TECHNICAL MEMORANDUM

TO: Steve Raabe, P.E.
Director of Technical Services
San Antonio River Authority

FROM: Terry McLendon, KS2 Ecological Field Services

SUBJECT: PHASE 1 SAN ANTONIO BAY EDYS MODEL: PROGRESS REPORT

DATE: 20 June 2012

EXECUTIVE SUMMARY

This report presents a summary of the results of the development of the Phase 1 EDYS model of San Antonio Bay. The purpose of the Phase 1 EDYS model was to provide a proof-of-concept of how EDYS could be used to develop an ecological model for the Bay, including 1) the open Bay, 2) the surrounding terrestrial ecosystems, 3) the marsh/estuarine ecosystems that link the Bay and the surrounding terrestrial ecosystems, and 4) the river system flowing into the Bay. Specific objectives of Phase 1 were to 1) develop a spatially realistic model of plant community distribution in San Antonio Bay and its surrounding landscape, and 2) simulate logical and realistic changes in vegetation response to changes in water level and changes in salinity.

1.0 INTRODUCTION

San Antonio Bay is one of the six major bays on the Texas Coast. The San Antonio River flows into the Guadalupe River approximately 12 miles northwest of the mouth of the Guadalupe, from which the combined flow of both rivers enters into San Antonio Bay. The San Antonio River Authority (SARA) has the dual responsibility of managing water quality and quantity in the San Antonio River and its tributaries. The ecology and the dynamics of the Bay are important to SARA, in part because the San Antonio River is as a major supplier of freshwater to the San Antonio Bay and decisions made by SARA affect the quality and quantity of this freshwater supply.

SARA recognizes the importance of making good management decisions relative to both the San Antonio River and San Antonio Bay ecosystems. However, both of these are complex ecological systems and simple, often single-factor, approaches are not adequate to provide the necessary tools for effective management of these integrated systems. One tool that would be of substantial benefit for decision making in the San Antonio River-San Antonio Bay complex is a dynamic ecological simulation model that could integrate hydrological and ecological responses in a practical and scientifically valid way.

EDYS is a general ecosystem simulation model that is mechanistically based and spatially explicit. It has been used for ecological simulations, watershed management, land management decision making, environmental planning, and revegetation and restoration design analysis in Texas, 11 other states, and internationally. EDYS simulates natural and anthropogenic-induced changes in hydrology, soil, plant, animal, and watershed components across landscapes at spatial scales ranging from 1-m^2 or less to watershed levels (10^3 km^2 or larger). Numerous validation studies have shown EDYS to be 85-95% accurate in simulating responses in a wide-variety of hydrologic and vegetation variables.

SARA is interested in the potential of EDYS to provide an integrated management tool for use on the San Antonio River watershed, including San Antonio Bay. Although there have been many applications of EDYS to terrestrial ecological systems, applications in aquatic systems have been few. In order to determine the potential of EDYS to simulate ecological dynamics in aquatic systems, SARA and the US Army Corps of Engineers Environmental Research and Development Center (ERDC) funded a Phase 1, proof of concept, study of the application of EDYS to San Antonio Bay. The specific objectives of this Phase 1 study were to: 1) develop a spatially realistic model of plant community distribution (terrestrial and marsh) over the San Antonio Bay footprint and 2) realistically simulate changes in vegetation response of the marsh and adjacent terrestrial vegetation to change in water levels and change in salinity. More specifically, Phase 1 was to concentrate on developing 1) the spatial footprint of the Bay and surrounding ecosystems, 2) the major plant communities of the area, 3) the hydrologic components of the systems, including overland flow, river discharge, and tidal and wind action on bay waters, 4) salinity and sediment dynamics, and 5) interaction of these factors along with climatic fluctuations. Following successful demonstration of these Phase 1 model capabilities, it is proposed that work on the model continue under Phase 2, which will add the much more complex hydrologic, chemical, and animal components.

KS2 Ecological Field Services (KS2) submitted a proposed Scope of Work entitled "Development of an Ecological Model of the San Antonio Bay Based on the EDYS Ecological Model" to SARA in May 2011. That Scope of Work included both Phase 1 and Phase 2. On 10 June 2011, SARA authorized KS2 to proceed with Phase 1 of that Scope of Work under Purchase Order No. P1100451. The KS2 Scope of Work called for a 16-month period for completion at a cost of $ 238,000 (combined SARA and ERDC components). The purpose of this memorandum is to report on the results of that Phase 1 EDYS model.

2.0 MODEL DEVELOPMENT

2.1 Spatial Footprint

The first step in developing an EDYS model application is to define the spatial domain (i.e., the spatial footprint). For the San Antonio Bay application, we defined the spatial footprint as the area within the polygon formed by 1) a western line running from Cedar Bayou north through approximately the center of Aransas National Wildlife Refuge to Tivoli, 2) a northern boundary following Highway 35 to approximately 2 miles east of Highway 185, 3) an eastern line running southeast approximately 2 miles east of Highway 185 and crossing through Matagorda Island just west of Espirto Santo Bay, and 4) a southern boundary formed by the open Gulf. This footprint includes an area of 192,401 hectares (1924 km^2) or approximately 475,400 acres (Fig. 1).

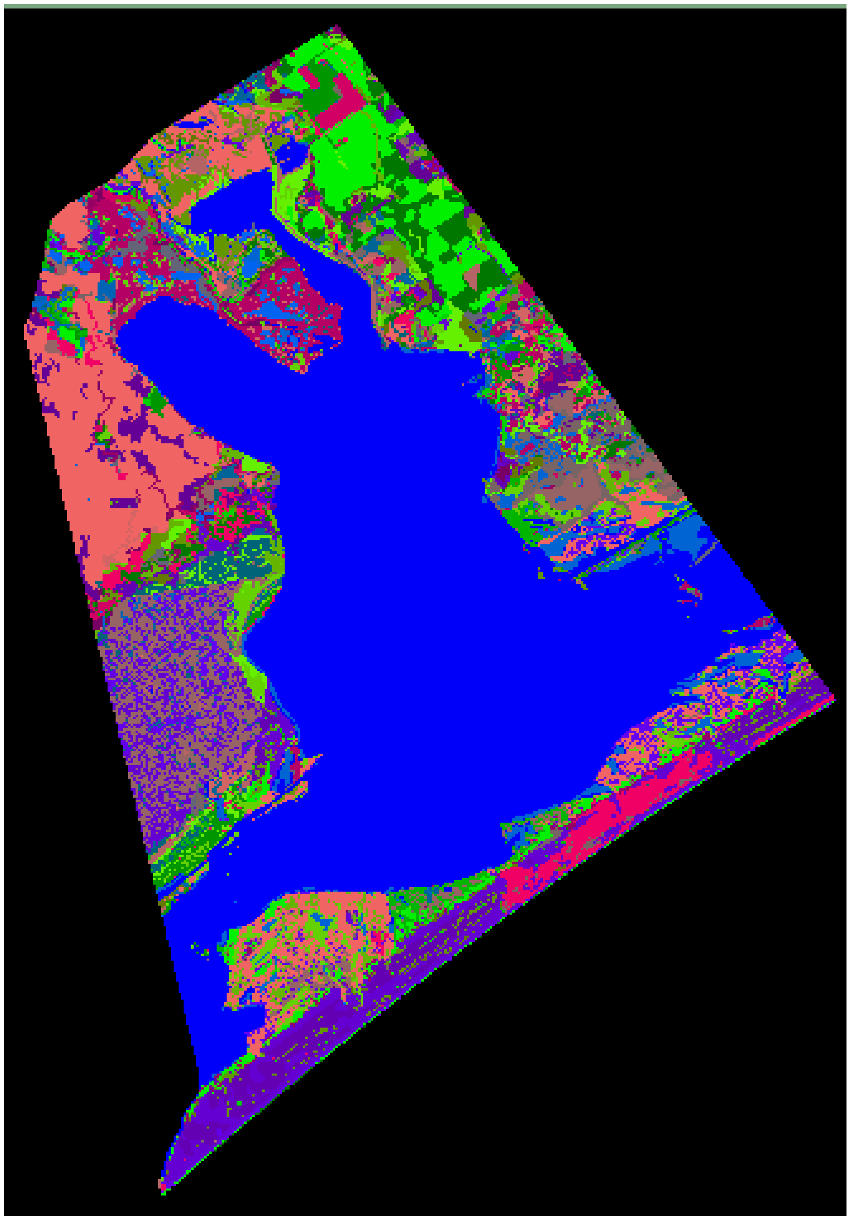

Figure 1. Spatial footprint of the San Antonio Bay EDYS model.

In EDYS, the spatial footprint is divided into cells. A cell is the smallest unit that EDYS simulates in a particular application and can be of any size, as determined by the requirements of the application. EDYS averages values for each variable across an individual cell, therefore the cell size selected is a balance between 1) the largest size for which average values are acceptable and 2) acceptable simulation run times and memory requirements (i.e., the larger the number of cells in an application the slower the run time per time step and the larger the memory requirement).

A 40 m x 40 m cell size was selected for the San Antonio Bay model. The spatial footprint (Fig. 1) was divided into a grid of 881 columns and 1365 rows, resulting in 1,202,565 cells, with each cell representing 1600 m^2 (40 m x 40 m) of the landscape.

EDYS also allows for sub-units of the footprint to be modeled at a finer scale. Simulation results for these high resolution "pop-ups" can be displayed individually (i.e., separate from the overall footprint model) but they are linked to the larger model so landscape processes simulated by the larger model also affect the fine-scale model and results from the fine-scale model affect the adjacent portions of the large-scale model. High-resolution pop-up models are used in EDYS applications to simulate ecological and hydrological dynamics of critical areas of interest where the increased resolution is necessary for both 1) accurately simulating the processes in that area and 2) providing sufficiently accurate simulation results.

To illustrate this feature in the Phase 1 model, an area of marsh near the mouth of the Guadalupe River was selected (Fig. 2). The marsh pop-up was simulated at a 5 m x 5 m resolution, or at 64 times the resolution of the large-scale model (i.e., 25 m^2 compared to 1600 m^2 cell size). The grid for the spatial footprint of the marsh pop-up consisted of 636 columns and 700 rows, or 445,200 cells.

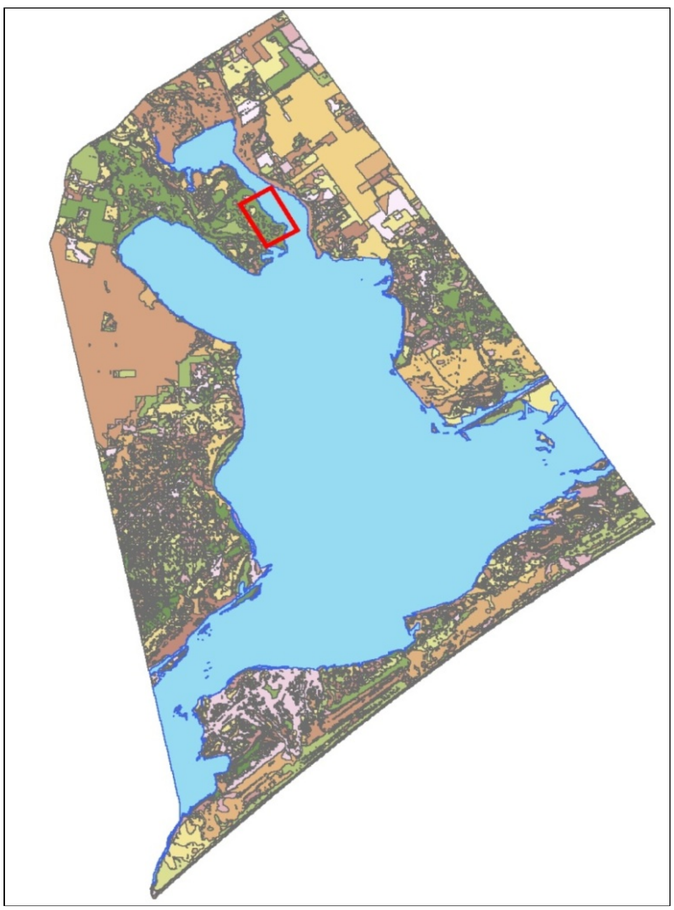

Figure 2. Location of the high-resolution marsh pop-up area (rectangle outlined in red) included in the San Antonio Bay Phase 1 EDYS model.

2.2 Precipitation

Precipitation is a major factor affecting ecological responses in most ecosystems. As such, it is an important input (driving) variable in EDYS. Numerous aspects of precipitation are important ecologically, including 1) amount, 2) seasonality, 3) intensity, and 4) variability. In EDYS, precipitation is entered as a daily amount, with simulation of shorter-period effects (e.g., hourly) possible if necessary (e.g., high-intensity storms).

Precipitation variability is also important ecologically. In order to simulate as much of this variability as feasible, the precipitation input data used in EDYS is based on as long a period as possible for an application. Long-term (50-100$^+$ years) precipitation data are often not available for most recording stations located near the spatial footprint of an EDYS application. When long-term data are not available, a long-term data set is constructed based on precipitation data sets from as many local stations as possible. The construction process is: 1) data are listed for each station by year; 2) data from the station or stations closest to the footprint are used as the primary data source; 3) average differences (or regressions, depending on which provides the best fit) are calculated for the data from each location compared to the base location; 4) for months where data are available from the base location, those data are used for the respective months in the constructed data; and 5) for months were data are not available for the base location, data from the location most similar (based on overall average difference or regression equation) to the base location and that has data for that month is used by adjusted for the average difference or regression equation.

The base location for the Phase 1 model was Aransas National Wildlife Refuge. Monthly precipitation data were available for 833 months from 1940-2010 for that station. Data from the following stations (in order of similarity to Aransas National Wildlife Refuge) were used to extend the precipitation data set: Port Lavaca, Woodsboro, Austwell, Rockport, and Victoria. The resulting constructed 113-year data set (Fig. 3) contained monthly values for 1898-2010.

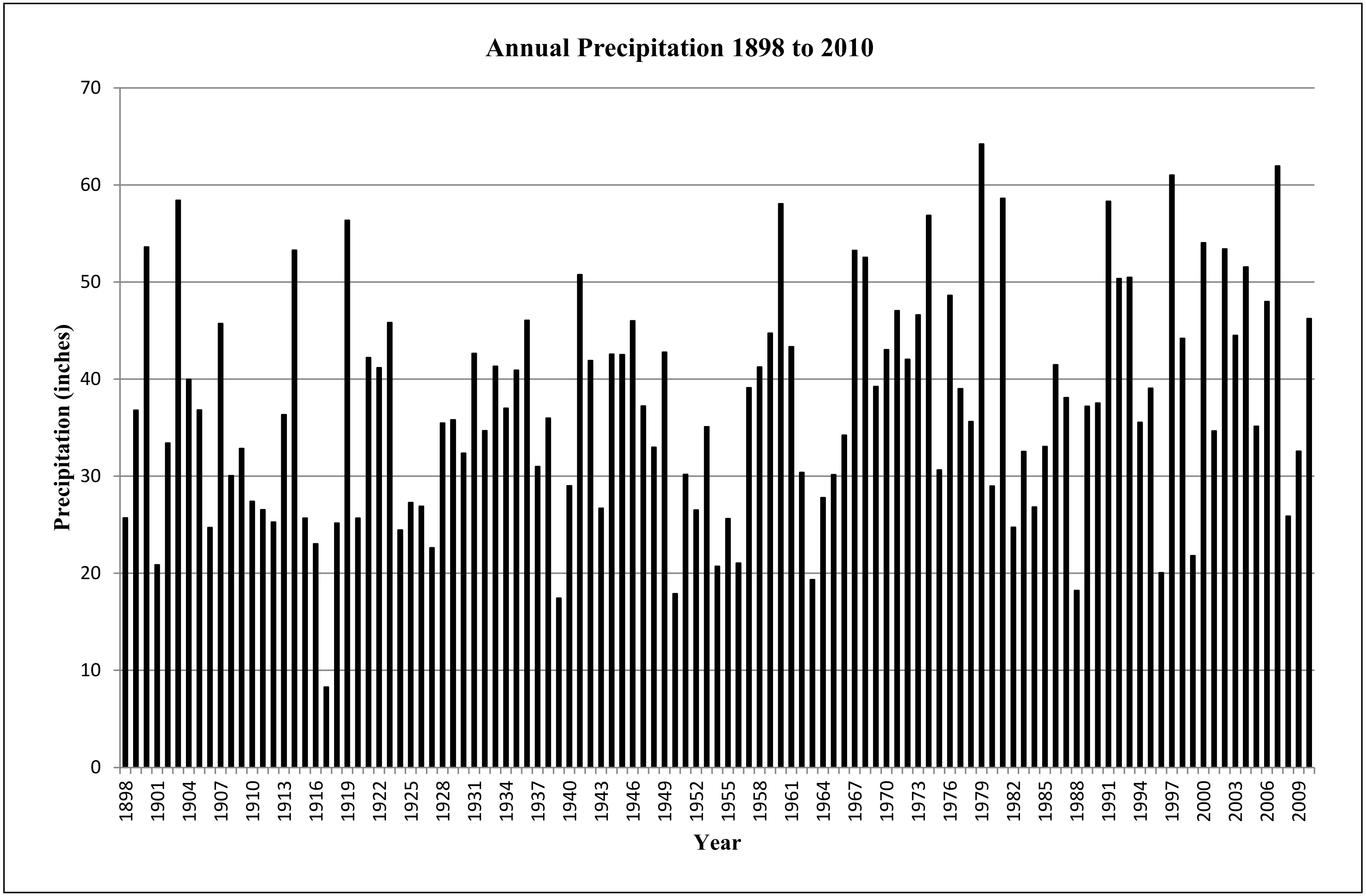

Figure 3. Annual precipitation (inches) from the constructed long-term (1898-2010) precipitation data set used in the Phase 1 San Antonio Bay EDYS model.

The constructed monthly precipitation data set was further modified by dividing each monthly value into daily values. This was done by 1) taking the Aransas National Wildlife Refuge data from each month that had daily values, 2) calculating an average daily proportion of monthly precipitation for each month, and 3) multiplying each monthly value (1898-2010) by the respective daily proportion.

Several precipitation input options are available in EDYS. A simulation run can begin in the initial year of the constructed data set (January 1898 in this case) and run consecutively by month for the designated simulation period (e.g., 50 years). Alternatively, any year in the constructed precipitation data set can be selected and the simulation run will begin in that year. Regardless of starting year, EDYS allows for multipliers to be used to alter the amount of precipitation occurring but retaining the pattern. For example, a 1.10 multiplier would increase each precipitation event by 10%. A 1.00 multiplier uses the constructed data set values without alteration. For any of the precipitation input options, if the simulation run period exceeds the length of the constructed data set (113 years in this case) or the remaining period of the data set if an alternative starting year is selected (e.g., 50 years if 1961 was selected as the starting year) EDYS cycles back through the constructed precipitation data set beginning in the first year (1898 in this case) and continuing until the simulation run period is completed.

In EDYS, a precipitation event (e.g., 1 cm) is applied to each cell throughout the grid. The Phase 1 San Antonio Bay model uses only one constructed precipitation data set, which is based on Aransas National Wildlife Refuge. Multiple constructed precipitation data sets can be used, in which case the grid is 1) divided into precipitation zones, each zone corresponding to a specific constructed precipitation data set, or 2) precipitation amounts for each event are averaged between precipitation data locations across the grid. Although the second approach provides a more realistic response pattern, it requires more computational time.

2.3 Soils

Each cell in the spatial footprint is assigned a soil type, with the corresponding soil profile and physical, chemical, and biological variables. The soil types and their spatial distributions were taken from Natural Resource Conservation Service (NRCS) county soil surveys. For the San Antonio Bay EDYS model, these were Aransas (Guckian and Garcia 1979), Calhoun (Mowery and Bower 1978), and Refugio (Guckian 1984) Counties. Additional data on soil properties and appropriate values for soil variables were also taken from other literature sources and from the EDYS data bank.

Based on the soil surveys, 67 soil types were included in the Phase 1 model (Appendix Table 1). Generalized substrate profiles were developed for cells where permanent standing water occurred (e.g., bay floor, river channel).

2.4 Vegetation

The number of plant species included in an EDYS application is flexible. How many and which species included depends on the requirements of the application and the level of complexity desired. The inclusion of more species increases the potential for the model to simulate the ecological complexity common to most landscapes but it also increases the run times and memory requirements. In addition, plant parameter data are lacking for many species and therefore there tends to be more estimation of these parameter values as the number of species increases beyond about 40-60. A total of 57 plant species were included in Phase 1 model (Table 1).

Table 1. Plant species included in the Phase 1 San Antonio Bay EDYS model.

Lifeform	Species	Common Name
Tree	*Acacia farnesiana*	huisache
Tree	*Carya illinioensis*	pecan
Tree	*Celtis laevigata*	hackberry
Tree	*Magnolia virginiana*	sweet bay
Tree	*Prosopis glandulosa*	mesquite
Tree	*Quercus virginiana*	live oak
Shrub	*Borrichia frutescens*	sea oxeye
Shrub	*Lycium carolinianum*	Carolina wolfberry
Cacti	*Opuntia lindheimeri*	prickly pear
Shrub	*Sesbania drummondii*	rattlepod
Vine	*Vitis mustangensis*	mustang grape
Grass	*Andropogon glomeratus*	bushy bluestem
Grass	*Andropogon virginicus*	broomsedge bluestem
Grass	*Bothriochloa saccharoides*	silver bluestem
Grass	*Bouteloua curtipendula*	sideoats grama
Grass	*Buchloe dactyloides*	buffalograss
Grass	*Cenchrus incertus*	sandbur
Grass	*Chloris pluriflora*	trichloris
Grass	*Cynodon dactylon*	bermudagrass
Grass	*Distichlis spicata*	saltgrass
Grass	*Leersia hexandra*	clubhead cutgrass
Grass	*Monanthochloe littoralis*	shoregrass
Grass	*Panicum virgatum*	swithchgrass
Grass	*Paspalum lividum*	longtom
Grass	*Paspalum monostachyum*	gulfdune paspalum
Grass	*Paspalum plicatulum*	brownseed paspalum
Grass	*Paspalum vaginatum*	seashore paspalum
Grass	*Phragmites australis*	common reed
Grass	*Schizachyrium scoparium*	little bluestem
Grass	*Schizachyrium scoparium littoralis*	seacoast bluestem
Grass	*Setaria geniculata*	knotroot bristlegrass
Grass	*Setaria leucopila*	plains bristlegrass
Grass	*Sorghastrum nutans*	indiangrass
Grass	*Spartina alterniflora*	smooth cordgrass
Grass	*Spartina patens*	marshhay cordgrass
Grass	*Spartina spartinae*	gulf cordgrass
Grass	*Sporobolus virginicus*	seashore dropseed
Grass	*Stipa leucotricha*	Texas wintergrass
Grass	*Uniola paniculata*	sea oats
Grass	*Zizanopsis miliacea*	marsh millet
Grass-like	*Cyperus odoratus*	fragrant flatsedge
Grass-like	*Eleocharis* spp.	spikerush
Grass-like	*Scirpus americanus*	Olney bulrush
Grass-like	*Typha latifolia*	cattail
Forb	*Alternanthera philoxeroides*	alligatorweed
Forb	*Ambrosia psilostachya*	ragweed
Forb	*Aster spinosus*	spiny aster
Forb	*Cassia fasciculata*	partridge pea
Forb	*Clematis drummondii*	old-man's beard
Forb	*Croton punctatus*	gulf croton
Forb	*Cymodocea filiformis*	manatee-grass

Table 1. (Cont.)

Lifeform	Species	Common Name
Forb	*Heterotheca subaxillaris*	camphorweed
Forb	*Ipomoea pes-caprae*	railroad vine
Forb	*Oenothera drummondii*	beach evening primrose
Forb	*Rhynchosia texana*	Texas snoutbean
Forb	*Salicornia virginica*	glasswort
Forb	*Suaeda* spp.	sea blite

Each cell in an EDYS application receives an initial vegetation composition. For each cell, this can be any combination of the species included in the application (e.g., Table 1). The variation in species composition, and corresponding initial biomass values, among the cells provides the method for establishing the spatial vegetation mosaic across the simulation landscape.

In large applications (e.g., > 500,000 cells), allocating unique vegetation composition to each cell and keeping track of changes in each cell during a simulation generally results in very slow run times and large memory requirements. To shorten the run times and reduce the memory requirements, cells with similar initial species composition can be pooled into clusters, each cluster representing a plant community. When this is done, vegetation responses are simulated on the plant community level rather than the cell level. If however, environmental conditions change in one part of the community differently than in another (e.g., fire burns across part of the community, erosion features begin to form in some cells before others, a flooding event covers only part of the community, one part is reseeded), EDYS splits the community into parts with each part representing the area subjected to a specific environmental response and including only those cells subjected to that response. From that point, each of the differently impacted areas is simulated as a separate plant community (plot type). It is not unusual in an EDYS simulation for the number of plot types (plant community types) to quadruple from the starting number.

In the Phase 1 San Antonio Bay model, 220 plant communities are used for the initial conditions in a simulation. These 220 plant communities are variations of the NRCS ecological sites (Appendix Table 1) modified to incorporate 1) additional vegetation data from the literature and from ecological experience in the area, 2) differences in woody plant cover (trees and shrubs) not accounted for in the NRCS descriptions but observable from aerial photographs, and 3) landscape features not included in the NRCS site descriptions (e.g., cultivated land, improved pasture, urban and industrial sites, aquatic sites). Primary sources of vegetation data for the Phase 1 model other than the NRCS soil surveys were Shiflet (1963), Dahl et al. (1975), McLendon and DeYoung (1976), Drawe et al. (1978), Scifres et al. (1980), Diamond and Smeins (1984), Cutshall (1994a, 1994b), Drawe (1994a, 1994b), and Alongi (1998). USFWS Natural Wetlands Inventory data were also consulted for locations of wetlands and seagrass beds were mapped on the basis of data from the Texas General Land Office.

Each cell was classified into one of the 220 plant communities based on 1) NRCS soil survey maps and 2) variations observable from aerial photographs. When combined with the 67 soil types (Appendix Table 1), an initial vegetation grid containing 687 plot types (unique combinations of plant community and soils) was developed. These 687 plot types are the initial response units in the Phase 1 model. They are potentially subdivided during a simulation as environmental conditions change in one part of a plot type differently than in another part of the same plot type.

2.5 Elevations and Bathymetry

Surface topography (land and beneath permanent water) is an important component in EDYS simulations. Topography determines the patterns and rates of water movement across the landscape and therefore also affects the movement of organic (e.g., water-borne litter) and inorganic (e.g., sediments) materials, along with erosion patterns.

An average elevation is entered for each cell in an EDYS application. EDYS calculates slope and aspect based on elevation differences among adjacent cells. Elevations are entered in relation to mean sea level. These differences in elevation allow water to move from higher elevations to lower and the greater the difference in elevation between cells, the higher the velocity the water moves downslope. As the differences in elevation become smaller, water velocity decreases, and sediments and litter carried by the water begin to drop out and are deposited in cells with more gradual slopes. Similarly, as water rises from bays, rivers, and streams, the water moves first into cells with the lowest elevations and then moves to cells with higher elevations if the quantity of water is sufficient. As standing water recedes, it moves from cells of higher elevation to cells of lower elevation. In areas with standing water (e.g., bay, lakes, ponds, streams, river), the height of the water column in each cell is determined by the difference between the current water level and the elevation of the particular cell (i.e., negative elevation relative to mean sea level).

The elevations above mean sea level for the Phase 1 San Antonio Bay EDYS model were taken from USGS DEMs. Elevations below mean sea level (bathymetry) were obtained from NOAA (Department of Oceanography, Texas A&M University).

2.6 River Flow and Tidal Movement

Inflow data inputs into the Phase 1 model were taken from TXBlend output. There were two sources of inflow: 1) discharge from the Guadalupe River and 2) tidal inflow/outflow from Espirito Santo Bay on the northeast and the northwest mouth of Mesquite Bay on the southwest.

EDYS simulates river flow by dividing the river channel into cells with each cell divided into layers analogous to soil layers in the soil profile component of EDYS. The number of layers is flexible. In the Phase 1 model, three layers were used (surface, middle, and benthic) with an underlying streambed layer (Fig. 4). At each time step, the quantity of water passing the Tivoli gauge station enters the first cell of the river channel (allocated proportionately among the three layers) and then moved cell by cell down the channel. Changing width of the channel is accounted for by adjusting the height of the water column in the respective cells. As the water moves past the mouth of the river, it is allocated to each bay cell adjacent to the river mouth, mixed with the water in these bay cells, and then entered into the Bay distribution system. All along the river channel, water is added to each cell during each precipitation event and any runoff from overland flow is added to the appropriate cells along the river channel. Water is also removed from each cell at each time step to account for evaporation, with evaporation rate adjusted for month of the year and time of day.

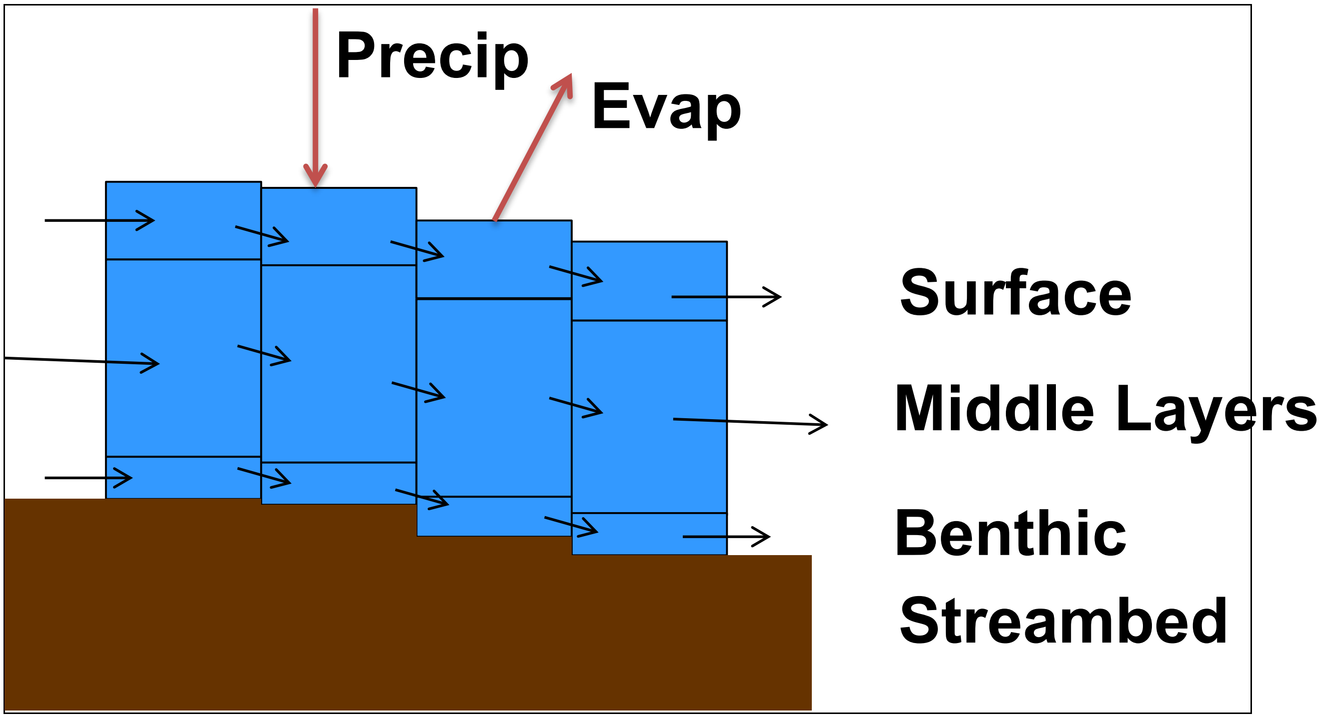

Figure 4. Schematic of a river segment with linked cells and layers per cell as simulated in the Phase 1 San Antonio Bay EDYS model.

Water movement in the Bay is modeled in a manner similar to that of river flow, except water movement in the Bay is multi-directional on an hourly basis. At each time step, water input into the Bay is calculated. The amount entering the Bay from tidal action and the amount from river flow are taken from TXBlend output. The respective amounts are added to the cells adjacent to inflow, temporarily increasing the height of the water column in those cells. Within the same time step, the difference in water column height between those adjacent cells and the TXBlend tidal height or the elevation of the river at the discharge line is calculated. These respective height differences are summed across the area of the cells adjacent to these tidal or river input lines to arrive at volume of water to be moved to the next line of cells. This process is repeated within each time step to move water from one line of cells to the next line of cells throughout the Bay system, adding any overland flow water at the appropriate cells at the Bay-land interface, including marsh cells. As the "flow-front" moves across the Bay system, the number of cells along the leading edge of the flow-front is taken into account to properly distribute the water across the Bay (Fig. 5) and into adjacent marsh areas. If cells are encountered with elevations above the height of the water column at the flow-front, the flow moves around those cells (light blue cells, Fig. 5). If the water column height along the flow-front is higher than the elevation of the adjacent land cells, water moves across the land cells (i.e., inundation), and these cells have a corresponding water column height (i.e., inundation depth) during that time step.

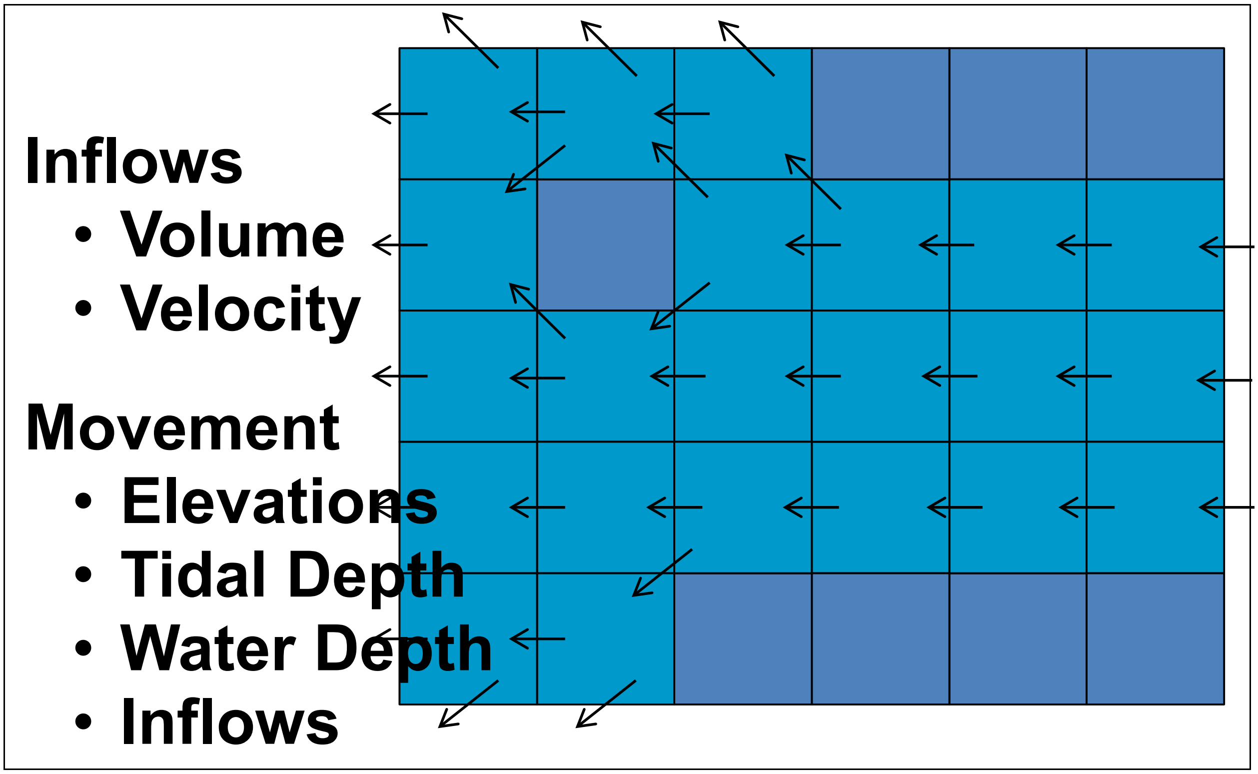

Figure 5. Schematic of directional water movement in the Bay, with darker-blue cells indicating submerged cells (either open Bay or marsh) and lighter-blue cells indicating cells with surfaces above the water line at that time step.

As tide moves out, a reverse pattern of water movement is simulated where water waters from higher elevations along the edges of the Bay (e.g., marshes) to lower elevations at the lines of tidal inflow/outflow in the spatial footprint (Fig. 6). Water movement in the Bay is simulated in a single layer in the Phase 1 model, but the number of layers will be increased in subsequent phases.

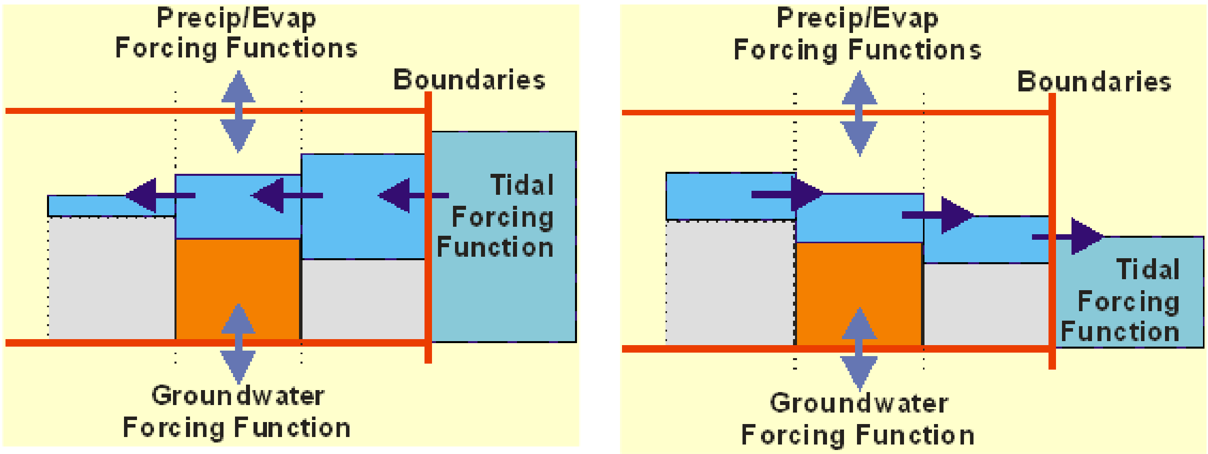

Figure 6. Schematic illustrating two-directional movement of tidal movement in the Phase 1 San Antonio EDYS model.

If the height of the bay/marsh water column at the mouth of the river is greater than the height of water column in the cells in the mouth of the river, bay water moves upstream into the river channel (e.g., storm surge). Likewise, if the height of the water column in the river after adjustment is made for downstream movement, water moves from the river channel outward onto adjacent land cells (i.e., overland flooding). Lateral movement of overland flooding continues within a time step until the height of water column equals the elevation of the next line of land cells.

The ability of the model to simulate changes in depth of water allows for the simulation of flooding effects to vegetation. Both aspects of flooding, soil saturation and depth of submergence are simulated. Each plant species in the Phase 1 model has response functions included for tolerance to soil saturation and to depth and length of submergence. The ability of some marsh and tidal flat species to succeed on a particular site is the result of greater ability on their part to tolerate conditions of flooding than competing species. EDYS allows these competitive interactions to be modeled.

2.7 Sediment and Salinity Dynamics

As water moves from one cell to another, suspended (e.g., sediments) or dissolved (e.g., salts, oxygen) substances in the water column mix with those of the cells into which the water moves. The resulting concentration of these materials at the end of a time step is calculated on the basis of the concentrations in the pre-mixed water proportional to the amounts of water in each cell. This process is similar to the process whereby concentrations of nutrients and contaminants are determined in the various soil layers of the terrestrial system as water percolates downward through the soil profile following a rainfall or flooding event, or moves upward in the soil by capillarity.

Each plant species in the Phase 1 model has a response range to salinity included in the plant parameter matrices. For most species, as salinity increases the growth rate decreases after a certain threshold level. At a higher threshold level, most species begin to suffer tissue loss (death) as salinity increases past their tolerance levels. Because different species have different tolerance and optimum levels for salinity (as for other substances), there is a shift in competitive advantage among species as salinity levels change. EDYS is able to simulate these differential responses and therefore simulate vegetation changes associated with changes in salinity.

2.8 Aquatic and Terrestrial Linkage

An important aspect of EDYS is the ability to simulate the linkage between the aquatic and terrestrial components of the bay ecosystem, especially including the dynamics of the marsh communities. In the Phase 1 San Antonio Bay EDYS model, water and water-borne substances (e.g, salinity, sediments, litter) move back and forth among the terrestrial, marsh, and open bay cells.

Modeling the entire Phase 1 footprint (1.2 million cells) in a single model requires considerable memory and relatively slow run times. To reduce these memory requirements and speed up run times while maintaining the ability to integrate terrestrial, marsh, and open bay ecosystems, we have utilized three linked models instead of a single large model. One model is the standard EDYS Terrestrial model which simulates terrestrial processes and supplies surface runoff, erosion (sediments), nutrient, and litter inputs into the EDYS Aquatic model. The EDYS Aquatic model receives input data from the EDYS Terrestrial model and simulates abiotic processes in the aquatic systems (river and open bay). When appropriate (e.g., high tide, storm surges, river flooding), outputs from the EDYS Aquatic model are supplied as inputs into the EDYS Terrestrial model. The third model, EDYS Aquatic-Biology model, will be developed as part of Phase 2. The EDYS Aquatic-Biology model will simulate biological dynamics in the aquatic systems.

At each time step, EDYS Terrestrial runs and the appropriate output files are supplied to EDYS Aquatic. EDYS Terrestrial then temporarily stops (goes to "sleep") while EDYS Aquatic runs through the time step. At the end of the EDYS Aquatic time step, it supplies appropriate output files to EDYS Terrestrial. EDYS Terrestrial then "wakes up", uses the EDYS Aquatic output as inputs into the next time step for EDYS Terrestrial. This process continues until the simulation is completed. This linkage of two models also allows for different time steps to be used effectively in each model if necessary. We have used a similar approach linking EDYS with MODFLOW, allowing EDYS to simulate ecological and hydrological dynamics above ground and throughout the rooting zone and allowing MODFLOW to simulate groundwater dynamics.

3.0 RESULTS

The purpose of the Phase 1 San Antonio Bay EDYS model is to provide a Proof of Concept relative to the ability of EDYS to realistically simulate aquatic ecological dynamics. There were two specific objectives for the Phase 1 effort: 1) to develop a spatially realistic model of plant community distribution and 2) show realistic changes in vegetation (primarily marsh communities) in response to changes in water level and salinity.

The first objective was met by the development of the spatial model consisting of 220 plant communities (Figs. 1 and 2 and Section 2.4). The second objective has also been met. Results are presented in the following three sub-sections that illustrate the ability of EDYS to simulate vegetation responses to changes in water level and salinity. These results are presented for three community types. EDYS produces simulation output for all community types, but these three serve as illustrations. EDYS also allows for any number of variations in level of the variables of interest (water level and salinity, in this case). Two levels of each are presented in this report. The simulations were run for five years.

3.1 Salt Marsh Community

Cell Type 201 is a salt marsh community (Shiflet 1963; Cutshall 1994a, 1994b). Four species comprised most of the vegetation in this community: smooth cordgrass, common reed, seashore paspalum, and saltgrass. Average annual aboveground production is typically about 1200 g/m^2 (Alongi 1998:48). At the end of the first summer of the baseline simulation total aboveground biomass was about 860 g/m^2, with 480 g/m^2 of smooth cordgrass (56% relative biomass), 260 g/m^2 of common reed (30% relative biomass), 80 g/m^2 of saltgrass (9% relative biomass), and 40 g/m^2 of seashore paspalum (5% relative biomass) (Fig. 7). Under baseline conditions, productivity and composition remained relatively stable over time. Aboveground biomass declined during winter months and increased during summer months, but there were only minor changes over the 5-year simulation period (Fig. 7). Smooth cordgrass decreased slightly (440 g/m^2 in Year 5 compared to 480 g/m^2 in Year 1) and common reed increased (260 g/m^2 in Year 1 and 330 g/m^2 in Year 5). Should this trend continue, the site would likely shift to dominance by common reed in 10-15 years.

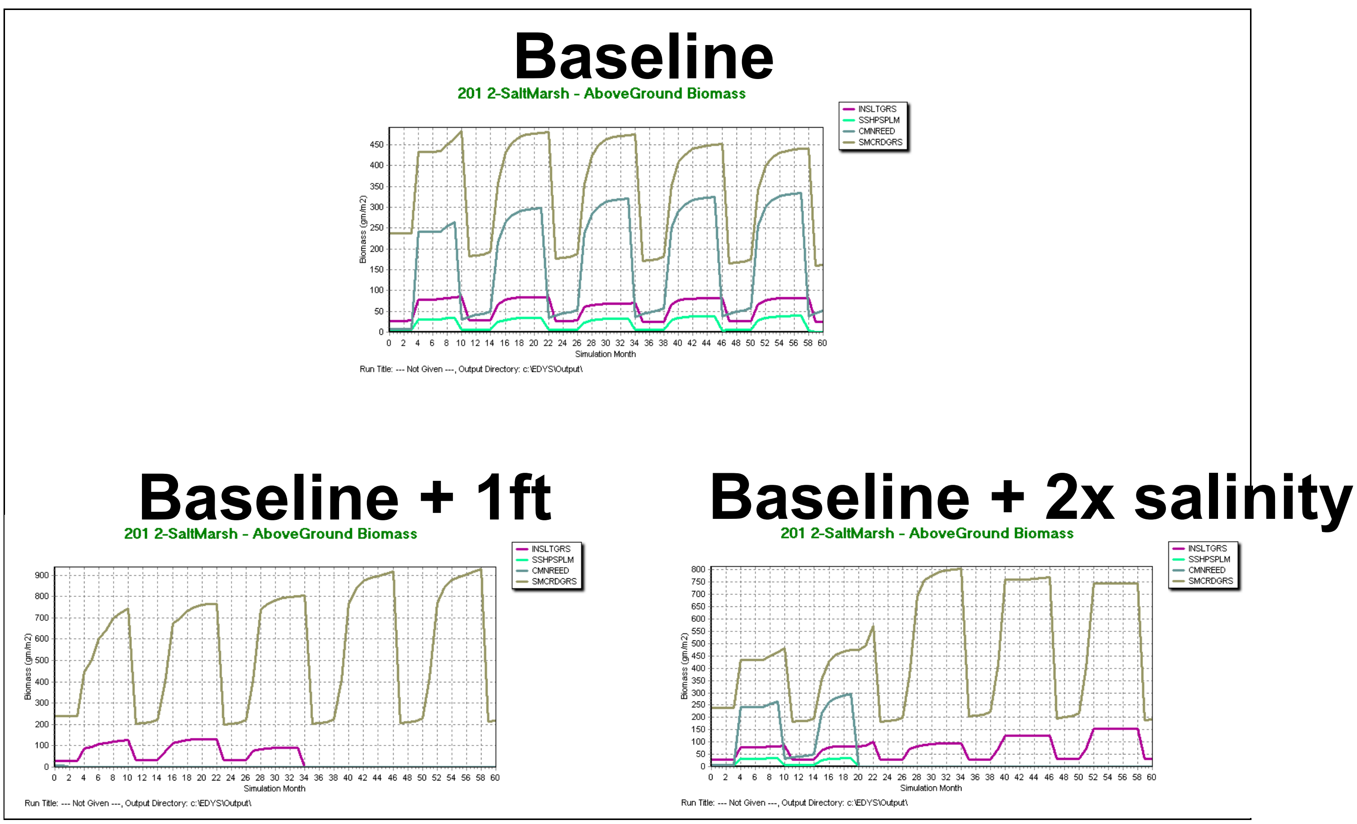

Figure 7. Aboveground biomass (g/m^2) dynamics in a salt marsh (smooth cordgrass) community in the Phase 1 San Antonio Bay EDYS model simulated under three scenarios: 1) baseline (2005-09 water and salinity levels), 2) water levels increased by 1 ft (Baseline + 1 ft), and 3) salinity levels doubled (Baseline + 2x salinity).

The flooding scenario (Baseline + 1 ft; Fig. 7) was simulated by increasing each baseline water height by 1 ft. Under this scenario, aboveground production by the community would increase over time, reaching about 1000 g/m^2 by Year 5, all of which would be from smooth cordgrass (Fig. 7). The higher water levels would have eliminated the other three species.

The effect of salinity was illustrated by doubling the baseline salinity levels. Under this scenario, community productivity would be higher than baseline (900 g/m^2), primarily because of an increase in smooth cordgrass (Fig. 7). Saltgrass also benefited from the higher salinity, increasing to 150 g/m^2 in Year 5 compared to 80 g/m^2 under baseline conditions. For both species, the increase in biomass at higher salinity levels was likely the result of less competition from common reed, which was eliminated from the community in the second year under higher salinity (Fig. 7). This is an example of greater tolerance (on the part of cordgrass and saltgrass) becoming a major factor in competitive displacement (of common reed).

3.2 Brackish Marsh

The brackish marsh community (EDYS Type 307) was a marshhay cordgrass community with saltgrass and seashore paspalum as sub-dominants (Shiflet 1963; Cutshall 1994a, 1994b). On average, marshhay cordgrass produces about 60% of the aboveground biomass of the community and saltgrass and common reed each produces about 15%. Four other species occur in lesser quantities: sea oxeye, common reed, smooth cordgrass, and seashore dropseed. Average annual aboveground production for this community is about 1200 g/m^2 (Alongi 1998:48).

The EDYS baseline scenario resulted in a fairly stable community, with marshhay cordgrass declining slightly and common reed increasing slightly (Fig. 8). Sea oxeye and saltgrass remained stable and the remaining three species were eliminated from the community.

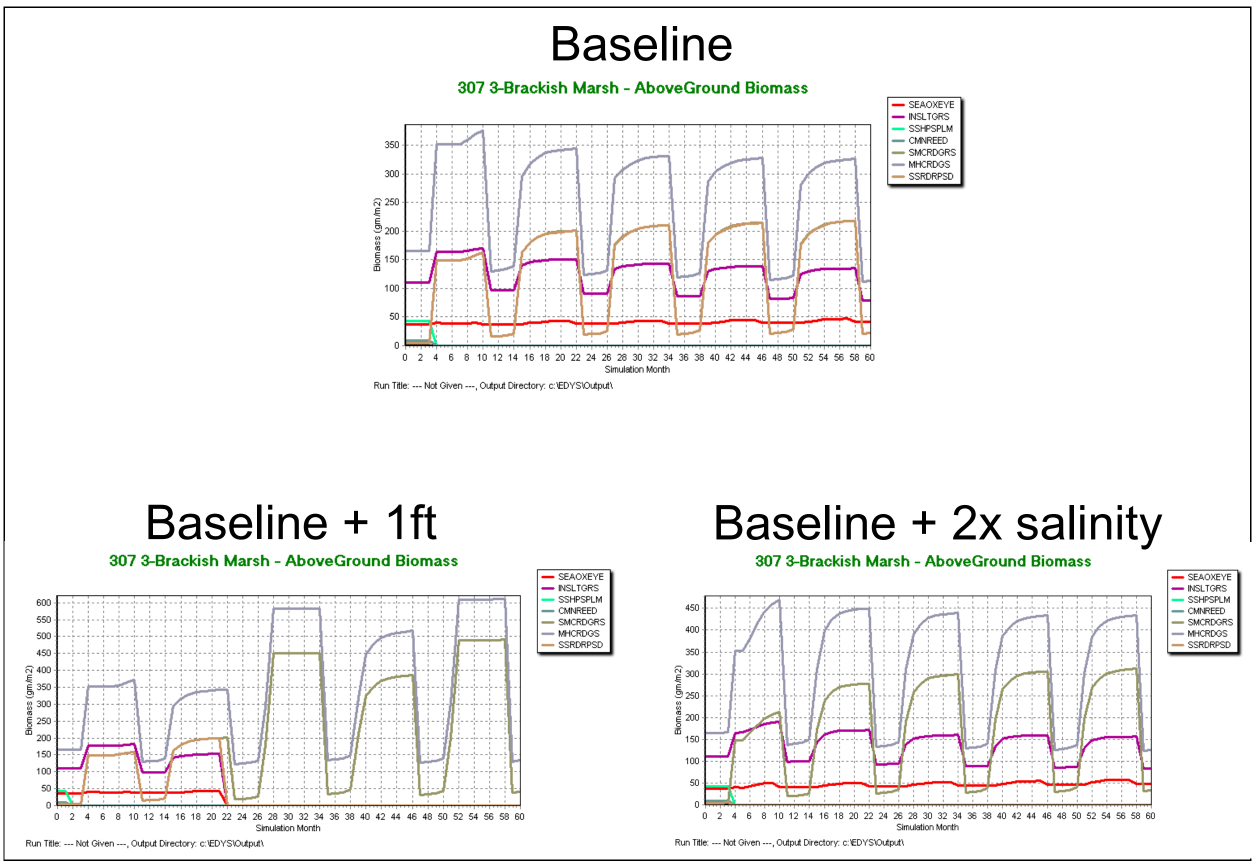

Figure 8. Aboveground biomass (g/m^2) dynamics in a brackish marsh (marshhay cordgrass) community in the Phase 1 San Antonio Bay EDYS model simulated under three scenarios: 1) baseline (2005-09 water and salinity levels), 2) water levels increased by 1 ft (Baseline + 1 ft), and 3) salinity levels doubled (Baseline + 2x salinity).

Under the higher water level scenario (Baseline + 1 ft), productivity of the community increased substantially (Fig. 8). Overall aboveground production in Year 5 was about 740 g/m^2 under baseline conditions and increased to about 1100 g/m^2 under the higher water level scenario. This increase was the result of increased production by marshhay cordgrass and common reed. The remaining species were eliminated by the higher water level.

Doubling salinity increased productivity of this community but had little effect on species composition compared to baseline (Fig. 8). Community aboveground production increased to about 960 g/m^2 in Year 5, mostly from increased productivity of marshhay cordgrass and common reed, but saltgrass also had higher production. Marshhay cordgrass remained the dominant species under higher salinity, but its degree of dominance decreased somewhat. Under the baseline scenario, marshhay cordgrass produced about 44% of the community biomass and common reed produced about 30% (Fig. 8). Doubling salinity increased the relative biomass of marshhay cordgrass to 45% and that of common reed to 32%. Relative biomass of saltgrass decreased slightly, from 18% under baseline to 16% under higher salinity.

Different ecological mechanisms were involved in controlling species responses to higher salinity in the brackish community than in the salt marsh community. In the salt marsh community, composition changes occurred in response to differences in tolerance to higher salinity. Smooth cordgrass was able to tolerate higher salinity than was common reed and therefore composition of common reed decreased and composition of smooth cordgrass increased. In the brackish marsh, the mechanism was potential growth rate. All three major species (marshhay cordgrass, common reed, saltgrass) could tolerate the higher salinity and the higher salinity levels did not adversely affect their potential growth rates. In the absence of a negative effect from salinity, the different potential growth rates were manifested. Marshhay cordgrass and common reed have higher potential growth rates than saltgrass and therefore the first two species increased their relative success in that community. The ability of EDYS to simulate not only different response patterns but also different controlling mechanisms is a major advantage in the use of such a mechanistic model.

3.3 Saline Clay Flat

The saline clay flat community (EDYS Type 801) was a gulf cordgrass community, with saltgrass and bermudagrass as subdominants (Drawe et al. 1978, Scrifres et al. 1980, Drawe 1994b). Gulf cordgrass produces 60-80% of the aboveground biomass in this community, with the remainder produced by 10-15 additional species. Average annual aboveground production for this community is about 600 g/m^2 (Garza et al. 1994).

The baseline scenario resulted in a stable community (Fig. 9). Aboveground production ranged between about 650-750 g/m^2 and gulf cordgrass remained the dominant species. The secondary species remained in the community and their biomass values also remained stable across years. Increasing the water depth (Baseline + 1 ft) increased the productivity of gulf cordgrass and the community overall, but eventually eliminated the secondary species. Increasing salinity also increased gulf cordgrass biomass and biomass of the community overall, but most of the secondary species remained in the community at production levels similar to those of baseline (Fig. 9).

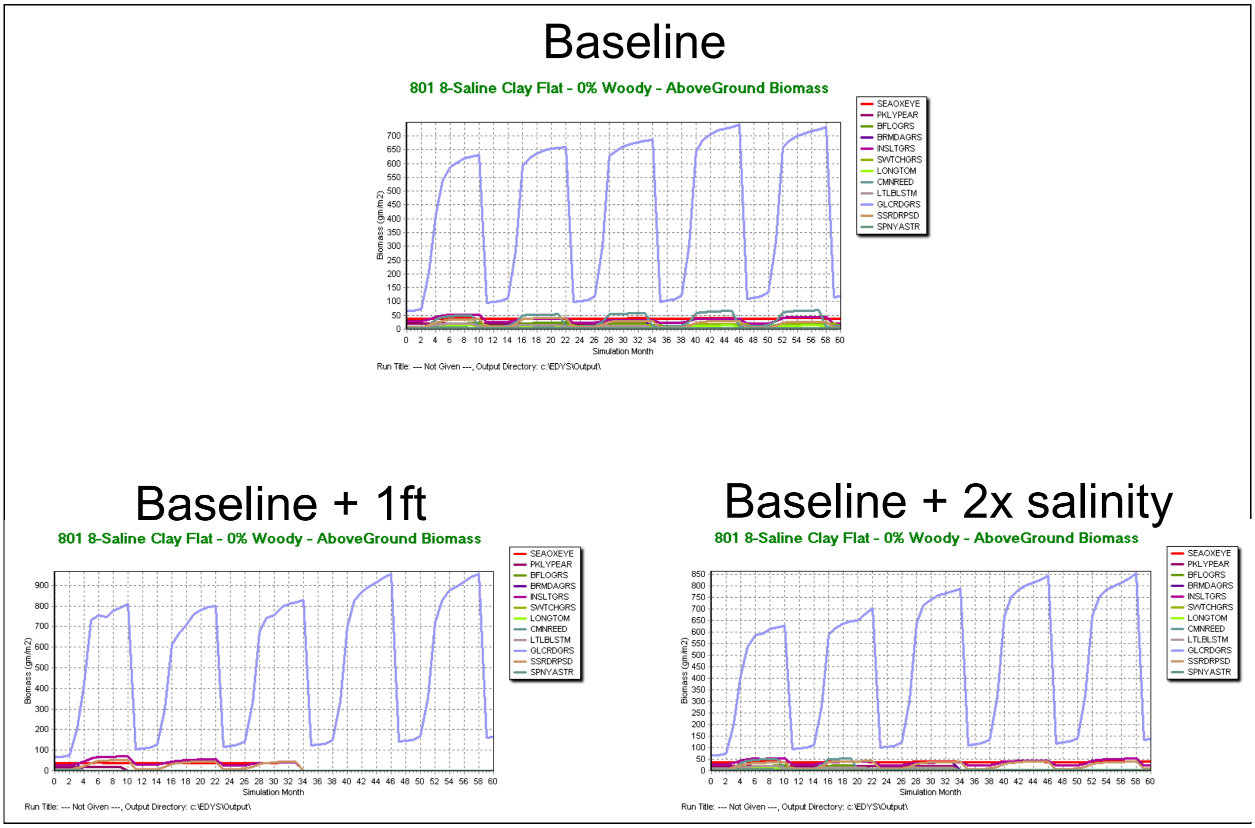

Figure 9. Aboveground biomass (g/m^2) dynamics in a saline clay flat (gulf cordgrass) community in the Phase 1 San Antonio Bay EDYS model simulated under three scenarios: 1) baseline (2005-09 water and salinity levels), 2) water levels increased by 1 ft (Baseline + 1 ft), and 3) salinity levels doubled (Baseline + 2x salinity).

3.4 Summary of Results

The Phase 1 San Antonio Bay EDYS model showed that EDYS capable of realistically modeling 1) the spatial patterns of the plant communities, 2) interactions among the terrestrial, marsh, and open bay ecosystems, and 3) vegetation effects of changes in water and salinity levels. The simulated vegetation effects varied among plant communities and reflected expected responses to the three major cordgrass species in relation to changes in salinity. The simulation results from EDYS also allowed for the recognition of the effects of different ecological response mechanisms controlling competitive displacement (i.e., tolerance and relative growth rate).

Phase 1 was designed as a proof of concept application. It met those objectives. The next phase in the development of the San Antonio Bay EDYS model should address at least some of the following objectives: 1) field validation of the vegetation responses, 2) integrate some aquatic and marsh animal components, 3) incorporate a fine-scale landscape with appropriate field measurements, and 4) begin to incorporate land use components.

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APPENDIX

Appendix Table 1. Soil series, with corresponding NRCS ecological sites, included in the spatial footprint of the Phase 1 San Antonio Bay EDYS model.

Symbol	Soil Series	NRCS Site	County
Ac	Aransas	Clayey Bottomland	Refugio
Af	Aransas	Clayey Bottomland	Refugio
Ar	Aransas	Clayey Bottomland	Calhoun
As	Aransas	Salty Bottomland	Aransas
As	Aransas	Clayey Bottomland	Calhoun, Refugio
HA	Arrada	Tidal Flats	Calhoun
At	Austwell	Salty Bottomland	Calhoun
Au	Austwell	Salty Bottomland	Calhoun
BT	Barrada	Salt Flat	Aransas
Be	Baycliff	Blackland	Calhoun
Ba	Bayucos	Mud Flat	Calhoun
Dn	Contee	Blackland	Calhoun
Md	Contee	Blackland	Calhoun
Dc	Dacosta	Blackland	Calhoun
Dn	Dacosta	Blackland	Calhoun
Mb	Dacosta	Blackland	Calhoun
Mc	Dacosta	Blackland	Calhoun
Dp	Dianola	Salty Prairie	Calhoun
Ds	Dianola	Salt Flat	Aransas
Dt	Dietrich	Sandy Coastal Flat	Refugio
Ed	Edna	Claypan Prairie	Calhoun
Ec	Edroy	Claypan Prairie	Refugio
Ed	Edroy	Lakebed	Refugio
Fd	Faddin	Loamy Prairie	Regugio
FA	Falfurrias	Sand Hills	Aransas
FfC	Falfurrias	Sand Hills	Refugio
Fr	Francitas	Salty Prairie	Calhoun
Ga	Galveston	Tidal Flats	Calhoun
GA	Galveston	Coastal Sand	Aransas
Gc	Galveston	Tidal Flats	Calhoun
GM	Galveston	Coastal Sand	Aransas
GmB	Galveston	Low Coastal Sand	Refugio
Hr	Harris	Salt Marsh	Calhoun
Hs	Harris	Salt Marsh	Calhoun
Ic	Ijam	Salty Prairie	Calhoun
Is	Ijam	Salty Prairie	Aransas
La	Laewest	Blackland	Calhoun
Lc	Laewest	Blackland	Calhoun
Lo	Livia	Salty Prairie	Calhoun
Lv	Livia	Salty Prairie	Calhoun
Lx	Livia	Salty Prairie	Calhoun
Ma	Matagorda	Salty Prairie	Calhoun
MoC	Monteola	Rolling Blackland	Refugio
MoD4	Monteola	Rolling Blackland	Refugio
Ad	Mustang	Low Coastal Sand	Calhoun
GM	Mustang	Low Coastal Sand	Aransas
Mu	Mustang	Low Coastal Sand	Aransas, Calhoun, Refugio
Na	Narta	Salty Prairie	Aransas, Refugio
Od	Odem	Loamy Bottomland	Refugio
Or	Orelia	Claypan Prairie	Refugio

Appendix Table 1. (Cont.)

Symbol	Soil Series	NRCS Site	County
Da	Palacios	Salty Prairie	Calhoun
PtA	Papalote	Tight Sandy Loam	Refugio
PtB	Papalote	Tight Sandy Loam	Refugio
PtC	Papalote	Tight Sandy Loam	Refugio
Pc	Placedo	Salt Marsh	Calhoun
Pr	Portalto	Tidal Flats	Calhoun
Ps	Psamments	Low Coastal Sands	Calhoun
PS	Psamments	Beaches	Calhoun
a	Rahal	Tidal Flats	Calhoun
Ro	Roemer	Tidal Flats	Calhoun
Te	Telferner	Loamy Prairie	Calhoun
Ve	Veston	Salty Prairie	Calhoun
Vs	Veston	Salty Prairie	Calhoun
Va	Victine	Salty Prairie	Aransas, Refugio
VcA	Victoria	Blackland	Aransas, Refugio
VcB	Victoria	Blackland	Refugio
Vd	Victoria	Blackland	Aransas, Refugio