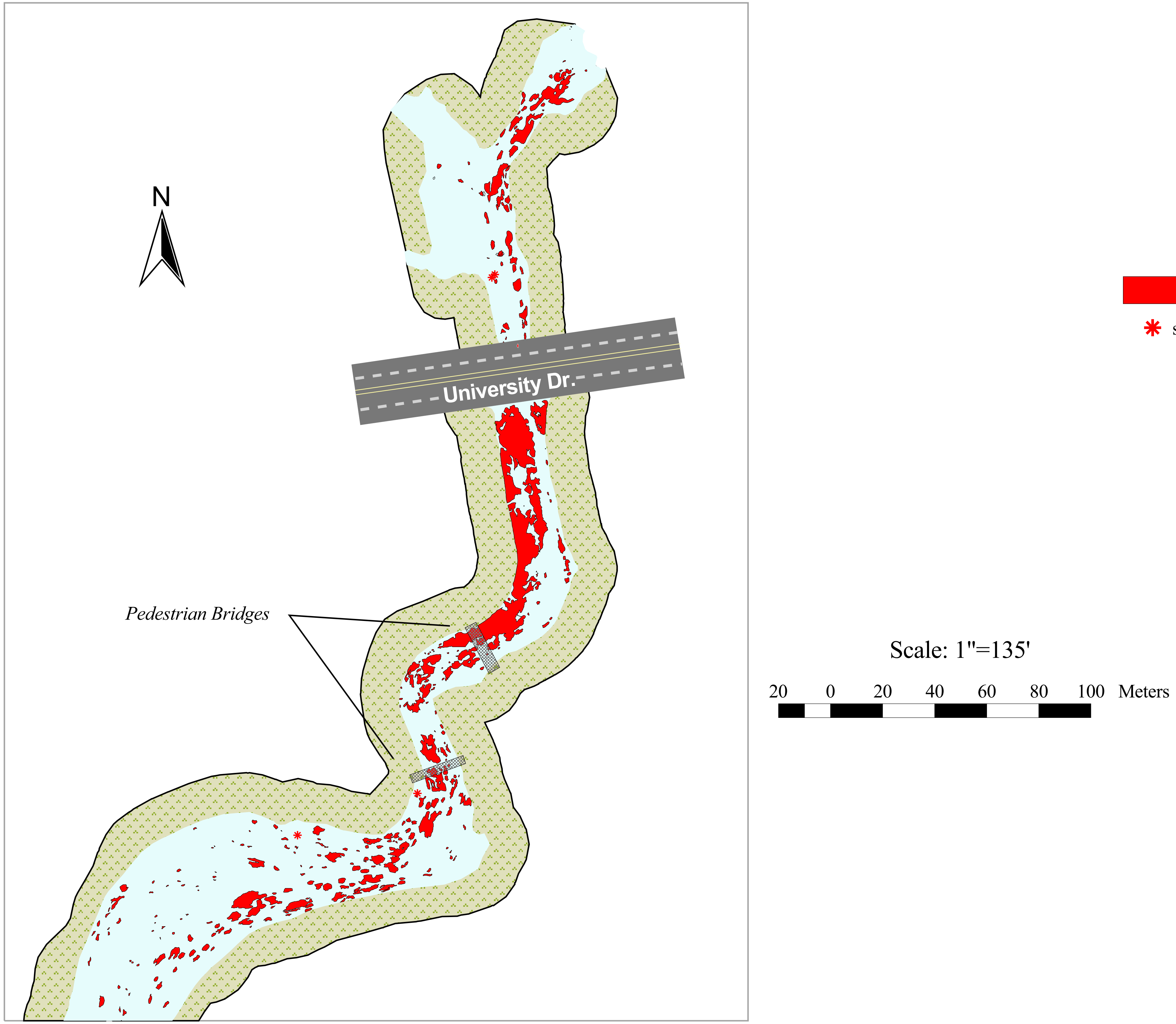
(Zizania texana)

Summer 2006 - Map 1 of 7

July 27 - August 5, 2006

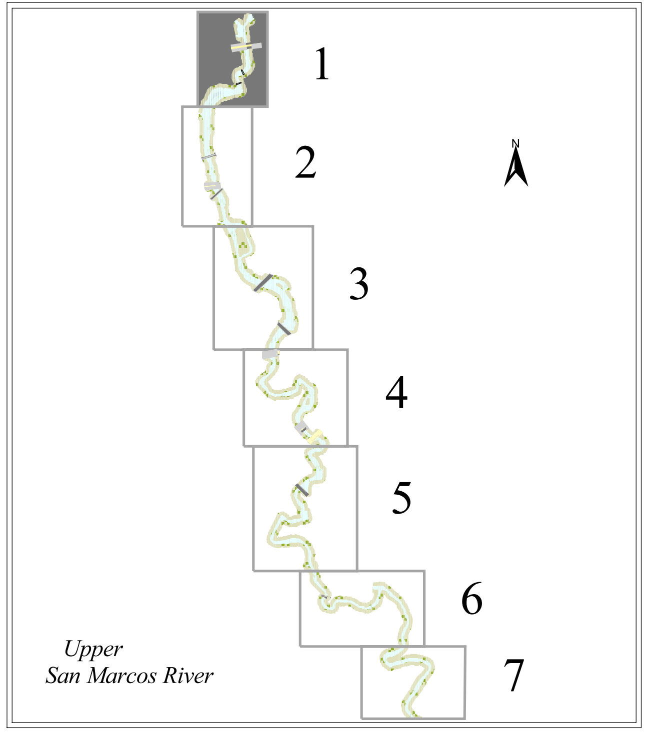
		Map 1 (m^2)	Total Population (m^2)
🟥	*Zizania*	2,079.5	3,335.7

✱ small *Zizania* plants



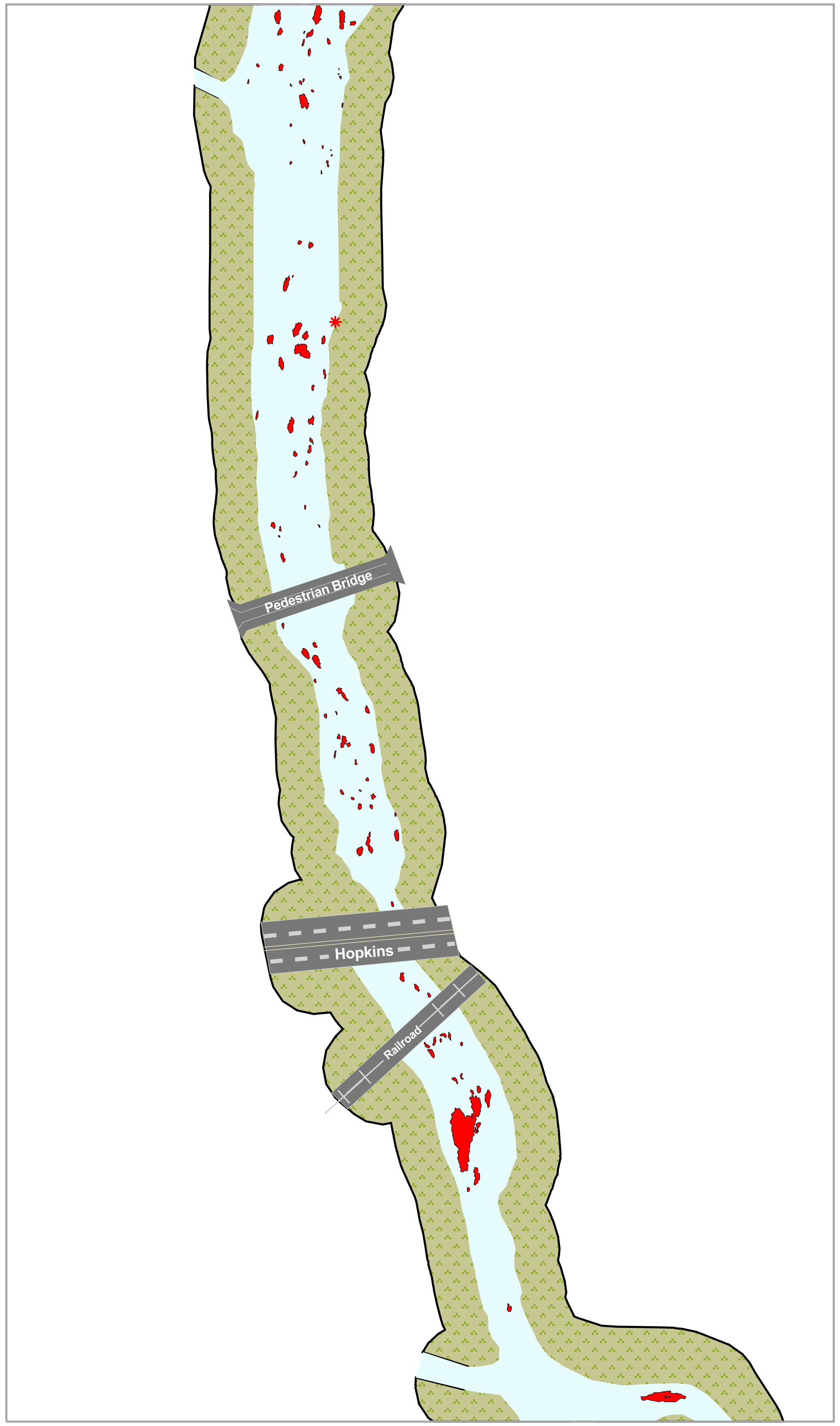
Scale: 1"=135'

Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

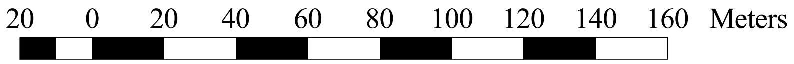
Summer 2006 - Map 2 of 7

July 27 - Augutst 5, 2006

		Map 2 (m^2)	Total Population (m^2)
🟥	*Zizania*	428.6	3,335.7

✱ small *Zizania* plants

Scale: 1"=175'



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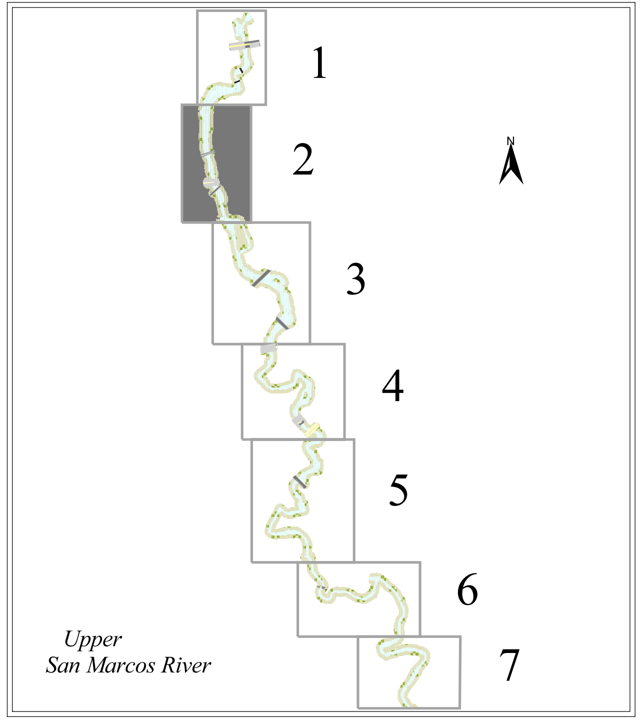
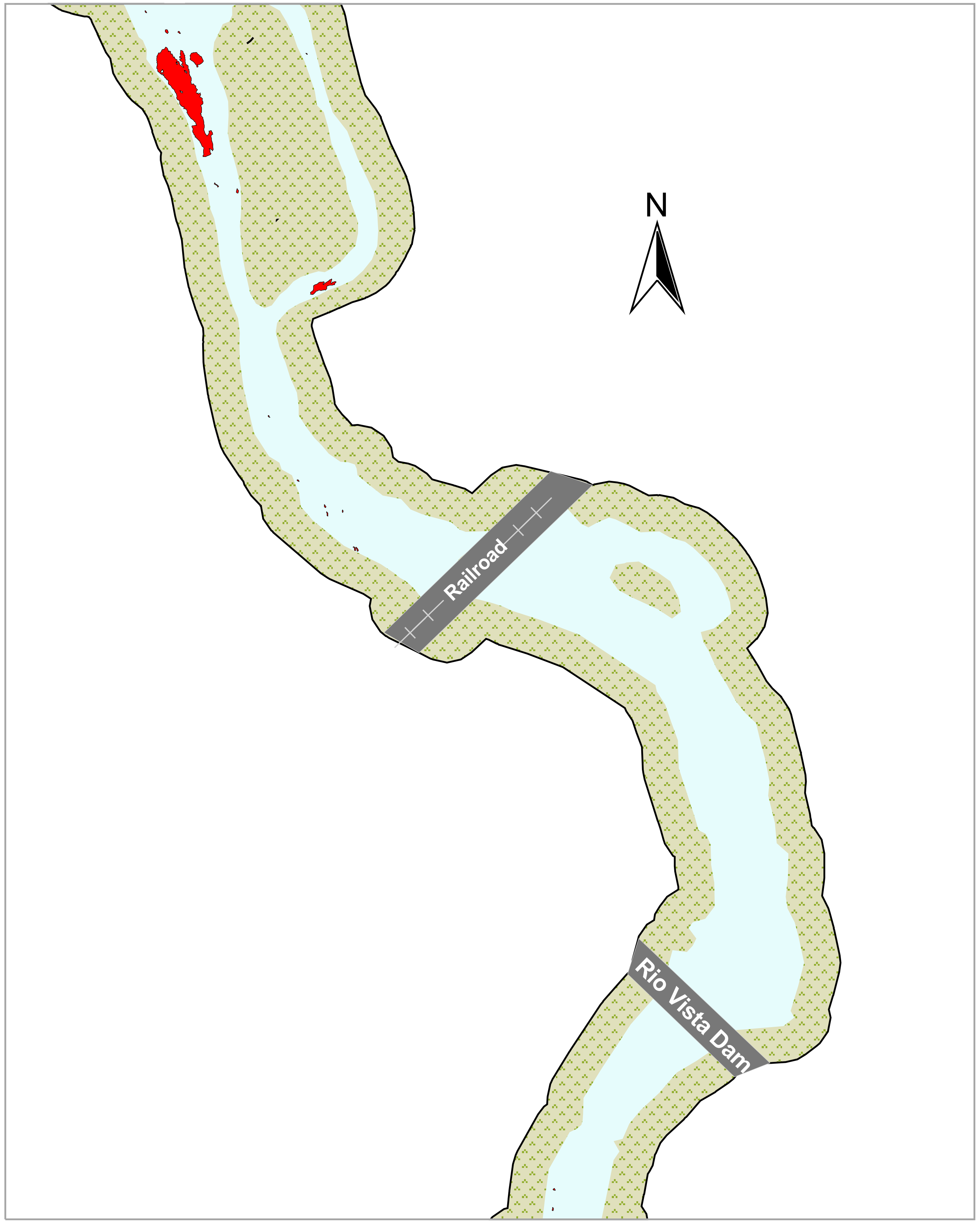


BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

Summer 2006 - Map 3 of 7

July 27 - August 5, 2006

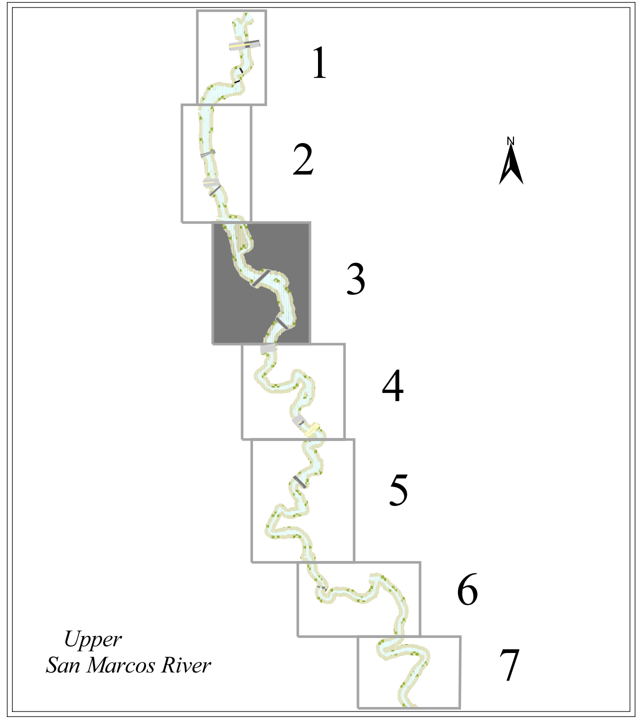
		Map 3 (m^2)	Total Population (m^2)
🟥	*Zizania*	386.3	3,335.7

✱ small *Zizania* plants

Scale: 1"=180'

20 0 20 40 60 80 100 120 140 Meters

Project Location



BIO-WEST, Inc.

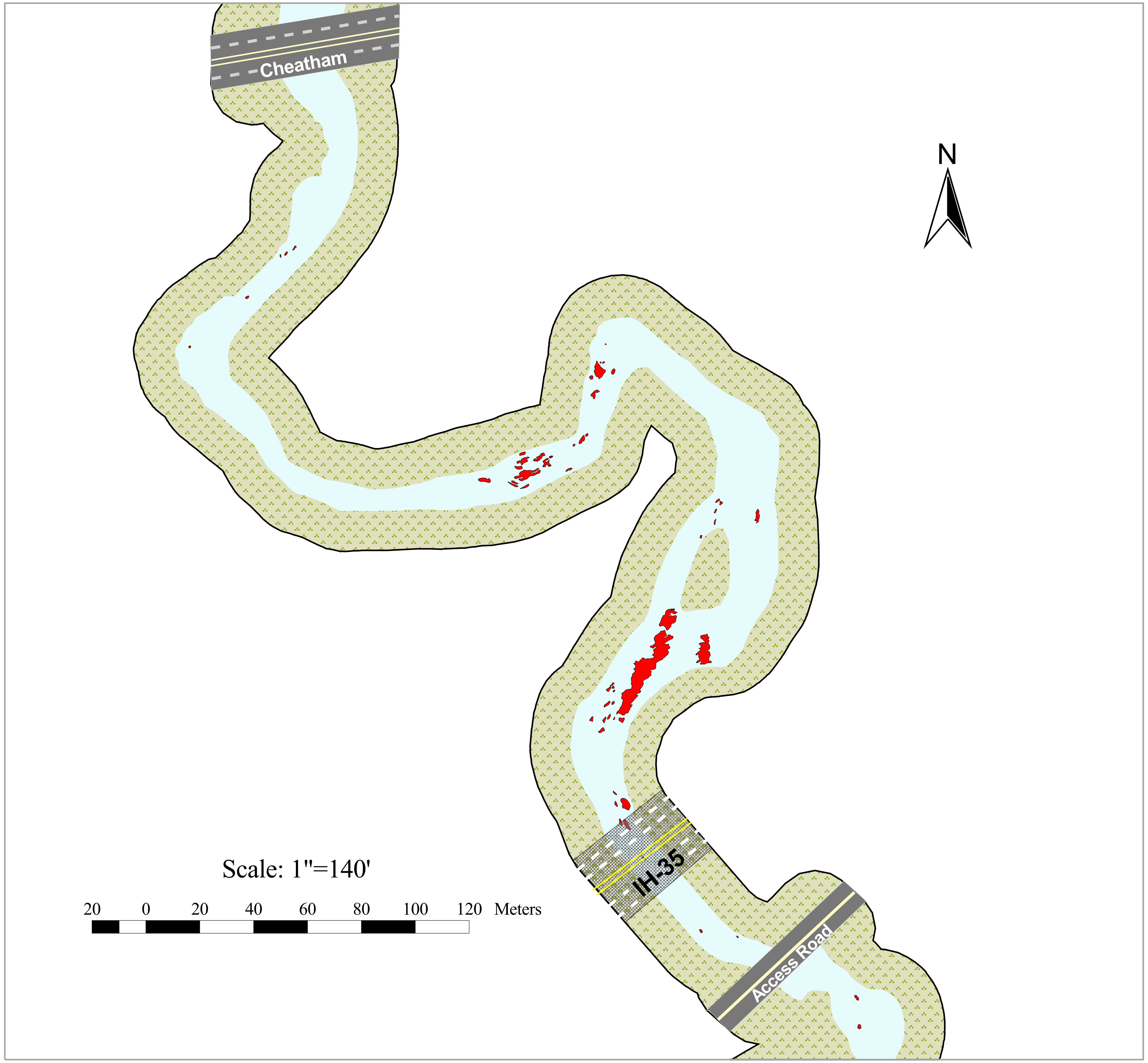
EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice

(Zizania texana)

Summer 2006 - Map 4 of 7

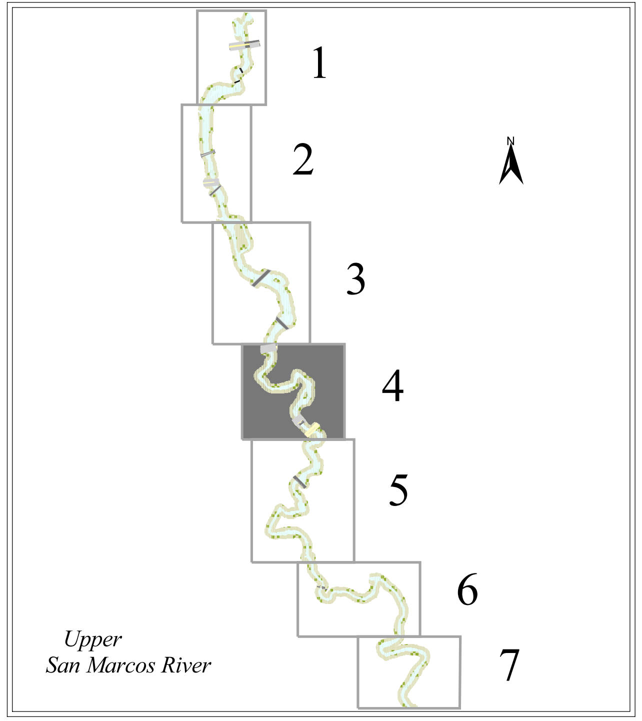
July 27 - August 5, 2006



		Map 4 (m^2)	Total Population (m^2)
🟥	*Zizania*	356.7	3,335.7

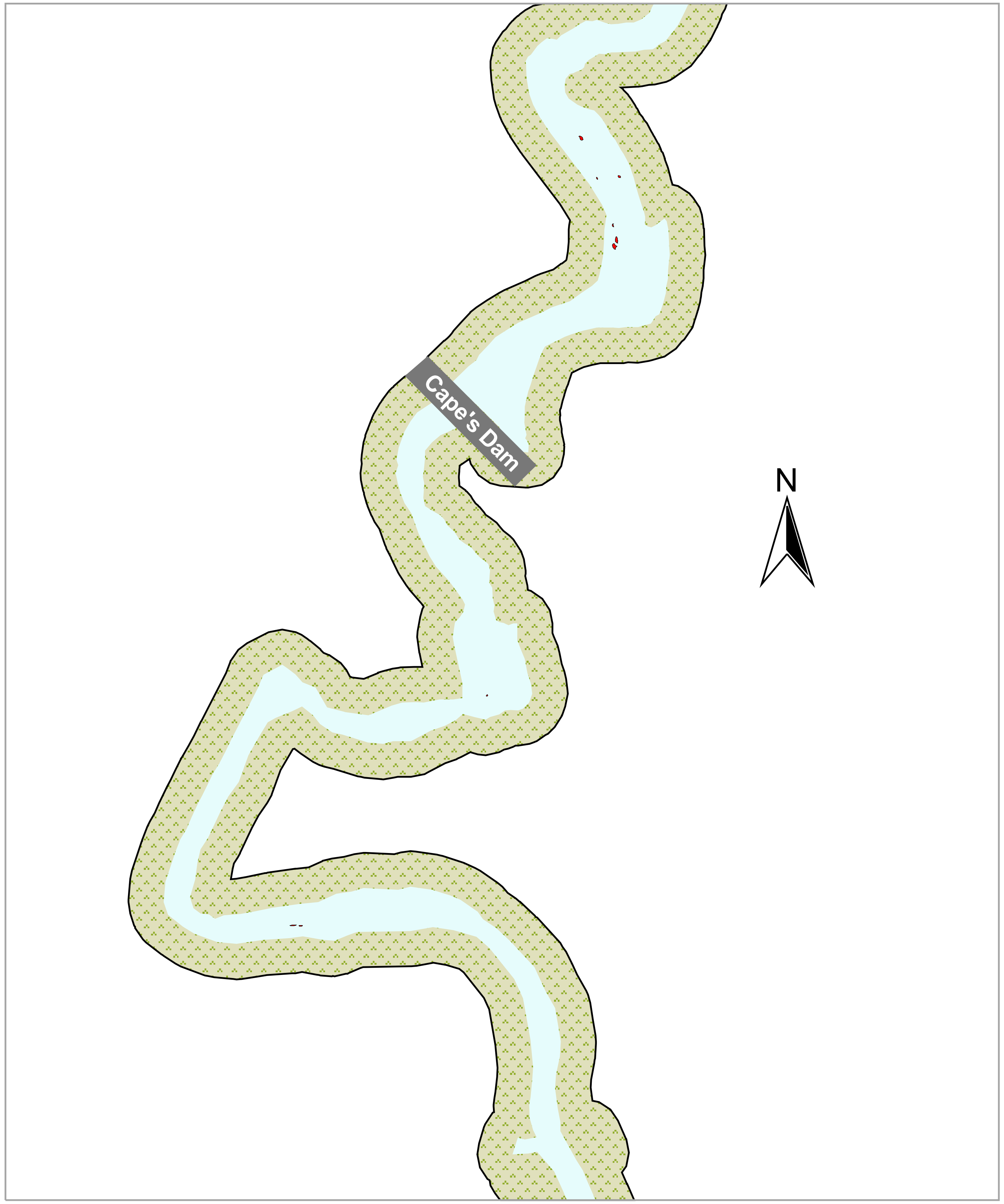
✱ small *Zizania* plants

Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

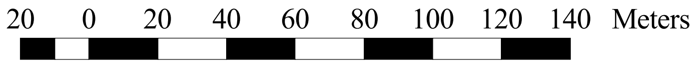
Summer 2006 - Map 5 of 7

July 27 - August 5, 2006

		Map 5 (m^2)	Total Population (m^2)
🟥	*Zizania*	9.3	3,335.7

✱ small *Zizania* plants

Scale: 1"=180'



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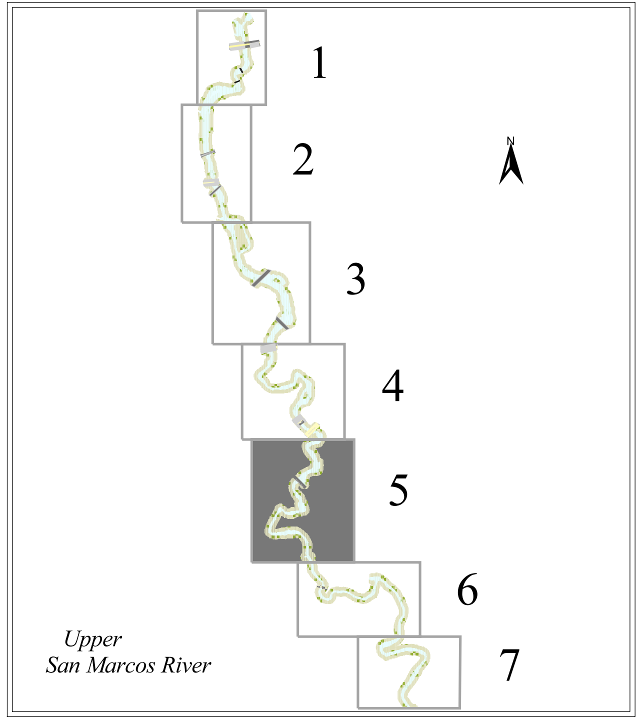


BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice

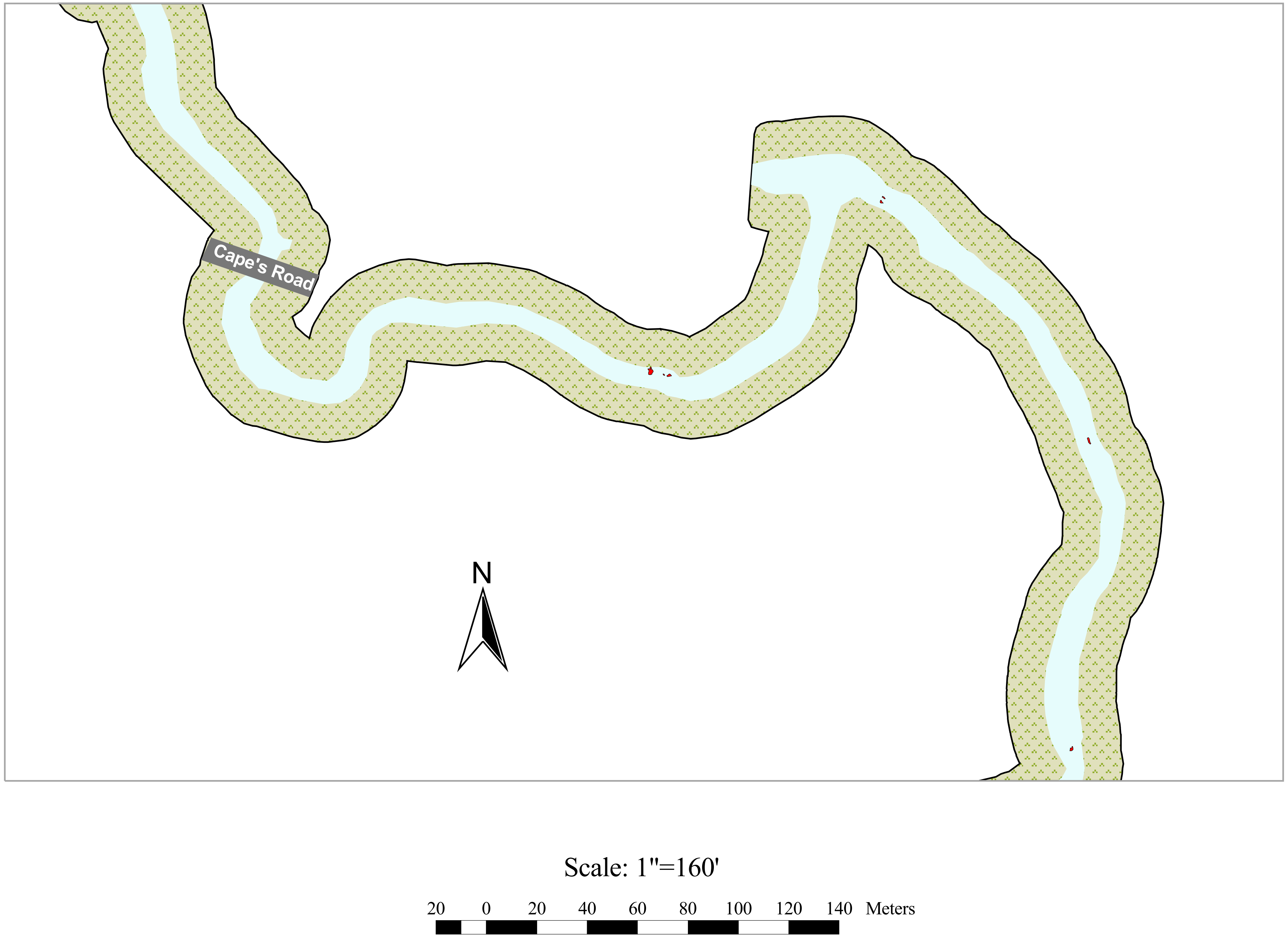
(Zizania texana)

Summer 2006 - Map 6 of 7

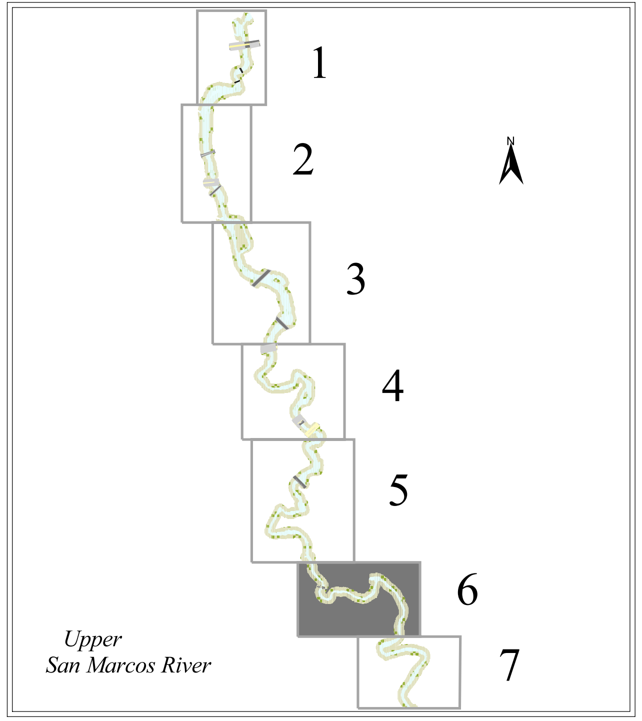
July 27 - August 5, 2006

		Map 6 (m^2)	Total Population (m^2)
🟥	*Zizania*	9.8	3,335.7

✱ small *Zizania* plants



Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice

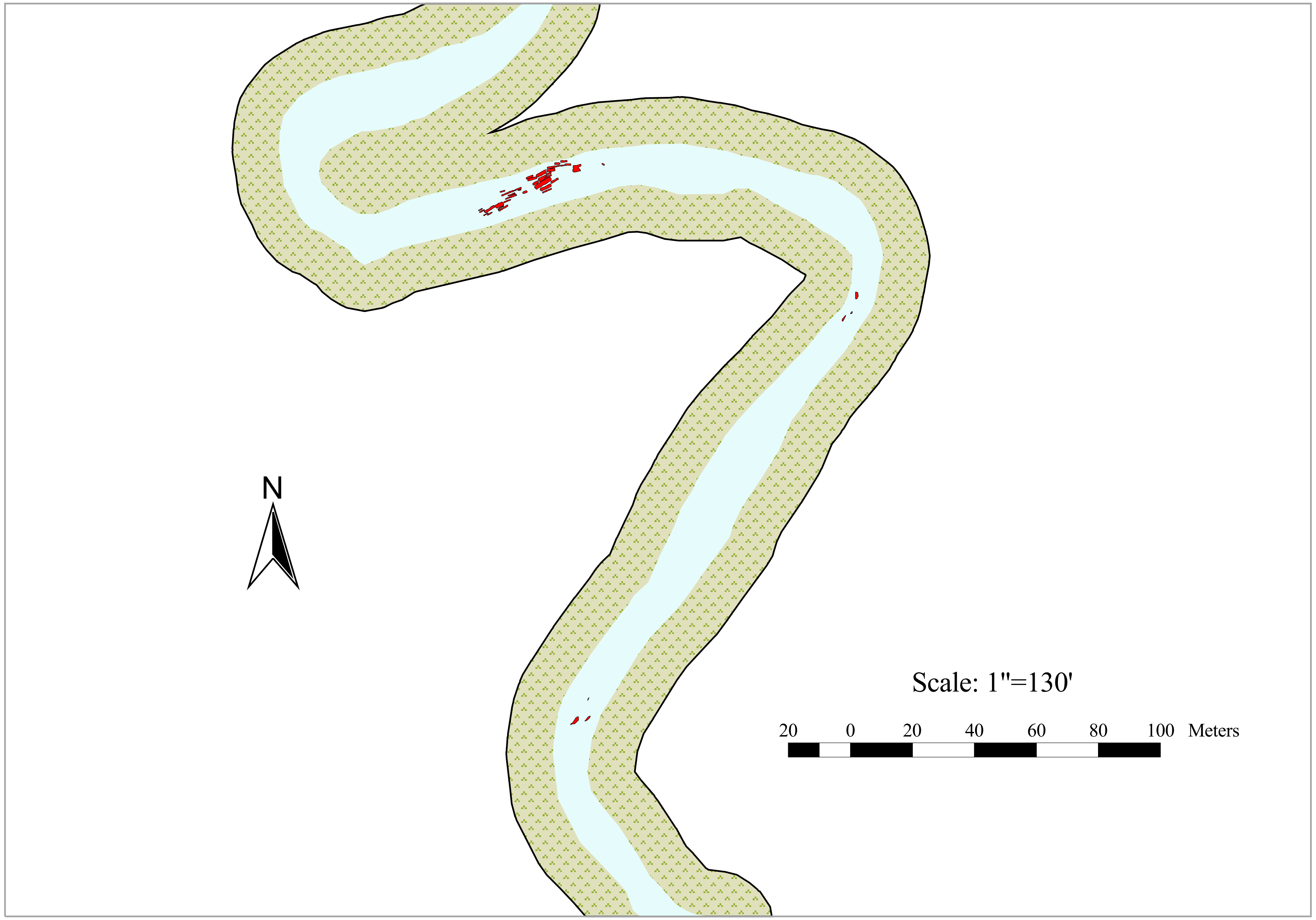
(Zizania texana)

Summer 2006 - Map 7 of 7

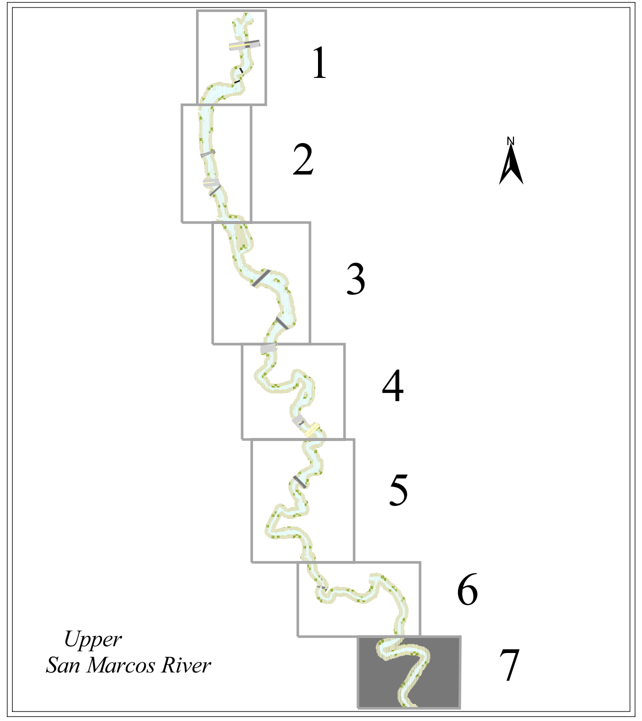
July 27- August 5, 2006

		Map 7 (m^2)	Total Population (m^2)
🟥	*Zizania*	65.5	3,335.7

✱ small *Zizania* plants

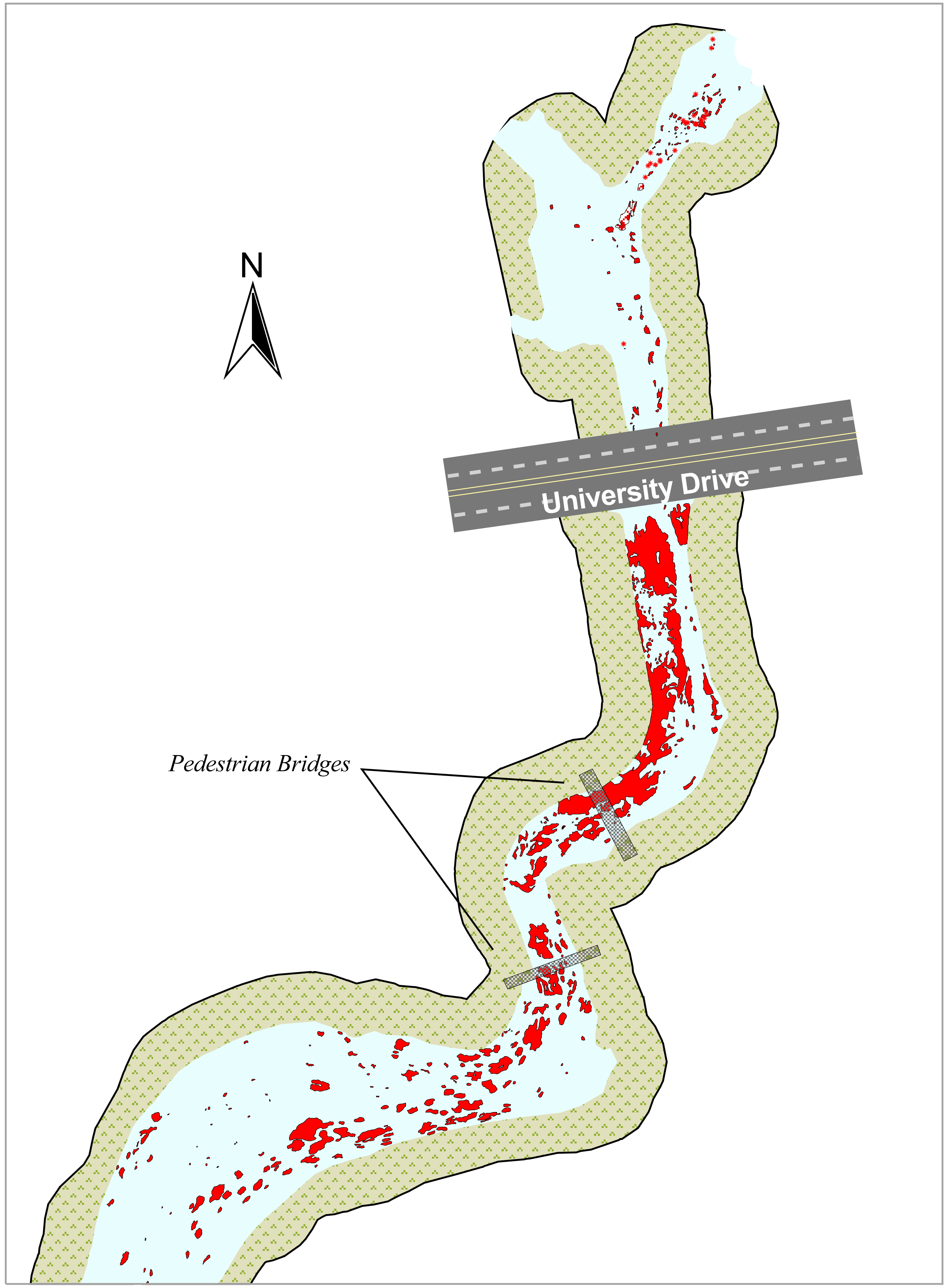


Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

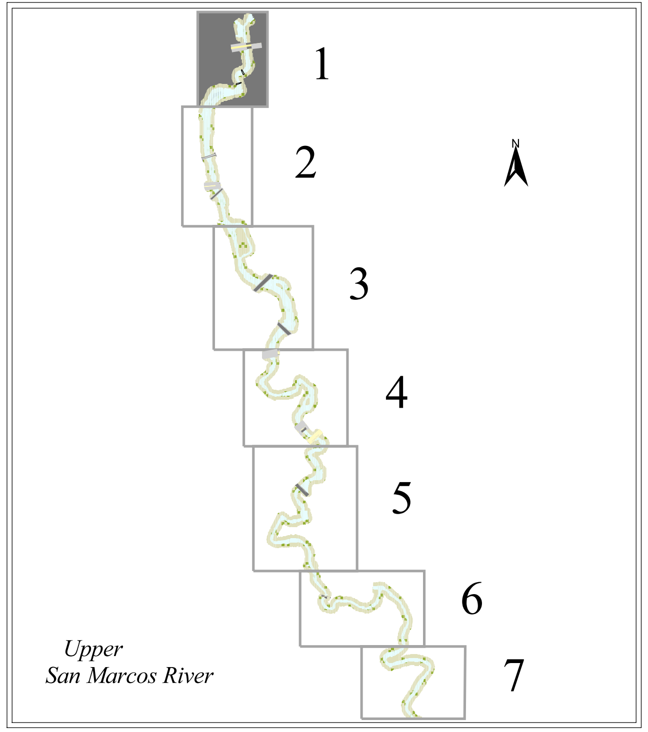
Critical Period 2 - Map 1 of 7

September 20 - October 3, 2006

		Map 1 (m^2)	Total Population (m^2)
🟥	*Zizania*	1,695.4	3,000.4

✱ small *Zizania* plants

Project Location

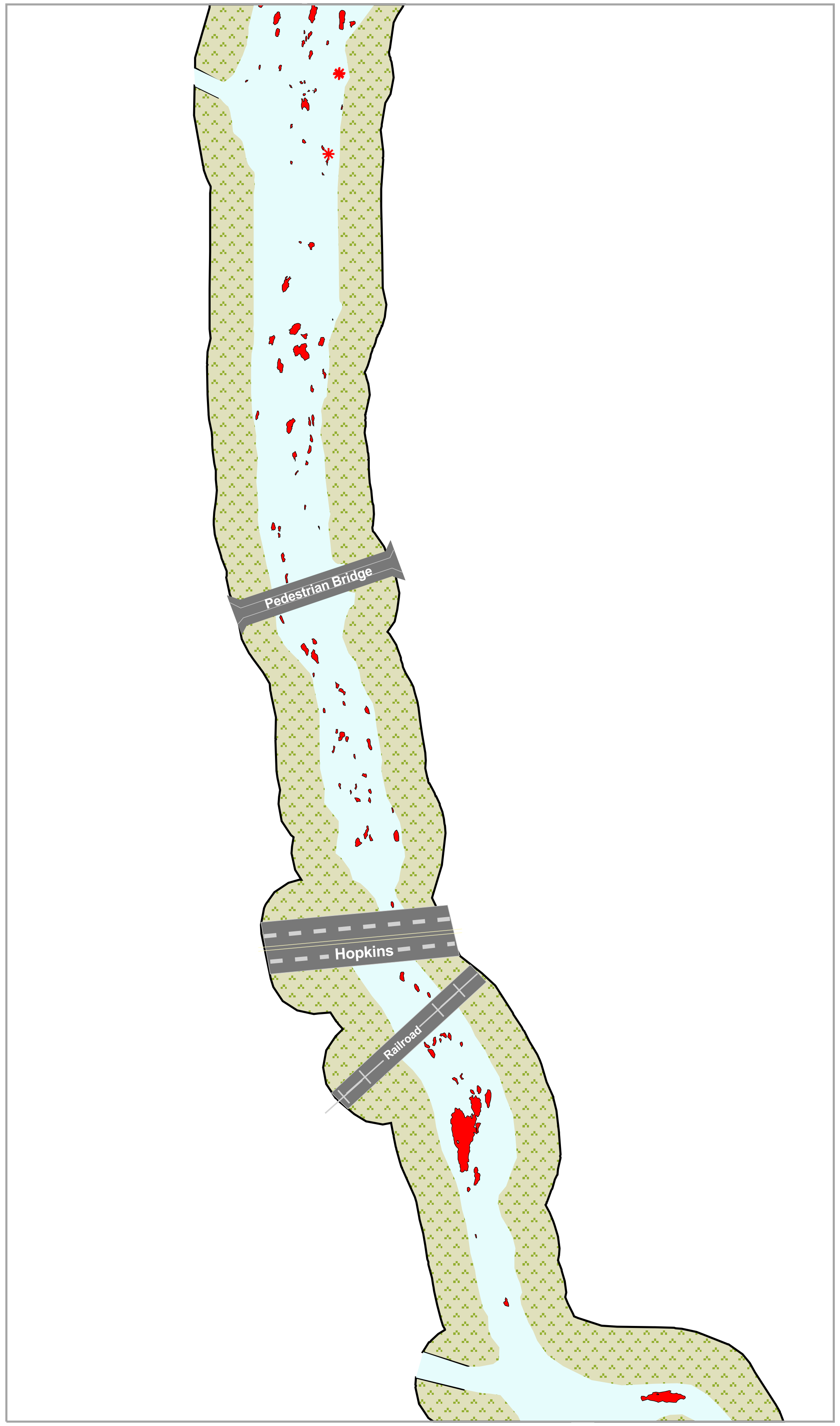


Scale: 1"=135'

20 0 20 40 60 80 100 Meters

BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

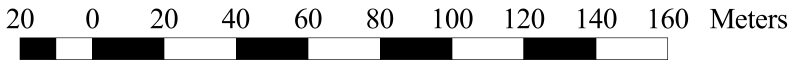
Critical Period 2 - Map 2 of 7

September 20 - October 3, 2006

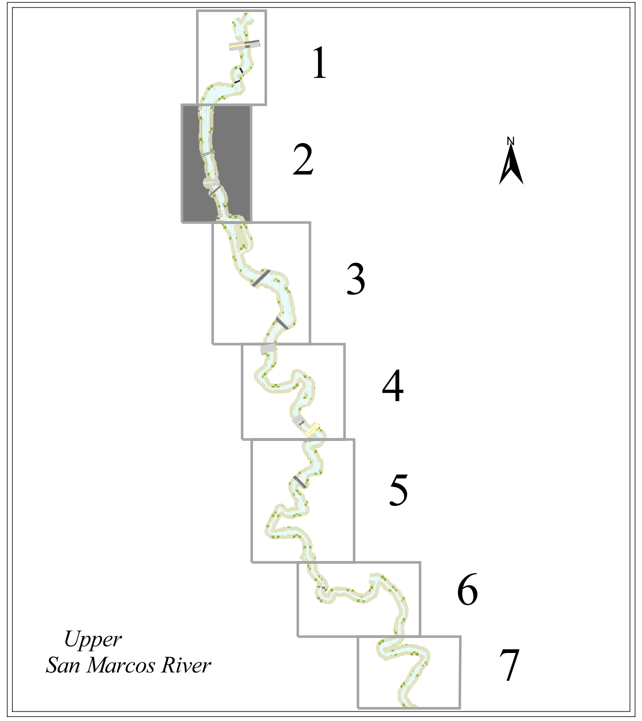
		Map 2 (m^2)	Total Population (m^2)
🟥	*Zizania*	430.8	3,000.4

✱ small *Zizania* plants

Scale: 1"=175'

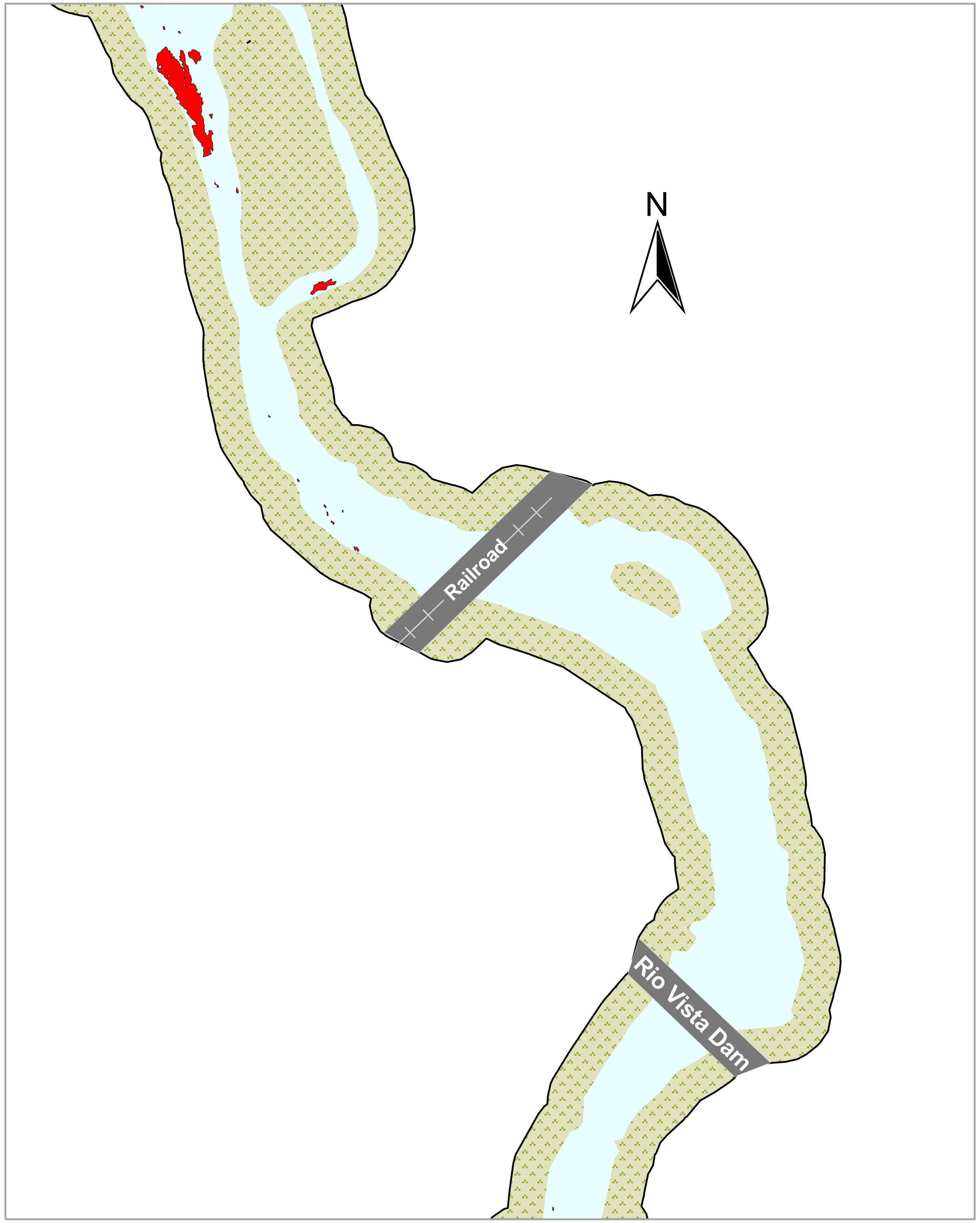


Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

Critical Period 2 - Map 3 of 7

September 20 - October 3, 2006

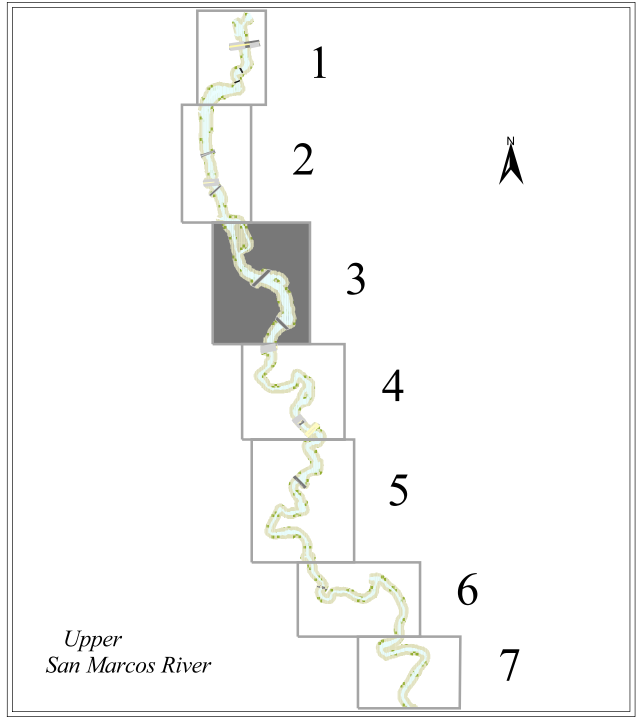
		Map 3 (m^2)	Total Population (m^2)
🟥	*Zizania*	385.8	3,000.4

✱ small *Zizania* plants

Scale: 1"=180'

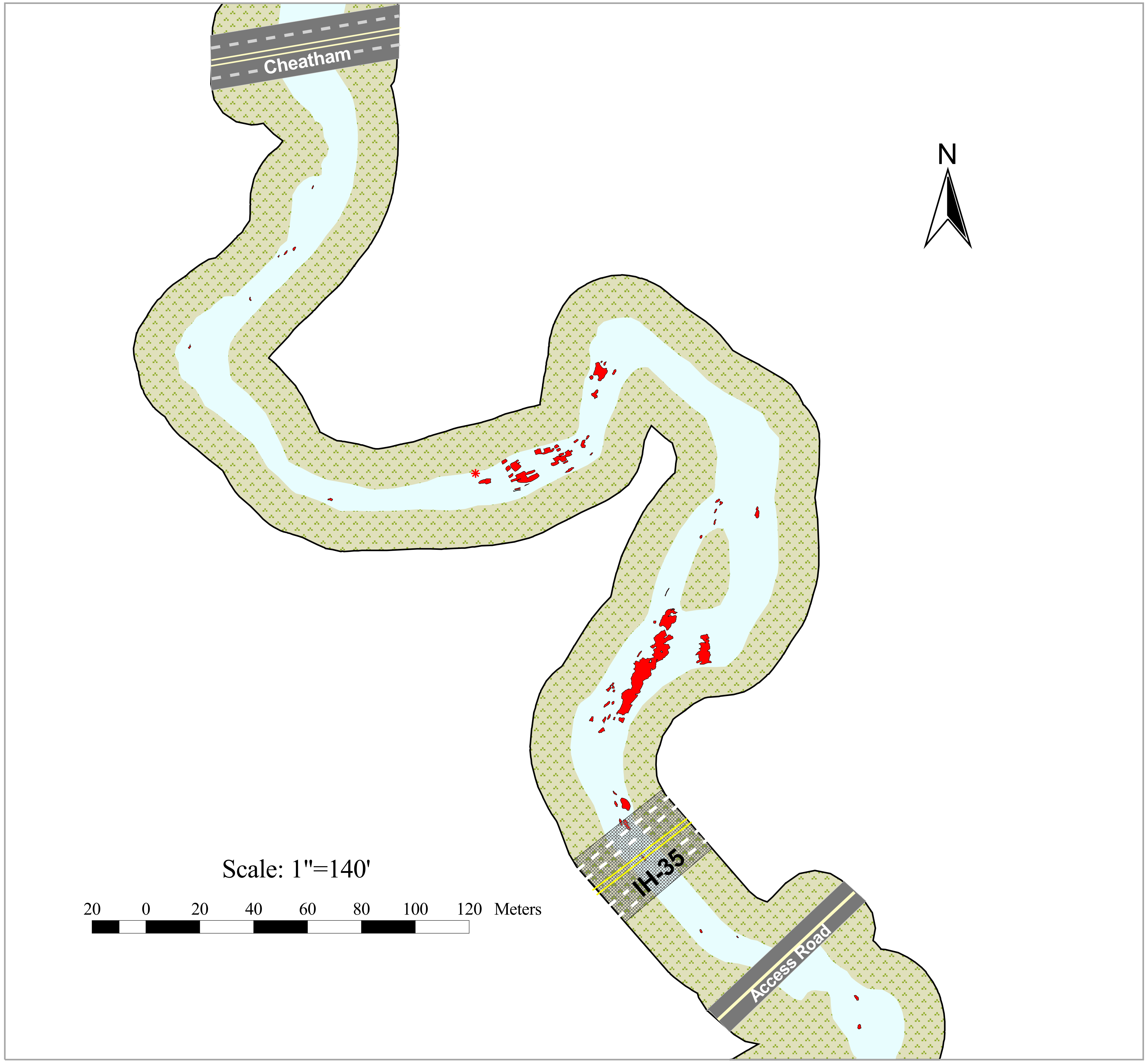
20 0 20 40 60 80 100 120 140 Meters

Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

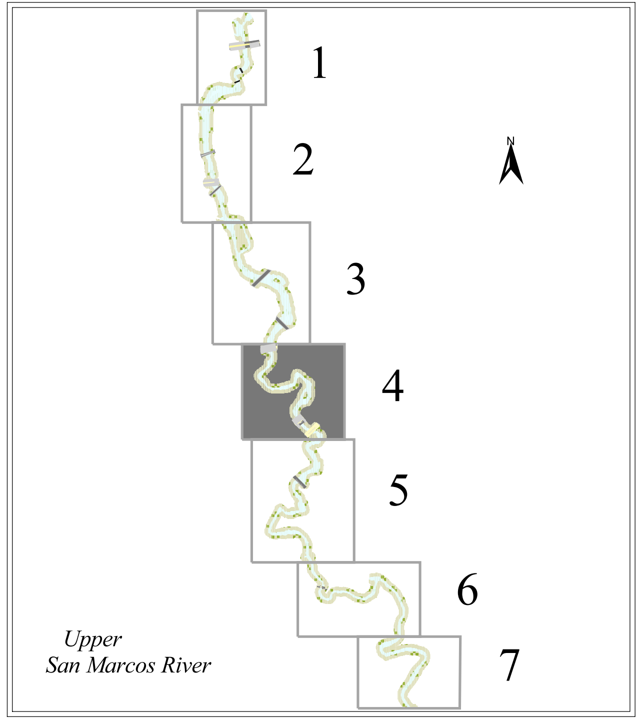
(Zizania texana)

Critical Period 2 - Map 4 of 7

September 20 - October 3, 2006

		Map 4 (m^2)	Total Population (m^2)
🟥	*Zizania*	400.2	3,000.4
✱	small *Zizania* plants		

Project Location



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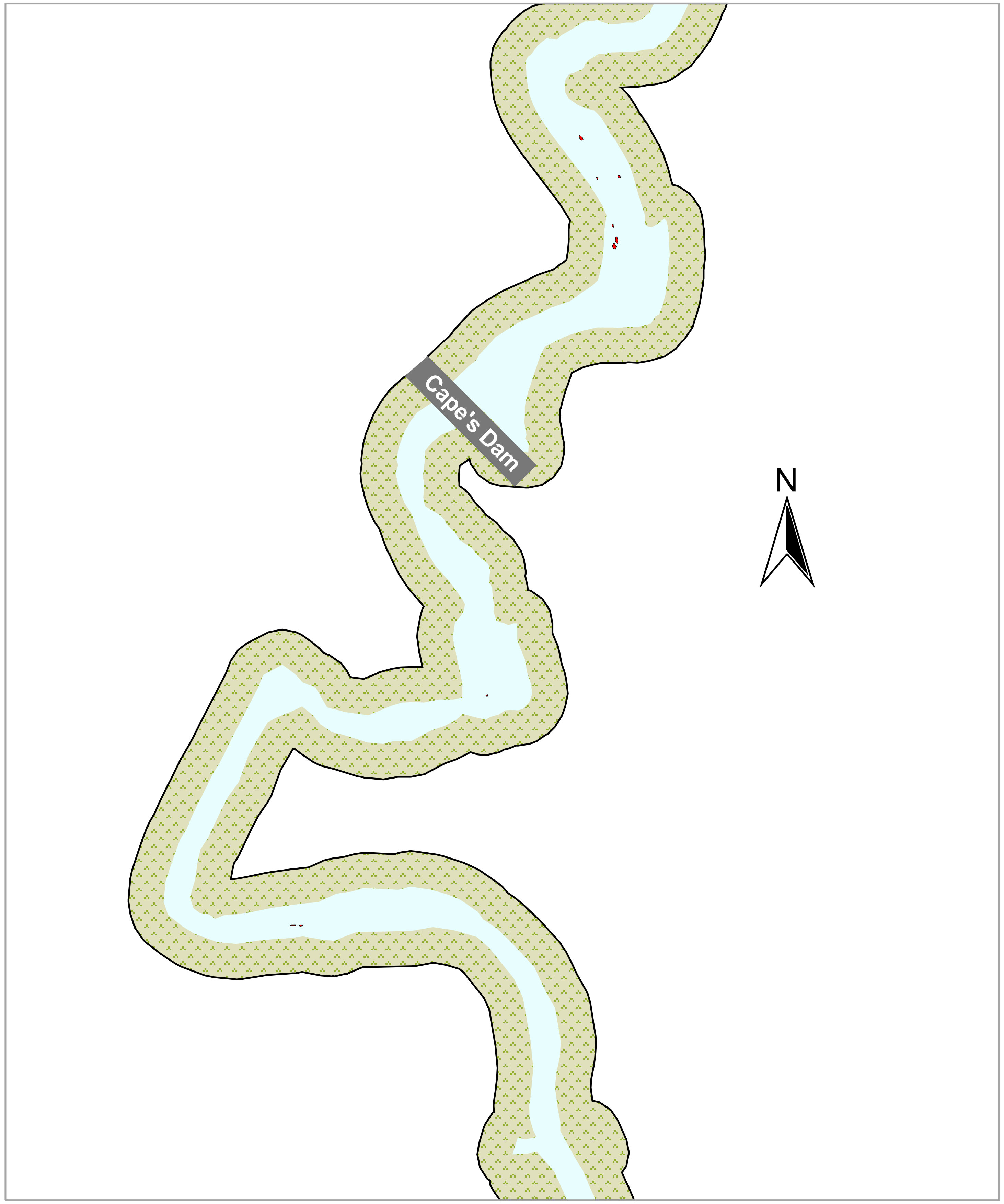
EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

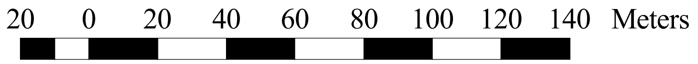
Critical Period 2 - Map 5 of 7

September 20 - October 3, 2006

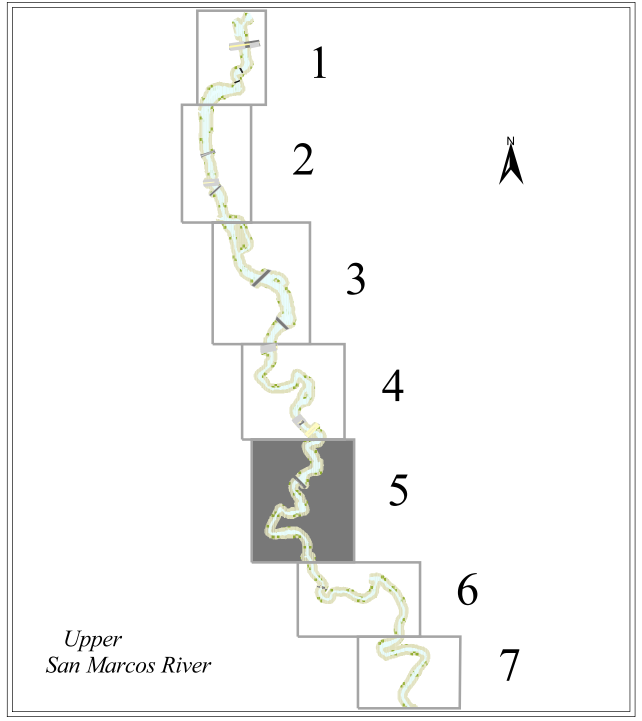
		Map 5 (m^2)	Total Population (m^2)
🟥	*Zizania*	10.2	3,000.4

✱ small *Zizania* plants

Scale: 1"=180'



Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice

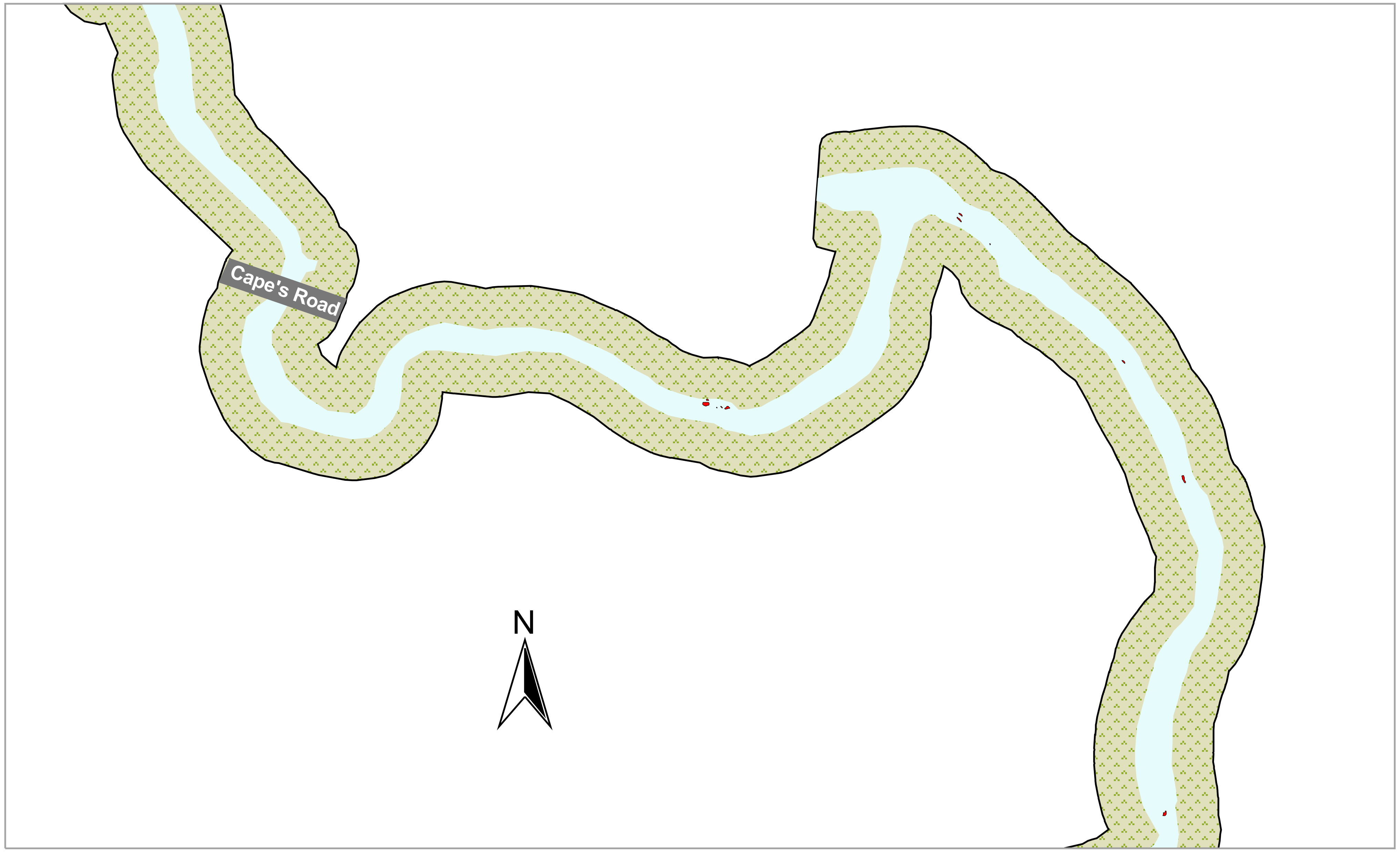
(Zizania texana)

Critical Period 2 - Map 6 of 7

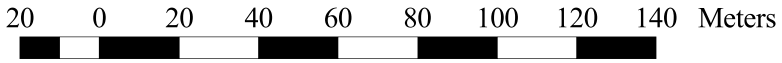
September 20 - October 3, 2006

		Map 6 (m^2)	Total Population (m^2)
🟥	*Zizania*	10.8	3,000.4

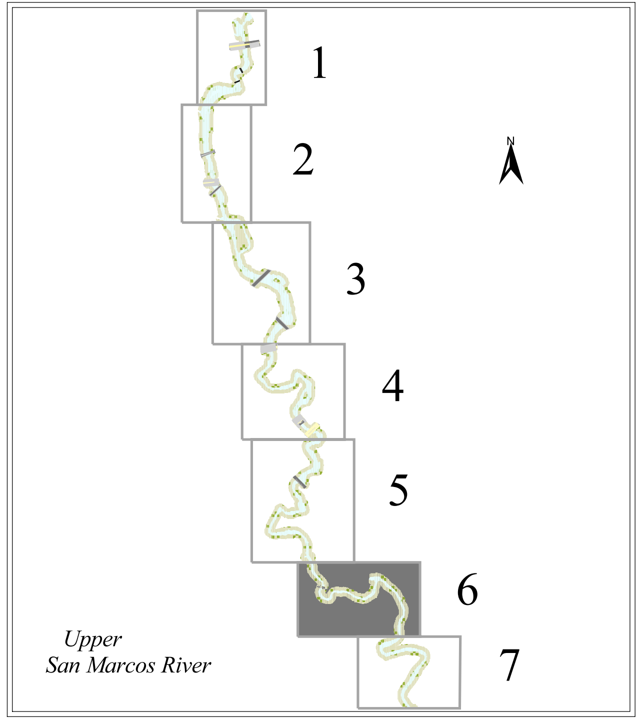
* small *Zizania* plants



Scale: 1"=160'



Project Location



BIO-WEST, Inc.

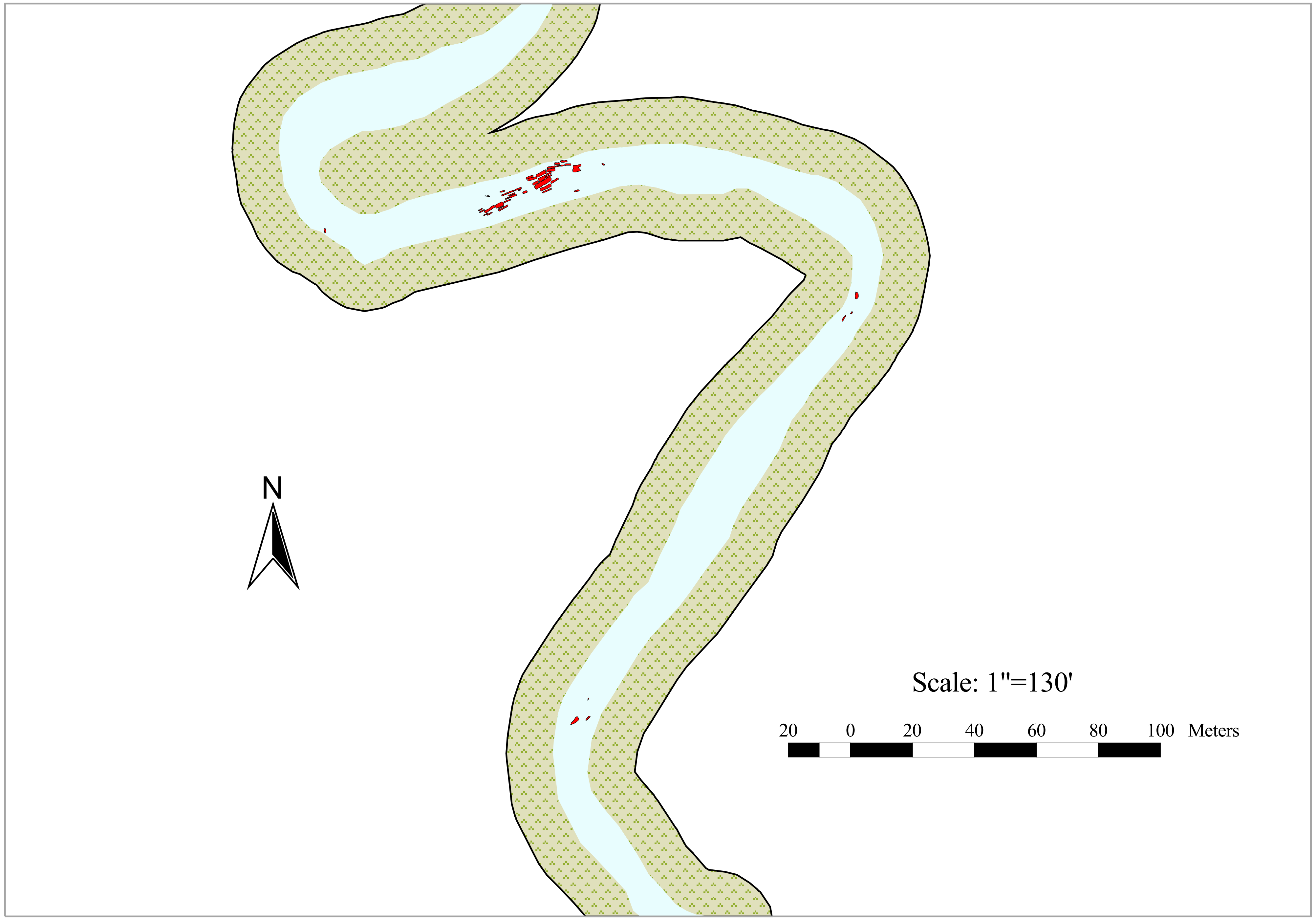
EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice

(Zizania texana)

Critical Period 2 - Map 7 of 7

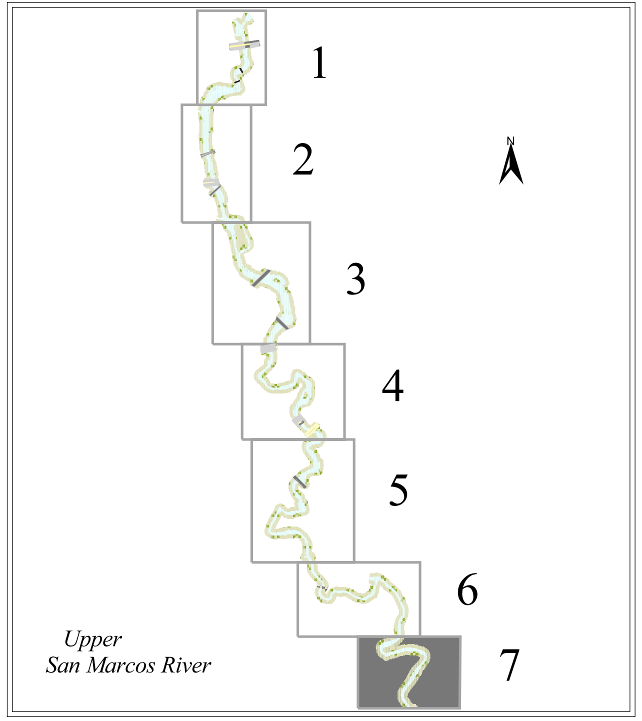
September 20 - October 3, 2006



		Map 7 (m^2)	Total Population (m^2)
🟥	*Zizania*	67.2	3,000.4

✱ small *Zizania* plants

Project Location



BIO-WEST, Inc.

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