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 2005 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 raw data obtained during two quarterly sampling events (Comprehensive Monitoring Effort) conducted on the San Marcos Springs/River ecosystem in 2005. There were no low-flow critical periods or high-flow events triggered in 2005. The data are reported here in an annual report format similar to previous reports; we have not been able to acquire the necessary range of data from all flow levels (specifically low flow) to conduct stringent data reduction techniques or statistical applications. These techniques will be applied once the appropriate data have been gathered to allow for a complete assessment of variable flow dynamics and will be included in a final report to the Edwards Aquifer Authority.

Springflow in the San Marcos River in 2005 started off higher than normal due to considerable rainfall in November 2004, but by the end of the year was below historic levels. There were no significant rain events in 2005, which contributed to the lowest discharge reading (136 cfs) in five years. By December flows had dropped to levels that were below that of average conditions over the historical period of record. If flows continue to decline in 2006, there may be critical period conditions that initiate low-flow sampling efforts in the San Marcos River.

Though water quality readings were not taken (except during drop net samples) in the San Marcos River in 2005, the biological community flourished as in previous years. Thermistor data have revealed a high degree of thermal uniformity throughout the San Marcos ecosystem despite the wide-ranging conditions experienced during the study. Temperatures at all sites did not exceed the water quality standards value (26.67 ˚C) in 2005. Though temperatures started to increase in the latter half of 2005, all stayed within the 20 ˚C to 26 ˚C range. The lowest temperatures were recorded in the winter months at Sessom's Creek (11.8 ˚C). Sessom's Creek has more direct input from runoff and as a result it is more prone to large temperature fluctuations. Temperatures at downstream sites (City Park, I-35) were more variable than upstream sites (Dam, Chute) because they are farther away from direct input of the springs, and are more influenced by environmental fluctuations in temperature. The lower flow conditions of 2005 may have an impact on temperatures in 2006 if they continue to decline. In addition, fixed station photographs documented physical changes in habitat at multiple locations throughout the San Marcos Springs/River ecosystem.

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. Vegetation in the I-35 reach had substantially more change in communities than the City Park and Spring Lake Dam reaches, as a result of the high flows in late 2004. *Cabomba* was reduced drastically in spring 2005 in the I-35 reach, but recovered somewhat by fall 2005. This vegetation type is important because it provides the highest-quality fountain darter habitat (of those sampled quantitatively) in the San Marcos River, and this reach is the only place where it is found (of the reaches sampled). The large vegetation mat in the City Park reach continued to grow due to lower flow conditions prevalent through the latter half of 2005. These vegetation mats can have substantial impacts on the vegetation below them since they often remain in one spot for months and severely reduce the sunlight for the covered plants. The impacts can be severe to Texas wild-rice (***Zizania texana***) plants that are covered for extended periods of time. Recreational impacts, though apparent in many places, appeared to be minimal for the majority of plant communities in 2005.

In contrast to previous years, total coverage of Texas wild-rice in the San Marcos River decreased from 2004 to 2005. Much of this is attributed to fragmentation of several larger stands following the high flows of 2004. The fragmentation took place in a shallow stretch in the I-35 reach where high flows can more easily uproot vulnerable plants. It also occurred at the lower extent of Texas wild-rice in the San Marcos River where several rice plants were planted by the United States Fish and Wildlife Service (USFWS) in 2003. Many small individual rice plants were apparently washed downstream in addition to a few larger plants that became fragmented in this section in 2005. It is unclear at this point if the scouring effects of the flood in 2004 will stimulate growth of existing stands into areas that are now bare, as has been shown in the past. Recreation may have also contributed to the decrease in Texas wild-rice coverage in the San Marcos River. Several plants in the Sewell Park reach have disappeared along a heavily used section between stairs leading into the river. Similar access points are present in the City Park reach, though it does not appear people adversely affected Texas wild-rice plants in 2005. The calculation of total Texas wild-rice coverage by the BIO-WEST project team differed substantially from the total area measured by the Texas Parks and Wildlife Department (TPWD). A difference in mapping technique may have attributed to the difference in total coverage between the BIO-WEST project team and the TPWD. This discrepancy probably occurred in the section where the USFWS planted Texas wild-rice. For example, if the rice plants in this section are mapped as one plant (as TPWD did), it can add approximately 200 m^2 more area than if the plants are mapped individually (BIO-WEST). Root exposure and instances of herbivory of Texas wild-rice were relatively low and similar to previous years.

Direct sampling of the fountain darter occurred in the same reaches with aquatic vegetation used to stratify 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 were highest in *Cabomba* and *Potamogeton*/*Hygrophila* vegetation types. The size-class distribution for fountain darters collected by drop nets from the San Marcos Springs/River ecosystem in 2005 is typical of a healthy fish assemblage. Though there are fewer small darters in the San Marcos system compared to the Comal system, the difference in reproduction is likely a result of less suitable vegetation types and higher current velocities in the San Marcos River. However, smaller individuals are abundant in dip net data from Spring Lake suggesting year-round reproduction at that site. In sampled river reaches, larger darters dominated fall samples while smaller individuals were more prevalent in the spring samples indicating a spring reproductive peak.

Only two giant ramshorn snails (*Marisa cornuarietis*) were found 2005 in the San Marcos River. However, because of the potential for a rapid population increase and the impact that this exotic species can have under heavier densities, close monitoring should continue. The gill parasite that has been reported to infect the fountain darter in the Comal system was not visually evident in fountain darters collected from the San Marcos system in 2005.

Salamander densities were highly variable between fall and spring in 2005, with fall having higher densities at 2 of 3 sites. Filamentous algae remained abundant throughout 2005 and each sampling event conducted in the Hotel Reach and the deep site in Spring Lake required clearing the algae prior to sampling efforts. This may have impacted sampling efficiency. Regardless, this site provided highly suitable habitat with consistent springflow, abundant cover, and an abundant food supply. Lower flows below the dam during the fall sampling effort at the spilling location likely contributed to more efficient searching of salamanders.

As described above, the data in this report remain preliminary due to the lack of low-flow data that are necessary to make a complete analysis. More data from periods of low-flow (particularly from an extended period of low-flow) are essential to fully evaluate the biological risks associated with future critical periods (high or low-flow). Fortunately, the Authority's Variable Flow monitoring program includes an extensive data-collection protocol for periods of critical flow that should address this current limitation. In the interim, efforts to evaluate response mechanisms of the threatened and endangered species to low-flow 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. Data collected during natural low-flow conditions (Critical Period sampling) is essential to verify any interim results and gather additional information to further evaluate low-flows.

Though the comprehensive portion of the study has been reduced to two annual samples (plus a limited summer effort), it is still adequate to maintain a continuous record of conditions. That is vital knowledge since antecedent conditions influence community-level response to reduced discharge conditions. Sampling only during a low-flow event will not provide the necessary context to adequately assess changes that occur during such conditions.

METHODS

In 2005, only two (reduced from three) full comprehensive sampling efforts were conducted with a sampling protocol that was slightly modified relative to 2000 - 2004. The new monitoring program was discussed among BIO-WEST, Inc. (BIO-WEST), the Edwards Aquifer Authority (Authority), and the U.S. Fish and Wildlife Service (USFWS). Modifications to summer sampling included only conducting the dip net sampling for fountain darters (*Etheostoma fonticola*), and Texas wild-rice (*Zizania texana*) annual mapping , while the spring and fall sampling periods remained the same. This maintained the continuity of the sampling plan through the summer while reducing the disturbance to the system from multiple sampling activities. The changes described above were intended to maximize the efficiency of this project. The comprehensive schedule included the following components twice in 2005 unless otherwise noted:

Aquatic Vegetation Mapping
- Texas wild-rice annual survey (summer effort)

Water Quality
- Thermistor Placement
- Thermistor Retrieval
- Fixed Station Photography

Texas Wild-Rice Physical Observations

Fountain Darter Sampling
- Drop Nets
- Dip Nets (additional summer effort)

San Marcos Salamander Observations

High-Flow Sampling

Unlike in 2001, 2002, and 2004 there were no high-flow sampling events in 2005.

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 water quality component of this study was reduced in 2003, but the two components necessary for maintenance of long-term baseline data, temperature loggers (thermistors) and fixed station photography, were included again in 2005. 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. When conditions trigger low-flow sample events in the future, the full range of water quality sampling parameters will be employed, including water quality grab samples and standard parameters from each of the water quality sites in the San Marcos/Springs ecosystem (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 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.

In addition to the water quality collection effort, a long term record 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.

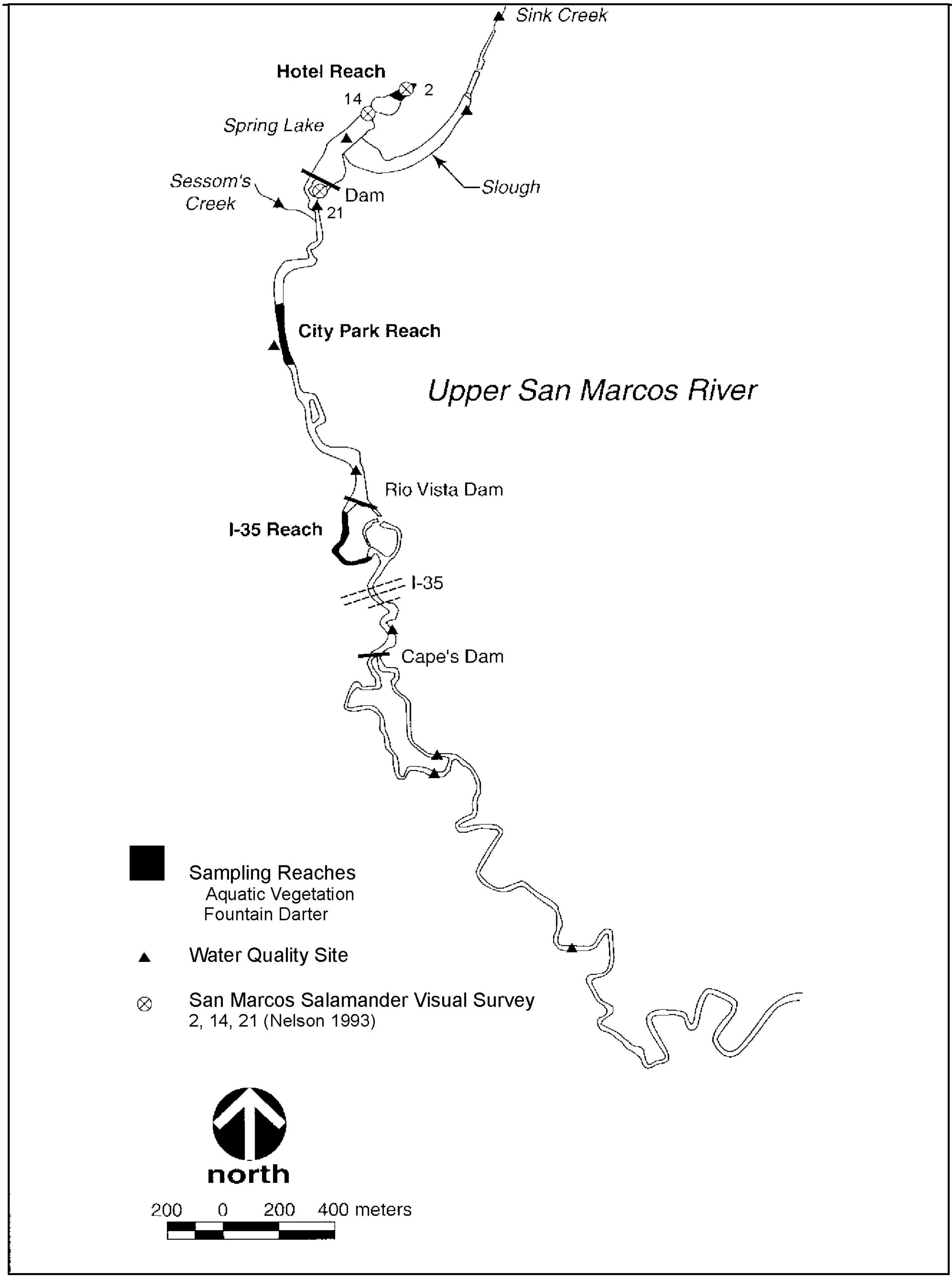

Figure 1. Upper San Marcos River water quality and biological sampling areas.

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

In addition to mapping all of the vegetation found within the three study reaches, the annual mapping of all Texas wild-rice in the San Marcos River occurred during the summer sampling effort.

Texas Wild-Rice Physical Observations

Texas wild-rice stand in the IH-35 reach

The aerial coverage of most vulnerable Texas wild-rice stands 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.

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 vulnerable 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, video images were taken during several Comprehensive and Critical Period samples using an underwater video camera.

Fountain Darter Sampling

Drop Nets

A drop net is a type of sampling device previously used by the USFWS to sample fountain darters and other fish species 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 quarterly 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 2000-2005 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 would be 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.

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.

Exotics / Predation Study

This sampling component was not included in the quarterly samples of 2005 but will be included in future low-flow sampling efforts.

OBSERVATIONS

The BIO-WEST project team conducted the 2005 sampling components as shown in Table 1.

Table 1. Components of 2005 sampling events.

EVENT	DATES	EVENT	DATES
Spring Sampling		**Fall Sampling**	
Vegetation Mapping	Apr 11 - 13	Vegetation Mapping	Sept 26 - 28
Texas Wild-rice Physical Observations	Apr 28	Texas Wild-rice Physical Observations	Sept 29
Fountain Darter Sampling	Apr 18 - 22	Fountain Darter Sampling	Oct 5 - 6
San Marcos Salamander Observations	Apr 18 - 19	San Marcos Salamander Observations	Sept 30
Summer Sampling			
Texas wild-rice Annual Survey	Aug 16 - 18		
Fountain Darter Sampling	July 25		

Springflow

Springflow in the San Marcos River in early 2005 was higher than normal, but by the end of the year was below average historic levels. The flooding that occurred in November 2004 contributed to the highest mean daily flow level (1,280 cfs) recorded since the inception of this study (Figure 2). The flow in the river decreased rapidly throughout 2005 due to few significant rain events (especially in the latter half of 2005) in the areas that provide localized recharge for the San Marcos River. This led to the lowest discharge reading in 5 years (Table 2), which occurred in December (a normally wet month) rather than in the historically drier summer months. Discharge was consistently high in 2005 until late November when it dropped below average historic levels (Figure 3). Flow levels will be carefully monitored in 2006 to see if a low-flow Critical Period sampling event is triggered.

Table 2. Lowest discharge 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

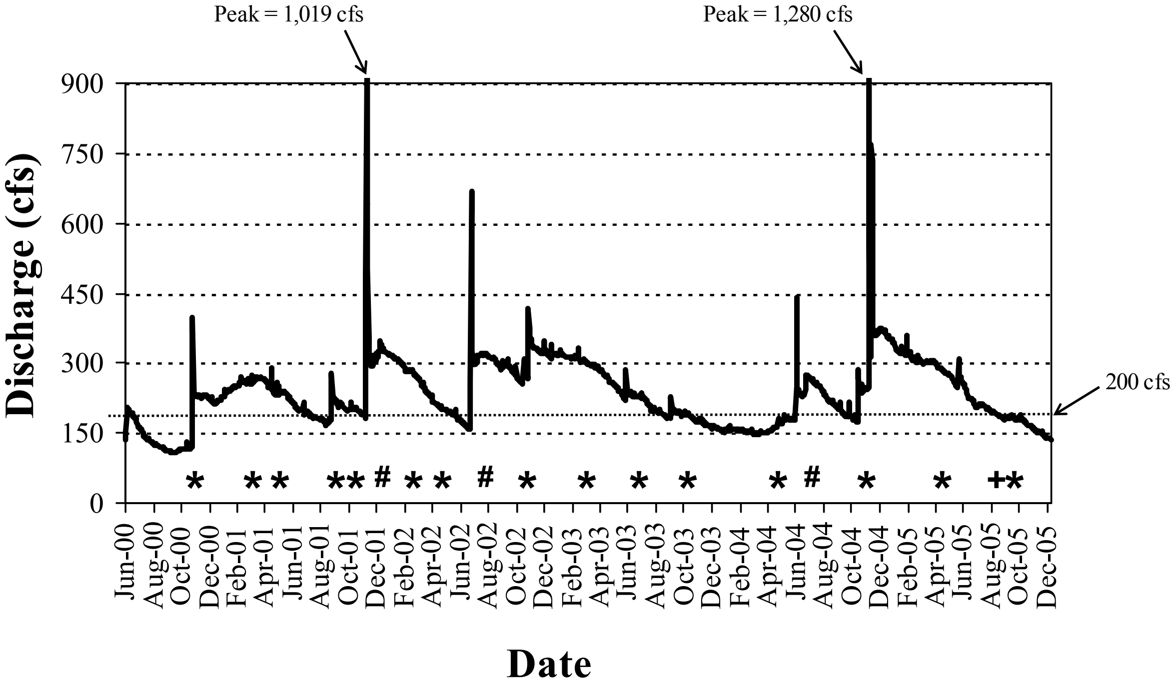

Figure 2. Mean daily discharge in the San Marcos River during the study period; approximate dates for quarterly (*) and high-flow sampling efforts (#) are indicated. A modified summer sampling trip was added in 2005 (+).

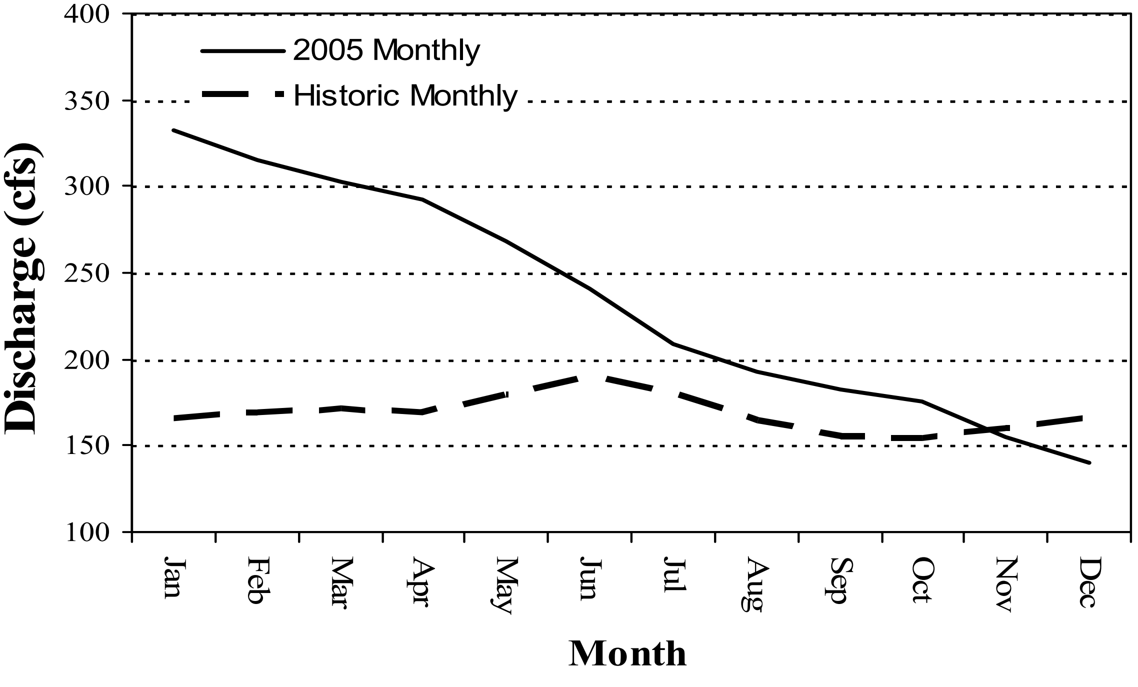

Figure 3. Mean monthly discharge in the San Marcos River during the 1956-2005 period of record.

WATER QUALITY

The thermistor data for important/representative reaches are presented in Figures 4 - 6, 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 all sites did not exceed the water quality standards value (26.67 ˚C) in 2005. Though temperatures started to increase in the latter half of 2005, all stayed within the 20 ˚C to 26 ˚C range. At the chute site (below Spring Lake) recorded water temperatures were higher than at any point previously monitored in this study. It is unclear if this is due to the lack of any significant rainfall in 2005 or a drifting thermistor; more data will need to be analyzed to come to this conclusion. Downstream, water temperatures at the City Park, I-35, and Thompson's Island reaches, were highest in the summer months and began to drop by the beginning of fall. These are normal fluctuations likely due to increased air temperatures and lack of precipitation (Appendix B).

The lowest temperatures in 2005 occurred in the winter months at Sessom's Creek (11.8 ˚C) and the historic channel at Thompson's Island (16.0 ˚C). The graph shows much lower temperatures late in 2004 for Sessom's Creek, but this was likely due to drifting readings from the thermistor as after it was replaced the temperature jumped up substantially and was more stable. Sessom's Creek has more direct input from runoff and as a result it is more prone to large temperature fluctuations. Similarly, the Thompson's Island reaches are farthest downstream and have the least amount of influence from the springs resulting in more variable water temperatures. As with other components of this study, more data are needed to determine the potential impacts of high air temperatures and low flows during an extended period of reduced recharge.

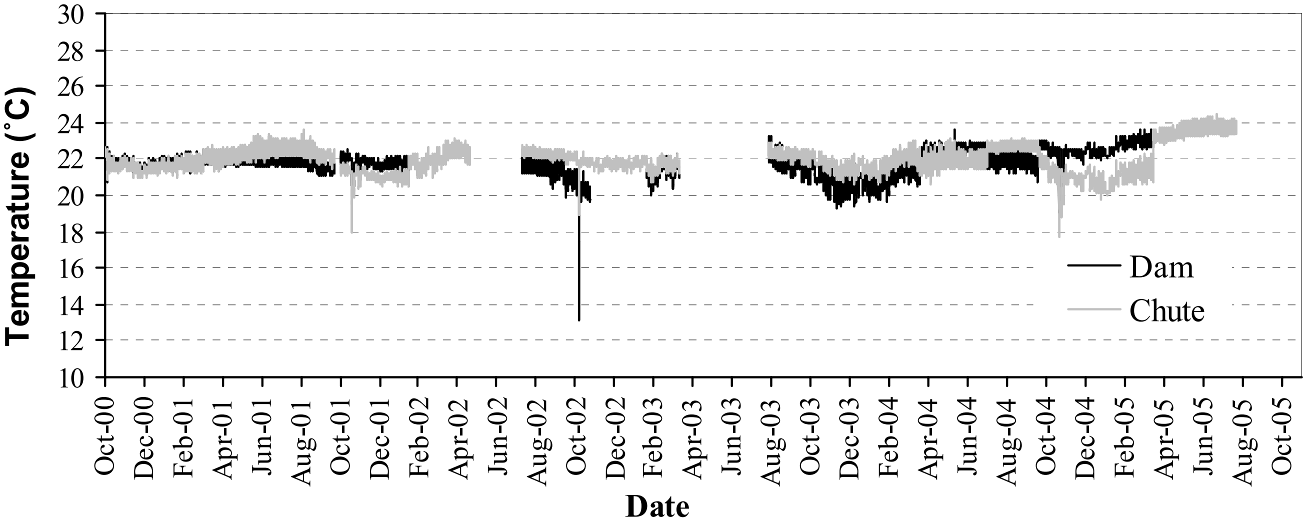

Figure 4. Thermistor data from the dam and chute tailrace areas below Spring Lake.

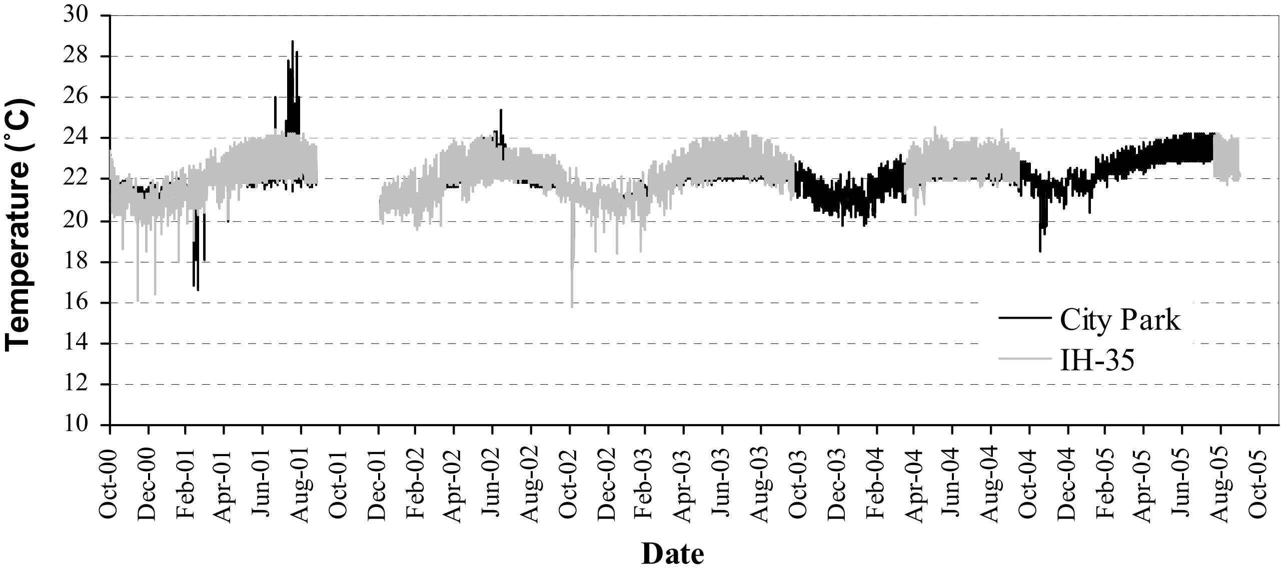

Figure 5. Thermistor data from the City Park and I-35 Reaches.

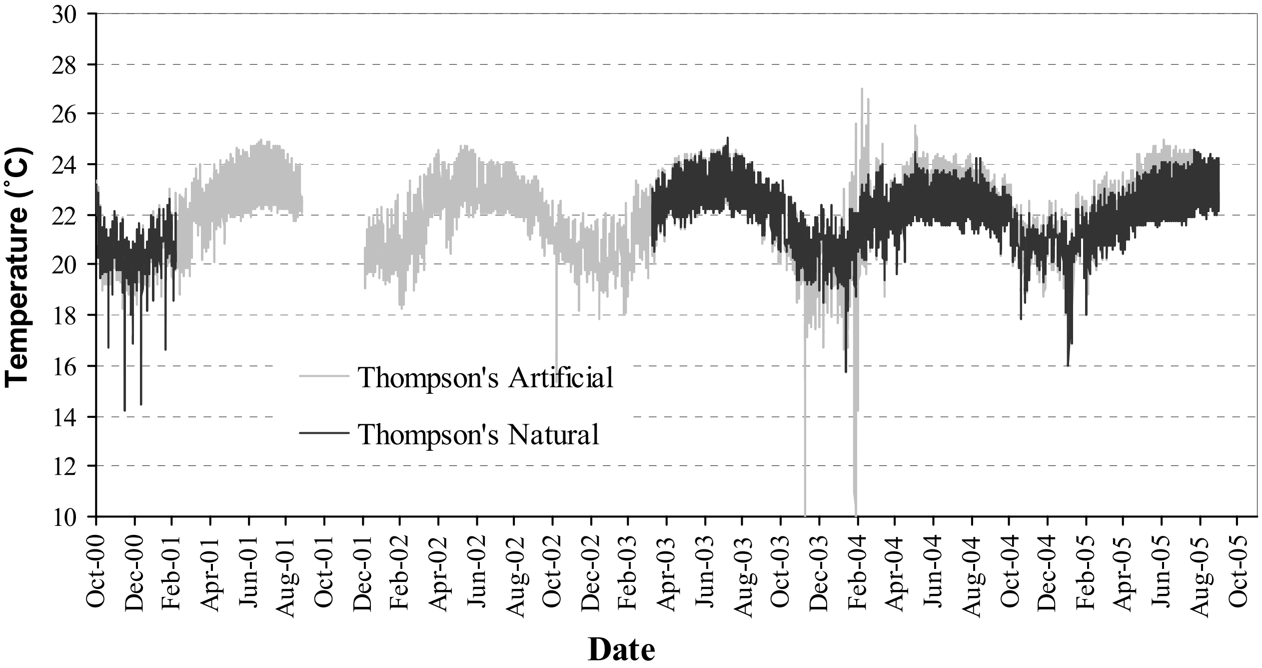

Figure 6. Thermistor data from the Thompson's island natural and artificial canal sites.

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

The reach between Spring Lake Dam and the University Drive Bridge was added to those mapped for aquatic vegetation in 2002 and was mapped in all subsequent sample efforts. Overall, total vegetation coverage changed very little over 2005. The western spillway of Spring Lake Dam is deep (~15 ft) and the turbulence of the spill limits suitable conditions for vegetation growth, though small patches of *Hydrilla* and *Potamogeton* did have a foothold here in fall 2004. By spring 2005 these patches had disappeared along with a large patch of *Potamogeton* further downstream. With the significant flow event in November 2004 it is likely these patches were scoured out and replaced with bare substrate. In addition, patches of *Potamogeton* and *Hydrilla* near the mouth of Sessom's Creek present in fall 2004 were wiped out during that event and have not reappeared. Sessom's Creek enters the river on the western shore, and little vegetation persists in this area because of the tendency of the creek to scour the area following even moderate rain events. However, the fall 2004 event was a major event completely removing the gravel bar that was previously there.

Pure stands of *Potamogeton* were drastically reduced in 2005. *Potamogeton* was reduced from 270.7 m^2 in the spring to 76.5 m^2 by fall. At the same time the mix of *Potamogeton*/*Hydrilla* more than doubled from spring (216.0 m^2) to fall (514.1 m^2) indicating *Hydrilla* had infiltrated many of the pure stands of *Potamogeton*, which can be seen easily on the maps (Appendix A). In addition, a pure stand of *Potamogeton* in the central section of the reach appears to have been replaced by bare substrate possibly due to mechanical disturbance from recreation.

This reach also has a great deal of *Hydrocotle* mixed among the other vegetation types. It is unknown what level of habitat quality this plant type provides to fountain darters since it is not sampled. It does grow close to the substrate and may provide favorable cover, but it tends to grow in areas with higher water velocities than those that typically support high densities of fountain darters and it also frequently grows in mixed stands of vegetation (e.g., with *Hydrilla*, *Potamogeton* or *Hygrophila*). *Hydrocotle* does not grow in much abundance in the areas sampled for fountain darters in this study (i.e., City Park and I-35 Reaches). Pure stands of *Hydrocotle* changed very little from fall 2004 to fall 2005, but total area has been steadily decreasing over the study period.

Texas wild-rice stands changed little from fall 2004 (274.9 m^2) to spring 2005 (271.9 m^2), but decreased by fall 2005 (257.1 m^2). Most of this decrease appears to have taken place in the eastern arm of the reach. Larger stands have become patchier, though it is unclear why. The eastern spillway of the dam is shallow, largely shaded, and in places has very swift currents and may have contributed to vulnerable plants becoming dislodged. At times recreation can also be heavy in this area with people snorkeling and fishing (as was observed during the fall 2005 sample).

Recreation also may be an important factor limiting vegetation in other sections of this reach. Public access is allowed on the western shoreline between Sessom's Creek and the western spillway and, at times, this is a heavily used access point. In 2005, there did not appear to be any major impacts from recreation as several plants continued to persist along the steps and wall in this section of the reach. The loss of vegetation, though not proportionally high, potentially affects the fountain darter population in this area by reducing total available habitat.

City Park Reach

While this reach receives heavy recreational use, there was little change in overall vegetation coverage from spring to fall 2005. *Hydrilla* decreased from fall 2004 (1,651.2 m^2) to spring 2005 (1,355.9 m^2) along the western side of the river probably due to swimmers using this area and disturbing the vegetation. *Hydrilla* coverage remained relatively constant throughout 2005, though it did colonize some bare spots in the middle of the reach. The *Hydrilla*/*Potamogeton* mix expanded in 2005 in the central and lower sections of the reach. This mix expanded into areas that were previously pure stands of *Hydrilla* and also contributed to the decrease in *Hydrilla* area from 2004. This is in direct contrast to the Spring Lake Dam site where *Hydrilla* grew into *Potamogeton* areas. The competition between these plants is poorly understood in the San Marcos River, though monitoring of their interaction will continue to provide insights.

The *Hygrophila*/*Potamogeton* mix in the upper and lower part of the reach became more widespread in 2005 replacing areas that were primarily *Potamogeton* and *Potamogeton*/*Sagittaria* in 2004. It is unclear whether *Potamogeton* provides a different quality of habitat to fountain darters since only the mixture of the two species (and *Hygrophila* alone) is sampled with drop nets. However, it seems likely that *Potamogeton* is less important as fountain darter habitat when it occurs alone, since the structure does not provide much cover at the substrate level. Also, drop-net samples of the *Potamogeton*/*Hygrophila* mix in which the *Hygrophila* is less abundant typically have fewer fountain darters. *Hygrophila* also decreased substantially in 2005 because *Sagittaria* grew into areas that were primarily pure *Hygrophila* stands (can be seen in extreme northwest section of the reach). Because of the low habitat quality of *Sagittaria*, the integration of that species in the *Hygrophila* patch in the northwest corner of the reach may negatively affect fountain darter populations.

With lower flow conditions prevalent throughout the latter half of 2005, the vegetation mat in the middle of the reach continued to grow. These vegetation mats can have substantial impacts on the vegetation below them since they often remain in one spot for months and severely reduce the sunlight for the plants. The impacts can be severe to Texas wild-rice plants that are covered for extended periods of time. By fall 2005, the mat had grown to cover several wild-rice plants and discoloration of the leaves became more widespread on these plants. It is in this area where the decrease in Texas wild-rice coverage from spring (166.0 m^2) to fall (118.3 m^2) 2005 has occurred. If the mat has moved by the first 2006 sampling, we will have a better idea of how well the plants survive in this environment.

One other event in 2005 served to change some of the vegetation within this reach. The large overhanging tree directly adjacent to the runoff culvert on the west side of the reach was cut down sometime between the spring and fall 2005 samples. This resulted in some loss of *Hydrilla* just downstream of where the tree was previously. The mechanical disturbance associated with cutting it down probably caused this reduction in vegetation. It will be interesting to see what (if any) vegetation colonizes this area of bare substrate in 2006.

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. For the Texas wild-rice survey (when the canopy was most dense) in summer, an extra amount of time was devoted to gathering the most precise data possible for each Texas wild-rice stand.

The I-35 reach differs from the other two San Marcos reaches in that *Cabomba* sp. occurs there, and has been abundant in the past. It 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. The flood of November 2004 was likely the driving factor in the reduction of *Cabomba* from fall 2004 (182.5 m^2) to spring 2005 (65.6 m^2). In addition, *Sagittaria* also grew in areas that were previously pure *Cabomba* stands. With lower flows dominating the latter half of 2005, *Cabomba* area increased (108.8 m^2) especially in the lower reaches of the site.

Many other vegetation types were also affected by the flushing flows of 2004. *Hygrophila*, *Sagittaria*, and *Justicia* all decreased substantially from 2004 to 2005. Over 80% of *Hydrilla* coverage was lost from fall 2004 (295.3 m^2) to spring 2005 (57.3 m^2), with most of the loss coming in the central part of the reach near the bulk of the Texas wild-rice stands. These *Hydrilla* stands may have been protecting

the rice from displacement in these shallow areas during high flows. As a result, the Texas wild-rice also decreased in the reach. While the wild-rice was reduced in total coverage, it was able to persist because the plants have a dense root structure that anchors the plants more effectively than other types and retains sediment in areas that are otherwise deeply scoured. *Heteranthera* seemed to be the only plant positively affected by the flood. It increased from fall 2004 (6.2 m^2) to fall 2005 (42.6 m^2) with a large area of expansion in the central portion of the reach.

Texas Wild-Rice Surveys

Maps generated from the 2005 summer survey of the San Marcos River (downstream of Spring Lake) can be found in Appendix A. The calculation by the BIO-WEST project team differed substantially from the total area measured by the TPWD (Table 3). In addition, this is the first time total area of Texas wild-rice has decreased from year to year since the inception of this project.

Table 3. Total coverage of Texas wild-rice (m^2) in the San Marcos River as measured by the TPWD for 1996-2005 and BIO-WEST in 2001-2005.

YEAR/EVENT	1996	1997	1998	1999	2000	2001[a]	High-Flow[a]	2002	2003	2004	2005
TPWD	1,652.1	1,584.2	1,949.0	1,644.9	1,791.1	1,895.6		1916.3	2776.0	3390.0	3992.7
BIO-WEST						1,901.2	1,765.9	1913.2	2560.7	3145.3	2949.7

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

Much of this decrease in total area is attributed to loss of plants, especially in downstream reaches. The flood of November 2004 displaced many plants that were vulnerable due to location within the channel. Some plants are more likely to be dislodged because they are in shallow areas with little protection from other plants during flushing flows. This was the case in the section where Texas wild-rice had been planted in 2003 (Appendix A, Map 7). A large plant in this region was almost completely wiped out from 2004. In addition, this area was mapped slightly differently during 2005. In 2004 there were too many small plants to map individually in a timely manner, so many were estimated. However, in 2005 many of these plants were dislodged, so all plants were mapped individually. This difference in mapping technique may also have attributed to the difference in total coverage between the BIO-WEST project team and the TPWD. For example, if the rice plants in this section are mapped as one plant, it can add approximately 200 m^2 more area than if the plants are mapped individually. The Texas wild-rice plants in this section are especially vulnerable to floods because there is little vegetation in the water to protect them (unlike upper reaches where other aquatic vegetation is prevalent).

Mechanical disturbance due to recreation may also have played a role in the decrease in Texas wild-rice coverage in 2005. Coverage decreased from 1,896.2 m^2 in 2004 to 1,832.8 m^2 in 2005 in the Sewell Park area (Appendix A, Map 1). This area is heavily used by people for swimming and boating due to its proximity to the university. A large patch immediately downstream of University Drive is relatively unaffected by people because much of it is emergent resulting in a large floating mat that discourages swimmers and boaters from entering that area. However, downstream between the two pedestrian bridges the water is deeper and there are several sets of stairs leading to the river. As a result, many people swim in this area, and mechanical disturbance to plants is much more likely to occur. Along the eastern wall several plants that were present in 2004 have since disappeared. When the BIO-WEST project team was mapping this area in 2005, swimmers were observed using this side to swim and walk in the water in between stair sets, and likely attribute to the loss of these plants.

Similarly, the City Park area exhibited a loss in Texas wild-rice coverage, and it is also heavily impacted by recreation. Tubers use this park as an entry point to the river, and often walk in the water where plants are rooted. This reach also showed a decrease that may be attributed to mechanical disturbance (Appendix A, Map 2). A few plants also were displaced from the area below Rio Vista Dam, a result of the flood of November 2004 (Appendix A, Map 3).

Texas wild-rice in the I-35 reach decreased from 2004 to 2005, especially in the site where comprehensive vegetation sampling is performed (Appendix A, Map 4). As described in the previous section, this likely occurred due to a combination of shallow water and loss of other plants protecting the Texas wild-rice stands. Little change occurred in overall coverage below Cape's Dam, but two plants that were present in 2004 were not found in summer 2005 (Appendix A, Map 5). Similarly, in the reach below Cape's Road overall coverage did not change substantially, but two larger plants that were present in 2004 were reduced to one smaller plant (Appendix A, Map 6).

Overall the loss in Texas wild-rice coverage in 2005 can be attributed to the flood of 2004 and subsequent mechanical damage from recreation. The flood in 2004 facilitated the removal of other aquatic vegetation that may have been protecting wild-rice plants leaving them more vulnerable to mechanical disturbance from swimmers and boaters. However, several new plants were discovered this year in downstream reaches. As some of these plants were relatively large, they were unlikely to have grown from seed, but were likely plants dislodged from upstream areas.

Texas Wild-Rice Physical Observations

Total coverage of Texas wild-rice observed during 2005 in each stand is presented in Table 4, 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. Total area was highest in spring 2005 and lowest in summer at all reaches. Area varied little over 2005 in the I-35 reach, but changed drastically in the Sewell Park reach. Several plants were uprooted on the river right side where it is much shallower. A few rain events in late spring of 2005 likely contributed to increased flows that displaced this vulnerable part of the larger stand. As in most years, the Sewell Park and I-35 reaches had the greatest proportion of Texas wild-rice emergence during 2005 (Appendix B). In the I-35 reach, emergence continued to increase over 2005 likely because flows dropped over the year, and in this system increased emergence is often associated with decreased flows. In the Sewell Park reach, emergence actually decreased with lower flows, however, a large vegetative mat often covers much of the Texas wild-rice in this reach at lower flows and prevented emergence in this reach.

Sewell Park Reach

The average aerial coverage of the Texas wild-rice stands considered to be in vulnerable areas in this reach decreased dramatically from 2004 (842 m^2) to 2005 (662 m^2). Coverage was highest in spring

(788.4 m^2) likely due to the high flows of 2004 triggering new growth in this reach. Coverage decreased in summer (537.3 m^2), but increased again by fall (660.7 m^2). Texas wild-rice likely decreased in coverage in summer because of the interaction of shallow water and recreation. As flows decreased, depths also decreased in the Texas wild-rice stand allowing people more access to the side of the river where the plants are rooted. As weather conditions improved (less rain) in summer more people used this reach of the river and mechanical disturbances of the Texas wild-rice plants increased leading to less total coverage. As in past years, all Texas wild-rice plants in this reach remained deeper than 0.5 ft in the water column in 2005. Percent emergence of leaves and flowers of Texas wild-rice followed the same trend as aerial coverage, highest in spring and lowest in fall 2005. Usually emergence is highest with low discharge, but this was not the case at Sewell Park. More likely, emergence was highest in spring because there was more plant coverage, which resulted in more emergent plants.

Table 4. Texas wild-rice areal coverage (m^2) for each stand by sampling period (2005 only).

REACH-STAND NO.[a]	Spring 2005	Summer 2005[b]	Fall 2005
Sewell Park-1	27.6	15.0	22.3
Sewell Park-2			
Sewell Park-3	119.7	92.3	113.5
Sewell Park-4	9.8	10.0	11.6
Sewell Park-5			
Sewell Park-6	631.3	420.0	513.4
Sewell Park-7			
Sewell Park-8			
Total Area	**788.4**	**537.3**	**660.7**
I-35-1	0.2	0.1	0.1
I-35-2	-	-	-
I-35-3	1.7	0.5	1.8
I-35-4	-	0.5	-
I-35-5	7.6	6.8	8.0
I-35-6	9.5	4.5	7.0
I-35-7	38.6	27.4	30.6
I-35-8	151.5	153.0	158.2
Total Area	**208.9**	**192.8**	**205.7**
Thompson's Island - 1	-	-	-
Thompson's Island - 2	7.1	-	4.9
Thompson's Island - 3	1.7	-	1.3
Total Area	**8.8**	**-**	**6.2**

[a] Many stands grew together to form individual stands after the first sampling period. [b] Cross sections were not done at Thompson's Island for the summer 2005 sample.

Root exposure increased at Sewell Park over the year, but still remained very low. Many of the plants in this reach are found in deeper water that can better buffer the effect of high flows like those of fall 2004. The increase may have been caused by mechanical disturbance due to the high volume of swimmers and boaters in this reach. People walking in the water in this reach can scour out the sediment around plants and expose roots; this can also be achieved by boat paddles pushing the sediment in shallower areas (like the river right side of this reach).

Evidence of herbivory increased over 2005 and was likely related to flow levels in this reach. As flows decreased over the year more plants may have been exposed to avian feeders that had an easier time getting to the leaves of the plant. Herbivory was lowest in spring because flows were still high from the flooding in 2004, and leaves were farther below the surface of the water.

I-35 Reach

The average areal coverage of the eight Texas wild-rice stands considered to be in vulnerable areas in this reach decreased from 2004 (238 m^2) to 2005 (203 m^2). Though some plants were uprooted and have not re-established, much of the decrease is due to fragmentation of plants in the middle part of the reach. This is a shallow section of the reach, and the flushing flows of 2004 likely led to this fragmentation and overall decrease in coverage. There have been some observations of "new" plants in very shallow areas along the western shoreline at the upstream edge of this reach (near Cheatham Street). There has also been scouring, re-growth and appearance of "new" plants just downstream on the inside of the large bend.

This variability has occurred primarily during flood events and most of the (small) plants deposited along the shallow edges have not remained for long. It has also caused some difficulty in monitoring the same plants over time, several times the monitored plant has disappeared and a nearby plant was substituted during quarterly observations. This combination of new plants in very shallow areas and occasionally using one of these plants to substitute for a displaced one has resulted in some observations with a water depth of <0.5 ft in the past, but that was not the case this year.

Texas wild-rice emergence increased over 2005 with a decrease in flow. This is expected because many of the plants in this area are in shallow water, and low flows result in many more leaves exposed above the water. Consequently, herbivory also increased over the year because these plants were exposed and easier for herbivores to feed on them.

Thompson's Island Reach (Natural)

As noted in 2001, one of the three Texas wild-rice stands in this reach had disappeared by the early sampling efforts of this study. The average coverage of the remaining two stands was 7.5 m^2 in 2005 compared with 5.6 m^2 and 5.1 m^2 in the two previous years of the study. This increase was mostly due to growth in spring 2005 that subsequently dropped by the fall.

Emergence remained non-existent in 2005 as it was in 2004. Similarly, root exposure and herbivory were low and constant over 2005, though root exposure did increase slightly probably due to the high flows of 2004 scouring the sediment. The plants in this reach have remained in very good condition throughout this study. These plants appear to be the least affected by minor changes in conditions, but were somewhat impacted by the major flooding in 2004. However, it remains important to monitor these plants to evaluate the impact of low-flow conditions on plants in the downstream range of the population and on those that have shown minimal variability to habitat changes under moderate- to high-flow conditions.

Fountain Darter Sampling

Drop Nets

The number of drop net sites and vegetation types sampled per reach is presented in Table 5. 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 5. 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 habitats with a wide 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 11.4/m^2 and 6.7/m^2, respectively. In the San Marcos River, these same vegetation types yield fountain darter densities of 4.8/m^2 (*Cabomba*) and 3.7/m^2 (*Hygrophila*) (Figure 7). 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 5, BIO-WEST 2006). In both systems bare substrates contain very few, if any, fountain darters showing the overall importance of aquatic vegetation as fountain darter habitat.

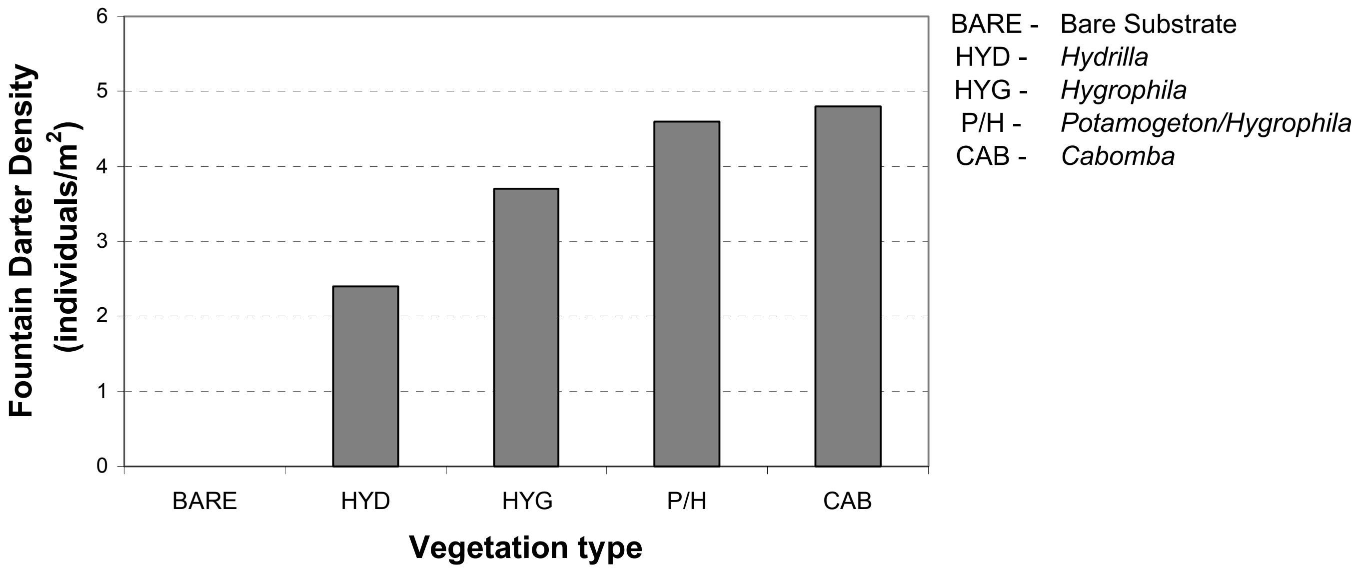

Figure 7. Density of fountain darters collected by vegetation type in the San Marcos Springs/River ecosystem (2000-2005).

The size-class distribution for fountain darters collected by drop net from the San Marcos Springs/River ecosystem in 2005 is presented in Figure 8. The distribution is similar to the distribution observed throughout the project (Appendix B) 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. Presence of 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.

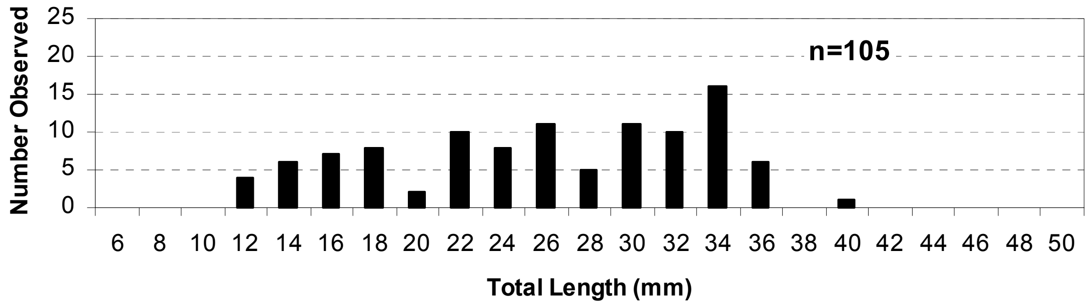

Figure 8. Fountain darter size-class distribution among all drop net sampling events in the San Marcos River during 2005.

When examined by reach and season (Figure 9) 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. More darters, as well as a wider range of size classes, were collected in the I-35 reach, which is indicative of the more suitable habitats (*Cabomba*) found within this reach.

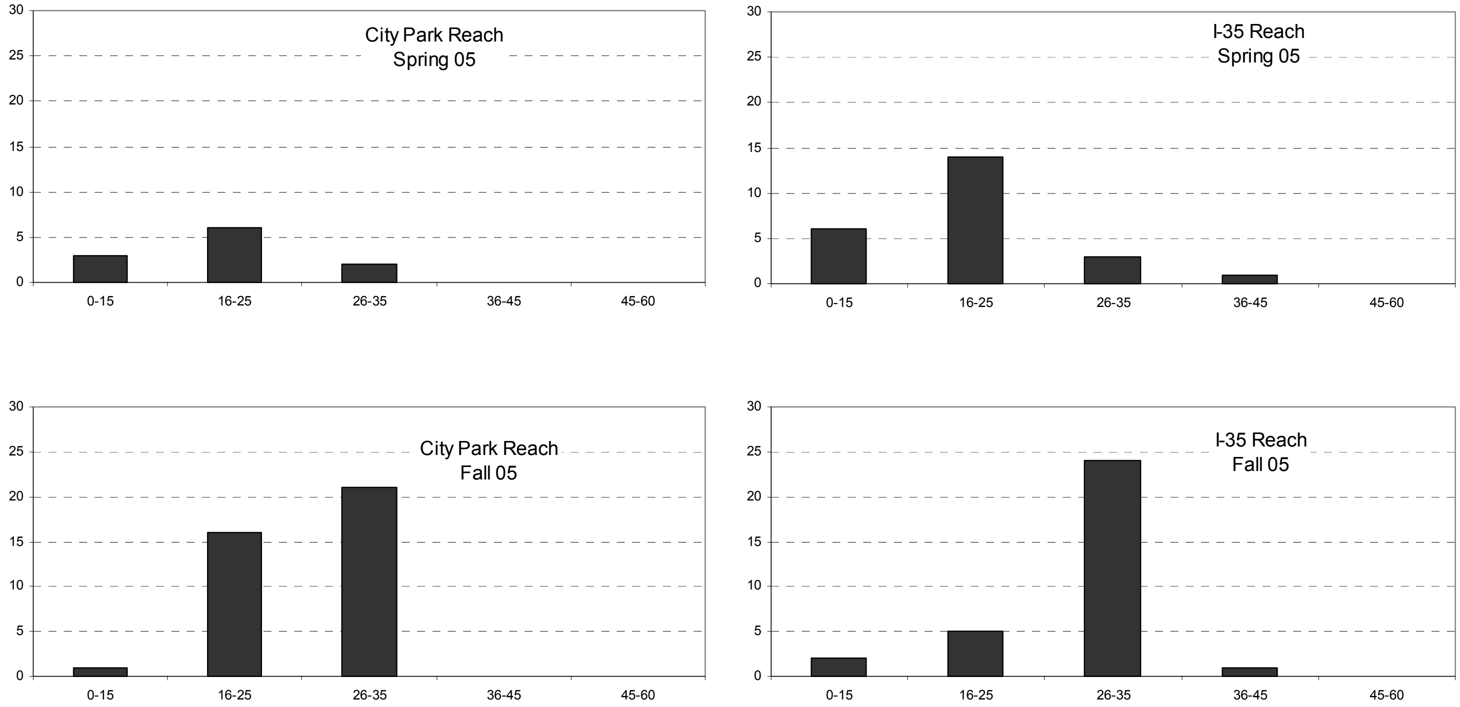

Figure 9. Size class distributions of fountain darters collected in spring and fall 2005 in the City Park and I-35 reaches.

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 10). As in the Comal River, high-flows resulted in decreased amounts of vegetation and thus, lower population estimates. In previous cases, estimates quickly rebounded following high-flows. However, coverage of several types of aquatic vegetation decreased within the sample reaches during this period and had failed to return to previous levels by fall 2005 (see Aquatic Vegetation Mapping). Therefore, overall population estimates have continued to decline since the high-flow event in fall 2004. Continued monitoring of fountain darter densities and vegetation coverage will allow further insight into any trends in population.

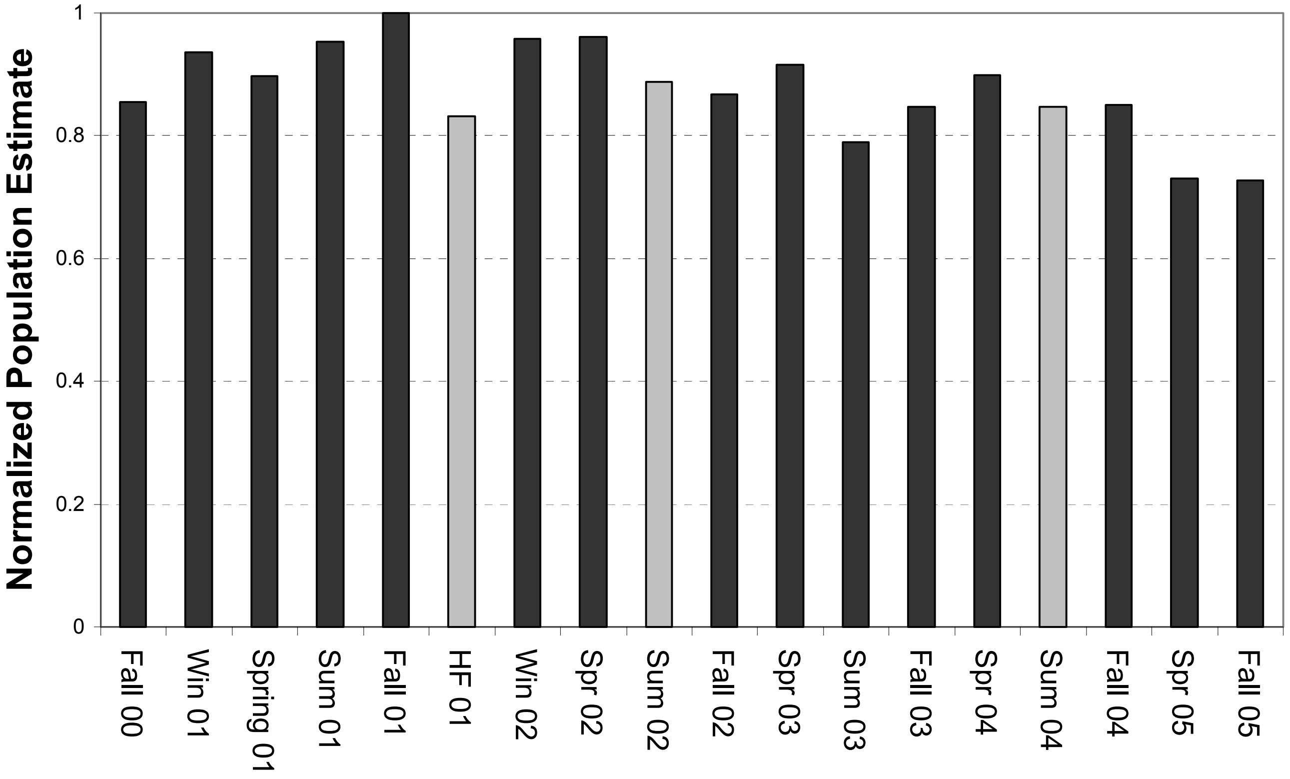

Figure 10. Population estimates of fountain darters in the San Marcos River; values are normalized to a proportion of the maximum observed in any single sample. Light-colored bars represent high-flow Critical Period sampling events.

In addition to fountain darters, there have been 8,047 fishes representing 27 other taxa collected by drop netting since 2001 (Table 6). Of these, 8 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*).

Among exotic species, the giant ramshorn snail elicits the most 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 2004-2005, there were 9 giant ramshorn snails collected. Although data suggests that giant ramshorn snail numbers are rather low, close monitoring should continue because of the impact that this exotic species can have on the vegetation community under heavier densities.

Table 6. 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	2005	2001-2005
Rock bass	*Ambloplites rupestris*	Introduced	53	259
Black bullhead	*Ameiurus melas*	Native		2
Yellow bullhead	*Ameiurus natalis*	Native	2	52
Mexican tetra	*Astyanax mexicanus*	Introduced	6	13
Rio Grande cichlid	*Cichlasoma cyanoguttatum*	Introduced		11
Roundnose minnow	*Dionda episcopa*	Native	2	19
Fountain darter	*Etheostoma fonticola*	Native	105	1133
Gambusia	*Gambusia sp.*	Native	1394	6794
Suckermouth catfish	*Hypostomus plecostomus*	Exotic	2	14
Redbreast sunfish	*Lepomis auritus*	Introduced	3	35
Green sunfish	*Lepomis cyanellus*	Native	1	5
Warmouth	*Lepomis gulosus*	Native	3	20
Bluegill	*Lepomis macrochirus*	Native	2	63
Longear sunfish	*Lepomis megalotis*	Native		3
Spotted sunfish	*Lepomis punctatus*	Native	42	436
Sunfish	*Lepomis sp.*	Native/Introduced	14	95
Largemouth bass	*Micropterus salmoides*	Native	2	31
Gray redhorse	*Moxostoma congestum*	Native		3
Blacktail shiner	*Cyprinella venusta*	Native		6
Texas shiner	*Notropis amabilis*	Native		13
Ironcolor shiner	*Notropis chalybaeus*	Native	12	31
Unknown shiner	*Notropis sp.*	Native/Introduced		4
Madtom	*Noturus sp.*	Native	4	4
Logperch	*Percina caprodes*	Native		2
Dusky darter	*Percina sciera*	Native	1	13
Sailfin molly	*Poecilia latipinna*	Introduced	11	85
Unknown molly	*Poecilia sp.*	Introduced		30
Tilapia	*Tilapia sp.*	Exotic		4

Dip Nets

The boundary for each section where dip net collections were conducted is depicted on Figure 11. 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 12, 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.

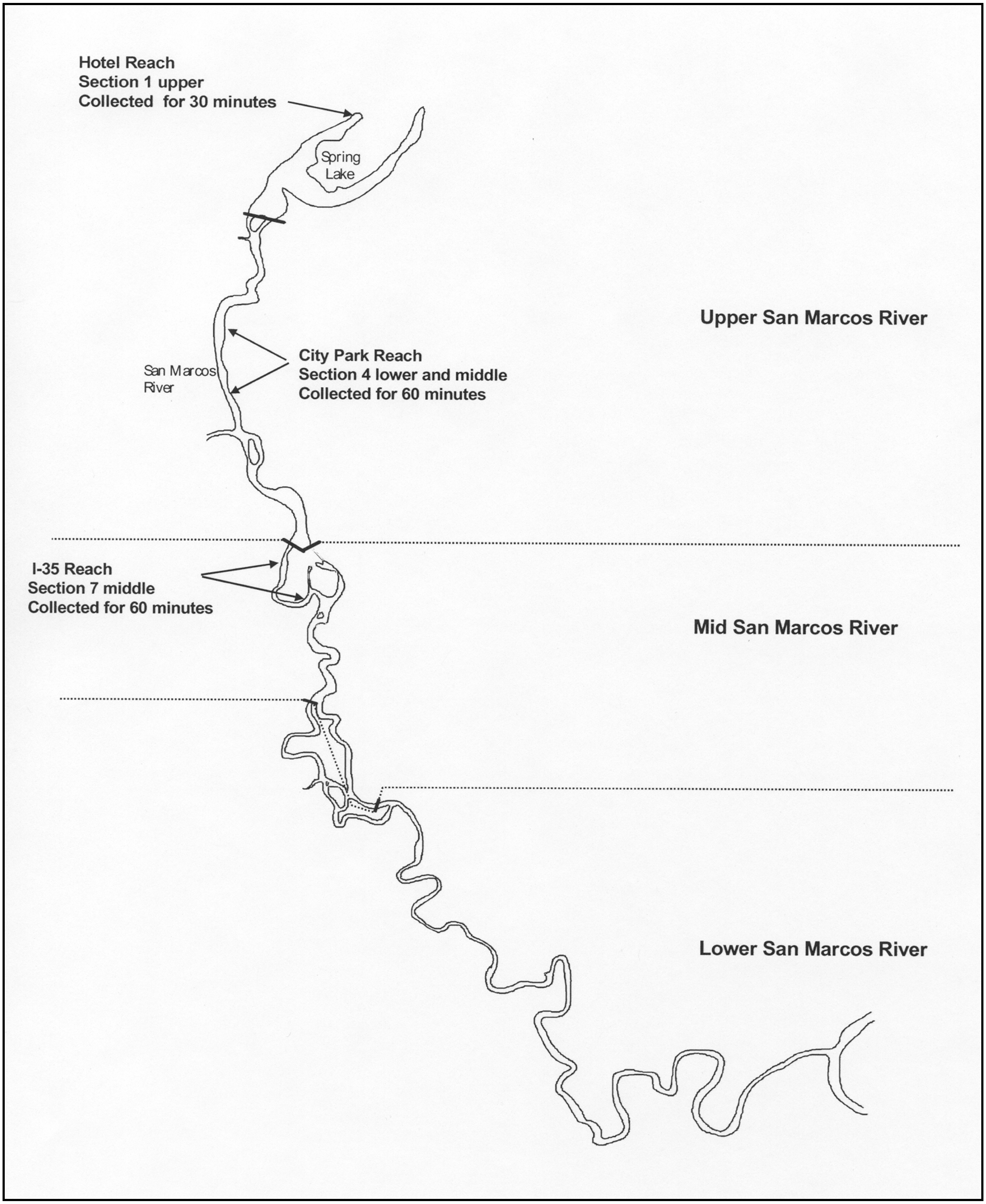

Figure 11. Areas where fountain darters were collected with dip nets, measured, and released in the San Marcos River.

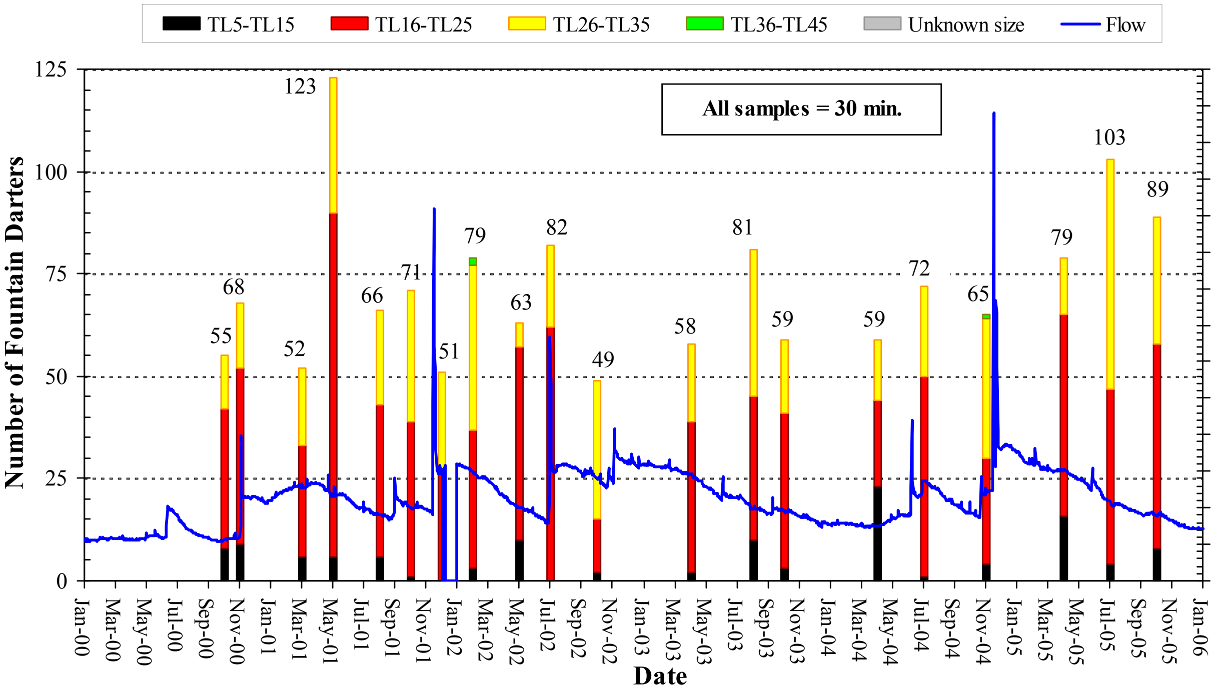

Figure 12. Number of fountain darters collected from the Hotel Reach (section 1 upper) using dip nets.

In 2005, small darters were collected only during spring samples from the City Park and I-35 reaches (Appendix B). In these reaches with lower quality habitat, reproduction appears to be much more seasonal. Reproduction in the I-35 and City Park Reaches may also be event-driven. Presence of small fountain darters in these reaches has been noted after flood events. Shoreline habitat that is inundated with higher flows may provide a refuge for fountain darters and thus stimulate reproduction.

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 2005. 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 San Marcos salamanders were observed when clearing the area. In addition, the disturbance associated with cleaning the area may have alerted the San Marcos salamanders to the presence of the divers and impelled some individuals to retreat into deeper cavities within the rocks. Although this wasn't an ideal methodology, it was consistent each year and allowed valid comparisons among sites and seasons.

As shown in Table 7, San Marcos salamanders were observed during each survey effort.

Table 7. 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

Overall, salamander densities were highly variable in 2005 between spring and fall samples. Salamander density in sample Area 2 increased substantially from fall 2004 to spring 2005, and then decreased to nearly the same number in fall 2005. Salamander densities in sample Area 14 also changed significantly, but instead decreased from fall 2004 to spring 2005 and then increased to nearly the same density in fall 2005. Overall, a thriving San Marcos salamander population has been observed in sample site 2 throughout the study to date and San Marcos salamanders continue to be abundant under rocks despite the presence of algae that covers the rocks and potentially provides increased three-dimensional habitat for them to disperse into.

Sample Area 21 salamander densities decreased slightly by spring 2005 and then nearly quadrupled in size by the fall sample. The high fall 2005 observation is likely a result of sampling methodology rather than a substantial change in the San Marcos salamander population; sampling during lower-flow conditions is much easier than during higher flows when turbulence reduces visibility and the observer's effectiveness. As mentioned above, sample site 21 is located immediately below Spring Lake Dam and, because this area is located in the river, the sampling technique is much more difficult under higher-flow conditions that occurred during the rest of the study. In addition, there is an increase in suitable habitat for salamanders that result from lower flows.

Overall, the estimated population densities of the San Marcos salamander in 2005 were consistent with populations of previous years. A lack of substantial low-flow data precludes discussion of potential influences of lower flows on the population at this time.

Exotics / Predation Study

Because there were no low-flow events in 2005, no samples were made for the exotics / predation component of this study.

Summary

This study remains the most comprehensive biological evaluation that has ever been conducted on the San Marcos Springs/River ecosystem. Overall, flora and fauna flourished in 2005 even though flows declined over much of the year. Variable flow conditions encountered to date have provided an excellent confirmation that the study design is well suited to address the concerns of variable flow and water quality on the biological resources in the Comal and San Marcos River ecosystems. With rainfall events scarce in 2005, we will closely monitor flows in these systems to assess possible critical low-flow periods in 2006. As noted in previous annual reports, this study meets three critical criteria to assure the greatest possible success in assessing impacts to biological communities of variable flow conditions: (1) the endangered species are evaluated directly (some studies make conclusions based on surrogate species and attempt to describe dynamics of the endangered species), (2) continuous sampling is used to evaluate current conditions to properly assess changes relative to flow variation (one-time sampling events or limited sampling during particular seasons will not yield accurate conclusions), and (3) multiple collection techniques are used to evaluate multiple components of the ecosystem (important observations may be missed using limited sampling means).

REFERENCES

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

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

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

U.S. Geological Survey (USGS). 01/2006. Provisional data for Texas. Location: http://tx.waterdata.usgs.gov/niwis/help/provisional.

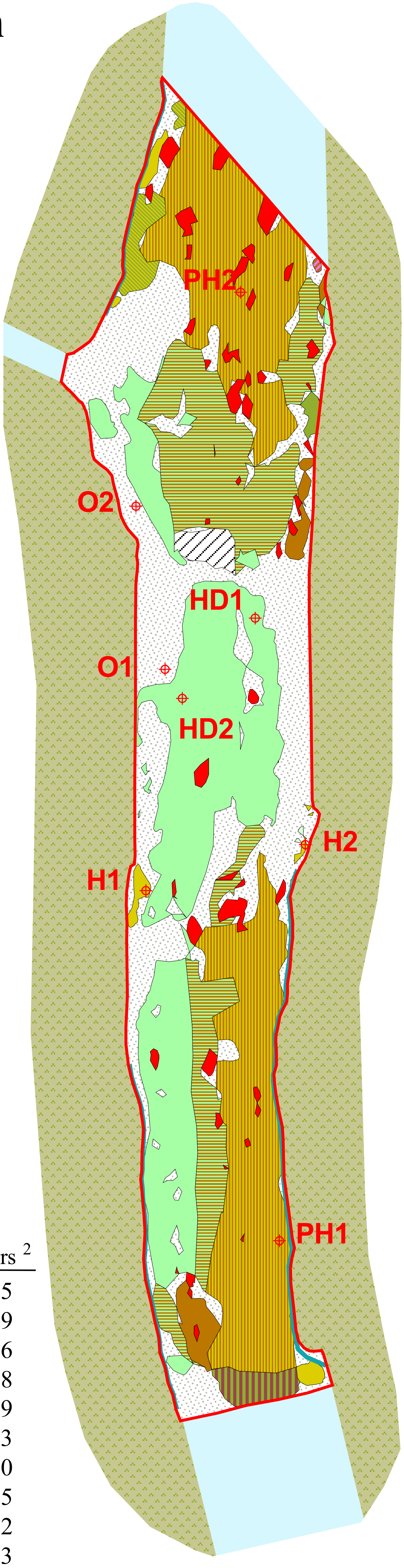
APPENDIX A:
AQUATIC VEGETATION MAPS

City Park Reach

San Marcos River Aquatic Vegetation

City Park - Spring

April 13, 2005



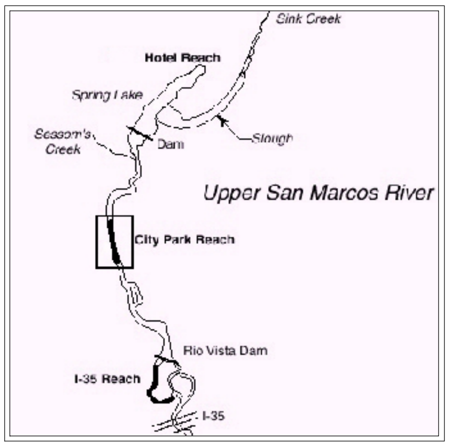
Scale: 1" = 60'

10 0 10 20 30 40 Meters

- ▨ Shore and Islands
- ▭ River
- ▭ Study Area (5,991.8 m^2)
- ▨ Bare Substrate
- ∧ *Colocasia*
- ⊕ Drop netting not conducted

	Meters^2
Floating Vegetation Mat	53.5
Hydrilla	1,355.9
Hygrophila	52.6
Potamogeton	94.8
Sagittaria	14.9
Vallisneria	1.3
Zizania	166.0
Hydrilla / Potamogeton	873.5
Hygrophila / Potamogeton	1,541.2
Hygrophila / Sagittaria	74.3
Potamogeton / Sagittaria	67.4
Potamogeton / Hydrocotle	2.4

Project Location



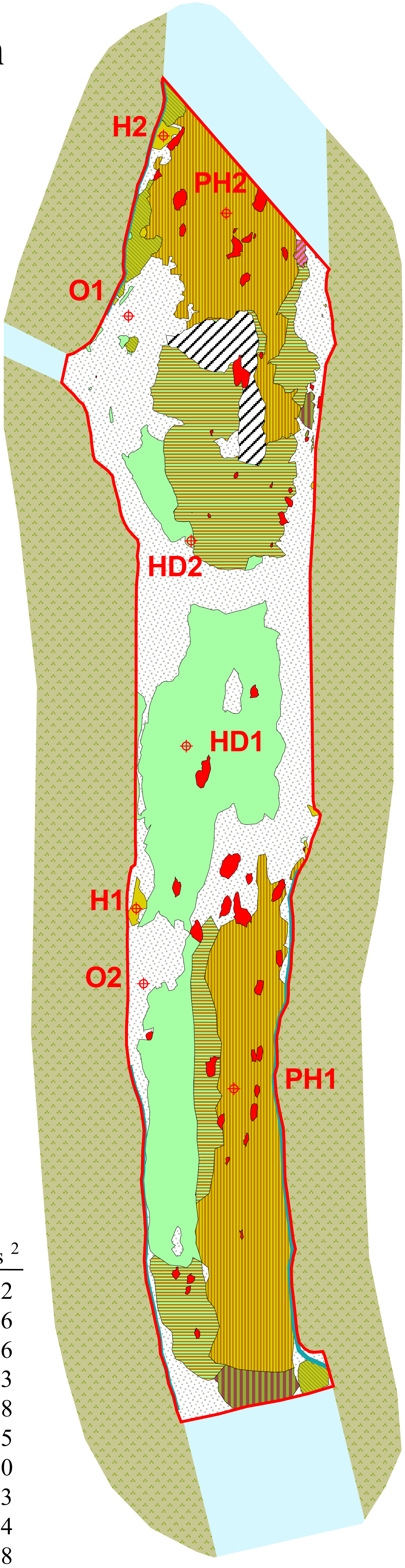
BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River Aquatic Vegetation

City Park - Fall

September 26, 2005



Scale: 1" = 60'

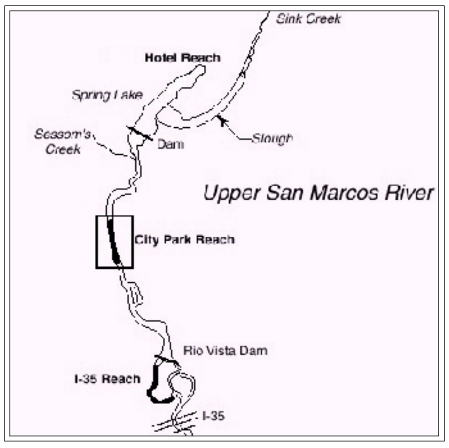
10 0 10 20 30 40 Meters

N

- ▨ Shore and Islands
- 🟦 River
- 🟥 Study Area (5,991.8 m^2)
- ▨ Bare Substrate
- *Colocasia*
- ⊕ Drop netting not conducted

	Meters ^{2}
Hydrilla	1,310.2
Hygrophila	30.6
Vallisneria	0.6
Zizania	118.3
Floating Vegetation Mat	263.8
Hydrilla / Potamogeton	884.5
Hygrophila / Potamogeton	1,526.0
Hydrocotle / Potamogeton	7.3
Potamogeton / Sagittaria	80.4
Hygrophila / Sagittaria	96.8

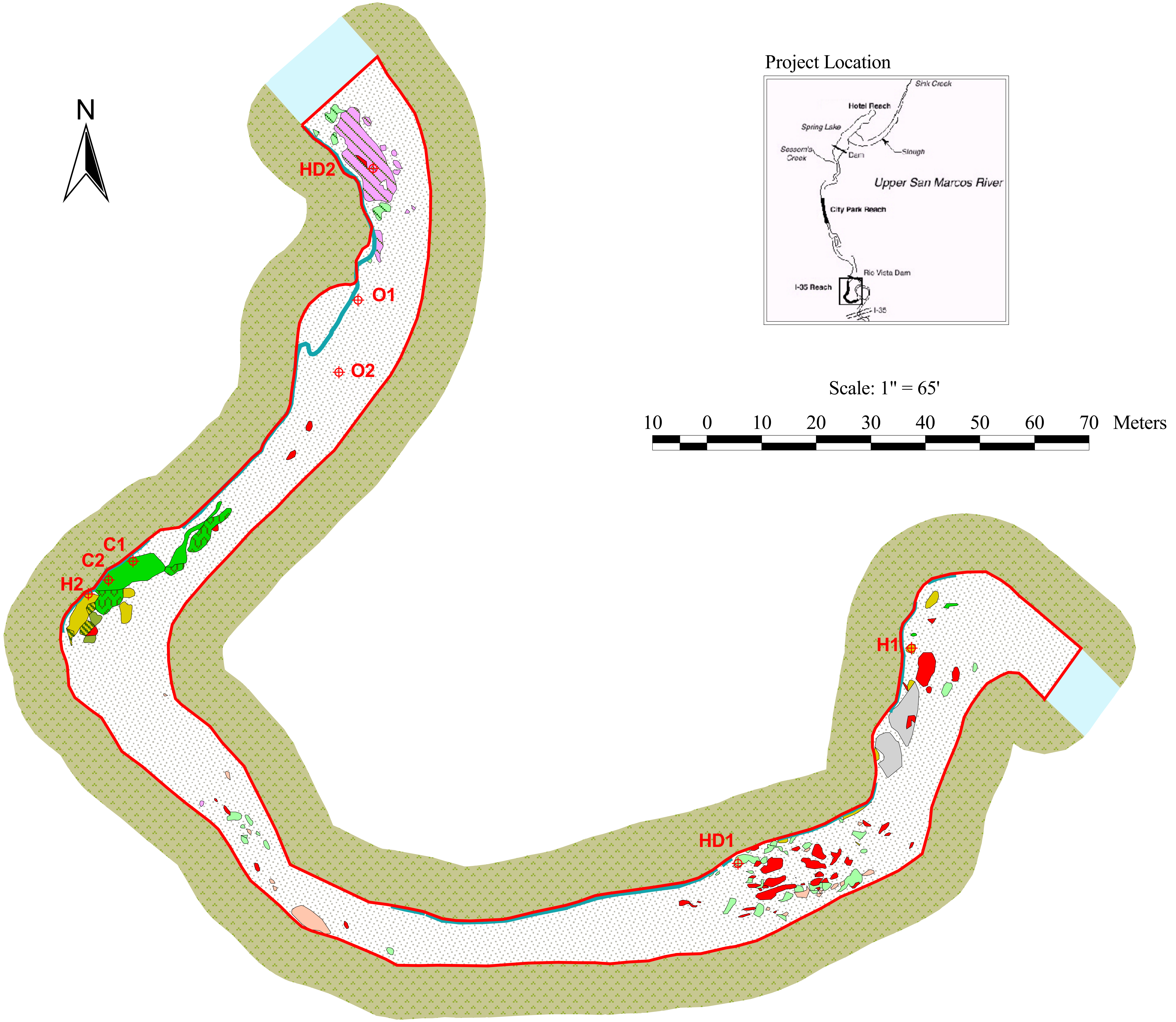
Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

IH-35 Reach



San Marcos River Aquatic Vegetation

I-35 Reach - Spring

April 12, 2005

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

	Meters^2
■ *Cabomba*	65.6
■ *Heteranthera*	28.9
■ *Hydrilla*	57.3
■ *Hygrophila*	46.7
■ *Justicia*	5.6
■ *Sagittaria*	6.4
■ *Zizania*	87.2
■ *Algae*	60.7
▨ *Hygrophila / Sagittaria*	9.3
▨ *Hydrilla / Algae*	14.6
▨ *Justicia / Algae*	100.7
▨ *Cabomba / Sagittaria*	42.4

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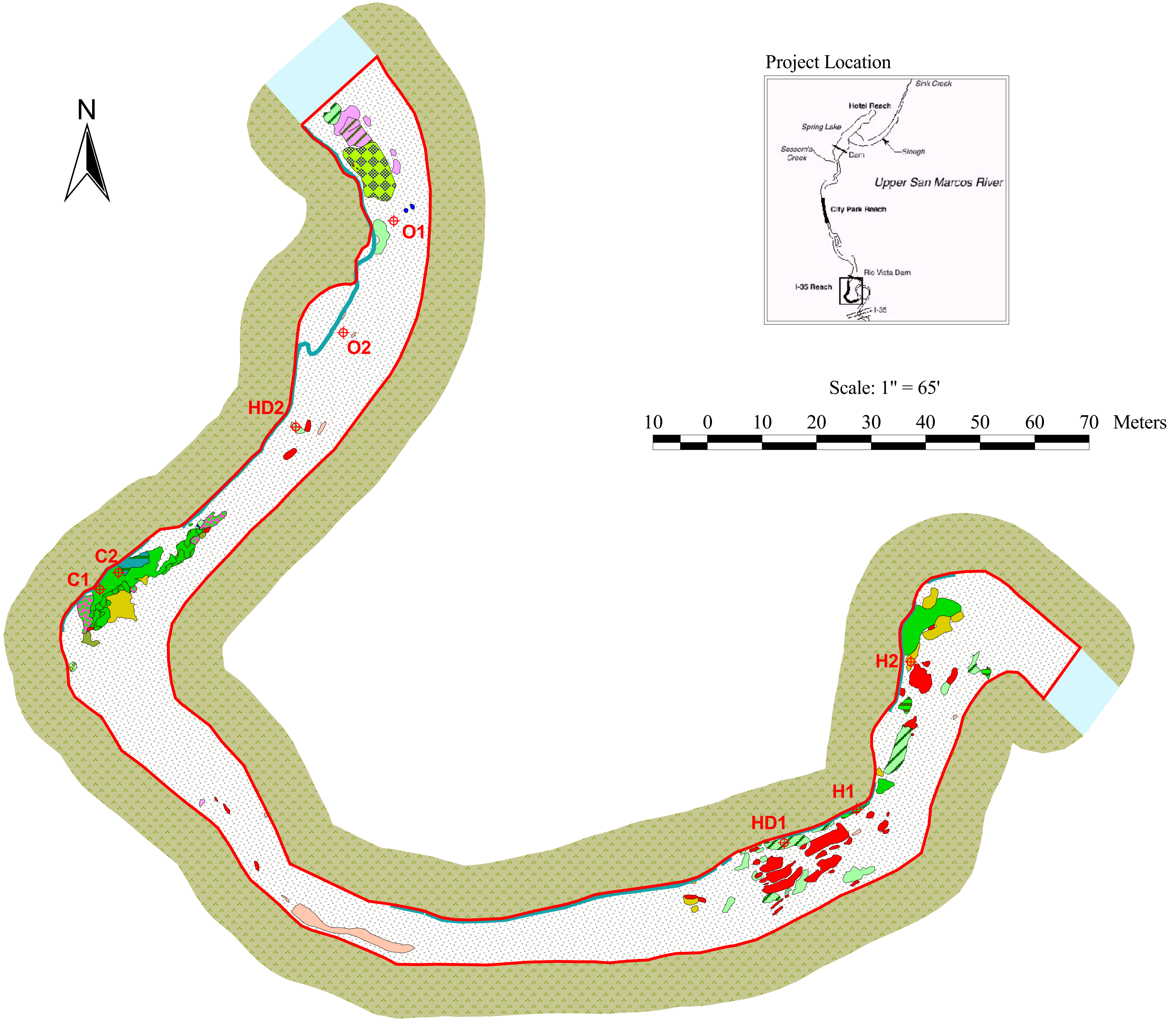
EDWARDS AQUIFER AUTHORITY

San Marcos River Aquatic Vegetation

I-35 Reach - Fall

September 27, 2005



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

	Meters^2
🟩 *Cabomba*	108.8
Heteranthera	42.6
Hydrilla	45.1
Hygrophila	57.6
Justicia	17.6
Hydrocotle	1.1
Sagittaria	5.3
🟥 *Zizania*	113.1
▨ *Hygrophila / Sagittaria*	23.9
▨ *Hydrilla / Algae*	57.9
▨ *Justicia / Algae*	19.7
▨ *Sagittaria / Ludwigia*	1.4
▤ *Hygrophila / Algae*	12.7
▤ *Hygrophila / Cabomba*	12.1
▨ *Cabomba / Sagittaria*	31.6
▨ *Hydrilla / Justicia / Algae*	61.2

BIO-WEST, Inc.

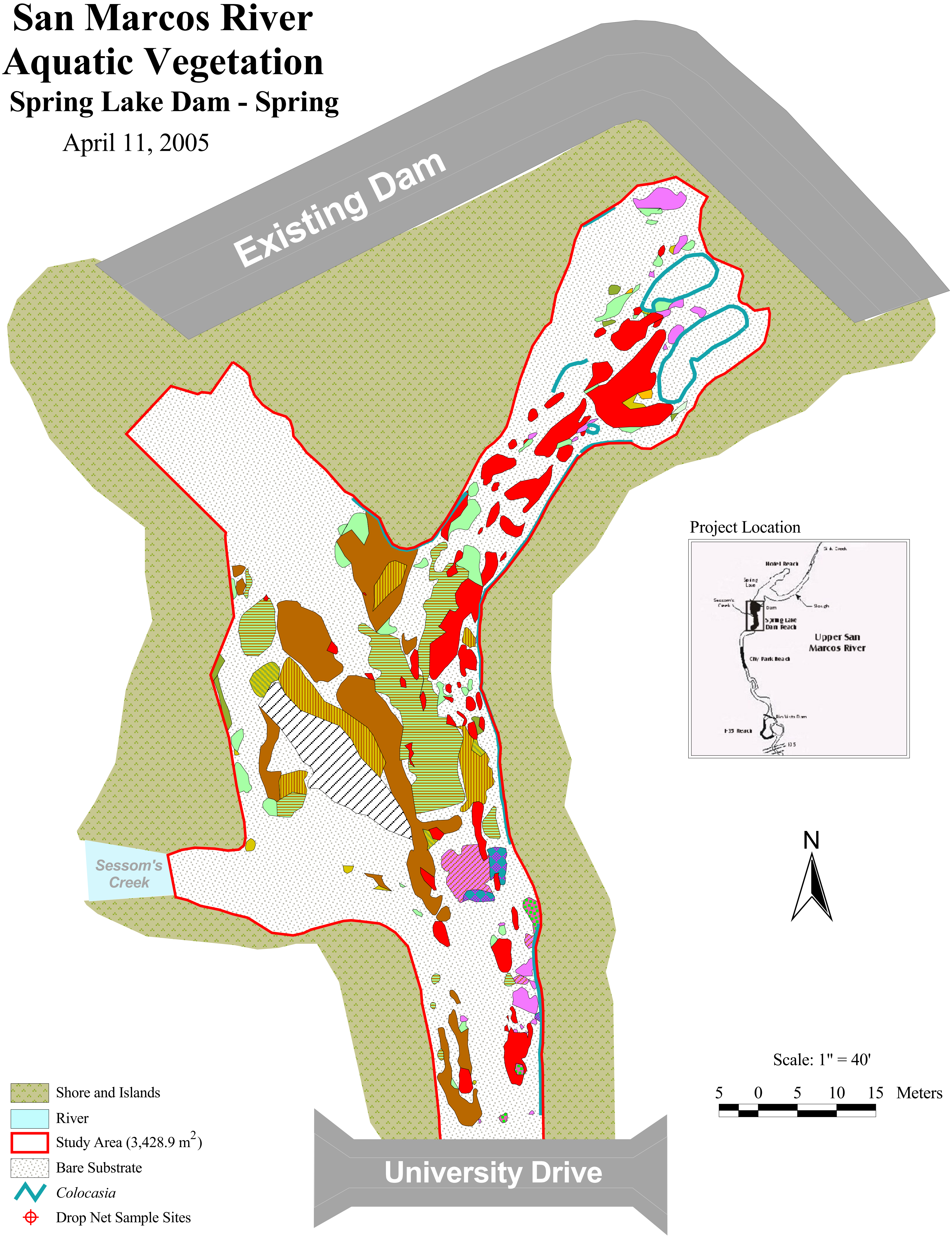
EDWARDS AQUIFER AUTHORITY

Spring Lake Dam Reach

San Marcos River Aquatic Vegetation

Spring Lake Dam - Spring

April 11, 2005



	Meters^2
🟩 *Hydrilla*	84.1
🟪 *Hydrocotyle*	39.0
🟨 *Hygrophila*	6.8
🟧 *Ludwigia*	2.1
🟫 *Potamogeton*	270.7
🟩 *Sagittaria*	11.3
🟩 *Vallisneria*	1.2
🟥 *Zizania*	271.9
▨ *Floating Vegetation Mat*	124.3

	Meters^2
▨ *Potamogeton / Hydrocotyle*	39.0
▤ *Potamogeton / Hydrilla*	216.0
▥ *Potamogeton / Hygrophila*	103.5
▩ *Hydrocotle / Hydrilla*	9.7
▧ *Potamogeton / Sagittaria*	14.7
▩ *Potamogeton / Hydrocotyle / Hydrilla*	14.5

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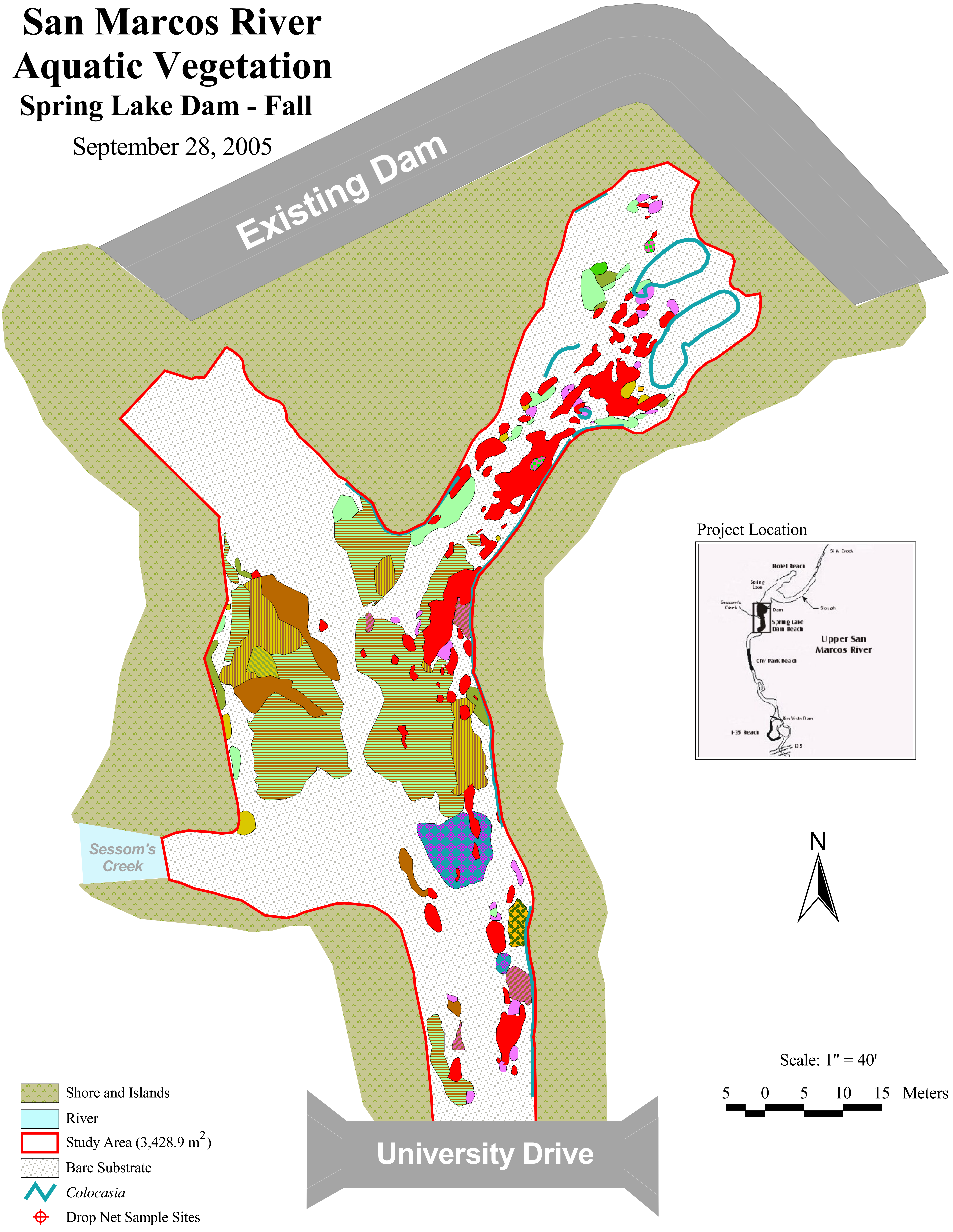
EDWARDS AQUIFER AUTHORITY

San Marcos River Aquatic Vegetation

Spring Lake Dam - Fall

September 28, 2005



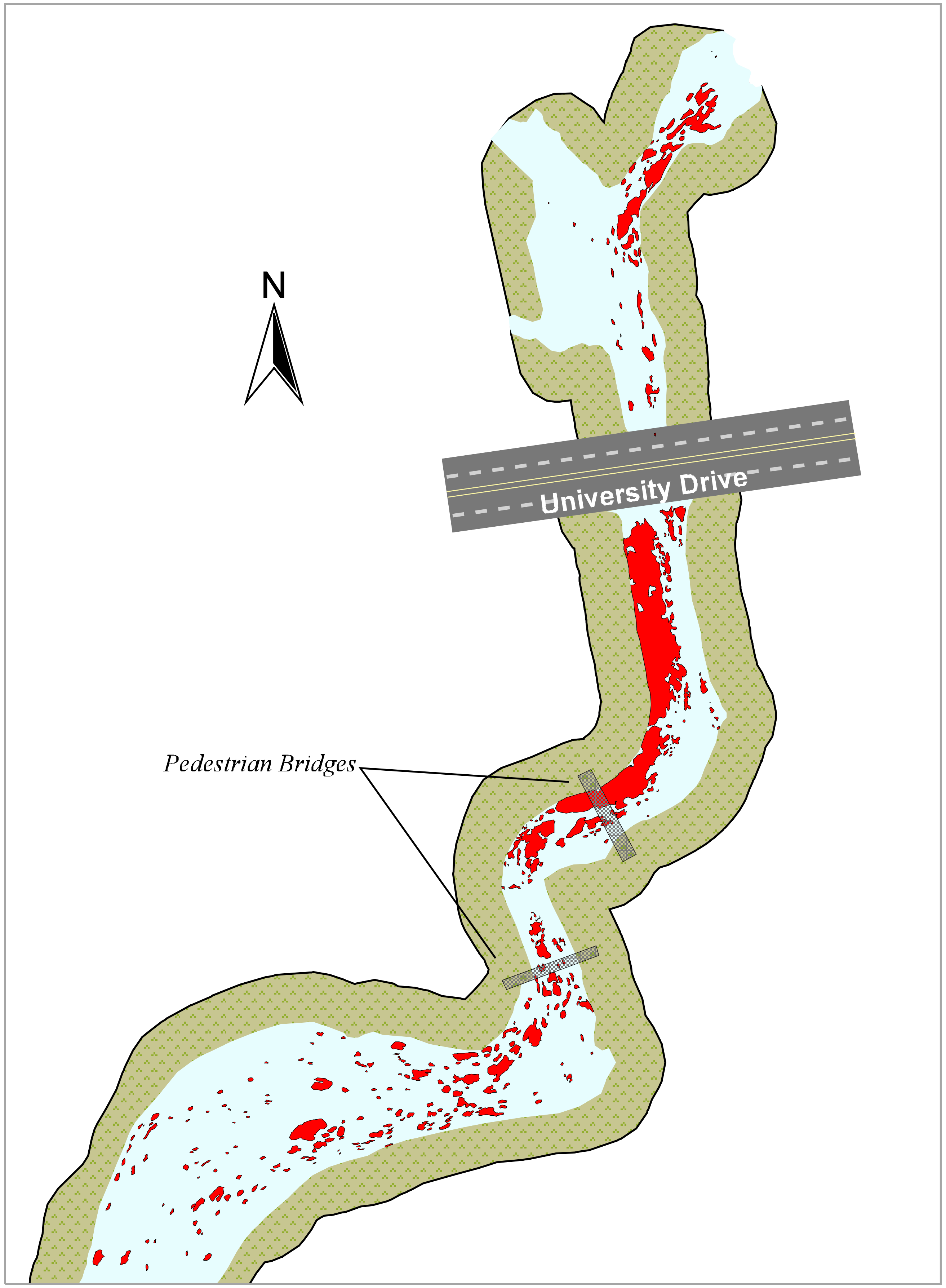
	Meters ^{2}
Hydrilla	70.9
Hydrocotyle	33.9
Hygrophila	14.7
Ludwigia	0.4
Potamogeton	76.5
Sagittaria	25.6
Vallisneria	0.6
Zizania	257.1
Cabomba	2.6

	Meters ^{2}
Potamogeton / Hydrocotyle	26.7
Potamogeton / Hydrilla	514.1
Potamogeton / Hygrophila	106.0
Hydrocotle / Hydrilla	4.0
Potamogeton / Sagittaria	11.5
Potamogeton / Hydrocotyle / Hydrilla	66.8
Hydrocotle 50 %	13.0

BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

Texas Wild-Rice



San Marcos River
Texas wild-rice

(Zizania texana)

Summer 2005 - Map 1 of 7

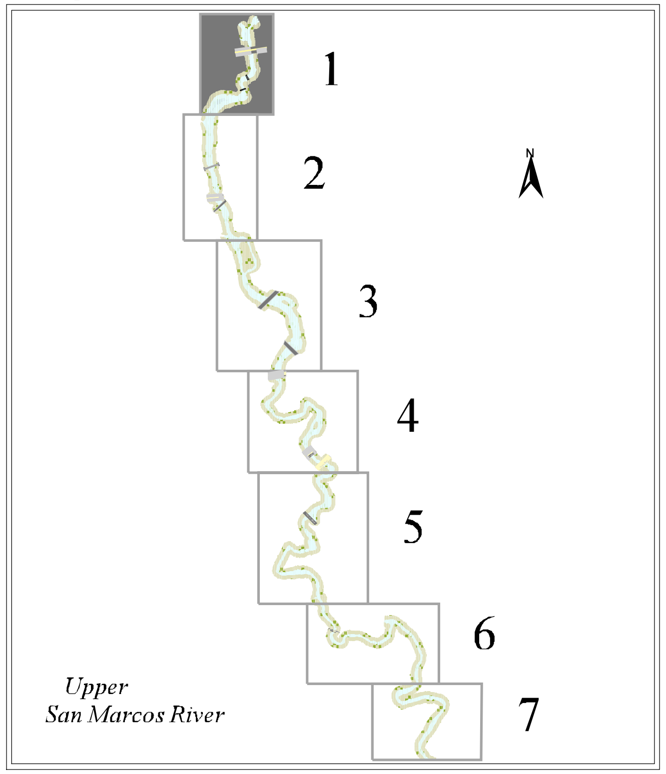
August 16 - August 18, 2005

		Map 1 (m^2)	Total Population (m^2)
🟥	*Zizania*	1,832.8	2,949.7

Scale: 1"=135'

20 0 20 40 60 80 100 Meters

Project Location



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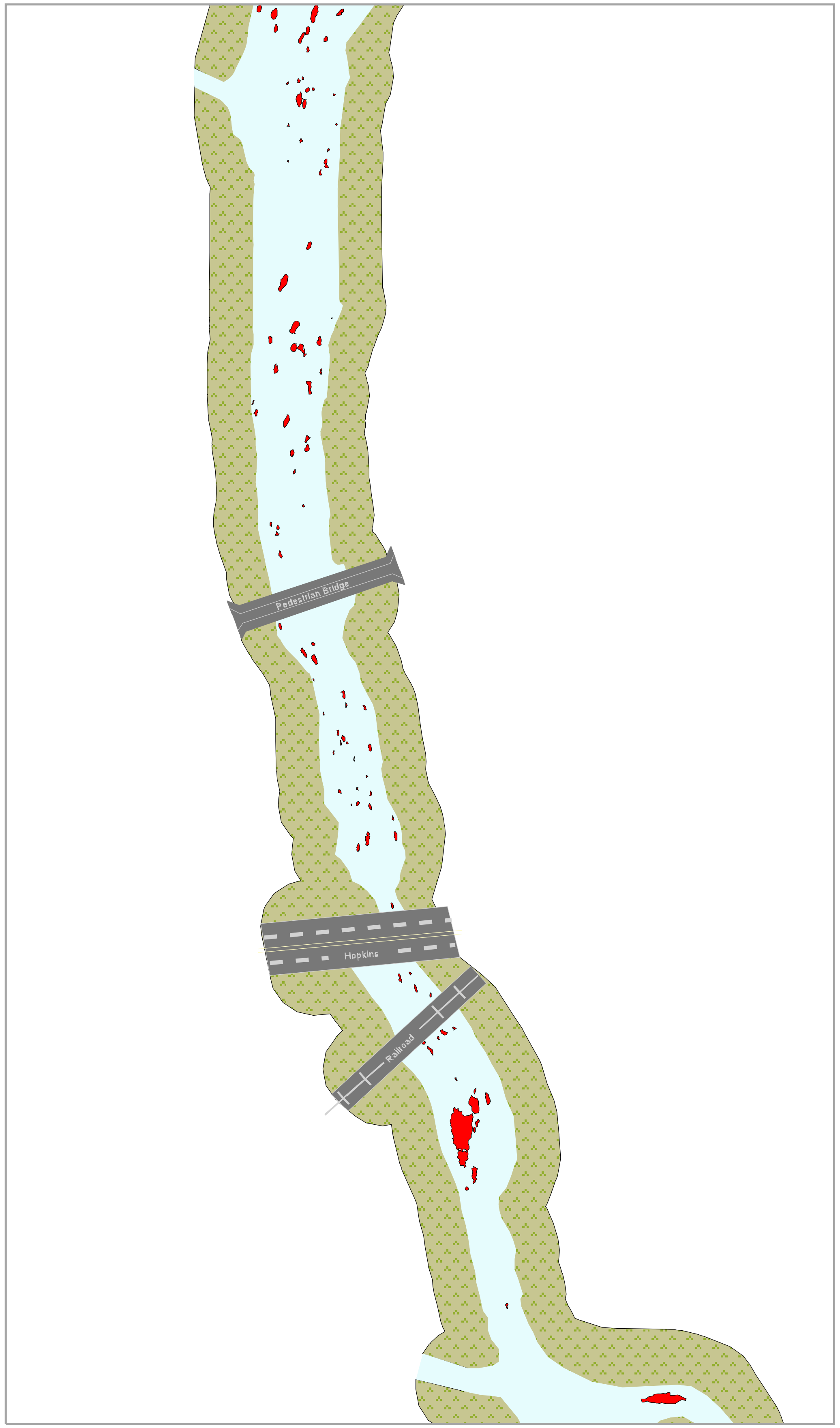
EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

Summer 2005 - Map 2 of 7

August 16 - August 18, 2005

N

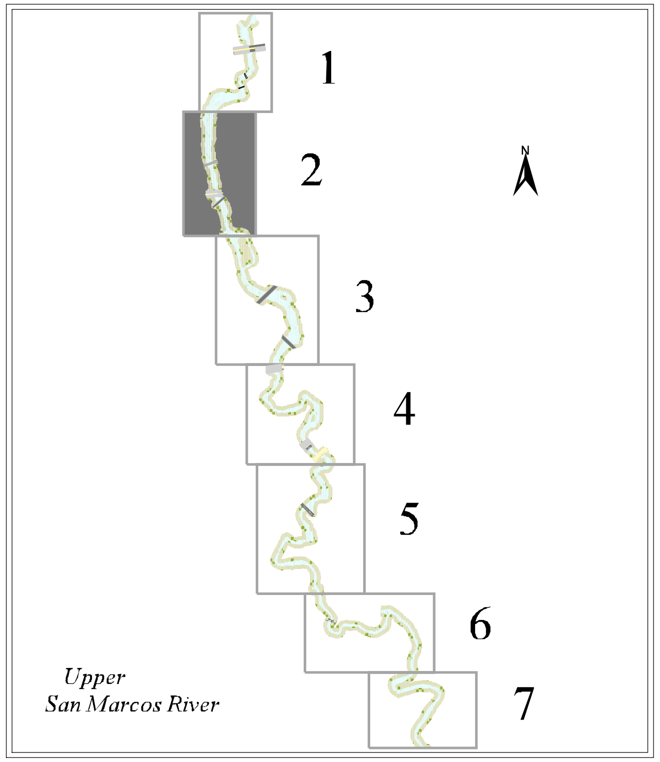
		Map 2 (m^2)	Total Population (m^2)
🟥	*Zizania*	330.5	2,949.7

✱ small *Zizania* plants

Scale: 1"=175'

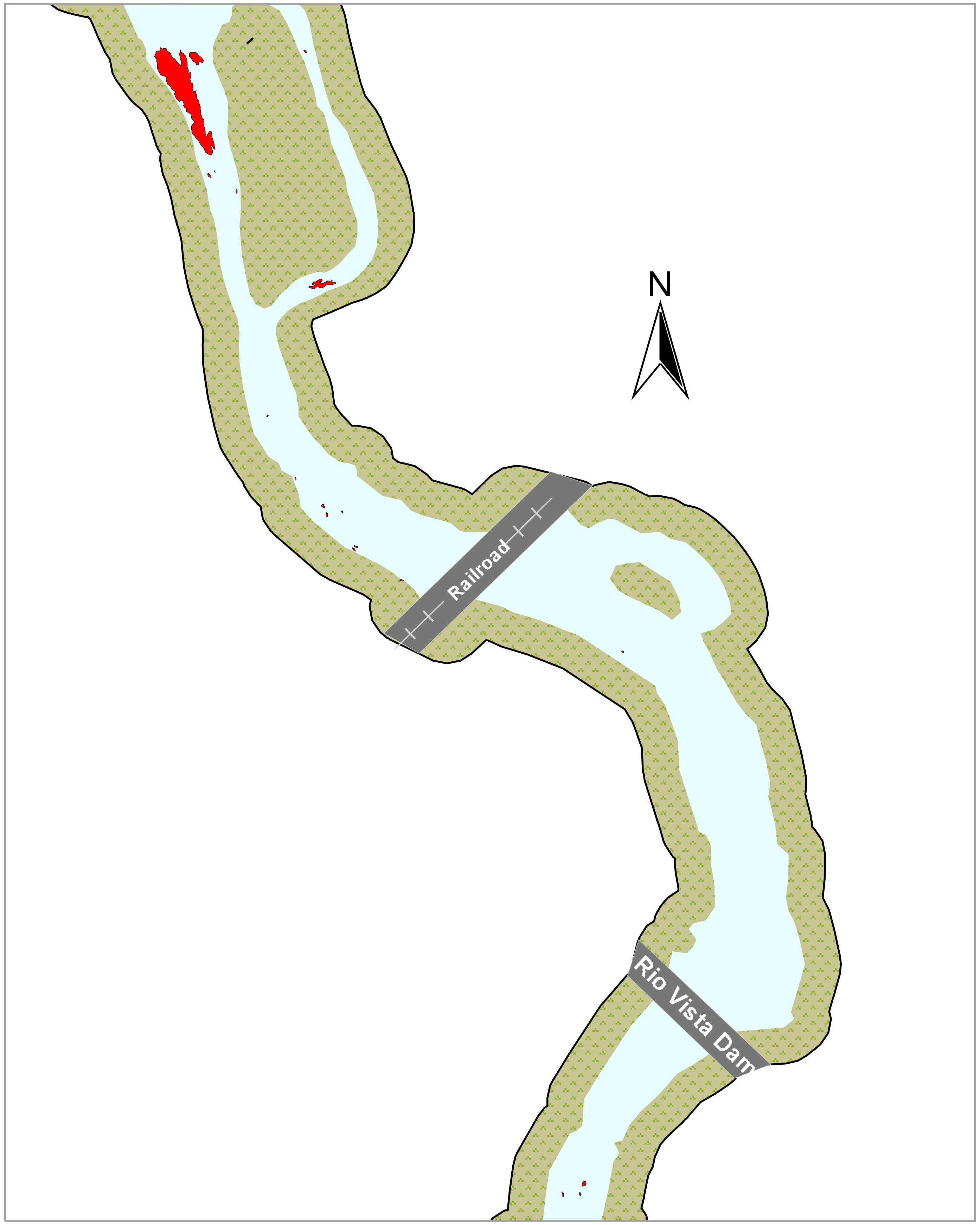
20 0 20 40 60 80 100 120 140 160 Meters

Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

Summer 2005 - Map 3 of 7

August 16 - August 18, 2005

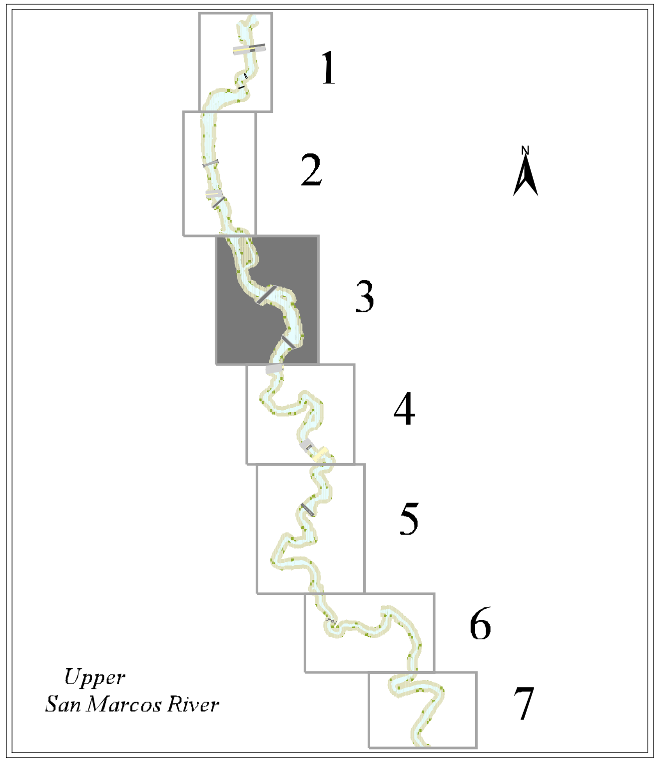
		Map 3 (m^2)	Total Population (m^2)
🟥	*Zizania*	374.5	2,949.7

* small *Zizania* plants

Scale: 1"=180'

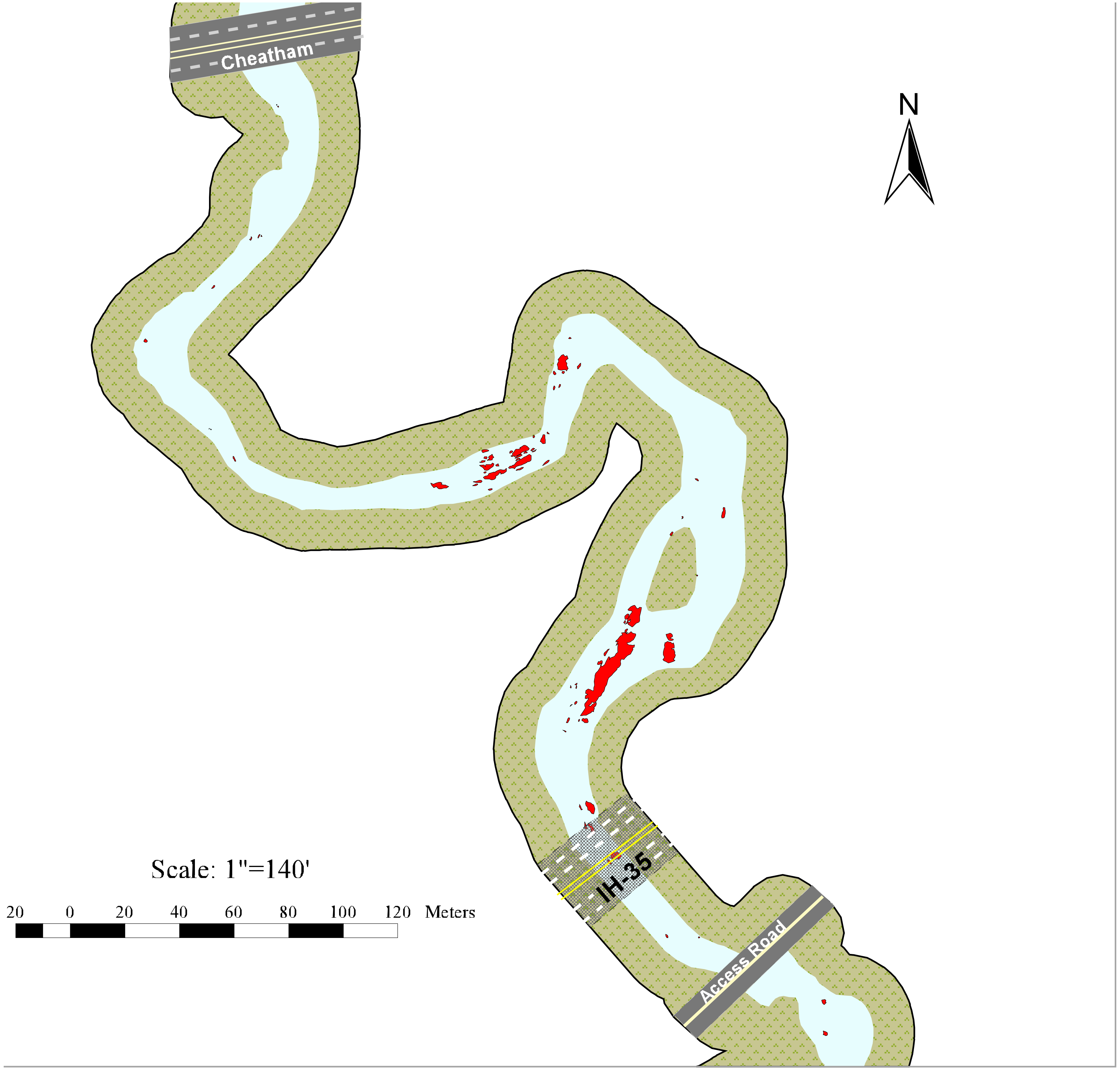
20 0 20 40 60 80 100 120 140 Meters

Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

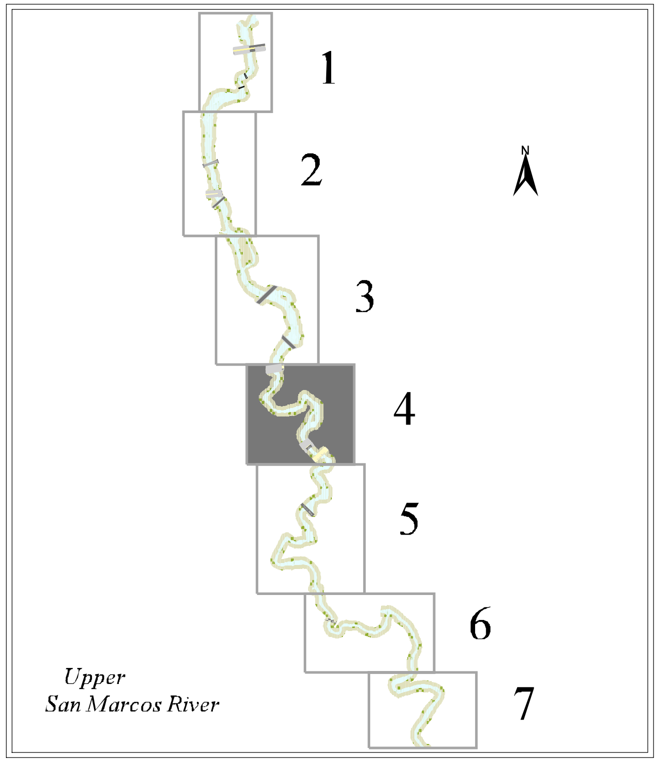
Summer 2005 - Map 4 of 7

August 16 - August 18, 2005

		Map 4 (m^2)	Total Population (m^2)
🟥	*Zizania*	361.9	2,949.7

* small *Zizania* plants

Project Location



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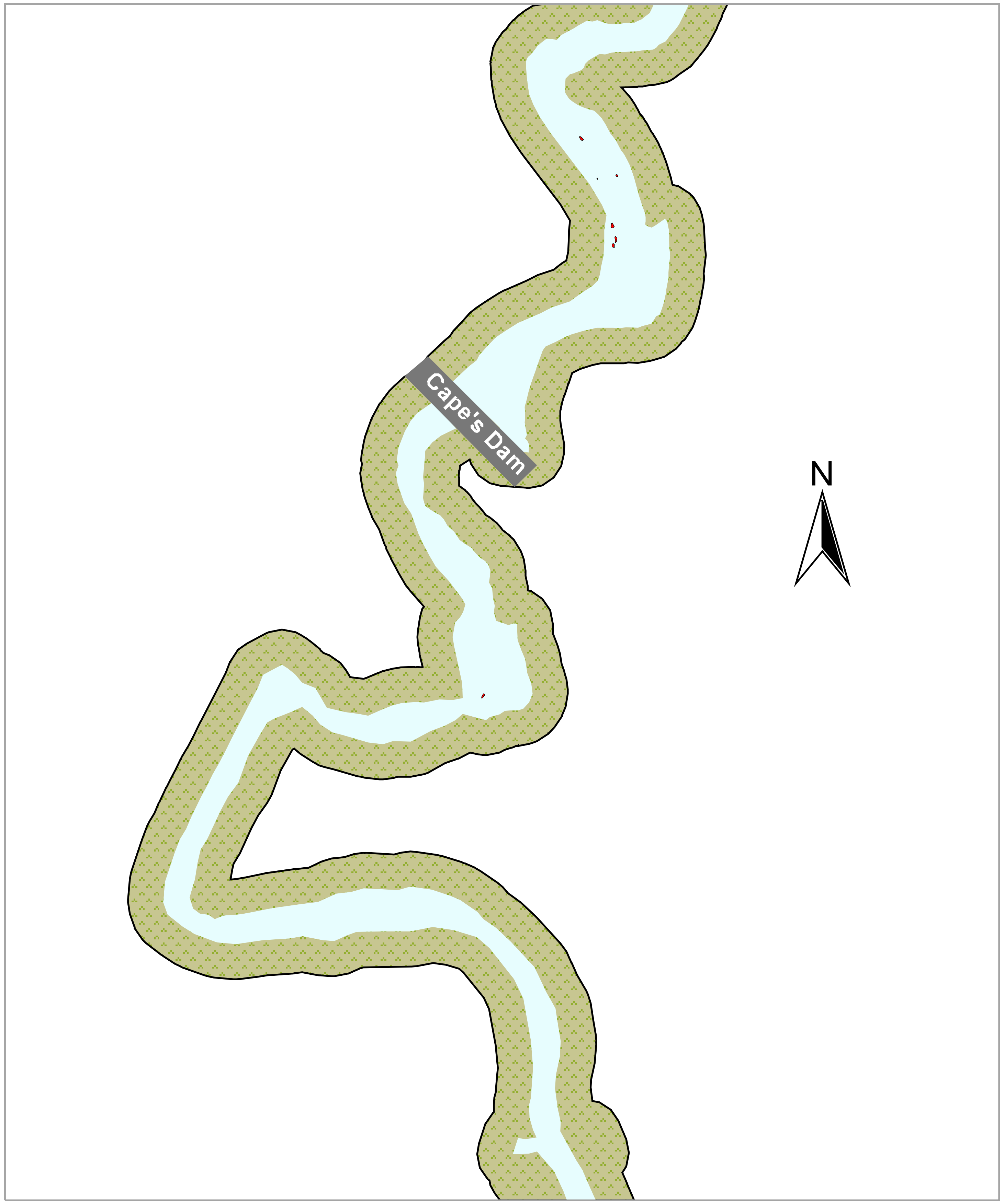
EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

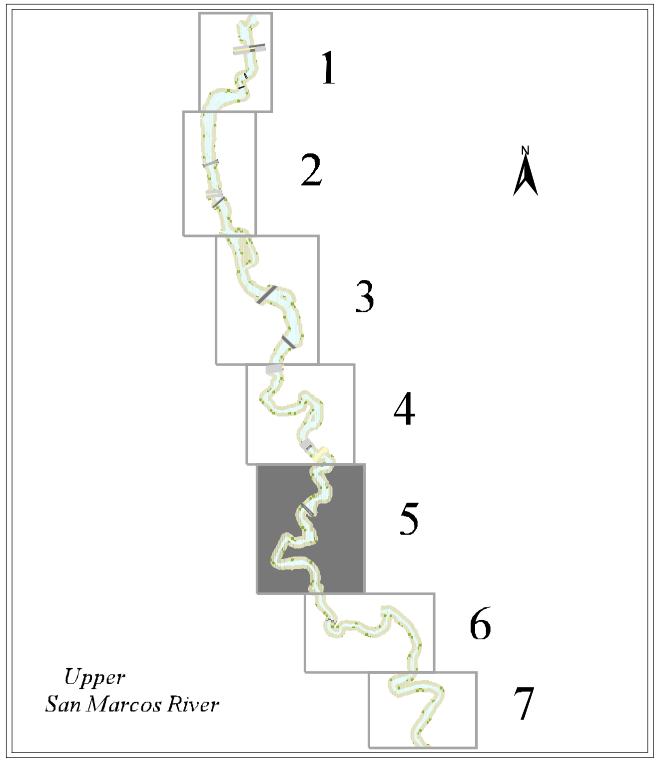
Summer 2005 - Map 5 of 7

August 16 - August 18, 2005

		Map 5 (m^2)	Total Population (m^2)
🟥	*Zizania*	8.7	2,949.7

✱ small *Zizania* plants

Project Location



Scale: 1"=180'

20 0 20 40 60 80 100 120 140 Meters

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San Marcos River
Texas wild-rice

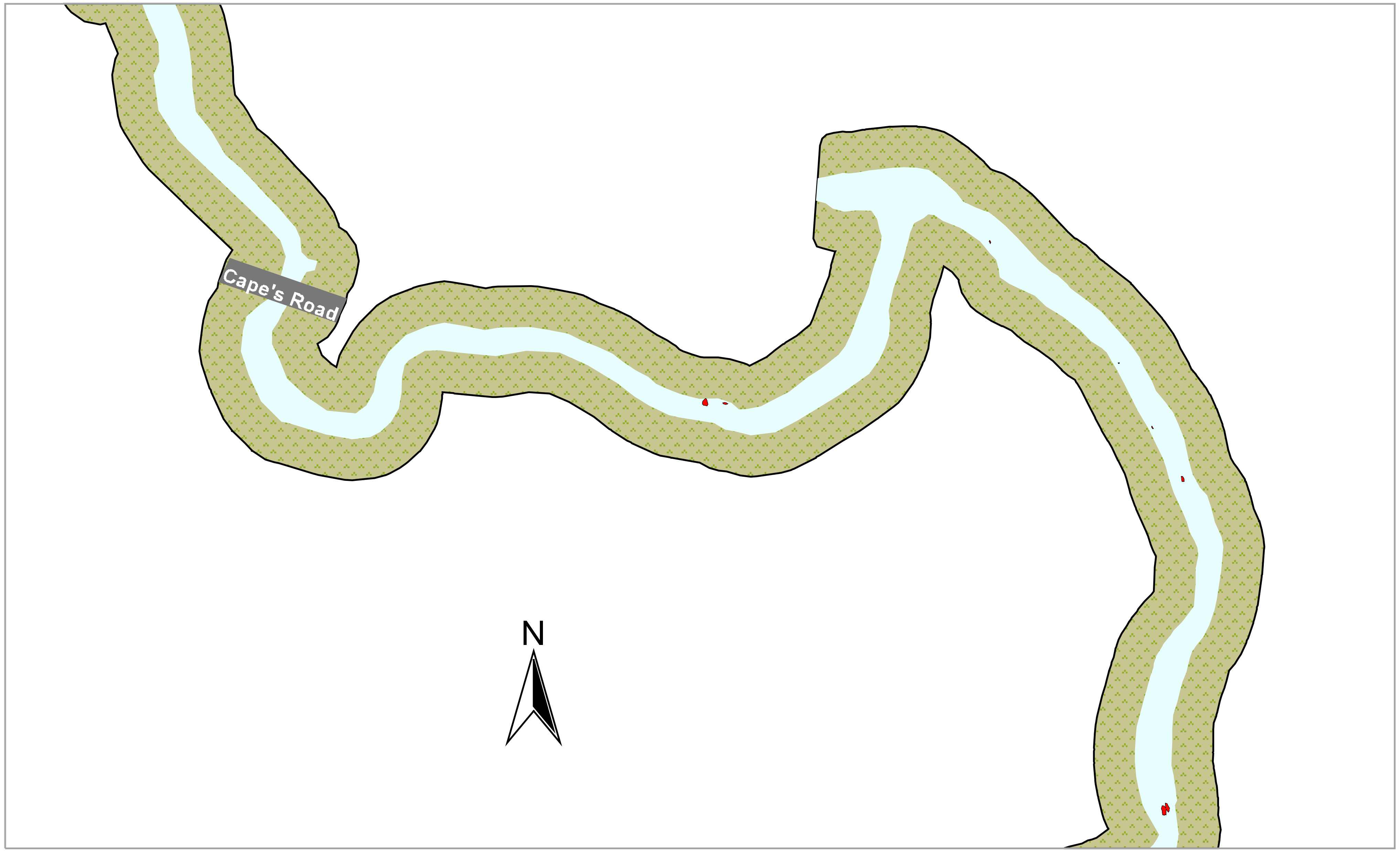
(Zizania texana)

Summer 2005- Map 6 of 7

August 16 - August 18, 2005

		Map 6 (m^2)	Total Population (m^2)
🟥	*Zizania*	15.1	2,949.7

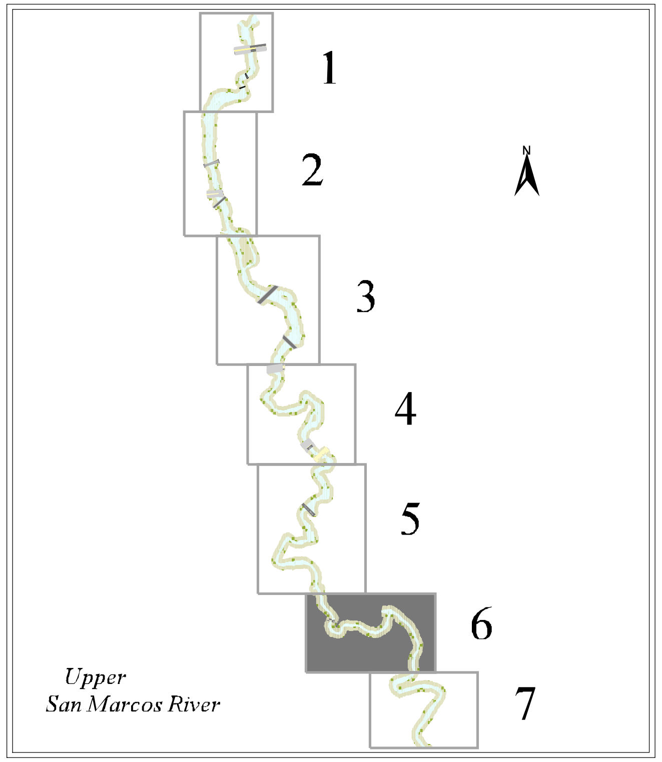
✱ small *Zizania* plants



Scale: 1"=160'

20 0 20 40 60 80 100 120 140 Meters

Project Location



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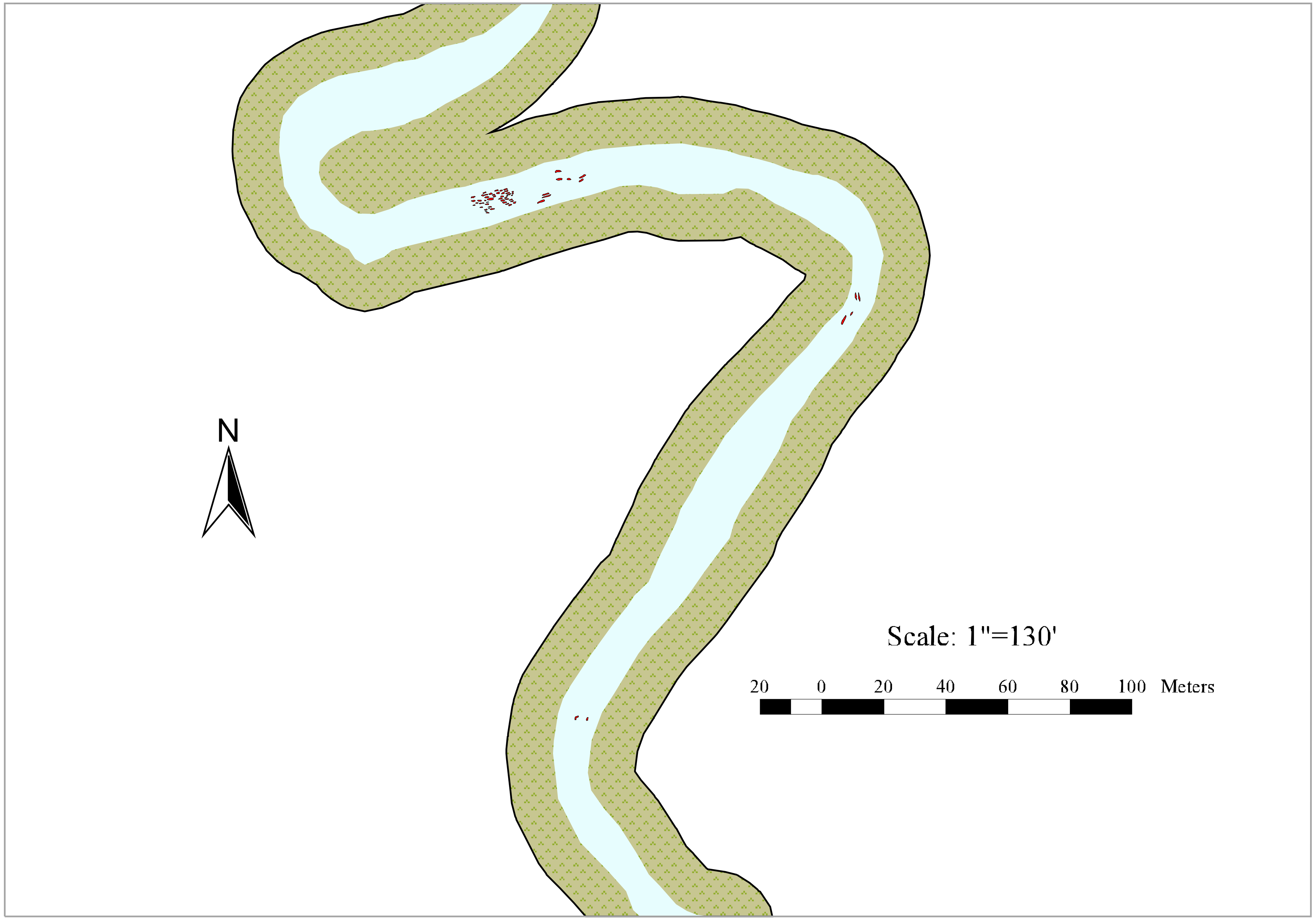
San Marcos River
Texas wild-rice

(Zizania texana)

Summer 2005- Map 7 of 7

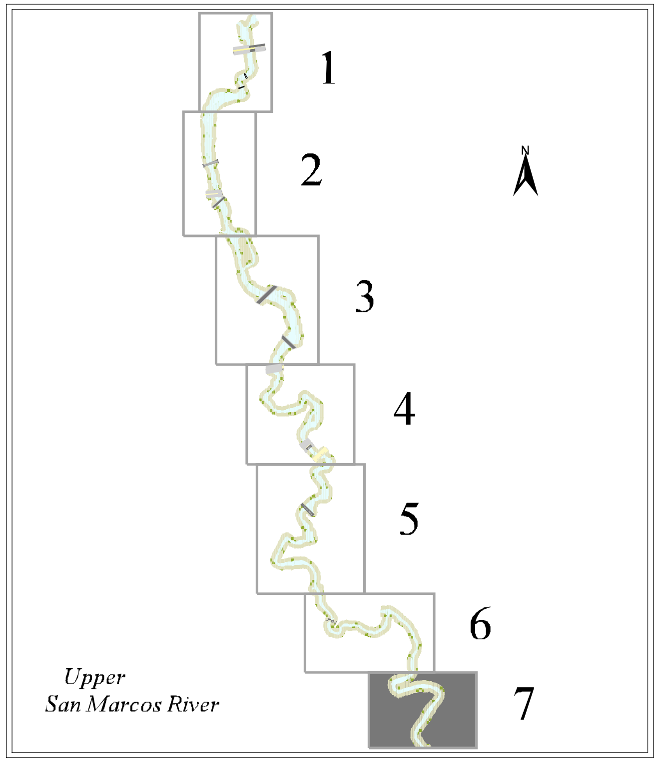
August 16 - August 18, 2005



		Map 7 (m^2)	Total Population (m^2)
🟥	*Zizania*	26.2	2,949.7

✱ small *Zizania* plants

Project Location



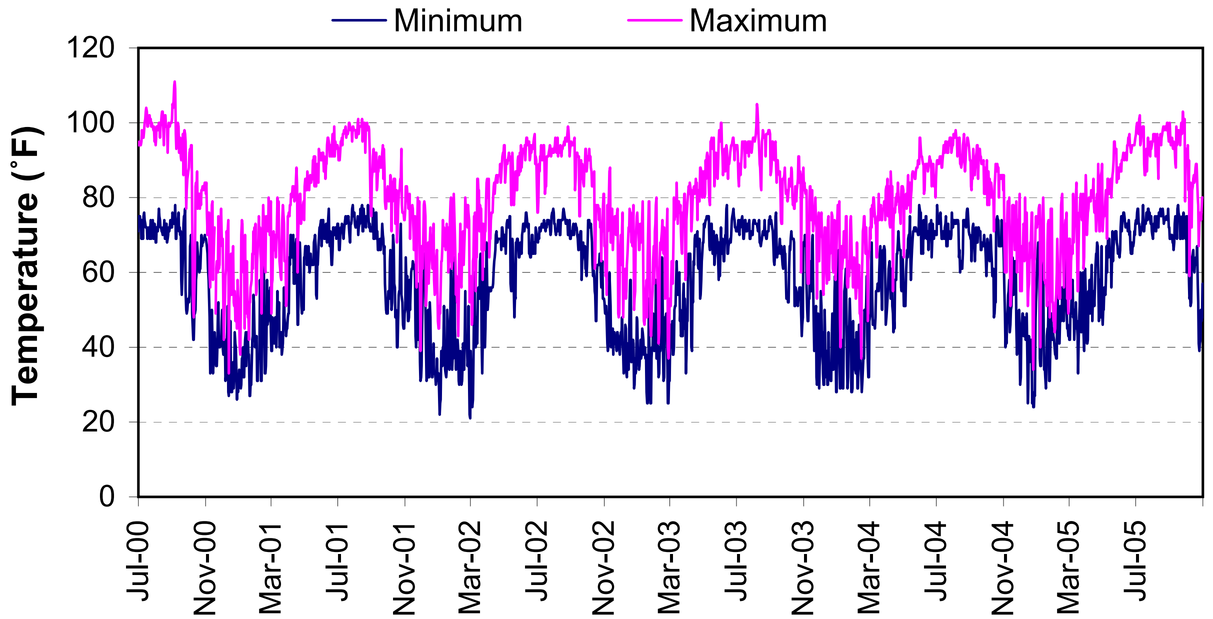
BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

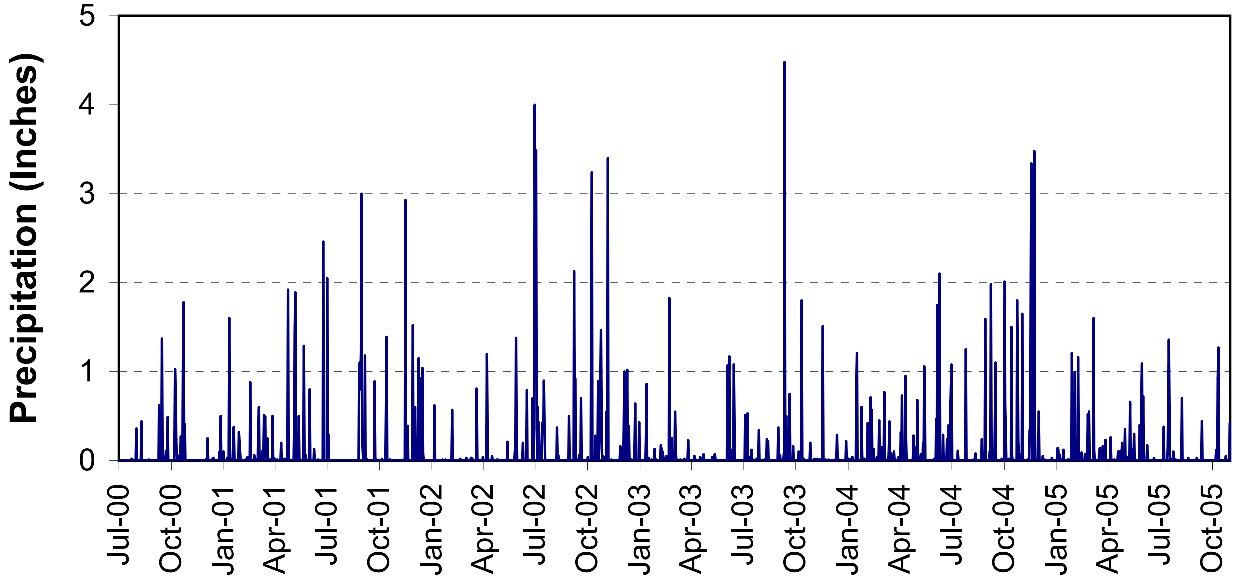
APPENDIX B:
DATA AND GRAPHS

Water Quality Data
and
Thermistor Graphs

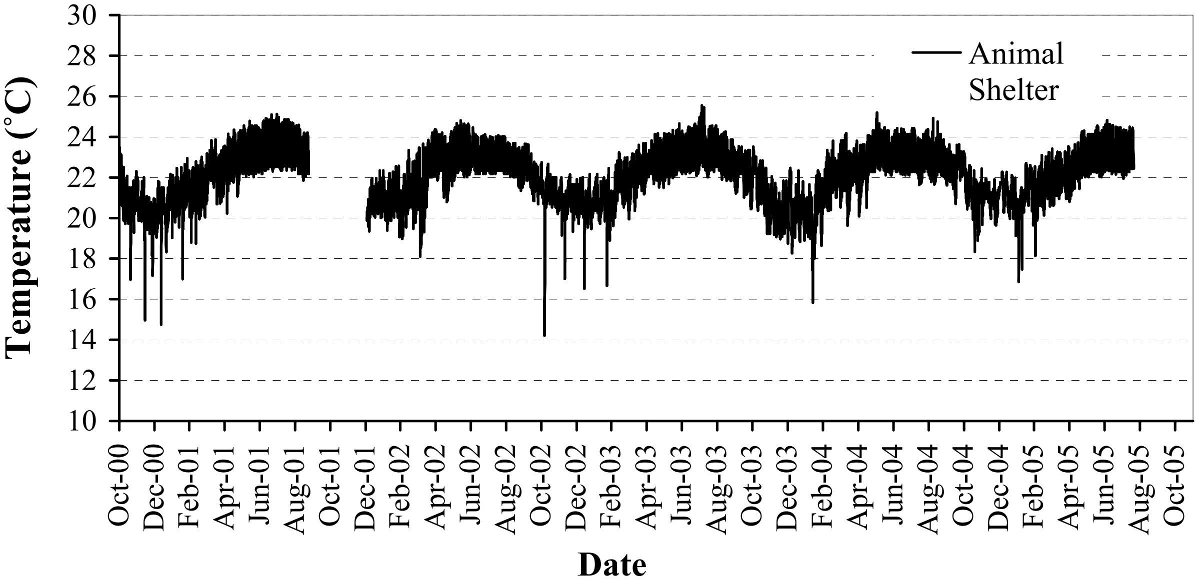
Daily Air Temperature Data for San Marcos, Texas



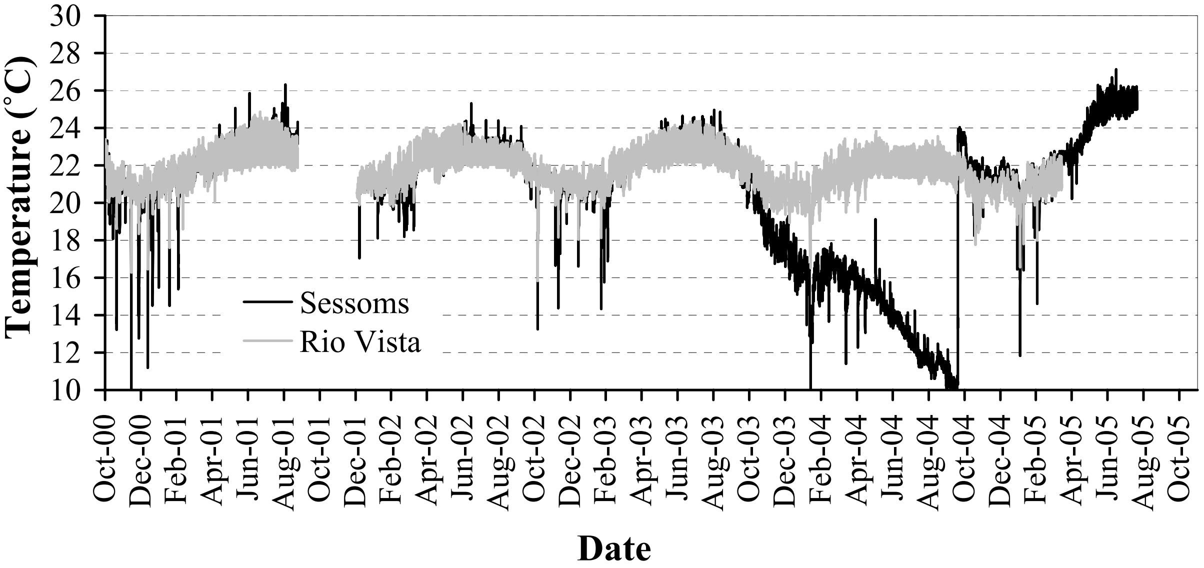
Daily Precipitation Data for San Marcos, Texas



Thermistor Data: Animal Shelter

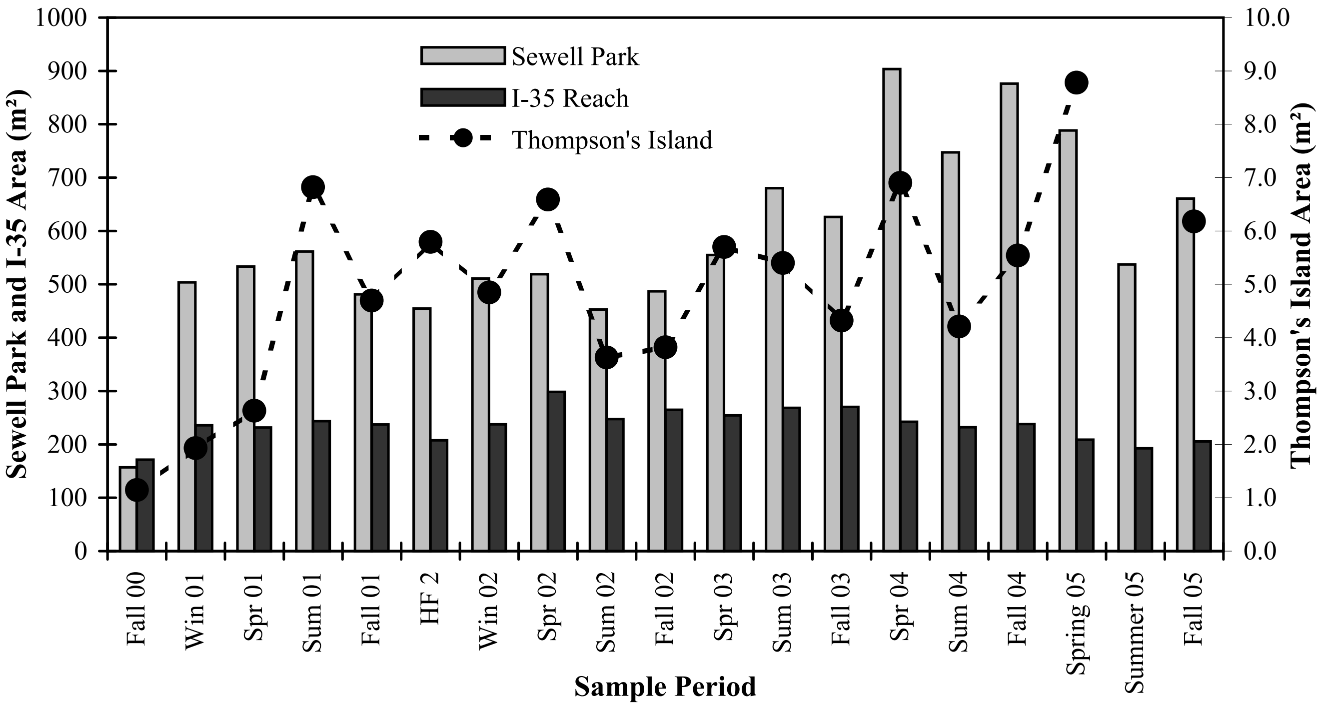


Thermistor Data: Sessoms Creek and Rio Vista Dam

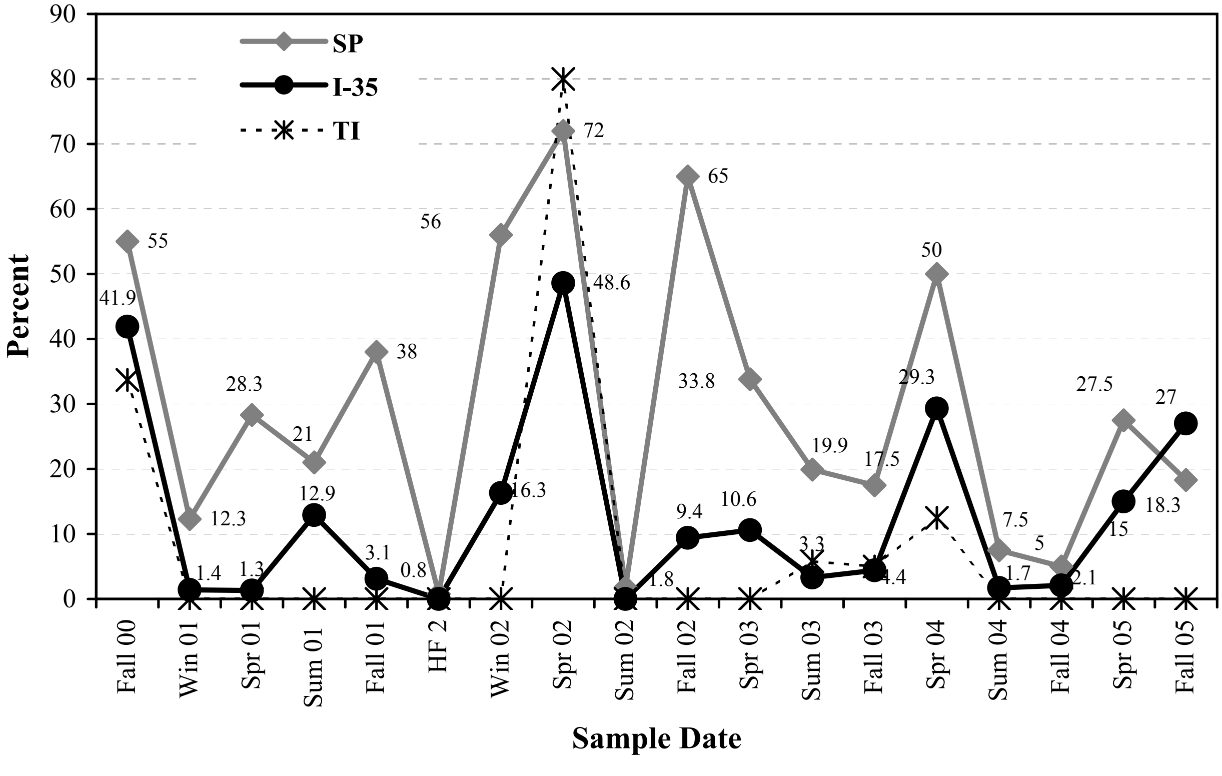


Texas Wild-Rice Observation Data

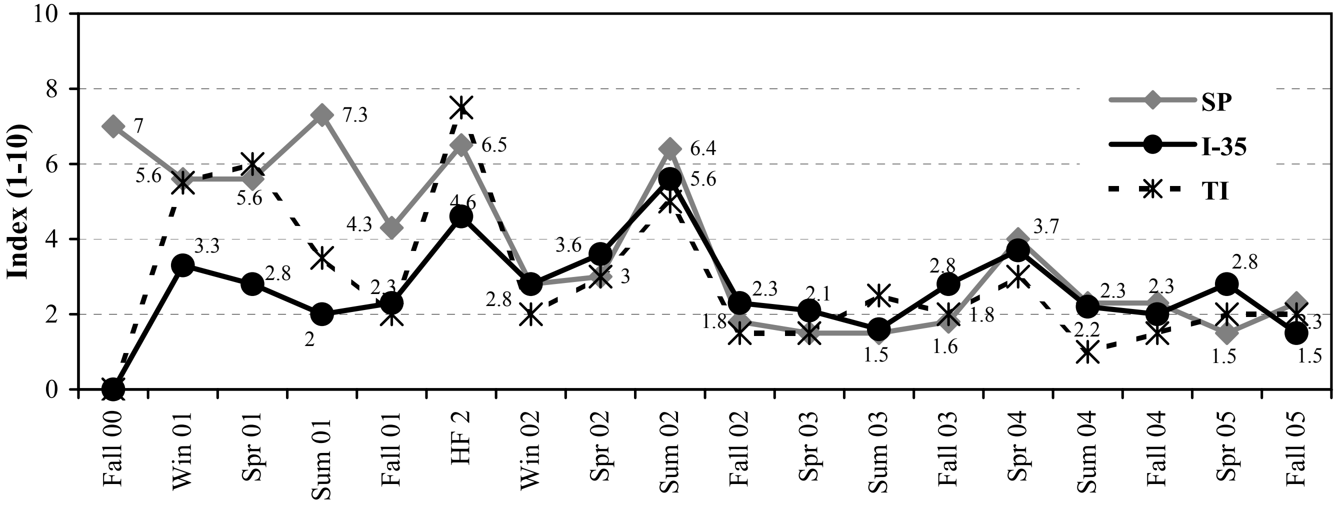
TWR Area by Season



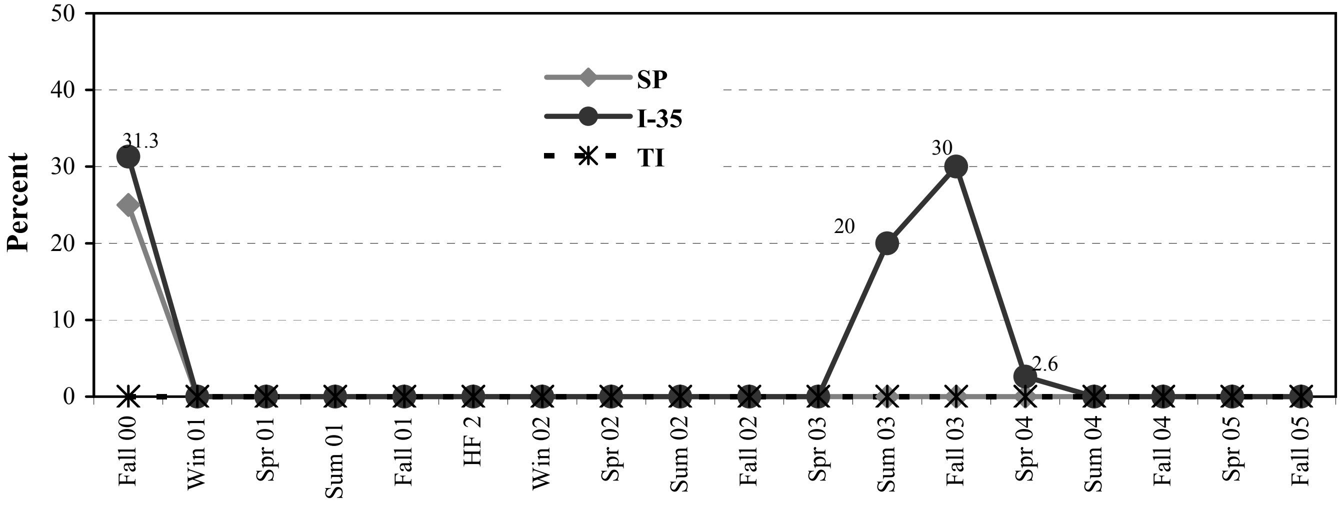
Percent Emergent TWR



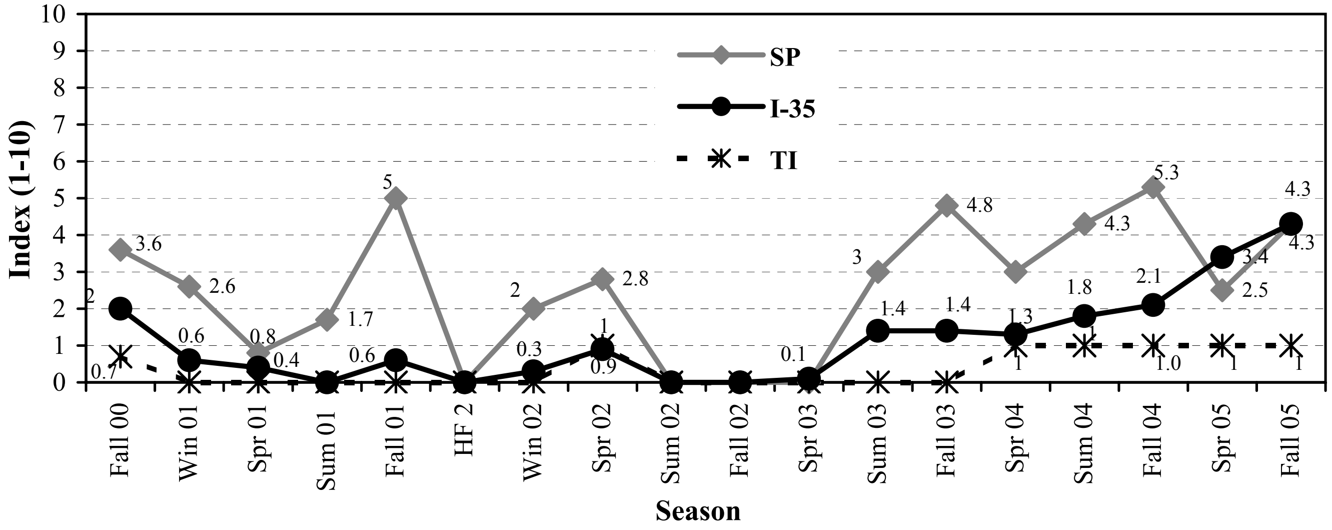
Index of Root Exposure for TWR Stands



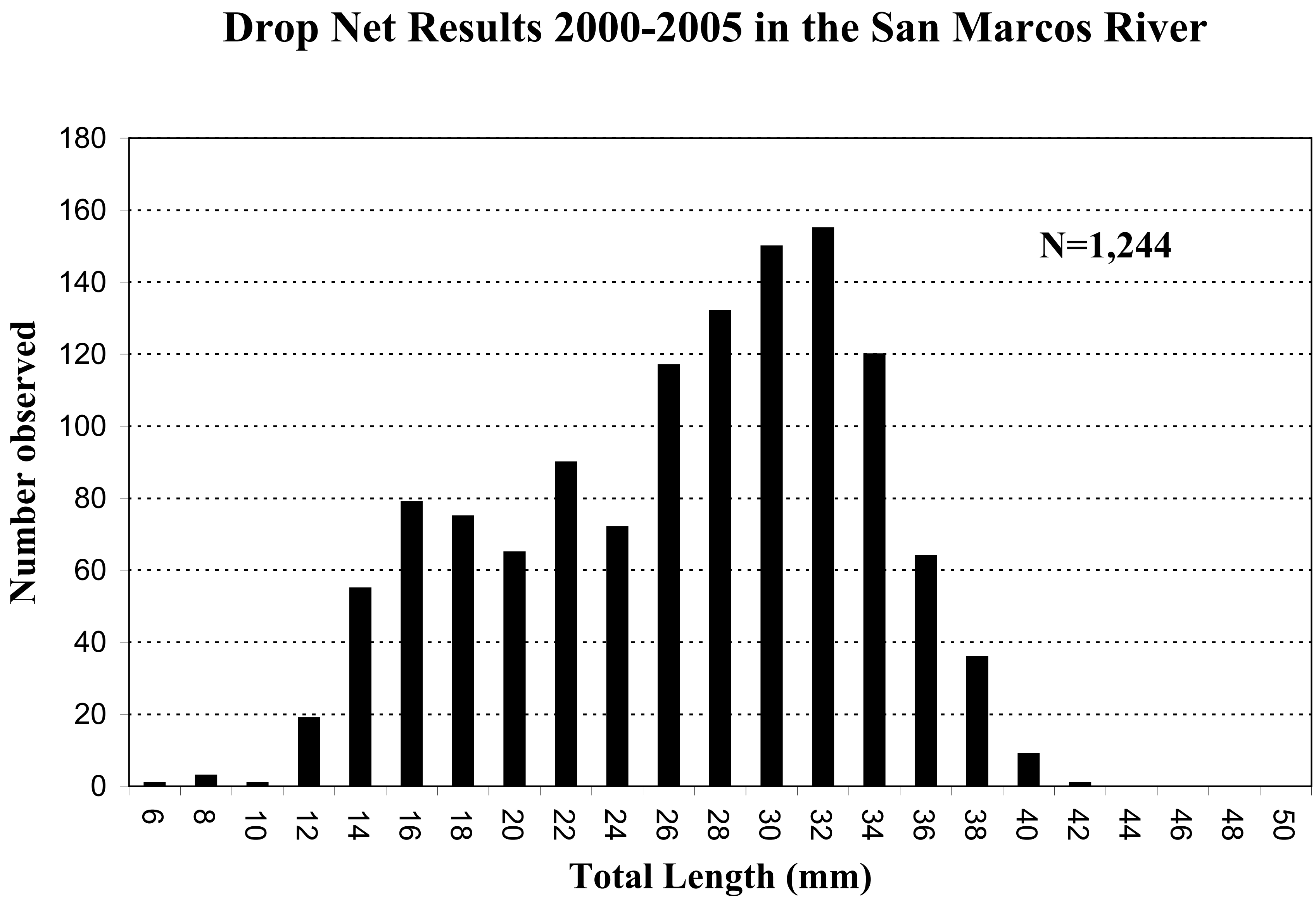
Percent of TWR Stands < 0.5 Feet



Index of Herbivory for TWR Stands

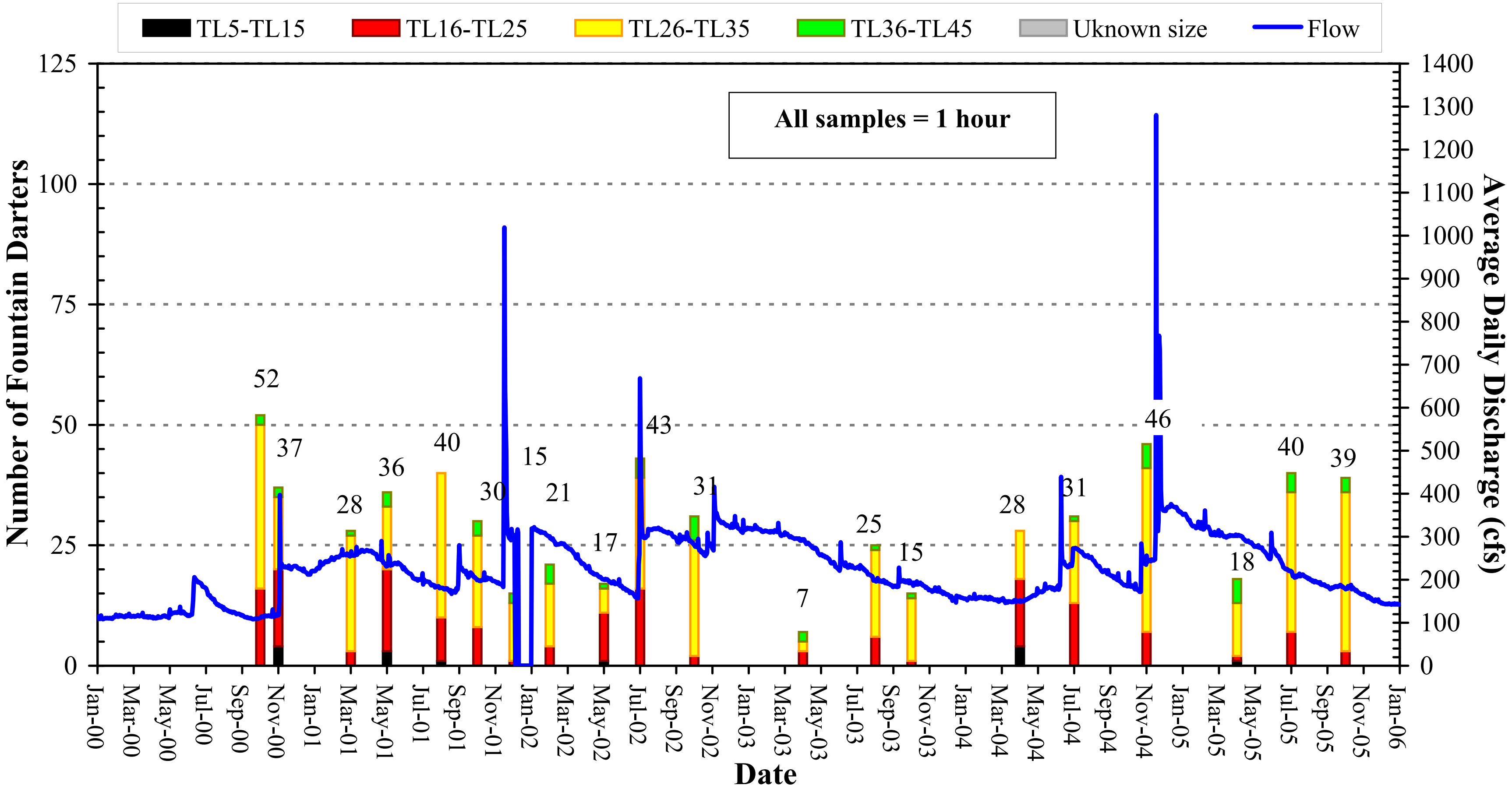


Drop Net Graph

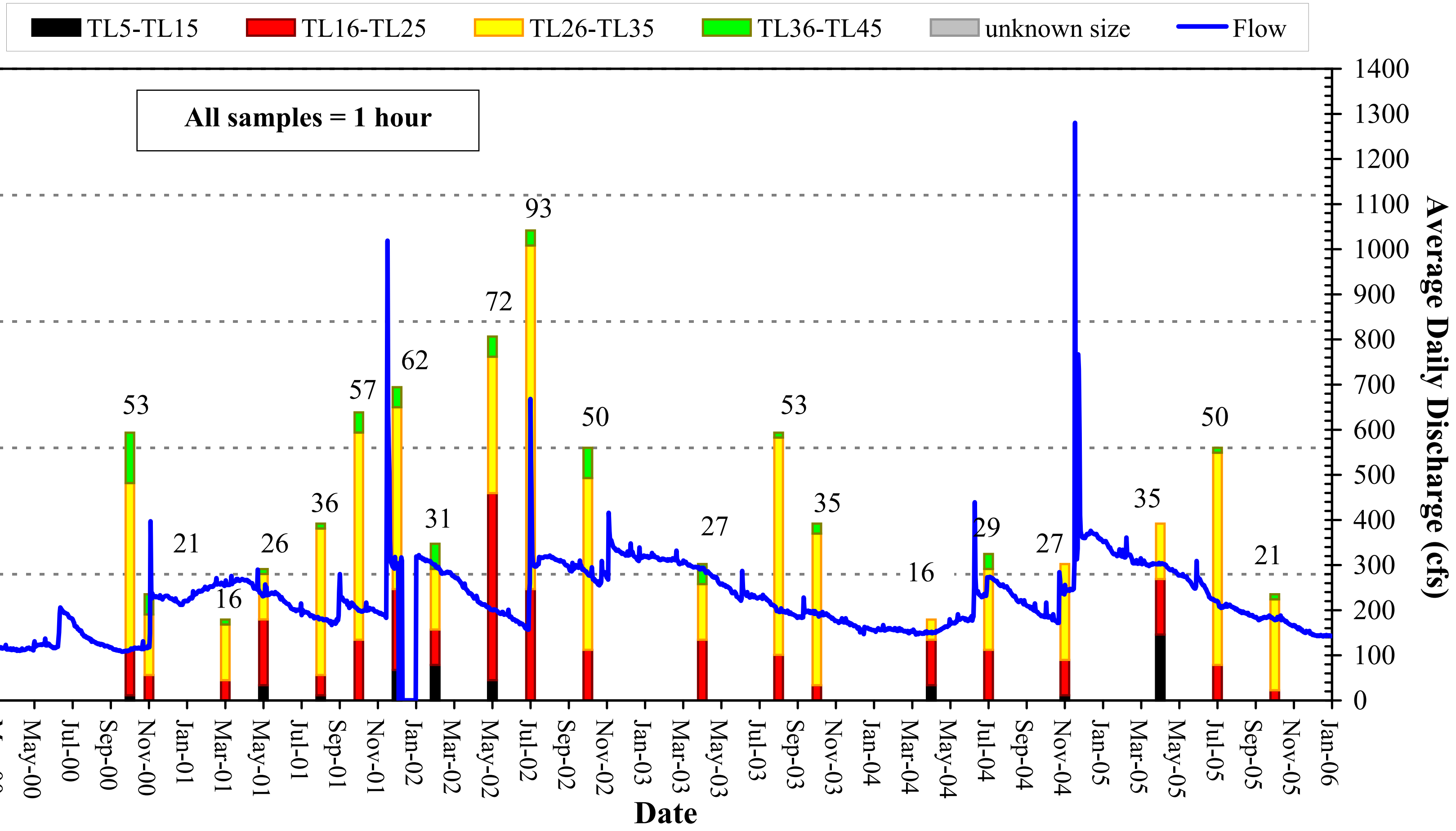

Drop Net Results 2000-2005 in the San Marcos River
N=1,244
Number observed
0
20
40
60
80
100
120
140
160
180
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
Total Length (mm)

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)