SAN ANTONIO BAY EDYS MODEL PHASE 2
ANNUAL REPORT

REPORT PREPARED FOR:

SAN ANTONIO RIVER AUTHORITY
100 EAST GUENTHER STREET
SAN ANTONIO, TEXAS78282-9980

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EXECUTIVE SUMMARY

San Antonio River Authority (SARA) is interested in developing an integrated management tool based on the EDYS ecological simulation model for use on the San Antonio River and San Antonio Bay. In May 2011, KS2 Ecological Field Services LLC (KS2) submitted a Scope of Work to SARA for the development of that modeling tool. SARA authorized KS2 to begin by developing a proof of concept model of the Bay and surrounding marshes and uplands. This Phase 1 model was developed and delivered to SARA in June 2012. SARA then authorized KS2 to further develop this initial model as Phase 2. There were six tasks associated with Phase 2. This report provides a review of five of these tasks (Task 6 was Project Management and Meetings).

Task 1 Field Verification of Spatial Data

The Phase 1 model utilized spatial data from existing sources, primarily NRCS soil surveys for soil, vegetation, and landuse patterns and USGS DEM data for elevations. These data were sufficient for Phase 1 requirements, but are not likely to suffice for more rigorous future requirements. Extensive field verification (i.e., ground-truthing) of the spatial footprint was beyond the scope of Phase 2. However, a limited field verification effort was included (Task 1). This limited effort was concentrated on the northeastern quadrant, approximately between Mission Lake and Seadrift. A two-person experienced field vegetation team spent three days making a visual reconnaissance of as many of the Phase 1 vegetation polygons as possible from land and one day from the water. The team was able to compile data on about 15% of the Phase 1 polygons in the area and compare current visual data with data that had been estimated from previously existing sources.

Results of this effort indicated an agreement between Phase 1 sources and 2013 existing conditions of about 60%, based on vegetation type (e.g., brackish marsh, saline clay flat). The NRCS maps used to develop the proof of concept Phase 1 vegetation maps were 30-35 years old. Many of the differences between the Phase 1 and the 2013 field verification data can be attributed to 1) increases in woody species (primarily huisache and mesquite), 2) changes in landuse (e.g., improved pastures, roads and urban development), and 3) difficulty in distinguishing between freshwater marshes and brackish marshes using aerial photos. The field verification effort revealed important species composition aspects in many of the marsh and other wetland communities that were not available from the earlier sources. Of particular importance were the greater amounts of common reed and lower amounts of some of the cordgrasses at some of these sites.

This task provided important information that will be used to increase the precision of the model. These results also indicate the need for further field verification of the locations and composition of these plant communities, especially the marsh and tidal flat communities.

Task 2 Development of Animal Sub-Modules

The purpose of Task 2 of Phase 2 was to begin to develop sub-modules for shrimp and clam dynamics in the San Antonio Bay model. The purpose of Task 2 was not to simulate the full range of dynamics of the two organisms, but only the most basic responses. Development of the full models of the animal dynamics was not expected to occur until later phases.

During the progress of Phase 2, the project team made the decision that it would be more productive to concentrate on development of the vegetation components of the model in Phase 2 and postpone work on animal sub-modules. This decision was based on two factors. First, the vegetation dynamics are fundamental to the functioning of the Bay system and these dynamics, along with their linkage to salinity and water levels, are what is most lacking in work on the Bay ecosystem. Secondly, it had been hoped that funds would become available from other sources in 2012-2013 to work on the animal sub-modules. These did not materialize and it was felt that only minimal progress could therefore be made on the animal sub-modules in Phase 2. Task 2 funds were therefore re-allocated to Tasks 3-5.

Task 3 Inclusion of Additional Existing Data

Substantial amounts of pertinent ecological, hydrological, and water chemistry data relative to San Antonio Bay currently exist from various sources. Some of these data were accessed in Phase 1. The purpose of Task 3 of Phase 2 was to continue the process of gathering and summarizing these data and incorporating it into the model. Of particular interest in Phase 2 was securing additional data on salinity and submergence tolerances of the major plant species, decomposition and mineralization of marsh detritus, and adding conceptual models of plant zonation in the major toposequences of the San Antonio Bay complex (freshwater, saltwater, and barrier island).

The Phase 1 model contained 57 plant species. Another 20 species have been added to the Phase 2 model and one species has been removed. Salinity tolerance values (no effect, upper threshold, and no growth) have been collected from the literature for 28 species and estimated for the remaining 44 species in the model. Additional salinity response data have been collected from the literature on the major marsh species. Inundation data have been collected from the literature for 28 wetland and marsh species.

Vegetation zonation is strongly developed in coastal and marsh ecosystems, in large part because of the responses of individual species to changes in salinity and inundation. Two other factors of major importance, especially in the distribution of species in adjacent upland sites, are soil texture and depth to soil saturation. Data collected in Task 3 were also used to 1) develop conceptual models of the basic vegetation patterns of three important toposequences (freshwater, brackish-saline, and barrier island) and 2) use these toposequences and the data collected to build a fine-scale EDYS model to more precisely simulate small-scale ecological processes in marsh and wetland systems.

The effects of salinity, inundation, soil texture, and depth to saturation on the major species included in the model were used to develop the three conceptual models. Each conceptual model represents a primary vegetation gradient of the San Antonio Bay complex illustrated in the conceptual model along a topographic gradient (toposequence) from the water edge to upland vegetation. These three models do not represent any single unique location on the landscape. Instead, they are representative of basic vegetation patterns likely encountered throughout the upland-marsh-bay complex. They can, however, be easily adapted to apply to specific local patterns.

The EDYS model for the overall San Antonio Bay complex contains over 560,000 cells, each cell 40 m x 40 m in size. This spatial resolution is adequate to simulate many landscape-level processes. However, simulation of spatially-realistic small-scale ecological processes will require finer resolution. In anticipation of this need, an example of a fine-scale model was developed in Task 3. This fine-scale model is based on two of the toposequence conceptual models (freshwater and brackish-saline) and uses a 50 cm x 50 cm (0.25 m^2) cell size. The spatial footprint of the fine-scale model is 200 m long x 40 m wide (8000 m^2 = about 2 acres) and contains 32,000 cells. Similar to the conceptual models, this fine-scale model can be adapted to any similar-sized area in the San Antonio Bay complex, provided adequate spatial and vegetation data are available (or can be reasonably estimated).

A fourth subtask within Task 3 was to refine the EDYS decomposition/mineralization sub-routine with special emphasis on marsh dynamics. A preliminary conceptual model was developed based on literature in the literature and professional knowledge. It is expected that this conceptual model will be continually refined and updated as progress continues through subsequent phases of the development of the San Antonio Bay model. A substantial number of literature articles on decomposition, mineralization, and nitrogen dynamics have been collected and are being reviewed for pertinent data. As these data are extracted, the data will be used to quantify details of the conceptual model and update the EDYS sub-modules.

Task 4 Increase the Complexity of the Aquatic Model

This task consisted of three additions to the aquatic model. The first addition was to increase the Bay model from a single-layer aquatic model to a multiple-layer aquatic model. The river and pond aquatic systems already had multiple-layer capability. Water movement dynamics of the Bay are more complex than either river or pond dynamics, in large part because of tidal effects and the larger size of the Bay. Consequently, the Phase 1 model of the Bay consisted of a single water layer within each cell.

Coding of the multi-layer Bay model was being funded by the US Army Corps of Engineers. Mid-way through FY13, the Federal Government experienced a significant fiscal limitation and ended their funding of this work for the remainder of FY13. Although a substantial amount of the coding was completed by the time funding ended, it was not complete. The Bay circulation component is working. Water moves around and through the Bay in the model in response to tidal changes and produces realistic patterns of water and salinity movement. Water also flows between cells and the water depths (by layers) in cells increases or decreases as water supply increases or decreases. Linkages between freshwater inflows and the multiple layers in the Bay are partially in place, but not complete. Wind effects and temperature changes have not been added but the approach to do so is in place.

The second addition to the Bay aquatic model is to add nitrogen. This will be completed once the multi-layer coding is in place. Data from Task 3 will be used to parameterize this addition.

The third addition was to develop a conceptual approach to adding temperature to the Bay aquatic model. This approach has been developed, based on both solar energy input into the upper water layer and temperature (heat) transfer among layers and between the water and the atmosphere. Temperature will be added to the Bay aquatic model once the multi-layer coding has been completed.

Task 5 Evaluate Varied Precipitation Levels

In EDYS precipitation is entered cell by cell across the landscape at each time step (e.g., daily). This allows hydrologic and hydro-ecological processes to be simulated realistically across the landscape. In the Phase 1 model, only one set of precipitation is used for the entire footprint, i.e., each cell receives the same amount of precipitation. Although the precipitation values vary over time, they do not vary spatially. In the real world, precipitation also varies spatially. The purpose of Task 5 was to evaluate the probable magnitude of this spatial variation across the San Antonio Bay landscape and to evaluate several methods for developing a spatially-explicit pattern of precipitation for the model.

Precipitation data from 14 stations along the middle Texas coast were summarized and used for the evaluations. Comparisons of data from these stations indicate a substantial spatial variation in precipitation in the region of the middle Texas coast. On average, monthly precipitation differs by 0.8 inch between Aransas NWR and Austwell, a distance of only 6 miles. This amount equals 28% of the average monthly precipitation at Aransas NWR. Average annual precipitation decreases by about 1 inch per 10 miles in an east-west direction along the middle coast (Point Comfort, Palacios, and Matagorda in the east compared to Aransas Pass and Rockport in the west) and 1 inch per 13 miles in a north-south direction (Goliad and Victoria in the north and Aransas NWR and Port O'Connor in the south). These data from the 14 stations were also used to develop a long-term (1898-2011) constructed precipitation data set for the San Antonio Bay footprint.

Four methods were evaluated to evaluate spatial variation in precipitation across the Bay landscape: linear distance adjustments between means, linear distance adjustments using average differences between events, regression equations, and kriging. The linear distance adjustments between means method was selected to calculate spatial variation in precipitation because of its ease of use. Based on this method, annual precipitation varies by about 5% across the footprint, in both north-south and east-west directions. This equates to about a decrease in annual precipitation of about 1 (dry years) to 3 (wet years) inches across the landscape, with the highest precipitation received along the south and east edges.

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 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 San Antonio Bay are important to SARA, in part because the San Antonio River is a major supplier of freshwater to the 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 (Anderson et al. 2006). This is especially true should some of the changes occur in tidal marsh systems that are being predicted by some researchers (Craft et al. 2009). A 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 manner.

EDYS is a dynamic ecological simulation model that is mechanistically based and spatially explicit. It has been widely used for ecological simulations, watershed management, land management decision making, environmental planning, regulatory compliance, and revegetation and restoration design analysis, with projects in Texas, 11 other states, and international.

SARA is interested in applying EDYS as an integrated management tool for use on the San Antonio watershed, including San Antonio Bay. KS2 Ecological Field Services (KS2) submitted a 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 a multi-phase approach to the development of the model. In June 2011, SARA authorized KS2 to proceed with Phase 1 of that Scope of Work under Purchase Order No. P1100451 and the US Army Corps of Engineers Environmental Research and Development Center (ERDC) contributed additional funding for the Phase 1 proof of concept study of the application of EDYS to San Antonio Bay. The specific objectives of the 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) simulate realistic changes in vegetation response of the marsh and adjacent terrestrial vegetation to change in water levels and change in salinity. The Phase 1 model was successfully completed and the report delivered to SARA in June 2012 (McLendon 2012).

Following completion of Phase 1, KS2 submitted a Scope of Work for a second phase of the model entitled "Development of an EDYS Model for the San Antonio Bay: Phase 2" to SARA in July 2012. SARA authorized KS2 to proceed with Phase 2 per that Scope of Work as Amendment 1 to Purchase Order No. P1100451, dated 12 July 2012. ERDC also contributed in-kind services to the Phase 2 effort in the form of time for Dr. Cade Coldren to continue working with KS2 on model development.

The general purpose of Phase 2 was to further develop the proof of concept Phase 1 model. The Phase 2 Scope of Work provided for six tasks associated with this development:

- Provide some limited field verification of spatial data;
- Begin development of animal sub-modules;
- Include additional existing data into the model;
- Increase the complexity of the aquatic model;
- Evaluate varied precipitation inputs across the Bay footprint; and
- Provide for meetings and reports.

This annual report provides a review of these Phase 2 activities.

2.0 TASK 1 FIELD VERIFICATION OF SPATIAL DATA

2.1 Background

The Phase 1 model utilized spatial data from existing sources. The spatial patterns of the vegetation, including locations of the various plant communities, and water bodies were estimated from aerial photographs and Natural Resource Conservation Service (NRCS) soil maps. Topographic input data were based on USGS DEM data which had 10 m spatial resolution (i.e., contour lines drawn at 10-m intervals and differences in elevation between adjacent contour lines assumed to be uniformly averaged between the contour elevations). Both the vegetation and topographic data were sufficiently accurate for the proof of concept approach of Phase 1. However, there are vegetation differences that are important in the ecological dynamics of the upland-marsh-bay complex that may not be apparent from aerial photographs. Likewise, microtopograhic differences are often important in determining ecological characteristics and responses in these ecosystems. The purpose of Task 1 was to gather site-specific field data to be used to refine the vegetation grid and improve the delineation of important topographic features such as mud flats, depressions, drainage pathways, and knolls. An extensive field verification of these factors was beyond the scope of Phase 2. Instead, data were to be collected in one area of the Bay system. The area selected was the northeast quadrant.

The approach defined in the Scope of Work was for an experienced field team to visually reconnaissance as much of the area as possible. Much of the area is private land. Until permission can be obtained to access this private land, visual reconnaissance of these areas must be conducted from public access areas such as roads and from the open Bay. Using these public access areas, the field team was to delineate plant communities on aerial photographs and compare these vegetation maps to the spatial location of vegetation types from Phase 1. Particular emphasis was to be placed on mapping the dominant plant species in marshes, water bodies, and river edges. Topographic features and land-use activities were to be mapped as they were observed. The refinements from the mapping effort were to be translated into the spatial footprint of the EDYS model.

2.2 Results

The field team conducted the verification reconnaissance the week of 15 April 2012. They spent three days collecting information from land, traveling all public accessible roads on all three sides of the area south of Mission Lake and north of Seadrift. Dan Alonso from the San Antonio Bay Foundation provided a shallow-draft boat and guided the team along the Bay sides of the same area for one day. The boat was not an airboat, so it could not travel into the marsh areas, but they were able to view most of the area from relatively short distances. Dan Alonso offered to make contacts with landowners and managers in the area to provide access to private lands for the KS2 in the coming year. The additional data that could be collected from such access, plus closer viewing of the marshes in an airboat, would provide a substantial amount of additional verification data for the model.

The field team used maps of the Phase 1 vegetation types and made corrections to these maps in the field based on their observations. Following the field work, the team summarized this information. Field verification was concentrated in the northeast quadrant of San Antonio Bay and approximately 15% of the EDYS vegetation polygons in this area were observed. These polygons represented 9 of the 20 primary vegetation types (NRCS sites; Appendix Table 1, McLendon 2012) in the Phase 1 model. Two comparisons between the field data and the Phase 1 mapped units were used, one based on primary vegetation type and the second on composition of the major species. Based on primary vegetation type, the field data matched the Phase 1 units for 46 of the 79 polygons (58% agreement). However, 6 of the polygons with vegetation not in agreement with the Phase 1 classification had landuse changes in the intervening years. Eliminating these six polygons from the count raises agreement to 63%.

Species composition was different between the Phase 1 estimates and the results of the Phase 2 field observations in a number of the observed polygons. The most substantial changes were an increase in amount of huisache and mesquite in many polygons, and larger amounts of common reed in a number of the wetland types in 2013 than estimated in Phase 1.

Twenty-one of the verified polygons had been estimated in Phase 1 to be bluestem prairie, based on NRCS ecological sites and soil types. Although the NRCS site description was bluestem prairie, it was obvious from the aerial photographs that most of the polygons had a substantial invasion of woody plants (trees and shrubs). The field verification mapping substantiated this observation (Table 2.1). Of the 21 polygons, 13 now have a tree or shrub as the dominant species. Coverage by woody plants averaged over the 21 polygons is about 30%, with huisache and mesquite the most abundant species. King Ranch bluestem (or in some cases perhaps Kleberg bluestem, *Dichanthium annulatum*) has become the most abundant grass in many of the polygons, either by natural invasion or the result of seeding.

Table 2.1 Estimated composition (% cover) in 2013 of major species in 21 polygons that had been classified in Phase 1 as bluestem prairie (with substantial amounts of trees).

Polygon	Vegetation Type	Major Species
S03	bluestem prairie	45% seacoast bluestem, 20% mesquite, 10% KR bluestem
S31	bluestem prairie	30% KR bluestem, 10% Texas wintergrass, 5% paspalum
S40	bluestem prairie	25% KR bluestem, 10% mesquite, 5% seacoast bluestem
S32	bluestem prairie	10% seacoast bluestem, 10% KR bluestem, 5% paspalum
S04	bluestem prairie	70% sea myrtle, 10% seacoast bluestem, 5% mesquite
S08	bluestem prairie	65% huisache, 10% retama, 5% mesquite
S11	bluestem prairie	65% huisache, 10% retama, 5% mesquite
S15	bluestem prairie	50% huisache, 20% sea myrtle, 10% mesquite
S63	bluestem prairie	45% huisache, 25% mesquite, 10% seacoast bluestem
S45	bluestem prairie	30% huisache, 15% mesquite, 10% hackberry
S67	bluestem prairie	15% mesquite, 10% huisache, 10% KR bluestem
S69	bluestem prairie	15% mesquite, 10% huisache, 10% little bluestem
S39	bluestem prairie	20% mesquite, 30% KR bluestem, 10% paspalum
S68	bluestem prairie	20% mesquite, 20% huisache, 10% little bluestem
S27	bluestem prairie	20% mesquite, 15% huisache, 10% hackberry
S34	bluestem prairie	20% mesquite, 5% huisache, 5% seacoast bluestem
S33	bluestem prairie	30% mesquite, 10% huisache, 10% seacoast bluestem
S41	urban (house)	
S28	improved pasture	50% KR bluestem, 25% bermudagrass
S29	improved pasture	50% KR bluestem, 25% bermudagrass
S17	saline clay flat	50% gulf cordgrass, 20% huisache

Four of the 21 bluestem prairie polygons were not bluestem prairie, even allowing for woody plant coverage (Table 2.1). Three of these four were different types because of changes to the landscape since the aerial photographs were made. The photographs are 30-35 years old (Mowery and Bower 1978; Guckian 1984) and changes have occurred on the landscape since then. One polygon now contains a house and two support improved pasture. One polygon (S17) was misclassified in Phase 1. It should have been classified as a saline clay flat (cordgrass flat) type.

Brackish marsh was the second most frequent type included in the Phase 2 verification, with 13 polygons observed (Table 2.2). Field mapping indicated that 7 of these polygons remained brackish marsh in 2013. Although general type (brackish marsh) remained the same, composition was substantially different from in the Phase 1 model in 5 of the 7 polygons. Common reed was the dominant or co-dominant species in these 5 polygons, instead of some species of cordgrass. Of the remaining 6 polygons, 2 should have been classified as saline clay flat (cordgrass flat) instead of brackish marsh. One polygon was found to be freshwater marsh instead of brackish marsh and one polygon is now improved pasture. Two polygons now are wet woodlands (riparian woodland) and could have been freshwater marsh when the aerial photographs were taken.

Table 2.2 Estimated composition (% cover) in 2013 of major species in 13 polygons that had been classified in Phase 1 as brackish marsh.

Polygon	Vegetation Type	Major Species
S55	brackish marsh	55% smooth cordgrass, 20% common reed, 10% sea myrtle, 5% sea oxeye
S54	brackish marsh	55% marshhay cordgrass, 20% common reed, 5% sea myrtle
S59	brackish marsh	50% common reed, 5% hackberry, 5% mesquite, 5% Chinese tallow
S49	brackish marsh	85% common reed (area has been burned)
S58	brackish marsh	80% common reed, 10% sea myrtle
S62	brackish marsh	85% common reed, 5% retama, 5% mesquite
S51	brackish marsh	40% Olney bulrush, 30% common reed, 10% sea myrtle
S56	improved pasture	75% bermudagrass, 10% seacoast bluestem, 5% paspalum
S52	tidal flat	75% glasswort, 10% gulf cordgrass, 5% sea oxeye
S53	tidal flat	75% glasswort, 10% gulf cordgrass, 5% sea oxeye
S60	fresh marsh	30% Chinese tallow, 20% common reed, 10% hackberry, 10% mesquite
S48	riparian woodland	20% hackberry, 15% mesquite, 15% Chinese tallow, 15% common reed
S61	riparian woodland	25% hackberry, 15% mesquite, 10% Chinese tallow, 5% retama

Twelve polygons were observed that had been classified in the Phase 1 model as freshwater marsh. Only four of these were observed to be freshwater marsh, although one is now improved pasture and could have been freshwater marsh earlier (Table 2.3). Four of the polygons are saline clay flat (cordgrass flat) and three are tidal flats. One polygon is a grassland, with little bluestem and bermudagrass the most abundant species. This polygon could be either a bluestem prairie type or an improved pasture type. Species composition in the four freshwater marsh polygons is different than estimated in the Phase 1 model. Major species in the Phase 1 model were marshmillet, cattail, and Olney bulrush. Major species now are sea myrtle and common reed.

Table 2.3 Estimated composition (% cover) in 2013 of major species in 12 polygons that had been classified in Phase 1 as freshwater marsh.

Polygon	Vegetation Type	Major Species
S74	fresh marsh	75% common reed, 10% Olney bulrush, 5% sea myrtle, 5% spikerush
S21	fresh marsh	20% seacoast bluestem, 10% common reed
S23	fresh marsh	70% sea myrtle, 10% seacoast bluestem, 5% bermudagrass
S09	fresh marsh	80% sea myrtle, 5% huisache, 5% seacoast bluestem, 5% KR bluestem
S76	bluestem prairie	25% little bluestem, 25% bermudagrass, 10% KR bluestem
S10	saline clay flat	75% gulf cordgrass, 10% sea oxeye, 5% seacoast bluestem, 5% saltgrass
S12	saline clay flat	75% gulf cordgrass, 10% sea oxeye, 5% seacoast bluestem, 5% saltgrass
S19	saline clay flat	75% gulf cordgrass, 10% sea oxeye, 5% seacoast bluestem, 5% saltgrass
S16	saline clay flat	50% gulf cordgrass, 10% sea oxeye, 10% saltgrass
S14	tidal flat	40% sea oxeye, 30% gulf cordgrass, 5% saltgrass, 5% glasswort
S13	tidal flat	20% sea oxeye, 20% gulf cordgrass, 30% glasswort, 10% saltgrass
S20	tidal flat	75% glasswort, 10% gulf cordgrass, 5% sea oxeye

Eleven polygons were observed that had been classified in the Phase 1 model as improved pasture. All but one of these were observed to be improved pasture, although most had substantial amounts of huisache or mesquite (Table 2.4). The one misclassified polygon (S66) appeared to be a bluestem prairie type, now supporting mostly mesquite (50%) and huisache (15%). Bermudagrass and KR bluestem are the most common grass species in the 10 improved pasture polygons, but some have substantial amounts of native species, particularly seacoast bluestem. Woody plant cover, mostly huisache and mesquite, in the 11 polygons averaged 25%.

Table 2.4 Estimated composition (% cover) in 2013 of major species in 11 polygons that had been classified in Phase 1 as improved pasture.

Polygon	Vegetation Type	Major Species
S35	improved pasture	50% bermudagrass, 20% seacoast bluestem, 20% KR bluestem (mowed)
S44	improved pasture	15% bermudagrass, 15% KR bluestem, 15% Texas wintergrass
S70	improved pasture	25% KR bluestem, 20% bermudagrass, 10% little bluestem
S43	improved pasture	15% huisache, 20% bermudagrass, 15% KR bluestem
S64	improved pasture	20% huisache, 10% mesquite, 30% KR bluestem, 25% seacoast bluestem
S65	improved pasture	20% huisache, 10% mesquite, 25% KR bluestem, 20% bermudagrass
S42	improved pasture	25% huisache, 20% KR bluestem, 15% bermudagrass
S46	improved pasture	25% huisache, 20% bermudagrass, 15% KR bluestem
S26	improved pasture	30% mesquite, 20% ryegrass, 20% KR bluestem, 10% Rhodesgrass
S47	improved pasture	30% mesquite, 15% huisache, 10% hackberry, 10% bermudagrass
S66	bluestem prairie	50% mesquite, 15% huisache, 10% little bluestem

Ten of the polygons observed in 2013 were classified in Phase 1 as saline clay flat (gulf cordgrass flats). Of these, only one was observed to be dominated by gulf cordgrass in 2013 (Table 2.5). Three of the polygons were observed to be brackish marsh and could be considered transitional to saline clay flat. Three polygons were improved pasture, one of which (S01) was a reseeded area along a roadway and could have been a gulf cordgrass flat in the past.

Table 2.5 Estimated composition (% cover) in 2013 of major species in 10 polygons that had been classified in Phase 1 as saline clay flat.

Polygon	Vegetation Type	Major Species
S07	saline clay flat	75% gulf cordgrass, 10% sea oxeye, 10% seacoast bluestem, 5% saltgrass
S01	improved pasture	20% bermudagrass, 10% KR bluestem, 10% windmillgrass
S72	improved pasture	25% paspalum, 25% bermudagrass, 20% KR bluestem, 20% marshhay
S30	improved pasture	20% mesquite, 20% KR bluestem, 10% windmillgrass
S25	fresh marsh	30% common reed, 30% Olney bulrush, 15% cattail
S73	brackish marsh	20% common reed, 10% sea myrtle, 10% Olney bulrush
S06	brackish marsh	75% sea myrtle, 15% seacoast bluestem, 10% bermudagrass
S75	brackish marsh	95% sea myrtle
S71	urban	25% St. Augustine grass, 25% bermudagrass, 25% KR bluestem (lawns)
S76	bluestem prairie	30% KR bluestem, 30% little bluestem, 10% Texas wintergrass

Four other primary types were included in the Phase 2 verification (Table 2.6). Two polygons had been classified as disturbed/weedy in the Phase 1 model, three as ponds, one as river bottomland (grassland), and six as riparian woodland. Of the two disturbed/weedy polygons in Phase 1, one remained so in Phase 2 but the other was an improved pasture. The Phase 1 designation, based on earlier aerial photographs, may have been when the polygon was recently cleared and planted. Of the three pond polygons, one could still be classified as a pond and the other two probably should be considered freshwater marshes, although this change may be the result of silting in of a shallow pond. The bottomland polygon can still be considered as bottomland, but it is no longer a grassland. Of the six riparian woodland polygons, four can still be considered as riparian woodlands. The other two probably should be classified as freshwater marshes, although both have considerable amounts of trees.

Table 2.6 Estimated composition (% cover) in 2013 of major species in 12 polygons that had been classified in Phase 1 as disturbed/weedy, ponds, river bottomland, or riparian woodland.

Polygon	Vegetation Type		Major Species	
	Phase 1	Phase 2		
S36	disturbed	disturbed	15% huisache, 20% ragweed, 10% bermudagrass	(weedy)
S37	disturbed	improved pasture	30% KR bluestem, 20% bermudagrass	(mowed)
S77	pond	pond	95% Olney bulrush	
S22	pond	fresh marsh	40% common reed, 10% cutgrass, 5% KR bluestem	
S79	pond	fresh marsh	20% common reed, 10% Olney bulrush, 10% mesquite	
S24	bottomland	bottomland	75% sea myrtle	
S05	riparian	riparian	15% hackberry, 10% huisache, 5% pecan, 5% Texas ash	
S38	riparian	riparian	15% hackberry, 10% mesquite, 5% pecan	
S18	riparian	riparian	25% huisache, 15% retama, 15% sea myrtle, 10% bermudagrass	
S57	riparian	riparian	30% bush palmetto, 15% mesquite, 15% Chinese tallow	
S02	riparian	fresh marsh	40% Chinese tallow, 40% common reed	
S50	riparian	fresh marsh	50% common reed, 20% Chinese tallow, 10% mesquite	

Several conclusions can be drawn from the results of the field observations. First, a 60% agreement in general vegetation types using 30-35 year old aerial photos is encouraging. More recent photos or additional field reconnaissance should increase the spatial accuracy substantially. Secondly, there appear to be substantial species composition differences in some types between what was used in Phase 1 and what was observed in the field. For some types (e.g., bluestem prairie, riparian woodland), these differences are probably not critical for obtaining reasonable simulation results for hydrological variables (e.g., runoff, water quality). For these variables, there may not be much of an effect whether a site has 30% mesquite and 15% huisache or 30% huisache and 15% mesquite, or whether the primary riparian species is hackberry or pecan. However for other sites, such as the marshes, an accurate estimate of composition of the major species becomes very important. Dynamics of some of these marsh species are a primary focus of the San Antonio Bay EDYS model, e.g., the interaction among smooth cordgrass, marshhay cordgrass, and common reed.

The field verification task in Phase 2 was designed as a very limited effort. A more extensive effort is planned for future phases, should they be funded. Species composition data from the Phase 2 verification effort will be useful in re-defining the vegetation units containing the observed polygons. Rather than make these updates at this point, it will be more efficient to combine these data with data that may be collected in the next phase. The more extensive data set that would then be available would allow for a more comprehensive classification system to be developed, including a revised plant species list for the model.

3.0 DEVELOPMENT OF ANIMAL SUB-MODULES

The Phase 1 model does not include any animal components, other than herbivory by terrestrial herbivores. The purpose of Task 2 of Phase 2 was to begin the process of adding animal species to the model. Two groups, shrimp and clams, were to be added in Phase 2. The purpose in Phase 2 was not to simulate the full range of dynamics of the two organisms, but only the most basic responses. Development of the full models of the animal dynamics was not expected to occur until later phases.

At the January progress meeting (22 Jan 13), discussions were held relative to each of the tasks. At this meeting, the project team decided that it would be more productive to concentrate on the vegetation components of the project in Phase 2 and postpone work on the animal components until a later phase. This decision was based on two factors. First, the vegetation dynamics are fundamental to the functioning of the Bay system and these dynamics, along with their linkage to Bay dynamics (e.g., inundation and salinity levels), are what is most lacking in work on the Bay ecosystem. It was felt that developing the vegetation dynamics components to the model held the most value from a modeling standpoint in making immediate progress on developing a useful model of the San Antonio Bay complex. Secondly, it had been hoped that additional funds would become available from other sources during 2012-13 and these funds would supplement the work funded under Task 2 of Phase 2. Without these additional funds, it was felt that only minimal progress would be made in developing the animal sub-modules during Phase 2. Task 2 funds were therefore re-allocated to Tasks 3-5.

This is not to imply that the animal sub-modules are not important or that they will not be added in future phases. The animal sub-modules are critical to the development of the complete EDYS model for San Antonio Bay. The decision was instead to concentrate on first things first. Once the vegetation (upland-marsh-bay) components are complete and their dynamics linked to Bay circulation factors, then emphasis can shift to the animal components.

4.0 INCLUSION OF ADDITIONAL EXISTING DATA

4.1 Background

Substantial amounts of pertinent ecological, hydrological, and water chemistry data relative to San Antonio Bay currently exist from various sources. Some of these data were accessed for use in developing the Phase 1 model. However, there are substantial amounts of additional data that would be useful in the further development of the model. It is unlikely that this store of data will be exhausted at any time during the development of the model. Instead, additional data will be accessed and incorporated into the model throughout the developmental period. Some of this data currently exists and some will become available in the near future.

The purpose of Task 3 of Phase 2 was to continue the process of gathering and summarizing these data and incorporating it into the model. Of particular interest in Phase 2 was securing additional data on salinity and submergence tolerances of the major plant species, decomposition and mineralization of marsh detritus, and adding conceptual models of plant zonation in the major toposequences of the San Antonio Bay complex (freshwater, saltwater, and barrier island).

4.2 Results

4.2.1 Plant Responses to Salinity

The Phase 1 model contained 57 plant species. Another 20 species have been added to the Phase 2 model (although all parameter values have not been updated for all of the 20 new species) and one species was removed (manatee-grass, replaced by widgeon grass), bringing the current total to 76 species (Table 4.1). Additional species may be added in future phases of model development, should this be necessary in order to adequate simulate some aspects of future development (e.g., animal sub-modules).

Table 4.1 Plant species included in the Phase 2 San Antonio Bay EDYS model.

Lifeform	Species	Common Name	Phase 2 Addition
Trees			
	Acacia farnesiana	huisache	
	Carya illinoensis	pecan	
	Celtis laevigata	hackberry	
	Parkinsonia aculeata	retama	*
	Persea bornoia	sweetbay	
	Prosopis glandulosa	mesquite	
	Quercus virginiana	live oak	
Shrubs			
	Baccharis halimiflora	sea myrtle	*
	Borrichia frutescens	sea oxeye	
	Celtis pallida	granjeno	*
	Lycium carolinianum	Carolina wolfberry	
	Sesbania drummondii	rattlepod	
Vine			
	Vitis mustangensis	mustang grape	
Succulents			
	Batis maritima	saltwort	*
	Opuntia lindheimeri	prickly pear	
	Salicornia virginica	glasswort	
	Suaeda linearis	sea blite	
Grasses			
	Andropogon glomeratus	bushy bluestem	
	Andropogon virginicus	broomsedge bluestem	
	Aristida purpurescens	arrowfeather threeawn	*
	Bothriochloa saccharoides	silver bluestem	
	Bouteloua curtipendula	sideoats grama	
	Buchloe dactyloides	buffalograss	
	Cenchrus incertus	sandbur	
	Chloris pluriflora	trichloris	
	Cynodon dactylon	bermudagrass	
	Distichlis spicata	saltgrass	
	Leersia hexandra	clubhead cutgrass	
	Monanthochloe littoralis	shoregrass	
	Panicum hemitomon	maidencane	*
	Panicum virgatum	switchgrass	
	Paspalum lividum	longtom	
	Paspalum monostachyum	gulfdune paspalum	
	Paspalum plicatulum	brownseed paspalum	
	Paspalum setaceum	thin paspalum	*
	Paspalum vaginatum	seashore paspalum	
	Phragmites australis	common reed	
	Schizachyrium scoparium	little bluestem	
	Schizachyrium scoparium var. *littoralis*	seacoast bluestem	
	Setaria geniculata	knotroot bristlegrass	

Table 4.1 (Cont.)

Lifeform	Species	Common Name	Phase 2 Addition
	Setaria leucopila	plains bristlegrass	
	Sorghastrum nutans	indiangrass	
	Sorghum halepense	Johnsongrass	*
	Spartina alterniflora	smooth cordgrass	
	Spartina patens	marshhay cordgrass	
	Spartina spartinae	gulf cordgrass	
	Sporobolus virginicus	seashore dropseed	
	Stipa leucotricha	Texas wintergrass	
	Uniola paniculata	sea oats	
	Zizaniopsis miliacea	marshmillet	
Grass-Likes			
	Cyperus odoratus	fragrant flatsedge	
	Eleocharis interstincta	spikerush	
	Fimbristylis castana	fimbry	*
	Ruppia maritima	widgeon grass	*
	Scirpus americanus	Olney bulrush	
	Typha latifolia	cattail	
Forbs			
	Alternanthera philoxeroides	alligatorweed	
	Ambrosia psilostachya	ragweed	
	Aster spinosus	spiny aster	
	Baptistia leucophaea	whitestem wild indigo	*
	Chamaecrista fasciculata	partridge pea	
	Clematis drummondii	old-man's beard	
	Croton punctatus	gulf doveweed	
	Erigeron myrionactis	Corpus Christi fleabane	*
	Helianthus annuus	sunflower	*
	Heterotheca subaxillaris	camphorweed	
	Ipomoea pes-caprae	railroad vine	
	Iva annua	seacoast sumpweed	*
	Nelumbo lutea	lotus	*
	Oenothera drummondii	beach evening primrose	
	Parthenium hysterophorus	false ragweed	*
	Phyla nodiflora	frogfruit	*
	Rhynchosia texana	Texas snoutbean	
	Rumex crispus	curly dock	*
	Sagittaria falacata	bulltongue	*
Algae			
	Schizothrix spp.	algae	

Salinity is a major factor affecting the distribution and productivity of vegetation in the San Antonio Bay complex. Salinity tolerance varies among species, with some species capable of tolerating high levels of salinity (e.g., twice seawater concentration) while other species are very sensitive to even low salinity levels. Salinity response also varies among species as to patterns of response between their "no effect" levels, the range of levels at which productivity decreases with increasing salinity, and non-tolerance (zero growth or death) levels. Some species show no decrease in productivity as salinity increases up to their no-effect threshold and then a rapid decrease thereafter, while other species show a gradual decrease between no-effect and zero growth.

Other factors also affect a species response to salinity. Examples include nitrogen availability, drought (lack of water, as opposed to physiological drought caused by the salinity of the water), competition from other species, level of herbivory, temperature stress, and soil texture. As this type of information becomes available for the various species in the model, these factors can be accounted for. As a first approximation in Phase 2 however, salinity response is based on three response levels to salinity: 1) no effect, 2) upper tolerance, and 3) no growth.

At and below the NOEL (no obvious effect level) for a particular species, changes in salinity of water do not affect the productivity or distribution of the species. The UPTL (upper tolerance level) is that salinity level at which there is a major effect on productivity of the species. The species can still grow at that salinity level, but at a reduced rate. For modeling purposes, the decrease in growth for that species is considered to be linear between the NOEL and UPTL. The NGRL (no growth level) is that salinity level at which the growth stops in the species. If salinity remains at that level, or higher, the plant will die. The shape of the response function between UPTL and NGRL is also linear, but not necessarily with the same slope as between NOEL and UPTL. If only values for two of the three levels are available, an estimate of the third level is made based on the values of the other two levels and corresponding levels for other species.

These three levels were taken from the literature for species where data are available (Table 4.2). Where data are not available for that species, the values were estimated from data for most similar species (taxonomic or ecological). Most of the species in the San Antonio Bay model are salt-intolerant or relatively salt-intolerant. This includes most of the upland species and species adapted to freshwater ponds and marshes.

Table 4.2 Literature values for salinity tolerances (ppt) of plant species in the San Antonio Bay model or similar species. NOEL = no obvious effect level; UPTL = upper tolerance level; NGRL = no growth level.

Lifeform	Species	NOEL	UPTL	NGRL	Reference
Tree					
	Quercus virginiana	9.0			McLendon and DeYoung (1976)
	Quercus virginiana		22.2		Fowells (1965:585)
Shrubs					
	Borrichia frutescens	14.4			Scifres et al. (1980)
	Borrichia frutescens		38.2		Antlfinger and Dunn (1983)
	Lycium carolinianum	11.2	17.6		estimated from Scifres et al. (1980)
Succulents					
	Batis maritima		38.2		Antlfinger and Dunn (1983)
	Salicornia virginica		38.2		Antlfinger and Dunn (1983)
Grasses					
	Cynodon dactylon	4.0			Shiflet (1963)
	Cynodon dactylon		14.4		Scifres et al. (1980)
	Distichlis spicata	22.4		67.2	Alpert (1990)
	Distichlis spicata		28.7		Adams (1963); Allen and Cunningham (1983);Allison (1995)
	Leersia hexandra		11.2	17.6	estimated from Scifres et al.. (1980)
	Panicum hemitomon	0.4	2.8		estimated from Shiflet (1963)
	Paspalum lividum	5.0	7.8	11.2	estimated from Scifres et al. (1980)
	Paspalum vaginatum		25.0		Shifet (1963)
	Phragmites australis	5.0	20.0		Shiflet (1963); Angradi et al. (2001)
	Setaria geniculata	0.6	11.2	17.6	estimated from Scifres et al. (1980)
	Spartina alterniflora	25.7	36.0	45.0	Adams (1963); Anderson & Treshow (1980)
	Spartina alterniflora			50.0	Shiflet (1963)
	Spartina patens	12.5		25.0	Shiflet (1963)
	Spartina patens		20.6		Adams (1963)
	Spartina spartinae	10.0		35.0	Shiflet (1963)
	Spartina spartinae		21.0		Allen (1950)
	Sporobolus virginicus	31.0			Blits and Gallahger (1991)
	Zizaniopsis miliacea	0.0		4.3	Shiflet (1963)
Grass-Likes					
	Eleocharis spp.	1.9	11.2	17.6	estimated from Scifres et al. (1980)
	Fimbristylis spadicea	1.9	11.2	17.6	estimated from Scifres et al. (1980)
	Scirpus americanus	7.5	20.0		Broome et al. (1995)
Forbs					
	Iva annua	0.6	1.9	10.4	estimated from Scifres et al. (1980)
	Lemna perpusilia	1.3	1.9	11.2	estimated from Scifres et al. (1980)
	Limonium carolinanum		35.4		Adams (1963)
	Phyla nodiflora	0.6	11.2	17.6	estimated from Scifres et al. (1980)
	Polygonum ramosissimum	0.6	11.2	17.6	estimated from Scifres et al. (1980)
	Rumex chrysocarpus	1.9	11.2	17.6	estimated from Scifres et al. (1980)
	Sagittaria latifolia	1.9	11.2	17.6	estimated from Scifres et al. (1980)

Live oak (*Quercus virginiana*) is a common, and often dominant, tree along the Gulf Coast and the southeastern Atlantic coast. It is highly salinity tolerant, mature trees being able to tolerate salinities of 22 ppt provided the soils have good drainage (i.e., sands and sandy loams; Fowells 1965). A primary reason for dominance by live oak along the coast is its tolerance to salt spray (Fowells 1965).

Saltgrass (*Distichlis spicata*) is a common grass on saline sites both along the coast and inland, often forming dense and extensive stands. The salinity response of this species has been reported on in a number of studies. Shiflet (1963) reported salinity ranges of 5-50 ppt are common on saltgrass sites along the Gulf Coast, and Adams (1963) and Allison (1995) reported levels of 28-30 ppt are typical. Antlfinger and Dunn (1995) reported maximum levels of 38.2 ppt at their sites and Branson et al. (1988) reported that saltgrass can tolerate salinities of at least up to 45 ppt. Jackson (1952) considered 11.8-17.1 ppt to be optimum for saltgrass. Alpert (1990) reported no effect on saltgrass at salinities of 22.4 and a 33% death loss at 67.2 ppt, implying that over two-thirds of the saltgrass plants survived concentrations of 67 ppt. Allen and Cunningham (1983) reported a 14% reduction in aboveground biomass at 28.7 ppt (compared to 0 ppt) and only a 16% reduction at 57.4 ppt. The same authors found a 46% increase in belowground biomass (roots and rhizomes) at 28.7 ppt and an 8% decrease at 57.4 ppt. This study, along that of Albert (1990), suggest the NGRL for the species is probably higher than the 67.2 ppt value listed in Table 4.2.

Smooth cordgrass (*Spartina alterniflora*) and marshhay cordgrass (*S. patens*) are the two major dominant species in the salt marshes along the Texas coast, as well as most of the remainder of the Gulf Coast and the southeast and middle Atlantic coasts. The two species often occur in adjacent stands and their dynamics are strongly influenced by water salinity, smooth cordgrass being the more tolerant species. Shiflet (1963) reported that salinity in smooth cordgrass stands typically varies between 12-50 ppt, whereas salinity in marshhay stands is typically 0-25 ppt. NOEL for smooth cordgrass is 20-32 ppt depending on site conditions (Anderson and Treshow 1980) and NOEL for marshhay cordgrass is approximately 20-21 ppt (Adams 1963). Smooth cordgrass often occurs in three forms within the same area: tall, medium, and short forms. Most research suggests that the differences are attributable to environmental conditions, primarily nitrogen availability and salinity, and therefore the differences in heights are reflections of differences in productivity. There is however some indication that the forms may also reflect some ecotypic variation (Anderson and Treshow 1980).

Common reed (*Phragmites australis*) is a large wetland grass that has the potential for becoming co-dominant with, or replacing, marshhay cordgrass (Windham 2001). Salinity is one factor associated with the replacement of marshhay cordgrass by common reed (Anderson et al. 1968), others including soil disturbance, sedimentation, and nutrient enrichment (Angradi et al. 2001). Angradi et al. (2001) reported that common reed can tolerate salinities up to about 17 ppt, whereas Shiflet (1963) placed the upper limit at 20 ppt. Studies by Adams and Bate (1999) suggest that common reed can tolerate salinities as high as 35 ppt provided the rhizomes are exposed to water with salinities less than 20 ppt. Burdick et al. (2001) reported relatively rapid colonization by common reed at salinities of 11-16 ppt, but much slower rates of colonization at salinities of 19-24 ppt.

Olney bulrush (*Scirpus americanus*) often occurs as a co-dominant with marshhay cordgrass and it is similar to common reed in its relationship to salinity. Olney bulrush is little affected by increasing salinity up to about 10 ppt, but then growth declines steadily at higher concentrations (Broome et al. 1995).

These differences in salinity tolerance are a major factor in defining the distribution patterns and productivity of marsh and other wetlands along the Texas and Gulf coasts. Chabreck (1972) separated the bays and marshes into four zones, based on typical salinity values. The saline zone includes those areas of daily tidal inundation. Typical salinity values are 20-35 ppt. The brackish zone includes those areas receiving saltwater mostly during seasonal tides and storm surges. Typical salinity values are 5-19 ppt. The intermediate zone receives saltwater only during extreme storm events and typical salinity values are 0.5-5 ppt. The fourth zone is the freshwater zone which does not receive saltwater and salinity values are less than 0.5 ppt. Anderson et al. (1968) considered the boundary between the freshwater and saltwater zones to be about 0.3 ppt. Salinity values over 40 ppt are considered to be hypersaline (Cowardin et al. 1979) and few salt marsh plant species can tolerate salinities above 70 ppt (Adams 1963).

Salinity values in San Antonio Bay decrease from the inland side of Matagorda Island to the upper bay around the Guadalupe River Delta and Hynes Bay. Historic values range from 15-25 ppt near Matagorda Island, to 15-19 ppt in the Bay mouth, to 5-9 ppt in the upper portions on either side of the northern peninsula (Longley 1994).

4.2.2 Depth of Inundation

A second factor affecting plant distribution in the marsh-wetland complex is depth of inundation. Most plant species cannot tolerate flooding for extended periods of time (e.g., a few days to a few weeks). In most cases, these intolerant species are adversely affected by saturated soil conditions. The specific adverse factor associated with saturated soils for these species is a lack of sufficient oxygen for root respiration. Often associated with these low oxygen and low respiration levels is a buildup of toxic substances.

Wetland and marsh species, and some upland species, are adapted to frequent flooding. For these tolerant species, depth of inundation is often an important factor controlling their distribution within the wetland and marsh communities. For example, in North Carolina salt marshes smooth cordgrass is most abundant at elevations equal to about mid-way between high and low tides, marshhay cordgrass and sea oxeye (*Borrichia frutescens*) most abundant at elevations about 13 cm higher, and saltgrass about 1-2 cm below marshhay cordgrass (Adams 1963). Table 4.3 presents threshold inundation values for some marsh and wetland species, based on depth of water above the soil surface. The values listed in Table 4.3 are conservative (i.e., known to tolerate these depths, may be able to tolerate deeper) depths the species can tolerate for extended periods (one month or more). Most of the species can tolerate much deeper inundation for short periods (e.g., one week).

Table 4.3 Inundation tolerance values (cm above soil surface) for some marsh and wetland species. Short-term refers to periods generally less than a month and long-term refers to periods of at least 3-6 months.

Lifeform	Species	Short-term	Long-term	Reference
Shrubs				
	Borrichia frutescens	13	1	Scifres et al. (1980)
	Lycium carolinianum	17	0	Scifres et al. (1980)
Grasses				
	Cynodon dactylon	17	1	Scifres et al. (1980)
	Distichlis spicata	---	5	Shiflet (1963)
	Leersia hexandra	17	1	Scifres et al. (1980)
	Panicum hemitomon	---	5	Shiflet (1963)
	Paspalum lividum	17	1	Scifres et al. (1980)
	Paspalum vaginatum	---	5	Shiflet (1963)
	Phragmites australis	---	8	Armstrong et al. (1999)
	Setaria geniculata	7	---	Scifres et al. (1980)
	Spartina alterniflora	90	35	Boumans et al. (1997)
	Spartina patens	10	5	Shiflet (1963); Broome et al. (1995)
	Spartina spartinae	5	0	Shiflet (1963); Scifres et al. (1980)
	Sporobolus virginicus	---	3	Breen et al. (1977)
	Zizaniopsis miliacea	---	30	Shiflet (1963)
Grass-Likes				
	Eleocharis spp.	17	1	Scifres et al. (1980)
	Fimbristylis spadicea	17	1	Scifres et al. (1980)
	Scirpus acutus	25	15	Bruba et al. (1999)
	Scirpus americanus	30	20	Broome et al. (1995)
	Scirpus robustus	---	5	Shiflet (1963)
	Typha domingensis	115	42	Grace (1989)
	Typha latifolia	95	58	Grace (1989)
Forbs				
	Iva annuua	8	---	Scifres et al. (1980)
	Lemna perpusilla	17	---	Scifres et al. (1980)
	Phyla nodiflora	8	---	Scifres et al. (1980)
	Polygonum ramosissimum	7	---	Scifres et al. (1980)
	Rumex chrysocarpus	17	1	Scifres et al. (1980)
	Sagittaria latifolia	17	---	Scifres et al. (1980)

Like with response to increasing salinity, plant response to depth of inundation is somewhat proportional to water depth. For example, transplants of common reed had 100% survival at a 4-cm water depth, 95% survival at 8 cm, and 50% survival at 12 cm (Armstrong et al. 1999). Compared to the amount of aboveground production when depth of water was maintained at 10 cm below the soil surface, production of marshhay cordgrass decreased 12% when depth of water was maintained at 10 cm above the soil surface and declined 72% when maintained at 30 cm above the soil surface. By comparison, aboveground production of Olney bulrush increased 34% at 10-cm inundation and declined 9% (from production at water level 10 cm below soil surface) at 30-cm inundation (Broome et al. 1995).

Twenty-four of the 76 species included in the San Antonio Bay EDYS model, or surrogate species of the same genus, are included in Table 4.3. Inundation data on the other 52 species are not available from the literature, or have not yet been discovered. Most of these remaining 52 species are upland species that are intolerant of sustained inundation. However some are wetland or marsh species, or upland species that can tolerate flooding. Based on knowledge of where the species occur along the upland-marsh-bay toposequence and on observational knowledge at other locations, these 52 species can be divided into groups based on relative tolerance to flooding (Table 4.4). Three groups are defined as: 1) intolerant species = those that show a detrimental effect when subjected to standing water or saturated soil for about 1-2 weeks; 2) tolerant upland species = those that occur on both upland and lowland sites and that can tolerate surface flooding or saturated soils for periods of about 1-2 months; and 3) wetland species = species that can tolerate long-term (six months or more) standing water or saturated soils, but that are not included in Table 4.3. For the third group, estimates of the typical depth of standing water that these species can tolerate for extended periods.

Table 4.4 Estimated responses of those species for which inundation data are not available, based on non-quantitative information. The number following the wetland species is the estimated typical inundation depth (above soil surface) for that species.

Intolerant Species	Tolerant Upland Species	Wetland Species	Depth (cm)
Trees			
Carya illinoensis	*Acacia farnesiana*		
Prosopis glandulosa	*Celtis laevigata*		
Quercus virginiana	*Parkinsonia aculeata*		
	Persea bornoia		
Shrubs			
Celtis pallida	*Baccharis halimiflora*		
Vitis mustangensis	*Sesbania drummondii*		
Succulents			
Opuntia lindheimeri		*Batis maritima*	tidal
		Salicornia virginica	tidal
		Suaeda linearis	tidal
Grasses			
Aristida purpurescens	*Panicum virgatum*	*Andropogon glomeratus*	20
Bothriochloa saccharoides	*Paspalum monostachyum*	*Andropogon virginicus*	20
Bouteloua curtipendula	*Paspalum plicatulum*	*Monanthochloe littoralis*	tidal
Buchloe dactyloides	*Schizachyrium scoparium* var. *littoralis*		
Cenchrus incertus			
Chloris pluriflora	*Sorghum halepense*		
Paspalum setaceum	*Uniola paniculata*		
Schizachyrium scoparium			
Setaria leucopila			
Sorghastrum nutans			
Stipa leucotricha			
Grass-Likes			
		Cyperus odoratus	20
		Ruppia maritima	100
Forbs			
Baptistia leucophaea	*Ambrosia psilostachya*	*Alternanthera philoxeriodes*	50
Croton punctatus	*Chamaecrista fasciculata*	*Aster spinosus*	20
Helianthus annuus	*Clematis drummondii*	*Nelumbo lutea*	floating
Parthenium hysterophorus	*Erigeron myrionactis*	*Rumex crispus*	25
Rhynchosia texana	*Heterotheca subaxillaris*	*Sagittaria falacata*	25
	Ipomoea pes-caprae		
	Iva annua		
	Oenothera drummondii		
	Phyla nodiflora		

4.2.3 Vegetation Patterns

Native vegetation in most areas is composed of a mosaic of plant communities distributed across the landscape in response to changes in environmental factors. Plant communities are composed of assemblages of species, with the specific combination of species or the relative abundance of each species (species composition) varying among communities. Therefore the vegetation of a particular area can be viewed as overall pattern of distributions of the individual species. Description and classification of plant communities, and subsequently the mapping of their locations, is to some degree an abstraction of reality because species are seldom confined to unique combinations (McLendon et al. 2013). However, vegetation groupings such as plant communities provide a very useful means for conceptualizing our understanding of plant-environmental relationships.

Vegetation zonation is strongly developed in coastal marsh ecosystems, in large part because of the responses of individual species to changes in salinity and inundation. Two other factors of major importance, especially in the distribution of species in adjacent upland sites, are soil texture and depth to soil saturation. Both of these factors primarily affect vegetation through soil moisture relationships. Land use, disturbance history, herbivory level, and a number of other factors may modify the vegetation patterns associated with these four major factors (salinity, inundation, soil texture, depth to saturation).

The spatial footprint of the San Antonio Bay EDYS model contains 563,152 cells, each cell 40 m x 40 m in size. In the Phase 1 model, each cell was assigned to one of 687 plot types, a plot type consisting of a plant community-soil type combination. There were 220 plant communities based on NRCS ecological site descriptions, modified using data from other literature and experience in the area. Primary sources of vegetation data other than the NRCS soil surveys were Alongi (1998), Cutshall (1994a, 1994b), Dahl et al. (1975), Diamond and Smeins (1984), Drawe (1994a, 1994b), Drawe et al. (1978), McLendon and DeYoung (1976), Scifres et al. (1980), Shiflet (1963), Texas General Land Office, and USFWS Natural Wetlands Inventory. The Phase 1 vegetation grid is updated as additional data become available. Additional data were collected in the northeast quadrant in Phase 2 (Task 1) and additional literature data were collected in this task (Task 3).

The information on vegetation distribution that were collected and summarized in Task 3 were also used to 1) develop conceptual models of the basic vegetation patterns of three important toposequences (freshwater, brackish-saline, and barrier island) and 2) use these toposequences and the data collected to build a fine-scale EDYS model to more precisely simulate small-scale ecological processes in marsh and wetland systems. The literature sources listed in the previous paragraph were used to develop the conceptual models, along with additional sources reviewed as part of Phase 2.

4.2.3.1 Conceptual Models

The effects of salinity, inundation, soil texture, and depth to saturation on the major species included in the model were used to develop the three conceptual models. Each model represents a primary vegetation gradient of the San Antonio Bay complex illustrated along a topographic gradient (toposequence) from the water edge to upland vegetation. These three models do not represent any single unique location on the landscape. Instead, they are representative of basic vegetation patterns likely encountered throughout the upland-marsh-bay complex. Brief descriptions of each of the plant communities along these three toposequences are presented below. Lists of those plant species included in the EDYS San Antonio Bay model by each of these plant communities are presented in Appendix A.

Brackish-Saline Toposequence

The first conceptual model represents a typical gradient through a salt marsh, beginning at the bay floor and ending in a live oak woodland (Fig. 4.1).

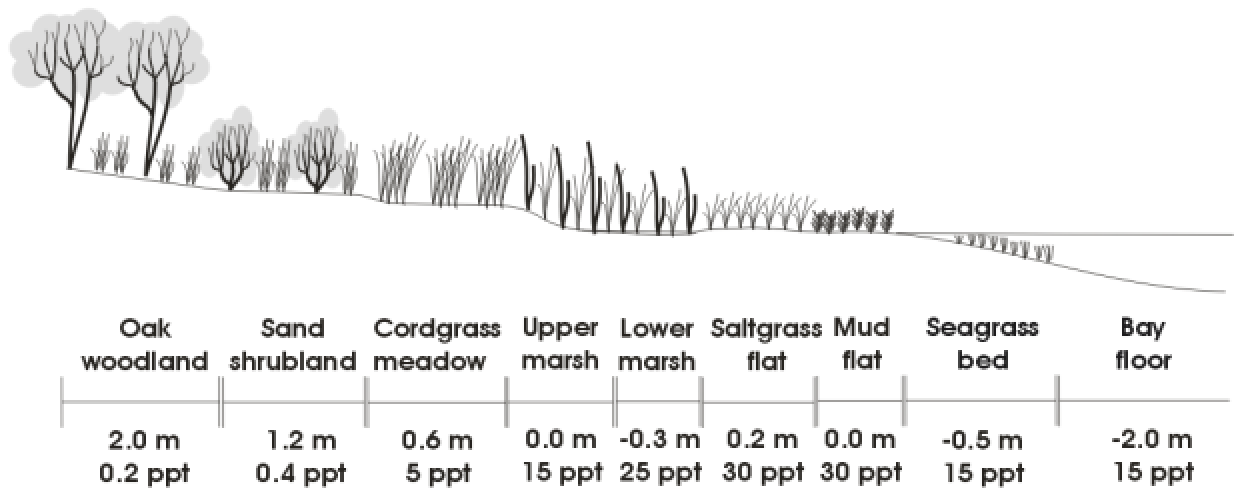

Figure 4.1 Schematic illustrating vegetation change along a typical brackish-saline toposequence on the edge of San Antonio Bay. The first row of values below the community names represent typical differences in relative elevation (meters) across the toposequence. The second row of values represents typical differences in salinity (parts per thousand) across the toposequence.

At depths of about 1.5 m and more below the bay surface, the bay floor is considered to be un-vegetated. The substrate of the bay floor varies depending on location. Types of substrate include mud, clay, sand, and shell. From about a depth of 1.5 m to near the limit of low tide, seagrass beds occur at some locations. Species may vary, but a common one is widgeon grass (*Ruppia maritima*; Britton and Morton 1989) and is used to illustrate this community in the model. Salinities in the northern portion of San Antonio Bay (Hynes Bay, Mission Lake, Guadalupe Bay) historically have ranged between 3-10 ppt and salinities in the middle portion of San Antonio Bay have averaged 15-20 ppt (Longley 1994).

Along the central and southern Texas coast, tidal flats are the most common structural type immediately above the limit of low tide. The irregular tidal regime and high temperatures of sheetwater on flats often raise soil salinities above salt marsh vegetation tolerance limits (Britton and Morton 1989). These tidal flats are divided into two communities in the conceptual model (Fig. 4.1). The lower elevation zone supports a community of saltwort (*Batis maritima*), glasswort (*Salicornia virginica*), and sea blite (*Suaeda linearis*). This zone is inundated at high tide and is exposed at low tide. These succulent halophytes can tolerate high salinities, on the order of 40-70 ppt (Adams 1963; Antlfinger and Dunn 1983). The next community in the saline toposequence is the saltgrass-shoregrass community. It occurs at elevations about 10-15 cm higher than the succulent mudflat community. Saltgrass (*Distichlis spicata*) and shoregrass (*Monanthochloe littoralis*) are the two dominant species in this community and sea oxeye (*Borrichia frutescens*) becomes an important component along the upper edges of the community (Britton and Morton 1989). Sites supporting these communities tend to be slightly higher in elevation than the communities on each side (Fig. 4.1) and are generally washed by tidal flows but do not frequently have deep standing water (generally 5 cm or less; Shiflet 1963). Salinities are high (20-40 ppt, or higher; Shiflet 1963) because of evaporation during low tides and a resulting concentration of salts in the upper soil substrate.

Marsh communities commonly occur behind the tidal flats, although in some cases the lower marsh community may extend into standing water in front of the tidal flat communities. The low marsh community is dominated by smooth cordgrass (*Spartina alterniflora*) and typically occupies sites 10-50 cm lower in elevation than the tidal flats (Shiflet 1963). The low marsh occurs in standing water, generally less than about 30 cm deep. Salinity in these communities varies by location, with lower values (10-20 ppt) where the community extends into the bay water and higher values (20-30 ppt) behind the mud flats where evaporation from the standing water increases the salt concentration. The upper marsh community is most abundant in a zone immediately above the lower marsh community. Surface elevation is 30-50 cm higher than in the lower marsh and water depth is subsequently less (0-5 cm standing water). Salinity is generally 10-20 ppt. The community is dominated by marshhay cordgrass (*Spartina patens*), with Olney bulrush (*Scirpus americanus*), seashore paspalum (*Paspalum vaginatum*), and saltgrass commonly associated species (Shiflet 1963; Britton and Morton 1989; Cutshall 1994a; White et al. 1998), the latter two becoming more abundant as depth of standing water or cover of marshhay cordgrass decreases. Stands of common reed (*Phragmites australis*) can also occur in this community, especially as salinity decreases (Shiflet 1963; Chambers et al. 1999; Angradi et al. 2001).

At elevations above about 30-50 cm, direct tidal effects become minimal except during storm events and extreme high tides (Britton and Morton 1989). Extensive stands of gulf cordgrass (*Spartina spartinae*) typically occur as the first community in this intermediate zone (Shiflet 1963; Chabreck 1972; Britton and Morton 1989). Gulf cordgrass often forms almost monoculture stands in these communities. Salinity tends to be lower (5-10 ppt) than in the upper marsh and standing water seldom occurs for extended periods. Depth to saturation varies seasonally and spatially, but ranges from at or near the surface to as deep as 1.5 m (Shiflet 1963; Scifres et al. 1980).

A sand shrubland often occurs in a band immediately above the gulf cordgrass community at elevations of about 1-2 m. Salinity of the soil water decreases to less than 1 ppt and the top 1-3 m of the soil tends to remain unsaturated except during wet periods. Composition of the shrub community varies somewhat but the most common dominant species are sea myrtle (*Baccharis halimiflora*) and Carolina wolfberry (*Lycium carolinianum*)(Britton and Morton 1989).

On sand sites at elevations of about 2 m and higher, the shrub communities may transition into sand prairies (freshwater toposequence) or oak woodlands. Live oak (*Quercus virginiana*) is the primary large tree but sweetbay (*Persea borbonia*) may form dense stands of short to medium height trees or large shrubs (Dahl et al. 1975; McLendon and DeYoung 1976; Britton and Morton 1989). Soil water salinity is generally low (less than 0.5 ppt) but live oak can tolerate relatively high salinity levels on sandy soils and is particularly tolerant of salt spray (Fowells 1965). Well-developed herbaceous communities are often associated with these oak woodlands and the grasslands between the oak stands. Inland from the oak woodlands, sand prairies often occur, some of which can be extensive.

Freshwater Toposequence

The freshwater toposequence (Fig. 4.2) is typical of the transition upland from gulf cordgrass communities on clay and clay loam soils. Salinities in the communities tend to be low (e.g., less than 0.2 ppt) but can increase seasonally for short periods of time as high as 10-15 ppt (Scifres et al. 1980).

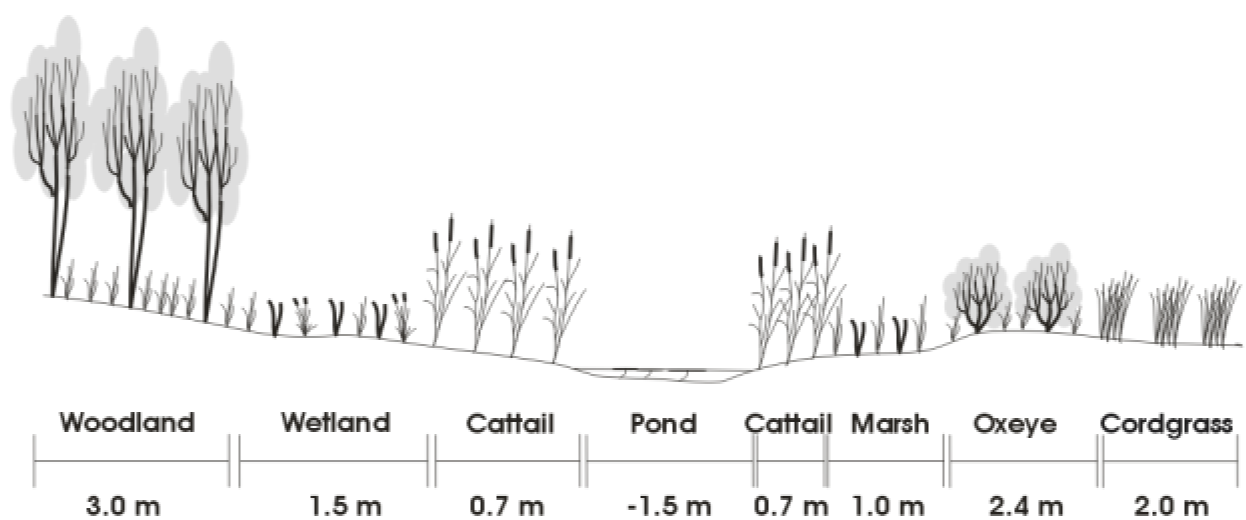

Figure 4.2 Schematic illustrating vegetation change along a typical freshwater toposequence in uplands adjacent to San Antonio Bay. Values below community names represent typical differences in elevation across the toposequence.

Gulf cordgrass communities tend to be most extensive on saline clay and clay loam soils, but can also occur on sandy loam sites (Scifres et al. 1980). Sea oxeye can form dense stands on slightly higher elevations adjacent to the gulf cordgrass communities with gradation into woodlands if elevation continues to increase. However at many locations elevation decreases, forming freshwater marshes and ponds.

Freshwater marshes are dominated by a mixture of species, including common reed, maidencane (*Panicum hemitomon*), marshmillet (*Zizaniopsis miliacea*), marshhay cordgrass, flatsedge (*Cyperus odoratus*), and bulrush (*Scirpus americanus*)(Cutshall 1994b). Standing water may be as deep as 10-20 cm but generally it is 0-5 cm, with soils saturated near the surface most of the time. Cattail (*Typha latifolia* and *T. domingensis*) stands often form a distinct community around the edges of open ponds (Scifres et al. 1980; White et al. 1998). Ponds can be open water or have surface vegetation such as lotus (*Nelumbo lutea*).

Frequently flooded areas that are upslope from the cattail and pond communities and that have saturated soils near the surface support wetland communities. Composition can vary, but tends to be dominated by grasses such as clubhead cutgrass (*Leersia hexandra*), longtom (*Paspalum lividum*), broomsedge bluestem (*Andropogon virginicus*), bushy bluestem (*Andropogon glomeratus*), knotroot bristlegrass (*Setaria geniculata*), and bermudagrass (*Cynodon dactylon*) and grass-likes such as spikerush (*Eleocharis* spp.) and flatsedges (*Cyperus* spp.). Rattlepod (*Sesbania drummondii*) is a shrub that is often associated with these wetlands.

As elevation continues to increase, depth to saturated soil and frequency of flooding decrease. Woody species then increase, forming a woodland community. Common overstory trees are huisache (*Acacia farnesiana*) and retama (*Parkinsonia aculeata*), both of which can tolerate frequent flooding. Spiny aster (*Aster spinosus*) can form dense stands that occur between the wetlands and the woodland communities.

Barrier Island Toposequence

Topography is a major factor affecting the vegetation of barrier islands such as Matagorda Island (White et al. 1998). Elevation and distance from the bay or gulf have a major effect on salinity and moisture availability. On the bay side of the island, there is a series of about five communities that are similar to those described for the brackish-saline toposequence. The spatial distribution of these communities is primary determined by changes in salinity and depth of inundation.

Dunes may form along both sides of the island, on the bay side and the gulf side (Fig. 4.3). These dunes support a grassland community (Dahl et al. 1975; Drawe 1994b), which may vary from a sparse stand to a moderately-dense stand. The dominant grasses are sea oats (*Uniola paniculata*) and gulfdune paspalum (*Paspalum monostachyum*). Forbs, particularly railroad vine (*Ipomoea pes-caprae*) and beach evening primrose (*Oenothera drummondii*), are also important components of this community.

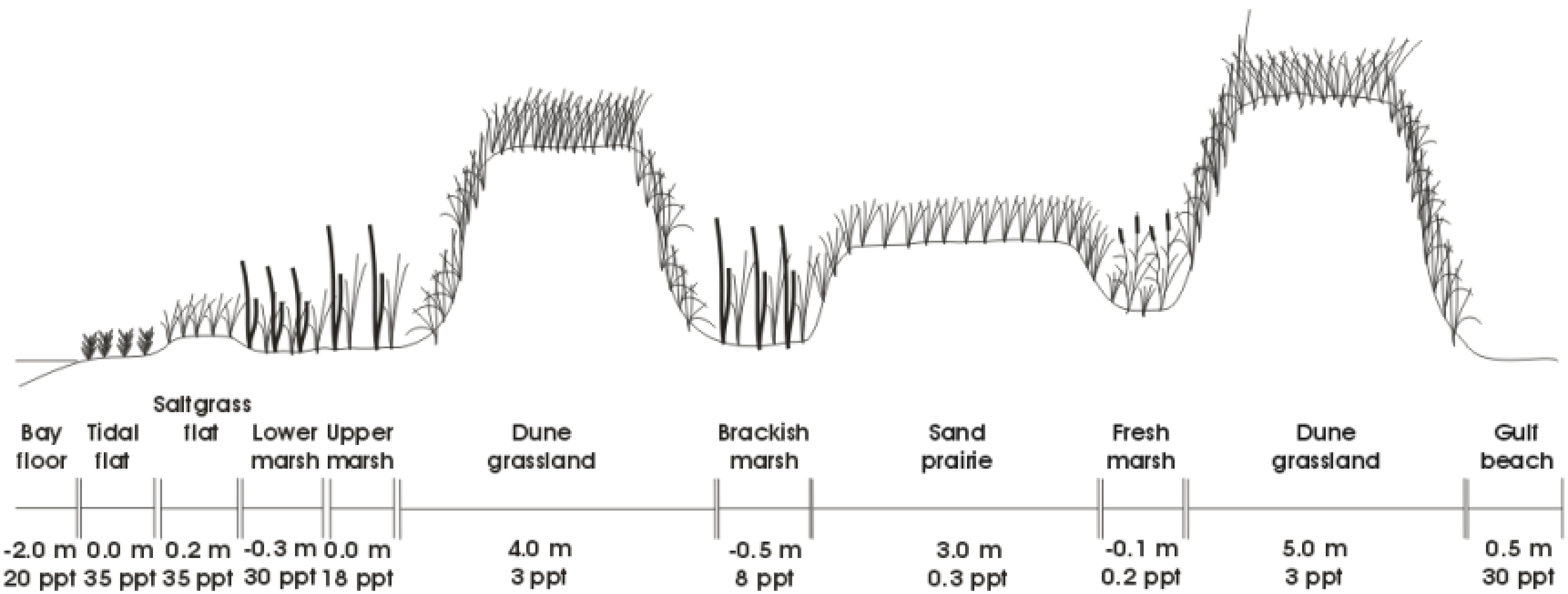

Figure 4.3 Schematic illustrating vegetation change along a typical toposequence across Matagorda Island, from the Bay-side on the left to the Gulf-side on the right. The first row of values below community names represents typical differences in relative elevation (meters) across the toposequence. The second row of values represents typical salinity values (ppt) across the toposequence.

Between the dunes, and on the interior sides of both sets of dunes, the vegetation consists of a mosaic of sand prairie and marshes, depending on elevation (Dahl et al. 1975). The sand prairie occurs on the higher elevations where flooding occurs only during major storm events and salinity is low (0.1-0.3 ppt). Composition of this midgrass prairie is similar to the inland sand prairies, with seacoast bluestem (*Schizachryium scoparium* var. *littoralis*), arrowfeather threeawn (*Aristida purpurescens*), brownseed paspalum (*Paspalum plicatulum*), and thin paspalum *(Paspalum setaceum*) major species, but the dune species sea oats and gulfdune paspalum also occur, especially on slightly higher ridges. Numerous forbs are also present.

Low elevation sites occur throughout the inter-dune area, scattered in small to medium sized depressions in the sand prairie. The inter-dune area supports a shallow, discontinuous, perched water table that is sustained by infiltration of rainfall into the sandy soils. Relatively shallow depressions accumulate sufficient amounts of water from this shallow water table to support freshwater marshes. The composition of these freshwater marshes is largely determined by the depth and permanency of the standing water (or depth to saturation), but major species include marshhay cordgrass, broomsedge bluestem, seacoast bluestem, bushy bluestem, gulfdune paspalum, Olney bulrush, and cattail.

Some depressions are sufficiently deep that they reach the saline water table that underlies the freshwater zone. These depressions support brackish marsh communities, with species composition similar to that of the upper marsh communities of San Antonio Bay. Major species include marshhay cordgrass, gulfdune paspalum, and seashore dropseed. The seashore dropseed on these sites is the dune ecotype instead of the marsh ecotype that occurs on the tidal flats (Blits and Gallagher 1991).

4.2.3.2 Fine-Scale Model

It is likely that the completed EDYS model of San Antonio Bay will be used to investigate numerous management and ecological issues. One likely example is to investigate the amount of river discharge required to maintain Bay salinity levels, given various precipitation scenarios, such that there is not a detrimental shift in marsh composition among the major species (i.e., smooth cordgrass, marshhay cordgrass, and common reed). This is likely to be an issue addressed at the scale of the overall bay, i.e., concern may not be that each specific area of a particular marsh community remain that community, but that the overall balance within the bay complex remains stable. As such, this issue can be addressed using the 40 m x 40 m cell grid.

Other issues will likely need to be addressed at a finer scale. Examples might include, areas containing a localized population of a key management species, fine-resolution monitoring of sediment discharge effects at the mouth of the Guadalupe River, potential storm effects on an area of critical habitat for threatened or endangered species. For these examples, and for purposes of model validation, simulations at spatial scales much less than the 40 m x 40 m cell size will be required.

In anticipation of this future need, KS2 suggested at the 22 January 2013 progress meeting in San Antonio that KS2 develop a prototype fine-scale model based on the toposequence conceptual models. KS2 offered to develop the prototype of this fine-scale EDYS model within the Phase 2 Scope of Work and at no additional cost to SARA. SARA accepted this offer and authorized KS2 to work on the prototype under the Phase 2 Scope of Work.

Results

The fine-scale EDYS model has been developed. It is a functional prototype that is general to any combination, or all, of the communities included in the freshwater and brackish-saline toposequences described above. Although it is currently structured as a conceptual application (i.e., not specific to any one spatial location in the San Antonio Bay complex), it can be adapted to a specific location, or multiple locations, when such a location is chosen.

A major requirement for the fine-scale model to be applied to an actual specific location is that elevation and vegetation data are available at the appropriate scale for that area. Elevation data could be from LIDAR data or from field surveying the site. Appropriate vegetation data could be collected from a field reconnaissance over a 1-2 day period.

The fine-scale model currently consists of a 200 m (length) x 40 m (width) spatial grid. The 8000 m^2 are divided into 32,000 cells, each cell 50 cm x 50 cm (= 0.25 m^2). The first (upper elevation) 60 m of the 200-m length contains the 8 plant communities of the freshwater toposequence, with the lengths of each community varying between 20 m (cordgrass community) and 3 m (cattail communities). Each community extends 40 m laterally. The 9 communities of the brackish-saline toposequence begin at the lower edge of the cordgrass community of the freshwater toposequence and then extend 140 m, terminating with a 10-m segment of the bay floor. The first (upper elevation) community of the brackish-saline toposequence is the oak woodland community. In the fine-scale model, the oak woodland occurs as a sand ridge on the down-slope side of the cordgrass community and extends 46 m downslope until replaced by the sand shrubland community.

Each of the 32,000 cells has a soil profile, an elevation, a plant species composition, and a location on the simulated landscape. Elevations vary within each community to represent micro-topographic variations across the landscape. Because of the variations in elevations, water (fresh water moving downslope or saltwater moving upslope during high tides and storm events) can move differentially within a community and among communities, thereby simulation natural flow patterns. Because of these flow patterns, salinity will vary across the landscape. Plant species then respond to both salinity and inundation on both the micro- (50 cm x 50 cm) and macro- (8000 m^2 landscape) levels.

4.2.4 Decomposition/Mineralization

This subtask was approached in two parts. First a preliminary conceptual model of decomposition/mineralization dynamics and nitrogen dynamics was compiled, based on information in the literature and professional knowledge. It is expected that this conceptual model will be continually refined and updated as progress continues through subsequent phases of the development of the San Antonio Bay EDYS model. Secondly, data from scientific publications are being used to quantify the specific components of the conceptual model.

Conceptual Model

Figure 4.5 presents the preliminary conceptual model of nitrogen dynamics in an aquatic system.

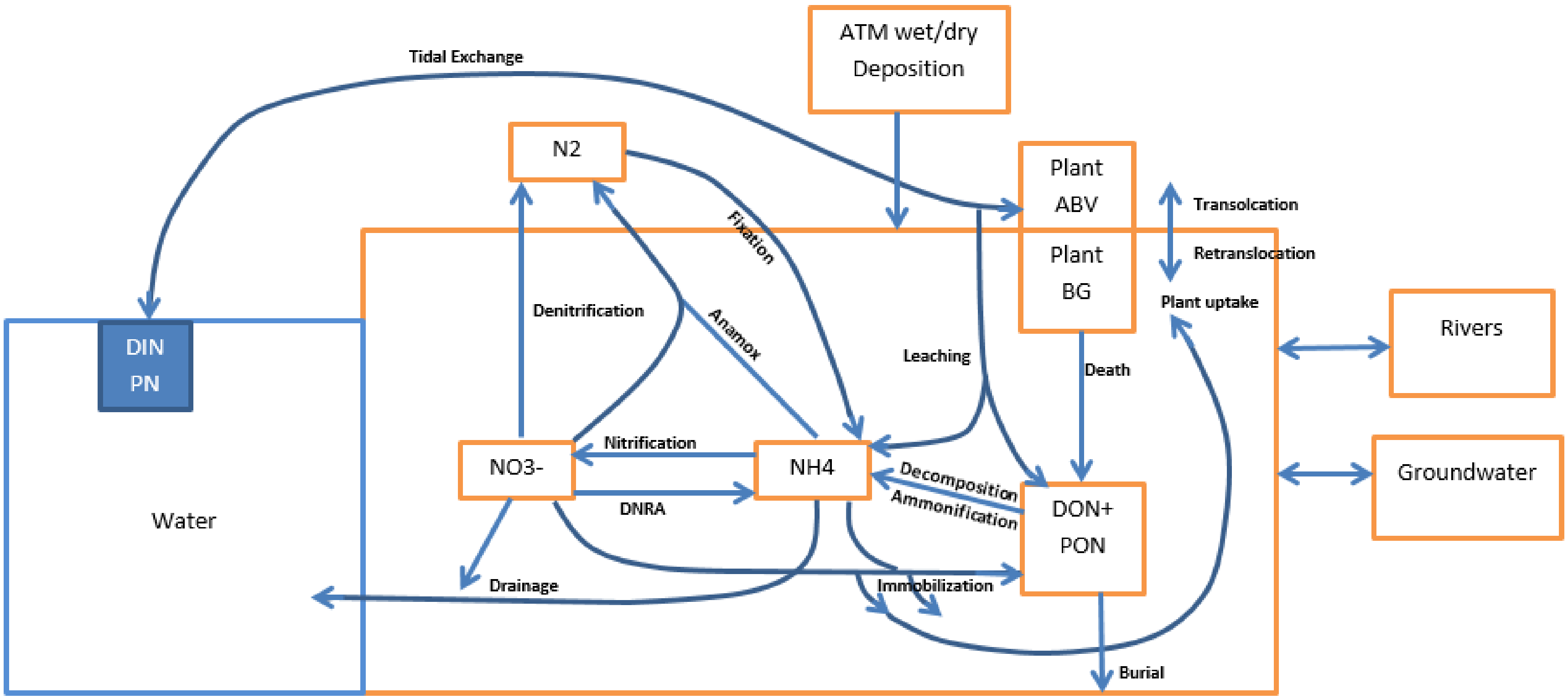

Figure 4.4 Preliminary conceptual model of nitrogen dynamics and pathways in salt marshes and tidal creeks.

Literature Data

A substantial number of publications have been collected relating to decomposition, mineralization, and nitrogen dynamics, especially in marsh and wetland ecosystems. Extraction of data from these publications is underway but has not been completed. A partial list of these publications is presented in Table 4.5 and the corresponding citations are presented in Section 8 of this report.

Table 4.5 Literature materials being reviewed to provide additional information on nitrogen dynamics, decomposition, and mineralization.

Wetland, Marsh, and Aquatic Systems

Almazan and Boyd (1978)
Argyrou et al. (1997)
Boar et al. (1989)
Boot and den Dubbelden (1990)
Bouchard et al. (2003)
Bouma et al. (2001)
Boustany et al. (1997)
Bowden (1986)
Boyd and Vickers (1971)
Boyer and Zedler (1999)
Boyer et al. (2000)
Boyer et al. (2001)
Boynton et al. (1995)
Bradley and Morris (1990)
Bridgham et al. (1998)
Brinson et al. (1981)
Brusch and Nilsson (1993)
Brix et al. (2002)
Broome et al. (1975a)
Broome et al. (1975b)
Burdick et al. (1989)
Buresh et al. (1980)
Buresh et al. (1981)
Burgin and Hamilton (2007)
Burke et al. (2000)
Burke et al. (2002)
Buttery et al. (1965)
Buzzelli et al. (1999)
Cahoon and Stevenson (1986)
Cannell and Thornley (2000)
Chalmers (1979)
Chescheir et al. (1991)
Childers and Day (1990)
Childers et al. (1993)
Childers et al. (2003)
Christian (1984)
Christian et al. (1978)
Christian et al. (1990)
Cizkova and Bauer (1998)
Clarke and Baldwin (2002)
Conner and Day (1992)
Cooper (1990)
Cooper et al. (1987)
Craft and Casey (2000)
Craft et al. (1988)
Craft et al (1989)
Craft et al. (1991)
Cross et al. (2003)
Currin et al. (1995)
Dacey and Howest (1984)
D'Angelo and Reddy (1994a)
D'Angelo and Reddy (1994b)
Gallagher (1975)
Gallagher (1979)
Gallagher et al. (1976)
Gallagher et al. (1980)
Gerritsen and Greening (1989)
Haines and Dunn (1976)
Korner et al. (2003)
Lillebo et al. (1999)
Mason and Bryant (1975)
Mendelssohn (1978)
Mendelssohn (1979)
Newman et al. (1996)
Otto et al. (1999)
Scifres et al. (1980)
Shea et al. (1975)
Shure et al. (1986)
Smart and Barko (1980)
Sullivan and Daiber (1974)
Thrush et al. (2004)
Valiela and Teal (1974)
Valiela et al. (1978)
White and Trapani (1982)
Willis and Mitsch (1995)
Windham (2001)

General Studies

Burns et al. (1997)
Chapin (1988)
Chapin et al. (1986)
Cho and Mills (1979)
Christensen et al. (1990a)
Christensen et al. (1990b)
Killingbeck (1996)
Pastor and Binkley (1998)
Seastedt et al. (1992)
Van der Krift et al. (2001)
Walker et al. (2003)
Wright et al. (2003)

5.0 INCREASE COMPLEXITY OF THE AQUATIC MODEL

The Scope of Work included three additions to be made to the aquatic model to increase its complexity and realism.

5.1 Expansion of the Aquatic Model to Include Multiple Layers

5.1.1 Concept

The Phase 1 aquatic model for the Bay contained only one water layer. The river and pond aquatic modules contain multiple layers. However, the water movement dynamics of the Bay are more complex than either river or pond dynamics, in large part because of the effects of tides and wind and the larger size of the Bay which results in more complex mixing dynamics than those in rivers and ponds. Time constraints were the major reason for keeping the Bay model a single-layer model in Phase 1. Part of Task 4 of Phase 2 was to expand the Bay model to include multiple layers.

The concept behind multiple-layers in aquatic systems is straightforward, although the process of developing such a model is complex. The basic concept is similar to that used in EDYS to model soil profiles. In EDYS, a soil profile for a particular cell has multiple layers. Both the number of layers and the thickness of each layer are flexible and are designated during model setup for a particular application. Once established, layer thickness can change during a simulation in response to erosion (decrease in thickness) or deposition (increase in thickness). Although these processes begin at the surface layer in each cell, either process can result in a change in number of layers if erosion is sufficient to remove all of a previous layer or if deposition is sufficient to add enough material on the surface to create a new layer. In addition to erosion and deposition, the constituents (e.g., nutrients, water, organic matter, contaminants) in each layer are also changing during a simulation as materials are added to the layer or transported out.

Each soil column (soil profile in a cell) consists of mineral particles (soil particles: sand, silt, clay), organic matter, air (volume of pore space not occupied by water), and water, in addition to the nutrients and contaminants contained in the water, in the organic matter, or attached to soil particles. At saturation, all pore space is occupied by water. At permanent wilting (about - 1.5 MPa for many agronomic species), most of the pore space is occupied by air. And these proportions can be different in each soil layer.

The soil column in EDYS could be extended vertically above the soil surface, although this is not a common practice in terrestrial systems. If extended vertically, the column would contain mostly air, although it would contain some water (water vapor and hence humidity) and some minerals (dust and contaminants). If the surface was flooded, some of the lower layers of the air column would contain mostly water, with some minerals (sediments) and air.

The water column in an aquatic system is basically the same concept (Fig. 4.6). The lower layers are the sediments and underlying substrate. The upper layers are the layers of the water column.

Each layer, upper and lower, contains some combination of water, minerals, air, and organic matter, along with nutrients and contaminants. As more water enters the cell (e.g., rainfall, surface runoff entering the water body, incoming tide), the upper layer gets thicker or additional layers are added. As water leaves the system (e.g., outgoing tide, evaporation, drainage), the upper layers become thinner or disappear. If the cell dries up, the upper sediment layer now becomes the top soil layer and begins to dry out. Drying out of the cells is a common occurrence in shallow ponds, but also happens to some degree in tidal systems such as tidal flats and shallow marshes.

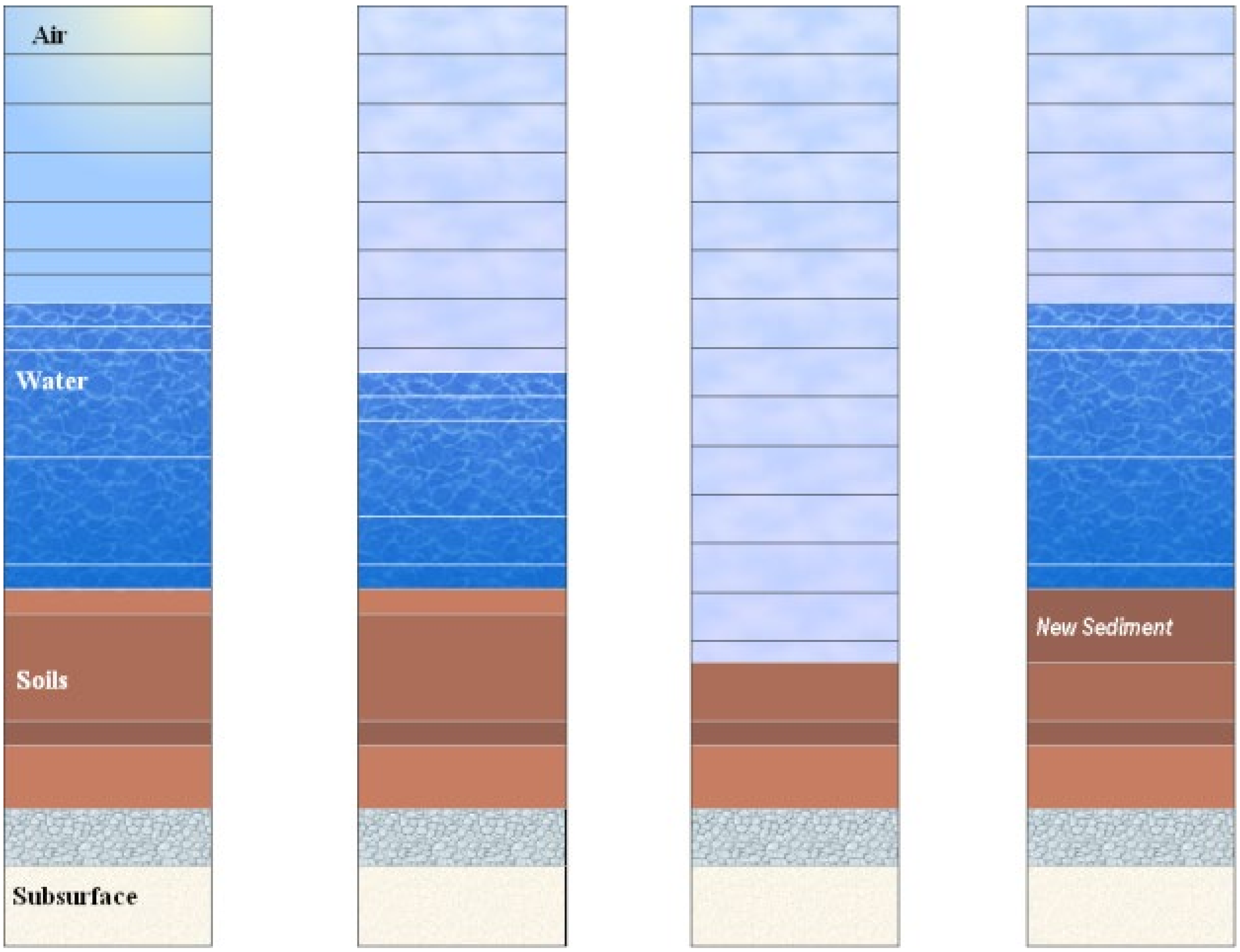

Figure 4.6 Schematic of water columns in aquatic cells in the EDYS model, illustrating changes in sediment, water, and air layers.

That is the rather straightforward concept. Coding those vertical dynamics takes some effort, but it is not overly difficult. Coding horizontal dynamics is much more complicated and presents much more of a challenge. To code horizontal dynamics, care must be taken that interchanges among layers in both vertical and horizontal dimensions are accounted for. Vertical interchanges are two-dimensional (up and down). Horizontal interchanges are three-dimensional (up, down, and all surrounding cells).

5.1.2 Results

Coding of the multi-dimensional aquatic transfers (multiple-layers) was being funded by the US Army Corps of Engineers. Funding provided by the Fort Worth District was being provided to ERDC to support the work by Dr. Cade Coldren who is with ERDC. Mid-way through FY13, the Federal government experienced a major fiscal limitation. Funds were temporarily withdrawn from a number of projects in order to cover minimum operating costs. The work by Dr. Coldren on the coding of the multi-dimensional aquatic transfers was one of those projects for which USACE funds were no longer available. Although Dr. Coldren had completed a sizable amount of work on the coding, it was not complete.

The following is the status of the multi-layer Bay module.

- The Bay circulation is working. Water moves around and through the Bay in response to tidal changes in logical and apparent reasonable patterns. Further testing should be conducted using gauged data to verify that the circulation patterns are indeed realistic.
- Water flows between cells and overall depths increase and decrease (i.e., water gets deeper or shallower depending on circulation and other inputs). Again, further testing should be conducted to verify the realism of the changes in depths.
- Linkages between freshwater inflows (river discharge, overland flow) and the multiple layers in the Bay have not been completed. The linkage appears to be nearly complete, but it is not yet operational. Completion of the linkage should not require too much additional effort.
- Constituents (nitrogen, sediments, contaminants) have not yet been added to the multiple layer circulation module. This should not require too much effort, but it has not yet been added.
- Wind effects and temperature changes (thermal energy transfer) have not been added but they also should be relatively straightforward once the previous two items are completed.

In summary, much of the effort to develop the multiple-layer Bay module has been completed. What remains is not expected to present any serious difficulties in coding. As with any major coding effort, there are always surprises. However, the major challenges in developing this module have been met. Once funding is renewed, we expect progress to be made quickly and the module operational within 4-6 months.

5.2 Inclusion of Nitrogen Into the Aquatic Model

The second addition to the aquatic model called for in the Scope of Work was to include nitrogen (N) as a constituent. This was the next item to be added to the multiple-layer Bay module when work on that task stopped (fourth bullet in the preceding section). Data being summarized in the decomposition/mineralization subtask (discussed in Section 4.2.4) will be used to parameterize the N component of the multi-layer Bay module as soon as that module is ready. This will allow transfer of N from the surrounding uplands and marshes to the Bay (overland flow, decomposition in marshes, and tidal movement), from the Bay to the marshes (from tidal movement), and within the various layers of the Bay.

5.3 Conceptual Approach to Adding Temperature

The third addition relating to the aquatic model in the Scope of Work was to develop a conceptual approach to adding temperature. Our approach will be in two parts. One input will be solar radiation. This will be added in a similar manner as precipitation or atmospheric N deposition are added. It will be top-down (i.e., arrives at the surface, then moves downward one layer at a time based on concentration differences) and will be based on the amount of energy striking the surface. A given quanta of energy per unit time will raise the temperature of the surface layer by an amount based on the quantity of water in that layer and the existing temperature of that layer of water. If air temperature is less than the temperature of the surface layer of the water, energy (heat) is transferred from the surface layer of the water to the air.

Once the temperature (heat or energy content) of the surface layer is calculated, energy (heat) will be allowed to transfer downward in a similar manner as how nutrient concentrations are balanced between layers and water moves downward in the soil. Rates of transfer will be accounted for as will potential lateral movement.

As a first approximation, average monthly solar energy and temperature values will be used. In following approximations, more detailed (e.g., daily) values will be used. Sensitivity testing will be conducted to determine how much more detailed air temperature and solar radiation data are useful.

6.0 EVALUATE VARIED PRECIPITATION LEVELS

6.1 Introduction

Precipitation is an extremely important ecological factor. In EDYS, precipitation is entered cell by cell across the spatial footprint. This allows hydrologic and hydro-ecological processes (e.g., infiltration, runoff, erosion, atmospheric inputs of nutrients and contaminants, rise in water level) to be simulated realistically across the landscape. In the Phase 1 model, only one data set is used for the entire footprint, i.e., each cell receives the same amount of precipitation at each event. In the real world, precipitation varies across the landscape. How important this variation is ecologically depends, in part, on the size of the landscape and the rate of change in precipitation across the landscape. The purpose of Task 5 in Phase 2 was to evaluate the significance of the spatial variation in precipitation across the San Antonio Bay spatial footprint and to develop an algorithm for accounting for varied precipitation amounts across the landscape.

Precipitation data are available for 14 official stations along the middle Texas coast (Table 6.1). None of the 14 stations have complete data sets for their period of record (i.e., there are some years with missing data for at least one month of the respective year). In addition, the periods of record vary substantially among the 14 sites. Victoria has the longest record with complete data available for 100 years between 1898-2011 and some incomplete data dating back to 1893.

Table 6.1 Precipitation stations along the middle Texas coast used to construct the precipitation (PPT) data grid for the San Antonio Bay EDYS model.

Station	Location		Mean Annual PPT (inches)	Period of Record	Number of Years with Complete Data
Aransas Pass	West	Bay	32.43	1942-1971	24
Rockport	West	Bay	35.31	1902-2011	72
Aransas NWR	Central	Bay	38.69	1941-2011	59
Austwell	Central	Bay	32.94	1910-1958	47
Port O'Connor	Central	Bay	41.06	1949-2011	35
Port Lavaca	East	Bay	39.92	1901-2011	55
Point Comfort	East	Bay	44.31	1957-2011	48
Palacios	East	Bay	43.61	1943-2011	65
Matagorda	East	Bay	42.66	1911-2011	91
Woodsboro	West	Inland	31.70	1916-1964	43
Refugio 2	West	Inland	38.16	1991-2011	14
Refugio	West	Inland	38.91	1948-2011	55
Goliad	West	Inland	35.10	1910-2011	96
Victoria	Central	Inland	37.27	1898-2011	100

West, Central, and East are in relation to San Antonio Bay.
Bay locations are those nearest the coast and on or near a bay. Inland locations are not within 10 miles of a bay.

Aransas National Wildlife Refuge (Aransas NWR), Austwell, and Port O'Connor are the stations most representative of the San Antonio Bay footprint. Aransas NWR and Austwell are on the western edge of the Bay and Port O'Connor is east of San Antonio Bay approximately 7 miles from the center of the Bay. Complete data exist from Aransas NWR for 59 years, from 1941-2011, and for Austwell for 47 years, from 1910-1958. Complete data exist for Port O'Connor for 35 years, from 1949-2011.

The value of precipitation data in simulation modeling, as in most ecological studies, increases substantially as the length of the period of record increases. Precipitation typically varies with patterns that are short-, medium-, and long-term. Short-term fluctuations include 1) annual variations around a mean, with some years being either drier or wetter than average, and 2) series of below- or above-average precipitation years, the series generally lasting 2-5 years but sometimes lasting a decade or more. For example, the long-term (1898-2011) mean annual precipitation at Victoria is 37.27 inches (Table 6.2). The driest year on record was 1917 with 11.15 inches (30% of long-term mean) and the wettest year on record was 2004 with 73.65 inches (195% of long-term mean). The driest short-term (3-year) period on record was 1915-17, during which annual precipitation averaged 21.15 inches (57% of long-term mean) and the wettest short-term (4-year) period was 2004-07 during which annual precipitation averaged 54.94 inches (147% of long-term mean). The 2004-07 wet years have been followed by four years (2005-11) with an annual average of 28.05 inches (75% of long-term mean), and the last year (2011) received only 13.07 inches, the second-driest year on record.

Table 6.2 Annual precipitation (PPT; inches) at Victoria, Texas (1898-2011).

Year	PPT	Year	PPT	Year	PPT	Year	PPT	Year	PPT	Year	PPT
										1898	25.75
										1899	36.88
										MEAN	31.32
1900	53.71	1910	30.23	1920	28.36	1930	-----	1940	35.67	1950	-----
1901	23.01	1911	36.44	1921	-----	1931	44.32	1941	51.03	1951	-----
1902	32.03	1912	-----	1922	33.92	1932	30.33	1942	38.33	1952	-----
1903	44.47	1913	41.20	1923	44.67	1933	35.17	1943	37.55	1953	-----
1904	33.94	1914	51.40	1924	29.54	1934	38.57	1944	43.48	1954	23.75
1905	45.34	1915	25.73	1925	27.15	1935	37.29	1945	-----	1955	30.34
1906	26.99	1916	26.57	1926	41.00	1936	46.69	1946	34.46	1956	14.32
1907	44.00	1917	11.15	1927	24.41	1937	25.52	1947	-----	1957	42.45
1908	40.21	1918	36.37	1928	30.59	1938	32.26	1948	19.59	1958	-----
1909	32.83	1919	59.57	1929	51.81	1939	20.58	1949	-----	1959	-----
MEAN	37.65	MEAN	35.41	MEAN	34.61	MEAN	34.53	MEAN	37.16	MEAN	27.72
1960	-----	1970	39.78	1980	32.54	1990	35.77	2000	36.76	2010	46.62
1961	-----	1971	36.06	1981	45.10	1991	56.72	2001	42.77	2011	13.07
1962	25.89	1972	42.41	1982	32.53	1992	51.38	2002	39.13		
1963	22.05	1973	45.65	1983	42.41	1993	51.40	2003	38.67		
1964	33.32	1974	43.34	1984	33.92	1994	43.67	2004	73.65		
1965	30.85	1975	36.96	1985	39.99	1995	33.47	2005	34.93		
1966	35.42	1976	43.25	1986	39.19	1996	28.74	2006	39.44		
1967	33.90	1977	39.21	1987	43.09	1997	67.18	2007	71.76		
1968	49.32	1978	43.08	1988	15.91	1998	46.39	2008	21.71		
1969	44.64	1979	49.30	1989	25.79	1999	27.01	2009	30.78		
MEAN	34.42	MEAN	41.90	MEAN	35.05	MEAN	44.17	MEAN	42.96	MEAN	29.85

Overall mean (1998-2011, excluding incomplete years) = 37.27 inches

Medium-term changes tend to be on the order of 40-60 years and, in the southwestern United States, are correlated with both the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation (Hidalgo 2004). For example, mean annual precipitation in San Antonio during 1892-1956 was 20% less than the annual average during 1957-2004. More humid regions also experience similar cycles. Tree-ring data from North Carolina indicate that region has undergone alternating wet-dry periods of about 30 years each and that 1956-1984 was one of the five wettest periods during the past 1600 years (Stahle et al. 1988). Oxygen ratios from stalagmites in Belize indicate that major droughts have occurred in the Yucatan at 100-200 year intervals over the past 1800 years and have lasted 50-80 years each occurrence (Kennett et al. 2012). In addition to annual precipitation patterns, El Nino-Southern Oscillation events affect Gulf Coast estuary water levels and marsh inundations on about a 25-year cycle (Childers et al. 1990).

Mean annual precipitation at Victoria during 1901-1967 (a 67-year period with 53 years of complete data) was 34.27 inches. Over the next 40 years (1968-2007), annual precipitation averaged 42.06 inches, or an average of 22% more each year than during the preceding 67 years.

Data for the last four years (2008-11) suggest that a new dry cycle has begun (average of 28.07 inches).

In addition to these annual and decadal fluctuations, precipitation changes over longer periods of time, e.g., centuries and millennia. Climatic patterns may be relatively stable for periods on the order of centuries and then, relatively rapidly (e.g., decades), change sufficiently to cause major vegetation changes in the region. Much of the western United States underwent a 2000-year period of increasing aridity beginning about 2600 years ago during which many woodlands in the region decreased in extent and shrublands increased (Tausch et al. 2004). Then about 650 years ago, the Little Ice Age began and conditions became much cooler, resulting in an increase in extent of woodlands, grasslands, and wetlands. Vegetation patterns were very different during this period compared to current patterns (Tausch et al. 2004). Little Ice Age conditions lasted until about 150 years ago and then climate shifted again, with aridity once again increasing. Similarly, Neilson (1986) suggested that the black grama desert grasslands encountered in the northern Chihuahuan Desert 100 years ago was a vegetation established under and adapted to 300 years of Little Ice Age conditions and is only marginally supported and perhaps not likely to be re-established under present climatic conditions.

In addition to temporal variability in precipitation, there is spatial variability. Precipitation amounts vary not only across relatively large distances, but can also vary substantially across relatively short distances. For example, stations at Aransas NWR and Austwell were only 6 miles apart, but the average monthly precipitation for the 232 months in which data are available at both sites was 2.90 inches for Aransas NWR and 2.75 inches for Austwell. The average monthly deviation between stations for these 232 months was 0.80 inch, or 28% of the mean for Aransas NWR. This 28% average deviation in monthly mean was over a distance of only 6 miles. San Antonio Bay is about 10 miles wide at its mouth (along the Intracoastal Waterway) and about 20 miles long from its northern-most point to the edge of Matagorda Island.

The precipitation station at Port O'Connor is 27 miles east of Aransas NWR. There are 556 months with precipitation data for both stations and the monthly mean for these 556 months is 3.11 inches for Aransas NWR and 3.35 inches for Port O'Connor. The average monthly deviation is 1.27 inches, or 41% of the monthly mean for Aransas NWR.

The precipitation station at Port Lavaca is 25 miles northeast of Aransas NWR. There are 589 months with precipitation data for both stations and the monthly mean for these 589 months is 3.18 inches for Aransas NWR and 3.39 inches for Port Lavaca. The average monthly deviation is 1.29 inches, or 41% of the monthly mean for Aransas NWR.

These deviations over the spatial footprint of the San Antonio Bay suggest that precipitation received at various locales throughout the Bay footprint are likely to vary substantially from those received at other locales. The ability of the model to accurately simulate precipitation-influenced processes is therefore likely to be improved if some of this spatial variation in precipitation can be accounted for.

Because of these temporal fluctuations and spatial variations in precipitation and because of their potential effects on the dynamics of the ecological systems, it is desirable to have a precipitation data set for the San Antonio Bay EDYS model that is relatively long-term and spatially representative.

6.2 Methodology

6.2.1 Temporal Data

No continuous long-term (more than 100 years) precipitation data set exists for the central Texas coast. The longest data set is for Victoria, with 100 years of complete data for the period 1898-2011, but these 100 years are not continuous. Fourteen of the 114 years have missing data. The three stations most representative of the San Antonio Bay footprint (Aransas NWR, Austwell, and Port O'Connor) all have periods of record of less than 60 years and complete data sets are not available for all years during the period of record at any of the stations. However, a longer period of record can be constructed using data from other stations.

Aransas NWR was selected as the precipitation station with data most representative of the San Antonio Bay. The following method was used to construct a long-term precipitation data set for Aransas NWR for daily, monthly, and annual values for the period of 1898-2011. This constructed data set was then used to develop a spatially representative precipitation data set for the San Antonio Bay EDYS footprint.

1. Station-specific data were used for all dates that such data were available.

2. For each month where data were not available for Aransas NWR, estimated amounts were used. Regression analysis was used to determine the r^2 values for correlation of precipitation between the Aransas NWR station and each of the other stations (Table 6.3). Each station was ranked on the basis of r^2 values between it and the Aransas NWR station.

   Regressions were conducted for daily, monthly, and annual precipitation values. Results of the regressions using the annual data were used because temporal variability between stations for each respective date was less for annual data than for daily or monthly data (mean r^2 values, Table 6.3). The major reason for this is that daily comparisons are affected more by the timing of the precipitation event than are monthly values and monthly values are more affected than annual values. A rain event might begin at one site before midnight but begin at a site 20 miles away just after midnight. The two events might result in a similar amount of rainfall, but the amount would be recorded at the first station for the day before the day it was recorded at the second station. In monthly totals, this would potentially affect the results only 1 day out of 28-31 days (i.e., the last day of the month) and for annual totals it would potentially affect the results only 1 day out of 365-366 (i.e., last day of the year).

3. Ratios of the mean annual precipitation at Aransas NWR to the mean annual precipitation at each of the other stations were calculated (Table 6.4). In each case, only years with complete data for both stations were used. These ratios were then available for use as conversion factors to estimate precipitation at Aransas NWR based on precipitation at another station.

4. For each date with missing data at Aransas NWR an estimated value was calculated by multiplying the value from the station with the highest r^2 value (Table 6.3) that had data for that date by its respective conversion factor (Table 6.4).

Table 6.3 Regression coefficients (r^2) for annual, monthly, and daily precipitation at Aransas NWR (dependent variable) to annual, monthly, and daily precipitation at 11 other precipitation stations along the central Texas coast.

Annual Precipitation				Monthly Precipitation				Daily Precipitation			
Station	N	r^2	Miles	Station	N	r^2	Miles	Station	N	r^2	Miles
Port Lavaca	32	0.792	25	Austwell	232	0.787	6	Austwell	1710	0.413	6
Woodsboro	21	0.785	31	Rockport	766	0.617	24	Rockport	6086	0.326	24
Austwell	16	0.764	6	Port Lavaca	595	0.604	25	Point Comfort	5269	0.316	31
Rockport	52	0.694	24	Palacios	818	0.573	47	Aransas Pass	1787	0.273	38
Point Comfort	40	0.611	31	Point Comfort	632	0.565	31	Port Lavaca	5065	0.250	25
Palacios	52	0.596	47	Woodsboro	285	0.543	31	Refugio	6177	0.227	34
Port O'Connor	30	0.583	27	Matagorda	842	0.534	56	Woodsboro	1591	0.211	31
Victoria	49	0.576	39	Refugio	513	0.513	34	Matagorda	6964	0.201	56
Matagorda	51	0.545	56	Port O'Connor	639	0.483	27	Palacios	7553	0.186	47
Refugio	45	0.529	34	Victoria	770	0.477	39	Goliad	7064	0.145	42
Goliad	55	0.495	42	Aransas Pass	331	0.447	38	Port O'Connor	5553	0.144	27
				Goliad	831	0.406	42	Victoria	7246	0.112	39
MEAN		0.634		MEAN		0.546		MEAN		0.234	

N = number of dates with data for both stations.
Miles = distance between Aransas NWR station and station being compared.

Table 6.4 Comparison of annual precipitation (inches) data for Aransas NWR to other stations along the central Texas coast for years with data available for both stations in the comparison.

Comparison	Years	Ratio (Totals)	Factor
Aransas NWR/Austwell	16	540.5/ 516.9	1.046
Aransas NWR/Port O'Connor	31	1149.3/1216.8	0.945
Aransas NWR/Port Lavaca	33	1289.0/1411.9	0.913
Aransas NWR/Point Comfort	38	1538.5/1681.9	0.915
Aransas NWR/Palacios	53	2054.0/2319.6	0.885
Aransas NWR/Matagorda	51	1947.2/2200.6	0.885
Aransas NWR/Woodsboro	21	736.3/ 691.0	1.066
Aransas NWR/Rockport	52	2005.5/1832.3	1.095
Aransas NWR/Victoria	49	1904.4/1907.6	0.998
Aransas NWR/Goliad	55	2146.1/2055.2	1.044

Years = number of years with complete data for both stations.
Ratio (Totals) = annual precipitation totaled over the included years.

6.2.2 Spatial Data

The purpose of this subtask was to develop an estimated precipitation grid for the spatial footprint of the San Antonio Bay EDYS model that would reflect probable spatial variation in precipitation received across the footprint. Data are available from 14 sites along the central Texas coast. None of the 14 sites have data for all of the same years, so direct comparisons of mean values should be made with care. In general, annual mean precipitation decreases from east to west (Table 6.5), averaging 43-44 inches at the eastern stations (Point Comfort, Palacios, and Matagorda) and 32-35 inches at the western stations (Aransas Pass and Rockport), an east-west distance of about 90 miles (Table 6.3). This east-west decrease in precipitation has been reported to be a major factor affecting marsh vegetation and bay salinity values along the Texas coast (Britton and Morton 1989; White et al. 1998). There is also a general decrease in annual precipitation as distance from the coast increases. Annual precipitation averages 38-41 inches near the coast (Aransas NWR and Port O'Connor) compared to 35-38 inches at more interior locations (Goliad and Victoria), over a southeast-northwest distance of about 40 miles (Table 6.3).

Table 6.5 Average annual precipitation (inches) and period of record (years) for 14 sites along the central Texas coast.

Station	Location		Average Precipitation (inches)	Period of Record	Number of Years with Complete Data
Aransas Pass	West	Bay	32.43	1942-1971	24
Rockport	West	Bay	35.31	1902-2010	71
Aransas NWR	Central	Bay	38.69	1941-2010	58
Austwell	Central	Bay	32.94	1910-1958	47
Port O'Connor	Central	Bay	41.06	1949-2010	34
Port Lavaca	East	Bay	39.92	1901-2010	54
Point Comfort	East	Bay	44.31	1957-2010	47
Palacios	East	Bay	43.61	1943-2010	64
Matagorda	East	Bay	42.66	1911-2010	91
Woodsboro	West	Inland	31.70	1916-1964	43
Refugio 2	West	Inland	38.16	1991-2010	14
Refugio	West	Inland	38.91	1948-2010	54
Goliad	West	Inland	35.10	1910-2010	95
Victoria	Central	Inland	37.51	1898-2010	99

2011 data are available for the active stations but have not yet been included into the means.

Additional precipitation data are available from a number of unofficial stations located throughout the area. Most of these sites have data for only short periods of time (e.g., 5 years). These data are not being used to develop the initial precipitation spatial grid, but will be used to validate the results of the initial grid.

A grid layer containing 106 cells was superimposed on the spatial footprint of the San Antonio Bay EDYS domain (Fig. 6.1). Each cell was 4000 m x 4000 m (2.49 mi x 2.49 mi). Each precipitation grid cell therefore contains 10,000 (100 x 100) EDYS spatial cells (40 m x 40 m;

McLendon 2012). This 4000 m x 4000 m grid size was selected as a practical level of resolution for variations across the footprint and compatible with the EDYS spatial cells used for other model functions (i.e., 10,000 regular EDYS cells fit into one precipitation grid cell). Smaller precipitation grid cells can be developed in the future should it become apparent that a finer-resolution is useful.

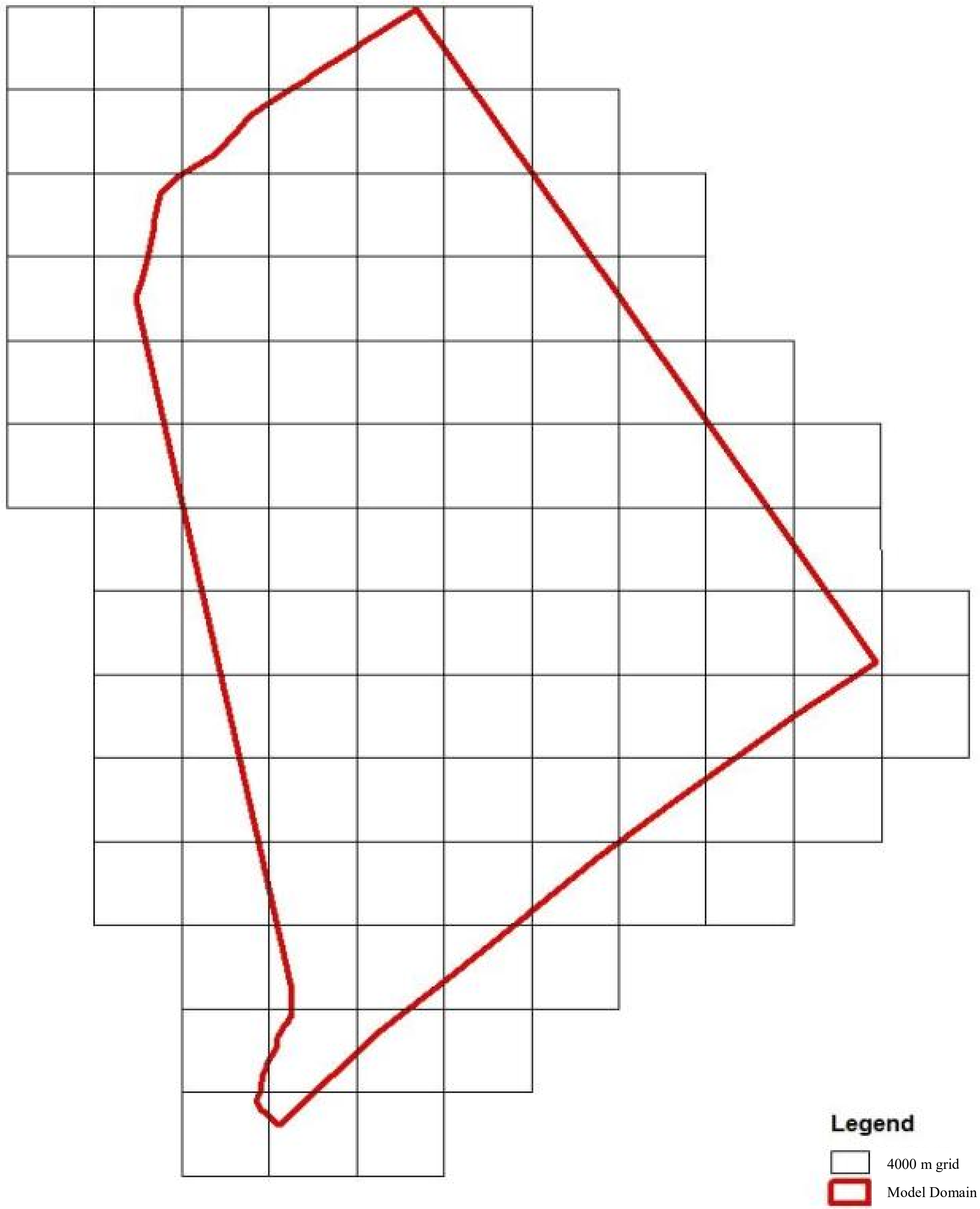

Figure 6.1 Precipitation grid layer (squares) superimposed on the EDYS spatial footprint (red lines) for the San Antonio Bay model.

Four methods were used to estimate spatial variation of precipitation across the San Antonio Bay area: 1) linear distance adjustments between means, 2) linear distance adjustments using average differences between events, 3) regression equations, and 4) kriging. For each method, data from a subset of the 14 precipitation stations were used in the calculations. In each case, Aransas NWR was considered as the base precipitation station, i.e., the single station most representative of precipitation patterns in the San Antonio Bay.

Linear Distance Adjustments Between Means

Locations of each of the 14 stations were plotted and lines drawn between Aransas NWR and each of the other stations. If lines between two or more other stations were less than one grid cell apart over most of the grid, an average of the two stations was used to represent that grid cell. This process resulted in 10 stations being selected (Fig 6.2).

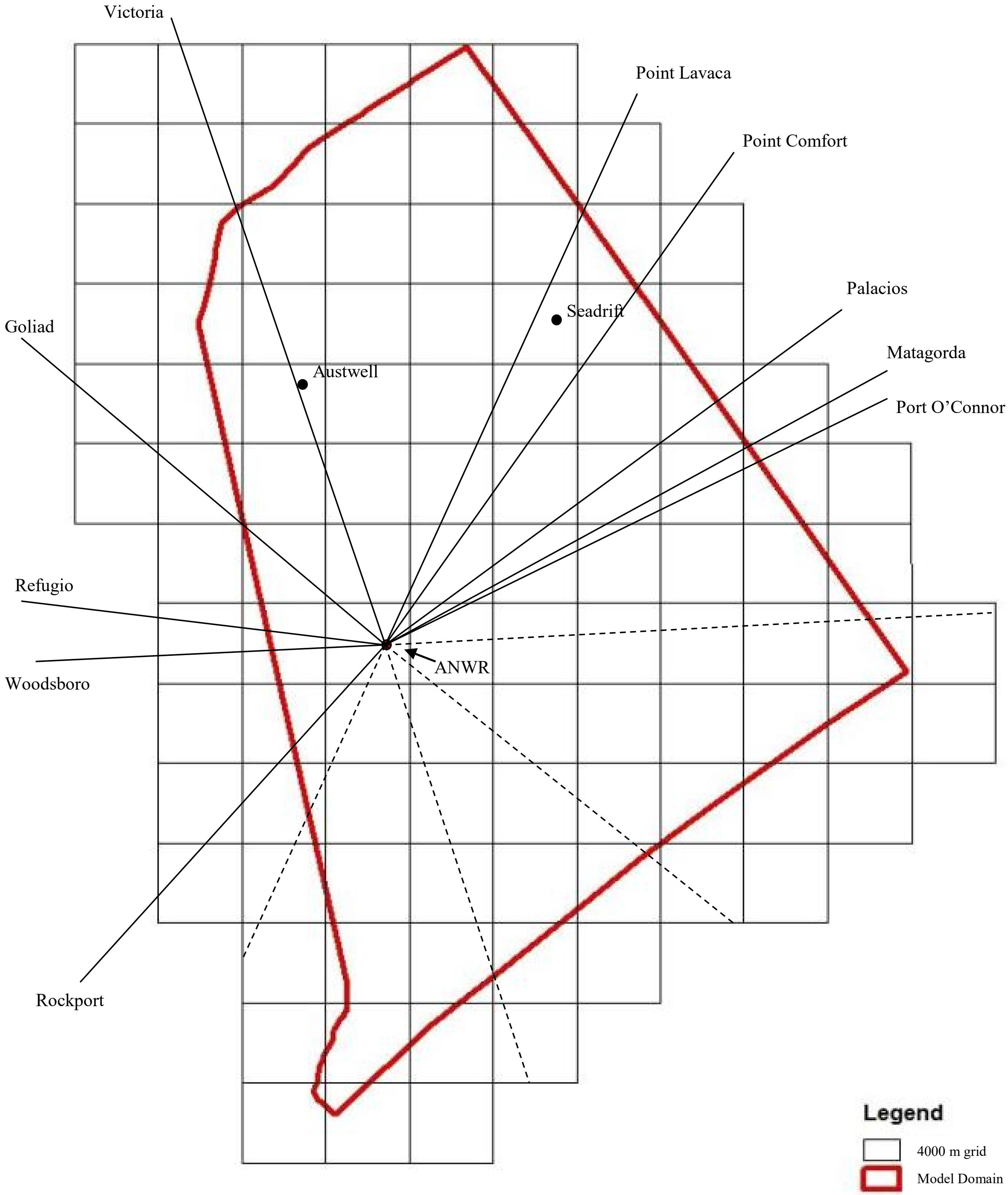

Figure 6.2 Directional lines between Aransas NWR and surrounding precipitation stations used to estimate spatial precipitation distribution patterns over the San Antonio Bay footprint.

For each grid cell occurring along a particular line, its proportional distance between the two stations was calculated. This proportional distance was then multiplied by the conversion factor between the two stations (Table 6.4) to calculate a difference factor for each cell along the line. Difference factors were calculated for each cell that did not occur along a line between stations. These were calculated by using weighted averages. For each of these cells, the proportional distance between that cell and the two nearest "line cells" (i.e., cells occurring along a particular line) was used to average the values from the two "line cells". This weighted average was then used as the difference factor for that cell. If a particular cell average was considered too high or too low compared to those of the surrounding cells, the average was smoothed by averaging among all immediately adjacent cells.

A grid map was produced containing the conversion values for each grid cell, the conversion factor being the proportion of average annual precipitation received at Aransas NWR estimated or the particular grid cell (Fig. 6.3). These conversion values are then multiplied by the precipitation received for each event at Aransas NWR using the 1898-2011 constructed precipitation data set (Section 6.1) to determine precipitation received across the spatial footprint.

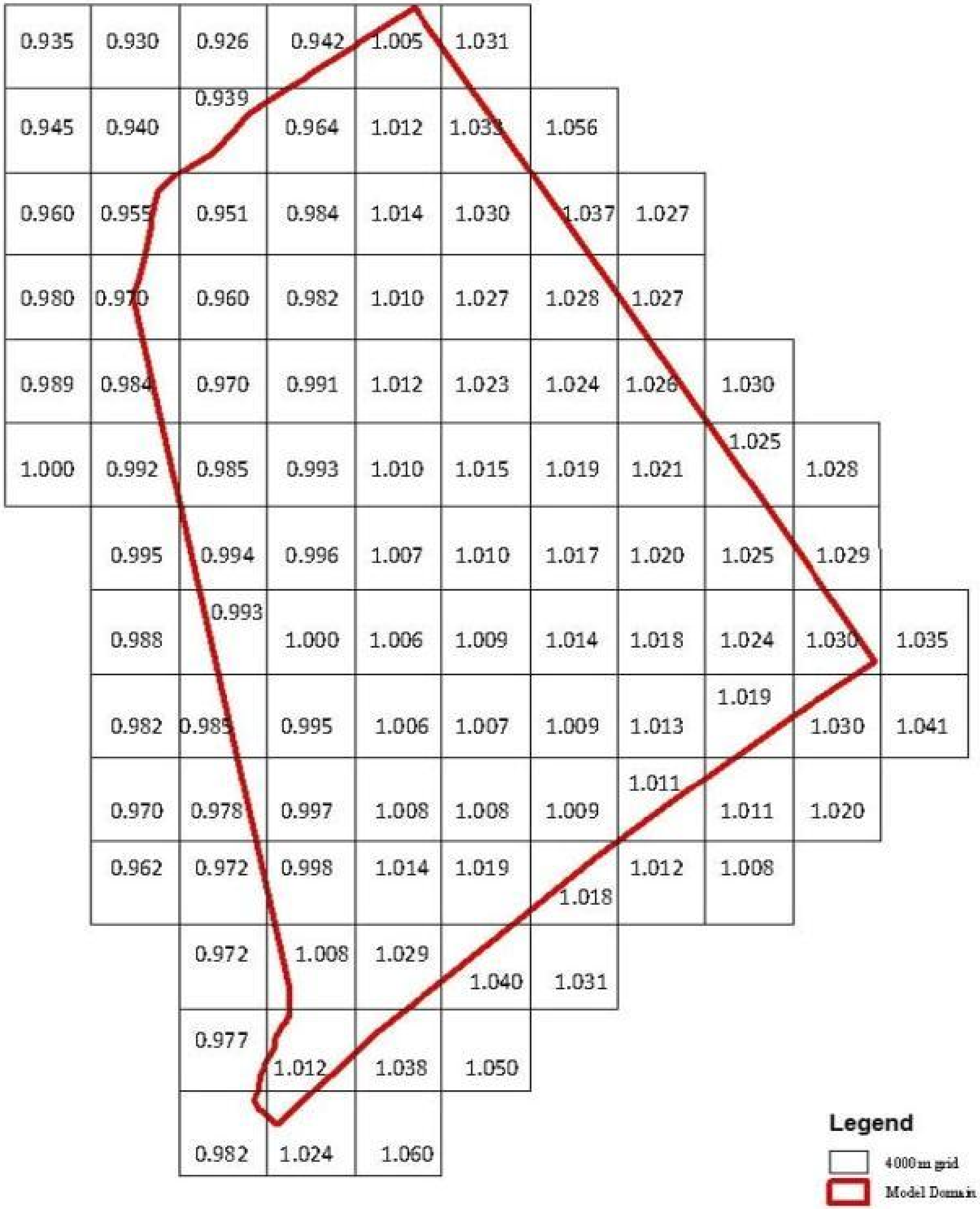

Figure 6.3 **Proportional conversion factors for precipitation distribution across the San Antonio Bay footprint using the Linear Distance Adjustments Between Means approach. Values are the calculated proportions of precipitation received at Aransas NWR estimated to occur in the particular grid cell.**

Linear Distance Adjustments Using Average Differences Between Events

This method used the same basic approach as the first method except average differences between events (Table 6.6) were used instead of the conversion factors (Table 6.4). Average differences between events (Table 6.6) were calculated by comparing monthly totals for Aransas NWR and the station being compared for each month with complete data for each station. The absolute values of these differences were summed for the period of record and an average calculated by dividing the sum by the number of corresponding months with complete data for both stations.

Table 6.6 Comparison of monthly rainfall data from Aransas NWR with data from other sites along the central Texas coast, using data from months with complete data for both stations of a comparison.

Sites Being Compared	Distance (mi)	Direction from Aransas NWR	Mean Monthly Deviation (inches)	Monthly Mean (inches) Aransas NWR	Monthly Mean (inches) Compared Site	Number of months
Aransas NWR:Austwell	6	N	0.80	2.90	2.75	232
Aransas NWR:Victoria	39	N	1.57			764
Aransas NWR:Port Lavaca	25	NNE	1.29	3.18	3.39	589
Aransas NWR:Point Comfort	31	NNE				
Aransas NWR:Palacios	47	NNE				
Aransas NWR:Port O'Connor	27	ENE	1.27	3.11	3.35	556
Aransas NWR:Matagorda	58	ENE				
Aransas NWR:Goliad		NW				
Aransas NWR:Refugio		W				
Aransas NWR:Woodsboro		WSW				
Aransas NWR:Rockport		SW				
Aransas NWR:Aransas Pass		SW				

NOTE: This process has been completed for only 4 comparisons (Table 6.6). Table 6.6 will be completed as the analyses are completed for the other stations.

Regression Equations

This method used the same basic approach as the first method except regression equations were used to estimate the amount of precipitation received at the compared site, based on precipitation received at Aransas NWR for each monthly precipitation total in the constructed precipitation data set. The regression equations used (Table 6.7) were those developed for the monthly values. The r^2 values reported in Table 6.3 were from the same regression analyses.

Table 6.7 Regression equations, with corresponding r^2 values, for predicting monthly precipitation (inches) at each of 12 stations along the central Texas coast from monthly precipitation at Aransas NWR.

	Equation	r^2
Aransas Pass	= (Aransas NWR - 1.30)/0.60	0.447
Austwell	= (Aransas NWR - 0.28)/0.92	0.787
Goliad	= (Aransas NWR - 0.98)/0.73	0.406
Matagorda	= (Aransas NWR - 0.76)/0.67	0.534
Palacios	= (Aransas NWR - 0.51)/0.73	0.573
Point Comfort	= (Aransas NWR - 0.61)/0.76	0.565
Port Lavaca	= (Aransas NWR - 0.58)/0.76	0.604
Port O'Connor	= (Aransas NWR - 1.19)/0.63	0.483
Refugio	= (Aransas NWR - 0.95)/0.72	0.513
Rockport	= (Aransas NWR - 0.79)/0.82	0.617
Victoria	= (Aransas NWR - 0.82)/0.74	0.477
Woodsboro	= (Aransas NWR - 0.66)/0.81	0.543

Kriging

A kriging routine was used to calculate values for each cell, based on values from each of 12 precipitation stations. One kriging analysis is required for each set of data used to create a response surface. Rather than conduct thousands of such analyses, the method was evaluated by using three analyses. Annual precipitation values were used from 1954, 1958, and 2010. For each kriging routine, data must be available for all data points. Years with complete data for the most stations were selected as possible examples to use for this method. Compete annual data were available for 12 stations for 5 years of the respective periods of record: 1954, 1956, 1957, 1958, and 1962. 1954 was selected because it was a dry year (20.7 inches at Aransas NWR). 1958 was selected because it was a year with above average precipitation (41.3 inches at Aransas NWR). These two years therefore provided a contrast between dry and above average conditions. Complete data were available for 11 stations in 2010 and this year was also included in the analysis to provide an example of a recent year. It was also an above average rainfall year (46.2 inches at Aransas NWR).

Three kriging analyses were conducted, one each for 1954, 1958, and 2010 annual precipitation totals. Values were plotted on the grid map for each of the respective grid cells. The results from 1954 (a dry year) and 2010 (a wet year) are presented as examples (Figs. 6.4 and 6.5; respectively). These values were then compared to values calculated for the same years using the other three methods.

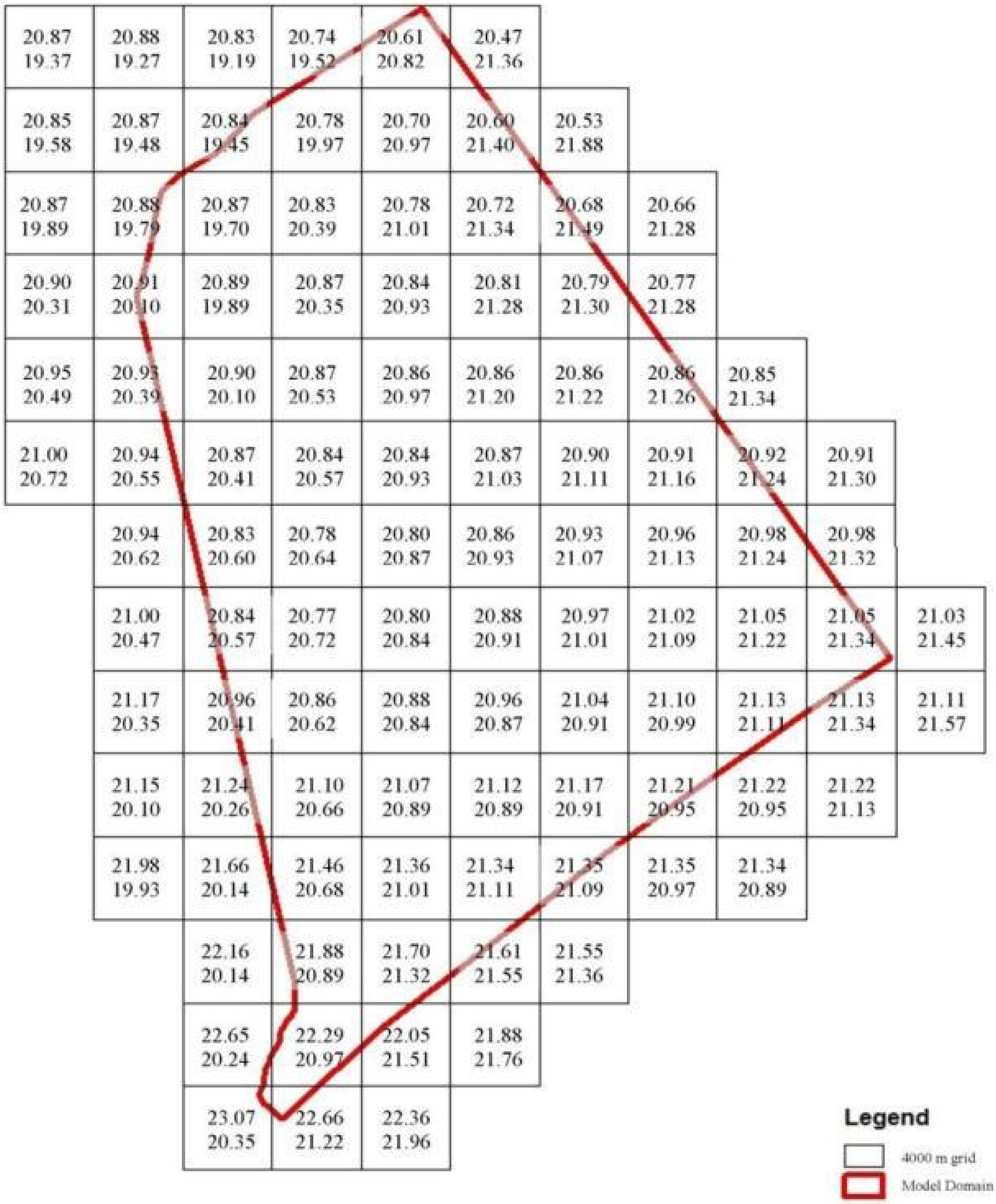

Figure 6.4 **Estimated annual precipitation (inches) received across the San Antonio Bay footprint in 1954, based on a kriging routine using data from 12 surrounding precipitation stations (upper value) compared to the estimated values using the Linear Distance Adjustments Between Means approach (lower value).**

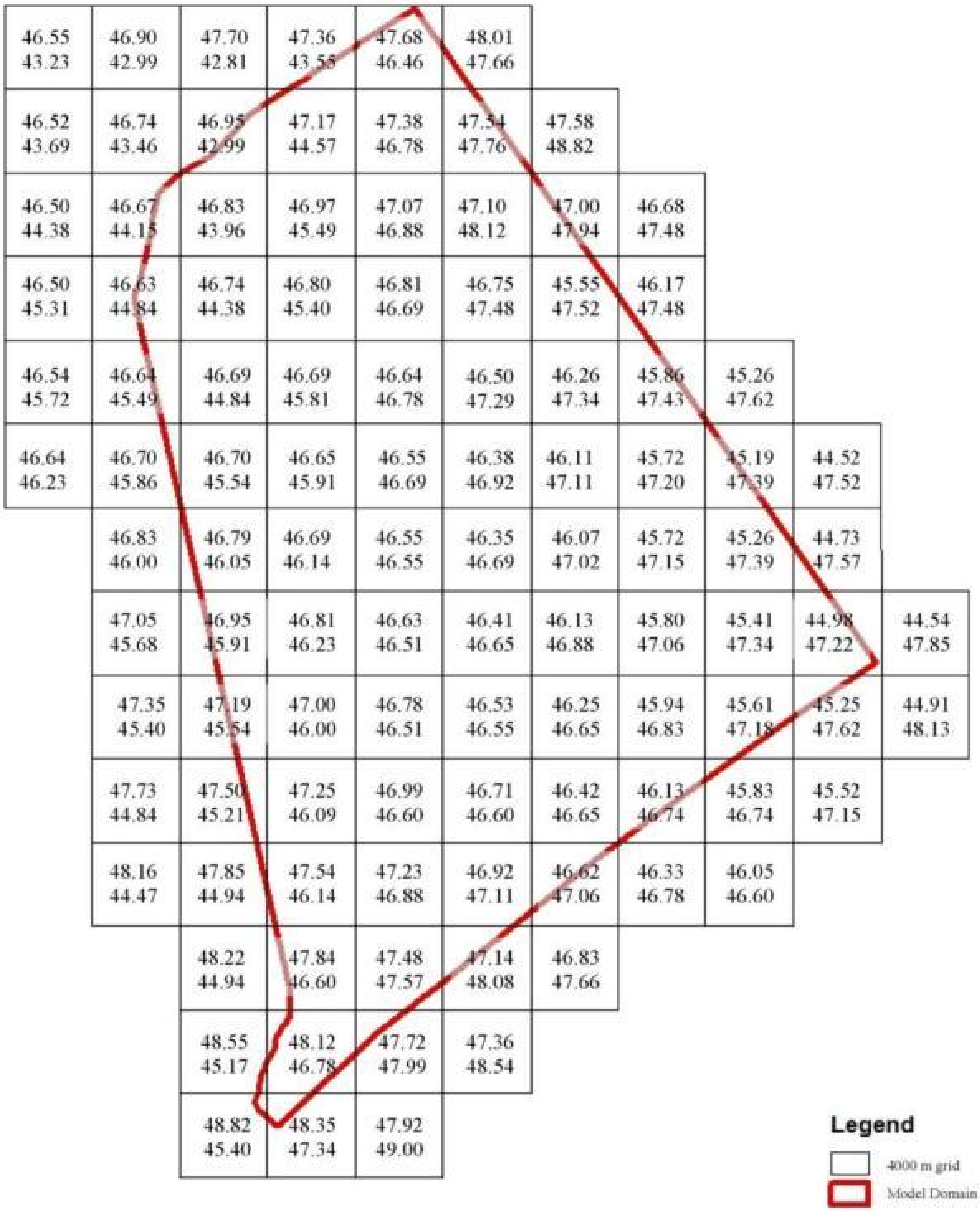

Figure 6.5 **Estimated annual precipitation (inches) received across the San Antonio Bay footprint in 2010, based on a kriging routine using data from 11 surrounding precipitation stations (upper value) compared to the estimated values using the Linear Distance Adjustments Between Means approach (lower value).**

Total precipitation in 2010 across the grid ranged from 44.52 to 48.82 inches based on kriging (Fig. 6.5), a range in values of 4.30 inches, or 9% of the total for Aransas NWR in that year. In 1954, a dry year, the range in precipitation was 20.47 to 23.07 inches (Fig. 6.4), a difference of 2.60 inches (13% of the Aransas NWR total for that year).

Differences between estimated annual precipitation based on kriging and values based on Linear Distance Adjustments varied spatially and by year. For 1954 values, the two methods produced estimates that were within 0.1-11.8% of each other for individual cells (Fig. 6.4) and within 0.2-10.3% using 2010 data (Fig. 6.5).

The Linear Distance Adjustment method was selected as the method to use to account for spatial variability because 1) it incorporates a longer period of record in the data and 2) it is much simpler to use. Based on this method, annual precipitation decreases across the San Antonio Bay landscape by about 5% (1-3 inches) between the south (higher) and north (lower) edges and by about the same about between east (higher) and west (lower) edges.

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APPENDIX A

LIST OF SPECIES INCLUDED IN THE SAN ANTONIO BAY EDYS MODEL THAT ARE MAJOR SPECIES IN THE PLANT COMMUNITIES OF THE THREE CONCEPTUAL MODEL TOPOSEQUENCES (SECTION 4.2.3.1 OF REPORT)

Appendix Table A.1 Major species included in the EDYS model of a freshwater toposequence adjacent to San Antonio Bay. Lifeforms are listed in order of ecological importance in each community and species are listed in order of ecological importance within lifeform.

Community	Lifeform	Species	Common Name
Woodland	tree	*Acacia farnesiana*	huisache
	tree	*Parkinsonia aculeata*	retama
	shrub	*Lycium carolinianum*	Carolina wolfberry
	shrub	*Sesbania drummondii*	rattlepod
	shrub	*Celtis pallida*	granjeno
	shrub	*Borrichia frutescens*	sea oxeye
	grass	*Setaria geniculata*	knotroot bristlegrass
	grass	*Andropogon glomeratus*	bushy bluestem
	grass	*Cynodon dactylon*	bermudagrass
	grass	*Paspalum plicatulum*	brownseed paspalum
	grass	*Sorghum halepense*	Johnsongrass
	grass	*Bothriochloa saccaroides*	silver bluestem
	grass	*Paspalum lividum*	longtom
	grass	*Buchloe dactyloides*	buffalograss
	forb	*Ambrosia psilostachya*	ragweed
	forb	*Clematis drummondii*	old-man's beard
	forb	*Aster spinosus*	spiny aster
Wetland	grass	*Leersia hexandra*	clubhead cutgrass
	grass	*Paspalum lividum*	longtom
	grass	*Andropogon virginicus*	broomsedge bluestem
	grass	*Andropogon glomeratus*	bushy bluestem
	grass	*Setaria geniculata*	knotroot bristlegrass
	grass	*Cynodon dactylon*	bermudagrass
	grass-like	*Eleocharis interstincta*	spikerush
	grass-like	*Fimbristylis castana*	fimbry
	grass-like	*Cyperus odoratus*	flatsedge
	shrub	*Sesbania drummondii*	rattlepod
	forb	*Sagittaria falacata*	bulltongue
	forb	*Phyla nodiflora*	frogfruit
	forb	*Rumex crispus*	curly dock
Cattail Marsh	grass-like	*Typha latifolia*	cattail
	grass-like	*Eleocharis interstincta*	spikerush
	grass-like	*Fimbristylis castana*	fimbry
	grass	*Leersia hexandra*	clubhead cutgrass
	grass	*Paspalum lividum*	longtom
	forb	*Sagittaria falacata*	bulltongue
Pond	forb	*Nelumbo lutea*	lotus

Table A.1 Freshwater toposequence (Cont.)

Community	Lifeform	Species	Common Name
Freshwater Marsh	grass	*Phragmites australis*	common reed
	grass	*Panicum hemitomon*	maidencane
	grass	*Zizaniopsis miliacea*	marshmillet
	grass	*Spartina patens*	marshhay cordgrass
	grass	*Paspalum lividum*	longtom
	grass-like	*Scirpus americanus*	bulrush
	grass-like	*Cyperus odoratus*	flatsedge
	grass-like	*Eleocharis interstincta*	spikerush
	grass-like	*Typha latifolia*	cattail
	forb	*Alternanthera philoxeroides*	alligatorweed
	forb	*Sagittaria falacata*	bulltongue
Sea oxeye Flat	shrub	*Borrichia frutescens*	sea oxeye
	shrub	*Baccharis halimiflora*	sea myrtle
	shrub	*Sesbania drummondii*	rattlepod
	grass	*Cynodon dactylon*	bermudagrass
	grass	*Spartina spartinae*	gulf cordgrass
	grass	*Paspalum lividum*	longtom
	grass	*Setaria geniculata*	knotroot bristlegrass
	grass	*Andropogon virginicus*	broomsedge bluestem
	forb	*Aster spinosus*	spiny aster
	forb	*Iva annua*	seacoast sumpweed
	forb	*Helianthus annuus*	sunflower
	grass-like	*Scirpus americanus*	bulrush
	grass-like	*Cyperus odoratus*	flatsedge
	tree	*Acacia farnesiana*	huisache
Cordgrass Flat	grass	*Spartina spartinae*	gulf cordgrass
	grass	*Setaria geniculata*	knotroot bristlegrass
	grass	*Paspalum lividum*	longtom
	grass	*Cynodon dactylon*	bermudagrass
	shrub	*Borrichia frutescens*	sea oxeye
	tree	*Acacia farnesiana*	huisache
	tree	*Parkinsonia aculeata*	retama
	grass-like	*Eleocharis interstincta*	spikerush
	grass-like	*Fimbristylis castana*	fimbry

Appendix Table A.2 Major species included in the EDYS model of a brackish-saline toposequence on the edge of San Antonio Bay. Lifeforms are listed in order of ecological importance in each community and species are listed in order of ecological importance within lifeform. Salinity (ppt) refers to the upper tolerance level of the species.

Community	Lifeform	Species	Common Name	Salinity
Oak Woodland	tree	*Quercus virginiana*	live oak	2.0
	tree	*Persea borbonia*	sweetbay	
	shrub	*Baccharis halimiflora*	sea myrtle	2.5
	grass	*Schizachyrium scoparium littoralis*	seacoast bluestem	2.0
	grass	*Paspalum plicatulum*	brownseed paspalum	
	grass	*Paspalum monostachyum*	gulfdune paspalum	
	grass	*Paspalum setaceum*	thin paspalum	2.0
	grass	*Cynodon dactylon*	bermudagrass	10.0
	grass	*Cenchrus incertus*	sandbur	2.0
	grass	*Andropogon glomeratus*	bushy bluestem	2.5
	forb	*Croton punctatus*	gulf doveweed	10.0
	forb	*Erigeron myrionactis*	Corpus Christi fleabane	2.5
	forb	*Parthenium hysterophorus*	false ragweed	
	forb	*Heterotheca subaxillaris*	camphorweed	10.0
	forb	*Baptisia leucophaea*	whitestem wild indigo	10.0
	forb	*Cassia fasciculata*	partridge pea	
	forb	*Rhynchosia texana*	snoutbean	2.0
Sand Shrubland	shrub	*Baccharis halimiflora*	sea myrtle	2.5
	shrub	*Lycium carolinianum*	Carolina wolfberry	
	grass	*Schizachyrium scoparium littoralis*	seacoast bluestem	2.0
	grass	*Paspalum monostachyum*	gulfdune paspalum	
	grass	*Aristida purpurescens*	arrowfeather threeawn	
	grass	*Cynodon dactylon*	bermudagrass	10.0
	grass	*Paspalum setaceum*	thin paspalum	2.0
	grass	*Cenchrus incertus*	sandbur	
	forb	*Croton punctatus*	gulf doveweed	10.0
	forb	*Erigeron myrionactis*	Corpus Christi fleabane	2.5
	forb	*Parthenium hysterophorus*	false ragweed	
	forb	*Heterotheca subaxillaris*	camphorweed	10.0
	forb	*Baptisia leucophaea*	whitestem wild indigo	10.0
	forb	*Cassia fasciculata*	partridge pea	
	forb	*Rhynchosia texana*	snoutbean	2.0
	grass-like	*Scirpus americanus*	bulrush	25.0
Cordgrass Meadow	grass	*Spartina spartinae*	gulf cordgrass	35.0
	grass	*Distichlis spicata*	saltgrass	60.0
	grass	*Cynodon dactylon*	bermudagrass	10.0
	grass	*Sporobolus virginicus*	seashore dropseed	50.0
	shrub	*Borrichia frutescens*	sea oxeye	43.7

Table A.2 Brackish-saline toposequence (Cont.)

Community	Lifeform	Species	Common Name	Salinity
Upper Marsh	grass	*Spartina patens*	marshhay cordgrass	30.0
	grass	*Phragmites australis*	common reed	20.0
	grass	*Paspalum vaginatum*	seashore paspalum	25.0
	grass	*Distichlis spicata*	saltgrass	60.0
	grass	*Spartina alterniflora*	smooth cordgrass	50.0
	grass-like	*Scirpus americanus*	bulrush	25.0
Lower Marsh	grass	*Spartina alterniflora*	smooth cordgrass	50.0
Saltgrass Flat	grass	*Distichlis spicata*	saltgrass	60.0
	grass	*Monanthochloe littoralis*	shoregrass	50.0
	grass	*Sporobolus virginicus*	seashore dropseed	50.0
	grass	*Paspalum vaginatum*	seashore paspalum	25.0
	grass	*Spartina patens*	marshhay cordgrass	30.0
	shrub	*Borrichia frutescens*	sea oxeye	43.7
	grass-like	*Scirpus americanus*	bulrush	25.0
Mud Flat	succulent	*Salicornia virginica*	glasswort	70.0
	succulent	*Batis maritima*	saltwort	70.0
	succulent	*Suaeda linearis*	sea blite	70.0
	grass	*Distichlis spicata*	saltgrass	60.0
	grass	*Spartina alterniflora*	smooth cordgrass	50.0
	algae	*Schizothrix* spp.	blue-green algae	75.0
Seagrass Bed	grass-like	*Ruppia maritima*	widgeon grass	35.0

Appendix Table A.3 Major species included in the EDYs model of a toposequence across Matagorda Island, beginning on the bay-side and ending on the gulf-side. Lifeforms are listed in order of ecological importance in each community and species are listed in order of ecological importance within lifeform. Salinity (ppt) refers to the upper tolerance level of the species.

Community	Lifeform	Species	Common Name	Salinity
Tidal Flat	succulent	*Salicornia virginica*	glasswort	70.0
	succulent	*Batis maritima*	saltwort	70.0
	succulent	*Suaeda linearis*	sea blite	70.0
	grass	*Distichlis spicata*	saltgrass	60.0
	grass	*Monanthochloe littoralis*	shoregrass	50.0
Saltgrass Flat	grass	*Distichlis spicata*	saltgrass	60.0
	grass	*Monanthochloe littoralis*	shoregrass	50.0
	grass	*Sporobolus virginicus*	seashore dropseed	50.0
	shrub	*Borrichia frutescens*	sea oxeye	43.7
Lower Marsh	grass	*Spartina alterniflora*	smooth cordgrass	50.0
	grass	*Distichlis spicata*	saltgrass	60.0
Upper Marsh	grass	*Spartina patens*	marshhay cordgrass	30.0
	grass	*Paspalum monostachyum*	gulfdune paspalum	
Dune Grassland	grass	*Uniola paniculata*	seaoats	
	grass	*Paspalum monostachyum*	gulfdune paspalum	
	forb	*Ipomoea pescaprae*	railroad vine	
	forb	*Oenothera drummondii*	beach evening primrose	
	forb	*Cassia fasciculata*	partridge pea	
	forb	*Croton punctatus*	gulf doveweed	10.0
Brackish Marsh	grass	*Spartina patens*	marshhay cordgrass	30.0
	grass	*Paspalum monostachyum*	gulfdune paspalum	
	grass	*Sporobolus virginicus*	seashore dropseed	50.0
	forb	*Ipomoea pescaprae*	railroad vine	
Sand Prairie	grass	*Schizachyrium scoparium littoralis*	seacoast bluestem	2.0
	grass	*Aristida purpurescens*	arrowfeather threeawn	
	grass	*Uniola paniculata*	seaoats	
	grass	*Paspalum monostachyum*	gulfdune paspalum	
	grass	*Paspalum plicatulum*	brownseed paspalum	
	grass	*Paspalum setaceum*	thin paspalum	2.0
	forb	*Ambrosia psilostachya*	ragweed	
	forb	*Croton punctatus*	gulf doveweed	10.0
	forb	*Baptisia leucophaea*	whitestem wild indigo	10.0
	forb	*Cassia fasciculata*	partridge pea	
	forb	*Heterotheca subaxillaris*	camphorweed	10.0
	forb	*Oenothera drummondii*	beach evening primrose	
	forb	*Rhynchosia texana*	snoutbean	2.0
	forb	*Erigeron myrionactis*	Corpus Christi fleabane	2.5

Table 1.3 Matagorda Island toposequence (Cont.)

Community	Lifeform	Species	Common Name	Salinity
Fresh Marsh	grass	*Spartina patens*	marshhay cordgrass	30.0
	grass	*Andropogon virginicus*	broomsedge bluestem	3.0
	grass	*Schizachyrium scoparium littoralis*	seacoast bluestem	2.0
	grass	*Andropogon glomeratus*	bushy bluestem	2.5
	grass	*Paspalum monostachyum*	gulfdune paspalum	
	grass	*Sporobolus virginicus*	seashore dropseed	50.0
	grass-like	*Scirpus americanus*	bulrush	25.0
	grass-like	*Typha latifolia*	cattail	1.5
	grass-like	*Eleocharis interstincta*	spikerush	
	grass-like	*Fimbristylis castana*	fimbry	
	shrub	*Sesbania drummondii*	rattlepod	
	forb	*Phyla nodiflora*	frogfruit	
Dune Grassland	grass	*Uniola paniculata*	seaoats	
	grass	*Paspalum monstachyum*	gulfdune paspalum	
	forb	*Ipomoea pescaprae*	railroad vine	
	forb	*Oenothera drummondii*	beach evening primrose	
	forb	*Cassia fasciculata*	partridge pea	
	forb	*Croton punctatus*	gulf doveweed	10.0