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

FINAL 2002 ANNUAL REPORT

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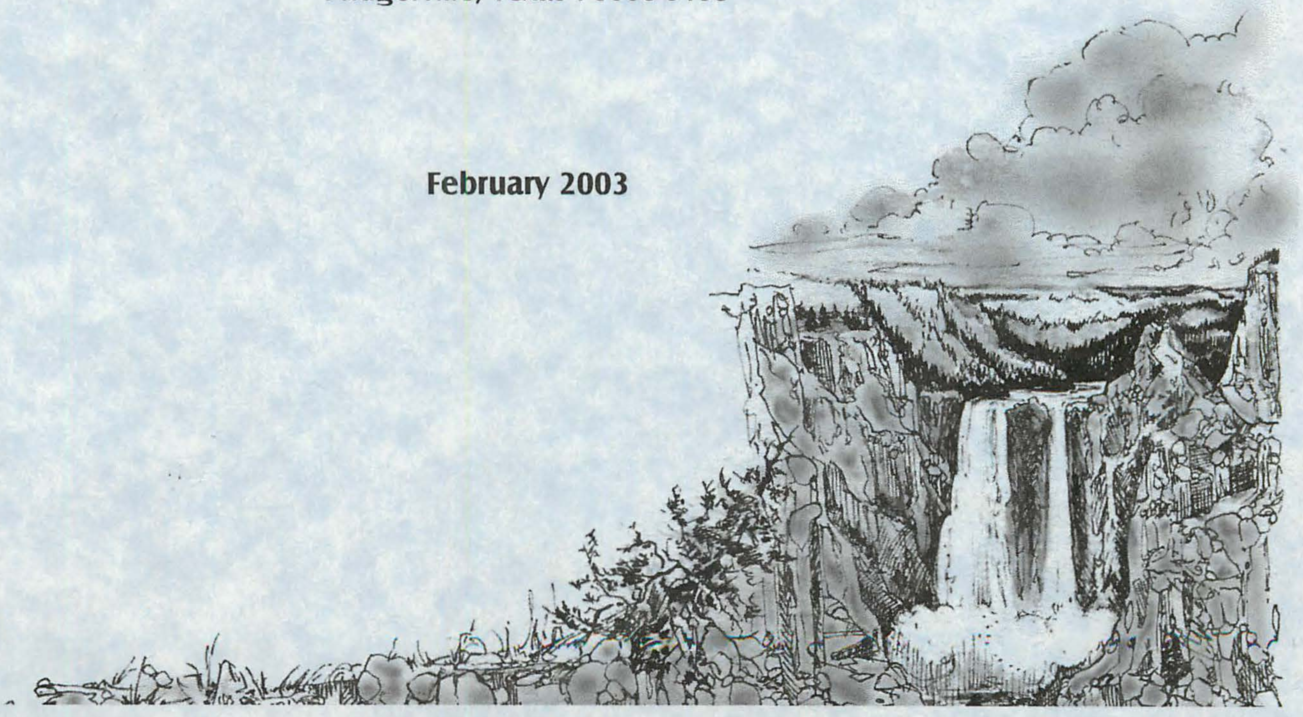

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EXECUTIVE SUMMARY

This annual summary report presents a synopsis of methodology used and an account of sampling activities, including sample conditions, locations and raw data obtained during three quarterly sampling events (Comprehensive Monitoring Effort), conducted on the Comal Springs / River ecosystem in 2002. As in 2001, there were no low-flow critical periods triggered in 2002; however, a high-flow event occurred during the summer (24-hour mean discharge reached levels that have occurred less than 0.1% of the time in the recorded hydrograph). This sample event replaced the summer quarterly sample and a previously unscheduled fall quarterly sample was conducted as a result. The data are reported here in an annual report format similar to previous reports; we have not been able to acquire the necessary range of data from all flow levels (specifically low flow) to conduct stringent data reduction techniques or statistical applications. These techniques will be applied once the appropriate data have been gathered to allow for a complete assessment of variable flow dynamics and will be included in a final report to the Edwards Aquifer Authority.

Although low flows in late summer 2000 initiated the monitoring program, flows since that time have been largely above average levels. Significant rainfall events in late fall 2001 and during summer 2002 yielded near record high-flow conditions that have maintained the aquifer levels and higher flows in the Comal River. Typical summertime conditions occurred in summer 2001, but flows never declined to trigger levels. Prior to the typical low summertime flows and extremely wet fall in 2001, the winter and spring were representative with typically wet conditions. However, unlike in summer 2000, an unseasonable rainfall event during late summer (September 2001) ended low flows and initiated a substantially wet fall and winter.

Overall, the Comal River ecosystem has experienced a wide range of environmental conditions, including variable flows, during this study, but primarily flows have been above average. Baseline data have continued to show that the Comal River is an ecosystem with very high water quality according to the chemical and physical variables that were measured. Thermistor data have revealed a high degree of thermal uniformity throughout the Comal River ecosystem, despite the wide-ranging conditions experienced during the study. The range of water temperatures in the Heidleberg Lodge site, in Landa Lake, and in the spring runs was no more than 1° C (except for one event in Landa Lake). Downstream of Landa Lake, temperature variations were greater – from 20° C to 26° C – with a maximum of approximately 27.7° C for a few days in late summer 2001. Upstream of the spring runs and Landa Lake, on Blieder's Creek, water temperatures also fluctuated greatly (16.5 – 28.5° C; Figure 4). Throughout the course of the study, water temperatures have occasionally exceeded the water quality standards value of 26.67° C, as distance increases away from the spring runs and Landa Lake. Overall, water temperature data do not present any cause for concern in the Comal River, but low-flow conditions will warrant a continued evaluation throughout the system. Other water quality parameters revealed no upstream to downstream pattern and only the total dissolved solids (TDS) parameter was not consistently well below state water quality standards. The TDS value will need to be monitored closely during future low-flow sample efforts. Overall, there continues to be no clear or dramatic change in any water quality variable that might raise concern when comparing data from all sample dates.

Aquatic vegetation has remained abundant throughout the study period (2000-present) and has provided suitable habitat for biological communities. As in previous years, sizable mats of floating vegetation appeared in Landa Lake during the spring but were mostly flushed out during the summer high-flow event. The high-flow events have had considerable impacts on the aquatic vegetative communities by removing or significantly thinning large areas of vegetation in the upper Spring Run and New Channel Reaches. Prior to the summer flooding (winter and spring 2002), most vegetation types displayed rapid growth. This was presumably a recovery response following the fall 2001 flooding and in many cases resulted in an expansion of vegetation beyond the previous boundaries before the summer flood scoured them again. In the Old Channel Reach, filamentous algae was nearly completely scoured in 2002 as it was by the flood in fall 2001. This is significant because of the importance of this vegetation type to fountain darters (*Etheostoma fonticola*). Following the high-flow event in 2001, fountain darters in the filamentous algae were found in higher concentrations than had been observed during any previous trip, but after the summer 2002 flood, fountain darter densities were low relative to the previous sampling event. This highlights the difference between the two flood events. The fall 2001 event was a substantial flushing flow that subsided within a few days, whereas the summer 2002 event began with a similar flushing flow but lasted for over a week because reverse flow from the Guadalupe River moved upstream into the lower portions of the Comal River (including the Old Channel). Because of several moderate flushing events in fall 2002, we did not see the rapid recovery of filamentous algae that was observed after the fall 2001 flood. There were also additional reductions in vegetation coverage in Landa Lake during the fall, which suggests a cumulative effect of the multiple fall flushing flows.

Fountain darters were collected from each sample reach during each sampling event in 2002. The suitability of the various vegetation types in the Comal River ranges dramatically from supporting densities of virtually 0 fountain darters (in *Sagittaria*) to nearly 30 per square meter (m^2) (in filamentous algae). The bryophytes (*Riccia* and *Amblistegium*) and *Ludwigia* also support high densities of fountain darters (>10 per m^2). In 2002, the bryophytes in Landa Lake increased dramatically in areal coverage, which may be a result of higher flow conditions in 2001-2002; however, fountain darter densities decreased in the vegetation type relative to 2001 as they presumably dispersed into the new habitat. As in the San Marcos River ecosystem, flooding has had significant short-term impacts on fountain darter habitat and the vegetation types with the greatest suitability were the most susceptible (filamentous algae and bryophytes). Although impacts from the summer 2002 flooding have not been quickly ameliorated because of repeated flushing events, recovery from the 2001 flooding was rapid and in many cases vegetation (habitat) expanded into new areas. This suggests that positive long-term effects offset short-term losses in fountain darter habitat and possibly even population abundance.

The overall size-class distribution for the Comal ecosystem represents a healthy fish assemblage, though some differences in reproduction in individual sample reaches yielded variable size-class distributions by season in some reaches. As in 2001, the size-class distribution in the Old Channel Reach has remained stable throughout the study period, whereas the other reaches have experienced reproductive peaks with corresponding shifts in size-class distribution.

In 2000-2001, we observed differences in seasonal variation patterns in fountain darter abundance between the San Marcos and Comal River ecosystems, but in 2002 the variation in number observed between seasons was similar; both systems had high numbers in the spring and substantially lower numbers in the winter. The San Marcos River ecosystem had trends that were similar to previous years and it appears that the difference in 2002 (compared with 2000-2001) is largely in the Comal River ecosystem. The changes in seasonal abundance patterns in the Comal River ecosystem may be a result of frequent flooding and general high-flow conditions, which we hypothesize may have altered reproductive stimuli.

Two additional parameters were noted during fountain darter sampling, the density of giant ramshorn snails (*Marisa cornuarietis*) and evidence of gill parasites on fountain darters. By all indications the densities of giant ramshorn snails observed in the Comal ecosystem during the study period to date (including the 2000 low-flow events) pose no serious threat to the aquatic vegetative community. However, because of the impact that this exotic species can have under heavier densities, close monitoring of this species should continue. The gill parasite that has been reported for the fountain darter was evident in a number of collected fountain darters.

In 2002, the gill parasite component of the Variable Flow Study expanded upon the preliminary trials conducted in 2001. Cage trials with fountain darters held in eight locations throughout the Comal River revealed that gill parasite infection rates varied among sites and were greatest near an island in Landa Lake that supports dense populations of birds (vultures and geese). The trials also revealed that the habitat in which fountain darters with intense gill-flaring (a sign of the parasite) are most common (the Old Channel Reach) produced a relatively low rate of infections in fountain darters. Cage trials in 2001 and 2002 produced virtually identical results in each site, but another method, dip netting for resident fish, resulted in very different numbers of parasites per fish sampled. These two methods are being compared for their potential value as a long-term monitoring strategy, and although the cage trials require significantly more effort, that method appears to provide more valuable information. Another method of monitoring, filtering water samples for drifting parasites, was significantly improved between 2001 and 2002 by adding a dilute formalin solution to the sample and this method may be useful either in concert with one of the others or as the sole method for long-term monitoring of parasite conditions.

Drift net sampling for benthic macroinvertebrates was completed with the spring quarterly sample. In the spring runs and at the springs' orifices, suitable habitat for the federally endangered invertebrates was observed throughout the study period. Several endangered Comal Springs riffle beetle (*Heterelmis comalensis*) adults and larvae were collected in the drift nets throughout the year. The analysis of the complete data set produced many interesting observations and trends including several differences between the two spring runs sampled (1 and 3). First, samples from the two spring runs differed primarily due to habitat differences; site 1 had greater habitat complexity and greater species richness. The types of invertebrates that were dominant also differed between spring runs. Mayflies and crayfish were most abundant in Spring Run 1 while a caddisfly species, the water penny, and midges were dominant in Spring Run 3. There was daily fluctuation in drift observed in both spring runs – the number of drifting insects increased nearly twofold on average at night – but peaks in nightly drift were more pronounced in Spring Run 1. There was also a seasonal pattern in drift rates in both spring runs; they were generally highest from late winter to early spring and declined from late summer through early winter. The dominant taxa (mayflies in Spring Run 1 and caddisflies in Spring Run 3) showed the most significant relationship between drift rate and seasonality (Julian day). The overall drift rate (number / 24-hour period) was higher in Spring Run 1 than Spring Run 3 and both showed high drift rates during the lowest observed flows. There also appeared to be a general trend toward increased drift at lower water levels in Spring Run 1 but no pattern between drift density and discharge in Spring Run 3. Another difference between the two spring runs was the result for the endangered Comal Springs riffle beetle; this species tended to increase in the drift with lower flows in Spring Run 1 but increased with higher flows in Spring Run 3. These contradictory results suggest that populations in the two spring runs differ in response to changing habitat conditions but highlight the need for more data on invertebrate drift during low flows to refine assessments of how reductions in stream flow affect the benthic community in Comal Springs. Finally, several potential indicator species were identified that may be useful for long-term monitoring.

Suitable habitat for the Comal Springs salamander (*Eurycea* sp.) was noted in the spring runs and Spring Island area; Comal Springs salamanders were observed in each area during each sampling event. The sediment accumulation in Spring Run 3 following high-flow events did appear to have an acute effect on the number of Comal Springs salamanders present. As documented via SCUBA surveys, the Comal Springs salamander population was maintained in the deeper portion of Landa Lake throughout the study period.

The exotic / predation component of the study was conducted during each sampling event except for the fall 2002 quarterly effort, but in future monitoring, these samples will only be collected during low-flow efforts. Overall, fountain darters and salamanders do not appear to be susceptible to predation by fish predators in either the San Marcos or Comal Rivers. Out of the 437 stomachs examined, only three fountain darters and two San Marcos salamanders were recovered from largemouth bass and warmouth stomachs during the study; no Comal Springs salamanders were observed. Conditions may vary during low flow, however, and the threat of predation may increase; thus predation sampling will be conducted during future low-flow sampling events.

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

This study remains the most comprehensive biological evaluation that has ever been conducted on the Comal River ecosystem. Variable flow conditions encountered to date have provided an excellent confirmation that the study design is well suited to address the concerns of variable flow and water quality on the biological resources in the Comal and San Marcos River ecosystems. As noted in the 2001 annual report, this study meets three critical criteria to assure the greatest possible success in assessing impacts to biological communities of variable flow conditions: (1) the endangered species are evaluated directly (some studies make conclusions based on surrogate species and attempt to describe dynamics of the endangered species), (2) continuous sampling is used to evaluate current conditions to properly assess changes relative to flow variation (one-time sampling events or limited sampling during particular seasons will not yield accurate conclusions), and (3) multiple collection techniques are used to evaluate multiple components of the ecosystem (important observations may be missed using limited sampling means).

METHODS

In 2002, one high-flow and two quarterly sampling efforts were conducted following the sampling protocol used in 2000 and 2001, but the final sampling event (fall quarterly) in 2002 was modified in scope. That sampling event was adjusted according to a new monitoring program for future sampling efforts discussed among BIO-WEST, Inc. (BIO-WEST), the Edwards Aquifer Authority (EAA), and the U.S. Fish and Wildlife Service (USFWS) during a meeting in August 2002. The first three sampling events in 2002 included a 2-week effort and the following components:

Water Quality
- Standard Parameters
- Thermistor Placement
- Thermistor Retrieval
- Water Quality Grab Samples
- Habitat Quality Index / Fixed Station Photographs

Aquatic Vegetation Mapping

Fountain Darter Sampling
- Drop Nets
- Dip Nets
- Visual Observations
- Gill Parasite Evaluation

Salamander Observations

Macroinvertebrate Sampling
- Drift Nets

Exotic / Predation Study

The fall 2002 sampling event did not include the water quality (except for thermistors), macroinvertebrate, or exotic / predation components of the study, but the other components were sampled in the same manner as before.

High-Flow Sampling

In 2002, there was one high-flow sampling event, which corresponded with the timing of the summer sampling event that it replaced. The intense period of rain that triggered the high-flow sampling event began on June 30, 2002, and flows remained high through July 12. The last 8 days of the high flows (July 5-12) were primarily influenced by intense flooding on the Guadalupe River that backed up water into the Comal River and resulted in reverse flow and lentic conditions. For 7 days (July 5-11) the U.S. Geological Survey (USGS) gage was inundated and no accurate flow estimate could be determined. Prior to that, the instantaneous discharge peaked at 2,170 cubic feet per second (cfs) and the maximum 24-hour mean discharge was 1,150 cfs. Flows remained above our high-flow trigger level (500 cfs) for 4 consecutive days (June 30 - July 3). In order to evaluate the post-flooding effects, sampling for this event was conducted after the ecosystem had returned to normative conditions but not so soon that sampling would be influenced by immediate, ephemeral impacts occurring during the elevated flow conditions.

The high-flow sampling efforts were designed to focus on those factors most likely to experience a shift in conditions following the natural disturbance. Aquatic vegetation mapping was conducted first to examine physical changes in vegetative distribution and abundance. Because the presence of various species of vegetation affects the amount of habitat available to fountain darters and other species, this is a vital component of all sampling activities. Fountain darter sampling included standard drop net sampling, dip netting, and visual observations; gill parasites were not examined. Comal Springs salamander observations and the predation study were conducted as in a normal quarterly sampling effort.

Unlike previous high-flow sampling events, the water quality component was conducted during the summer / high-flow sampling event because this event directly replaced the planned quarterly sampling event. As before, the drift net component was not included in this high-flow sampling event because of the period of time necessary to allow the benthic community to return to normative conditions.

Springflow

All discharge data were acquired from USGS water resources division. The data are provisional as indicated in the disclaimer on the USGS website and, as such, may be subject to revision at a later date. According to the disclaimer, "recent data provided by the USGS in Texas – including stream discharge, water levels, precipitation, and components from water-quality monitors – are preliminary and have not received final approval" (USGS 2000). The discharge data for the Comal ecosystem was taken from USGS gage 08169000 from the Comal River at New Braunfels. This site represents the cumulative discharge of the springs that form this river system. In addition to these cumulative discharge measurements, which are used to characterize the Comal Springs ecosystem during sampling, spot water velocity measurements were taken during each sampling event using a Marsh McBirney model 2000 portable flowmeter.

Water Quality

The water quality component of this study was conducted during the first three sampling events of 2002 and included measuring standard water quality parameters using a Hydrolab data sonde and gathering water samples for laboratory analyses at each of the water quality sites in the Comal Springs ecosystem (Figure 1). Thermistors were deployed and retrieved during all four sampling events in 2002 and are included in the new plan for future monitoring; the other water quality components will be included only during low-flow periods in future sampling. 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. Dr. Alan Groeger of Southwest Texas State University (SWT) supervised all aspects of the water quality component in 2002, and the chemical analyses for each quarterly sampling event was conducted in Dr. Groeger's laboratory at SWT.

Hydrolab measurements included conventional in-situ physico-chemical parameters that were collected each time a water and/or biological station was occupied. The parameters included: water temperature, conductivity compensated to 25° C, pH, dissolved oxygen, water depth at sampling point, and observations of local conditions. These data were gathered at the surface, mid-depth, and near the bottom at all biological stations when there was stratification, but only near the surface at water quality stations. In addition, thermistors were placed in select water quality stations along the Comal River and

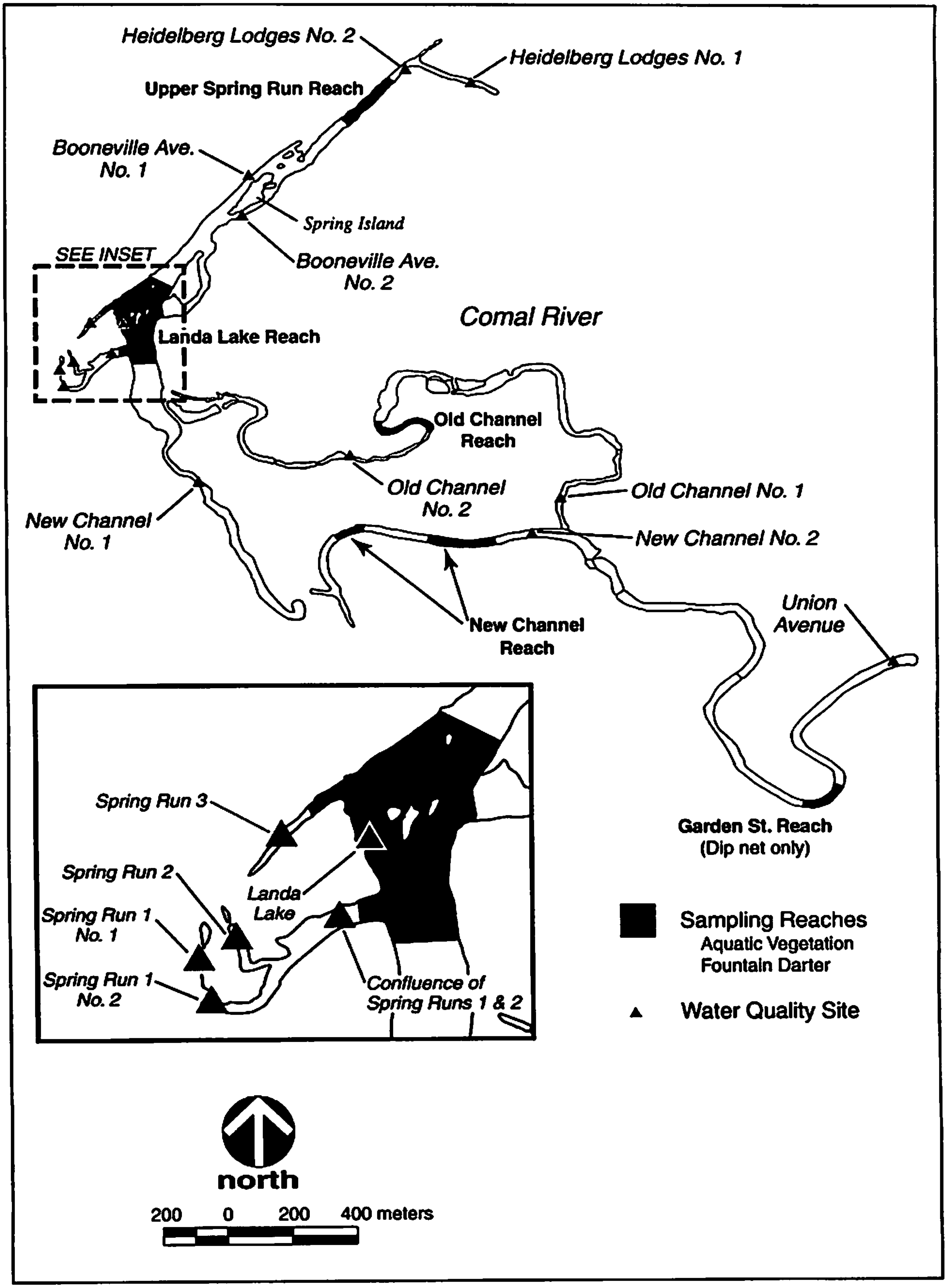

Figure 1. Comal River water quality and biological sampling areas.

downloaded at regular intervals to provide continuous monitoring of water temperatures in these areas. The thermistors were placed using SCUBA in deeper locations within the ecosystem and set to record temperature data every 5 minutes. The water quality station locations will not be described in detail here to minimize the potential for unauthorized tampering with field equipment.

Conventional water chemistry parameters from water samples taken at each of the water quality stations were also analyzed in the laboratory. Water "grab" samples were taken in 1-liter polyethylene bottles with caps. Prior to sample collection, the bottles were soaked in Contrad 70 overnight, rinsed repeatedly in DI water, and rinsed once in Milli-Q water before being dried for 24 hours. At the sampling site, each bottle was rinsed with river water prior to sample collection; all samples were collected from under the surface of the water to avoid surface-active particulates and floating debris. Samples were then stored in the dark, under ice, for the remainder of the collection period. Samples were transported to the laboratory within 4-6 hours and warmed to room temperature, at which point the samples were partitioned into fractions for the following analyses. Whole water samples were also frozen for a few weeks prior to some analyses; once frozen the samples are stable for many months. Table 1 summarizes the parameters, methodology, minimum analytical levels (MAL) and minimum detection limits (MDL) of the data gathered from this chemistry analysis.

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

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

* micrograms.

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

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

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

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

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

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

Aquatic Vegetation Mapping

The aquatic vegetation mapping effort for the first two quarterly sampling events and summer / high-flow sampling in 2002 consisted of mapping all of the vegetation in each of the four reaches (Upper Spring Run, Landa Lake, New Channel [two sections], and Old Channel; Appendix A). In the fall quarterly sample – and for future efforts – only one section of the New Channel was mapped (the lower section). The additional section does not increase habitat coverage substantially, but the effort required to map the additional section is extensive. In addition, most of the upper section is too deep to sample with the drop net and the one *Hygrophila* site sampled that is sampled quarterly is typically similar in species composition to samples in the lower section.

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

Filamentous algae (in the old channel) and bryophytes (*Riccia* and *Amblistegium* in upper spring run and Landa Lake) were included in all 2002 sampling events. Difficulties with mapping these vegetation types (patchiness, obscured by filamentous algae, etc.) precluded it from early samples; however, these vegetation types are clearly important fountain darter habitat and were included in all sample events beginning in the summer of 2001.

Fountain Darter Sampling

Drop Nets

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

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

Dip Nets

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

To balance the effort expended across samples, a predetermined time constraint was used for each reach (Upper Spring Run - 0.5 hour, Spring Island area - 0.5 hour, Landa Lake - 1.0 hour, New Channel - 1.0 hour, Old Channel - 1.0 hour, Garden Street - 1.0 hour). The areas of fountain darter collection were marked on a base map of the reach. Though information relating the number of fountain darters by vegetation type was not gathered by this method (as in the drop net sampling), it did permit a more thorough exploration of various habitats within the reach. Also, spending a comparable length of time sampling the entirety of each reach allowed comparisons to be made between the data gathered during each sampling event.

Visual Observations

Visual surveys were conducted using SCUBA in Landa Lake to verify the continued fountain darter and Comal Springs salamander use of habitat in deeper portions of the lake. The locations of these time-constrained surveys were deeper than conventional sampling methods allow. Observations were conducted in the early afternoon for each effort. Subsequently, gill nets were set in these areas for the predation component of the study.

An additional component to these surveys was a grid (0.6 m x 13 m) added in summer 2001, and subsequent sampling was used to quantify the number of fountain darters using these deeper habitats. To sample the area, all fountain darters within the grid were counted, and larger rocks were moved at the substrate surface to expose any fountain darters.

Gill Parasite Evaluation

The objectives of this study component are to examine the variation in spatial and temporal concentration of *Centrocestus formosanus* in the water column and infection intensity on the gills of caged and resident fountain darters in the Comal ecosystem.

The BIO-WEST project team is evaluating whether relationships exist among the numbers of *C. formosanus* drifting, the numbers that attach to caged fish, and the numbers attached to resident fountain darters, and assessing each method for viability as a long-term monitoring tool. In 2001, preliminary trials were conducted to evaluate the use of cages to hold fountain darters in one location and evaluate parasite infestation over time. These trials revealed that this is a viable method for future monitoring. The experiments were conducted in eight sites throughout the Comal River, and the results show that infestation increased over time and occurred at a much greater rate than in largemouth bass subjected to the same conditions. The results also revealed that there is spatial variation in parasite infestation rates throughout the system. In 2002, the experiment was repeated to evaluate consistency across samples and to compare to other potential methods for long-term monitoring. Comparisons among methods were conducted to evaluate which is most sensitive to variations in parasite infections in the fountain darter due to springflow fluctuations. In addition to the cage method, dip-net sampling of resident fish was conducted in 2001 and 2002. Dip nets were used in a manner similar to data collected previously by the USFWS (in 1997-1998) in which resident fountain darters are collected and their cumulative parasite load counted. A third method that may be useful for monitoring either independently or in concert with one of the other methods is filtering the water column to assess abundance of drifting *C. formosanus*. This method was conducted in two locations with sampling repeated at 3-hour intervals for 24 hours to examine diel patterns. The step of immediately fixing the sample with 0.1% formalin was evaluated and found to greatly increase the percentage of parasites recovered. Summer and fall samples taken in 2002 were "fixed" with 0.1% formalin.

This component will continue through 2003 with an additional sampling effort incorporating all three methods during at least winter and spring sampling events. This additional sampling will provide greater precision for comparing methods and allow for an evaluation of change in parasite intensity throughout the Comal River. As with other components of the study, more data are needed from critical period flows to fully evaluate the change in parasite effects at lower discharge levels; however, the data being gathered are vital to maintain a record of ongoing conditions to properly assess low-flow conditions when they do occur.

Comal Springs Salamander Visual Observations

In addition to the visual observations made in the deeper portions of Landa Lake for fountain darters and Comal Springs salamanders, the BIO-WEST project team performed presence / absence surveys for the Comal Springs salamanders in the spring reaches located at the head of the Comal River during all 2001 sampling events. Surveys were conducted in Spring Run 1, Spring Run 3, and the Spring Island area (Figure 1) and performed by two people in each spring reach. Each survey began at the downstream-most edge of the sampling area and involved turning over rocks located on the substrate surface within the spring run while moving upstream toward the main spring orifice. A dive mask and snorkel were utilized when depth permitted. The Comal Springs salamander locations were noted, along with time and water depth information. In order to maintain consistency between samples, all surveys were initiated in the morning and terminated before noon.

Within Spring Run 1, surveys were conducted from the first pedestrian bridge below Landa Park Drive up to 9 m below the head spring orifice. Spring Run 3 was surveyed from the pedestrian bridge closest to Landa Lake up to 9 m below the head spring orifice. In the Spring Island area, surveys were conducted within the entire spring reach including approximately a 15-m radius from each spring run outfall. These two areas include the spring outfall on the east side of Spring Island (closest to Edgewater Drive) and the area north of Spring Island (upstream).

Macroinvertebrate Sampling

Benthic (bottom-dwelling) macroinvertebrates are reliable indicators of localized alterations in stream conditions (Gore 1977, Corrarino and Brusven 1983, Rosenberg and Resh 1992), because differential habitat requirements make it possible to assess water quality and water quantity issues in stream ecosystems. Drift net sampling of benthic macroinvertebrates was continued in the first two samples of 2002 as in previous sample efforts, but future sampling – in 2003 and beyond – will include a modified sampling approach that focuses more on spring openings and laboratory studies. The drift net sampling has been important though because these samples have explored the movement of organisms through the spring runs. Drifting downstream is one of the most important methods for dispersal by benthic invertebrates (Smock 1996). This study measured the drift rates, densities, and patterns of selected aquatic invertebrates, and determined if changes in depth, season, and current velocity affect the composition and abundance of selected indicator insects. Drift nets were placed at the downstream end of Comal Spring Runs 1, 2, and 3. Two nets were placed in Spring Run 1 approximately 15 m downstream of Landa Park Drive. Spring Run 2 had one net placed just upstream of the road crossing before the wading pool, but the amount of time required to separate samples and identify all organisms was greater than anticipated and samples from spring run 2 were collected and saved but not examined at this time. One net was also placed in Spring Run 3 approximately 6 m downstream of the last footbridge.

Drift nets were anchored into the substrate using rods, with the net face perpendicular to the direction of flow of water. The nets consisted of a 0.45 m by 0.30 m rectangular opening, which connected to a 1-m-long net with a mesh size of 600 µm. The tail of the net was connected to a detachable 0.15-m-long cylindrical bucket. The bottoms of the nets were positioned 2-3 cm above the sediment to reduce the possibility of macroinvertebrates crawling into the nets. The depth of the water column entering the net was then measured at three locations across the mouth of the net, and a flowmeter was used to measure water velocity at the mouth of the net. Collecting buckets were then connected to the end of the nets and the time was recorded. The buckets were removed at 3-hour intervals, and the cup contents were washed into sealable bags. A squirt bottle filled with water was used to remove any macroinvertebrates that were clinging to the inside of the cups. The samples were preserved in 90% ethanol, and the bags were labeled with the date, net number, and the time of the sampling interval. This process was repeated over a 24-hour period and then all samples were transported to the Stream Ecology Lab at SWT and stored for analysis.

In the SWT laboratory, all organisms were separated from the debris contained in the samples with the use of a stereomicroscope. The macroinvertebrates collected were then stored in vials of 70% ethanol for future identification. All identifications were made with the use of Merritt and Cummins (1996) and Thorpe and Covich (1996). Upon identification, the organisms were counted, data were recorded, and drift density and drift rate were calculated. Drift rate, the number of organisms drifting past a point per 24-hour-period, drift density, and the number of organisms per 100 cubic meters (m^3) of water were used to estimate drift in the spring runs. Drift rate was calculated by merely summing the total number of organisms collected in a net over a 24-hour period. Drift density was calculated using the following formula:

$$\text{Drift Density} = \frac{(N)\,(100)}{(t)\,(W)\,(H)\,(V)\,(3600\ s/h)},$$

Where N is the number of macroinvertebrates in a sample; t, length of time of sampling (hours); W, net width (m); H, height of water column in the net mouth (m); and V is the mean velocity of water at the mouth of the net (m/s). Drift density was expressed as the number of macroinvertebrates drifting per 100 m^3 of water sampled (Smock 1996).

Exotics / Predation Study

As in previous sampling, a 45.72 m (150-foot) experimental gill net with mesh sizes ranging from 1.9 to 7.6 cm (0.75 to 3.0 inches) was placed in Landa Lake to collect predatory fish of various species and sizes during the first two quarterly sampling events and summer / high-flow sampling event in 2002. This sampling component was not included in the final sample of 2002 and will not be used in quarterly sampling during future efforts; it will be included in low-flow sampling in 2003 and beyond, however. This sampling was conducted to attempt to determine the density of various exotic fish species in Landa Lake and to perform stomach content analyses with particular emphasis on potential predation on endangered species. The gill net was placed in the area previously identified as supporting fountain darters and Comal Springs salamanders through SCUBA surveys. All fish collected in the gill net were identified, enumerated, weighed, and measured. The original intention was to retain a few representative individuals of each species within different size classes; however, sample sizes were smaller than anticipated so all fishes were used in the stomach analysis. Fishes collected in the field were stored on crushed ice until transferred to the SWT Aquatic Center or the BIO-WEST Nekton Laboratory where the stomachs were removed and contents examined. Although the focus was on fountain darter and / or Comal Springs salamander predation by the various species and size classes, all stomach contents were recorded.

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

OBSERVATIONS

The BIO-WEST project team conducted the 2002 sampling events as shown in Table 2.

Table 2. Components of 2002 sampling events.

EVENT	DATES	EVENT	DATES
Winter Sampling		**Summer / High-Flow Sampling**	
Water Quality Sampling	Mar 7	Water Quality Sampling	Aug 13
Vegetation Mapping	Feb 19 - 21	Vegetation Mapping	July 31 - Aug 6
Fountain Darter Sampling	Feb 25 - 27	Fountain Darter Sampling	Aug 6-8
Comal Salamander Observations	Feb 28	Comal Salamander Observations	Aug 5
Macroinvertebrate Sampling	Feb 19	Exotic / Predation Study	Aug 8-9
Exotic / Predation Study	Feb 27-28		
Spring Sampling		**Fall Sampling**	
Water Quality Sampling	May 30	Vegetation Mapping	Oct 28-29
Vegetation Mapping	May 14-16	Fountain Darter Sampling	Nov 18-20
Fountain Darter Sampling	May 20-22	Comal Salamander Observations	Nov 21
Comal Salamander Observations	May 23		
Macroinvertebrate Sampling	May 20		
Exotic / Predation Study	May 22-23		

High-Flow Sampling

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

Springflow

Daily 2002 springflow averages were similar to those in 2001; discharge was greater than 300 cfs for most of the year (Figure 2). The lowest discharge in 2001 was 243 cfs, while it was 247 cfs in 2002, but the low in 2002 occurred earlier than in 2001. In both years, there was a steady decline in discharge from spring into summer, but in 2002 the low was reached in late June, while in 2001 the low occurred in the end of August. In both years the steady decline into and during the summer was ended abruptly with intense rain events. There were not as many peaks in discharge during 2002, but the one major peak in the summer far surpassed the peak observed in 2001 (discharge values were so high that the USGS could not accurately measure them and has not provided an estimate for those days). During this flooding, water from the Guadalupe River backed up into the Comal River and completely covered the USGS gage, resulting in a net upstream movement of water in the Comal system for several days. Relative to monthly averages during the period of record (Figure 3), all but the month of June in 2002 was significantly higher than normal, daily averages in June actually dropped to below the historical average

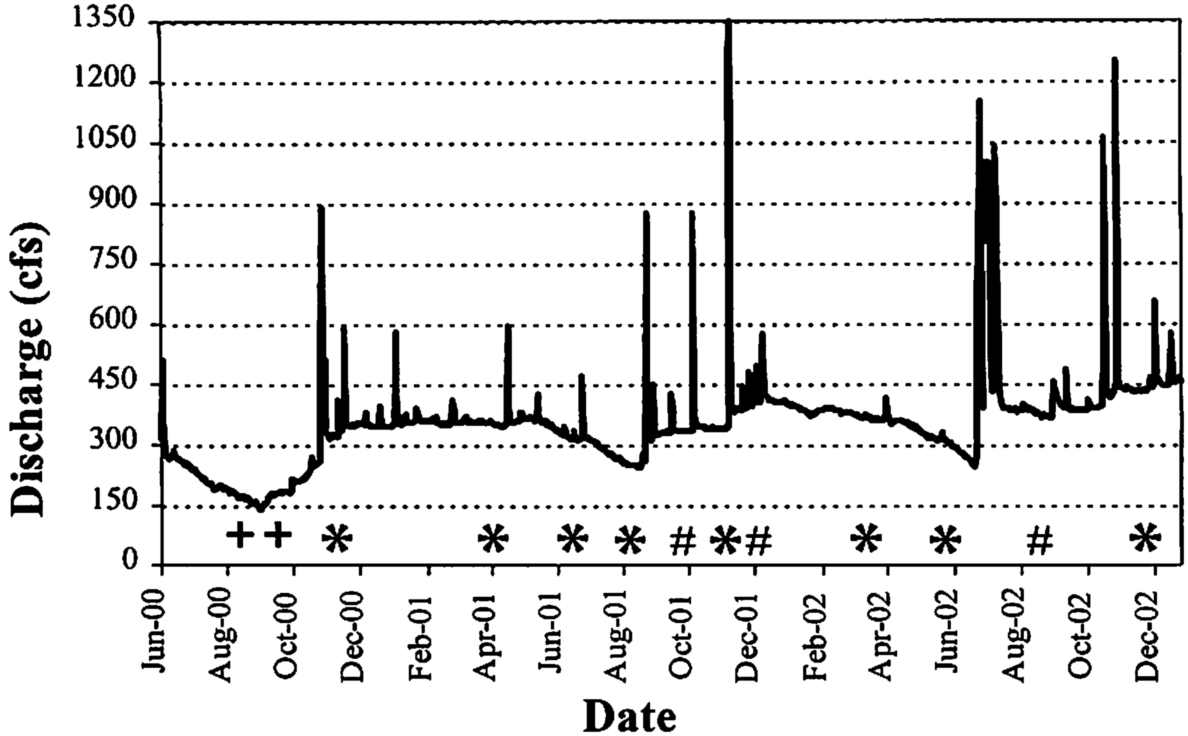

Figure 2. Mean daily discharge in the Comal River during the study period; approximate dates for quarterly (*), low (+), and high-flow (#) sampling events are indicated.

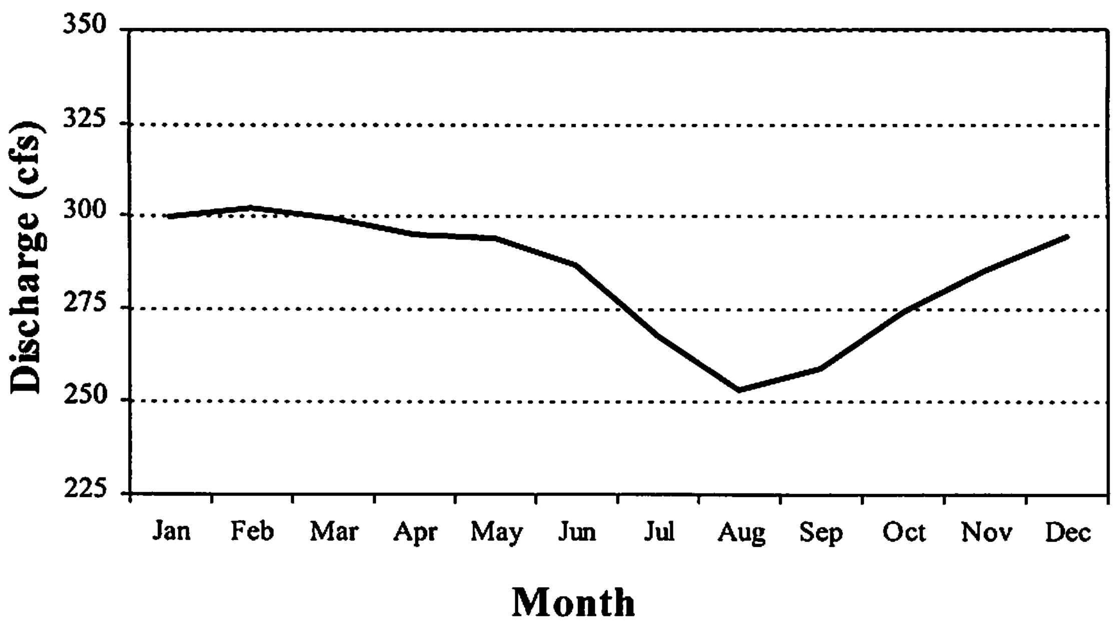

Figure 3. Mean monthly discharge in the Comal River during the 1934-1996 period of record.

for the month. Conditions in early summer of 2002 were leading to a steady, rapid decrease in discharge, and may have triggered low-flow sampling if not for the intense flooding in early July. That rain event and several smaller events in the fall kept the discharge levels significantly higher than historical means for the remainder of the year.

Water Quality

Hydrolab profiles were conducted at all 15 sites during each quarterly sample, while water quality data were collected at only 12 of the sites (Figure 1). The water quality sites were as follows:

Blieder's Creek (BC),
Heidleberg (HMC) (furthest upstream site),
Booneville 1 (IPF) (far channel of Island Park),
Booneville 2 (IPN) (near channel of Island Park),
Spring Run 1 (SR1) (spring furthest from the lake proper),
Spring Run 2 (SR2) (spring running parallel Spring 1),
Spring Run 3 (SR3) (spring closest to Landa Lake),
New Channel 1 (NCU)(located across from the park office),
New Channel 2 (NCD) (located upstream of the confluence of the old and new channel),
Old Channel 1 (OCU) (located in the Schlitterbahn employee parking area by the railroad trestle),
Old Channel 2 (OCD) (upstream of footbridge before the confluence with the New Channel), and
"The Other Place" Lodges (OP) (farthest downstream site).

Hydrolab profiles only were taken at the confluence of Spring Runs 1 and 2, the bank of Landa Lake, and a downstream section of Spring Run 1. In the Comal ecosystem, water quality sites were visited from upstream in the early hours of the day toward downstream sites in the late morning and early afternoon.

A summary of the water quality data for this project is presented in Tables 3 and 4; graphs of thermistor data for important/representative reaches are presented in Figures 4-7. A more detailed list of data for each sample and additional graphs can be found in Appendix B.

The continuously sampled water temperature data provide a significant amount of information regarding fluctuations due to climate and springflow influences in the Comal River. Water temperature fluctuated with changes in air temperature and fluctuations were greatest in sites with the least springflow influence. While the amount of precipitation also may influence water temperatures, the relationship is more directly associated with air temperature because of the influence of air temperatures on precipitation temperatures. The range of water temperatures in the Heidleberg site (Figure 4), in Landa Lake (Figure 5), and in the spring runs (Figure 6) was no more than 1° C (except for one event in Landa Lake). Downstream of Landa Lake, temperature variations were greater – from 20° C to 26° C – with a maximum of approximately 27.7° C for a few days in late summer 2001 (Figure 7). On Blieder's Creek, upstream of the spring runs and Landa Lake, water temperatures also fluctuated greatly (16.5 – 28.5° C; Figure 4). Water temperatures at sites furthest away from the spring runs and Landa Lake occasionally exceeded the water quality standards value of 26.67° C. The lethal limit for the fountain darter is 34.8° C (Brandt et al. 1993).

Table 3. Summary of Comal River ecosystem physical water quality measurements, 2000 to 2002.

SITE	TEMPERATURE (Celsius)			pH			DISSOLVED OXYGEN (mg/L)[a]			CONDUCTIVITY (µmhos/cm)[b]			TURBIDITY (NTU)[c]			ALKALINITY (meq/L)[d]		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Blieder's Creek	23.45	20.87	25.38	7.27	6.87	7.66	6.05	3.19	10.50	524	481	640	1.83	1.20	3.00	4.03	3.61	4.34
Heidleberg, Main Channel	24.16	23.54	26.56	7.17	6.88	7.41	5.91	4.48	6.86	532	492	667	1.74	1.10	2.10	4.15	3.94	4.52
Island Park, Far Channel	23.62	22.57	24.11	7.21	6.88	7.37	6.62	5.88	7.88	532	495	672	1.44	1.10	1.70	4.26	3.97	4.51
Island Park, Near Channel	23.74	22.85	24.36	7.15	6.82	7.36	6.21	4.81	8.40	531	491	671	1.23	1.00	1.50	4.26	3.97	4.50
Spring Run 1	23.39	23.18	23.72	7.14	6.87	7.34	5.79	5.10	6.84	531	491	667	0.83	0.07	1.20	4.17	3.83	4.59
Spring Run 2	23.47	23.14	23.62	7.15	6.81	7.37	5.56	5.02	6.24	531	491	665	0.88	0.09	1.20	4.18	3.94	4.54
Spring Run 3	23.44	23.17	23.58	7.15	6.82	7.42	5.82	5.23	6.84	529	492	665	0.87	0.09	1.20	4.22	4.04	4.54
New Channel, upstream	23.99	22.61	25.47	7.33	6.93	7.70	8.43	7.17	9.68	531	491	670	1.47	1.10	2.00	4.22	3.94	4.54
New Channel, downstream	23.94	22.02	25.11	7.56	7.20	7.77	9.39	7.81	10.05	529	490	665	1.48	1.00	2.10	4.28	4.00	4.56
Old Channel, upstream	23.54	20.39	25.17	7.55	7.15	7.87	7.98	6.12	9.85	537	492	664	1.86	1.40	2.80	4.32	4.00	4.60
Old Channel, downstream	23.68	21.63	26.05	7.58	7.36	7.84	8.44	6.58	9.90	533	496	665	2.07	1.60	2.80	4.29	4.07	4.66
The Other Place (Iverness)	23.73	21.22	25.51	7.67	7.25	7.89	8.94	6.70	9.75	530	491	662	2.44	1.10	3.20	4.30	4.00	4.60

[a] milligrams per liter; [b] micromhos per centimeter; [c] nephelometric turbidity units; [d] milliequivalents per liter.

Table 4. Summary of Comal River ecosystem nutrient measurements, 2000 to 2002.

SITE	SOLUBLE REACTIVE PHOSPHORUS (ugP/L)[a]			TOTAL PHOSPHORUS (ug/L)[b]			AMMONIUM (ug/L)			NITRATE (mg/L)[c]			T NITROGEN (mg/L)			TOTAL SUSPENDED SOLIDS (g/L)[d]		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Blieder's Creek	9.0	2.2	22.0	21.1	8.2	42.0	115.5	43.0	283.9	1.74	1.32	2.23	1.95	1.36	2.44	0.018	0.006	0.026
Heidleberg Main Channel	7.6	2.3	15.7	16.2	7.8	24.3	93.2	20.6	199.9	1.91	1.65	2.21	2.07	1.28	2.38	0.020	0.005	0.028
Island Park, Far Channel	6.8	2.6	13.3	19.5	10.7	47.8	46.2	10.0	188.6	1.91	1.56	2.24	1.96	0.92	2.40	0.018	0.004	0.049
Island Park, Near Channel	7.4	1.9	11.4	18.4	7.1	34.0	53.7	13.8	288.4	2.31	1.46	5.97	1.91	0.62	2.37	0.012	0.005	0.019
Spring Run 1	8.1	2.8	17.0	19.4	9.5	37.1	69.7	25.0	165.9	2.06	1.69	2.48	2.07	1.24	2.76	0.007	0.004	0.018
Spring Run 2	8.0	2.6	13.0	18.0	12.4	26.5	48.9	19.0	138.6	2.01	1.79	2.25	1.94	1.06	2.32	0.007	0.000	0.022
Spring Run 3	7.0	3.3	13.1	14.6	8.5	22.0	70.9	21.0	159.1	2.01	1.74	2.37	2.08	1.21	2.52	0.009	0.000	0.021
New Channel, upstream	7.9	1.5	25.1	17.4	6.5	45.4	52.3	11.0	168.0	1.94	1.73	2.19	2.15	1.71	2.39	0.017	0.003	0.038
New Channel, downstream	7.9	2.1	14.4	18.5	8.9	23.4	54.2	29.0	106.8	1.85	1.26	2.25	2.03	1.28	2.34	0.016	0.004	0.044
Old Channel, upstream	10.7	3.2	26.7	20.0	9.2	35.1	44.1	11.5	131.8	1.83	1.61	2.15	1.94	1.38	2.32	0.033	0.004	0.164
Old Channel, downstream	7.6	2.4	14.3	37.4	14.3	188.9	44.4	9.0	134.1	1.96	1.64	2.22	1.97	0.63	2.42	0.053	0.002	0.366
The Other Place (Iverness)	8.0	1.4	16.5	16.9	2.7	29.6	71.1	20.6	202.0	2.37	1.62	5.83	2.14	1.00	2.56	0.016	0.005	0.029

[a] milligrams of phosphorus per liter; [b] micrograms per liter; [c] milligrams per liter; [d] grams per liter.

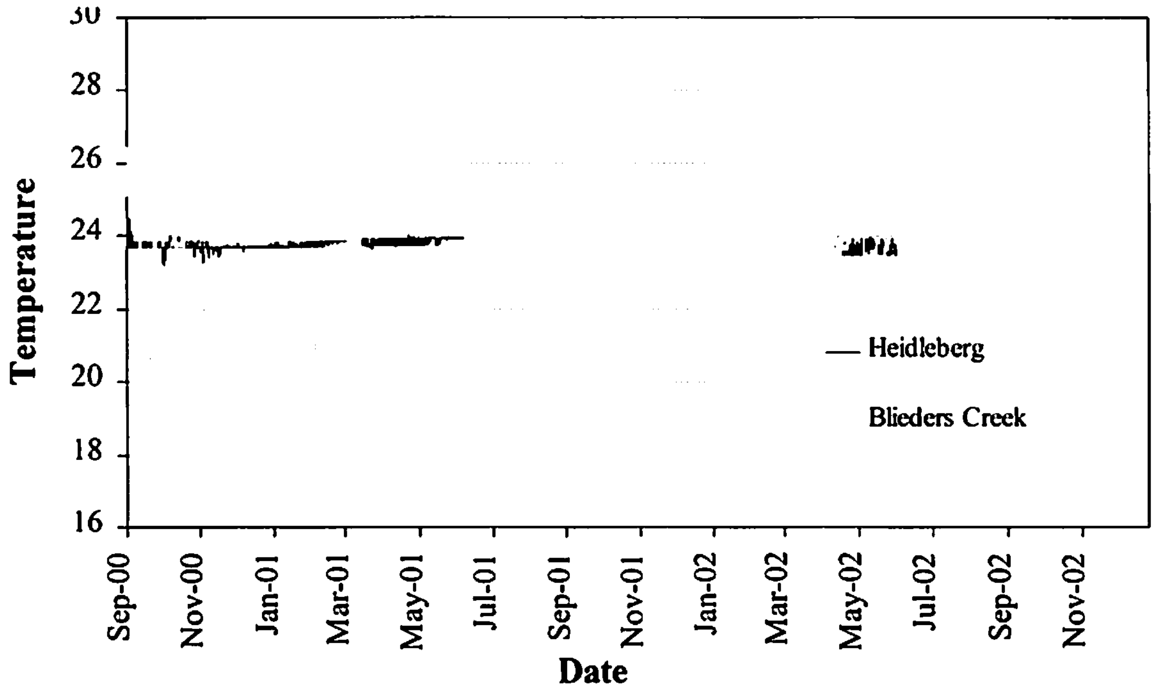

Figure 4. Thermistor data from the Blieder's Creek / Heidleberg Lodge areas.

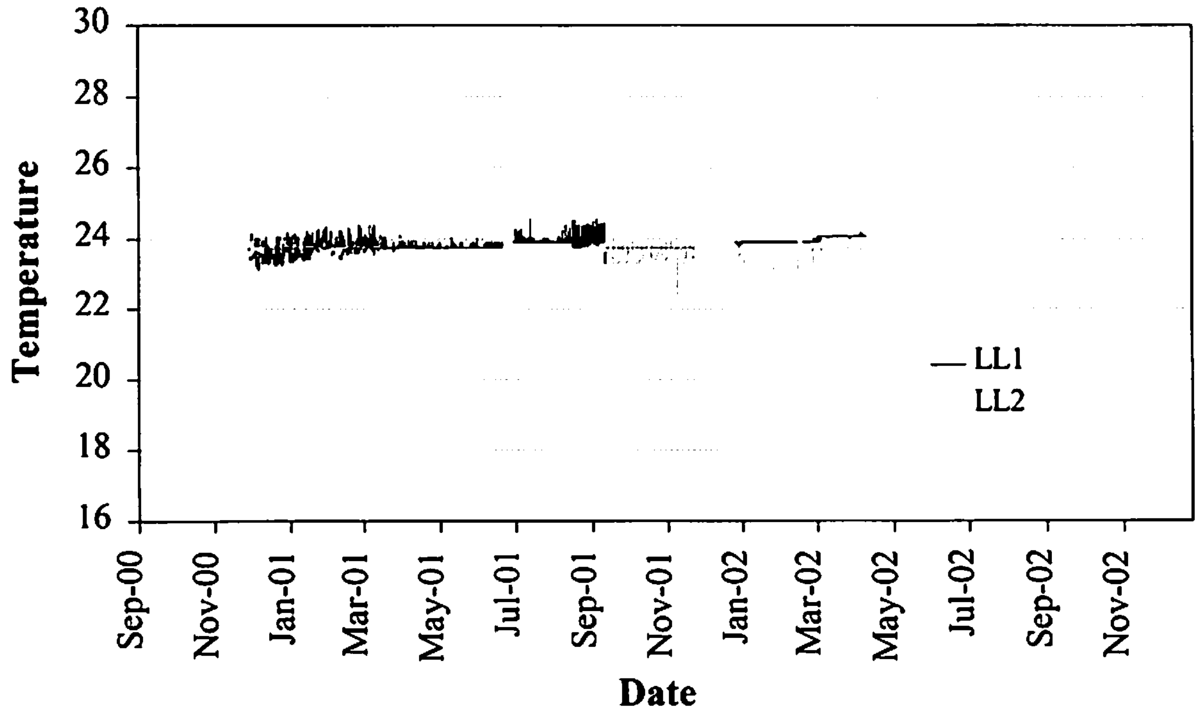

Figure 5. Data from the two Landa Lake thermistors; both were located in the deepest portion of Landa Lake at a depth of approximately 2.4 meters.

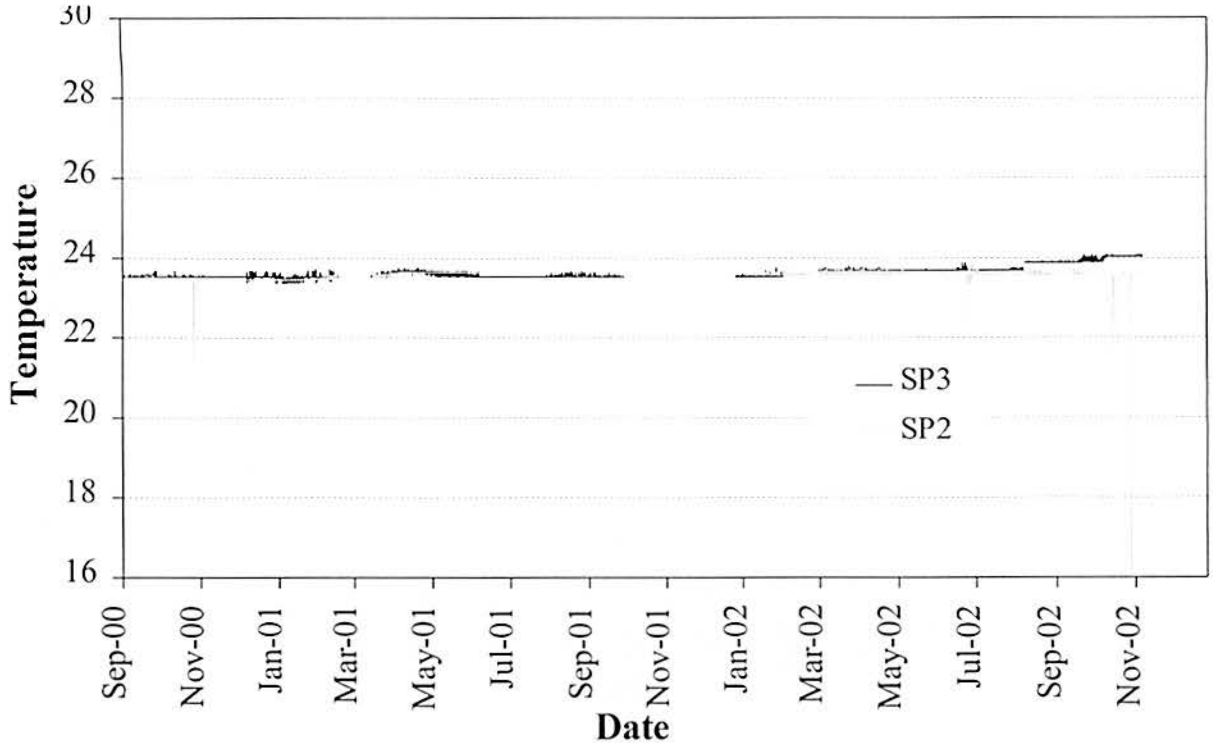

Figure 6. Thermistor data from Spring Runs 2 and 3.

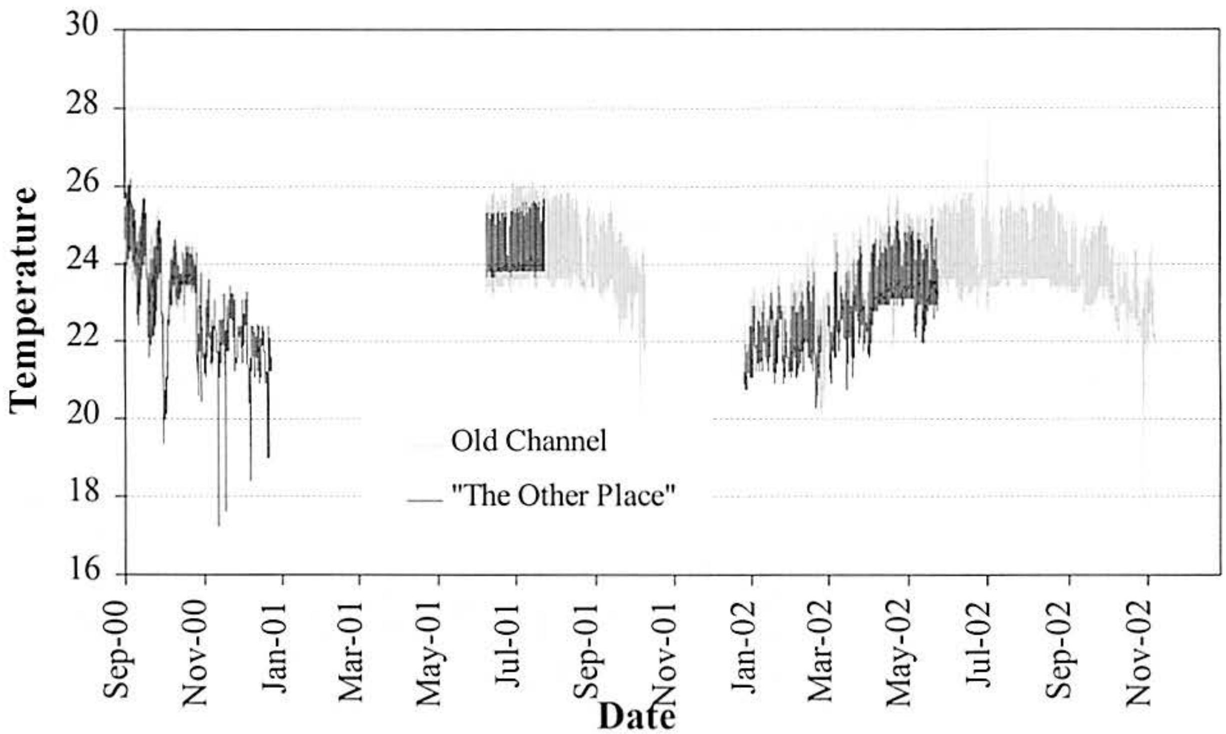

Figure 7. Thermistor data from the Old Channel and "The Other Place" sites.

The lowest water temperatures occurred in the winter on Blieder's Creek and at the furthest downstream sites; winter minimum temperatures occasionally dropped as low as 16.5° C downstream of Landa Lake but usually remained above 22° C (Figure 7). These sites have the least influence from the constant temperatures of the spring's water. Springflow keeps temperatures fairly constant in the upper reaches of the river system, compared with conditions that would occur in a stream without significant springflow. Significant water temperature decreases coincided with lower air temperatures; to compare water temperatures with air temperatures and precipitation, see Appendix B.

The continuously sampled temperature data provide a more valuable data set than the temperature data collected quarterly with the water quality data. Quarterly data do capture the full range of water temperatures, daily fluctuation, or extreme values that are present in the continuous thermistor data. Temperatures recorded for the quarterly sampling events do not exceed the water quality standards value (Appendix B).

Dissolved oxygen concentrations met the water quality standard of 5.0 milligrams per liter (mg/l) for dissolved oxygen in all Comal River samples except on two occasions at the Heidleberg site (in August 2000 and May 2001) and during three summer sampling events in Blieder's Creek. Blieder's Creek is apparently minimally influenced by spring flows and will have highly variable flows throughout the year (Appendix B). The Heidleberg site is located upstream of Landa Lake and downstream of Blieder's Creek. Runoff and flow from the creek may affect water quality conditions at the Heidleberg site to a greater extent than at the other Comal River sites. Overall, dissolved oxygen concentrations recorded at the sites located in the upper portion of the Comal River (Blieder's Creek, Heidleberg, and Spring Island sites) were lower than concentrations recorded in the spring run sites and downstream (Appendix B).

Generally, an upstream to downstream pattern in water quality values, other than temperature, has not been observed during the study. Values remain fairly constant throughout the system or fluctuate minimally from site to site. There does not appear to be much influence on water quality from surface water inflow to the river from either runoff or outfalls (according to the 1996 State of Texas 305(b) Water Quality Inventory, three domestic outfalls are permitted to release a total of 1.05 MGD, and one industrial outfall is permitted to release a total of 0.06 MGD on the Comal River.). The spring water quality conditions generally prevail within the study reaches to maintain high water quality in the Comal River ecosystem.

Conductivity does not vary among sites within the river system. 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 Comal River sampling site during the August 2001 sampling event exceeded the water quality standard values of 400 mg/l. The high TDS values recorded in August 2001 may be related to relatively low-flow conditions in the river. The TDS value will need to be monitored closely during future low-flow sampling efforts. If future monitoring reveals additional exceedences, the Texas Commission on Environmental Quality (TCEQ; formerly the Texas Natural Resource Conservation Commission [TNRCC]) will need to investigate the appropriateness of the water quality standard for this river segment. No previous mention of exceedences has been indicated by the TCEQ, which suggests that this water quality parameter is not a concern.

Turbidity values were low at all sites during the quarterly sampling events (Appendix B). The highest value of 3.2 nephelometric turbidity units (NTU) was recorded in November 2001 at the downstream-most site on the Comal River, the Other Place site. The maximum values for the spring runs was 1.2 NTU and the maximum values at the remaining sites ranged from 1.5 to 2.8 NTU.

The TSS values were low at all sites in the river. The highest recorded values were found in the Old Channel (see Table 4). The TSS and turbidity values probably increase during rainfall events; however, values remain low and should not have any negative consequence to biological communities.

The SRP concentrations and TP concentrations on the Comal River were well below the TCEQ's screening values of 0.1 mg/l and 0.2 mg/l respectively (Appendix B). The three highest values (ranging between 27 and 30 ug/l) occurred at the Old Channel Upstream site, New Channel Downstream site, and on Blieder's Creek. Point source discharges include the wastewater treatment plant located on the Dry Comal River which enters near the New Channel Upstream site and the Schlitterbahn Water Park which enters the Old Channel. Non-point source discharges include runoff from urban areas (City of New Braunfels), some agricultural areas and a municipal golf course. Although values are higher at these sites, it should be stressed that these SRP values are well below the TCEQ's screening levels for surface waters.

Nitrate values exceeded the water quality standards screening level of 1.0 mg/l in most cases, whereas, ammonium values were well below the screening level of 1.0 mg/l (Appendix B). The TN values for the Comal River are influenced by the high nitrate concentrations. These high values are not the result of anthropogenic inputs to the immediate surface waters. The spring flow is the most likely source of high nitrate values found at all sites in the Comal River system. The median concentration of nitrate in the Edward's Aquifer ranges from 1.4 to 1.7 mg/l (Bush et al. 1998). Nitrate values in the Comal River were fairly constant throughout the river and throughout the year (ranging from 1.3 to 2.5 mg/l), except at two sites during the August 2000 sampling event, (the Other Place and Island Park) where nitrate values reported were near 6.0 mg/l (Appendix B). In contrast, ammonium concentrations varied throughout the sampling period and among sites (Appendix B), and they were well below the screening level.

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 (quarterly and high flow) ordered chronologically. It is difficult to make sweeping generalizations about seasonal and other trip-to-trip characteristics, since most changes occurred in fine detail; however, some of the more interesting observations are described below.

Upper Spring Run Reach

The upper Spring Run Reach appears to have relatively stable habitat based on these mapping data, but this reach experienced a general trend of increasing vegetative coverage through 2002. *Cabomba* increased steadily in total coverage in this reach and had the highest total coverage in summer 2002 relative to any other sample during the study, despite the recent flooding. As in 2001, there was moderate growth of *Hygrophila* during the winter and significant growth into the spring; however, unlike in 2001, much of this was recovery from flooding. This rapid growth probably occurred up to the high-flow period in late June; the decrease in *Hygrophila* coverage between spring and summer (post-high flow) was only 12% compared with nearly 25% after the fall 2001 flood. If the same proportion of

Hygrophila were scoured during the two floods, then the pre-flood total coverage in 2002 would have been over 1,000 m^2, (rapid growth between winter and spring - 27% increase - suggests this was possible). Alternatively, the plants found in the Comal River ecosystem may be more resistant to flooding during the summer than in spring, or this flood may have been less intense on the upper portion of the Comal River than gage readings in the lower segment suggest. The high discharge values may have been more a consequence of water backup from the intense flooding on the Guadalupe River. *Sagittaria* and *Ludwigia* decreased in coverage following the flooding after a steady increase that had occurred during the two previous sampling events.

In the 2001 report, *Riccia* is the only bryophyte (moss) mentioned; however, we have since determined that there is an additional type, *Amblistegium*, which is abundant in the upper spring run reach (relative to *Riccia*) and present (but less common than *Riccia*) in Landa Lake. For consistency, the 2002 map legends continue to indicate the bryophytes as *Riccia*, but future mapping will be adjusted to include the new category "bryophytes." The bryophytes, which had decreased only slightly in the upper spring run following the fall 2001 flood, doubled in total coverage during the winter and increased by almost 20% in the spring. As in previous high-flow events, there was a substantial reduction in bryophytes in this reach following the summer 2002 flood. The susceptibility of the bryophytes in this reach is important because of their high suitability as fountain darter habitat (second only to filamentous algae in importance). Mapping the bryophytes presents unique difficulties because the outline of a patch is not as distinct as a patch of filamentous algae and there is more subjectivity relative to other plant types. In places the plants grow in dense clumps, but in other areas individual plants are greatly dispersed. To help account for these difficulties, a new category was assigned for areas that had <50% bryophyte coverage. Between the spring and summer sampling events in 2002 the total bryophyte coverage decreased but the area with <50% coverage was an order of magnitude higher. This suggests that the rapid growth of bryophytes that occurred in the spring probably continued into early summer before flushing flows reduced coverage and left large areas with sparse distributions. Green algae was also common in this stretch during certain periods because of an open canopy and typically slow-moving (lentic) waters; however, the extreme patchiness of that vegetation makes it impossible to map accurately. In general, the green algae was limited in 2002 because of higher flows, but the growth that occurred in late spring and early summer was completely washed away during the high-flow event.

Landa Lake Reach

Landa Lake is a complex reach encompassing many different habitat types. There are several vegetation types within the reach, but it is clearly dominated by a pure stand of *Vallisneria*. This stand did not change much in total coverage, although some scouring and re-growth was evident in certain areas and some areas were filled in with *Riccia* (particularly during the fall 2002 sampling event). The large patch of pure *Hygrophila* in the shallow area between the three islands exhibited the most response of any vegetation type to the flushing flows that have been so common during the study. Large areas were scoured after flooding but quickly regrew. The *Ludwigia* that is immediately downstream of the *Hygrophila* also exhibits some response to flooding, but overall the proportion of vegetation lost was less than *Hygrophila*; the *Ludwigia* also regrows quickly. The bryophytes are the most important of the vegetation types sampled in Landa Lake (some filamentous algae is present in water too deep to sample), but we have seen relatively little change resulting from flooding. If anything, flooding has stimulated growth of *Riccia* and *Amblistegium* in Landa Lake. After the second high-flow event in 2001 (fall) the bryophyte coverage increased dramatically. Also, the coverage was almost exclusively *Riccia* up until the winter of 2002, but *Amblistegium* became much more common in the upper one-third of the reach in all subsequent samples. By spring 2002, the total bryophyte coverage had doubled from 1,956

m^2 to 3,985 m^2. With such a marked increase in total coverage, it is unsurprising that there was a reduction following the summer 2002 flood (but it was not substantial). Previously the high-flow events resulted in virtually no change in total coverage of bryophytes (primarily *Riccia*), although much had been moved and the density changed in various locations.

Sagittaria, *Nuphar*, and *Vallisneria* were all minimally impacted by high flows. These species often occupy deeper habitats where the water velocity is likely dispersed, but even in shallow areas these species seem resistant to the scouring effects of flooding events. Even *Cabomba*, despite its tendency to grow in silty areas that are readily scoured, was minimally impacted during all high-flow events. Overall, the Landa Lake reach is well buffered from significant flooding impacts. Although the old channel and upper spring run are highly susceptible to flooding impacts, a substantial proportion of the fountain darter habitat and thus the fountain darter population (in the Comal system) is contained within the Landa Lake reach and resistant to flood effects.

Old Channel Reach

Of the four reaches, the Old Channel Reach is the most stable habitat with a structure (culvert) that regulates flow through this section at approximately 40 cfs (P. Connor, USFWS, pers. comm.). This is apparent with the relatively stable distribution and abundance of the two species of macrophytes that are found there. *Nuphar* remained very similar in its distribution throughout all samples and *Ceratopteris* exhibited some variation in distribution between seasons, but the only clear impact was following high-flow events. *Ceratopteris* became much more patchy after each of the two flood events that produced flushing flows (fall 2001 and summer 2002). Filamentous algae was even more directly affected by flushing flows and was nearly scoured completely from the substrate during each of the two events with flushing flows. This is significant because of the importance of this vegetation to fountain darters. The filamentous algae recovered quickly after the fall 2001 flooding, but several rain events subsequent to the summer 2002 event left the substrate mostly free of algae through the fall 2002 sample effort.

New Channel Reach

The New Channel Reach is divided into two sections, both dominated by *Hygrophila*. In the lower reach, *Hygrophila* increased by about 10% during the springtime but was reduced following flooding to almost exactly the same coverage as during the winter 2002 sample. *Cabomba* decreased during the spring but then increased during the summer despite flooding. The *Cabomba* in this reach appears to be well positioned to avoid scouring by flooding, as almost all patches remained after flooding in 2002 and most had increased in size. In 2001, *Cabomba* also was relatively unaffected by the higher flows. The decrease in *Cabomba* coverage between the winter and spring 2002 may have been a result of increased *Hygrophila* coverage and density; *Hygrophila* may have covered portions of *Cabomba* and made patches appear smaller than they actually were.

In the upper section of the New Channel Reach *Cabomba* is much more heavily influenced overall and *Hygrophila* is proportionally more influenced by flooding. There is also *Ludwigia* in this reach, which similarly decreased as a result of the 2002 flood. Following that event the *Cabomba* disappeared completely and the other two species were reduced to half of their previous coverage. Because of continuously high flows in the fall, no sampling effort was conducted that quarter. Despite some differences between this and the lower section, the inclusion of this section does not substantially increase the habitat coverage in the New Channel Reach. Also, drop-net sampling is difficult in this section because of the water's depth. Therefore, this section will be not be mapped or drop-net sampled in the future.

Fountain Darter Sampling

Drop Nets

The number of drop net sites and vegetation types sampled per reach is presented in Table 5.

Table 5. Drop net sites and vegetation types sampled per reach.

UPPER SPRING RUN REACH	LANDA LAKE REACH	NEW CHANNEL REACH	OLD CHANNEL REACH
Open / Bryophytes[a] (2)	Open / Bryophytes[a] (2)	*Hygrophila* (3)[b]	Open (2)
Sagittaria (2)	*Hygrophila* (2)		Filamentous Algae (2)
Hygrophila (2)	*Cabomba* (2)		*Ceratopteris* (2)
	Vallisneria (2)		
	Ludwigia (2)		
Total (6)	Total (10)	Total (3)	Total (6)

[a] Switched to *Riccia*, summer 2001.
[b] Upper section removed starting fall 2002; only two sites in lower section will be conducted in future sampling.

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

As in previous sampling, we found a wide range of suitability of the various vegetation types in both the Comal and San Marcos Rivers (Figure 8). Compared to the San Marcos, the Comal River has a greater diversity of habitats available to fountain darters, and we have observed a wider range of suitability. In the San Marcos River, most vegetation types are similar in suitability based on the densities of fountain darters observed in them. The densities of fountain darters in the Comal River vegetation types ranged from virtually zero in *Sagittaria* to nearly 30 per m^2 in filamentous algae (the type found in the Old Channel Reach [Comal] and Spring Lake Reach [San Marcos], which differs from the finer algae found in the Landa Lake and Upper Spring Run Reaches). The bryophytes (*Riccia* and *Amblistegium*) also contained high numbers of fountain darters (~20 per m^2) but fewer than in 2001. The reduction in fountain darter density in bryophytes compared with 2001 is probably a result of the rapid and dramatic increase in total coverage of this vegetation type; the fountain darters probably did not have time to exploit the increased resources and dispersed throughout the new vegetation in lower densities. These two vegetation types provide cover at the substrate level and high numbers of amphipods, which provide the fountain darters with an ample food supply. In addition to filamentous algae and bryophytes, *Ludwigia* provides high-quality habitat (>10 per m^2). *Hygrophila* is an exotic species found in both the San Marcos and Comal Rivers, but this species provides substantially lower-quality habitat than the native *Ludwigia*, which is very similar in structure. The suitability of the different vegetation types varies somewhat by season (e.g., most vegetation types tend to have the highest densities in the spring and much lower values in the winter). Higher-than-normal flows and scouring flood events during the 2 years of data collection have had an influence on fountain darter densities in various vegetation types.

Flooding has occurred several times in the system during the study and there have been some interesting observations of its effects on fountain darters. Acute impacts to habitat availability (vegetation) have been obvious; there has generally been significant scouring and thinning of different vegetation types.

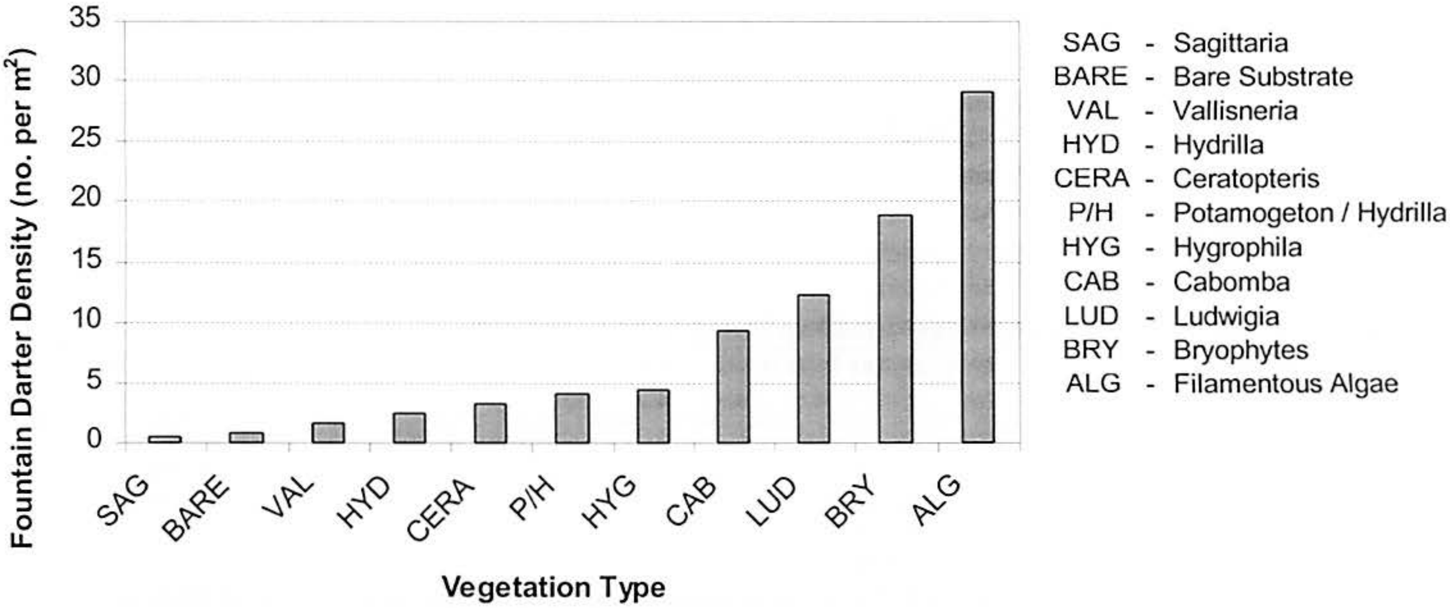

Figure 8. Density of fountain darters collected by vegetation type.

An interesting trend is that the highest-quality vegetation types (i.e., filamentous algae, bryophytes, *Cabomba* [in the San Marcos system]) are also the most susceptible to scouring during flooding. This is primarily because these vegetation types attach loosely to the substrate, do not attach at all, or are found in very silty substrates that are easily scoured. The density of fountain darters in the remaining vegetation has also been generally lower immediately after flooding, which is probably due to the sparseness of the remaining vegetation. In some instances, there appears to have been a "concentration effect" where fountain darters congregate in remaining habitat (e.g., algae in the Old Channel Reach), but the variation observed in densities during each sampling event limits conclusions about direct consequences to the fountain darter abundance after a flood. We can conclude that the habitat is negatively affected and assume that fountain darters are forced to move to remaining (less suitable) habitat; it is also possible that a short-term reduction in the fountain darter population abundance occurs. Flooding may also create pockets of temporary habitat by inundating shallow shoreline habitat and, in lesser quality reaches (i.e., in the San Marcos reaches), may stimulate reproduction.

In the long-term, however, flooding appears to have substantial positive effects for fountain darters, which would mediate for any short-term population reductions. Scoured vegetation has filled in quickly following flooding and in many instances has expanded beyond the previous boundaries of individual stands. The bryophytes appear to have benefited greatly from the higher flows during the past 2 years and *Ludwigia* also appears to have expanded in some areas in fall 2002 after extended periods of higher flows. The total coverage of bryophytes (primarily *Riccia*) in Landa Lake doubled between fall 2001 (when it flooded) and spring 2002, resulting in dramatic changes in fountain darter population estimates in this high-quality habitat. Figure 9 shows these changes of Landa Lake fountain darter population estimates, which were calculated by multiplying total coverage of each vegetation type by the average density of two drop net samples and standardized by making each sample a proportion of the greatest number observed. This figure reveals that the estimated population decreased slightly after the first two high-flow events (both in 2001), but that a substantial increase occurred in spring 2002 and peaked in the summer (despite recent flooding and slight reduction of bryophytes).

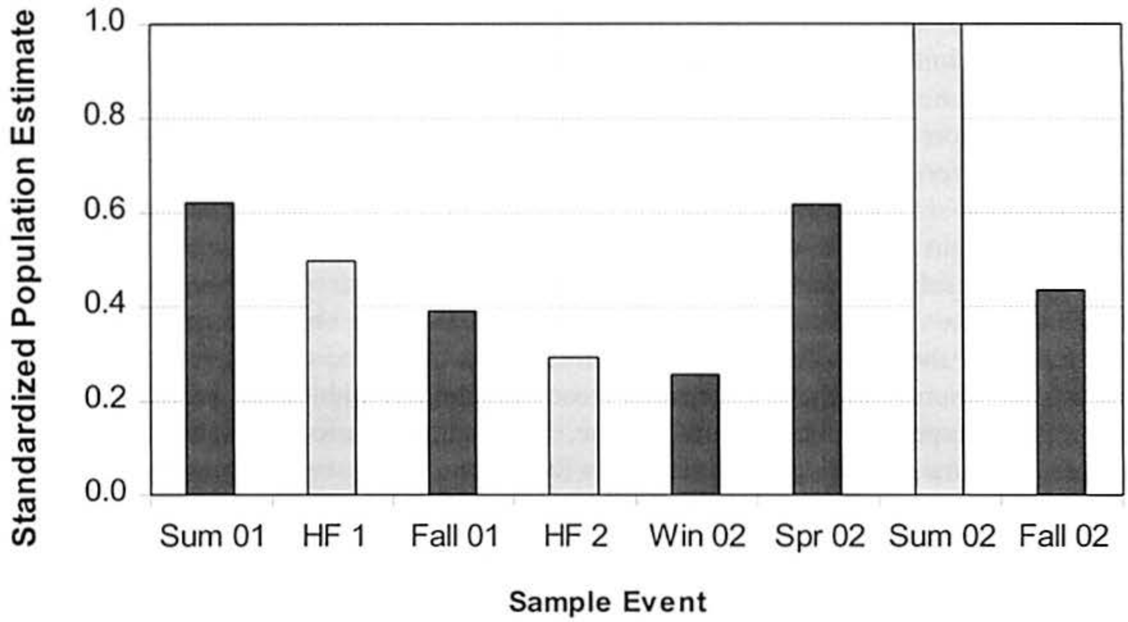

Figure 9. Population estimates of fountain darters in the Landa Lake Reach; values are standardized to a proportion of the maximum observed in any single sample. Light bars represent high-flow (flood) events, which were triggered by flows that exceeded a 0.5% likelihood of occurrence based on the period of record.

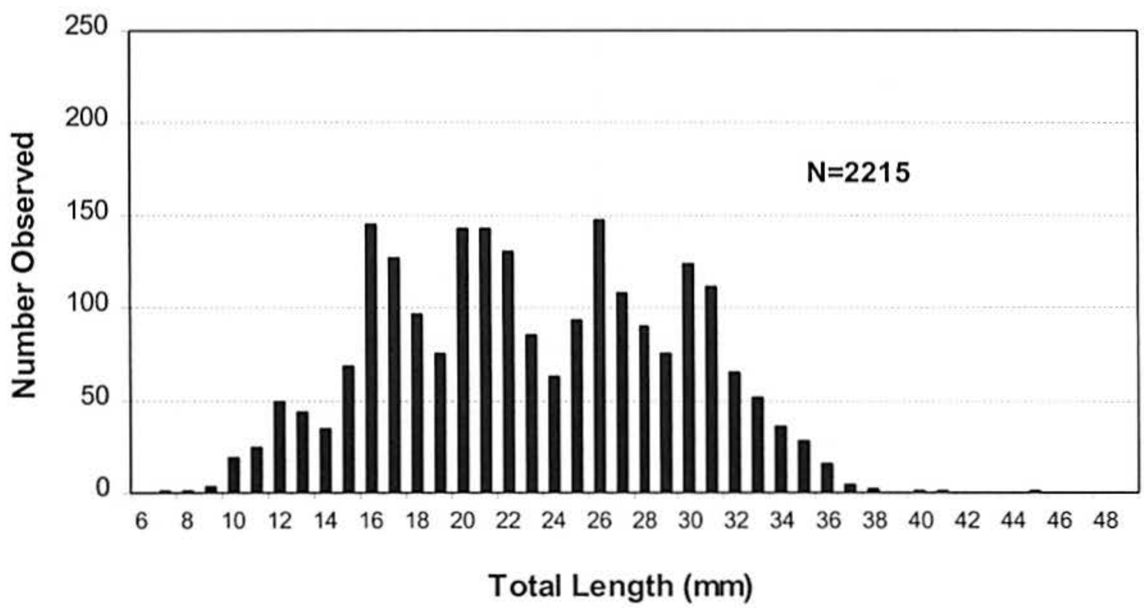

Figure 10. Fountain darter size-class distribution among all 2002 drop-net sampling events in the Comal River.

The size-class distribution for fountain darters collected by drop nets from the Comal ecosystem in 2002 is presented in Figure 10 (all data collected from 2000-2002 is presented in Appendix B). The overall distribution is similar to that observed in 2001 and is typical of a healthy fish assemblage. As in 2001, the size-class distribution in the Old Channel Reach has remained stable throughout the study period, whereas the other reaches have experienced reproductive peaks with corresponding shifts in the size-class distribution. Figure 11 reveals that in 2002, size-class distributions in the Old Channel and Upper Spring Run Reaches were very similar in the winter and spring with a moderate proportion of the total observed in the lowest size class (indicating recent reproduction). In the Old Channel Reach in summer and fall, young fountain darters were observed and zero individuals >35 mm were captured. In the Upper Spring Run Reach, the cohort from the early part of the year resulted in a histogram skewed toward larger individuals in the summer; no young individuals were observed in the summer and very few were observed in the fall. A number of factors could influence the consistent reproduction and stable size-class distribution in the Old Channel Reach including an abundant food supply, presence of preferred vegetation type, consistent flow regime, high parasite infection rates, etc. The periodic reproduction that occurs in the Upper Spring Run Reach and other reaches may be a consequence of lower-quality habitats providing conditions suitable to reproduction only under certain conditions (i.e., during the spring or following flooding).

Observations of seasonal variation in fountain darter collections in 2000-2001 remained consistent through 2002, but the lowest numbers occurred during winter 2002 rather than in the fall. The impacts of flooding and annual variation in other environmental factors may shift the peaks and low points across seasons slightly, but our data suggest seasonal variation in the population. In 2000-2001, we observed differences in seasonal variation patterns between the San Marcos and Comal systems, but in 2002 the variation in number observed between seasons was similar; both systems had high numbers in the spring and substantially lower number in the winter.

In 2002, as in previous sampling, the most fountain darters were collected in spring. This coincides with the reproductive peak for most reaches, but the peak appeared to have occurred in Landa Lake during the summer of 2002. Although the Old Channel Reach always had fountain darters within the smallest size class (thus continuous reproduction) there was a peak of reproduction in the Old Channel Reach in spring 2002. Competing theories have been reported in the literature regarding wild fountain darter reproductive cycles; some researchers support continuous spawning (Strawn 1955, Hubbs 1985), while others have noted peaks in reproductive activity (Schenck and Whiteside 1977). Our data support both theories and suggest that the mode of reproduction may depend upon local conditions.

Observations of potential low-flow impacts are still limited because of inadequate opportunities to conduct low-flow samples. However, the seasonal variation and year-to-year variation in fountain darter populations re-emphasizes the importance of detailed examination of a system to determine the dynamics that dictate both the total population numbers and densities of fountain darters under various conditions rather than a one-time sampling event when low-flows occur.

In addition to fountain darters, a total of 21 fish species and 21,368 individuals were collected from the Comal ecosystem in 2002; of these, 7 species are considered exotic (introduced) (Table 6).

The giant ramshorn snail was also recorded and measured at each drop net location. Figure 12 shows the densities of live giant ramshorn snails by vegetation type in the Comal ecosystem. The greatest

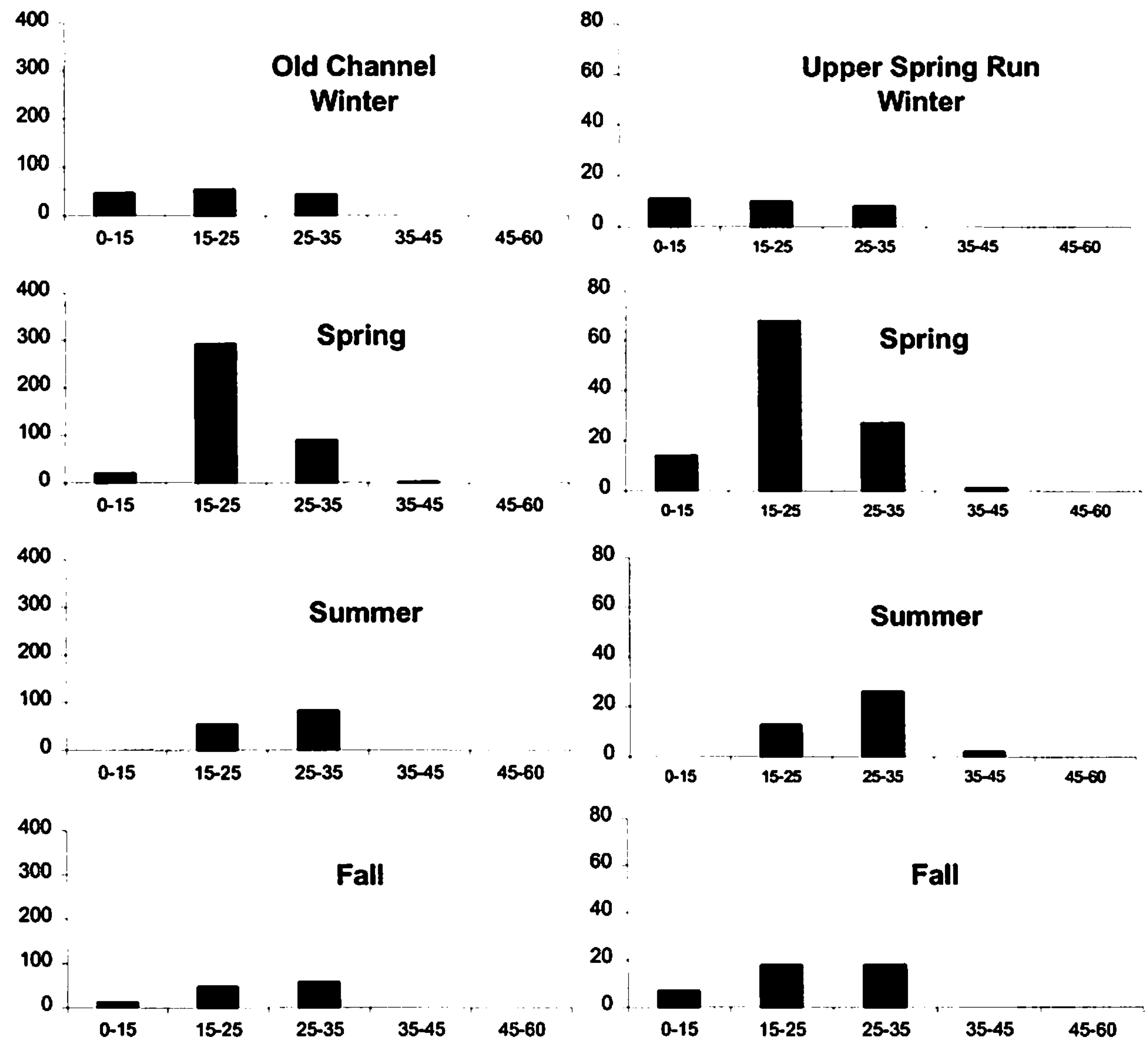

Figure 11. Fountain darter size-class distributions by reach and season (2002 only) in the Old Channel and Upper Spring Run Reaches.

density was 1.13 snails per m^2 in *Vallisneria*, which is similar to 2001 findings. The greatest density in 2000-2001 was *Ludwigia* (2.38 per m^2), but numbers were lower in that vegetation type in 2002 (0.95 per m^2). *Hygrophila* was slightly higher in 2001 (1.06 per m^2) compared with 2000-2001 (0.89 m^2). The two preferred fountain darter vegetation types (bryophytes and filamentous algae) had essentially no giant ramshorn snails present. In the past, the giant ramshorn snails were observed in far greater densities than those reported here. For perspective, the maximum value on the y-axis of Figure 11 is 10 m^2, which was among the lowest concentrations reported in the early 1990s when the giant ramshorn snail population was booming (T. Arsuffi, SWT aquatic ecologist, pers. comm.). During that period the greatest giant ramshorn snail density was near 400 snails per m^2, and the vegetative community was literally being devoured (T. Arsuffi, SWT aquatic ecologist, pers. comm.). By all indications the densities of giant ramshorn snails observed in the Comal ecosystem during the study period to date (including the 2000 low-flow events) pose no serious threat to the aquatic vegetative community. However, because of the impact that this exotic species can have under heavier densities, close monitoring should continue.

Table 6. Fish species and the number of each collected during 2002 drop-net sampling.

COMMON NAME	SCIENTIFIC NAME	STATUS	TOTAL NUMBER
Rock bass	*Ambloplites rupestris*	Introduced	3
Black bullhead	*Ameiurus melas*	Native	0
Yellow bullhead	*Ameiurus natalis*	Native	10
Mexican tetra	*Astyanax mexicanus*	Introduced	23
Central stoneroller	*Campostoma anomalum*	Native	1
Rio Grande perch	*Cichlasoma cyanoguttatum*	Introduced	53
Roundnose minnow	*Dionda episcopa*	Native	13
Minnow species	*Dionda* sp.	Native	3
Fountain darter	*Etheostoma fonticola*	Native	2215
Greenthroat darter	*Etheostoma lepidum*	Native	4
Gambusia	*Gambusia* sp.	Native/Introduced	9456
Suckermouth catfish	*Hypostomus plecostomus*	Introduced	4
Redbreast sunfish	*Lepomis auritus*	Introduced	40
Green sunfish	*Lepomis cyanellus*	Introduced	6
Warmouth	*Lepomis gulosus*	Native	9
Bluegill	*Lepomis macrochirus*	Native	1
Longear sunfish	*Lepomis megalotis*	Native	4
Spotted sunfish	*Lepomis punctatus*	Native	187
Sunfish	*Lepomis* sp.		108
Largemouth bass	*Micropterus salmoides*	Native	14
Texas shiner	*Notropis amabilis*	Native	1
Sailfin molly	*Poecilia latipinna*	Native	543
Tilapia	*Tilapia* sp.	Introduced	1

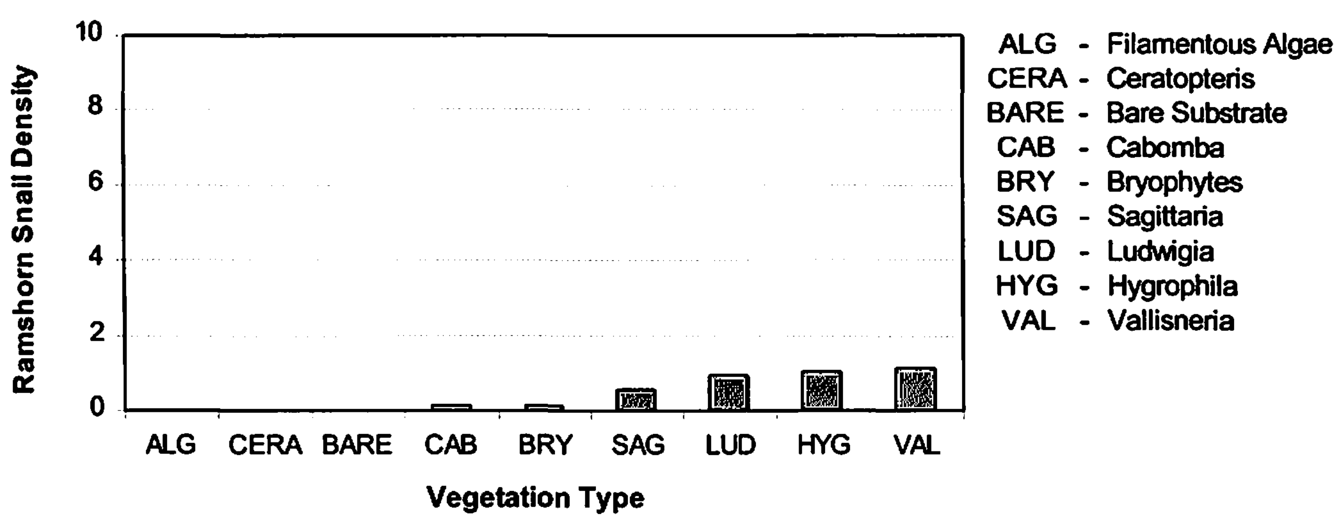

Figure 12. Density of giant ramshorn snails by vegetation type (averaged across all sites).

Dip Nets

The boundaries for each section of the dip net collection efforts are depicted on Figure 13. Data gathered using dip nets for all sections are graphically represented in Appendix B. High water and turbid conditions prevented the collection activities from the New Channel and Garden Street sites on a few occasions.

Compared with 2000-2001, the Old Channel Reach did not have the same level of year-round reproduction in 2002 (Figure 14). Some small fountain darters were captured in every sampling effort, but substantially more of the smallest size class (5-15 mm) were collected in the winter than during any other sampling event. This correlates well with the drop net results, which showed an increase in slightly larger fountain darters (15-25 mm) in the spring. This was the only reach that displayed a substantial spike in the number of small individuals during the spring (there was a less-substantial spike in small fountain darters in Landa Lake in the fall). This contradicts observations in 2001 of a spring peak in reproduction in all reaches except the Old Channel. It is not clear why the typical spring peak was not observed in the other reaches in 2002. The contradiction may be linked to higher flows, which could have stimulated reproduction in some individuals immediately after flooding (in fall 2001) and otherwise disrupted natural stimuli in others that would have triggered a spring reproductive peak. The near-complete scouring and rapid regrowth of filamentous algae in the Old Channel after the same flood event may have been a stimulus to initiate reproduction in most fountain darters in that reach, which could have resulted in a peak in an area where year-round reproduction is more typical in favorable conditions. Had the scouring been more dramatic in other reaches, there may have been a similar post-flood peak in those areas. Dip net samples in the New Channel Reach were similar to previous samples, with larger individuals dominating the size class distribution (26-35 mm); the total numbers were also similar. The Upper Spring Run Reach also had results similar to 2000-2001, with relatively few fountain darters caught during all seasons except spring when total number captured was nearly twice the number captured during other sampling events. The results for the Landa Lake Reach were similar to results from earlier sampling events but high numbers of small fountain darters were found in the fall, which may have resulted from the substantial increase in bryophytes during the spring and summer. As discussed in the drop net section, the rapid growth of this vegetation resulted in a more dispersed population of fountain darters (i.e., densities declined in that vegetation type) and dispersal into a favorable habitat would presumably result in population increase. The relatively high proportion of the smallest size class of fountain darters in the fall suggests that the species had begun to exploit the major increase in new habitat with a reproductive peak.

Visual Observations

Fountain darters were observed in the deepest portions of Landa Lake (depths greater than 2 m) during each sampling event, including all low-flow and high-flow events to date. Fountain darters were observed throughout the reach in bare areas and surrounding vegetation, with the greatest concentrations occurring near areas with *Riccia*. Throughout the study period, the fountain darter population has remained consistently abundant in these deeper areas of Landa Lake. The quantitative sampling (started in summer 2001) results are limited to a single grid per sampling event; therefore, the numbers are only suggestive of what the true population size might be in the area sampled. Table 7 shows the number of fountain darters observed in the 7.8 m^2 grid per sampling event.

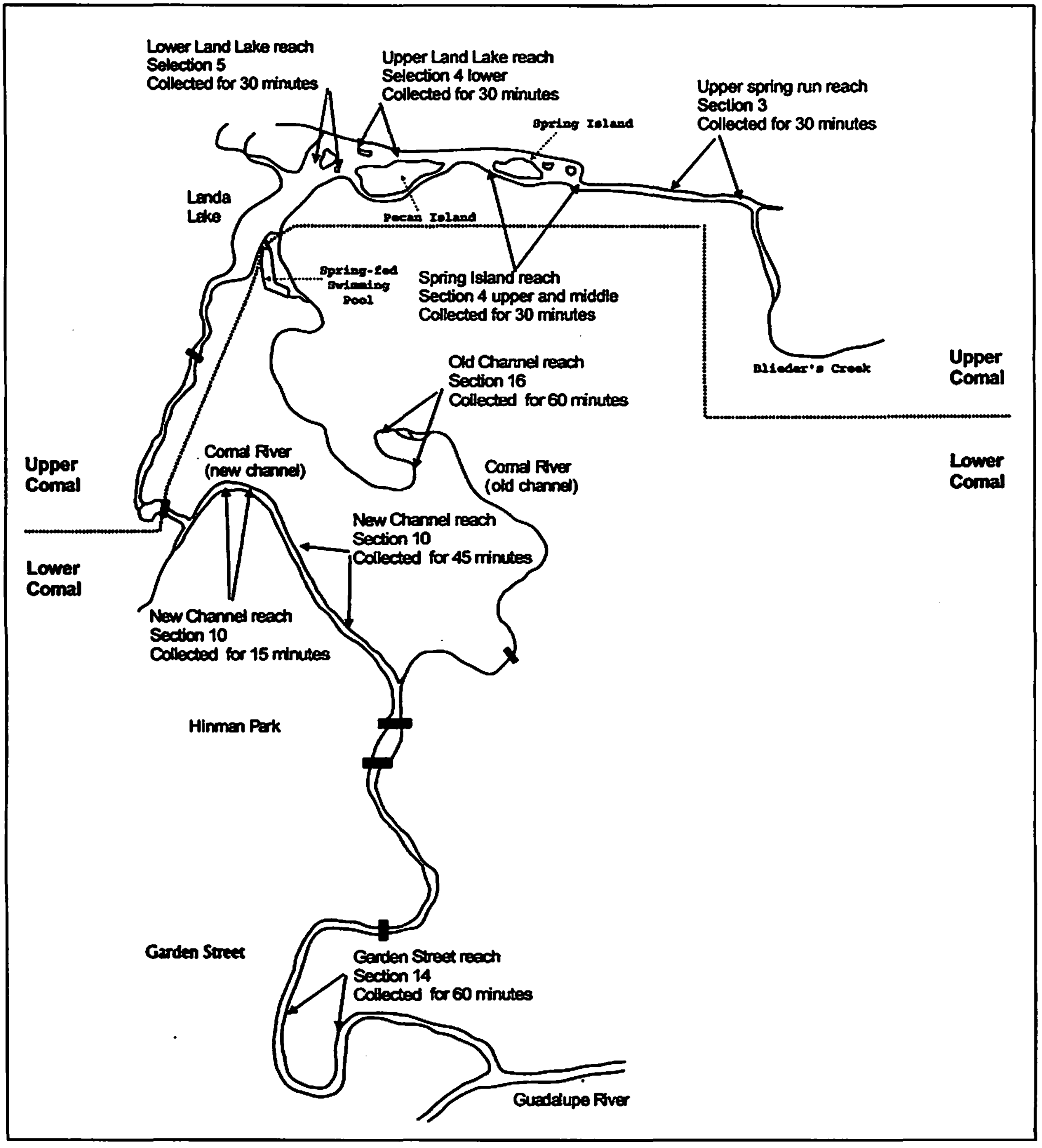

Figure 13. Areas where fountain darters were collected with dip nets, measured, and released in the Comal River.

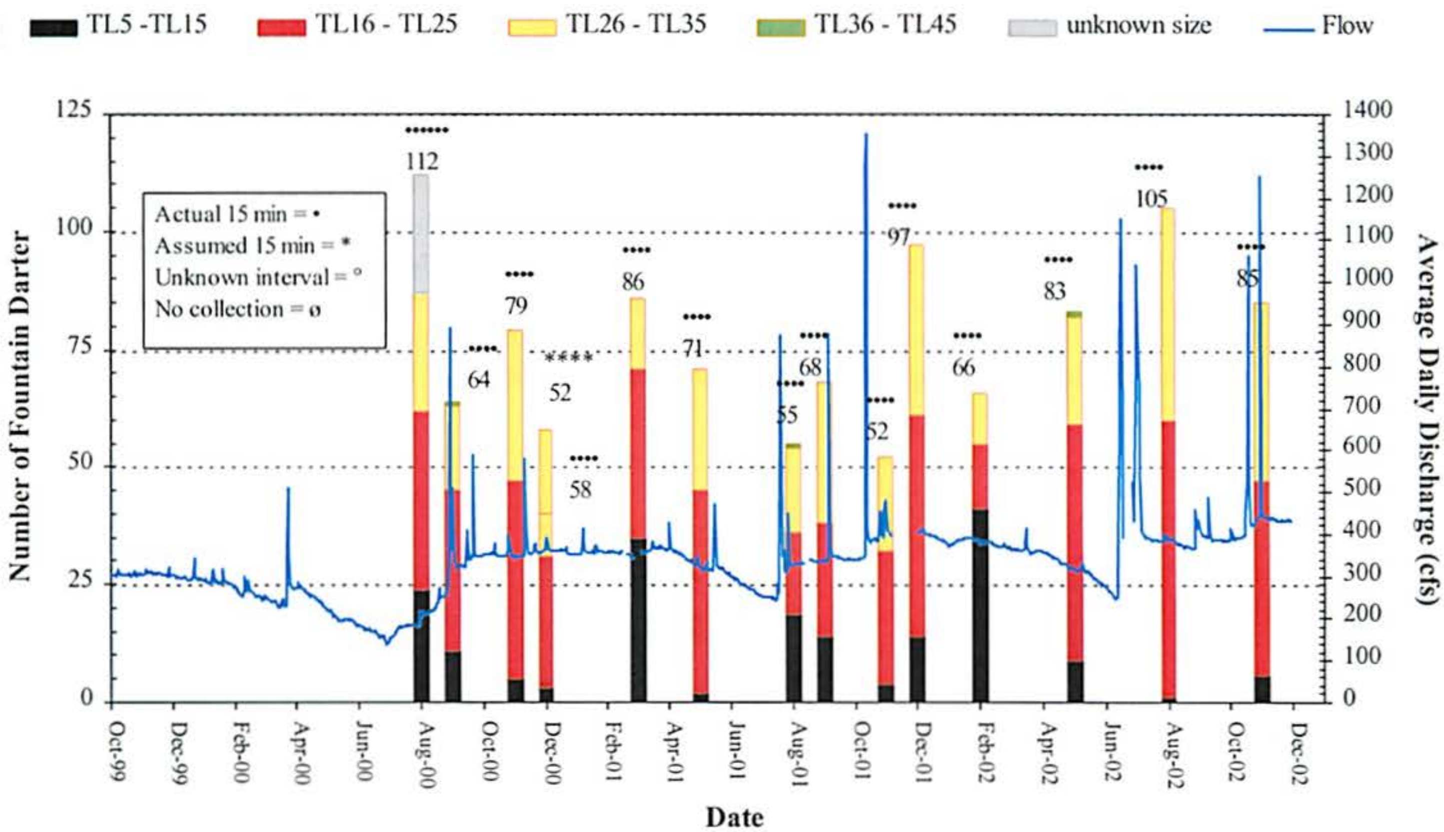

Figure 14. Number of fountain darters, by size class, collected from the Old Channel Reach (section 16) using dip nets.

Table 7. The number of fountain darters observed per grid/sampling event.

SAMPLE DATE	NUMBER OF FOUNTAIN DARTERS	PERCENT RICCIA WITHIN GRID
	2001	
Summer	24	50
High Flow 1	31	50
Fall	44	65
High Flow 2	39	60
	2002	
Winter	50	90
Summer / High Flow	21	40
Fall	88	80

These quantitative results support the consistency in the population and importance of aquatic vegetation. Our observations continue to reinforce the hypotheses that (1) Landa Lake is an integral component to the habitat of species found in the Comal Springs ecosystem, and (2) a sizable portion of the fountain darter population is found there.

Gill Parasite Evaluation

All results from the gill parasite evaluation are preliminary, but some interesting trends have been revealed. Cage trials from summer 2002 produced nearly identical results by location compared with trials in spring 2001 (Figure 15). This suggests that cage experiments will produce highly repeatable results across samples, but also suggests that seasonal variation is limited – at least between the spring and summer seasons. More seasonal sampling – in the fall and winter – would provide valuable information on seasonal variation in *Centrocestus formosanus* (cercariae) throughout the year. Clearly, there is a great deal of variation in the infection rate across sites within the system with mean infection rates of ~193 cercariae per fish in Landa Lake (near "Bird Island") down to ~20 cercariae per fish in the Upper Spring Run Reach and at the confluence of Spring Runs 1 and 2 and less than 10 per fish in all other sites. Interestingly, the site where fountain darters appear to be most infected (the Old Channel Reach) was among the lowest in caged fountain darter infection rates.

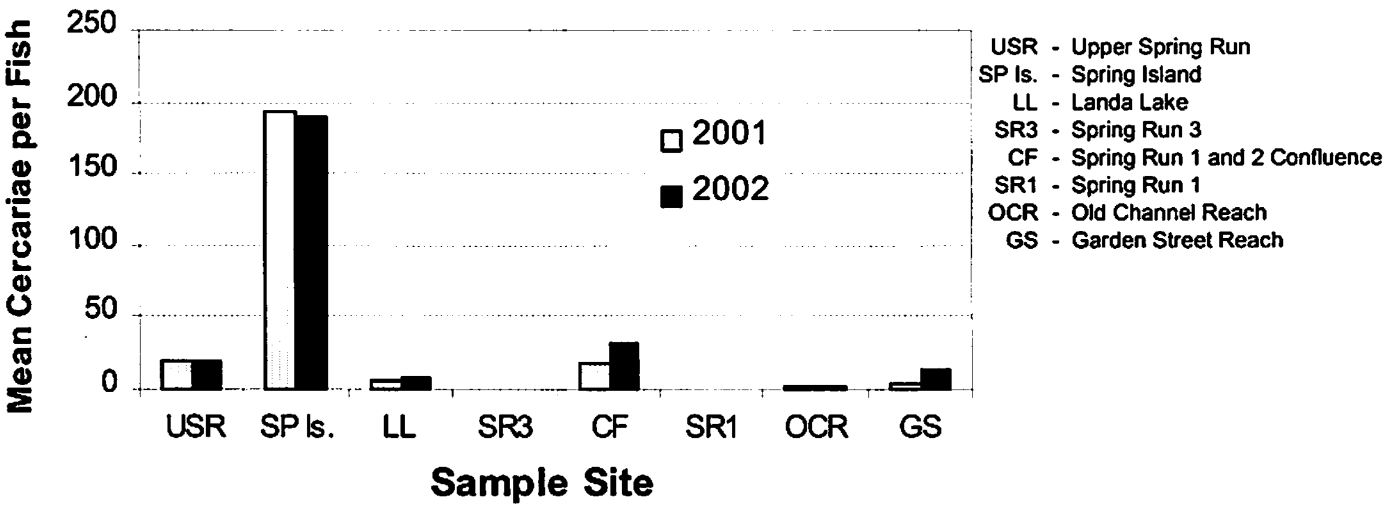

Figure 15. Results of cage trials to evaluate infection rates of parasites in fountain darters at eight sites in the Comal River in 2001 (□) and 2002 (■).

Dip netting was conducted in the same time frame as the cage method, but the dip-net results differ markedly between spring 2001 and summer 2002 samples (Figure 16). The wide variation in parasite intensity measured with dip netting is associated with temporal differences in parasite infection dynamics that the two methods estimate; the cage measures short-term infection potential whereas the dip net measures cumulative and long-term infection potential. Sampling resident fountain darters is easy and can provide a means of rapid assessment, but because it measures cumulative parasite infestation and the history of the individual's movements and habitat use is unknown, a great deal of variation must be expected. Dip netting may provide a means of assessing the current health of the population as a whole, but it will not be valuable in assessing rates of parasite infestation or seasonal or diel variation in the threat of infestation (i.e., presence of drifting *C. formosanus*).

Filtration was the third method evaluated for use as a tool to measure the threat of parasite infestation in fountain darters. In 2001, filtration efforts yielded very low concentrations of *C. formosanus* from the water column in all sample sites (Figure 17). In 2002, an experiment conducted on a known sample size in the laboratory suggested that a substantial improvement in recovery of cercariae could be realized with addition of a 0.1% formalin solution to the sample. The resulting 2002 sample yielded much

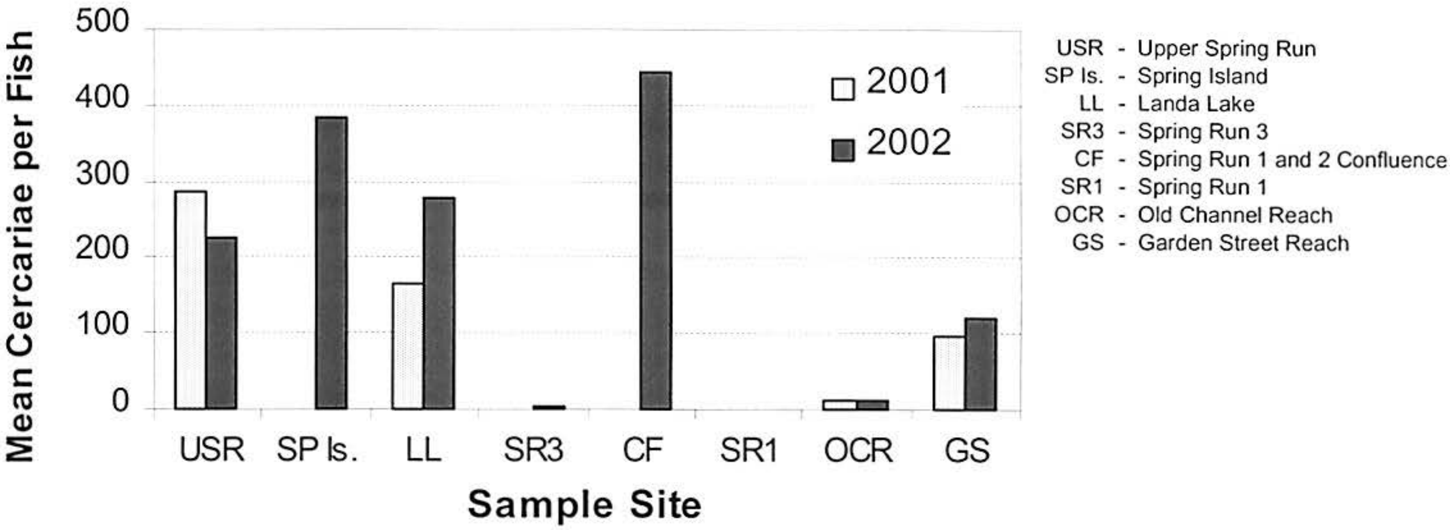

Figure 16. Results of dip net samples used to evaluate parasite infection in resident fountain darters at eight sites in the Comal River in 2001 (□) and 2002 (■).

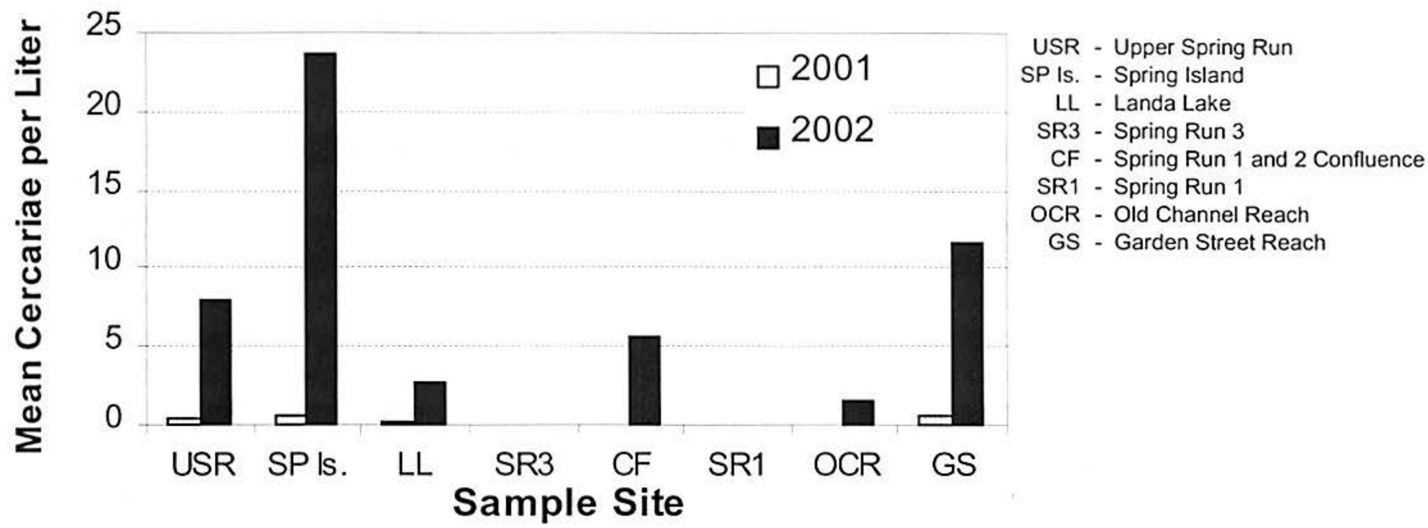

Figure 17. Results of filtration samples to evaluate abundance of drifting cercariae (parasites) at eight sites in the Comal River in 2001 (□) and in 2002 (■).

higher numbers of cercariae from the water column. Also in 2002, a diel effort was conducted at two sites (the confluence of Spring Runs 1 and 2 and in the Old Channel Reach) to evaluate the presence of *C. formosanus* during various times of the day and night. In the site at the spring run confluence, drifting cercariae remained in low concentrations throughout the 24-hour sampling event, but the highest concentrations were observed between 7:30 am and 1:30 pm (Figure 18). In the Old Channel Reach, more variation and much higher concentrations of cercariae were observed. The peak was around the same time as at the confluence site, 9:30 am to 12:30 pm. This diel experiment provides valuable information and suggests that sampling should be conducted in the mid-to-late morning interval when drifting cercariae densities are highest.

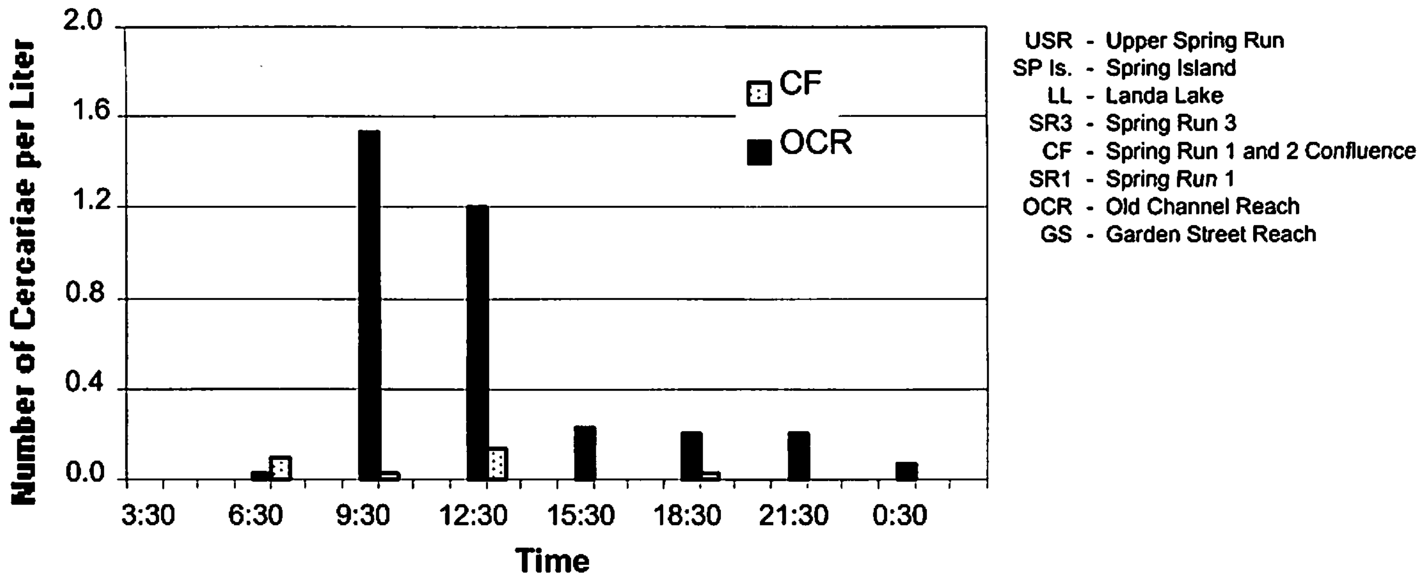

Figure 18. Results of 24-hour diel filtration samples (at 3-hour intervals) at the confluence of Spring Runs 1 and 2 (CF) (□) and in the Old Channel Reach (OCR) (■) in the Comal River in 2002.

Comal Springs Salamander Visual Observations

All Landa Lake SCUBA surveys revealed the presence of Comal Springs salamanders along the lake bottom and in each sampled spring run. Comal Springs salamanders were observed around portions of the springs, under rocks at depths of up to 2.4 m. No Comal Springs salamanders were observed in any areas with excessive sediment. Since the inception of the project, Comal Springs salamanders have been observed in each sample location during each sample period. The total number of Comal Springs salamanders observed at each survey site during each sampling event is presented in Table 8.

The greatest cumulative number of Comal Springs salamanders observed for all sites during any one sampling event was 67, which occurred during summer 2002; the fewest (18) occurred during fall 2000. Spring Run 1 had the greatest number of Comal Springs salamanders among all areas sampled during the study to date (21.3 average per effort). This is not surprising since the amount of area covered and time spent searching was the greatest in Spring Run 1.

The winter 2002 sampling event supports the preliminary theory discussed in the 2001 annual report (BIO-WEST 2001) that under situations of acute disturbance/habitat modification, the Comal Springs salamanders simply retreat into the substrate and return to the surface when conditions are again suitable. The number of Comal Springs salamanders observed in Spring Run 3 following heavy rainfall events in 2000-2001 (fall 2000, high-flow 1 and high-flow 2) declined substantially. This was attributed to a sizable amount of sediment that was transported into the preferred habitat along the shoreline from the adjacent embankment. Because the number of Comal Springs salamander observations increased after these events, it suggests that the Comal Springs salamanders move to avoid unfavorable conditions but return when conditions improve. Because the surface layer of substrate in the entire spring run is sampled (not just the preferred habitat), we would argue that the Comal Springs salamanders move

Table 8. Total number of Comal Springs salamanders observed at each survey site during each sample period.

SAMPLE PERIOD	SPRING RUN 1	SPRING RUN 3	SPRING ISLAND SPRING RUN	SPRING ISLAND EAST OUTFALL
August 2000	9	13	11	1
September 2000	5	14	6	5
Fall 2000	8	4	4	2
Winter 2001	16	9	8	1
Spring 2001	25	7	17	6
Summer 2001	23	15	4	4
High-flow 1 2001	31	12	1	6
Fall 2001	11	8	13	7
High-flow 2 2001	18	2	6	5
Winter 2002	34	9	7	3
Spring 2002	36	15	6	5
High Flow 2002	41	7	3	16
Fall 2002	20	10	8	9
Average	21.3	9.6	7.2	5.4

vertically rather than horizontally to avoid the siltation of preferred habitat. The flood in summer 2002 had a, impact similar to the high-flow events in 2001 where siltation reduced the number of Comal Springs salamander observations in Spring Run 3; but the constant flow cleared the sediment quickly and the Comal Springs salamanders increased in the subsequent sample (fall 2002).

Macroinvertebrate Sampling

The drift net sampling for benthic macroinvertebrates was completed with the spring quarterly sample; Tables 9 and 10 display the dominant taxa with slight changes in the order relative to data presented in the 2000-2001 annual report (BIO-WEST 2001). A thorough analysis was conducted on the complete 2-year data set by Dr. Tom Arsuffi and Chad Norris (both with SWT). A summary of their findings is presented below. The new plan for sampling in 2003 and beyond does not include drift net sampling, but it includes sampling around spring openings, regular monitoring of Comal Springs riffle beetles in several locations, and laboratory studies designed to assess habitat requirements of the federally listed invertebrate species in more detail.

Habitat Availability

The analysis of invertebrates captured by drift nets placed in Spring Runs 1 and 3 from August 2000 to May 2002 showed differences by location primarily due to habitat differences between sites. Spring Run 1 has a more open tree canopy, which permits greater exposure to direct sunlight and promotes growth of aquatic plants. Spring Run 1 is longer, wider, and more shallow, with more depth and flow variety than in the other sampling areas. Spring Run 3 is more shaded and has an adjacent escarpment and dense tree canopy, which limits aquatic vegetation. Spring Run 3 is also shorter, deeper, more narrow, and channelized to a greater extent with less depth and flow variety within the run. With this

Table 9. Dominant taxa in drift net samples from Spring Run 1, with total abundance across all samples and number observed during each sample period.

FAMILY	TAXA	TOTALS	8/00	9/00	11/00	3/01	5/01	9/01	11/01	2/02	5/02
Baetidae	*Baetis*	2,727	260	121	199	294	423	179	216	828	207
Elmidae	*Microcylloepus* (L)	1,754	36	151	128	254	208	252	248	346	131
Tricorythidae	*Trichorythodes*	1,252	23	124	121	234	146	322	136	44	102
Cambaridae		995	180	364	9	1	0	4	6	4	427
Hydroptilidae	*Leucotrichia*	932	62	7	21	347	269	37	19	119	51
Hydroptilidae	*Ochrotrichia*	721	8	31	18	495	83	2	15	52	17
Psephenidae	*Psephenus* (L)	623	47	105	69	100	93	47	66	39	57
Chironomidae	Larvae	463	133	38	40	87	56	16	16	55	22
Coenagrionidae	*Argia*	256	9	20	46	7	80	14	43	4	33
Pyralidae	*Petrophila*	252	6	26	2	67	99	4	4	25	19
Elmidae	*Microcylloepus*	232	4	21	14	24	67	18	34	31	19
Helicopsychidae	*Helicopsyche*	191	19	118	5	4	15	1	1	10	18
Chironomidae	Pupae	176	18	65	18	36	28	0	0	9	2
Baetidae	*Baetodes*	126	3	6	1	22	65	1	8	9	11
Veliidae	*Rhagovelia*	105	12	63	6	4	4	9	3	0	4

Table 10. Dominant taxa in drift net samples from Spring Run 3, with total abundance across all samples and number observed during each sample period.

FAMILY	TAXA	TOTALS	8/00	9/00	11/00	3/01	5/01	9/01	11/01	2/02	5/02
Hydroptilidae	*Leucotrichia*	2,756	147	190	96	386	507	117	132	632	549
Elmidae	*Microcylloepus* (L)	1,484	63	178	150	246	243	129	84	143	248
Chironomidae	Larvae	1,390	344	773	64	41	59	17	23	37	32
Psephenidae	*Psephenus* (L)	957	29	68	143	220	224	0	0	74	199
Baetidae	*Baetis*	474	24	38	12	36	107	13	4	207	33
Hydroptilidae	*Ochrotrichia*	357	0	23	23	164	57	0	4	40	46
Pyralidae	*Petrophila*	310	32	26	37	76	31	15	11	42	40
Baetidae	*Baetodes*	279	17	13	42	67	30	38	25	28	19
Chironomidae	Pupae	248	55	112	10	37	13	0	0	15	6
Elmidae	*Microcylloepus* (A)	227	11	30	19	34	58	14	18	26	17
Psephenidae	*Psephenus* (A)	192	7	6	12	16	14	62	52	14	9
Tricorythidae	*Trichorythodes*	150	19	37	1	49	5	6	3	23	7
Elmidae	Pupae	133	7	20	23	24	28	0	0	28	3
Hyalellidae	*Hyalella*	118	5	31	17	30	15	3	6	6	5

greater habitat complexity, Spring Run 1 showed a greater species richness (55 species collected), and mayflies and crayfish were dominate. Spring Run 3 had lower species richness with 44 species; this run was dominated by a caddisfly species, the water penny, and midges.

Daily and Seasonal Drift Fluctuation

Drift is commonly used as a dispersal mechanism to avoid unfavorable conditions (Ciborowski et al. 1977, Corkum and Pointing 1979); however, the conditions that induce drift vary according to requirements of the organism. Variation in drift during the day is a common observation in many stream invertebrates and is often described as a response to the threat of predation. This diel variation was observed overall in both spring runs – the number of drifting insects increased nearly twofold on average at night – which indicates that changes in light intensity affect activity. Peaks in nightly drift were more pronounced in Spring Run 1 (Figure 19), which may be a consequence of the greater range of light intensity (canopy is sparser) relative to Spring Run 3.

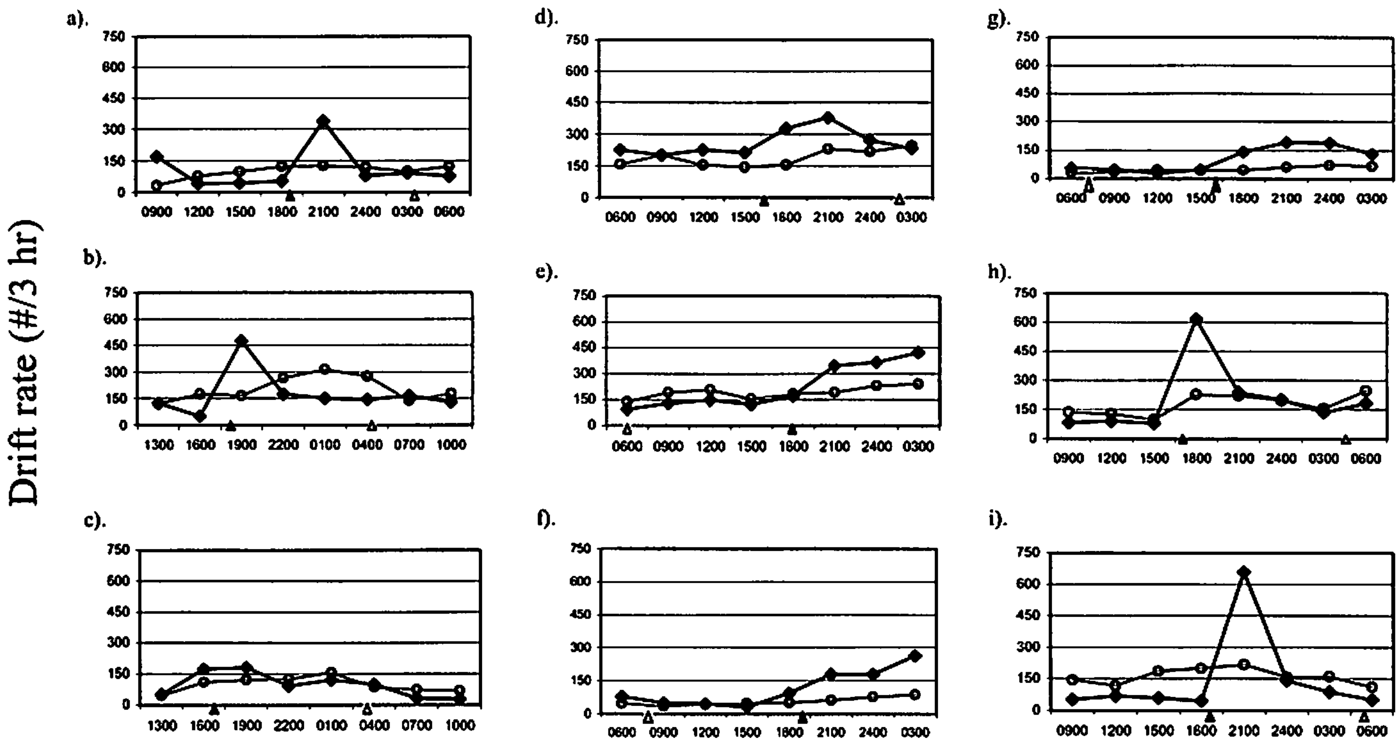

Figure 19. Diel drift rate for both Spring Run 1 (♦) and Spring Run 3 (○) on (a) 28 August 2000, (b) 14 September 2000, (c) 21 November 2000, (d) 20 March 2001, (e) 23 May 2001, (f) 12 September 2001, (g) 5 November 2001, (h) 19 February 2002, and (i) 20 May 2002. Sunset (▲) and sunrise (△) are indicated.

Fluctuations in drift can also occur in response to season (reproduction and dispersal cycles). Graphical analysis comparing mean current velocity (Figure 20a) and season to total drift rates in both spring runs (Figure 20b) shows a seasonal pattern where drift rates were generally highest from late winter to early spring and declined from late summer through early winter. This pattern is similar to that found in a subtropical Florida stream (Cowell and Carew 1976). The taxa showing the most significant relationship between drift rate and seasonality (Julian day) were mayflies in Spring Run 1 and caddisflies in Spring Run 3; these were the dominant taxa in the respective spring runs. Water pennies –

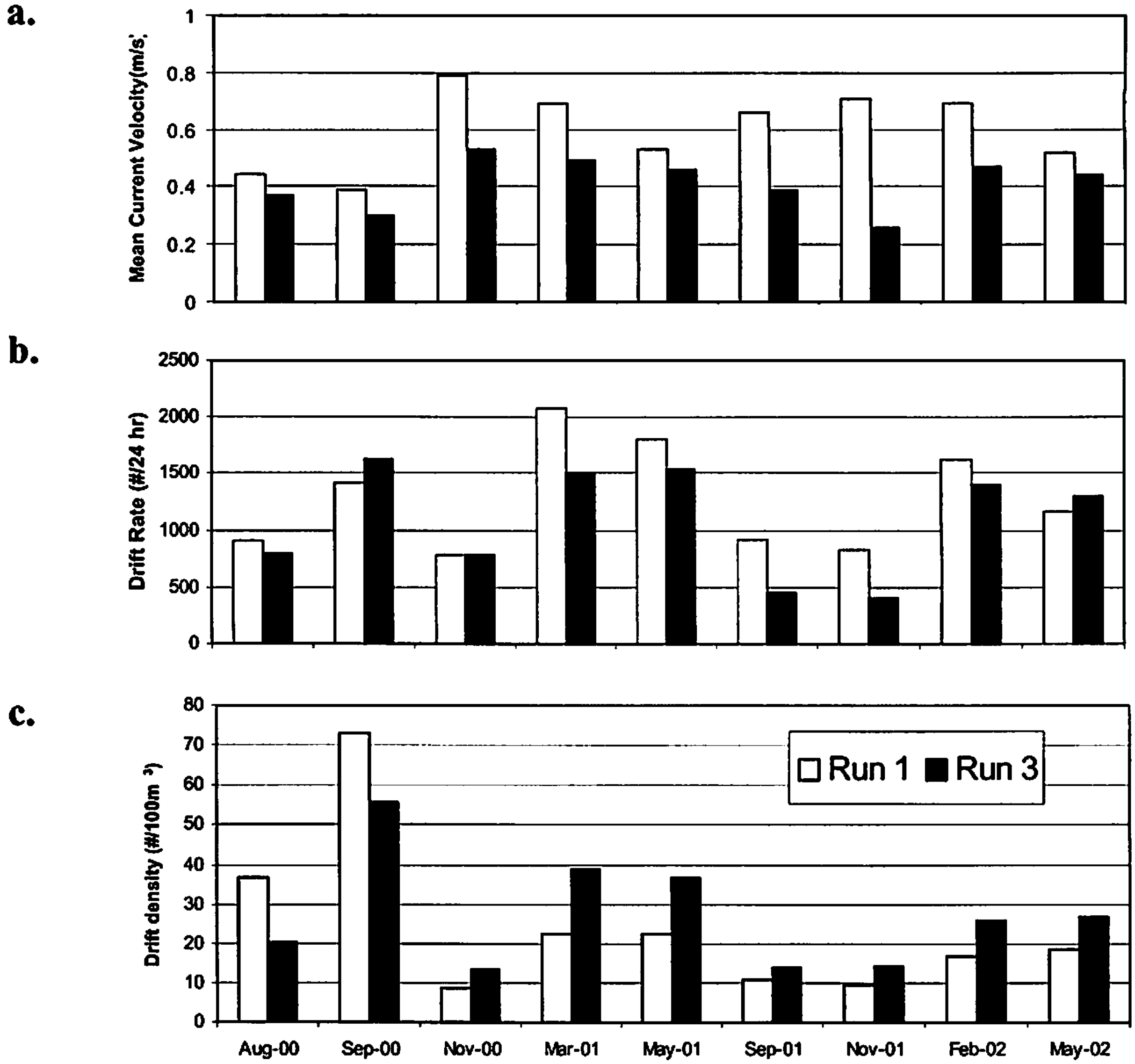

Figure 20. Mean current velocity (a), drift rate (b), and drift density (c) for both spring runs across all sampling dates.

common aquatic beetles in all spring runs – had the highest drift rates during the spring (both in 2001 and 2002). This coincides with the time of year when mature larvae are actively seeking pupation sites above the water line.

Relationship between Drift and Flow Rate

The overall drift rate (number / 24-hour period) was higher in Spring Run 1 than Spring Run 3, and both showed high drift rates during the lowest observed flows of September 2000 (Figure 20b). Drift density (number / 100 m^3) showed similar results (Figure 20c). By comparing drift rate with water depth (a surrogate for discharge in the spring run), a strong significant relationship was displayed in Spring Run 1 and none was shown in Spring Run 3. It appears as though changes in water depth have a greater effect on drift in Spring Run 1, with a general trend toward increased drift at lower water levels.

Some species showed a significant relationship between drift rate and the variable flows encountered. The relationship was generally negative in Spring Run 1 (higher drift at lower flows) and positive in Spring Run 3 (higher drift at higher flows). In Spring Run 1 these interactions were strongest in the dragonfly (*Perithemis* sp.), and the caddisfly, *Helicopsyche sp*. Whereas these species may actively seek preferred habitat during lower flows, these relatively large-bodied aquatic insects probably move to more protected environments during higher flows to avoid the increased risk of being dislodged and potentially preyed upon. Contrary to Spring Run 1, many species in Spring Run 3 showed statistically significant increases in drift with increased flows. These include Comal Springs riffle beetles, water pennies (*Psephenus texanus*), a moth caterpillar (*Petrophila* sp.), and a blind cave-dwelling amphipod (*Stygobromus* sp.). When current velocities increase, the species with life history characteristics that expose them to scouring are more likely to be dislodged (Bird and Hynes 1981, Brittain and Eikeland 1988). The species in Spring Run 3 that increased in the drift – including the Comal Springs riffle beetle, water penny and moth caterpillar – are characterized as scrapers (Merritt and Cummins 1996) that graze on the tops of stones, thus their feeding activities make them more susceptible to being dislodged during periods of increased current velocity. The increased drift of the cave-dwelling amphipod may result from increased dislodgment from spring openings or from the presumably helpless condition of this blind organism once above ground. Flow rate may have a direct relationship to the ability of individuals to settle to the substrate after being expelled from the aquifer.

Assessment of Low Flows

Assessing the effects of low-flow events on invertebrate drift with this data set is difficult considering that flows were "low" only on the first two sampling dates and were high for all subsequent sampling dates. However, there are some interesting trends in the data. Higher drift rates of 54% in Spring Run 1 and 265% in Spring Run 3 during low flows (September 2000) relative to average flow conditions (September 2001) indicate that low flows may cause an increase in invertebrate drift (although overall there was a positive trend in the relationship between drift and current velocity in Spring Run 3). This comparison suggests an increase in drift overall, but the endangered Comal Springs riffle beetle appears more likely to increase drifting with higher flows (as observed in Spring Run 3). In Spring Run 1 though, there was a significant negative relationship between water depth and the number of riffle beetles in the drift, which suggests decreased flows (and thus lower water depths) may increase drift of the species. These contradictory results for *the* Comal Springs riffle beetle suggest that populations in the two spring runs differ in response to changing habitat conditions, but the results also highlight the need for more data on invertebrate drift during low flows to refine assessments of how reductions in stream flow affect the benthic community in Comal Springs.

Indicator Species

The following criteria were used to select candidate invertebrates to be studied as indicator flow species for Comal Springs. Candidates should (1) be widely distributed within the riffle-spring runs, (2) occur in large enough numbers that significant changes in their abundance are observed relative to changes in current velocity and/or water depth, (3) be present through much of the year, and (4) have literature published about them that describes life history characteristics and biological requirements available. No species or genus fit these criteria across both spring runs; however, each spring run had species that are proposed as candidates for further study as indicator flow species. *Perithemis* and *Helicopsyche* are proposed as indicators of hydrologic change in Spring Run 1 because the drift rate and drift density of these species showed significant negative relationships to current velocity and water depth in Spring Run 1. Additionally, the drift rate for both species showed a significant negative relationship to discharge of the Comal River. Although *Stygobromus* sp. and *H. comalensis* were less abundant in the Spring Run 3 drift than *Petrophila* and *P. texanus*, changes in their drift rates and densities were detected and were significantly related to changes in current velocity; thus these four species appear to be good indicators of hydrologic change.

Exotics / Predation Study

A summary of the number of individuals of each species collected in the Comal and San Marcos ecosystems during the study and the contents of their stomachs can be found in Tables 11 and 12, respectively. In 2002, no fountain darters or Comal Springs salamanders were observed in the 160 stomachs sampled in 2002, but one San Marcos salamander was recovered. Overall 437 potential predators were examined between 2000-2002 and only three fountain darters and two salamanders (both San Marcos salamanders) were observed.

The largemouth bass (*Micropterus salmoides*) and warmouth (*Lepomis gulosus*) were the two predator species observed to feed on fountain darters (none in 2002) and on San Marcos salamanders. Other fish prey were found in the stomachs of the largemouth bass. However, no other fish prey were found in any warmouth; they fed primarily on crayfish in the San Marcos River and both crayfish and other aquatic invertebrates in the Comal River. Fish and crayfish were the most common items in the diet of the largemouth bass, although the one instance of a San Marcos salamander in the diet occurred in a San Marcos largemouth bass. Fish were found in about 31% of all largemouth bass stomachs; crayfish were abundant in the diet of Comal individuals (56%) but less common in the San Marcos largemouth bass diet (14%). From this data set, it appears that both fountain darters and salamanders may be incidental prey items for the largemouth bass, which tends to be an opportunistic species. The warmouth may, however, be more suited to target these species as prey, given the larger size of the mouth relative to other sunfish and the tendency to focus on benthic fauna (unlike the bass). Nonetheless, the occurrence of fountain darters and San Marcos salamanders in the warmouth diet is limited to just one of each.

The spotted gar (*Lepisosteus oculatus*) is another predator (in the San Marcos River) with fish as a common food item; however, no fountain darters were found in their diet. Tilapia was abundant in the Comal and Rio Grande cichlid (*Cichlasoma cyanoguttatum*) that were sampled in both systems, but the primary food item for these species was algae. The remainder of the fishes sampled were sunfish species, which fed primarily on aquatic invertebrates.

Overall, the data from both 2001 and 2002 reveal limited predation on any threatened or endangered species and, although differences in food availability and prey organisms between the two systems is interesting, this component of the Variable Flow Study will not be conducted in future baseline sampling. There remains the possibility, however, that low-flow conditions alter feeding activities and result in a greater predation threat to Comal Springs salamanders and fountain darters; therefore, predator diets will be examined when low-flow sampling is triggered.

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

SPECIES DATA				STOMACH CONTENTS (PERCENTAGE OF PREY ITEM)							
Taxa	Number	Mean Length (mm)[a]	Mean Weight (g)[b]	Empty	Algae	Fountain Darter	Other Fishes[c]	Comal Springs Salamander	Crayfish and Grass Shrimp	Aquatic Invertebrates	Other[d]
C. cyanoguttatum	25	153.4	106.8	32.0	44.0				12.0	28.0	
L. auritus	9	137.7	45.9	22.2			11.1		11.1	77.8	
L. cyanellus	1	105.0	57.0							100.0	
L. gulosus	6	129.7	58.2	16.7					33.3	33.3	16.7
L. megalotis	23	127.7	54.2	21.7					17.4	65.2	8.7
L. punctatus	79	126.5	66.0	25.3	8.9		3.8		30.4	38.0	7.6
M. salmoides	50	288.7	482.3	22.0		4.0	36.0		56.0	4.0	4.0
H. plecostomus	2	410.0	893.0	100.0							
T. aurea	59	367.9	980.7	55.9	37.3					16.9	
A. natalis	1	191.0	186.0	100.0							
A. rupestris	1	111.0	28.0	100.0							

[a] Millimeter.
[b] Gram.
[c] Includes unidentifiable fish remains; fountain darter numbers could be higher than indicated.
[d] Terrestrial insects, unidentifiable material, etc.

Table 12. Predator diet summary for gill-net- and rod-and-reel-surveyed fish in the San Marcos ecosystem.

SPECIES DATA				STOMACH CONTENTS (PERCENTAGE OF PREY ITEM)							
Taxa	Number	Mean Length (mm)[a]	Mean Weight (g)[b]	Empty	Algae	Fountain Darter	Other Fishes[c]	San Marcos Salamander	Crayfish and Grass Shrimp	Aquatic Invertebrates	Other[d]
C. cyanoguttatum	6	222.5	228.7	40.0	60.0						
L. oculatus	17	682.8	1428.0	52.9			41.2				5.9
L. auritus	7	190.0	150.7	28.6						57.1	28.6
L. gulosus	14	195.1	184.9	42.9		7.1		7.1	57.1		
L. machrochirus	22	151.3	79.4	18.2	4.5				4.5	81.8	31.8
L. megalotis	11	183.5	134.1	36.4					9.1	54.5	
L. microlophus	4	170.8	122.5	75.0						25.0	
L. punctatus	44	126.6	57.8	22.7						70.5	6.8
M. salmoides	56	266.5	306.3	41.1			23.2	1.8	14.3	5.4	21.4

[a] Millimeter.
[b] Gram.
[c] Includes unidentifiable fish remains; fountain darter numbers could be higher than indicated.
[d] Terrestrial insects, unidentifiable material, etc.

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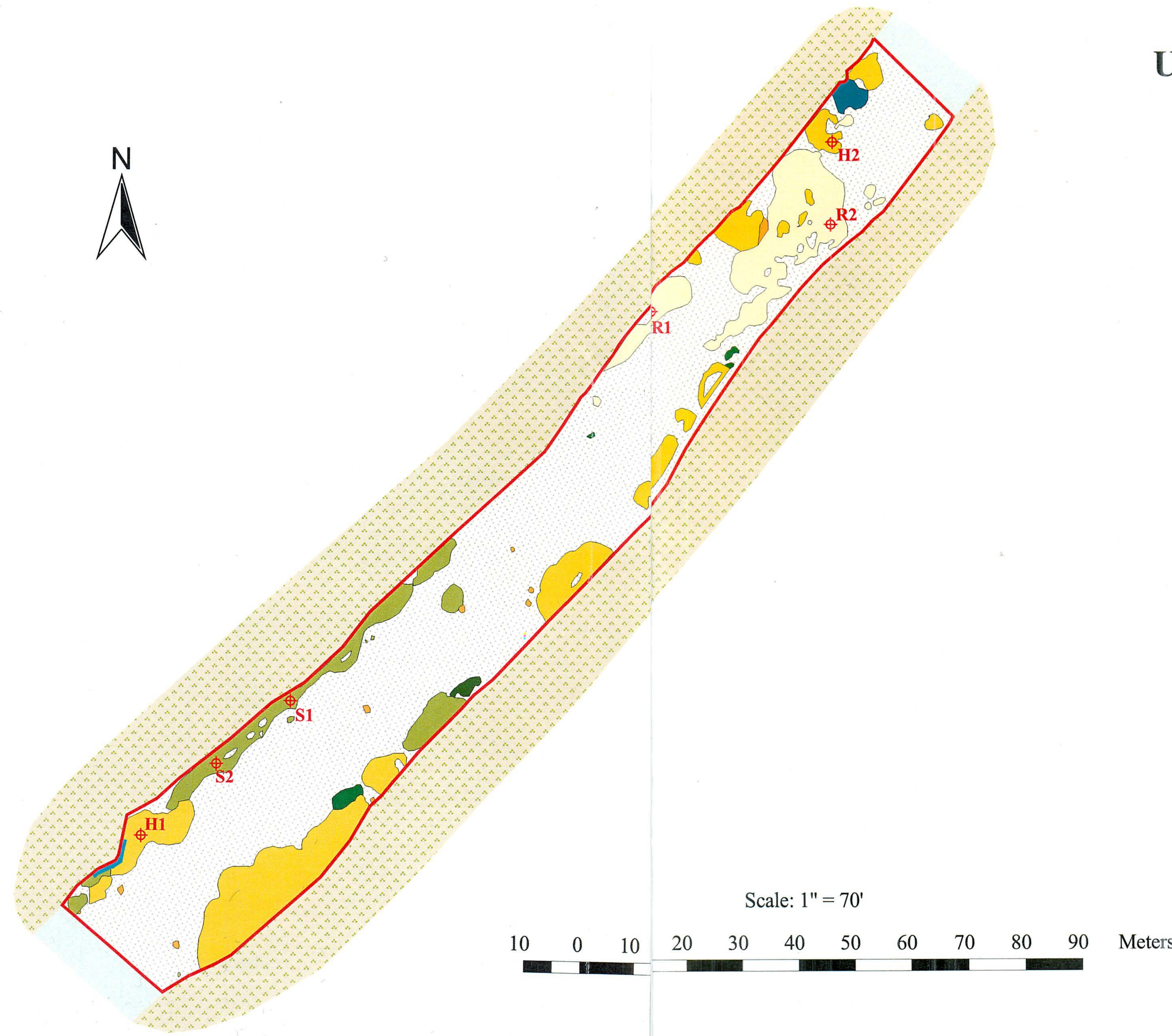
APPENDIX A: AQUATIC VEGETATION MAPS

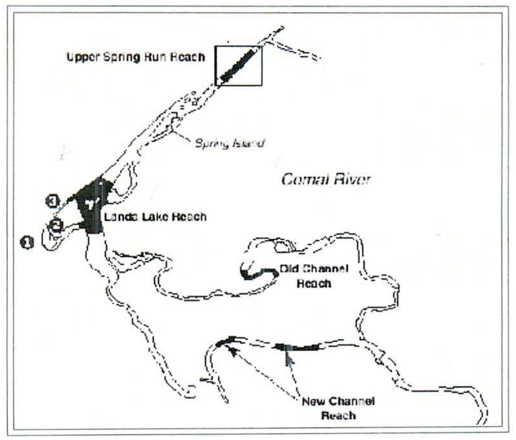
Comal River
Aquatic Vegetation
Upper Spring Channel Reach
Winter
February 20, 2002



Shore and Islands
River
Study Area (4,723.5 m^2)
Bare Substrate
Colocasia
Drop Net Sample Sites

	Meters^2
Cabomba	18.3
Algae	10.2
Hygrophila	708.2
Limnophila	25.0
Ludwigia	12.1
Nuphar	0.3
Riccia	384.1
Sagittaria	249.1

Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

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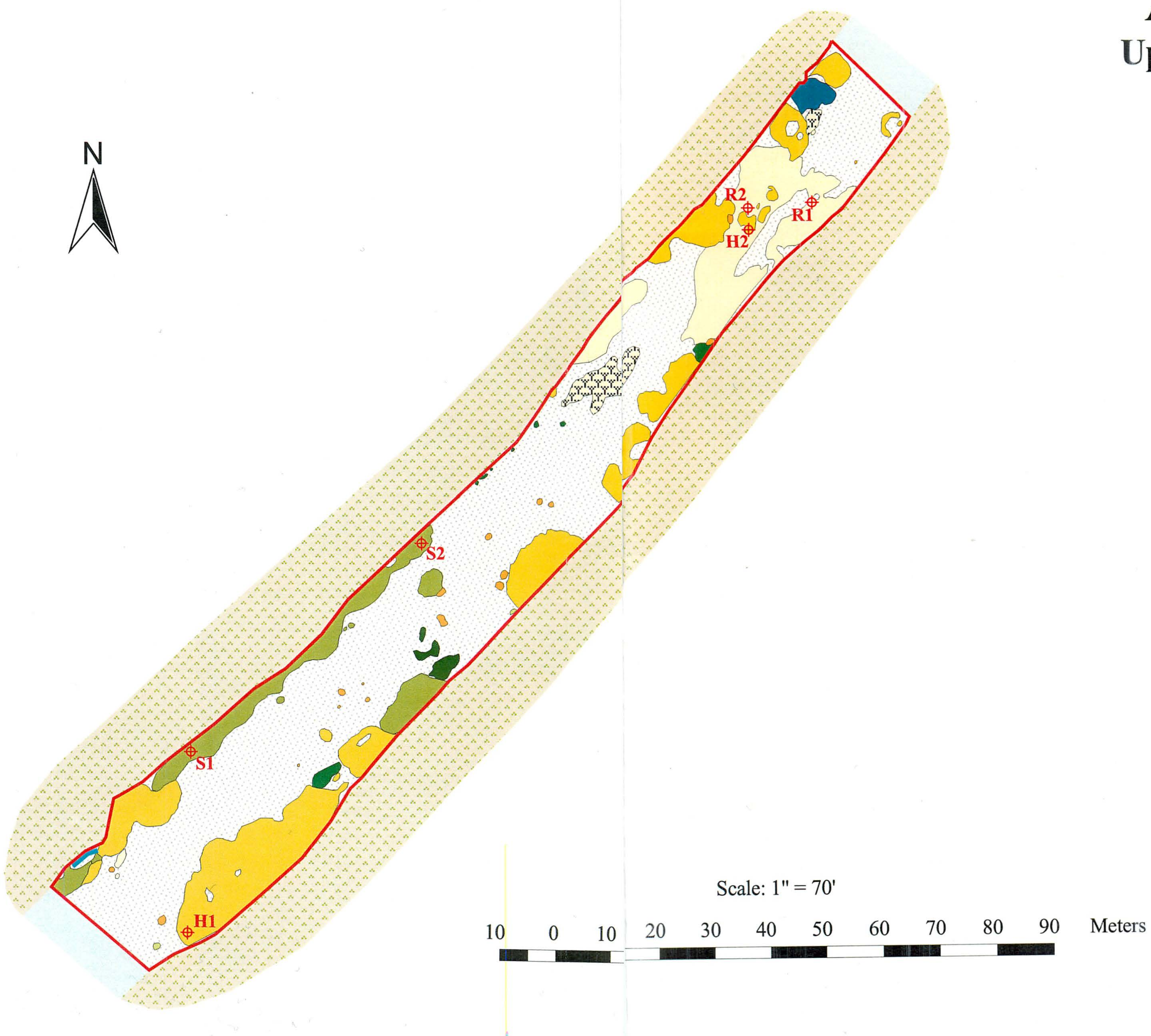


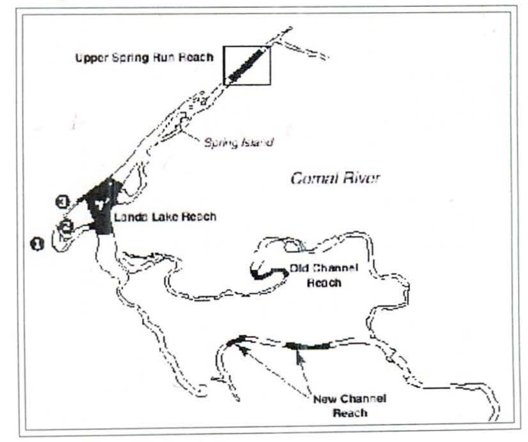
Comal River
Aquatic Vegetation
Upper Spring Channel Reach
Spring

May 14, 2002

- Shore and Islands
- River
- Study Area (4,723.5 m^2)
- Bare Substrate
- *Colocasia*
- Drop Net Sample Sites

	Meters^2
Cabomba	22.5
Algae	24.1
Hygrophila	881.1
Limnophila	31.7
Ludwigia	18.0
Nuphar	2.0
Riccia	457.4
Sagittaria	285.6
Riccia < 50%	85.1

Project Location



EDWARDS AQUIFER AUTHORITY

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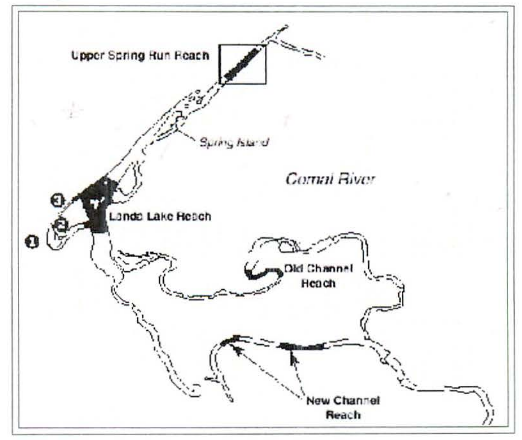
Comal River
Aquatic Vegetation
Upper Spring Channel Reach
Summer
July 31, 2002

Shore and Islands
River
Study Area (4,697.5 m^2)
Bare Substrate
Colocasia
Drop Net Sample Sites

	Meters^2
Algae	9.3
Cabomba	26.9
Hygrophila	774.4
Limnophila	26.2
Ludwigia	13.8
Riccia	214.3
Sagittaria	262.3
Riccia / Sagittaria	7.0
Riccia < 50%	844.1

Project Location



EDWARDS AQUIFER AUTHORITY
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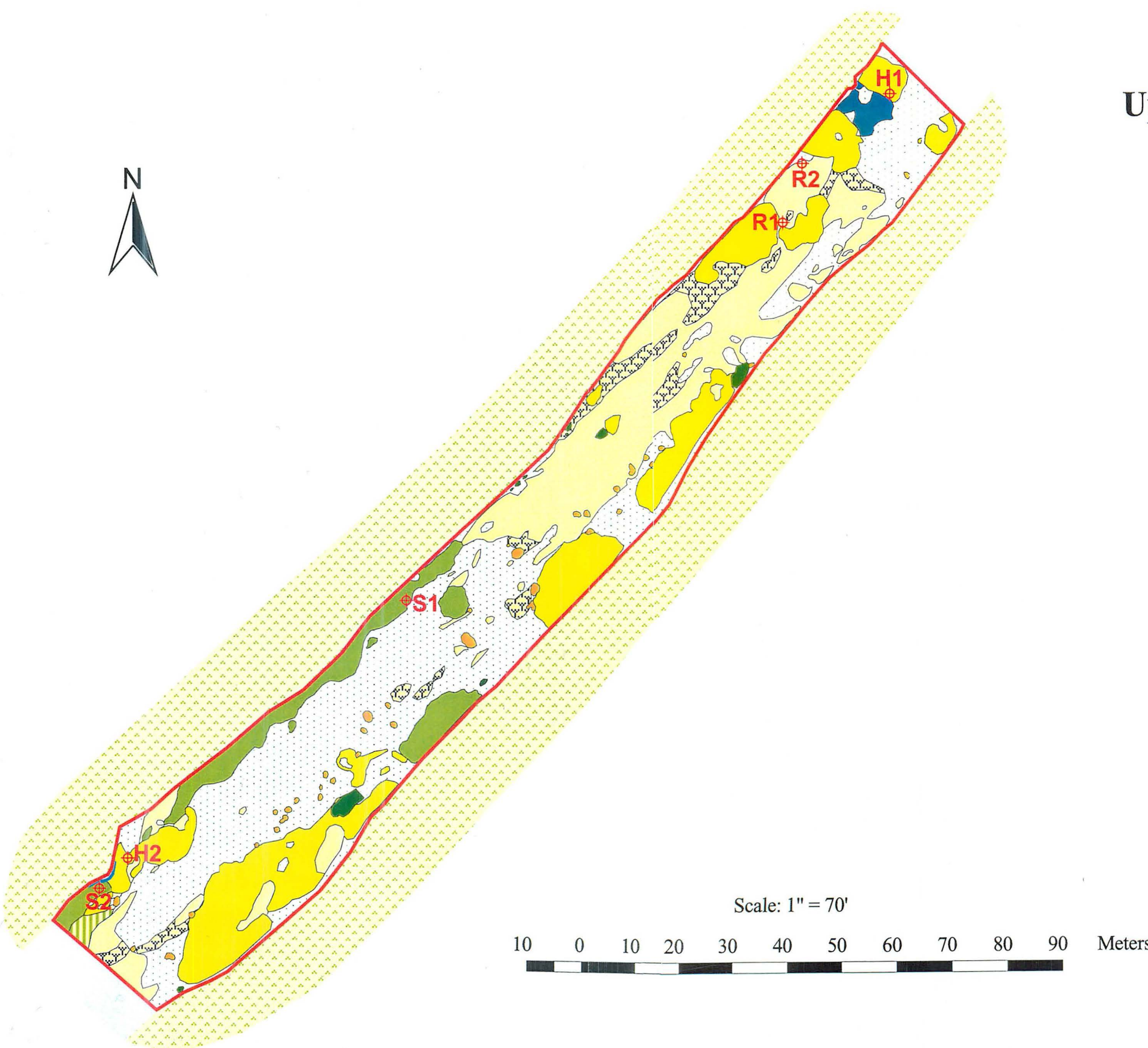
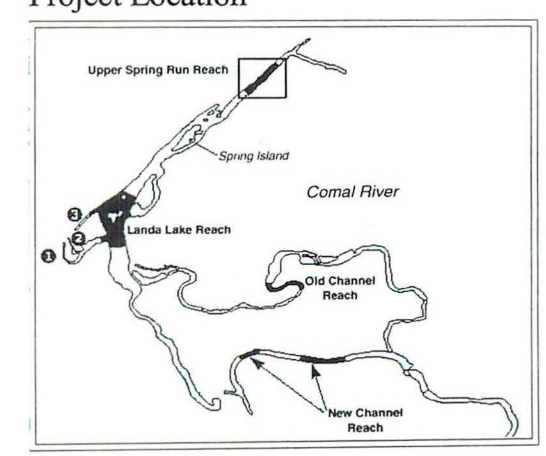
Comal River
Aquatic Vegetation
Upper Spring Channel Reach
Fall
October 28, 2002



Shore and Islands
River
Study Area (4,723.5 m^2)
Bare Substrate
Colocasia
Drop Net Sample Sites

	Meters ^{2}
Algae	1.0
Cabomba	26.9
Hygrophila	992.1
Limnophila	41.3
Ludwigia	39.3
Riccia	1155.7
Sagittaria	309.8
Riccia / Sagittaria	21.2
Riccia < 50%	230.3

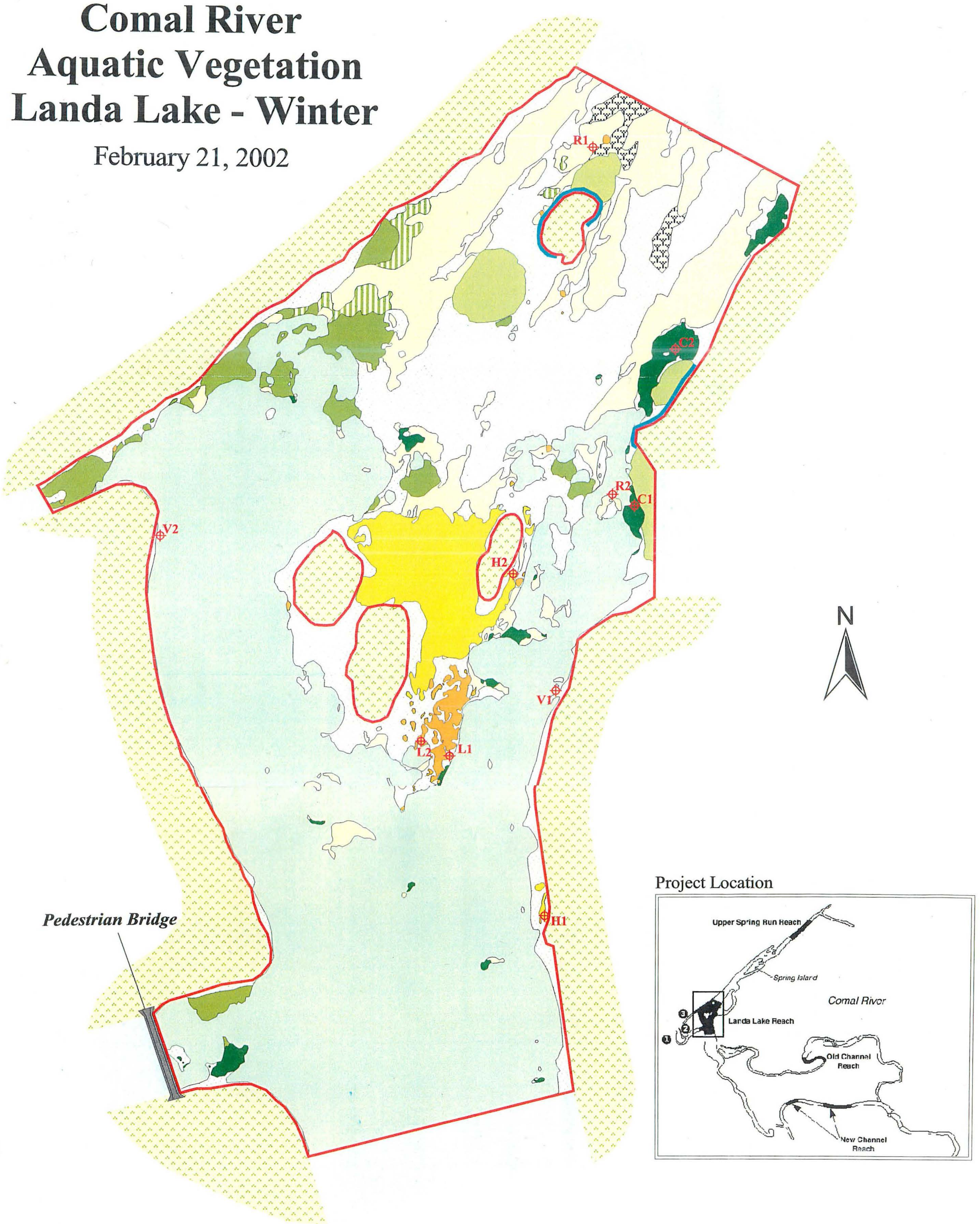
Project Location



BIO-WEST, Inc.
EDWARDS AQUIFER AUTHORITY

Comal River Aquatic Vegetation Landa Lake - Winter

February 21, 2002



	Meters^2
Cabomba	302.6
Hygrophila	858.0
Ludwigia	156.6
Nuphar	484.9
Riccia	2,651.1
Sagittaria	715.0
Vallisneria	11,955.7
Riccia < 50%	166.0
Riccia / Sagittaria	167.8

Shore and Islands
River
Study Area (22,502.3 m^2)
Bare Substrate
Colocasia
Drop Net Sample Sites

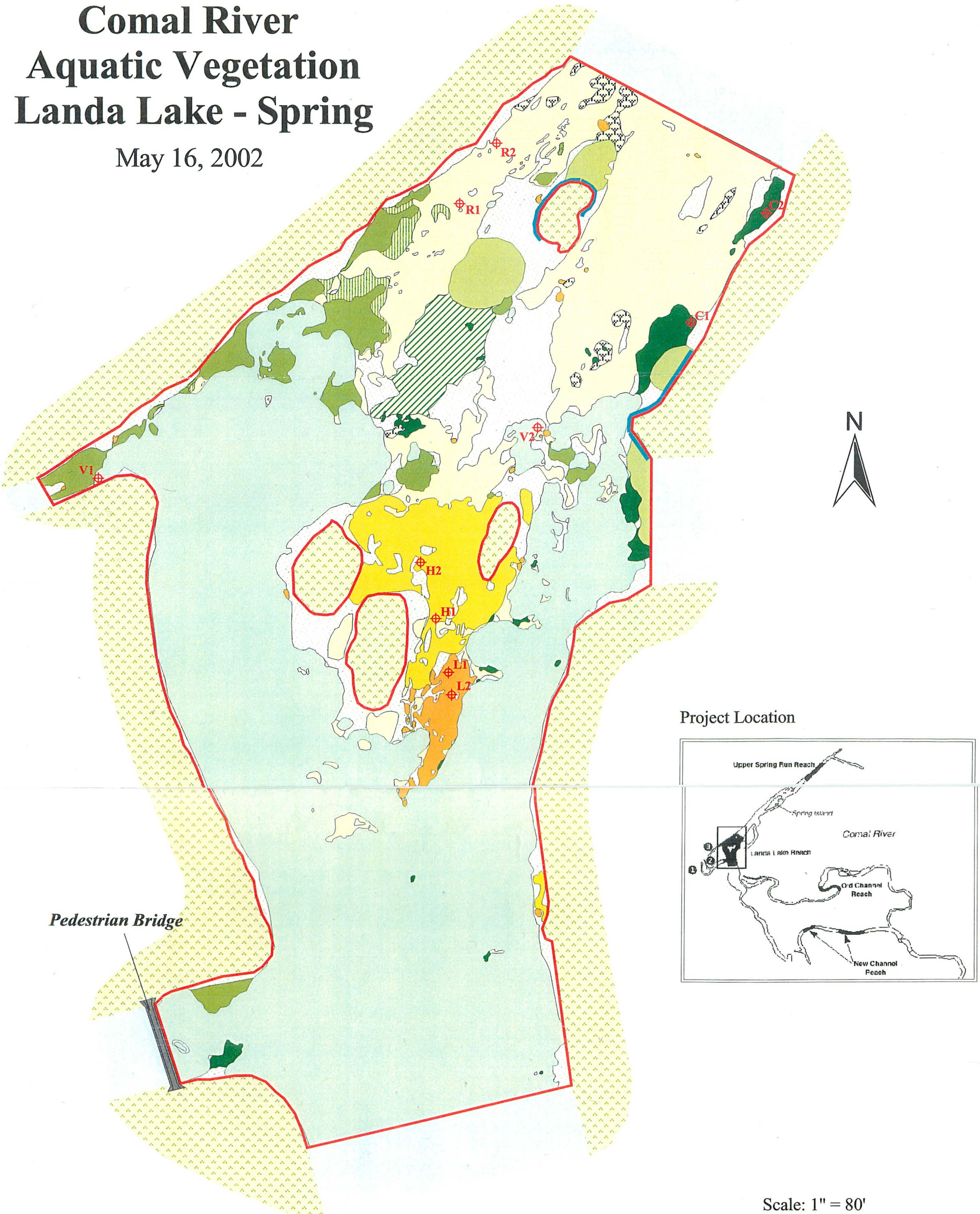
EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

Comal River
Aquatic Vegetation
Landa Lake - Spring

May 16, 2002



Scale: 1" = 80'

Meters 10 0 10 20 30 40 50

	Meters^2
Cabomba	316.3
Hygrophila	904.3
Ludwigia	259.1
Nuphar	486.4
Riccia	3,985.0
Sagittaria	796.8
Vallisneria	12,289.0
Riccia < 50%	175.1
Riccia / Algae	439.8
Riccia / Sagittaria	151.7

Shore and Islands
River
Study Area (22,521.6 m^2)
Bare Substrate
Colocasia
Drop Net Sample Sites

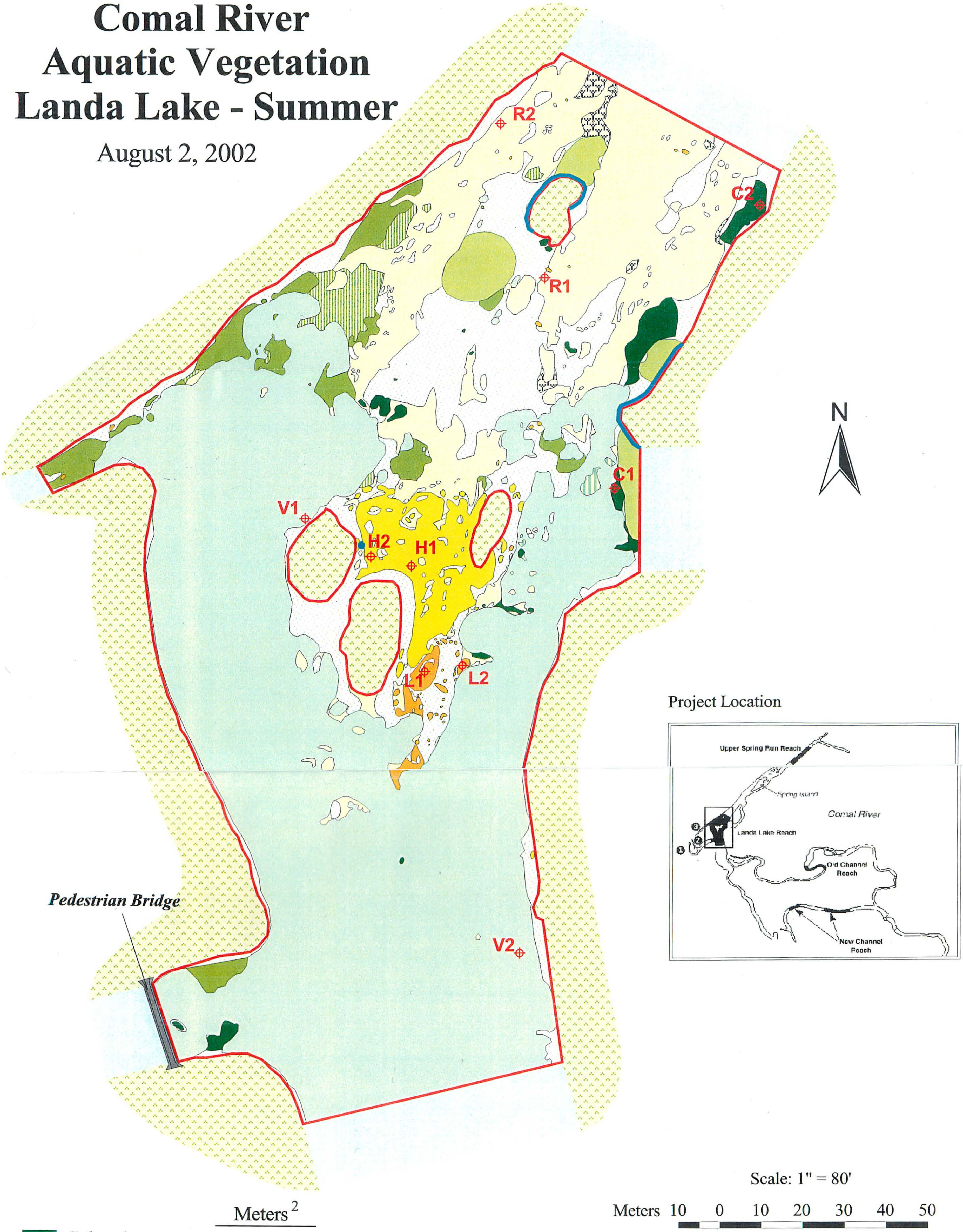
EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

Comal River
Aquatic Vegetation
Landa Lake - Summer

August 2, 2002



	Meters^2
Cabomba	312.0
Hygrophila	721.6
Ludwigia	136.1
Nuphar	491.4
Riccia	3,772.9
Sagittaria	661.7
Vallisneria	12,431.4
Riccia < 50%	107.3
Riccia / Sagittaria	276.0
Vallisneria / Riccia	24.6

Shore and Islands
River
Study Area (22,521.6 m^2)
Bare Substrate
Colocasia
Drop Net Sample Sites

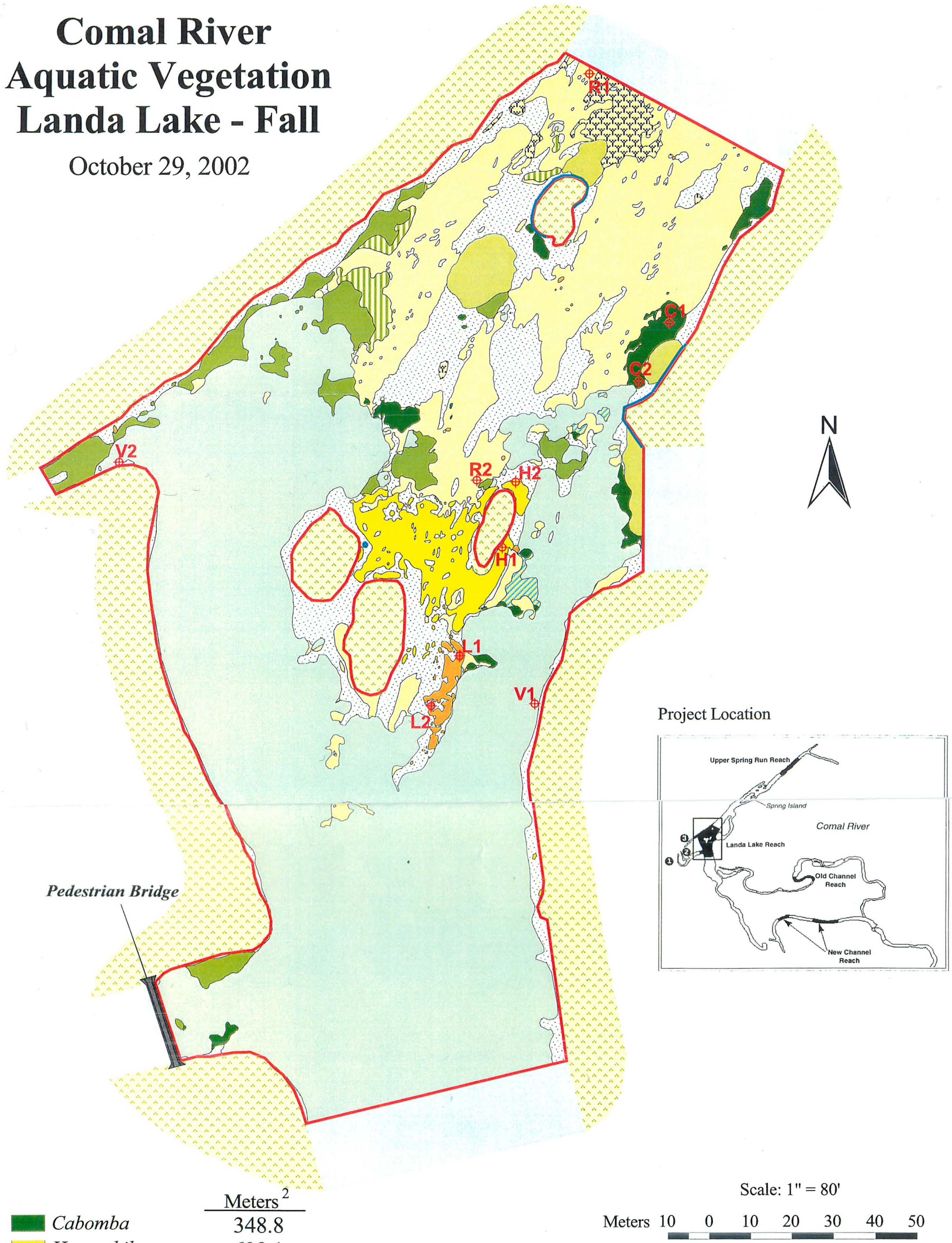
EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

Comal River
Aquatic Vegetation
Landa Lake - Fall

October 29, 2002



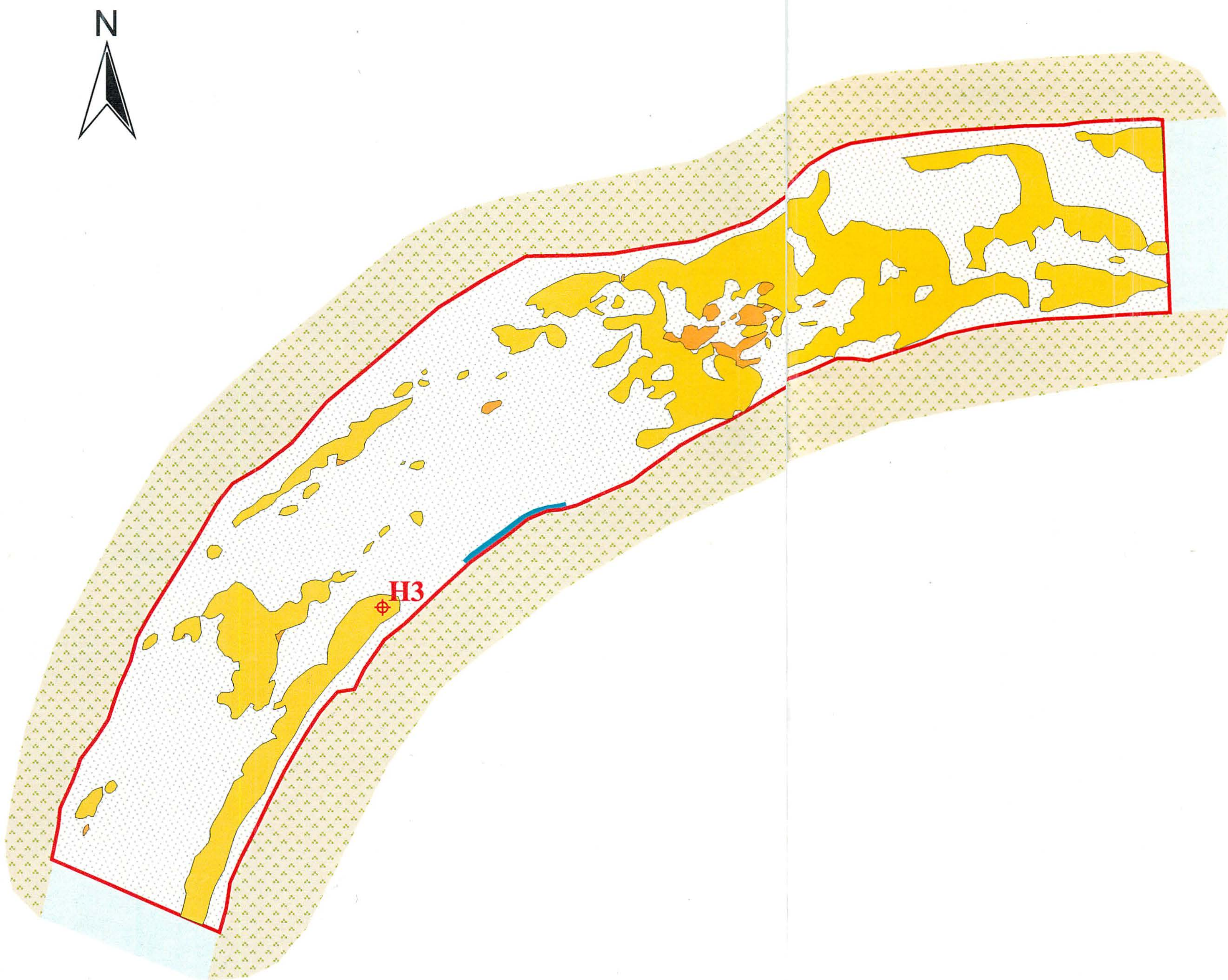
	Meters^2
Cabomba	348.8
Hygrophila	638.1
Ludwigia	99.5
Nuphar	444.1
Riccia	3964.1
Sagittaria	824.2
Vallisneria	12,316.5
Ceratopteris	0.9
Riccia < 50%	304.6
Riccia / Sagittaria	180.0
Vallisneria / Riccia	65.1

Shore and Islands
River
Study Area (22,502.3 m^2)
Bare Substrate
Colocasia
Drop Net Sample Sites

BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

Comal River
Aquatic Vegetation
New Channel Upper Reach
Winter
February 19, 2002



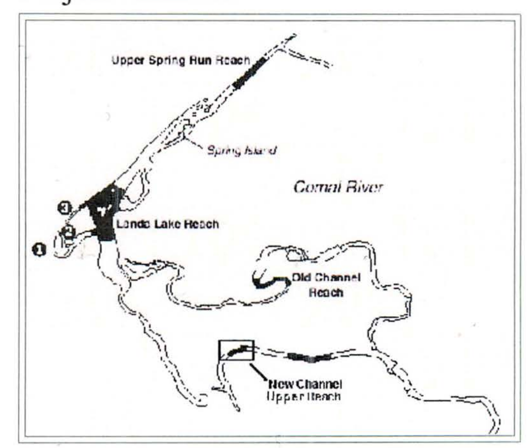
Scale: 1" = 50'

10 0 10 20 30 40 50 60 70 Meters

- Shore and Islands
- River
- Study Area (3,171.2 m^2)
- Bare Substrate
- *Colocasia*
- Drop Net Sample Sites

	Meters^2
Hygrophila	923.3
Ludwigia	33.2

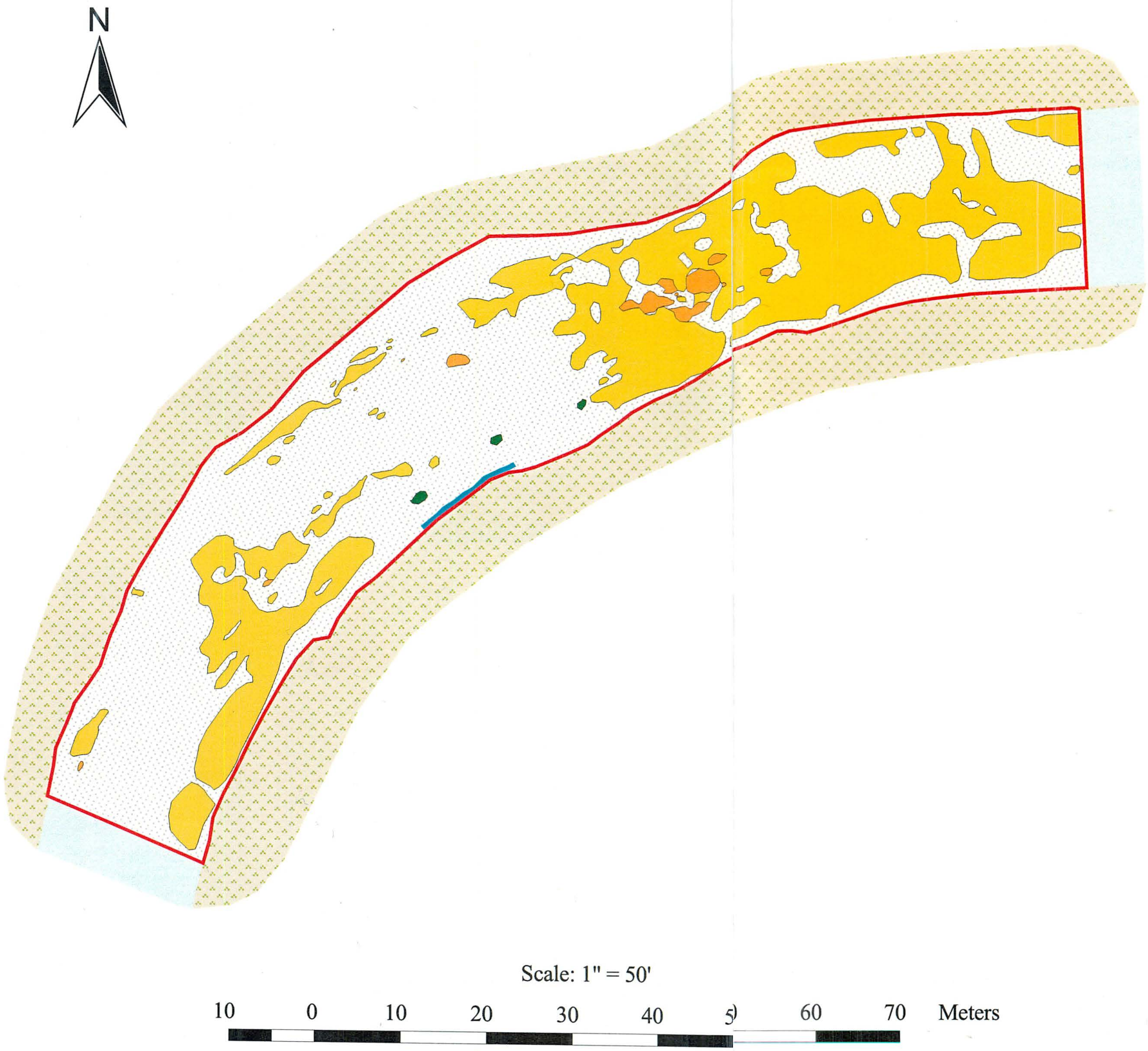
Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

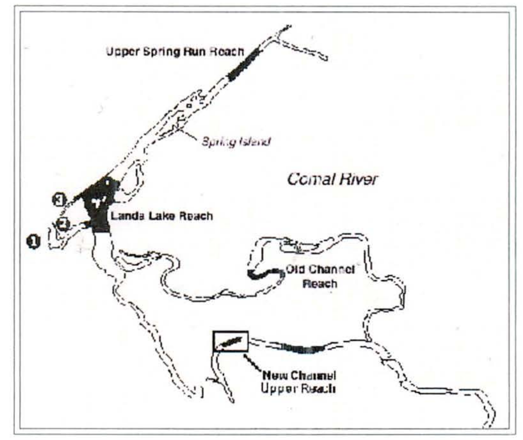


Comal River
Aquatic Vegetation
New Channel Upper Reach
Spring
May 14, 2002

- Shore and Islands
- River
- Study Area (3,171.2 m^2)
- Bare Substrate
- *Colocasia*
- Drop Net Sample Sites

	Meters^2
Cabomba	3.8
Hygrophila	1,163.6
Ludwigia	33.4

Project Location



EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

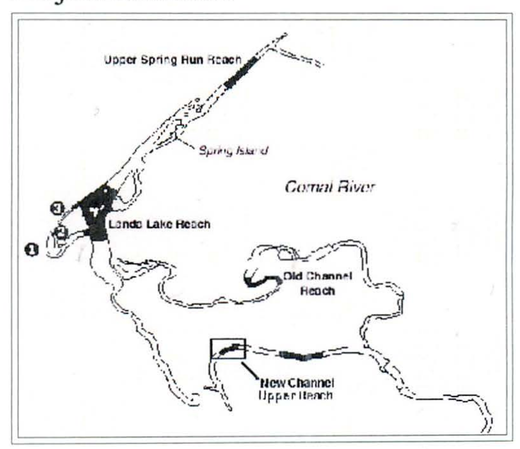
PBS&J

Comal River
Aquatic Vegetation
New Channel Upper Reach
Summer
July 31, 2002

Shore and Islands
River
Study Area (3,171.2 m^2)
Bare Substrate
Colocasia
Drop Net Sample Sites

	Meters^2
Hygrophila	536.54
Ludwigia	14.7

Project Location

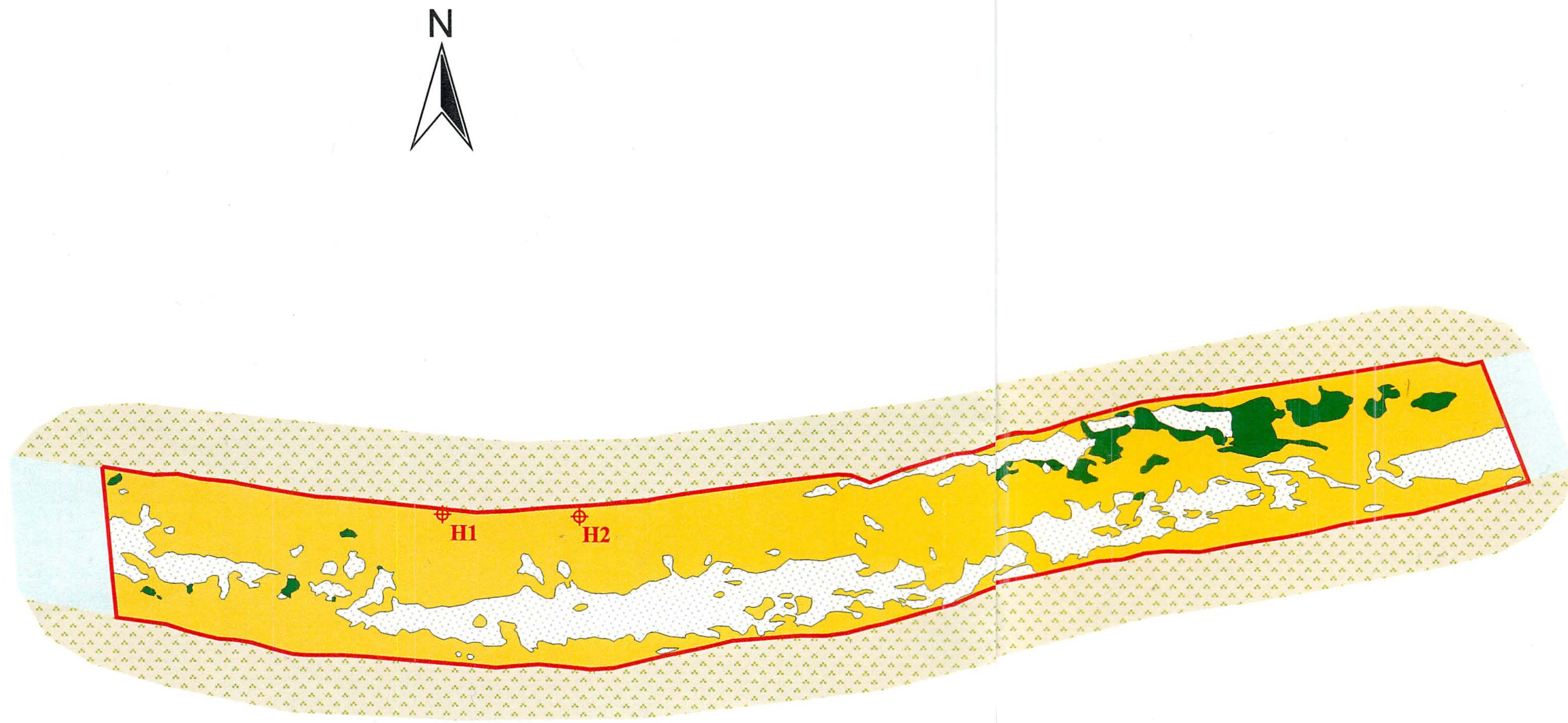


EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

Comal River
Aquatic Vegetation
New Channel Lower Reach
Winter
February 19, 2002



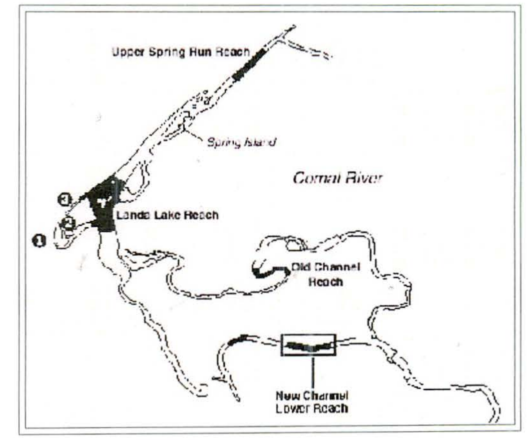
Scale: 1" = 70'

10 0 10 20 30 40 50 60 70 80 90 100 Meters

- Shore and Islands
- River
- Study Area (4,133.4 m^2)
- Bare Substrate
- Drop Net Sample Sites

	Meters^2
Cabomba	188.4
Hygrophila	2,842.7

Project Location

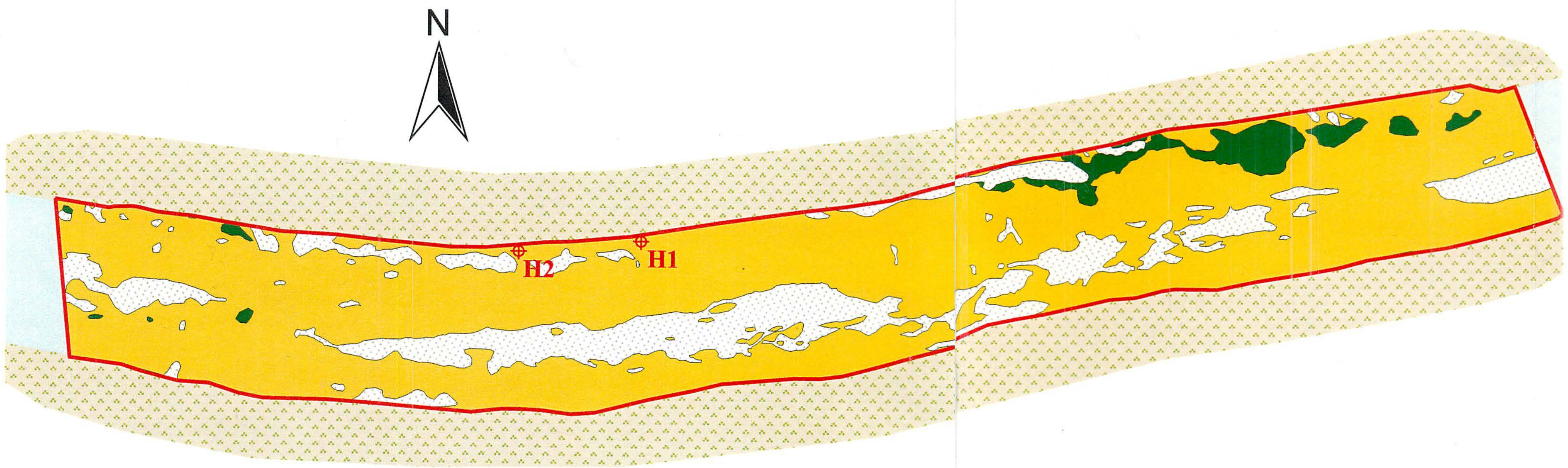


EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

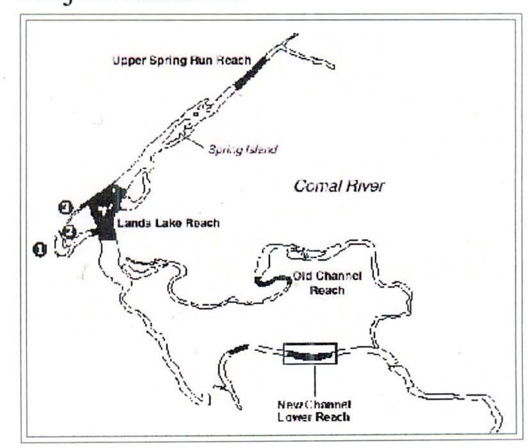
Comal River
Aquatic Vegetation
New Channel Lower Reach
Spring
May 15, 2002



- Shore and Islands
- River
- Study Area (4,173.7 m^2)
- Bare Substrate
- Drop Net Sample Sites

	Meters ^{2}
Cabomba	146.2
Hygrophila	3,157.9

Project Location



Scale: 1" = 70'

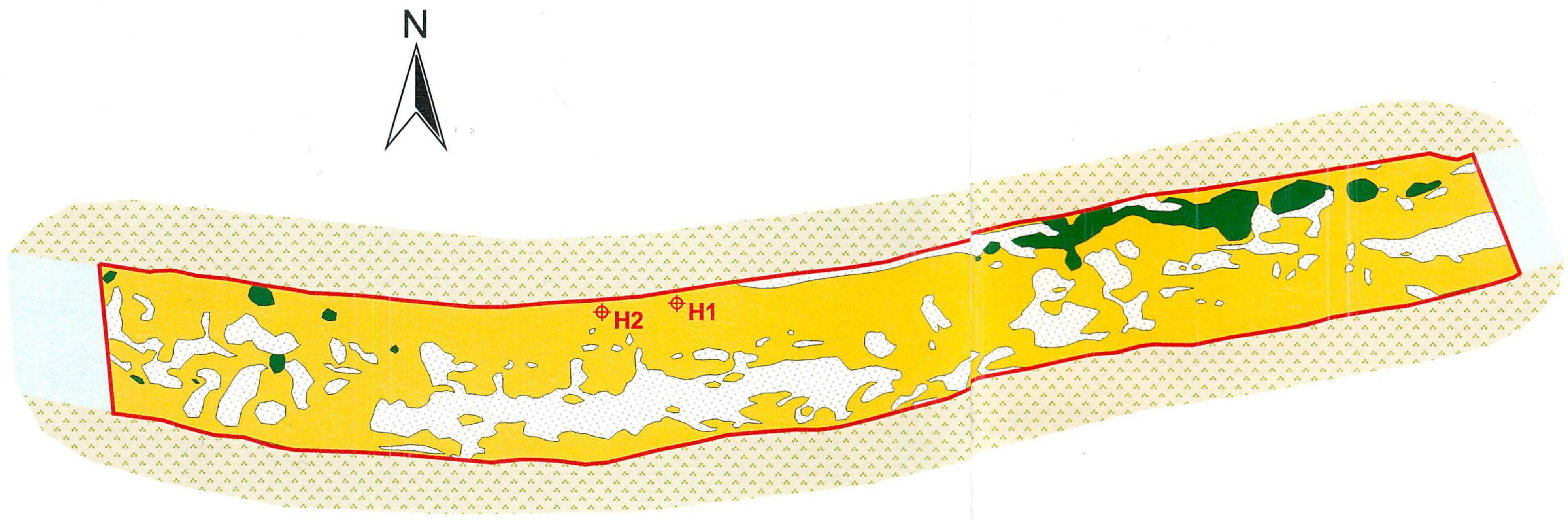
10 0 10 20 30 40 50 60 70 80 90 100 Meters

EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

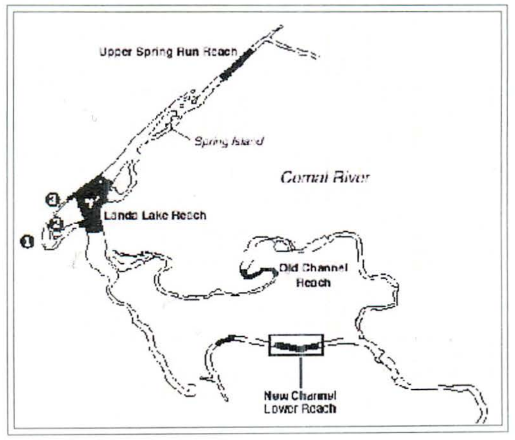
Comal River
Aquatic Vegetation
New Channel Lower Reach
Summer
August 1, 2002



Shore and Islands
River
Study Area (4,173.7 m^2)
Bare Substrate
Drop Net Sample Sites

	Meters^2
Cabomba	180.9
Hygrophila	2,862.4

Project Location



Scale: 1" = 70'

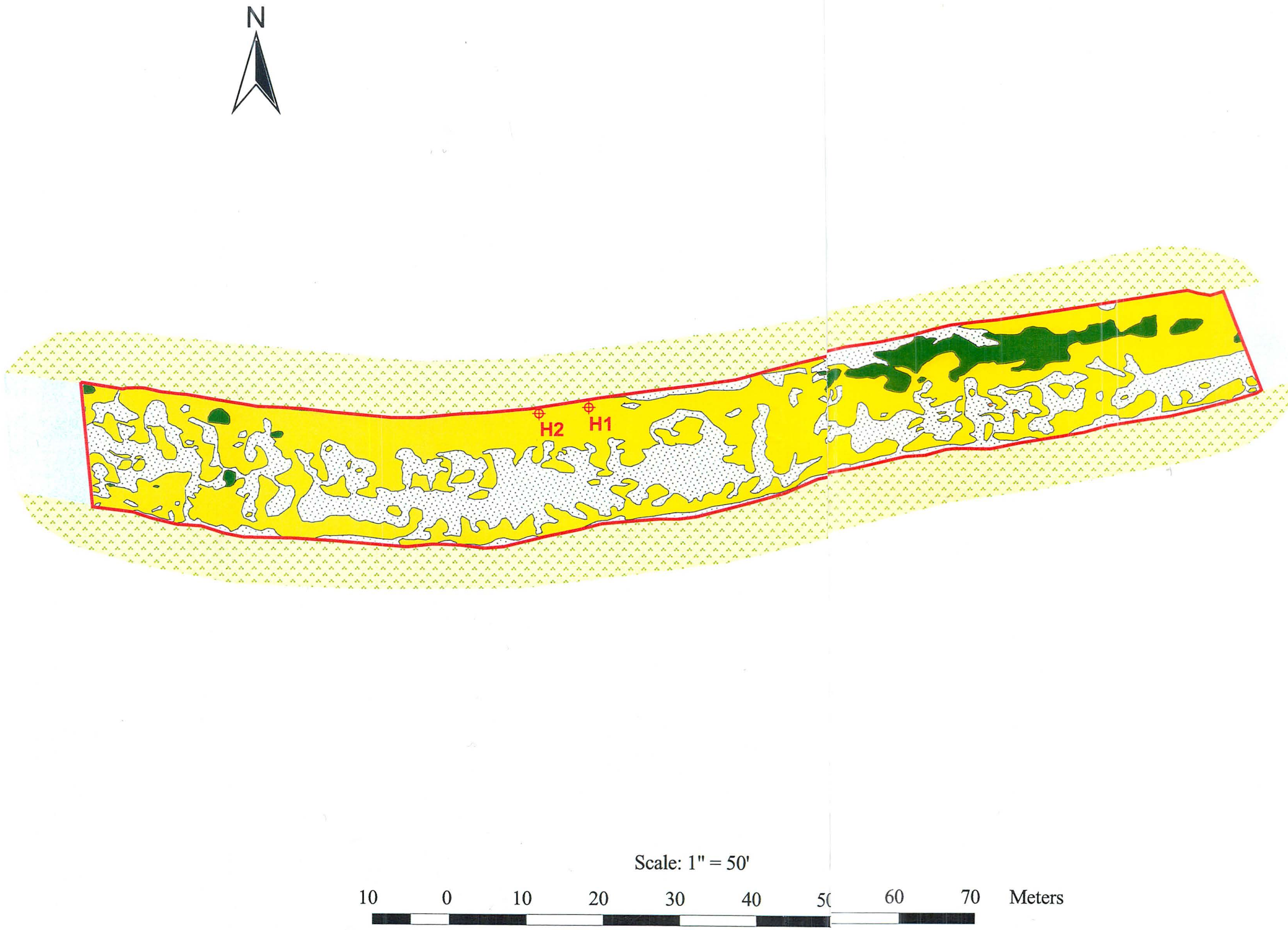
10 0 10 20 30 40 50 60 70 80 90 100 Meters

EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

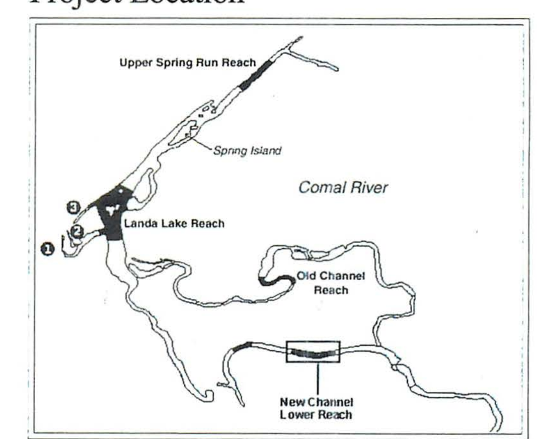
Comal River
Aquatic Vegetation
New Channel Lower Reach
Fall
November 21, 2002



Shore and Islands
River
Study Area (4,173.7 m^2)
Bare Substrate
Drop Net Sample Sites

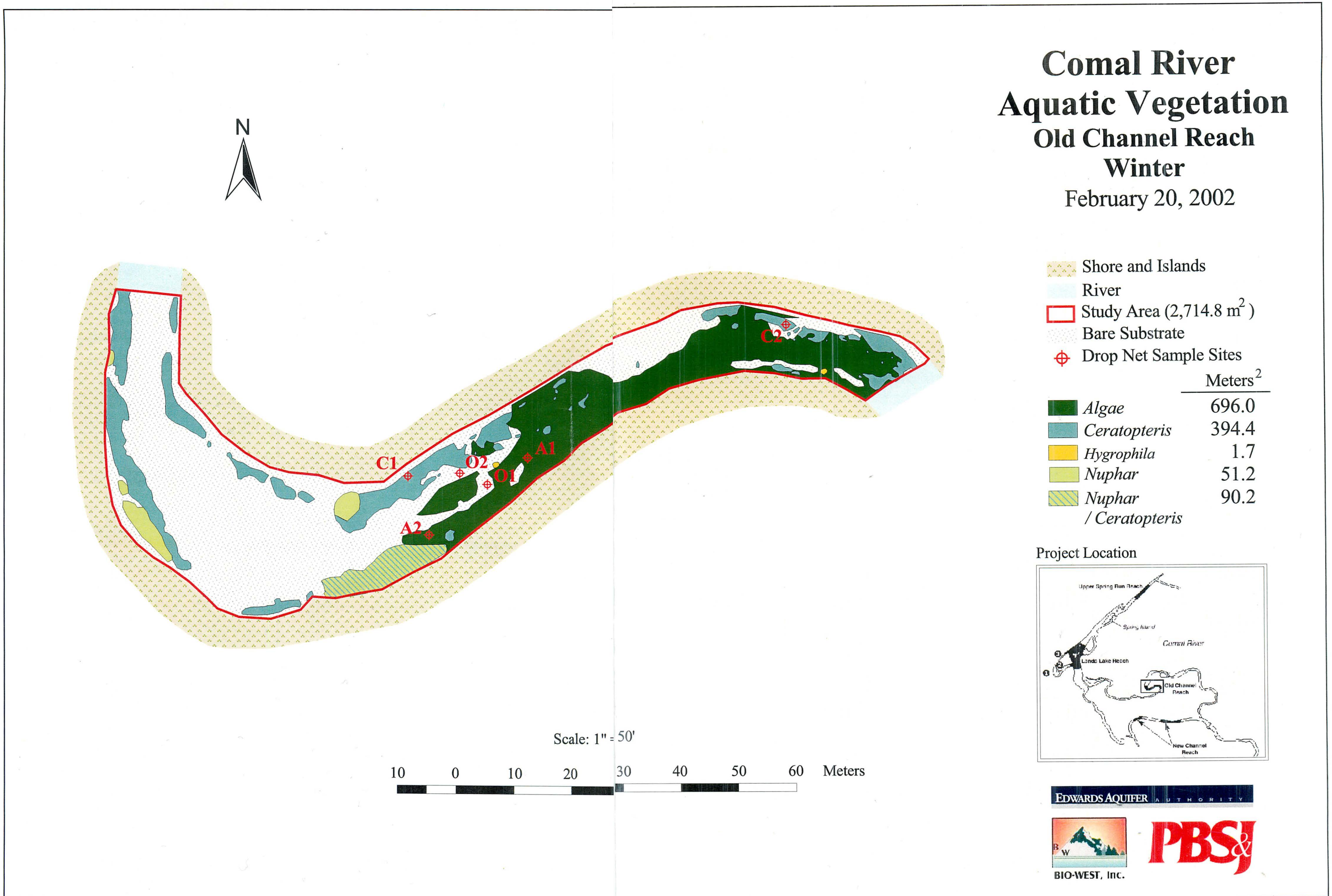
	Meters ^{2}
Cabomba	244.7
Hygrophila	2309.7
Ludwigia	0.8

Project Location

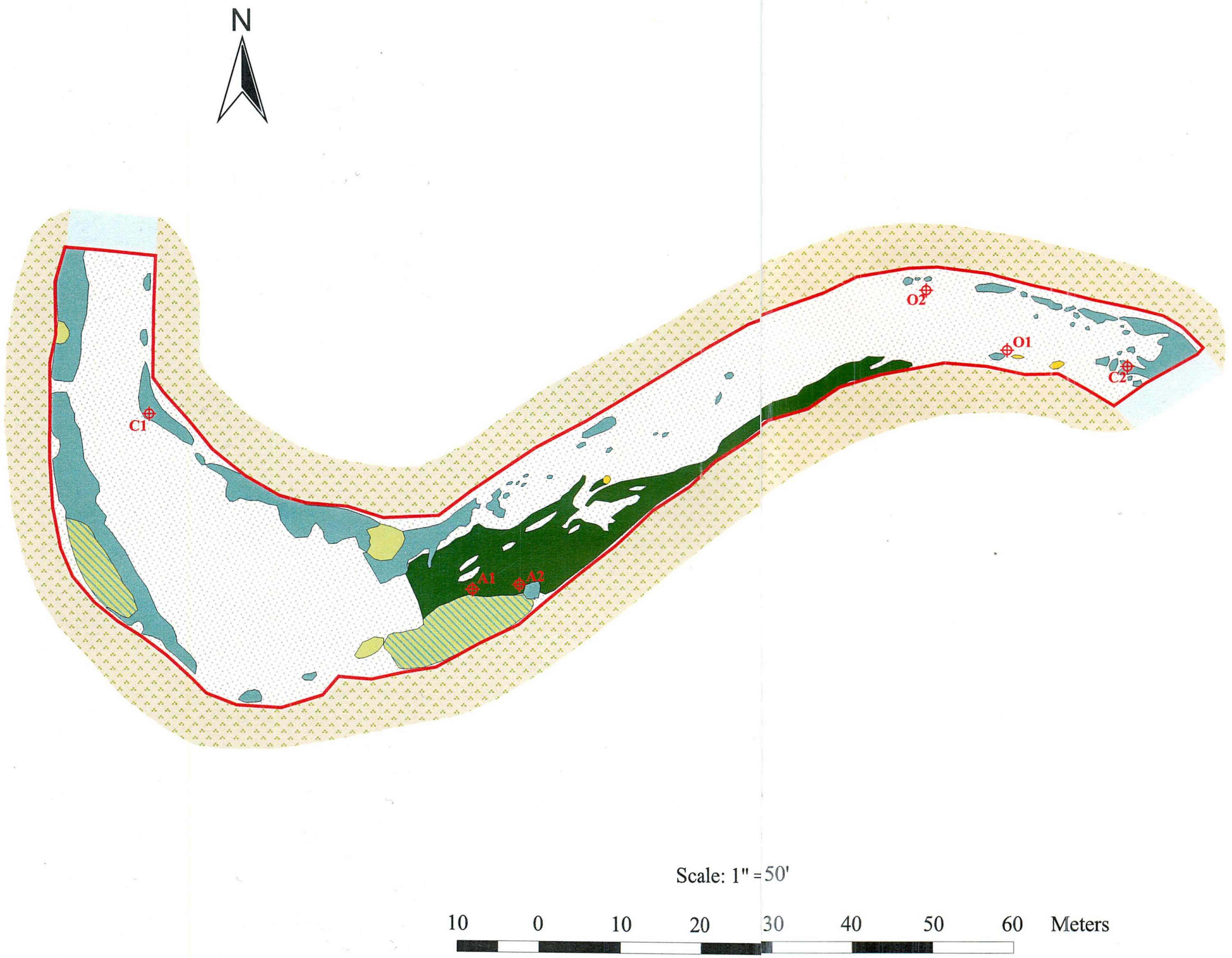


BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY


Comal River
Aquatic Vegetation
Old Channel Reach
Winter
February 20, 2002
N
C1
O2
O1
A1
A2
C2
Shore and Islands
River
Study Area (2,714.8 m^2)
Bare Substrate
Drop Net Sample Sites
Meters^2
Algae 696.0
Ceratopteris 394.4
Hygrophila 1.7
Nuphar 51.2
Nuphar / Ceratopteris 90.2
Project Location
Comal River
Landa Lake Reach
Old Channel Reach
New Channel Reach
Scale: 1" = 50'
10 0 10 20 30 40 50 60 Meters
EDWARDS AQUIFER AUTHORITY
BIO-WEST, Inc.
PBS&J

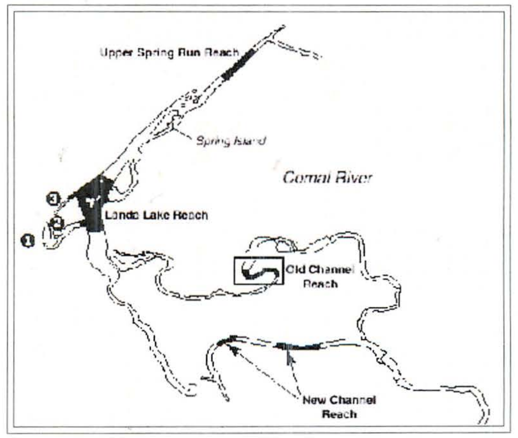
Comal River
Aquatic Vegetation
Old Channel Reach
Spring
May 15, 2002



Shore and Islands
River
Study Area (2,714.8 m^2)
Bare Substrate
Drop Net Sample Sites

	Meters^2
Algae	274.0
Ceratopteris	349.2
Hygrophila	2.6
Nuphar	24.3
Nuphar / *Ceratopteris*	132.6

Project Location

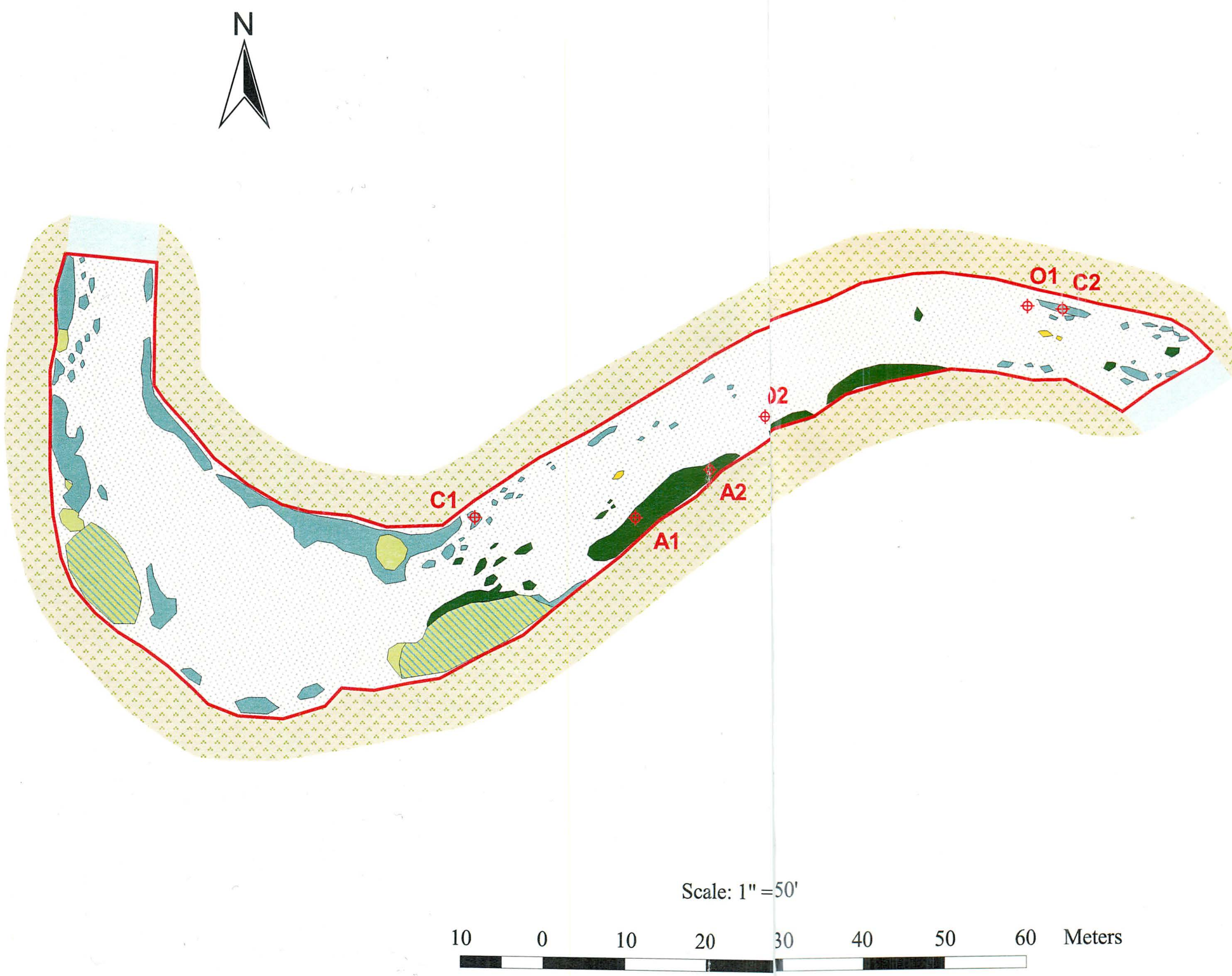


EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

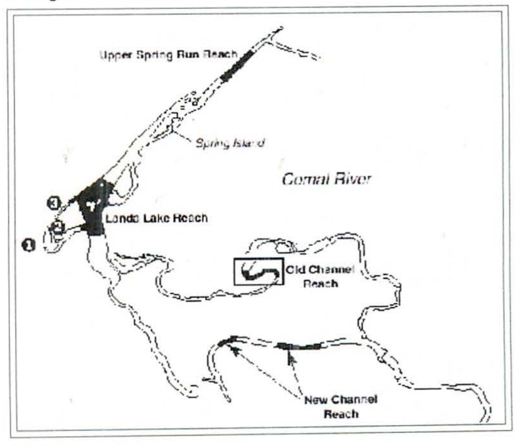
PBSJ

Comal River
Aquatic Vegetation
Old Channel Reach
Summer
August 1, 2002



	Meters^2
Shore and Islands	
River	
Study Area (2,714.8 m^2)	
Bare Substrate	
Drop Net Sample Sites	
Algae	110.3
Ceratopteris	226.9
Hygrophila	2.0
Nuphar	26.8
Nuphar / *Ceratopteris*	163.7

Project Location

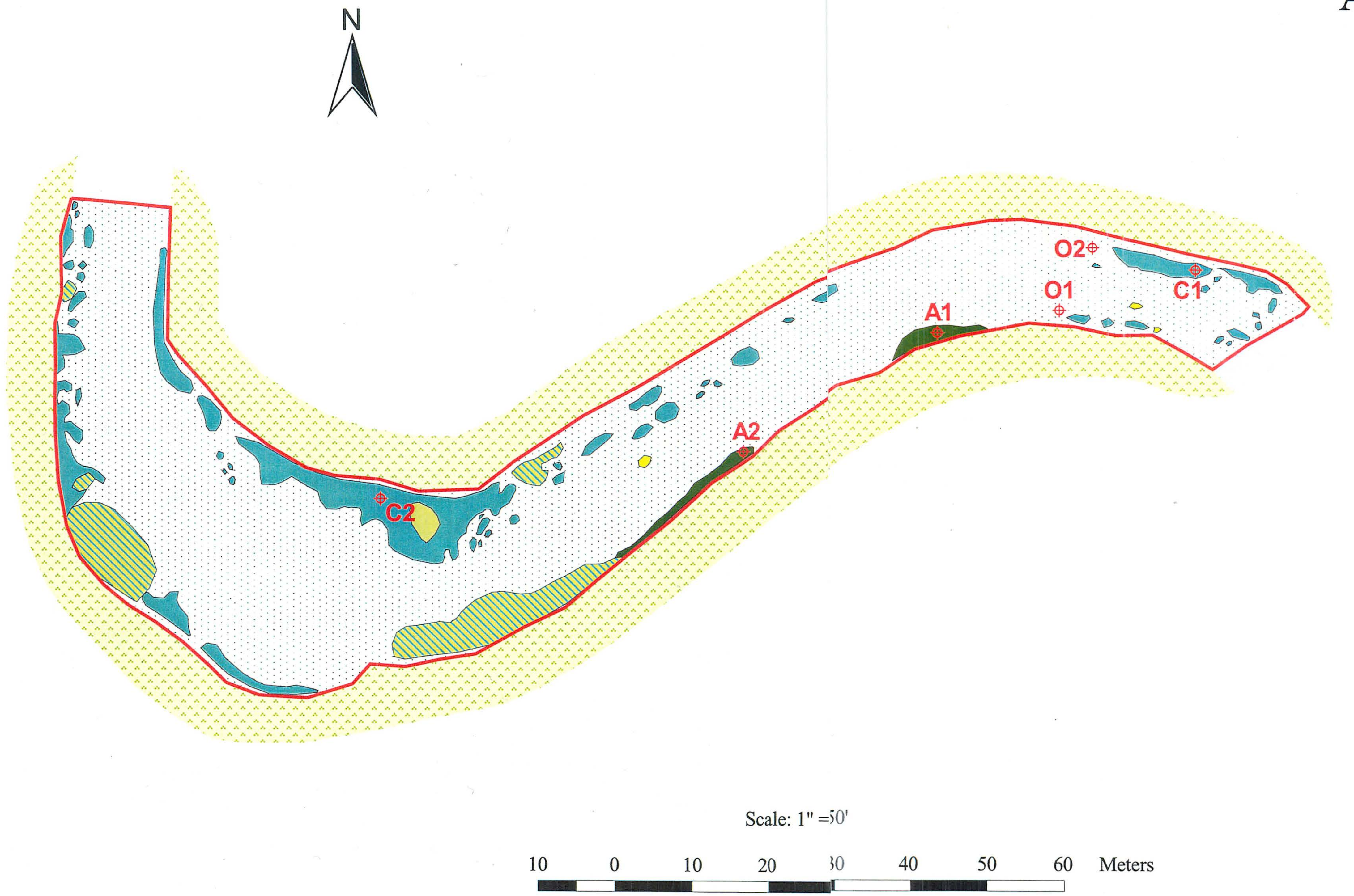


EDWARDS AQUIFER AUTHORITY

BIO-WEST, Inc.

PBS&J

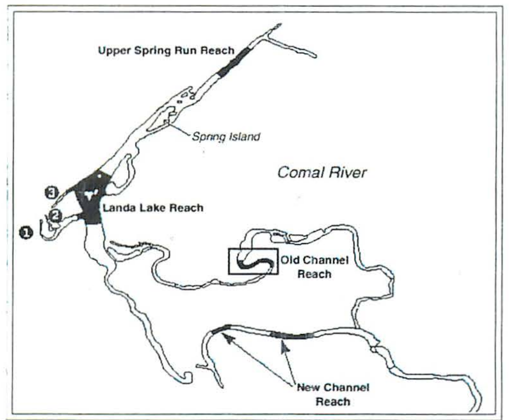
Comal River
Aquatic Vegetation
Old Channel Reach
Fall
October 28, 2002



Shore and Islands
River
Study Area (2,714.8 m^2)
Bare Substrate
Drop Net Sample Sites

	Meters ^{2}
Algae	32.7
Ceratopteris	298.4
Hygrophila	2.4
Nuphar	10.0
Nuphar / Ceratopteris	175.1

Project Location



BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

APPENDIX B: DATA AND GRAPHS

Water Quality Data

Physical water cuality and nutrient measurements for the Comal River system from 2000 to 2002.

Site	Date	Temp	pH	D.O.	Cond	Turb.	Alkalinity	SRP ugP/l	TP ug/l	NH4-N(ug/L)	N03-N(mg/L)	TN-N(mg/L)	TSS (mg/L)
spring run one	8/28/2000	23.72	7.23	5.10	508	1.1	4.080	2.79	19.90	25.12	2.08	2.13	0.0180
spring run one	9/11/2000	23.50	7.04	5.12	504	0.9	3.827	3.66	18.52	165.86	2.38	1.24	0.0040
spring run one	11/13/2000	23.18	7.32	6.32	531	0.6	4.307	6.10	22.66	131.81	1.98	2.11	0.0040
spring run one	3/21/2001	23.19	7.32	5.60	531	0.9	4.072	9.67	10.83	75.00	2.48	2.76	0.0060
spring run one	5/24/2001	23.27	7.22	5.35	518	0.8	4.072	8.34	37.14	90.00	1.99	2.18	0.0090
spring run one	8/27/2001	23.42	7.34	5.81	667	0.1	4.036	3.24	9.48	72.00	2.01	2.11	0.0050
spring run one	11/8/2001	23.45	7.17	5.38	521	0.8	4.069	17.03	24.56	51.00	2.05	2.10	0.0040
spring run one	3/7/2002	23.37	6.98	6.84	503	0.8	4.102	12.39	17.66	25.00	1.69	1.87	0.0060
spring run one	5/30/2002	23.42	6.91	5.95	491	1.2	4.576	13.13	19.00	26.00	1.86	1.93	0.0090
spring run one	8/13/2002	23.42	6.87	6.40	539	1.1	4.585	4.60	14.11	35.00	2.11	2.32	0.0050
	MEAN	23.39	7.14	5.79	531	0.83	4.173	8.09	19.39	69.68	2.06	2.07	0.0070
	MAX	23.72	7.34	6.84	667	1.20	4.585	17.03	37.14	165.86	2.48	2.76	0.0180
	MIN	23.18	6.87	5.10	491	0.07	3.827	2.79	9.48	25.00	1.69	1.24	0.0040
spring run two	8/28/2000	23.62	7.17	5.08	507	0.9	4.118	4.70	20.93	21.00	2.12	1.06	0.0003
spring run two	9/11/2000	23.53	7.13	5.02	505	1.2	4.042	2.61	26.45	70.52	1.99	1.38	0.0220
spring run two	11/13/2000	23.14	7.34	6.24	532	0.8	4.249	7.31	21.97	138.62	1.90	2.13	0.0040
spring run two	3/21/2001	23.44	7.37	5.35	531	0.9	4.136	10.45	13.29	21.00	2.08	2.21	0.0060
spring run two	5/24/2001	23.45	7.26	5.22	518	0.7	4.195	7.15	18.52	52.00	1.84	2.10	0.0020
spring run two	8/27/2001	23.55	7.36	5.56	665	0.1	4.036	3.75	12.35	56.00	2.17	2.32	0.0090
spring run two	11/8/2001	23.48	7.19	5.30	520	0.9	3.937	11.92	16.06	49.00	2.25	2.32	0.0060
spring run two	3/7/2002	23.48	6.96	5.40	503	0.9	4.036	10.91	16.34	19.00	1.79	1.91	0.0040
spring run two	5/30/2002	23.50	6.88	6.22	491	1.2	4.536	12.96	19.22	35.00	1.91	2.02	0.0090
spring run two	8/13/2002	23.50	6.81	6.21	536	1.2	4.535	8.68	14.37	27.00			0.0090
	MEAN	23.47	7.15	5.56	531	0.88	4.182	8.04	17.95	48.91	2.01	1.94	0.0071
	MAX	23.62	7.37	6.24	665	1.20	4.536	12.96	26.45	138.62	2.25	2.32	0.0220
	MIN	23.14	6.81	5.02	491	0.09	3.937	2.61	12.35	19.00	1.79	1.06	0.0003
spring run three	8/28/2000	23.55	7.17	5.23	506	1.1	4.137	3.31	17.83	24.96	2.34	2.50	0.0170
spring run three	9/11/2000	23.47	7.09	5.37	505	1.0	4.042	6.10	19.55	159.05	1.98	1.21	0.0210
spring run three	11/13/2000	23.17	7.37	6.84	525	0.6	4.229	3.66	21.97	134.08	1.74	1.87	0.0001
spring run three	3/21/2001	23.58	7.42	5.95	524	0.8	4.129	11.32	10.71	91.00	2.33	2.52	0.0040
spring run three	5/24/2001	23.44	7.24	5.51	519	0.7	4.293	4.26	8.52	58.00	1.85	2.11	0.0120
spring run three	8/27/2001	23.43	7.36	5.56	665	0.1	4.203	4.01	10.98	76.00	1.89	1.96	0.0060
spring run three	11/8/2001	23.43	7.17	5.58	521	1.2	4.036	13.11	14.10	61.00	2.37	2.43	0.0050
spring run three	3/7/2002	23.50	6.95	5.50	502	0.9	4.069	8.00	14.24	21.00	1.75	1.82	0.0080
spring run three	5/30/2002	23.43	6.87	6.22	492	1.2	4.536	9.79	15.42	49.00	1.85	1.93	0.0070
spring run three	8/13/2002	23.41	6.82	6.39	533	1.1	4.540	6.30	12.30	35.00	1.99	2.41	0.0050
	MEAN	23.44	7.15	5.82	529	0.87	4.221	6.98	14.56	70.91	2.01	2.08	0.0085
	MAX	23.58	7.42	6.84	665	1.20	4.540	13.11	21.97	159.05	2.37	2.52	0.0210
	MIN	23.17	6.82	5.23	492	0.09	4.036	3.31	8.52	21.00	1.74	1.21	0.0001

Physical water cuality and nutrient measurements for the Comal River system from 2000 to 2002 (continued).

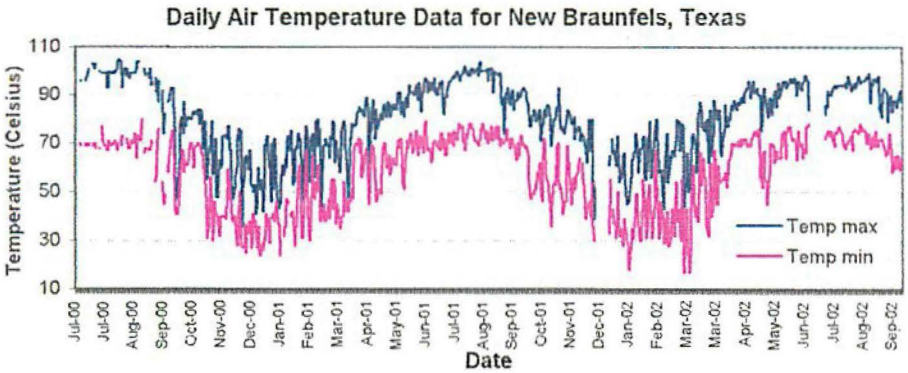
Site	Date	Temp	pH	D.O.	Cond	Turb.	Alkalinity	SRP ugP/l	TP ug/l	NH4-N(ug/L)	N03-N(mg/L)	TN-N(mg/L)	TSS (mg/L)
New Channel, upstream	8/28/2000	25.47	7.41	8.60	503	1.7	4.156	2.26	27.14	N.D.	1.73	1.71	0.0300
New Channel, upstream	9/11/2000	24.01	7.54	7.81	507	2.0	4.092	25.08	45.41	N.D.	1.86	1.95	0.0200
New Channel, upstream	11/13/2000	22.61	7.47	9.04	529	1.1	4.319	6.79	22.31	29.66	2.09	2.10	0.0180
New Channel, upstream	3/21/2001	24.06	7.50	9.52	530	1.1	4.189	8.88	11.62	168.00	1.92	2.38	0.0380
New Channel, upstream	5/24/2001	23.81	7.32	7.17	518	1.5	4.286	4.43	6.45	25.00	1.77	2.23	0.0030
New Channel, upstream	8/27/2001	24.05	7.70	7.46	670	1.4	4.118	1.53	8.10	11.00	2.19	2.30	0.0090
New Channel, upstream	11/8/2001	23.99	7.34	9.68	521	1.3	3.937	1.53	9.88	16.00	2.18	2.39	0.0080
New Channel, upstream	3/7/2002	23.44	7.08	7.73	503	1.1	4.069	9.88	12.99	89.00	1.73	1.92	0.0230
New Channel, upstream	5/30/2002	24.29	7.05	8.64	491	1.6	4.536	12.47	17.20	31.00	1.90	2.24	0.0120
New Channel, upstream	8/13/2002	24.21	6.93	8.64	536	1.9	4.536	5.96	12.79	49.00	2.03	2.33	0.0060
	MEAN	23.99	7.33	8.43	531	1.47	4.224	7.88	17.39	52.33	1.94	2.15	0.0167
	MAX	25.47	7.70	9.68	670	2.00	4.536	25.08	45.41	168.00	2.19	2.39	0.0380
	MIN	22.61	6.93	7.17	491	1.10	3.937	1.53	6.45	11.00	1.73	1.71	0.0030
New Channel, downstream	8/28/2000	25.11	7.66	9.98	502	1.5	4.213	2.09	18.52	31.93	1.79	2.11	0.0440
New Channel, downstream	9/11/2000	24.01	7.54	7.81	507	2.1	4.080	2.44	23.35	106.84	1.26	1.28	0.0220
New Channel, downstream	11/13/2000	22.02	7.72	10.05	523	1.1	4.561	7.14	23.34	31.93	1.83	1.84	0.0120
New Channel, downstream	3/21/2001	24.30	7.77	9.93	531	1.1	4.363	8.80	8.86	93.00	1.95	2.34	0.0120
New Channel, downstream	5/24/2001	23.75	7.59	8.77	516	1.3	4.396	9.42	17.83	40.00	1.74	2.01	0.0040
New Channel, downstream	8/27/2001	23.98	7.74	9.54	665	1.5	4.006	7.66	19.73	29.00	2.25	2.32	0.0090
New Channel, downstream	11/8/2001	23.93	7.63	9.82	520	1.4	4.003	12.09	19.06	32.00	2.09	2.21	0.0100
New Channel, downstream	3/7/2002 2	23.33	7.38	9.13	504	1.0	4.102	9.98	18.96	94.00	1.76	1.96	0.0160
New Channel, downstream	5/30/2002 2	24.49	7.34	9.04	490	1.8	4.536	14.35	23.00	42.00	1.84	1.98	0.0240
New Channel, downstream	8/13/2002 1	24.46	7.20	9.87	536	2.0	4.556	4.77	12.35	41.00	1.98	2.25	0.0040
	MEAN	23.94	7.56	9.39	529	1.48	4.282	7.87	18.50	54.17	1.85	2.03	0.0157
	MAX	25.11	7.77	10.05	665	2.10	4.561	14.35	23.35	106.84	2.25	2.34	0.0440
	MIN	22.02	7.20	7.81	490	1.00	4.003	2.09	8.86	29.00	1.26	1.28	0.0040
Bleider's Creek	8/28/2000	24.97	7.15	3.91	510	2.6	4.099	10.10	33.00	261.20	1.79	1.96	0.0260
Bleider's Creek	9/11/2000	25.38	7.19	3.19	507	3.0	4.024	2.79	25.41	283.90	1.32	1.36	0.0260
Bleider's Creek	11/13/2000	20.87	7.51	8.40	529	1.2	4.054	5.57	41.97	93.22	1.77	1.80	0.0220
Bleider's Creek	3/21/2001	21.67	7.66	10.50	523	1.3	4.059	10.88	8.17	77.00	2.23	2.41	0.0060
Bleider's Creek	5/24/2001	23.96	7.31	5.12	500	1.6	4.118	8.00	16.79	120.00	1.34	1.66	0.0240
Bleider's Creek	8/27/2001	24.40	7.37	3.72	640	1.4	3.937	2.21	9.60	109.00	1.41	1.63	0.0180
Bleider's Creek	11/8/2001	22.35	7.35	6.70	521	1.3	3.606	21.96	25.06	56.00	2.22	2.40	0.0210
Bleider's Creek	3/7/2002 1	21.93	7.27	8.39	497	1.3	3.870	8.30	15.95	56.00	1.70	1.92	0.0090
Bleider's Creek	5/30/2002 1	24.70	7.00	5.80	481	2.4	4.335	15.96	22.45	56.00	1.62	1.88	0.0230
Bleider's Creek	8/13/2002 1	24.24	6.87	4.77	534	2.2	4.236	4.43	12.98	43.00	2.03	2.44	0.0060
	MEAN	23.45	7.27	6.05	524	1.83	4.034	9.02	21.14	115.53	1.74	1.95	0.0181
	MAX	25.38	7.66	10.50	640	3.00	4.335	21.96	41.97	283.90	2.23	2.44	0.0260
	MIN	20.87	6.87	3.19	481	1.20	3.606	2.21	8.17	43.00	1.32	1.36	0.0060

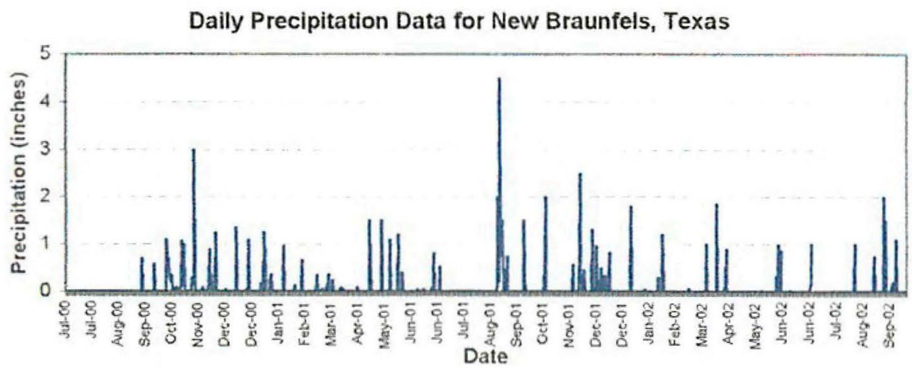
Physical water cuality and nutrient measurements for the Comal River system from 2000 to 2002 (continued).

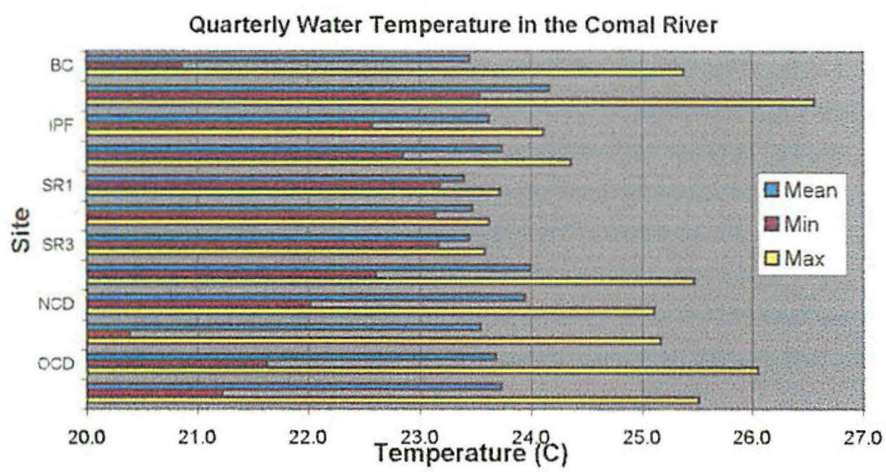
Site	Date	Temp	pH	D.O.	Cond	Turb.	Alkalinity	SRP ugP/l	TP ug/l	NH4-N(ug/L)	N03-N(mg/L)	TN-N(mg/L)	TSS (mg/L)
Heildelburg, Main Channel	8/28/2000	24.09	7.19	4.99	513	1.4	3.967	2.26	17.14	20.58	1.70	1.80	0.0280
Heildelburg, Main Channel	9/11/2000	26.56	*	6.25	508	2.1	4.042	4.01	23.35	199.91	1.65	1.28	0.0210
Heildelburg, Main Channel	3/21/2001	23.70	7.41	6.86	531	1.6	4.099	9.93	7.83	93.00	2.08	2.38	0.0180
Heildelburg, Main Channel	5/24/2001	23.85	7.26	4.48	519	1.9	4.276	5.45	11.97	153.00	1.94	2.30	0.0240
Heildelburg, Main Channel	8/27/2001	23.95	7.39	6.31	667	1.5	4.118	2.90	10.13	128.00	2.03	2.22	0.0200
Heildelburg, Main Channel	11/8/2001	23.67	7.25	5.79	523	1.1	3.937	15.67	17.05	65.00	2.21	2.37	0.0260
Heildelburg, Main Channel	3/7/2002 1	23.54	7.06	6.50	503	2.1	3.936	9.38	18.73	70.00	1.70	1.90	0.0200
Heildelburg, Main Channel	5/30/2002 1	24.17	6.93	6.16	492	2.0	4.516	14.30	24.30	79.00	1.96	2.07	0.0190
Heildelburg, Main Channel	8/13/2002 1	23.89	6.88	5.82	536	2.0	4.478	4.94	15.47	30.00	1.93	2.34	0.0050
	MEAN	24.16	7.17	5.91	532	1.74	4.152	7.65	16.22	93.17	1.91	2.07	0.0201
	MAX	26.56	7.41	6.86	667	2.10	4.516	15.67	24.30	199.91	2.21	2.38	0.0280
	MIN	23.54	6.88	4.48	492	1.10	3.936	2.26	7.83	20.58	1.65	1.28	0.0050
Island Park, Far Channel	8/28/2000	23.84	7.16	5.97	509	1.6	4.269	4.88	22.31	16.04	1.56	1.68	0.0490
Island Park, Far Channel	9/11/2000	24.06	7.15	5.88	509	1.4	4.138	4.53	22.31	188.56	1.62	0.92	0.0110
Island Park, Far Channel	11/13/2000	22.57	7.36	7.88	522	1.7	4.257	5.75	47.83	25.12	1.93	1.99	0.0100
Island Park, Far Channel	3/21/2001	23.58	7.30	6.01	532	1.6	4.221	11.32	13.69	71.00	2.06	2.40	0.0400
Island Park, Far Channel	5/24/2001	23.53	7.24	6.31	521	1.6	4.356	4.77	17.72	16.00	1.92	2.14	0.0050
Island Park, Far Channel	8/27/2001	24.11	7.37	6.92	672	1.4	4.276	2.55	10.70	10.00	2.14	2.25	0.0040
Island Park, Far Channel	11/8/2001	23.45	7.26	6.68	521	1.1	3.970	2.90	11.10	16.00	2.24	2.30	0.0050
Island Park, Far Channel	3/7/2002 1	23.41	7.03	7.20	505	1.1	4.135	12.17	17.96	71.00	1.70	1.72	0.0230
Island Park, Far Channel	5/30/2002 1	23.83	6.88	6.57	495	1.5	4.496	13.30	19.43	19.00	1.93	2.01	0.0160
Island Park, Far Channel	8/13/2002 1	23.81	7.32	6.82	537	1.4	4.505	5.79	11.64	29.00	2.04	2.19	0.0130
	MEAN	23.62	7.21	6.62	532	1.44	4.262	6.79	19.47	46.17	1.91	1.96	0.0176
	MAX	24.11	7.37	7.88	672	1.70	4.505	13.30	47.83	188.56	2.24	2.40	0.0490
	MIN	22.57	6.88	5.88	495	1.10	3.970	2.55	10.70	10.00	1.56	0.92	0.0040
Island Park, Near Channel	8/28/2000	23.80	7.11	4.81	508	1.1	4.289	3.48	19.21	29.66	5.97	0.62	0.0180
Island Park, Near Channel	9/11/2000	23.96		5.08	508	1.1	4.118	10.10	26.10	288.44	1.46	1.70	0.0180
Island Park, Near Channel	11/13/2000	22.85	7.28	6.90	524	1.1	4.366	6.79	34.03	13.77	1.82	1.91	0.0100
Island Park, Near Channel	3/21/2001	23.97	7.36	8.40	530	1.3	4.257	10.80	27.40	46.00	1.89	2.14	0.0160
Island Park, Near Channel	5/24/2001	23.61	7.24	5.32	520	1.5	4.381	6.30	8.86	18.00	1.86	2.07	0.0060
Island Park, Near Channel	8/27/2001	23.84	7.34	6.05	671	1.4	4.118	1.87	7.07	24.00	2.24	2.37	0.0050
Island Park, Near Channel	11/8/2001	23.61	7.23	6.18	520	1.0	3.970	6.30	12.06	32.00	2.18	2.32	0.0070
Island Park, Near Channel	3/7/2002 3	23.57	7.03	6.71	504	1.1	4.069	11.00	19.58	36.00	1.78	1.90	0.0190
Island Park, Near Channel	5/30/2002 2	24.36	6.90	6.25	491	1.2	4.496	11.36	18.54	21.00	1.90	1.96	0.0120
Island Park, Near Channel	8/13/2002 3	23.83	6.82	6.39	537	1.5	4.500	5.62	11.54	28.00	2.03	2.10	0.0090
	MEAN	23.74	7.15	6.21	531	1.23	4.256	7.36	18.44	53.69	2.31	1.91	0.0120
	MAX	24.36	7.36	8.40	671	1.50	4.500	11.36	34.03	288.44	5.97	2.37	0.0190
	MIN	22.85	6.82	4.81	491	1.00	3.970	1.87	7.07	13.77	1.46	0.62	0.0050

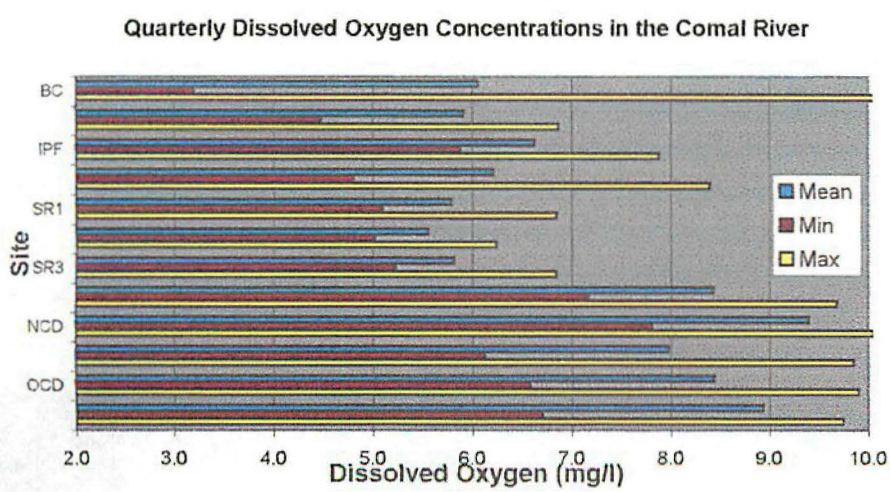
Physical water cuality and nutrient measurements for the Comal River system from 2000 to 2002 (continued).

Site	Date	Temp	pH	D.O.	Cond	Turb.	Alkalinity	SRP ugP/l	TP ug/l	NH4-N(ug/L)	N03-N(mg/L)	TN-N(mg/L)	TSS (mg/L)
Old Channel,Upstream	8/28/2000	25.17	7.60	7.10	511	2.2	4.401	5.75	25.41	11.50	1.77	1.70	0.0230
Old Channel,Upstream	9/11/2000	24.40	7.48	6.12	512	2.8	4.231	7.49	30.24	131.81	1.82	1.38	0.0220
Old Channel,Upstream	11/13/2000	20.39	7.87	8.99	533	1.6	4.444	9.93	35.07	34.20	1.65	1.70	0.0520
Old Channel,Upstream	3/21/2001	22.51	7.86	9.85	534	1.4	4.359	10.45	9.45	57.00	1.72	1.99	0.1640
Old Channel,Upstream	5/24/2001	22.93	7.62	6.57	525	1.5	4.343	8.34	12.31	34.00	1.61	2.00	0.0080
Old Channel,Upstream	8/27/2001	23.92	7.70	7.09	664	1.5	4.203	N.D.	11.02	29.00	2.04	2.11	0.0100
Old Channel,Upstream	11/8/2001	23.82	7.58	8.46	522	1.5	4.003	26.73	33.26	25.00	2.08	2.21	0.0100
Old Channel,Upstream	3/7/2002 1	23.09	7.38	8.56	578?	2.1	4.069	10.77	17.99	57.00	2.15	2.32	0.0160
Old Channel,Upstream	5/30/2002 1	24.60	7.25	8.56	492	2.0	4.576	13.30	16.33	26.00	1.89	2.02	0.0190
Old Channel,Upstream	8/13/2002 1	24.55	7.15	8.49	538	2.0	4.596	3.24	9.24	35.00	1.61	1.98	0.0040
	MEAN	23.54	7.55	7.98	537	1.86	4.323	10.67	20.03	44.05	1.83	1.94	0.0328
	MAX	25.17	7.87	9.85	664	2.80	4.596	26.73	35.07	131.81	2.15	2.32	0.1640
	MIN	20.39	7.15	6.12	492	1.40	4.003	3.24	9.24	11.50	1.61	1.38	0.0040
Old Channel,Downstream	8/28/2000	26.05	7.60	8.38	505	2.0	4.269	2.44	21.28	25.12	1.64	0.63	0.0210
Old Channel,Downstream	9/11/2000	24.18	7.38	6.58	508	2.2	4.194	2.79	24.38	38.74	1.87	1.27	0.0230
Old Channel,Downstream	11/13/2000	21.63	7.62	9.90	530	1.7	4.307	5.40	38.52	134.08	2.20	2.34	0.0300
Old Channel,Downstream	3/21/2001	24.17	7.80	9.81	531	1.6	4.269	10.71	188.86	75.00	2.02	2.39	0.3660
Old Channel,Downstream	5/24/2001	23.48	7.52	7.46	520	1.6	4.303	8.68	18.86	16.00	1.75	1.99	0.0020
Old Channel,Downstream	8/27/2001	24.21	7.84	7.86	665	1.8	4.118	4.60	15.59	9.00	2.09	2.11	0.0060
Old Channel,Downstream	11/8/2001	22.29	7.65	8.40	527	1.9	4.069	10.39	17.11	10.00	2.22	2.42	0.0090
Old Channel,Downstream	3/7/2002 1	22.34	7.46	8.38	508	2.4	4.201	14.25	19.25	75.00	1.76	2.02	0.0220
Old Channel,Downstream	5/30/2002 1	24.02	7.56	9.06	496	2.8	4.656	10.66	16.24	19.00	1.98	2.26	0.0360
Old Channel,Downstream	8/13/2002 1	24.42	7.36	8.53	542	2.7	4.539	6.13	14.33	42.00	2.04	2.30	0.0170
	MEAN	23.68	7.58	8.44	533	2.07	4.293	7.60	37.44	44.39	1.96	1.97	0.0532
	MAX	26.05	7.84	9.90	665	2.80	4.656	14.25	188.86	134.08	2.22	2.42	0.3660
	MIN	21.63	7.36	6.58	496	1.60	4.069	2.44	14.33	9.00	1.64	0.63	0.0020
The Other Place,(Iverness)	8/28/2000	25.51	7.79	9.51	505	1.9	4.289	2.79	17.14	25.12	5.83	1.00	0.0190
The Other Place,(Iverness)	9/11/2000	24.30	7.57	6.70	509	2.8	4.118	3.48	23.35	138.62	1.92	1.89	0.0250
The Other Place,(Iverness)	11/13/2000	21.22	7.85	9.18	525	3.2	4.405	10.45	29.55	20.58	1.78	1.81	0.0280
The Other Place,(Iverness)	3/21/2001	23.12	7.88	9.75	532	3.1	4.270	10.71	2.66	50.00	2.28	2.53	0.0180
The Other Place,(Iverness)	5/24/2001	23.70	7.71	8.52	516	2.7	4.404	6.13	9.21	202.00	1.62	2.27	0.0070
The Other Place,(Iverness)	8/27/2001	24.33	7.89	9.27	662	2.5	4.203	1.36	9.03	36.00	2.31	2.55	0.0050
The Other Place,(Iverness)	11/8/2001	23.29	7.72	9.10	521	2.2	4.003	10.05	14.07	45.00	2.19	2.31	0.0090
The Other Place,(Iverness)	3/7/2002 1	23.16	7.54	9.08	504	1.1	4.135	10.97	24.16	53.00	1.78	2.13	0.0090
The Other Place,(Iverness)	5/30/2002 1	24.38	7.47	8.61	491	2.5	4.596	16.50	23.96	98.00	1.93	2.31	0.0290
The Other Place,(Iverness)	8/13/2002 2	24.29	7.25	9.68	535	2.4	4.603	7.49	16.20	43.00	2.05	2.56	0.0110
	MEAN	23.73	7.67	8.94	530	2.44	4.303	7.99	16.93	71.13	2.37	2.14	0.0160
	MAX	25.51	7.89	9.75	662	3.20	4.603	16.50	29.55	202.00	5.83	2.56	0.0290
	MIN	21.22	7.25	6.70	491	1.10	4.003	1.36	2.66	20.58	1.62	1.00	0.0050

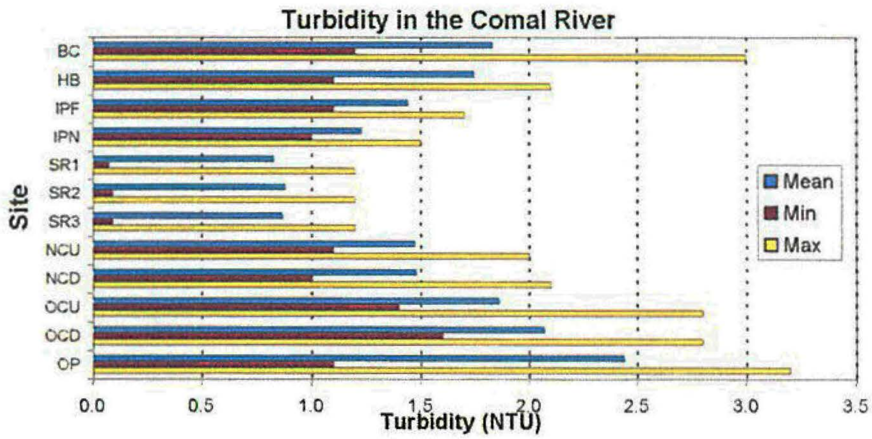


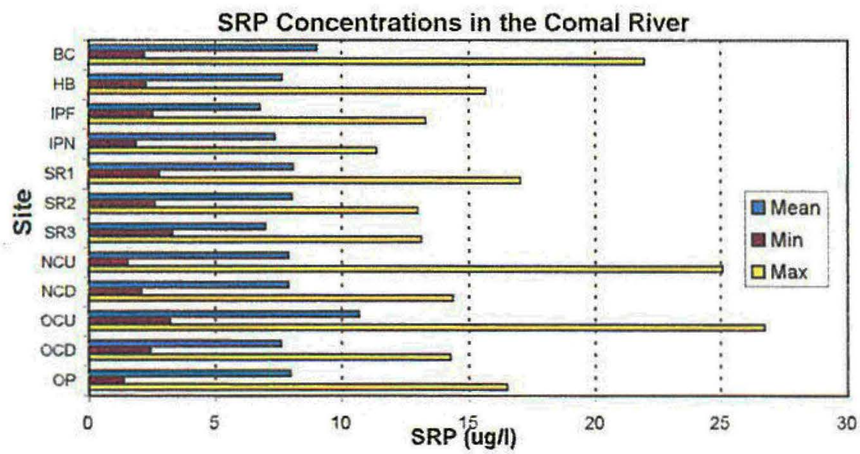


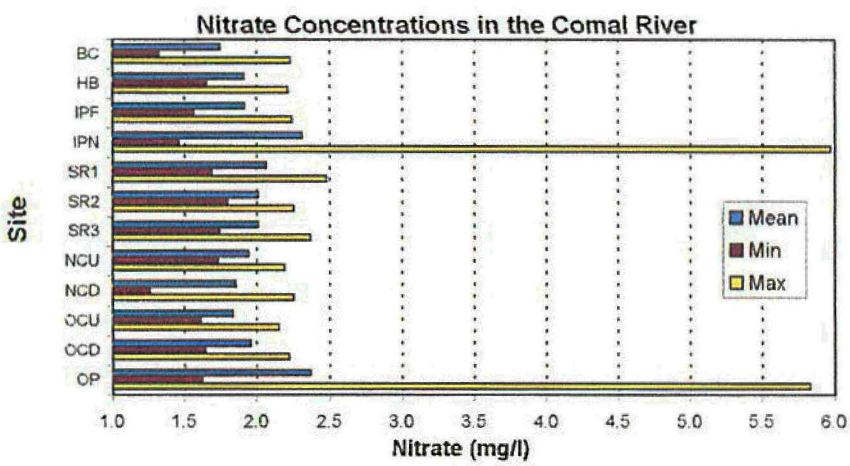


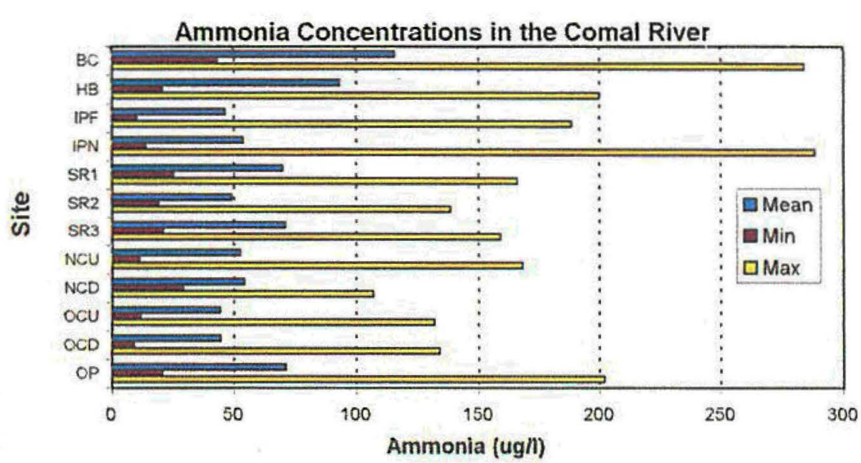


BC - Bleider's Creek
HB - Heildelburg, Main Channel
IPF - Island Park, Far Channel
IPN - Island Park, Near Channel
SR1 - Spring run one
SR2 - Spring run two
SR3 - Spring run three
NCU - New Channel, upstream
NCD - New Channel, downstream
OCU - Old Channel,Upstream
OCD - Old Channel,Downstream
OP - The Other Place,(Iverness)









- BC - Bleider's Creek
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- SR1 - Spring run one
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- SR3 - Spring run three
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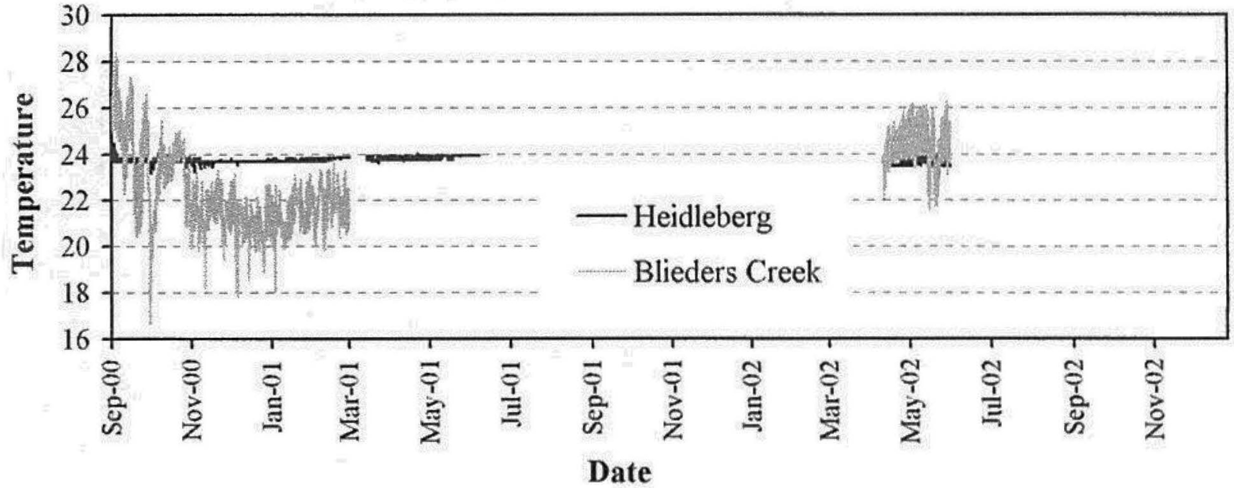
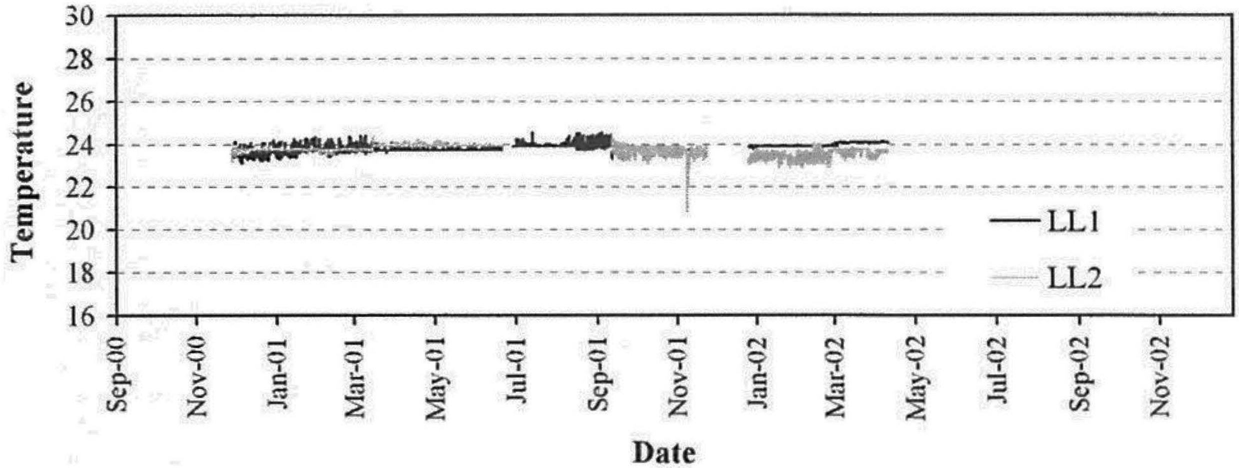
- NCD - New Channel, downstream
- OCU - Old Channel,Upstream
- OCD - Old Channel,Downstream
- OP - The Other Place,(Iverness)

Thermistor Graphs

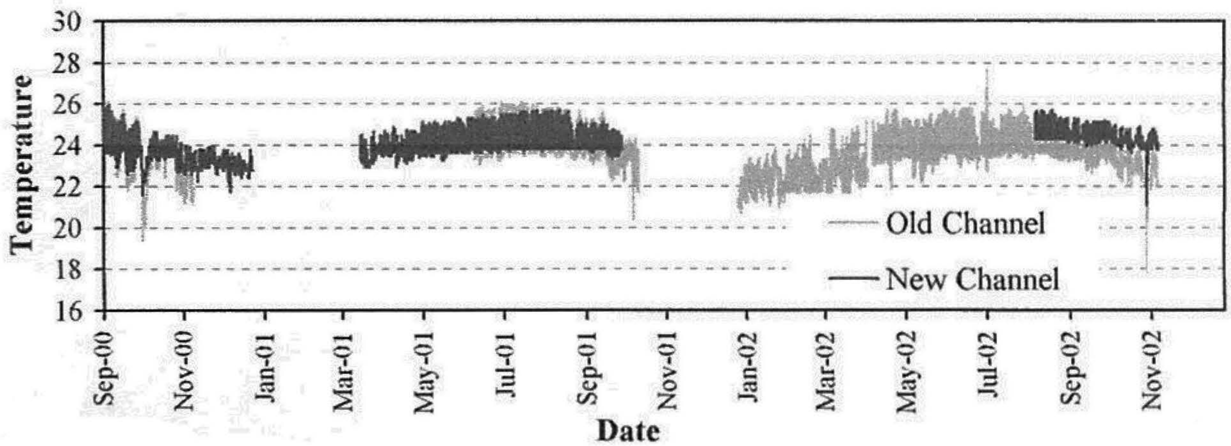
Thermistor Data: Comal Headwaters



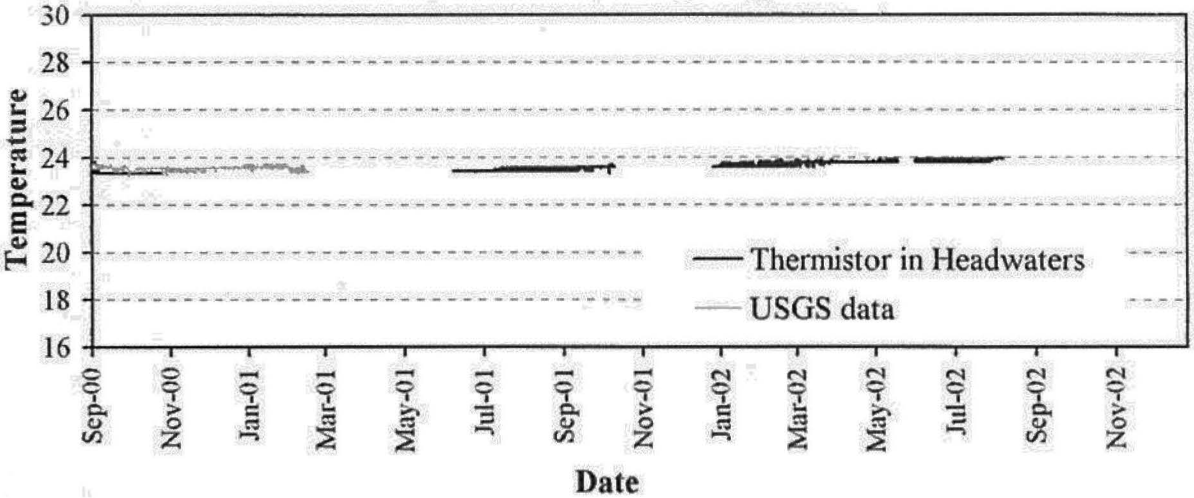
Thermistor Data: Landa Lake Bottom



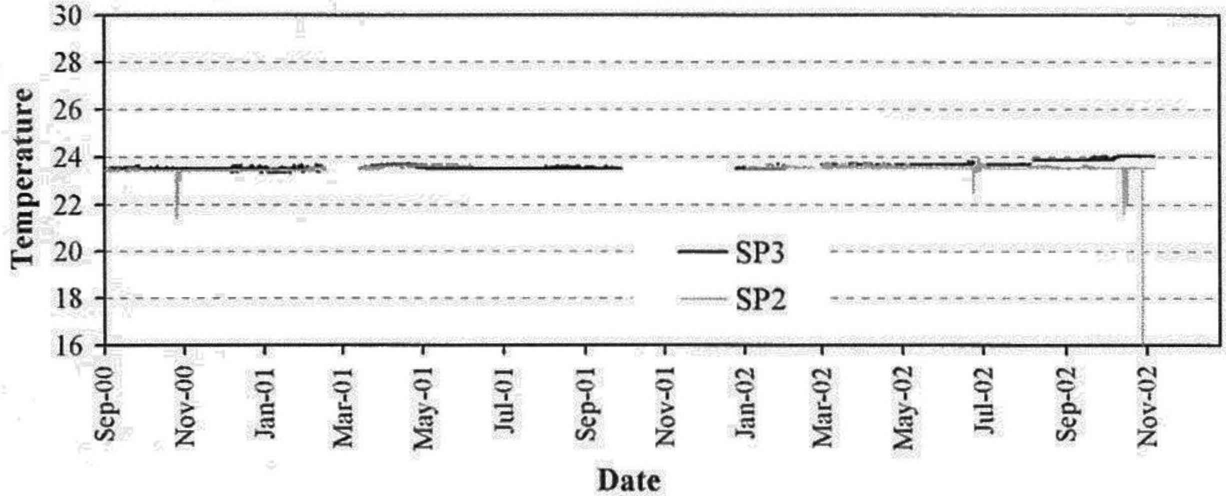
Thermistor Data: Old & New Channels



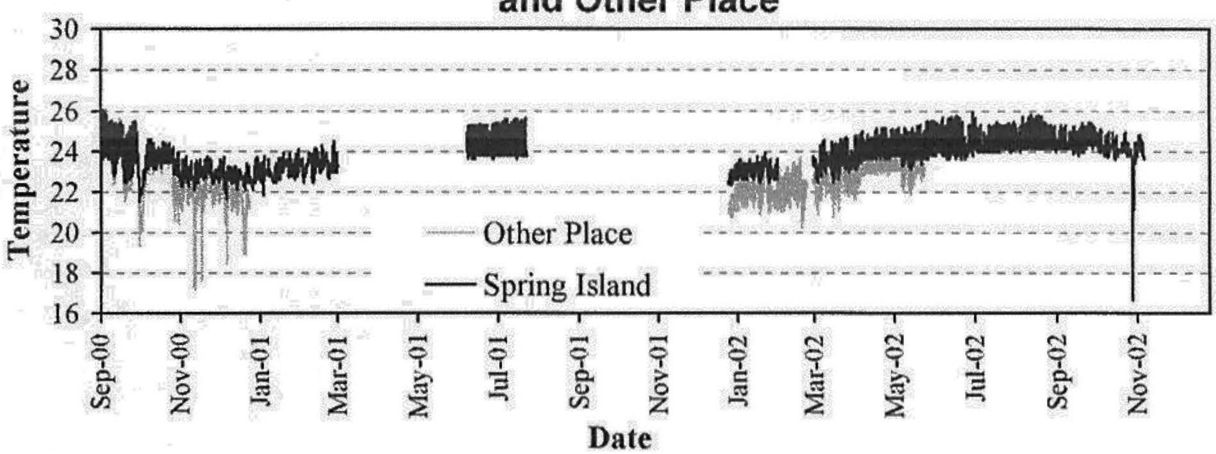
Thermistor Data: Spring Run 1



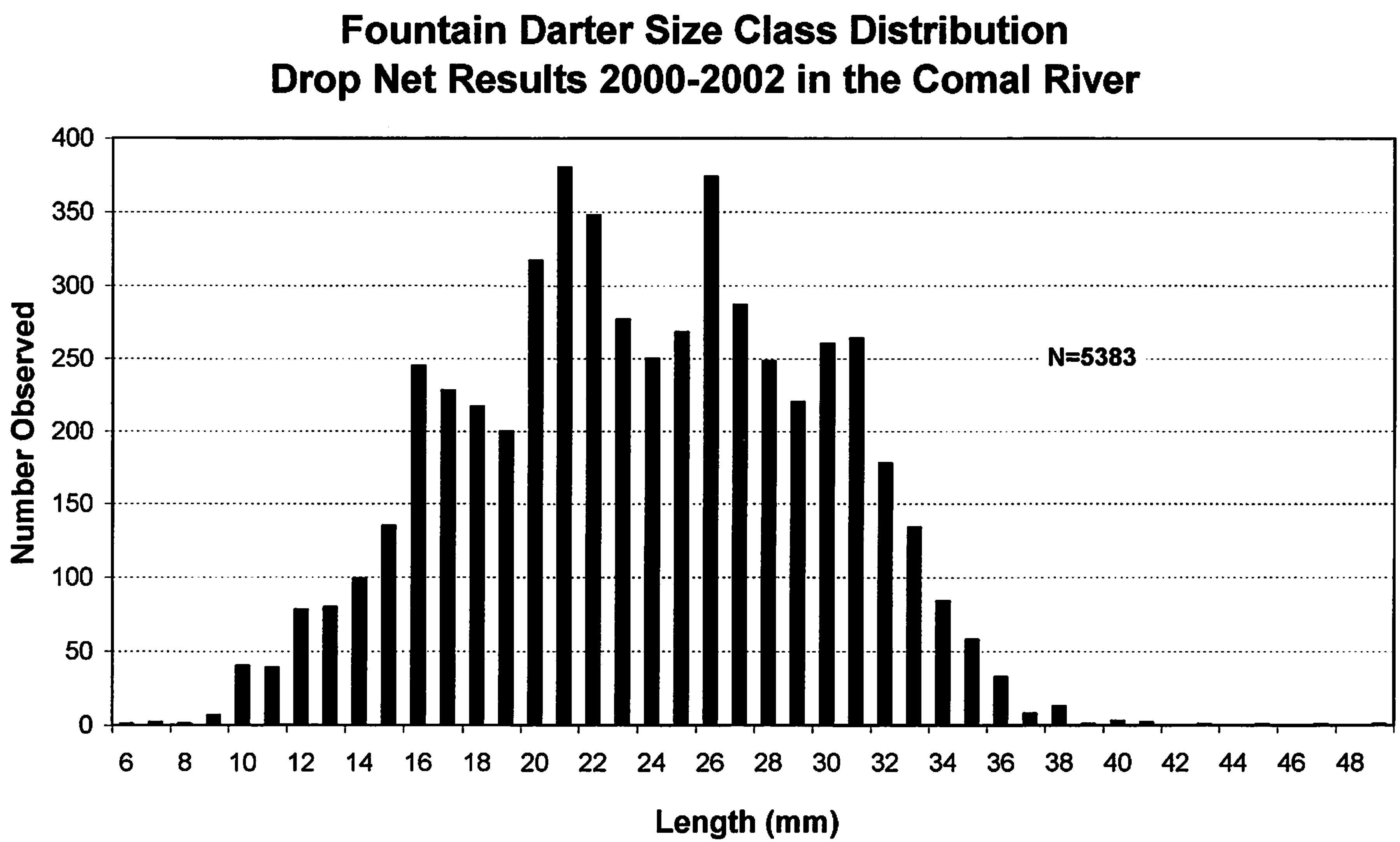
Thermistor Data: Spring Runs 2 & 3



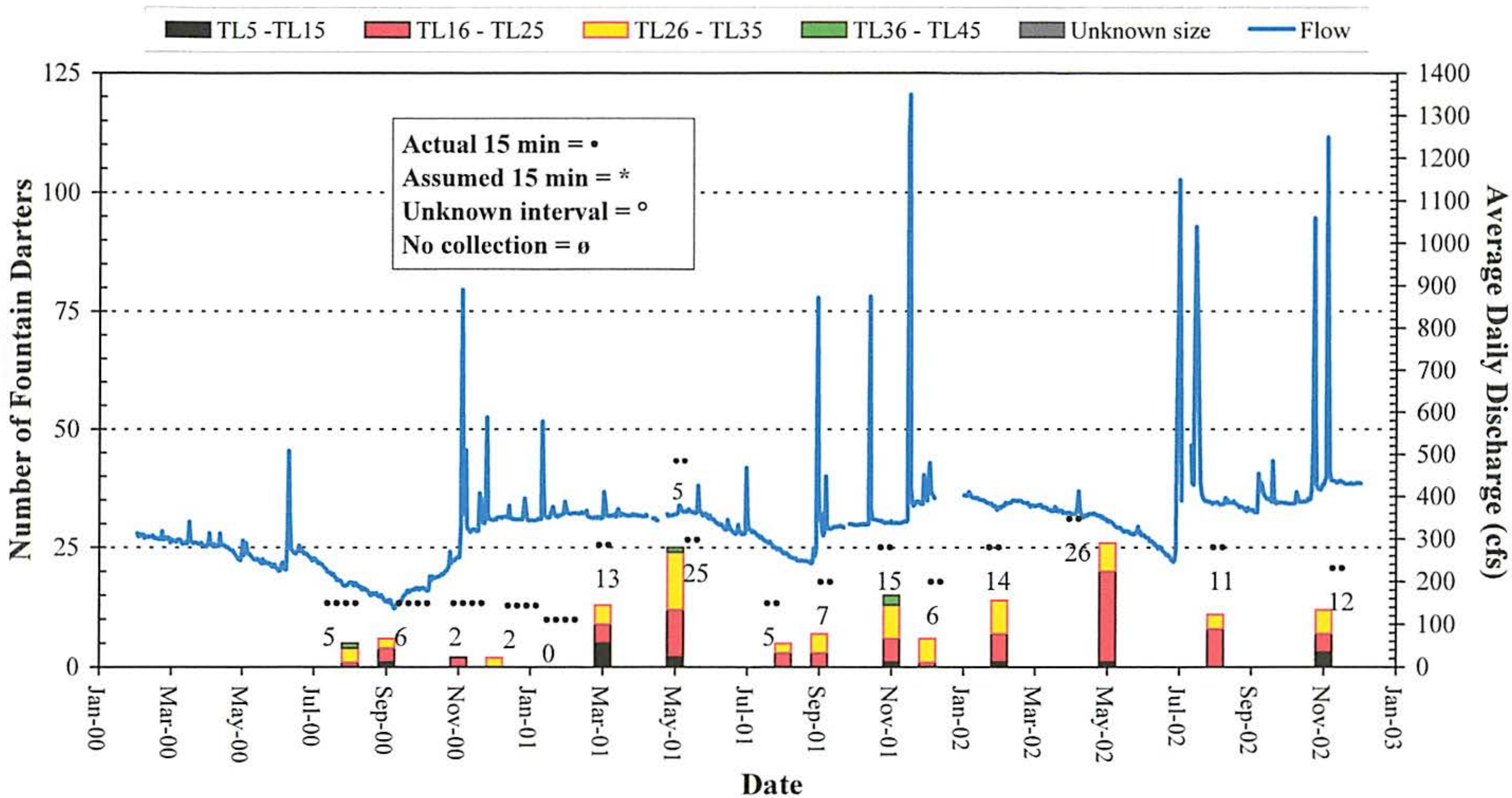
Thermistor Data: Spring Island and Other Place



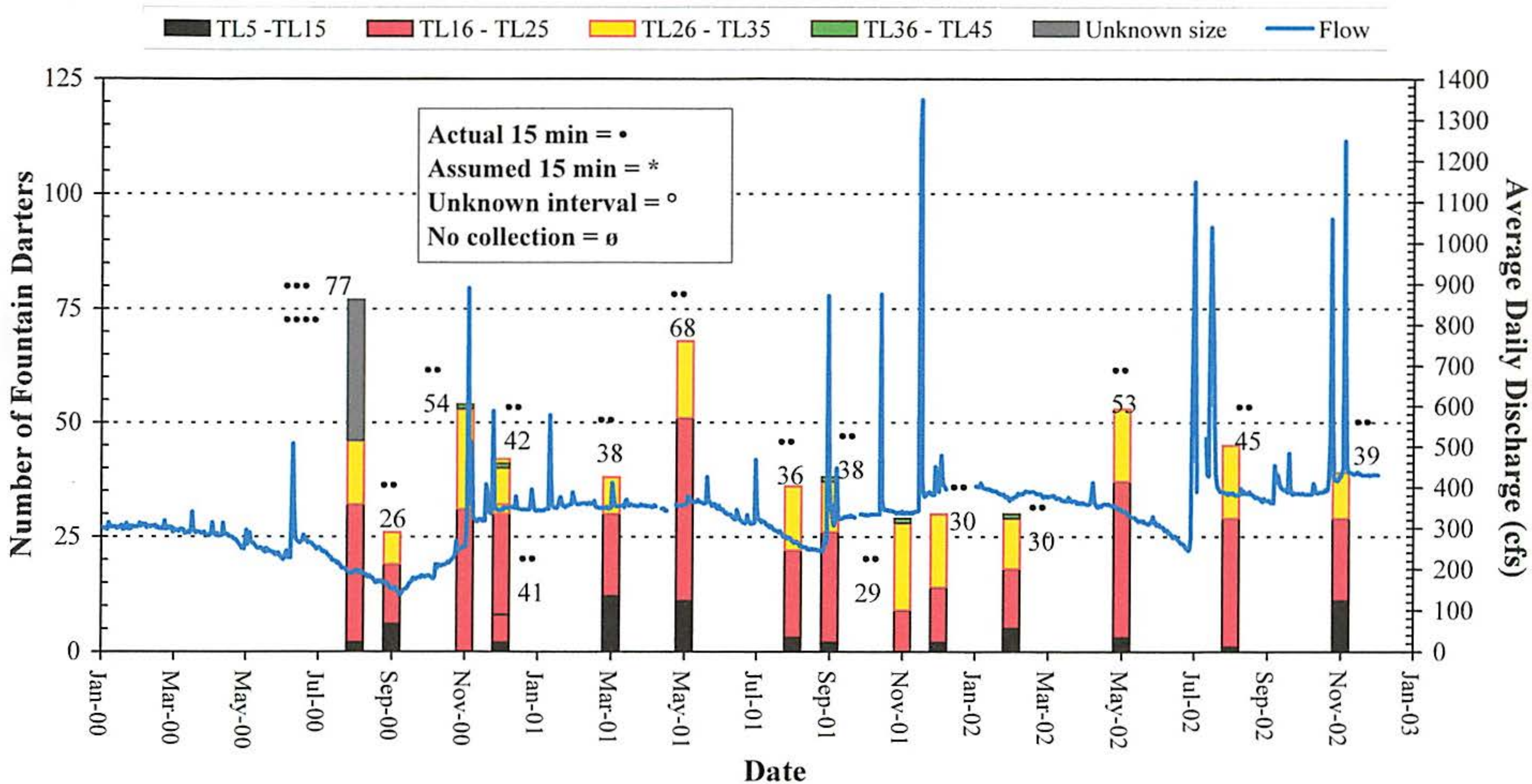
Fountain Darter Data

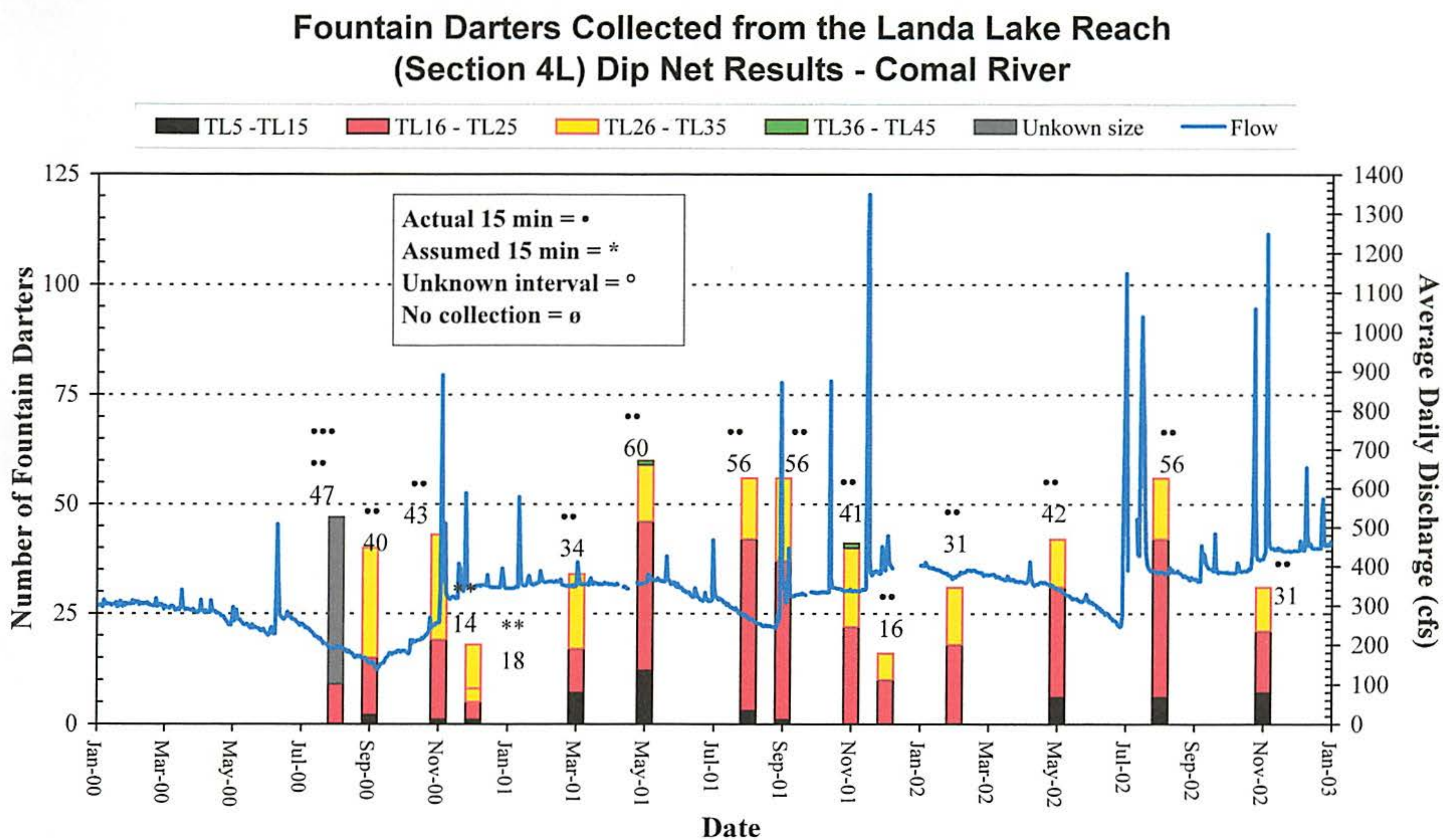

Fountain Darter Size Class Distribution
Drop Net Results 2000-2002 in the Comal River
Number Observed
0
50
100
150
200
250
300
350
400
N=5383
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
Length (mm)

Fountain Darters Collected from the Upper Spring Run Reach (Section 3) Dip Net Results - Comal River

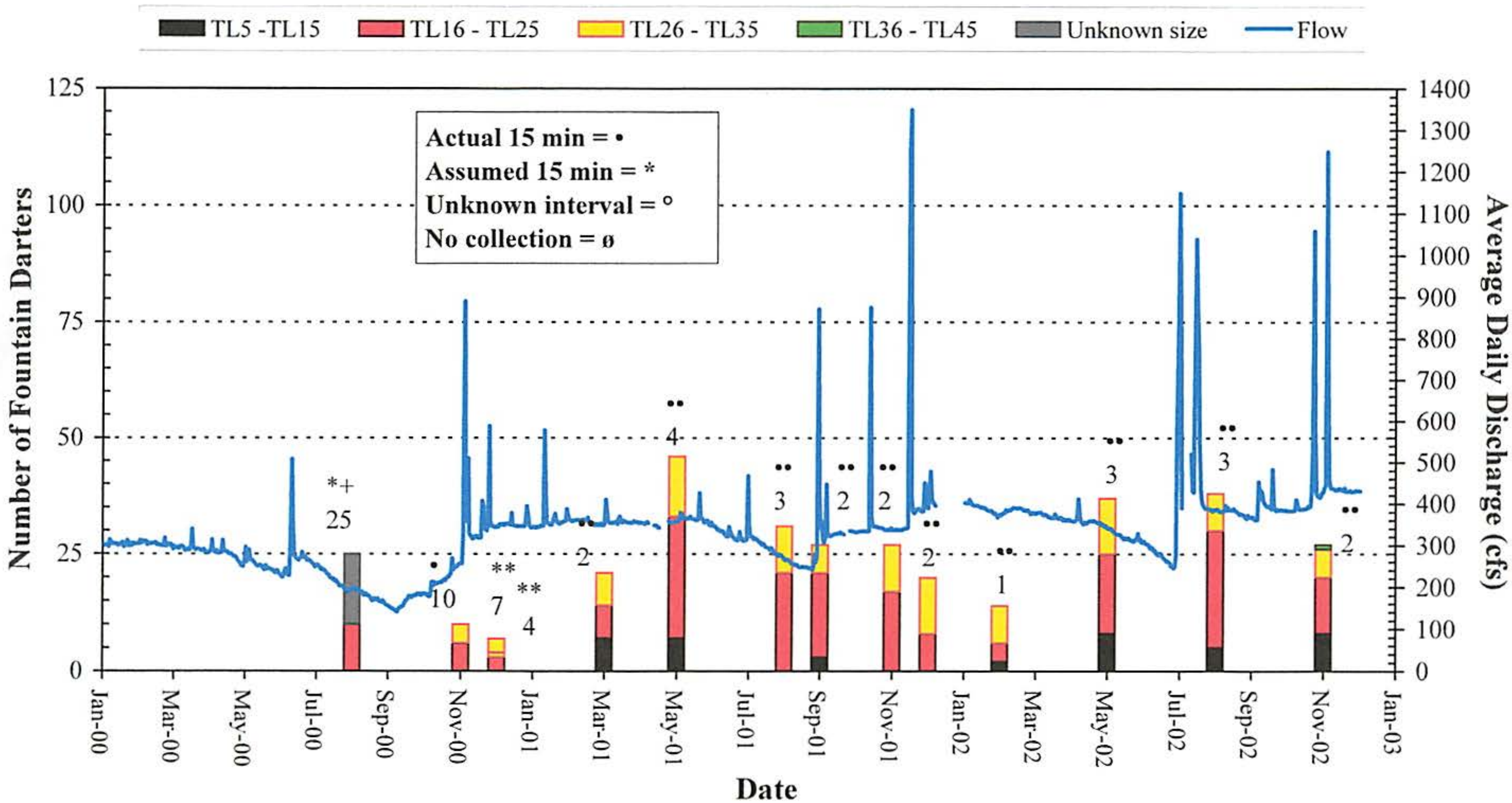


Fountain Darters Collected from the Spring Island Area (Section 4U-M) Dip Net Results - Comal River

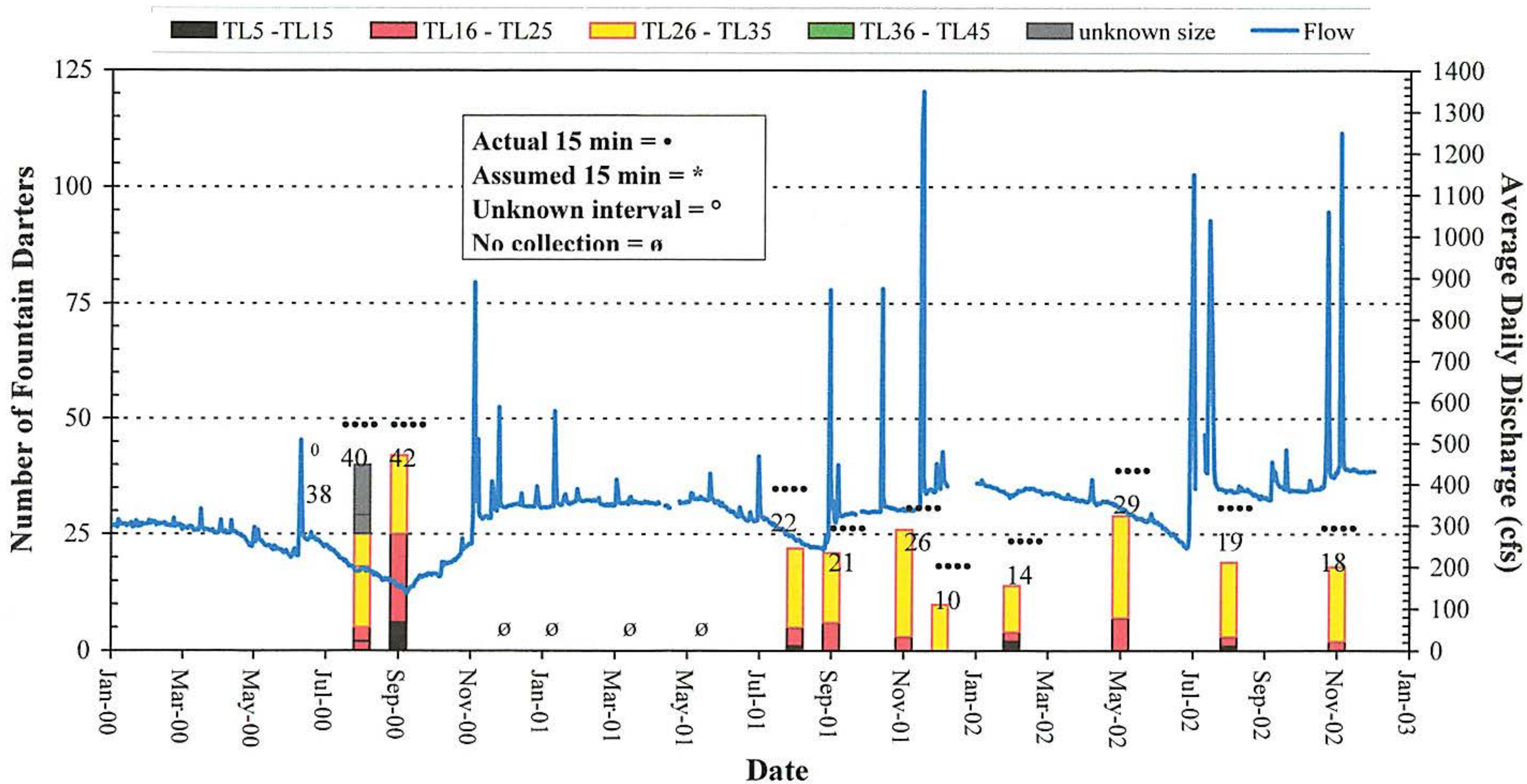



Fountain Darters Collected from the Landa Lake Reach
(Section 4L) Dip Net Results - Comal River
TL5 -TL15
TL16 - TL25
TL26 - TL35
TL36 - TL45
Unkown size
Flow
Actual 15 min = •
Assumed 15 min = *
Unknown interval = °
No collection = ø
Number of Fountain Darters
Average Daily Discharge (cfs)
Date

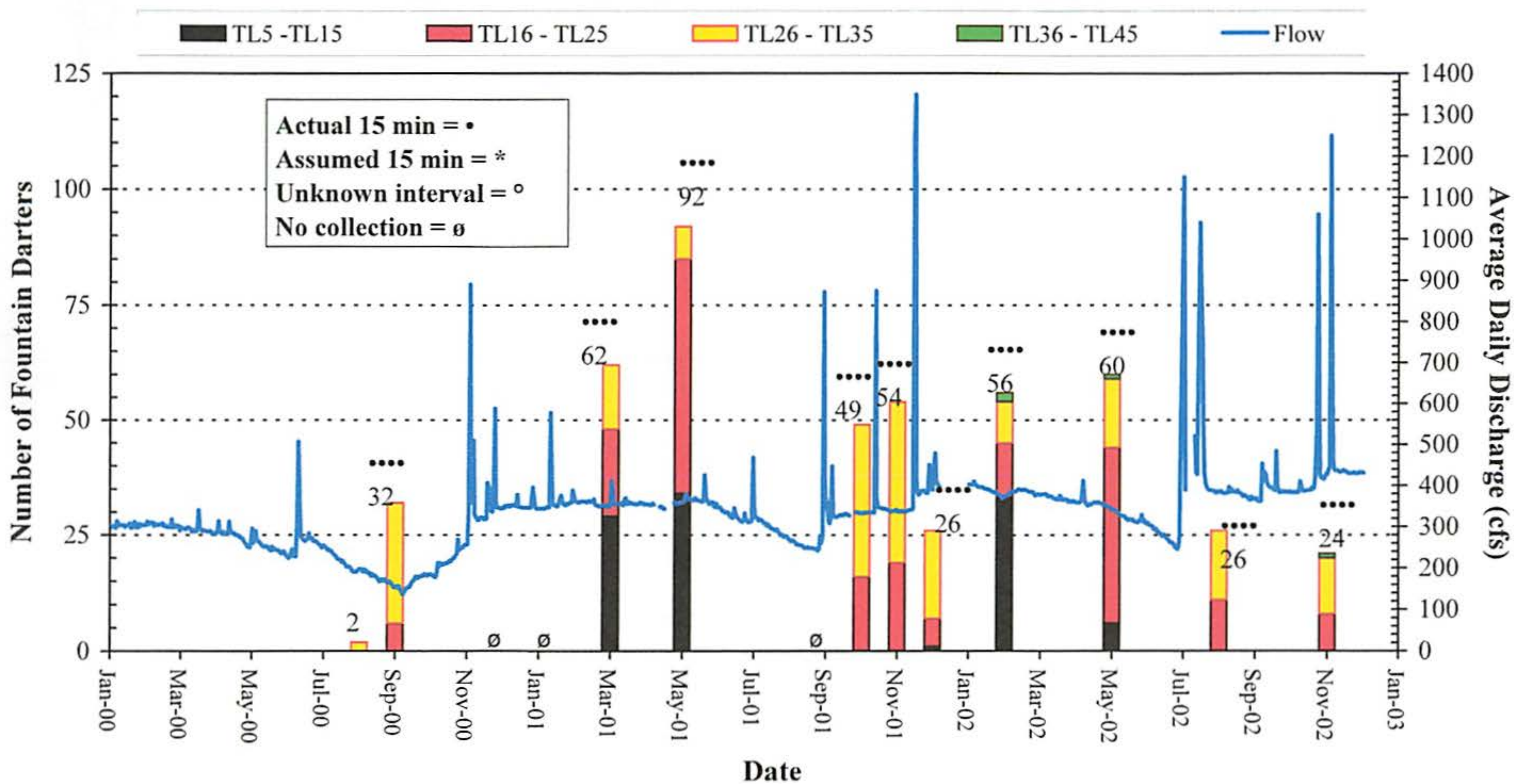
Fountain Darters Collected from the Landa Lake Reach (Section 5) Dip Net Results - Comal River



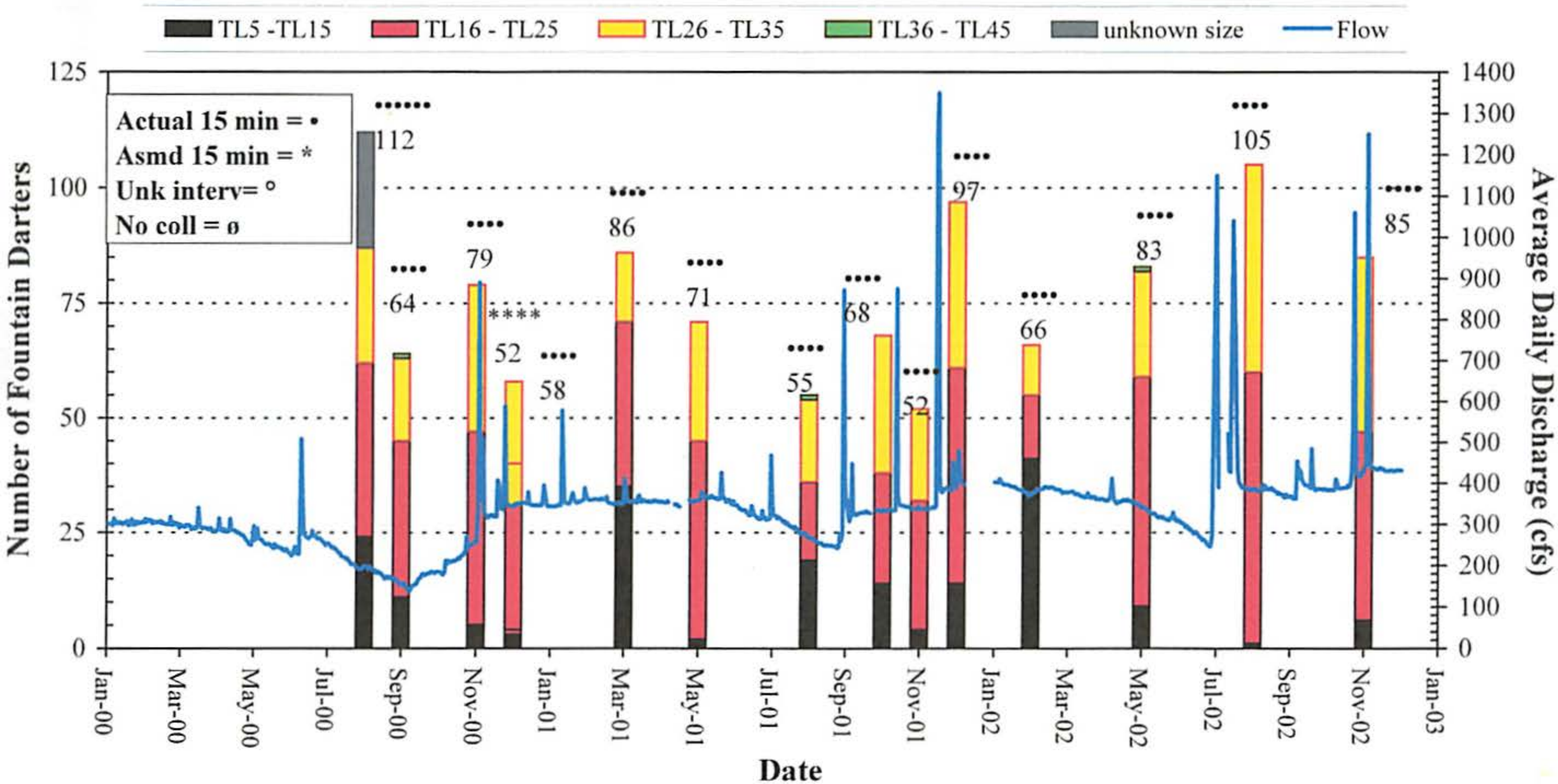
Fountain Darters Collected from the New Channel Reach (Section 4U-M) Dip Net Results - Comal River



Fountain Darters Collected from "The Other Place" Reach (Section 14) Dip Net Results - Comal River



Fountain Darters Collected from the Old Channel Reach (Section 16) Dip Net Results - Comal River



Exotics / Predation Data

LANDA LAKE GILL NET DATA
COMAL RIVER - SPRING 2002 QUARTERLY SAMPLING

Species	Total Length (mm)	Total Weight (gr)	Stomach Contents
Micropterus salmoides	268	268	1 crayfish, 1 unident. fish
	323	459	1 crayfish
	204	128	2 shrimp, 2 amphipods, fish remains
	265	242	1 unident. fish, crayfish parts
	262	226	1 gambusia, 1 unident. fish
	369	752	1 crayfish
	344	539	1 crayfish
Lepomis punctatus	124	41	crayfish parts, mayfly gill filaments
	101	20	1 crayfish, incidental riccia
	112	25	amphipods, burrowing mayfly parts
	102	20	amphipods, 1 mayfly
	132	46	empty
	132	49	unidentified remains
	138	54	empty
	133	50	1 unident. Fish
	126	69	1 crayfish, 1 snail
	142	60	crayfish remains
	146	78	1 crayfish
	132	42	empty
	120	37	Riccia
Lepomis megalotis	97	19	4 water pennies, 4 amphipods
	115	29	unidentified insect parts
	141	60	1 crayfish
Cichlasoma cyanoguttatum	126	45	Riccia and algae
Tilapia aurea	390	997	Not examined
	416	1384	Not examined
	400	1321	Not examined
Plecostomas sp.	380	680	Not examined

LANDA LAKE GILL NET DATA
COMAL RIVER - SUMMER 2002 QUARTERLY SAMPLING

Species	Total Length (mm)	Total Weight (gr)	Stomach Contents
Micropterus salmoides	166	130	Molly (45 mm)
	204	222	1 crayfish, 1 shrimp
	232	358	Molly (35 mm)
	276	620	empty
	286	636	crayfish (75 mm)
	295	814	2-3 small fish, mostly digested
	360	1310	1 thiara snail, remains of large bodied fish
	398	2140	empty
Lepomis punctatus	108	58	crayfish remains
	108	54	crayfish remains
	119	78	unknown material
	125	92	empty
	128	96	crayfish remains
	133	130	crayfish remains
	134	124	crayfish remains
	135	112	crayfish remains riccia (incidental)
	136	124	empty
	138	118	large gill filaments (prob crayfish), 8 isopods, 1 terrestrial beetle
	140	146	riccia (incidental)
	141	114	crayfish remains
	144	164	riccia (incidental)
	146	156	3 crayfish remains, riccia (incidental)
	147	160	empty
	152	174	empty
	154	174	empty
	162	212	large gill filaments (prob crayfish)
Ameirus natalis	191	186	empty
Tilapia aurea	204	350	algae

LANDA LAKE GILL NET DATA
COMAL RIVER - WINTER 2002 QUARTERLY SAMPLING

Species	Total Length (mm)	Total Weight (gr)	Stomach Contents
Micropterus salmoides	211	109	fish remains; 1 crayfish or shrimp
	281	296	2 crayfish; 1 molly
	308	476	2 crayfish
	312	424	2 shrimp; crayfish claw; fish remains (possible darter: TL~ 26)
	318	469	1 crayfish
	341	593	empty
Lepomis punctatus	92	12	2 fish remains; water penny; amphipod; mayfly
	95	16	crayfish claw
	98	18	mayfly; amphipod; crayfish remains
	103	17	1 crayfish; water pennies
	108	22	fish remains; crayfish remains; mayfly
	123	40	empty
Lepomis gulosus	173	92	1 crayfish
	195	156	1 crayfish
Lepomis megalotis	115	27	amphipods; mayfly
	134	46	Odonate larvae; snail; caddisflies
	153	66	water penny; amphipod; mayfly
Cichlasoma cyanoguttatum	188	165	algae
Ambloplites rupestris	111	28	empty
Tilapia aurea	283	475	not examined
	309	596	not examined
	325	695	not examined
	336	719	not examined
	372	846	not examined
	377	1217	not examined
	378	1086	not examined
	379	1135	not examined
	396	1144	not examined
	398	1333	not examined
	400	1098	not examined
	402	1181	not examined
	403	1286	not examined
	415	1258	not examined
	435	1366	not examined