Point Blue Conservation Science

SCIENCE PROGRAM FRAMEWORK

South Bay Salt Pond Restoration Project Phase 2

June 2020

South Bay Salt Pond Restoration Project
Phase 2 Science Program Framework

Report to the South Bay Salt Pond Restoration Project and the California Wildlife Foundation

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SAN FRANCISCO BAY
RESTORATION AUTHORITY

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TABLE OF CONTENTS

GLOSSARY OF TERMS

Adaptive Management Plan (AMP): The guiding document written prior to the start of restoration actions to help direct the Project. The plan emphasized the importance of utilizing an adaptive management strategy for the Project, set forth Project Objectives, and established the initial Key Uncertainties associated with the Project (Trulio et al. 2007).

Applied Studies: Scientific studies and monitoring conducted in and around the Project area specifically designed to address the Project's Key Uncertainties as outlined in the AMP.

Causal pathways: The processes through which an outcome is brought into being. Causal pathways are used in the conceptual models to illustrate how management actions can act through stressors and other drivers to impact outcomes for a Restoration Target.

Conceptual model: graphical depictions and accompanying text description that illustrate the linkages among management actions, environmental stressors, and the achievement of Restoration Targets. The conceptual model provides the basis for developing and testing causal hypotheses.

Driver: Any natural or human-induced factor that plays a causal role in inducing change in the ecosystem.

Key Uncertainties: From the AMP, the components of the Project in which knowledge gaps significantly limit the ability to achieve Project Objectives.

Logic model: a graphic depiction (road map) to address a particular question that presents the shared relationships among the resources, activities, outputs, and outcomes. Logic models are also referred to as "results chains."

Project Objectives: The six South Bay Salt Pond Restoration Project Objectives, as set forth in the AMP.

Restoration Target: The desired condition of an indicator or set of indicators, expressed in numeric terms, that the Project should achieve to successfully meet the Project Objectives. [*Note this definition is based on the AMP, page 26*.]

Restoration Target Category: A basic element or group of elements of conservation concern. These may be monitored directly or indirectly through the use of indicators. For example, sediment is a Restoration Target Category that is assessed by measuring Restoration Target Indicators such as the area of marsh and mudflat habitat. The Restoration Target Categories are based on the Adaptive Management Summary Table (Appendix 3 in Trulio et al. 2007).

Restoration Target Indicator: An element of the ecosystem that is measured directly to determine whether the Restoration Targets are being met or are likely to be met in the future. These are based on the "Category/Project Objective" column in the Adaptive Management Summary Table (Appendix 3 in Trulio et al. 2007).

San Francisco Estuary: The geographic area containing San Francisco Bay, San Pablo Bay, and Suisun Bay, as well as the Sacramento-San Joaquin River Delta and referred to as "Estuary" in this report.

EXECUTIVE SUMMARY

This Science Program Framework (Framework) provides a transparent, rational approach for identifying and implementing the most relevant science to inform restoration and management decisions in pursuit of the South Bay Salt Pond Restoration Project's (Project) mission, which is the restoration and enhancement of wetlands in the South San Francisco Bay while providing for flood risk management and wildlife-oriented public access and recreation.

This Framework is intended as a tool for the Project Management Team (PMT) to determine the most critical and immediate science needs to advance Project goals for South San Francisco Bay wetlands and shoreline management. The Framework provides a prioritization process that is intended to serve as a guide for discussions and decision-making among PMT members and relevant stakeholders about how to prioritize limited resources for science to address the most critical and immediate needs of the Project. This Framework does not prescribe or describe in detail the plans or products that the PMT might develop but rather serves to guide those efforts.

The primary intended user of this Framework is the PMT. Regulators, scientists, land managers, and other decision-makers can also use the Framework document to identify potential synergies between their activities and goals and the Project's science activities. These other users can also benefit from the Framework document, which should be useful to any stakeholder interested in a better understanding of the Project's decision-making process.

Activities are broken down into five main steps described below. We anticipate that Steps 1 and 2 will be completed primarily by the PMT with input from other experts. Step 3 will likely require consultation and review by scientists outside the PMT. Step 4 will be largely accomplished by Principal Investigators (PIs), but it is important that the PMT understand the process and the anticipated results and how they will be used. Step 5 will involve the PMT as this includes reconsidering the prioritization from Step 1.

The Framework approach is as follows:

Step 1	Prioritize Restoration Targets and develop management questions
Step 2	Develop knowledge brief and identify key science questions
Step 3	Develop logic models and immediate science needs
Step 4	Implement the science
Step 5	Evaluate, interpret, iterate

Step 1 **Prioritize Restoration Targets and develop management questions**

Review the status of each Restoration Target from the Adaptive Management Plan (AMP; Trulio et al. 2007) using summary and synthesis reports to identify those that are declining or below levels that trigger management actions. A Restoration Target is the desired condition of a Restoration Target Indicator, expressed in numeric terms, which the Project should achieve to successfully meet Project Objectives. Restoration Targets that are not being met or not likely to be met in the future or for which there is high uncertainty whether they can be met and require science to address are prioritized. Drawing from the AMP and Project summary reports, the PMT can develop management questions around how to improve outcomes for the high priority Restoration Targets. This step can be accomplished by the PMT.

Step 2 **Develop knowledge brief and identify key science questions**

Develop a knowledge brief to summarize the state of knowledge of a high priority Restoration Target Indicator and the system it is related to (see examples in Appendices A.2 through A.5). The brief should include high level background information, the Restoration Target numeric objectives, relevant spatial extents, a description of the management question(s) and a conceptual model that identifies key drivers and management levers. The potential management levers identified in the conceptual model can be used to determine what the most important uncertainties are and to identify key science questions to address these uncertainties. Ultimately, answering these questions will give the Project confidence that the management actions will result in positive outcomes for the Restoration Target Indicator. This step can be accomplished by the PMT and can be informed or reviewed by other experts.

Step 3 **Develop logic models and immediate science needs**

Each key science question from Step 2 will have a logic model that charts the path to answering the question. The logic model outlines a sequence of steps which might include developing a study design, collecting data, modeling, and analyzing the results of management actions. The first actions or information needs in the logic model represent the immediate science needs. This step can be led by the PMT but will likely require input from other experts. The immediate science needs can be used by the PMT to develop RFPs or directed studies.

Step 4 **Implement the science**

This step involves carrying out the actions described in the logic models to address the science needs. The exact nature of these actions (study sites, field protocols, and analytical methods), will be described by the PI who can work with the PMT to ensure their approach is consistent with the guidance provided in the previous steps.

Step 5 **Evaluate, interpret, iterate**

Once studies are completed, the results should be evaluated in terms of how well the key science questions were answered. The results may lead the PMT to revisit strategies or management actions, conceptual models, or even to re-prioritize the Restoration Targets.

CASE STUDY EXAMPLES

Frameworks can be abstract and difficult to apply to real world situations, particularly given the complexities of restoring and managing multiple ecosystems. In Appendix A of the Framework, we present examples to illustrate how the Framework can be used to identify Project's real science needs. The case studies are real examples of management and science questions that were prioritized by the PMT with input from other experts. These example case studies can be used to develop a Science Plan, Monitoring Plan, and RFPs to guide and implement science that addresses the most critical management questions for the Project. For the case studies, we focused on four Restoration Target Indicators: 1) the Western snowy plover, 2) migratory shorebirds and waterfowl, 3) sediment, and 4) mercury/water quality.

INTRODUCTION

The San Francisco Estuary (Estuary) contains some of California's most important ecosystems, providing human communities with invaluable benefits ranging from commercial fishing, recreation, pollutant filtration, strengthened shorelines, and habitat for diverse species including many endangered and endemic species. The people of the San Francisco Bay Area value these benefits and as such, in an attempt to recover massive losses that occurred historically, have invested in the restoration of vast acres of baylands to tidal marsh and other wetland habitats.

The South Bay Salt Pond Restoration Project (Project) exemplifies this investment in the protection and restoration of the Estuary. The Project seeks to restore and adaptively manage 15,100 acres of former industrial salt ponds to a rich mosaic of tidal wetlands and other habitats. "The overarching goal of the Project is the restoration and management of wetlands in the South San Francisco Bay while providing for flood management and wildlife-oriented public access and recreation" (Trulio et al. 2007).

All restoration activities implemented by the Project are guided by and inform its Adaptive Management Plan (AMP; Trulio et al. 2007). The AMP established Project Objectives (see below) and developed Restoration Targets relating to each Objective. Restoration Targets are the desired condition of an indicator, expressed in numeric terms, which the Project should achieve to successfully meet the Project Objectives. Further, the AMP identified a set of Key Uncertainties that could limit how far the Project can move toward restoring full tidal action and still meet all its Objectives. The understanding around these Key Uncertainties has evolved since the completion of Phase 1 (Valoppi 2018; Wood et al. 2019). This Framework is intended to guide Phase 2 science in a way that is consistent with the AMP. Phase 1 science addressed many of the Project's Key Uncertainties, and the beginning of Phase 2 implementation is a good time to reassess and re-prioritize the remaining uncertainties and newer questions.

This Framework was developed to provide a transparent, scientifically sound approach for investing in science (e.g., research and monitoring) to guide restoration and management decisions toward achieving the Project's Objectives as they are stated in the AMP.

***Objective 1*.** Create, restore, or enhance habitats of sufficient size, function, and appropriate structure to:

- A. Promote restoration of native special-status plants and animals that depend on South San Francisco Bay habitat for all or part of their life cycles.
- B. Maintain current migratory bird species that utilize existing salt [managed] ponds and associated structures such as levees.
- C. Support increased abundance and diversity of native species in various South San Francisco Bay aquatic and terrestrial ecosystem components, including plants, invertebrates, fish, mammals, birds, reptiles and amphibians.

Objective 2. Maintain or improve existing levels of flood risk management in the South Bay area.

***Objective 3*.** Provide public access opportunities compatible with wildlife and habitat goals.

***Objective 4*.** Protect or improve existing levels of water and sediment quality in the South Bay and take into account ecological risks caused by restoration.

***Objective 5*.** Implement design and management measures to maintain or improve current levels of vector management, control predation on special status species and manage the spread of non-native invasive species.

***Objective 6*.** Protect the services provided by existing infrastructure (e.g. power lines).

Achieving these Objectives requires management supported by input from diverse scientific disciplines including biology, ecology, geomorphology, hydrology, and environmental chemistry. The Project Management Team (PMT) recognizes that an approach siloed by discipline or geography will not be successful in addressing the complex and interrelated management issues that characterize the Project. This Framework will provide scientific rigor and transparency in decision-making and provide direction for identifying and prioritizing the science that best addresses the most critical issues facing the Project.

Framework objectives

- Focus science activities to efficiently address uncertainties that must be resolved in order to manage and restore habitats to achieve Project Objectives and measure success.
- Inform decisions to proceed (or not) with additional tidal restoration in future Project phases.
- Describe a process for developing and prioritizing studies that address ongoing, previously identified, or newly emerging science questions, and that are responsive to evolving climate projections.
- Provide guidance on how to leverage existing regional efforts, use emerging technology, integrate studies from different disciplines and collaborate efforts with external projects such as the South Bay Shoreline Project, SAFER Bay, and others.
- Make the science prioritization process transparent for regulators and other relevant stakeholders.

HOW TO USE THE DOCUMENT

The Framework provides the Project with a transparent process for assessing and prioritizing science needs for Phase 2. As such, the primary user of this Framework is the PMT. The Framework also seeks to advance science integration across agencies, organizations, and initiatives and across spatial geographies beyond the Project footprint. Therefore, other users of this document will include additional audiences (Table 1).

Table 1. Examples of additional users and uses of the Science Program Framework document.

Regulators	- Coordinate permit monitoring requirements that are synergistic with Program science activities. - Understand Project decision-making and prioritization process.
Scientists	- Identify and communicate scientific information that addresses critical Project uncertainties. - Anticipate priority areas for research and collaboration.
Collaborative Initiative Leads	- Identify opportunities to collaborate with the Project. - Anticipate Project science actions that benefit or conflict with those of existing initiatives.
Agency Decision-makers	- Local agencies and landowners anticipate Project activities and objectives for specific areas.

OVERVIEW OF SCIENCE PROGRAM FRAMEWORK

This Framework differs from the Phase 1 science approach that relied on discrete hypothesis-driven studies that addressed specific questions. These intentionally narrowly focused studies were planned and conducted independently. The Phase 2 science approach adds an emphasis on coordinating resources and data-collection across efforts funded by the Project as well as with external projects or regional monitoring and scientific collaborations. During Phase 2, science that is integrated across disciplines, incorporates landscape-level processes, and integrates other related research and monitoring activities will be prioritized. The Framework is designed to support the AMP and is representative of the adaptive management cycle in the following five steps.

Step 1 Begins the process by prioritizing the Project's Restoration Targets and developing overarching management questions for each high priority Restoration Target. This step is accomplished by the PMT.

Step 2 Provides the context and ends with key science questions that need to be addressed. This step is also accomplished by the PMT but may involve consultation with others as needed.

Step 3 Explores the key science questions, describes how they will be answered, and lays out a sequence of activities that will lead to the answer. Depending on the complexity of the question, this step may involve input from other experts. This step ends with a list of specific science needs (e.g., specific studies and components of studies such as baseline data and study designs) and can help the PMT develop requests for proposals or directed studies.

Step 4 Involves implementing the science outlined in the previous steps and is largely accomplished by Principal Investigators (PIs).

Step 5 Involves evaluating and interpreting the results. Was the original question answered satisfactorily? If so, management practices can be revised and implemented. If not, the previous steps may need to be revisited. This step can also involve revisiting the original management questions, reprioritizing, or revisiting the Restoration Targets, or the associated numeric objectives and/or metrics. Ultimately, Step 5 involves integrating the knowledge gained into practices and reassessing the state of knowledge about the system.

THE SCIENCE PROGRAM FRAMEWORK IN FIVE STEPS

STEP 1- PRIORITIZE RESTORATION TARGETS AND DEVELOP MANAGEMENT QUESTIONS

Achieving Project goals with constrained resources available for science requires focusing on the uncertainties that could block progress toward the Project's core mission to restore tidal habitat so long as other Project Objectives are met (Trulio et al. 2007). There is also limited time to address all the uncertainties if the Project is to restore tidal habitat in the near future to increase resilience to sea level rise as recommended by the Goals Project (2015). For this reason, the Project cannot wait to answer all questions before moving forward with restoration. Restoring tidal wetlands after 2030 may not be successful in all locations and may require costly interventions, such as sediment augmentation. Identifying the most critical management issues that need to be resolved to move the Project forward in a timely fashion is the focus of this step. Here we describe a process and set of criteria for prioritizing management issues facing the Project that require science to address.

The prioritization process described below is not intended to be a quantitative process but rather serves as a guide for discussions and decision-making among PMT members, and relevant stakeholders, about how to dedicate limited resources for science that addresses the most critical and immediate needs of the Project. If the uncertainties associated with a particular set of questions have been quantified and the understanding of the relevant system is sufficiently detailed and agreed upon, the process described below could be used to develop a more quantitative prioritization process. However, there are many uncertainties related to the Project's Restoration Targets that have not been quantified and are not fully formed or agreed upon. This lack of knowledge leads to different assumptions and interpretations about what is important and can complicate a numerically-based prioritization process. Therefore, this Framework describes a prioritization process that relies heavily on structured thought processes and oral and written dialogues. Here we provide a suggested prescription of needed tasks.

Review the Restoration Targets

Develop a list of Restoration Target Categories (see AMP Appendix 3, Restoration Target Category), which can encompass one or more Restoration Targets. The PMT may include any revisions to those Restoration Targets or additional conservation objectives that are critical to pursuing the Project's mission and that require science to address.

Apply the Prioritization Criteria

Describe the degree to which the Restoration Targets meet the criteria in Table 2. Refer to the Science Synthesis Report (Wood et al. 2019), the Climate Change Synthesis Report (Hayden et al. 2020), and other Project summary reports for information on each Restoration Target as it applies to the prioritization criteria. Are the indicator values uncertain or trending in the wrong direction? Could undesired trends force the Project to halt additional tidal breaches if they reach a certain point? Are active interventions required to reverse undesired trends? Restoration Target Indicators that are trending in the wrong direction or with substantial probability of trending in the wrong direction with additional tidal restoration or without additional management interventions are higher priority, from a science needs perspective, than those trending toward meeting Project Objectives and not expected to trend in the wrong direction with future tidal restoration or without intervention. Restoration Target Indicators associated with future restoration must consider sea level rise and other climate change impacts (see Hayden et al. 2020). The goal of this process is to describe the status of each Restoration Target Indicator, the predicted impact of additional tidal restoration or changes in management actions on the Restoration Target Indicator and the level of certainty around this knowledge. Appendix 3 in the AMP lists Restoration Targets that, if not met, could result in a reconsideration of additional tidal restoration and or management interventions.

Table 2. The criteria for prioritizing PMT questions and uncertainties that require science to address are in order of importance from highest to lowest. The degree to which the Restoration Targets and their indicator values are consistent with the criteria affects its priority.

Prioritization Criteria	
1	Restoration Targets are not being met and additional tidal restoration would be detrimental to the Restoration Target.
2	Restoration Targets are not likely to be achieved in the future and additional tidal restoration or the lack of management interventions would be detrimental.
3	Restoration Target Indicator values are uncertain, and additional tidal restoration or the lack of management interventions would likely be detrimental to chances of meeting Project Objectives.
4	Restoration Target Indicators are not adversely affected by tidal restoration but would be likely to require management to achieve Project Objectives.

Identify Restoration Targets with High Priority Science Needs

The next step involves reviewing the prioritization rationale (Restoration Target Indicator values, trends, and potential future status given tidal restoration, management actions, and climate change) and applying the criteria in Table 2. For example, Restoration Targets that meet criterion 1 "Restoration Targets are not being met, and additional tidal restoration would be detrimental" are higher priority than Restoration Targets that meet criterion 2 "Restoration Targets are not likely to be met and additional tidal restoration or the lack of management interventions would be detrimental." In criterion 1, the Restoration Target is already not being met whereas in criterion 2, the Restoration Target is presumably being met but may not in the future if management interventions cease or as more managed ponds are converted to tidal marsh. It is up to the discretion of the PMT to choose how to organize the prioritized Restoration Targets which can be ranked or organized into different categories. In the example provided in Appendix A.1, the Restoration Targets were organized in two tiers, those that met criteria 1 or 2 were tier 1 (higher priority) and those that only met criteria 3 or 4 were tier 2 (lower priority).

Develop Management Questions for Priority Restoration Targets

For each Restoration Target Category, develop overarching management questions that need to be addressed during Phase 2 before additional tidal restoration can continue in Phase 3. Many high level management questions have already been articulated in Project documents. Refer to the Key Uncertainties in the AMP, the Science Synthesis Report (Wood et al. 2019), and other Project documents.

In some cases, the high priority management questions will be broad and contain multiple nested questions or sub-questions. This may be true for Restoration Target categories that contain multiple objectives and Indicators, some of which fit the criteria and some that don't. In these cases, a second round of applying the criteria may be useful. The final management questions should address the higher priority Restoration Target(s). If different Restoration Targets have similar needs and constraints, the management questions may be combined and articulated to address more than one Restoration Target.

This step ends with the production of clearly articulated high priority management questions based on the latest understanding of the state of the Restoration Targets.

STEP 2- DEVELOP A KNOWLEDGE BRIEF AND IDENTIFY KEY SCIENCE QUESTIONS

Overview

For each high priority Restoration Target Category, develop a "knowledge brief" that summarizes the state of knowledge and describes the system and key interactions. The knowledge brief will include relevant background information on the Restoration Target and Restoration Target Indicators such as the quantitative objectives and their spatial extents, as described in the AMP, and any known knowledge gaps from Project summary documents, including the Science Synthesis Report (Wood et al. 2019). The brief includes a conceptual model that identifies key drivers and potential but realistic management actions that can influence the Restoration Target. There are likely to be uncertainties around the potential restoration or management actions and how they might affect outcomes. These uncertainties are stated as key science questions to be explored in the next step. Below, we outline the components of the knowledge brief.

Summarize the State of Knowledge

Provide detail and context for the management question as stated in Step 1. Does the question have multiple parts? If there are multiple objectives for or relevant to the Restoration Target, which one is management likely to act on? Could other Restoration Target Categories benefit from answering the question? Provide important background information including the Restoration Target Indicator values relative to the numeric objectives. Include a description of the metrics and methods used to measure the Restoration Target's status. Summarize the state of knowledge of the Restoration Target, Restoration Target Indicators, and relevant drivers in the ecosystem using Project reports and summary documents. Describe the different spatial extents related to the Restoration Target Indicators and natural history. For physical Restoration Targets, describe the relevant geomorphic and hydrologic spatial scales that should be considered. For example, some objectives are limited to the Project footprint while others include the entire South San Francisco Bay or broader Estuary. Most Restoration Targets will have objectives and drivers that operate at various spatial scales. Below, we provide the common spatial scales discussed in this Framework.

Spatial extent of the Restoration Targets

i. West Coast and beyond- This scale is especially applicable to the drivers and processes related to Restoration Targets. For some wildlife Restoration Targets, this scale includes the Pacific flyway and breeding grounds in the Arctic. For nutrients, this scale may include drivers originating in the Central Valley or in the upper watersheds around the San Francisco Estuary.

ii. San Francisco Estuary- The regional scale of the San Francisco Bay including San Pablo Bay, South San Francisco Bay, Suisun, and the Delta.
iii. South San Francisco Bay- The portion of the Bay south of the Bay Bridge and contains the Project area.
iv. Project footprint- Many Restoration Targets are defined as within the Project boundaries.
v. Pond or Marsh- Specific complexes or ponds within the Project area.

Develop a Conceptual Model

Develop a conceptual model that highlights the drivers and causal pathways from management actions and stressors through to ecosystem change (clean water, abundant wildlife, etc.), leading to achievement and maintenance of Restoration Targets (e.g., adequate dissolved oxygen (DO) or the number and success of breeding snowy plovers). In some cases, a single conceptual model may be developed to address more than one closely related management question (e.g., see Appendix A.1 Case Study management questions for the sediment and tidal marsh habitat establishment categories). The conceptual model will help to identify key limiting factors and key dependencies (e.g., drivers that are under control/influence by the Project and those that are not). The conceptual model can also identify important uncertainties and assumptions and can reveal which of these assumptions are most in need of validation.

Conceptual models can take many forms, but they typically include a graphical depiction and accompanying text description of drivers and causal pathways that, in this case, lead to the achievement of Restoration Targets. Following the terminology and process described in Reynolds et al. (2016), in addition to the Restoration Targets, the conceptual model describes:

1. *Proximate determinants* of the Restoration Targets Indicators and their components, defined as factors that immediately determine the state of the indicator or its components. For example, the number of breeding birds (a Restoration Target Indicator) may have declined. The proximate determinant may have been because of low survival of juveniles and adults during the fall and winter.
2. *Ultimate determinants*, or drivers which underlie the proximate determinants. Following the above example, the ultimate determinant may be due to predation of juveniles and adults during extreme tide events when the species is exposed to predators.
3. *Management actions* that can influence the drivers. Here there are three important considerations:
    a. **Which of the above ultimate determinants have the strongest influence** with respect to determining Restoration Target Indicator values? We should consider both the influence of natural variation in the driver as well as management actions. Such information may be missing or insufficient.
    b. **Which of the ultimate determinants are most amenable to management?** Which determinants can be successfully managed? Is the potential management action consistent with the core mission of the Project? Is this a realistic action the Project is willing to pursue?
    c. **For which of the ultimate determinants is the stress or pressure the greatest?** For example, the resuspension of legacy mercury following channel scour may have a strong influence on water quality, but the effect may be short-lived.

Identify Key Science Questions

This task considers the question, "What are the most important science questions that will best be able to inform the management question?" This task also addresses the science questions associated with the key drivers in the conceptual model that can be influenced through management. The point here is not to list all the uncertainties in the conceptual model but to focus on those that are associated with key drivers (known or highly likely to be important drivers) that can be influenced by management. In Step 3, each key science question will be addressed in a logic model that illustrates how the question will be tackled, what the data and analysis needs are, and what the advantageous sequencing of filling those needs is likely to be.

STEP 3- DEVELOP LOGIC MODELS AND IMMEDIATE SCIENCE NEEDS

Overview

The knowledge brief and accompanying conceptual model in Step 2 allows us to see how the system works relative to the achieving the Restoration Target, what the stressors are, where the uncertainties are, and to identify key drivers that can be influenced by management. In this step, we outline the process to answer each key science question using a logic model. Each question will be addressed in one or sometimes multiple logic models. Logic models help to envision where a managemetn action or strategy influences key drivers and results in positive outcomes for the Restoration Target. Many of the tasks within this step are iterative and the models can be refined as knowledge is gained. Laying out the path of discovery and being explicit about the steps required to answer the key science question can also help prioritize logic models that are more efficient or that are more likely to lead to successfully answering the key science question. The information and actions identified in the logic model (e.g., baseline data or a study design) represent the most immediate science needs. Step 3 culminates with a list of immediate science needs for the highest priority logic models. The PMT can lead the development of logic models with input from other experts as needed. The PMT can decide the appropriate level of detail in the logic model, which may influence their decision about whether to solicit input from other experts. The methods used to gather input from other experts can range from brief communications (e.g., email or phone call) to organized workshops.

Develop Logic Models

Logic models are used to chart a path to answering the science question or addressing the uncertainty. Logic models should include drivers, management levers, and the desired Restoration Target outcomes from the conceptual model. The PMT will generally lead or oversee the development of logic model diagrams but is not expected to produce the content described in the logic model (e.g., the PMT will not need to produce a study design before the next steps in the logic model are undertaken).

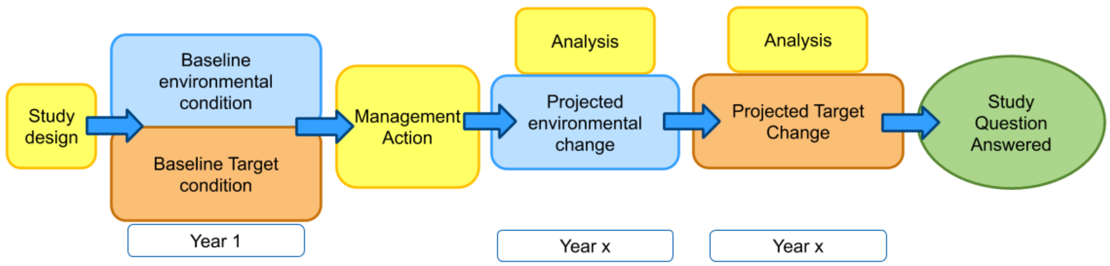

Figure 2. Example of a general logic model showing the need for information on the Restoration Target condition (orange) or other information (blue) before and after a management action (yellow) and ultimately leading to answering the key study question (green). The logic model shows the sequencing of information needs and timing of potential management actions, monitoring, and analysis.

When developing each logic model, consider including the following concepts:

- Other disciplines that influence the Restoration Target (e.g., physical properties for biotic Restoration Targets or biological processes for physical Restoration Targets, vegetation, invertebrates).
- Landscape scale effects, and Restoration Target movement at larger spatial scales.
- Relevant timelines (e.g., what is the expected response timeline? What is the order and timeline for sequencing studies when one study is dependent on the results of another study?).

Prioritize the Logic Models

Once the logic models are developed, it may become apparent that funding is insufficient to implement all the activities described. This might not have been known until all the activities were outlined in the logic models. Prioritizing within and among logic models may be needed in these cases. The following questions are designed to identify the most important logic models or logic model components to pursue given a limited science budget. Prioritizing logic models should be done by the PMT and can involve consultation with other experts if needed. The questions for prioritizing logic models are not necessarily of equal weight nor are they in order of importance.

- Which logic models are most likely to reach conclusive answers?
- Which logic models test strategies that are the most promising (e.g., strategies most likely to influence key drivers)?
- Which can be sufficiently answered with existing data or in a relatively short time frame (i.e., that do not rely on implementing a management experiment)?
- Which may be of overriding importance, such that failure to address the issue may lead to failure to achieve Restoration Targets?

Identify Immediate Science Needs

List the most immediate (near term) and specific science needs associated with the selected high priority logic models. In most cases, the first step in the logic model is for the PI or PIs to develop a study design that outlines the details of how their particular study will be carried out. The study design is an immediate science need and will be outlined by the PI in a proposal and, if awarded, will be developed at the beginning of the project as indicated by the logic model (Figure 2). In the generic example, the study design would describe what kind of baseline data are needed to assess the response to management. Other key science needs will involve integrating information from specific studies (as outlined in a logic model); these integrative efforts are the most critical for answering the management question. The sequencing of the additional science needs and project activities the PI will undertake are represented by Year x in Figure 2. The sequencing and timing of activities should be described in the study design.

Once the logic model figures are completed and the science needs are identified, the PMT can consider issuing an RFP or soliciting direct studies to implement the science represented in the logic model. In the generic example, the RFP would include the key science question and would request that proposals include a study design that identifies what baseline information is needed and how the response to management will be assessed. Successful proposals would describe how the logic models would be implemented and how synergies and new technologies can be leveraged to answer the key science question.

In the Figure 2 example, the immediate/specific science needs are as follows:

Year 1

- Study design- This critical step will inform what kind of baseline data are needed in addition to laying the groundwork for testing the management action, selecting treatment, control and/or reference sites.
- Baseline environmental conditions- quantitative information on the environmental conditions that are expected to change as a result of the management action (e.g., water temperature, vegetation density) as well as other drivers including a description of the appropriate spatial scales.
- Baseline Restoration Target condition- quantitative information on the Restoration Target condition that is subject to potential management actions via improved environmental conditions (e.g., dissolved oxygen, number of breeding adults).

Other Considerations

When soliciting and prioritizing studies, the PMT is encouraged to also consider:

- Use of novel technology (e.g., as described in the Science Synthesis Report, Wood et al. 2019).
- Data collection and compilation that facilitates integration with regional datasets; prioritize studies that actively integrate data, analyses, and models, spatially and across disciplines.
- Studies that Incorporate climate science projections.
- Studies that leverage past and/or current monitoring data from within or outside the Project footprint if such data exists and relates to a key component in the conceptual model.

STEP 4- IMPLEMENT THE SCIENCE

With the most important and immediate science needs identified in Step 3, this next step involves the PIs implementing the science, collecting or acquiring information on baseline conditions from which to compare change or to begin designing the models or statistical analyses or field studies needed to answer the key science questions. In some cases, an analysis may be needed to increase the understanding of conceptual model components and reduce or characterize the uncertainty. Quantifying conceptual model components is particularly important when the Restoration Target includes specific quantitative objectives that must be met. This step will be accomplished by the PIs. The PMT can work with the PIs during this time to ensure that the guidance in this Framework is reflected in the PI's study design and overall approach. This step culminates in study results that, ideally, answer the science question or at least reduce uncertainty associated with the study question.

STEP 5 - EVALUATE, INTERPRET, ITERATE

The PMT will review the study results and assess how well the key science question was answered. If the question was successfully answered there may be recommended management actions or strategies that can be implemented. If the question was not adequately answered, the PMT and/or the PIs should retrace the steps to see where the study fell short and what corrective actions may need to be taken. In some cases, the logic model or conceptual model may need to be revised. In other cases it may be determined that the baseline information or study design was not adequate to detect an action's effect. After evaluating the results of multiple studies the PMT may find it necessary to revisit or re-prioritize the Restoration Targets.

NEXT STEPS

In implementing this Framework, the PMT may develop additional plans and products to help guide the science needed to address the key science questions. This Framework does not prescribe or describe in detail the plans or products that the PMT might develop but rather serves to guide those efforts. For example, the PMT can use this Framework to prioritize the most critical science needs and develop a targeted Monitoring Plan that addresses those needs, as opposed to investing in a Monitoring Plan that describes all the monitoring that could be done. Not every Restoration Target will require the same monitoring intensity, and not every aspect of even the highest priority Restoration Targets requires the same monitoring intensity, or the same temporal or spatial scales. Conceptual and logic models can be used to identify the most critical data needs. The Case Studies (Appendices A.1 through A.5) developed in support of the Framework serve as examples of how the Framework can be used to develop components of plans and products that focus science on addressing critical questions for the Project. Below are examples of plans or products that may be developed by the PMT and informed by this Framework.

<u>A Science Plan</u> describes a set of shared goals and outlines strategies for implementing science and monitoring that helps the Project achieve its mission. This Framework can guide the development of specific components of the Science Plan, including prioritizing management questions and using conceptual and logic models to identify critical uncertainties and to develop strategies to address those uncertainties. A Science Plan may also include details on how to achieve regional synergy in research and monitoring activities and to coordinate resource management actions at broader spatial scales.

<u>A Monitoring Plan</u> can be developed that outlines how to efficiently gather information on the status of the Restoration Targets and to fill information gaps that address key science questions. Implicit in this Framework is the assumption that information on all the Restoration Targets will be available to inform the prioritization process as described in Step 1. The PMT will need to know the status of Restoration Targets to know which need attention. Less intensive monitoring is needed in cases where the Restoration Target Indicators are on a trajectory toward their objective or have already met their objective and are stable. Some Restoration Targets are monitored by other entities who are willing to share that information. Restoration Target Indicators that are not doing well or are not being tracked may require Project-sponsored surveillance monitoring. For evaluation of Restoration Targets, baseline data is key but has yet to be clearly defined for many Restoration Targets and this can be incorporated into the Monitoring Plan. For example there is a need to specify baseline data with regard to season and habitat types (managed ponds compared to other habitats) and region of the Estuary. Additionally, there is a need for providing a rigorous statistical basis for the evaluation of changes or stability. This will allow for the development of efficient sampling schemes with sufficient power to track progress of stated objectives. The AMP states that, "Restoration targets are expected to evolve as more information about the system is collected" (page 26 in Trulio et al. 2007). In addition to tracking Restoration Target status, monitoring data are often needed to help answer key science questions. A successful Monitoring Plan will address both of these needs.

<u>A request for proposals</u> (RFP) can be developed by the PMT to identify and fund the research and monitoring activities that address the most urgent science needs. RFP priorities can be identified using the prioritization process described in Step 1. The specific science questions can be identified through the use of conceptual models that highlight where the greatest and impactful uncertainties lie that, if answered, will allow the Project to identify the appropriate management actions. The case study

examples in Appendices A.2 through A.5 illustrate how to develop key science questions based on priorities identified by the PMT in early 2020. The process of using logic models to describe how to address key science questions can also inform the development of an RFP or evaluate proposals. The PMT will also likely seek input from external scientists and restoration practitioners to refine conceptual models, key science questions and logic models. Looking across logic models, the PMT may also identify the need for synergies and coordination in cases when the same or similar information needs are shared by multiple logic models.

Data accessibility, the making of monitoring data and derived data products openly available will facilitate collaboration and learning among other regional efforts and across disciplines. The Science Synthesis Report (Wood et al. 2019) and case studies have identified many opportunities for Phase 2 science to integrate with other regional and cross disciplinary efforts. The PMT can give greater weight to proposals that pledge to make data and data products openly available quickly and efficiently using existing data platforms where appropriate. In addition, the PMT can encourage PIs to utilize widely used protocols and metadata standards for data and data products so that new data and data products can be integrated more readily.

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APPENDIX A. APPLYING THE FRAMEWORK TO PROJECT CASE STUDIES

OVERVIEW

In this section, we present examples illustrating how the Framework can be applied to develop other products (e.g., a Science Plan or RFP) including how to prioritize and address important science questions whose answers will help the Project achieve its goal. Appendix A walks the reader through Steps 1 through 3 of the Science Program Framework. Step 1 is illustrated in Appendix A.1 and begins with a review of the status of each Restoration Target to identify priority Restoration Targets that may require management actions. Steps 2 and 3 are carried out for selected high priority Restoration Targets. From all the possible Restoration Targets identified in Step 1, we selected Western snowy plover (Appendix A.2), migratory shorebirds and waterfowl (Appendix A.3), sediment (Appendix A.4) and mercury/water quality (Appendix A.5) to illustrate how Steps 2 and 3 can be carried out. The Restoration Targets were selected for their utility in illustrating how to use the Framework to address diverse Restoration Targets. For example, the case studies include biological (snowy plover and migratory waterbirds) and physical (sediment and water quality) examples of Restoration Targets. The two biological Restoration Targets differ from each other in that the snowy plover case study is focused on reproductive success and involves a smaller spatial scale than the migratory shorebirds and waterfowl, which is focused on abundance outside the breeding season and considers processes at larger spatial scales.

APPENDIX A.1. PRIORITIZATION

STEP 1- PRIORITIZE RESTORATION TARGETS AND DEVELOP MANAGEMENT QUESTIONS

Review of Restoration Targets

The PMT began by listing all the Restoration Target Categories from the AMP with some minor changes. Categories like those associated with tidal marsh habitat were grouped together. Waterfowl were added to the migratory shorebird Restoration Target Category for the Case Study because Applied Studies and the conceptual model in the AMP explicitly included waterfowl even though the stated Restoration Target did not. We note that diving ducks were included as one of the Restoration Targets in the AMP. The "flood risk management" Restoration Target is a revision of the original AMP Restoration Target, "flood protection." The resulting Restoration Target Categories are presented in Table 2 as well as in Table A.1-1.

Application of the Prioritization Criteria

The PMT described how the Restoration Target Categories met the criteria in Table A.1-1. Project summary reports and syntheses were used to describe the prioritization rationale for each Restoration Target.

Table A.1-1. The criteria for prioritizing PMT questions and uncertainties that require science to address are in order of importance from highest to lowest. The degree to which the Restoration Targets and their Indicator values are consistent with the criteria affects its priority.

Prioritization Criteria	
1	Restoration Targets are not being met and additional tidal restoration would be detrimental to the Restoration Target.
2	Restoration Targets are not likely to be achieved in the future and additional tidal restoration or the lack of management interventions would be detrimental.
3	Restoration Target Indicator values are uncertain, and additional tidal restoration or the lack of management interventions would likely be detrimental to chances of meeting Project Objectives.
4	Restoration Target Indicators are not adversely affected by tidal restoration but would be likely to require management to achieve Project Objectives.

The Prioritization Rationale in Table A.1-2 describes, in brief, the degree to which the Restoration Targets met the criteria in Table A.1-1. Restoration Targets Categories that are not meeting stated Objectives and are likely to be negatively impacted by tidal restoration are the highest priority to address using science. Restoration Target Indicators that are neither likely to worsen with additional tidal restoration nor likely to need management are the lowest priority in terms of science needs.

Table A.1-2. Restoration Target Categories from the AMP (Appendix 3) and any new objectives that have been adopted by the Project and a summary of their status as it relates to the prioritization criteria. Prioritization Rationale was based on Project summary and synthesis documents (Valoppi 2018, Wood et al. 2019, and Hayden et al. 2020). "Criterion Met" numbers indicate the most important criterion from Table A.1-1 that was met.

Restoration Target Category	Prioritization Rationale	Criterion Met
Sediment dynamics	Meeting Project Objectives but future success (achieving vegetation colonization elevation) is uncertain due to accelerating sea level rise. If sediment availability is limited in the future, sediment deficits may occur in other restoring marshes and may require increasingly intensive management interventions.	Criterion 2
Flood risk management*	Uncertain but likely meeting Project Objectives. Not fully addressed in summaries or syntheses. Increases in flood risk in some areas may occur with sea level rise, regardless of Project actions, but current restoration and management practices are not likely detrimental. There is uncertainty around potential actions taken outside the Project that may negatively affect flood risk management within or adjacent to the Project footprint.	Criterion 4
Water Quality (RWQCB standards and DO levels)	Uncertain. The extent to which the Project has contributed to low DO and primary productivity relative to other inputs such as water treatment plants and pond management is uncertain. Water quality is likely improved by tidal restoration over the long term.	Criterion 4
Mercury	Trending toward meeting Project Objectives for tidal restoration and pond management, but elevated and toxic levels of MeHg were found in sentinel species during and immediately after construction activities in or around ponds that lasted several months. Tidal restoration and associated slough scour did not increase MeHg concentrations on a gravimetric basis (ng/g) in marsh slough, and bay-associated sentinel species.	Criterion 4
Algal composition and abundance	Little change but some uncertainty about meeting Project Objectives. Chlorophyll concentrations have been largely stable since 2005 but detections of harmful algal blooms in the south bay have increased following phase 1 restoration but the attribution to Phase 1 activities is difficult. Water quality within ponds will be more of a challenge for pond management in the future as waters may become warmer with the possibility of triggering harmful algal blooms.	Criterion 4
Tidal marsh habitat establishment, Ridgway's rail, salt marsh harvest mouse	Trending toward meeting Project Objectives but future success is uncertain with climate change and in particular, sea level rise. Additional tidal restoration is not likely detrimental.	Criterion 4

Restoration Target Category	Prioritization Rationale	Criterion Met
Vector Control	Meeting Project Objectives. Phase 1 designs minimized limitations on access for mosquito abatement. Warmer temperatures could cause problems in the future. Unlikely that tidal restoration would exacerbate the problem. Phase 2 actions will continue to include design considerations developed in coordination with the abatement districts, which would reduce the need for science to inform this topic.	None
Migratory shorebirds and waterfowl**	Trending towards meeting Project Objectives. Concern remains that Phase 2 and future tidal restoration will cause substantial declines in Restoration Target Indicator values. There is also uncertainty around the potential impacts of sea level rise which will threaten the levees and infrastructure supporting managed pond habitat but may also lead to more open water and mudflat habitat that is beneficial to the Restoration Target Indicator.	Criterion 2
Salt pond associated migratory birds (phalaropes, grebe, gull)	Objectives for phalaropes are not likely being met but studies are underway to verify observed trends. Eared grebe and Bonaparte's gull are trending towards meeting Project Objectives but additional tidal restoration may reduce Restoration Target Indicator values.	Criterion 1 (phalaropes)/ Criterion 2 (other high-saline species)
Breeding avocets, stilts, and terns	Restoration Target Indicator values are low and declining for American avocet, black-necked stilt, Forster's Tern, and Caspian tern; cause for concern regarding additional tidal restoration. Phase 2 tidal restoration likely to further reduce Restoration Target Indicator values without improved management.	Criterion 1
Western snowy plover	Not meeting Project Objectives; the last 10 years show substantial variability in annual plover counts with no overall increase in their numbers while decreasing potential available habitat. Tidal restoration may further reduce Restoration Target Indicator values without improved management.	Criterion 1
California least tern	Uncertain but trending toward not meeting Project Objectives. Additional tidal restoration and sea level rise may worsen the values as dry ponds are converted.	Criterion 2
Diving ducks	Mixed trends, but expected to worsen with tidal restoration. However, in the long term, sea level rise may drown marshes and create more areas of open water habitat.	Criterion 3
Estuarine fish	Trending toward meeting Project Objectives and likely benefited by additional tidal restoration. Climate change may negatively impact the Restoration Target Indicators, independent of Project activities.	None

Restoration Target Category	Prioritization Rationale	Criterion Met
Steelhead	Uncertain due to a lack of baseline information and limited sampling efficacy. Evidence suggests that the positive effects of tidal restoration outweigh potential negative effects. Climate change may negatively impact the Restoration Target, independent of Project activities.	None
Harbor seals	Trending toward meeting Project Objectives and not worsened by tidal restoration or pond management.	None
Public Access	Public enjoyment is trending toward meeting Project Objectives and likely benefited by tidal restoration which may provide other public enjoyment benefits. The negative effects of public access on wildlife Restoration Targets is uncertain but trending in the right direction.	None

*Stated as Flood Protection in the AMP and subsequently revised.
**Waterfowl other than diving ducks were not explicitly included in the AMP Restoration Target Summary Table.

Identify Restoration Targets with High Priority Science Needs

It is up to the discretion of the PMT to choose how to organize the prioritized Restoration Targets. Because of the high number of Restoration Targets meeting the criteria, two prioritization tiers were developed. The PMT reviewed the prioritization rationale in Table A.1-2 and determined which criteria, if any, applied to each Restoration Target. All Restoration Targets meeting the most important criteria (criteria 1 and 2 in Table A.1-1) were placed in Tier 1.

Develop Management Questions for Priority Restoration Targets

For each Restoration Target Category, management questions were developed to be addressed during Phase 2 before additional tidal restoration can continue in Phase 3 or in association with outside projects that overlap with the Project's planned program area (Table A.1-3). Here we summarize for each Restoration Target the overarching management question that, if answered, will allow the Project to take actions to achieve its Objectives.

Table A.1-3. High priority management questions for each Restoration Target meeting the prioritization criteria (numbers indicate the most important criterion from Table A.1-1 that was met). Tier 1 management questions are higher priority than tier 2. The management questions within each tier are not in prioritized order.

Restoration Target Category (Criterion)	Management Question
Tier 1	
Western snowy plover (1)	How can the Restoration Targets for the number and success of breeding snowy plovers be supported in a changing (reduced salt pond) habitat area?
Breeding avocets, stilts, and terns (1)	How many managed ponds will be needed to meet waterbird Restoration Targets? Where and how should managed ponds be retained and/or enhanced? What other management will be needed?
Salt pond associated migratory birds (phalaropes, grebe, gull) (1/2)	How many managed ponds will be needed to meet salt pond associated migratory bird Restoration Targets? Which ones? And how should they be managed or constructed?
Migratory shorebirds and waterfowl (2)	How many managed ponds will be needed to meet shorebird and waterfowl Restoration Targets, and how should they be managed or constructed?
California least tern (2)	How can the Restoration Targets for the number and success of breeding least terns be supported in a changing (reduced salt pond) habitat area?
Sediment (2)	Will additional tidal marsh restoration be successful in the context of sea level rise in terms of meeting Restoration Targets for desired marsh elevation?
Tier 2	
Mercury/water quality (4)	Can the A8 Ponds (A5, A7, A8, A8S) be restored with fully tidal connections to Guadalupe Slough, Alviso Slough, and/or Calabazas and San Tomas Aquino Creeks with minimal risks from methylmercury production in restoring wetlands? Will the management of remaining ponds lead to degraded water quality, including increased incidence of harmful algal blooms in the South Bay?
Flood risk management (4)	Where can the Project work to expand flood risk management actions beyond the Project footprint? Who should the Project work with to minimize flood risk due to additional breaches and sea level rise (e.g., flood management agencies, SAFER Bay)? What are the most effective ways the Project can engage with others to achieve flood risk management objectives?
Tidal marsh habitat establishment (RIRA, SMHM target) (4)	Will additional tidal marsh restoration be successful in the context of sea level rise in terms of meeting Project goals for desired wildlife?

To illustrate how Steps 2 and 3 can be applied, four Restoration Targets from Table A.1-3 were selected, starting with the snowy plover (Appendix A.2) because it is substantially below Restoration Target levels and would likely be further impacted by tidal restoration. Snowy plovers in the South Bay nest in the large dry salt flats that must be managed for their breeding, but such use is in conflict with tidal restoration. The snowy plover is also a single-species Restoration Target with limited geographic range and a focus on a specific time of year (spring/summer breeding season), all of which makes for a less complex example compared to multi-species Restoration Targets with multiple habitat needs covering broader areas.

For the second example, we selected migratory shorebirds and waterfowl (Appendix A.3) that together provide an informative contrast with the snowy plover case study. This example allows us to demonstrate use of the Framework to tackle more complex management questions that involve multiple species with diverse habitat needs and that include the need for science integration at spatial scales beyond the Project footprint and South Bay.

The last two case studies, sediment (Appendix A.4) and mercury/water quality (Appendix A.5) contrast with the two previous biological Restoration Targets and illustrate using the Framework to address physical Restoration Targets. The mercury and water quality Restoration Targets were combined into a single case study because the objectives and metrics for the two Restoration Targets overlapped.

APPENDIX A.2. SNOWY PLOVER CASE STUDY

STEP 2- DEVELOP KNOWLEDGE BRIEF AND IDENTIFY KEY SCIENCE QUESTIONS

Here we illustrate how to apply Step 2 of the Framework for the Western snowy plover (also referred to as snowy plover) management question. To provide context we review and expand on the management question, describe relevant background information including details on the Restoration Target numeric objectives, and key points from the Science Synthesis Report (Wood et al. 2019) and Climate Change Synthesis Report (Hayden et al. 2020). Together, these elements make up the knowledge brief, which then leads to the conceptual model.

Summarize the State of Knowledge

Management Question: How can the Restoration Targets for the number and success of breeding snowy plovers be supported in a changing (reduced salt pond) habitat area?

More specifically, how many managed ponds are needed for snowy plovers, which ones, and what habitat conditions are needed within these ponds? What additional management actions are needed, including predator management? The key science question is addressed with respect to the Project's numeric Restoration Targets for snowy plovers.

Background

The Pacific coast population of Western snowy plovers is a federally-threatened species. The San Francisco Estuary is an important subpopulation within the total Pacific coast population, and is termed Recovery Unit 3 (RU3; USFWS 2007). Between 1978 and 2006, the number of breeding individuals in the Pacific coast population declined by 68%. The number one reason for the decline was thought to be low hatching and fledging success (Neuman 2005). Supporting the recovery of the Pacific coast population is a priority for the Project, which entails increasing the number of breeding birds and achieving and maintaining sufficient reproductive success as detailed below. However, snowy plovers in San Francisco Bay are dependent upon managed ponds (including active salt ponds) for breeding habitat; thus the conversion of ponds to tidal marsh habitat presents a major challenge. An even greater challenge is that ponds must have specific conditions conducive to breeding of snowy plovers. Ponds must have dry areas but be near shallow water for foraging, and vegetation must be sparse (neither highly vegetated nor completely bare). Ponds that are well-suited for other migrating waterbirds are generally not suitable for breeding snowy plovers at the same time, and so management practices to benefit breeding snowy plovers need to specifically address their needs during the breeding season.

Restoration Targets from the AMP

To contribute to recovery of snowy plovers in the South Bay region by:

- **Supporting an increase in the number of breeding snowy plovers in the Estuary as a whole**. 500 breeding individuals in RU3 (USFWS 2007) with a Project-specific Restoration Target of 250 breeding individuals. Recent surveys indicate about 70% of this Project-level goal has been achieved (Pearl et al. 2019). The highest number of individuals was recorded in 2010 and the population has not increased since then.

- **Achieving 1.0 fledged young per breeding male per breeding season (USFWS 2007).** Current monitoring is not able to provide the number of fledged young per male, but recent and current monitoring results show that nesting success (fraction of clutches which successfully hatch one or more chicks) is low and fledging success (proportion of hatched chicks that survive to fledging age, c. 28 days post-hatching) is also low (Pearl et al. 2019 and earlier reports).

Summary from Science Synthesis (Wood et al. 2019) **and Climate Change Synthesis** (Hayden et al. 2020)

- The conclusion from the Science Synthesis Report (Wood et al. 2019) was that there had been some success in increasing numbers of breeding snowy plovers, especially in comparison to the number of breeders in 2004-2006, the baseline period. Furthermore, oyster shell enhancement proved to be successful in increasing the number of birds attempting to breed. However, high rates of nest failure and chick mortality have been observed in all years, with the number one cause of this mortality being predation on nests and chicks from both avian and mammalian predators. Important questions including how to reduce predation rates and how to effectively monitor survival of chicks to fledging, a key component of the reproductive success Restoration Target, need to be addressed (Pearl et al. 2019).

- Climate change will affect snowy plovers in multiple ways including levee failure (and therefore pond inundation) due to extreme weather events, influencing predator populations and behavior, and impacting other populations of snowy plovers, which may be providing immigrants to the Project area. For example, sea level rise may not affect snowy plovers in the Project area if levees around their managed pond habitat are able to be adequately maintained, but it is expected to impact snowy plovers on coastal beaches and elsewhere. Increased wind and storm events can adversely affect chick survival. While changes in mean temperature and mean precipitation are of lower concern, increased climate variability is a concern, which may result in droughts or extreme precipitation.

Develop a Conceptual Model

The conceptual model lays out the ecological relationships for snowy plovers that determine the number and success of breeding snowy plovers (i.e., Restoration Targets; Figure A.2-1).

Snowy Plover Conceptual Model

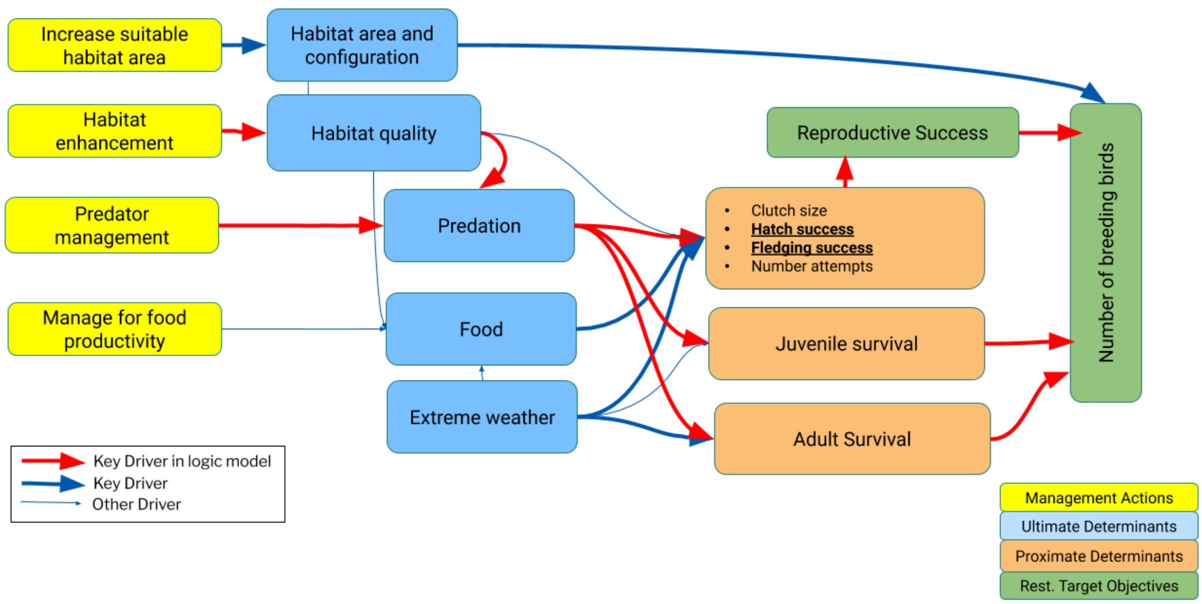

Figure A.2-1. Snowy plover conceptual model showing causal pathways from the ultimate determinants (blue boxes) to the proximate determinants (orange boxes), as well as management actions (yellow boxes) designed to reduce stressors and achieve Restoration Targets (green boxes), in this case the number and success of breeding snowy plovers. Key causal pathways captured in the logic models are shown in red.

We identify four spatial scales of interest with regard to the snowy plover conceptual model:

i. The entire Pacific coast population of snowy plovers, which is actually a metapopulation consisting of subpopulations
ii. The regional scale of the San Francisco Estuary, which is a subpopulation within the metapopulation (RU3)
iii. The Project area within the San Francisco Estuary
iv. Ponds within the Project area

The conceptual model focuses on scales ii, iii, and iv, but it is helpful to note that the Recovery Plan (USFWS 2007) covers scale i and ii.

Number of Breeding Birds- The first Restoration Target, the number of breeding birds, has two components: 1) the number of adults in the Project area and 2) the decision of adults to breed and where to breed. The four proximate determinants that influence the number of adults in the Project area are as follows:

a. Number of surviving adults
b. Number of fledged young that survive to adulthood (juvenile survival)
c. Dispersal of adults (movement in and out of the Project area)
d. Dispersal of fledged young (juvenile dispersal into and out of the Project area)

The first two proximate determinants are the most important and are represented in the conceptual model. Note that b) reflects the number of fledglings produced (which is the primary focus of reproductive success Restoration Target) as well as reflecting the proportion of those fledglings that survive to adulthood.

The conceptual model identifies three ultimate determinants of the number of breeding adults. The first two are of highest concern:

1. Predation. Identified as the most important ultimate determinant that is amenable to management. See below for details and discussion.
2. Extreme weather. This is important for survival of eggs, juveniles, and adults and affects the number of individuals returning to breed.
3. Food availability. Note this may be of particular importance for survival of fledglings (component b, above). This also likely interacts with predation: predation risk increases where food is less available.

The decision of adults to breed and where to breed is influenced by the availability of suitable habitat (area and quality) and reproductive success/failure which can cause breeders to move to other areas.

"Where to breed" includes which ponds to breed in (spatial scale iv) as well as whether to attempt to breed in the Project area or outside (spatial scales ii and iii above). Thus, the distribution of breeding habitat (e.g., distributed among many ponds or only a few ponds) is important as well as the quality of the habitat which is measured. Note that habitat quality is assessed during the breeding window survey and occurs at all four spatial scales.

Also, included in the above "decision to breed" is "when to breed?" Habitat conditions may result in earlier or later breeding; delayed breeding may be disadvantageous. These habitat conditions will be influenced by extreme weather, but are also subject to management actions, at least to an extent. This is especially the case with respect to extent of water (dry vs. shallow-flooded) in breeding habitat early in the breeding season. However, in very wet years, or when rains have come late in the season management actions are much more limited.

Reproductive success- The second Restoration Target (≥ 1.0 fledged young/breeding male) can be partitioned into four proximate determinants. For completeness we list all four, but hatch and fledging success are of primary interest for the conceptual model:

a. Clutch size (number of eggs laid per nest)
b. Hatch success (number of hatchlings per egg laid)
c. Fledging success
d. Number of nesting attempts per breeding male

The product of these four components equals the number of fledged young per breeding male per breeding season. The conceptual model highlights hatch and fledging success because these are highly variable (unlike clutch size which is very constant in snowy plovers) and can be influenced by management actions (see below).

The ultimate factors that determine hatch and fledging success are listed below with the first two being the most important:

1. Predation. Identified as an important and amenable to management.

2. Extreme weather. This important determinant can affect nests, juveniles, and adults but is less amenable to management.
3. Food availability. Starvation may not be a major factor, but food availability could influence predation risk. That is, there may be an interaction between predation and food availability such that predation rates are highest where food availability is low.

Many factors in turn influence the above three ultimate determinants. For example, predation can be influenced by disturbance. Also, habitat conditions (e.g., quality and distribution of breeding habitat) can influence predation rates.

Management actions- To determine where to focus management, we consider which drivers have the strongest influence on the Restoration Targets and which factors are most amenable to management.

The conceptual model highlights predation and habitat suitability as the highest priority drivers for management. While there is value to distinguishing these two drivers, they also must be considered simultaneously because habitat conditions can influence predation rates. It is important to not create an ecological sink, e.g., an area that is preferred for nesting by breeding snowy plovers, but which is subject to high predation rates and does not support population growth.

Predation on nests, juveniles, and adults is a concern and is the focus of the logic models outlined below in Step 3. Predator management, in this case study, refers to any actions taken to reduce predation on snowy plovers and can include control (removing individual predators) and deterrence such as hazing and perch removal. Predator management represents a major challenge because of the large number of potential predator species and types (terrestrial vs. avian) and the highly dynamic nature of predation on nests and chicks. The predominant predator in one year may not be the predominant predator the following year. Predation rates appear to be influenced by the presence and density of conspecifics and other nesting species, such as least terns who are also subject to the same predators. As noted, habitat conditions influence predation rates. For example, providing more or better cover for nests or chicks or providing suitable foraging areas near nests can reduce predation rates. For this reason, habitat enhancement is often considered in conjunction with other forms of predator management.

Habitat suitability strongly affects reproductive success, including the decision of where and when to breed. Water levels are a key determinant to habitat suitability and their manipulation can affect the timing of breeding which, in turn, affects breeding success. Early breeding may be advantageous compared to late breeding, but that will also depend on conditions as they change during the breeding season. Initiating breeding late in the season also limits the ability of breeders to renest, which is an important component of the snowy plover life history strategy. Cover or camouflage, from existing vegetation or the addition of oyster shells or other enhancements, may also be important.

Habitat conditions can affect predation rates. Manipulation of habitat suitability can result in high or low density of conspecifics, which affects predation rates; this includes but is not limited to controlling the amount of water in a pond. The presence of other nesting species such as least terns can affect nest and chick predation rates. Some of the common predators on snowy plovers are themselves protected species (for example, peregrine falcons and other migratory birds). Thus reducing predation must fit within the regulatory framework.

Adjacent habitat characteristics, especially proximity to urban development and tidal marsh habitat, will also have important effects on snowy plover predation rates; many of the predators that impact tidal marsh-dependent wildlife are also predators on snowy plover nests and chicks.

Identify Key Science Questions

The following are the key science questions that follow from the conceptual model and are addressed in more detail in Step 3 with the development of logic models. The two logic models focus on the following overarching question, "What factors determine nest and chick predation rates in snowy plovers?" Potential factors to explore include habitat and landscape characteristics, abundance of nest predator species, density of snowy plovers, and proximity/access by predators to snowy plover breeding areas.

1. What are the high priority predator management and habitat enhancement strategies that should be tested for their ability to reduce predation and achieve snowy plover population Restoration Targets? How should these strategies be tested?

2. What predator management and habitat enhancement strategies are needed to achieve the desired reproductive success Restoration Target?

STEP 3- DEVELOP LOGIC MODELS AND IMMEDIATE SCIENCE NEEDS

Develop Logic Models

Here we present two logic models, which address the objective of determining the best strategies for reducing snowy plover nest and chick predation, as a means of attaining the Restoration Target of 1.0 chicks fledged per breeding male. Implementing the logic models will also contribute to the knowledge needed to achieve the second Restoration Target: 250 breeding individuals in the Project area. As indicated in the conceptual model, reproductive success feeds into the number of breeding birds. The two logic models presented are sequential and illustrate the information needs and actions that lead to answering the two key science questions.

The first logic model (Figure A.2-2) illustrates how a synthesis of predator management and habitat enhancement studies from areas within and outside the Project area can be used to identify potentially effective strategies that the Project can consider testing.

Snowy Plover Logic Model- Predator Management and Habitat Enhancement Synthesis

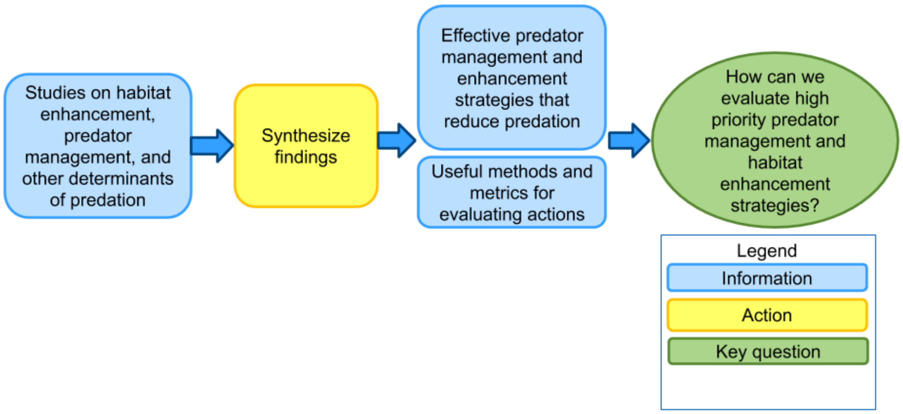

Figure A.2-2. Logic model for a predator management and habitat enhancement synthesis that identifies high priority strategies with potential to improve snowy plover reproductive success.

Results from the first logic model (Figure A.2-2) can be used to design predator management and habitat enhancement strategies to be tested in the field for their efficacy in improving snowy plover reproductive success. The next logic model (Figure A.2-3) illustrates the steps involved in designing a study that explores the effectiveness of the high priority predator management and habitat enhancement strategies identified in the first logic model.

Snowy Plover Logic Model- Predator Management and Habitat Enhancement

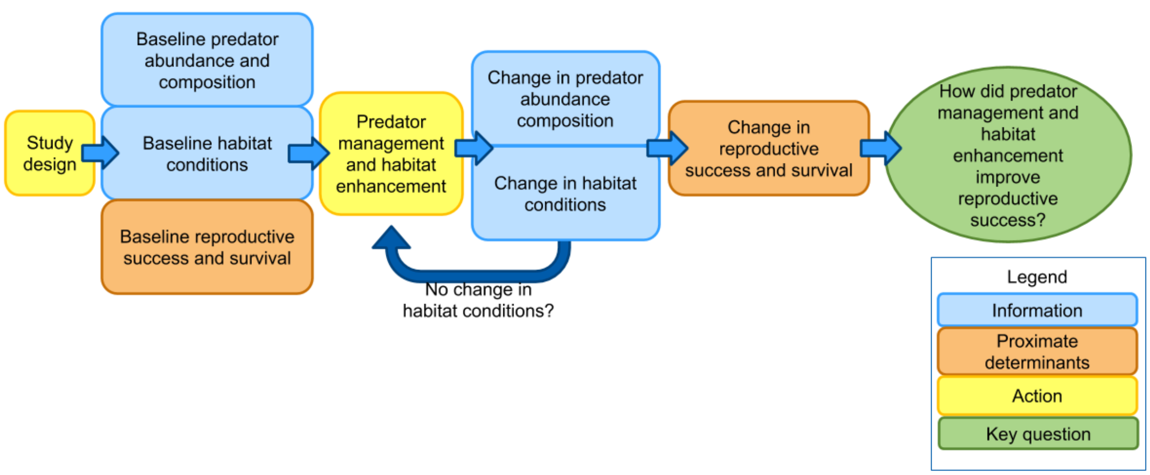

Figure A.2-3. Logic model for designing and implementing studies exploring the effectiveness of predator management and habitat enhancement strategies on improving reproductive success in Western snowy plovers. "Baseline" conditions refer to conditions prior to implementing actions. Depending on the management and enhancement actions being investigated, the studies will likely span multiple years.

The initial step, study design, will describe what information to compile or collect about (1) baseline predator abundance and composition, habitat characteristics, and (2) snowy plover reproductive success and survival. The study design will be written by the PI and will describe important factors that should be controlled for or considered in the analysis. These important factors will likely be identified in the synthesis report that is a product of the logic model in Figure A.2-2 and may include proximity and characteristics of adjacent habitat, especially urban/suburban development and tidal marsh habitat.

The next step is to implement predator management and habitat enhancement at selected sites as part of a designed study. Some actions such as predator control and deterrence could also occur at larger spatial scales and could include collaboration with partners outside the Project footprint. This step will involve deciding which predator species to target and how to implement control or other management. What is the intensity of predator management effort needed to be most effective and efficient? Which sites should be targeted? Which predator species should be targeted and how? What is the consequence of controlling predator X, but not predator Y? It is important to collect information on the management actions themselves as this will help with the evaluation.

These and similar questions are to be addressed in a designed study to allow comparison among sites subject to different actions, such as different levels of predator management and habitat enhancement. If possible, reference sites with no management action or enhancement would also be included.

An important feature of the logic model is that information on predator abundance and behavior is also collected, as well as information on predation rates (including predator identity, where this can be established). Thus, the logic model provides a pathway to analyze the relationship between the management actions and predator abundance/behavior, and how this translates into predation rates, and, ultimately, reproductive success. The goal of the analysis is not to determine if there is any effect of predator management but to characterize the quantitative relationship between management actions (including habitat enhancement) and the response (changes in predation rates and changes in reproductive success), so that management actions can be effective and efficient.

The two logic models presented address reproductive success specifically, which was the Restoration Target of immediate concern. Additional logic models could be developed to consider the “number of breeding individuals” Restoration Target.

Identify Immediate Science Needs

The logic models are used to determine the science needs which can then be inserted into an RFP. In this case study, the authors produced the logic model figures but in the future, the PMT can produce logic model figures for other Restoration Targets, with or without consultation with other experts. The first steps within the logic models represent the immediate science needs. For logic models with fewer steps, such as Figure A.2-2, the entire logic model can represent the immediate science need (e.g., a synthesis of predator management studies).

Immediate Science Needs:

- Synthesis of predator management and habitat enhancement studies.
- Baseline predator information at sites designated for manipulation (“test sites”) and potentially at reference sites. This information may be an index of abundance or simply presence/absence and could involve existing and/or new data.

- Baseline snowy plover reproductive success (nest and juvenile survival) and adult survival at test and reference sites.
- Baseline habitat conditions at test and reference sites and assessment of the surrounding habitat. For the "surrounding habitat," remote sensing or other GIS layers may suffice, but for habitat assessment at breeding sites, on-the-ground or automated (e.g., use of drones) data collection will be needed.

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APPENDIX A.3. MIGRATORY WATERBIRDS CASE STUDY

STEP 2- DEVELOP A KNOWLEDGE BRIEF AND IDENTIFY KEY SCIENCE QUESTIONS

To review, in Step 1, we described the prioritization rationale for the migratory shorebirds and waterfowl Restoration Target as, "Trending positive. Concern that current and additional tidal restoration will cause substantial declines in Restoration Target values." Hereafter, we refer to the "migratory shorebirds and waterfowl" Restoration Target as "migratory waterbirds" and here focus on this group of species during winter and the fall and spring migratory periods only. However, the Restoration Target discussed in this case study does not include all waterbirds such as salt-pond associated waterbirds like grebes and phalaropes because they are covered by their own Restoration Targets. Breeding shorebirds and terns are a high priority as well and are also covered by their own Restoration Targets. In Step 2, we present a high-level summary of the Restoration Target status and background.

Summarize the State of Knowledge

Management Question: How many managed ponds will be needed to meet migratory waterbird Restoration Targets? Which ponds and how should they be managed or modified? What other management will be needed? This question was originally articulated in the AMP and has been modified by the PMT.

First, we review the Restoration Target numeric objectives as identified in Step 1. Note that the original Restoration Targets in the AMP specified migratory shorebirds and diving ducks, but language in the AMP, including the Applied Studies and Key Uncertainties, referred to waterfowl more generally, e.g., "foraging and roosting shorebirds and waterfowl" and we follow that guidance (see, e.g., Tarjan 2019).

Background

The San Francisco Estuary is recognized as a site of hemispheric importance for migratory stopover of shorebirds during fall and spring; the Estuary is equally important for waterfowl, especially during the winter (SF Bay Joint Venture Implementation Plan). In this regard, the South Bay plays a critical role, especially with regard to managed ponds. Managed ponds, which includes former commercial salt ponds, support a great abundance of waterbirds in the fall, winter, and spring periods (De La Cruz et al 2018, Wood et al. 2019), though other habitats are also of value. Because of the dependence of shorebirds, waterfowl, and other waterbirds on managed ponds, several of the Restoration Targets concern maintaining the abundance of species or species-groups during the winter and migratory periods (Trulio et al. 2007, Tarjan 2019). That is, the Restoration Target is not to allow declines below baseline levels (as established in circa 2006). Because conversion of managed ponds to tidal marsh (through levee-breaching) entails a change in habitat type, the critical question for migratory waterbirds is, How can we prevent or minimize negative impacts to waterbirds, such that this and other Restoration Targets are still met? The Case Study addresses this fundamental question.

Migratory shorebirds and waterfowl Restoration Target: Maintain numbers of migratory shorebirds and waterfowl at pre-ISP baseline numbers, if known, or as close to that baseline as can be determined. The Restoration Target, described in the AMP, applied to the entire South Bay, not just the Project footprint (Trulio et al. 2007, pp. 119, 121). This Restoration Target has two metrics: 1) the number of individuals of shorebirds and waterfowl in the Project area (see Tarjan 2019 for details) and 2) the percentage of shorebirds and waterfowl in the South Bay compared to the entire Bay (Trulio et al. 2007, p. 119).

Details for the Restoration Target metrics are lacking in the AMP with respect to which species or guilds should be used and for which time periods, or how the survey results should be analyzed (see Restoration Targets Table in AMP). Guided by the language in the AMP, Tarjan (2019) provides a more detailed and quantitative version of the Restoration Targets in assessing waterbird trends in the South Bay.

Develop a Conceptual Model

The conceptual model lays out the ecological relationships for migratory waterbirds that will determine whether and how Restoration Targets can be achieved, including proximate and ultimate determinants. We reiterate that in this case study, we use “waterbirds” to refer specifically to shorebirds and waterfowl.

Overview: The migratory waterbird Restoration Targets concern the number of foraging and roosting waterbirds during the fall, winter, and spring in the South Bay.

There are five spatial scales of significance with regard to migratory waterbirds:

i. The entire Pacific Flyway
ii. The regional scale of the San Francisco Estuary
iii. The sub-regional scale of the South San Francisco Bay
iv. The Project area within South San Francisco Bay
v. Individual ponds and tidal marshes within the Project area

The Restoration Targets focus on the sub-regional scale (iii), but it is important to consider both broader spatial scales and finer spatial scales.

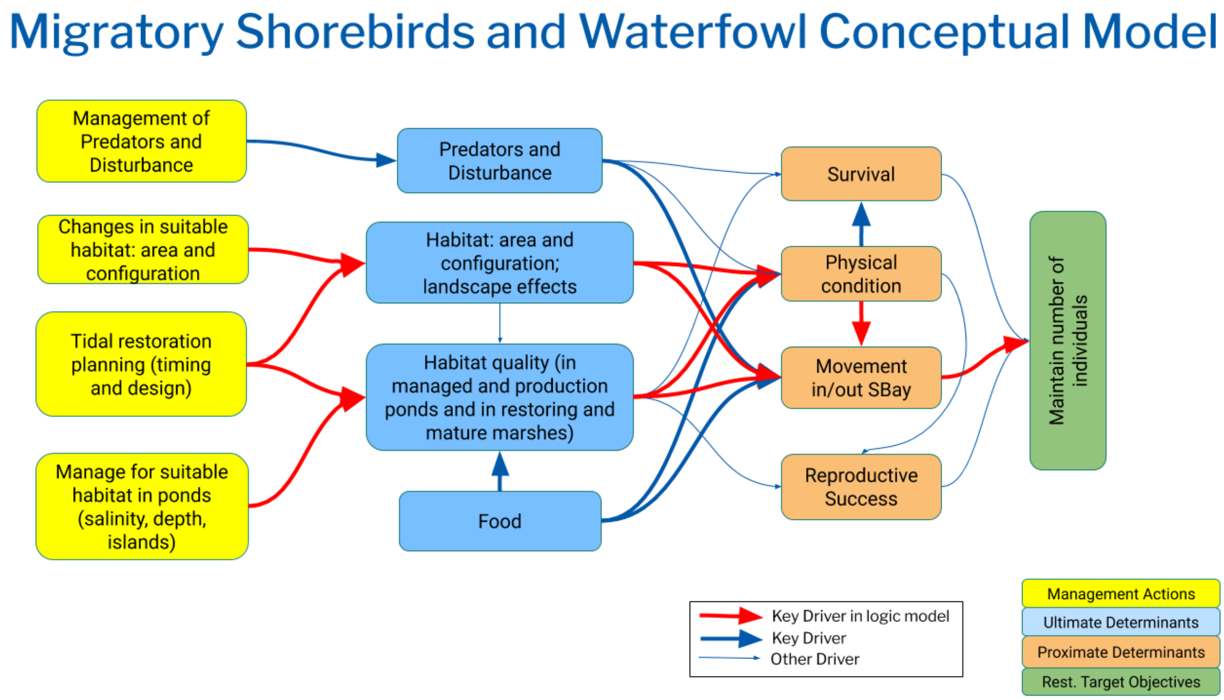

Figure A.3-1. Migratory shorebird and waterfowl conceptual model.

The number of foraging and roosting birds for each species or species groups reflects **two components**:

1. **The abundance (population size)** of individuals for that species or species-group
2. **Decision of where and when to forage or roost**. Here we refer to the behavior of the migratory waterbirds, not just foraging and roosting behavior, but also dispersal.

We restrict consideration of the abundance component to the three broadest spatial scales (i-iii). The decision of where and when to forage is one we consider with regard to the three finest spatial scales (iii-v). Note that spatial scale iii concerns both components. Consequently, the conceptual model mainly focuses on spatial scale iii (the South Bay), but refers to the other spatial scales as appropriate.

Considering component #1:

Number of individuals per species or species-group in the South San Francisco Bay.

This component will reflect <u>three proximate determinants</u>:

- **Dispersal into and out of South San Francisco Bay** (spatial scale iii).
- **Survival of adults and younger age classes**, from one year to the next.
- **Reproductive success** (here assumed to be the production of fledged young).

All three determinants are also highly important for breeding shorebirds and terns (which are the subject of their own priority Management Question). For migratory waterbirds, we discuss these in order of presumed importance:

Dispersal is most broadly relevant of the three proximate determinants to the abundance component. Migratory waterbirds could decide to "migrate through" the South San Francisco Bay and not stop over or over-winter. They may instead be stopping over in other parts of the San Francisco Estuary (scale ii) or other parts of the Flyway (scale i). For shorebirds, for instance, coastal areas could provide stop-over habitat instead of areas within the San Francisco Estuary. For waterfowl, the Delta could provide stop-over or over-wintering areas. We bring up the decision by migratory waterbirds of whether to over-winter or stop-over in South San Francisco Bay, because it may depend on availability and suitability of habitat elsewhere. Thus, even if the quality or quantity of habitat in the South Bay were to increase for waterbirds, if areas outside of the South Bay were to increase in extent or suitability, this could result in a net decrease in the metric of interest, number of foraging or roosting waterbirds, even though habitat quality/quantity may have increased in the South Bay.

Survival of adults and juveniles is likely relevant for species that over-winter in the SF Estuary: low levels of prey and/or high levels of predation during the non-breeding period could lead to low annual survival rates, thus reducing the abundance of such species. For species that only stop over during migration, annual survival rates may also reflect conditions at stopover sites, for example, if body condition is reduced for migratory birds as a result of poor feeding conditions (see below).

Reproductive success must be considered, but by definition, reproduction by migratory waterbirds occurs away from South San Francisco Bay. Instead the Project can consider that favorable conditions on wintering and stopover grounds can have positive effects on the following season's reproductive success which may in turn lead to a greater number of individuals in the following winters. At the same time, the number of waterbirds of a species or species-group might decline precipitously due to reproductive failure caused by stressors outside the South San Francisco Bay (spatial scales i and ii).

<u>**Ultimate determinants.**</u> We identify four ultimate determinants that collectively influence the three proximate determinants, in presumed order of importance.

Prey/food. Migratory shorebirds and waterfowl represent multiple trophic levels. For many waterbirds, their principal prey is invertebrates, either micro- or macro-invertebrates. In addition, dabbling ducks primarily feed on plants. Low levels of prey/food could lead to waterbirds dispersing out of the South Bay or not stopping over (during migration or during the winter). For over-wintering waterbirds, low prey/food levels could impact body condition, which may ultimately influence over-winter survival and reproduction.

Habitat (i.e., physical) conditions. Tidal flats are especially important for shorebirds; if little tidal flat is available this could lead to dispersal out of the area or deciding not to stop over. Salinity and depth of water are especially important determinants of where waterbirds forage and roost (De La Cruz et al. 2018). If no suitable foraging/roosting habitat is available, certain species or species-groups may leave the South Bay or choose not to stop over or over-winter. Here we distinguish between physical aspects of habitat and prey/food, but the former can certainly affect the latter. Still, suitable habitat conditions do not assure or dictate suitable food conditions; hence there is value to separating the two. In the conceptual model we also separate habitat area and configuration as a determinant from that of habitat quality, since different management actions will target each of these (see logic model, below).

Predation. This could potentially affect survival during the winter period as well as during migratory stopovers. Also, presence or activity of predators could lead to dispersal out of South San Francisco Bay or decision to not stop over or over-winter in the South Bay.

Disturbance. Similar to the presence or activity of predators, disturbance by humans and other species could lead to dispersal and to lower foraging success.

Significance of physical condition. While the four ultimate determinants can directly impact survival, dispersal, and reproductive success, these determinants also influence the physical condition of migratory waterbirds. Poor body condition can then lead directly to dispersal out of the South San Francisco Bay, reduced survival, and lower reproductive success on the breeding grounds. Thus, physical condition is an important intermediary determinant, one that can be monitored.

Considering component #2:

Decision of where and when to forage and roost:

Here we do not identify proximate determinants as distinct from ultimate determinants. The following can be considered ultimate determinants, i.e., they are factors that directly determine or influence the decision of where/when to forage and/or roost.

The four factors we list below were also listed above with respect to number of individuals but the focus in that case was the South San Francisco Bay and beyond (spatial scales i-iii), whereas here the focus is the spatial scale of the South Bay and finer scales, especially ponds and marshes within the South Bay (spatial scales iii-v).

Within the South Bay, the primary focus for waterbirds are managed ponds, but commercial salt-production ponds and tidal marsh must also be considered, the latter including mature tidal marsh and recently breached ponds that are in the process of evolving into tidal marsh habitat.

The conceptual model with regard to component #2 considers not just the presence or absence of waterbird species or species-groups, but also their density, especially when foraging. In other words, the number of waterbirds foraging in a particular pond or marsh (e.g., in tidal channels or tidal flats of a marsh), at spatial scale v, depends on: (1) the total number of waterbirds of a species or species-group (see the "abundance component" above, considering specifically the number in the South San Francisco Bay, i.e., spatial scale iii), (2) conditions at that pond or marsh (spatial scale v), and (3) conditions at other ponds, marshes, as well as open water (spatial scales iii and iv).

Determinants:

Prey/food. We consider this to be the primary determinant of where waterbirds forage, though not as important for where they roost. Prey/food will also be closely tied to habitat conditions (see below); but one difference is that prey may vary over finer spatial and temporal scales than habitat. For example, the habitat may not change much over the course of several weeks but the abundance of invertebrate prey may change sharply (positive and negative), due to life cycle, die-offs, etc. The study by De La Cruz et al. (in press) provides insights into the importance of invertebrate prey for waterbirds in the South Bay region (spatial scale iii).

Habitat (i.e., physical) conditions. Salinity and depth of water are the most important factors here, though there are additional factors such as variation in bathymetry and presence of islands in ponds (De La Cruz et al. 2018, De La Cruz et al. in press). Water quality (e.g., DO, water temperature, sediment) is also important. In addition, adjacent land-use is important at the finer spatial scales; thus, not just habitat but habitat configuration. A pond that is adjacent to a tidal marsh has been shown to support higher densities of waterbirds than a pond that is adjacent to another pond; the same is true for tidal marsh use (Stralberg et al. 2009).

Different waterbird groups prefer (or require) different salinity regimes, as addressed in the logic model. Depth of water will also affect foraging decisions and the preferred (or required) depths will differ by species groups. Both of these drivers are amenable to management action and have strong influences on prey/food.

Conditions in tidal marsh should be considered, too. For example, mudflats within or adjacent to a tidal marsh may provide critical foraging areas for shorebirds, just as mudflats outboard of managed ponds are important. Supratidal flats may be especially important to shorebirds with sea level rise.

Predation and disturbance. The presence and/or density of foraging and roosting birds may be influenced by the presence or activity of predators as well as by disturbance (for example by dogs or due to recreational use).

Timing considerations. In addition to considering **where** waterbirds forage and roost, it is also important to consider **when** they forage and roost. The latter refers to both timing and duration. For example, changes in the habitat, whether due to management action or not, may lead to a shorter over-wintering period by migratory waterbirds. Changes in the habitat (including changes in prey availability) could lead to a shift (earlier or later) in timing of stop-over, which can have important consequences. In addition, the timing of the tidal cycle affects availability of foraging habitat; supratidal habitat may become especially important in the future.

Management actions that can influence components #1 and #2.

Habitat conditions in managed ponds, especially salinity and water depth are the two dimensions of habitat suitability that are most important to maintain diversity and abundance of waterbirds. Water depth can be influenced through water control structures; it reflects “water level” but also bathymetry. Thus, variation in bathymetry can serve to provide a range of water depth, even within the same pond. Islands associated with ponds also play an important role (De La Cruz et al. 2018).

What is challenging is that different waterbird groups require different salinity levels and depths; sometimes at different times of the year (e.g., during fall migration vs during the winter), but sometimes at the same time. Nevertheless, management actions can target different guilds at different times of the year.

Abundance and availability of prey (invertebrate and vertebrate, as well as biofilms) is also important with respect to waterbird diversity and abundance, but this is less amenable to direct management action. Instead, prey display a correlated response to habitat conditions and how they change (e.g., salinity and water depth; see above). While some management actions could affect habitat conditions, others could target prey directly, such as prevention of anoxic episodes.

Habitat conditions in marshes (especially water depth and extent of vegetation), including restoring marshes (i.e., breached ponds). The younger the marsh (i.e., the more recent the breach) the more waterbirds are supported (Stralberg et al. 2009, De La Cruz and Casazza 2019). An additional factor is the availability of channels within a marsh, especially at high tide. The availability of tidal flats (created during the early restoration process) within a marsh is important, as are tidal flats in managed ponds and on the outboard side of ponds.

Predation or the abundance/activity of predators; disturbance. Management actions can target reduction of predators, predation, or disturbance. For example, by providing cover from predators.

Identify Key Science Questions

There are three sets of key science questions to address the management question concerning the managed ponds needed to meet waterbird Restoration Targets (how many ponds? which? how much total area?) and, just as importantly, how should they be managed? The first two sets of questions lead us to the third overarching set of questions.

1. How do migratory waterbirds use tidal wetlands, especially restoring marshes (former ponds that have been breached) and also tidal flats? Waterbird use of tidal wetlands will change as the habitat evolves from a breached pond to a tidal flat and ultimately to vegetated marsh. How does landscape configuration affect this? How will climate change affect restoring marshes, and thus impact waterbirds?

2. How does the distribution and abundance of foraging and roosting waterbirds vary with pond and landscape characteristics, and in relation to management of ponds and the surrounding landscape? Use of managed ponds by migratory waterbirds cannot be understood at a pond by pond level: the surrounding habitat will be changing (see Question #1, above) and this will change the use of ponds. In addition, we need to consider management activities that can benefit foraging and roosting waterbirds, such as reduction of predation and disturbance and enhancement of food availability.

Information addressing the above two questions will feed into the following overarching question for migratory waterbirds:

3. How are migratory waterbird populations in the South Bay expected to respond as restoration proceeds under different restoration scenarios and management scenarios? What restoration and management plans can provide the greatest likelihood that Restoration Targets can be met given the conversion of ponds to tidal wetlands and the impacts of climate change?

Answering the above requires synthesizing information at the scale of the entire South Bay, but this can be informed by studies that have been completed or ongoing in the North Bay and Suisun.

STEP 3- DEVELOP LOGIC MODELS AND IMMEDIATE SCIENCE NEEDS

Develop Logic Models

The logic model presented addresses the main science question of how to plan tidal restoration and implement pond management to maximize the number of migratory shorebirds and waterfowl using Project habitat, thus meeting Restoration Targets.

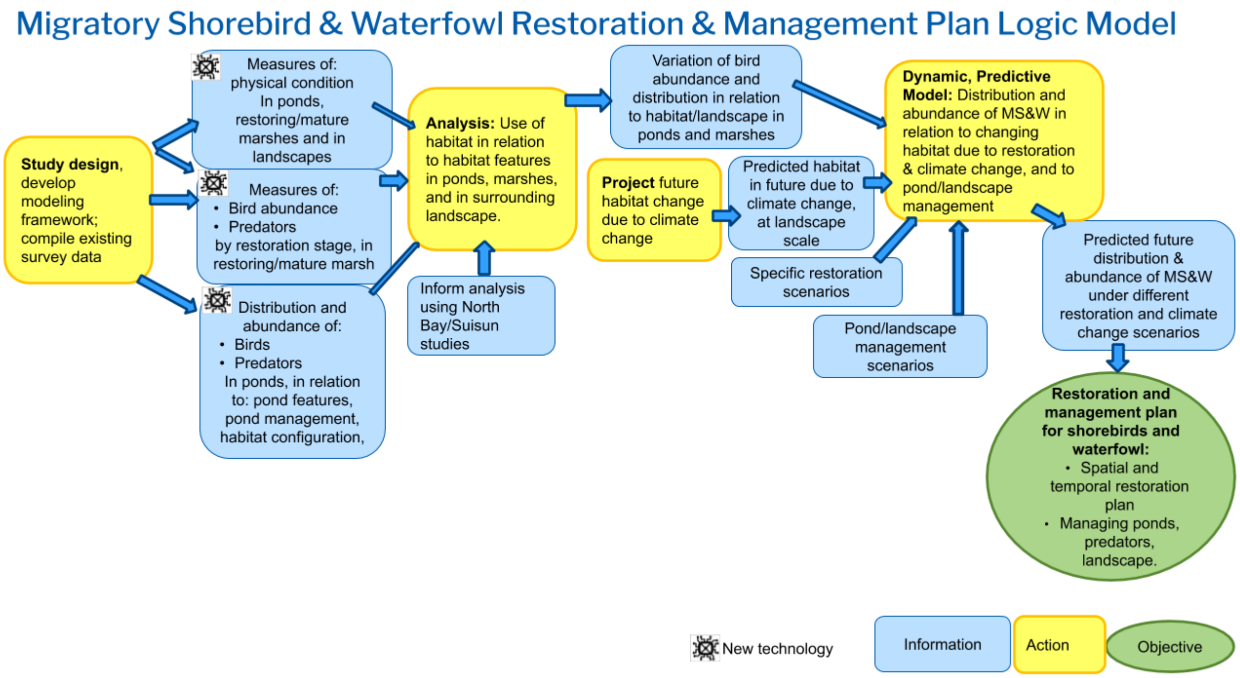

Figure A.3-2. Overarching logic model to address the main management question (green oval) of how to plan tidal restoration and implement pond management to maximize the number of shorebirds and waterfowl using Project habitats. Actions shown in yellow; information collected or produced shown in blue. Opportunities for using new technology to collect data are indicated.

The centerpiece of the logic model is a predictive and synthetic model to guide restoration planning as well as management of ponds and surrounding landscape. The model incorporates the evolution of habitat due to restoration, impacts of climate change, and the influence of management practice on the distribution, diversity, and abundance of migratory shorebirds and waterfowl. To complete the model requires a sequence of steps as illustrated in Figure A 3-2.

The first step concerns developing the study design for implementing the logic model. This includes designing field studies as needed (where, when, what), as well as compiling available information that will inform the subsequent statistical analysis and modeling. Doing so will also identify data gaps. The first step also includes developing the modeling framework; this includes the structure of the model, its scope, temporal resolution, etc. This step just concerns developing the model framework and not the specific information, to be obtained later.

The next phase involves data collection (new data) and data compilation (already collected data). Information on physical conditions in tidal wetlands (tidal flats, marshes), managed ponds, and surrounding landscape is needed. This includes information on degree of vegetation, availability of tidal flats and tidal channels, inundation, etc., and provides an opportunity for the use of new technology, in addition to established technology, such as telemetry. Information on water depth, salinity, and metrics of water quality needs to be compiled but there are opportunities to coordinate with water quality studies (Appendix A.5). Information on distribution and abundance of migratory waterbirds in ponds is extensive and would be updated. However, there is much less information on the use of habitat by migratory waterbirds in breached ponds and in marshes as well as tidal and supratidal flats. The final component is information on predators and level of disturbance.

To obtain critical information at broad spatial scales, there is a need for improved monitoring methods for surveying waterbird use of restoring (i.e., breached) ponds, because access to restored ponds is difficult. UASs may provide a good means to obtain this information and would be part of the logic model. New technology may also be able to provide information on predators and disturbance, which is difficult to collect otherwise. Combining established methodology (field observers and telemetry) with novel methods will be necessary.

Information will come from two types of studies: (1) analysis of time-series (same locations surveyed across years), where such studies have already been pursued, and (2) from comparisons of ponds and restoring marshes that are at different points along the timeline of restoration.

The next step is to analyze the compiled data at multiple spatial scales (both the individual marsh or pond and the larger landscape to identify the determinants and influences on distribution and abundance of the migratory waterbirds species and species groups of interest, focusing on habitat characteristics and the surrounding landscape. The analysis will address both spatial (at multiple scales) and temporal patterns (within and between seasons). Here it will be important to integrate data and findings from the North Bay and Suisun.

Completion of the analysis will then provide the basis for development and implementation of a predictive model of how the distribution and abundance of migratory waterbirds is expected to change as habitats change, due to conversion of ponds to tidal wetlands, the evolution of tidal wetland habitat, and impacts from climate change. Pond management scenarios (e.g., regarding salinity and water levels) must also be included.

To carry out such predictive modeling of change over time under different scenarios requires four types of input: 1) information on how habitat will change under different restoration scenarios; 2) projections of climate change impact on tidal and nontidal wetland habitat; 3) quantitative relationships of migratory waterbird abundance and distribution in relation to habitat and landscape features (habitat features, habitat configuration, etc.); and 4) how these relationships may be modified due to influences of predators and disturbance, which may be the subject of management action.

The dynamic predictive model will then be used to address the question of how can Restoration Targets for migratory waterbirds be most effectively and efficiently achieved and with what certainty of outcome. The model will consider different restoration planning scenarios (e.g., differing with respect to the number and timing of breaching ponds for marsh restoration), as well as management scenarios (e.g., with regard to water level, salinity, and presence of islands), while incorporating projected climate change impacts.

One strength of the modeling is that it provides predictions of change over time, which can be directly assessed. Comparing predicted change to observed change can validate the model and lead to improvements while also providing important monitoring benchmarks. Comparison of predicted and observed changes will enable managers to understand and react to changes in population that are observed, as well as to refine our understanding. Information on predicted change over time can be used to improve the sampling design of data collection to be efficient yet powerful.

Spatial scale: Data collection and modeling will need to take into account multiple spatial scales, noted above. With regards to modeling, the scope of the model described above must consider the entire South Bay. Within that scale are parcels of pond or marsh, each of which will be changing over time due to habitat evolution, management, and climate change. In addition, some areas will be intertidal mudflats or subtidal but in the future may transition to another habitat stage. The configuration of ponds, marshes, mudflats, and subtidal areas must be considered in the modeling. The larger spatial scales of the entire Estuary or the entire Pacific Flyway though not explicitly modeled, will provide context and allow for comparison. Thus, the observed and projected abundance of specific waterbird species groups can be compared in the South Bay vs the North Bay, to the extent possible, and such a comparison is one of the metrics stated in the AMP.

Identify Immediate Science Needs

Immediate, short-term science needs include the following:

- Compilation and assessment of relevant data for birds and physical features at multiple spatial scales throughout the South Bay, and at different temporal scales (short-term vs long-term data; within and between years; etc.), for tidal and non-tidal habitat. This would include information on relevant management practice in the past and at present.
- Evaluate the above to identify data gaps.
- Develop field studies to address data gaps and inform the modeling.
- Compile relevant baseline information into time series.
- Develop initial modeling framework. This will depend, in part, on availability of data, assessed as above.
- Evaluate and determine how to incorporate findings and data from the North Bay and Suisun. This might best be facilitated through a regional workshop, as has been suggested.
- Investigate how to collect data, where there are major challenges (e.g., in breached ponds), at multiple spatial scales, using novel technology as needed.
- Compile information on projected impacts of climate change; determine how to best incorporate these.
- Compile information on restoration plans and management practices that can and should be assessed in the modeling.

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APPENDIX A.4. SEDIMENT CASE STUDY

STEP 2- DEVELOP A KNOWLEDGE BRIEF AND IDENTIFY KEY SCIENCE QUESTIONS

Summarize the State of Knowledge

Management Question: Will additional tidal marsh restoration be successful with sea level rise in terms of meeting Restoration Targets for desired marsh elevation?

Background

The restoration actions conducted during Phase 1 of the Project have largely met or exceeded expectations of vertical accretion and are on pace to meet marsh formation Restoration Targets. However, the priority management question identified in step 1 (Appendix A.1) is whether future tidal marsh restoration projects will achieve similar success given accelerating sea level rise and changing sediment dynamics. A synthesis of recent science was included in the Sediment Dynamics chapter of Wood et al. (2019), and how climate change may affect sediment dynamics and impact intertidal habitats was synthesized in Hayden et al. (2020).

Restoration Targets as laid out in AMP

The Restoration Target related to the prioritized management question is:

- Accretion rate of the restored ponds is sufficient to reach [and maintain] vegetation colonization elevations

Develop Conceptual Model

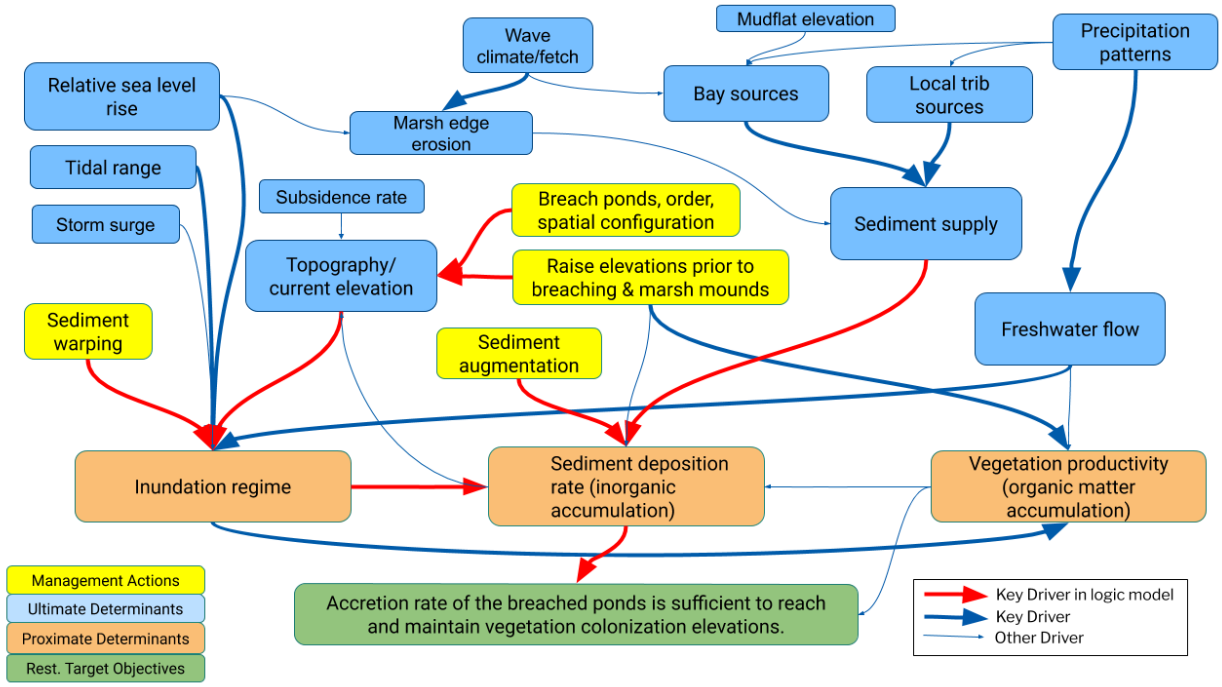

Figure A.4-1. Conceptual model for marsh accretion, modified from Lowe and Bourgeois (2015). Ultimate determinants (blue boxes) to the proximate determinants (orange boxes) and management actions (yellow boxes) that are designed to achieve and improve Restoration Targets (green boxes). Arrows show connections between determinants, management actions and Restoration Targets with red connections highlighted in the logic models (below). Thicker arrows indicate key drivers. Temporal changes and feedback loops are not shown, but are important to consider (e.g., relative importance and relative rates of drivers will change through time, with feedbacks as the marsh accretes and elevations change, and with climatic changes [e.g., sea level rise]).

The restoration target for this management question is that accretion rates in restored ponds should be sufficient to achieve and maintain vegetation colonization elevations. Marsh accretion rates are largely determined by (1) the elevations of ponds when tidal flows are initiated and (2) suspended sediment concentrations (Stralberg et al. 2011). We lay out a conceptual model that includes additional factors that the Project may need to consider (Figure A.4-1), which was derived from the 2015 science update to the Baylands Ecosystem Habitat Goals Project (Lowe and Bourgeois 2015).

There are still relatively high levels of uncertainty over the sources for sediment in the South Bay and how sediment supply is changing over time. “Bay Sources" include (1) sediment delivered to the Estuary from the Delta, (2) sediment transported and redistributed locally within the South Bay, and (3) sediments transported into the Estuary from the ocean (expected to be relatively unimportant for the South Bay). Estuarine circulation, driven largely by freshwater input from the Delta, also determines whether there is net sediment flux from the Central Bay into or out of the South Bay. Science Synthesis workshop participants suggested that more precisely understanding the provenance of sediment in the South Bay could improve predictions of future changes in sediment supply to the South Bay. However, factors that affect sediment supply to both the Bay and local tributaries, such as upland land use and precipitation patterns, are largely beyond the control of Project management and how those factors are expected to change in the future are also highly uncertain. Additionally, there isn’t yet sufficient monitoring of sediment in local tributaries to determine current trends and thus limiting our confidence in future predictions.

In general, there are several physical drivers determining sediment deposition and ultimately marsh accretion. Relative sea level, tidal range, fresh water flows and current elevation largely determine the inundation regime of intertidal habitats. Precipitation patterns (and upstream water management) dictate freshwater flows into the system and have an effect on the source of sediment in the South Bay. For example, in high rainfall years, the Central Bay can become fresher than the South Bay, which causes an inverse estuarine salinity gradient that enhances export of sediment out of South Bay, reducing sediment availability in the Project area (McCulloch et al. 1970, Shellenbarger et al. 2013). The amount of suspended inorganic sediment within the water column that moves over intertidal habitats during the tidal cycle has a strongly positive correlation with how much sediment is deposited on the surface during each tidal cycle. Areas at lower elevations will be inundated more frequently and for longer periods of time which will allow more time for sediment to settle and thus experience higher rates of inorganic sediment deposition than higher elevations (Lowe and Bourgeois 2015). However, as the marsh surface approaches vegetation colonization elevations, the vegetation helps trap additional inorganic sediment and contributes organic sediment through decomposition bolstering higher productivity leading to slightly higher accretion at these elevations. Higher amounts of freshwater flows can increase vegetation productivity.

Since the major drivers of marsh accretion are initial elevations and sediment supply, management actions that affect these parameters can potentially have the greatest influence over marsh accretion rates during restoration. Prior to restoration, managers can raise the elevations of ponds by importing sediment from other sources such as dredge spoils. Recently some projects are experimenting with the creation of mounds prior to restoration that are intended to not only increase initial elevations but more importantly to help increase sediment deposition. In ponds that have functional water control infrastructure, a technique referred to as ‘sediment warping’ can be used to bring in added sediment from the open Estuary. In this technique, water enters a pond during high tides and is held in the pond to let the sediment settle. Once the sediment has settled, the water is discharged during a low tide cycle or allowed to evaporate. Greater accretion rates with this technique are likely in areas with the greatest naturally occurring suspended sediment concentrations.

Once ponds are breached there are several other potential sediment augmentation strategies that the Project could consider. Direct sediment placement involves applying a thin layer of sediment directly to marsh surfaces to increase accretion rates while minimizing impacts to marsh fish and wildlife. Indirect sediment placement (also referred to as ‘strategic placement’) involves the delivery of sediment to mudflats adjacent to restoring marshes and timed so that tidal cycles will deliver the sediment to the marsh surfaces.

In all cases of sediment augmentation, managers need to consider several factors. External sediment supplies of suitable characteristics (e.g., grain size and composition) must be available at times that correspond to Project needs. In addition, there needs to be sufficient infrastructure to deliver the sediment to the restoration site which can be a challenge given the location of sites, i.e. shallow bay waters limiting boat access. There are also permits that would be required that result in additional costs and other challenges. Finally, the cost of the sediment itself and the costs for delivery can make any of the strategies prohibitive.

Identify Key Science Questions

Improving our predictions of changes in the supply of sediment coming into the South Bay would raise our confidence in selecting appropriate restoration management strategies. Improving the monitoring of sediment flux within the South Bay and tributaries is a high science priority but there are several regional efforts that are working on addressing this need (e.g. the Bay Regional Monitoring Program, see synthesis in Wood et al. 2019). We recommend that Project staff engage in those efforts where feasible but shouldn't use its limited resources to try and lead these efforts. In the meantime, the studies below can all use scenarios of changes in sediment supply to assess how changes in sediment supply could alter the outcomes from management actions.

Key science question 1- What is and what will be the spatial variability in suspended sediment concentrations and accretion rates among and within complexes?

Projects that can best take advantage of naturally occurring sediment will necessarily reduce the costs and potentially increase the chances of achieving Restoration Targets successfully. However, there is still considerable uncertainty around spatial patterns of sediment concentrations and composition in the South Bay. Prior studies indicate that suspended sediment concentrations within the Eden Landing and Ravenswood complexes are likely to be lower than the concentrations within the Alviso complex and thus accretion rates observed in the Phase 1 Alviso Pond restorations may not be transferable to other complexes (Jaffe and Foxgrover 2006a and b, Foxgrover et al. 2004). Therefore an initial study question that increases the understanding of the spatial variation in suspended sediment concentrations and resulting marsh accretion rates across the South Bay is a priority.

Key science question 2- What is the relative effectiveness of different sediment augmentation measures?

We assume that it is highly unlikely that sediment supplies will increase substantially in the future and with increasing sea levels, meeting the restoration target in the AMP will likely require some active sediment management. Whether the costs of the various sediment augmentation measures are worth the investment may depend on how well any of the measures actually increase accretion rates and thus shorten the time to marsh formation and increase chances of persistence. Although these methods have been tested in other areas, pilot studies of each of the measures could reduce uncertainty around how well each method actually works. Initial feasibility studies could potentially rule out certain methods that are clearly prohibitively expensive. The results from pilot studies would then lead to an overall sediment management strategy that applies one or more of the measures tested.

Key science question 3- Can the breaching of additional ponds beyond those slated for restoration during Phase 2 reach Restoration Targets?

Projections of marsh accretion from Stralberg et al. (2011), Takekawa et al. (2013), Schile et al. (2014), and the Goals Project (2015) indicate that the ponds planned for restoration during the next phase of the Project should be initiated as soon as possible to increase likelihood of achieving Project success. Understanding spatial patterns of sediment concentrations and how that translates to accretion (Key Question #1), and how well sediment augmentation strategies function (Key Question #2) can enable the development of long term restoration plans for other ponds within the Project and for other ponds in the South Bay.

STEP 3- DEVELOP LOGIC MODELS AND IMMEDIATE SCIENCE NEEDS

Develop Logic Models

Predicting where both sediment augmentation strategies and restoration itself will be most effective largely depends on the locally available suspended sediment. The first logic model below describes a pathway of studies to better understand the spatial variability in suspended sediment concentrations in the South Bay (Figure A.4-2), addressing key science question #1.

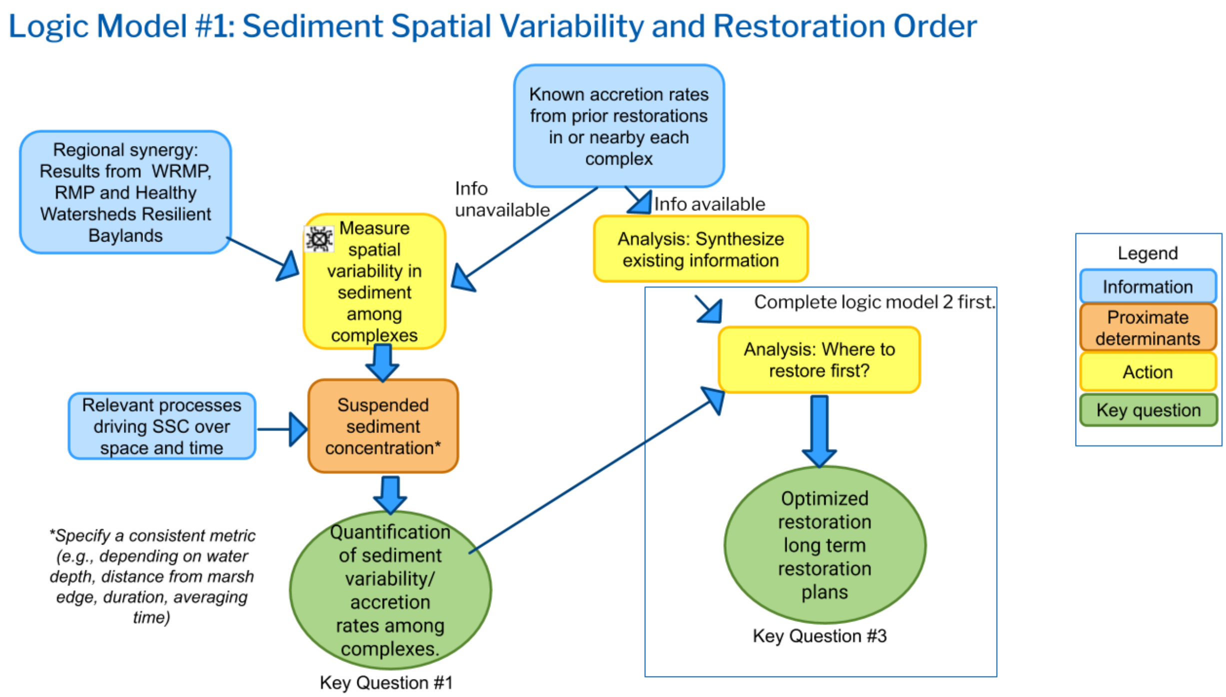

Figure A.4-2. Logic model 1 showing studies to assess the spatial variability of sediment across the South Bay, addressing Key Science Question #1. A second analysis that will inform the order of restoration within complexes (addressing key science question #3) is also shown but would be completed following the studies shown in logic model 2 (see below).

Based on synthesis of existing science (Wood et al. 2019), patterns of the spatial variability of sediment concentrations in the South Bay, particularly the differences between the far South Bay and the areas around the Eden Landing and Ravenswood complexes, are still not well described. However accretion rates at restoration projects already completed at Eden Landing and nearby the Ravenswood complexes (Bair Island) could provide indications of accretion rates of future projects if this information is available. Thus our logic model shows an initial split depending on whether sufficient information is available to understand variation in accretion rates among complexes or not. If the information is available it may need to be synthesized but science could then turn to other questions (logic model 2 below).

If sufficient information is not available, studies that quantify the variability in sediment availability are needed. These studies should be able to leverage results or ongoing work by the Wetland Regional Monitoring Program (WRMP), Bay Regional Monitoring Program (RMP) and the Healthy Watersheds Resilient Baylands project led by SFEI. Additionally, they may be able to take advantage of remote sensing for sediment mapping and quantification. The final metrics reported will depend on the specifics of the study (e.g. suspended sediment concentrations in the open bay vs. accretion rate on marsh surface). If the Project wants predictive ability, there is a need to relate suspended sediment concentration (SSC) to actual marsh accretion, and it would be important to account for several key spatial and temporal factors that influence SSC (e.g., depth, distance from marsh edge, duration, and averaging time), as well as factors that affect sediment transport onto the marsh plain (e.g., wind and wave direction and tides). A final consideration is the influence of neighboring restoration (e.g., breaching deeply subsided ponds) potentially reducing SSC for other nearby sites.

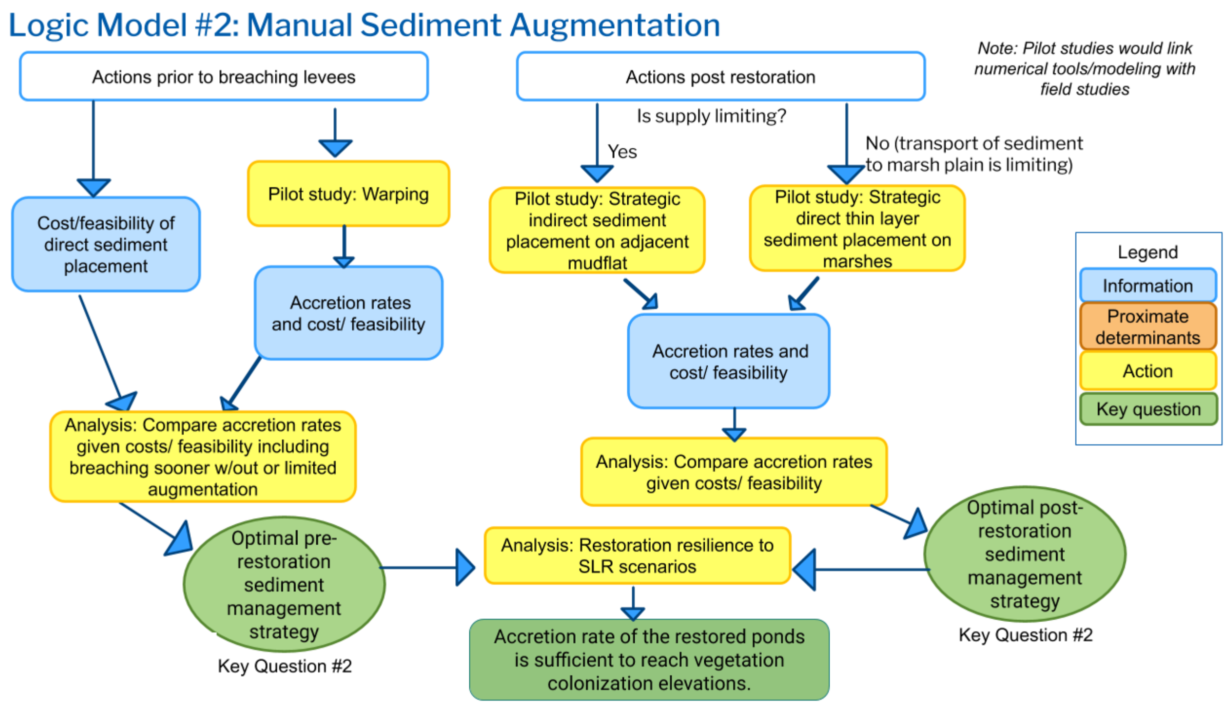

Figure A.4-3. Logic model 2 illustrating a set of studies to optimize manual sediment augmentation pre- and post-restoration (addressing key science question #2). Implicit in the model is the need to determine that augmentation actions are necessary (i.e., natural sediment delivery will be insufficient to achieve Restoration Targets), based on conclusions from logic model #1. Pilot studies would link numerical tools/modeling with field studies.

The second logic model lays out a set of studies that could be used to guide a plan for sediment augmentation at Project restoration sites (Figure A.4-3), addressing key science question #2. Implicit in the model is that it has first been determined that augmentation actions are necessary (i.e., natural sediment delivery will be insufficient to achieve Restoration Targets), based on conclusions from logic model #1. The logic model is broken up into a set of studies that look at management actions that can be taken prior to restoration and those that can be used post-restoration. The primary uncertainty around raising elevations pre-restoration with external sediment is with feasibility (including costs and permit acquisition). Therefore feasibility studies could rule out whether this is a measure that is worth additional investment. Pilot studies could be implemented to measure accretion rates of sediment warping studies at each of the restoration areas. Once completed, an analysis could be conducted to compare accretion rates from earliest possible breaching, raising initial elevations by sediment placement, and through sediment warping techniques to determine what measure or combination of measures leads to the highest elevations over a given time period.

Other pilot studies (including use of numerical tools/models in combination with field studies) could measure accretion rates as well as assess other benefits and impacts from direct and indirect sediment placement, building from previous work done in the Estuary in partnership with the US Army Corps of Engineers (e.g., work by J. Lowe, M. MacWilliams, and others), as well as lessons learned from other regions like the Chesapeake, Louisiana, and southern California. A key factor to consider is whether supply of sediment is limiting marsh accretion, or whether transport processes are limiting the movement of sediment onto the marsh plain. The results from these pilot studies, including feasibility, could then inform an analysis designed to find an optimal sediment placement strategy.

Once completed, an analysis could look at modeled projections for the application of pre- and post-sediment strategies to assess whether marshes are likely to be resilient to scenarios of future sea level rise.

The optimized sediment management strategy and assessment of spatial variability of sediment could then be used to design a long term restoration plan beyond Phase 2 to best achieve Restoration Targets for the Project (Figure A.4-2). Thus we propose a sequence for the key study questions that both informs the restoration in Phase 2 while also guides other long term restoration.

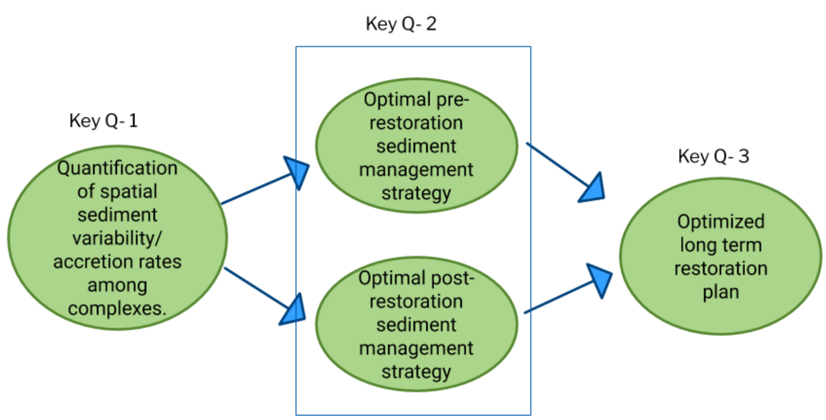

Figure A.4-4. Key science questions for sediment marsh accretion management and proposed sequence for science studies.

Identify Immediate Science Needs

Immediate, short-term science needs include the following:

- Assess whether information on accretion rates from prior restoration is available and sufficient to estimate the spatial variability of suspended sediment in the South Bay.
- Review results from the Healthy Watersheds Resilient Baylands study. Identify whether monitoring and studies conducted by the RMP and WRMP will sufficiently assess the spatial variability of sediment in the South Bay. Assess whether additional monitoring is needed and if so how much.
- Conduct feasibility studies for direct sediment placement in any of the Phase 2 restoration ponds.
- Assess candidate sites for pilot sediment warping studies and potentially implement studies.

- Assess whether existing models or studies can address whether sediment supply or transport from adjacent mudflats limits accretion rates within the South Bay. Consider feasibility of pilot studies for either indirect sediment placement on adjacent mudflats or thin layer sediment placement on restoring marshes.

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APPENDIX A.5. MERCURY/WATER QUALITY CASE STUDY

STEP 2- DEVELOP A KNOWLEDGE BRIEF AND IDENTIFY KEY SCIENCE QUESTIONS

Summarize the State of Knowledge

Management Questions: Can additional ponds be restored with fully tidal connections with minimal risks from methylmercury (e.g., A8 ponds) or impacts to other water quality standards? Can we continue to manage remaining ponds without creating adverse water quality outcomes?

Background

Recent studies and data from throughout the San Francisco Estuary suggest that the continued management of Project ponds and the restoration of tidal marsh through the Project can lead to water quality and methylmercury issues. The Project largely has potential to affect water quality and methylmercury production through the design of tidal restoration projects and through the designs to enhance and manage the remaining ponds. Results from Phase 1 studies do indicate that methylmercury impacts from restoration are short term and there is an expectation that this will be true for Phase 2 restorations as well. However, best practices for managing the remaining ponds to limit adverse water quality conditions while providing high quality fish and wildlife habits are still in development. Therefore, we recommend that the key science questions addressed initially in the Phase 2 science program focus on informing these the development of best management practices across the range of environmental conditions in the South Bay. A synthesis of recent science was included in the Mercury and Water Quality chapters of Wood et al. (2019), and how climate change may affect the Project's ability to achieve its Objectives was synthesized in Hayden et al. (2020).

Restoration Targets as laid out in AMP

The Restoration Targets related to the prioritized management question are:

- Water quality parameters in ponds meet RWQCB standards
- South Bay water quality will not decline from baseline levels
- DO levels meet Basin Plan Water Quality Objectives
- Nuisance and invasive species of algae are not released from the Project into the Bay
- Algal blooms do not cause low DO within managed ponds
- Levels of Hg in sentinel species do not show increases over baseline conditions
- Levels of Hg in sentinel species are not higher in target restoration habitats than in existing habitats

Develop Conceptual Model

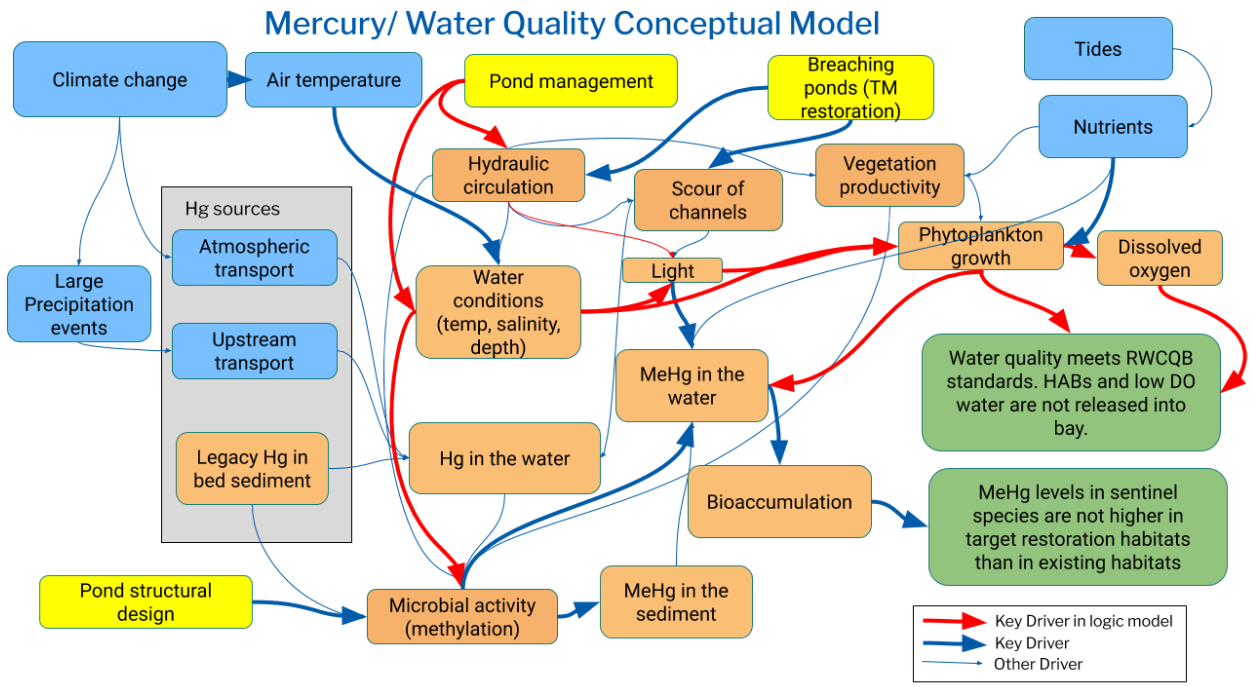

Figure A.5-1. Conceptual model for mercury and water quality. Ultimate determinants (blue boxes) to the proximate determinants (orange boxes) and management actions (yellow boxes) that are designed to achieve and improve Restoration Targets (green boxes). Arrows show connections between determinants, management actions and Restoration Targets with red connections highlighted in the logic models (below). Thicker arrows indicate key drivers.

Studies conducted through Phase 1 of the Project have largely found that increases in methylmercury production and resuspension/recirculation following earthwork or other construction activities in areas with legacy mercury contamination resulted in short term and generally localized impacts to biota (fish and birds). The Project has control of methylmercury production with respect to tidal restoration through the design of breaches (size and placement) and the engineering of channels within the restored ponds. However, there is uncertainty with the amount and distribution of legacy Hg in the sediments in and around potential restoration sites. Pond restorations are designed to limit adverse impacts from the scour of connected channels and the ponds themselves thus reducing, but not eliminating the mobilization of mercury from these habitats. Additionally, more tidal flushing is ultimately better at reducing methylmercury production than stagnant conditions that lead to MeHg build-up, simply due to dilution and exchange. Given lessons learned from both Phase 1 projects and restoration projects in other parts of the estuary, such as the tidal marsh restoration in the Napa salt ponds (Wood et al. 2019), we expect that restorations planned during Phase 2 of the Project will likely have similar levels of impact as past projects, e.g. short term spikes in mercury mobilization and methylmercury production that will decline relatively quickly.

Pond management may have the ability to lessen the production of methylmercury in the remaining ponds. We have evidence that the management of hydraulic conditions within the ponds can limit the production of algae and other organic matter while also reducing the drying of contaminated sediments both of which can lead to the production of methylmercury. However, there is a gradient of water conditions within ponds throughout the Project and we don't yet know what combination of conditions (water temperature, salinity, depth, etc.) best limits the production of methylmercury while also creating high quality habitat for target species. An effort to address this uncertainty is underway in Suisun and is explicitly testing a set of best management practices for managed ponds (Gillenwater et al. 2019).

It is worth noting that our conceptual model does not provide details on how methylmercury bioaccumulates up food webs. This is not to dismiss important ecological processes that could have an impact but rather that we are focusing on physical processes that the Project has the ability to manage. Ideally, we would understand how changes in abiotic conditions result in changes in ecological communities within pond and marsh habitats providing better insights on the mechanisms that drive bioaccumulation of MeHg in the food web. However, it is not the role or intent of the Project to do research to understand and manage the interactions between abiotic conditions and ecological communities. Thus, it is not a science priority for the Project to lead the scientific studies investigating all of the ecological changes that would result in changes of management. Still, if the Project could support these studies in other ways, results could enhance the understanding of how management affects the whole system.

The management of the water conditions within the ponds can also have an effect on water quality beyond the production of methylmercury. Increases of nutrients and warmer waters will tend to lead to higher phytoplankton productivity which can result in lower dissolved oxygen (DO) conditions within ponds and bay waters through the decomposition of the algae that is deposited in the benthos. There is uncertainty as to what the optimal temperatures are for phytoplankton growth (Kimmerer 2015), but warmer temperatures do drive microbes involved with nutrient recycling that can lead to increasing blooms with warmer water temperatures. The shallow South Bay waters result in warmer water temperatures relative to other parts of the estuary. Higher air temperatures in late spring through early fall can lead to conditions that promote phytoplankton productivity and thus potential for low DO in pond waters that then get released in adjacent channels. Management that can decrease water temperatures within ponds and otherwise limit phytoplankton productivity could mitigate the potential for low DO excursions. Reducing primary productivity within the ponds will also reduce the export of organic material to adjacent channels and sloughs, thus reducing water quality impacts to those waters as well. Finally, warmer water temperatures and high nutrient waters are also conducive to harmful algal blooms (HAB). Increasing temperatures and improving circulation should also reduce the potential for HABs within the ponds. As with management of pond conditions to limit methylmercury production, we don't know what the optimal conditions are that can limit phytoplankton growth and HAB while still meeting habitat objectives.

An important finding from the Science Synthesis Report (Wood et al. 2019) and discussions with focus group participants was that many of the parameters that should be monitored to quantify MeHg production and other water quality factors are the same. Surprisingly, the scientists in these fields have not historically coordinated monitoring efforts. Thus coordination could be an important synergy that could result in more efficient monitoring.

Climate change will lead to changes in conditions that could exacerbate water quality conditions within the Project. Climate models consistently project increasing air temperatures in the South Bay thus improving the conditions for phytoplankton growth and HABs. Not only will air temperatures lead to increasing water temperatures but these increases in water temperature will occur earlier in the spring and last later into the fall. Thus ponds will be under greater pressure for water quality issues for longer periods of each year.

Identify Key Science Questions

The management of ponds and the design of pond restorations are the actions that the Project staff can take that most influence the production of methylmercury and affect other water quality parameters. Thus improving our understanding of how management can affect water quality will most directly lead to improved water quality at the Project scale.

Key science question 1: What factors within managed ponds help constrain the production and bioaccumulation of methylmercury in biosentinel species and production of phytoplankton?

Water conditions such as nutrient concentrations, temperature, salinity, depth, and sediment concentrations can affect the production of methylmercury though changes in microbial activity and through the changes in phytoplankton productivity. In addition, changes in phytoplankton productivity will affect levels of DO in the water and will affect the probability of HABs occurring. Understanding what conditions both limit methylmercury production and phytoplankton production will inform pond management activities throughout the Project.

The Restoration Target related to methylmercury production is that: *Levels of Hg in sentinel species are not higher in target restoration habitats than in existing habitats* and *Levels of Hg in sentinel species do not show increases over baseline conditions*. Answers to key science question 1 will provide recommendations for the management of pond habitats that can reduce methylation but ultimately, we will need to know if changes in management result in increases in methylmercury bioaccumulation in biosentinel species.

Key science question 2: What changes in pond management and landscape composition would result in a change in water quality and bioaccumulation of methylmercury in target biosentinel species?

The Project can apply recommendations based on the findings from key science question 1 to assess whether the management actions result in changes in water quality and the bioaccumulation of methylmercury in target biosentinel species. As noted above, the bioaccumulation of MeHg in target biosentinel species depends on how changes in abiotic factors affects food web structure, but since the Project only can directly manage the abiotic conditions and the Restoration Targets are focused on biosentinel species, it isn’t necessary for the Project to investigate how MeHg moves through the food web as long as the response of MeHg in biosentinel species is consistent to management actions.

Key science question 3: How will climate change drive changes in water quality in and around the Project area?

Understanding the vulnerability of the Project to degraded water quality from climate change can inform long term management and restoration decisions. If future climate will cause longer periods with potential for lower water quality, the Project may need to alter its management to adapt to these changes.

STEP 3- DEVELOP LOGIC MODELS AND IMMEDIATE SCIENCE NEEDS

Develop Logic Models

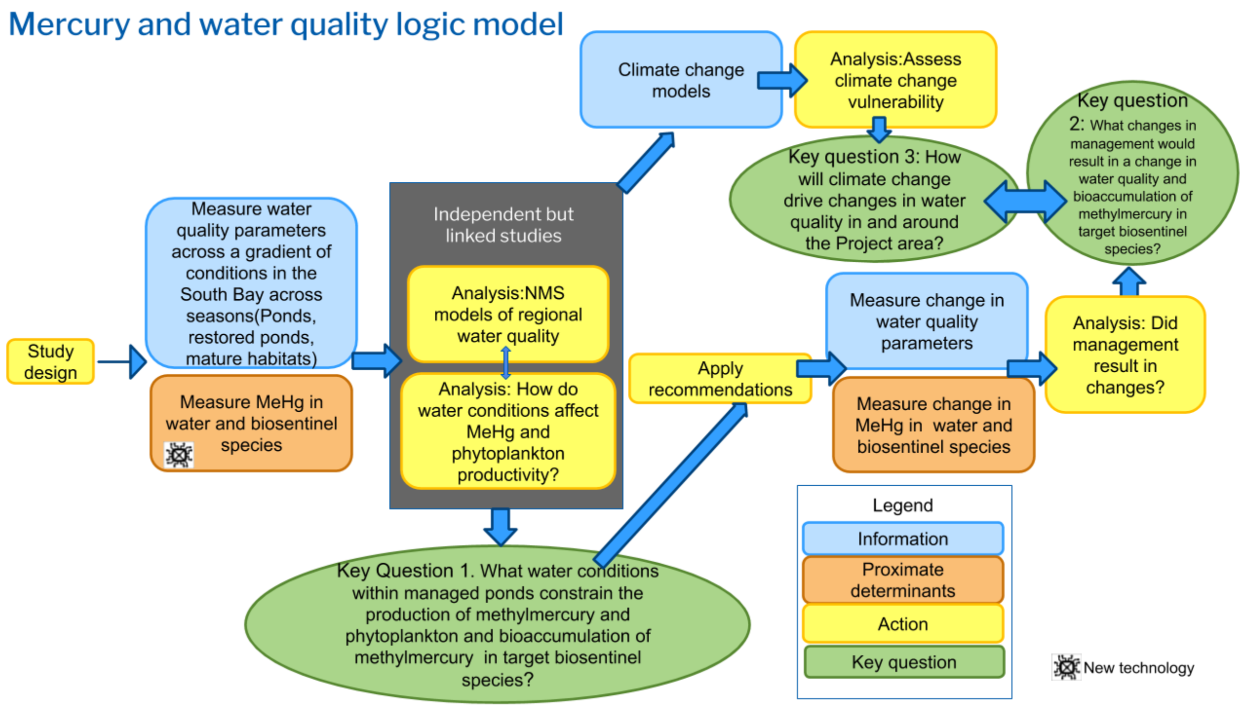

Figure A.5-2. Logic model showing studies to measure critical water quality metrics across the South Bay.

We can use the gradient of physical conditions at sites across the South Bay to better understand how water quality is affected by management and external conditions such as air temperature, rainfall, wind etc. Participants in the Science Synthesis workshop recommended that the Project develop a network of sensors that spans physical gradients among ponds and complexes within the South Bay. Workshop participants noted that many of the parameters to monitor were consistent whether the Restoration Target was methylmercury production or other water quality metrics. The first step would be to design the study to optimally sample from the existing gradient in conditions. The study would also be designed to sample across seasons so that we can see how water quality metrics vary across weather gradients. Participants in the Science Synthesis workshop suggested that important parameters to include in the monitoring program should include temperature, suspended-sediment concentrations, salinity, nutrients, productivity rates, chlorophyll, harmful algal blooms and nutrient cycling. In addition to sampling water quality parameters, the study design would also need to include a sampling strategy to establish a baseline for methylmercury in biosentinel species occurring at sites across the study area. All of the parameters would need to be monitored in the same time period so that changes including responses to management can be detected.

Ideally, the monitoring described above would include managed ponds, breached ponds/emergent marshes post-restoration, and fully established restored tidal marshes. Examining all of these habitats would provide better insight into how restoration will affect water quality in the South Bay. However, it may not be feasible to monitor all of the habitats, in which case, the monitoring in the managed ponds should be prioritized as this is the habitat in which the Project has the ability to directly modify its management.

The data from the monitoring study will be used in an analysis to assess what conditions limit the production of methylmercury and phytoplankton while still providing habitat that is necessary to achieve other Project Objectives. In addition, the monitoring data could be used in a regional hydrodynamic model in development by the Nutrient Management Strategy (NMS) to understand how Project's actions influence water quality in adjacent channels and the bay. Currently this model specifies conditions within pond and marsh habitats, and so empirical data from these habitats would greatly improve the accuracy of model outputs. The results from both of these analyses will lead to a set of recommendations for how to manage ponds and for the design of future restorations

There are opportunities for the Project to coordinate monitoring with other regional efforts and to take advantage of new technology as part of the study proposed above. For example, the NMS has a set of moored sensors in the South Bay, some of which will continue to collect data in their current locations, while some may be moved. The sampling design of the monitoring proposed should account for these sensors and the data they are collecting. In addition, the NMS will be starting intensive field sampling in the South Bay and Lower South Bay for two years starting in the Fall of 2020 that is directed towards understanding sediment and nutrient fluxes. The Project should leverage these efforts if possible. Additionally, the Project should explore whether satellite imagery or other remote sensing data products can be used to accurately map water quality parameters across the South Bay. Initial field data could be used to classify these images and reduce the need for intensive field studies to detect changes through time.

The next phase of the study design would be to implement recommended changes in management and to monitor whether those changes have any observable effects on water quality parameters and methylmercury in biosentinel species. The results of this study will be used to guide long term management of the remaining ponds.

A final analysis will identify how future climate change will challenge the Project's ability to achieve mercury and water quality Restoration Targets. Several scenarios may be needed to assess whether management will be able to achieve water quality Restoration Targets with a range of potential climate conditions. Water quality monitoring during summer months and during particularly warmer years can give an indication of whether the management actions recommended from the studies above will continue to prevent adverse water quality outcomes with climate change.

Identify Immediate Science Needs

Short term actions needed to implement the Science Plan:

- Assess the level of monitoring needed to adequately sample the gradient of conditions within habitats of the South Bay and to determine baseline MeHg in biosentinel species. This should include leveraging the monitoring and modeling to be conducted by NMS.
- Assess feasibility of the required monitoring of all habitats, select habitats or just managed ponds.
- Assess whether remote sensing images could be used to augment field monitoring, particularly if monitoring in all relevant habitats is not feasible.

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