Framework for the Development of DRERIP Ecosystem Conceptual Models

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1 Introduction

The Adaptive Management Planning Team (AMPT) is overseeing preparation of the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) under the auspices of the CALFED Bay-Delta Program Ecosystem Restoration Program (ERP). The DRERIP will identify ecosystem restoration actions to be pursued in the Delta to achieve ERP strategic goals and objectives. This document provides information and guidance from the AMPT to individuals and groups who will be tasked with developing ecosystem conceptual models for use in preparing the DRERIP.

The intent of this framework is to ensure that each DRERIP Ecosystem Conceptual Model contains a similar structure and baseline level of information, but not to impose a rigid formula on the model development. The framework describes the purpose for developing conceptual models, the intended scope of the models, and guidelines regarding the content and structure of the models. The framework also provides a discussion about scale issues (including concepts on nesting) and a recommended step-by-step process for developing models.

The Ecosystem Restoration Program Plan (ERPP) identifies 116 ecosystem elements sorted into four general categories: ecological processes (7), habitats (14), stressors (16), and species or species groups (79). Species life history conceptual models will be developed for the species and species groups. The remaining set of ecosystem elements (grouped as processes, habitats and stressors) were refined by the AMPT to a list of 26 proposed DRERIP ecosystem conceptual models that reflect anticipated needs for the DRERIP scientific input process. Appendix A provides a full listing of the ecosystem elements identified in the ERPP and a brief discussion of how this list was refined for the purposes of DRERIP, including a crosswalk between the ERPP elements and the proposed DRERIP ecosystem models. The AMPT recognizes that once model development commences the list of models needed may change as we identify gaps or overlaps and we investigate the complexities of some issues more fully. Further models may also be developed later in the DRERIP planning process.

2 Definition of Terms

To put the DRERIP Ecosystem Conceptual Models (Models) in context it is necessary to define terms in existing planning documents as well as those used in describing the model structure. Many of the following definitions were derived from terminology used in the Ecosystem Restoration Program Plan, but the definitions themselves have been modified to better characterize how they will be applied in the context of the DRERIP ecosystem conceptual models.

Actions: Potential ecosystem restoration actions for the Delta as identified in multiple ERP planning documents. These documents include the Ecosystem Restoration Program Plan (ERPP) Volumes I and II, ERP Strategic Plan, Phase 2 Report, Water Quality Program Plan, Draft Stage 1 Implementation Plan and Record of Decision (ROD; ERP-Multi Species Conservation Strategy Milestones).

Critical Threshold: A condition of an attribute that when exceeded (or fallen below) causes the influence of the attribute on the dynamics of the ecosystem to change in method rather than magnitude.

Cumulative Effects: The interactive, synergistic, or contradictory combination of multiple changes in ecosystem function. For DRERIP, the focus is on the combined effect of multiple restoration actions, but may also need to consider non-ERP actions.

Driver : an ecosystem element with a known or hypothesized important effect on another ecosystem element. In coupled models, a driver can be an outcome from one model that feeds into and influences the behaviour of another model (e.g., using a Delta hydrodynamic model to generate salinity variation that is an input to a vegetated habitat model). Drivers may be categorized as follows:

Uncontrolled drivers: A driver that comes from the world external to the model and is not under management control or influence

Managed driver: A driver that is under direct management control or influence.

Ecosystem element: A basic component or function which, when combined with other ecosystem elements, makes up an ecosystem. An ecosystem element can be categorized as a process, habitat, stressor (see definitions below), species or group of species (community).

Habitat: A collection of environmental conditions, abiotic resources, and living resources that together define particular locations in the ecosystem that are used by a given species or group of functionally similar species. Examples include riparian habitat and tidal freshwater marshes.

Importance: The degree to which a linkage controls the outcome relative to other drivers and linkages within the same system. Models are designed to encompass all identifiable drivers, linkages and outcomes but this concept recognizes that some are more important than others in determining how the system works. If the concept is potentially more important in some areas than others, the graphic should display the maximum level of importance with the narrative explaining the spatial variation.

Linkage: Cause-effect relationships among model elements. Linkages are depicted by arrows connecting components within the model.

Outcome: A result, effect, or consequence. In the context of the DRERIP conceptual models, outcomes reflect the terminal environmental responses of the model in question to specific drivers. Outcomes of one conceptual model that serve as drivers for another conceptual model are called **intermediate functional outcomes** in this framework.

> *Management Outcome:* A specific type of outcome that is an objective of management. Examples of management outcomes are the ecosystem element Stage 1 expectations found in ERPP Volume I.
>
> *Ecological Outcome*: An outcome relevant to the functioning of the ecosystem but which is not specifically and objective of management (e.g., the shift from autotrophy to heterotrophy as the canopy closes over a restored segment of stream and floodplain).

Predictability: The degree to which current understanding of the system can be used to predict the performance of the linkages or drivers, or the nature of the outcome. This is based on understanding of the model components and their variability. For example, understanding of processes may be high but there may be natural variability either on an inter-annual and/or a seasonal basis that is unpredictable. Or the strength of relationships and magnitude of effects may be variable such that properly measuring and statistically characterizing inputs to the model is difficult.

Process: A physical, biological, or chemical mechanism that allows or determines the transfer of energy or materials. Examples include (1) sediment transport, which moves sediment across the landscape, or (2) food web processes which transfer energy and nutrients through the food web.

Stressor: Physical, chemical, or biological factors that adversely affect natural processes, habitats, or living resources of concern. Examples include: state and Federal water project operations, in-Delta agricultural diversions, excessive fine sediment, or invasive non-native species.

System Boundaries: The specification of what is to be included in the model (geographic domain, ecosystem elements, management and ecological outcomes, management inputs).

Understanding: A description of the known, established, and/or generally agreed upon scientific understanding of the nature of a driver, linkage or outcome. Understanding may be limited due to lack of knowledge and information or due to disagreements in the interpretation of existing data and information; or because the basis for assessing the understanding of a linkage or outcome is based on studies done elsewhere and/or on different organisms, or conflicting results have been reported. Understanding should reflect the degree to which the model that is used to represent the system does, in fact, represent the system.

3 Purpose of DRERIP Ecosystem Conceptual Models

The AMPT intends that the full set of DRERIP Ecosystem Conceptual Models will depict our current state of knowledge about how the Delta ecosystem works, particularly with regard to interrelationships among physical and biological processes, habitats, and stressors. In situations where there are fundamental differences of opinion about how the system works, two or more alternative models of the process or the ecological subsystem may be provided.

The DRERIP Ecosystem Conceptual Models will serve two main objectives:

(1) document our current scientific knowledge about Delta ecosystems including our degree of understanding and the predictability of various model components; and

(2) provide tools that can be used for vetting ERP actions in the Delta region, and later used in other CALFED regions (as applicable).

Collectively the models will document of our current state of knowledge within the following constraints:

- The focus is on conditions in the Delta region (i.e., how the system works) and drivers or linkages external to the Delta will not be considered in detail.

- Models will identify:
  - Those physical, chemical and biological attributes of the Delta that determine its dynamics. Models should include only those system attributes considered to have an identifiable influence on the Delta ecosystem.
  - The ways in which ecosystem drivers cause change (i.e., the relationships among drivers, linkages and outcomes).
  - Critical thresholds of ecological processes and environmental conditions
  - Assumptions and gaps in the state of knowledge, especially those that limit the predictability of management outcomes.
  - Current characteristics of the Delta ecosystem that may limit the achievement of management outcomes.
- Model application should enable evaluation of:
  - Cumulative effects of restoration and non-ERP actions
  - The dynamic nature of the Delta system including the role of uncontrolled drivers.
  - Importance of variability and long-term averages (e.g., seasonality, flows, temperatures)

Models as Tools:

- Evaluate current ERP actions - provide information to evaluate ecological and management outcomes, both positive and negative, the level of understanding on which each outcome is based, and potential information value relative to current level of understanding and predictability.
- Identify potential new actions to meet ERP goals and objectives.
- Provide a conceptual basis for guiding future research and increasing understanding or predictability.

The models need to encompass the many uncontrolled drivers of the system including climate change, human population growth, and catastrophes that dramatically alter the Delta landscape (e.g., earthquakes, massive floods or large-scale levee failures), as well as the number of large-scale system modifications such as altered hydrodynamics, Delta export pumping, dams and levees, environmental water quality and non-native invasive species. Within the DRERIP context many of these drivers are beyond the scope of individual restoration actions. The models should include them as drivers where they are considered to have an identifiable influence on the ecosystem within 50 years, or if they are considered to impose a severe limitation of the achievement of management outcomes.

How DRERIP Ecosystem Conceptual Models will be Used

The DRERIP Ecosystem Conceptual Models will be used in the vetting process to help make informed decisions about the types of ERP actions that should be pursued in the Delta, and whether those actions should be pursued as targeted research, pilot projects, or full-scale projects. By depicting the current state of knowledge regarding the ecosystem, the DRERIP conceptual models will provide a basis for evaluating the expected management and ecological outcomes of various actions.

The AMPT has developed a process for systematically evaluating proposed ERP actions (see Vetting Process Document). This process requires documenting the expected positive and negative outcomes of a given action, the expected magnitude of those outcomes and the level of understanding on which it is based, the extent to which outcomes are reversible, and the opportunities for learning. The ecosystem conceptual models and the species life history models will serve as information sources for making these assessments.

4 Scope of DRERIP Ecosystem Conceptual Models

The geographic scope of the DRERIP Ecosystem Conceptual Models is the ERP Delta Ecological Management Zone. Models will acknowledge that the Delta is part of the larger Central Valley watershed and San Francisco Estuary and highlight where conditions external to the Delta are important system drivers (uncontrolled or managed). The models will also address internal dynamics that influence the Delta, such as current management activities that continually alter Delta condition and new species introductions

The models will illustrate how drivers, both controlled and managed, influence relationships among processes, habitats, and stressors. The effects on species will be ascertained by using the ecosystem models in conjunction with species life history models. Development of species models is described in a separate document (reference?). All models will utilize a common list of keywords to initially identify common threads among models. The relationship of the ecosystem models and species models to the actions will be established in the vetting process, rather than specifically embedding the hundreds of ERP actions within the models themselves.

Table 1 presents an initial list of process and habitat conceptual models to be developed. Stressors and their effect(s) can be included in these models but may also be modeled separately.

Table 2 provides an initial listing of stressors that should be considered by the Action Team in developing the process and habitat models listed in Table 1. Some of these stressors may require their own detailed models that can then be linked to the process and habitat models. As noted in Table 2, the AMPT has evaluated the need for separate models for the chemical stressors. Priority was given based on the scale and/or ranges of anticipated effects these stressors. The AMPT anticipates that additional models may be needed as the DRERIP process unfolds.

Questions to Consider when Evaluating the Scope of a Conceptual Model

The following questions should be considered when evaluating the scope and completeness of a conceptual model.

- Does the conceptual model encompass all identifiable processes and factors influencing the ecosystem component as the system was bounded?
- Does the conceptual model identify hypotheses and data supporting the model?
- Is the level of detail of the model commensurate with both the hypotheses and data available, and model's purpose within DRERIP?
- Is the model developed at the right scales given the drivers and outcomes considered?
- Does the conceptual model describe linkages among drivers and outcomes and how these linkages could affect an outcome?
- Does the conceptual model clearly delineate the level of understanding and predictability associated with each linkage, the rationale for the assigned levels, and how lack of understanding and variability propagate through the model to influence outcomes?
- Does the conceptual model allow for future changes in the magnitude, frequency, and/or management of system drivers?

Table 1. DRERIP Processes and Habitats Ecosystem Conceptual Models

Processes (5)

Bay-Delta Hydrodynamics (nested inflow model)
    Includes turbidity and sedimentation, temperature, salinity
Natural Floodplains and Flood Processes
Stranding
Sediment Supply
Bay-Delta Aquatic Foodweb

Habitats (14)

Open water perennial:
    Tidal perennial aquatic
    Isolated perennial aquatic
Seasonal wetlands
    Vernal Pools
    Other natural
    Managed wetlands (eg, duck clubs)
Fresh herbaceous emergent wetlands
    Tidal
    Isolated (non tidal, upland)
Shaded riverine aquatic
Riparian
Inland Dune Scrub Habitat
Perennial Grassland
Agricultural Lands, wildlife friendly
    Seasonally flooded
    Not seasonally flooded
Natural shorelines

Table 2. DRERIP Stressor Conceptual Models*

Physical Stressors (5)	**Biological Stressors (2)**
SWP + CVP operations (incl. current & planned pumping rates, South Delta fish facilities)	Invasive species *(may include separate species life history models; see species list)*
In-Delta diversions	Fish and wildlife harvest in the Delta
Water control structures (e.g., Delta Cross Channel, through-Delta facility, South Delta temporary barriers and future permanent operable barriers)	
Hardened shorelines (Levees, Bridges, Bank Protection)	
Dredging and Sediment Disposal	

Chemical Stressors

A) with Known Delta Exposure (5) **[Separate Detailed Models]**	**B) with Unknown Delta Exposure (5)** **[Separate Simple Descriptive Models]**
Low dissolved oxygen	Toxicity of unknown origin
Mercury	Persistent organic contaminants
Selenium	Trace metals
Organic carbon	Endocrine disrupting chemicals
Pesticides	Pharmaceuticals and personal care products

***Note**: The need for separate physical and biological stressor models is to be determined.

5 Conceptual Model Content

It is important that the DRERIP Ecosystem Conceptual Models are standardized enough in their basic structure and content to ensure that there is consistency among the models and that they can be linked together to form a comprehensive set of models that describe how the Delta works. The APMT acknowledges that deviations from the proposed approach may be required to capture unique aspects of various systems and interrelationships.

Each conceptual model developed for DRERIP will consist of three main components:

1. Narrative: The narrative describes our current understanding of the conceptual model subject and the interactions among the model components. The narrative should:

    - State the spatial, temporal, and ecological scales and boundaries of the model (what is included and excluded)
    - State the objectives of the model. What is it supposed to do?
    - State assumptions and limitations of the model.
    - Clearly identify the outcomes or response variables.

- Identify the drivers and linkages affecting the outcomes.
- Describe the interactions and feedback processes (i.e., linkages) among the drivers, intermediate functional outcomes, and the outcomes.
- Provide information on the understanding of the effect or relationship.
- Provide information on the nature (i.e., positive or negative) of the effect as well as the importance of the relationship (qualitatively or quantitatively, if possible).
- Provide information on the predictability of the effect or relationship.
- Describe the mechanism underlying a response or change in outcome
- Provide information on the interrelationships with other ecosystem or species conceptual models.

The length of the narrative should reflect the complexity of information being presented. An example of some narrative for a conceptual model of the draft Tidal Freshwater Emergent Wetlands model is included in Appendix A.

2. Graphics: Well-presented figures or graphics of the conceptual model or sub-model. This should identify relationships between drivers and outcomes using arrows to depict linkages, and show importance, understanding and predictability of the linkages. An example graphic from the draft Tidal Freshwater Emergent Wetlands model is included in Appendix B.

3. References: This section includes complete citations for all literature referenced in the narrative. Reference and citation of the relevant literature are key to the development of a technically sound and defensible conceptual model.

6 Proposed Conceptual Model Structure

The AMPT proposes a common approach to constructing ecosystem conceptual models for DRERIP. The approach is intended to provide a general recipe for constructing models that will promote standardization without imparting an unnecessary degree of rigidity to the process.

The Driver-Linkage-Outcome (DLO) Approach

DRERIP ecosystem conceptual models should be structured to clearly identify and describe drivers (D), linkages (L), and outcomes (O). Drivers are physical, chemical, or biological forces (natural or human created) that have a large influence on the system of interest; linkages are cause and effect relationships among system elements; and outcomes are response variables that the conceptual model is attempting to explain. In coupled models, a driver for one model can be an outcome from another model (e.g., using a Delta hydrodynamic model to generate salinity variation that is an input to a vegetated habitat model).

The DLO approach can be reflected graphically as shown. In this example, S represents species.

Model 1 Model 2 Model 3 Species Model

D->L->O/D->L->O/D->L->O/D->L->S[1]

In most cases there will be multiple "branches" within a given model reflecting several different drivers and outcomes, including intermediate functional outcomes which in turn may be drivers within the model or may influence a linked model. The above diagram is a simplified chain representing a single branch (or series of relationships).

Drivers may be physical, chemical or biological factors of natural or human origin. Outcomes may be physical, chemical or biological but may also be social and economic.

Once drivers and outcomes have been identified, the cause and effect linkages between these two groups can be explored and described. Specific attributes of each linkage should be defined including:

- Nature and direction of the effect - Positive/negative effect: +/-/0 (0 means no effect)
- Importance or magnitude of the effect - displayed using width of line.
- Understanding underlying the effect – displayed using color/shading of line
- Predictability of the effect - displayed using solid, dashed or dotted line.

The DLO approach bears many similarities to the well-established Pressure-State-Effect-Response (PSER) approach to conceptual modeling (e.g. is a reference needed here?) In PSER models pressures or stressors are identified that change the state of the system and specific responses. The relations among key 'initiating' factors, systems characteristics and important consequences are still retained. The main difference between the PSER model and the DLO approach is that natural unimpaired processes can be the drivers whereas in PSER, 'pressures' are usually characterized as artificial or anthropogenic 'stressors' to the system. Thus, the DLO approach allows the conceptual models to capture all aspects of system dynamics, both natural and altered, to portray how the system works (a main purpose of DRERIP CMs) rather than focus more specifically on alterations to the system of interest.

The ecosystem conceptual models should be structured to allow for the examination of key linkages between various factors. How the various ecosystem conceptual models intersect should also be considered throughout the conceptual model development process.

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[1] For instance, Hydrodynamic Model <=> Bay-Delta Food Web<=> Species-life history model.

7 Issues of Scale and Nesting

It is important to clearly identify the focus of the model as a starting point. It may be helpful to specify the key drivers of the model, related environmental components, and the spatial and temporal scales. For example, “The focus of this conceptual model is on the physical factors affecting estuarine primary productivity on a time step of x. This conceptual model represents the relationships between water turbidity, water temperature, dissolved oxygen, light penetration and primary productivity and how hydrodynamics affects each of these factors. This model is not representing zooplankton grazing on phytoplankton.” Each conceptual model should be developed at spatial, temporal, and ecological scales appropriate to the ecosystem elements and outcomes considered.

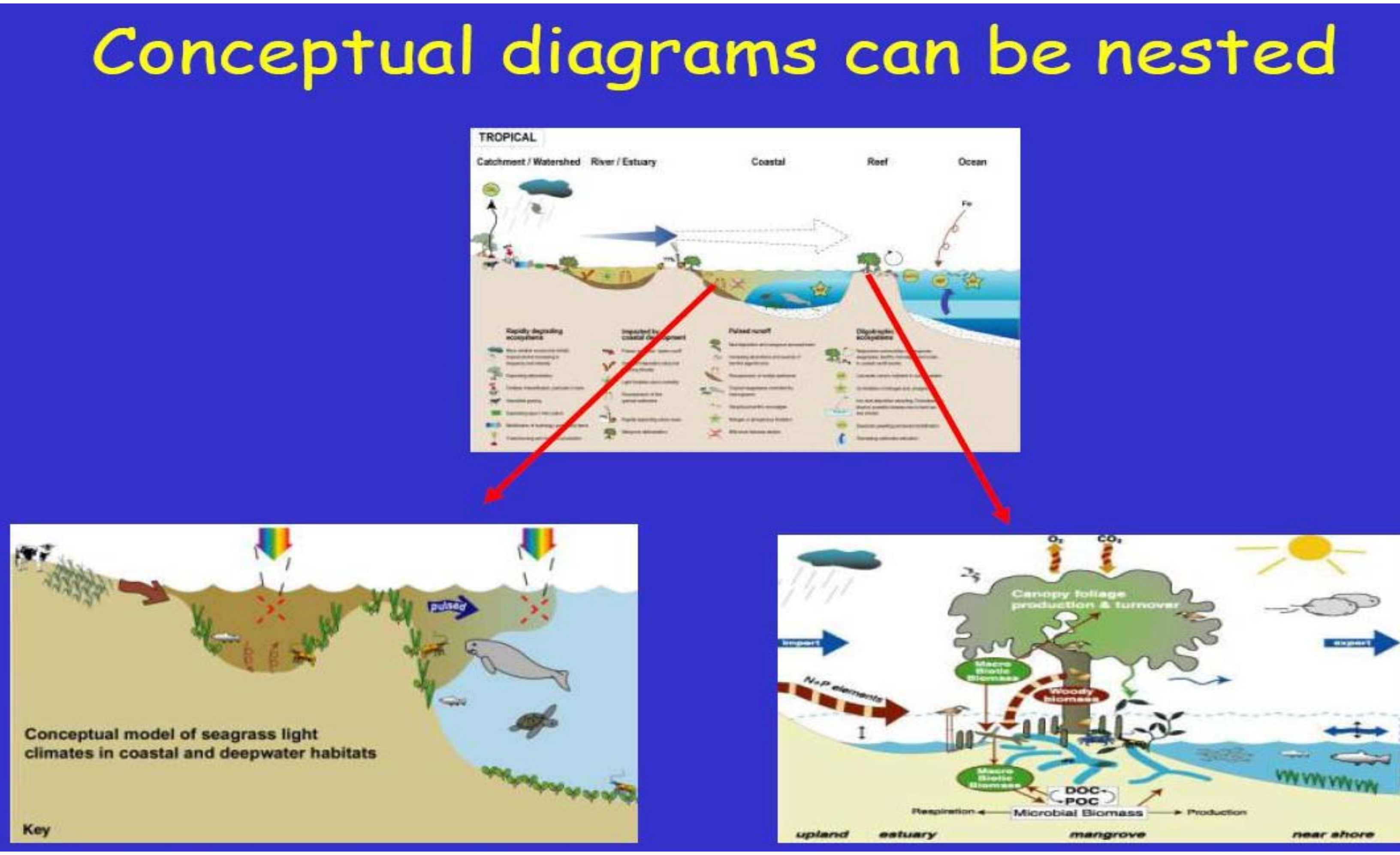
Conceptual models can consist of multiple and inter-related levels or layers each of which is a conceptual model unto itself. Such an approach can be effective to describe increasing levels of specificity – i.e., working from large spatial and temporal processes to focused ecological processes. It may be possible to collapse part of one model that is providing input to a second model because parts of the first model are not relevant to the behavior of the second. The benefit of such an approach is the avoidance of cramming too much information into single conceptual model diagrams and the ability to describe attributes of widely differing scales. In this instance, nesting helps to pull out areas of detail and areas of commonality across multiple models (see Figure 1).

8 Process for Creating Conceptual Models

Creating conceptual models entails a methodical progression through a number of steps all of which have been described above. These steps are:

1. Prepare list of “ingredients” – all the drivers and outcomes relevant to the particular ecosystem component that is being modeled.
2. Identify and sketch the linkages between these ingredients
3. Prepare list of other models that link to or from this model, including species models where available
4. Develop initial narratives to explain the relationships among the drivers, linkages and outcomes. Bring in supporting materials and references
5. Include connections through other ecosystem models where appropriate.
6. Test to ensure the model can be applied to address restoration actions by examining several example actions in relation to the model and assessing whether the ingredients in the model are adequate to identify the effects of the action on the ecosystem.

Figure 1. Example of nesting conceptual models to explain particular details and retaining clarity of primary model.
Source: University of Maryland Center for Environmental Science



Conceptual diagrams can be nested

Appendix A

Extract from Tidal Freshwater Emergent Wetlands Conceptual Model

Delta Regional Ecosystem Restoration Implementation Plan (DRERIP)

Prepared by:
Denise Reed, University of New Orleans
Stuart Siegel, Wetlands and Water Resources
Darren Gewant, Wetlands and Water Resources
Sean Avent, Wetlands and Water Resources

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Submodel No. 1 – Initiating Controls

This model's structure is based on the idea that five physical drivers (tides, freshwater flows, substrate elevation and morphology, relative sea level rise [RSLR], and sediment supply) control conditions of the vegetated marsh plain. The first four directly influence the frequency and duration of marsh plain inundation and sediment supply drives the deposition of sediments on the marsh plain, contributing along with peat accumulation net accretion (vertical building) of the marsh plain. The type of habitats on the vegetated marsh plain (the model outcomes) are controlled by these physical drivers and by key biophysical linkages, namely inundation regime and net accretion. The narrative below describes the importance of the various drivers, linkages, and their associations, as well as our current level of understanding and ability to predict future tidal marsh conditions.

A note regarding tidal creeks (channels) in Delta tidal marshes. Unlike the lower estuary, where we know that tidal marshes include channel networks, much uncertainty exists about whether natural Delta tidal marshes contain limited or extensive channel networks. No large, intact historic tidal wetlands remain in the Delta to serve as a reference. None of the historic U.S. Coast and Geodetic Survey maps show anything but the largest (and very uncommon) sloughs within the Delta's tidal wetland islands; plane-table survey methods in the vast, flat, and tall-vegetation marshes of the Delta precluded mapping these channels. The tidal marshes found today in the Delta are either small, remnant historic or somewhat larger restored systems, and collectively they show a range of presence to absence of channel networks. Therefore, while this conceptual model includes channels to varying degrees, a core uncertainty exists regarding their natural extent and therefore the extent to which they should be incorporated into restoration efforts using historical conditions as the sole determinant. To the extent that intertidal and subtidal channels within tidal marshes provide ecological function, then their inclusion in restoration efforts should be considered in this modern ecological context, not a murky historical setting.

1.1 Drivers

We have identified five drivers for this Initiating Controls Model: tides, freshwater flow, elevation and morphology, relative sea level rise, and sediment supply.

Tides

The rise and fall of the tide is a fundamental characteristic of these habitats, driving fortnightly, monthly, and seasonal variations in water level. The mean tidal range within the Delta varies from 2.8 ft at Antioch to 3.1ft at Stockton and 2.3 ft at Sacramento (see the Delta Hydrodynamics Conceptual Model for more details). Our understanding of tidal dynamics within the Delta is extensive, with the exception of local-scale phenomena, and our ability to predict hydrology based on tidal factors developed for primary tide stations in the Delta is also extensive.

Freshwater Flow

The role of freshwater flow is also important to tidal wetlands in the Delta; during periods of increased Delta inflows, water levels through the system can be increased (see Delta Hydrodynamics Conceptual Model for more details). Freshwater inflows are monitored at Freeport and Vernalis by USGS, and our understanding of recent inflows is adequate. Our understanding of freshwater flows as a whole is limited by uncertainties surrounding operational and climatic influences and consequently, our ability to predict freshwater flows in the future is minimal.

Elevation and Morphology

The role of substrate elevation in controlling tidal marsh evolution and function is well established (e.g., Allen, 1990; Mitsch and Gosselink, 2000; Reed, 1990). Marsh elevation fundamentally controls the frequency and duration of marsh surface inundation. High marsh areas are flooded rarely by tides, while lower areas are inundated more regularly. The role of surface elevation in controlling marsh inundation is very important and is clearly established. Predicting the effect of elevation on inundation is straightforward if survey work and water level data reference a consistent datum. However, predicting future elevation changes depend on understanding the processes controlling net accretion (see Linkages).

Our understanding and ability to predict these processes become more complex when considering the “drainage isolation” concept, which states that there are areas on the marsh plain that drain poorly and thus have extended inundation periods. We know that marsh vegetation communities respond directly to these conditions through variable plant physiological tolerances (e.g., Bertness and

Pennings, 2000). When considering tidal marshes, we do not know what the specific relationships are between environmental conditions and the plant species found locally, but we do know they explain plant community composition where elevation alone falls short. We cannot predict where these depressions occur, how large they are, and how deep they are because we poorly understand how they form and we do know that their formative processes are inherently stochastic.

Relative Sea Level Rise

During the last 100 years, globally averaged sea level has risen approximately 10-20 cm, or about 1 to 2 mm per year (IPCC 1996). Estimated local rates of relative sea level rise range from -10 to +2 mm/yr along the Pacific Coast (Nicholls and Leatherman 1996; Zervas 2001). Local variations are caused by differences in groundwater and oil withdrawal, compaction of muddy soils, subsidence, isostatic rebound, and tectonic uplift. At the Golden Gate, the National Ocean Service has identified a 0.2 ft rise in mean tide level between the current tidal epoch (1983-2001) and the prior tidal epoch (1960-1978), or 0.01 ft/yr (3 mm/yr) during this period. Over the next 100 years, global warming is expected to accelerate the rate of sea level rise by expanding ocean water and melting alpine glaciers (IPCC 2001). The full range of model projections from the most recent Intergovernmental Panel on Climate Change assessment (IPCC 2001)predict a 9 to 88 cm rise in global sea level by 2100. Other model averages predict a more narrow range of 31 to 49 cm. These projections are broadly consistent with previous studies (IPCC 1996; Titus and Narayanan 1996; Wigley 1999) and the Canadian and Hadley models (Boesch et al. 2000; NAST 2001). It is important to note that, even if greenhouse gas emissions are stabilized, the rate of sea-level rise will likely continue to increase beyond 2100 because of the time required for oceans and ice sheets to achieve equilibrium with the atmosphere. Regional differences in land movement and the impacts of climate change on atmospheric pressure and alongshore winds will continue to produce differences in local sea level relative to the land. However, uncertainty about local future sea levels is about 50% greater than the global average (IPCC 2001) because current models are cannot reliably estimate whether particular areas will experience a smaller or greater rise.

RSLR is important to this model due to its role in altering marsh inundation regimes over time (see Linkages), and its contributing factors are well described (see above). Predicting sea-level rise is unlikely due to local effects and model uncertainties.

Appendix B

Example graphic from the draft Tidal Freshwater Emergent Wetlands model.