A Report to the San Francisco Estuary Project

Development of Environmental Indicators of the Condition of San Francisco Estuary

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In collaboration with
the Bay Institute, Novato, California

Center for Ecosystem Management and Restoration

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Executive Summary

The U.S. Environmental Protection Agency (US EPA) has requested that all National Estuary Programs adopt a set of environmental indicators of ecological condition for their respective regions. These indicators are needed to help regulatory agencies, stakeholders, and the public answer the commonly posed question “How is the Bay doing?”

The objective of this report is to provide a framework to develop San Francisco Estuary indicators, propose appropriate assessment questions, and set of indicators, indices, and metrics that the San Francisco Estuary Project (SFEP) may use to periodically assess the condition of San Francisco Estuary. We consulted a number of sources in our effort to create a single, unified set of indicators for SFEP. Many other estuaries around the United States have already initiated or implemented indicator programs. We used the information gained and lessons learned in these programs to guide this framework. Additionally, we reviewed several national reports that contain guidance for development of indicators (NRC, 2000; EPA, 2000; 2002). These, as well as several previous projects that considered San Francisco Estuary indicators (SFEI, 1995; Levy *et al*., 1996; CALFED, 1999, Goals Project, 1999; Pawley, 2000), proved particularly useful. We drew much of the content of this report from these previous efforts. Additionally, we relied heavily upon The Bay Institute’s Ecological Scorecard (TBI, 2003) and a report on indicators for South Bay (Gunther and Jacobson, 2002).

Our framework identifies a number of important ecosystem attributes that should be tracked. We selected these attributes based on environmental regulations and goals and a general understanding of estuarine science. From these attributes we have posed assessment questions that can be answered by specific indicators and metrics.

We propose the use of twelve Primary Indicators to describe the condition of the Estuary. These include the state of major habitat and biological components as well as the impacts of public behavior and government management. Each Primary Indicator consists of several indices or metrics that address specific assessment questions. Each set of metrics will need to be aggregated into an expression of condition before it can be used as a Primary Indicator. We have not yet determined how to aggregate the metrics, but we envision some type of numerical calculation similar to those used in TBI’s Ecological Scorecard.

We identify nearly 50 metrics that measure different environmental or management variables. We describe each metric and justify its recommendation with a rationale. We based our recommendations on indicator selection criteria from NRC, EPA, the Habitat Goals Project, and others (see Appendices).

Many different agencies and organizations currently monitor the Bay environment, and many of the recommended metrics are already being measured by their programs. However, a means will need to be found to support the collection of other recommended metrics in the future. Ideally, the Estuary assessments will rely on data collected by these groups, and their participation in the SFEP Indicator Program will be essential for its long-term success.

Although most of the indicators, indices, and metrics proposed for SFEP have been identified in previous projects, they should be considered preliminary. There is still much discussion among local experts regarding exactly which metrics to use, where and how these should be measured, and how to produce numerical indicators and indices.

Once each metric is approved, it must be measured, and its Primary Indicator derived, published, and peer reviewed.

SFEP plans to refine and detail the proposed indicators and metrics further in 2004. A Steering Committee will be formed to oversee this process. Its mandate will include identifying funding sources to review, develop, test, and demonstrate all of the proposed indicators and metrics.

The development, application, and refinement of Estuary indicators will be an ongoing process. Peer review, advances in estuarine science, and other forces will combine to improve each report on the condition of San Francisco Estuary. The data and information used to calculate the indicators, indices and metrics, will be made available to the public for use and interpretation by other organizations and stakeholders. In this way, SFEP can produce increasingly more authoritative and valuable reports on the ecological condition of the San Francisco Estuary for consideration by all members of our community.

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Introduction

Probably the most common questions asked of environmental managers and estuarine researchers are, "How is the Bay doing" or "Is the Bay 'healthy'?" These questions reflect the public's concern for the condition of the Estuary and the understanding that human activities may impair its natural systems. The answers have major implications for environmental decision-making. The citizens of the Bay Area have a right to a comprehensible health assessment of the region's most important waterway. They want to know whether we are doing enough to protect the Estuary for future generations. An assessment that tracks both the impacts of our actions and the status of the ecosystem is essential to develop good public policies. The need for such information is reflected in numerous regulations and goals governing the management of the Estuary.

The U.S. Environmental Protection Agency (US EPA) has requested that all National Estuary Programs adopt a set of environmental indicators of ecological condition for their respective regions. The purpose of this request is to establish regional environmental indicators that can convey information about the condition of estuaries to regulatory agencies and other stakeholders, including the public. The San Francisco Estuary Project's (SFEP) plan for developing indicators of condition for the San Francisco Estuary has two phases. The first phase involves using guidance provided by the National Research Council (2000) and the US EPA (2000; 2002) to obtain local scientific consensus on a set of indicators. The second phase involves quantifying and reporting those indicators in a manner that is both scientifically sound and meaningful to the public.

This report has three primary objectives: (1) to provide a framework to develop San Francisco Estuary indicators; (2) propose appropriate assessment questions; and (3) propose a set of indicators, indices, and metrics (defined on page 13) that might be used by SFEP to assess the condition of San Francisco Estuary. The first section of the report presents background on the subject of ecological indicators, and includes a summary of laws and policies that document the need for a cogent means to measure the ecological condition of the Estuary. The second section presents a conceptual framework, based on guidance from authoritative sources and past local efforts, for selecting indicators. The third section presents a preliminary set of indicators that were developed by the project team, vetted at a workshop in the summer of 2003, and presented at the biennial State of the Estuary Conference in October 2003. Throughout this project, we made every effort to respect and build upon previous efforts to develop indicators for San Francisco Estuary. We believe this approach will help build technical consensus and free up more resources to execute this ambitious plan. This report considers the area of the Bay bounded by the head-of-tide. It includes both the Delta and the lower sections of Bay tributary watersheds, but focuses on the confluence of these watersheds with the Bay. It includes only those indicators most closely related to the aquatic components of the Estuary ecosystem.

No program in the San Francisco Estuary is currently charged with integrating measurements and indicators into an assessment of ecosystem condition, nor has any program been asked to identify attributes defining ecosystem condition, or pinpoint gaps in that knowledge. A consensus set of indicators for use by all stakeholders is needed. Recently, The Bay Institute (TBI) made the first-ever attempt to assess the ecological condition of the Estuary and reported the results using language accessible to the general public in its Environmental Scorecard (TBI, 2003). Additionally, the City of San Jose sponsored a study to develop an approach for assessing the ecological condition of the South Bay (Gunther and Jacobson, 2002). Information from both efforts is incorporated into this report.

We have identified five steps which must be completed in order to establish an ecological assessment program for the Estuary: (1) develop a consensus on which ecosystem attributes are most valued by the public or have been identified as representative assessments of ecological condition by scientists; (2) identify indicators of these attributes that are meaningful to the public, scientifically justified, and can be objectively measured; (3) determine what indicator changes will be considered "healthy"; (4) establish benchmark values or "targets" for each indicators in order to measure progress; and (5) determine how to present the indicators in order to garner maximum public interest while retaining scientific credibility (Gunther and Jacobson, 2002). This report addresses only the first two steps. The remaining steps will be addressed by future workgroups that will review and expand on the indicators proposed in both this report and the TBI Scorecard.

The questions we pose about the Estuary's condition are complicated to answer. They require a good understanding of the structure (habitats, influence of environmental factors) and function (food web, ecological interactions) of the San Francisco Estuary and how it has changed over time. They also requires consensus about what constitutes a "healthy" estuary, and how to report the relative status of the system in a manner that is useful to elected officials and the public. Our present scientific understanding of the Estuary is well developed but remains incomplete in critical areas. As a result, our efforts to assess the Estuary's ecological condition are likely to be imprecise. More importantly, our initial attempts should focus on indicators that are widely useful to both the public and Estuary managers. Refining the precision and accuracy of the framework's metrics and indicators will be an iterative, long-term process in which assessment attempts are constantly being critiqued and improved.

Indicator Development in Other Estuaries

Many U.S. estuaries have established, or are attempting to establish, programs that assess the condition or "health" of their estuaries (Appendix 1). We reviewed information from many of those efforts to design a pilot assessment of ecological condition for the South Bay. These other efforts may serve as models for, or provide guidance to, this project. The projects reviewed vary considerably, often because of differing environmental goals or the intended audience. They frequently mix measurements of ecosystem status or condition with measurements of stressors and assessments of management.

In general, the reports identified in Appendix 1 share one objective: to assess the overall health and condition of an ecosystem, typically by analyzing monitoring data for selected indicators. Most of the reports reviewed assume that issues of societal importance, such as public health, economics, water quality and living resources, should be considered in the assessment. Ecosystem goals can vary from loosely defined restoration objectives to extremely specific, government-mandated environmental standards. Some regions set a general goal that may be broad and poorly defined, but serves as a starting point to establish more specific objectives.

Indicators in San Francisco Estuary

Several previous projects have considered environmental indicators for San Francisco Estuary (SFEI, 1995; Levy *et al*., 1996; CALFED, 1999, Goals Project, 1999; Pawley, 2000; Gunther and Jacobson, 2002; CBDA, 2003; TBI, 2003). All of these efforts take a similar approach and recommend similar indicators. Much of the content of this report was drawn from these extensive and well-thought-out projects.

A number of organizations already monitor indicators of Estuary health. These groups include federal, state, and local government agencies (e.g. Department of Fish and Game, U.S. Fish and Wildlife Service, Department of Water Resources U.S. Geological Survey), as well as private organizations (e.g. SFEI, Marine Science Institute, Point Reyes Bird Observatory). The factors they track include water and sediment chemistry, and the abundance and distribution of organisms from plankton and invertebrates to fish and birds. However, tidal wetlands and riparian corridors currently receive little attention. Although data may exist for sports fish catches, water use, and other regulatory measurements, they have not been routinely applied in assessment and tracking.

Framework for Indicator Development

While researching this report, we reviewed three previously published indicator frameworks. These include a report by the National Research Council (NRC, 2000), and two EPA reports--one by the agency's Science Advisory Board (EPA, 2002), and another by its Environmental Monitoring and Assessment Program (EPA, 2000). Based on this guidance, we constructed a conceptual framework for indicator development (Figure 1). The framework identifies important ecosystem attributes based on goals and objectives in public laws and plans, as well as knowledge of estuarine science. We then developed a set of publicly meaningful assessment questions from these attributes and identified indicators that could answer the questions. Each of these steps is explained below. Eventually (in a scheme not part of this report) the indicators may be combined to produce an overall assessment of Estuary condition similar to TBI's Environmental Scorecard (TBI, 2003).

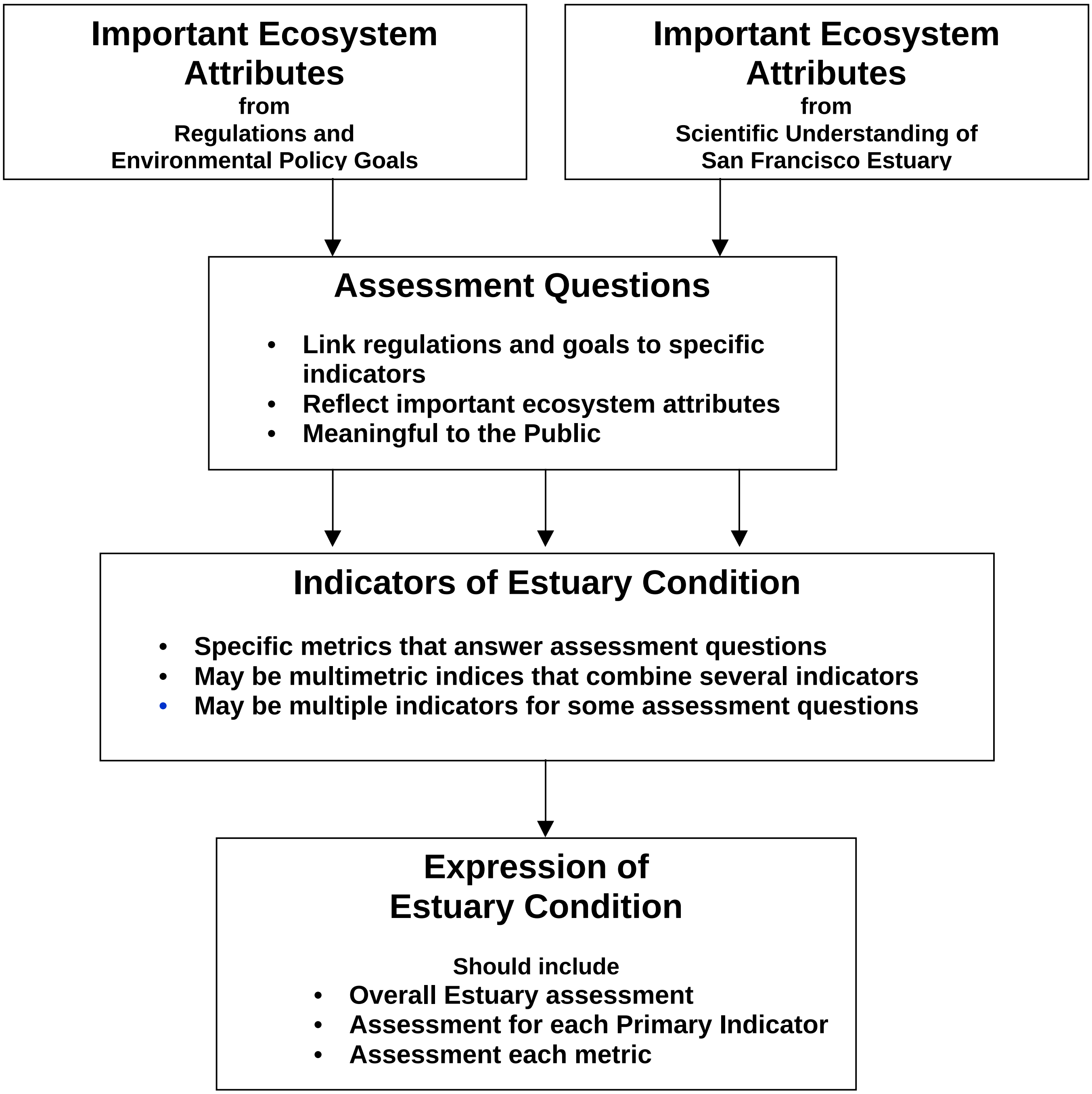
We used four principles to guide indicator development (Gunther and Jacobson, 2002): First, an assessment should be relevant to existing legal and regulatory mandates, as well as the adopted goals and objectives in public planning documents. This helps ensure that the assessment will continue for many years, and therefore yield the most useful information. This will allow public agencies to make assessments part of carrying out existing mandates. Some of these public mandates are the result of extensive negotiations among stakeholders in the region. The assessment will be most useful if it can build on these agreements rather than being tangential to them.

Second, the assessment should be meaningful to the general public. An assessment that relies upon technical concepts and scientific jargon will be opaque and uninteresting to the general public, and consequently will be less useful to decision-makers. Instead, it should employ straightforward language and "common-sense" concepts. The ultimate audience for the assessment must be interested citizens and their elected representatives.

Third, the assessment must retain scientific credibility or it will lose effectiveness. An assessment's scientific credibility depends on (1) consistently using scientific understanding, in addition to publicly adopted goals and objectives, to derive data; and (2) making sure that assessments are based on data collected with defensible methods. Indicators such as organic carbon cycling or sediment supply data may not be immediately meaningful to the public, yet help ensure that the assessment represents the most rigorous scientific thinking. The challenge of using these indicators is developing publicly meaningful descriptions. However, doing so also provides an opportunity for public education.

Finally, the assessment must rely on data from existing monitoring and research programs whenever possible. Given the many demands on natural resource agencies and private foundations, a new program is unlikely to secure enough funds to build a long-term picture of ecological condition on its own. The initial success of the Indicator Program will help persuade existing programs to provide additional data. However, highlighting critical gaps in the existing information base is an important way to cultivate public support for monitoring (Heinz Center, 1999; EPA, 2002).

Figure 1. Framework for Indicator Development.



Important Ecosystem Attributes

A major feature of the framework (Figure 1) is the identification of important ecosystem attributes that define environmental quality. These attributes create or sustain the biota, habitat, and human uses of the Estuary. Important attributes may be drawn from environmental regulations and goals, as well as from estuarine science (Gunther and Jacobson, 2002).

California has a complex and intensively managed water storage and distribution system. The system seeks to balance the needs of the environment with those of the economy. The state's water resources are managed and regulated to assure that clean water is distributed among agricultural, municipal, industrial, as well as environmental uses. Many of the regulations and goals germane to this project also deal with water in the San Francisco Estuary (Appendix 2). The State's Water Rights Decisions, The Bay-Delta Accord of 1995, and the Central Valley Project Improvement Act all address water use and diversion, while the Porter-Cologne Water Quality Act, the Clean Water Act, and the Regional Water Quality Control Plan ("Basin Plan") of the San Francisco Bay Regional Water Quality Control Board all address water quality.

Water regulations are often aimed at maintaining habitat for biological resources in general, but other regulations may focus directly on estuarine habitats and important species. For example, the California Environmental Quality Act (CEQA), the Fish and Game Code. and the Endangered Species Act including its subsequent recovery plans, all include specifications for the condition of habitats and biota. The McAteer-Petris Act is specific to the San Francisco Bay, and provides the Bay Conservation and Development Commission (BCDC) with the authority to oversee responsible use of Bay land use and resources.

There are also several non-regulatory documents that have been formally adopted as policy or guidance for Estuary management. Key programs and policies include the SFEP Comprehensive Conservation and Management Plan (CCMP), the San Francisco Bay Habitat Goals, the CALFED Bay-Delta Program, the Santa Clara Basin Watershed Management Initiative, and the Long Term (sediment) Management Strategy (LTMS).

Regulations and goals often mention explicit attributes of the ecosystem that need to be assessed, but attributes may also be implied or generic. Some of the attributes commonly found in regulations and goals include maintaining balanced indigenous wildlife, protecting of endangered species, increasing the amount of wetlands (including riparian habitats and tidal marshes), and maintaining chemical water quality, commercial and sport fishing (including shellfish harvest), navigation, and protection against toxic effects.

Important ecosystem attributes must also be derived from scientific knowledge of ecosystems in general and the San Francisco Estuary in particular. One of the guiding principles listed above is to provide scientifically meaningful indicators. The following section summarizes scientific understanding of San Francisco Estuary processes and ecology. It also identifies key ecosystem attributes that focus on indicators. The summary may be considered a conceptual model of the Estuary and is intended to provide background, context, and a rationale for the assessment questions and indicators that follow. It is necessarily brief, and focuses on the most important chemical and physical processes, habitats and ecological compartments determined from decades of research in the Estuary. Detailed information about the San Francisco Estuary ecosystem is contained in Conomos (1979), Kockelman *et al*. (1982), Cloern and Nichols (1985), and Hollibaugh (1996).

Summary of Estuary Processes and Ecology

Estuaries are defined by salinity gradients created by the fresh water inflows and ocean tides. The main source of fresh water to the San Francisco Estuary is through the Delta of the Sacramento and San Joaquin Rivers. These rivers drain about 40% (153,000 km^2) of California and contribute about 90% of the fresh water in to the system. The majority of this flow enters the Estuary between November and April. The sources of this water are rainfall and snowmelt. Precipitation in California varies substantially from year to year. A series of wet or dry years can have a large effect on Estuary habitats and biota. Summers are generally dry, and little or no rain or runoff reaches the Estuary (Conomos *et al*., 1985).

Freshwater inflows and their resulting salinity gradients have been related to the abundances of numerous estuarine organisms (Jassby *et al*., 1995). However, the precise mechanisms by which freshwater inflows may affect biological resources remain poorly understood. Salinity variations promote primary production in the spring through stratification of the water column, and plant and animal communities are adapted to daily and seasonal cycles of salinity change.

Water and sediment quality are influenced by nutrients, organic material, and contaminants (dissolved and particulate) transported to the Estuary via inflows. Municipal and industrial effluent; stormwater from local tributaries; resuspension of sediments due to tides, wind, and dredging; and air deposition all influence the quality of water and sediments. Major factors influencing sediment quality are salinity, temperature, dissolved oxygen, nutrient levels, sediment type, organic carbon levels, and anthropogenic contaminants. Nearly 80% of the Estuary's wetlands have been altered by fill or dikes. Thus, land use is a key stressor on the region's historic wetlands. Remaining wetland habitats may be influenced by water quality and sediment supply. Wetland alterations affect sources of detrital carbon, and habitat usage by organisms. The condition of a wetland may also be related to its successional stage following restoration and degree of habitat fragmentation.

The Estuary's sediment supply is expected to decline over the coming decades. The causes include a combination of mudflat and marsh erosion, slower sediment accretion, and reduced suspended sediment concentrations in the water column. These factors could produce significant changes in the Estuary (Goals Project, 1999; Williams, 2001). Given that primary productivity by phytoplankton is generally light-limited in San Francisco Bay, a decrease in sediment supply could also cause increased primary production (more light reaches deeper in water) and the attendant problems of eutrophication.

Numerous local tributaries provide freshwater and sediment to the Estuary. Like wetlands, nearly 80% of these riparian habitats have disappeared to fill, development, and channelization. Most stormwater runoff enters the Estuary untreated. Runoff may transport contamination from spills, auto discharges, and air deposition into the Estuary via local tributaries. Natural erosion, grazing, and development make these local tributaries major conduits for the transport of sediment to the Estuary. Natural riparian habitats provide a degree of flood control, sediment catchment, and habitat for important species such as endangered salmon and steelhead.

A rich array of organisms inhabit the water, sediments (Nichols *et al*., 1986), and tidal marshes (Grossinger *et al*., 1998) of the Estuary. The Estuary's three major habitat types--Bay, Wetland, and Watershed--may be further subdivided into biological communities based on physical and chemical differences. Biotic communities are often described using measurements such as abundances of key species, species diversity, dominance, or trophic structure. Communities are further subdivided into major biological groups (plants, microbes, invertebrates, fish, birds, and mammals) composed of populations of individuals. The distribution and abundance of populations depends on both abiotic (e.g. salinity, flow) and ecological factors (e.g. competition, predation). Parameters such as growth, mortality, reproduction, and recruitment define the life history characteristics of a species. Successful reproduction is crucial to maintain a sustainable population, and is an indicator easily understood by the general public. Many populations are linked in the community by functional relationships (e.g. food chains), or by organisms providing habitat for others (e.g. attachment, sharing burrows).

Some of the species that make up an assemblage of organisms are considered to be more important than others for various reasons. Species that structure a community or habitat, that dominate the community, top carnivores, threatened and endangered species, or invasive species may all be considered important. However, the public often has a different perception of importance, basing its judgments on factors such as "charisma" not supported by science.

Numerous human stressors affect Estuary habitats and the distribution and abundance of biota. These include land use, dredging and dredged material disposal, sport and commercial fishing, discharge of contaminants and organic material, and water diversions. Urban development increases impervious surfaces, runoff volume, and velocity, thereby accelerating the transport of sediment and contamination into the Estuary. High concentrations of sediments suspended in the water column can inhibit photosynthesis, while excessive bottom sedimentation may inhibit the development of benthic communities. Water diversions affect the salinity regime of the Estuary and decrease the geographic range of low salinity habitats.

We have identified several important ecosystem attributes based on the facts described above, our review of current environmental regulations and goals, and other estuary indicator projects. These attributes are freshwater inflows; water and sediment quality; the quality of subtidal bay, tidal wetland, and riparian habitats; key biological compartments such as aquatic plants, plankton, invertebrates, fish, birds, and mammals; and the estuary food web that binds these components together. Human factors such as land use, dredging, fishing pressure, and water supply and reuse are also important ecosystem attributes. We use these attributes to develop assessment questions and identify indicators in subsequent sections.

Assessment Questions

"Indicators of what?" is a frequently asked question when considering indicators. The next step in the indicator development process (Figure 1) is to select assessment questions. Assessment questions help articulate, in a simple and easy-to-understand manner, the kinds of information needed to track ecosystem attributes. Assessment questions link the regulation or goal with a specific measurement to be made, such as an indicator or metric. The choice of assessment questions is critical (EPA 2000), since the questions point to indicators that are useful for managing estuaries. The assessment questions also give public relevance to the scientific measurements. Consistent with the guiding principles, these questions should be phrased using non-scientific language so that the importance of answering the question is obvious to non-scientists.

The assessment questions proposed for SFEP are listed in Table 1. These questions, derived to address key ecosystem attributes, include questions used in TBI's Scorecard, and posed for the South Bay (Gunther and Jacobson, 2002). They were reviewed by SFEP workshop participants, staff from key regulatory agencies, and environmental groups.

Some of the assessment questions include words that require some type of value judgment. Both regulatory guidelines and scientific understanding may be used to define terms such as healthy, sufficient, harmful, etc. The use of such guidelines and thresholds will be determined in more detail through future workgroups that will refine the indicators in this report.

Proposed Indicators of Estuary Condition

Several terms used in this report need to be defined. An ecological indicator may be a measurement of an environmental variable or state, an index composed of several environmental metrics, or a model that characterizes an ecosystem or ecosystem component (EPA, 2000). Indicators are usually expressed in meaningful or useful terms, and are not necessarily quantitative. An index is a numerical aggregation of several different types of related information that expresses condition or status. A metric is a measurement of a single environmental variable, such as number of acres of tidal marsh, number of shorebirds, or number of water quality exceedances. Ecological assessments commonly include multimetric indices. For example, an Index of Biotic Integrity (IBI) for fish, may consider the number of fish taxa, and the abundances of several fish species, as part of a single indicator that describes the condition of fish (Karr and Chu, 1999; Weisberg *et al*., 1997). All of these terms are often simply referred to as "indicators", and may be used interchangeably; an index may be an indicator, and an index may be composed of several different indices.

We used a tiered approach for the indicator scheme proposed for SFEP because numerous indicators, indices, or metrics are required to describe the condition of the many habitats and biological resources of the Estuary. Twelve Primary Indicators of the condition of San Francisco Estuary are proposed (Table 1). Each of the 12 Primary Indicators is composed of several indices or metrics, similar to the approach used in the TBI Scorecard (TBI, 2003). These indicators represent important ecosystem attributes identified in the Summary of Estuary Processes and Ecology above. Additionally, a Human Use and Governance category of indicators is included. These indicators were included because Estuary managers desire a means to track the success of their actions, goals and regulations. In an effort to create a single, unified set of indicators for SFEP, the Primary Indicators include those used in TBI's Scorecard (2003) and recommended for use in South Bay (Gunther and Jacobson, 2002), as well as others considered important to SFEP.

Table 1. Assessment Questions, Primary Indicators and Metrics proposed for the San Francisco Estuary.

Primary Indicators

Assessment Questions	I. ESTUARY HABITATS	Recommended Metrics
Are freshwater inflows changing over time? Are freshwater inflows sufficient to maintain important habitats and biota of special concern?	**1. Freshwater Inflow**	1. Duration of Yolo Bypass flooding 2. Total amount of Delta water diverted Jan – Jun annually 3. Percentage of total annual Delta diversions Jan – Jun.
Are Estuary waters and sediments becoming more contaminated? Are Estuary waters and sediments harmful to the biota?	**2. Water and Sediment Quality, and Contaminants**	4. Nutrient and contaminant concentrations (Indices) 5. Incidence of Toxicity 6. Benthic impact assessment 7. Fish and bird tissue bioaccumulation
	3. Habitat Quality	
Do the Bay's waters and sediments provide healthy habitat?	a. Subtidal Bay	See Water and Sediment Quality metrics
What are the distributions and amounts of specific wetland types? Are wetland restoration efforts creating tidal wetlands of historic quality?	b. Tidal Wetlands	8. Acres of tidal wetland, various habitats 9. Tidal channel density 10. Distribution of *Salicornia* (pickle weed) 11. Annual sediment supply
How have habitat quality and usage of the Bay's tributaries changed over time?	c. Riparian Areas	12. Acres of riparian corridor 13. Percent hydro-modification 14. Percent impervious area 15. Anadromous fish usage

Primary Indicators

Assessment Questions	II. BIOLOGICAL RESOURCES	Recommended Metrics
Are abundances of important species increasing or decreasing over time? Are these species successfully reproducing? Is a diverse biological community present? Are the kinds and abundances of threatened or endangered species increasing or decreasing over time? Are the kinds and abundances of introduced species increasing or decreasing over time?	**4. Invertebrates, including Shellfish**	16. Average abundance and YOY biomass of: -crab and shrimp -*Neomysis* -*Macoma, Mya ,or Potamocorbula* 17. Average diversity and dominance of benthos and zooplankton 18. Abundance / long-term trends of T&E invertebrates 19. Percent / trends of non-native invertebrates
Same questions as above, but for fish	**5. Fish**	20. Average abundance of all native fish in selected habitats: 21. Average abundance and YOY biomass of: -striped bass -longfin smelt -Pacific herring -winter run salmon 22. Average diversity and dominance of native fish 23. Abundance / long-term trends of T&E fish 24. Percent / trends of non-native fish
Same questions as above, but for birds	**6. Birds**	25. Average abundance and YOY biomass of selected birds in selected habitats: 26. Average diversity and dominance of selected communities. 27. Abundance / long-term trends of T&E birds 28. Percent / long-term trends of non-native birds
Does the Estuary support a “healthy” (size, condition) population of Harbor Seals?	**7. Mammals**	29. Average abundance of harbor seals
Are there adequate food resources to support important species?	**8. Estuary Food Web**	30. Annual biomass of phytoplankton, intertidal plant chlorophyll 31. Annual biomass of zooplankton, benthos, and fish.

Primary Indicators

Assessment Questions	III. HUMAN USE and GOVERNANCE	Recommended Metrics
How quickly are we converting estuary habitats (open water, wetland, riparian) to urban use?	**9. Land use**	32. Ratio of urban to non-urban area 33. Area of wetland restoration
How much dredging occurs annually? How much dredged material is disposed of in the Estuary?	**10. Dredging**	34. Amount dredged annually 35. Amount disposed in the Estuary
Are the commercial and sport fish catches increasing or decreasing? Is it safe to eat fish and shellfish from the Estuary? Is the Bay safe for contact recreation? What is the quality of drinking water prior to treatment?	**11 Fishable, Swimmable, Drinkable**	36. Number of fish consumption advisories 37. Pounds per year landed of selected fish. Suggested targets include salmon, sturgeon, herring, shellfish, striped bass, shiner perch, bat rays, and white croaker 38. Number of pathogen exceedances or the number of beach closures (days) 39. Number of drinking water exceedances
How much of the Bay is “impaired”? (per CWA 303d)? Are water and sediment quality standards being met? How much water does the average person use? Are salinity standards being met? What percent of domestic and industrial water used is recycled?	**12. Stewardship**	40. Area of the Bay on 303(d) list 41. Lbs. of pesticides applied in Bay Area counties. 42. Percent of water quality objectives achieved 43. Pounds of trash in the Bay 44. Area of Estuary being monitored 45. Average annual residential water use 46. Number of days when the salinity standard has been exceeded. 47. Total amount of water recycled.

Recommended Metrics

Deciding which indices and metrics will be included in each Primary Indicator is challenging. It requires judging which measurements best reflect key ecosystem processes and ecology, and will answer the assessment questions. Additionally, the metrics selected to evaluate ecosystem health often reflect local management goals. The environmental indicators and metrics described below were chosen based on several sets of criteria and principals:

- They address a formal environmental regulatory issue or established environmental goal (Appendix 2), where progress may be tracked.
- They address an Assessment Question posed on Table 1.
- They address SFEP CCMP program areas (SFEP, 1993).
- They are consistent with indicator principles and frameworks described by the EPA (1995; 2000; 2002) and National Research Council (2000).
- Many of them are currently used in existing San Francisco Estuary monitoring programs (Table 2) or have been recommended by other indicator efforts.

The forty-seven metrics we recommended for SFEP's use are listed in Table 1. We describe each proposed metric below, and rationale for the choice of each. The metrics may be obtained from raw data, derived or standardized metrics, or indices that aggregate several metrics. The metrics may be used to assess current status and/or track trends over time.

The metrics listed in Table 1 include many of those included in the TBI Scorecard, recommended for the South Bay (Gunther and Jacobson, 2003), or recommended in previous San Francisco Estuary indicator projects. The metrics should be considered recommendations subject to further consideration and refinement. Many are generic or conceptual at this time. Some are not currently measured in the region and, if adopted, would require a means of collection and analysis. Some will require further development and testing before they are suitable for use and implementation as envisioned, and some may not withstand rigorous discussion and review.

I. Estuary Habitats

Primary Indicator 1. Freshwater Inflow

Freshwater inflow is considered the single most important ecological factor in the region. It has a major influence on salinity (Peterson *et al*., 1996), the springtime stratification critical for phytoplankton production (Jassby *et al*., 1996), the distribution and maintenance of various marsh habitats, and populations of important biota (Bennett and Moyle, 1996). Salinity in the Estuary varies as a result of seasonal freshwater inflows, and most estuarine plants and animals are adapted to salinity changes. Tracking freshwater inflows provides an indication of salinity-related habitat condition in the Estuary.

Metric 1. **Duration of Yolo Bypass flooding**. The number of days that the Yolo Bypass is flooded annually.

Rationale. The number of days that the Yolo Bypass is flooded may be used as a surrogate for several important indicators: total inflow, peak inflows, and sediment loading from the Delta. The highest inflows create low salinity habitats necessary for the survival of many Estuary organisms. This new indicator may require development and verification of these relationships. Freshwater inflow is a major CCMP program area. Flow indicators were recommended by CMARP and Levy *et al*. (1996) and used in the TBI Scorecard (2003).

Metric 2. **Total amount of water diverted from the Delta between January and June**. The amount of water that is diverted from the Delta during the ecologically sensitive time between January and June.

Rationale. Diversion indicators were used in the TBI Scorecard, address Bay-Delta Accord and State Water Rights Decisions, were recommended by CMARP, and are a monitoring requirement for the Environmental Monitoring Program (EMP) conducted by DWR.

Metric 3. **The percentage of total annual water diversion in the Delta that occurs between January and June**.

Rationale. This metric provides additional information when used with Metrics 1 and 2 above. Together with Metric 2, it estimates the amount of diverted water likely to affect most out-migrant salmon, spawning Delta smelt, etc. This new metric will require development and testing to determine how it can best express the effect of water diversions on aquatic life. Same institutional needs as Metrics 1 and 2.

Primary Indicator 2. Water and Sediment Quality, and Contaminants

Indicators of water quality are probably the most commonly used environmental indicators throughout the U.S. This is largely due to formal regulatory guidelines that are part of most monitoring programs. These guidelines, which are well developed and widely understood, reflect perceived linkages with Estuary ecology and human health. Clean Water Act and State Basin Plans also include narrative guidelines for toxicity and biological impacts.

The conceptual basis for using these tools is not without uncertainty. Laboratory tests and concentrations do not always predict the impacts in a given environment. Species used in EPA-approved standard laboratory toxicity tests are not necessarily resident in the Bay, and resident species could be more or less sensitive to contaminants.

Metric 4. Water and sediment nutrient and contaminant concentrations. Concentrations of water nutrients, and water and sediment contaminants compared to existing water quality objectives and criteria. A multimetric index could be developed for this metric.

Rationale. Addresses and tracks state water quality objectives (Basin Plan), federal criteria (Calif. Toxic Rule), and CCMP Actions. Long-term trends will show how well regulatory programs reduce contaminants entering the Estuary and clean up problem areas. Sediment objectives are currently being developed by the State Water Board. Sediments were used as indicators in the National Coastal Assessment (EPA, 2002b), are currently used in RMP, recommended by CMARP and other programs, and used in the TBI Scorecard.

Metric 5. Incidence of Toxicity. The proportion of samples collected by RMP annually that exhibit sediment and aquatic toxicity. Aquatic and sediment toxicity will be expressed separately.

Rationale. Addresses Basin Plan narratives of “no toxicity” and Clean Water Act. However, the linkage between laboratory toxicity and actual ecological effects are poorly understood. Currently used in RMP, recommended by CMARP and other programs.

Metric 6. Benthic Impact Assessment. An IBI-type index of the degree of impact due to sediment contamination is proposed. Such an assessment method has been developed for San Francisco Estuary (Thompson and Lowe, 2004).

Rationale. Addresses Clean Water Act, Basin Plan narrative goal of “balanced populations” of an important ecological component. Benthic condition reflects the health of sediment habitats and the availability of food for higher trophic level fish and birds. Used in National Coastal Assessment (EPA 2002), currently being monitored by several groups, being developed for RMP and State Water Board, recommended by CMARP.

Metric 7. Fish tissue and seabird egg contaminant bioaccumulation. Concentrations of contaminants in tissues, or an index of samples that exceed tissue concentration guidelines or regulatory screening levels for human consumption and ecological risks.

Rationale. This is a commonly used indicator of the safety and availability of fish for consumption. Addresses Clean Water Act, California Water Code, Fish and Game Code, and Basin Plan goals for the bioaccumulation of contaminants in tissues. Bioaccumulation in fish tissue will be used to assess risks to humans from consumption, and bioaccumulation in birds may be used to assess ecological risks. Used in National Coastal Assessment (EPA 2002), currently monitored by RMP and others, used in the TBI Scorecard.

Primary Indicator 3. Habitat Quality

The natural habitats of the Bay are the foundation of its environment. Key habitats for the region include the subtidal Bay’s water and sediments, intertidal wetlands, and riparian corridors that lead to the Bay. These three habitats host the Bay’s biological resources and provide ecological and recreational functions. Therefore, assessing the condition of Bay habitats is an important part of the SFEP Indicator Project. Indicators or indices for these major habitat-types are envisioned. Each habitat-type indicator or index may be composed of several metrics that characterize each habitat.

a. Subtidal Habitats

The Bay’s waters are its most obvious habitat, and also the most taken for granted. The Bay’s water and sediments provide habitat for fish and invertebrates and food for birds and mammals. Water and Sediment Quality Metrics 5 through 8 will be used to characterize subtidal habitats.

b. Tidal Wetlands

The protection and restoration of wetland habitats in the Bay Area enjoys widespread consensus and support due mainly to the well-documented loss of wetlands and the endangered species that rely on these habitats. Measures of the erosion and degradation of wetlands and seagrass beds are common indicators of estuarine habitat quality (EHMP, 2001; Saginaw Bay, 2000)

Metric 8. Acres of Tidal Wetland. The total number of tidal wetland acres in the Estuary includes totals from several types of wetland habitat, as employed in the Goals Project (1999).

Rationale. This indicator was selected to track loss and restoration of wetlands. Wetland loss was used in the National Coastal Condition Report, recommended by CMARP and the Habitat Goals Project, and used in the TBI Scorecard (2003).

Metric 9. Tidal Channel Density. The aerial density of intertidal wetland channels in various tidal wetlands habitats.

Rationale. Recommended in the California Rapid Assessment Method, Goals Project, and CMARP.

Metric 10. Distribution of *Salicornia* (pickleweed) marsh. The percent of intertidal area dominated by pickleweed.

Rationale. *Salicornia* forms a dense mat in mature, undisturbed tidal marshes. It is therefore a good indicator of completed restoration and conservation. Recommended in the California Rapid Assessment Method.

Metric 11. Annual Sediment Supply. Total amount of sediment entering the Bay from all tributaries (may be estimated or modeled). This value may be compared to loads from an “average” water year or standardized to annual rainfall data. Trends may be tracked.

Rationale. Sediment processes play a critical role in forming the habitats that sustain the estuarine ecosystem. Marshes, mudflats, and tidal channels are maintained over time by a dynamic equilibrium between sediment supply and loss, and the processes that redistribute sediment through the system. This indicator addresses Basin Plan goals, LTMS, and CCMP issues. This indicator will track trends in sediment loads from development and land use changes, and compared to historic loading estimates. Not currently monitored in most tributaries.

c. Riparian Areas

Riparian corridors that lead to the Bay are also important to a set of dependent species. This project will focus on the bayward end of riparian corridors. However, sediment and water derived from the tops of the watersheds influence the Bay.

Metric 12. Acres of Riparian Corridor.

Rationale. Addresses Basin Plan Beneficial Uses, Habitat Goals, important in considering 303(d) impairment and stormwater runoff TMDLs.

Metric 13. Percent of tributary length with hydro-modification. The percent of Bay's tributaries, measured in linear miles, that have been modified from their natural water courses (channelized streams, culverts, etc.); used in the TBI Scorecard (2003).

Rationale. Addresses McAteer-Petris Act and Basin Plan goals. This indicator will show trends in the condition of local Estuary tributaries and riparian corridors. Recommended by CMARP. Not currently monitored.

Metric 14. Percent impervious area in each watershed. Percent of area in each watershed that has been paved or developed.

Rationale. Addresses McAteer-Petris Act and Basin Plan goals. Will show trends in urbanization, land use that affect tributary hydrograph and sediment loadings. Data not currently being collected for all Bay area watersheds.

Metric 15. Percent of watershed with anadromous fish usage. Estimated percent of watersheds that have annual runs of salmon, coho, or steelhead.

Rationale. Several threatened and endangered salmonid fish use Bay tributaries for spawning. This indicator will track the usage of these areas. Addresses Basin Plan anadromous fish beneficial use.

II. Biological Resources

Assessments of ecological condition must include information about biota in the Estuary. As there are too many species in the Estuary to track, we selected a few as publicly and scientifically meaningful indicators. General considerations for selecting biological indicators for the Estuary have been discussed in the literature (Simberloff, 1998; Zacharias and Roff, 2000), and for San Francisco Estuary (Gunther and Jacobson, 2002; Goals Project, 1999). The condition of biological resources generally reflects the quality of habitat, but most Estuary indicator programs also use a variety of biological indicators to confirm this concept. Additionally, many regulations require biological resource assessment or inventory. These assessments are generally related to the take (number killed) of game species, and the recovery of Threatened and Endangered species.

Indicator species selection frequently focuses on functional “keystone” or "umbrella species" whose presence reflects the welfare of a relatively large number of other neighboring species. Umbrella species tend to be high in the food web and/or public consciousness.

San Francisco Estuary still supports several threatened and endangered species (formally listed on Endangered Species list). These taxa are often tied to particular habitats that have become rare or fragmented. Tracking them is required in recovery plans and is of public and management interest.

Introduced species are also a major issue in the San Francisco Estuary. While most of these species might be present in only small numbers that do not greatly influence other biota, some introduced species can cause considerable ecological change. Examples include the introduced marsh cordgrass, *Spartina alterniflora* (Goals Project, 1999), and the Asian clam, *Potamocorbula amurensis* (Kimmerer and Orsi, 1996). Therefore, indicators of the status of introduced species are included below.

Identifying appropriate indicator species for San Francisco Estuary will require applying selection criteria and professional judgment. In the San Francisco Estuary, The Habitat Goals Project produced a set of eight criteria to select indicator species (Appendix 3). Because of the diversity of organisms from which to choose indicators, and the lack of information justifying most choices, we have identified a suite of indicators that are "important" in the Estuary, or that represent major compartments and habitats, as recommended by Karr and Chu (1999).

In addition to important species assessments, measures of populations, community composition and structure, and ecosystem function may be used. One of the most important population response indicators for key species is reproduction. It is also a concept easily understood by the general public. Successful reproduction integrates many factors, including food and habitat availability, predictability, predation, and physiological health. Community indicators may include metrics for species composition, species diversity, total abundance of major taxonomic groups, dominance indices, etc. The integrity of the estuarine food web is a fundamental attribute of healthy ecosystems, and is understandable by the public. Therefore, the indicators proposed below include metrics that will assess the condition of the food web. The biological resources indicators proposed for use by SFEP are divided into five components: four are major animal groups that inhabit most of the Estuary's habitats, and the fifth addresses ecological function, and includes an assessment of plants in contribution to the Estuary food web. The five assessment questions listed first under biological resources (Table 1) are the same for Invertebrates and Shellfish, Fish and Birds. However, the recommended metrics for each animal group differ slightly.

Primary Indicator 4. Invertebrates, including Shellfish

Invertebrates are a critical ecosystem components in both water and sediment habitats. They account for a large portion of estuary biomass and diversity. Many are herbivores and detritivores. As such, they mark a key step in the transformation of energy from the lower levels of the food web to the upper levels. Higher in the food web, predatory and carnivorous invertebrates serve as food for Estuary fish and birds. Shellfish are included explicitly because of their ecological value as food for other animals as well as their economic and cultural value as food for humans. The biological resource indicators proposed can provide a broad-based assessment of important Bay species, diversity, and ecological health of the Estuary's resources.

Metric 16. Average annual abundance and young-of-the-year biomass of representative invertebrates and shellfish.

- crabs and shrimp
- *Neomysis* (mysid shrimp)
- *Macoma, Mya*, or *Potamocorbula* (clams)

The organisms listed are considered important invertebrate and shellfish groups or species. We propose using several indices or abundances of each shellfish group or species.

These indicators will be used to track the stability of populations compared to either known reference abundances or past trends. The young-of-the-year biomass measurements are will also be used to address the question of successful reproduction.

Rationale. Addresses Clean Water Act, and Basin Plan narratives, major CCMP Program area, and has very high public interest. Many of the recommended taxa are currently monitored. Recommended by CMARP, Habitat Goals, and other indicator Projects; used in the TBI Scorecard (2003).

Metric 17. Average diversity and dominance of benthos and zooplankton in selected communities. Diversity may be considered the total number of taxa identified to the lowest practical taxon in annual samples collected from key Estuary communities. The purpose is to evaluate any multi-year or multi-decadal trends. Alternatively, several diversity and dominance indices are described in the literature, but need to be tested regionally. May be measured as part of Metric 7.

Rationale. The number of taxa and dominance are two community metrics commonly used in biological assessments to assess community diversity. Addresses Clean Water Act and Basin Plan goals. Diversity is used and recommended by NRC. Currently monitored by several programs, recommended by CMARP.

Metric 18. Abundance or trends in abundance of Threatened and Endangered species. The proportion of target abundances for each aquatic Threatened and Endangered taxon as stated in recovery plans.

Rationale. Addresses the Endangered Species Act and specific Recovery Plans. Selected to track progress towards recovery of T&E species in the Bay. Recommended by CMARP and other indicator projects. Partially monitored by current programs.

Metric 19. Percent of total community, trends in total abundance, or numbers of introduced invertebrate species. This indicator will reflect the status and any changes in the kinds and abundances of invertebrates known to be introduced to San Francisco Bay estuarine habitats.

Rationale. This is a new focus area for SFEP. The US EPA is also developing programs to track biological invasions. This metric, recommended by CMARP and others, will be used to track invasions in the Estuary. Several groups are monitoring various components, but no group is currently tracking all invasions, and data may be difficult to obtain for all invertebrate groups / habitats.

Primary Indicator 5. Fish

Fish are obviously an important ecosystem component. Most fish occupy middle or upper trophic levels, many are predators, and many are eaten by birds, marine mammals, and humans. They integrate and reflect the health of lower trophic levels and may accumulate some contaminants from them. Fish are perceived by the public as key ecosystem components. Fish have high economic and recreational value as a food source. The indicators proposed will provide an assessment of the species composition, diversity, and ecological health of this important Estuary compartment.

Metric 20. Average abundance of all native fish in selected habitats.

Rationale. Addresses Clean Water Act and Basin Plan, and MLMA goals. Fish are currently being monitored in several programs. Recommended by CMARP, Habitat Goals Project, and other Indicator Projects. Major CCMP Program area (aquatic resources), has very high public interest, and was used in the TBI Scorecard (2003).

Metric 21. Average annual abundance and young-of-the-year biomass of representative fish from selected communities.

- Striped bass
- Longfin smelt
- Pacific herring
- Winter run salmon

The species listed are considered to be important representatives of their habitats or key sport- or endangered fish (TBI, 2003). Abundances for each species, as well as a multimetric index that combines information about all tracked fish, may be developed. Indices of abundances are currently used for several fish taxa by DFG. These indicators will be used to track the stability of those populations, compared to either known reference abundances or to trends in the past. The young-of-the-year biomass measurements are intended to be used to address the successful reproduction assessment question.

Metric 22. Average diversity and dominance of fish in selected communities. Diversity may be considered the total number of taxa identified to the lowest practical taxon in annual samples collected in key Estuary communities. Alternatively, several diversity and dominance indices are described in the literature, but need to be tested regionally.

Rationale. The number of taxa and dominance are two community metrics commonly used in biological assessments to assess community diversity. Addresses Clean Water Act and Basin Plan goals. Diversity is used and recommended by NRC. Currently monitored by DFG, recommended by CMARP.

Metric 23. Abundance or trends of Threatened and Endangered fish taxa. Proportion of target abundances for each aquatic T&E taxon, as stated in recovery plans.

Rationale. Addresses the Endangered Species Act and specific Recovery Plans. Selected to track progress towards recovery of T&E species in the Bay. Recommended by CMARP and other Indicator Projects; current monitoring status unclear.

Metric 24. Percent or trends in introduced fish. Annual estimate and trends over time of the number of fish taxa known to be introduced to SF Bay estuarine habitats.

Rationale. A new focus area for SFEP and EPA developing programs. Recommended by CMARP and others. Will be used to track invasions in the Estuary. Several groups are monitoring various components, but no group is currently tracking all invasions. It may be difficult to obtain adequate data.

Primary Indicator 6. Aquatic Birds

Aquatic birds require aquatic-related habitats for some part of their existence such as feeding or nesting. Birds are one of the most-loved biological components of the Estuary. Ecologically, they are also important as consumers of lower trophic levels. As most aquatic birds are predatory, this indicator is composed of four metrics that measure the condition of important species, bird communities, threatened and endangered, and non-native birds.

Metric 25. Average annual abundance and young-of-the-year biomass of important and representative birds from selected habitats. Several bird species have been recommended, including cormorants, night herons, and snowy plovers, but the choices need to be discussed further before an agreement is reached. The species selected should represent several habitats, communities, seasonal groupings (migratory or resident), or trophic niches. Abundances or multimetric indices may be developed. These indicators will be used to track the stability of those populations, compared to either known reference abundances, or to trends in the past. Young-of- the-year biomass measurements are intended to be used to address the successful reproduction assessment question.

Rationale. Addresses Clean Water Act and Basin Plan goals, MLMA, CCMP Program area, and has very high public interest. Annual census information is currently used for some bird indicators, but no program monitors all birds. Recommended by the Habitat Goals Project.

Metric 26. Average diversity and dominance of birds in selected communities. Diversity may be considered the total number of taxa identified to the lowest practical taxon in annual samples collected in key Estuary communities. Alternatively, several diversity and dominance indices are described in the literature, but these need to be tested regionally.

Rationale. The number of taxa and dominance are metrics commonly used to assess community diversity. Addresses Clean Water Act and Basin Plan goals. Diversity is used and recommended by NRC.

Metric 27. Abundance or trends of Threatened and Endangered birds. Proportion of target abundances for each aquatic Threatened and Endangered taxon is stated in recovery plans.

Rationale. Addresses the Endangered Species Act and specific Recovery Plans. Selected to track progress towards recovery of T&E species in the Bay. Recommended by Habitat Goals Project.

Metric 28. Percent or trends in introduced birds. The total abundance or estimated number of bird taxa known to be introduced to SF Bay estuarine habitats.

Rationale. New focus area for SFEP, EPA developing programs. Recommended by CMARP and others. Will be used to track invasions in the Estuary. Several groups are monitoring various components, but no group is currently tracking all invasions and it may be difficult to obtain adequate data.

Primary Indicator 7. Marine Mammals

Metric 29. Annual harbor seal census. Population estimates from annual haul-out area census.

Rationale. This species is a fish-eating resident of the South Bay with high public interest. This metric is being developed as an indicator by RMP.

Primary Indicator 8. Estuary Food Web

Examining the food resources available to key species provides an important means to evaluate of ecosystem function (see discussion by Gunther and Jacobson, 2002). The timing and magnitude of the phytoplankton bloom measures productivity at the base of the food web, where solar energy is converted to fixed carbon. Aquatic plants also contribute to the riparian and marsh food web. Other major compartments (zooplankton, benthos, and fish) may comprise additional trophic levels. Alternatively, several specific key, or representative food chains maybe targeted.

Metric 30. Annual biomass of chlorophyll and intertidal plants. This indicator may be developed into a multimetric index that includes annual estimates of phytoplankton chlorophyll and intertidal plant biomass.

Rationale. Addresses Clean Water Act and Basin Plan goals, and SWRCB Water Rights Decisions. Chlorophyll determines primary productivity, thus provides an indicator of a fundamental ecological function, and is a critical component of a healthy estuarine food chain. Currently monitored by USGS and DWR monitoring programs. Recommended by CMARP, used in the TBI Scorecard (2003).

Metric 31. Annual biomass of zooplankton, benthos, and fish. Estimates of average biomass in major aquatic communities or compartments. This indicator may be a multimetric index, to be developed, that includes annual estimates of zooplankton, benthos, and fish biomass.

Rationale. Addresses CWA and Basin Plan goals. Provides estimates of potential food availability to higher trophic levels. Currently monitored by several monitoring programs.

III. Human Use and Governance

San Francisco Estuary has been called the Urbanized Estuary (e.g., Conomos, 1979). Humans have substantially altered the Estuary over the past two centuries. In recent years regulations intended to protect and restore its remaining habitats and biological resources have been instituted. We recommend a set of response indicators to track the successes of environmental regulations and programs, following the example of The TBI Scorecard (2003).

The proposed Human Use and Governance indicators may improve assessments of progress towards regulatory and management goals. Based on the understanding of Estuary processes and ecology summarized above, many of the proposed metrics for habitats and biological resources may be used to show possible links between changes in environmental condition and human use. Four categories of Human Use and Governance indicators are proposed. Land Use and Dredging relate to CCMP priority areas. The Fishable, Swimmable and Drinkable aspects of the Bay are important public concerns, while Stewardship reflects the public's efforts at reducing the impact of waste discharge and conserving water. Each of the four components is envisioned as a multimetric index or other numerical expression of the metrics recommended. Together they will comprise an overall assessment of progress towards achieving key environmental goals.

Primary Indicator 9. Land Use

The development of land around the Bay and its watersheds for urban use and farming, and the reclamation of riparian and wetland habitat, have affected the composition of runoff. Erosion of sediments and the transport of contaminants are the primary culprits. It also reduces the amount of habitat for riparian and wetland plants and animals. Land use was a major CCMP Program area.

Metric 32. Ratio of urban to non-urban area (annual). The ratio of urban to non-urban areas calculated from ABAG GIS data annually.

Rationale. Addresses the McAteer-Petris Act goals, major CCMP program area. This indicator may help explain observed changes in water quality and sediment loads to the Bay. Recommended by CMARP. Data available from ABAG land use database.

Metric 33. Area of wetlands and riparian corridor restored. Areas of tidal wetland and riparian corridor where restoration has been begun or been completed.

Rationale. Addresses McAteer-Petris Act, and CCMP goals. This indicator will reflect how much restoration has been accomplished, and will compare it against restoration and Habitat Goals. Data are available through Coastal Conservancy and tracked by SFEI's Wetland Tracker.

Primary Indicator 10. Dredging

Dredging is critical to maintaining the vitality of the Bay's marinas and harbors, with large economic implications. However, dredging disturbs subtidal sediment habitats both when sediment is removed, and when it is deposited (in-bay disposal). Dredging mobilizes previously buried contaminants into the water column, dispersing them farther afield. The proposed metrics should be interpreted within the context of needed dredging for a given time period, and disposal options.

Metric 34. Amount dredged annually. The total amount of dredging that occurs annually (million cubic yards), and how it was disposed of.

Rationale. Addresses LTMS and CCMP Program goals. Data are available through Corps of Engineers Permits (DMMO).

Metric 35. Amount of in-bay dredge material disposal (annually). The amount of dredged material deposited in tidal and subtidal baylands annually.

Rationale. Addresses LTMS and CCMP Program goals. This indicator will reflect dredging activities and progress towards achieving LTMS goals for in-bay disposal. Use for wetland restoration will also be reflected in Indicator 21. Data available through Corps of Engineers Permits and the Dredged Material Management Office (DMMO).

Primary Indicator 11. Fishable, Swimmable, Drinkable

This indicator measures three important human uses of the Estuary. Each is already defined by formal regulations. Commercial and sport fishing are traditional human uses of productive aquatic ecosystems, and are identified as Beneficial Uses of the Estuary. Changes in the amount of fish or shellfish harvested by humans is an easily understood measure of condition. Sustainable sport and commercial fisheries are a public and management priority for the Estuary. The toxicity of fish and shellfish caught in the Estuary are also a public and management priority. Health advisories exist for San Francisco Estuary fish and shellfish due to the presence of certain contaminants (OEEHA, 1994). These indicators can be used with tissue bioaccumulation indicators described in Metric 8. The human health impacts of water contact recreation are also well understood by the public and directly address formal, numeric water quality regulations.

Metric 36. Number of fish consumption advisories. The number and nature of fish consumption advisories.

Rationale. Addresses Basin Plan goals for human health, and tracks DFG and OEEHA fish consumption guidelines; high public interest. Data available from CA DFG and OEEHA.

Metric 37. Pounds of selected fish and shellfish caught annually. Pounds (tons) of sport and commercial fish landed in the Estuary annually. Suggested targets include salmon, sturgeon, herring, shellfish, striped bass, shiner perch, bat rays, and white croaker. This metric could be expressed in a variety of ways, such as by grouping fish by commercial-, sport-, or subsistence fishing, or by fish trophic and life history traits.

Rationale. Addresses MLMA, Fish and Game Code provisions, and Basin Plan Beneficial Uses; high public interest. This indictor reflects the status of Estuary fisheries and will track the sustainability of the fisheries. Data from DFG and/or fishing association record.

Metric 38. Number of aquatic pathogen guideline exceedances, or the number of beach closures. The number of exceedances (area and duration) of microbial pathogen standards based on water testing conducted by local agencies. Alternatively, the number of beach closures may be selected.

Rationale. Addresses Basin Plan and local health code objectives for Estuary discharge and Beneficial Use, enjoys high public interest, included in the TBI Scorecard.

Metric 39. Number of drinking water exceedances. Annual percentage of drinking water suppliers that reported exceedances of standards in their source water (TBI, 2003).

Rationale. The quality of drinking water reflects the health and management of the source watershed. Addresses state and county drinking water regulations.

Primary Indicator 12. Stewardship

Stewardship reflects personal actions that collectively affect the condition of the Estuary. This Indicator focuses on the amounts of fresh water, contaminants, and other human generated materials entering the Bay relative to water quality requirements (TBI, 2003). We propose eight metrics a that measure how well we are reducing the input of contamination and trash to the Bay, maintaining adequate freshwater inflows, as well as how much water we are using and returning to the Bay.

Metric 40. The area of the Estuary on the State's 303(d) list. Area of the Bay and each "waterbody" deemed "Impaired" (human health or ecological impact) by the State Water Board.

Rationale. 303(d) is a Clean Water Act provision and is the current paradigm for water quality assessment and regulation by the Regional Board. Addresses Clean Water Act and Basin Plan regulations.

Metric 41. Pounds of pesticide applied in Bay Area counties. Total pounds of all pesticides applied in the Bay area counties, based on Department of Pesticide Regulation records.

Rationale. Pesticides are commonly discharged in runoff, and some pesticides have been associated with toxicity to Bay organisms. Addresses Clean Water Act and Basin Plan regulations.

Metric 42. Percent of Water Quality Objectives achieved. Percent of all current numerical water quality criteria and objectives met annually in the Bay.

Rationale. Assesses how well Clean Water Act and Basin Plan regulations are being met. This is probably the most commonly measured metric at present and has high public interest. Recommended by CMARP, currently monitored by RMP.

Metric 43. Pounds of trash in the Bay. Estimated total pounds of trash along the Bay shores based on random samples and annual cleanup data.

Rationale. Addresses Basin Plan goals, high public interest.

Metric 44. Area of the Estuary that is being monitored. Estimated area of the Estuary and Delta that is being monitored each year for indicators (TBI, 2003).

Rationale. Measures the efficacy of the Indicators and metrics collected in annual assessments, and helps identify gaps in our knowledge and information.

Metric 45. Average annual residential water use. Estimated amount of water used in nine Bay area counties (TBI, 2003).

Rationale. Residential water use affects water treatment and may require more water diversion. Measures progress towards EPA and local water conservation goals.

Metric 46. “Extra” Inflows to the Bay beyond those required. Number of days each year that the position of X2 (Jassby *et al*., 1995) is within Bay-Delta Accord guidelines (TBI, 2003).

Rationale. Measures compliance with inflow standards: Bay-Delta Accord, and State Water Rights Decisions, recommended by CMARP. The position of the near-bottom 2 psu isohaline in the Northern Estuary is prescribed as a means of regulating freshwater inflows from the Delta into the Bay. The mean annual position compared to that prescribed will show how well the goal was met and help document trends in water flows.

Metric 47. Amount of water that is recycled annually. Estimated total amount of water recycled in Bay area counties annually (TBI, 2003).

Rationale. Reflects amount of water that may reduce diversion from natural sources, and that reduces wastewater discharges. High public interest.

Sources of Data and Collaboration

The Indicators chosen for use by SFEP will eventually need to be based on quantitative data. The indicator metric, index, or trends will probably be calculated based on monitoring data. Fortunately, numerous agencies and organizations currently are, or are planning to collect, this type of data as part of monitoring and research programs (Table 2). Where no data are currently collected for a recommended indicator, the means may need to be found to begin data collection.

Table 2. List of organizations that study or monitor recommended metrics. Some of the Human Use and Governance data sources are from TBI (2003)

Ecological Compartment and Indicator or Index	Agency(s)	Parameters	Web address
I. Estuary Habitats			
A. Freshwater Inflow	DWR, USBR	X2 (position of the 2 psu isohaline)	http://www.water.ca.gov/
	IEP	total Delta input - diverted water	http://www.iep.ca.gov
B. Water & Sediment Quality, Contaminants	SFEI	RMP & WRMP trace contaminants, water quality in Estuary/wetlands	http://www.sfei.org
	DWR	EMP sampling in delta and SPB and Suisun Bay	http://www.iep.ca.gov/emp/pdfFiles/EMP%20parameters.pdf
	USGS	pesticides, water quality	http://sfbay.wr.usgs.gov/access/wqdata/
	SFEI	RMP sediment and aquatic toxicity	http://www.sfei.org
	NOAA/EPA	EMAP benthic abundance	http://www.epa.gov/emap/
	SFEI	benthic community data	http://www.sfei.org
	IEP	benthos abundance - monthly sampling in delta	http://www.iep.ca.gov/emp/pdfFiles/EMP%20parameters.pdf
	SFEI	trace contaminants in fish (CISNet and RMP) and bird eggs (CISNet)	http://www.sfei.org
	SFEI	trace contaminants in sediment	http://www.sfei.org
	USGS	bivalve studies	
C. Habitat Quality	SFEI	wetland area	http://www.ecoatlas.org/custom/index.html
	USFWS	wetland area	http://www.nwi.fws.gov/
	DWR	Suisun Marsh	
	SFEI	wetland projects	http://www.wrmp.org/projectsintro.html
	SFBJV	wetland projects	http://sfbayjv.org/
	USGS SFEI	SF Bay sediment transport Watershed Program	http://ca.water.usgs.gov/projects02/ca530
	UCB	mapping of land use	http://www.regis.berkeley.edu/rhome/baydelta.html
	Greenbelt Alliance	land use issues/urban sprawl	http://www.greenbelt.org/
	SFEI	watershed mapping	http://www.ecoatlas.org/custom/index.html
	ABAG / BCDC	mapping of land use	http://gis.abag.ca.gov/website/welcome.html
II. Biological Resources			
	USGS DWR SFSU/RTC	chlorophyll data	http://sfbay.wr.usgs.gov/access/wqdata/ http://online.sfsu.edu/~phytopl/htmlresearch.htm
	SFSU/RTC	zooplankton	http://online.sfsu.edu/~kimmerer/research.htm
	DWR	zooplankton in the delta - monthly	http://www.iep.ca.gov/emp/pdfFiles/EMP%20parameters.pdf
	DWR	benthos abundance	http://www.iep.ca.gov/emp/pdfFiles/EMP%20parameters.pdf
	SFEI	Benthos	http:/sfei.org

Ecological Compartment and Indicator or Index	Agency(s)	Parameters	Web address
	CADFG	fish biomass	http://www.delta.dfg.ca.gov/historical.html
	SFSU/RTC	fish population	
	USGS, BRD	waterfowl	
	PRBO	Birds	http://www.prbo.org/cms/index.php?mid=222&module=browse
	MMC SFSU	seals - tagging and surveying	http://www.marinemammalcenter.org/learning/research/tagging.asp
	CADFG	status of T&E species	http://www.dfg.ca.gov/hcpb/species/t_e_spp/tespp.shtml
	SFEI	biological invasions program	http:/sfei.org
	SFSU/RTC	invasions in ballast water	http://online.sfsu.edu/~kimmerer/BallastProject.htm
III. Human use and Governance			
	ABAG	land use GIS database	
	USACE, DMMO	dredging database	http://www.spn.usace.army.mil/conops/annualreports.html
	OEHHA, DFG	sport fish consumption advisory	http://www.oehha.ca.gov/fish/nor_cal/index.html
	CADFG	commercial fishing records	http://www.dfg.ca.gov/mrd/fishing.html
	SFBRWQCB	pathogen accidences	
	Calif. Dept. of Health Services	drinking water quality database	
	CDFG Comm. Passenger Fishing Vessel Database	Fall Midwater Trawl; survey Sport Catch	
	DWR EBMUD Pacific Inst.	water use data	http://www.h2ouse.org
	SWRCB Bay Area Water Recycling Program	recycled water use	
	SFBRWQCB	permit data, 303(d) list	
	Dept. of Pest. Regul.	pesticide use database	

Expression of Estuary Condition

The final, and possibly most important step in the indicator framework, is the expression of Estuary condition. The indicator scheme proposed for use by SFEP is tiered, as described above. As a result, expression of Estuary Condition may be tiered. However, exactly how this expression will be calculated and presented has not been determined. We envision the need for a verbal summary of overall Estuary condition derived from the 12 Primary Indicators. This statement will probably be widely used by the news media, so it must be concise, easily understood by the public, and supported by the quantitative indicators, indices and metrics. The next tier will probably include more quantitative assessments for each Primary Indicator. This assessment should include some numerical index or assessment for each Primary Indicator listed in Table 1. The third tier will make detailed information for each metric available in the form of technical reports likely produced by several collaborating organizations. Estuarine managers and scientists will be the primary audience for these reports.

The interpretation of the information used in the Estuary assessments is critical if the assessments are to be meaningful and useful. While each individual metric or indicator will provide basic information about condition, the context for interpretation and the demonstrated relationships among indicators will provide the most insights into the Estuary ecosystem. Considering indicator results in the context of historical changes in the ecosystem, such as annual climatic variability, consequences of biological invasions, changes in pesticide usage, and large-scale restorations, will improve the ability to identify real problems and improvements in Estuary condition. Interpretation plans for each Primary Indicator could describe how each indicator should be interpreted through the range of possible values. For example, what would a high or low indicator value mean when considered in the context of environmental variability discussed above. What reference conditions might be used, etc? Such a plan would allow various interpretations to be considered and discussed among Estuary managers, stakeholders, and scientists so that the public presentation of indicator results is clear. Developing an Interpretation Plan should be part of future work on indicators for the San Francisco Estuary.

We envision that the proposed Indicators will be featured in annual or biennial reports on the condition of San Francisco Estuary under the auspices of SFEP. SFEP currently publishes a Bay-Delta Report Card that tracks progress on CCMP actions (SFEP, 2003). An assessment of environmental condition would be a natural extension of that Report Card. Others may find and offer different interpretations of the data. Advocacy organizations may use the data to further their missions.

A tremendous amount of work will be needed to collect, analyze, and reduce the data for all of the proposed indicators and metrics. Fortunately, as pointed out in the preceding section, numerous agencies and organizations already collect this data. Those groups and others could collaborate to produce of a SFEP Estuary Condition Report. For example, the Bay-Delta Division of the Department of Fish and Game currently monitors fish and produces several fish indices. That group could potentially contribute the Fish Indicator portion of the Estuary Condition Report. There would need to be some coordination of all such groups to produce a coherent assessment, possibly through a standing SFEP Indicators Steering Committee.

Follow-up funding through SFEP in 2004 will permit further refinement of several of the proposed indicators and metrics. A Steering Committee will be formed to oversee further development of the SFEP Indicators. This report and the TBI Scorecard will be reviewed and refined in workgroups of regional experts and managers. These workgroups ill focus on Indicators for Wetland Habitat, Water Quality, and Birds. Additional funding will be needed to form workgroups to review, develop, test and demonstrate the use of all of the indicators and metrics proposed in this report, or their alternatives. The Steering Committee will oversee preparation of proposals for agency and foundation support to continue working on Indicators for SFEP.

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Inventory of Government Literature on Report Cards (Meyers, 1997):
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• The State of Boston Harbor
• The State of Tampa Bay
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• Integrating Environmental Monitoring and Research in the Mid-Atlantic Region
• Chesapeake Bay Environmental Indicators: Measuring our Progress
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Silicon Valley: 1999 Environmental Index (SVEP, 1999)
Southern California Environmental Report Card (UCLA, 2000)
State of the Derwent: Year 2000 Report Card (DEP, 2000)
Sustainable Calgary (2001): State of Our City
The State of the Boston Harbor (MWRA, 1997)
The State of the Great Lakes (Environment Canada and US EPA, 2001)
Wallis Lake Catchment Management Plan (Great Lakes Council, New South Wales, 2001)

Appendix 2. List of current environmental regulations and goals that may be used to identify indicators.

Regulation or Policy	Summary
Water Code 1243.5, 13165 & 13163(b) (YEAR?)	In regulating the amount of water available for appropriation, the SWRCB must take into account unregulated water needed for the protection on Beneficial Uses (Water Code section 1243.5). SWRCB will conduct studies to get information regarding the outflow needs of the SFBay (initiate in 1979; 13165 & 13163(b)).
SWRCB Water Right Decision D-1379 (1971-1978) & D-1485 (1978-1999) & D-1641 (1999-present)	SWRCB Water Right Decision 1379 (D-1641 currently in effect) for Sacramento-San Joaquin Delta and Suisun Marsh. Permittees will participate in research studies in outflow needs (1971). IEP-EMP implements this in collaboration with others. Primary purpose: to provide necessary information for compliance with flow-related water quality standards specified in the water right permits. In addition, the EMP also provides information on a wide range of chemical, physical and biological baseline parameters.
Marine Life Mngmt. Act (AB 1241) (YEAR?)	Marine Life Management Act (MLMA), January 1, 1999, expands the jurisdiction of the CA Fish & Game Commission for regulation of fisheries in oceans(?) and bays.
California Resources Agency & Dept. of Fish & Game	California Resources Agency: Oversees California Fish and Game Commission & California Department of Fish and Game. Both have jurisdiction about sport fisheries, kelp harvesting, and commercial fisheries; creating ecological reserves; and taking emergency actions. Legislation about fisheries resides in Fish and Game Code.
ESA (1973) (reissued 1988)	The Endangered Species Act of 1973 is administered by the U.S. Fish and Wildlife Service (Department of the Interior) and the National Marine Fisheries Service (Department of Commerce). Under section 6 of the Endangered Species Act, each state must maintain conservation programs for resident federally listed threaten and endangered species.
Suisun Marsh Preservation Act (1974) and D-1485 (1978)	Nejedly-Bagley-Z'berg Suisun Marsh Preservation Act of 1974 required that a protection plan be developed for the Marsh. In 1978, the SWRCB issued D-1485, setting water salinity standards for Suisun Marsh from October through May to preserve the area as a brackish-water tidal marsh and to provide optimum waterfowl food plant production. The Suisun Marsh Preservation Agreement (1984?) has this date been determined? entered into among the four agencies has also been authorized by an Act of Congress in PL 99-546.
Bay-Delta Accord (1994) and the CALFED Bay-Delta Program	The 1994 Bay-Delta Accord was an historic agreement that established a framework for the CALFED Bay-Delta Program. The mission of the CALFED Bay-Delta Program is to develop and implement a long-term comprehensive plan that will restore ecological health and improve water management for beneficial uses of the Bay-Delta System.
BCDC (1965)	State of California San Francisco Bay Conservation and Development Commission (BCDC): dedicated to the protection and enhancement of San Francisco Bay and to the encouragement of the Bay's responsible use. The BCDC, established in 1965 pursuant to the McAteer-Petris Act, is the federally-designated state coastal management agency for San Francisco Bay and has jurisdiction to administer the San Francisco Bay Plan, and the Suisun Marsh Preservation Act. In all decisions involving wetlands, the BCDC and its staff evaluate projects in light of the McAteer-Petris Act (the BCDC's primary law) sounds awkward—should it be primary legislation? Or primary enabling legislation?, the San Francisco Bay Plan, the Suisun Marsh Preservation Act, the Suisun Marsh Protection Plan, the federal Coastal Zone Management Act, and the California Environmental Quality Act.
Bay Plan (1969)	The San Francisco Bay Plan of 1969, Developed by BCDC pursuant to the McAteer-Petris Act, includes policies on 18 issues critical to the wise use of the Bay ranging from ports and public access to design considerations and weather. It is an enforceable plan to guide the future protection and use of San Francisco Bay and its shoreline.
California Environmental Quality Act (CEQA: 15021) (YEAR?)	Under the California Environmental Quality Act (CEQA: 15021), public agencies have a duty to minimize environmental damage and balance competing public objectives. The public agencies must regulate public or private activities, giving major consideration to preventing environmental damage.
Strategic Plan (2001)	The State Water Resources Control Board's Strategic Plan has six main goals. meant to encourage balanced and efficient use of water through water transfers, recycling and conservation.
Dickey Water Pollution Act	The Dickey Water Pollution Act of 1949 created the State Water Pollution Control Board that set statewide policy for pollution control and coordinated the actions of those state agencies and political

Regulation or Policy	Summary
(1949)	subdivisions of the state in controlling water pollution. It also created nine Regional Water Quality Control Boards that were given the responsibility for protecting the surface, ground and coastal waters of their regions.
Clean Water Act (CWA 1972))	Clean Water Act, in US Code (1972), established the basic structure for regulating discharges of pollutants into the waters of the United States. The CWA places primary responsibly for the control of water pollution and planning the development and use of water resources with the states. The CWA §101 requires that the chemical, physical, and biological integrity of the nation's waters be maintained. It gave EPA the authority to implement pollution control programs such as setting wastewater standards for the states.
Porter-Cologne Act (1970)	The Porter-Cologne Act grants the SWRCB and RWQCBs broad powers to protect water quality and is the primary vehicle for implementation of California's responsibilities under the federal Clean Water Act. The Porter-Cologne Act grants the SWRCB and the RWQCBs authority and responsibility to adopt plans and policies, to regulate discharges to surface and groundwater, to regulate waste disposal sites and to require cleanup of discharges of hazardous materials and other pollutants.
McAteer-Petris Act (1965)	McAteer-Petris Act (1965) established the San Francisco Bay Conservation and Development Commission (BCDC) as the state agency charged with preparing planning and oversight for the long-term use of the Bay and regulating development in and around the Bay.
Basin Plan (1995)	RWQCB, Water Quality Control Plan (1995) for the San Francisco Bay Region is the master policy document that describes legal, technical, and programmatic basis of water quality regulation in the San Francisco Bay region. It contains a statement of beneficial water uses, water quality objectives, and strategies and timing for achieving the water quality objectives.
California Toxics Rule (40 CFR Part 131: Aug 5, 1997)	The EPA's water quality standards provides a proposed rule for numeric water quality criteria for priority pollutants necessary to fulfill the requirements of section 303[c] (2) (B) of the Clean Water Act in the state of CA.
LTMS (2001)	The Long Term Management Strategy for the Placement of Dredged Material is a management plan implemented by the US Army Corps, USEPA, BCDC, and SFBRWQCB, and provides guidance for dredging and dredged material disposal in the Estuary.
Habitat Goals (1999)	This report presents recommendations for the kinds, amounts, and distribution of wetlands and related habitats that are needed to sustain diverse and healthy communities of fish and wildlife resources in the Estuary.
SFEP CCMP (1993)	US EPA – State sponsored Comprehensive Conservation and Management Plan to identify management actions required to restore and protect San Francisco Estuary. Identified management goals in six major program areas. SFEP continues to produce a biennial report card on progress towards CCMP goals.

Appendix 3. EPA indicator selection guidelines (EPA, 2000).

Conceptual Relevance. Is the indicator relevant to the assessment question (management concern) and to the ecological resource or function at risk?

- Relevance to assessment
- Relevance to ecological function

Feasibility of Implementation. Are the methods for sampling an measuring the environmental variables technically feasible, appropriate, and efficient for use in a monitoring program?

- Data collection methods
- Logistics
- Information management
- Quality assurance
- Monetary costs

Response Variability. Are human errors of measurement and natural variability over time and space sufficiently understood and documented?

- Estimation of measurement error
- Temporal variability, within the field season
- Temporal variability, across the years
- Spatial variability
- Discriminatory ability

Interpretation and Utility. Will the indicator convey information on ecological condition that is meaningful to the environmental decision maker?

- Data quality objectives
- Assessment thresholds
- Linkage to management actions.

Appendix 4. Indicator selection criteria from The National Research Council's publication, Ecological Indicators for the Nation (NRC, 2000; summary from Gunther and Jacobson, 2002).

General Importance. The indicator must reflect something of importance that has public meaning or can be easily related to something that has public meaning. If the indicator does not track a characteristic of the ecosystem that is easily understood and of significance to many people, it will be less likely to be observed and acted upon.

Conceptual Basis. There must be a clear scientific rationale for how the indicator relates to the assessment question, so that measurements can be interpreted in a manner consistent with our present scientific understanding. That understanding is often most usefully expressed in the form of a conceptual model that relates changes in the ecosystem to changes in the indicator, and provides guidance for how the indicator should be measured.

Reliability. Is there existing evidence that the proposed indicator has been successfully used in the past to indicate ecological condition in a meaningful way? Such an indicator will engender more public trust than a new untested indicator. Reliability of new indicators can be tested with a retrospective analysis. If a dataset for retrospective analysis is unavailable, then reliability can only be determined through experience.

Temporal and Spatial Scales. Selected indicators must be appropriate to the spatial scale of South Bay, so that a change in the condition of the Bay will be reflected by the indicator. Similarly, the indicator should respond on a temporal scale that makes it useful, rather than lagging behind changes in the ecosystem. For example, the health of migratory species or animals that spend a significant amount of time foraging outside the Bay will not necessarily reflect local conditions.

Statistical Properties. The statistical properties of the indicator (accuracy, precision, sensitivity) should be adequate for the job. Given the normal variability in environmental measurements, an indicator will be more useful if it can separate a "signal" of a significant ecological change from the "noise" of normal variability.

Data Requirements. Assessments of ecological condition will be based on examining trends in indicators over time, and the necessary length of the data set one may need to collect to observe trends should be considered. Some changes, such as those driven by climatic alterations, will take longer to observe, while changes driven by disturbance can be observed over a shorter timescale.

Necessary Skills. To be useful, indicators must not be so unusual or difficult to measure that only a few specialists are capable of producing defensible data. This is important to ensuring that a long-term database can be developed and increases the possibility of involving citizens in monitoring, making the indicators more cost-effective.

Cost/Benefit and Cost Effectiveness. In general, the costs to develop and implement a program to measure an indicator are easier to estimate than the benefits, which is the value of the information obtained. However, consideration of costs and benefits still must be part of indicator selection, especially when several alternative indicators for an assessment question are possible. It is quite likely that certain indicators can be measured for much lower cost than others.

Appendix 5. Habitat Goals Project criteria for indicator species selection (Goals Project, 1999)

Community Indicator: Species is indicative of a community, guild, or assemblage of species. A community indicator can represent other species because of similar habitat requirements.

Habitat Indicator: Species is indicative of a key habitat. The presence of the species helps define the habitat.

Sensitive Species: Slight changes in habitat conditions might cause large changes in population status, or the species has been recommended for legal protection (differentiated from "candidate" status below).

Protected Species: Species is listed, or is a candidate to be listed, for protection under state and/or federal law because it is rare, threatened, or endangered.

Economic Indicator: Species is an important commercial or recreational species.

Dominant Species: Species strongly influences community structure as a major prey item, keystone species, pollinator, or ecological engineer. In the strictest sense, a keystone species is a predator that exerts a strong measurable influence on the relative abundance of other species in the community. The term applies to any species, predator or not, that exerts such influence. An ecological engineer is a plant or animal that changes the physical environment in a way that strongly affects other species.

Pest Species: Species is an invasive species or a pest to people.

Practical Species: Species is a convenient indicator of a community, guild, assemblage or habitat because it is well studied or easily studied. This criterion helps to select among the many possible community or habitat indicator species.