Implementation of the San Marcos River Observing System: a Spatially Explicit Delineation of a Spring System based on Physical, Hydrologic, Chemical, and Biological Monitoring[1]

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Abstract: The San Marcos River originates from a large karstic spring complex discharging an average of 5 m^3/s at San Marcos, Texas. The Upper San Marcos River flows 7.4 km downstream to the confluence with the Blanco River. The San Marcos Observing System (SMOS) has been established to integrate physical, hydrologic, chemical, and biological research to investigate aquatic resource responses to variation in flow regimes, anthropogenic impacts, and interactions between native and introduced flora/fauna. The river contains a number of imperiled native species (Texas wild rice (*Zizania texana*), fountain darter (*Etheostoma fonticola*), and the San Marcos salamander (*Eurycea nana*)), and a number of introduced species. High spatial resolution mapping of in-channel topographies, LIDAR and 0.25 meter aerial photography have been obtained. Riparian community composition and distribution has been completed. Aquatic vegetation has been mapped at a 1 meter polygon resolution and includes annual Texas wild rice monitoring data since 1989. Ten years of seasonal aquatic resource monitoring data has also been integrated into the GIS. Continuous logging of hydrologic and chemical parameters at multiple spring orifices, perennial and ephemeral tributaries, and monitoring wells at key locations of the recharge zone continues. Water quality monitoring for temperature and dissolved oxygen at ten locations is being expanded to a broader suite of parameters including rainfall/flood event driven monitoring. GIS coverage of land use and land cover characteristics in the entire watershed has been updated and includes development of a distributed rainfall-runoff model linked to hydrodynamic models of water quality and aquatic resource habitat.

Keywords: San Marcos River, aquatic resource monitoring, water quality, physical habitat, anthropogenic impacts, aquifer, hydrology, GIS, watershed modeling.

Introduction

The San Marcos River originates from San Marcos Springs in Spring Lake, San Marcos, Hays County, Texas. Fed by a large karstic spring complex discharging an average of 5 m^3/s from the Edwards Aquifer, the Upper San Marcos River flows 7.4 km downstream to the confluence with the Blanco River and continues for another 115 km to join the Guadalupe River (Figure 1). The springs at San Marcos (the second largest spring system in Texas) historically have exhibited the greatest flow dependability and environmental stability of any spring system in the southwestern United States. The Upper San Marcos River contains a number of native aquatic species including the endangered Texas wild rice (*Zizania texana*), threatened fountain darter (*Etheostoma fonticola*), and the San Marcos salamander (*Eurycea nana*). It also harbors a large number of introduced species including plants, fish, invertebrates, and parasites. Anthropogenic impacts to the upper 7.4 km section of river include a dam to create Spring Lake below the spring system, channel modifications, fine sediment and nonpoint source pollution from groundwater and surface water sources, and physical disturbance from high recreational use.

The San Marcos Observing System (SMOS) has been established within the upper San Marcos River (first 7.4 km) and associated watershed as a long-term effort to integrate physical, hydrologic, chemical, and biological monitoring to further the scientific understanding of the responses of aquatic resources to variation in flow regimes, anthropogenic impacts from watershed development, and interactions between native and introduced flora and fauna. The characterization of the system is also being undertaken to support the testing and evaluation of sampling and monitoring approaches that address both temporal and spatial scales in river systems. The SMOS includes a public information and education outreach

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emphasis. This effort includes a comprehensive watershed characterization of the system based on land use/cover, terrestrial/aquatic vegetation, impervious layers, stream gages, water quality sampling locations, aquifer monitoring wells, meteorological stations, demographics, economics, and other important spatially explicit data. These data are being used to develop education modules for a number of school curriculums and includes a drainage level standardized watershed characteristic report and supports on-going stakeholder driven strategic watershed planning and protection efforts.

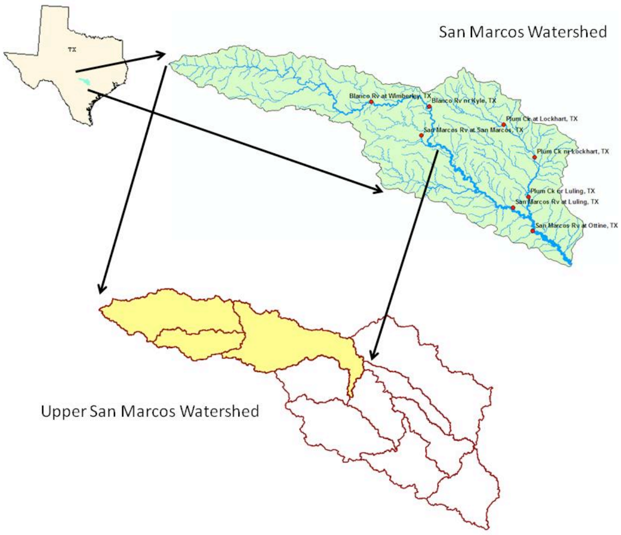

Figure 1. Upper San Marcos River watershed boundaries, Texas, USA.

Materials and Methods

Available data on land use and land cover, stream networks, digital elevation models, water rights, water use, demographics, economic sectors, water quantity and quality monitoring stations, aquifer well monitoring stations, weather data and related watershed characterization information have been compiled. We have developed a watershed characterization tool that relies on a series of defined database structures that are compatible with the existing geospatial databases developed to date to automate the generation of a standardized report for any arbitrary drainage (sub-basin) or combination of drainages up to the full spatial extant of the Upper San Marcos watershed.

Additional public information and outreach material will include the development of integrated learning modules for use in public school and university curriculums that incorporate field visits to the Aquarena Center located at the headwater spring system. These educational materials are targeted to support K-12 teacher recertification credits and meet state level curriculum subject material learning objectives.

The watershed characterization databases have also been linked to a watershed level rainfall-runoff model Hydrologic Simulation Program -- FORTRAN (Bicknell et al., 1997) capable of simulating drainage level outputs of sediment, nutrients, water quality, temperature, and discharge for the 1970 to 2006 period. Land use/cover from 1987 and 2006 were developed covering historical changes to present conditions for evaluating trends in water quality and sediment loading to compare with historical aquatic resource monitoring data. In addition, land use and land cover changes have been evaluated based on population projections and land zoning for conditions in 2020 and 2050.

Aquatic resource monitoring data has been collected since 1990 at ten standardized locations throughout the longitudinal river profile of the Upper San Marcos River that targets the population structure, density, and habitat associations for fountain darters, Texas wild rice, and the San Marcos salamander. The monitoring program is being expanded to target the complete aquatic resource community on a seasonal basis as well as additional spatial sampling locations. These efforts will target fish, invertebrates, and amphibians and include data on habitat associations.

Aquatic vegetation has been enumerated at a 1 meter minimum polygon level for the entire river and includes integration with annual Texas wild rice monitoring data collected since 1989. The aquatic vegetation delineations are at the species level and include the collection of depth of water, height of vegetation, substrates, and replicate velocity profiles within monotypic and mixed vegetation stands by river section.

LIDAR data has been integrated with 0.25 meter resolution multispectral imagery for the river to generate the 3-dimensional riparian community structure. Ground based measurements of densitometer readings were collected in over 200 locations in monotypic and mixed riparian canopy structures throughout the entire river corridor during summer and winter foliage conditions. Riparian vegetation polygons were ground verified to species within a 100 meter swath on both sides of the river corridor. The 3-d canopy structure was used in GIS to ray cast seasonal shadow polygons that were then modified with the densitometer readings to estimate spatially explicit shading polygons for the river. These data are being used to assess Texas wild rice distribution as a function of shading and used as input to the system wide water quality/temperature model.

A spatially explicit multidimensional water quality model is currently being developed for the river that incorporates seasonal aquatic macrophyte dynamics and integrated to receive point and non-point sediment, nutrient, and water quality constituent inputs from the watershed level HSPF modeling.

In channel topographies have been collected throughout the entire Upper San Marcos River. The goal of this effort was to develop a highly accurate spatial delineation that could support detection of channel changes over time as well as permit evaluation of spatial sampling strategies used to generate hydrodynamic modeling of rivers. Approximately 2500 to 3000 topography points were collected per 100 meter section of river channel using a systematic irregular sampling strategy to define all breaks or changes in channel topography. River channel topographies below Spring Lake were mapped using standard survey techniques and/or echo sounding in deeper sections tied to differentially corrected GPS. At each point, the substrate and/or vegetation was recorded in addition to water depth. Discharge estimates and the profile of the water surface elevation were collected on a daily basis as each section of river was mapped. Spring Lake topography was collected using ground penetrating radar (GPR), GPS, and an echo sounder. The GPR provided bottom topography and sediment structure of the river bed down to approximately 3 meters. The echo sounder provided the height of vegetation and used with the aquatic plant polygon mapping data to generate the 3-dimensional structure of the aquatic vegetation within Spring Lake. GPR is being used to map subsurface sediment characteristics along cross sections within the river channel at approximately 100 meter spacing below Spring Lake to the confluence with the Blanco River to permit evaluation of sediment transport or channel changes over time.

Hydrologic monitoring includes continuous logging of hydrologic and chemical parameters at multiple spring orifices, perennial and ephemeral tributaries, and in monitoring wells in key locations throughout a portion of the recharge zone in the upper watershed. Water quality monitoring currently exists for temperature and dissolved oxygen at 10 locations longitudinally from Spring Lake to the confluence with the Blanco River since 1990 and is being expanded to include a broader suite of water quality parameters as well as rainfall and flood event driven monitoring. Geochemical analysis of specific sprig orifices includes stable isotopes and monitoring changes associated with rainfall and runoff events within the watershed.

The detailed channel topography data is being used to create 3-dimensional hydrodynamic computational mesh for use in modeling the depth and velocity fields for the entire system at 0.5 meter grid resolution. The USGS Geomorphology and Sediment Transport Laboratory is collaborating to modify their multidimensional hydrodynamic model MD_SWMS (McDonald et al., in press) to utilize the field based velocity profiles by aquatic vegetation species to directly incorporate plant morphology to resistance to improve the hydrodynamic simulations. The water quality model will be used to update the aquatic macrophyte densities on a seasonal basis in the simulations. The combined GPR derived subsurface substrate data, surface substrate delineations from topography mapping, storm event sediment monitoring data, and sediment input from the HSPF model output will permit the use of the sediment transport modeling capability of MD_SWMS to dynamically evolve the bed at each time step (i.e., flow time series) as part of the hydrodynamic modeling.

The linked HSPF, water quality model, and hydrodynamic models will be utilized to model target aquatic resource (i.e., fountain darter and Texas wild rice) habitat quantity and quality as a function of flow regime, changes in land use/land cover, and support ongoing evaluation of restoration and mitigation activities as part of strategic watershed planning.

Results and Discussion

The standardized watershed characterization report covers 11 key characteristics that range from land cover and soil types, water resource structures, water use statistics by sector, to economics and population demographics (see Figure 2). The tool automatically produces a camera ready report that incorporates both tabular and graphical output summaries that adjusts the output to account for missing datasets on a drainage by drainage basis. The strength of the tool is that the database structures are developed and tested and can allow the incremental addition and/or updating of information without the need to 'reprogram' the report tool.

Figure 2. Watershed characterization tool report sections.

This tool is greatly aiding citizen stakeholder and resource agencies involved in strategic watershed planning efforts and guiding development of land use planning throughout the basin. It is also being utilized in curriculum development that supports state-wide learning objectives.

As part of the HSPF modeling, land use/land cover changes were compared for 1987 and 2006 and the impacts of these changes on flow, water quality, temperature, and sediment loadings were examined. An example of land use changes are illustrated in Figure 3 and the residual differences in flow at the San Marcos gage for changes in discharge are illustrated in Figure 4.

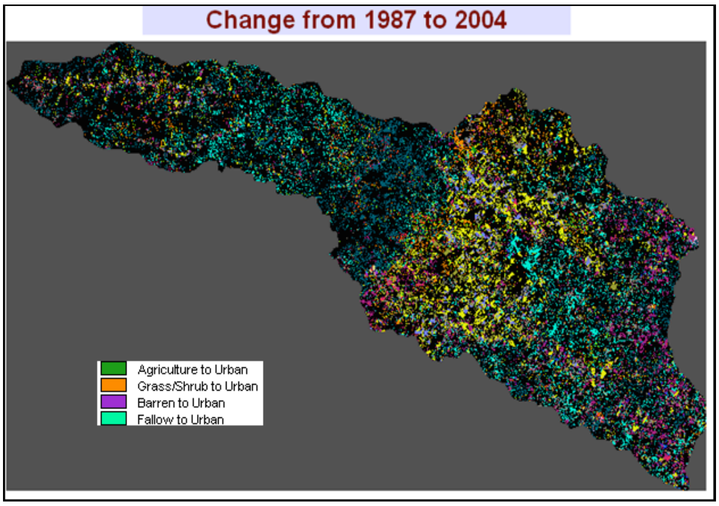

Figure 3. Land use changes between 1987 and 2006 within the Upper San Marcos Watershed.

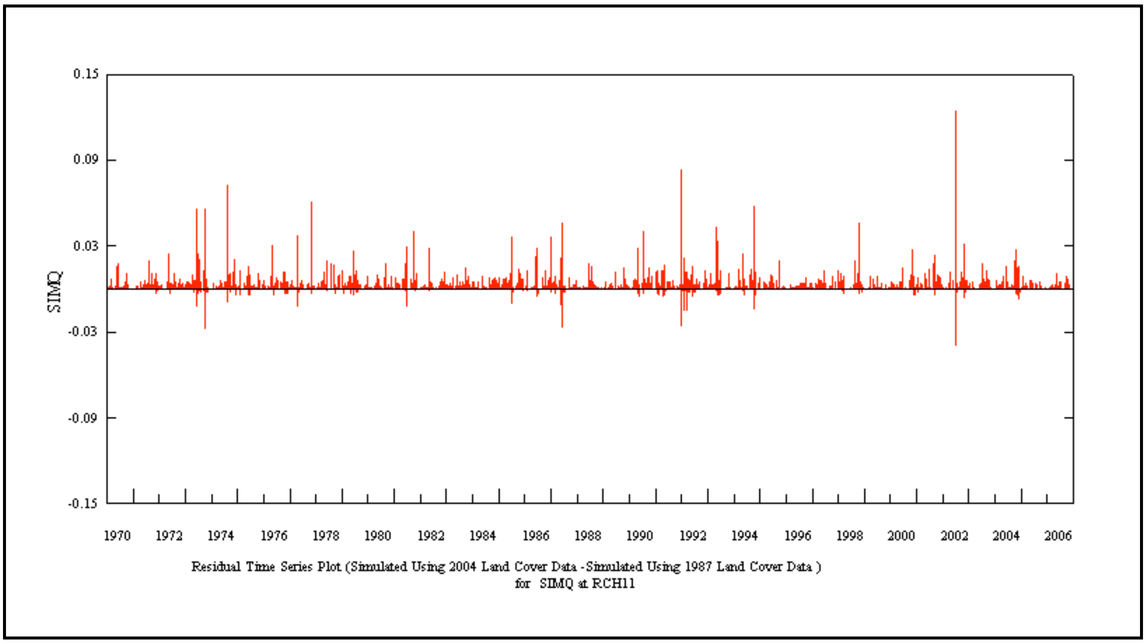

Figure 4. Residual time series plot of discharge changes from the 2004 and 1987 land use/cover simulations.

Figure 5 provides an example of the LIDAR and shade simulations for a section of the San Marcos River where shading intersects an area within the defined water's edge. As noted previously, each polygon is adjusted according to riparian species, canopy structure, and densitometer readings to generate seasonal percent shading.

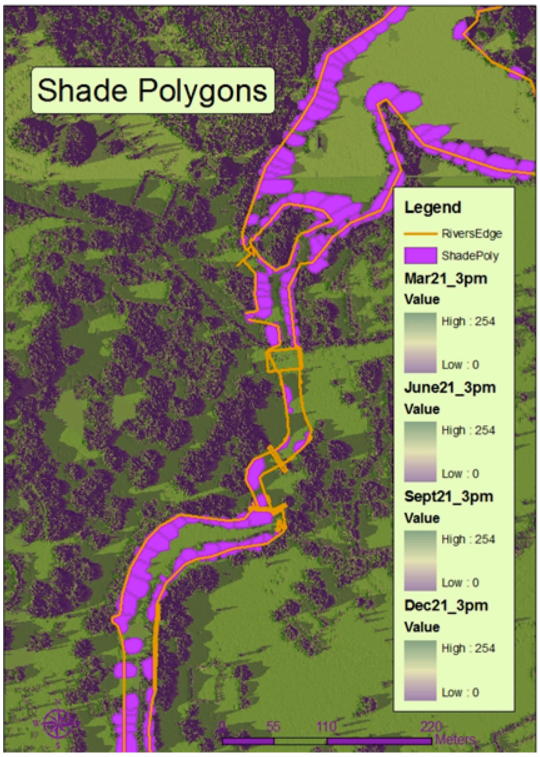

Figure 5. Example of shade polygons derived from 3-dimensional riparian canopy structure and densitometer readings for a section of the San Marcos River.

An illustration of the high resolution aquatic vegetation mapping within the San Marcos River is illustrated in Figure 6.

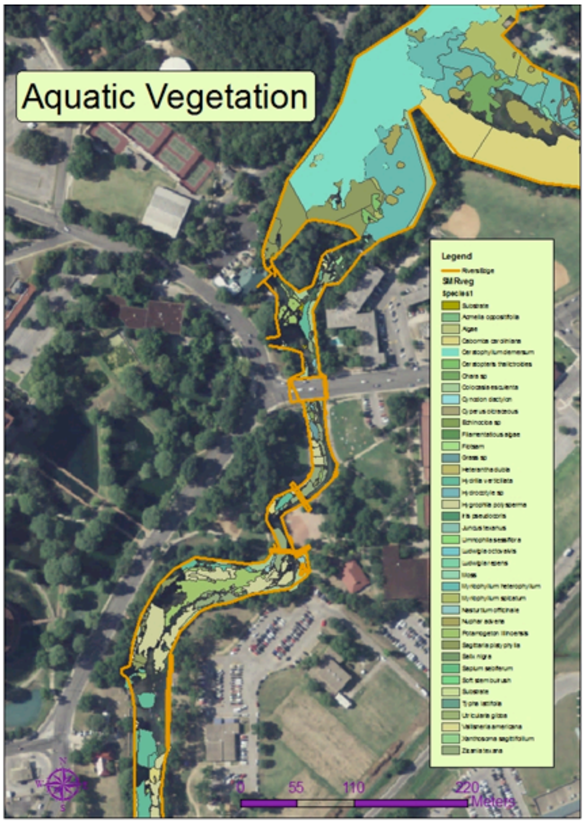

Figure 6. Example of the aquatic vegetation mapping polygons within the San Marcos River.

Figure 7 illustrates results generated from the integration of the hydrodynamic modeling and biological response functions for Texas wild rice compared to observed rice locations (red dots) for a section of the San Marcos River. Similar modeling is being undertaken for fountain darters and other aquatic resources as habitat association data is obtained and analyzed.

Conclusion

The San Marcos Observing System represent an integrated multidisciplinary effort covering physical, chemical, and biological characterization and monitoring at very high spatial and temporal scales. This effort is linked to on-going and developing public information and education programs as well as stakeholder driven watershed protection and planning processes. The field sampling efforts within the Upper San Marcos River specifically target the development of a high spatial resolution baseline for in-channel topographies, aquatic vegetation, riparian, fish, amphibian, and marcorinvertebrate community structure and composition. The detailed watershed characterization data linked to a distributed rainfall-runoff watershed water quality model provides important linkages to changes in land use and land cover conditions that are integrated directly to river water quality and hydrodynamic models suitable for evaluating habitat quantity and quality for endangered and threatened aquatic taxa. The datasets developed to date are ideal for testing existing and new monitoring protocols that can address both spatial and temporal scales.

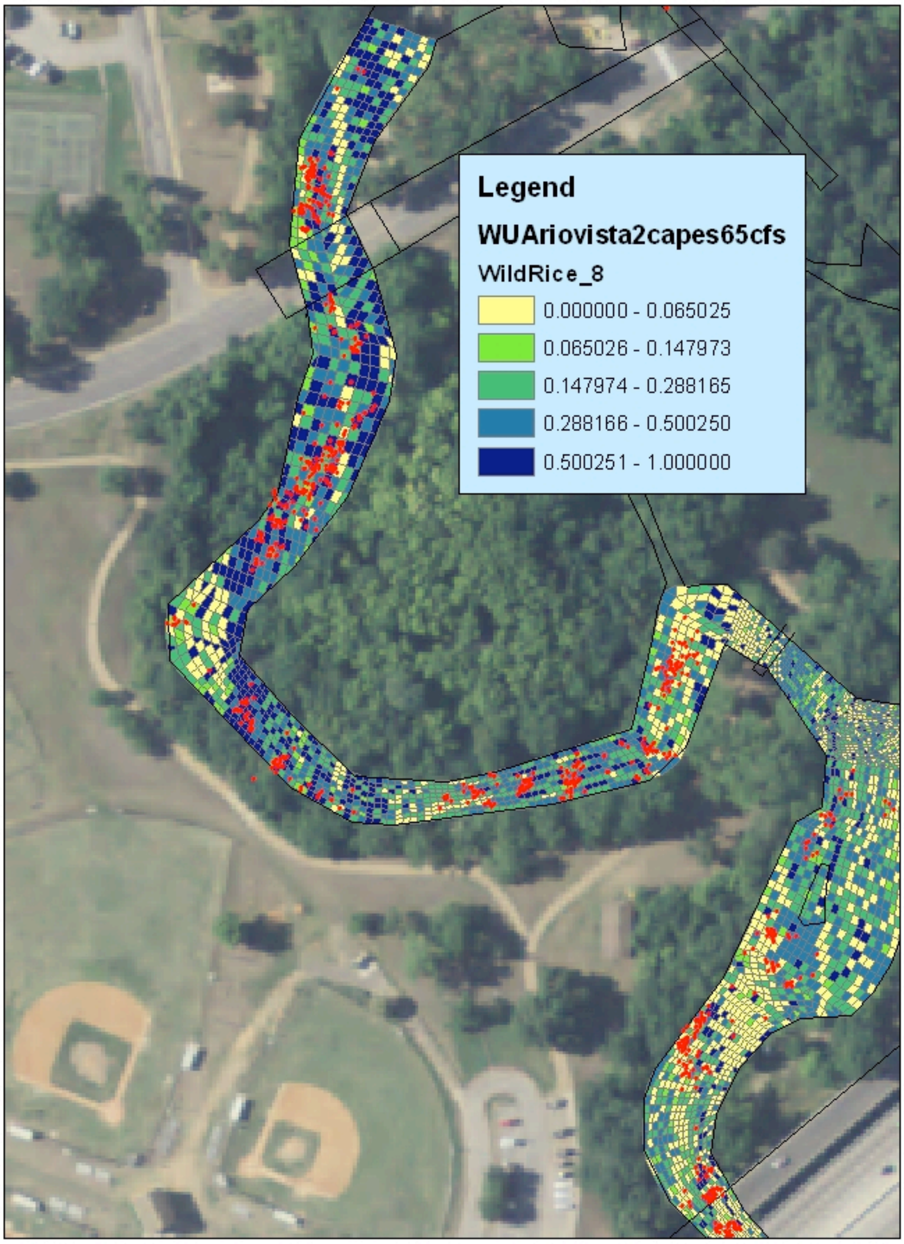

Figure 7. Example of habitat simulated Texas wild rice habitat and observed locations for a section of the San Marcos River based on the simulations from the hydrodynamic model.

References

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