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 2003 ANNUAL REPORT

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February 2004

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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 three quarterly sampling events (Comprehensive Monitoring Effort) conducted on the San Marcos Springs/River ecosystem in 2003. There were no low-flow critical periods or high-flow events triggered in 2003. 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.

Although low flows in late summer 2000 initiated the Variable Flow Study, flows since that time have been largely above average levels. Significant rainfall events in late fall 2001 and summer 2002 yielded near record high-flow conditions that have maintained the aquifer levels and higher flows in the San Marcos River throughout 2003. However, discharge steadily declined through 2003 (the lowest flow occurred on the final day of the year) and dropped to slightly below the historical average for the month of December. This decline occurred despite continued high flows in the Comal River and low water demand from the aquifer. If discharge continues to decline in 2004 as it did in 2003, there may be critical period conditions that initiate low-flow sampling efforts in the San Marcos River.

Overall, the San Marcos Springs/River ecosystem has experienced a wide range of environmental conditions including variable flows during this study, but primarily flows have been above average. Baseline data have continued to show that the San Marcos River is an ecosystem with high water quality according to the chemical and physical variables that were measured. Thermistor data have revealed a high degree of thermal uniformity throughout the San Marcos ecosystem despite the wide-ranging conditions experienced during the study. Apart from acute disturbances, water temperatures fluctuated by less than 2˚C daily and by approximately 1˚C seasonally at the two sites located directly below Spring Lake in the eastern (chute) and western (dam) spillways. Further downstream in the City Park and I-35 reaches temperatures varied by greater than 2˚C daily and approximately 2.5˚C seasonally; the maximum deviation was approximately 7˚C from the average value in the late summer (observed in 2001). There were no observations that exceeded of the state water quality standards value (26.67°C) in 2003. Overall, water temperature data have not presented any cause for concern during the study, but it will continue to be important to evaluate low-flow conditions. There continues to be no clear or dramatic change in any water quality variables that might raise concern when comparing data from all sample dates.

Aquatic vegetation remained abundant throughout the study period and provided suitable habitat for biological communities. As in previous years, sizable vegetation mats developed in the City Park Reach. This type of vegetation mat development was also observed in the reach below Spring Lake Dam at moderate flows. Recreational impacts were distinct in the reach just below Spring Lake Dam and also noticeable in the City Park Reach. A clear line in the vegetation is obvious on the Spring Lake Dam Reach summer map where the same path was used repeatedly to access deeper water. There was a moderate-sized patch of Texas wild-rice on the spring map that is clearly along this pathway that disappeared between the spring and summer samples. Texas wild-rice remained abundant in the Spring Lake Dam reach in 2003; this area has changed dramatically since 2000 in the amount of Texas wild-rice below the dam. In the City Park Reach, Texas wild-rice decreased slightly in total coverage over 2003, but the total number of plants increased. Over time, these plants will grow under favorable conditions and increase the total coverage in this reach. The I-35 Reach maintained a very stable vegetation community under the steadily decreasing flows of 2003. Data from 2001 and 2002 show that vegetation in the I-35 Reach is highly susceptible to flooding impacts, but relatively stable flows led to stable conditions in 2003. This information provides valuable baseline data that will allow a detailed evaluation of the full impacts of low-flow conditions when they occur.

As occurred in 2002, there was a substantial increase in total coverage of Texas wild-rice throughout the San Marcos River in 2003 relative to the previous sample. The scouring events in 2001 and 2002 have had a positive long-term impact on Texas wild-rice total coverage. Although there were short-term losses following each flood, the total coverage in the river has increased to the highest levels recorded during this study or by the Texas Parks and Wildlife (TPWD). These scouring events appear to stimulate growth of individual stands and also result in displacement of small Texas wild-rice plants, which settle into new areas and grow rapidly. Stands of Texas wild-rice that remain in place after flooding are generally smaller, but they experience rapid growth. Despite the high total coverage observed in 2003, the total coverage of the species in the lower portions of its range (below the I-35 Bridge) remains very small. Unlike most areas above the I-35 Bridge, no plants were displaced from upstream of these areas during the 2001 and 2002 floods to compensate for lost plants. Also, plants that remained after flooding did not experience the rapid growth that occurred in upstream habitats. This trend downstream of I-35 traces back to the massive flood of 1998 when the TPWD data revealed significant declines in areal coverage following that event; the Texas wild-rice population in those areas has never recovered from that event and continues to decrease with each significant flood event.

Fountain darters were collected from each sample reach during each sampling event in 2003. The suitability of various vegetation types in the San Marcos River as habitat for fountain darters are similar. *Hydrilla* is slightly less suitable than average and *Cabomba* is slightly higher than average, but the range of suitability is minimal compared with the Comal River system. The size-class distribution for fountain darters collected by drop nets from the San Marcos Springs/River ecosystem in 2003 is typical of a healthy fish assemblage. However, the distribution is shifted towards larger fish than those observed in the Comal Springs/River ecosystem and this may be a function of lower quality habitat in the two sampled reaches compared with the Comal River reaches. Also, currents tend to be stronger in the San Marcos River reaches and may contribute to finding larger, but fewer, fish.

In general, the number of fountain darters per net in the San Marcos River was much lower than in the Comal River. This is likely related to the quality of habitat sampled in each ecosystem and the ability of the habitat to support various densities of fountain darters. In the Comal system, habitat (sampled for the Variable Flow Study) tends to be much more favorable for fountain darters, and densities are much higher (although densities in Spring Lake on the San Marcos River are very high – based on visual [SCUBA] observations). There also appears to be a seasonal trend in fountain darters collected in the San Marcos River of low abundance in the fall and winter with increasing abundance in the spring and into summer.

No giant ramshorn snails (*Marisa cornuarietis*) were observed in the San Marcos River in 2002 or 2003. 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 2003.

Estimated population densities of the San Marcos salamander in 2003 were consistent with observations in 2001-2002. Filamentous algae remained abundant throughout 2003 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, the sample site adjacent to the former Aquarena Springs Hotel consistently had the highest number of San Marcos salamanders. This site provided highly suitable habitat with consistent springflow, abundant cover, and an abundant food supply. The other Spring Lake site had lower San Marcos salamander densities, but it also provided high-quality habitat. Population estimates have varied greatly between seasons at each site, overshadowing any seasonal or discharge-related trend that may be present. A lack of substantial low-flow data precludes discussion of potential influences of lower flows on the population at this time.

As described above, the data in this report are preliminary and although they have been carefully evaluated to determine trends and observations of particular interest, stringent data reduction techniques and/or statistical applications have not yet been applied to this incomplete data set. More data from periods of low-flow (particularly from an extended period of low-flow) are essential to fully evaluate the biological risks associated with future critical periods (high or low-flow). Although quarterly sampling does not yield the vital low-flow data, these samples are extremely important to maintain a continuous understanding of current conditions in order to be prepared for a period of low-flow and to monitor conditions following such a period. Sampling only during a low-flow event will not provide the necessary context to adequately assess changes that occur during such conditions.

This study remains the most comprehensive biological evaluation that has ever been conducted on the San Marcos system. Variable flow conditions encountered to date have provided an excellent confirmation that the study design is well suited to address the concerns of variable flow and water quality on the biological resources in the San Marcos system. As noted in the 2002 annual report, 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).

METHODS

In 2003, three quarterly sampling efforts were conducted with a sampling protocol that was slightly modified relative to 2000 - 2002. 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) during a meeting in August 2002 and implemented beginning with the Fall 2002 quarterly sample effort. Modification included a reduced evaluation of water quality during quarterly sample efforts to include thermistors and fixed station photographs and removal of the exotic / predation component during quarterly sample efforts. One new component for 2003 was a laboratory study to evaluate various water quality and flow on key aquatic vegetation types found in the Comal and San Marcos Springs/River ecosystems. This study is detailed in BIO-WEST (2004) and summarized in the 2003 Variable Flow Study annual report for the Comal Springs/River ecosystem. The resulting schedule included the following:

Aquatic Vegetation Mapping
  Texas wild-rice annual survey

Water Quality
  Thermistor Placement
  Thermistor Retrieval
  Fixed Station Photography

Texas Wild-Rice Physical Observations

Fountain Darter Sampling
  Drop Nets
  Dip Nets

San Marcos Salamander Observations

High-Flow Sampling

Unlike in 2001 and 2002, there were no high-flow sampling events in 2003.

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 2000). The discharge data for the San Marcos River ware 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 during quarterly sampling events for 2003, but the two

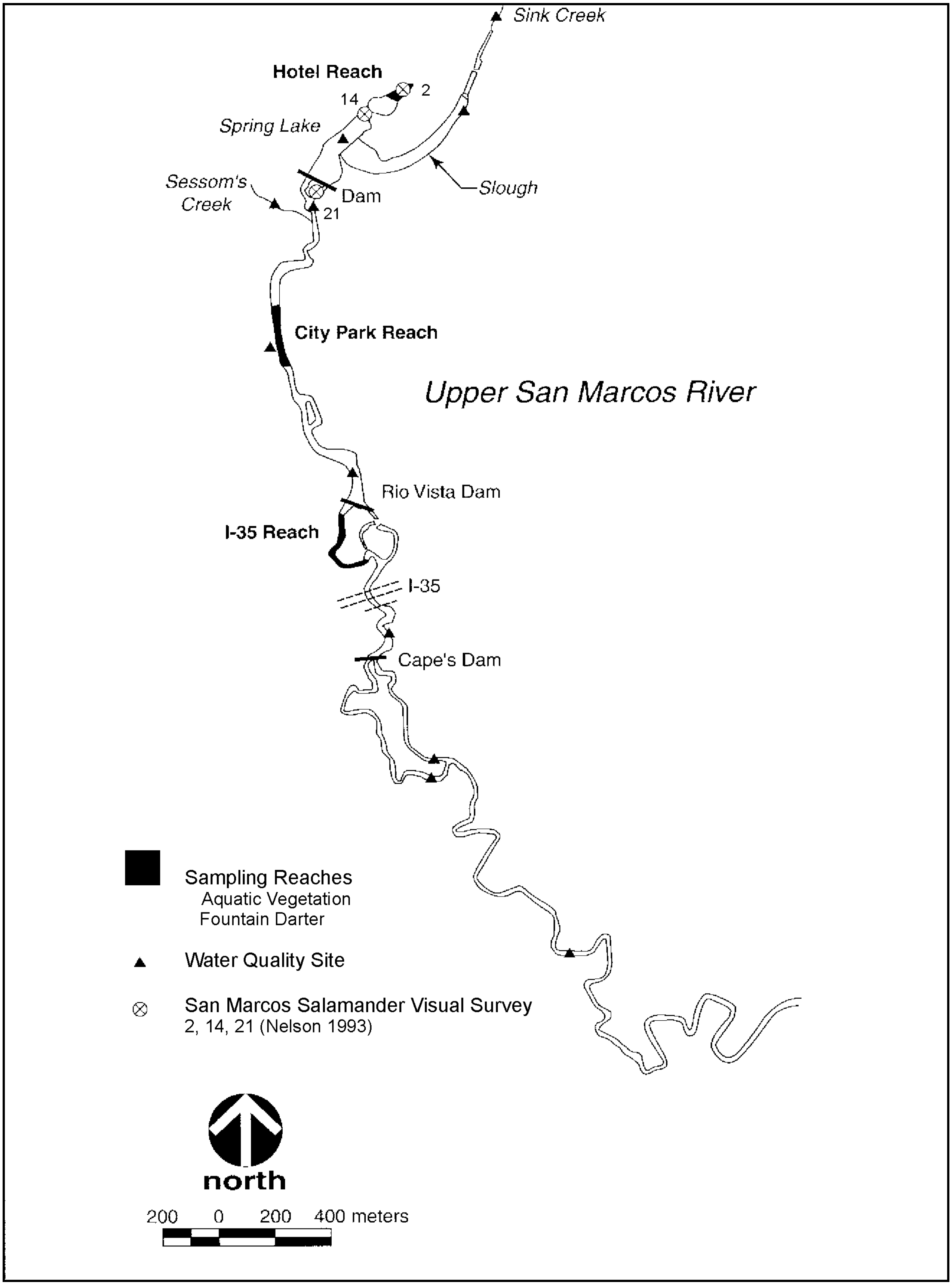

Figure 1. Upper San Marcos River water quality and biological sampling areas.

components necessary for maintenance of long-term baseline data, thermistors and fixed station photography, were included. 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 dropnet sampling sites using a Hydrolab Quanta. When conditions trigger low-flow sampling 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/River 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 set to record temperature data every 10 minutes. The water quality station locations will not be described in detail here to minimize the potential for unauthorized tampering with field equipment.

Fixed station photography allowed for temporal habitat evaluations; these photographs included an upstream, a cross-stream, and a downstream picture were taken at each water quality site depicted on Figure 1.

Aquatic Vegetation Mapping

The aquatic vegetation mapping effort consisted of mapping all of the vegetation in each of three reaches (Spring Lake Dam, City Park, and I-35; Appendix A). Mapping was conducted using a Trimble Pro-XRS global positioning system (GPS) unit with real-time differential correction capable of sub-meter accuracy. The GPS unit was linked to a Fujitsu Stylistic 2300 laptop computer with Aspen software that displays field data as they are gathered and improves efficiency and accuracy. The GPS unit and computer were placed in a 10-ft Perception Swifty kayak with the GPS unit antenna mounted on the bow. The aquatic vegetation was identified and mapped by gathering coordinates while maneuvering the kayak around the perimeter of each vegetation type at the water's surface. Except for Texas wild-rice, vegetation stands less than 0.5-meter (m) in diameter were not mapped.

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

Texas Wild-Rice Physical Observations

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

After an evaluation of the general condition of all stands of Texas wild-rice along the San Marcos River from Spring Lake Dam to the confluence with the Blanco River in September 2000, 19 representative stands were selected for study. These included eight stands in the Sewell Park Reach, eight stands in the reach from Rio Vista Dam to I-35, and three stands between Cape's Dam and the City of San Marcos sewage treatment facility (one of the latter stands was lost in 2001).

During each quarterly sampling effort in 2003, all stands of Texas wild-rice were measured for depth, maximum length, and maximum width. The length measurement was taken at the water surface parallel to streamflow and included the distance between the base of the roots to the tip of the longest leaf. The width was measured at the widest point perpendicular to the stream current (this usually did not include roots). The length and width measurements were used to calculate the area of each stand according to a method used by the TPWD (J. Poole, TPWD, pers. comm.) in which percent cover was estimated for the imaginary rectangle created from the maximum length and maximum width measurements. In addition to recording areal coverage with these methods, GPS with real-time differential correction was used to map each stand and provide improved precision on the location and a secondary means of estimating areal coverage.

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

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

Fountain Darter Sampling

Drop Nets

A drop net is a type of sampling device previously used by the USFWS to sample fountain darters and other fish species. The design of the net is such that it encloses a known area (2 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 during the previous week) of that reach.

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

Dip Nets

In addition to drop net sampling for fountain darters, a 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.

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

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

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

Exotics / Predation Study

This sampling component was not included the quarterly samples of 2003 but will be included in future low-flow sampling efforts.

OBSERVATIONS

The BIO-WEST project team conducted the 2003 sampling components as shown in Table 1.

Table 1. Components of 2003 sampling events.

EVENT	DATES	EVENT	DATES
Spring Sampling		**Fall Sampling**	
Vegetation Mapping	Apr 9-11	Vegetation Mapping	Oct 20 - 21
Texas Wild-rice Physical Observations	Apr 7	Texas Wild-rice Physical Observations	Oct 28
Fountain Darter Sampling	Apr 15-16	Fountain Darter Sampling	Oct 30 - 31
San Marcos Salamander Observations	Apr 8	San Marcos Salamander Observations	Nov 6
Summer Sampling			
Texas wild-rice Annual Survey	Jul 28 – Aug 1		
Vegetation Mapping	Aug 5-7		
Texas Wild-rice Physical Observations	Aug 4		
Fountain Darter Sampling	Aug 11-12		
San Marcos Salamander Observations	Aug 8		

Springflow

The flooding that occurred in July of 2002 and a wet fall raised the aquifer to record levels, which were maintained through the first half of 2003 (Figure 2). In the first half of 2003, discharge levels in the San Marcos River remained high, but steadily decreased from the peak in July 2002. Precipitation was low in 2003 in the areas that provide localized recharge for the San Marcos Springs and discharge continued to decrease throughout the year to the point where the monthly mean for December 2003 (161.8 cfs) fell below the mean monthly value over the period of record (165.2 cfs). December was the only month in which that occurred (Figure 3).

There were no major peaks in discharge during 2003, which contributed to the steady decrease in flow throughout the year. This was the first full year of this study without a substantial flooding event. The low value for the year occurred on the last few days in December, typically a wet time period, rather than in the summer as in 2001-2002.

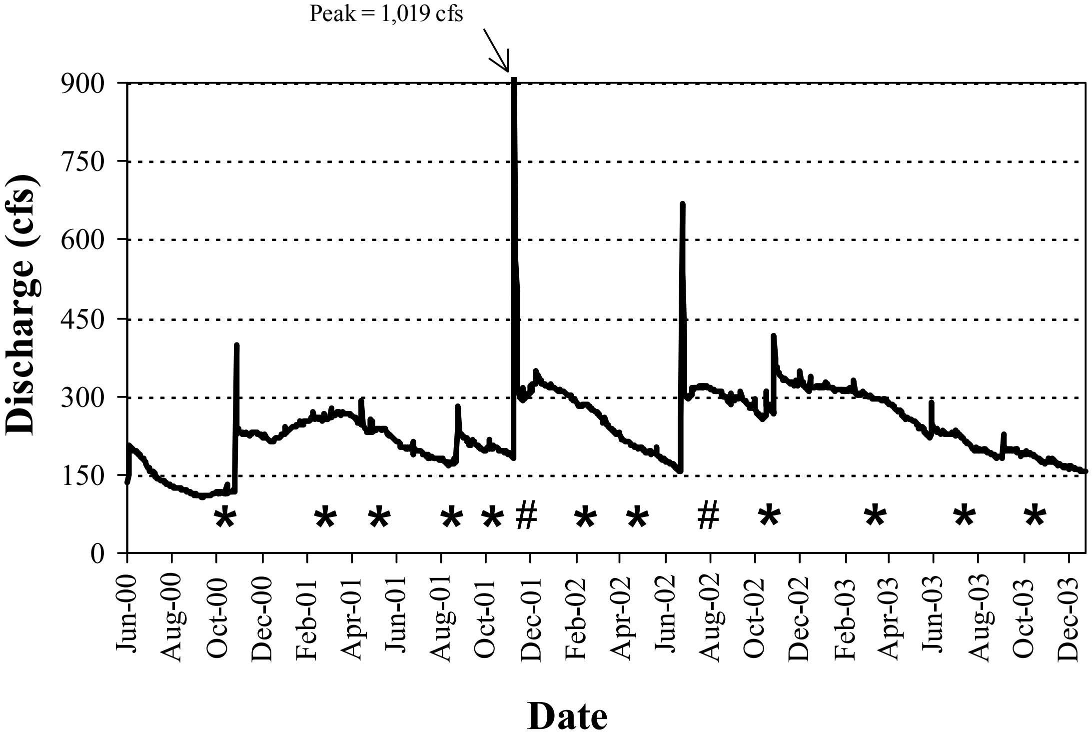

Figure 2. Mean daily discharge in the San Marcos River during the study period; approximate dates for quarterly (*) and high-flow sampling efforts (#) are indicated.

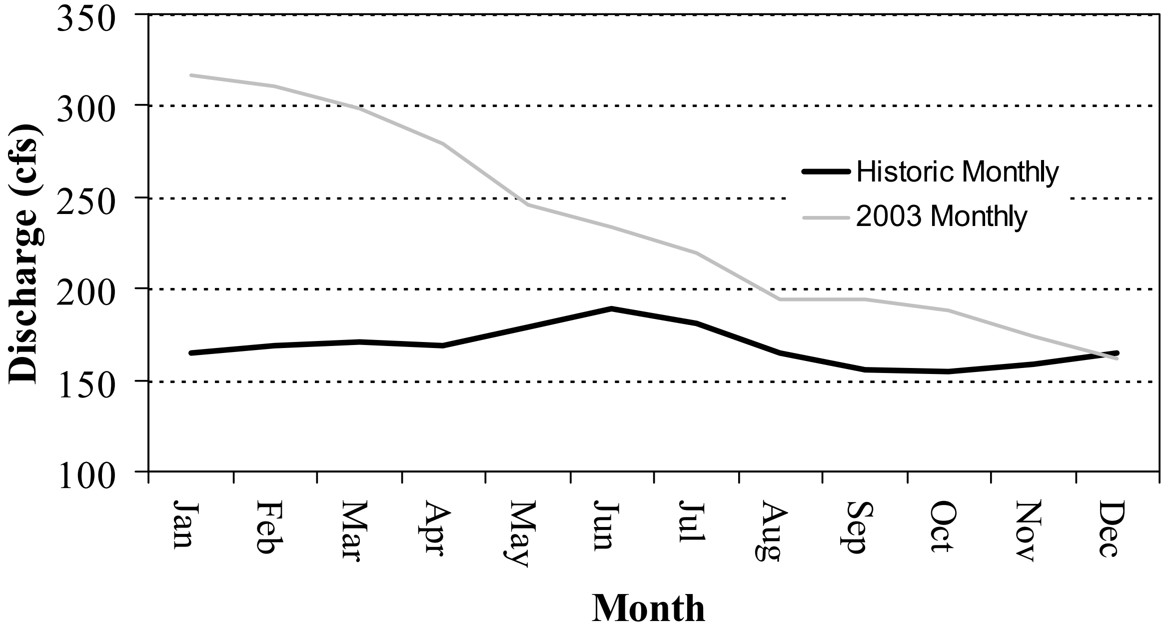

Figure 3. Mean monthly discharge in the San Marcos River during the 1956-2000 period of record.

WATER QUALITY

The thermistor data for important/representative reaches are presented in Figures 5-7, 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 influenced 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).

Apart from acute disturbances, water temperatures fluctuated by less than 2˚C daily and by approximately 1˚C seasonally at the two sites located directly below Spring Lake in the eastern (chute) and western (dam) spillways (Figure 4). Further downstream in the City Park and I-35 reaches (Figure 5) temperatures varied by greater than 2˚C daily and approximately 2.5˚C seasonally; the maximum deviation was approximately 7˚C from the average value in the late summer (observed in 2001). There were no observations of exceeding of the water quality standards value (26.67°C) in 2003. In 2001, Sessom's Creek reached a maximum temperature of 26.68°C on two occasions and the City Park thermistor registered values in excess of that temperature for several days in August. On two days in summer 2001 water temperatures were greater than 29°C in the City Park reach; the lethal limit for the fountain darter is 34.8°C (Brandt et al. 1993). To compare water temperatures with air temperatures and precipitation, see Appendix B.

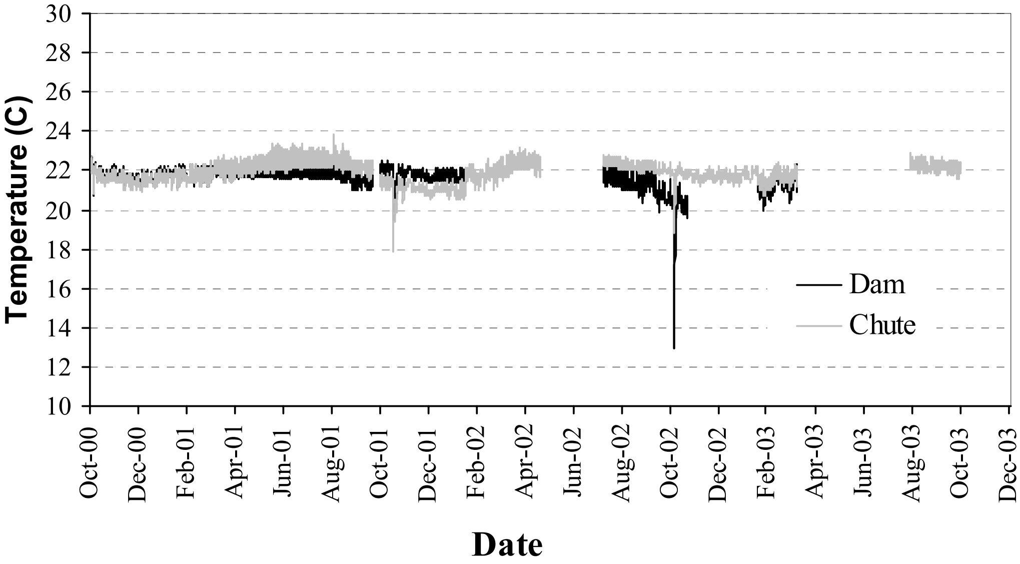

Figure 4. Thermistor data from the dam and chute tailrace areas below Spring Lake.

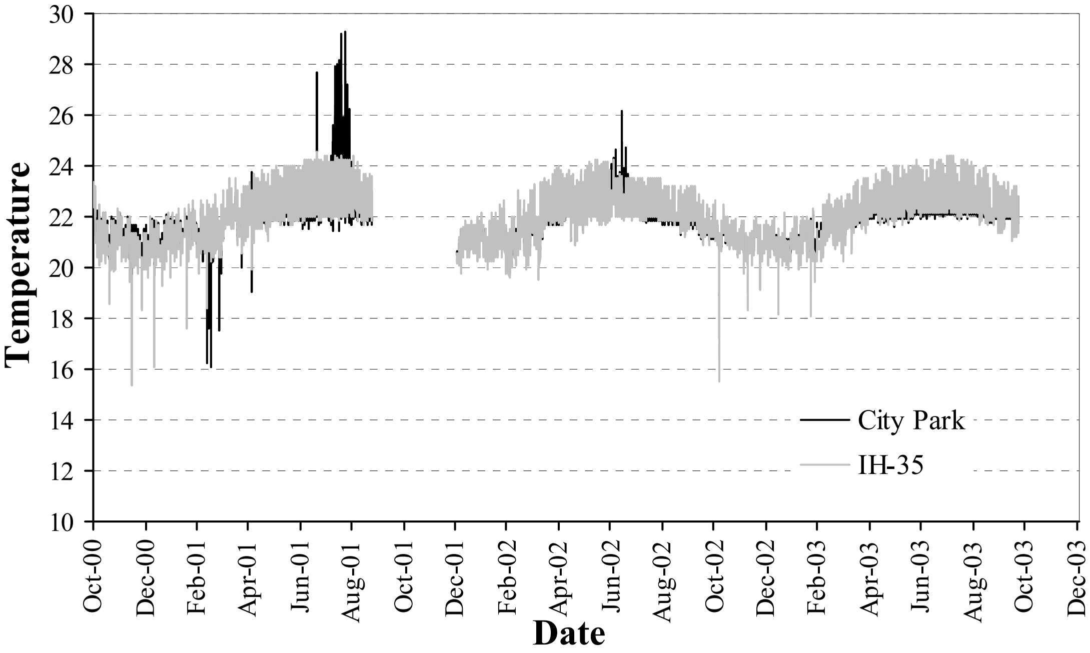

Figure 5. Thermistor data from the City Park and I-35 Reaches.

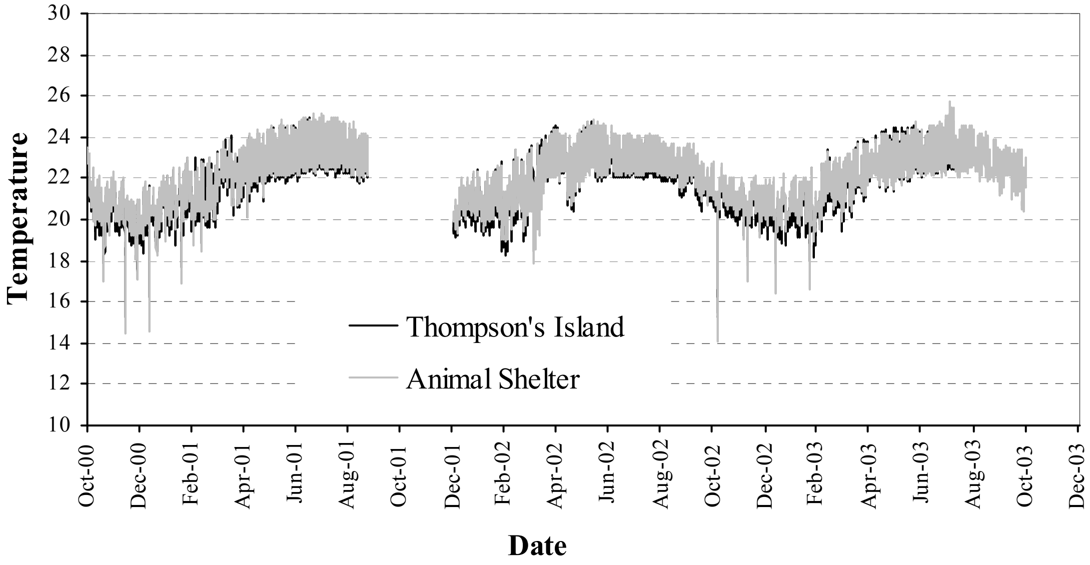

Figure 6. Thermistor data from the Thompson's island artificial canal and animal shelter sites.

Overall, water temperatures in 2003 followed similar patterns to those observed throughout the study with fewer extreme high or low measurements. The lowest water temperatures observed during the study occurred in the winter on Sessom's Creek and at the sites furthest downstream of the springs; winter minimum temperatures occasionally dropped as low as 14°C at the downstream sites. These downstream sites are the least influenced by the constant temperatures of spring water (Figure 6). Significant water temperature decreases in the San Marcos River coincided with lower air temperatures. Springflow keeps temperatures fairly constant in the upper reaches of the river system, compared with conditions that would occur in a stream without significant spring inputs.

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.

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 3 quarterly samples in 2003. The new reach includes a range of vegetation types, but it is dominated by *Hydrilla*, *Potamogeton*, and a mix of the two species. The western spillway of Spring Lake Dam is deep (~15 ft) and the turbulence of the spill limits suitable conditions for vegetation growth. The eastern spillway of the dam is shallow, largely shaded, and in places has very swift currents; these conditions support patchy vegetation coverage. The large area in the middle of the reach contains a dense coverage of *Potamogeton* with a *Potamogeton*/*Hydrilla* mix in some areas. 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 and the development and movement of a large gravel bar.

Recreational impacts are distinct in 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. As in 2002, there was a large area of vegetation scoured at the public access point including *Hydrilla*, *Potamogeton*, and a mix of the two species. A clear line in the vegetation is obvious on the summer 2003 map where people used the same path to access deeper water. There was a moderate-sized patch of Texas wild-rice on the spring 2003 map that is clearly along this pathway that disappeared prior to the summer sample. Recreation also appeared to affect the western spillway where vegetation became more patchy in the summer despite favorable flow conditions. There was also a distinct pathway in the downstream section of this reach where the water was shallow enough to wade. The loss of vegetation, though not proportionally high, potentially affects the fountain darter population in this area by reducing total available habitat. Between the summer and fall sample, much of the vegetation began to re-grow in areas that appeared to be affected by recreation, but many areas remained free of vegetation.

Another interesting observation during the summer was a substantial increase in *Eichornia* (Water Hyacinth). There was more *Eichornia* observed in the field than that depicted on the summer map because one large patch in the middle of the western spillway was moved to accurately map the vegetation (primarily Texas wild-rice) beneath it. This occurred as flows were decreasing (but still above average) and other vegetation became increasingly patchy in the western spillway.

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 typically 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).

The rapid increase in Texas wild-rice that occurred in 2002 in this reach has resulted in a substantial area of total coverage for that species. Between the spring and summer 2003 there was a slight decrease in coverage (possibly due in part to recreation) but an increase of approximately 20% occurred between the summer and fall samples. This area continues to have frequent occurrence of newly established plants and rapid growth of existing plants. The channel between the western spillway and the main river channel has become dominated by Texas wild-rice when it previously (2001) had only a few plants.

City Park Reach

This reach also had some influence from recreation. The large patch of *Hydrilla* in the middle of the reach was reduced along the edges as in 2001 and 2002. The pathway between the two shorelines was maintained throughout all of 2003.

Another observation in this reach was the large stand of *Potamogeton* that occurred in an area that had previously supported a mixture of *Potamogeton* and *Hygrophila*. The area is in the lower half of the reach along the eastern shoreline. This area was scoured and mostly free of vegetation in the fall of 2002 but quickly filled in with *Potamogeton*. The area has remained largely free of *Hygrophila* in 2003 despite its presence along the edges of this habitat. 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) are sampled with drop nets. However, it seems likely that *Potamogeton* is less important as fountain darters 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. Undoubtedly, the *Hygrophila* will fill in this area since there is very little habitat that contains only *Potamogeton* in this reach, but it is valuable to monitor the progress and extent of the habitat modification from flooding and subsequent re-vegetation.

In the fall, decreasing flows led to buildup of vegetation mats in the middle of the reach, primarily over *Hydrilla* and a mixture of *Hydrilla* and *Potamogeton* (these areas appear as “bare substrate” on the map). These vegetation mats can have substantial impacts on the vegetation below them since they often remain for extended times and severely reduce the sunlight for the plants. When the mats cover *Hydrilla*, the impact is negligible so fountain darter habitat loss as a result of the mats is minimal. However, the impacts can be severe to Texas wild-rice plants that are covered for extended periods of time. There was also a fallen tree in the upper portion of the reach along the western shoreline that covered *Hygrophila* and some *Hydrilla* (appears as “bare substrate” on the map) in the summer and fall of 2003. An extensive vegetation mat developed around the tree and has probably resulted in the loss of these areas as habitat for fountain darters. The loss of *Hygrophila* would be slightly more important than losing *Hydrilla*, but the total loss is still minimal.

Texas wild-rice decreased between the spring and summer 2003 samples and remained approximately the same between the summer and fall samples. Although there were more plants in the summer sample than in the spring, nearly all plants were smaller for some unexplained reason. The presence of more plants, however, should be beneficial in the long-term as these plants will grow under favorable conditions. Two small Texas wild-rice plants appeared along the eastern shoreline near the pathway between the *Hydrilla* stands and were joined by two more in the fall. Previously, in 2002, a very small plant appeared along the edge of the *Hydrilla* and quickly disappeared, and it is likely that recreation will have the same impact on these plants. The observation of more Texas wild-rice plants in this reach is interesting due to progressively decreasing flows between sampling events; plants should not have been displaced from upstream. However, observations of Texas wild-rice plants floating downstream during winter and spring sampling throughout the study suggests mechanical (human, dog, etc.) displacement was occurring and several plants must have settled into the reach and set down roots.

As seen during all previous sampling events, the downstream half of this reach remained relatively unchanged in 2003. This area is deeper and reveals little impact from recreation or flooding. Various mixtures of *Hydrilla*, *Potamogeton*, and *Hygrophila* occur with slight variations between trips.

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

Cabomba is one of the dominant plants in this reach because of suitable conditions along outside bends of the river (lentic backwaters, deep silty substrates). This plant type is important in that it provides the highest-quality fountain darter habitat (sampled in this study) in the San Marcos River. *Cabomba* increased in total coverage between the spring and summer samples and remained about the same between the summer and fall. Overall, the differences were negligible and the relatively constant conditions in this reach (compared to past years) resulted in a stable distribution of this vegetation type in 2003. Flooding in 2001 and 2002 had impacts on the *Cabomba* in this reach by decreasing the total coverage, but recovery is rapid and appears to stabilize quickly (within a few months). A dramatic decrease in the summer of 2002 during flooding led to a rapid return of *Cabomba* in the fall of 2002 and nearly the same amount was observed in the spring of 2003.

Hydrilla, *Hygrophila*, and Texas wild-rice all remained approximately the same in total coverage in this reach throughout 2003. Data from 2001 and 2002 show that vegetation in this area is highly susceptible to flooding impacts, but relatively stable flows (gradually decreasing through 2003) led to stable conditions in 2003. This information provides valuable baseline data that will allow a detailed evaluation of the full impacts of low-flow conditions when they occur.

Texas Wild-Rice Surveys

Maps generated from the 2003 summer survey of the entire San Marcos River (downstream of Spring Lake) can be found in Appendix A. This mapping effort occurred approximately one year after the flooding in the summer of 2002 and represents a period of recovery since that event. Unlike in 2001 and 2002, the calculation by the BIO-WEST project team differed somewhat from the data gathered by the TPWD during the same time frame (Table 2) however, both methods revealed a substantial increase over the previous year.

Table 2. Total coverage of Texas wild-rice (m^2) in the San Marcos River as measured by the TPWD for 1994-2003 and BIO-WEST in 2001-2003.

YEAR/EVENT	1994	1995	1996	1997	1998	1999	2000	2001[a]	High-Flow[a]	2002	2003
TPWD	1,456.3	1,624.0	1,652.1	1,584.2	1,949.0	1,644.9	1,791.1	1,895.6		1916.3	2776.0
BIO-WEST								1,901.2	1,765.9	1913.2	2560.7

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

As occurred in 2002, there was a substantial increase in total coverage of Texas wild-rice in 2003 relative to the previous sample. The increase in 2003 was much more substantial, probably because the 2002 sample occurred subsequent to heavy flooding. Without that flooding, the summer 2002 coverage may have been much higher (physical measurements of select Texas wild-rice plants gathered each quarter showed that coverage was increasing rapidly through the winter and spring of 2002). The period between the 2002 and 2003 samples was not marked by any major flooding events, but flows were higher than average and may have contributed to the rapid increase of the Texas wild-rice population. As noted following previous flooding events, numerous stands were found in new locations and had presumably been scoured out of upstream locations and relocated downstream. Many of the small plants that were observed in new locations in the summer of 2002 were substantially larger in 2003. The growth rate of plants found in new locations has been very high in most instances throughout the study.

A trend of increasing Texas wild-rice coverage has been observed since the TPWD started taking measurements in 1994, and this trend appears to be strongly influenced by flooding. Intense flooding has negative short-term consequences on total coverage, although flooding appears to help the population overall by allowing expansion into new areas and the plants that are moved into new locations grow quickly and increase the total coverage of the species. With several recent flood events in 2000-2003 there has been a dramatic increase in total coverage of Texas wild-rice. The timing of flooding probably has an important influence on the impact to Texas wild-rice; the amount of other vegetation immediately surrounding the Texas wild-rice plants may provide some protection. Many of the other vegetation types vary in areal coverage by season; also, residual impacts of a previous flood may result in more risk to plants that might otherwise be protected. The total coverage after flooding appears to be largely influenced by the opportunity for displaced Texas wild-rice plants from upstream locations to settle into an area.

In 2003, several plants occurred in locations where they had not occurred during previous sampling. This is despite the lack of major flood events that have been observed in previous years. This suggests that moderate increases in flow or human-caused mechanical removal (e.g., recreation) are enough to result in transplanted individuals. Because of the size of many of the plants it is unlikely that most of them grew from seeds; however, it is possible that some of the smaller plants were a result of seed germination. This data further supports the conclusion from the 2002 annual report that there is a tendency for Texas wild-rice plants to be relocated.

Overall, the population has generally increased the past three years by expanding into areas that were not occupied by Texas wild-rice plants at the beginning of the study and has decreased only following floods. Unlike in 2002, there was a slight increase in the total coverage downstream of the I-35 bridge (Appendix A, Maps 5-7) in 2003. Several plants appeared in the impounded water just upstream from Cape's Dam for the first time during this study and a few others appeared in the first one-third of a mile downstream (Appendix A, Map 5). Those Texas wild-rice plants that were already downstream of

Cape's road (Appendix A, Map 6) increased in size by a small amount. However, the areas downstream of I-35 remain a cause for concern because the increase in total coverage was minimal in 2003 despite conditions that appear to be highly favorable (based on increases in total coverage observed upstream). Further, there are still no Texas wild-rice plants in the lowest reaches of the study (Appendix A, Map 7).

The section of river downstream of the I-35 bridge to the lower boundary of the population appears to be the most vulnerable to the high-flow events based on our data and that of TPWD (2001); pre-1998 flood maps of Texas wild-rice revealed a greater number of stands in these lower reaches. This is a trend in which plants are displaced during significant flooding but not replaced by plants displaced from upstream locations. In most areas above the I-35 bridge, plants lost through displacement were generally replaced (in different locations) by plants from further upstream (frequently, individual plants are displaced from large stands in the upstream-most reaches, but the majority of the stand remains intact). For some reason, conditions are not amenable to plant re-establishment in these lower sections. This may be related to differences in water quality, less vegetation to slow the water down and allow displaced Texas wild-rice plants to settle, or narrower, deeper channel conditions in downstream sections. Any of these may limit the opportunities for individual Texas wild-rice plants to re-establish.

Texas Wild-Rice Physical Observations

Total coverage of Texas wild-rice observed during 2003 in each stand is presented in Table 3, 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.

As in 2002, the Sewell Park and I-35 reaches had the greatest proportion of Texas wild-rice emergence during the spring sampling effort in 2003 (Appendix B). In 2002, the Thompson's Island Reach also had the greatest proportion in the spring, but it was the lowest in the spring 2003 sample. These higher emergence observations occurred during the highest discharge values among the three samples. In previous years, the greatest emergence corresponded with the lowest flows. Previously, emergence was also low following a high-flow event, but none occurred in 2003. The higher than normal flows that occurred during the fall of 2002 through the spring of 2003 may have influenced the emergence of Texas wild-rice plants.

Sewell Park Reach

In this reach, the average areal coverage of the eight Texas wild-rice stands considered to be in vulnerable locations was 620 m^2 in 2003 compared to 493 m^2 in 2002. There was a substantial increase in total coverage between the spring (555 m^2) and summer (680 m^2) sampling events. There was rapid growth in this reach during that time, but part of the increase occurred because some plants that had been previously separated grew together and became a part of the large stand. There has been a great deal of variation in the connectivity of various plants in this reach during the study. Some plants are considered part of the monitored stand at times (when separated by <0.45 m) and distinct at other times.

As in past years, all Texas wild-rice plants in this reach remained deeper than 0.5 ft in the water column in 2003. In addition, emergence of leaves and flowering parts was relatively low during 2003. These data are consistent with discharge that remained higher than normal throughout the year. Consistently higher flows appear to reduce the emergence of flowering stems, although there has been high emergence observed during this study immediately after flood conditions when flows returned to more normal levels.

Table 3. Texas wild-rice areal coverage (m^2) for each stand by sampling period (2003 only).

REACH-STAND NO.[a]	Spring 2003	Summer 2003	Fall 2003
Sewell Park-1	27.3	12.1	26.4
Sewell Park-2			
Sewell Park-3	96.7	77.4	109.0
Sewell Park-4	11.3	9.5	12.4
Sewell Park-5			
Sewell Park-6	419.7	581.4	478.6
Sewell Park-7			
Sewell Park-8			
Total Area	**555.0**	**680.4**	**626.4**
I-35-1	0.2	0.2	0.1
I-35-2	0.3	0.5	0.3
I-35-3	0.1	0.8	0.8
I-35-4	1.0	0.2	1.0
I-35-5	49.8	59.1	54.9
I-35-6	9.5	7.1	5.9
I-35-7	34.6	30.8	31.2
I-35-8	158.8	169.8	176.0
Total Area	**254.3**	**268.5**	**270.2**
Thompson's Island - 1	-	-	-
Thompson's Island - 2	4.4	4.0	3.3
Thompson's Island - 3	1.3	1.4	1.0
Total Area	**5.7**	**5.4**	**4.3**

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

Root exposure remained very low in all reaches throughout 2003 due to a lack of flooding that scours sediment from around roots or low-flows that may expose roots. Although we have clearly observed the scouring effects of flooding on root exposure during this study there is little data for the potential effects of low-flow conditions on this parameter.

Evidence of herbivory was relatively high in this reach in the summer and fall samples of 2003. These data are similar to those observed in the summer and fall of 2001. There was also relatively high occurance of herbivory during the fall of 2000, but during the same time period in 2002, no evidence of herbivory was noted. This may have been a result of the extreme flooding in the summer of 2002 and an extended period of very high flows that effectively reduced emergence and subsequently, avian predation. Although flows in 2003 were higher than normal, Texas wild-rice plants appear to have adjusted to those conditions in this reach and emergence allowed leaves to be more accessible to potential herbivores.

I-35 Reach

The average areal coverage of the eight Texas wild-rice stands considered to be in vulnerable areas in this reach was nearly identical in 2003 (264 m^2) as in 2002 (262 m^2). The total area has remained relatively consistent throughout the study in this area, but some variation has been observed in the individual plants. There have been frequent observations of "new" plants in very shallow areas along the western shoreline at the upstream edge of this reach (near Cheatum Road). 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 displaced a displaced one has resulted in some observations with a water depth of <0.5-ft. One very small plant was entirely in water shallower than 0.5 ft in both the summer and fall and another had 60% of its area in these shallow conditions in the summer and 100% in the fall. With the higher-than-normal flows in 2003 that were decreasing over time, these new plants have established in areas that cannot support them.

As in the other reaches, root exposure was very low in 2003. Herbivory was also low in this reach in 2003. These observations are likely a result of higher flows. Unlike in the Sewell Park reach, growth was not substantial enough in Texas wild-rice plants in the I-35 reach to allow leaves to reach the water surface and become more accessible to herbivores.

Thompson's Island Reach (Natural)

As noted in 2001, one of the three Texas wild-rice stands had disappeared by the early sampling efforts of this study. The average coverage of the remaining two stands was 5.1 m^2 in 2003 compared with just 4.7 m^2 and 3.8 m^2 in the two previous years of the study. The two plants in this reach varied among seasons in 2003 after a substantial decline in coverage and rapid re-growth resulting from the 2002 flooding.

Emergence was low during all seasons in 2003 in this reach as was root exposure and herbivory. 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 2002. 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 4. 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 4. 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)**

As in previous sampling, we found a wide range of suitability of the various vegetation types in both the Comal and San Marcos Rivers (Figure 7). Compared with the Comal River, the suitability of the dominant vegetation types in the San Marcos is very similar. In the all *Hygrophila* samples from both systems, fountain darter densities are over 5.0 per m^2, but calculations from San Marcos River samples reveal that the mean density was only 3.5 per m^2. This compares to the mixture of *Potamogeton*/*Hygrophila* (sampled only in the San Marcos River) with 4.4 fountain darters per m^2 and both contained slightly higher densities than *Hydrilla* (2.4 per m^2) and lower densities than *Cabomba* (5.2 per m^2). All sampling conducted over bare substrate in 2003 yielded zero fountain darters, which supports 2000-2002 findings and those of previous studies; vegetation is clearly a key factor in the abundance of fountain darters within any area. *Cabomba* sites yielded the greatest number of fountain darters in the San Marcos River despite the apparently unfavorable conditions generally associated with these sites (silty substrate, minimal flow, presence of competitors/predators); *Cabomba* also supports high densities in the Comal River (13.8 per m^2). This preference for habitat containing silty substrate is interesting for a spring-adapted species and may indicate a greater tolerance of various habitat conditions for fountain darter compared with other spring-adapted species.

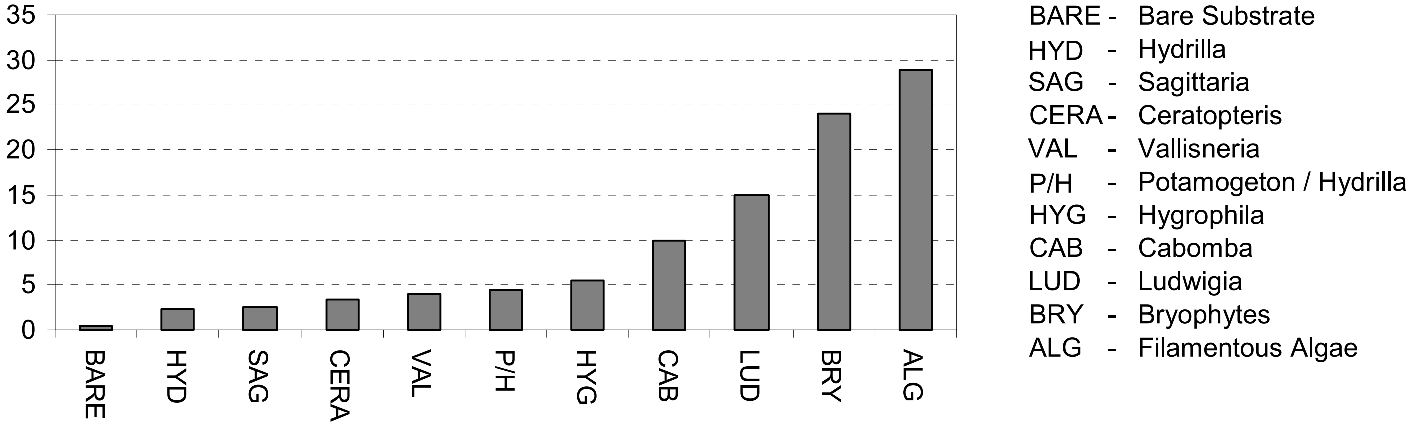

Figure 7. Density of fountain darters collected by vegetation type (data from both Comal and San Marcos Springs/River ecosystems included).

The size-class distribution for fountain darters collected by drop net from the San Marcos Springs/River ecosystem in 2003 is presented in Figure 8 (all data collected from 2000-2002 are presented in Appendix B). The distribution is very similar to the distribution observed throughout the project and is typical of a healthy fish assemblage. The distribution is shifted towards larger fish than those observed in the Comal ecosystem and this may be a function of lower quality habitat in the two sampled reaches compared with the Comal River reaches. Also, currents tend to be stronger in the San Marcos River reaches and may contribute to finding larger, but fewer, fish. Dip-net data from Spring Lake suggests that smaller individuals are present in high numbers there. This high-quality fountain darter habitat may be more comparable to sites in the Comal River than the two San Marcos River reaches that were sampled with drop nets. If drop-net sampling were possible in Spring Lake and the data added to that from the other two reaches, it would likely yield a size-class distribution similar to that of the Comal River ecosystem.

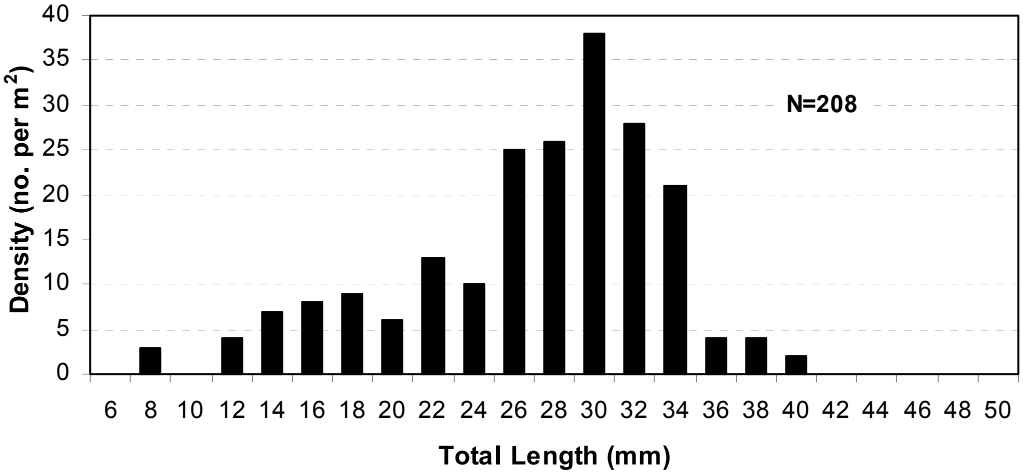

Figure 8. Fountain darter size-class distribution among all drop net sampling events in the San Marcos River during 2003.

When examined by reach and season (Figure 9) the size-class distributions reveal similar trends in the two reaches. As in 2002, the lowest size class (indicative of recent reproduction) was sampled in the spring in the I-35 reach, but only one individual was sampled in the spring and one in the fall in the City Park reach. This observation of a “peak” in reproduction during the spring, compared to year-round reproduction in reaches with high-quality habitat, suggests that lesser quality habitats provide conditions suitable for reproduction only under certain conditions (e.g., during spring or after flooding).

Figure 10 describes the number of fountain darters collected in the San Marcos Springs/River ecosystem by drop net sampling event. In general, the number of fountain darters per net in the San Marcos River was much lower than in the Comal River. Again, this is likely related to the quality of habitat sampled in each ecosystem and the ability of the habitat to support various densities of fountain darters. In the Comal River, habitat tends to be much more favorable for fountain darters and densities are much higher (although densities in Spring Lake on the San Marcos River are probably very high).

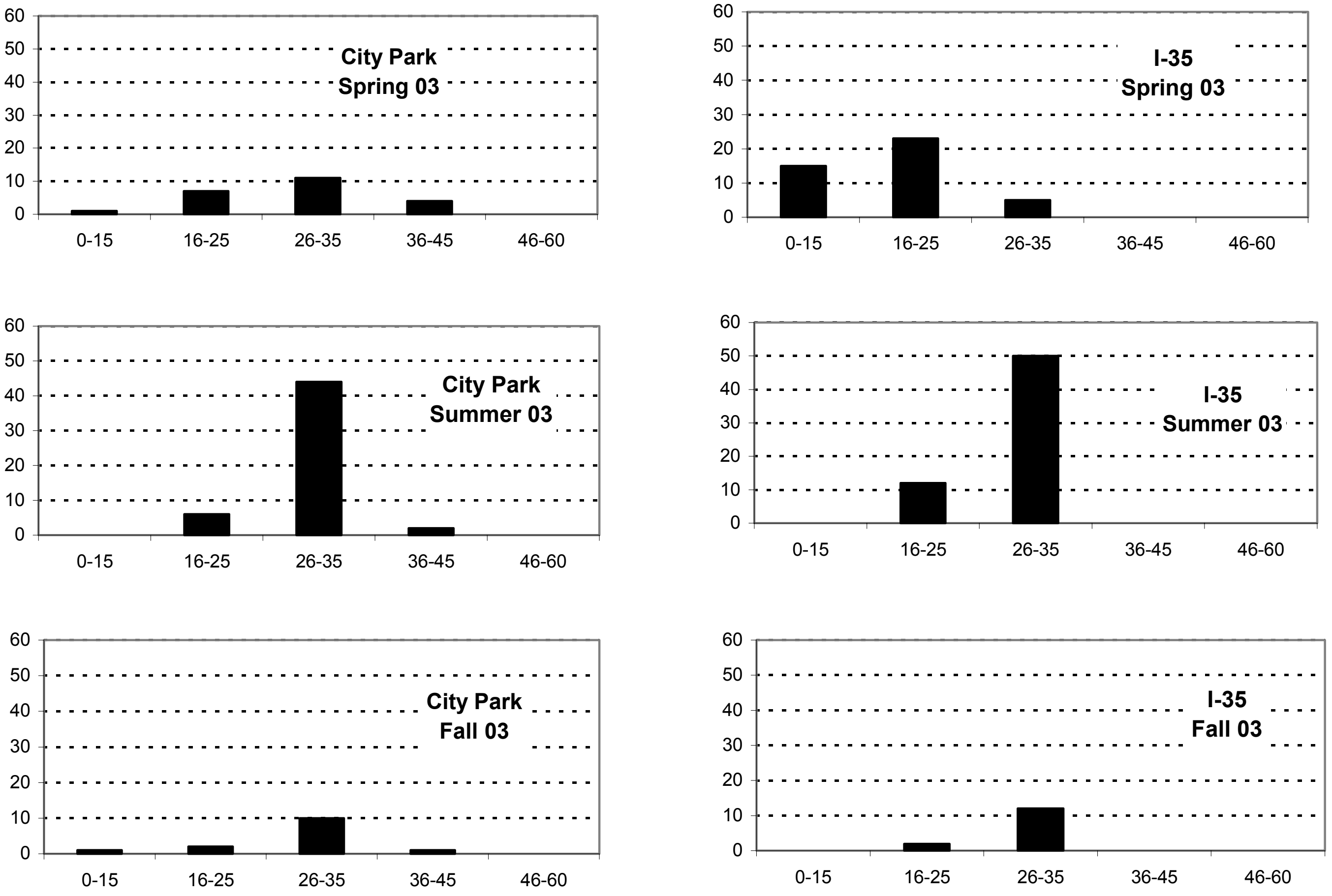

Figure 9. Fountain darter size-class distribution in 2003 by reach and season in the two San Marcos River Reaches.

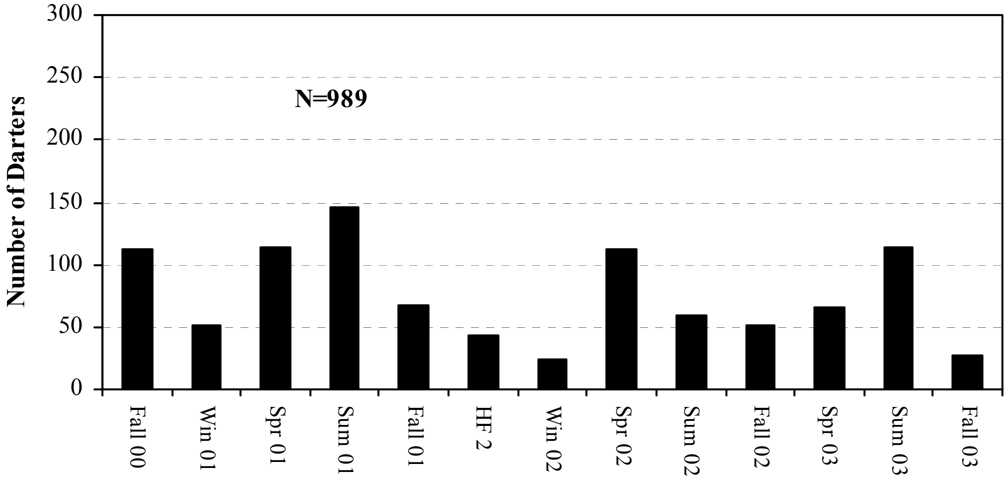

Figure 10. Number of fountain darters collected by drop net sampling event during the study.

There appears to be a seasonal trend in fountain darter collections in the San Marcos River of low abundance in the fall and winter with increasing abundance in the spring and into summer. The trend was affected by flow level in 2002 when flooding reduced the numbers observed in the summer, but the trend was clear in 2003. A graph of population estimates (Figure 11; derived from total coverage of each vegetation type sampled multiplied by density observed during the sample event) shows that the pattern was very similar in the two San Marcos reaches. Flooding in 2001 and 2002 coincided with sharp declines in population estimates.

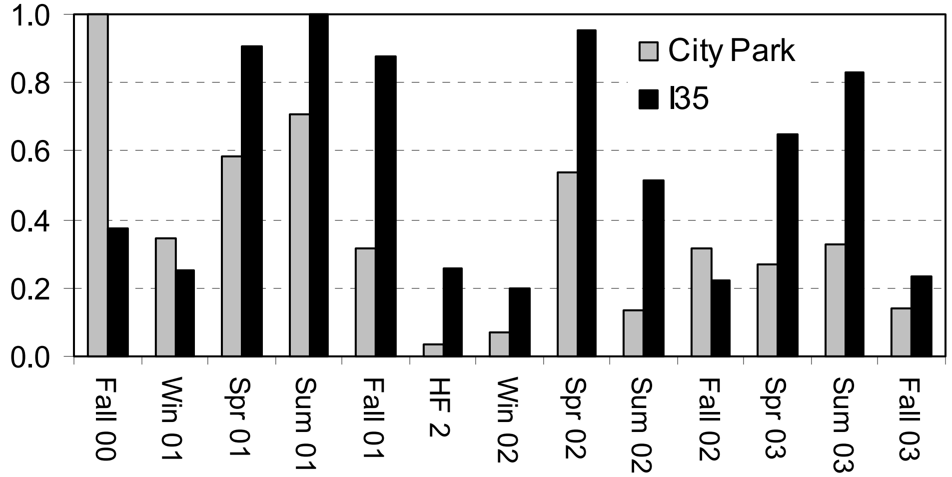

Figure 11. Population estimates of fountain darters in the two San Marcos River Reaches; values are normalized to a proportion of the maximum observed in any single sample in each reach.

Table 5 lists the fish species collected during the 2003 drop-net sampling on the San Marcos Springs/River ecosystem. In all, 24 species of fish totaling 945 individuals were collected. Of the 24 species, 8 are considered introduced (exotic) to the San Marcos Springs/River ecosystem, but only the sailfin molly (*Poecilia latipinna*) and rock bass (*Ambloplites rupestris*) were relatively abundant (> 10 individuals). The total number of individuals collected in 2003 was substantially lower than in each year since the study began (2000-2002). Two species that were observed in low numbers during sampling in 2000 and 2001 were not observed in 2002 or 2003 (blacktail shiner [*Cyprinella venusta*] and longear sunfish [*Lepomis megalotis*]).

Another exotic species, the giant ramshorn snail, was also recorded and measured when observed at any drop net location. As in 2002, there were no giant ramshorn snails observed in 2003; thus only 19 total specimens have been collected in all samples to date including a total of 208 drop net locations. Therefore, the densities of giant ramshorn snails currently found in the San Marcos Springs/River ecosystem (including the lower flow fall 2000 event) pose no serious threat to aquatic vegetation. However, because of the impact that this exotic species can have under heavier densities, close monitoring should continue.

Table 5. Fish species and the number of each collected during 2003 drop-net sampling.

COMMON NAME	SCIENTIFIC NAME	STATUS	TOTAL NUMBER
Rock bass	*Ambloplites rupestris*	Introduced	59
Black bullhead	*Ameiurus melas*	Native	1
Yellow bullhead	*Ameiurus natalis*	Native	15
Mexican tetra	*Astyanax mexicanus*	Introduced	1
Rio Grande perch	*Cichlasoma cyanoguttatum*	Introduced	2
Roundnose minnow	*Dionda episcopa*	Native	4
Minnow species	*Dionda* sp.	Native	2
Fountain darter	*Etheostoma fonticola*	Native	208
Gambusia	*Gambusia* sp.	Native/Introduced	581
Suckermouth catfish	*Hypostomus plecostomus*	Introduced	2
Redbreast sunfish	*Lepomis auritus*	Introduced	4
Green sunfish	*Lepomis cyanellus*	Introduced	1
Warmouth	*Lepomis gulosus*	Native	3
Bluegill	*Lepomis macrochirus*	Native	14
Spotted sunfish	*Lepomis punctatus*	Native	81
Sunfish	*Lepomis* sp.		20
Largemouth bass	*Micropterus salmoides*	Native	5
Gray redhorse	*Moxostoma congestum*	Native	1
Texas shiner	*Notropis amabilis*	Native	1
Iron color shiner	*Notropis chalybaeus*	Native	3
Texas Logperch	*Percina caprodes*	Native	1
Dusky darter	*Percina sciera*	Native	4
Sailfin molly	*Poecilia latipinna*	Introduced	15
Tilapia	*Tilapia* sp.	Introduced	1

Dip Nets

The boundary for each section where dip net collection efforts were conducted is depicted on Figure 12. Section numbers are included to be consistent with the USFWS classification system for the San Marcos River. Data gathered using dip nets for all sections are graphically represented in Appendix B. Using dip nets, fountain darters were collected from every section during every sampling event.

As in most previous samples, the Hotel Reach samples had individuals in the lowest size class (5-15 mm) during each sample effort in 2003 (Figure 13); this size class represents fountain darters <58 days old (Brandt et al. 1993). Their presence in all seasons suggests year-round reproduction. This reach also had high numbers of fountain darters in the next larger size class (16-25 mm) in each sample. There was no evidence of recent reproduction in dip-net samples from either the City Park Reach or I-35 Reach in 2003. In previous sampling, reproduction was evident in both reaches during the spring. Flooding also appeared to influence reproduction in these two reaches. It may be that reproduction is event-driven and stimulated by certain conditions. In 2003, no peaks/troughs in the hydrograph caused any major shift in habitat conditions, habitat remained very stable overall in 2003 and reproduction was not evident in the two river reaches in dip-net sampling (but was observed in drop-net sampling). Year-round reproduction was evident in the higher-quality habitat in Spring Lake in 2003.

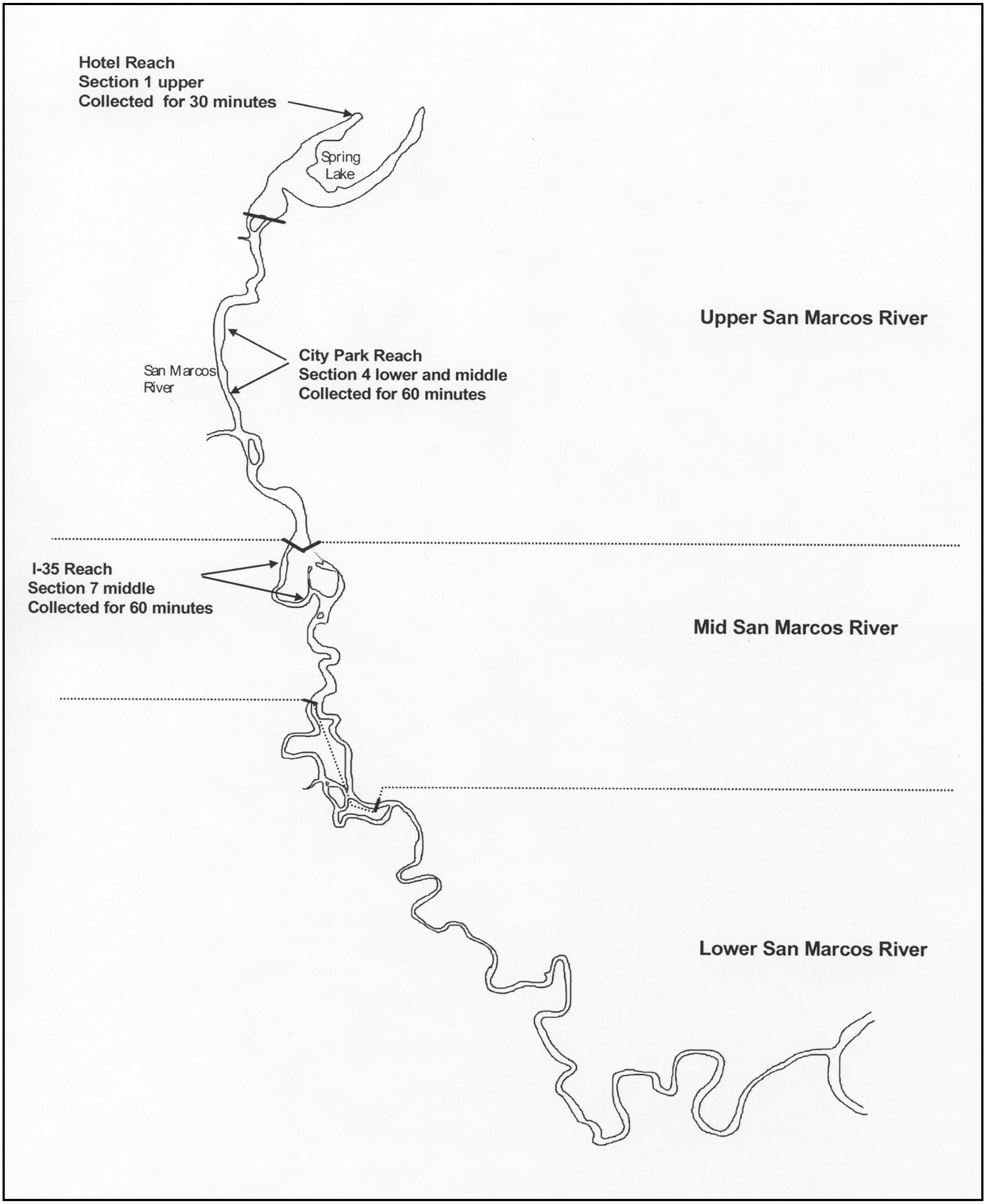

Figure 12. Areas where fountain darters were collected with dip nets, measured, and released in the San Marcos River.

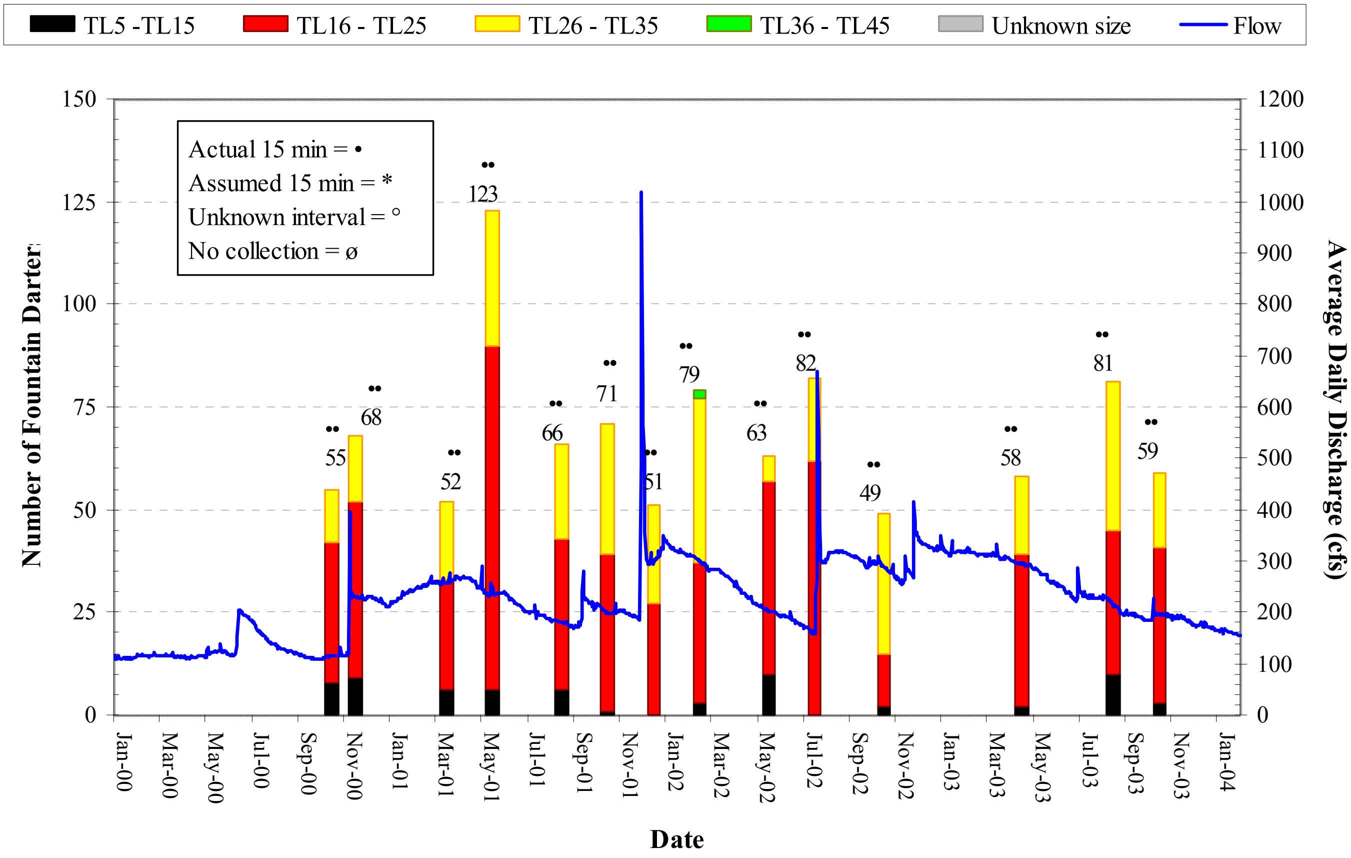

Figure 13. Number of fountain darters collected from the Hotel Reach (section 1 upper) using dip nets.

It appears that availability of suitable habitat may be more important in stimulating reproduction than seasonal timing in the City Park and I-35 Reaches. Data from 2001-2002 suggest that the proper conditions at any time of year may stimulate reproduction since evidence of recent reproduction was observed in 2001-2002 samples following flooding. During and immediately after flooding, shoreline habitat is inundated with the higher flow and appears to provide a refuge for fountain darters (based on qualitative observations by Dr. T. Brandt, USFWS). These conditions may stimulate reproduction.

According to BIO-WEST project team observations, the algae present in the Hotel Reach (Spring Lake) provides the highest quality habitat within the San Marcos River for the fountain darter with excellent cover and an abundance of food (visual observations only). Although drop-net sampling is not conducted in the Hotel Reach, dip-net sampling and observations during every San Marcos salamander SCUBA survey supports this statement. The City Park and I-35 Reaches both maintain lower quality habitat, and the number of fountain darters collected with dip nets in each reach was less than in Spring Lake, despite greater collection times. Also, fountain darters >35 mm in length are rare in Spring Lake (two were collected in 2002; none in 2003) while they continue to be collected in all sampling events in the City Park (except one) and I-35 Reaches. This supports the hypothesis that the higher currents in these habitats select for larger-bodied individuals. Like the apparent relationship between habitat quality and reproduction, the correlation between habitat quality and fountain darter size is an interesting observation that has persisted through the 2003 samples and will be explored in greater detail as more low-flow data are gathered to evaluate the dynamics of the relationship.

San Marcos Salamander Visual Observations

As in 2002 filamentous algae covered sample sites 2 (hotel reach) and 14 with thick mats and coverage was abundant throughout 2003. In 2002, flushing flows from intense flooding cleared the area prior to the summer sampling effort, but the algae was less abundant in all other samples in 2002 and 2003. 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.

As shown in Table 6, San Marcos salamanders were observed during each survey effort.

Table 6. 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

Sample site 2 has had the highest population densities throughout the study, but the densities have also varied substantially between seasons. For example, the lowest population estimate occurred in winter 2002, but this sample was followed with the highest population estimate in spring 2002. 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.

In sample site 21 the greatest estimated density of San Marcos salamanders (substantially higher than later samples) occurred during the fall 2000 event, which was a low flow period. This 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.

Overall, the estimated population densities of San Marcos salamander in 2003 were consistent with observations in 2001 and 2002. 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 2003, no samples were made for the exotics / predation component of this study.

REFERENCES

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APPENDIX A:
AQUATIC VEGETATION MAPS

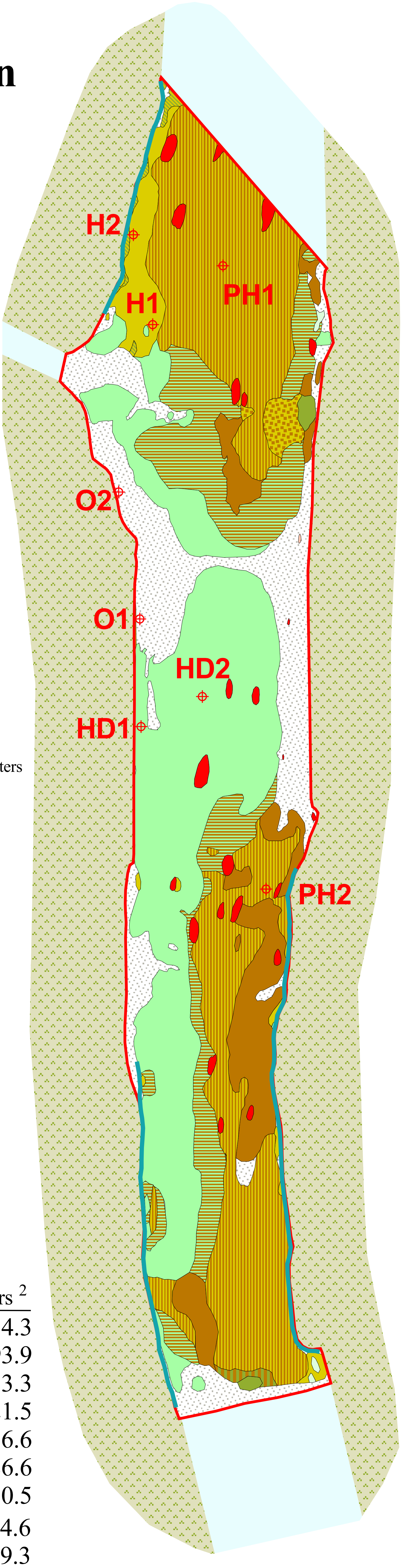
City Park Reach

Spring 2003
Summer 2003
Fall 2003

San Marcos River Aquatic Vegetation

City Park - Spring

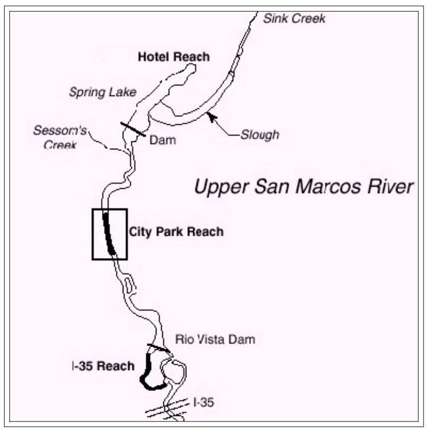
April 9, 2003



Scale: 1" = 60'

10 0 10 20 30 40 Meters

Project Location



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

	Meters ^{2}
🟩 *Hydrilla*	1,714.3
🟨 *Hygrophila*	193.9
🟫 *Potamogeton*	453.3
🟩 *Sagittaria*	21.5
▭ *Vallisneria*	6.6
🟥 *Zizania*	86.6
🟪 *Heteranthera*	0.5
▤ *Hydrilla / Potamogeton*	744.6
▥ *Hygrophila / Potamogeton*	1,679.3
▧ *Hygrophila / Sagittaria*	23.7
▥ *Potamogeton / Sagittaria*	16.7
▩ *Hygrophila / Potamogeton / Sagittaria*	52.7

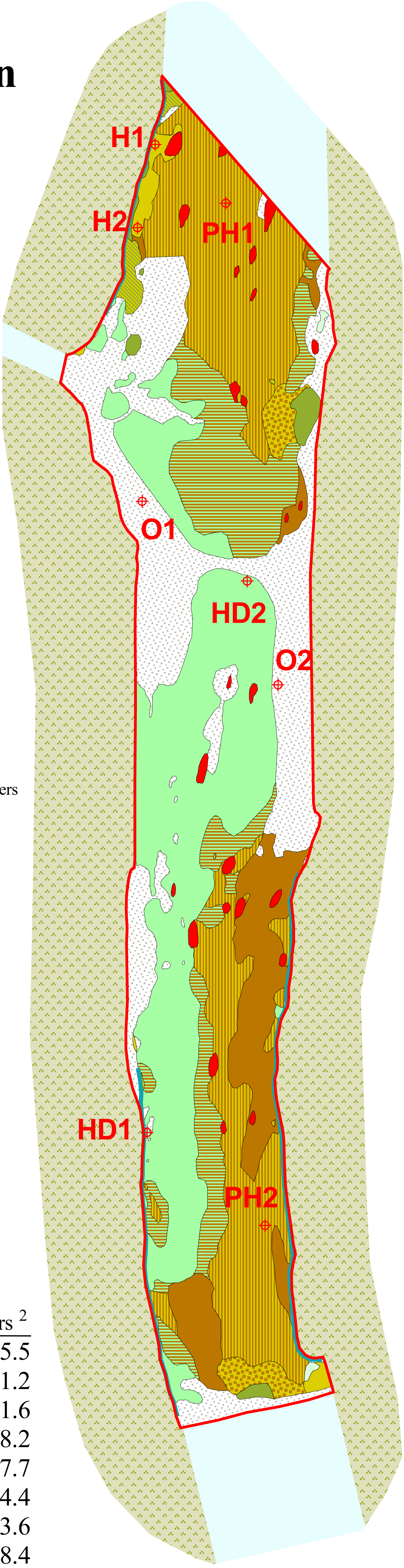
BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River Aquatic Vegetation

City Park - Summer

August 6, 2003



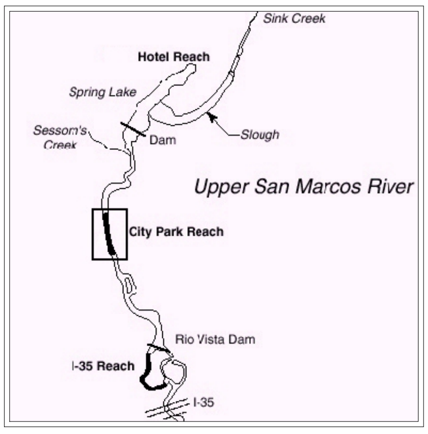
Scale: 1" = 60'

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}
Hydrilla	1,575.5
Hygrophila	61.2
Potamogeton	521.6
Sagittaria	58.2
Vallisneria	7.7
Zizania	74.4
Hydrilla / Potamogeton	753.6
Hygrophila / Potamogeton	1,408.4
Hygrophila / Sagittaria	43.0
Hygrophila / Potamogeton / Sagittaria	105.2

Project Location



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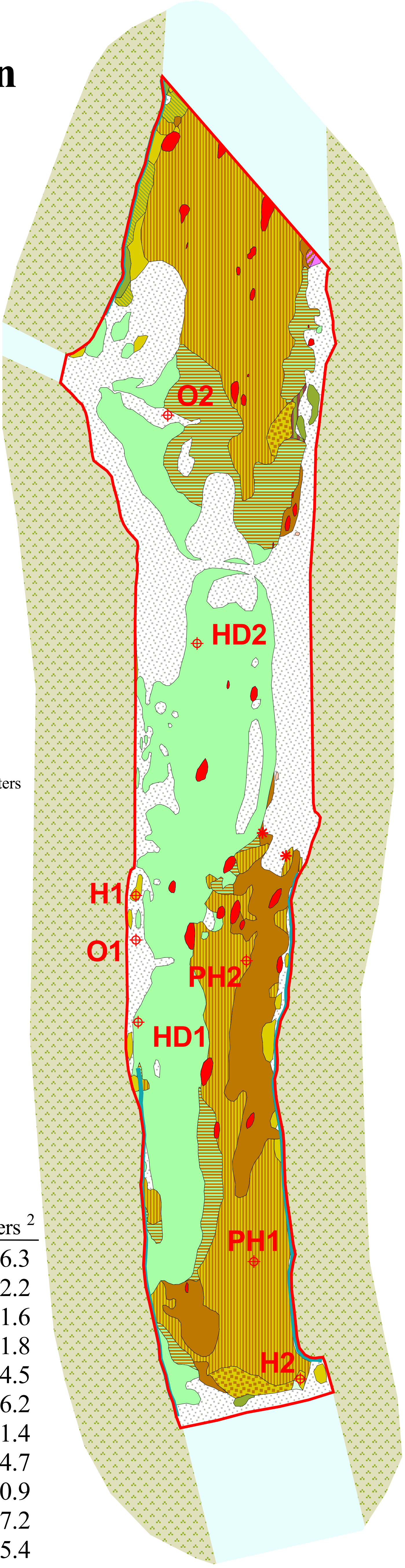
EDWARDS AQUIFER AUTHORITY

San Marcos River Aquatic Vegetation

City Park - Fall

October 20, 2003



Scale: 1" = 60'

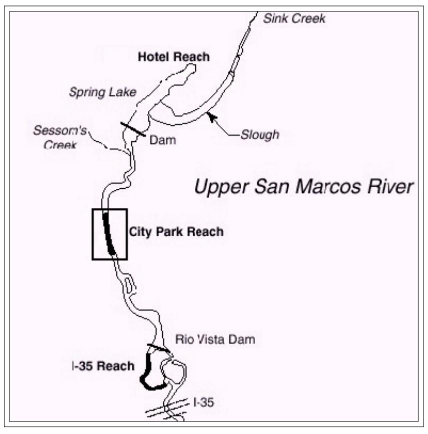
10 0 10 20 30 40 Meters

N

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

		Meters ^{2}
🟦	*Eichornia*	196.3
🟩	*Hydrilla*	1,622.2
🟨	*Hygrophila*	81.6
🟪	*Hydrocotle*	1.8
🟫	*Potamogeton*	414.5
🟩	*Sagittaria*	26.2
⬜	*Vallisneria*	1.4
🟥	*Zizania*	74.7
🟧	*Heteranthera*	0.9
▤	*Hydrilla / Potamogeton*	487.2
▥	*Hygrophila / Potamogeton*	1,575.4
▨	*Hydrocotle / Potamogeton*	3.2
▥	*Sagittaria / Potamogeton*	8.0
▨	*Hygrophila / Sagittaria*	42.0
▦	*Hygrophila / Potamogeton / Sagittaria*	59.6

Project Location



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EDWARDS AQUIFER AUTHORITY

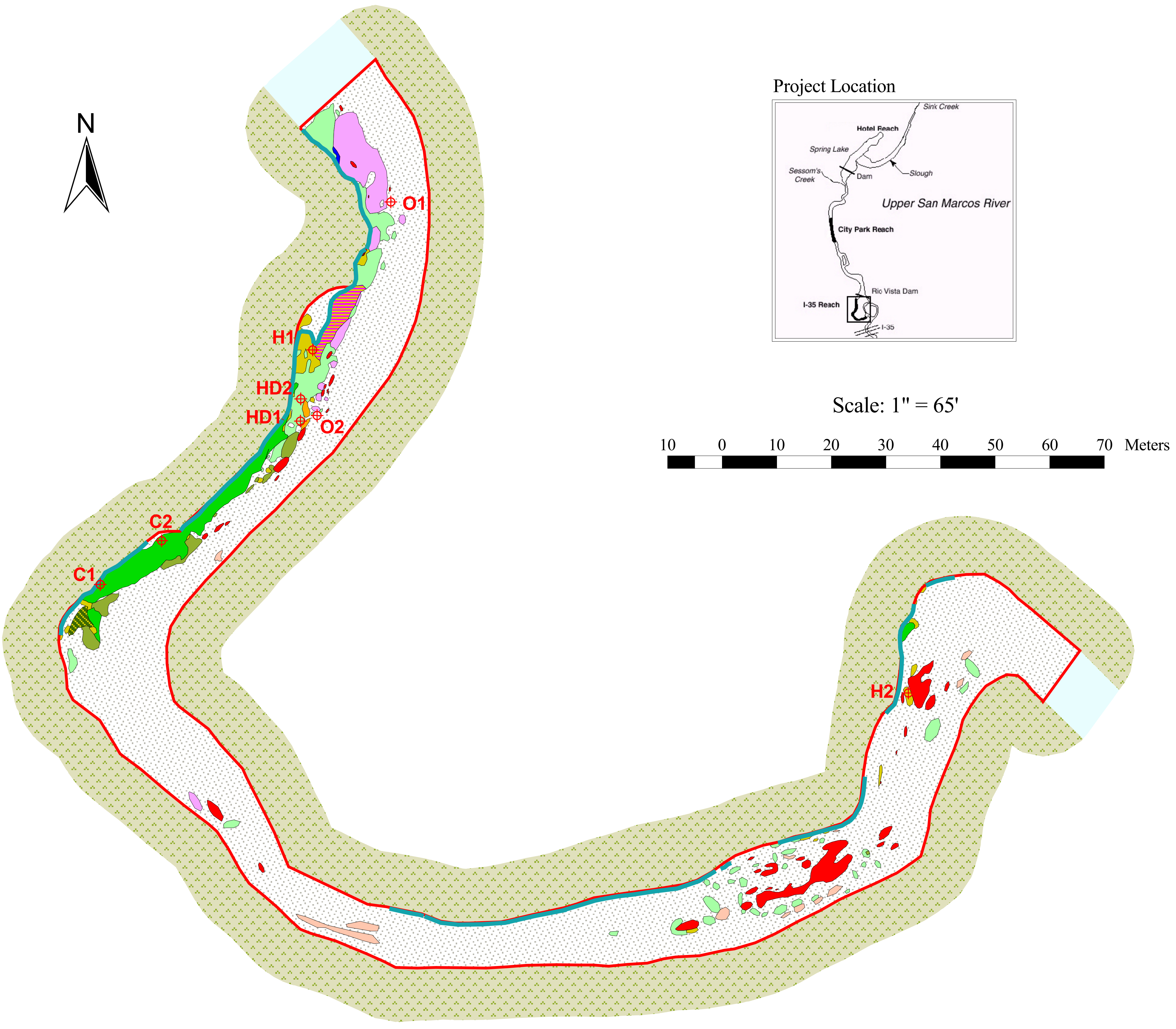
I-35 Reach

<u>Spring 2003</u>
<u>Summer 2003</u>
<u>Fall 2003</u>

San Marcos River Aquatic Vegetation

I-35 Reach - Spring

April 10, 2003



- ▨ Shore and Islands
- ▭ River
- ▭ Study Area (4,615.7 m^2)
- ▨ Bare Substrate
- ∧ *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters^2
🟩 *Cabomba*	159.4
🟧 *Heteranthera*	39.3
🟩 *Hydrilla*	199.6
🟨 *Hygrophila*	53.1
🟪 *Justicia*	123.7
🟧 *Ludwigia*	4.7
🟩 *Sagittaria*	44.2
🟥 *Zizania*	119.2
🟪 *Hydrocotyle*	2.1
🟫 *Rorripa*	1.0
▨ *Hygrophila / Justicia*	39.2
▨ *Sagittaria / Hygrophila*	11.3

B W

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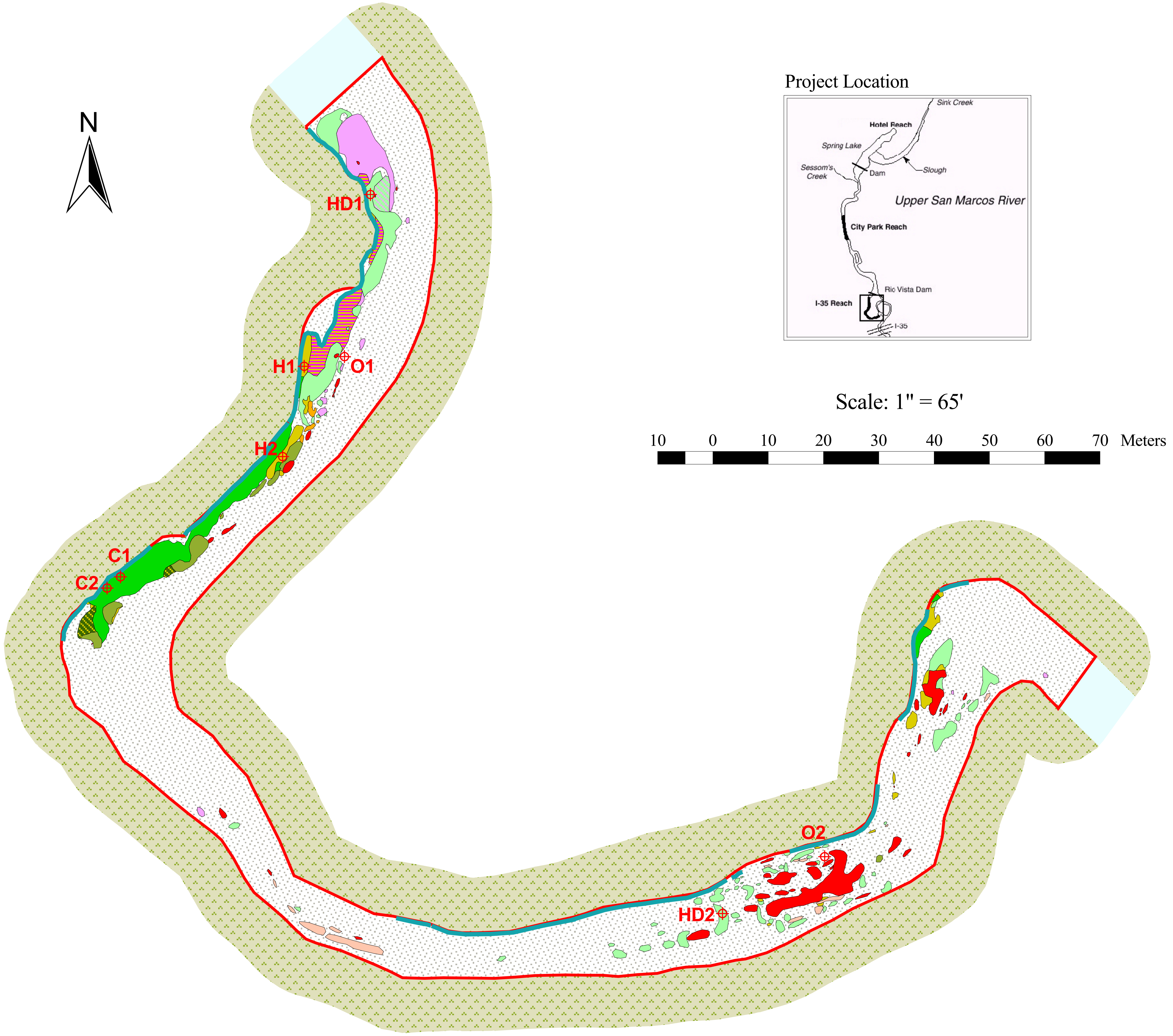
San Marcos River Aquatic Vegetation

I-35 Reach - Summer

August 11, 2003



- ▨ Shore and Islands
- ☐ River
- 🟥 Study Area (4,615.7 m^2)
- ☐ Bare Substrate
- *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters^2
🟩 *Cabomba*	171.8
Heteranthera	29.4
Hydrilla	221.4
Hygrophila	56.7
Justicia	83.9
Ludwigia	5.2
Nuphar	0.7
Sagittaria	45.7
🟥 *Zizania*	125.6
Hygrophila / Justicia	63.2
Hydrilla / Justicia	16.0
Sagittaria / Hygrophila	13.8

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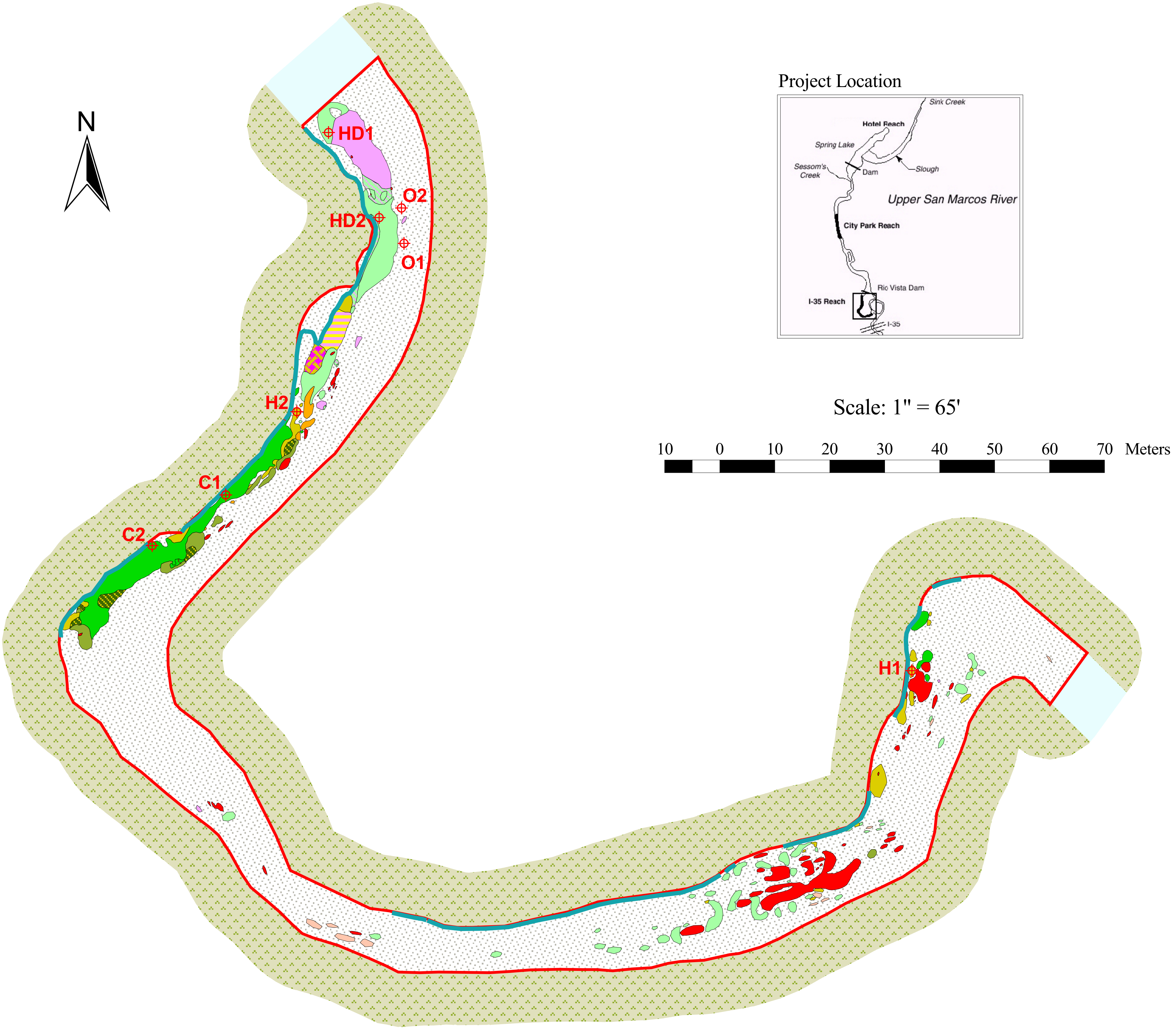
San Marcos River Aquatic Vegetation

I-35 Reach - Fall

October 21, 2003



- ▨ Shore and Islands
- ⬜ River
- □ Study Area (4,615.7 m^2)
- ▨ Bare Substrate
- *Colocasia*
- ⊕ Drop Net Sample Sites

	Meters^2
🟩 *Cabomba*	167.8
🟧 *Heteranthera*	12.7
🟩 *Hydrilla*	198.6
🟨 *Hygrophila*	58.7
🟪 *Justicia*	79.4
🟧 *Ludwigia*	10.9
🟩 *Sagittaria*	39.2
🟥 *Zizania*	121.3
▨ *Hygrophila / Justicia*	24.3
▨ *Hydrilla / Justicia*	23.4
▨ *Sagittaria / Hygrophila*	19.0
▨ *Cabomba / Sagittaria*	1.9
▨ *Hygrophila / Justicia / Ludwigia*	13.4

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EDWARDS AQUIFER AUTHORITY

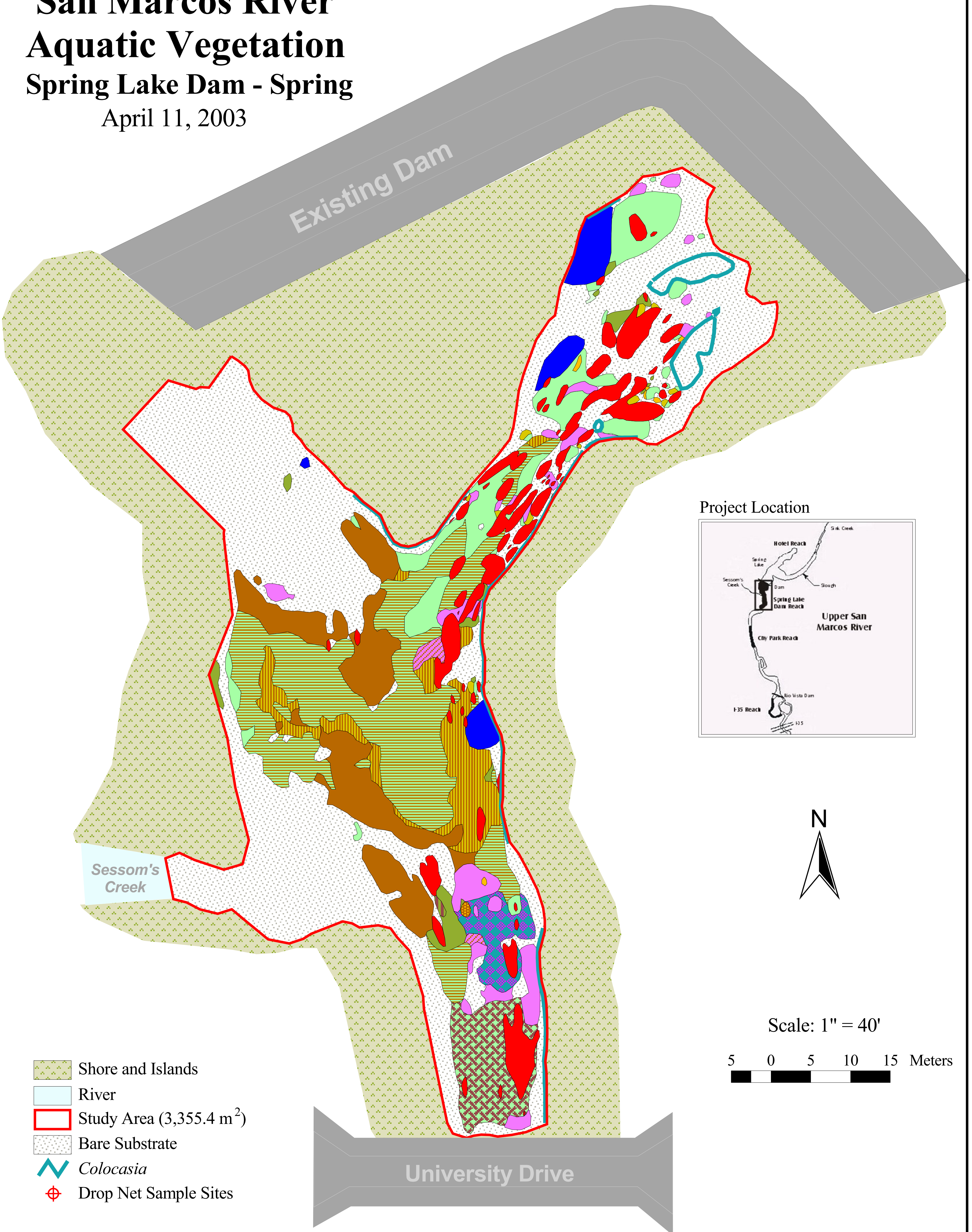
Spring Lake Dam Reach

<u>Spring 2003</u>
<u>Summer 2003</u>
<u>Fall 2003</u>

San Marcos River Aquatic Vegetation

Spring Lake Dam - Spring

April 11, 2003



		Meters^2
🟩	*Hydrilla*	202.0
🟦	*Eichornia*	75.8
🟪	*Hydrocotyle*	99.9
🟨	*Hygrophila*	8.0
🟧	*Ludwigia*	2.8
🟫	*Potamogeton*	280.6
🟩	*Sagittaria*	38.2
🟦	*Vallisneria*	1.0
🟥	*Zizania*	230.7

		Meters^2
▨	*Potamogeton / Hydrocotyle*	11.8
▤	*Potamogeton / Hydrilla*	507.6
▥	*Potamogeton / Hygrophila*	146.4
▥	*Potamogeton / Sagittaria*	2.0
▥	*Potamogeton / Ludwigia*	1.9
▩	*Potamogeton / Hydrocotyle / Hydrilla*	56.3
▩	*Potamogeton / Hydrocotyle / Hydrilla / Hygrophila*	112.6

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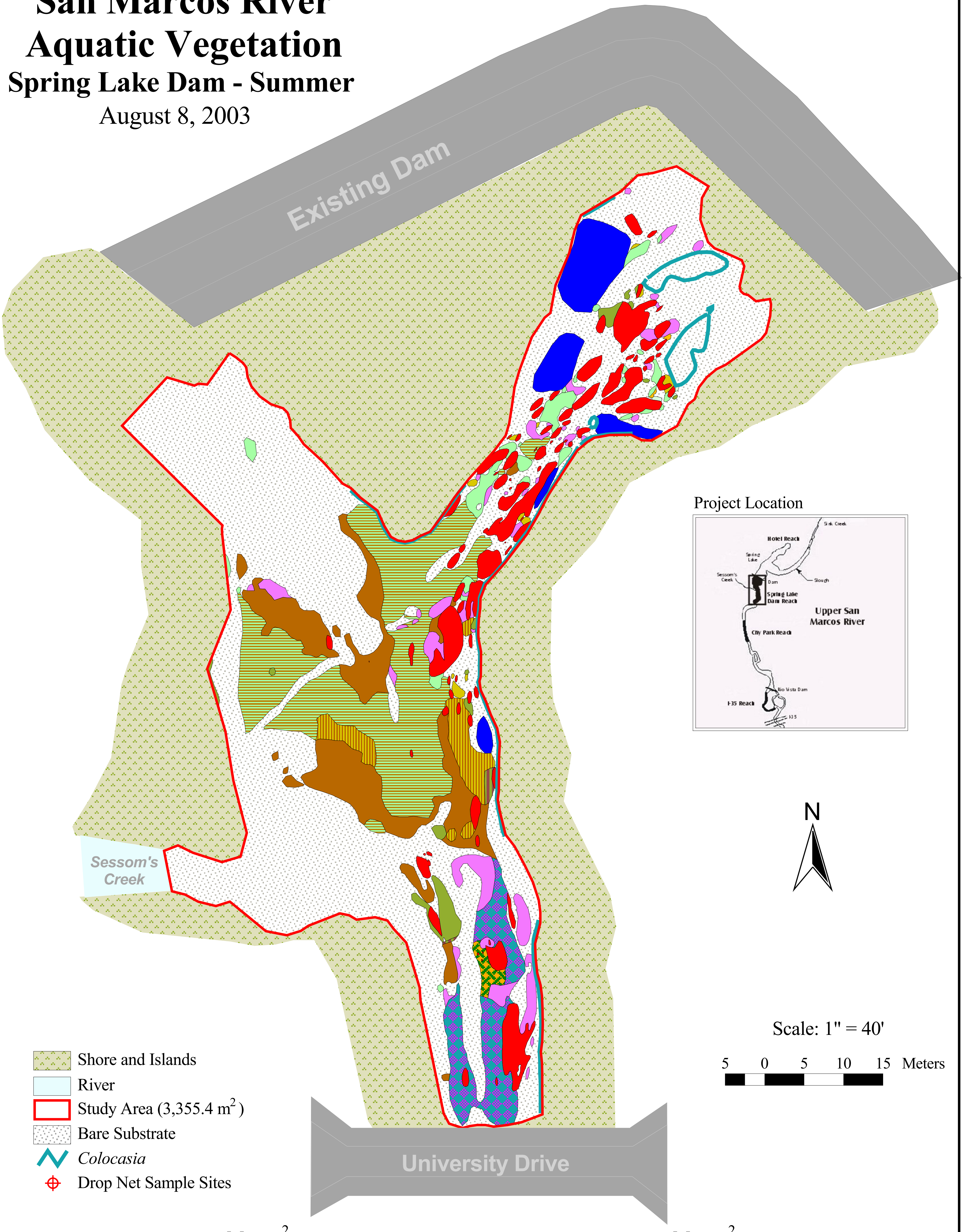
EDWARDS AQUIFER AUTHORITY

San Marcos River Aquatic Vegetation

Spring Lake Dam - Summer

August 8, 2003



- ▨ Shore and Islands
- ▭ River
- ▭ Study Area (3,355.4 m^2)
- ▨ Bare Substrate
- ∧∧ *Colocasia*
- ⊕ Drop Net Sample Sites

		Meters ^{2}
🟩	*Hydrilla*	52.7
🟦	*Eichornia*	124.8
🟪	*Hydrocotyle*	96.2
🟨	*Hygrophila*	7.7
🟧	*Ludwigia*	0.8
🟫	*Potamogeton*	253.5
🟩	*Sagittaria*	32.5
▭	*Vallisneria*	0.9
🟥	*Zizania*	222.1

		Meters ^{2}
▤	*Potamogeton / Hydrilla*	453.5
▥	*Potamogeton / Hygrophila*	63.6
▥	*Potamogeton / Sagittaria*	4.8
▨	*Hydrocotyle / Ludwigia*	12.4
▩	*Potamogeton / Hydrocotyle / Hydrilla*	125.8

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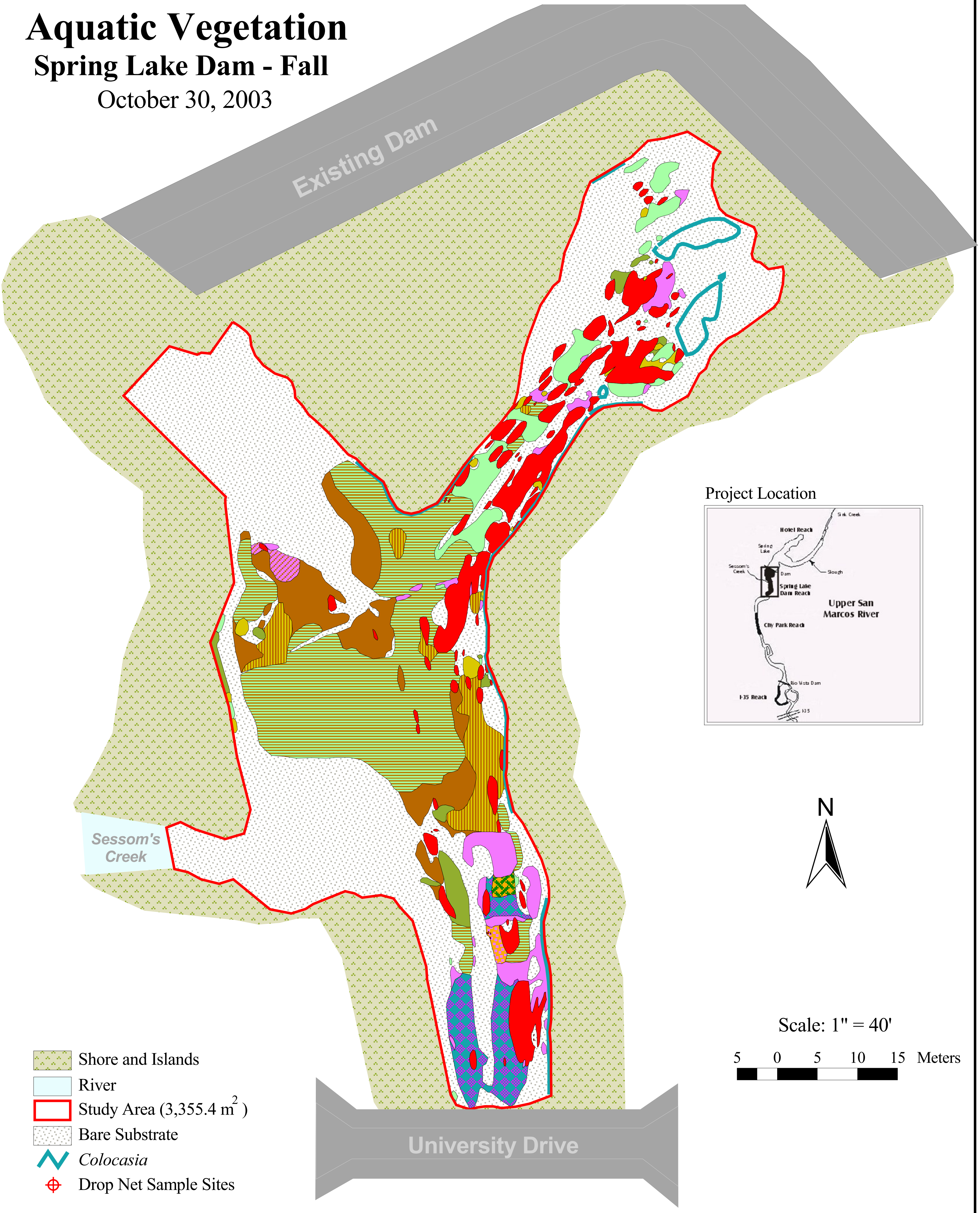
San Marcos River Aquatic Vegetation

Spring Lake Dam - Fall

October 30, 2003



	Meters^2
🟩 *Hydrilla*	102.1
🟦 *Eichornia*	82.7
🟪 *Hydrocotyle*	93.1
🟨 *Hygrophila*	17.3
🟫 *Potamogeton*	191.0
🟩 *Sagittaria*	39.6
⬜ *Vallisneria*	1.2
🟥 *Zizania*	266.7

	Meters^2
▨ *Potamogeton / Hydrilla*	593.7
▨ *Potamogeton / Hygrophila*	106.0
▨ *Potamogeton / Hydrocotle*	12.8
▨ *Sagittaria / Hygrophila*	0.6
▨ *Hydrocotyle / Ludwigia*	101.7
▨ *Potamogeton / Hydrocotyle / Hydrilla*	6.9
▨ *Potamogeton / Hydrilla / Hydrocotyle / Ludwigia*	7.1

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EDWARDS AQUIFER AUTHORITY

Texas Wild-Rice Annual Survey

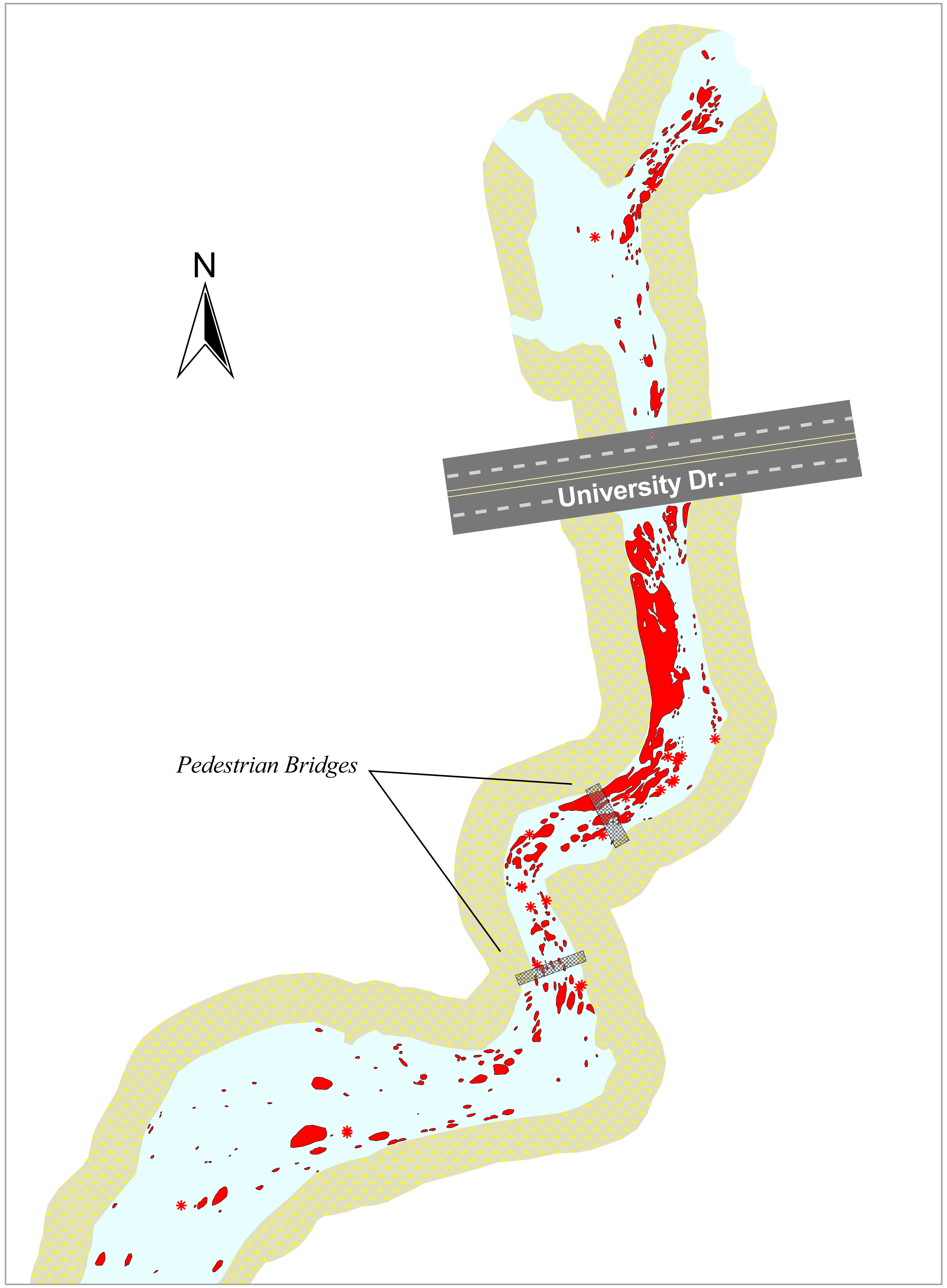
Summer 2003

San Marcos River
Texas wild-rice

(Zizania texana)

Summary 2003 - Map 1 of 7

July 30 - August 1, 2003

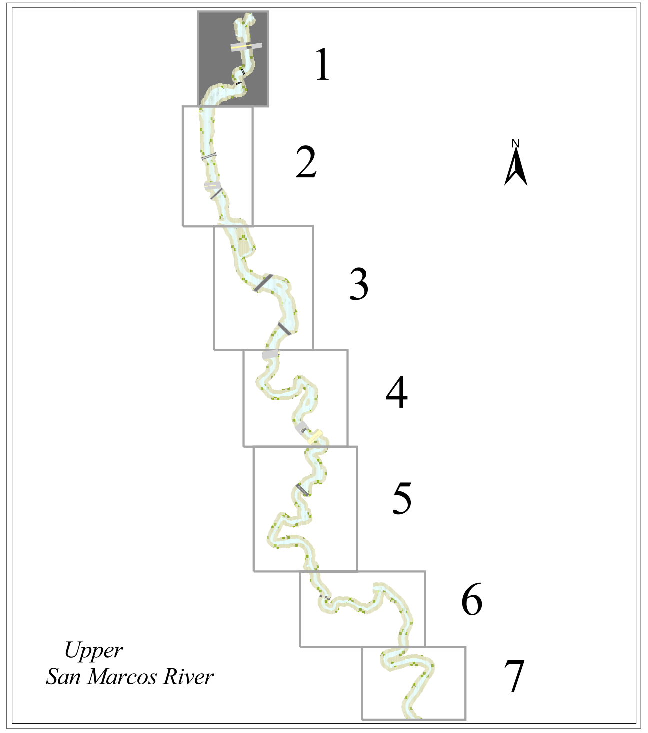


		Map 1 (m²)	Total Population (m²)
🟥	*Zizania*	1,479.8	2,560.7

Scale: 1"=135'

20 0 20 40 60 80 100 Meters

Project Location



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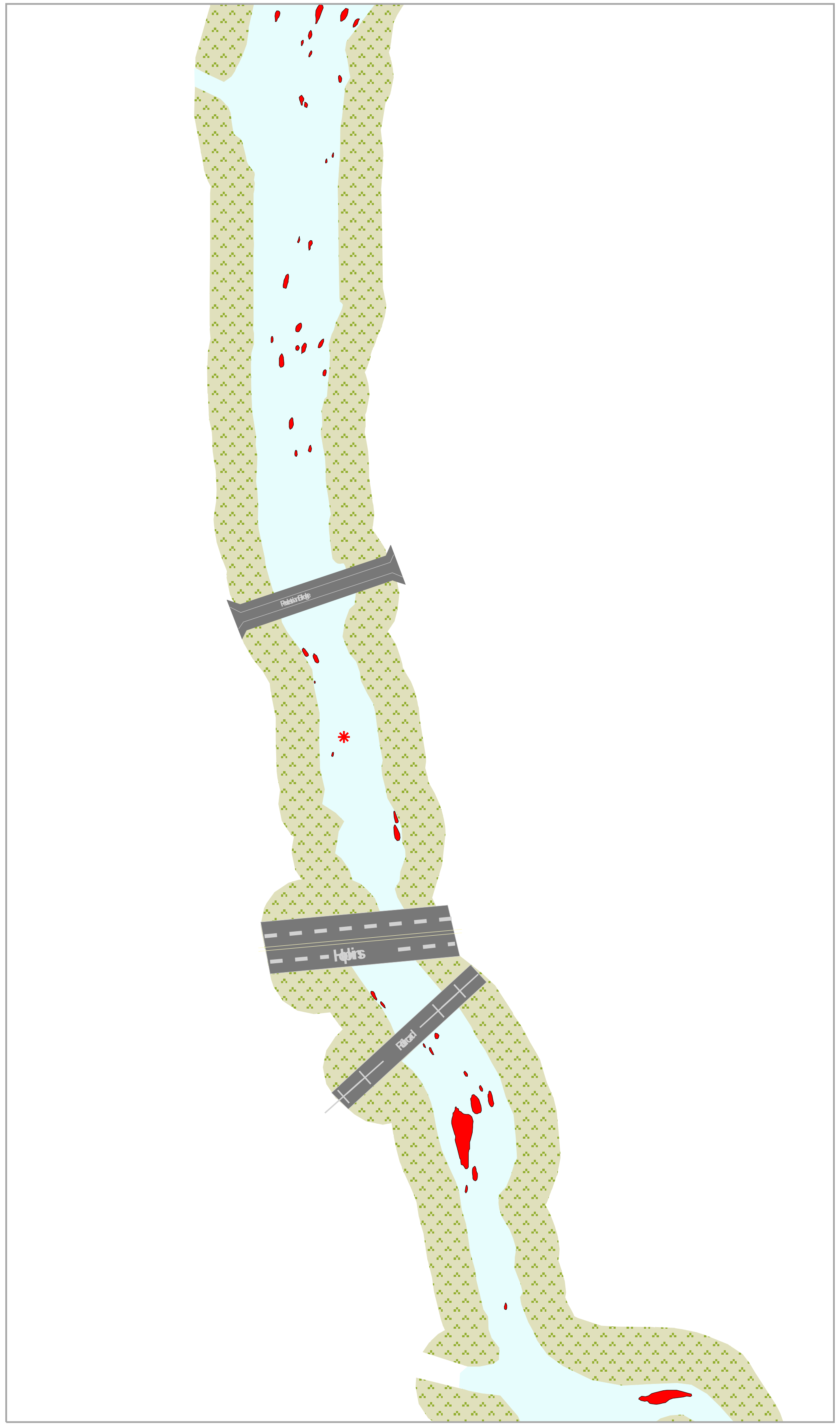
EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

Summer 2003 - Map 2 of 7

July 30 - August 1, 2003

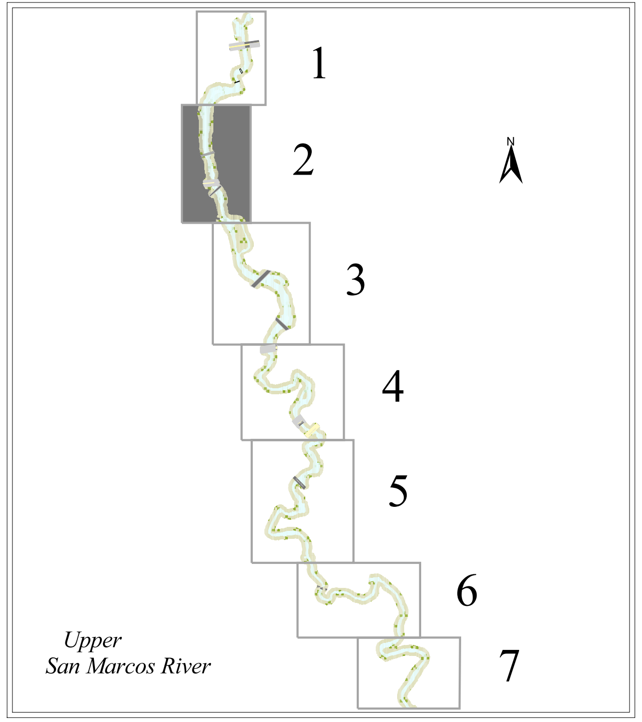
N

		Map 2 (m^2)	Total Population (m^2)
🟥	*Zizania*	287.0	2,560.7

Scale: 1"=175'

20 0 20 40 60 80 100 120 140 160 Meters

Project Location



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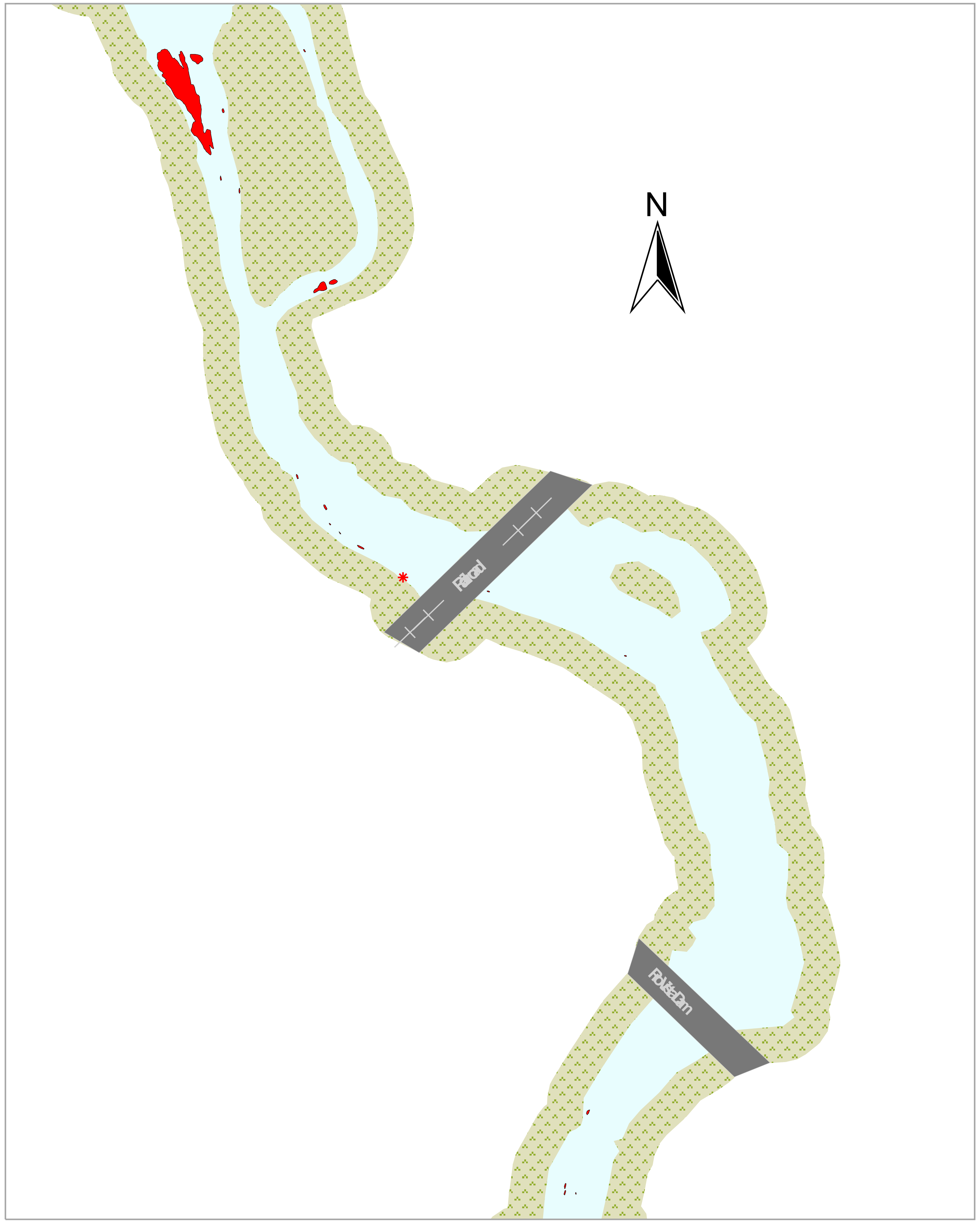
EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

Summer 2003 - Map 3 of 7

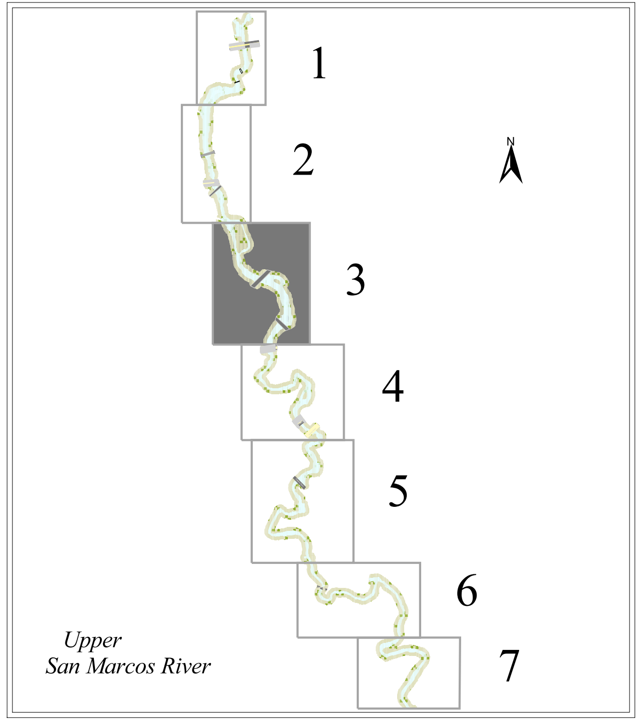
July 30 - August 1, 2003

		Map 3 (m^2)	Total Population (m^2)
🟥	*Zizania*	353.8	2,560.7

Scale: 1"=180'

20 0 20 40 60 80 100 120 Meters

Project Location



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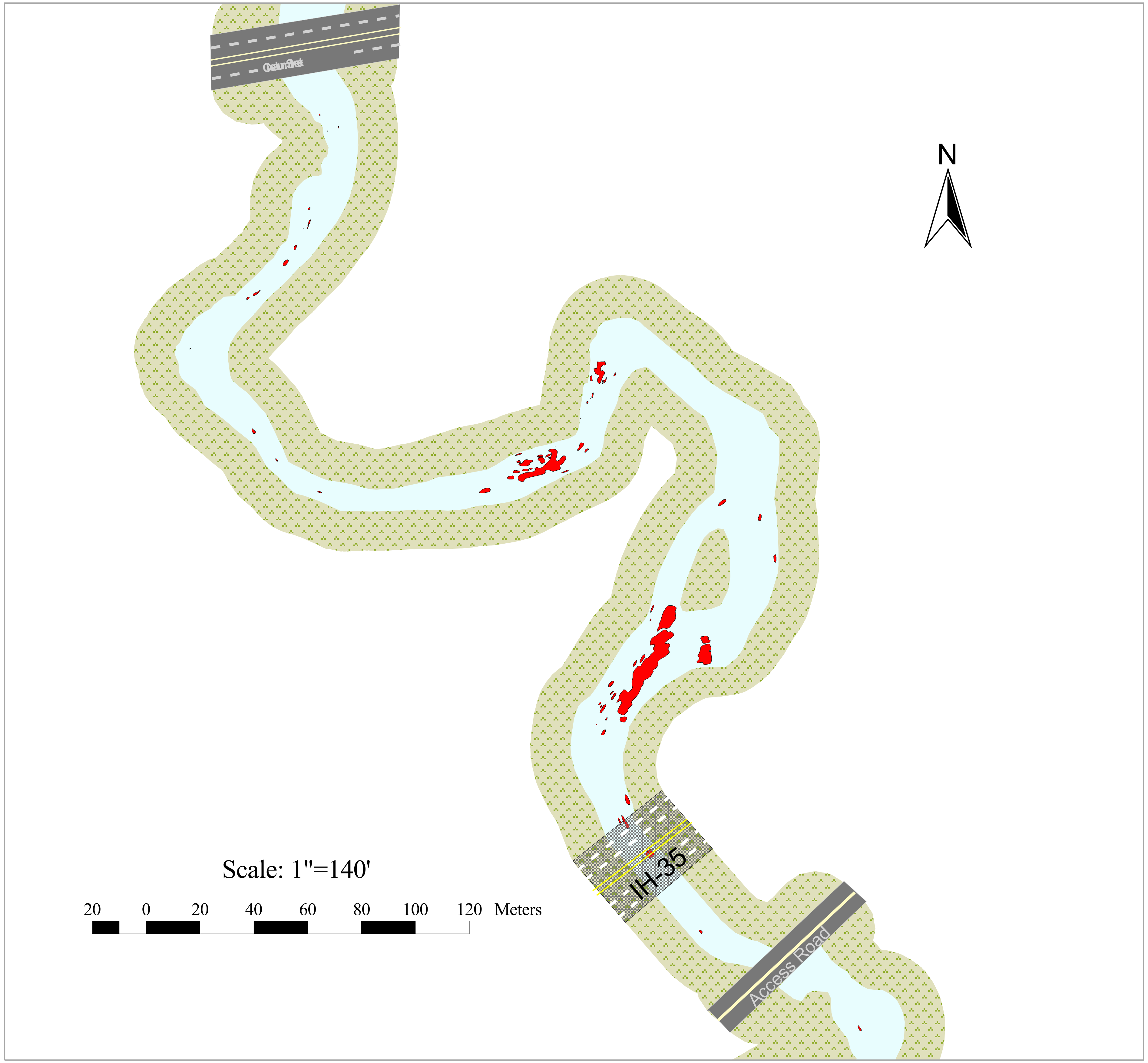
EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

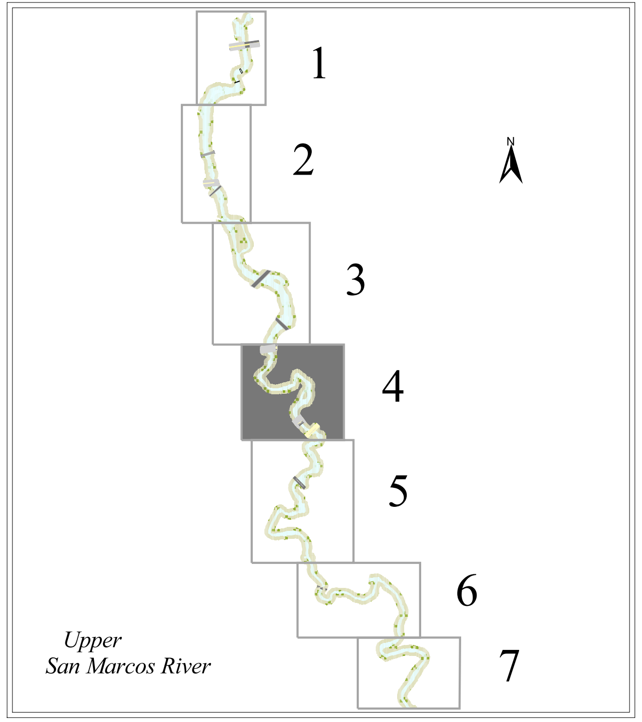
(Zizania texana)

Summer 2003 - Map 4 of 7

July 30 - August 1, 2003

		Map 4 (m^2)	Total Population (m^2)
🟥	*Zizania*	421.1	2,560.7

Project Location



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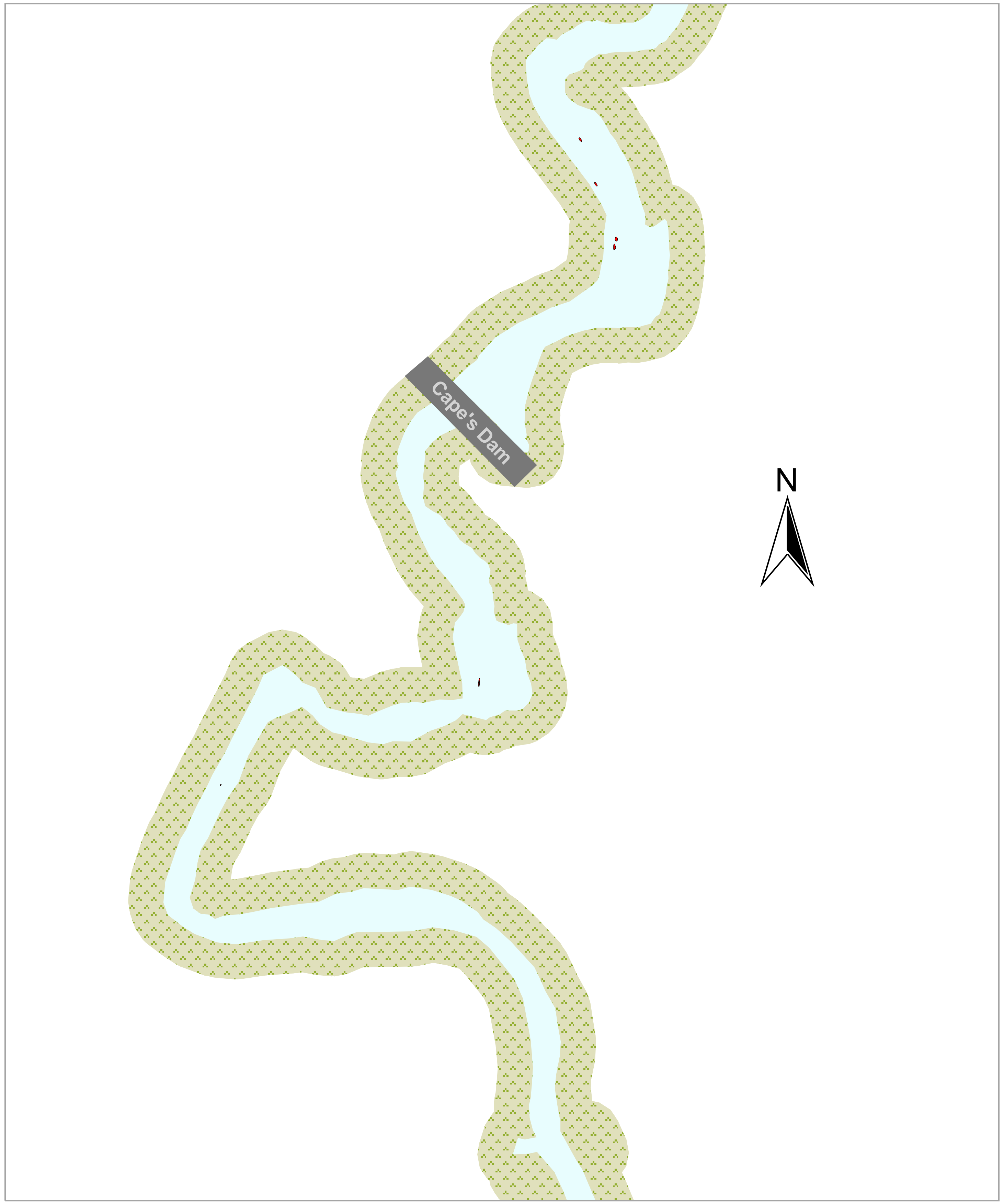
EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

(Zizania texana)

Summer 2003 - Map 5 of 7

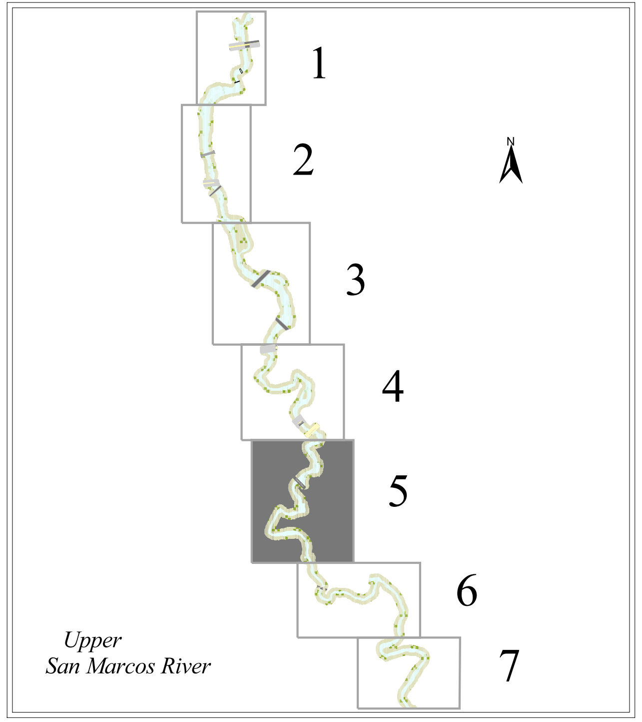
July 30 - August 1, 2003

		Map 5 (m^2)	Total Population (m^2)
🟥	*Zizania*	6.8	2,560.7

Scale: 1"=180'

20 0 20 40 60 80 100 120 Meters

Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

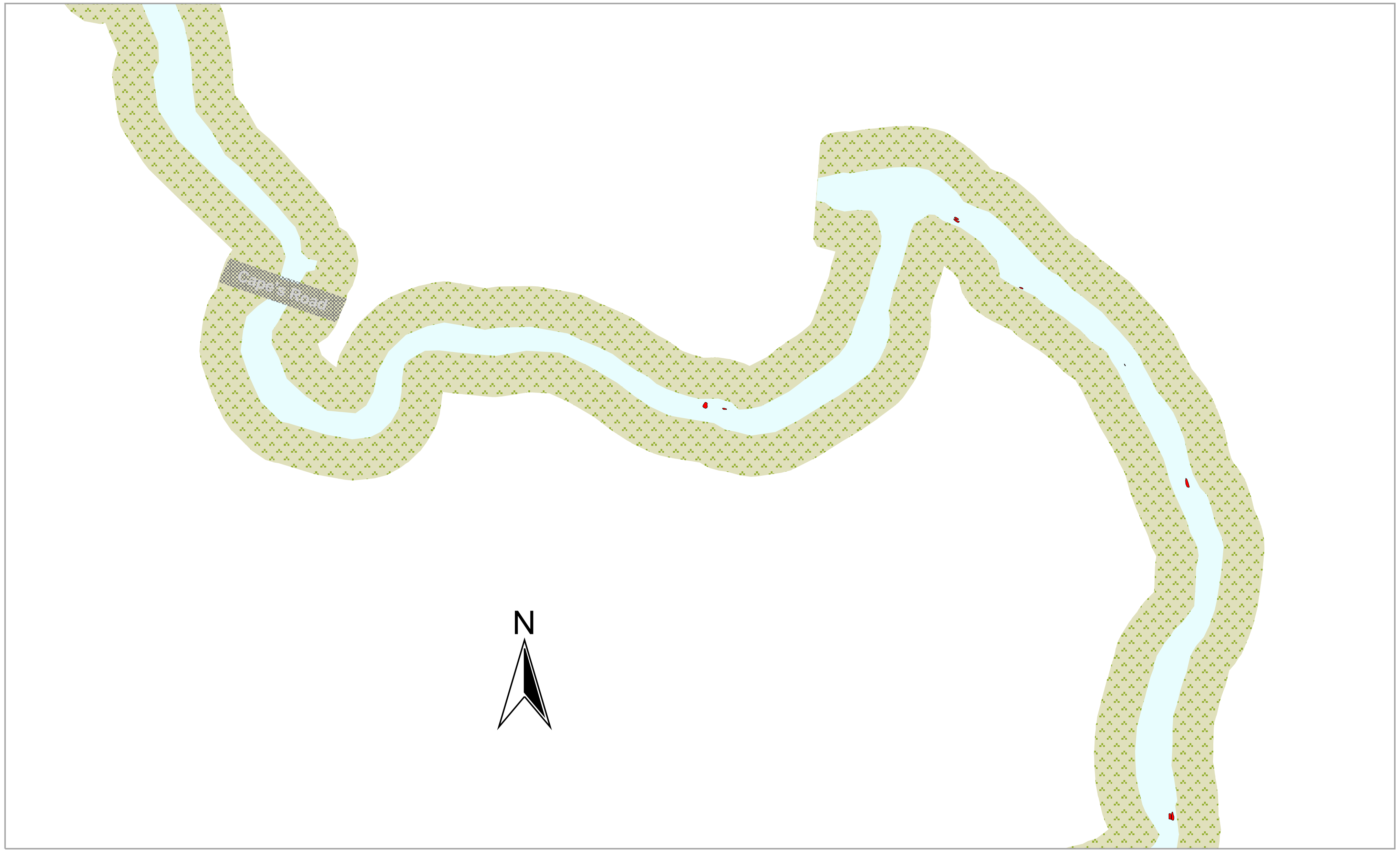
San Marcos River
Texas wild-rice

(Zizania texana)

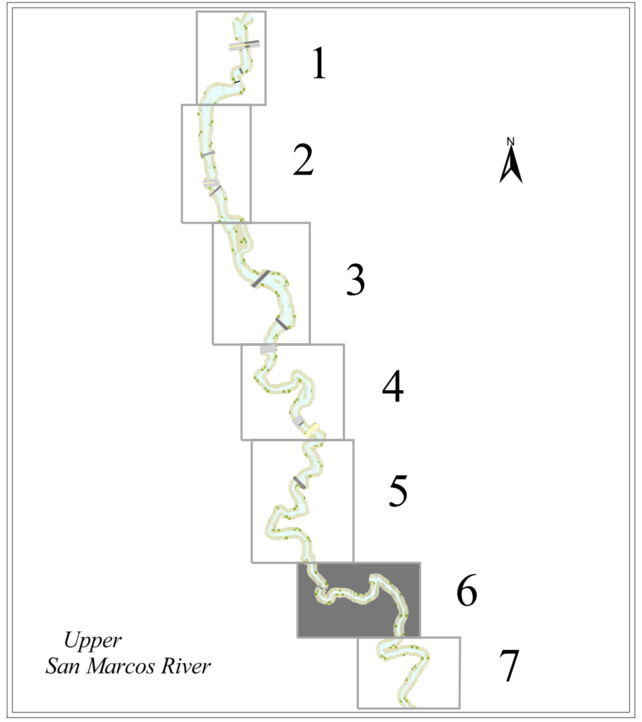
Summer 2003 - Map 6 of 7

July 30 - August 1, 2003

		Map 6 (m^2)	Total Population (m^2)
🟥	*Zizania*	12.2	2,560.7



Project Location

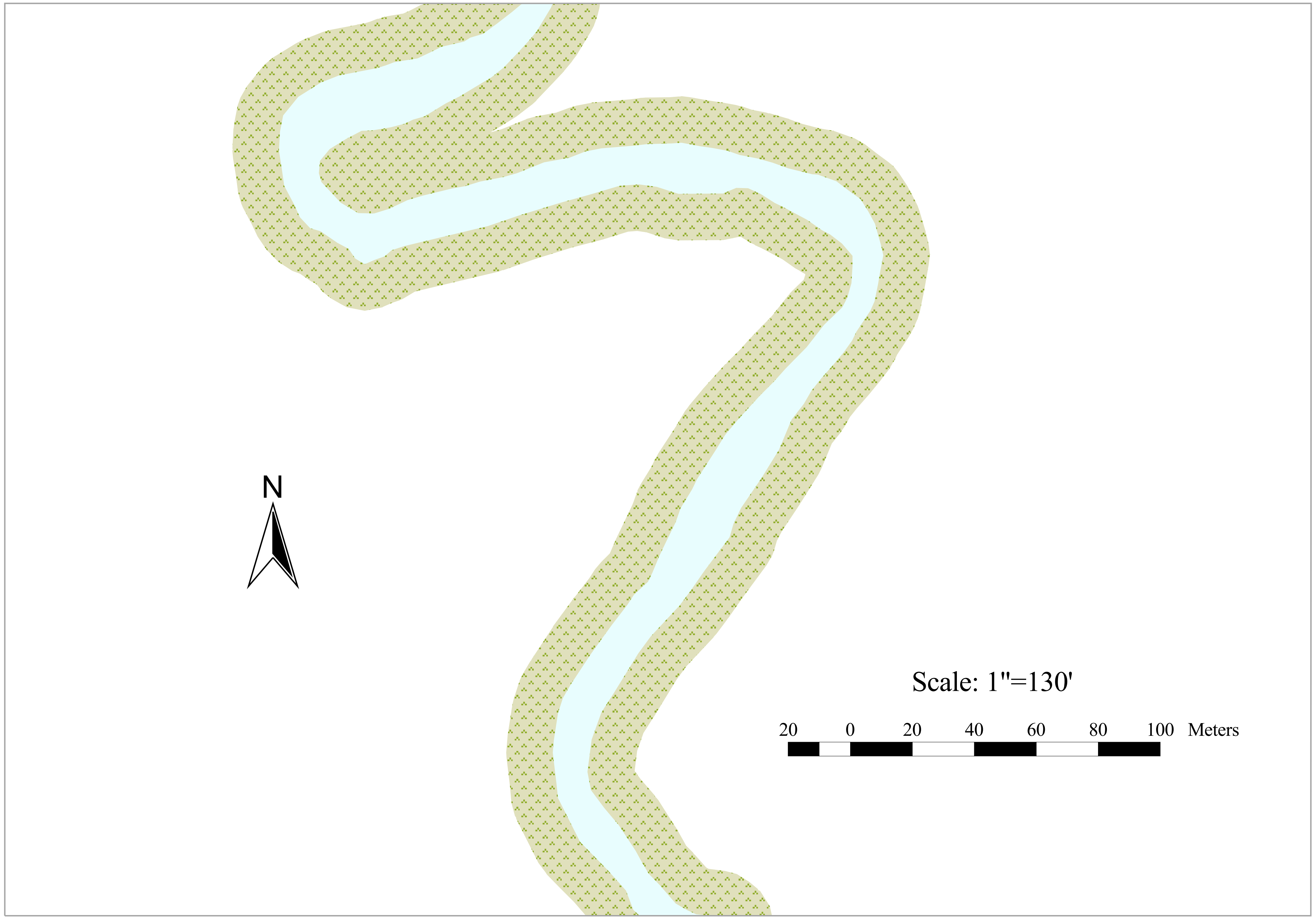


Scale: 1"=160'

20 0 20 40 60 80 100 120 Meters

BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice

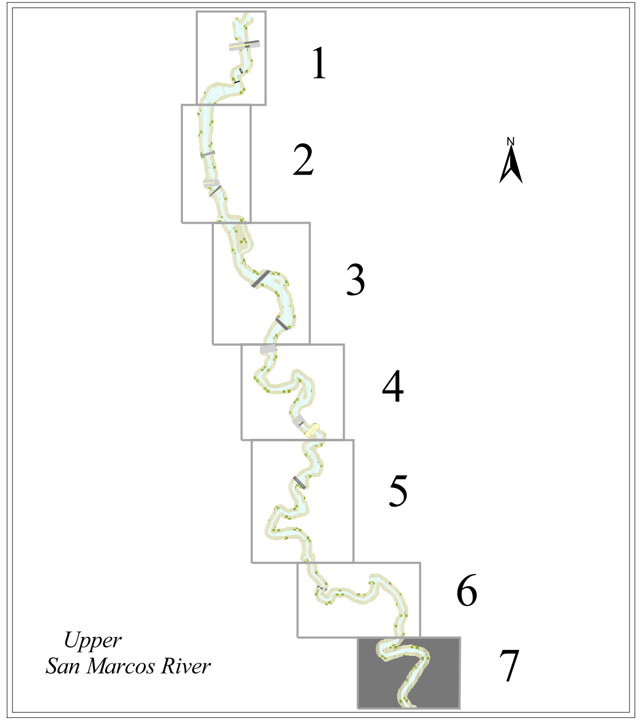
(Zizania texana)

Summer 2003 - Map 7 of 7

July 30 - August 1, 2003

		Map 7 (m^2)	Total Population (m^2)
🟥	*Zizania*	0.0	2,560.7

Project Location



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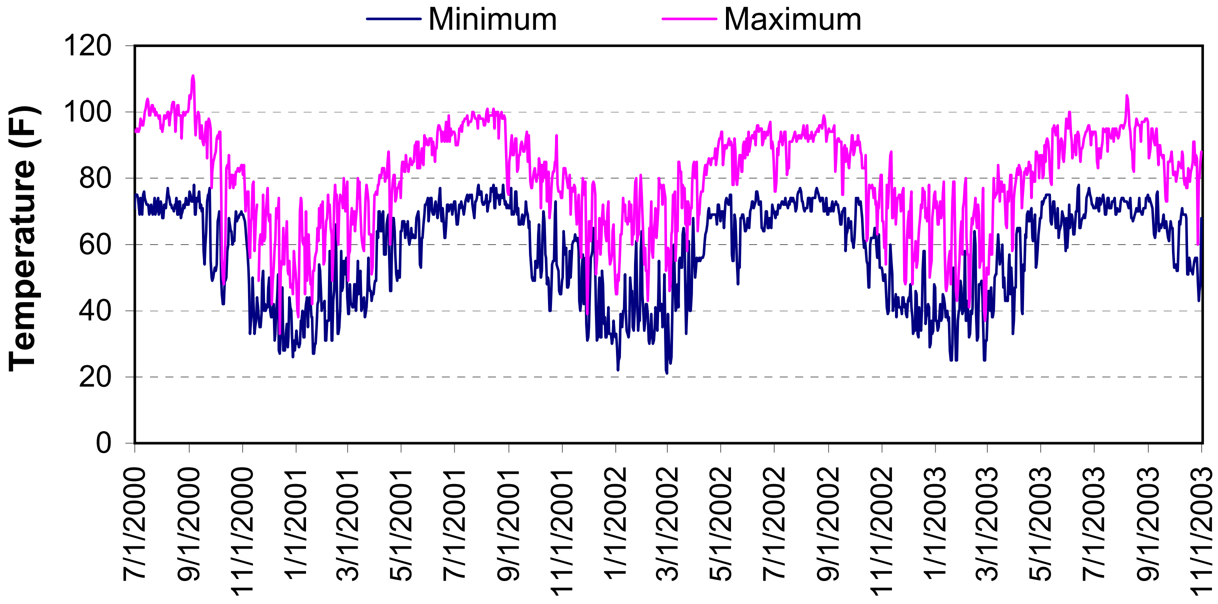
EDWARDS AQUIFER AUTHORITY

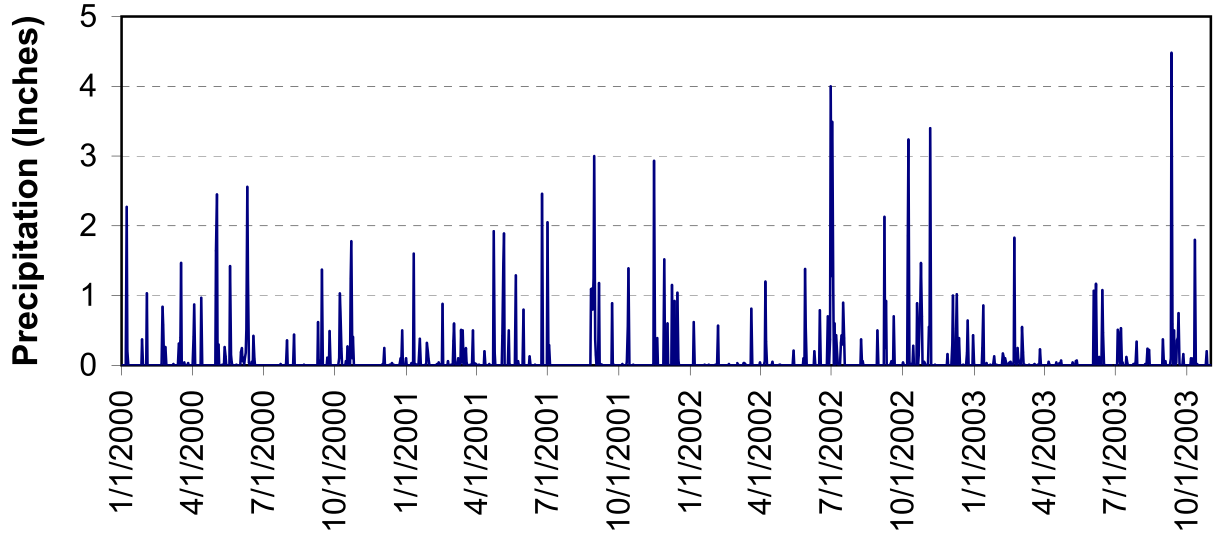
APPENDIX B:
DATA AND GRAPHS

Water Quality Data
and
Thermistor Graphs

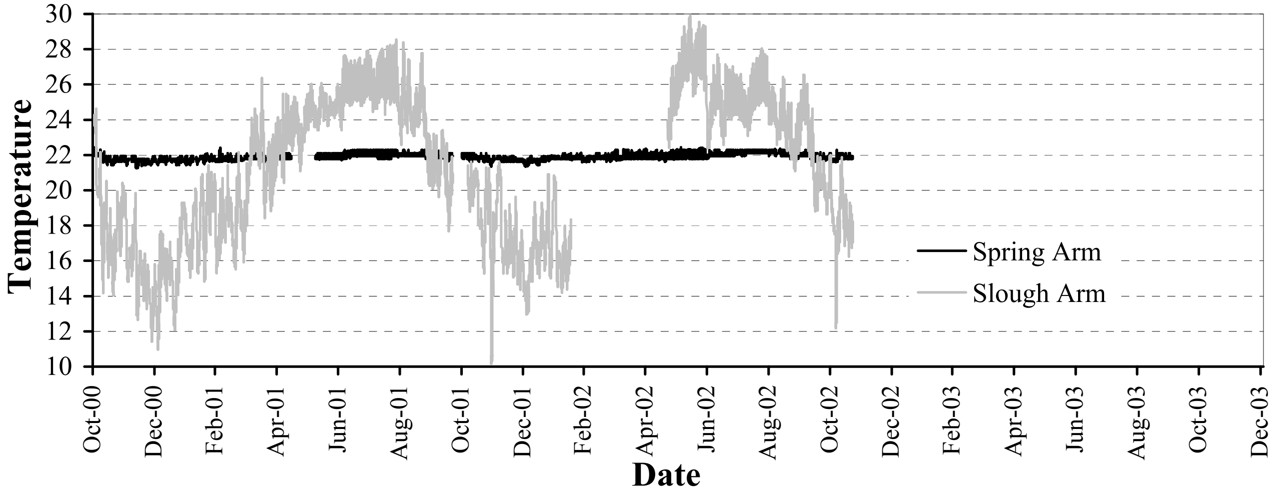
Daily Air Temperature Data for San Marcos, Texas



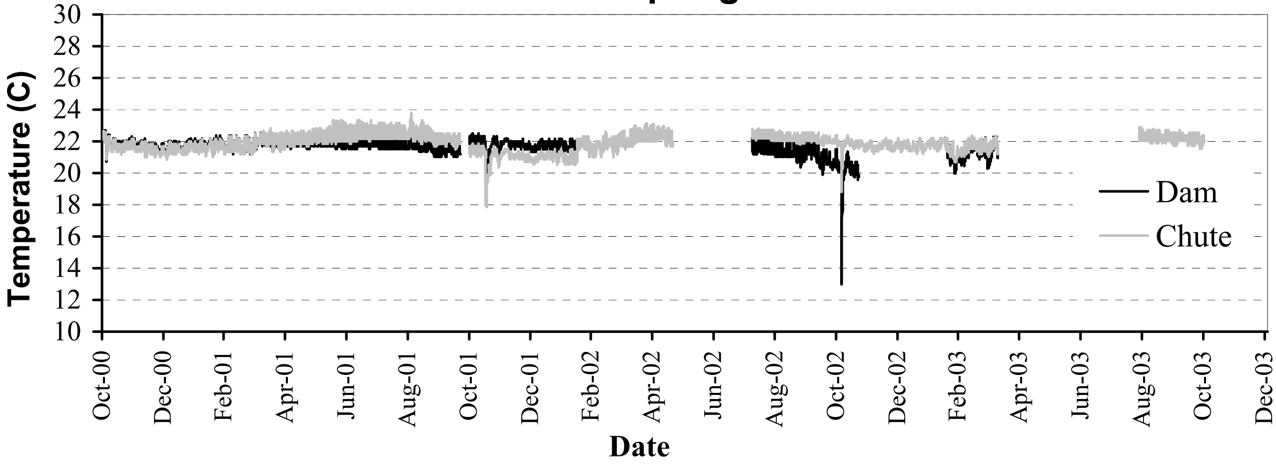
Daily Precipitation Data for San Marcos, Texas



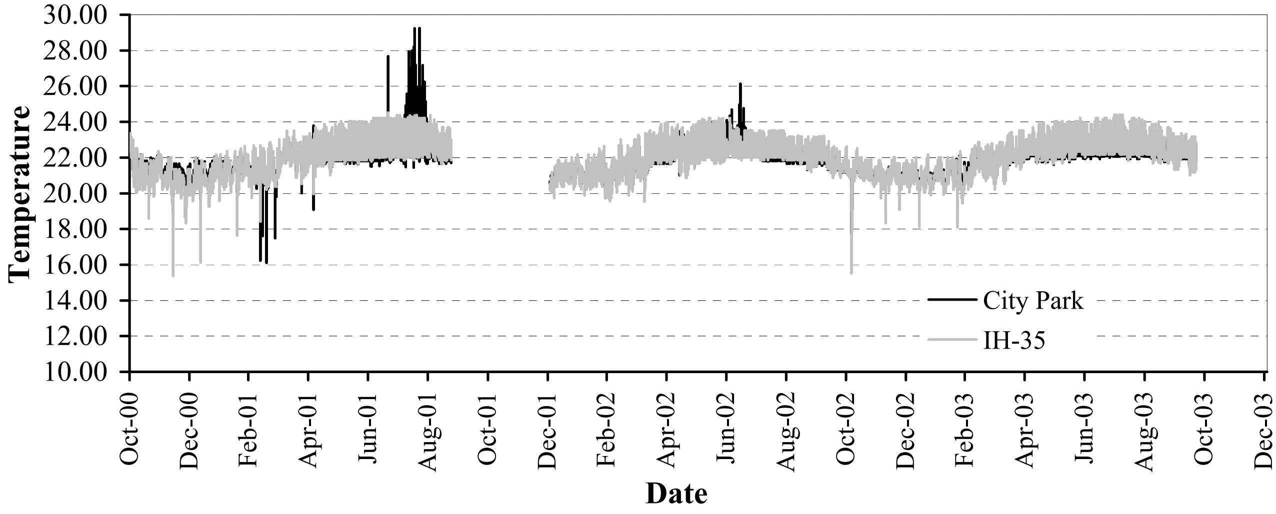
Thermistor Data: Spring Lake Sites

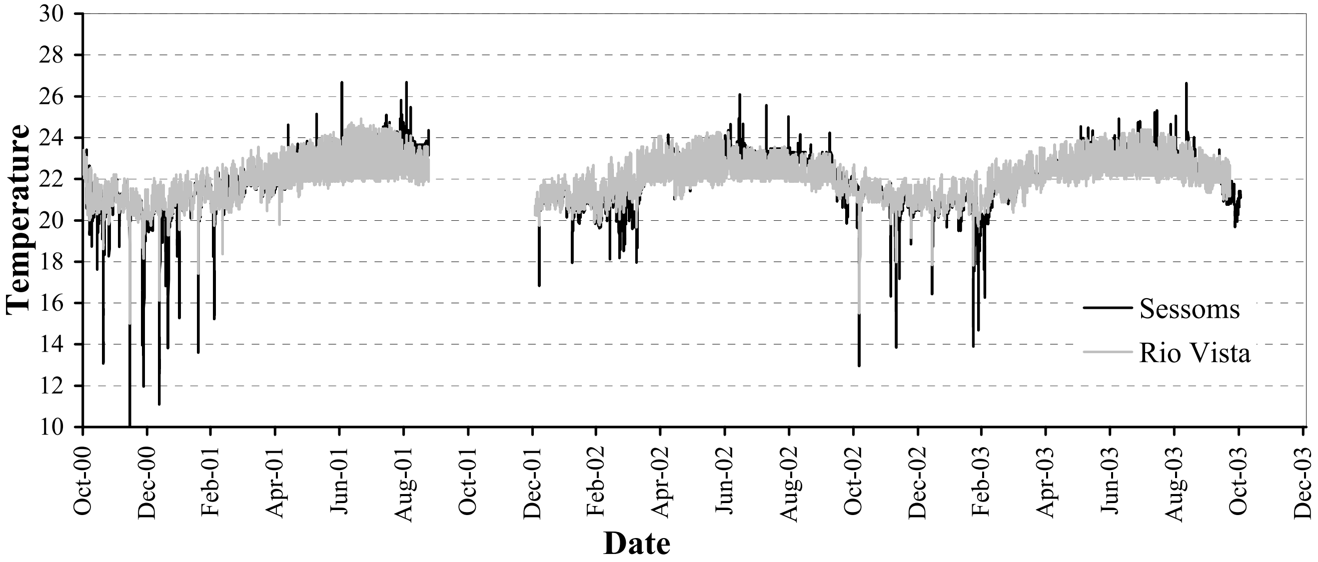


Thermistor Data: Dam and Chute Below Spring Lake

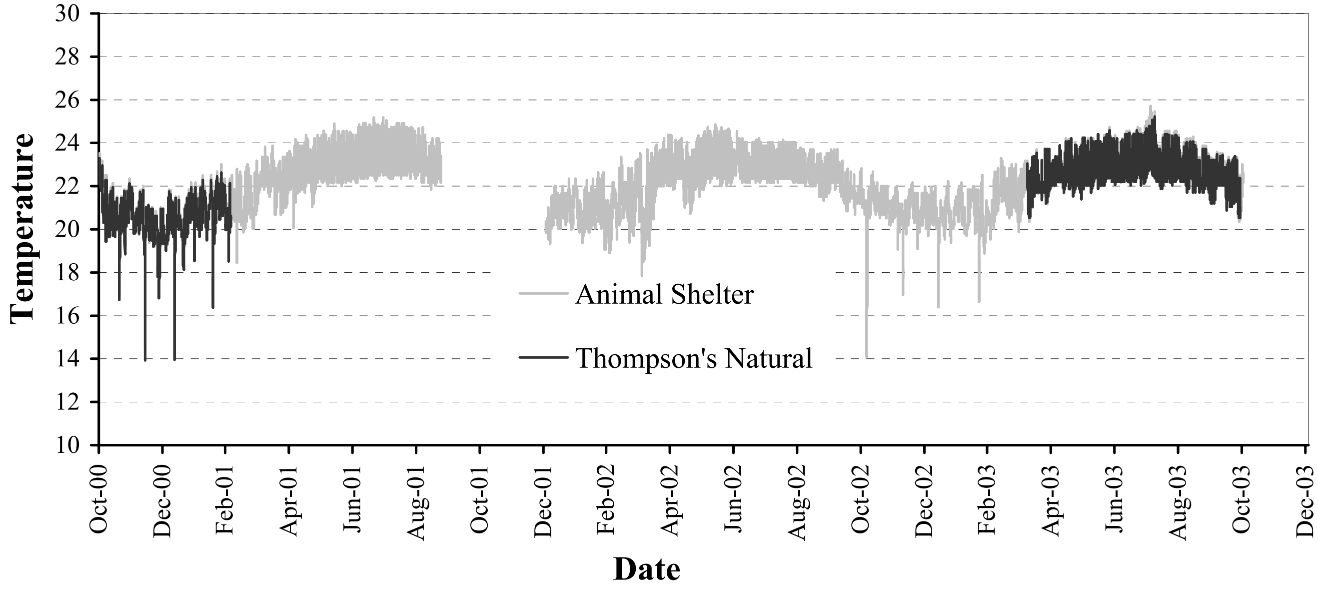


Thermistor Data: City Park and I-35 Reaches



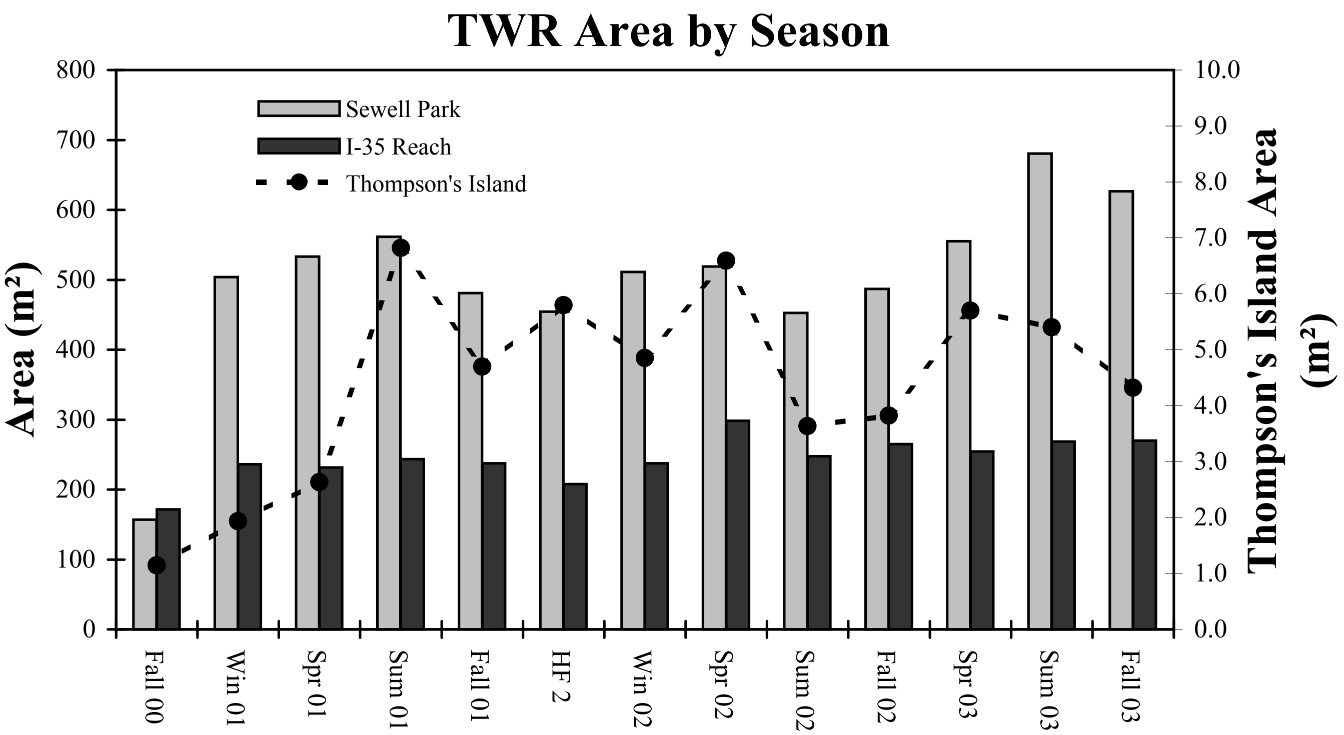


Thermistor Data: Sessoms Creek and Rio Vista Dam

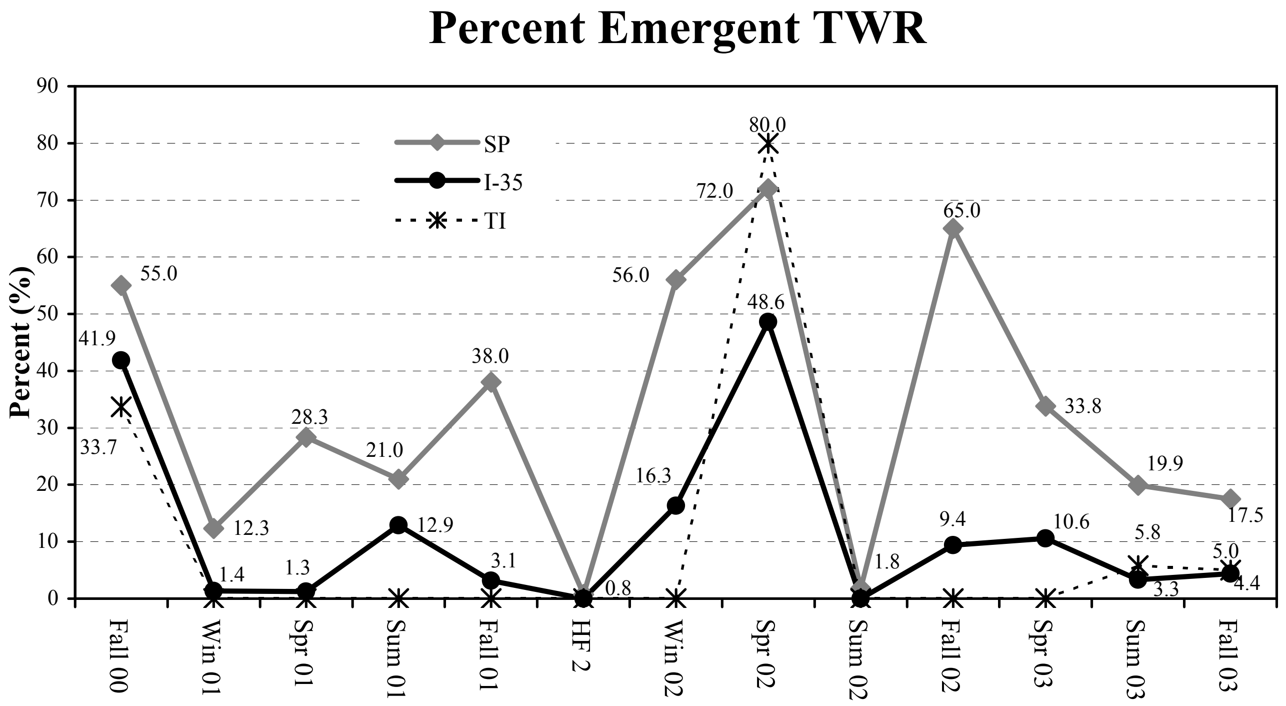


Thermistor Data: Thompson's Island and Animal Shelter

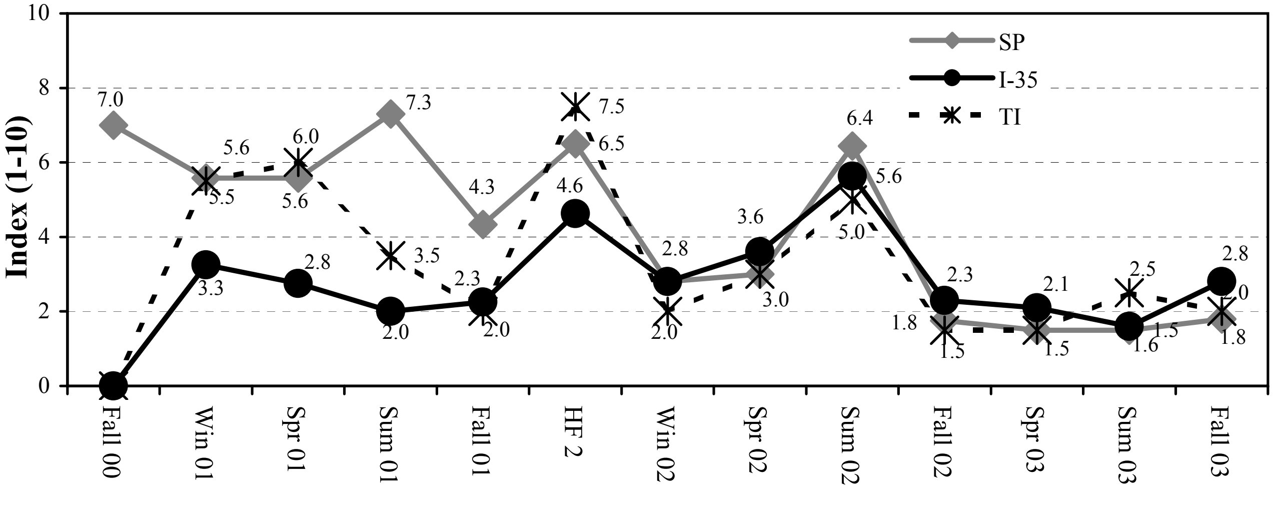
Texas Wild-Rice Observation Data



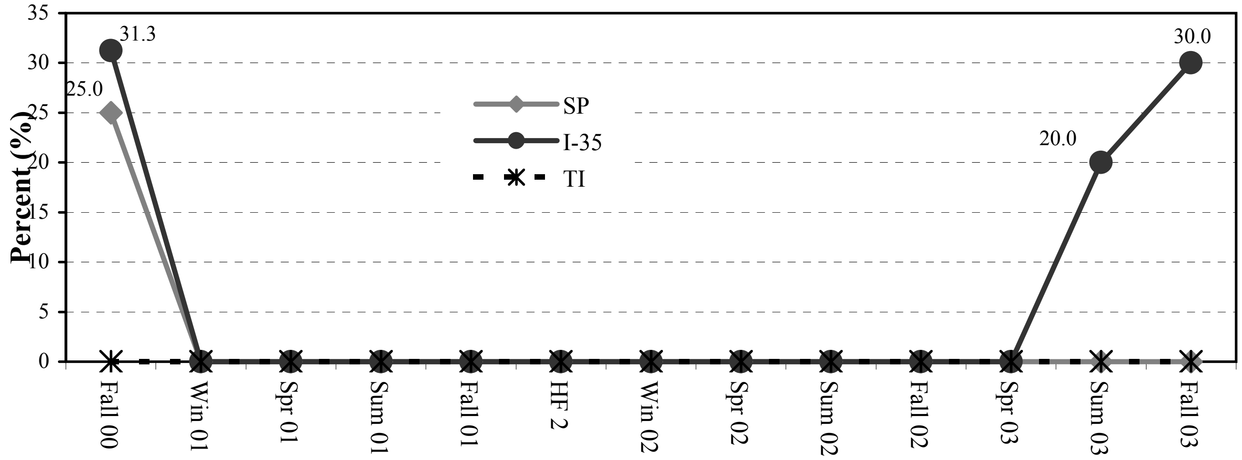
TWR Area by Season



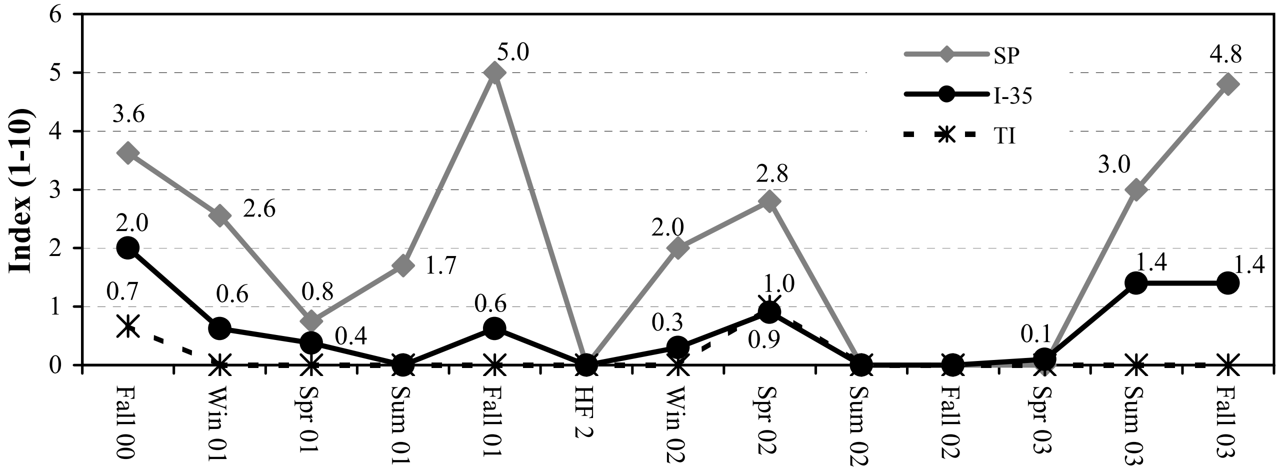
Percent Emergent TWR



Index of Root Exposure for TWR Stands



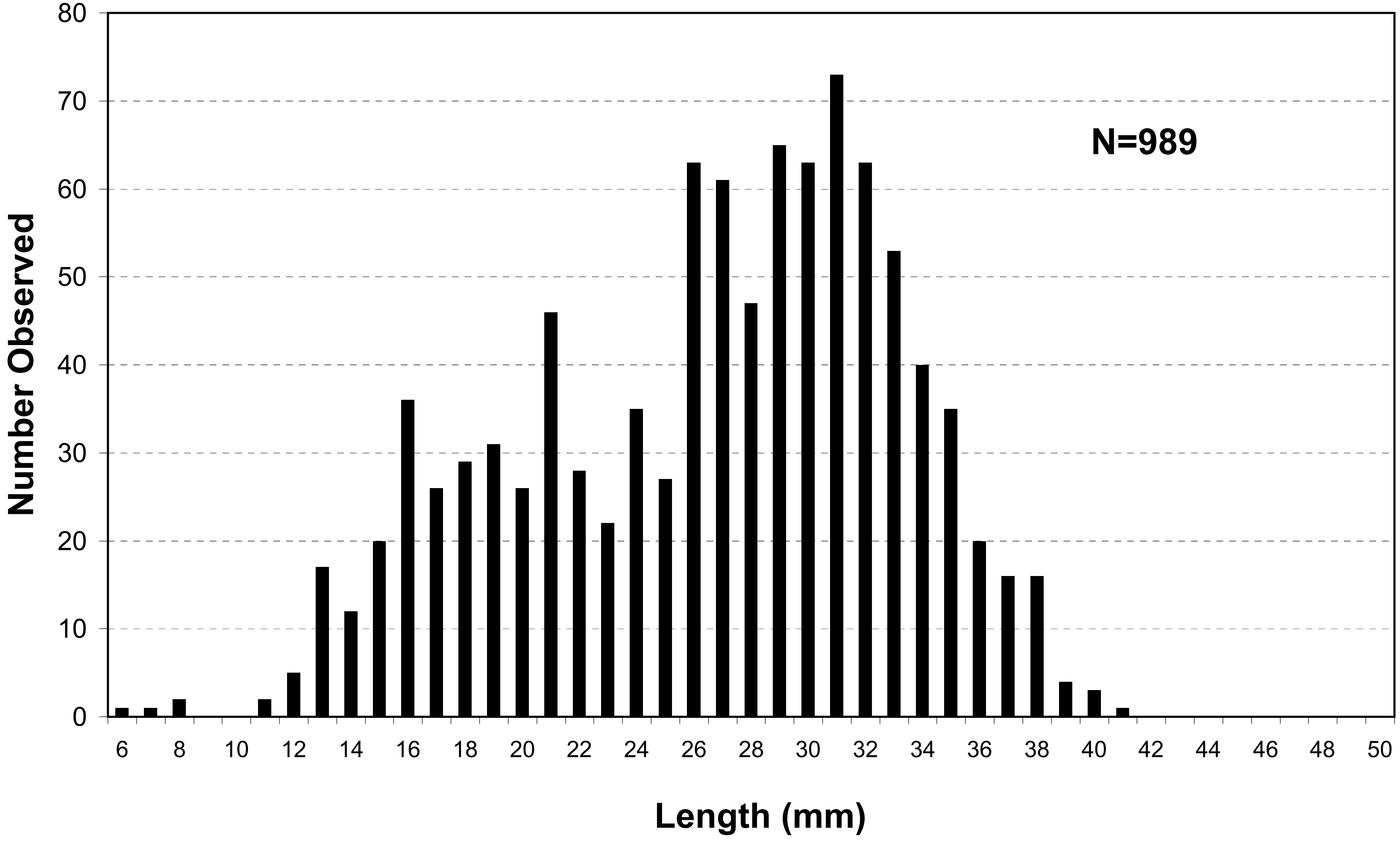
Percent of TWR Stands < 0.5 Feet



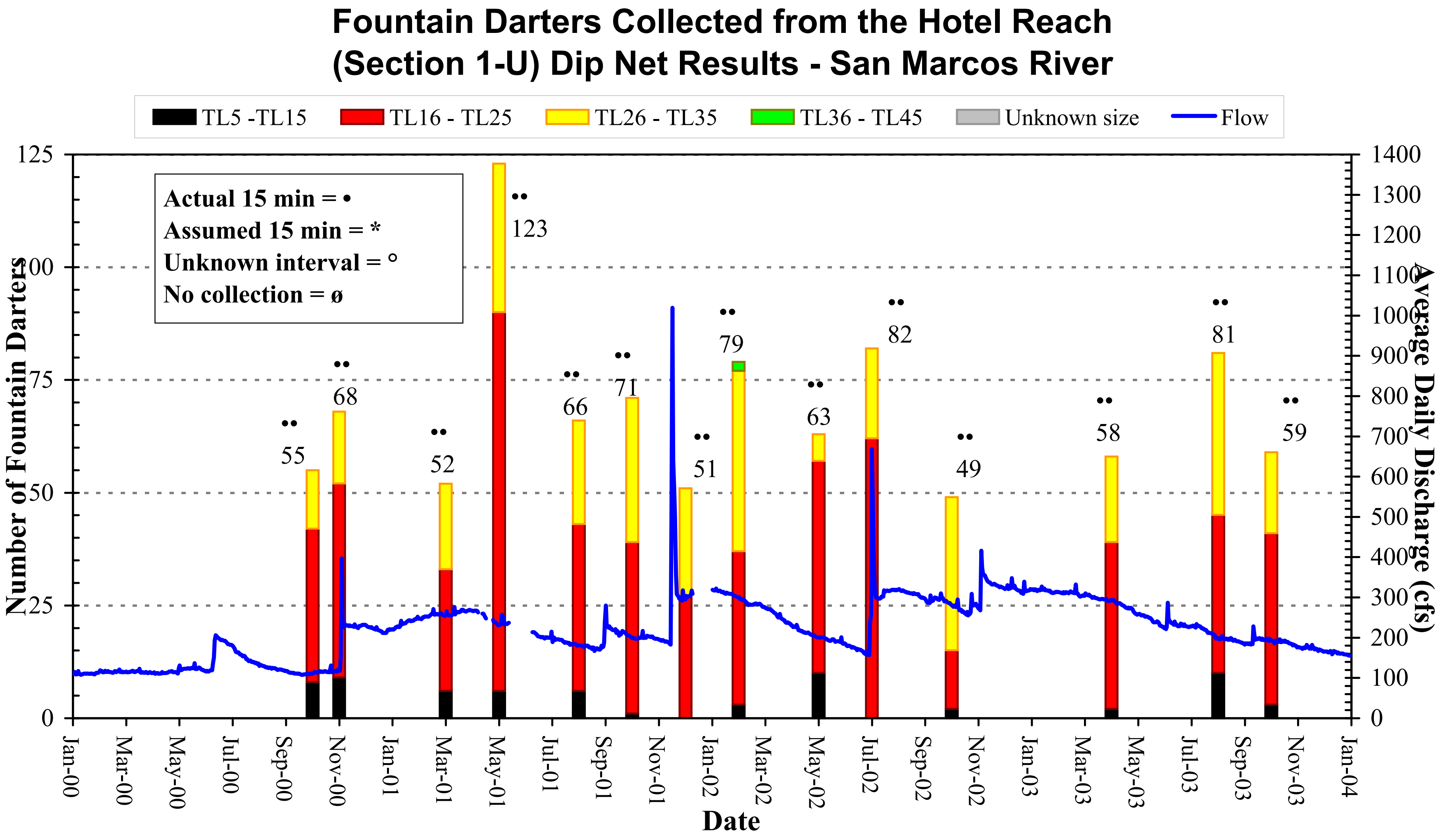
Index of Herbivory for TWR Stands

Drop Net Graph

Fountain Darter Size Class Distribution
Drop Net Results in the San Marcos River (2000-2003)

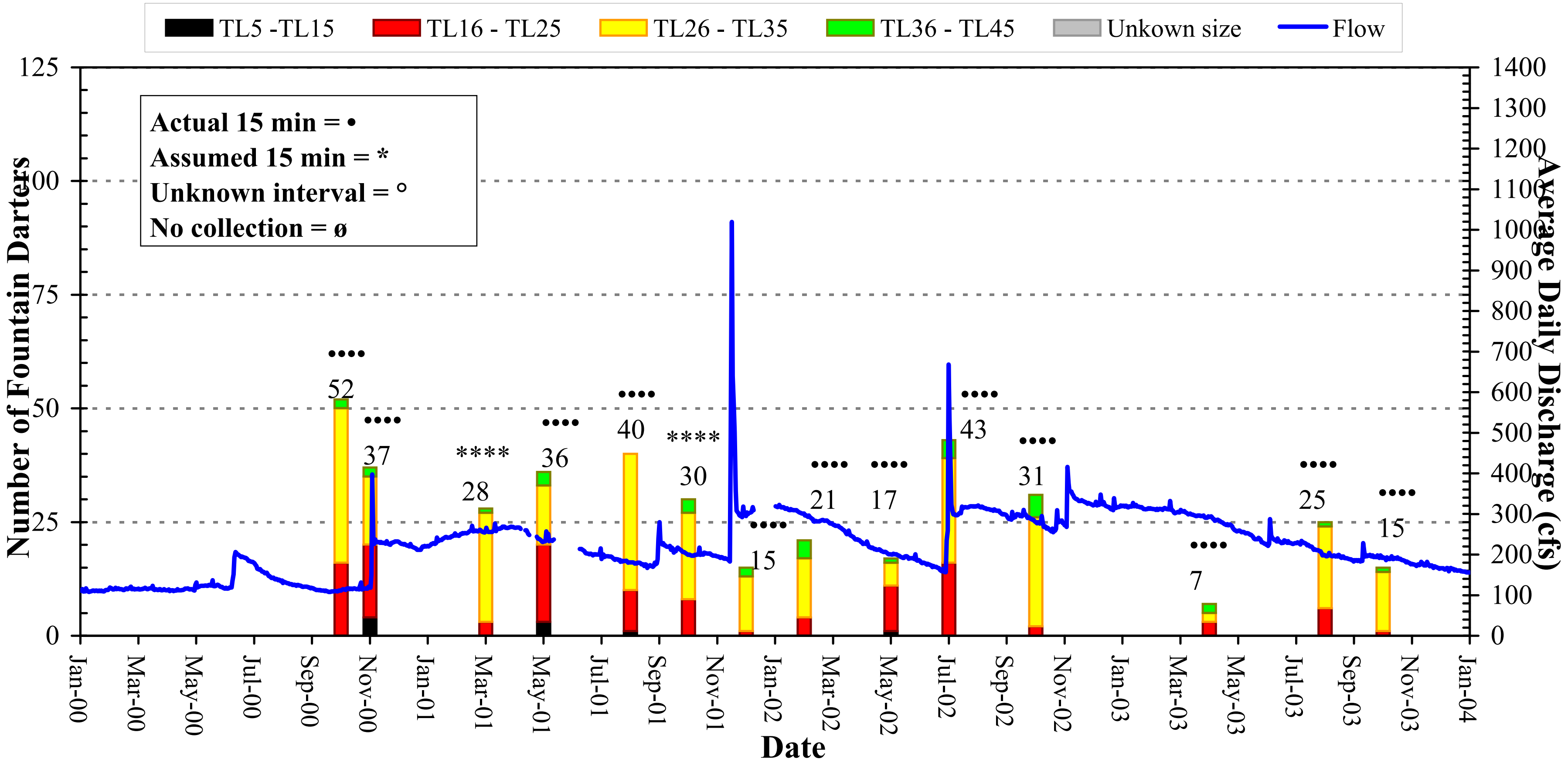


Dip Net Graphs

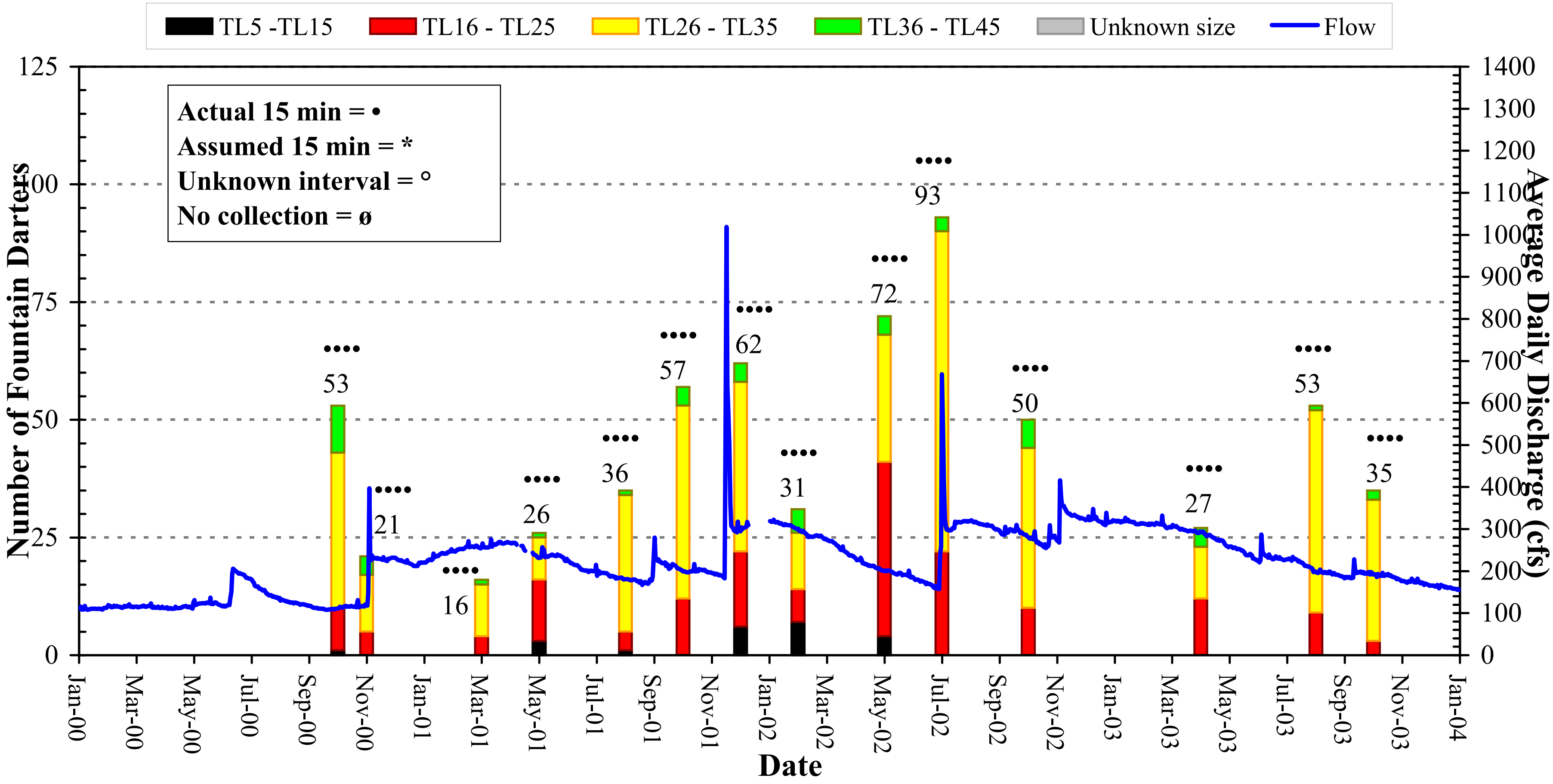


Fountain Darters Collected from the Hotel Reach (Section 1-U) Dip Net Results - San Marcos River

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)