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 2011 Annual Report

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Submitted: March 2012

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EXECUTIVE SUMMARY

This annual summary report presents a synopsis of methodology used and an account of sampling activities conducted during two Comprehensive Monitoring sampling efforts and one Critical Period low-flow event on the San Marcos Springs/River ecosystem in 2011. For ease of comparison, the data are reported in an annual report format similar to previous reports (BIO-WEST 2001a, b - 2011a, b).

After the lowest recorded discharge recorded in this study (83 cubic feet per second [cfs]) occurred in 2009, 2010 exhibited relatively constant flows above the historic average for most of the year. Near the end of 2010, flows started to decrease, and never recovered in 2011 when the second lowest discharge in this study was observed (88 cfs). These flows triggered a single low-flow Critical Period event in September after flows remained well below the historic average over summer. Flows in the San Marcos River dropped below 150 cfs in March and below 100 cfs in August where they remained for the rest of the year. Few precipitation events and high ambient air temperatures contributed to the exceptional drought plaguing much of Texas.

Although the exceptional drought continued through 2011, water temperatures varied little, especially near spring inputs. Temperatures were highest at the Thompson's Island (artificial channel) and Rio Vista Dam sites where water is pooled and current velocities are minimal. Grab samples of water were collected during the Critical Period event to examine how water chemistry changes in lower than average flows. Dissolved oxygen levels were low at sites near the spring inputs and comparable to previous low-flow years (2006, 2009). Nitrate levels in 2011 were lower than 2006 and 2009, while total phosphorous levels were undetectable at all sites.

As in previous lower than average years (2006, 2009), decreased depths and increased recreation pressure in summer contributed to vegetation loss at all reaches. Total vegetation area in the City Park Reach was below average for all sampling efforts in 2011. Vegetation in the middle section of the reach was essentially absent by the Critical Period event in September due to physical uprooting/trampling from recreation pressure. This phenomenon occurs on an annual basis, but is typically worse in low-flow years with extreme summer air temperatures because it leads to an increase in numbers of people using the river. As a result of this combination of factors, total vegetation area in the City Park Reach during fall 2011 was the second lowest recorded in this study. Aquatic vegetation in the I-35 Reach often follows a different trend. Total vegetation area was higher in both spring 2011 and September 2011 than in 2010 when flows were nearer the long-term average. Under normal flow conditions, this reach is characterized by lower depths, higher velocities, and less recreation pressure (fewer access points). During 2011, lower velocities associated with lower discharge and continued limited recreation benefited the aquatic vegetation in this reach through the summer months, although this reach did experience decreasing coverage by fall 2011. The Spring Lake Dam Reach is similar to the City Park Reach because it receives high amounts of recreation pressure (it is located on a university campus, and is adjacent to high-density housing). Vegetation fared well in this reach in the midst of the lower than average discharge in 2011. Although effects of recreation pressure were clear (paths developed through several plants), total aquatic vegetation were higher than in 2010, and similar to 2009. Impacts were greatest on Texas wild-rice (*Zizania texana*), where a reduction of 33% occurred from spring to fall in 2011. This decrease was far less than in 2006 (77%) when large swaths of these endangered plants were physically removed within the eastern spillway. Educational signs were installed along the river banks in 2007, and may have contributed to the lessened impacts observed in 2011.

The lower than average flows prevalent in 2011 resulted in two full Texas wild-rice mapping events (June, August/September) on the San Marcos River. Total coverage in June exhibited a 3% decline from 2010, and was below 4,000 meters squared (m^2) for the first time since 2009. The entirety of this decrease took place within the first 2 miles of the San Marcos River, which is also where 88% of the Texas wild-rice resides. This decline can partially be attributed to a large plant at Sewell Park that has been steadily shrinking in recent years. Bobdog Island (an expansion of the river-right bank) is an area at the mouth of Sessom's Creek in the Spring Lake Dam Reach that has been steadily expanding as a result of sediment carried down from the creek. This increasing bank has cut off much of the flow to the plants in Sewell Park. This reduction in flow along river right results in large mats of floating vegetation from Spring Lake covering Texas wild-rice in Sewell Park and inhibiting growth and reproduction. Several smaller plants within the City Park Reach were also uprooted or trampled due to recreation pressure, and contributed to this decline. The total amount of Texas wild-rice in the San Marcos River decreased further by September. By fall, the total coverage of Texas wild-rice in the river decreased by 9% relative to summer 2010, resulting in the lowest mapped total since 2009. As in June, the majority of this decrease occurred in the upper reaches of the San Marcos River. Measurements on vulnerable Texas wild-rice plants reflected these changes, especially at Sewell Park.

Abundant aquatic vegetation within the two drop net sample reaches resulted in one of the highest population estimates of the study during spring 2011. However, this estimate declined throughout the year resulting in the lowest population estimate since the inception of this study by fall. This reduction in population estimates from spring to fall happens during most years, and results from reductions in aquatic vegetation during the summer recreation season. This drop is particularly pronounced in low flow years. Although the fall 2011 estimate was the lowest recorded, it was only slightly lower than the estimate calculated in fall 2009 after a similar period of extended low flows. Although the magnitude of changes observed in fountain darter population estimates during 2011 may seem extreme, it is important to remember that these estimates are based on the coverage of aquatic vegetation within the sample reaches. Therefore, large changes in vegetation during 2011 led to large swings in population estimates. As in previous years, fountain darter dip net data suggests a rather dynamic but stable population with limited year-round reproduction supplemented by a strong late winter/early spring reproductive peak.

San Marcos salamander (*Eurycea nana*) densities in Spring Lake during spring 2011 were the highest observed during the study. These high densities continued into the fall at the Hotel reach reflecting high-quality habitat within this area. However, at the Big Riverbed study site, there was a 52% reduction from spring to fall 2011, which resulted in one of the lowest numbers observed during this study. This reduction was caused by the excessive overgrowth of aquatic vegetation and sedimentation that occurred due to the lack of aquatic gardening in this reach starting in late summer 2011. The consistent gardening that has occurred over the past decade was restricted due to construction activities associated with the Aquarena Springs restoration project. The aquatic gardening in this reach serves to maintain clean substrate areas which provides high quality habitat for the salamander. Without the gardening, the non-native vegetation prevalent in the lake takes over and quickly decreases the habitat quality for the San Marcos salamander. This event highlights the beneficial effect of an anthropogenic activity in the preservation of high quality habitat for this species, as well as the importance of long-term monitoring to tease out these cause and affect relationships over time. Salamander densities at the site located within the San Marcos River were higher in spring and fall than they have been since the inception of the study. While high quality habitat likely contributed to these high numbers, educational signs adjacent to this site extolling the benefit of this species likely helped in reducing recreation pressure here as well.

Flows in the San Marcos River in 2011 were similar to previous low flow years (2006, 2009), and similar effects were observed. A decrease in Texas wild-rice coverage and fountain darter population estimates reflected the impact of increased recreation pressure under low flow conditions. However, San Marcos salamander densities remained high despite the lower than average flow conditions. Since salamander habitat is limited to areas near spring upwellings at the head of the system (much of which is under Spring Lake and thus protected from recreation), habitat quality for these animals is influenced less by low-flow conditions and increased recreation pressure. Ongoing changes in spring discharge, recreation pressure, exotic species, and other factors make continued monitoring of this system critical to inform management decisions.

METHODS

Study Location

The upper San Marcos River is part of the Edwards Aquifer system, and extends approximately six kilometers (km) from its origin as a series of springs welling in Spring Lake to the confluence with the Blanco River in Hays County. The upper portion of the river is characterized by near constant water temperatures (21°C ± 2°C, Ono et al. 1983) and relatively constant flow. This portion of the river also includes several endemic organisms that are federally listed as threatened or endangered, including: Texas wild-rice, San Marcos Salamander, San Marcos Gambusia (*Gambusia georgei*), Comal Springs Riffle Beetle (*Heterelmis comalensis*), and fountain darter. This section of the river is located within an urban area, and is subjected to a substantial amount of recreational use. As such, sites were chosen in this section of the river to better understand the interactions between the biota, the surrounding environment, and recreational users of this unique ecosystem (Figure 1).

During 2011, two comprehensive sampling efforts (spring and fall), and one Critical Period low-flow event were conducted in the San Marcos River system. The 2011 sampling schedule included the following components during each sampling effort unless otherwise noted:

Aquatic Vegetation Mapping
- Texas wild-rice survey

(Critical Period and Summer)

Water Quality
- Thermistor Placement
- Thermistor Retrieval
- Fixed Station Photography
- Point Water Quality Measurements
- Grab Samples (Critical Period)

Texas Wild-Rice Physical Observations
- Cross-section data
- Physical measurements

Fountain Darter Sampling
- Drop Nets
- Dip Nets
- Visual Observations

San Marcos Salamander Observations

Low-Flow Sampling

Discharge in the San Marcos River decreased through much of 2011 culminating in one Critical Period event in September as initial flow data indicated that discharge dropped below 100 cfs in the river for approximately one month.

High-Flow Sampling

There were no high-flow sampling events in 2011.

San Marcos Springflow

All San Marcos River discharge data were acquired from the United States 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 2011). The discharge data for the San Marcos River were taken from USGS gage 08170500 at the University Drive Bridge. This site represents the cumulative discharge of the springs that form the San Marcos River system. In addition to the cumulative discharge measurements that were used to characterize this ecosystem during sampling, spot measurements of water velocity were taken during each sampling event using a SonTek® FlowTracker with handheld unit.

San Marcos 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. Due to the consistency in water quality conditions measured over the first several years of sampling, the water quality component of this study was reduced in 2003, but the two components necessary for maintenance of long-term baseline data, temperature loggers (thermistors) and fixed station photography were continued. In addition, conventional 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 in all drop-net sampling sites using a Hydrolab Quanta.

Following the same protocols used in previous years (BIO-WEST 2003, BIO-WEST 2007), water quality analysis was conducted during one Critical Period sampling event in 2011 at eighteen sites within Spring Lake and the San Marcos River. *In situ* measurements of temperature, pH, dissolved oxygen, conductivity, and turbidity were recorded at each site. In addition to the standard water quality parameters, surface water grab samples were collected at all sample sites to evaluate conventional water chemistry parameters (Figure 1). During the 2011 sample collection, two 500-mL surface water samples were collected at each site. One of the two samples was left unpreserved for nitrate, soluble reactive phosphorus (SRP), alkalinity and total suspended solid (TSS) analyses, and the other sample was acidified with sulfuric acid for ammonia, total nitrogen (TN), and total phosphorus (TP) analyses. Chemical analyses of surface water samples for the 2011 sampling event were conducted by the AnalySys, Inc. laboratory in Austin, Texas, where water chemistry parameters were determined utilizing EPA standard methods (Table 1; EPA 1983) as described in more detail below.

Nitrate Nitrogen, Nitrite Nitrogen and Soluble Reactive Phosphorus: Following standard EPA Method 300.0, the concentrations of anions in a 10-µL sample are determined using an ion chromatography system equipped with a conductivity detector.

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

Total Kjeldahl Nitrogen and Total Nitrogen: Following standard EPA Method 351.2, the sample is heated in the presence of sulfuric acid, potassium sulfate, and mercuric sulfate for two and one-half hours. The resulting residue is cooled, diluted to 25mL and determined by spectroscopy. Total Kjeldahl nitrogen is the sum of free-ammonia and organic nitrogen compounds which are converted to ammonium sulfate during the digestion. Total nitrogen is calculated as the sum of total Kjeldahl nitrogen, nitrate and nitrite.

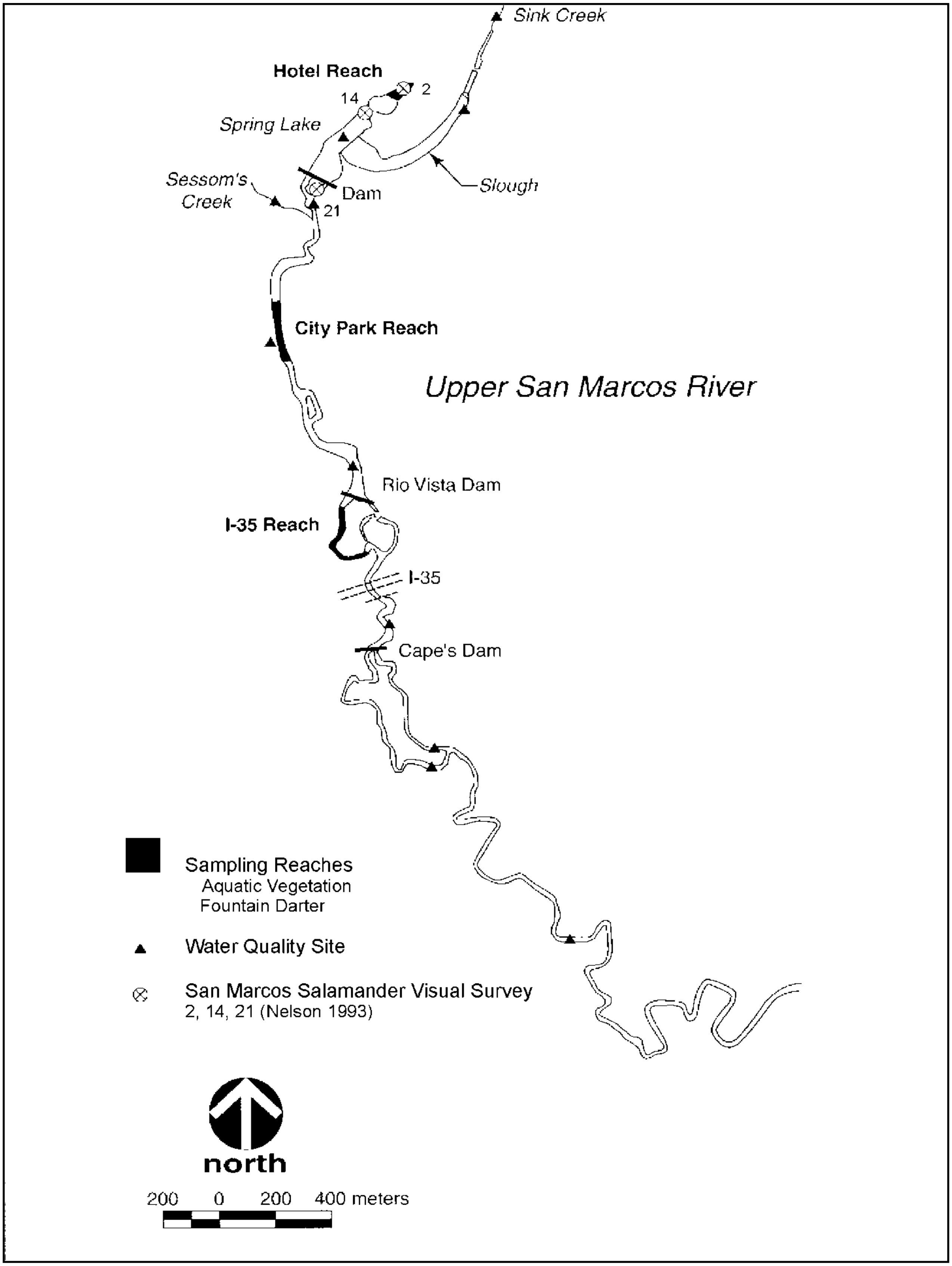


Figure 1. Upper San Marcos River water quality and biological sampling areas.

Total Phosphorus: Following standard EPA Method SM4500-P E, the sample is pretreated to select the phosphorus forms of interest; the forms are then converted to orthophosphate. Ammonium molybdate and antimony potassium tartrate react in an acid medium with dilute solutions of phosphorus to form an antimony-phospho-molybdate complex, which is reduced with ascorbic acid to form an intense blue-colored complex. The absorbance of the complex is measured by spectroscopy, and is proportional to the orthophosphate concentration.

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

Total Suspended Solids: Following standard EPA Method SM2540-D, a well-mixed sample is filtered through a glass fiber filter, and the residue retained on the filter is dried to a constant weight at 103-105°C.

Table 1. A list of the water quality analyses performed on surface water grab samples from 18 sites along the San Marcos Springs/River ecosystem in 2011, along with the analytical method, technique and minimum analytical detection levels of each analysis.

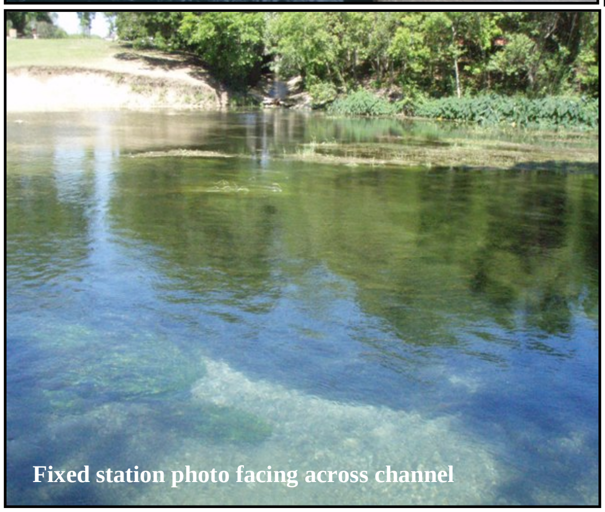
PARAMETER	EPA METHOD	TECHNIQUE (2009)	MINIMUM ANALYTIC LEVELS (per liter)
Total Suspended Solids	SM4500-D	Gravimetric	4 mg
Alkalinity	310.1	Titration	20 mg
Nitrate Nitrogen	300.0	Ion Chromatography	0.05 mg[a]
Nitrite Nitrogen	300.0	Ion Chromatography	0.02 mg[a]
Ammonia	350.2	Spectroscopy	0.01 mg
Total Kjeldahl Nitrogen	351.2	Spectroscopy	0.1 mg
Total Nitrogen	351.2	Spectroscopy	0.1 mg
Soluble Reactive Phosphorous	300.0	Ion Chromatography	0.05 mg
Total Phosphorous	SM4500-P E	Spectroscopy	0.02 mg

[a] micrograms.

In addition to the water quality collection effort, a long-term record of habitat conditions has been maintained with fixed station photography. Fixed station photographs allowed for temporal habitat evaluations and included an upstream, a cross-stream, and a downstream picture; each taken at all water quality sampling locations depicted in Figure 1.


Measuring standard water quality parameters


Fixed station photo facing upstream


Fixed station photo facing across channel


Fixed station photo facing downstream

Aquatic Vegetation Mapping

The aquatic vegetation mapping effort consisted of mapping all of the vegetation in each of three study reaches (Spring Lake Dam, City Park, and I-35). In addition, annual Texas wild-rice monitoring was performed in summer and one Critical Period low-flow event in the entire San Marcos River (to the most downstream Texas wild-rice plant). Mapping was conducted using a Trimble Pro-XH global positioning system (GPS) unit with real-time differential correction capable of sub-meter accuracy. The Pro-XH receiver was linked to a Trimble Recon Windows CE device (or similar device) with TerraSync software that displays field data as they are gathered and improves efficiency and accuracy. The GPS unit was placed in a 10.6 feet (ft) Necky Rip kayak with the GPS antenna mounted on the bow. The aquatic vegetation was identified and mapped by gathering coordinates while maneuvering the kayak around the perimeter of each vegetation type at the water's surface. Vegetation stands that measured between 0.5 and 1.0 m in diameter were mapped by recording a single point. Vegetation stands less than 0.5 m in diameter were not mapped.

GPS and kayak equipment used during aquatic vegetation mapping

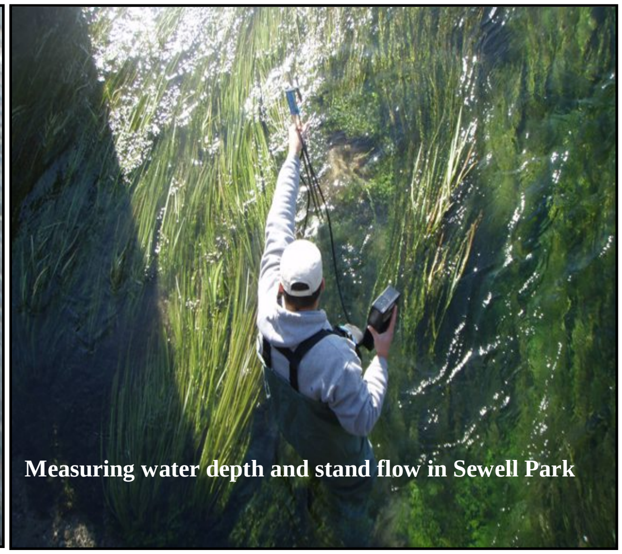
Texas Wild-Rice Physical Observations

At the beginning of the initial sampling activities for this project in 2000, Texas wild-rice stands throughout the San Marcos River were assessed and documented as being 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. Monitoring activities associated with "vulnerable" stands were designed following discussions with Dr. Robert Doyle, currently with Baylor University, and Ms. Paula Power, formerly with the USFWS National Fish Hatchery and Technology Center, San Marcos. The aerial coverage of Texas wild-rice stands in vulnerable locations were determined in 2011 by GPS mapping (described above), but some smaller stands were measured using maximum length and maximum width. The length measurement was taken at the water surface parallel to streamflow and included the distance between the base of the roots to the tip of the longest leaf. The width was measured at the widest point perpendicular to the stream current (this usually did not include roots). The length and width measurements were used to calculate the area of each stand according to a method used by the Texas Parks and Wildlife Department (J. Poole, TPWD, pers. comm.) in which percent cover was estimated for the imaginary rectangle created from the maximum length and maximum width measurements.


Recording GPS positions of Texas wild-rice in I-35 Reach


Measuring area of Texas wild-rice at Thompson's Island


Partially emergent stand of Texas wild-rice


Measuring water depth and stand flow in Sewell Park

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

Flow measurements were taken at the upstream edge of each Texas wild-rice stand and depth was measured at the shallowest point in the stand. Data on velocity, depth, and substrate composition were collected at 1-m intervals along cross-sections in the river in each area where Texas wild-rice plants were monitored. To complement all of the measurements made during each survey, photo sets were made for each of the sampling events in 2011.

Fountain Darter Sampling

Drop Net Sampling

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

Drop-netting in the City Park 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 the adjacent area within three meters of the net. Fountain darters were identified, enumerated, measured for total 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, and the rest were simply counted. Fish species not readily identifiable in the field were preserved for identification in the laboratory. All live giant ramshorn snails (*Marisa cornuarietis*) were counted, measured, and destroyed, while a categorical abundance was recorded (i.e., none, slight, moderate, or heavy) for the exotic Asian snails (*Melanoides tuberculata* and *Thiara granifera*) and the Asian clam (*Corbicula* sp.). A total count of crayfish (*Procambarus* sp.) and grass shrimp (*Palaemontes* sp.) was also recorded for each dip net sweep.

Drop Net Data Analysis

The fisheries data collected with drop nets were analyzed in several ways. First, fountain darter densities in the various vegetation types were calculated using the complete San Marcos River dataset (2000-2011). Comparing density values between vegetation types provides valuable information on species/habitat relationships. These average density values were then used with aquatic vegetation mapping data on total coverage of each vegetation type to create estimates of the population abundance in each reach (fountain darter density within a vegetation type x total coverage of that vegetation type in a given reach). Because there were generally only two drop net samples in each vegetation type within each reach, density estimates between sampling efforts had great variation and population estimates based on those densities are greatly influenced by this variation. Part of the variation would be due to changes in environmental conditions (discharge, temperature, etc.) that had occurred since the last sample, but part was due to natural variation between samples. Without adding samples (the total number is limited by federal permit and time constraints) it is impossible to tell how much of the variation is attributed to each source within a given sampling effort. Using the average density of fountain darters across all samples for a given vegetation type does not account for changes in density across samples (differences associated with changes in environmental conditions), but the increased sample size substantially reduces the high natural variability. This type of comparison between samples, where density values are held constant across all samples, is based entirely upon changes in vegetation composition and abundance between sampling efforts. Because these abundance estimates use the same density values across sites and seasons, and do not include estimates of fountain darters found in vegetation types that are not sampled with drop nets, the absolute numbers generated with this method have some uncertainty associated with them. Thus, the estimates are presented as relative comparisons by normalizing the data to the maximum estimate (the absolute value of all samples are converted to a percentage of the maximum value).

In addition to density and abundance calculations, drop net data were also used to generate length-frequency histograms for each season sampled. Analysis of these data, along with length-frequency data generated from dip netting, allows for inferences into reproductive seasonality.

Dip Net Sampling

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 method were identified, measured, recorded as number per dip net sweep, and returned to the river at the point of collection. The numbers of native and exotic snails were also enumerated and recorded for each dip.

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. In 2009, to assess changes occurring on the lower river, a new sample reach was added on the lower San Marcos River in Section 12 near Todd Island. Though information relating the number of fountain darters by vegetation type was not gathered by this method (as in the drop net sampling) it did permit a more thorough exploration of various habitats within the reach. Also, spending a comparable length of time sampling the entirety of each reach allowed comparisons to be made between the data gathered during each sampling event.

Dip Net Data Analysis

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

Presence/Absence Dipnetting

Presence/Absence dip netting was initiated on the San Marcos River during spring 2006. This method is designed to be a quick, efficient, and repetitive means of monitoring the fountain darter population. Also, since it is much less destructive than drop netting, it can be conducted during extremely low flow periods without harming critical habitat.

During each sample, fifty sites were distributed among three sample reaches based on total area, diversity of vegetation, previous fountain darter abundance estimates, and overall biological importance of each reach. Fourteen sites are chosen in the Spring Lake Dam Reach, 22 sites are chosen in the City Park Reach, and 14 sites are chosen in the I-35 Reach. Several sites are chosen in each of the dominate vegetation types in each reach. However, since vegetation coverage changes often, the number of sites within each vegetation type fluctuates slightly between samples.

Four dips were conducted at each site for a total of 200 dips per sample period. After each dip, presence or absence of fountain darters was noted and the entire contents of the net were placed into a plastic tub with river water to avoid recapturing organisms. After all dips were completed at a site, all organisms were released near the site of capture.

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 (known as Riverbed) 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 three smaller areas for a greater coverage of suitable habitat. San Marcos salamander densities in the three subdivisions below Spring Lake Dam were averaged as one.

SCUBA gear was used to sample habitats in Spring Lake, while a mask and snorkel were used in the site below Spring Lake Dam. For each sample, an area of macrophyte-free rock was outlined using flagging tape, and three timed surveys (5 minutes each) were conducted by turning over rocks >5 cm wide and noting the number of San Marcos salamanders observed underneath. Following each timed search, the total number of rocks surveyed was noted in order to estimate the number of San Marcos salamanders per rock in the area searched. The three surveys were averaged to yield the number of San Marcos salamanders per rock. The density of suitable sized rocks at each sampling site was determined by using a square frame constructed out of steel rod to take random samples within the area. Three random samples were taken in each area by blindly throwing the 0.25 m^2 frame into the sampling area and counting the number of appropriately sized rocks. The three samples were then averaged to yield a density estimate of the rocks in the sampling area. The area of each site was determined by physically measuring each sampling area.

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

OBSERVATIONS

The BIO-WEST project team conducted the study components for the 2011 Comprehensive sampling and Critical Period events on the dates shown in Table 2.

Table 2. Study components of the 2011 sampling events.

EVENT	DATES
Spring	
Vegetation Mapping	April 21 - 22, 28
Texas wild-rice physical observations	April 27
Fountain Darter Sampling	April 26 - 29, May 18
San Marcos Salamander Observations	May 18
Summer	
Texas wild-rice mapping	June 20 - 27
Critical Period 1	
Vegetation Mapping	Sept. 14 - 15
Texas wild-rice physical observations	Sept. 2, 21
Fountain Darter Sampling	Sept. 19 - 22
San Marcos Salamander Observations	Sept. 22
Texas wild-rice mapping	Aug. 29 - Sept. 2
Fall	
Vegetation Mapping	Nov. 1 - 3
Texas wild-rice physical observations	Nov. 7 - 8
Fountain Darter Sampling	Nov. 7 - 10
San Marcos Salamander Observations	Nov. 15

San Marcos Springflow

Springflows in the San Marcos River in 2011 were below 100 cfs for 124 consecutive days and below 120 cfs for 216 consecutive days. A minimum flow of 88 cfs occurred twice in 2011 (September 18-19), whereas the minimum flow in 2010 was almost twice that (163 cfs, Table 3). With a maximum single daily average of 173 cfs, 2011 was a below average rainfall year without any major rain events. This resulted in daily average discharge similar to 2006, 2008, and 2009 (Figure 2). The maximum mean daily discharge was reached very early in 2011 on January 9 when the river reached 173 cfs. This was the lowest maximum mean daily discharge since 2006 (145 cfs, Table 3). Mean daily discharge in

2011 also failed to top 200 cfs for the second time since this study was implemented in 2000. Mean monthly discharge did not exceed the historic average in 2011 resulting in 14 straight months where the flows of the San Marcos River were below the historical average (Figure 3).

Table 3. Minimum and maximum discharges (cfs) in the San Marcos River since the beginning of the study in 2000.

Year	Minimum Discharge	Maximum Discharge
2000	108	397
2001	167	1,019
2002	157	668
2003	156	332
2004	146	1,280
2005	136	361
2006	90	145
2007	101	971
2008	97	217
2009	83	206
2010	163	273
2011	88	173

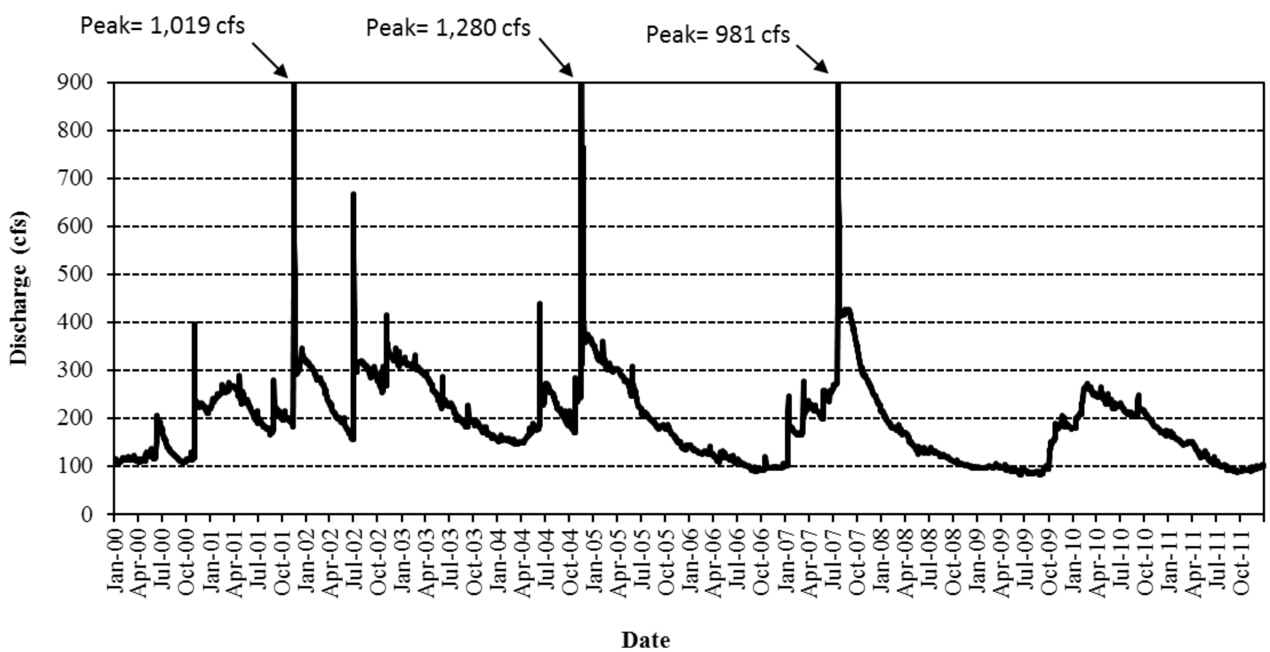


Figure 2. Daily average discharge (cfs) for the San Marcos River since the beginning of the study in 2000.

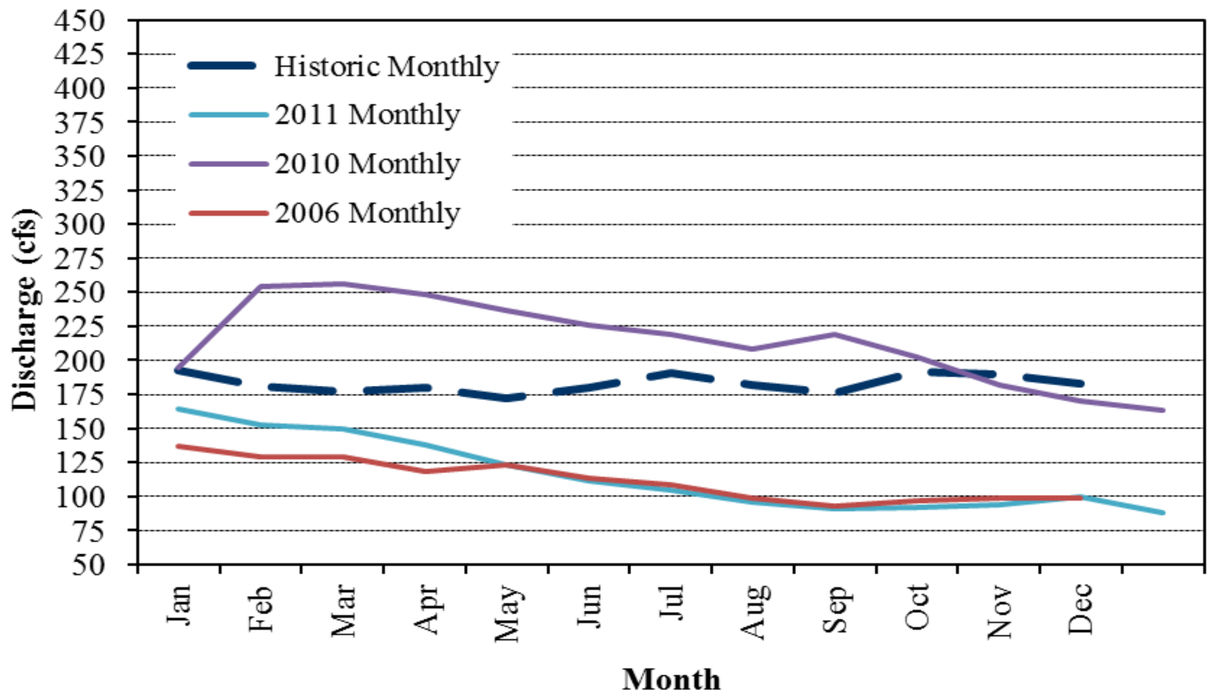


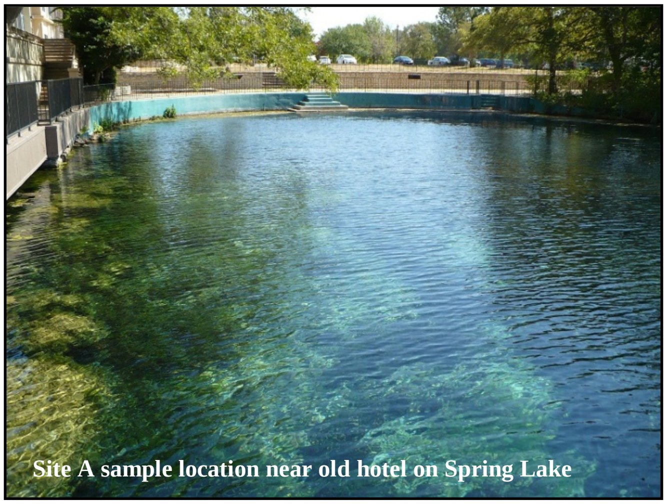
Figure 3. Mean monthly discharge (cfs) in the San Marcos River during the 1956-2011 period of record.

Water Quality Results

Spring Lake

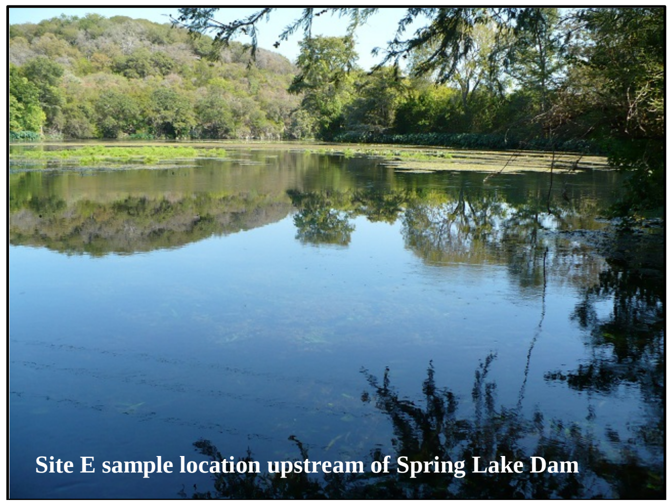
The original sampling sites (2000-2002) for Spring Lake were chosen based on historical locations that have been used during basic limnological sampling conducted at Texas State University (Figure 1). Those same nine water quality sampling sites were sampled during the Critical Period sampling event in 2011 (September 21, 2011). The Spring Lake sampling site locations were as follows:

Site A was located directly in front of the hotel on Spring Lake in a deep hole,
Site B was located in front of the “submarine” area,
Site C was located across from “The Landing,”
Site D was just upstream from the chute at Saltgrass Steakhouse,
Site E was located just upstream of the dam,
Site F was chosen to represent the mixing of the slough and spring arms,
Site G was located behind the softball fields and under a powerline in the slough,
Site H was located downstream of the road crossing in the slough arm, and
Site S was in Sink Creek.


Site A sample location near old hotel on Spring Lake


Site D sample location upstream of chute in Spring Lake


Site G sample location in slough of Spring Lake


Site E sample location upstream of Spring Lake Dam

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

Information on standard water quality parameter point measurements for each water quality site in Spring Lake is presented in Table 4. Average values from seven sampling events during 2000-2002 (Average 2000-2002; this mean does not include the high-flow event), values from the 2002 high flow event (High Flow), average values from the two 2006 low-flow Critical Period events (Low Flow 2006), average values from four 2009 low-flow sampling events (Low Flow 2009), and measurements from one 2011 low-flow Critical Period (Low Flow 2011) event are presented for comparison between varying annual discharge conditions. Similarly, information on water chemistry measurements for each site in Spring Lake is presented in Table 5.

Temperatures measured during the 2011 Critical Period sampling event were similar to mean temperatures recorded during previous sampling events (Table 4), with the exception of Site C at the lower end of the Slough Arm, which had a higher temperature (24.47 °C) than during previous sampling events (20.76 - 23.29 °C). In 2011, temperatures within the lower Slough Arm (Sites C, F, and G) ranged from 23.65 - 24.47°C and were slightly higher than those in the Spring Arm and sites upstream of the slough (21.68 - 22.85°C). This pattern was also observed in two of the summer low-flow sampling events in 2009, with Sites C, F, and G having elevated temperatures compared to the other

Spring Lake sites. These lower Slough Arm sites have shallower water depths in areas that do not receive much shade, likely contributing to elevated water temperatures.

Conductivity did not vary among sites within the lake for the period of the study. A conductivity-to-TDS conversion of 0.65 was used so that a comparison could be made with the TDS water quality standard. During the Critical Period event in 2011, TDS values at each of the Slough Arm sites approached or met the water quality standard value of 400 milligrams per liter (mg/l), which equals 615 micromhos per centimeter (µmhos/cm). Similar to low-flow sampling events in 2006 and 2009, conductivity of Spring Lake sites in 2011 was similar or lower than the average during 2000-2002 at all sites (Table 4).

As during previous sampling events, dissolved oxygen (DO) concentrations measured during the 2011 low-flow sampling event at sites A and B (nearest the springs), site H at the upstream end of the slough, and site S in Sink Creek did not always meet the TCEQ “high” water quality standard of 6.0 mg/l for DO for the Upper San Marcos River Segment No. 1814 (Table 4). Lower DO concentrations at the headwaters is typically due to aquifer water naturally having lower DO concentrations. However, DO concentrations at sites A and B were above 5 mg/l and higher in 2011 than during the low-flow sampling periods in 2009 (Table 4). Low DO concentrations at the upstream end of the Slough Arm have previously occurred due to the higher water temperatures in the summer and decomposition of the abundant plant material, which requires oxygen. Similarly, low DO concentrations are typical within Sink Creek, where the water is shallow with little to no flow to replenish DO.

Table 4. Average standard water quality parameters of surface water at sampling sites in Spring Lake during normal conditions (Mean), a high-flow event in 2002 (High Flow), low-flow conditions in 2006 (Low Flow 2006), low-flow conditions in 2009 (Low Flow 2009), and a low-flow event in 2011 (Low Flow 2011).

Sampling Period	Site								
	A	B	C	D	E	F	G	H	S
Temperature (°C)									
Mean*	21.73	21.97	22.18	22.54	22.56	23.83	22.85	22.49	20.61
High Flow[a]	21.56	21.63	22.00	22.28	22.44	25.49	26.16	24.79	23.59
Low Flow 2006[b]	21.86	22.72	22.86	22.84	22.81	22.61	27.01	23.89	24.02
Low Flow 2009[c]	21.76	22.03	22.18	22.15	22.00	22.91	23.85	21.41	20.30
Low Flow 2011	21.68	22.17	24.47	22.71	22.63	24.27	23.65	22.85	22.76
Conductivity (µS/cm)[a]									
Mean*	563	558	560	561	560	545	541	562	642
High Flow[a]	577	574	562	564	568	600	607	615	610
Low Flow 2006[b]	542	551	547	563	556	554	516	523	534
Low Flow 2009[c]	547	552	552	562	558	554	513	513	576
Low Flow 2011	567	587	585	599	592	585	581	583	569
pH									
Mean*	7.11	7.14	7.13	7.17	7.24	7.35	7.49	7.61	7.51
High Flow[a]	6.80	6.83	6.81	6.83	6.87	7.13	7.20	7.11	7.17
Low Flow 2006[b]	7.12	7.15	7.21	7.11	7.19	7.16	7.29	7.17	7.16
Low Flow 2009[c]	7.53	7.59	7.62	7.66	7.62	7.57	7.75	7.74	7.75
Low Flow 2011	7.34	7.34	7.48	7.50	7.35	7.42	7.55	7.32	7.25
DO (mg/l)									
Mean*	5.54	6.23	6.45	8.45	8.60	9.58	8.07	10.07	6.64
High Flow[a]	4.81	4.74	5.66	6.39	6.68	6.24	6.38	4.60	5.98
Low Flow 2006[b]	5.38	5.98	7.25	6.50	6.49	6.60	3.65	1.58	2.52
Low Flow 2009[c]	4.72	5.21	7.14	5.30	5.58	8.13	8.34	6.38	4.13
Low Flow 2011	5.11	5.72	10.25	6.62	6.73	10.44	5.96	3.05	2.68

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high-flow sampling event in fall 2002.
[a] High-flow sampling event conducted on August 5, 2002.
[b] Low-flow sampling events conducted on July 25 and September 14, 2006.
[c] Low-flow sampling events conducted on January 9, April 10, May 19, and June 24, 2009.

Total suspended solids (TSS) values were low at all sites in Spring Lake in 2011, reflecting the clear water conditions present in the lake, slough and creek. During the entire study period since 2000, the maximum TSS value of 11 mg/l was measured at Sink Creek in September 2006 (Appendix B). Alkalinity was fairly constant throughout Spring Lake for the duration of the study (Table 5, Appendix B).

Ammonium concentrations in 2011 were well below the TCEQ screening level of 1.0 mg/l at all sites (Table 5). Ammonium levels measured in 2011 were very similar to those measured during 2006 and 2009 low-flow sampling events, and very slightly higher than average levels measured under 2000-2002 conditions and the high-flow event. Nitrate concentrations of surface water in Spring Lake were much lower in 2011 than during previous sampling events, and well below the TCEQ water quality standards screening level of 1.0 mg/l (Table 5). Similar to previous years, nitrate concentrations in the Slough Arm (Sites G and H) and Sink Creek (Site S) were lower than sites in the Spring Arm. Also similar to previous sampling periods, TN concentrations in Spring Lake during the 2011 low-flow sampling event consisted of a high percentage of nitrate and a low percentage of ammonium. TN concentrations were much lower at all sites in 2011 than during previous low-flow and high-flow sampling events (Table 5). TN concentrations in the Slough Arm and Sink Creek (Sites F, G, H, and S) were similar to the low TN values measured under normal conditions (2000-2002), and were even lower at Spring Arm sites in 2011. As discussed below for the San Marcos River, the high nitrate values measured during previous sampling periods (2000-2009) in the San Marcos River and Spring Lake were not the result of anthropogenic inputs to the immediate surface waters (rainfall and overland flow was very low in 2006 and 2009). Spring flow is the most likely source of high nitrate values found at all sites in the San Marcos River and Spring Lake. The median concentration of nitrate in the Edward's Aquifer ranges from 1.4 to 1.7 mg/l (Bush et al. 1998). Nitrate values at the Spring Arm sites are typically constant among these sites and throughout the year (Appendix B), whereas nitrate concentrations at the Slough Arm sites and Sink Creek are much lower than the Spring Arm sites for most sampling events (Table 5). These lower concentrations may be due to uptake of nitrate by the abundant plants and algae in the Slough Arm and Sink Creek, or the fewer number of springheads in the Slough Arm contributing nitrogen. These values were much higher following the 2002 high-flow event, but further investigation (more high-flow events) will enable us to compare these data.

Soluble Reactive Phosphorus concentrations (SRP) and Total Phosphorous (TP) concentrations in Spring Lake during 2011 were below analytical detection limits at all sites (Table 5). Previously during normal flow conditions in 2000-2002, SRP and TP values fluctuated from season to season and site to site, but were well below the TCEQ's screening values of 0.1 and 0.2 mg/l, respectively (Appendix B). During this period, the Slough Arm and Sink Creek sites generally had higher concentrations of SRP than the Spring Arm sites. The higher SRP concentrations probably occurred due to recycling of SRP (as plant material decayed) and inputs of phosphorus from the immediate watershed.

Table 5. Average water chemistry parameters of surface water at sampling sites in Spring Lake during normal conditions (Mean), a high-flow event in 2002 (High Flow), low-flow conditions in 2006 (Low Flow 2006), low-flow conditions in 2009 (Low Flow 2009), and a low-flow event in 2011 (Low Flow 2011).

Sampling Period	Site								
	A	B	C	D	E	F	G	H	S
Alkalinity (mg/l)									
Mean*	232	233	244	245	242	249	240	247	278
High Flow[a]	263	261	261	257	257	265	257	267	271
Low Flow 2006[b]	260	255	260	265	265	260	210	230	230
Low Flow 2009[c]	260	257	265	265	260	265	223	240	250
Low Flow 2011	260	260	270	260	260	260	270	260	260
Ammonium (mg/l)									
Mean*	0.040	0.036	0.018	0.048	0.023	0.051	0.049	0.044	0.043
High Flow[a]	0.032	0.017	0.039	0.035	0.043	0.035	0.048	0.046	0.043
Low Flow 2006[b]	0.039	0.051	0.060	0.065	0.076	0.060	0.085	0.100	0.069
Low Flow 2009[c]	0.046	0.060	0.063	0.093	0.072	0.070	0.079	0.095	0.080
Low Flow 2011	0.029	0.018	0.044	0.054	0.054	0.069	0.079	0.105	0.114
Nitrate Nitrogen (mg/l)									
Mean*	1.261	1.327	1.512	1.621	1.717	0.890	0.680	0.559	0.195
High Flow[a]	2.621	1.608	1.813	1.659	1.532	1.431	1.174	1.251	1.404
Low Flow 2006[b]	1.320	1.205	1.158	1.360	1.220	1.120	0.166	<0.05	0.084
Low Flow 2009[c]	1.042	1.018	0.909	1.078	1.028	0.939	0.479	0.632	0.143
Low Flow 2011	0.410	0.557	0.467	0.578	0.545	0.462	0.230	<0.05	0.073
Total Nitrogen (mg/l)									
Mean*	1.497	1.634	1.889	2.055	2.002	1.126	0.910	0.885	0.938
High Flow[a]	2.458	2.218	2.325	2.109	1.952	1.813	1.598	1.692	1.894
Low Flow 2006[b]	3.53	2.415	4.085	2.280	2.115	2.110	1.215	1.065	2.360
Low Flow 2009[c]	2.05	1.970	2.125	2.073	2.210	2.013	1.454	1.873	2.030
Low Flow 2011	0.981	0.956	1.090	1.240	1.120	0.999	0.940	1.02	0.958
Soluble Reactive Phosphorus (mg/l)									
Mean*	0.016	0.018	0.014	0.016	0.015	0.018	0.024	0.019	0.039
High Flow[a]	0.010	0.013	0.008	0.007	0.009	0.009	0.010	0.008	0.019
Low Flow 2006[b]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Low Flow 2009[c]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Low Flow 2011	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total Phosphorus (mg/l)									
Mean*	0.021	0.048	0.017	0.027	0.037	0.023	0.048	0.024	0.073
High Flow[a]	0.004	0.022	0.018	0.028	0.043	0.028	0.065	0.027	0.059
Low Flow 2006[b]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Low Flow 2009[c]	0.009	0.016	0.008	0.004	0.003	0.005	<0.01	0.012	0.045
Low Flow 2011	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high-flow sampling event in fall 2002.
[a] High-flow sampling event conducted on August 5, 2002.
[b] Low-flow sampling events conducted on July 25 and September 14, 2006.
[c] Low-flow sampling events conducted on January 9, April 10, May 19, and June 24, 2009.

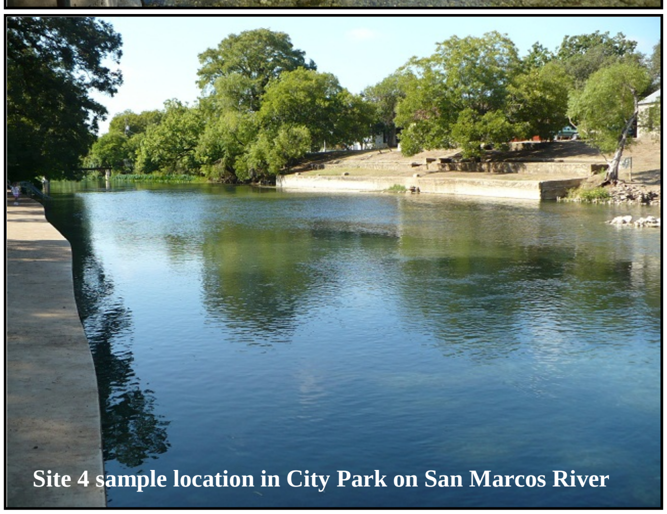
San Marcos River

The nine water quality sampling sites in the San Marcos River were the same in 2011 as the sites sampled during the initial water quality assessment in 2000-2002 and subsequent sampling events. The sites were as follows:

Site 1 was located directly downstream of the chute at Saltgrass Steakhouse;
Site 2 was located just downstream of Spring Lake Dam;
Site 3 was located in Sessom Creek at the Texas State University Aquatic Biology building, upstream of the confluence with the San Marcos River;
Site 4 was located within the City Park / Lion's Club Reach;
Site 5 was located in the far channel at Rio Vista Park;
Site 6 was located just upstream of the I-35 highway crossing;
Site 7 was located upstream of the falls within the artificial channel near the state fish hatchery;
Site 8 was located near the state fish hatchery outflow; and
Site 9 was located directly behind the old San Marcos Animal Shelter, near the current WWTP.


Site 1 sample location near chute on San Marcos River


Site 2 sample location downstream of Spring Lake Dam


Site 4 sample location in City Park on San Marcos River


Site 8 sample location on San Marcos River

Information on standard water quality parameter point measurements for each water quality site in the San Marcos River is presented in Table 6. Average values from seven sampling events during 2000-2002 (Average 2000-2002; this mean does not include the high-flow event), values from the 2002 high-flow event (High Flow), average values from the two low-flow Critical Period sampling events in 2006

(Low Flow 2006), average values from the four low-flow sampling events in 2009 (Low Flow 2009), and measurements from one Critical Period sampling event in 2011 (Low Flow 2011) are presented to compare between varying discharge conditions.

Table 6. Average standard water quality parameters of surface water at sampling sites in the San Marcos River during normal conditions (Mean), a high-flow event in 2002 (High Flow), low-flow conditions in 2006 (Low Flow 2006), low-flow conditions in 2009 (Low Flow 2009), and a low-flow event in 2011 (Low Flow 2011).

Sampling Period	Site								
	1	2	3	4	5	6	7	8	9
Temperature (°C)									
Mean*	22.53	22.55	22.75	22.67	22.64	22.47	22.00	22.22	22.08
High Flow[a]	22.78	22.76	22.90	22.83	23.17	23.12	22.71	22.97	22.65
Low Flow 2006[b]	22.48	22.61	23.18	22.35	22.37	22.18	22.33	22.28	22.56
Low Flow 2009[c]	22.18	22.03	19.97	21.93	20.77	21.45	20.49	20.40	21.28
Low Flow 2011	22.53	22.60	23.09	22.30	21.92	21.84	23.11	21.86	22.02
Conductivity (µS/cm)[a]									
Mean*	571	570	593	570	570	570	570	570	568
High Flow[a]	580	584	598	583	582	582	583	582	581
Low Flow 2006[b]	558	555	581	560	559	560	558	559	549
Low Flow 2009[c]	561	558	605	560	583	560	578	584	553
Low Flow 2011	595	592	615	593	595	592	587	591	584
pH									
Mean*	7.29	7.36	7.42	7.43	7.49	7.62	7.62	7.71	7.62
High Flow[a]	7.01	7.03	7.07	7.03	7.14	7.26	7.27	7.37	7.38
Low Flow 2006[b]	7.36	7.38	7.33	7.39	7.46	7.56	7.53	7.67	7.76
Low Flow 2009[c]	7.67	7.71	7.81	7.68	7.81	7.73	7.54	7.54	7.58
Low Flow 2011	7.58	7.54	7.56	7.57	7.60	7.84	7.72	7.76	7.93
DO (mg/l)									
Mean*	8.59	8.54	7.48	9.28	10.30	9.46	8.66	9.04	8.99
High Flow[a]	10.61	9.1	8.17	10.91	11.50	10.48	10.00	9.83	9.46
Low Flow 2006[b]	8.07	7.85	5.97	8.99	7.73	7.82	6.61	7.62	7.76
Low Flow 2009[c]	7.12	7.16	6.22	6.99	6.53	6.23	5.78	6.83	6.21
Low Flow 2011	8.31	7.84	6.37	8.06	6.39	8.00	6.99	7.43	7.26

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high-flow sampling event in fall 2002.
[a] High-flow sampling event conducted on August 5, 2002.
[b] Low-flow sampling events conducted on July 25 and September 14, 2006.
[c] Low-flow sampling events conducted on January 9, April 10, May 19, and June 24, 2009.

Continuing through the 2011 sampling event, an upstream-to-downstream pattern in water quality values other than temperature and pH has not been observed during the study. Values remain fairly constant throughout the system or they fluctuate minimally among sites. There does not appear to be much influence on water quality from surface water inflow to the river. The spring water quality conditions generally prevail within the study reaches of the San Marcos River system.

Conductivity did not vary among sites within the river system during the period of the study. Previously, a conductivity-to-TDS conversion of 0.65 was used so that a comparison could be made with the TDS standards for each system. The TDS values at each San Marcos River site during the Critical Period 2011 sampling event on Sessom Creek exceeded the TCEQ water quality standard value of 400 mg/l. The high TDS values recorded in August 2001 were thought to have been due to relatively low-flow conditions in the river at the time. However, average and below-average conductivity values measured during subsequent low-flow periods in 2006, 2009 and 2011 do not support this assumption (Table 6). No previous mention of exceedences has been indicated by the TCEQ.

Dissolved oxygen concentrations at the San Marcos River sampling locations met the TCEQ "high" water quality standard of 6.0 mg/l for DO during the 2011 low-flow sampling event (Table 6). Sites 1, 4, and 6 had the highest DO levels (8.00 - 8.31 mg/l), and the lowest levels were recorded at sites 3 and 5 (6.37 and 6.39 mg/l, respectively). In general, there was not an upstream-downstream gradient in DO, but concentrations were lower during the low-flow sampling events than the high-flow Critical Period in 2002 or the average quarterly sampling periods in 2000-2002.

Information on water chemistry measurements for each site in the San Marcos River is presented in Table 7. As previously mentioned, the TSS analysis conducted on 2006 - 2011 water samples was less sensitive than during the initial characterization, therefore one should be cautious when making comparisons to previous years. Total suspended solids values were very low at all sites in the San Marcos River in 2011, reflecting the clear water conditions present in the river. The maximum TSS value in 2011 was 6 mg/l, measured at the downstream-most sites (Site 8 and 9; Appendix B). Alkalinity was constant throughout the river during the 2011 sampling event, with values similar to those in Spring Lake (Table 7).

Ammonium concentrations at the San Marcos River sampling locations in 2011 varied among sites and were slightly lower than average concentrations during the 2006 and 2009 low-flow periods (Table 7). Additionally, ammonium concentrations were well below the TCEQ screening level of 1.0 mg/l at all sites. Nitrate values in 2011 were lower than average concentrations measured in all previous sampling periods and were below the TCEQ water quality standard screening level of 1.0 mg/l at all sites except Site 8 (Table 7). Site 8 is located near a fish hatchery outflow and had a nitrate concentration of 1.36 mg/l, which is similar to values measured during previous sampling periods. TN concentrations in 2011 were also lower than in previous sampling periods and an upstream-downstream gradient was not observed. However, there was a higher TN concentration at Site 8 (similar to nitrate) than at the other sites, likely due to the higher nitrate concentration measured at this site. Similar to Spring Lake sites, the TN values for the San Marcos River consist of a high percentage of nitrate rather than ammonium. Since the 2011 results are based on a single sampling event, it is difficult to establish whether there is a nitrate source at Site 8 or if the elevated reading is part of the natural variability in the river. The relatively variable TN measurements between sites and flow periods indicate the nitrogen levels are likely not the result of anthropogenic inputs to the immediate surface waters, but rather springflow.

Similar to Spring Lake, SRP and TP concentrations at San Marcos River sampling locations during 2011 were below analytical detection limits at all sites (Table 7). Due to the use of different analytical methods for these two analytes in 2006 - 2011, the detection limit was not as sensitive as in prior years (Appendix B). However, these analyses determined that during the 2011 low-flow sampling event, SRP was below 0.05 mg/l and TP was below 0.02 mg/l.

Table 7. Average water chemistry parameters of surface water at sampling sites in the San Marcos River during normal conditions (Mean), a high-flow event in 2002 (High Flow), low-flow conditions in 2006 (Low Flow 2006), low-flow conditions in 2009 (Low Flow 2009), and a low-flow event in 2011 (Low Flow 2011).

Sampling Period	Site								
	1	2	3	4	5	6	7	8	9
Alkalinity (mg/l)									
Mean*	239	233	231	239	236	237	232	236	226
High Flow[a]	259	259	259	259	262	263	259	261	259
Low Flow 2006[b]	270	260	270	270	260	270	265	265	260
Low Flow 2009[c]	260	260	260	260	265	270	260	265	265
Low Flow 2011	270	260	260	260	270	260	300	260	270
Ammonium (mg/l)									
Mean*	0.032	0.066	0.041	0.080	0.088	0.069	0.026	0.048	0.041
High Flow[a]	0.030	0.043	0.023	0.018	0.030	0.028	0.068	0.036	0.071
Low Flow 2006[b]	0.038	0.067	0.073	0.064	0.050	0.057	0.069	0.055	0.073
Low Flow 2009[c]	0.071	0.066	0.063	0.057	0.103	0.087	0.070	0.067	0.065
Low Flow 2011	0.036	0.054	0.042	0.051	0.091	0.087	0.082	0.027	0.033
Nitrate Nitrogen (mg/l)									
Mean*	1.284	1.439	1.631	1.453	1.531	1.421	1.331	1.318	1.278
High Flow[a]	1.661	1.169	1.598	1.116	1.218	1.218	1.577	1.207	1.217
Low Flow 2006[b]	1.455	1.245	1.368	1.380	1.330	1.350	1.300	1.310	1.250
Low Flow 2009[c]	1.115	1.058	1.138	1.090	1.048	1.068	1.010	1.055	1.030
Low Flow 2011	0.588	0.551	0.600	0.567	0.535	0.551	0.486	1.36	0.532
Total Nitrogen (mg/l)									
Mean*	1.477	1.798	1.766	1.664	1.983	1.560	1.550	1.528	1.506
High Flow[a]	2.019	1.396	1.719	1.299	1.410	1.658	1.948	1.616	1.542
Low Flow 2006[b]	2.395	3.030	2.430	2.380	2.740	2.395	3.395	2.395	3.635
Low Flow 2009[c]	1.943	2.155	2.540	2.338	2.325	1.958	2.135	2.180	2.393
Low Flow 2011	1.23	1.08	1.16	1.26	1.470	1.39	1.08	1.98	1.31
Soluble Reactive Phosphorus (mg/l)									
Mean*	0.008	0.008	0.007	0.010	0.005	0.007	0.007	0.006	0.011
High Flow[a]	0.006	0.006	0.010	0.008	0.009	0.008	0.049	0.009	0.006
Low Flow 2006[b]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Low Flow 2009[c]	<0.05	0.044	0.025	<0.05	<0.05	<0.05	<0.05	0.044	<0.05
Low Flow 2011	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total Phosphorus (mg/l)									
Mean*	0.014	0.012	0.016	0.021	0.012	0.014	0.011	0.012	0.018
High Flow[a]	0.010	0.010	0.015	0.015	0.016	0.014	0.052	0.014	0.016
Low Flow 2006[b]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.013	0.023
Low Flow 2009[c]	0.007	0.016	0.020	0.003	0.018	0.015	0.025	0.031	0.022
Low Flow 2011	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high-flow sampling event in fall 2002.
[a] High-flow sampling event conducted on August 5, 2002.
[b] Low-flow sampling events conducted on July 25 and September 14, 2006.
[c] Low-flow sampling events conducted on January 9, April 10, May 19, and June 24, 2009.

The thermistor temperature data for the Sessom Creek and Rio Vista Dam reaches are presented in Figure 4, and additional graphs for all reaches can be found in Appendix B. The continuously sampled water temperature data provides information regarding fluctuations due to atmospheric conditions, and springflow influences in the San Marcos River from 2000 - 2011. In many places the temperature remained nearly constant due to nearby spring inputs while other locations (typically further away from spring influences) were more substantially affected by atmospheric conditions. At times, it appears that precipitation can have acute impacts (typically very cold rainfall) in some locations causing a spike in temperature, 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). The thermistor at Sessom Creek was lost/stolen; therefore no data are available between October 2009 and April 2011. In addition, the thermistor at Spring Lake dam went missing, and no data are available between April and October 2011.

As in previous years water temperatures were most stable in the areas closest to the springheads (Dam and Chute Tailraces). Only at Rio Vista Dam and Thompson’s Island (artificial channel) did water temperatures exceed TCEQ’s standard of 26.67 ºC. At each of these sites temperatures were above this standard for 2 weeks. Both of these sites are well downstream of spring inputs, and are located in places where velocities are relatively slow.

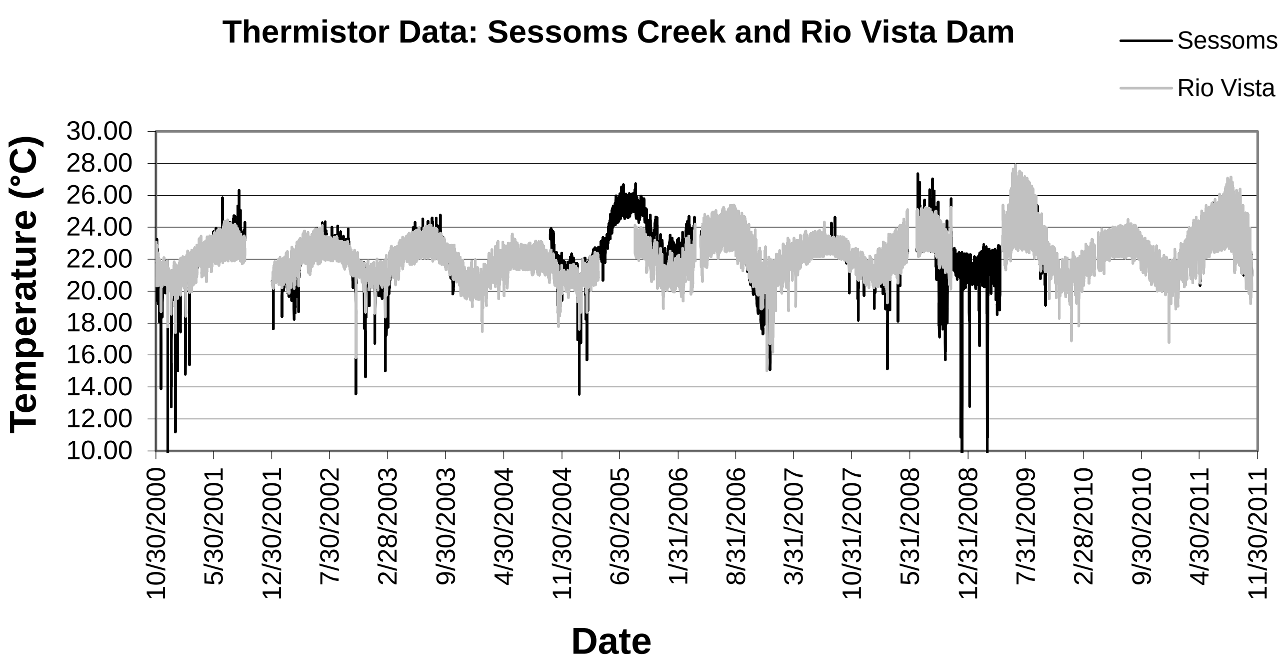


Figure 4. Thermistor data from the Sessom’s Creek and Rio Vista Dam sites.

Aquatic Vegetation Mapping

Maps of the aquatic vegetation observed during each sample effort can be found in the Appendix A map pockets. The maps are organized by individual reach with successive sampling trips ordered by date of occurrence. It is difficult to make broad 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.

City Park Reach

The boom/bust cycle typical of aquatic vegetation in the City Park Reach continued in 2011 as the extended drought settled into central Texas. Total vegetation in spring 2011 (4,334.8 m^2) was less than in spring 2010 (4,545.0 m^2), and below the spring average observed in this study (Figure 5). As summer continued and recreation impacts increased, total vegetation area dropped to the lowest level since 2009. This decrease continued into fall as typical fall rains were absent and springflows continued to decrease in a manner similar to 2006. Total vegetation in fall 2011 (3,300.9 m^2) was the second lowest (fall 2009 was the lowest) amount recorded in this study, and well below the fall long-term average (4,013.0 m^2) (Figure 5). While this yearly cycle of increased growth in the spring (due to decreased recreation pressure and increased springflows) and limited growth/trampling of plants was typical, the magnitude of vegetation loss was greater due to factors related to the exceptional drought.

The impact on individual species was dynamic and largely dependent on their location within the City Park Reach. As in previous years, *Hydrilla* experienced the largest impact decreasing from 2,298.2 m^2 to 1,497.7 m^2 in September and further to 1,393.0 m^2 by fall. This represents a 35% decrease from spring to Critical Period 1 (CP1), and a further 7% decrease from CP1 to fall. This cycle has been repeated each year because these non-native plants colonize the most heavily recreated sections of the reach. The middle section between the cement walls is not only channelized, but it is the location of two major access points to the San Marcos River. In addition, sediment inputs from runoff upstream have led to decreased depths, which in turn lead to easier access for recreation. *Hygrophila* did not reflect this increased recreation pressure as growth occurred from spring to CP1, and by fall had only fell by 2% overall in 2011. Unlike *Hydrilla*, most of the *Hygrophila* plants are found in relatively protected areas of the reach that see little recreation pressure.

The mixture of *Potamogeton* and *Hygrophila* (P/H) decreased dramatically from CP1 to fall (677.8 and 374.7 m^2, respectively); a 45% decrease. P/H has the lowest density of darters of all sampled vegetation types in the San Marcos River, but still holds about 5 darters/m^2. This decrease occurred in two sections in the reach normally immune to recreation damage. Consequently this may be a result of the low-flows of 2011 and the continued drought. Texas wild-rice exhibited a similar change in 2011 in the City Park Reach. These plants decreased by nearly 20 m^2 from spring to CP1 (342.4 m^2 to 323.2 m^2), but dropped precipitously from CP1 to fall (222.2 m^2). Much of this decrease occurred in areas that became shallower as the year progressed and springflows continued to drop. This 35% drop in 2011 in Texas wild-rice area in the City Park Reach was primarily a result of recreational impacts. The large open areas that developed as 2011 progressed invited other fast-establishing plants to colonize. In this case, filamentous algae gained a foothold near the culvert outflow along river-right in this reach. In the Comal River, the average fountain darter density in filamentous algae is 22.4 m^2 (the second highest density in these systems). However, these plants are prone to scouring in higher flows because of their inability to root firmly into the substrate. If these plants can establish in this reach it may be reflected in higher fountain darter numbers during dip-netting sampling efforts.

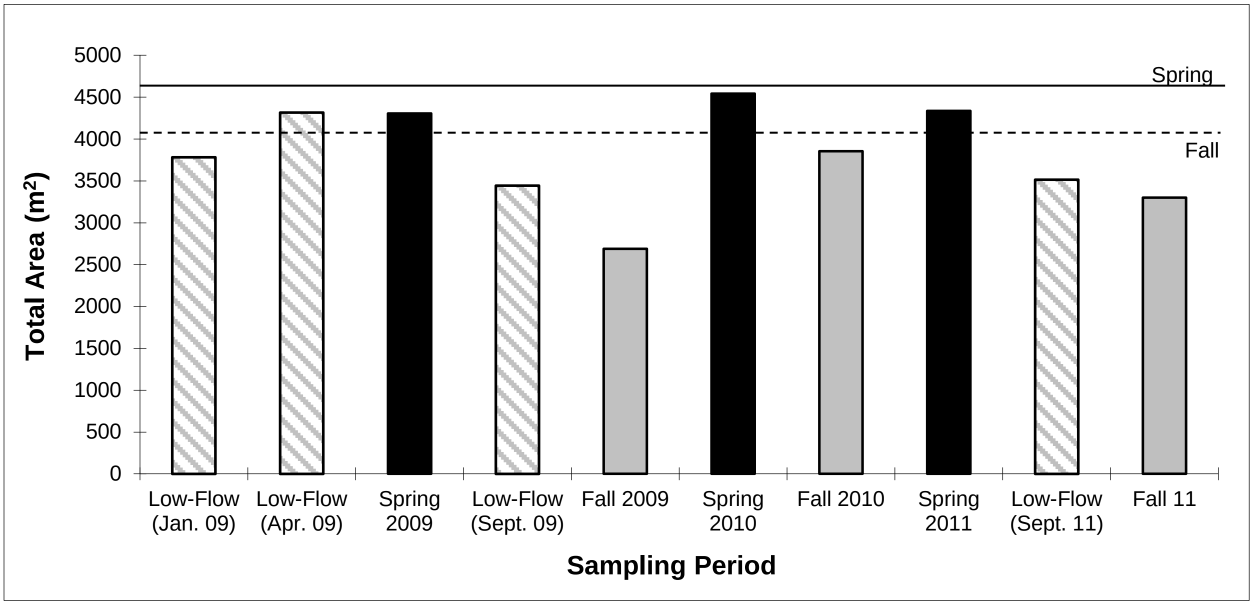


Figure 5. Changes in total aquatic vegetation area in the City Park Reach from 2009 to 2011. (Spring [solid] and Fall [dashed] lines represent historical averages)

I-35 Reach

Unlike the City Park Reach, aquatic vegetation in the I-35 Reach typically does not change as dramatically from season to season (Figure 6). Total vegetation in this reach in 2011 stayed below average, and changed little from spring to summer, but fell by 28% by the fall sampling effort. A possible reason for this "stability" in aquatic vegetation is the decreased recreation pressure compared to the Spring Lake Dam and City Park reaches. Downstream of Cheatham Street there are relatively few access points for the public. However, the river is more dynamic here with shifting banks and depths in certain areas of the reach. Since the removal of Rio Vista Dam, sediment has been accumulating and shifting in the upper portions of the I-35 Reach. As a result, aquatic vegetation that flourished in certain locations previous to dam construction now barely has a foothold in those areas. The river is still adjusting to the dam reconstruction and thus, changes in aquatic vegetation in this reach seem to be primarily related to sediment movement and channel reconfiguration resulting from differing flow patterns caused by the new Rio Vista dam.

While *Hydrilla* is typically common in this reach, shifting depths in the upper section displaced much of these plants by fall. As in previous years, *Hydrilla* grew prior to the spring sampling, and reached 300.1 m^2, the highest amount since June 2009. This decreased by 38% by CP1, and ended the year at only 64.4 m^2. Although this plant is non-native, it has shown some importance as fountain darter habitat in this reach and in other areas of the San Marcos River. *Hydrilla* that had been present in the upper section of the reach in previous years no longer remained. Most of the plants still present were small and fragmented. An important native plant, *Cabomba*, has exhibited higher densities of fountain darters in the past. It followed a similar trajectory as *Hydrilla* in 2011, but over 100 m^2 still remained in this reach by the fall. These plants flourish in deep, low-velocity backwaters and eddies, and are important fountain darter refuges during lower than average flows. Texas wild-rice also faired relatively well, increasing slightly between spring and CP1, but decreasing to 138.1 m^2 in fall. This was only a difference of 16.3 m^2 over the course of 2011.

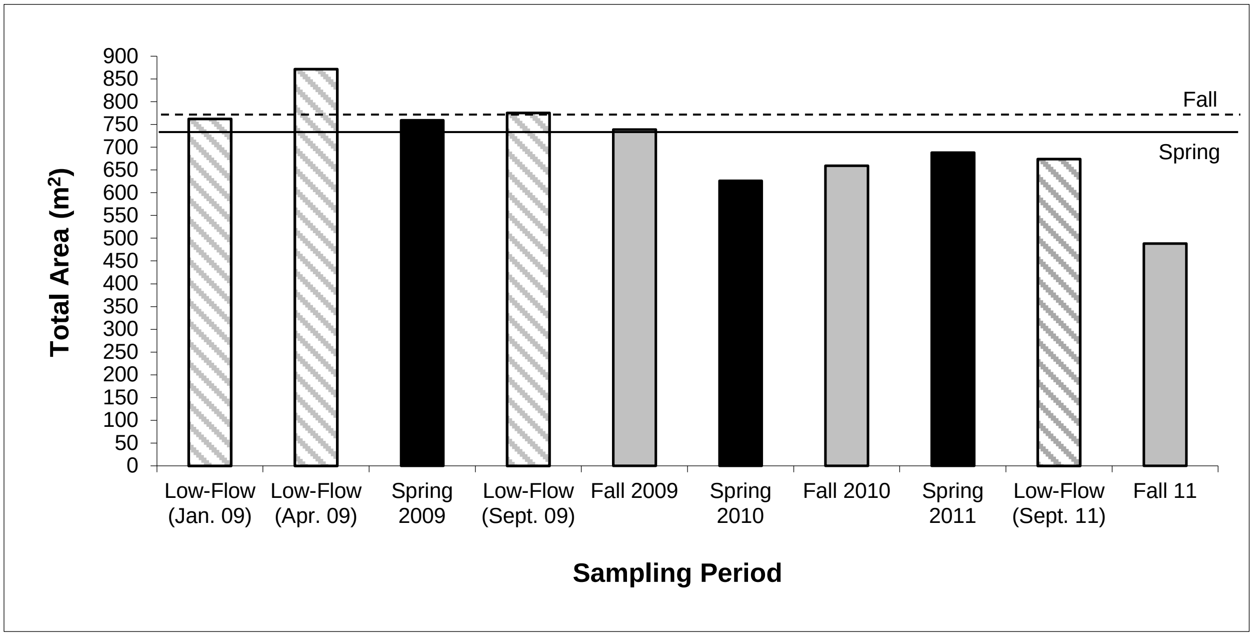


Figure 6. Changes in total aquatic vegetation area in the I-35 Reach from 2009 to 2011. (Spring [solid] and Fall [dashed] lines represent historical averages)

Spring Lake Dam

While the total aquatic vegetation at Spring Lake Dam Reach in spring 2011 (1,400.0 m^2) was the highest amount since 2008, it was still slightly below this studies' spring average (Figure 7). This total was also 43% more than the study low in fall 2009 (which occurred after an extended period of below average springflows). As in 2010, total vegetation decreased as the year progressed, and by fall was approximately 150 m^2 below the fall average for this reach. The degree of this loss of vegetation was far less than in previous low-flow years (2006, 2009) indicating the fast recovery time of these plants and/or less recreation pressure in this reach compared to other years.

Individual plant areas were relatively stable in this reach with the mixture of *Potamogeton* and *Hydrilla* (P/HD) decreasing the most from spring to fall (344.3 m^2 to 173.6 m^2). As in the City Park Reach, paths often develop from recreation impacts in relatively shallow areas of this reach. These appeared at the beginning of summer and expanded by fall impacting P/HD the most because they are located within shallow areas in this reach. Pure stands of non-native *Hydrilla* increased from spring to fall by 8% filling in areas around Texas wild-rice plants in the middle section of the Spring Lake Dam Reach. As in the City Park Reach, filamentous algae established in a lower velocity section of the reach by fall (see Appendix A maps). Establishment of filamentous algae will require close observation as it has proven to be important habitat to fountain darters in the Comal River.

Texas wild-rice decreased by 33% from spring to fall in the Spring Lake Dam Reach. This pales in comparison to 2006 when a 77% decrease occurred from spring to fall (where a large portion of stands were physically removed), but is still more than in 2009 (24% decrease), the last time Critical Period monitoring was triggered as a result of low flows (BIO-WEST 2007, 2010). As in previous low-flow years the impacts were most obvious within the eastern spillway of the reach where access points extend along much of the river-left shoreline. We can only speculate on whether this lessened impact (compared to 2006/2009) is due to the educational signs installed along this bank in 2007. In addition, a concerted effort was made in 2011 by the City of San Marcos to remove elephant ear along the banks, which opened up the banks giving easier access to the river in the Spring Lake Dam Reach.

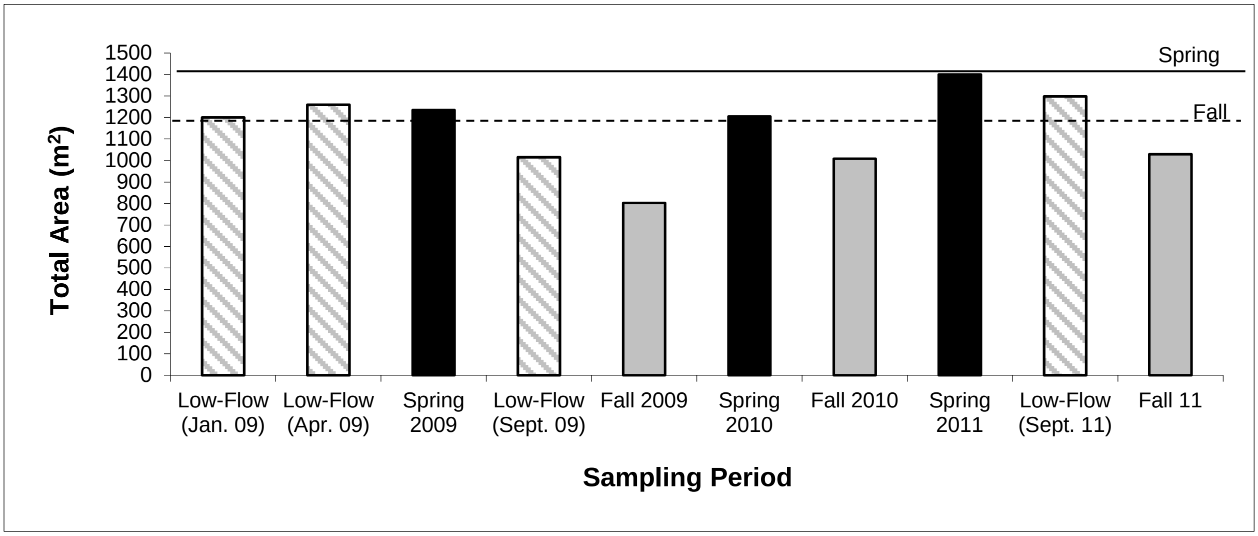


Figure 7. Changes in total aquatic vegetation area in the Spring Lake Dam Reach from 2009 to 2011. (Spring [solid] and Fall [dashed] lines represent historical averages)

Texas Wild-rice Annual Mapping

Texas wild-rice maps for the entire San Marcos River broken out by map segment for each sampling period can be found in the map pockets in Appendix A. After a prolonged drought (2008 - 2009) broke with near constant flows in 2010, an exceptional drought plagued central Texas in 2011. Flows that remained below their historic average resulted in two full Texas wild-rice mapping events. The summer sampling effort occurred in June, while the Critical Period low-flow event took place at the end of August and early September. The total amount of Texas wild-rice in the San Marcos River continued a decline that began in early 2009 (Table 8). Total areal coverage of Texas wild-rice in June 2011 was 3,916.8 m^2, a 3% decline from 2010, and the first time since 2009 total coverage was below 4,000 m^2. The entirety of this decrease took place within the first 2 miles of the San Marcos River, which is also where 88% of the Texas wild-rice resides. This section of the river is sinuous, closer to spring inputs, and compared to the other mapped sections has lower velocities. In addition, these sections are where most of the recreation pressure is found. Multiple access points, high density housing, and proximity to the university contribute to this pressure. As a result these sections often see dramatic changes in Texas wild-rice coverage from year to year. For example, the large plant located within Sewell Park has been steadily decreasing in coverage since 2009, and partially explains the 2% decrease in this section from 2010. A major contribution to this steady decline is the increasing size of Bobdog Island within the Spring Lake Dam Reach (Appendix A). Sediment carried down Sessom Creek has helped expand the river-right bank upstream of the large Texas wild-rice plant in Sewell Park. As a result much of the flow to the plant has been cut off, and to exacerbate matters, large mats of floating vegetation often cover the Texas wild-rice in Sewell Park inhibiting plant growth and reproduction. In City Park, recreation pressure in early summer resulted in uprooting/trampling of several plants within the middle section of the reach where depths are often under 2 – 3 feet during lower than average flows. Further downstream several plants were uprooted or died, but their effect on the total aerial coverage was minimal. The largest increase in coverage occurred near the downstream extent of Texas wild-rice in the San Marcos River. In this section total coverage increased from 14.0 m^2 to 66.0 m^2. Much of this increase occurred in an area where Texas wild-rice had been previously planted by USFWS.

As summer continued, flows decreased, while ambient air temperature and recreation pressure increased. As a result, total aerial coverage of Texas wild-rice decreased further to 3,671.6 m^2, the lowest total since 2009. As in June, the majority of this loss in Texas wild-rice plants (97%) occurred within the first couple miles of the San Marcos River. As highlighted above, the large plant at Sewell Park continued to fragment as vegetation mats settled over the plants in the lower than average flows. Unlike 2006 (another year with several low-flow Critical Period events) there was no major removal of Texas wild-rice within the Spring Lake Dam Reach. In 2006, large swaths of Texas wild-rice were physically removed resulting in a 77% loss in aerial coverage from spring to fall. The lack of any large scale removal in this reach may be a result of educational signs erected along the bank in this reach as a result of the 2006 damage. Further losses of Texas wild-rice plants within the Map 2 reach resulted in a 9% loss in coverage from the Summer (June) to Critical Period 1 (Aug./Sept.) sampling efforts. A 7% decrease was observed within the Map 3 reach which covers much of the area downstream of Rio Vista Park. Changes here are typically minimal during summer months because recreation pressure is less due to lack of access points to the river. Further downriver, changes were minimal with a loss of very few plants between sampling efforts. While this mapping gives us a good idea of changes in overall coverage, close observation of vulnerable Texas wild-rice plants in the San Marcos River helps us to understand stressors on individual plants.

Table 8. Total aerial coverage (m^2) of Texas wild-rice (*Zizania texana*) within each study reach in 2010 – 2011.

Sampling Period	Map 1	Map 2	Map 3	Map 4	Map 5	Map 6	Map 7	Total Area (m^2)
Summer 2010	2,518.6	696.6	383.8	372.7	19.3	3.1	14.0	**4,030.1**
Summer 2011	2,470.6	607.5	367.3	379.0	20.5	5.2	66.6	**3,916.8**
Critical Period 1 2011	2,289.7	550.6	342.2	392.4	33.3	4.0	59.4	**3,671.6**

Texas Wild-Rice Physical Observations

Texas wild-rice observations were conducted four times during 2011. These observations were made during comprehensive sampling events (spring and fall) and also during one low-flow observation period (<120 cfs) in early September 2011 (TWR1) and one critical low-flow period event in late September 2011 (CP1). Previously, 12 observation periods were conducted in 2009 during an extended low-flow period and 2 observation periods were conducted in 2010 during normal flow conditions. The dates of these observations are presented chronologically along with the corresponding average daily discharge value in Table 9. Daily discharge measurements for the 12 observations from 2009 are averaged in Table 9. In 2011, observations were made on vulnerable stands within the Sewell Park Reach and the I-35 Reach, and the Thompson's Island Reach was visited during each event to determine whether any new plants established in the reach. The total coverage of Texas wild-rice observed since the fall comprehensive event in 2009 in each "vulnerable" stand in the San Marcos River is presented in Table 10, and observations of trends in areal coverage within each study reach are discussed below. More detailed graphs on observations of root exposure, herbivory, emergence, flowering and seeding stands, coverage by floating vegetation, stand depth, and stand flow are found in Appendix B.

Table 9. The dates of Texas wild-rice observations conducted in 2009 - 2011 and the corresponding average daily discharge in the San Marcos River.

Texas Wild-Rice Observation Period	Event Type	Date	Average Daily Discharge (cfs)
2009 Average	12 Observation Periods	7 January-18 October 2009	98
2010 Spring	Comprehensive Sampling	21 April 2010	254
2010 Fall	Comprehensive Sampling	25 October 2010	198
2011 Spring	Comprehensive Sampling	27 April 2011	127
2011 TWR1	<120 cfs Observation	2 September 2011	93
2011 CP1	Critical Period 1	21 September 2011	89
2011 Fall	Comprehensive Sampling	7-8 November 2011	95

Two newly established Texas wild-rice plants were measured near the upstream end of the I-35 reach during the CP1 event and named Plant 4b and 4c (Table 10). These plants were located near the former site of several plants lost at the end of 2008. Similarly, a third plant established approximately 10 feet upstream of 4b (named 4a) and was measured in the fall 2011 event (Table 10). Average stand flow of vulnerable stands in the I-35 Reach were higher in 2011 than in 2009, although the flow during the TWR1 observation was similar to those measured in 2009 (Appendix B). Average stand flows in the Sewell Park Reach were low during the spring 2011 observation, but increased during subsequent events to levels recorded during normal conditions in 2010 (Appendix B). While vulnerable stands did not typically experience shallow water conditions (<0.5 feet depth) in 2010, portions of these stands in both Sewell Park and I-35 Reaches became shallow following the spring 2011 event (Appendix B). Almost 10 percent of vulnerable stand area in the I-35 Reach and five percent of those in Sewell Park were in shallow water during TWR1. However, for the remainder of 2011 these percentages remained constant in Sewell Park, and were reduced at I-35.

While approximately 17% of vulnerable plants in Sewell Park and 19% in I-35 were observed to be flowering or seeding in spring 2011, the trend generally decreased through the remainder of the year. Since the spring mapping effort, aerial coverage of Texas wild-rice vulnerable stands in Sewell Park declined 13% by CP1 in September and 42% by the fall (November). The area of vulnerable stands in fall 2011 was the lowest square footage mapped since fall 2000. As mentioned above, the duration of low-flow periods over the past few years coupled with the creation of Bobdog Island at the mouth of Sessom creek have increased the sedimentation and occurrence of floating vegetation matts occurring along the right side of the river in the Sewell Park Reach. These synergistic components coupled with intense recreation have had a deleterious effect on the vulnerable stands in this reach. Similarly, areal coverage of Texas wild-rice declined in the I-35 Reach in 2011, although not as drastically as in Sewell Park. The I-35 reach lost 3% of vulnerable stand area between spring and the CP1 event, and had lost 4% by the fall. As discussed above, these changes are less associated with recreation than they are with extended low flow periods and the changed flow patterns from the reconstructed Rio Vista dam.

Table 10. Areal coverage (m^2) of Texas wild-rice (*Zizania texana*) vulnerable stands during each sampling period from 2009 - 2011.

REACH-STAND NO.[a]	Fall 2009	Spring 2010	Fall 2010	Spring 2011	TWR 1	CP 1	Fall 2011
Sewell Park - 1	-	-	-	-	-	-	-
Sewell Park - 2 Sewell Park – 3	113.6	154.4	177	122.5	nm	81.7	83.8
Sewell Park - 4 & 5	41.6	44.4	36.7	46.8	nm	36.9	27.7
Sewell Park - 6	0.4	0.7	2.2	0.9	nm	1.3	***Gone***
Sewell Park - 7 & 8	219.8	300.8	276.6	323.3	nm	308.3	175.2
Total Area	**375.4**	**500.2**	**492.4**	**493.5**	-	**428.1**	**286.6**
I-35 – 4a	-	-	-	-	-	-	0.2
I-35 – 4b	-	-	-	-	-	0.1	0.2
I-35 – 4c	-	-	-	-	-	0.04	0.09
I-35 - 5	0.5	0.1	0.8	0.7	0.4	0.4	0.4
I-35 - 6	0.3	0.3	***Gone***	-	-	-	-
I-35 - 7	11.0	11.6	13.4	16.6	nm	18.6	18.2
I-35 - 8	134.6	111.2	109.7	104.5	nm	100.6	106.4
I-35 – 9 [b]	3.0	36.6	28.6	6.7	nm	5.3	2.9
I-35 – 10 [b]	12.2			24.8	nm	23.8	19.2
Total Area	**161.6**	**159.8**	**152.4**	**153.3**	-	**148.7**	**147.5**
Thompson's Island Reach	*Gone*	-	-	-	-	-	-
Total Area	***Gone***	**0**	**0**	**0**	**0**	**0**	**0**

[a] Many stands grew together to form individual stands after the first sampling period.
[b] New stands measured beginning in spring 2009.
[c] New stands measured beginning in summer 2011.
"nm" indicates a stand was not measured during a particular sampling event.

Fountain Darter Sampling Results

Drop Nets

In 2011, drop netting was conducted on the San Marcos River in the annual spring (April 28 - 29) and fall (Nov. 7 - 8) sampling events, as well as a Critical Period low-flow event on September 19 - 20. The number of drop net sites and vegetation types sampled in each reach per event is presented in Table 11. 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 11. Drop net sites and vegetation types sampled in each reach in 2011.

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)**

One hundred sixty-nine fountain darters were captured in the spring 2011 drop net sampling event, 170 darters were captured in the Critical Period event, and 183 darters were collected in the fall event. Over the course of the study, the number of darters captured per sampling effort has ranged from 24 in February 2002 to 616 in April 2007. To examine long-term trends in the fountain darter population relative to flow, abundance of fountain darters in each sample period were plotted over mean daily discharge throughout the study period (Figure 8). Due to the highly variable data no distinct discharge-abundance relationships are obvious from this comparison.

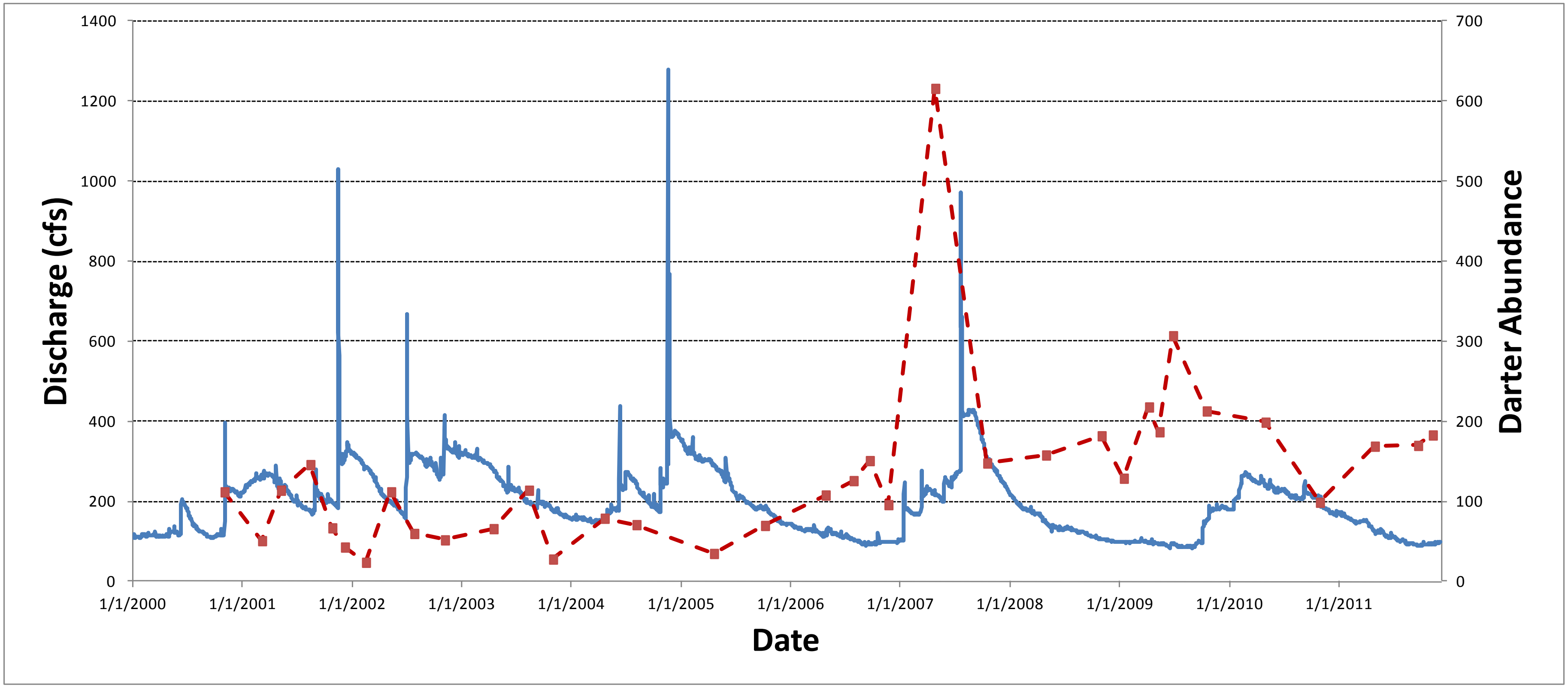


Figure 8. Mean daily discharge (blue line) and fountain darter abundance in drop net samples (red dotted line) over the study period.

To further explore the relationship between darter abundance and discharge, a scatterplot of daily mean discharge for each sample date and fountain darter abundance was developed (Figure 9). These data exhibit that as discharge increases, the number of fountain darters captured in each drop net event tends to decrease. This trend may represent clumping of darters into limited habitat under low flows, and may also be influenced by decreased drop net efficiency under high flows.

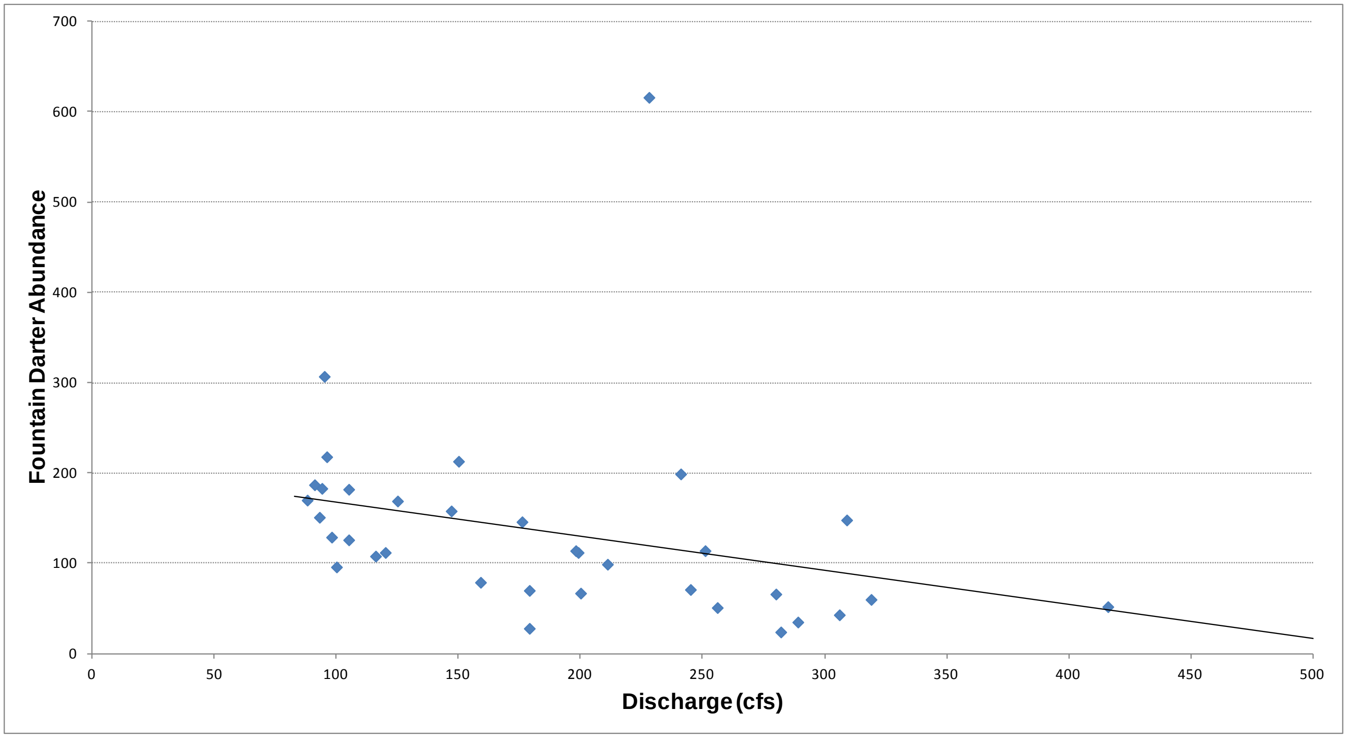


Figure 9. Scatterplot of fountain darter abundance in drop net samples versus daily mean discharge on each sample date.

Submerged aquatic vegetation is a critical component of fountain darter habitat in the San Marcos River, as demonstrated by the density of darters in open habitats (0.1/m^2) versus vegetated habitats (4.9 - 8.6/m^2) (Figure 10). However, fountain darter density varies considerably between vegetation types, demonstrating that some vegetation types provide more suitable habitat than others. For example, fountain darter densities calculated from drop netting data are high in the native vegetation type *Cabomba* (8.6/m^2), yet considerably lower in non-native *Hygrophila* (5.2/m^2). Fountain darter densities in native *Potamogeton* (5.6/ m^2) and non-native *Hydrilla* (6.4/m^2) are intermediate. *Potamogeton* and *Hygrophila* often grow together, and the density within this native/non-native mix is 4.9 darters/ m^2 (Figure 10).

Although there is variation in densities between vegetation types in the San Marcos River drop net data, the magnitude of this variation is considerably smaller than in the Comal Springs/River ecosystem (BIO-WEST 2012). In the Comal, certain vegetation types such as filamentous algae and bryophytes exhibit higher densities (22 - 28 fountain darters/m^2), resulting in an overall greater number of darters. Filamentous algae and bryophytes provide dense cover at the substrate level, and also harbor large numbers of invertebrates that fountain darters commonly feed on. In the San Marcos system, filamentous algae and bryophytes are only found in the Spring Lake Reach. Although this area is not sampled by drop netting, dip net data confirms a high abundance of fountain darters in these vegetation types within Spring Lake.

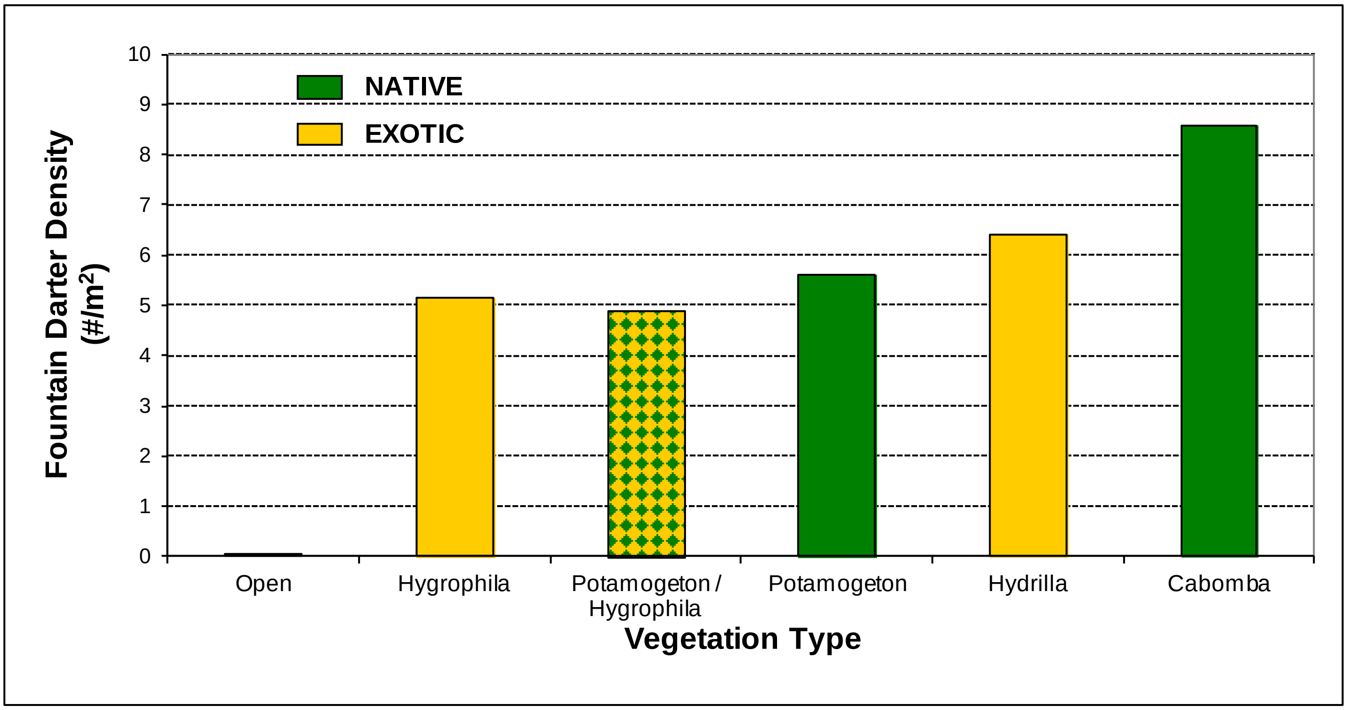


Figure 10. Density of fountain darters collected by vegetation type in the San Marcos Springs/River Ecosystem (2000 – 2011).

The length frequency distributions for fountain darters collected by drop net from the San Marcos Springs/River ecosystem during each 2011 sampling event are presented in Figure 11 (data collected in previous years is presented in Appendix B). When examined by reach and sample event, length frequency distributions reveal trends similar to those observed in the Comal Springs/River ecosystem. Lab studies have shown that darters of 16 mm TL are approximately 63 days old (Brandt et al. 1993). Therefore, presence of this size class in all collections suggests year-round reproduction. However, the much greater proportion of small individuals in spring collections suggests a strong reproductive peak in late winter/early spring.

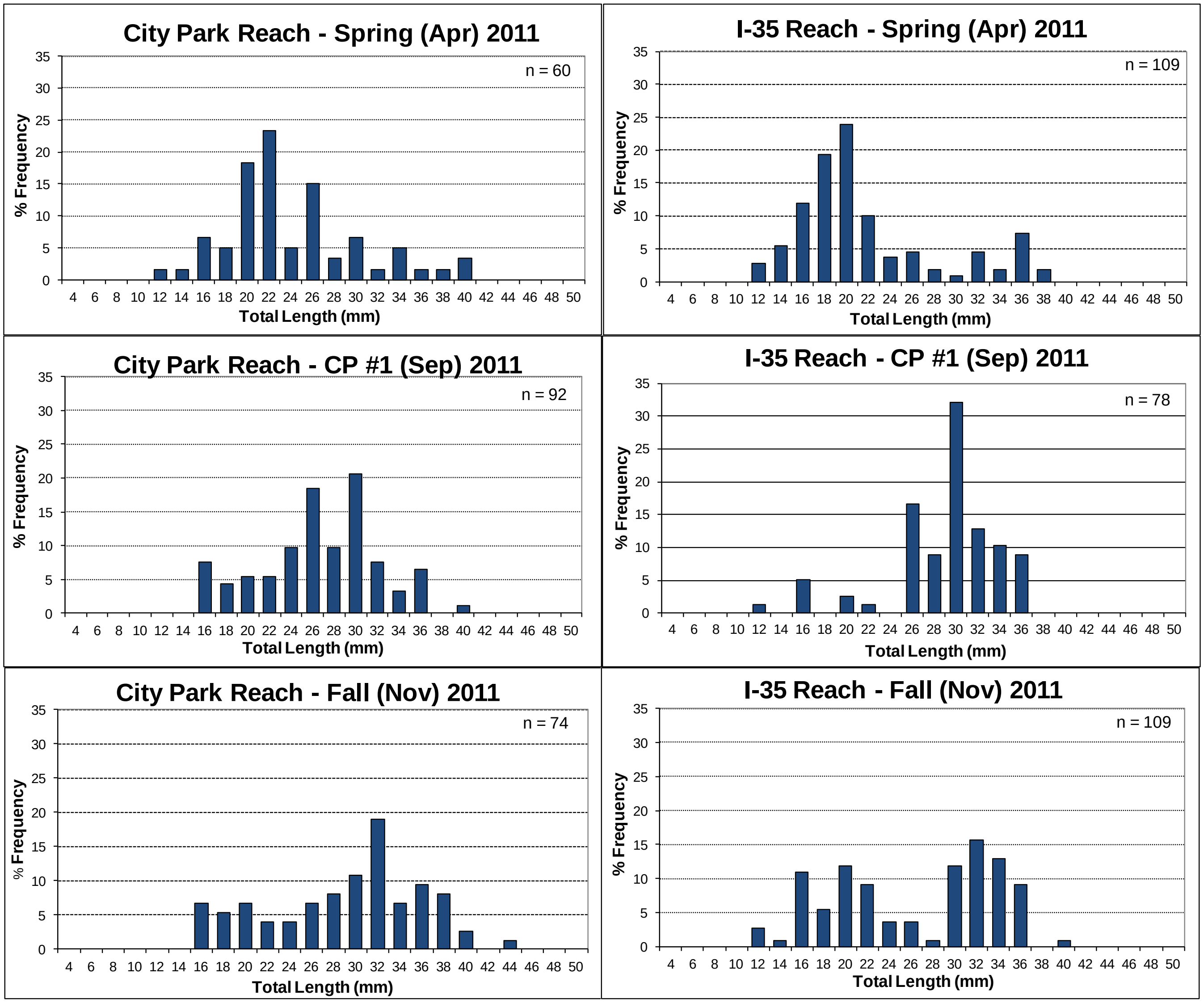


Figure 11. Length frequency distributions of fountain darters collected from each reach of the San Marcos River during each 2011 sampling event (CP indicates Critical Period low-flow event).

Estimates of fountain darter population abundance (Figure 12) were based on changes in vegetation composition and abundance and average density of fountain darters found in each, as described in the methods section. Data from the Spring Lake Dam Reach were not included in these estimates because drop net sampling was not conducted there.

Since there is less variation in the average density of fountain darters found among vegetation types in the San Marcos River than in the Comal River, population estimates are less variable between samples. Although of less magnitude in the San Marcos, trends in the two systems are similar. High flows result in scouring of vegetation, and thus, lower population estimates. Fountain darter population estimates under low flows are variable, but impacts have been noted. After extended low flows throughout 2011, the population estimate for fall 2011 was the lowest observed during the study period. This is mainly due to changes in vegetation within the City Park Reach. Under low flow conditions, the City Park Reach becomes shallower, and swimmers and tubers in this high-traffic area trample much of the aquatic vegetation. This same trend was noted in the summer and fall of 2009, after a similar period of extended low flows and presumed heavy recreational use. In this previous instance, the higher flows that returned by spring 2010, coupled with limited recreation over the winter resulted in a rapid recovery in aquatic vegetation and subsequently the highest population estimate of the study period. Typically, habitat conditions in the City Park Reach improve from fall to spring due to the reduced recreational traffic in the colder winter months. Continued monitoring will determine if this will be the case in the coming months.

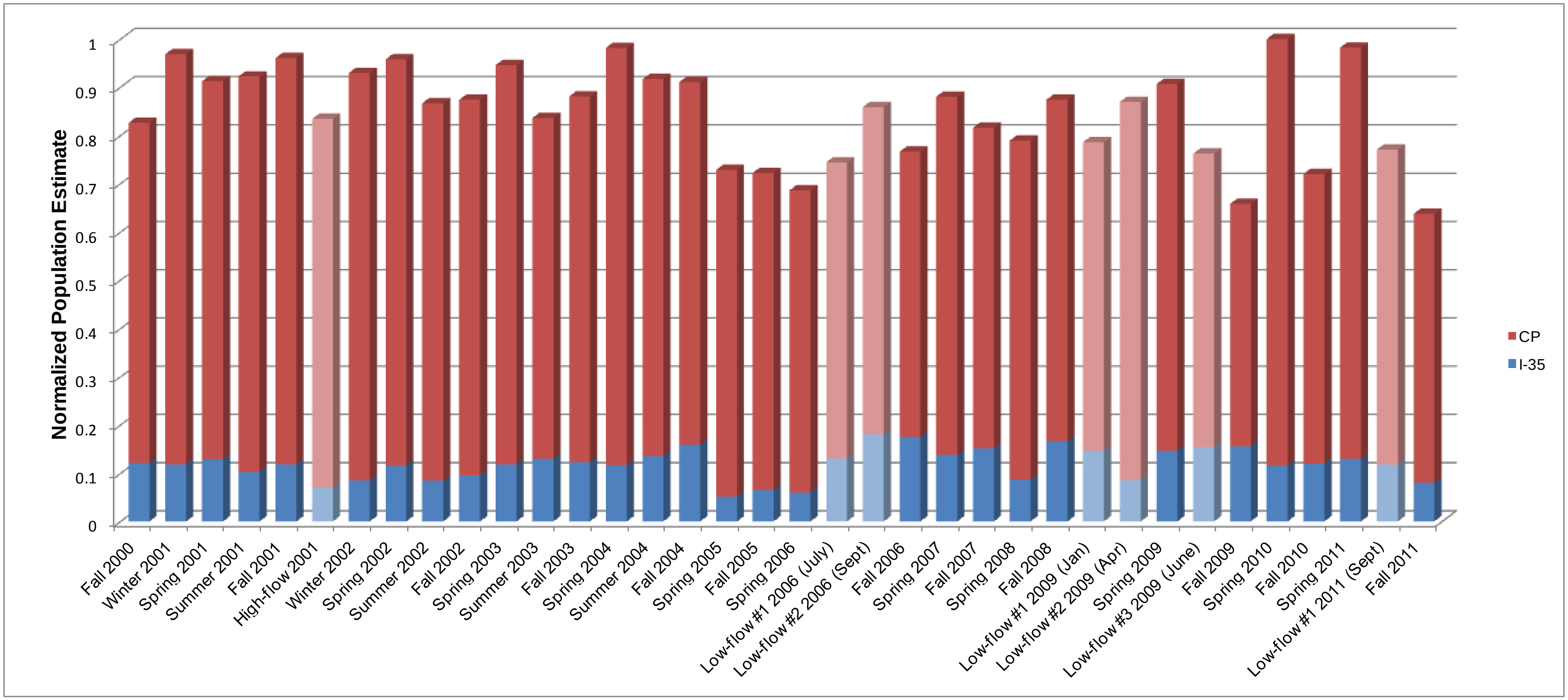


Figure 12. Population estimates of fountain darters in the San Marcos River; values are normalized to a proportion of the maximum observed in a single sample. Lighter colors represent Critical Period sampling events.

In addition to fountain darters, there have been 39,820 fishes representing at least 26 other taxa collected by drop netting since 2000 (Table 12). Of these, seven species are considered introduced or exotic to the San Marcos Springs/River ecosystem. Commonly captured exotic or introduced species include the rock bass (*Ambloplites rupestris*), Rio Grande cichlid (*Cichlasoma cyanoguttatum*), redbreast sunfish (*Lepomis auritus*), and the sailfin molly (*Poecilia latipinna*). Although these species are not native to the system, most have been established for decades, and negative impacts to the fountain darter have not been noted. However, one exotic fish of particular concern is the armadillo del rio (*Hypostomus plecostomus*). These fish are not commonly captured in drop nets, but are known to be extremely abundant in the system. This herbivorous species feeds by scraping algae/periphyton from the river substrate, and therefore, has the potential to drastically affect the vegetation community - impacting critical fountain darter habitat and food supplies. Therefore, continued monitoring and management of the *H. plecostomus* population in the San Marcos River is crucial.

Table 12. Fish species and the number of each collected during drop-net sampling in the San Marcos Springs/River ecosystem from 2000 - 2011.

Family	Scientific Name	Common Name	Status	Number Collected	
				2011	2000-2011
Lepisosteidae	*Lepisosteus oculatus*	Spotted gar	Native	0	1
Cyprinidae	*Cyprinella venusta*	Blacktail shiner	Native	0	6
	Dionda nigrotaeniata	Guadalupe roundnose minnow	Native	0	44
	Notropis amabilis	Texas shiner	Native	0	65
	Notropis chalybaeus	Ironcolor shiner	Native	25	123
	Notropis sp.	Unknown shiner	Native	0	4
Catostomidae	*Moxostoma congestum*	Gray redhorse	Native	0	2
Characidae	*Astyanax mexicanus*	Mexican tetra	Introduced	1	28
Ictaluridae	*Ameiurus melas*	Black bullhead	Native	0	1
	Ameiurus natalis	Yellow bullhead	Native	10	108
	Noturus gyrinus	Tadpole madtom	Native	0	4
Loricariidae	*Hypostomus plecostomus*	Armadillo del rio	Introduced	5	43
Poeciliidae	*Gambusia* sp.	Mosquitofish	Native	3,260	37,277
	Poecilia latipinna	Sailfin molly	Introduced	12	146
Centrarchidae	*Ambloplites rupestris*	Rock bass	Introduced	43	530
	Lepomis auritus	Redbreast sunfish	Introduced	3	62
	Lepomis cyanellus	Green sunfish	Native	0	8
	Lepomis gulosus	Warmouth	Native	0	23
	Lepomis macrochirus	Bluegill	Native	1	76
	Lepomis megalotis	Longear sunfish	Native	0	18
	Lepomis microlophus	Redear sunfish	Native	1	2
	Lepomis miniatus	Redspotted sunfish	Native	35	919
	Lepomis sp.	Sunfish	Native/Introduced	2	158
	Micropterus salmoides	Largemouth bass	Native	0	46
Percidae	*Etheostoma fonticola*	Fountain darter	Native	522	4,703
	Percina apristis	Guadalupe darter	Native	5	16
	Percina carbonaria	Texas logperch	Native	0	1
Cichlidae	*Cichlasoma cyanoguttatum*	Rio Grande cichlid	Introduced	7	93
	Oreochromis aureus	Blue tilapia	Introduced	0	16
Total				3,932	44,523

Another exotic species of concern is the giant ramshorn snail (*Marisa cornuarietis*). This herbivorous snail elicits concern because of its negative impacts to aquatic vegetation in the Comal River during the early 1990s (Horne et al. 1992, Arsuffi 1993). Only one giant ramshorn snail was collected during drop netting in 2011. However, during dip net surveys, 15 giant ramshorn snails were collected from one small area within the I-35 Reach. Additionally, giant ramshorn snail numbers seem to be increasing recently in the Comal River. Close monitoring of this species will continue because of the impact that this exotic species can have on the vegetation community under higher densities.

Dip Nets

Timed dip net collections were conducted on the San Marcos River three times during 2011: May 18 (Spring), September 22 (Critical Period low-flow event), and November 10 (Fall). The boundary for each section where dip net collections were conducted is depicted on Figure 13. Section numbers are included to be consistent with the USFWS classification system for the San Marcos River. Data gathered from the Hotel Reach at Spring Lake are presented in Figure 14, and data from all other sections are graphically represented in Appendix B.

The overall number of fountain darters collected in the Hotel Reach by dip netting is typically much greater than that found in the other two reaches. Filamentous algae and bryophytes present in this area provide the highest quality habitat found in the San Marcos Springs/River ecosystem. It should be noted that lower abundance at the Hotel Reach in fall 2010 resulted from moving the sampling area to a nearby location due to construction in the usual sampling area (Figure 14). Almost all samples collected from the Hotel Reach during the study period contained individuals in the smallest size class (5-15mm). This size class represents fountain darters <58 days old (Brandt et al. 1993) and their presence in all seasons indicate year-round reproduction. However, at the City Park and I-35 sites fountain darters in the smallest size class are usually only collected in the spring months, confirming the spring reproductive peak observed in drop net length frequency data from these locations.

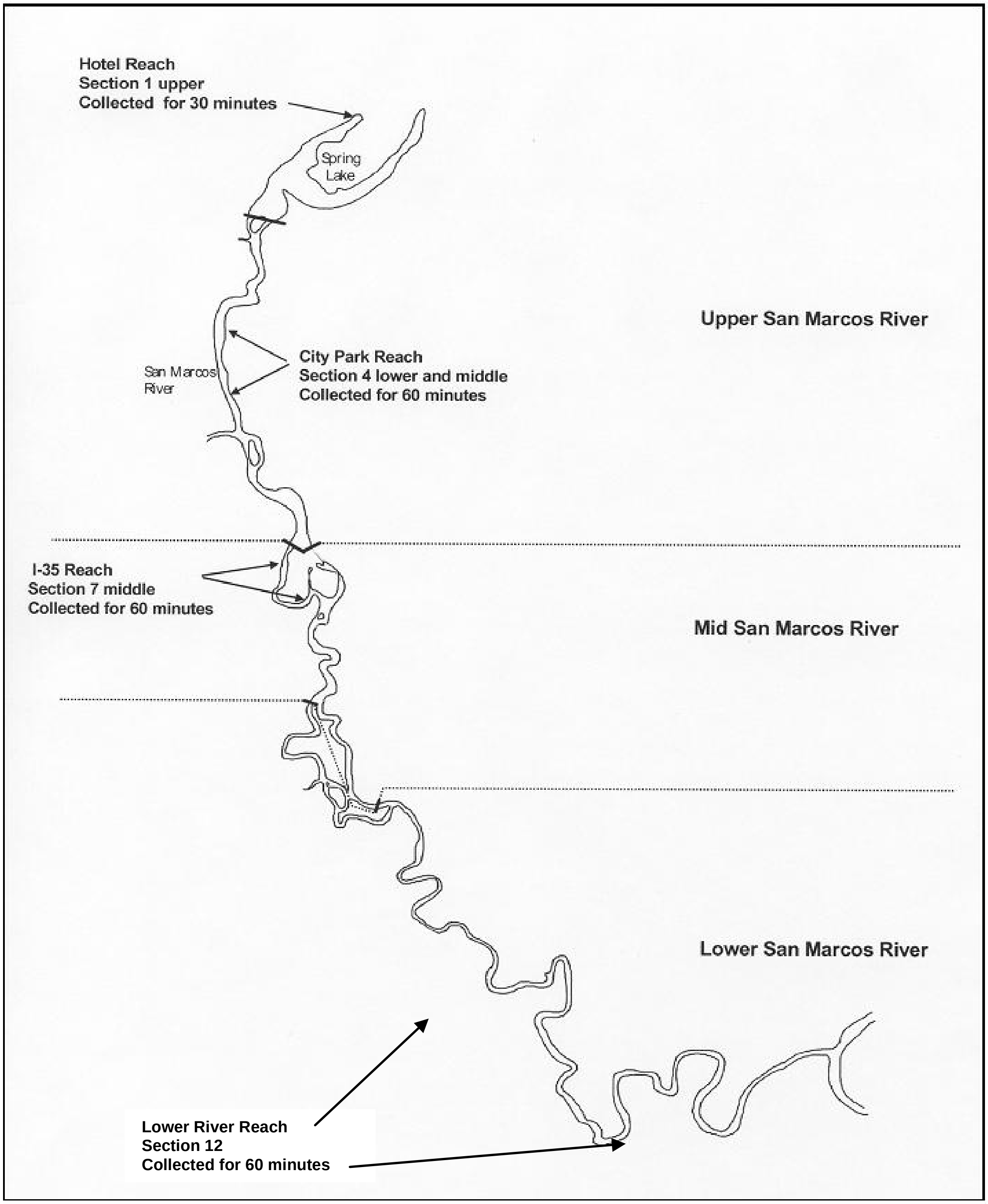


Figure 13. Areas where fountain darters were collected with dip nets, measured, and released in the San Marcos River.

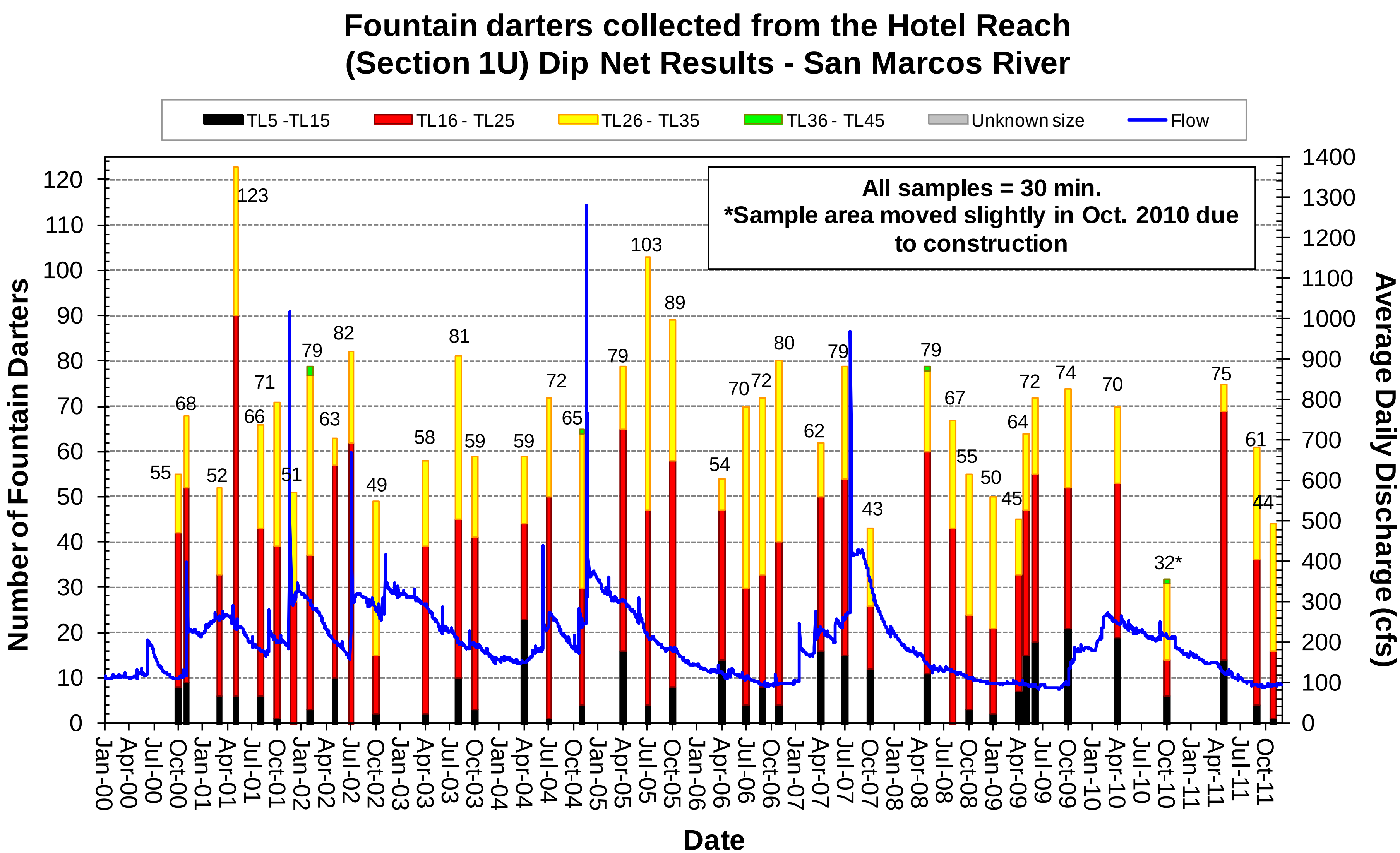


Figure 14. Number of fountain darters collected from the Hotel Reach (section 1 upper) of the San Marcos Springs/River ecosystem using dip nets.

Presence/Absence Dipnetting

The percentage of sites in which fountain darters were present during each sample is presented in Figure 15. Although this indicator had dropped to its lowest value (fountain darters present at 36% of sites) in fall 2009 after extended low flows, it quickly rebounded to its highest value in spring 2010 (62%). As seen in the figure, both of these values are extreme, and fall outside the 5th-95th percentile (represented by the blue box) based on the current dataset. This large swing in fall 2009 – spring 2010 is likely tied to habitat conditions, as population estimates based on drop net data (see Figure 12) showed a similar trend. Since that time, this metric has remained near the long-term average (50%), between 46% and 52%, despite continued below-average flows in 2011.

Although this technique does not provide detailed data on habitat use, and does not allow for quantification of population estimates, it does provide a quick and less intrusive method of examining large-scale trends in the fountain darter population. Data collected thus far provide a good baseline for comparison in future critical period events.

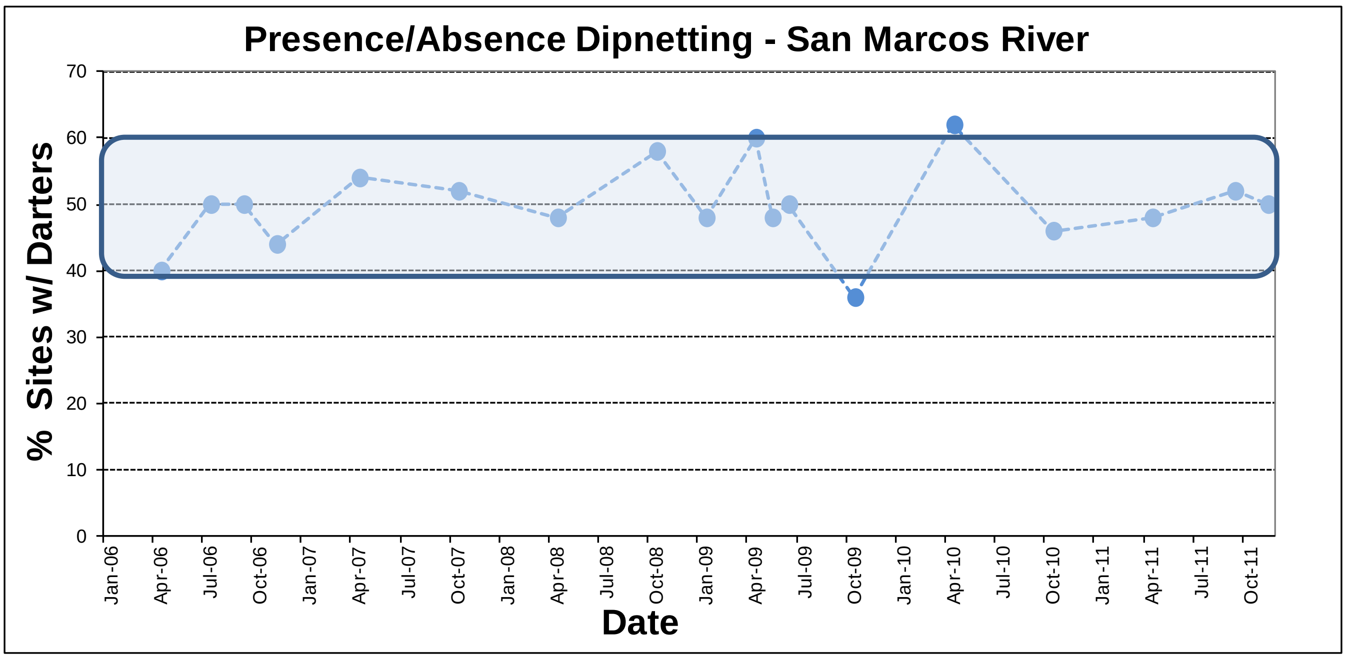


Figure 15. Percentage of sites (N = 50) in which fountain darters were present. Blue box encompasses 5th – 95th percentile.

San Marcos Salamander Visual Observations

Observations of salamander densities in Spring Lake and the San Marcos River were above historical averages at two of the three sites sampled (Figures 16 - 18). Sample area 2 (Hotel Reach) is located near the upstream end of Spring Lake, and in 2011 exhibited the highest densities of salamanders observed for this study. A density of 20.8/m^2 in spring reflected good habitat present in this section, while a fall density of 17.1/m^2 (2nd highest fall density [Fall 2000, not shown]) indicated that even in lower than average flows salamanders still thrive in this reach.

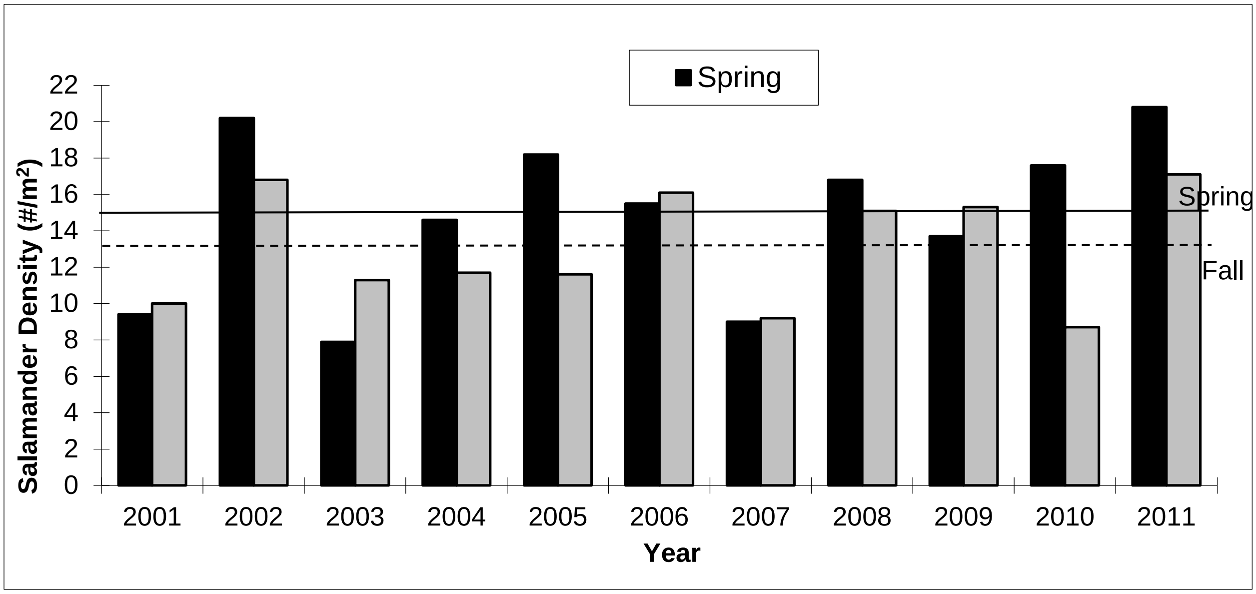


Figure 16. Salamander densities at sample area 2 (Hotel Reach) for spring and fall 2001-2011. (Spring [solid] and Fall [dashed] lines represent historical averages)

Sample area 14 (Riverbed Reach) is also located within Spring Lake, but is downstream of sample area 2. Although densities increased from fall 2010 to spring 2011, a 52% reduction was observed in the fall sample. This was due primarily to the construction activities associated with the restoration of Aquarena Springs. The construction activities that were initiated in fall 2011 resulted in limited aquatic gardening in this study reach that has subsequently led to an overgrowth of aquatic vegetation and siltation not presently witnessed in this reach. This event highlights the importance of long-term monitoring and the beneficial effect of an anthropogenic activity in the preservation of high quality habitat for this species.

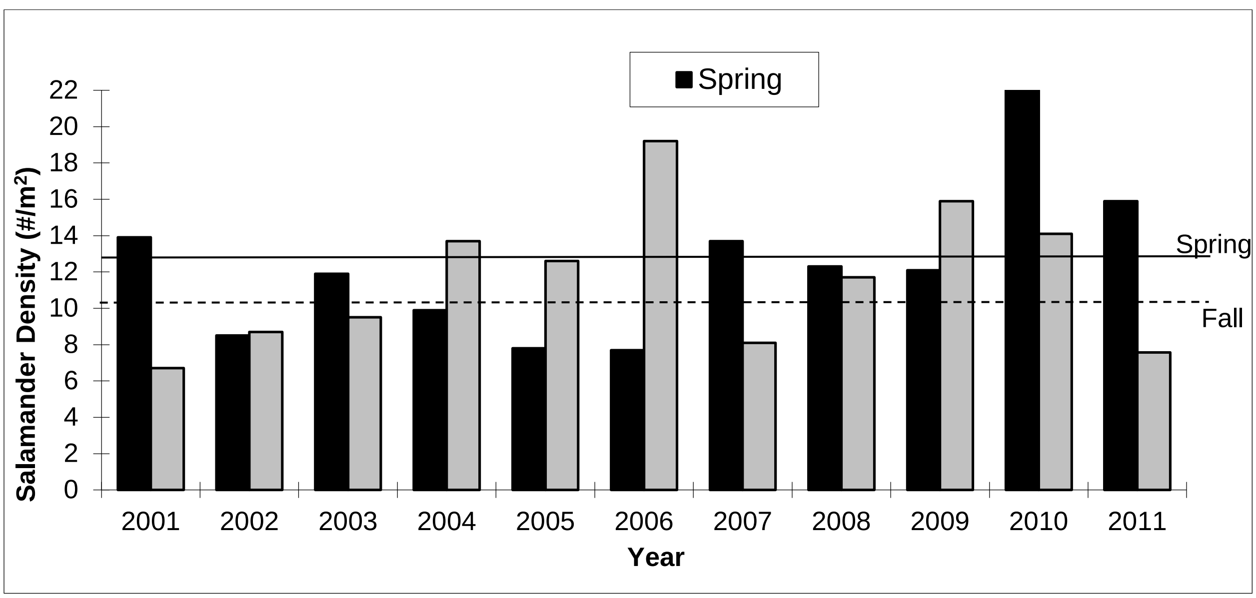


Figure 17. Salamander densities at sample area 14 (Riverbed Reach) for spring and fall 2001-2011. (Spring [solid] and Fall [dashed] lines represent historical averages)

Sample area 21 is the only site within the San Marcos River. This site is located within an area with heavy recreation, and rocks (preferred salamander habitat) are often used/moved for structures and dam construction. As a result, densities here are often lower than at other sites. However, in 2011 both spring and fall estimates (9.0 and 14.0/m^2, respectively) were the highest observed in the study. Like Texas wild-rice, educational signs installed in 2007 may have contributed to decreased recreation pressure for this reach. Continued monitoring of these sites will help us in understanding how changes in spring flow, vegetation composition, and recreation pressure can affect this federally threatened species.

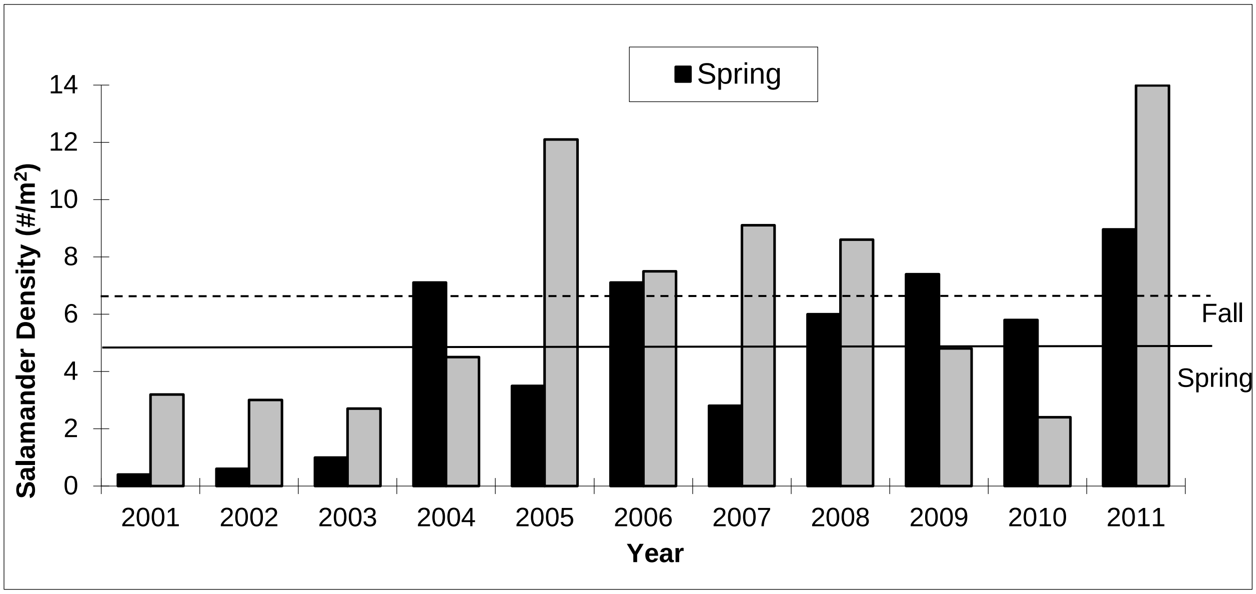


Figure 18. Salamander densities at sample area 21 (Spring Lake Dam Reach) for spring and fall 2001-2011. (Spring [solid] and Fall [dashed] lines represent historical averages)

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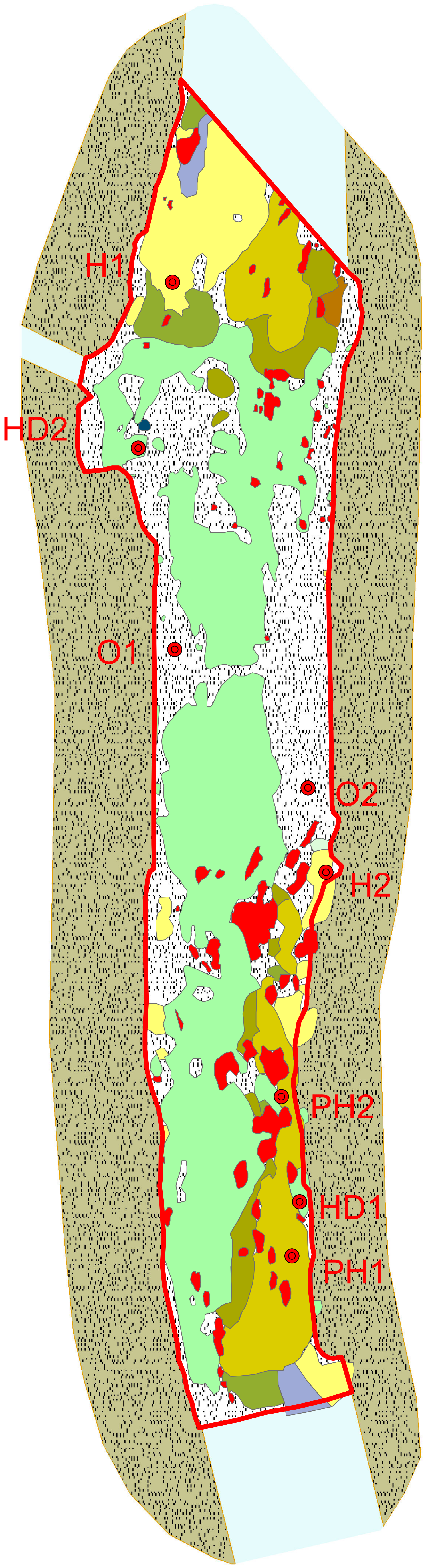
APPENDIX A:
AQUATIC VEGETATION MAPS

City Park Reach

San Marcos River Aquatic Vegetation

City Park - Spring

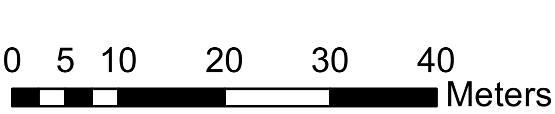
April 21, 2011



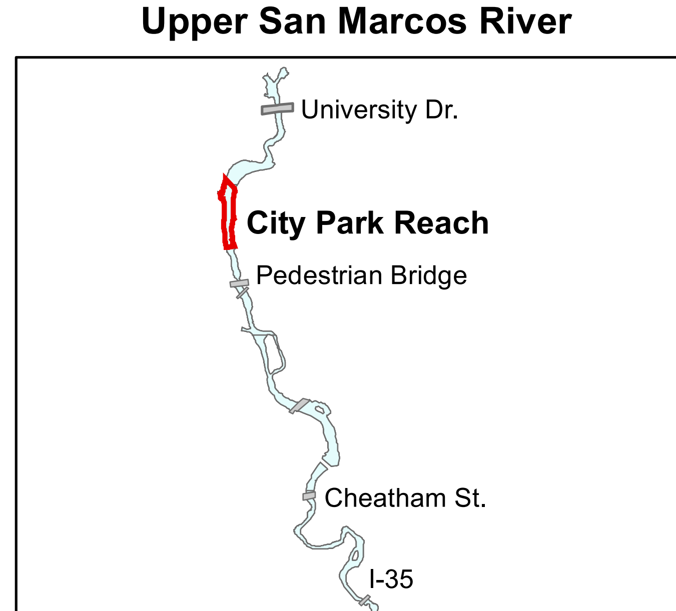
Legend
Land
Water
Bare Substrate
Study Area (6,010.5 m^2)
Drop Net Sample Sites

N

	Total Area (m^2)
Hydrilla	2,298.2
Hygrophila	551.1
Potamogeton	19.0
Potamogeton / Hydrilla	247.9
Potamogeton / Hygrophila	643.6
Sagittaria / Hygrophila	62.6
Hydrilla / Hygrophila	2.8
Sagittaria	163.6
Vallisneria	3.6
Zizania	342.4

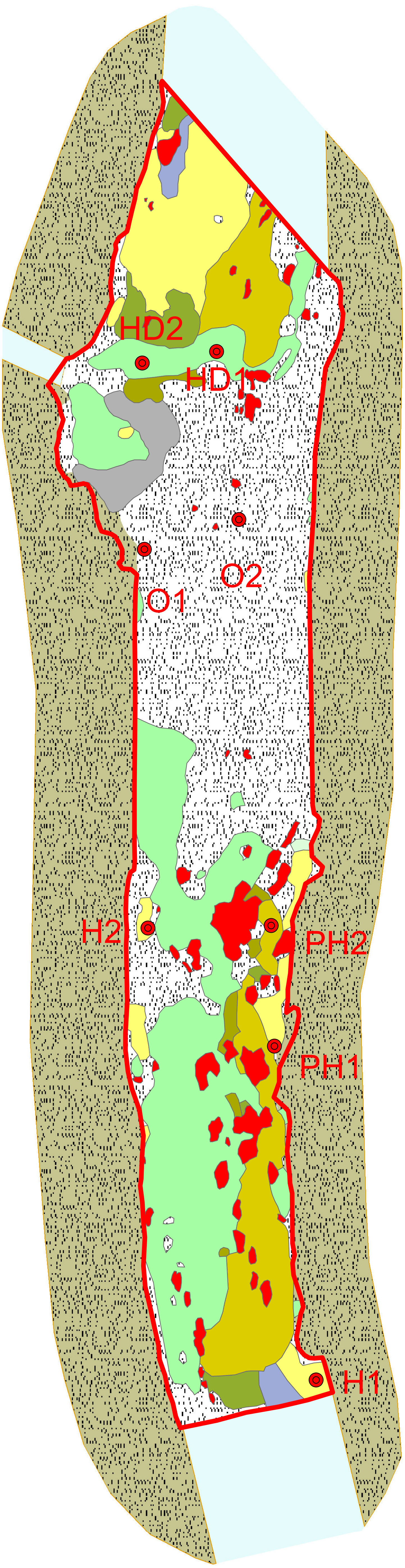


Upper San Marcos River



San Marcos River
Aquatic Vegetation
City Park
Critical Period 1

September 14, 2011

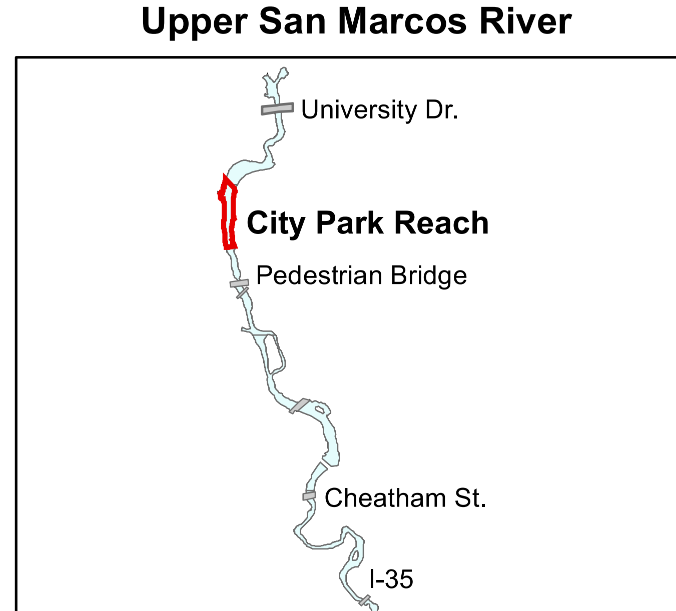


N

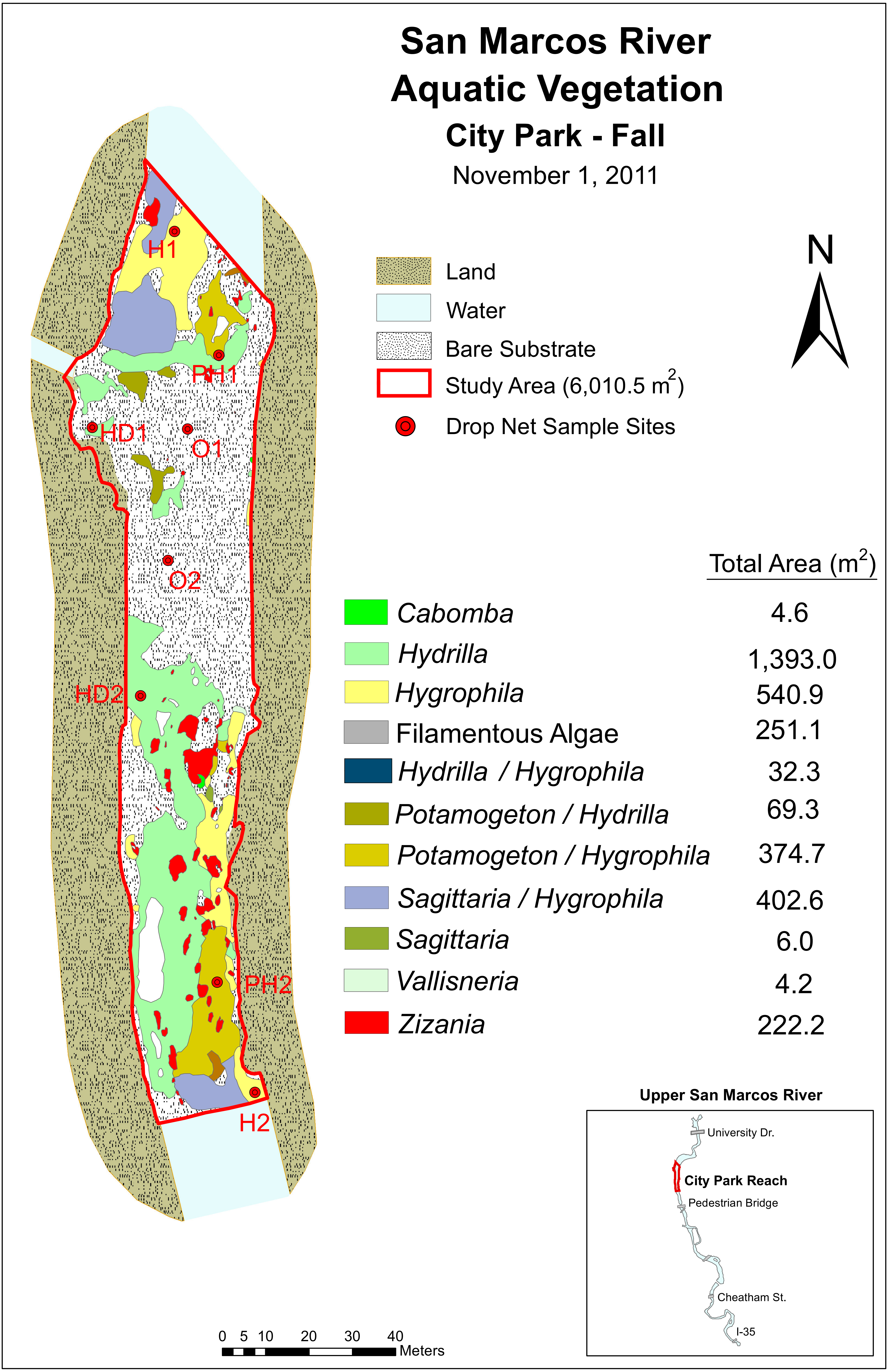
- Land
- Water
- Bare Substrate
- Study Area (6,010.5 m^2)
- Drop Net Sample Sites

	Total Area (m^2)
Hydrilla	1,497.7
Hygrophila	570.5
Filamentous Algae	143.4
Potamogeton / Hydrilla	70.6
Potamogeton / Hygrophila	677.8
Sagittaria / Hygrophila	62.7
Sagittaria	163.3
Vallisneria	5.8
Zizania	323.2

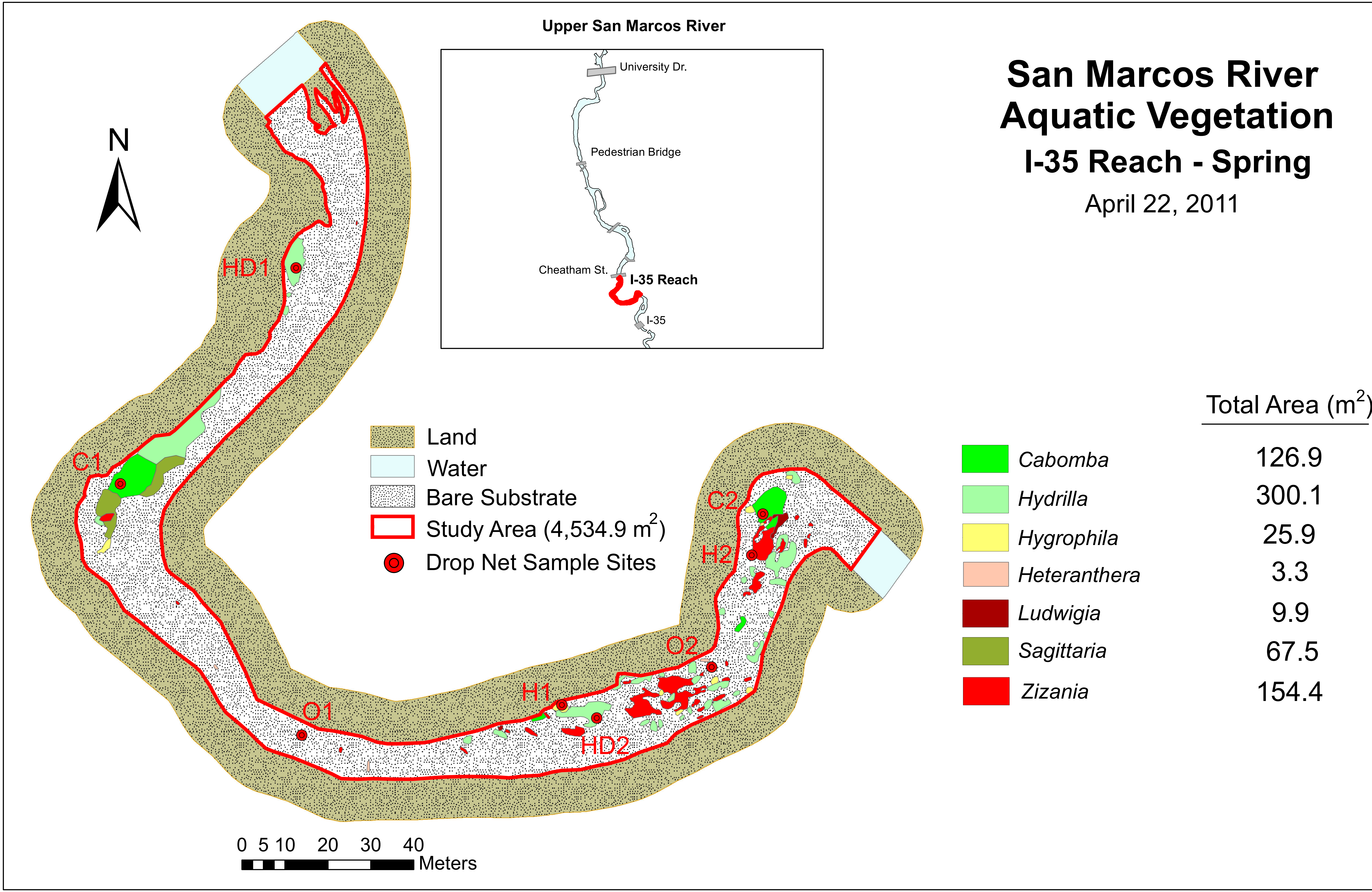
Upper San Marcos River



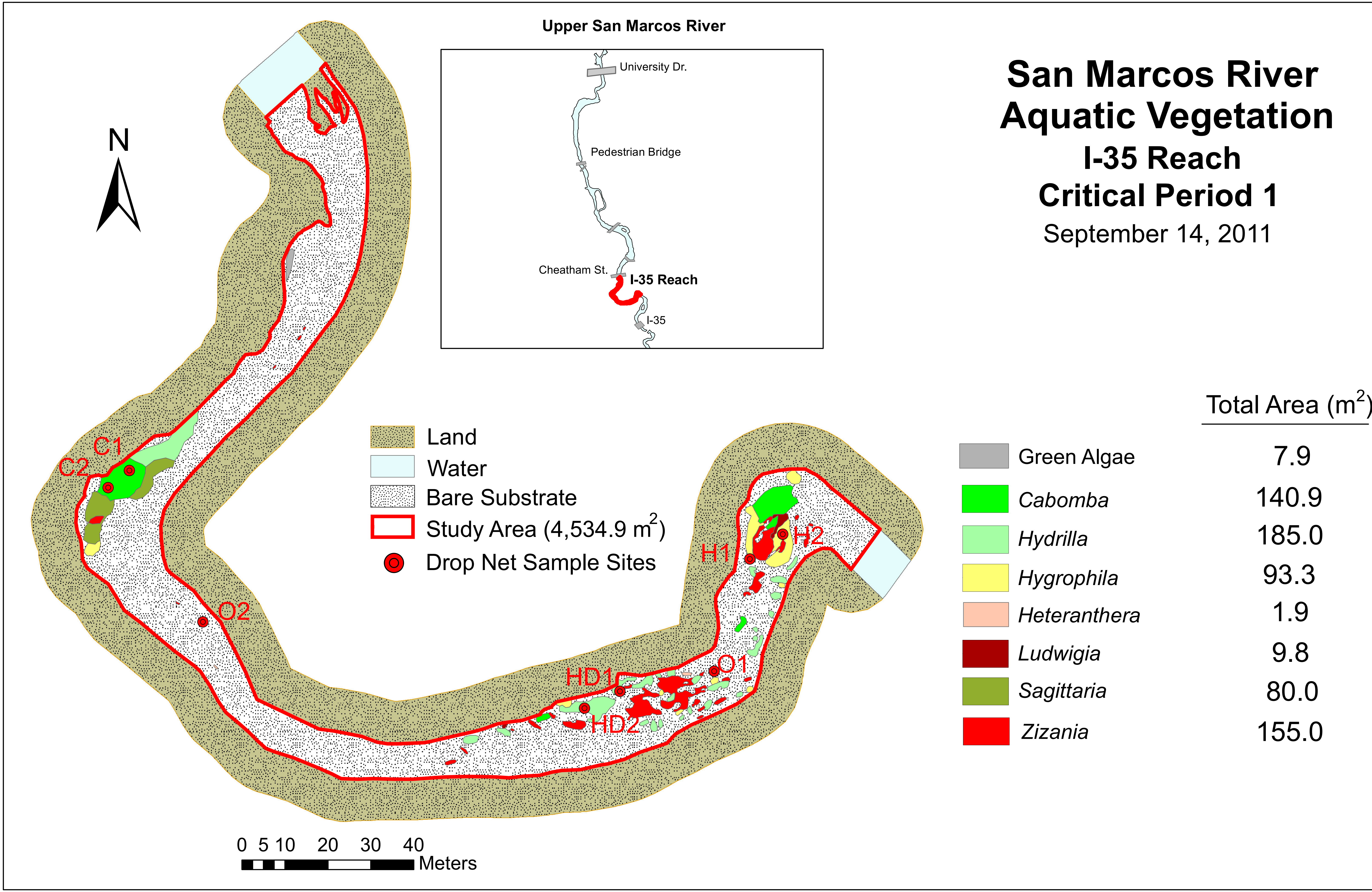
0 5 10 20 30 40
Meters


San Marcos River
Aquatic Vegetation
City Park - Fall
November 1, 2011
Land
Water
Bare Substrate
Study Area (6,010.5 m2)
Drop Net Sample Sites
N
H1
PH1
HD1
O1
O2
HD2
PH2
H2
Total Area (m2)
Cabomba 4.6
Hydrilla 1,393.0
Hygrophila 540.9
Filamentous Algae 251.1
Hydrilla / Hygrophila 32.3
Potamogeton / Hydrilla 69.3
Potamogeton / Hygrophila 374.7
Sagittaria / Hygrophila 402.6
Sagittaria 6.0
Vallisneria 4.2
Zizania 222.2
Upper San Marcos River
University Dr.
City Park Reach
Pedestrian Bridge
Cheatham St.
I-35
0 5 10 20 30 40
Meters

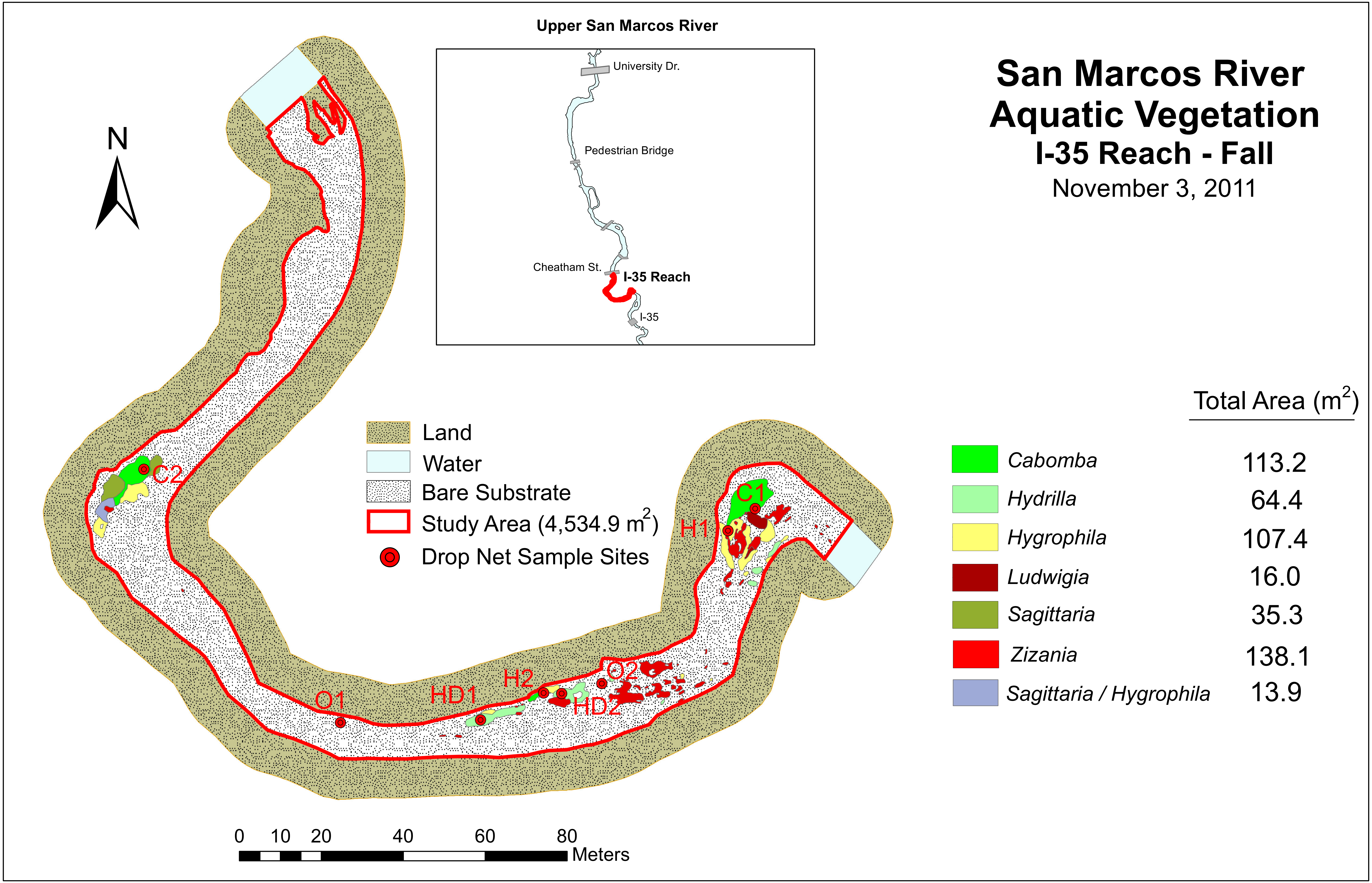
IH-35 Reach



San Marcos River
Aquatic Vegetation
I-35 Reach - Spring
April 22, 2011
Upper San Marcos River
University Dr.
Pedestrian Bridge
Cheatham St.
I-35 Reach
I-35
N
HD1
C1
C2
H2
O2
H1
O1
HD2
Land
Water
Bare Substrate
Study Area (4,534.9 m2)
Drop Net Sample Sites
Total Area (m2)
Cabomba 126.9
Hydrilla 300.1
Hygrophila 25.9
Heteranthera 3.3
Ludwigia 9.9
Sagittaria 67.5
Zizania 154.4
0 5 10 20 30 40
Meters



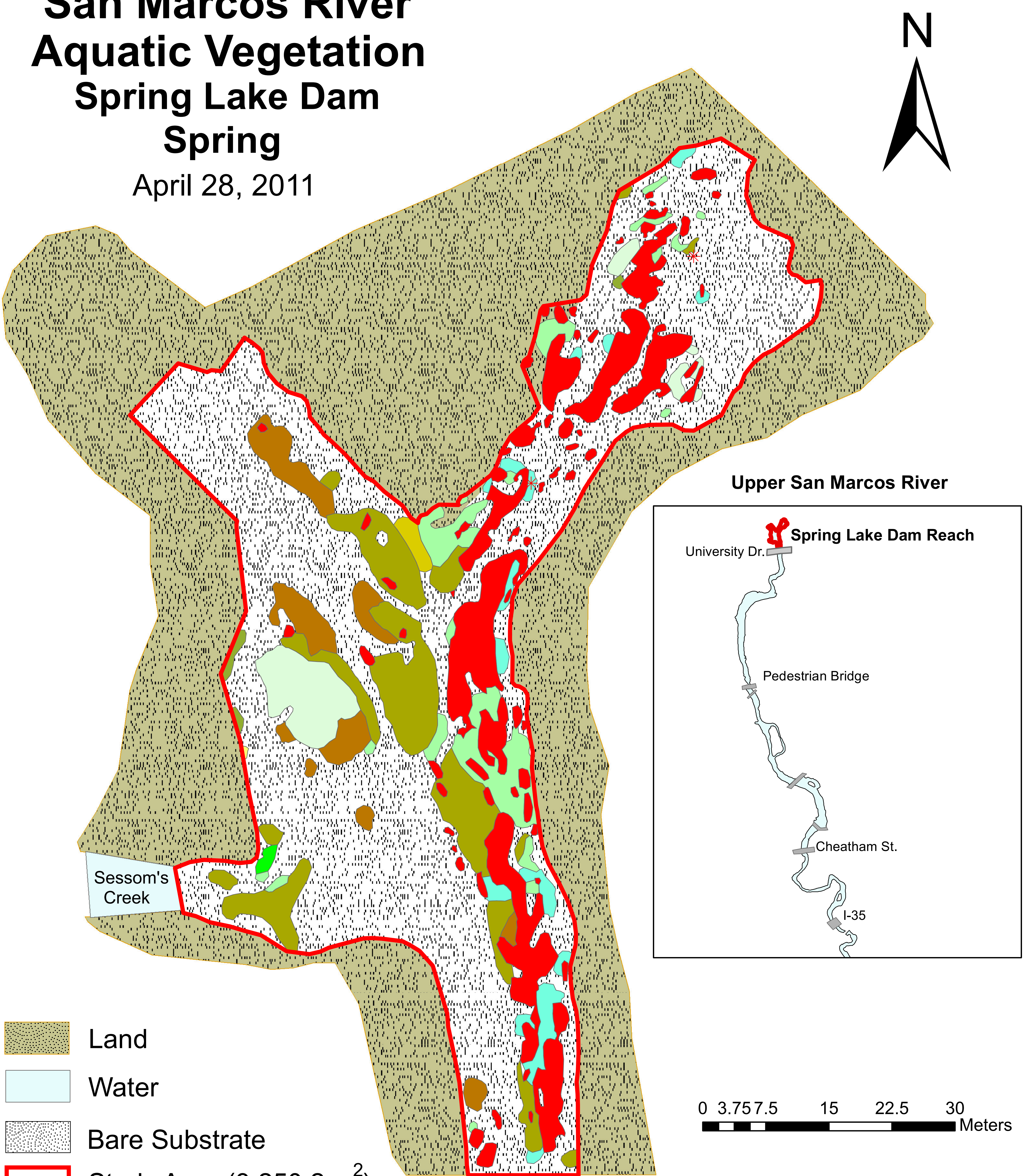
San Marcos River
Aquatic Vegetation
I-35 Reach
Critical Period 1
September 14, 2011
Upper San Marcos River
University Dr.
Pedestrian Bridge
Cheatham St.
I-35 Reach
I-35
N
Land
Water
Bare Substrate
Study Area (4,534.9 m2)
Drop Net Sample Sites
C1
C2
O2
H1
H2
HD1
HD2
O1
Total Area (m2)
Green Algae 7.9
Cabomba 140.9
Hydrilla 185.0
Hygrophila 93.3
Heteranthera 1.9
Ludwigia 9.8
Sagittaria 80.0
Zizania 155.0
0 5 10 20 30 40
Meters


San Marcos River
Aquatic Vegetation
I-35 Reach - Fall
November 3, 2011
Upper San Marcos River
University Dr.
Pedestrian Bridge
Cheatham St.
I-35 Reach
I-35
N
Land
Water
Bare Substrate
Study Area (4,534.9 m2)
Drop Net Sample Sites
C2
C1
H1
H2
HD1
HD2
O1
O2
Total Area (m2)
Cabomba 113.2
Hydrilla 64.4
Hygrophila 107.4
Ludwigia 16.0
Sagittaria 35.3
Zizania 138.1
Sagittaria / Hygrophila 13.9
0
10
20
40
60
80
Meters

Spring Lake Dam Reach

San Marcos River Aquatic Vegetation
Spring Lake Dam
Spring

April 28, 2011



Land

Water

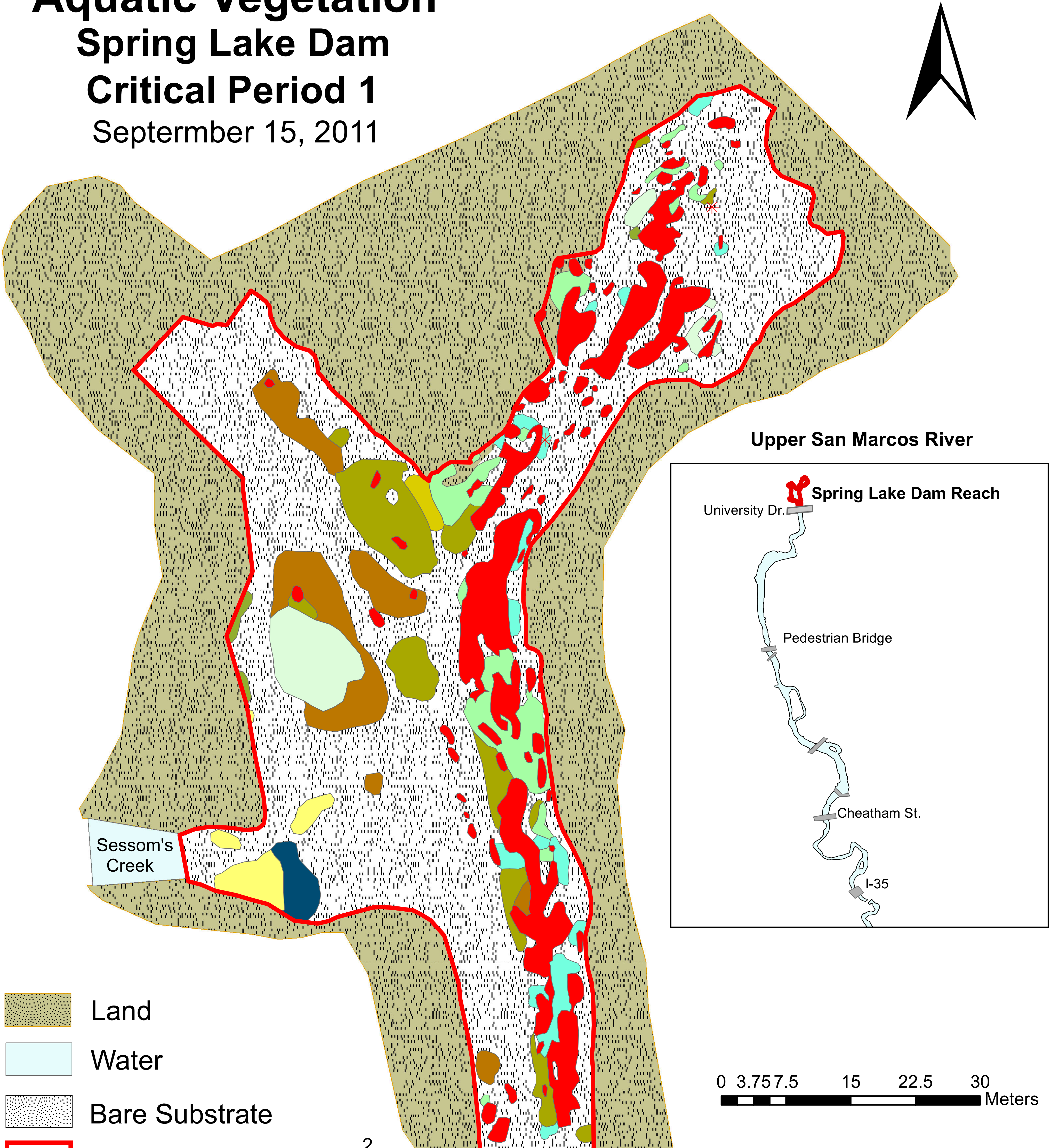
Bare Substrate

Study Area (3,250.2 m^2)

Small *Zizania* Plants

	Total Area (m^2)		Total Area (m^2)
Cabomba	5.2	*Zizania*	477.2
Hydrilla	142.9	*Vallisneria*	108.8
Hydrocotyle	74.8	*Potamogeton / Hydrilla*	344.3
Hygrophila	1.0	*Potamogeton / Hygophila*	13.2
Potamogeton	139.0	*Potamogeton / Vallisneria*	83.3
Sagittaria	10.4		

San Marcos River Aquatic Vegetation
Spring Lake Dam
Critical Period 1
Septermber 15, 2011



Land

Water

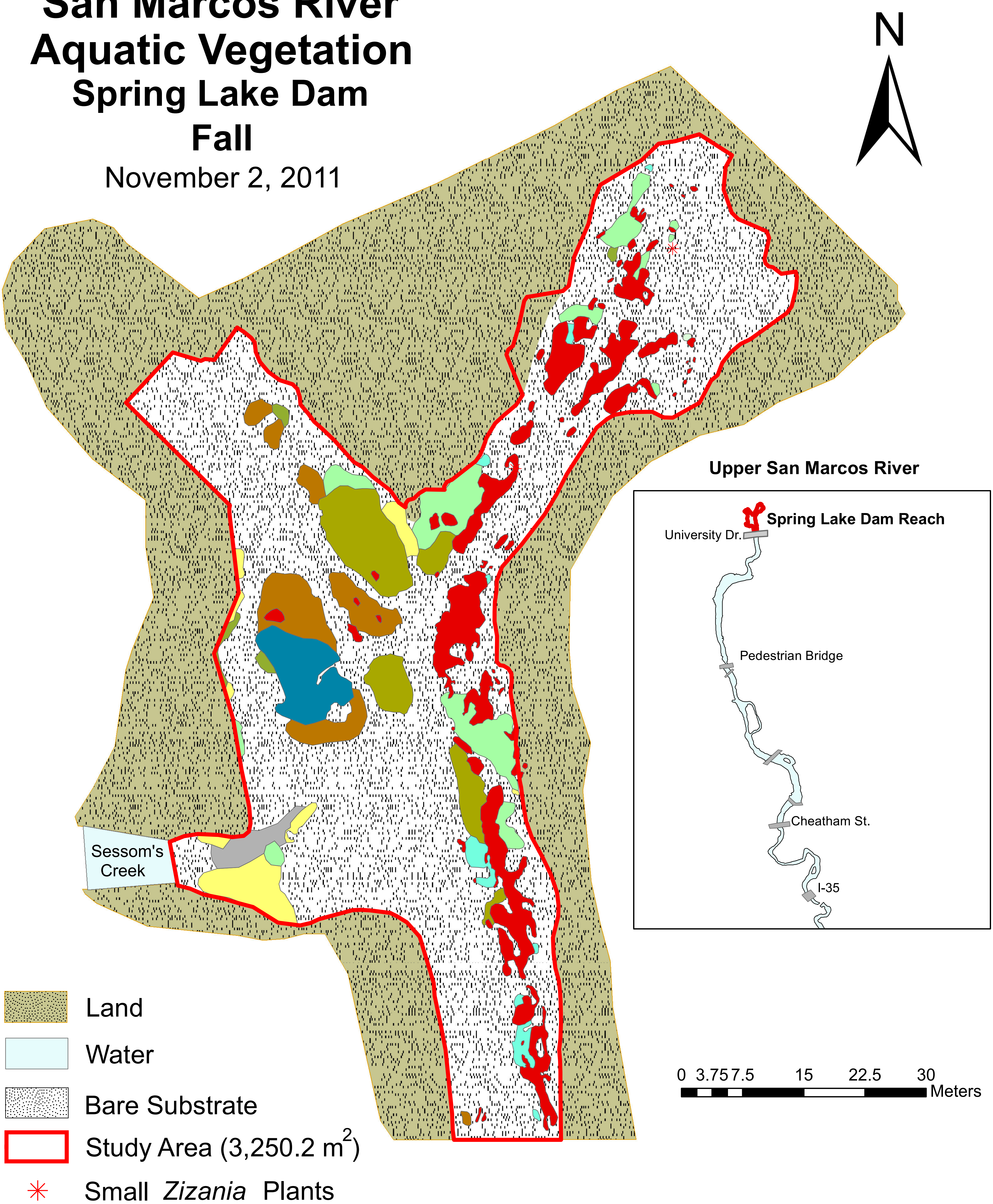
Bare Substrate

Study Area (3,250.2 m^2)

Small *Zizania* Plants

	Total Area (m^2)		Total Area (m^2)
Hydrilla	129.3	*Zizania*	477.9
Hydrocotyle	74.2	*Vallisneria*	107.4
Hygrophila	52.8	*Potamogeton / Hydrilla*	209.2
Potamogeton	193.0	*Potamogeton / Hygophila*	13.2
Sagittaria	10.5	*Hydrilla / Hygrophila*	31.0

San Marcos River Aquatic Vegetation
Spring Lake Dam
Fall
November 2, 2011

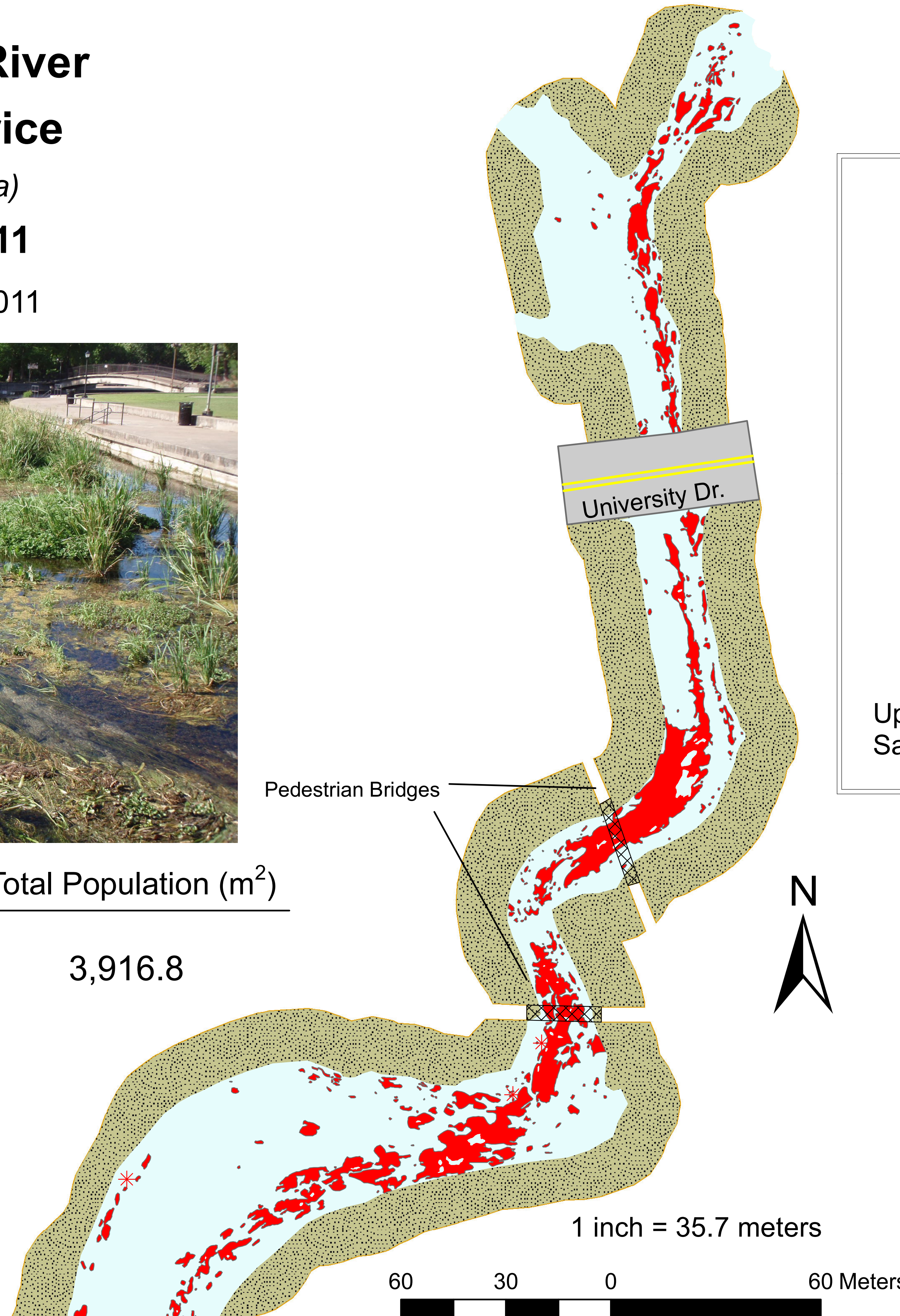


	Total Area (m^2)		Total Area (m^2)
Hydrilla	154.3	*Zizania*	317.7
Hydrocotyle	28.9	*Vallisneria*	0.7
Hygrophila	85.8	*Potamogeton / Hydrilla*	173.6
Potamogeton	139.5	*Potamogeton / Vallisneria*	83.5
Sagittaria	14.4	Filamentous Algae	30.4

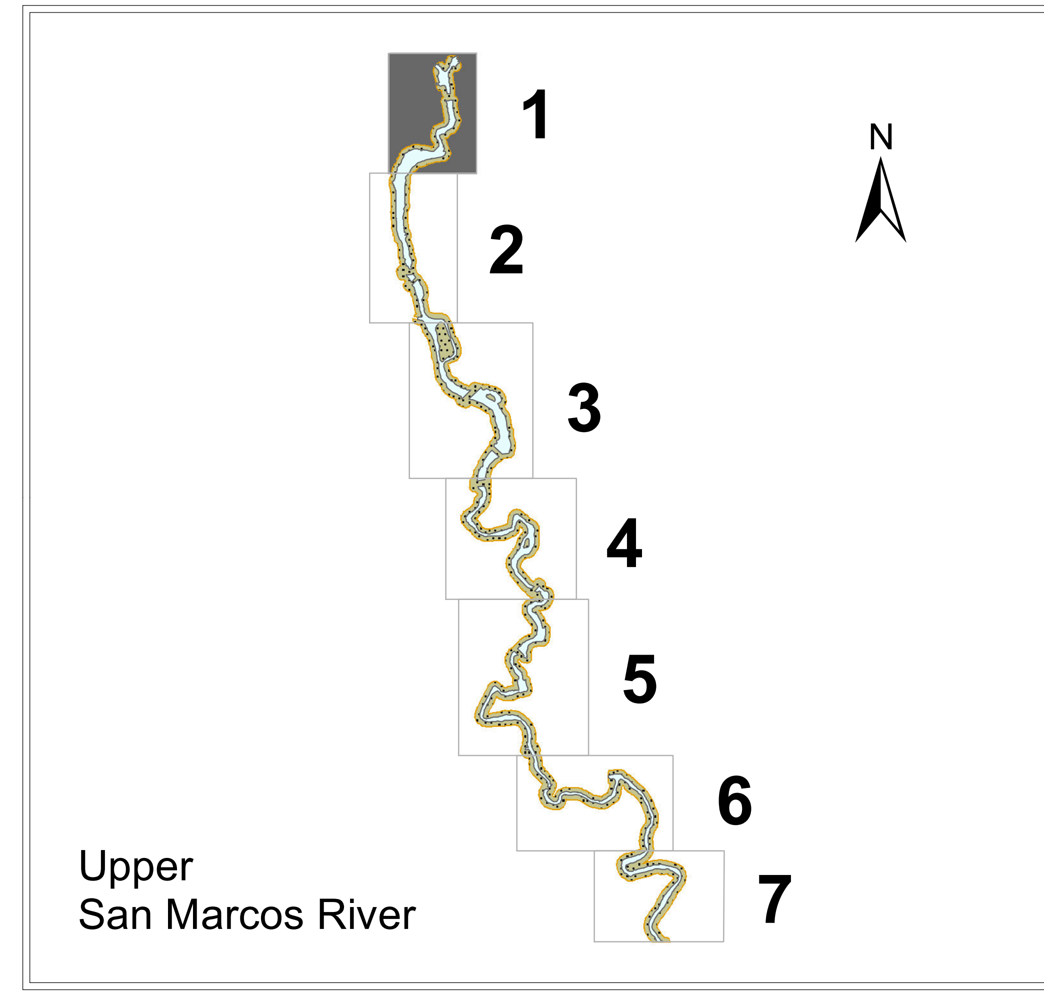
Texas Wild-Rice

San Marcos River
Texas wild-rice
(Zizania texana)
Summer 2011
June 20 - 27, 2011

	Map 1 (m^2)	Total Population (m^2)
Zizania	2,470.6	3,916.8
Small *Zizania* Plants		



Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice

(Zizania texana)

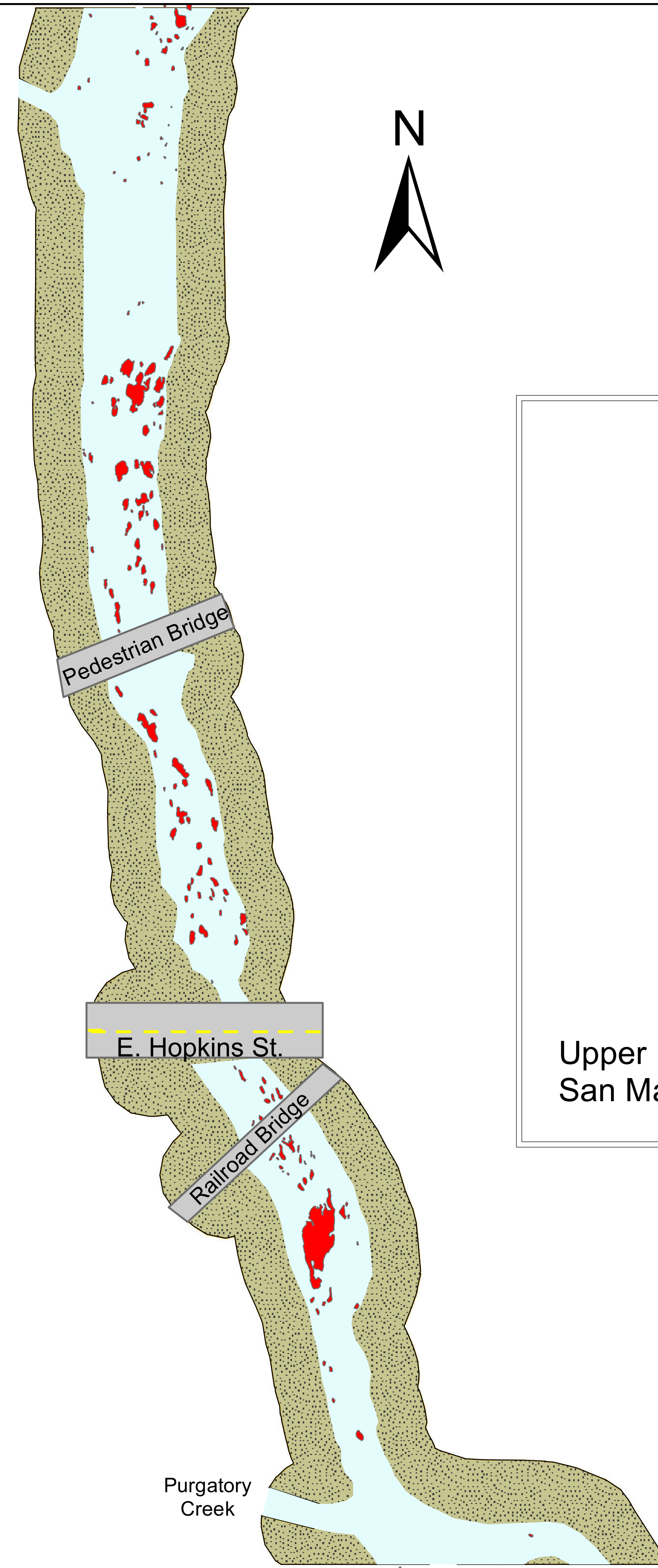
Summer 2011

June 20 - 27, 2011

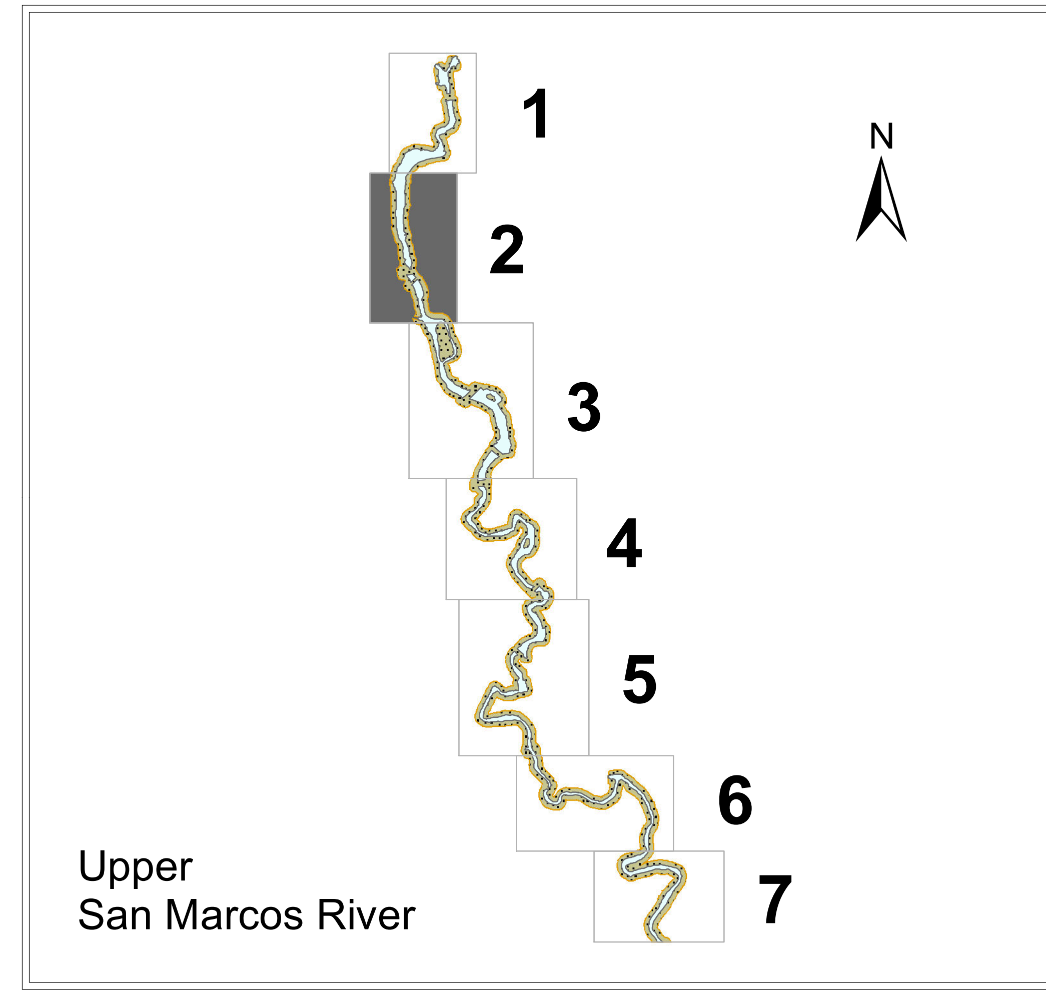
	Map 2 (m^2)	Total Population (m^2)
Zizania	607.5	3,916.8

1 inch = 45.8 meters

60 30 0 60 Meters



Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

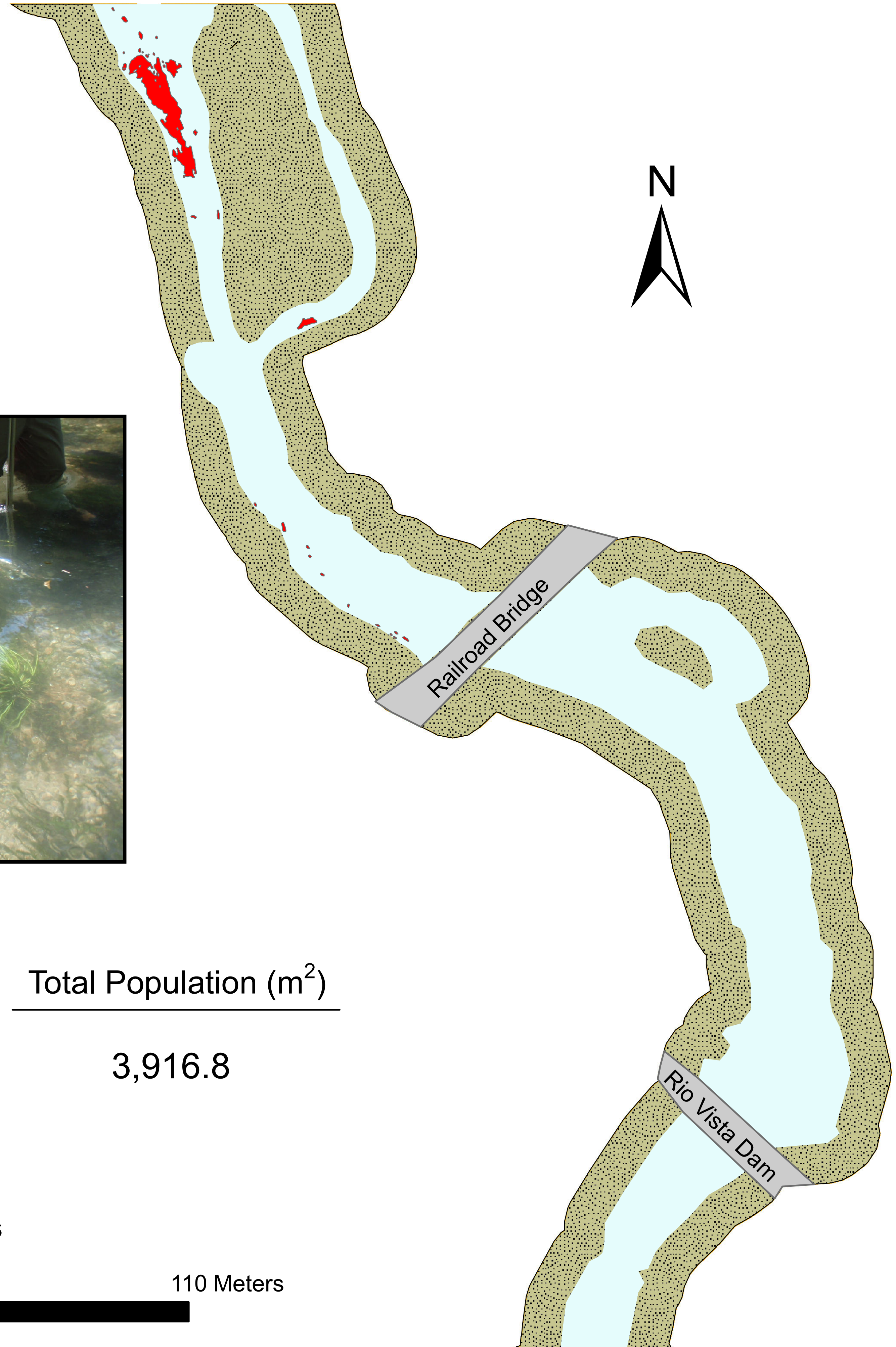
San Marcos River

Texas wild-rice

(Zizania texana)

Summer 2011

June 20 - 27, 2011

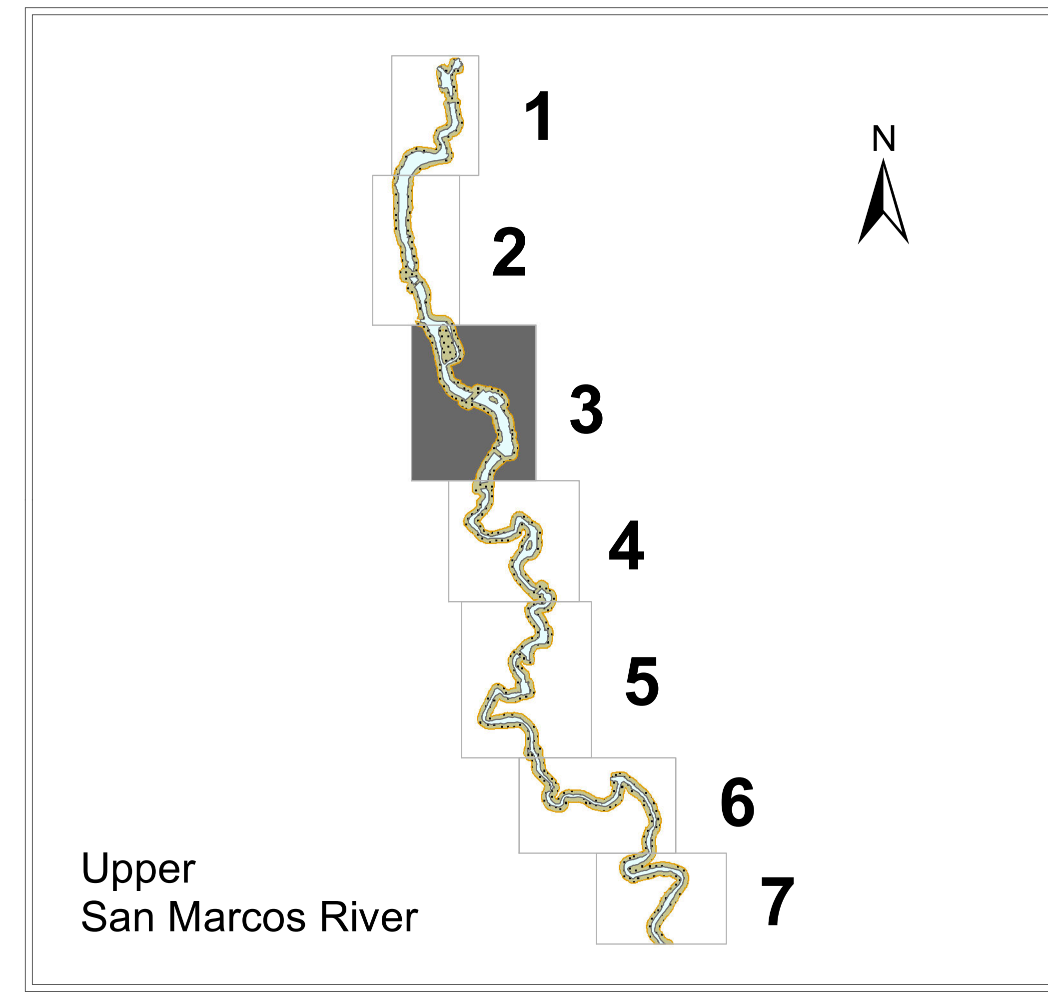


	Map 3 (m^2)	Total Population (m^2)
Zizania	367.3	3,916.8

1 inch = 48 meters

110 55 0 110 Meters

Project Location



BIO-WEST, Inc.

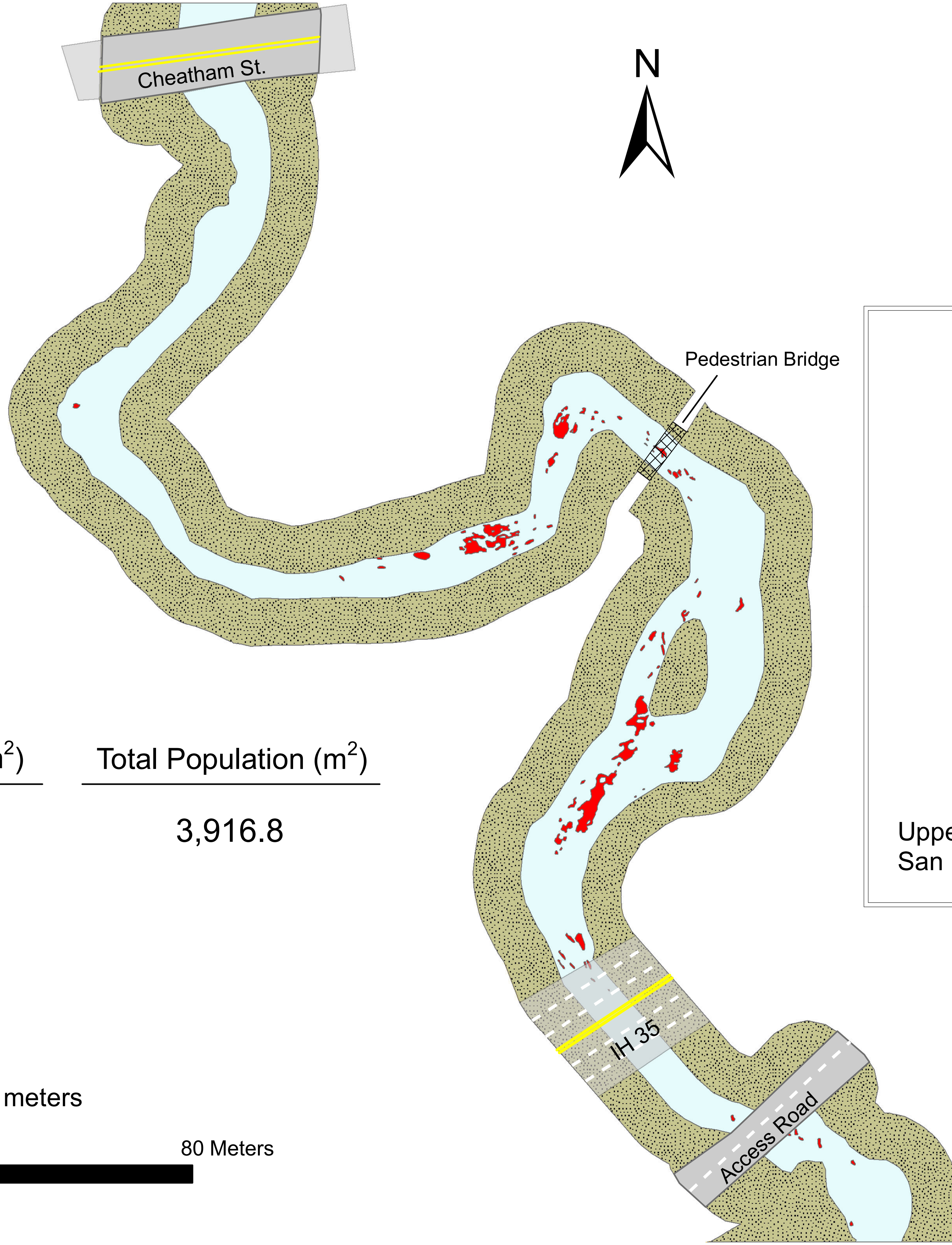
EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice

(Zizania texana)

Summer 2011

June 20 - 27, 2011

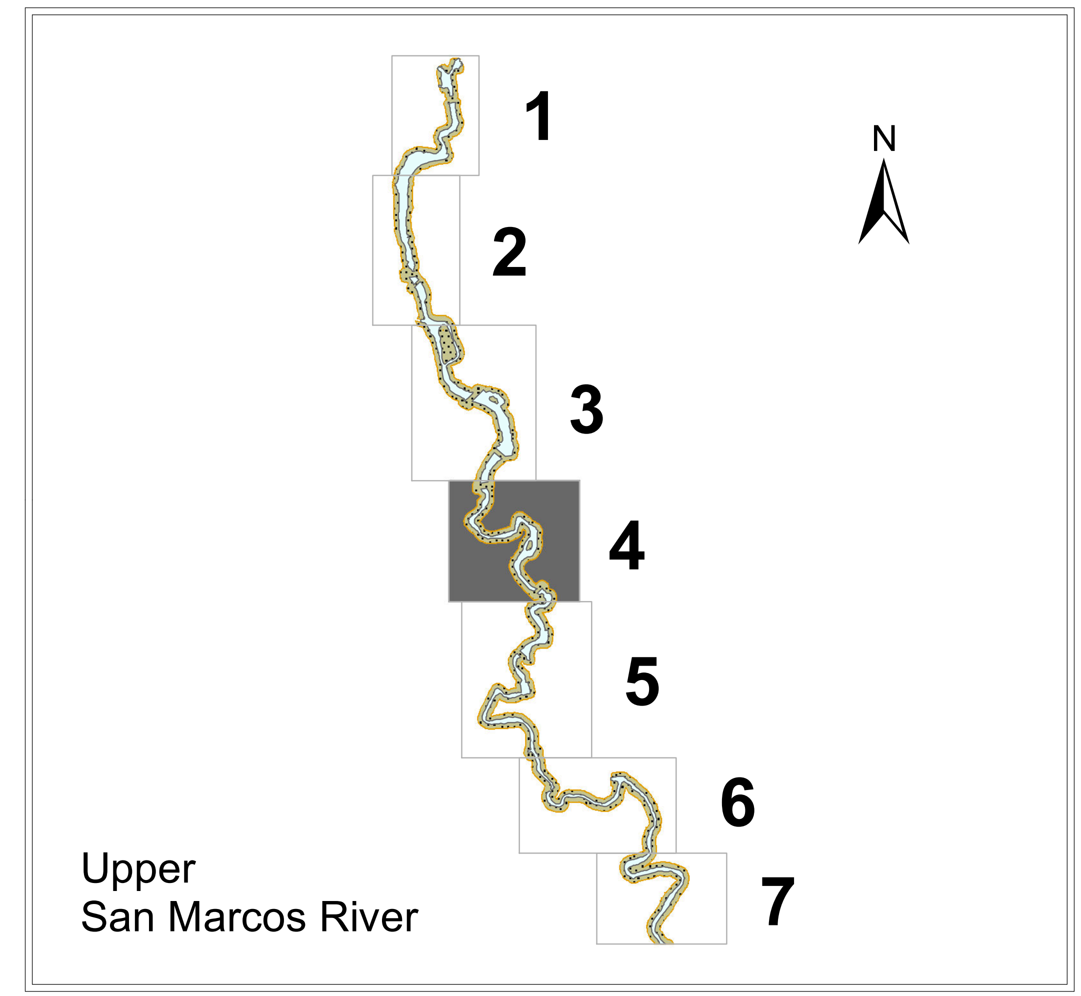


	Map 4 (m^2)	Total Population (m^2)
Zizania	379.0	3,916.8

1 inch = 37.2 meters

80 40 0 80 Meters

Project Location



BIO-WEST, Inc.

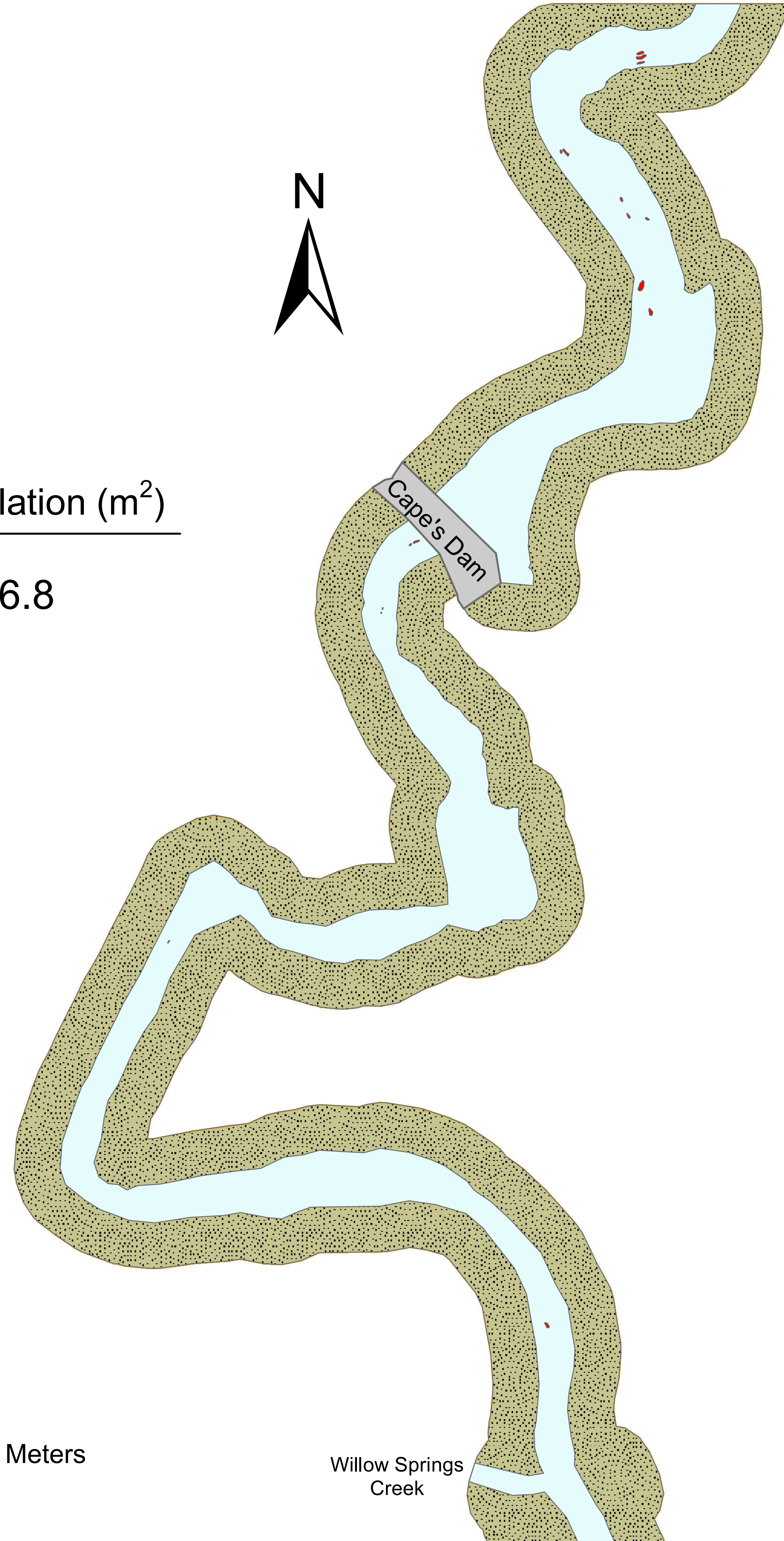
EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice
(Zizania texana)
Summer 2011
June 20 - 27, 2011

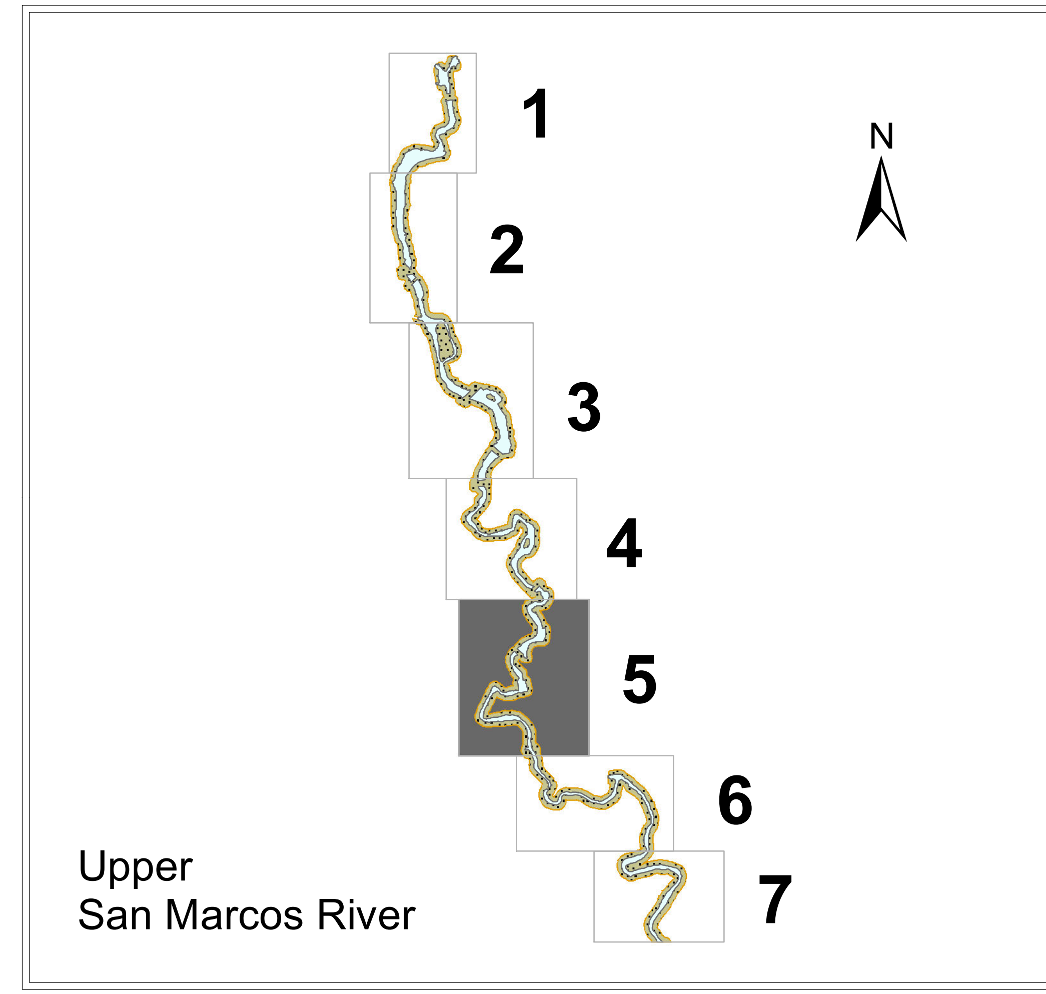
	Map 5 (m^2)	Total Population (m^2)
Zizania	20.5	3,916.8

1 inch = 48.1 meters

120 60 0 120 Meters

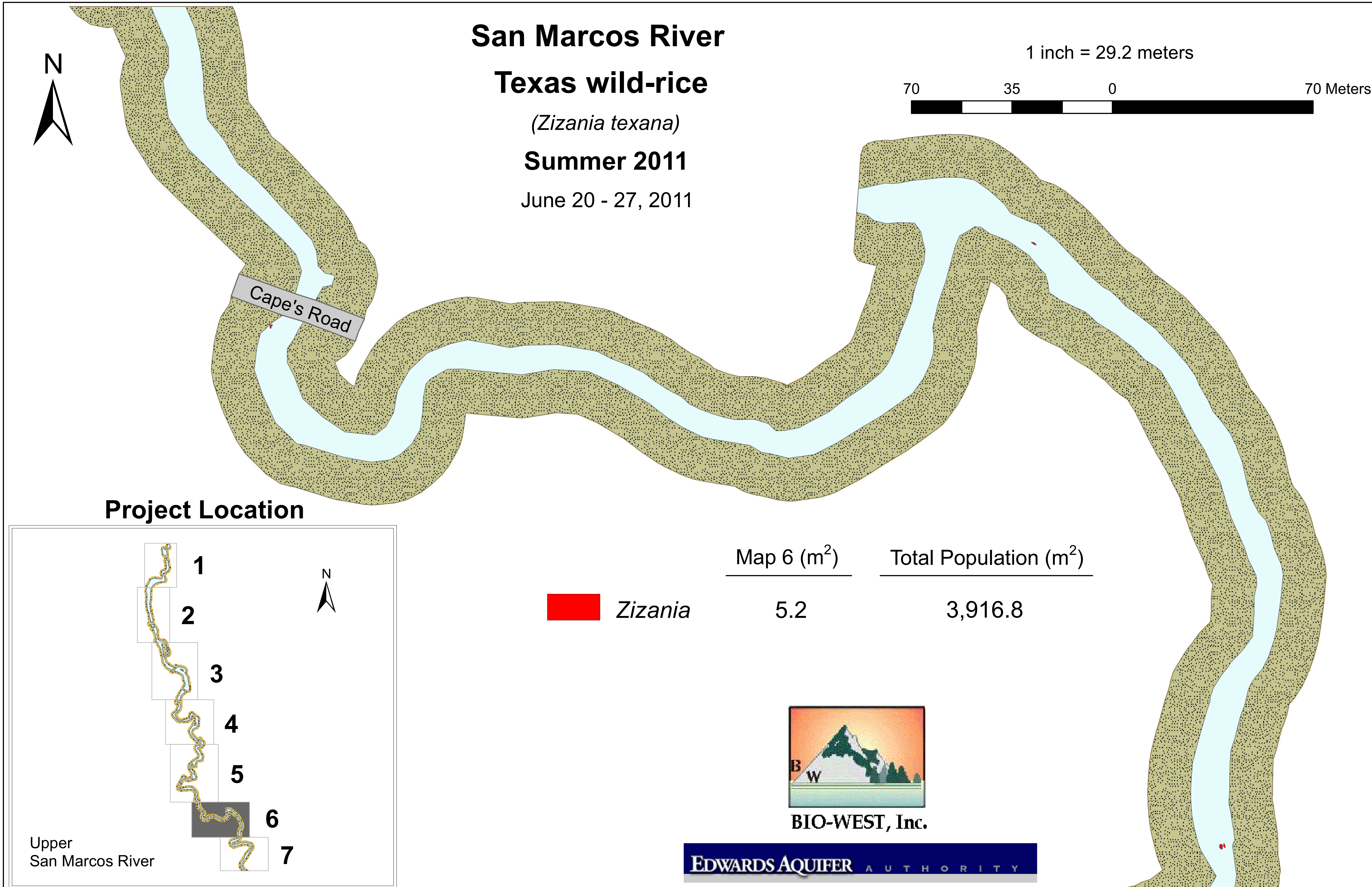


Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY



San Marcos River
Texas wild-rice
(Zizania texana)
Summer 2011
June 20 - 27, 2011
1 inch = 29.2 meters
70 35 0 70 Meters
N
Cape's Road
Project Location
1
2
3
4
5
6
7
N
Upper
San Marcos River
Map 6 (m2)
Total Population (m2)
Zizania
5.2
3,916.8
BIO-WEST, Inc.
EDWARDS AQUIFER AUTHORITY

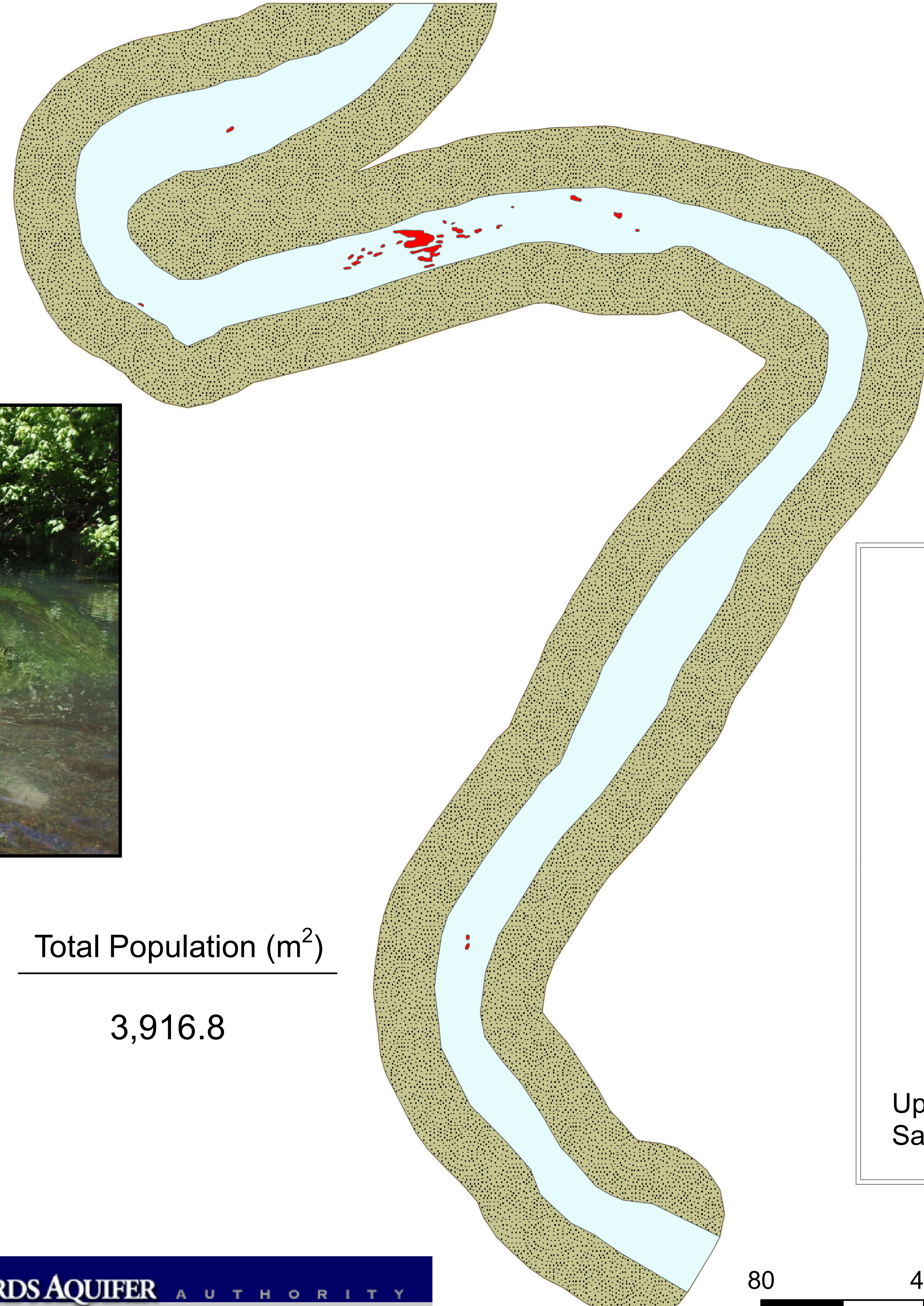
San Marcos River

Texas wild-rice

(Zizania texana)

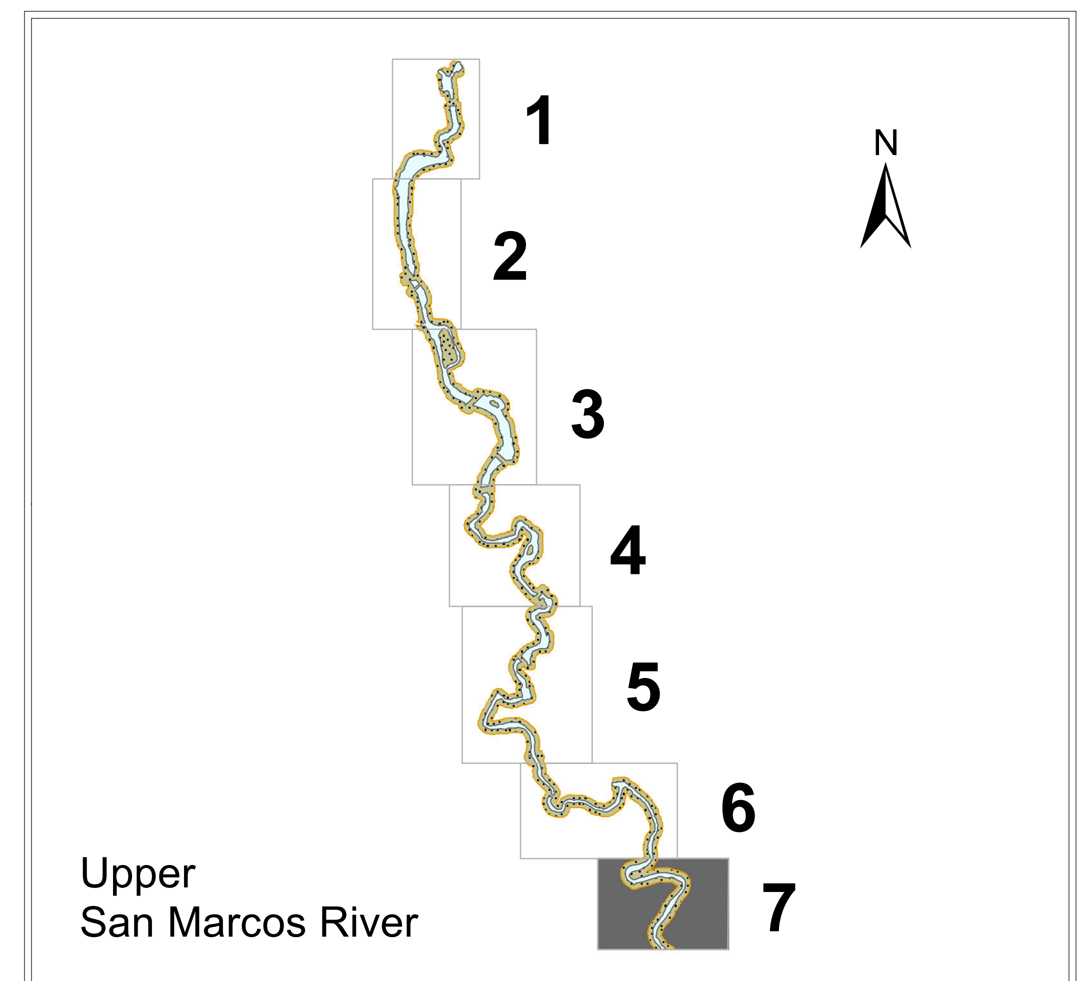
Summer 2011

June 20 - 27, 2011



	Map 7 (m^2)	Total Population (m^2)
Zizania	66.6	3,916.8

Project Location



1 inch = 30.6 meters

80 40 0 80 Meters

BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

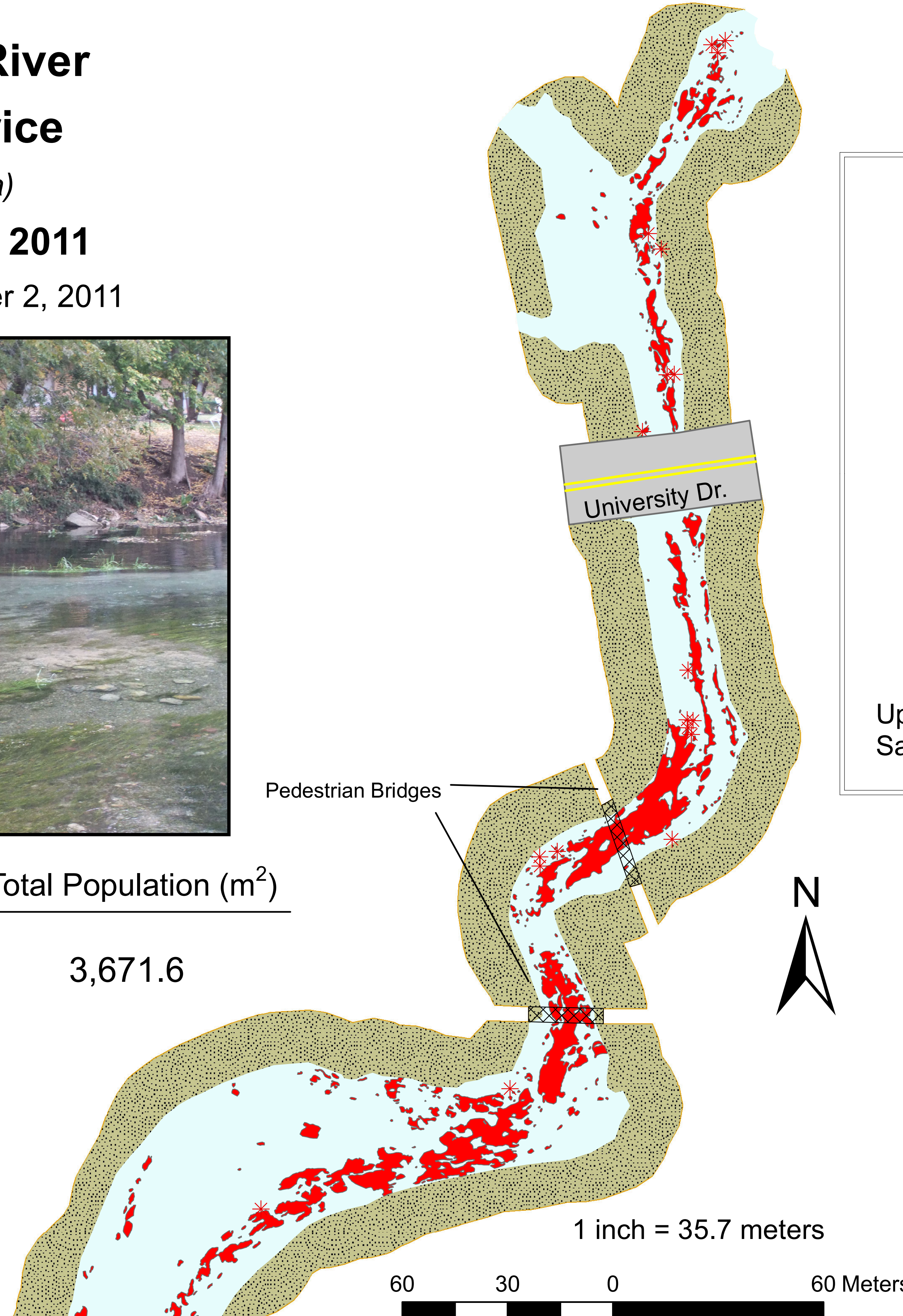
San Marcos River
Texas wild-rice

(Zizania texana)

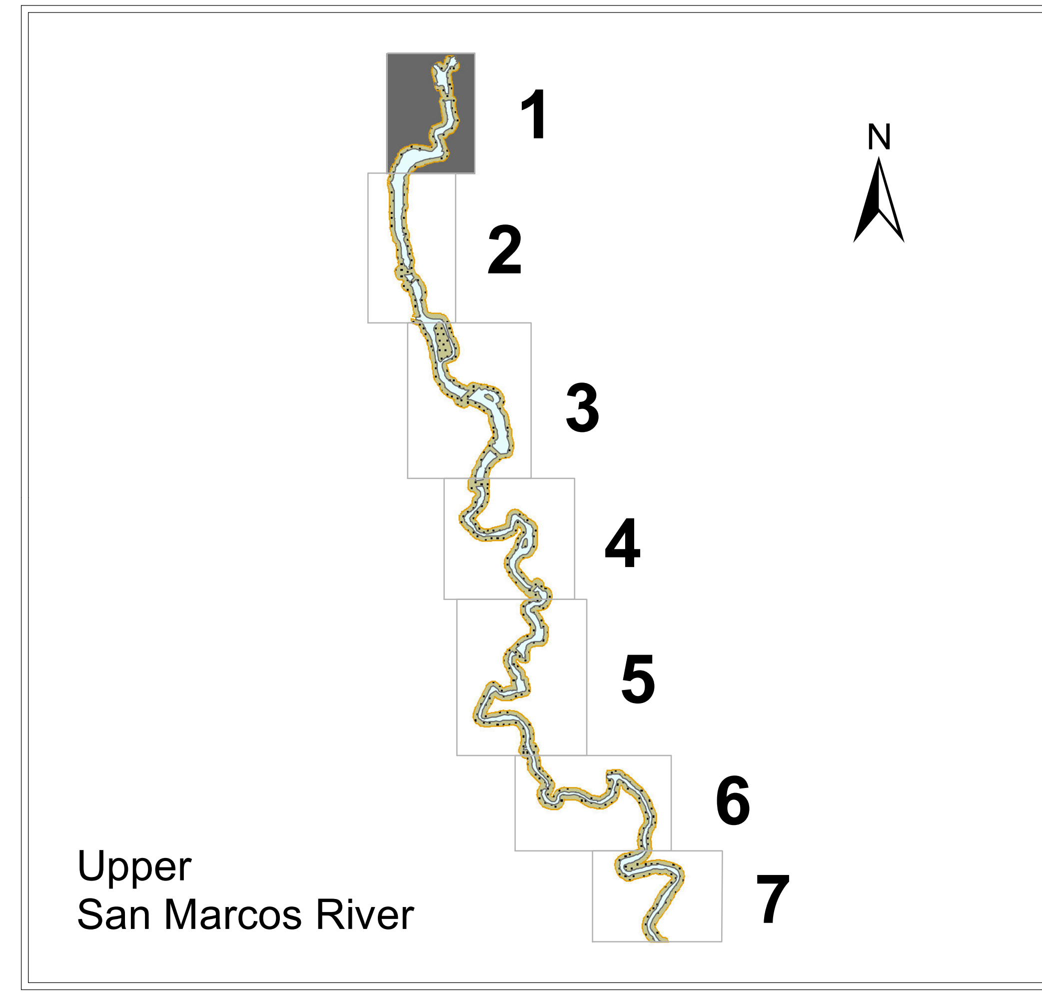
Critical Period 1 2011

August 29 - September 2, 2011

	Map 1 (m^2)	Total Population (m^2)
Zizania	2,289.7	3,671.6
Small *Zizania* Plants		



Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River

Texas wild-rice

(Zizania texana)

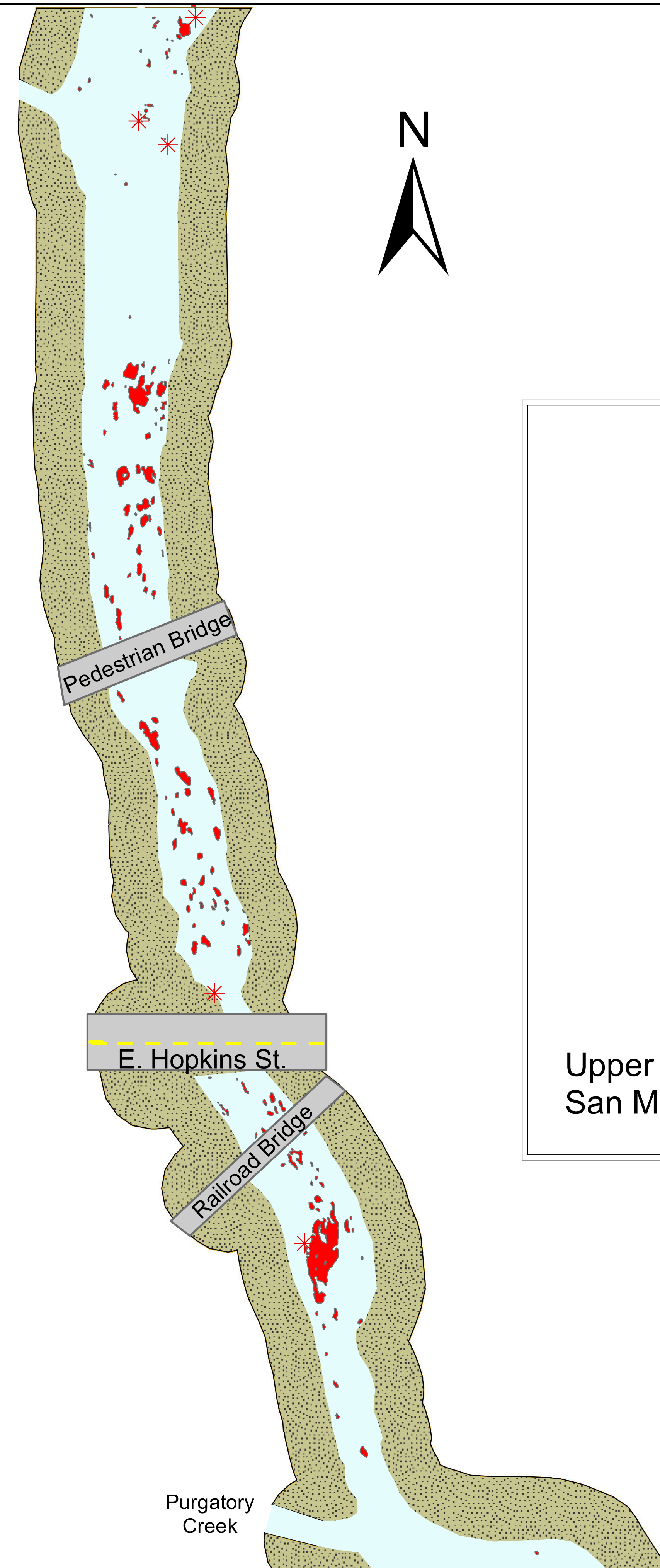
Critical Period 1 2011

August 29 - September 2, 2011

	Map 2 (m^2)	Total Population (m^2)
Zizania	550.6	3,671.6
✳ Small *Zizania* Plants		

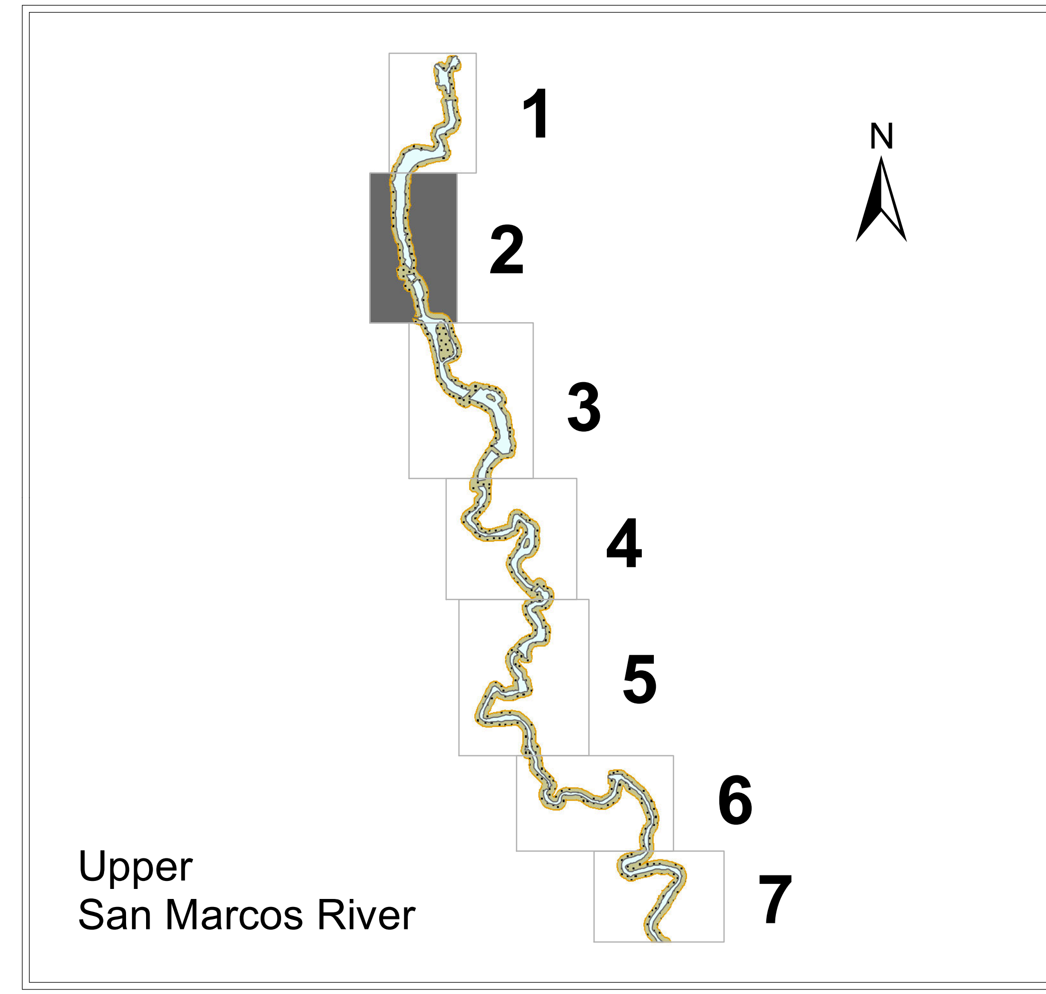
1 inch = 45.8 meters

60 30 0 60 Meters



N

Project Location



BIO-WEST, Inc.

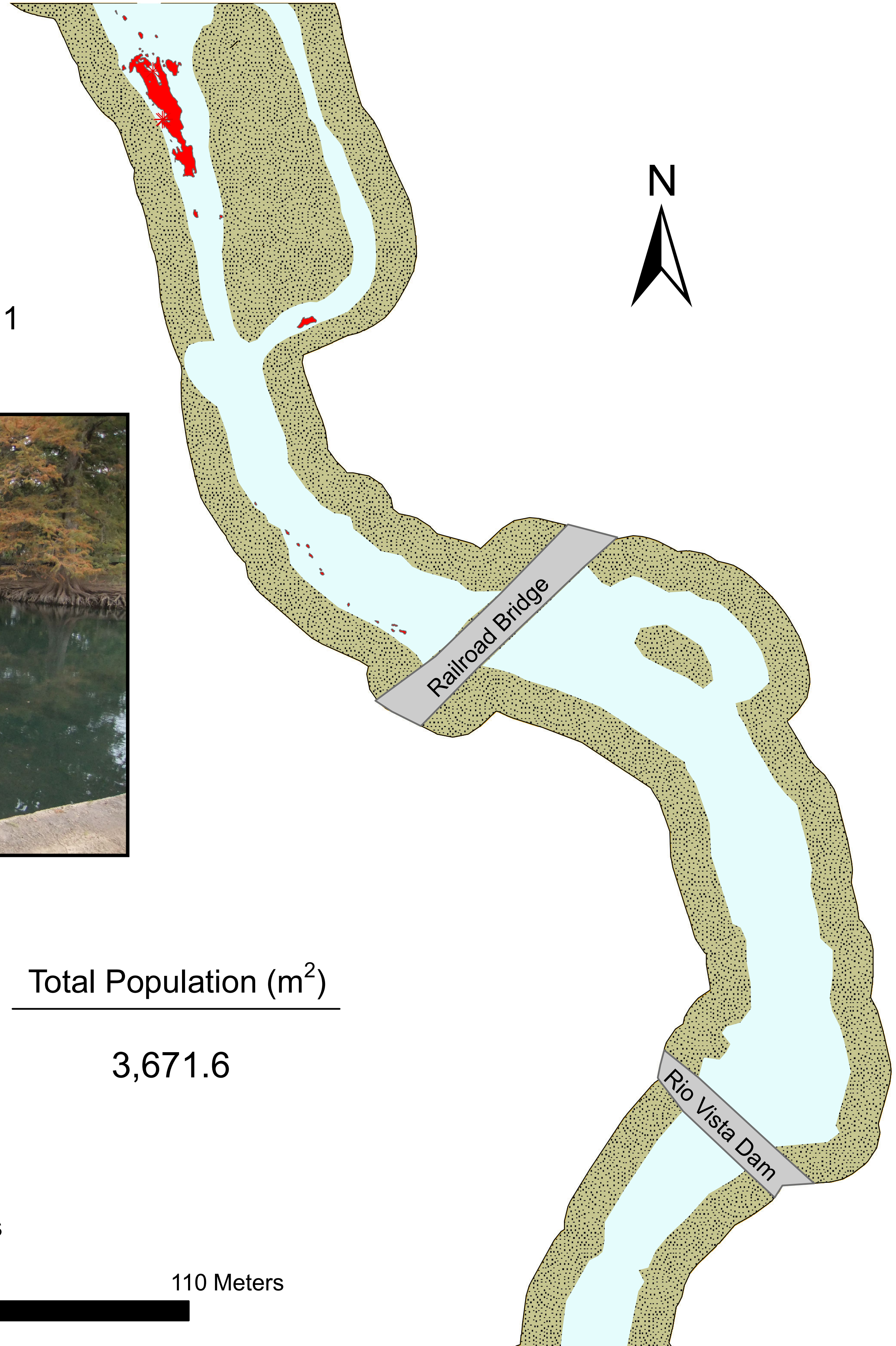
EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice

(Zizania texana)

Critical Period 1 2011

August 29 - September 2, 2011

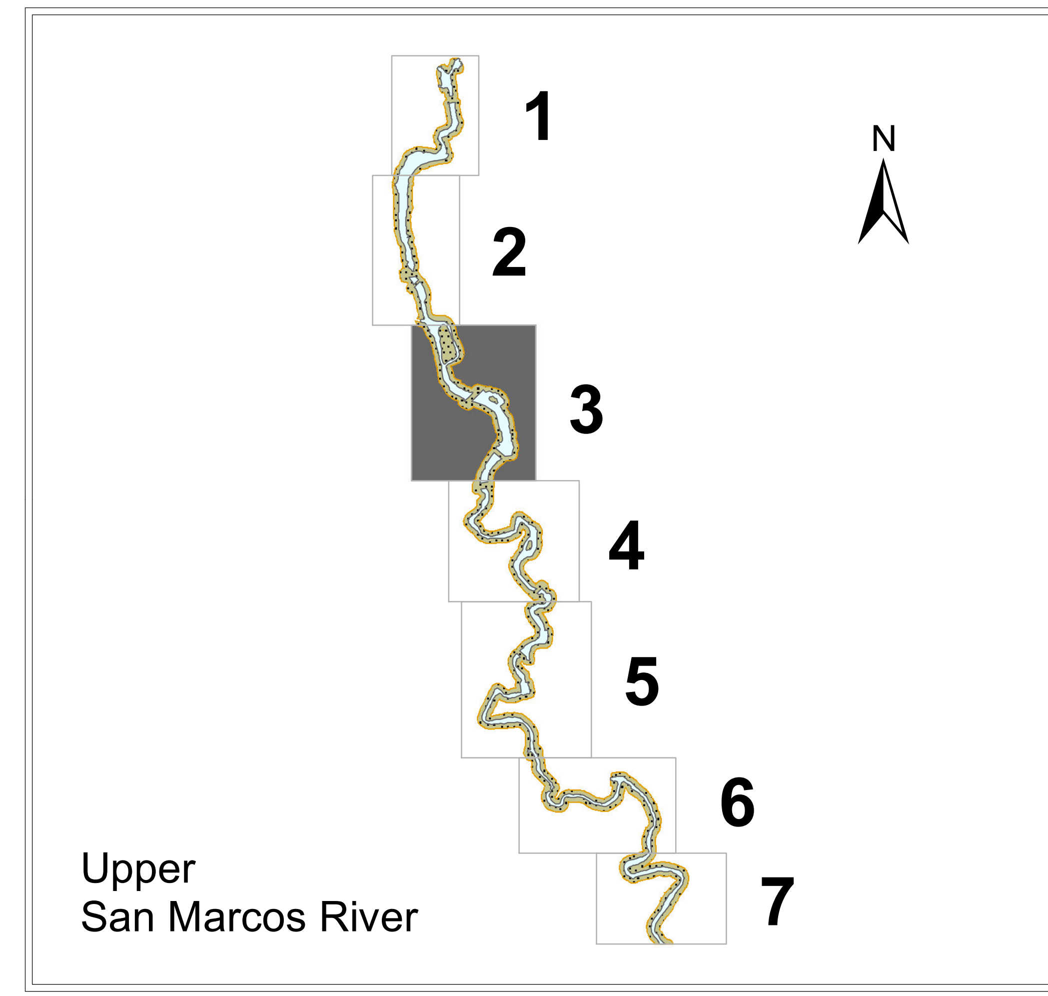


	Map 3 (m^2)	Total Population (m^2)
Zizania	342.2	3,671.6
Small *Zizania* Plants		

1 inch = 48 meters

110 55 0 110 Meters

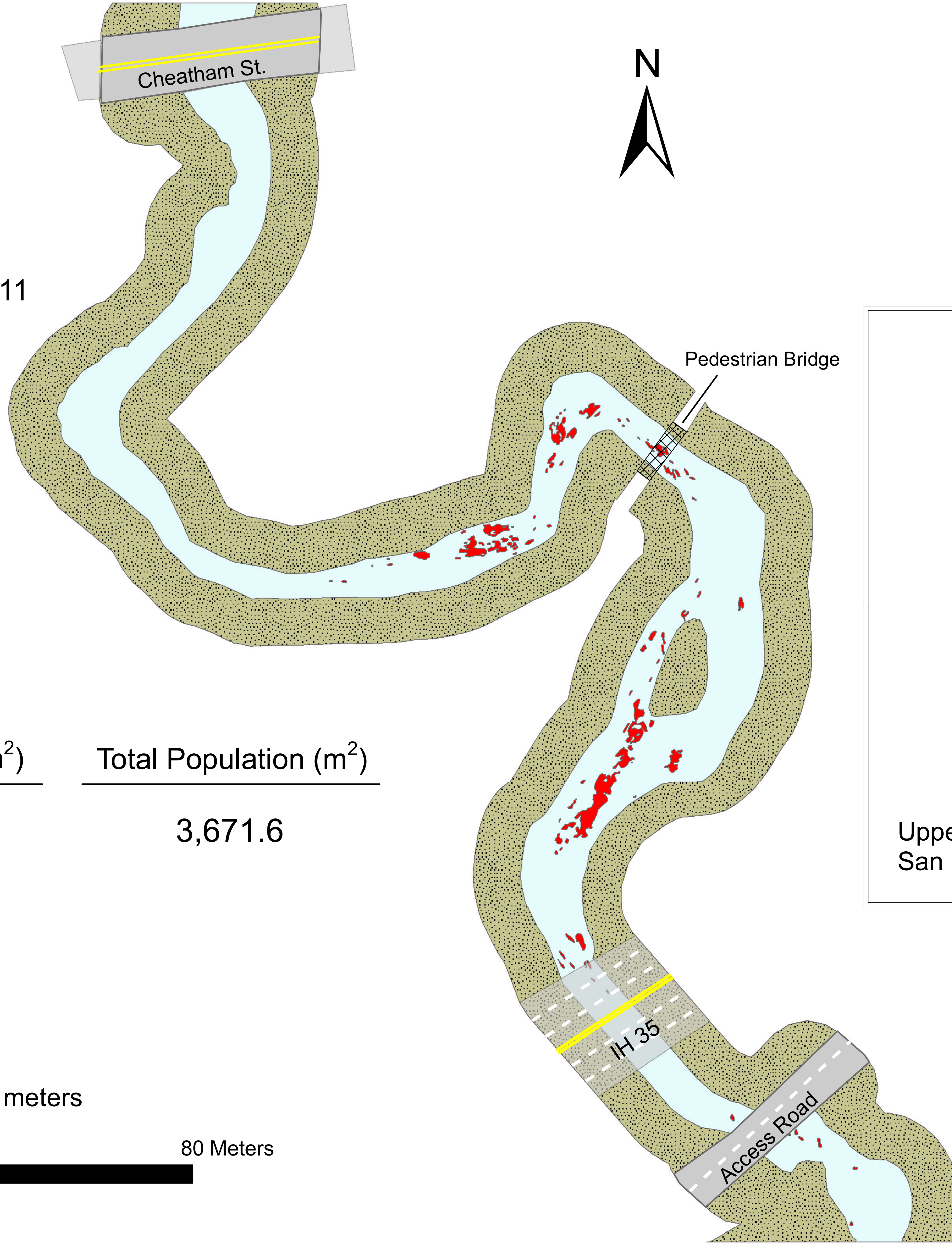
Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice
(Zizania texana)
Critical Period 1 2011
August 29 - September 2, 2011

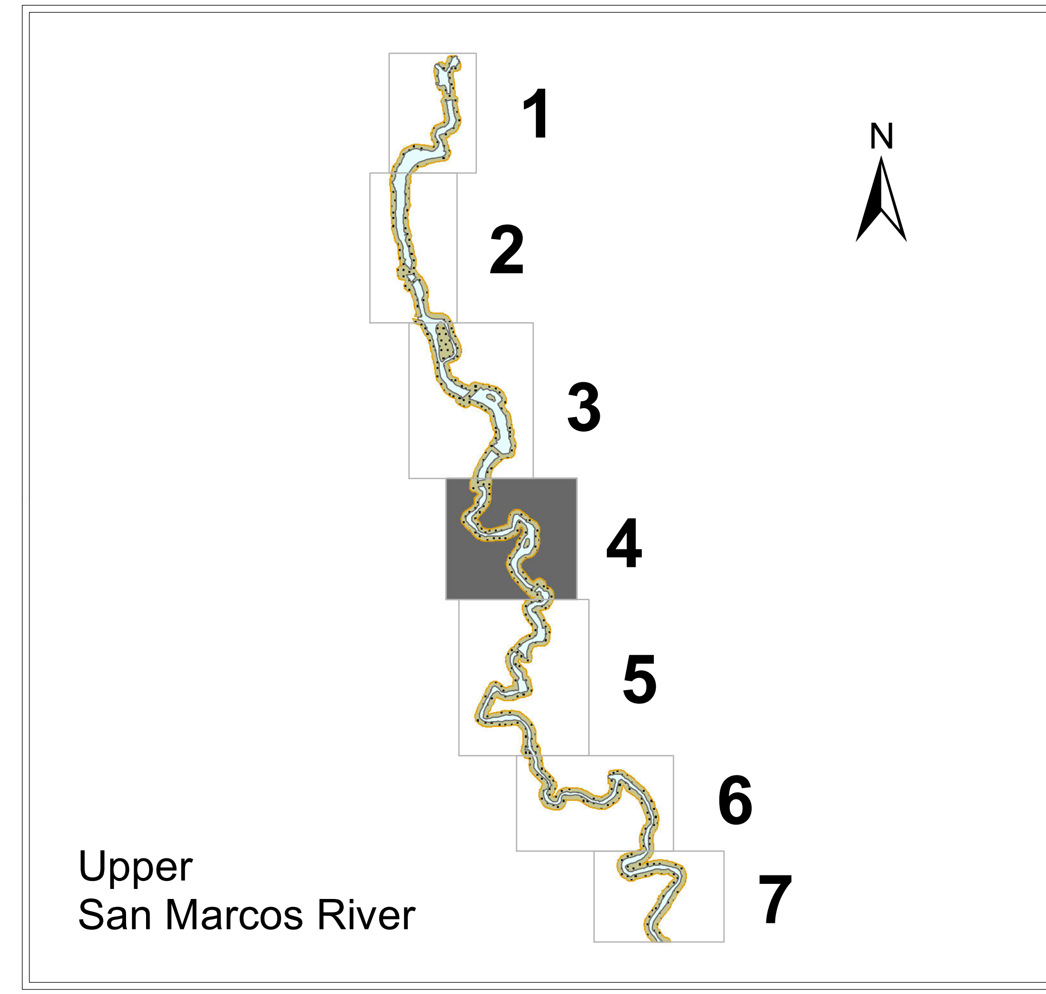


	Map 4 (m^2)	Total Population (m^2)
Zizania	392.4	3,671.6

1 inch = 37.2 meters

80 40 0 80 Meters

Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

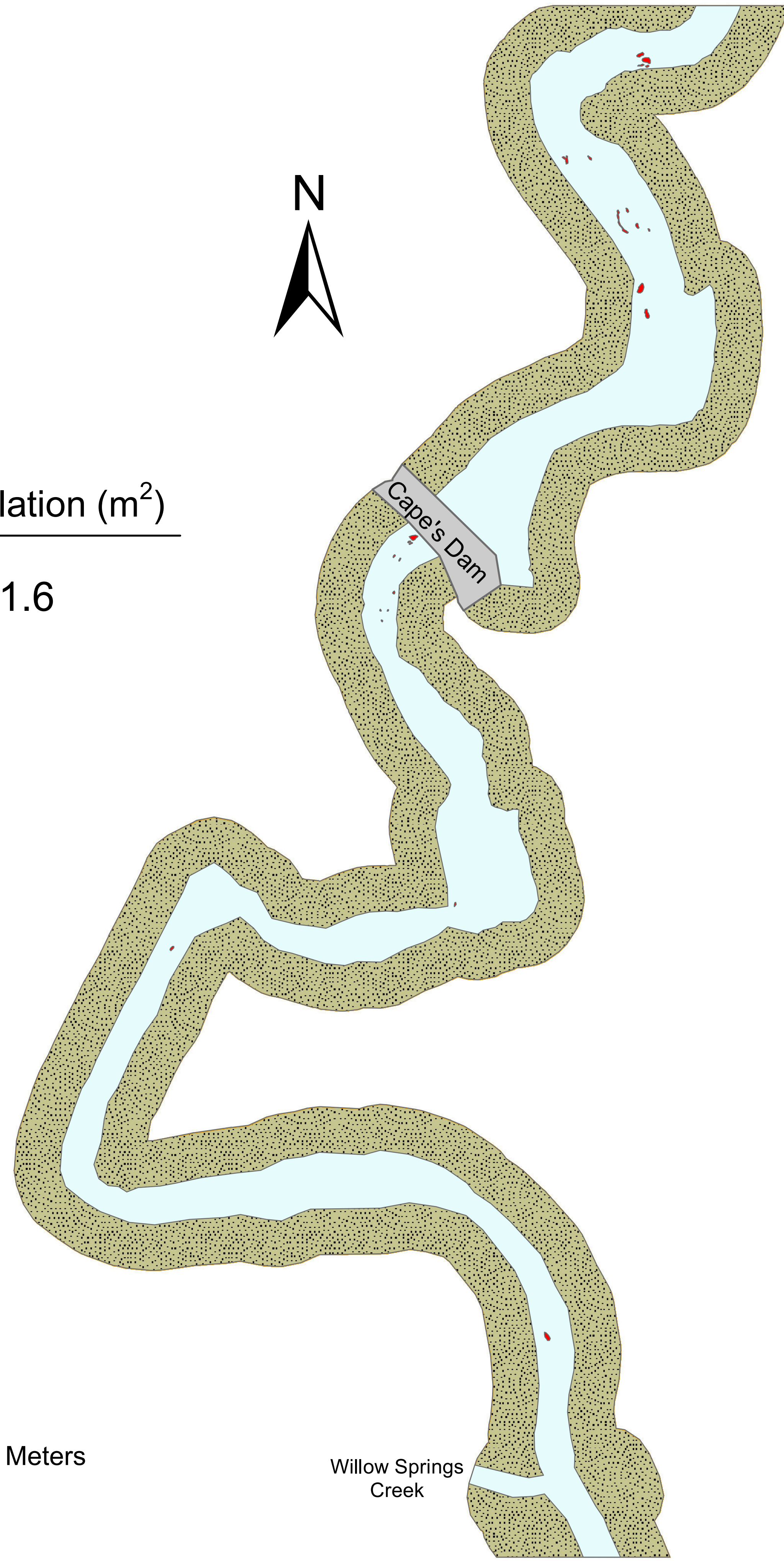
San Marcos River
Texas wild-rice
(Zizania texana)

Critical Period 1 2011
August 29 - September 2, 2011

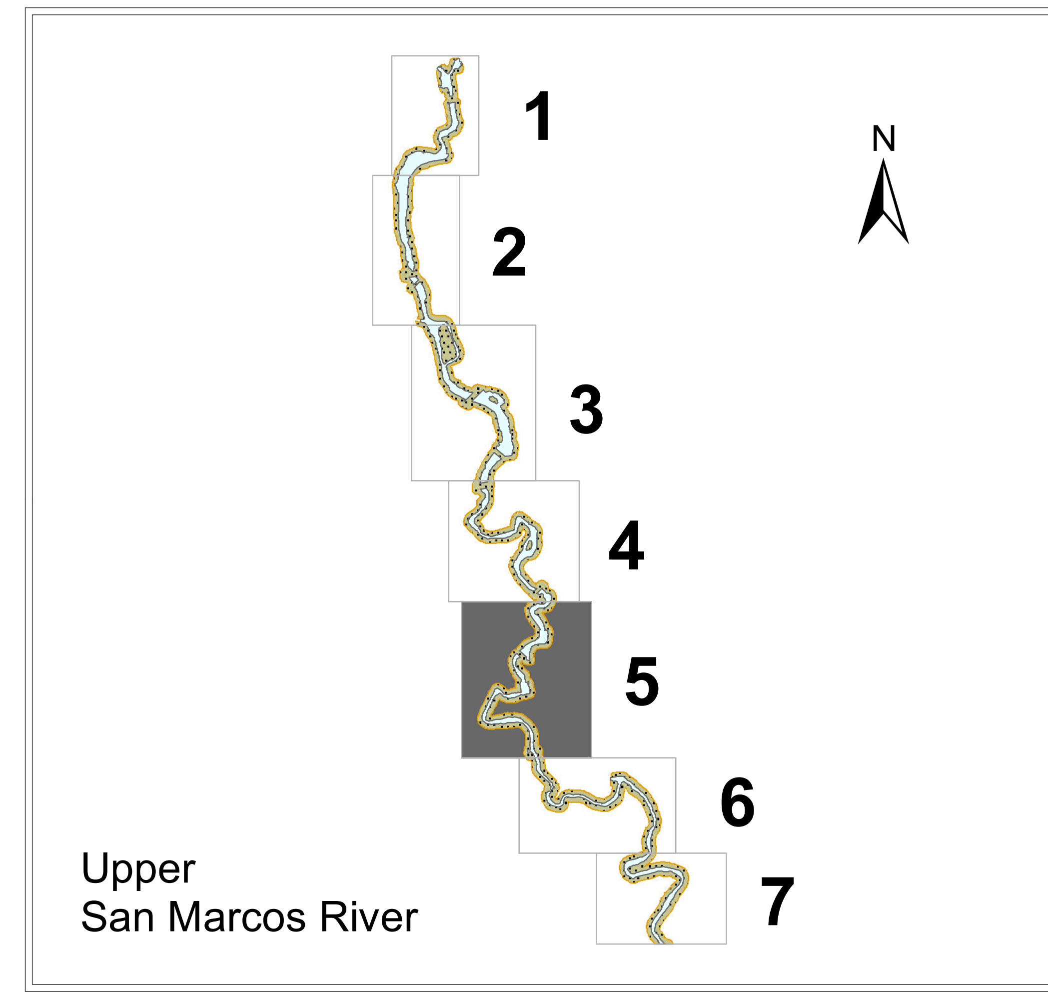
	Map 5 (m^2)	Total Population (m^2)
Zizania	33.3	3,671.6

1 inch = 48.1 meters

120 60 0 120 Meters

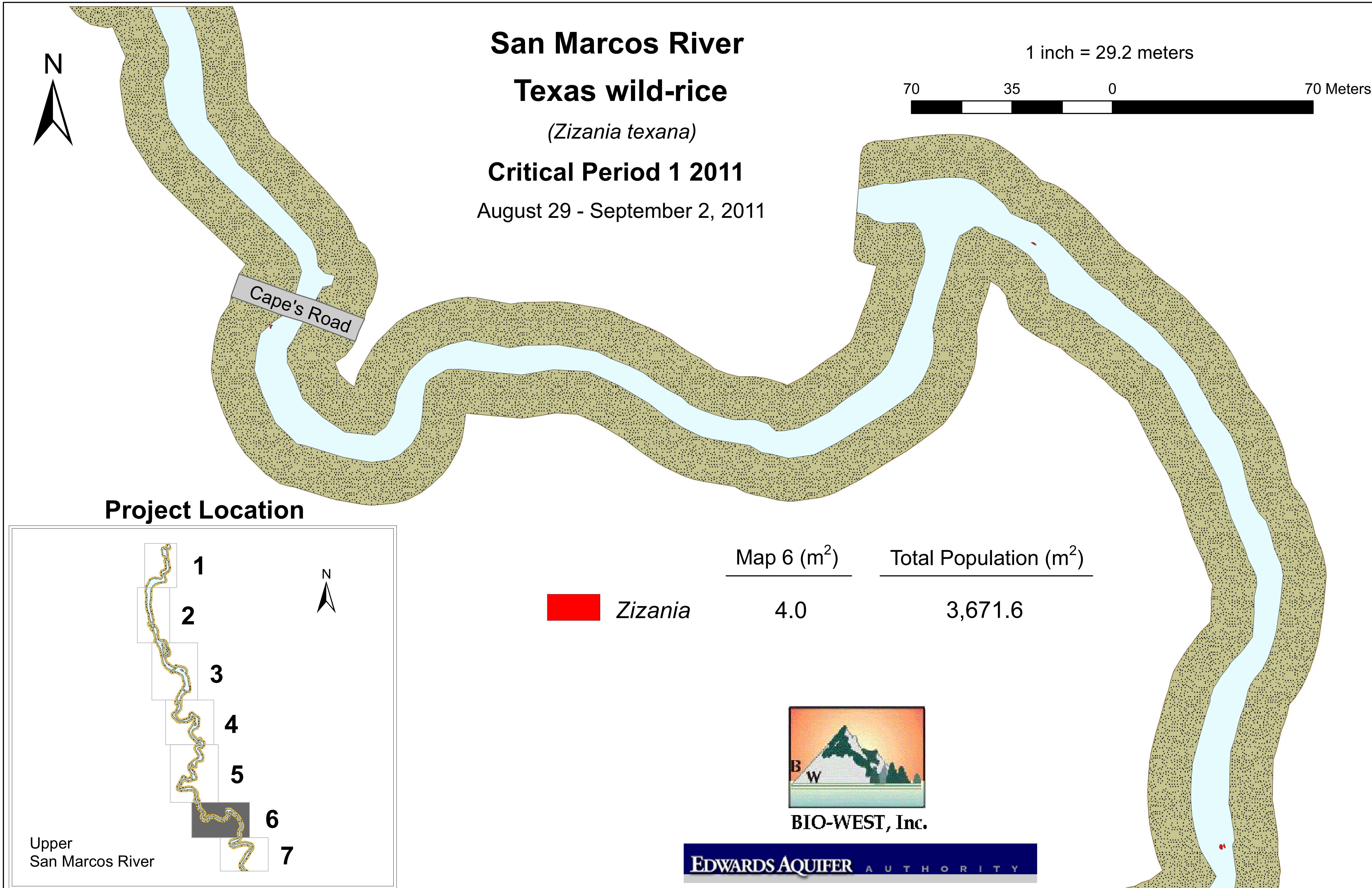


Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY


San Marcos River
Texas wild-rice
(Zizania texana)
Critical Period 1 2011
August 29 - September 2, 2011
1 inch = 29.2 meters
70 35 0 70 Meters
N
Cape's Road
Project Location
1
2
3
4
5
6
7
N
Upper San Marcos River
Map 6 (m2)
Total Population (m2)
Zizania
4.0
3,671.6
BIO-WEST, Inc.
EDWARDS AQUIFER AUTHORITY

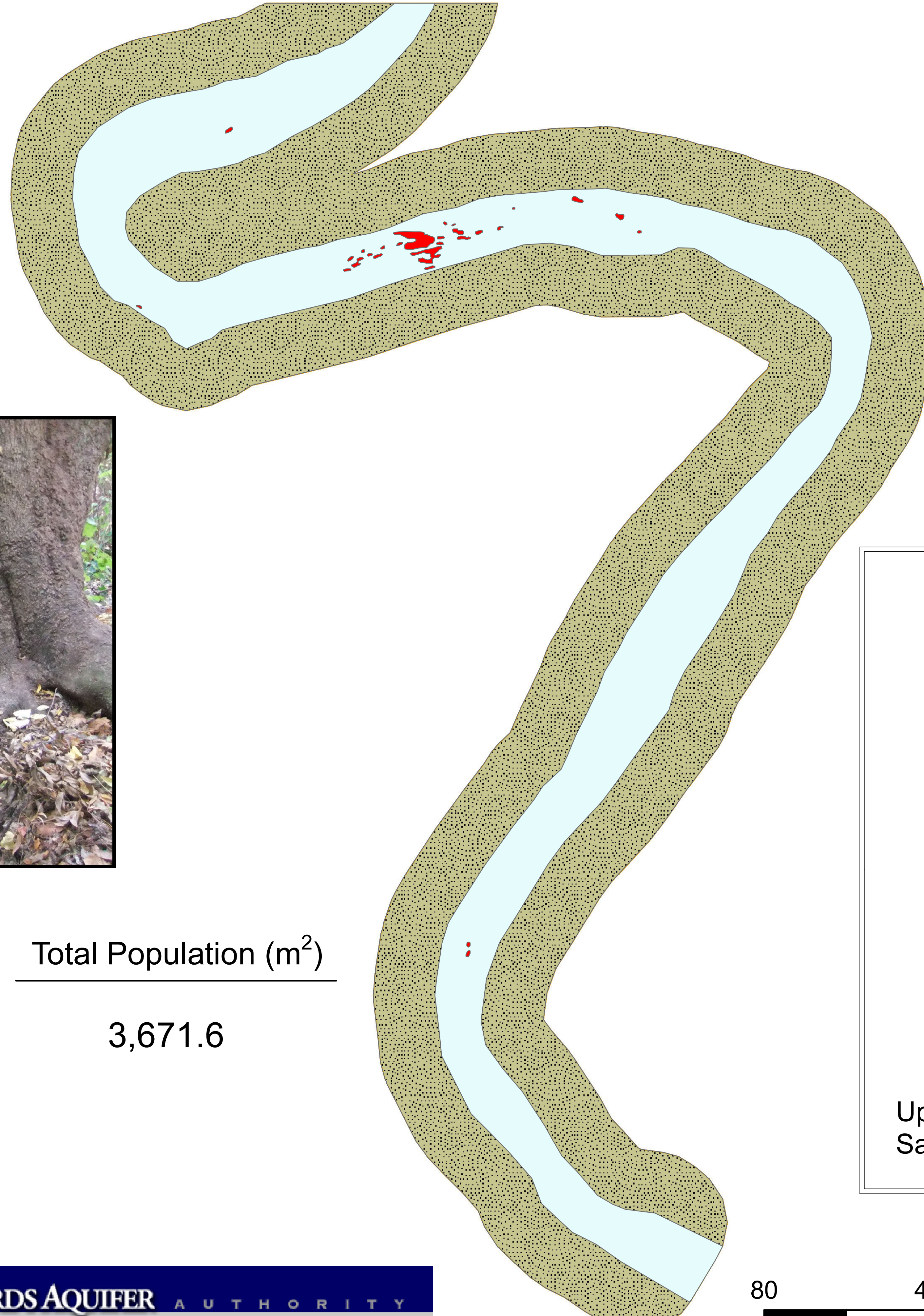
San Marcos River

Texas wild-rice

(Zizania texana)

Critical Period 1 2011

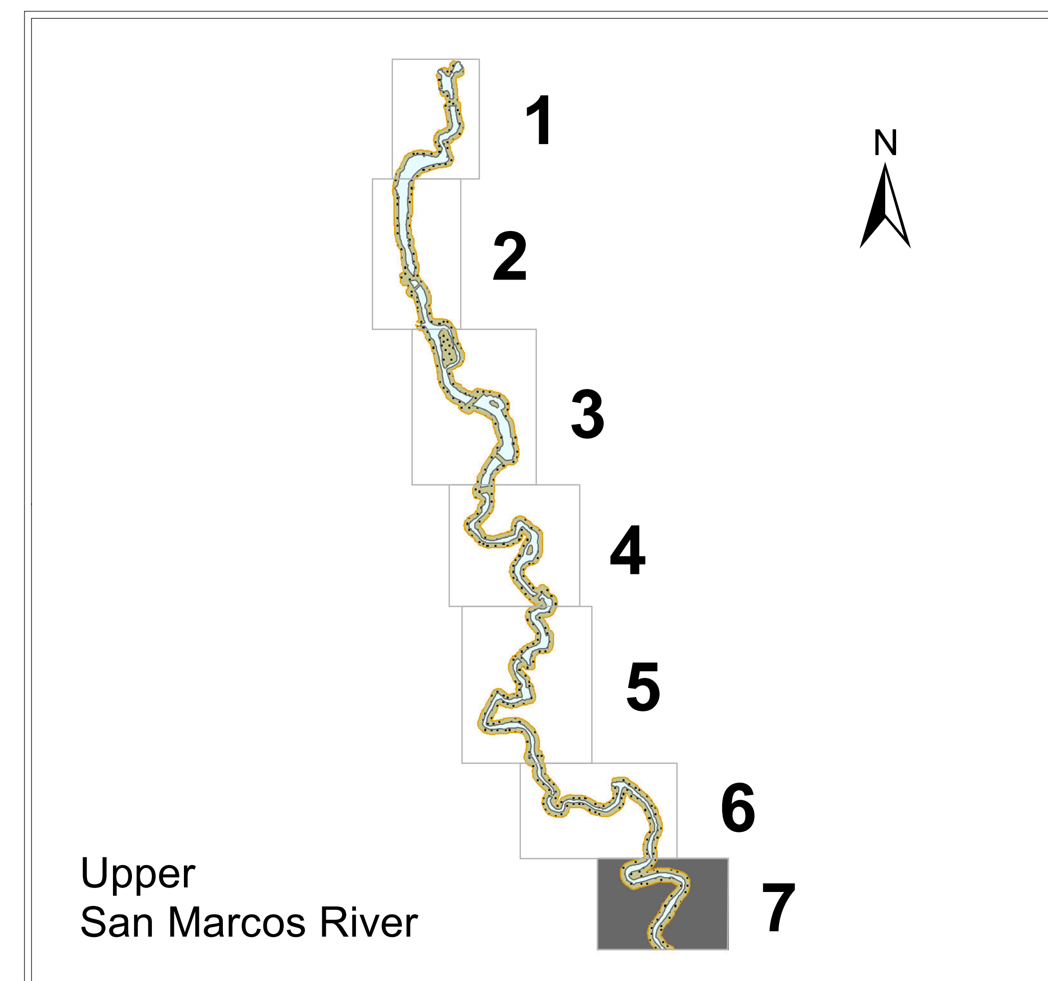
August 29 - September 2, 2011



	Map 7 (m^2)	Total Population (m^2)
Zizania	59.4	3,671.6

N

Project Location



1 inch = 30.6 meters

80 40 0 80 Meters

BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

APPENDIX B:
DATA AND GRAPHS

Water Quality Data
and
Thermistor Graphs

Water quality conditions at sites 1-9 on the San Marcos River during normal flows (2000-2002), a high-flow event in 2002, and low-flow critical period (CP) events in 2006, 2009 and 2011.

Sampling Date	Temp	pH	Cond (uS/cm)	D.O. (mg/L)	TSS (mg/L)	Alkalinity (mg/L)	NH3-N (mg/L)	N03-N (mg/L)	TN-N (mg/L)	SRP (mgP/L)	TP (mg/L)
Site 1											
10/31/2000	23.01	7.47	578	10.61	0.0000	261	0.043	1.160	1.180	0.005	0.008
3/5/2001	22.30	7.40	584	8.35	0.0020	237	0.021	1.240	1.660	0.011	0.010
5/7/2001	22.37	7.43	561	7.95	0.0800	237	0.025	0.510	0.800		
8/13/2001	22.73	7.39	596	7.75	0.0030	230	0.019	1.900	2.200	0.010	0.016
10/24/2001	22.55	7.04	580	8.35	0.0020	223		1.360	1.400	0.010	0.032
2/13/2002	22	7.15	560	8.63	0.0010	238	0.046	1.257	1.395	0.005	0.006
5/8/2002	22.74	7.13	538	8.5	0.0011	244	0.039	1.561	1.701	0.005	0.009
Average (2000-2002)	**22.53**	**7.29**	**571**	**8.59**	**0.01**	**239**	**0.032**	**1.28**	**1.48**	**0.008**	**0.014**
8/5/2002 (High Flow)	22.78	7.01	580	10.61	0.0080	259	0.030	1.661	2.019	0.006	0.010
7/25/2006 (Low Flow CP 1)	22.74	7.34	538	8.36	2	270	0.0388	1.72	2.7	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	22.21	7.37	578	7.77	3	270	0.0362	1.19	2.09	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.66	7.53	515	6.67	<1	260	0.1100	1.1	2.08	<0.05	<0.01
4/10/2009 (Low Flow CP 2)	21.76	7.97	518	7.66	<1	260	0.0655	1.1	1.92	<0.05	0.027
5/19/2009 (Low Flow Spring)	22.31	7.12	604	6.79	<4	280	0.0409	1.13	1.65	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	22.99	8.05	606	7.36	<4	240	0.0679	1.13	2.12	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	22.53	7.58	595	8.31	<4	270	0.036	0.588	1.23	<0.05	<0.02
Overall Average	**22.45**	**7.40**	**569**	**8.24**	**0.51**	**252**	**0.044**	**1.240**	**1.743**	**0.007**	**0.015**
Overall Min	**21.66**	**7.01**	**515**	**6.67**	**0.00**	**223**	**0.019**	**0.510**	**0.800**	**0.005**	**0.006**
Overall Max	**23.01**	**8.05**	**606**	**10.61**	**3.00**	**280**	**0.110**	**1.900**	**2.700**	**0.011**	**0.032**
2006 Average	**22.48**	**7.36**	**558**	**8.07**	**2.50**	**270**	**0.038**	**1.455**	**2.395**	**<0.05**	**<0.01**
2009 Average	**22.18**	**7.67**	**561**	**7.12**	**<4**	**260**	**0.071**	**1.115**	**1.943**	**<0.05**	**0.007**

Site 2											
10/31/2000	23.34	7.52	574	10.91	0.0010	238	0.032	1.200	2.330	0.004	0.003
3/5/2001	22.23	7.44	581	8.09	0.0040	229	0.082	1.350	1.800	0.016	0.016
5/7/2001	22.32	7.43	562	8.20	0.0640	229	0.084	1.390	1.630		
8/13/2001	22.68	7.29	598	7.20	0.0020	234	0.085	1.760	1.980	0.014	0.020
10/24/2001	22.71	7.46	580	7.95	0.0020	222	0.118	1.730	1.860	0.006	0.019
2/13/2002	21.75	7.23	559	8.73	0.0021	237	0.039	1.32	1.521	0.005	0.007
5/8/2002	22.83	7.15	537	8.69	0.0016	242	0.021	1.325	1.463	0.004	0.009
Average (2000-2002)	**22.55**	**7.36**	**570**	**8.54**	**0.01**	**233**	**0.07**	**1.44**	**1.80**	**0.008**	**0.012**
8/5/2002 (High Flow)	22.76	7.03	584	9.1	0.0080	259	0.043	1.169	1.396	0.006	0.010
7/25/2006 (Low Flow CP 1)	23.20	7.39	535	7.94	0	260	0.0848	1.46	3.13	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	22.02	7.37	575	7.75	2	260	0.0490	1.03	2.93	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.32	7.61	512	6.73	<1	260	0.0690	1.03	2.46	<0.05	0.0472
4/10/2009 (Low Flow CP 2)	21.50	7.50	515	7.88	<1	270	<0.01	1.02	1.95	0.10	0.0159
5/19/2009 (Low Flow Spring)	22.30	7.69	600	6.68	<4	270	0.0613	1.05	2.09	0.0774	<0.01
6/24/2009 (Low Flow CP 3)	22.99	8.05	606	7.36	<4	240	0.0679	1.13	2.12	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	22.60	7.54	592	7.84	<4	260	0.054	0.551	1.23	<0.05	<0.02
Overall Average	**22.44**	**7.45**	**567**	**8.07**	**0.21**	**247**	**0.064**	**1.234**	**1.993**	**0.026**	**0.016**
Overall Min	**21.32**	**7.03**	**512**	**6.68**	**0.00**	**222**	**0.021**	**0.551**	**1.230**	**0.004**	**0.003**
Overall Max	**23.34**	**8.05**	**606**	**10.91**	**2.00**	**270**	**0.118**	**1.760**	**3.130**	**0.100**	**0.047**
2006 Average	**22.61**	**7.38**	**555**	**7.85**	**1.00**	**260**	**0.067**	**1.245**	**3.030**	**<0.05**	**<0.01**
2009 Average	**22.03**	**7.71**	**558**	**7.16**	**<4**	**260**	**0.066**	**1.058**	**2.155**	**0.044**	**0.016**

Water quality conditions at sites 1-9 on the San Marcos River during normal flows (2000-2002), a high-flow event in 2002, and low-flow critical period (CP) events in 2006, 2009 and 2011.

Sampling Date	Temp	pH	Cond	D.O.	TSS (mg/L)	Alkalinity (mg/L)	NH3-N (mg/L)	N03-N (mg/L)	TN-N (mg/L)	SRP (mgP/L)	TP (mg/L)
Site 3											
10/31/2000	23.33	7.42	607	8.63	0.0020	231	0.105	1.350	1.090	0.004	0.018
3/5/2001	21.82	7.53	609	7.53	0.0040	236	0.002	2.260	2.710	0.011	0.013
5/7/2001	22.62	7.48	588	6.90	0.0150	235	0.002	1.260	1.350		
8/13/2001	23.70	7.50	611	7.08	0.0030	232	0.002	2.100	2.300	0.008	0.017
10/24/2001	22.93	7.48	610	6.77	0.0030	222	0.007	1.610	1.630	0.007	0.022
2/13/2002	21.78	7.29	571	8.17	0.0023	233	0.096	1.439	1.635	0.005	0.013
5/8/2002	23.06	7.22	553	7.26	0.0019	232	0.072	1.395	1.647	0.004	0.015
Average (2000-2002)	**22.75**	**7.42**	**593**	**7.48**	**0.00**	**231**	**0.04**	**1.63**	**1.77**	**0.007**	**0.016**
8/5/2002 (High Flow)	22.9	7.07	598	8.17	0.004	259	0.023	1.598	1.719	0.010	0.015
7/25/2006 (Low Flow CP 1)	23.62	7.37	563	6.18	3	270	0.0764	1.74	2.76	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	22.74	7.29	598	5.76	2	270	0.0700	1.00	2.10	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	13.94	7.57	628	7.90	2	240	0.0973	1.12	3.08	<0.05	0.042
4/10/2009 (Low Flow CP 2)	20.70	8.02	542	6.57	<1	270	0.0370	1.09	2.92	<0.05	0.037
5/19/2009 (Low Flow Spring)	21.65	7.34	618	5.06	<4	270	0.0643	1.20	1.96	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	23.59	8.31	630	5.33	<4	260	0.0541	1.14	2.20	0.101	<0.01
9/21/2011 (Low Flow CP 1)	23.09	7.56	615	6.37	<4	260	0.0420	0.60	1.16	<0.05	<0.02
Overall Average	**22.10**	**7.50**	**596**	**6.91**	**0.64**	**248**	**0.050**	**1.393**	**2.017**	**0.019**	**0.021**
Overall Min	**13.94**	**7.07**	**542**	**5.06**	**0.00**	**222**	**0.002**	**0.600**	**1.090**	**0.004**	**0.013**
Overall Max	**23.70**	**8.31**	**630**	**8.63**	**3.00**	**270**	**0.105**	**2.260**	**3.080**	**0.101**	**0.042**
2006 Average	**23.18**	**7.33**	**580.50**	**5.97**	**2.50**	**270**	**0.073**	**1.368**	**2.430**	**<0.05**	**<0.01**
2009 Average	**19.97**	**7.81**	**604.50**	**6.22**	**2.00**	**260**	**0.063**	**1.138**	**2.540**	**0.025**	**0.020**

Site 4											
10/31/2000	23.28	7.66	575	11.60	0.0020	263	0.116	1.240	1.530	0.005	0.012
3/15/2001	22.50	7.49	583	8.90	0.0020	245	0.099	1.400	1.900	0.016	0.024
5/7/2001	22.31	7.45	560	8.45	0.0940	238	0.024	1.500	1.750		
8/13/2001	22.76	7.42	595	8.25	0.0050	234	0.018	1.680	1.800	0.021	0.029
10/24/2001	23.06	7.53	579	8.81	0.0040	219		1.610	1.630	0.010	0.030
2/13/2002	21.84	7.26	559	9.68	0.0016	237	0.120	1.328	1.449	0.005	0.015
5/8/2002	22.92	7.17	538	9.27	0.0025	238	0.106	1.415	1.592	0.005	0.015
Average (2000-2002)	**22.67**	**7.43**	**570**	**9.28**	**0.02**	**239**	**0.08**	**1.45**	**1.66**	**0.010**	**0.021**
8/5/2002 (High Flow)	22.83	7.03	583	10.91	0.0060	259	0.018	1.116	1.299	0.008	0.015
7/25/2006 (Low Flow CP 1)	22.78	7.40	544	8.29	3	270	0.0703	1.65	2.65	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	21.92	7.38	575	9.68	5	270	0.0583	1.11	2.11	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.43	7.59	514	6.79	<1	260	0.0675	1.07	2.05	<0.05	<0.01
4/10/2009 (Low Flow CP 2)	21.54	7.93	519	7.87	1	260	0.0471	1.07	1.77	<0.05	0.013
5/19/2009 (Low Flow Spring)	22.07	7.09	601	6.95	<4	270	0.0526	1.11	2.87	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	22.69	8.10	606	6.34	<4	250	0.0610	1.11	2.66	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	22.30	7.57	593	8.06	<4	260	0.0510	0.57	1.26	<0.05	<0.02
Overall Average	**22.42**	**7.47**	**568**	**8.66**	**0.83**	**252**	**0.065**	**1.265**	**1.888**	**0.010**	**0.019**
Overall Min	**21.43**	**7.03**	**514**	**6.34**	**0.00**	**219**	**0.018**	**0.567**	**1.260**	**0.005**	**0.012**
Overall Max	**23.28**	**8.10**	**606**	**11.60**	**5.00**	**270**	**0.120**	**1.680**	**2.870**	**0.021**	**0.030**
2006 Average	**22.35**	**7.39**	**560**	**8.99**	**4.00**	**270**	**0.064**	**1.380**	**2.380**	**<0.05**	**<0.01**
2009 Average	**21.93**	**7.68**	**560**	**6.99**	**1.00**	**260**	**0.057**	**1.090**	**2.338**	**<0.05**	**0.003**

Water quality conditions at sites 1-9 on the San Marcos River during normal flows (2000-2002), a high-flow event in 2002, and low-flow critical period (CP) events in 2006, 2009 and 2011.

Sampling Date	Temp	pH	Cond	D.O.	TSS (mg/L)	Alkalinity (mg/L)	NH3-N (mg/L)	N03-N (mg/L)	TN-N (mg/L)	SRP (mgP/L)	TP (mg/L)
Site 5											
10/31/2000	22.85	7.57	579	11.68	0.0010	229	0.127	1.390	2.820	0.004	0.010
3/5/2001	22.64	7.62	581	10.15	0.0020	236	0.007	1.220	1.630	0.017	0.018
5/7/2001	22.13	7.54	559	8.81	0.0590	239	0.114	2.120	2.360		
8/13/2001	22.76	7.46	596	8.92	0.0040	242	0.000	1.770	1.900	0.002	0.014
10/24/2001	23.28	7.60	579	9.79	0.0040	222	0.127	1.490	1.630	0.001	0.003
2/13/2002	21.66	7.29	560	12.32	0.0023	236	0.123	1.306	1.763	0.004	0.013
5/8/2002	23.18	7.33	537	10.4	0.0023	246	0.121	1.422	1.776	0.005	0.016
Average (2000-2002)	**22.64**	**7.49**	**570**	**10.30**	**0.01**	**236**	**0.09**	**1.53**	**1.98**	**0.005**	**0.012**
8/5/2002 (High Flow)	23.17	7.14	582	11.5	0.007	262	0.03	1.218	1.41	0.009	0.016
7/25/2006 (Low Flow CP 1)	22.95	7.50	540	8.81	1	260	0.0521	1.60	3.19	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	21.79	7.41	577	6.64	3	260	0.0478	1.06	2.29	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.16	7.58	515	6.16	1	260	0.1440	1.02	3.37	<0.05	0.028
4/10/2009 (Low Flow CP 2)	21.15	8.14	518	6.23	2	260	<0.01	1.04	1.93	<0.05	0.042
5/19/2009 (Low Flow Spring)	18.00	7.23	694	8.24	<4	260	0.0438	1.06	1.94	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	22.77	8.29	606	5.50	<4	280	0.1220	1.07	2.06	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	21.92	7.60	595	6.39	5	270	0.0910	0.54	1.47	<0.05	<0.02
Overall Average	**22.09**	**7.55**	**575**	**8.77**	**0.91**	**251**	**0.082**	**1.288**	**2.103**	**0.006**	**0.018**
Overall Min	**18.00**	**7.14**	**515**	**5.50**	**0.00**	**222**	**0.000**	**0.535**	**1.410**	**0.001**	**0.003**
Overall Max	**23.28**	**8.29**	**694**	**12.32**	**4.80**	**280**	**0.144**	**2.120**	**3.370**	**0.017**	**0.042**
2006 Average	**22.37**	**7.46**	**559**	**7.73**	**2.00**	**260**	**0.050**	**1.330**	**2.740**	**<0.05**	**<0.01**
2009 Average	**20.77**	**7.81**	**583**	**6.53**	**1.50**	**265**	**0.103**	**1.048**	**2.325**	**<0.05**	**0.018**

Site 6											
10/31/2000	22.64	7.67	576	10.88	0.0020	225	0.127	1.450	1.120	0.005	0.011
3/5/2001	22.58	7.78	583	9.58	0.0070	237	0.016	1.640	2.260	0.020	0.032
5/7/2001	21.98	7.65	560	8.22	0.0910	248	0.030	1.330	1.460		
8/13/2001	22.61	7.61	596	8.21	0.0060	252	0.023	1.790	1.960	0.001	0.010
10/24/2001	23.24	7.74	578	8.95	0.0040	223		1.500	1.510	0.003	0.010
2/13/2002	21.04	7.41	559	10.88	0.0026	238	0.116	1.121	1.215	0.006	0.010
5/8/2002	23.19	7.45	537	9.5	0.0022	239	0.099	1.119	1.396	0.005	0.014
Average (2000-2002)	**22.47**	**7.62**	**570**	**9.46**	**0.02**	**237**	**0.07**	**1.42**	**1.56**	**0.007**	**0.014**
8/5/2002 (High Flow)	23.12	7.26	582	10.48	0.006	263	0.028	1.218	1.658	0.008	0.014
7/25/2006 (Low Flow CP 1)	22.68	7.56	543	7.63	0	270	0.0606	1.61	2.62	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	21.68	7.56	576	8.00	5	270	0.0536	1.09	2.17	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.06	7.56	514	6.42	<1	270	0.1190	1.04	2.16	<0.05	0.017
4/10/2009 (Low Flow CP 2)	21.07	8.04	517	6.62	2	270	0.0521	1.05	1.76	<0.05	0.042
5/19/2009 (Low Flow Spring)	20.99	7.11	602	6.35	<4	270	0.0803	1.09	1.66	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	22.69	8.19	606	5.54	<4	270	0.0978	1.09	2.25	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	21.84	7.84	592	8.00	<4	260	0.0870	0.551	1.39	<0.05	<0.02
Overall Average	**22.16**	**7.63**	**568**	**8.35**	**0.65**	**254**	**0.071**	**1.246**	**1.773**	**0.007**	**0.018**
Overall Min	**20.99**	**7.11**	**514**	**5.54**	**0.00**	**223**	**0.016**	**0.551**	**1.120**	**0.001**	**0.010**
Overall Max	**23.24**	**8.19**	**606**	**10.88**	**5.00**	**270**	**0.127**	**1.790**	**2.620**	**0.020**	**0.042**
2006 Average	**22.18**	**7.56**	**560**	**7.82**	**2.50**	**270**	**0.057**	**1.350**	**2.395**	**<0.05**	**<0.01**
2009 Average	**21.45**	**7.73**	**560**	**6.23**	**2.00**	**270**	**0.087**	**1.068**	**1.958**	**<0.05**	**0.015**

Water quality conditions at sites 1-9 on the San Marcos River during normal flows (2000-2002), a high-flow event in 2002, and low-flow critical period (CP) events in 2006, 2009 and 2011.

Sampling Date	Temp	pH	Cond	D.O.	TSS (mg/L)	Alkalinity (mg/L)	NH3-N (mg/L)	N03-N (mg/L)	TN-N (mg/L)	SRP (mgP/L)	TP (mg/L)
Site 7											
10/31/2000	22.57	7.67	580	8.37	0.0040	231	0.231	1.010	1.150	0.004	0.009
3/5/2001	21.68	7.91	578	11.47	0.0060	237	0.237	1.890	2.350	0.017	0.010
5/7/2001	21.69	7.64	559	7.59	0.0900	233	0.233	0.670	0.990		
8/13/2001	22.39	7.60	596	6.63	0.0080	233	0.233	1.460	1.610	0.004	0.012
10/24/2001	22.81	7.67	579	8.78	0.0050	222	0.222	1.250	1.300	0.005	0.014
2/13/2002	20.09	7.43	558	8.70	0.0043	234	0.077	1.662	1.950	0.005	0.010
5/8/2002	22.76	7.39	537	9.05	0.0042	235	0.079	1.376	1.502	0.005	0.011
Average (2000-2002)	**22.00**	**7.62**	**570**	**8.66**	**0.02**	**232**	**0.19**	**1.33**	**1.55**	**0.007**	**0.011**
8/5/2002 (High Flow)	22.71	7.27	583	10.00	0.0220	259	0.068	1.577	1.948	0.049	0.052
7/25/2006 (Low Flow CP 1)	22.85	7.52	540	6.69	3	270	0.0618	1.56	3.71	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	21.80	7.53	576	6.53	5	260	0.0770	1.04	3.08	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	20.28	7.42	514	5.76	1	260	0.0925	0.99	2.17	<0.05	0.058
4/10/2009 (Low Flow CP 2)	21.22	7.96	515	5.81	<1	260	0.0336	0.99	2.32	<0.05	0.040
5/19/2009 (Low Flow Spring)	17.20	6.72	682	6.64	4	270	0.0613	1.05	1.91	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	23.25	8.04	602	4.89	5	250	0.0909	1.01	2.14	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	23.11	7.72	587	6.99	4	300	0.0820	0.49	1.08	<0.05	<0.02
Overall Average	**21.76**	**7.57**	**572**	**7.59**	**1.62**	**250**	**0.125**	**1.201**	**1.947**	**0.013**	**0.024**
Overall Min	**17.20**	**6.72**	**514**	**4.89**	**0.00**	**222**	**0.034**	**0.486**	**0.990**	**0.004**	**0.009**
Overall Max	**23.25**	**8.04**	**682**	**11.47**	**5.20**	**300**	**0.237**	**1.890**	**3.710**	**0.049**	**0.058**
2006 Average	**22.33**	**7.53**	**558**	**6.61**	**4.00**	**265**	**0.069**	**1.300**	**3.395**	**<0.05**	**<0.01**
2009 Average	**20.49**	**7.54**	**578**	**5.78**	**3.53**	**260**	**0.070**	**1.010**	**2.135**	**<0.05**	**0.025**

Site 8											
10/31/2000	22.50	7.74	579	9.80	0.0040	233	0.021	1.050	1.380	0.004	0.012
3/5/2001	22.19	7.89	581	9.28	0.0040	240	0.081	1.280	1.630	0.017	0.019
5/7/2001	21.81	7.73	560	7.99	0.1360	235	0.014	1.410	1.600		
8/13/2001	22.51	7.72	596	7..68	0.0070	233	0.062	1.620	1.710	0.002	0.010
10/24/2001	22.95	7.85	579	8.74	0.0060	227	0.080	1.510	1.630	0.003	0.010
2/13/2002	20.60	7.51	558	9.35	0.0045	237	0.036	1.105	1.347	0.004	0.012
5/8/2002	22.97	7.55	537	9.07	0.0046	250	0.042	1.252	1.401	0.005	0.013
Average (2000-2002)	**22.22**	**7.71**	**570**	**9.04**	**0.02**	**236**	**0.05**	**1.32**	**1.53**	**0.006**	**0.012**
8/5/2002 (High Flow)	22.97	7.37	582	9.83	0.0060	261	0.036	1.207	1.616	0.009	0.014
7/25/2006 (Low Flow CP 1)	22.81	7.66	542	7.58	4	260	0.0545	1.56	2.63	<0.05	0.026
9/14/2006 (Low Flow CP 2)	21.74	7.68	576	7.65	10	270	0.0560	1.06	2.16	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	20.80	7.50	514	6.62	4	260	0.0690	1.02	3.12	0.177	0.094
4/10/2009 (Low Flow CP 2)	21.07	7.91	516	6.79	3	270	0.0857	1.04	1.87	<0.05	0.029
5/19/2009 (Low Flow Spring)	16.83	6.82	704	8.04	4	270	0.0526	1.08	1.78	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	22.88	7.93	602	5.87	5	260	0.0621	1.08	1.95	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	21.86	7.76	591	7.43	6	260	0.0270	1.36	1.98	<0.05	<0.02
Overall Average	**21.77**	**7.64**	**574**	**8.15**	**2.37**	**251**	**0.052**	**1.242**	**1.854**	**0.028**	**0.024**
Overall Min	**16.83**	**6.82**	**514**	**5.87**	**0.00**	**227**	**0.014**	**1.020**	**1.347**	**0.002**	**0.010**
Overall Max	**22.97**	**7.93**	**704**	**9.83**	**10.00**	**270**	**0.086**	**1.620**	**3.120**	**0.177**	**0.094**
2006 Average	**22.28**	**7.67**	**559**	**7.62**	**7.00**	**265**	**0.055**	**1.310**	**2.395**	**<0.05**	**0.013**
2009 Average	**20.40**	**7.54**	**584**	**6.83**	**3.95**	**265**	**0.067**	**1.055**	**2.180**	**0.044**	**0.031**

Water quality conditions at sites 1-9 on the San Marcos River during normal flows (2000-2002), a high-flow event in 2002, and low-flow critical period (CP) events in 2006, 2009 and 2011.

Sampling Date	Temp	pH	Cond	D.O.	TSS (mg/L)	Alkalinity (mg/L)	NH3-N (mg/L)	N03-N (mg/L)	TN-N (mg/L)	SRP (mgP/L)	TP (mg/L)
Site 9											
10/31/2000	22.62	7.78	575	10.39	0.0080	218	0.057	1.200	1.600	0.005	0.019
3/5/2001	21.85	7.88	582	9.45	0.0020	242	0.030	1.300	1.700	0.021	0.015
5/7/2001	21.74	7.73	559	7.90	0.1210	230	0.043	1.200	1.430		
8/13/2001	22.55	7.66	593	7.75	0.0080	230	0.026	1.650	1.960	0.031	0.034
10/24/2001	22.73	7.41	579	8.54	0.0060	217	0.012	1.370	1.390	0.002	0.005
2/13/2002	20.24	7.49	557	9.58	0.0084	219	0.056	1.012	1.095	0.005	0.020
5/8/2002	22.80	7.36	531	9.29	0.0078	228	0.065	1.215	1.364	0.005	0.018
Average (2000-2002)	**22.08**	**7.62**	**568**	**8.99**	**0.02**	**226**	**0.04**	**1.28**	**1.51**	**0.011**	**0.018**
8/5/2002 (High Flow)	22.65	7.38	581	9.46	0.0070	259	0.071	1.217	1.542	0.006	0.016
7/25/2006 (Low Flow CP 1)	23.10	7.79	531	7.45	7	260	0.0873	1.51	3.62	<0.05	0.046
9/14/2006 (Low Flow CP 2)	22.02	7.73	566	8.07	9	260	0.0595	0.99	3.65	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	20.34	7.63	511	6.25	2	270	0.0894	1.02	2.65	<0.05	0.036
4/10/2009 (Low Flow CP 2)	21.07	7.95	515	6.72	4	270	0.0471	1.02	2.74	<0.05	0.050
5/19/2009 (Low Flow Spring)	20.40	6.51	595	6.13	6	270	0.0526	1.06	1.71	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	23.29	8.22	592	5.72	6	250	0.0713	1.02	2.47	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	22.02	7.93	584	7.26	6	260	0.0270	1.36	1.98	<0.05	<0.02
Overall Average	**21.96**	**7.63**	**563**	**8.00**	**2.68**	**246**	**0.053**	**1.210**	**2.060**	**0.011**	**0.026**
Overall Min	**20.24**	**6.51**	**511**	**5.72**	**0.00**	**217**	**0.012**	**0.990**	**1.095**	**0.002**	**0.005**
Overall Max	**23.29**	**8.22**	**595**	**10.39**	**9.00**	**270**	**0.089**	**1.650**	**3.650**	**0.031**	**0.050**
2006 Average	**22.56**	**7.76**	**549**	**7.76**	**8.00**	**260**	**0.073**	**1.250**	**3.635**	**<0.05**	**0.023**
2009 Average	**21.28**	**7.58**	**553**	**6.21**	**4.40**	**265**	**0.065**	**1.030**	**2.393**	**<0.05**	**0.022**

Water quality conditions at sites A-S in Spring Lake during normal flows (2000-2002), a high-flow event in 2002, and low-flow critical period (CP) events in 2006, 2009, and 2011.

Sampling Date	Temp	pH	Cond	D.O.	TSS (mg/L)	Alkalinity (mg/L)	NH3-N (mg/L)	N03-N (mg/L)	TN-N (mg/L)	SRP (mgP/L)	TP (mg/L)
Site A											
10/31/2000	22.36	7.24	566	6.33	0.0004	244	0.048	1.4066	0.83	0.054	0.003
3/6/2001	21.49	7.17	596	4.5	0.0004	255	0.03	1.0393	1.196	0.011	0.037
5/14/2001	21.52	7.23	567	4.9	0.0018	199	0.004	1.0956	2.293	0.014	0.037
8/15/2001	22.1	7.26	*566*	6.8	0.002	233	0.025	1.2275	1.295	0.003	0.010
10/30/2001	21.6	7.15	546	5.44	0.004	210	0.139	0.9298	1.251	0.003	0.016
2/14/2002	21.46	6.91	568	4.58	0.0004	238	0.032	1.913	2.145	0.011	0.018
5/22/2002	21.55	6.82	530	6.24	0.0019	246	0.005	1.216	1.469	0.013	0.026
Average (2000-2002)	**21.73**	**7.11**	**563**	**5.54**	**0.00**	**232**	**0.04**	**1.26**	**1.50**	**0.016**	**0.021**
8/7/2002 (High Flow)	21.56	6.8	577	4.81	0.427	263	0.032	2.621	2.458	0.010	0.005
7/25/2006 (Low Flow CP1)	21.70	7.13	517	4.51	1	260	0.042	1.63	3.99	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	22.02	7.11	566	6.24	0	260	0.036	1.01	3.07	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.89	7.69	506	4.85	<1	260	0.075	0.986	1.87	<0.05	<0.01
4/10/2009 (Low Flow CP 2)	21.58	7.65	511	4.94	<1	260	0.015	1.01	2.06	<0.05	0.037
5/19/2009 (Low Flow Spring)	21.75	7.01	577	4.70	<4	250	0.029	1.04	2.53	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	21.81	7.77	593	4.40	<4	270	0.063	1.13	1.75	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	21.68	7.34	567	5.11	<4	260	0.029	0.41	0.981	<0.05	<0.02
Overall Average	**21.74**	**7.22**	**557**	**5.22**	**0.14**	**247**	**0.040**	**1.244**	**1.946**	**0.015**	**0.021**
Overall Min	**21.46**	**6.80**	**506**	**4.40**	**0.00**	**199**	**0.004**	**0.410**	**0.830**	**0.003**	**0.003**
Overall Max	**22.36**	**7.77**	**596**	**6.80**	**1.00**	**270**	**0.139**	**2.621**	**3.990**	**0.054**	**0.037**
2006 Average	**21.86**	**7.12**	**542**	**5.38**	**0.50**	**260**	**0.039**	**1.320**	**3.530**	**<0.05**	**<0.01**
2009 Average	**21.76**	**7.53**	**547**	**4.72**	**<4**	**260**	**0.046**	**1.042**	**2.053**	**<0.05**	**0.009**

Site B											
10/31/2000	22.44	7.26	564	8.15	0.001	242	0.098	1.2779	0.9571	0.046	
3/6/2001	21.73	7.22	584	5.61	0.0003	243	0.009	1.4241	1.633	0.014	0.172
5/14/2001	21.84	7.24	566	5.69	0.0012	199	0.008	1.542	3.129	0.011	0.029
8/15/2001	22.25	7.25	*567*	5.82	0.01	250	0.071	1.2363	1.312	0.031	0.035
10/30/2001	22.1	7.23	541	6.33	0.009	215	0.039	0.9289	1.105	0.002	0.009
2/14/2002	21.52	6.94	562	5.13	0.0005	230	0.019	1.431	1.679	0.012	0.015
5/22/2002	21.91	6.85	524	6.9	0.0016	249	0.011	1.451	1.623	0.012	0.028
Average (2000-2002)	**21.97**	**7.14**	**558**	**6.23**	**0.00**	**233**	**0.04**	**1.33**	**1.63**	**0.018**	**0.048**
8/7/2002 (High Flow)	21.63	6.83	574	4.74	0.343	261	0.017	1.608	2.218	0.013	0.022
7/25/2006 (Low Flow CP1)	23.17	7.18	530	6.06	2	250	0.0558	1.31	2.43	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	22.27	7.11	572	5.90	0	260	0.0455	1.10	2.40	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.86	7.50	507	4.88	<1	260	0.0612	0.988	1.65	<0.05	0.022
4/10/2009 (Low Flow CP 2)	21.77	7.68	513	5.55	3	260	0.0521	1.03	2.16	<0.05	0.042
5/19/2009 (Low Flow Spring)	22.25	7.38	587	5.48	<4	250	0.0453	0.965	1.92	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	22.25	7.78	602	4.92	<4		0.0794	1.09	2.15	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	22.17	7.34	567	5.72	<4	260	0.0180	0.557	0.956	<0.05	<0.02
Overall Average	**22.08**	**7.25**	**557**	**5.79**	**0.49**	**245**	**0.042**	**1.196**	**1.821**	**0.018**	**0.042**
Overall Min	**21.52**	**6.83**	**507**	**4.74**	**0.00**	**199**	**0.008**	**0.557**	**0.956**	**0.002**	**0.009**
Overall Max	**23.17**	**7.78**	**602**	**8.15**	**3.00**	**261**	**0.098**	**1.608**	**3.129**	**0.046**	**0.172**
2006 Average	**22.72**	**7.15**	**551**	**5.98**	**1.00**	**255**	**0.051**	**1.205**	**2.415**	**<0.05**	**<0.01**
2009 Average	**22.03**	**7.59**	**552**	**5.21**	**3.00**	**257**	**0.060**	**1.018**	**1.970**	**<0.05**	**0.016**

Water quality conditions at sites A-S in Spring Lake during normal flows (2000-2002), a high-flow event in 2002, and low-flow critical period (CP) events in 2006, 2009, and 2011.

Sampling Date	Temp	pH	Cond	D.O.	TSS (mg/L)	Alkalinity (mg/L)	NH3-N (mg/L)	N03-N (mg/L)	TN-N (mg/L)	SRP (mgP/L)	TP (mg/L)
Site C											
10/31/2000	22.42	7.17	576	7.07	0.0008	264	0.061	1.4784	1.3109	0.037	0.006
3/6/2001	22.01	7.22	581	6.18	0.0005	250	0.001	1.4881	1.798	0.016	0.030
5/14/2001	22.06	7.22	562	6.09	0.001	209	0.001	1.526	3.069	0.009	0.018
8/15/2001	22.73	7.28	*566*	7.34	0.003	283	0.025	1.2276	1.265	0.010	0.022
10/30/2001	22.1	7.19	550	5.87	0.005	220	0.032	1.7579	2.197	0.003	0.010
2/14/2002	21.85	6.94	555	5.84	0.0004	235	0.0014	1.581	1.656	0.013	0.013
5/22/2002	22.11	6.86	527	6.79	0.0012	250	0.0012	1.525	1.928	0.010	0.020
Average (2000-2002)	**22.18**	**7.13**	**560**	**6.45**	**0.00**	**244**	**0.02**	**1.51**	**1.89**	**0.014**	**0.017**
8/7/2002 (High Flow)	22	6.81	562	5.66	0.2	261	0.039	1.813	2.325	0.008	0.018
7/25/2006 (Low Flow CP1)	22.73	7.22	526	7.90	1	260	0.0655	1.38	4.25	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	22.99	7.20	567	6.60	1	260	0.0536	0.94	3.92	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.84	7.63	509	7.16	1	260	0.0627	0.988	2.02	<0.05	0.017
4/10/2009 (Low Flow CP 2)	20.76	7.78	509	9.10	7	260	0.0370	0.914	2.3	<0.05	0.016
5/19/2009 (Low Flow Spring)	22.84	7.32	585	7.85	<4	270	0.0497	0.957	2.4	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	23.29	7.74	605	4.43	<4	270	0.1040	0.775	1.78	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	24.47	7.48	585	5.72	<4	270	0.0440	0.467	1.09	<0.05	<0.02
Overall Average	**22.41**	**7.27**	**558**	**6.64**	**0.85**	**255**	**0.039**	**1.254**	**2.221**	**0.013**	**0.017**
Overall Min	**20.76**	**6.81**	**509**	**4.43**	**0.00**	**209**	**0.001**	**0.467**	**1.090**	**0.003**	**0.006**
Overall Max	**24.47**	**7.78**	**605**	**9.10**	**7.00**	**283**	**0.104**	**1.813**	**4.250**	**0.037**	**0.030**
2006 Average	**22.86**	**7.21**	**547**	**7.25**	**1.00**	**260**	**0.060**	**1.158**	**4.085**	**<0.05**	**<0.01**
2009 Average	**22.18**	**7.62**	**552**	**7.14**	**4.00**	**265**	**0.063**	**0.909**	**2.125**	**<0.05**	**0.008**

Site D											
10/31/2000	22.79	7.21	578	8.38	0.001	268	0.025	1.6596	1.6445	0.048	0.009
3/6/2001	22.09	7.26	582	6.92	0.0019	247	0.001	1.6759	1.936	0.013	0.076
5/14/2001	22.46	7.24	561	7.38	0.0008	203	0.001	1.892	3.895	0.009	0.018
8/15/2001	23.96	7.33	*569*	12.01	0.013	300	0.227	1.1239	1.361	0.016	0.033
10/30/2001	22.32	7.22	554	6.84	0.016	210	0.08	1.314	1.525	0.004	0.016
2/14/2002	21.78	7.05	556	8.16	0.002	233	0.001	1.756	1.921	0.013	0.019
5/22/2002	22.4	6.9	527	9.46	0.0009	253	0.0011	1.925	2.105	0.009	0.019
Average (2000-2002)	**22.54**	**7.17**	**561**	**8.45**	**0.01**	**245**	**0.05**	**1.62**	**2.06**	**0.016**	**0.027**
8/7/2002 (High Flow)	22.28	6.83	564	6.39	0.343	257	0.035	1.659	2.109	0.007	0.028
7/25/2006 (Low Flow CP1)	23.14	7.13	545	7.05	1	260	0.0836	1.61	2.52	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	22.53	7.09	581	5.94	3	270	0.0466	1.11	2.04	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.59	7.53	516	4.56	<1	260	0.0690	1.08	2.31	<0.05	<0.01
4/10/2009 (Low Flow CP 2)	21.63	7.87	518	6.02	<1	270	0.0555	1.07	2.02	<0.05	0.016
5/19/2009 (Low Flow Spring)	22.58	7.36	603	6.51	<4	260	0.0584	1.1	2.18	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	22.80	7.88	608	4.10	<4	270	0.1900	1.06	1.78	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	22.71	7.50	599	6.62	<4	260	0.0540	0.578	1.24	<0.05	<0.02
Overall Average	**22.47**	**7.29**	**564**	**7.09**	**0.44**	**255**	**0.062**	**1.374**	**2.039**	**0.015**	**0.026**
Overall Min	**21.59**	**6.83**	**516**	**4.10**	**0.00**	**203**	**0.001**	**0.578**	**1.240**	**0.004**	**0.009**
Overall Max	**23.96**	**7.88**	**608**	**12.01**	**3.00**	**300**	**0.227**	**1.925**	**3.895**	**0.048**	**0.076**
2006 Average	**22.84**	**7.11**	**563**	**6.50**	**2.00**	**265**	**0.065**	**1.360**	**2.280**	**<0.05**	**<0.01**
2009 Average	**22.15**	**7.66**	**561**	**5.30**	**<4**	**265**	**0.093**	**1.078**	**2.073**	**<0.05**	**0.004**

Water quality conditions at sites A-S in Spring Lake during normal flows (2000-2002), a high-flow event in 2002, and low-flow critical period (CP) events in 2006, 2009, and 2011.

Sampling Date	Temp	pH	Cond	D.O.	TSS (mg/L)	Alkalinity (mg/L)	NH3-N (mg/L)	N03-N (mg/L)	TN-N (mg/L)	SRP (mgP/L)	TP (mg/L)
Site E											
10/31/2000	23.11	7.56	573	9.96	0.0006	251	0.095	1.556	1.1247	0.050	0.008
3/6/2001	22.01	7.35	583	8.86	0.0004	246	0.002	2.291	2.459	0.011	0.155
5/14/2001	22.72	7.28	562	8.18	0.104	170	0.003	1.591	3.279	0.009	0.025
8/15/2001	23.07	7.22	*574*	8.18	0.003	316	0.032	1.5208	1.562	0.010	0.022
10/30/2001	22.48	7.29	546	8.33	0.006	220	0.023	1.2889	1.462	0.002	0.012
2/14/2002	21.92	7.06	556	8.08	0.0006	235	0.0021	2.115	2.314	0.011	0.015
5/22/2002	22.6	6.95	526	8.61	0.0015	255	0.0034	1.657	1.812	0.009	0.021
Average (2000-2002)	**22.56**	**7.24**	**560**	**8.60**	**0.02**	**242**	**0.02**	**1.72**	**2.00**	**0.015**	**0.037**
8/7/2002 (High Flow)	22.44	6.87	568	6.68	0.014	257	0.043	1.532	1.952	0.009	0.043
7/25/2006 (Low Flow CP1)	23.57	7.18	536	6.94	1	260	0.0715	1.42	2.34	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	22.05	7.20	575	6.04	0	270	0.0805	1.02	1.89	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.25	7.52	513	5.71	<1	270	0.1000	1.03	1.78	<0.05	<0.01
4/10/2009 (Low Flow CP 2)	21.48	7.75	515	6.22	<1	260	0.0521	1.02	2.64	<0.05	0.011
5/19/2009 (Low Flow Spring)	22.33	7.25	600	6.54	<4	240	0.0526	1.03	2.16	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	22.92	7.96	605	3.85	<4	270	0.0817	1.03	2.26	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	22.63	7.35	592	6.73	<4	260	0.0540	0.545	1.12	<0.05	<0.02
Overall Average	**22.44**	**7.32**	**562**	**7.26**	**0.11**	**252**	**0.046**	**1.376**	**2.010**	**0.014**	**0.035**
Overall Min	**21.25**	**6.87**	**513**	**3.85**	**0.00**	**170**	**0.002**	**0.545**	**1.120**	**0.002**	**0.008**
Overall Max	**23.57**	**7.96**	**605**	**9.96**	**1.00**	**316**	**0.100**	**2.291**	**3.279**	**0.050**	**0.155**
2006 Average	**22.81**	**7.19**	**556**	**6.49**	**0.50**	**265**	**0.076**	**1.220**	**2.115**	**<0.05**	**<0.01**
2009 Average	**22.00**	**7.62**	**558**	**5.58**	**<4**	**260**	**0.072**	**1.028**	**2.210**	**<0.05**	**0.003**

Site F											
10/31/2000	23.93	7.43	564	10.68	0.001	235	0.050	0.8868	1.0168	0.040	0.008
3/6/2001	22.48	7.61	574	13.8	0.001	245	0.036	0.8629	1.1106	0.014	0.007
5/14/2001	24.06	7.29	507	2.86	0.002	206	0.019	0.5629	1.265	0.019	0.040
8/15/2001	26.89	7.37	*560*	7.98	0.004	349	0.166	0.2482	0.0512	0.024	0.039
10/30/2001	23.04	7.34	539	8.23	0.009	220	0.043	1.2582	1.399	0.003	0.011
2/14/2002	22.12	7.12	554	10.26	0.0012	237	0.039	1.195	1.459	0.014	0.020
5/22/2002	24.28	7.27	517	13.26	0.0035	250	0.0023	1.215	1.583	0.017	0.034
Average (2000-2002)	**23.83**	**7.35**	**545**	**9.58**	**0.00**	**249**	**0.05**	**0.89**	**1.13**	**0.018**	**0.023**
8/7/2002 (High Flow)	25.49	7.13	600	6.24	0.068	265	0.035	1.431	1.813	0.009	0.028
7/25/2006 (Low Flow CP1)	22.78	7.16	537	7.51	0	260	0.0752	1.18	2.14	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	22.43	7.15	571	5.68	0	260	0.0455	1.06	2.08	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.83	7.64	511	7.70	<1	260	0.0957	1.01	2.24	<0.05	<0.01
4/10/2009 (Low Flow CP 2)	21.50	7.62	512	10.50	<1	270	0.0336	0.988	2.42	<0.05	0.021
5/19/2009 (Low Flow Spring)	24.20	7.20	584	8.76	<4	250	0.0511	0.956	1.49	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	24.12	7.82	610	5.55	<4	280	0.0989	0.803	1.9	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	24.27	7.42	585	10.44	4.4	260	0.0690	0.462	0.999	<0.05	<0.02
Overall Average	**23.56**	**7.37**	**555**	**8.63**	**0.41**	**257**	**0.057**	**0.941**	**1.531**	**0.017**	**0.023**
Overall Min	**21.50**	**7.12**	**507**	**2.86**	**0.00**	**206**	**0.002**	**0.248**	**0.051**	**0.003**	**0.007**
Overall Max	**26.89**	**7.82**	**610**	**13.80**	**4.40**	**349**	**0.166**	**1.431**	**2.420**	**0.040**	**0.040**
2006 Average	**22.61**	**7.16**	**554**	**6.60**	**0.00**	**260**	**0.060**	**1.120**	**2.110**	**<0.05**	**<0.01**
2009 Average	**22.91**	**7.57**	**554**	**8.13**	**<4**	**265**	**0.070**	**0.939**	**2.013**	**<0.05**	**0.005**

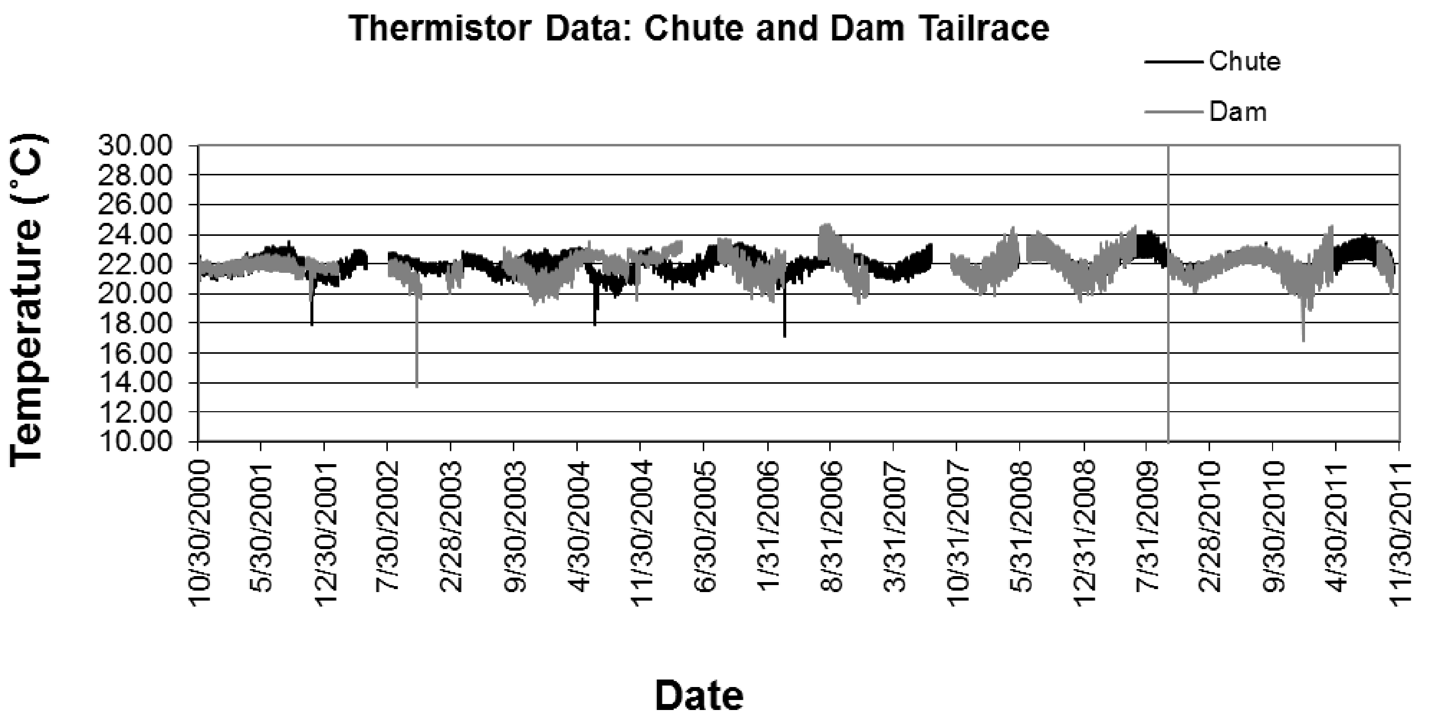
Water quality conditions at sites A-S in Spring Lake during normal flows (2000-2002), a high-flow event in 2002, and low-flow critical period (CP) events in 2006, 2009, and 2011.

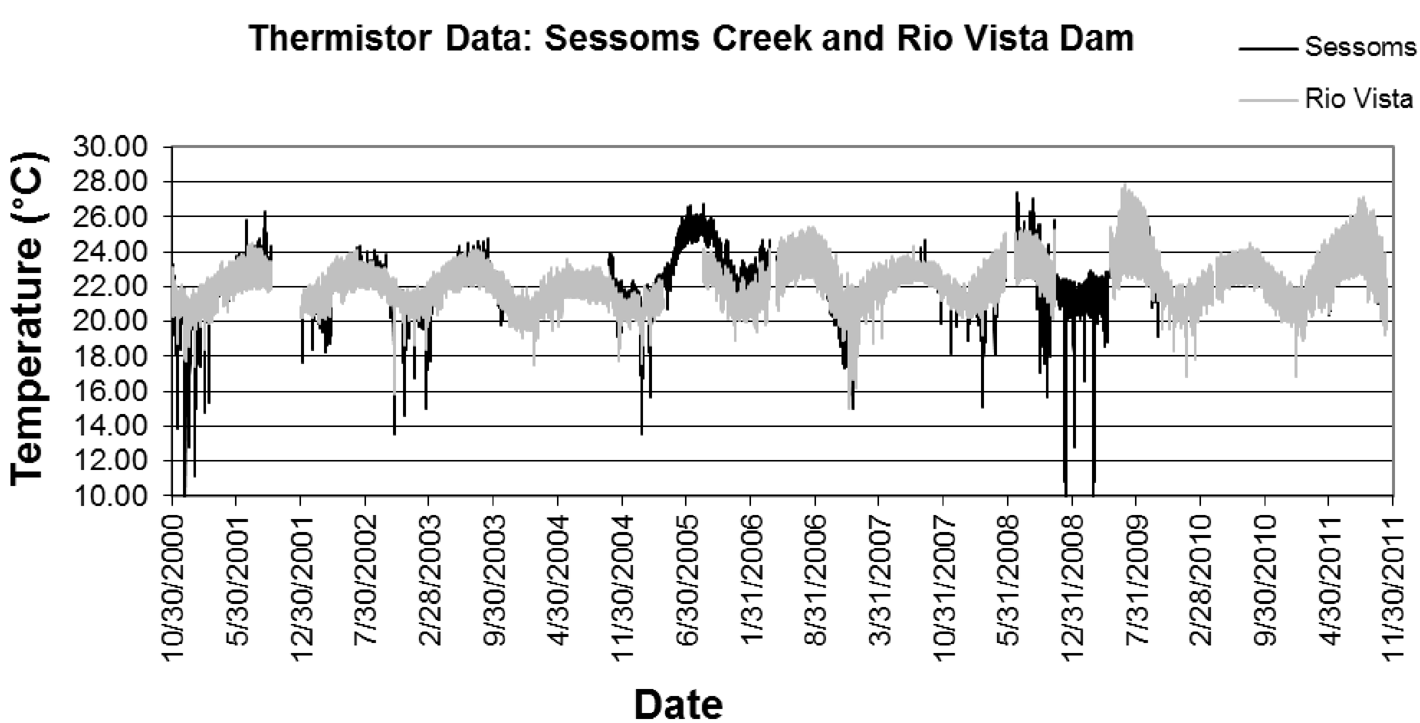
Sampling Date	Temp	pH	Cond	D.O.	TSS (mg/L)	Alkalinity (mg/L)	NH3-N (mg/L)	N03-N (mg/L)	TN-N (mg/L)	SRP (mgP/L)	TP (mg/L)
Site G											
10/31/2000	24.16	7.4	546	5.18	0.012	241	0.025	0.6094	0.5828	0.034	0.013
3/6/2001	18.45	8	577	11.99	0.015	245	0.059	0.5997	1.1009	0.018	0.087
5/14/2001	25.55	7.46	517	6.04	0.006	167	0.051	0.6104	1.326	0.049	0.118
8/15/2001	26.35	7.27	*571*	4.44	0.005	366	0.102	0.2667	0.0495	0.032	0.044
10/30/2001	20.67	7.71	536	11.68	0.009	214	0.043	0.5727	0.895	0.000	0.010
2/14/2002	20.47	7.18	553	7.8	0.0019	237	0.056	1.094	1.215	0.018	0.023
5/22/2002	24.29	7.44	489	9.37	0.0065	213	0.0039	1.009	1.198	0.020	0.039
Average (2000-2002)	**22.85**	**7.49**	**541**	**8.07**	**0.01**	**240**	**0.05**	**0.68**	**0.91**	**0.024**	**0.048**
8/7/2002 (High Flow)	26.16	7.2	607	6.38	0.324	257	0.048	1.174	1.598	0.010	0.065
7/25/2006 (Low Flow CP1)	28.54	7.26	486	1.90	7	190	0.0788	0	1.05	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	25.48	7.31	545	5.40	7	230	0.0910	0.33	1.38	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	21.17	7.65	512	5.42	<1	260	0.0769	0.96	2.21	<0.05	<0.01
4/10/2009 (Low Flow CP 2)	21.42	7.98	446	11.20	<1	230	0.0689	0.396	1.66	<0.05	<0.01
5/19/2009 (Low Flow Spring)	23.60	7.50	576	7.96	<4	200	0.0526	0.0798	1.01	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	29.22	7.88	518	8.79	<4	200	0.1190	<0.05	0.934	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	23.65	7.55	581	5.96	<4	270	0.0790	0.23	0.94	<0.05	<0.02
Overall Average	**23.95**	**7.52**	**537**	**7.30**	**1.44**	**235**	**0.064**	**0.567**	**1.143**	**0.023**	**0.050**
Overall Min	**18.45**	**7.18**	**446**	**1.90**	**0.00**	**167**	**0.004**	**0.000**	**0.050**	**0.000**	**0.010**
Overall Max	**29.22**	**8.00**	**607**	**11.99**	**7.00**	**366**	**0.119**	**1.174**	**2.210**	**0.049**	**0.118**
2006 Average	**27.01**	**7.29**	**516**	**3.65**	**7.00**	**210**	**0.085**	**0.166**	**1.215**	**<0.05**	**<0.01**
2009 Average	**23.85**	**7.75**	**513**	**8.34**	**<4**	**223**	**0.079**	**0.479**	**1.454**	**<0.05**	**<0.01**

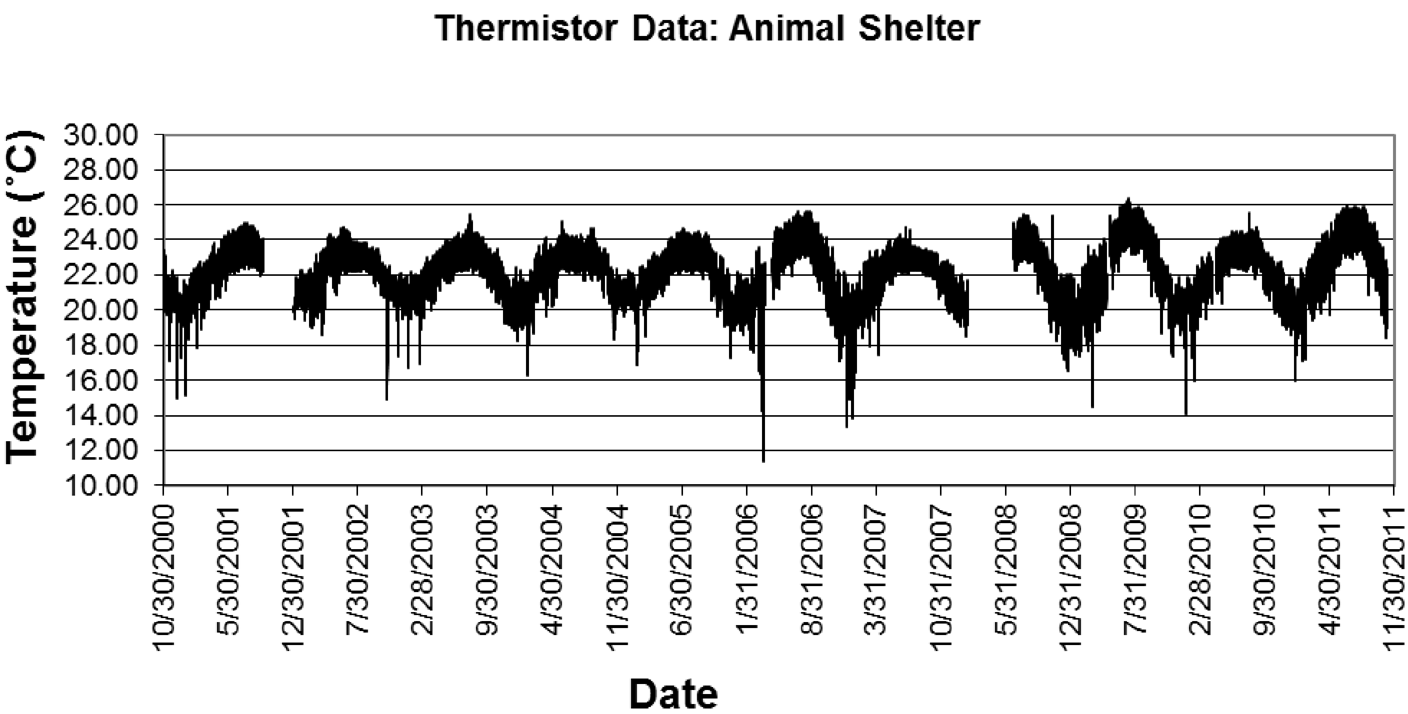
Site H											
10/31/2000	24.51	7.74	528	7.88	0.182	224	0.098	0.2712	1.1057	0.039	0.011
3/6/2001	19.61	8.25	586	18.72	0.295	246	0.012	0.6104	1.1029	0.017	0.006
5/14/2001	23.69	7.28	575	4.22	0.006	200	0.009	0.6593	1.354	0.029	0.056
8/15/2001	28.73	7.42	*581*	4.95	0.008	382	0.116	0.1521	0.0326	0.004	0.019
10/30/2001	20.65	7.53	563	9.2	0.095	210	0.036	0.2073	0.3651	0.001	0.013
2/14/2002	16.68	7.49	580	14.21	0.0025	238	0.032	0.9985	1.105	0.018	0.022
5/22/2002	23.54	7.59	519	11.31	0.0074	227	0.008	1.015	1.128	0.026	0.042
Average (2000-2002)	**22.49**	**7.61**	**562**	**10.07**	**0.09**	**247**	**0.04**	**0.56**	**0.88**	**0.019**	**0.024**
8/7/2002 (High Flow)	24.79	7.11	615	4.6	0.125	267	0.046	1.251	1.692	0.008	0.027
7/25/2006 (Low Flow CP1)	24.77	7.20	502	2.32	2	220	0.0824	0	1.01	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	23.01	7.13	544	0.83	0	240	0.1180	0	1.12	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	16.52	7.82	496	8.09	<1	260	0.0565	0.632	2.32	<0.05	0.022
4/10/2009 (Low Flow CP 2)	19.68	7.94	468	8.55	<1	240	0.1650	<0.05	1.16	<0.05	0.027
5/19/2009 (Low Flow Spring)	21.80	7.22	557	5.23	<4	240	0.0730	<0.05	2.57	<0.05	<0.01
6/24/2009 (Low Flow CP 3)	27.63	7.96	531	3.64	<4	220	0.0851	<0.05	1.44	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	22.85	7.32	583	3.05	<4	260	0.1050	<0.05	1.02	<0.05	<0.02
Overall Average	**22.56**	**7.53**	**549**	**7.12**	**0.27**	**245**	**0.069**	**0.527**	**1.235**	**0.018**	**0.024**
Overall Min	**16.52**	**7.11**	**468**	**0.83**	**0.00**	**200**	**0.008**	**0.000**	**0.033**	**0.001**	**0.006**
Overall Max	**28.73**	**8.25**	**615**	**18.72**	**2.00**	**382**	**0.165**	**1.251**	**2.570**	**0.039**	**0.056**
2006 Average	**23.89**	**7.17**	**523**	**1.58**	**1.00**	**230**	**0.100**	**0.000**	**1.065**	**<0.05**	**<0.01**
2009 Average	**21.41**	**7.74**	**513**	**6.38**	**<4**	**240**	**0.095**	**0.632**	**1.873**	**<0.05**	**0.012**

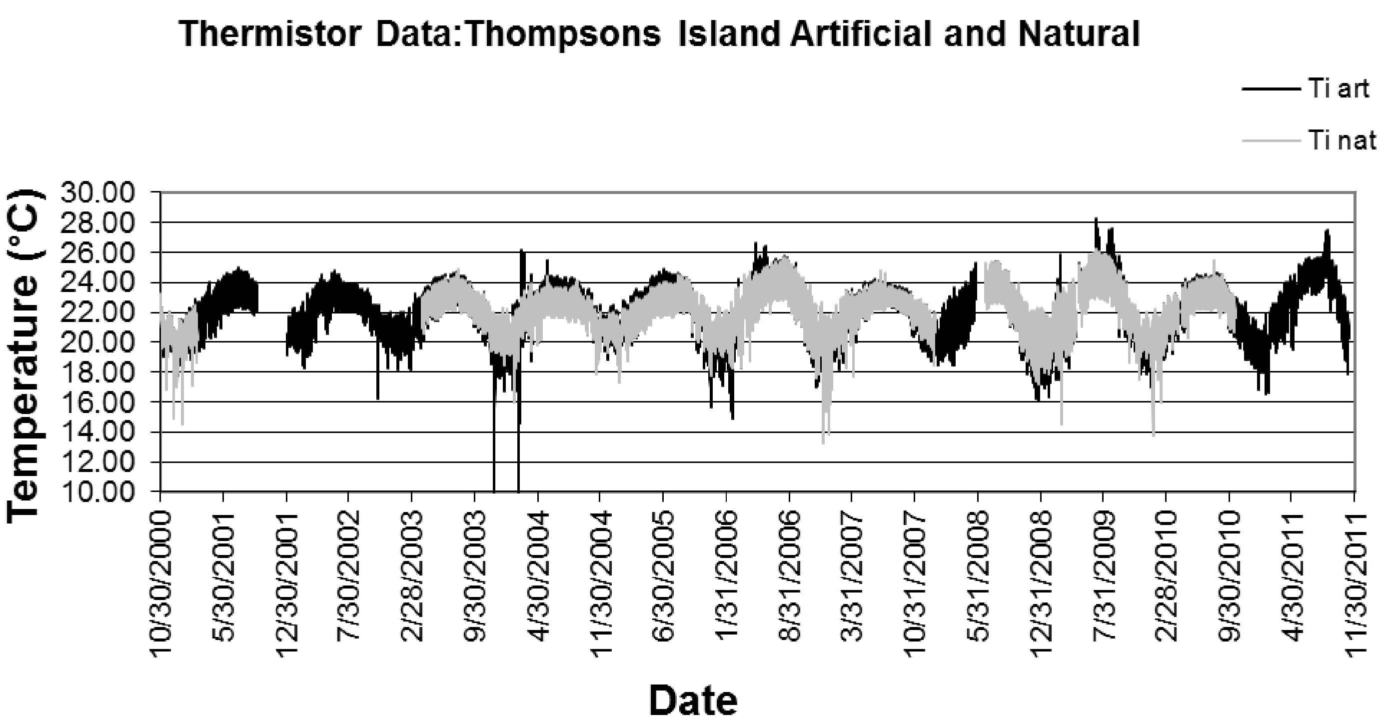
Water quality conditions at sites A-S in Spring Lake during normal flows (2000-2002), a high-flow event in 2002, and low-flow critical period (CP) events in 2006, 2009, and 2011.

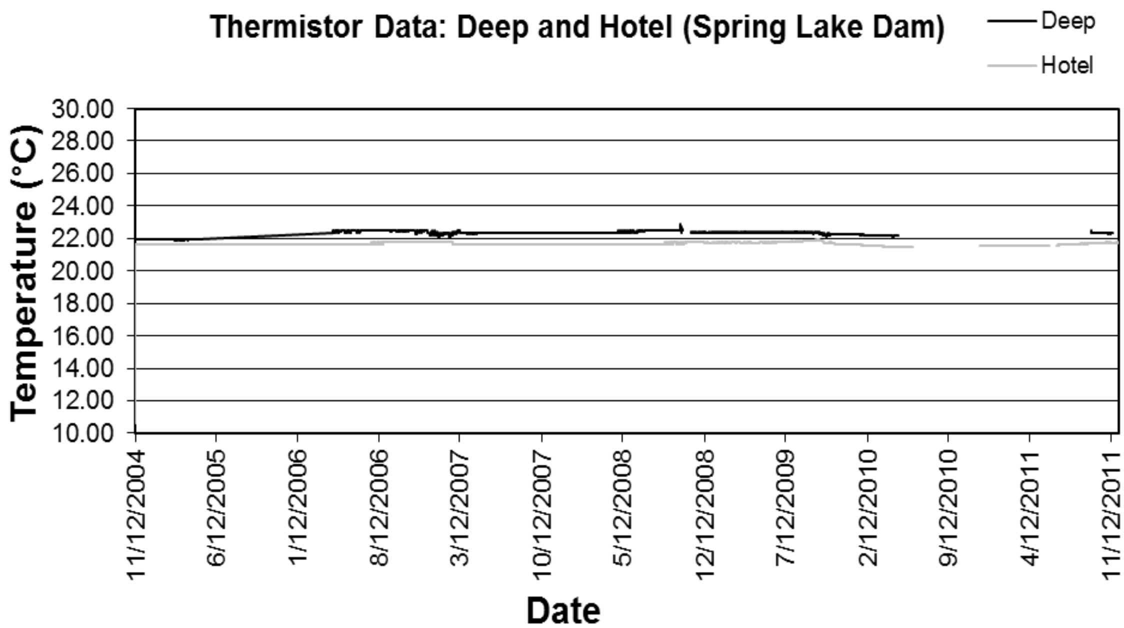
Sampling Date	Temp	pH	Cond	D.O.	TSS (mg/L)	Alkalinity (mg/L)	NH3-N (mg/L)	N03-N (mg/L)	TN-N (mg/L)	SRP (mgP/L)	TP (mg/L)
Site S											
10/31/2000											
4/2/2001	21.28	7.72	689	7.86	0.196	289	0.068	0.3442	1.151	0.055	0.118
5/14/2001	23.07	7.56	587	4.53	0.409	231	0.059	0.4296	1.236	0.089	0.130
8/15/2001											
10/30/2001	20.7	7.58	773	3.45	0.41	348	0.027	0.0477	0.0985	0.012	0.032
2/14/2002	15.6	7.83	564	15.05	0.0039	247	0.059	0.0654	1.119	0.022	0.029
5/22/2002	22.42	6.84	599	2.3	0.0035	276	0.0034	0.0895	1.085	0.016	0.054
Average (2000-2002)	**20.61**	**7.51**	**642**	**6.64**	**0.20**	**278**	**0.04**	**0.20**	**0.94**	**0.039**	**0.073**
8/7/2002 (High Flow)	23.59	7.17	610	5.98	0.173	271	0.043	1.404	1.894	0.019	0.059
7/25/2006 (Low Flow CP1)	24.83	7.19	509	2.18	6.0	220	0.0752	0.167	2.73	<0.05	<0.01
9/14/2006 (Low Flow CP 2)	23.21	7.13	559	2.86	11.0	240	0.0618	0	1.99	<0.05	<0.01
1/9/2009 (Low Flow CP 1)	18.65	7.71	497	5.96	2.0	250	0.0878	0.217	1.97	<0.05	<0.01
4/10/2009 (Low Flow CP 2)	20.07	7.95	498	4.21	8.0	250	0.0286	0.0826	2.72	<0.05	0.098
5/19/2009 (Low Flow Spring)	17.76	7.25	739	4.83	6.0	250	0.0789	0.128	1.93	<0.05	0.082
6/24/2009 (Low Flow CP 3)	24.72	8.10	570	1.50	4.0	250	0.1240	<0.05	1.5	<0.05	<0.01
9/21/2011 (Low Flow CP 1)	22.76	7.25	569	2.68	5.2	260	0.1140	0.073	0.958	<0.05	<0.02
Overall Average	**21.44**	**7.48**	**597**	**4.88**	**3.34**	**260**	**0.064**	**0.254**	**1.568**	**0.035**	**0.075**
Overall Min	**15.60**	**6.84**	**497**	**1.50**	**0.00**	**220**	**0.003**	**0.000**	**0.099**	**0.012**	**0.029**
Overall Max	**24.83**	**8.10**	**773**	**15.05**	**11.00**	**348**	**0.124**	**1.404**	**2.730**	**0.089**	**0.130**
2006 Average	**24.02**	**7.16**	**534**	**2.52**	**8.50**	**230**	**0.069**	**0.084**	**2.360**	**<0.05**	**<0.01**
2009 Average	**20.30**	**7.75**	**576**	**4.13**	**5.00**	**250**	**0.080**	**0.143**	**2.030**	**<0.05**	**0.045**


Thermistor Data: Chute and Dam Tailrace
Chute
Dam
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
10/30/2000
5/30/2001
12/30/2001
7/30/2002
2/28/2003
9/30/2003
4/30/2004
11/30/2004
6/30/2005
1/31/2006
8/31/2006
3/31/2007
10/31/2007
5/31/2008
12/31/2008
7/31/2009
2/28/2010
9/30/2010
4/30/2011
11/30/2011
Date


Thermistor Data: Sessoms Creek and Rio Vista Dam
Sessoms
Rio Vista
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
10/30/2000
5/30/2001
12/30/2001
7/30/2002
2/28/2003
9/30/2003
4/30/2004
11/30/2004
6/30/2005
1/31/2006
8/31/2006
3/31/2007
10/31/2007
5/31/2008
12/31/2008
7/31/2009
2/28/2010
9/30/2010
4/30/2011
11/30/2011
Date

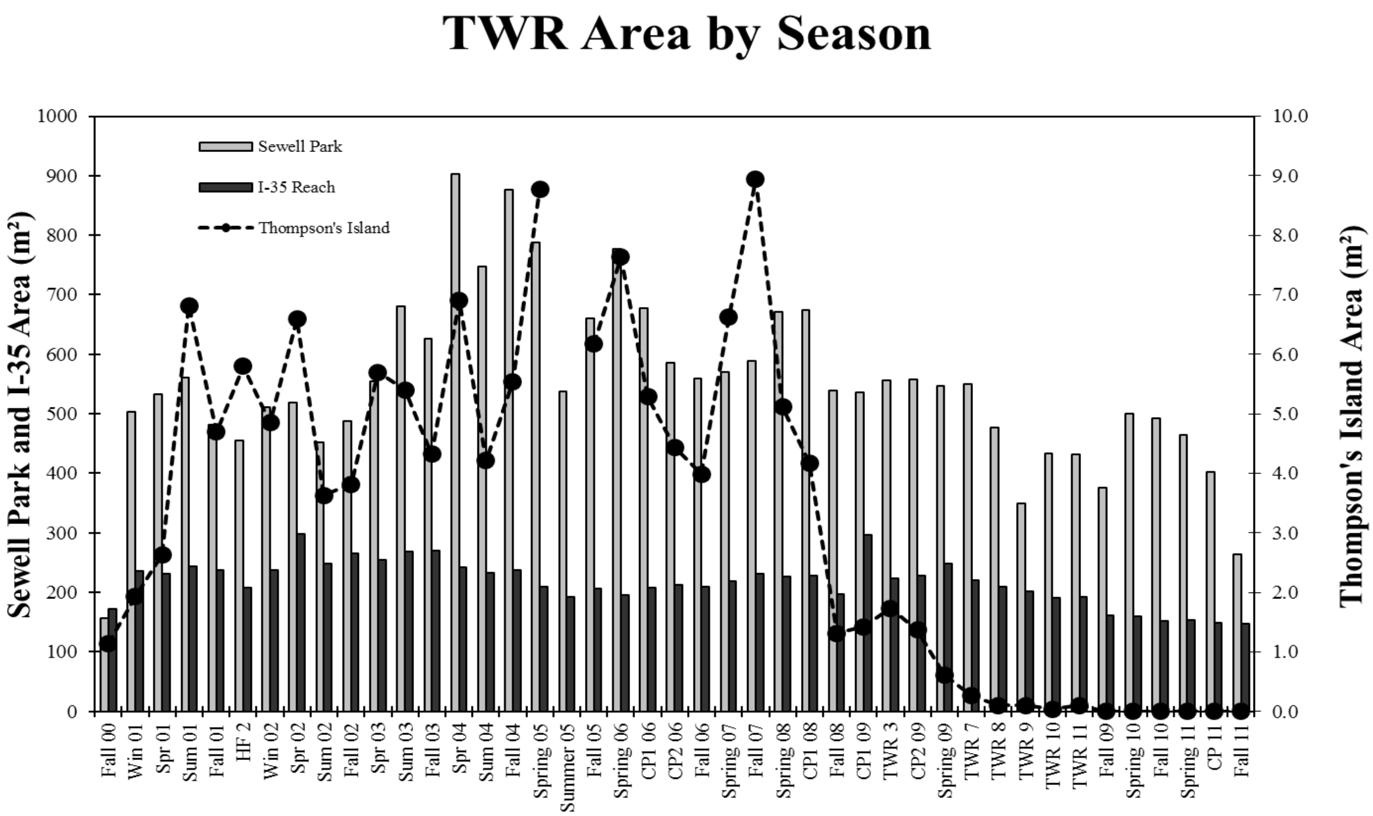

Thermistor Data: Animal Shelter
Temperature (˚C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
10/30/2000
5/30/2001
12/30/2001
7/30/2002
2/28/2003
9/30/2003
4/30/2004
11/30/2004
6/30/2005
1/31/2006
8/31/2006
3/31/2007
10/31/2007
5/31/2008
12/31/2008
7/31/2009
2/28/2010
9/30/2010
4/30/2011
11/30/2011
Date


Thermistor Data:Thompsons Island Artificial and Natural
Ti art
Ti nat
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
10/30/2000
5/30/2001
12/30/2001
7/30/2002
2/28/2003
9/30/2003
4/30/2004
11/30/2004
6/30/2005
1/31/2006
8/31/2006
3/31/2007
10/31/2007
5/31/2008
12/31/2008
7/31/2009
2/28/2010
9/30/2010
4/30/2011
11/30/2011
Date

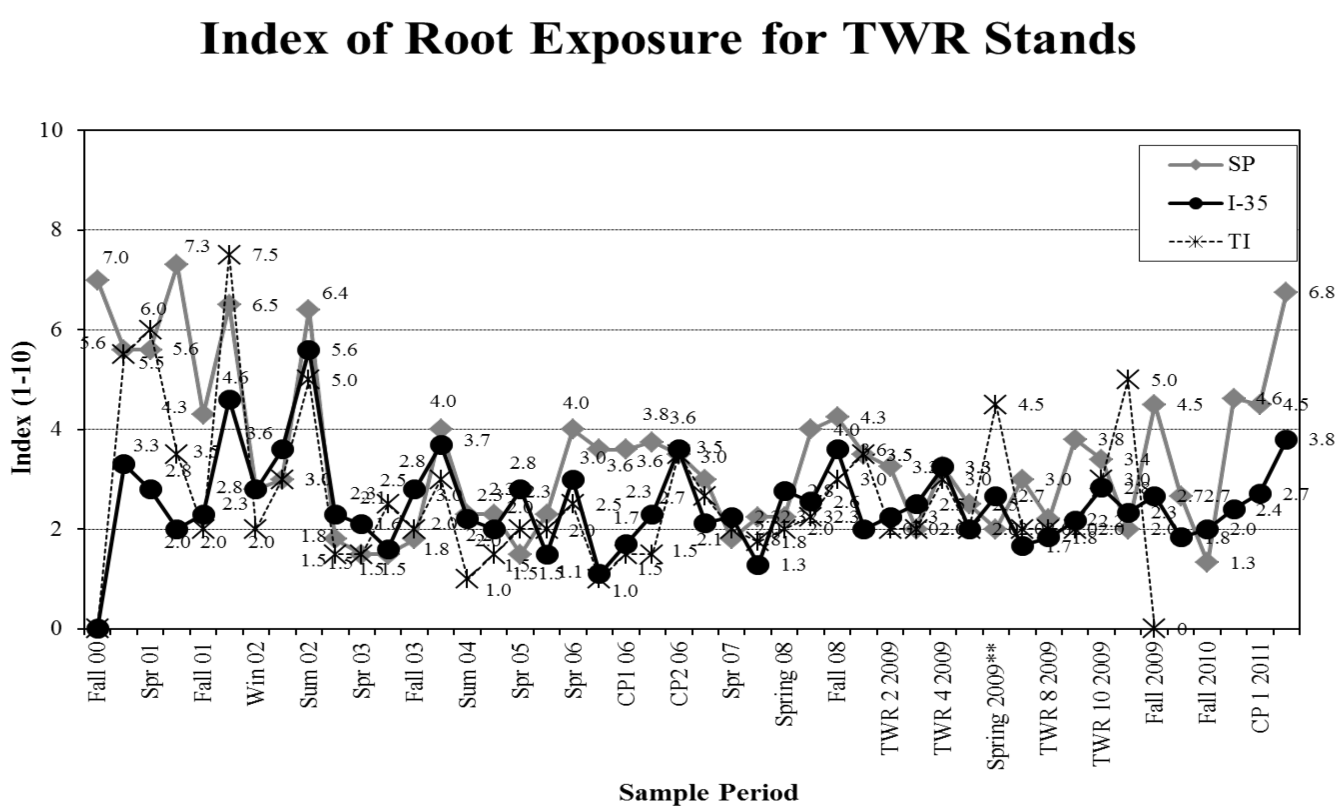


Thermistor Data: Deep and Hotel (Spring Lake Dam)
Deep
Hotel
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
11/12/2004
6/12/2005
1/12/2006
8/12/2006
3/12/2007
10/12/2007
5/12/2008
12/12/2008
7/12/2009
2/12/2010
9/12/2010
4/12/2011
11/12/2011
Date

Texas Wild-Rice Observation Data

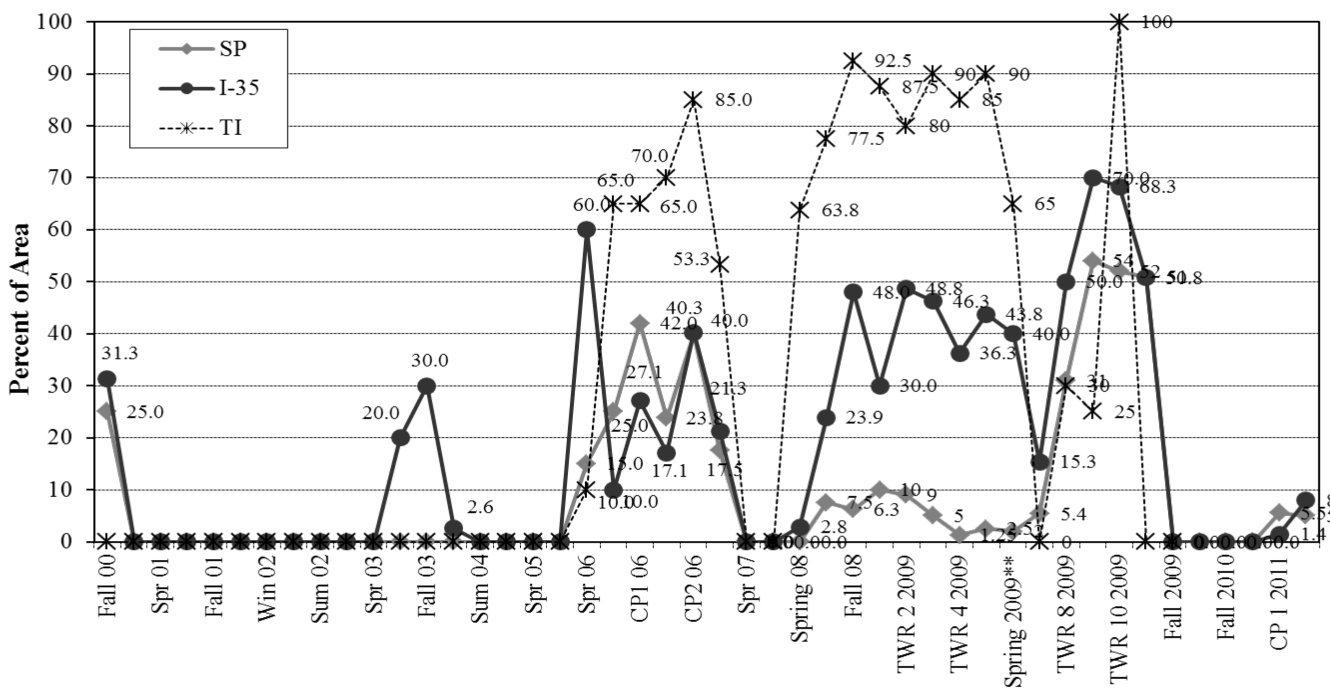


TWR Area by Season
Sewell Park
I-35 Reach
Thompson's Island
Sewell Park and I-35 Area (m²)
Thompson's Island Area (m²)
Fall 00
Win 01
Spr 01
Sum 01
Fall 01
HF 2
Win 02
Spr 02
Sum 02
Fall 02
Spr 03
Sum 03
Fall 03
Spr 04
Sum 04
Fall 04
Spring 05
Summer 05
Fall 05
Spring 06
CP1 06
CP2 06
Fall 06
Spring 07
Fall 07
Spring 08
CP1 08
Fall 08
CP1 09
TWR 3
CP2 09
Spring 09
TWR 7
TWR 8
TWR 9
TWR 10
TWR 11
Fall 09
Spring 10
Fall 10
Spring 11
CP 11
Fall 11

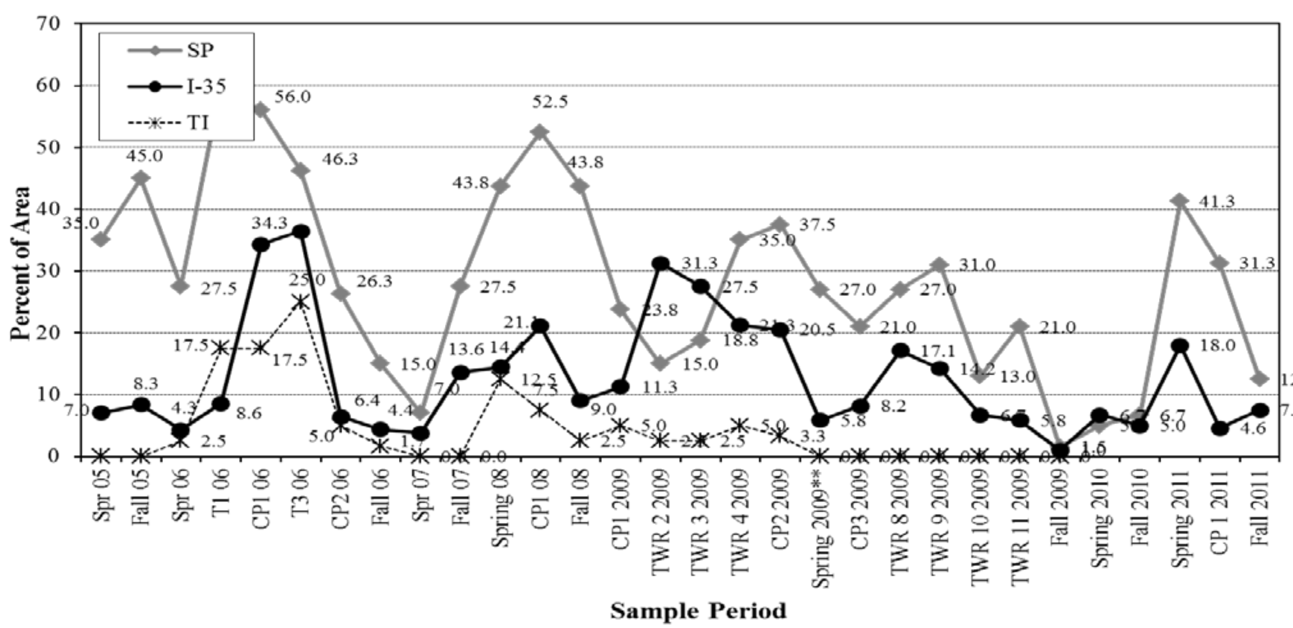


Index of Root Exposure for TWR Stands
SP
I-35
TI
Index (1-10)
Sample Period
Fall 00
Spr 01
Fall 01
Win 02
Sum 02
Spr 03
Fall 03
Sum 04
Spr 05
Spr 06
CP1 06
CP2 06
Spr 07
Spring 08
Fall 08
TWR 2 2009
TWR 4 2009
Spring 2009**
TWR 8 2009
TWR 10 2009
Fall 2009
Fall 2010
CP 1 2011

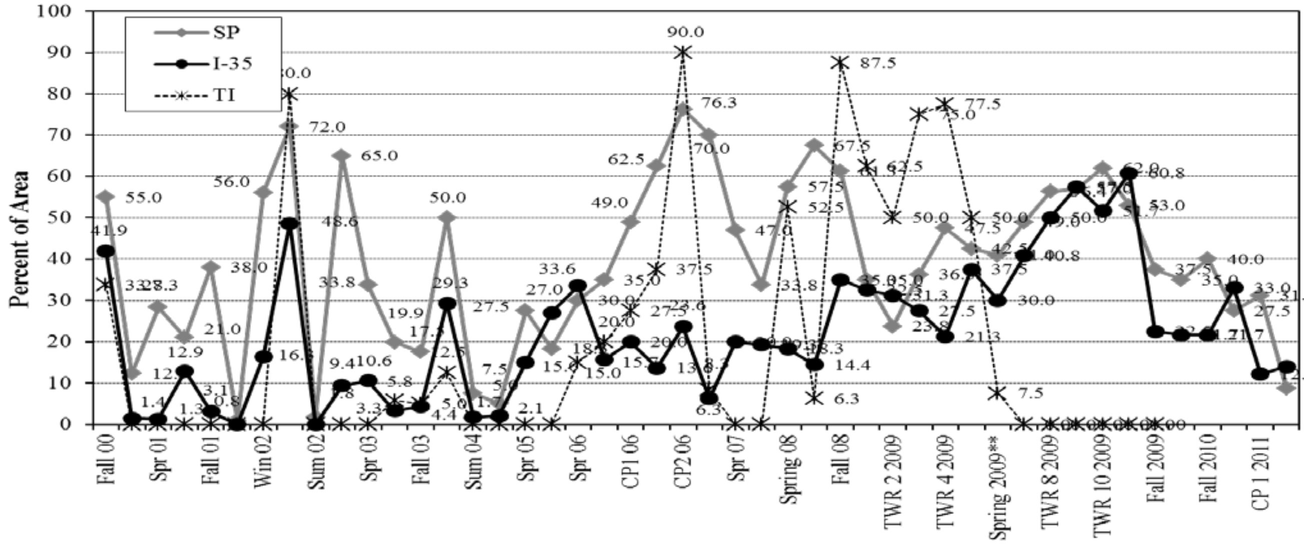
Percent of TWR Stands < 0.5 Feet



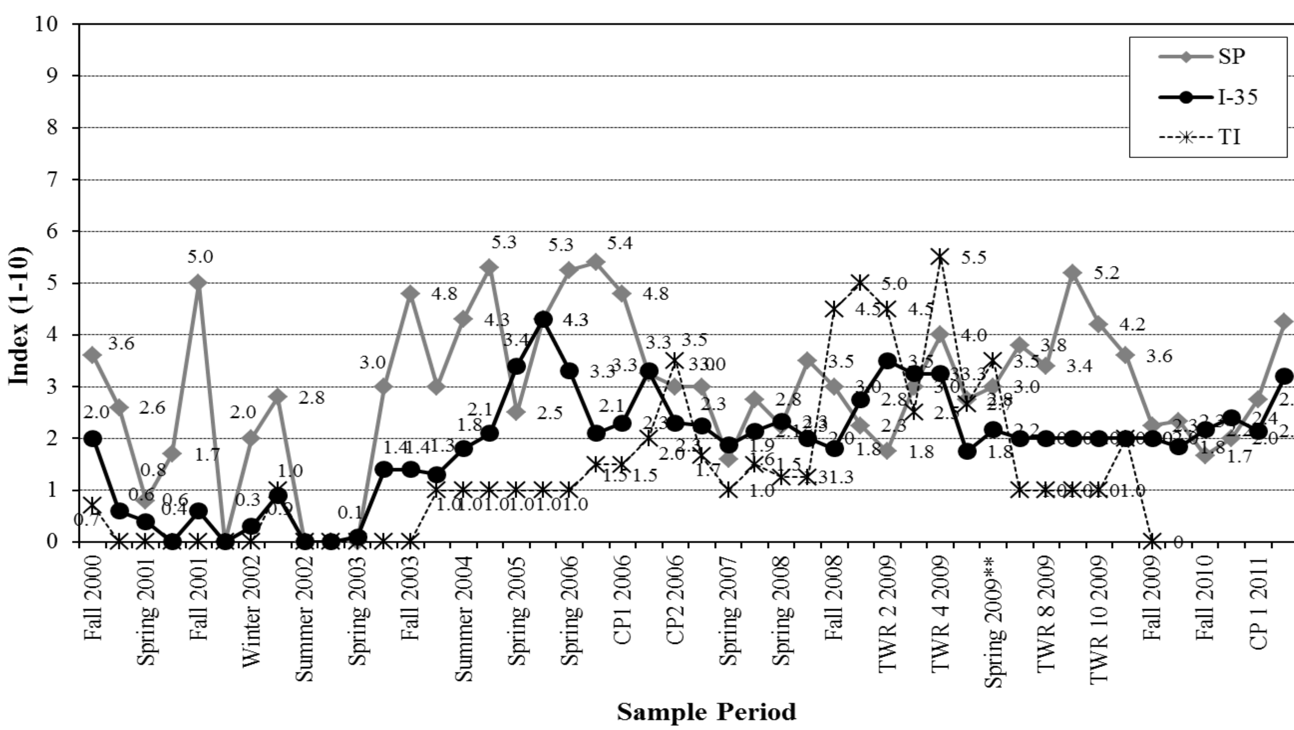
Percent of TWR Covered by Vegetation Mats



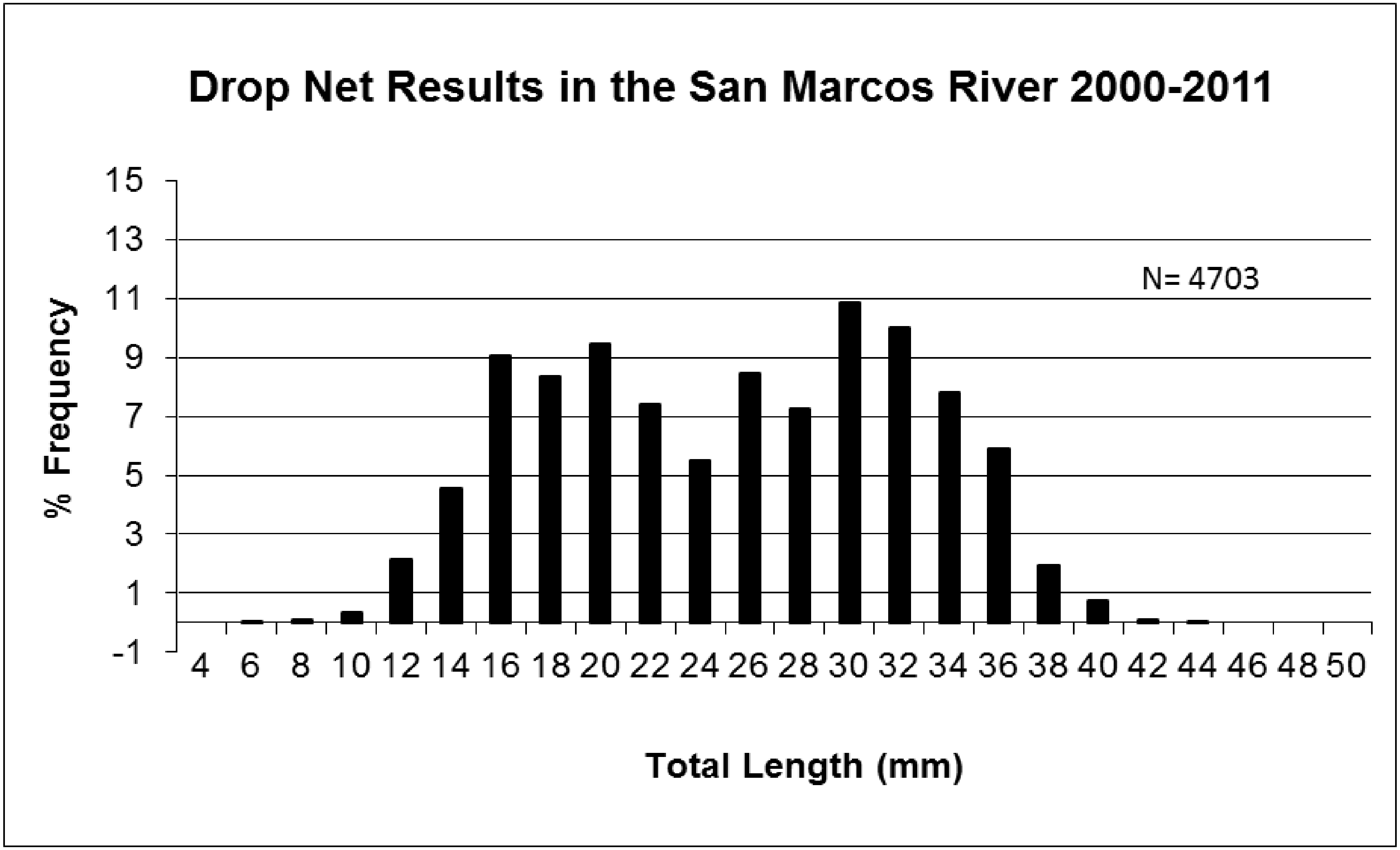
Percent Emergent TWR



Index of Herbivory for TWR Stands



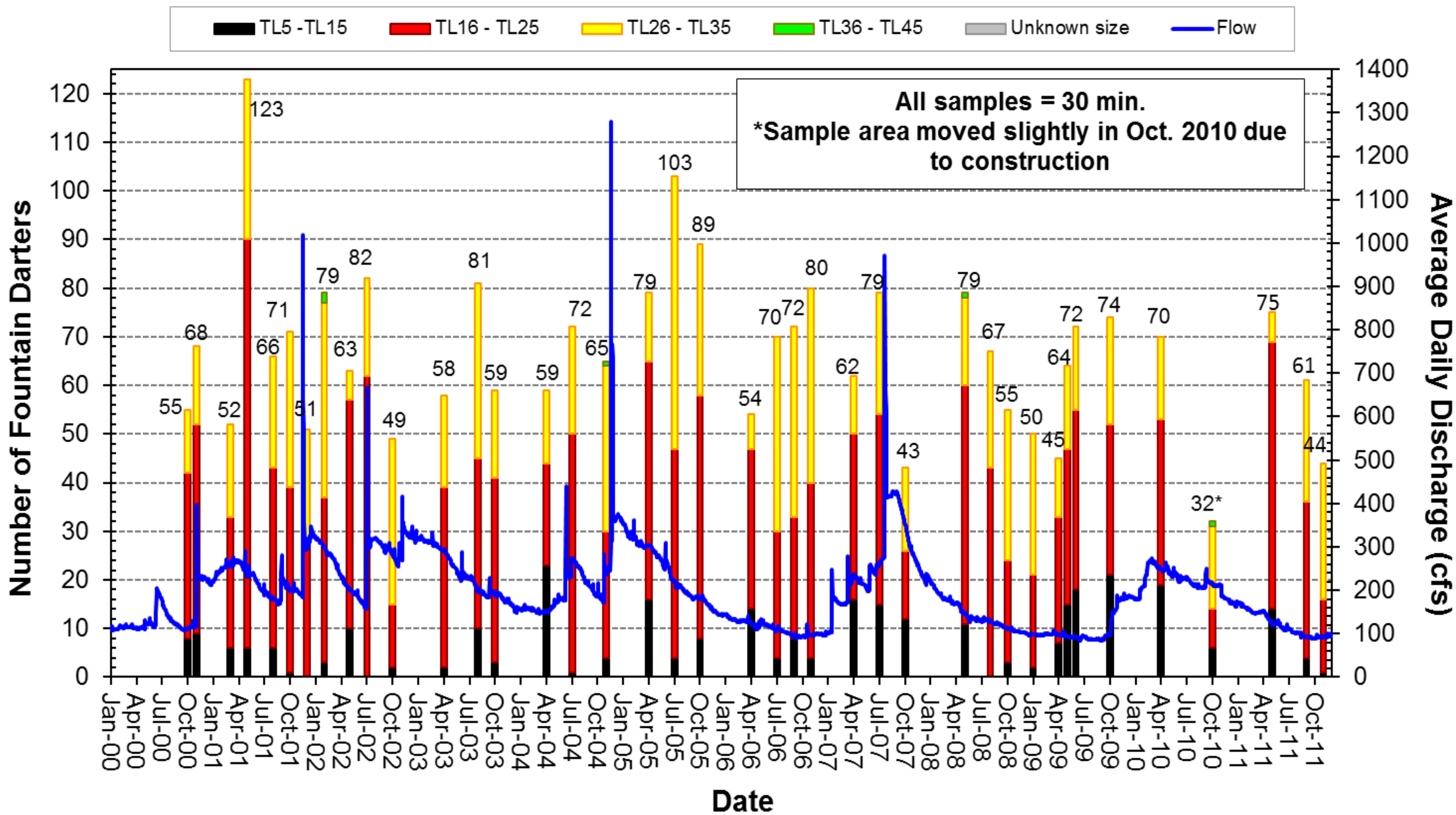
Drop Net Graph

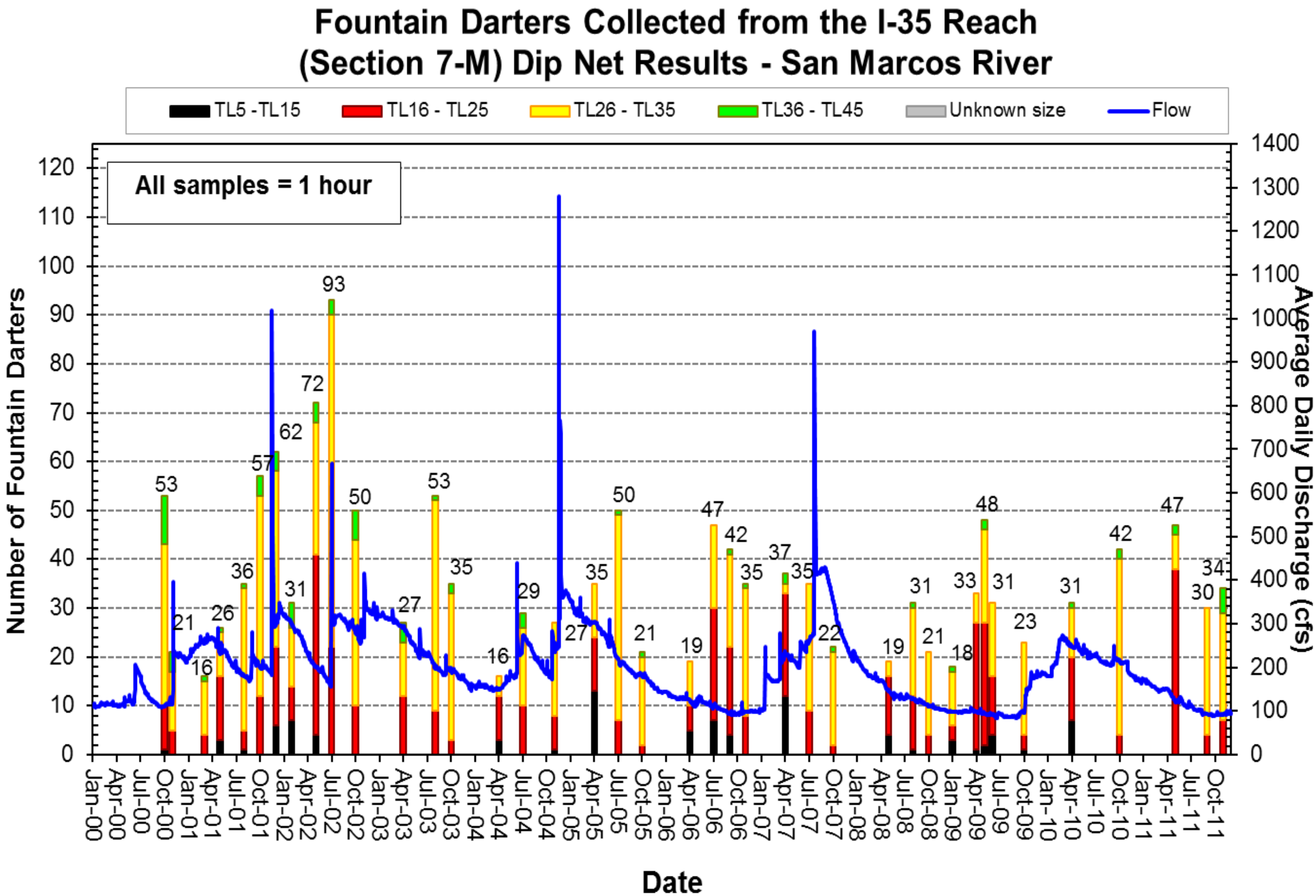


Drop Net Results in the San Marcos River 2000-2011
N= 4703
% Frequency
15
13
11
9
7
5
3
1
-1
4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
Total Length (mm)

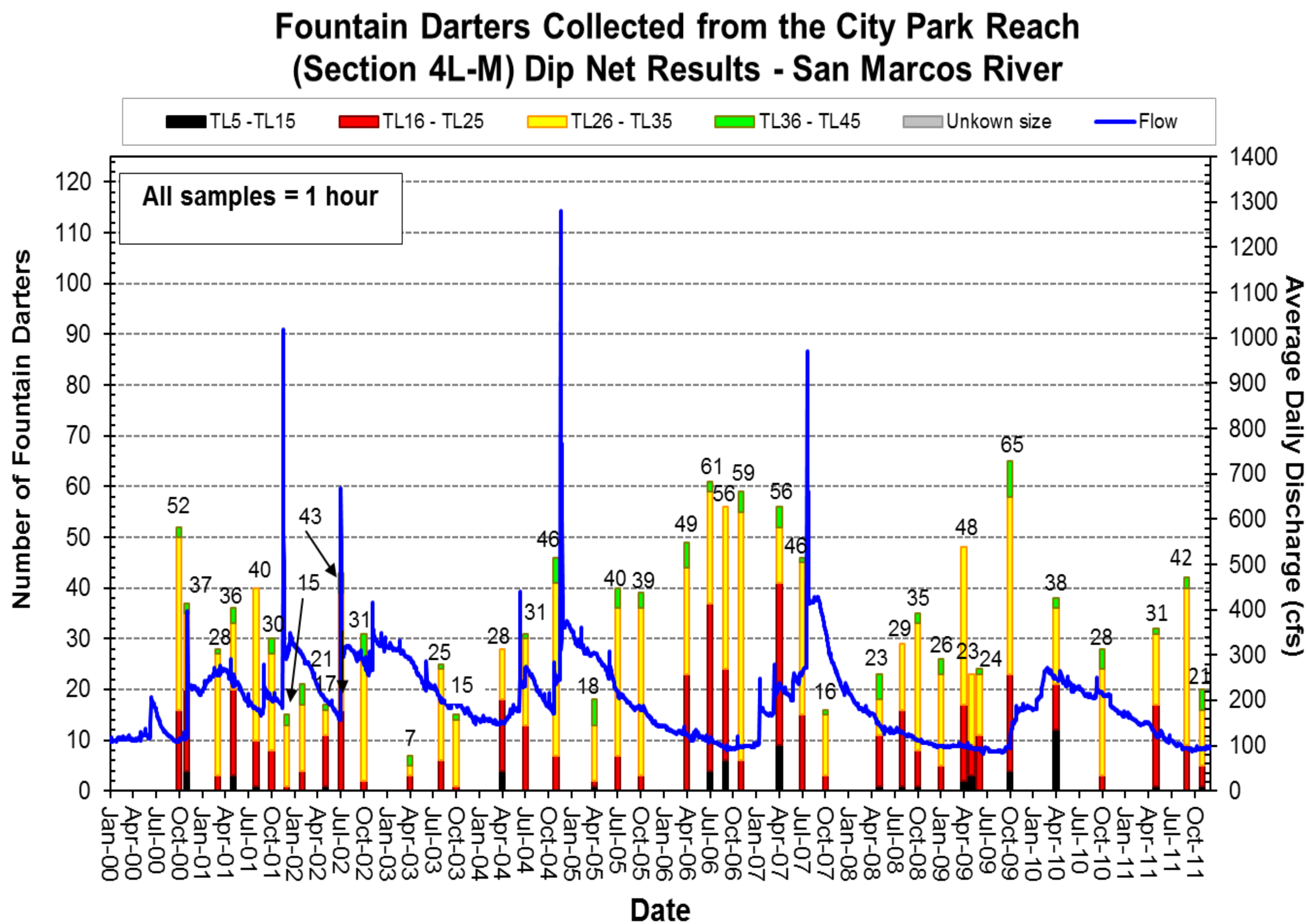
Dip Net Graphs

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

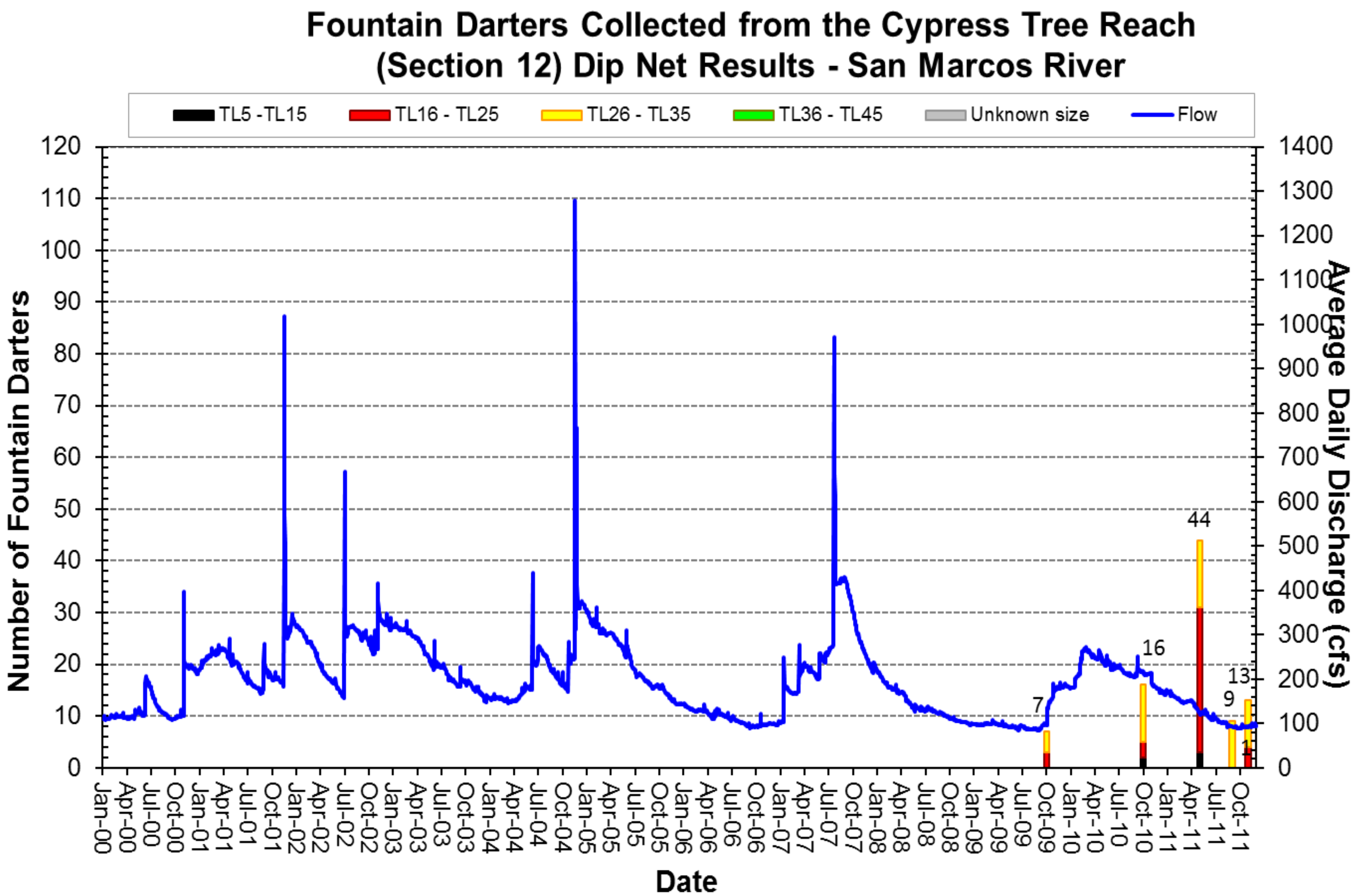




Fountain Darters Collected from the I-35 Reach
(Section 7-M) Dip Net Results - San Marcos River
TL5 -TL15
TL16 - TL25
TL26 - TL35
TL36 - TL45
Unknown size
Flow
All samples = 1 hour
Number of Fountain Darters
Average Daily Discharge (cfs)
Date



Fountain Darters Collected from the City Park Reach (Section 4L-M) Dip Net Results - San Marcos River
TL5 -TL15
TL16 - TL25
TL26 - TL35
TL36 - TL45
Unkown size
Flow
All samples = 1 hour
Number of Fountain Darters
Average Daily Discharge (cfs)
Date



Fountain Darters Collected from the Cypress Tree Reach
(Section 12) Dip Net Results - San Marcos River
TL5 -TL15
TL16 - TL25
TL26 - TL35
TL36 - TL45
Unknown size
Flow
Number of Fountain Darters
Average Daily Discharge (cfs)
Date
7
16
44
9
13
1

APPENDIX C:
DROP NET RAW DATA

(not available online)