Conceptual Framework for Indicator Development: Development of Key Ecological Attributes for the San Francisco Bay-Delta Watershed

Terry Young and Rod Fujita, EDF, Serge Birk, CVPWA, Douglas Morrison, USFWS, Anitra Pawley, Consulting Ecologist, The Bay Institue of San Francisco, Pete Rhoads, MWD

Summary

Restoring and protecting the ecological integrity of a complex ecosystem requires a basic understanding of the natural structure, function and organization of the system to be restored. Such understanding enables managers to assess the degree to which prospective restoration sites diverge from a "healthy" or "natural" condition, to design the restoration program accordingly, and to evaluate project progress and effectiveness later on. In this management context, one practical means of summarizing the most relevant existing information on ecosystems is to develop, over an appropriate hierarchy of spatial and ecological scales, a list of key system attributes — those fundamental natural ecological characteristics that together define and distinguish these systems, their status, and/or their interrelationships. The list of attributes serves as a convenient and necessary "check list" of environmental factors that might be addressed in an ecological restoration program; it provides a template for developing appropriate "indicators" (measurable parameters that provide a means to objectively and quantitatively evaluate individual attributes); and it provides the foundation for developing the conceptual models used to guide restoration activities.

Under the umbrella of the CALFED program, a broad-based group of stakeholder and agency scientists has developed the following conceptual framework for indicator development, including a draft set of key system attributes that can be used to guide the development of ecological indicators in the CALFED program, as well as to facilitate the integration of the ecological indicators with the conceptual models for the program. The full list of participants, many of whom contributed substantially to this effort, is available from CALFED.

Use of Attributes and Indicators Within CALFED

The first step in designing a restoration program is usually to develop a general, overarching goal statement that is then refined into a series of more specific objectives. The objectives are still quite general, however, much like "maintain a healthy circulatory system" might be an objective for a human patient. The objectives must therefore be translated into more specific terms so the program can be implemented and results can be assessed.

Within this context, the purpose of ecological indicators is to translate the goal and objectives into a series of specific measurements that can be taken to determine whether the goal and objectives have been met. In short, ecological indicators define success: the ultimate achievement of the desired indicator levels shows that ecological integrity has been restored, and incremental progress towards those levels over a predetermined timeframe shows that the program is on track.

The ecological indicators should therefore provide an accurate measure of the ecological integrity of the Bay/Delta watershed. The set of indicators must be scientifically derived, yet provide a picture of "success" that is understandable with minimal interpretation to a diverse audience of policymakers, elected officials, and the public. It should also be durable, so that long-term trends—and improvements resulting from implementation of the CalFed program—will be apparent over time.

Note that the ecological indicators perform a different function than the "implementation objectives" developed by the CALFED program. The implementation objectives, targets, and actions are supposed to provide a recipe for achieving the overall program objectives. They are the "to do" list for the restoration program. In contrast, the set of ecological indicators (with their associated numerical ranges) is the list of parameters that will be measured to determine whether the recipe is the right one. The indicators will show, in the aggregate, whether the ecological system is moving towards the healthy condition envisioned and therefore show whether the actions are having the intended effect. In short, they can be used to evaluate the effectiveness of restoration actions.

In order to develop both the implementation program and the indicators, a few fundamental tools are required. First, the understanding of ecosystem structure and function—and in this case that of an entire landscape—should be laid out in a methodical format. One useful tool for this purpose is the ecological conceptual model. Ecological conceptual models describe key ecological attributes and their interrelationships and can also incorporate the effects of human activities (termed stressors) on these attributes in ecosystems at risk (NRC 1990).

Hypotheses about natural ecosystem structure and function and the effects of anthropogenic stressors are the underlying bases for these models. By depicting—usually using a simple diagram—cause and effect relationships regarding environmental changes, conceptual models explain ecological restoration strategies, aid in the development of testable hypotheses to explain why particular effects should or should not occur, help synthesize ideas and knowledge, identify supporting scientific information needs, identify logical errors, and assist in the development of indicators (NRC 1986). Preliminary conceptual models for the Bay/Delta Watershed and a process for refining them have been outlined in a separate document by CALFED staff ("Developing a Strategic Plan for Ecosystem Restoration", a technical appendix to CALFED's programmatic EIS/EIR released in March 1998).

Within the context of the CALFED program, conceptual models should guide the development of the implementation objectives, actions, and targets mentioned earlier. Because the conceptual models incorporate essential ecosystem attributes, they also aid in the development of indicators.

In order to assure that the set of ecological indicators provides an accurate and comprehensive picture of system health, however, the ecological indicators should be derived using a separate—but complementary—methodical conceptual framework. The following description outlines the conceptual framework for indicator development that was developed in a series of meetings with stakeholder and CALFED agency scientists convened by CALFED over the past two years.

The keystones of this conceptual framework are a list of the major characteristics of ecological systems (the attribute list) and a classification of ecological zones and habitats (a typology). The attribute list and typology provide a template for the development of indicators that will address each of these essential system characteristics at every relevant scale and location. Using the generic attribute list also provides another important benefit because it facilitates the later aggregation of useful information, either for a particular characteristic or for a particular geographic region. In this way, the attribute list and typology provide a foundation for systematic, scientifically accurate reporting of the program's progress in achieving the desired outcome of the CALFED restoration program —a healthy, functional, and sustainable system. A provisional list of natural ecological attributes of the ecosystems of the Bay/Delta Watershed was developed by the working group and is presented below.

Method for Developing Ecological Indicators

The conceptual framework that we used provides for stepwise development and use of the indicator set.

Step 1: Divide the Bay/Delta/River system into manageable components that still reflect the natural organization of the ecological system. According to current ecological science, natural systems are organized according to a hierarchy: first, the whole system as a single unit possesses certain attributes that are important to consider and cannot be derived simply by adding up all the smaller pieces of the system (landscape level); second, the system can be divided into functional subunits, each of which can be treated as a discrete ecological system (ecosystem and habitat levels). The map of this organizational hierarchy is termed a "typology".

The typology used here to describe the Bay/Delta Watershed is summarized in Figure 1, and is based upon systematic differences in large-scale hydrological, geomorphic, and biological features of the landscape. This has been developed through several years of discussion and refinement by a wide variety of knowledgeable persons involved in the CALFED process (Levy *et al.* 1996).

Note that this typology is generic and can be used in many ways. It provides a framework for assembling information on the entire Bay/Delta watershed or on all upland or lowland river systems as a group. It also provides a framework for management of individual watersheds, because indicators that relate to the generic attributes can (and we assume will) be developed for the upper river/riparian, lowland river/floodplain, and—if applicable—delta portions of each watershed undergoing comprehensive restoration. (Where minimal restoration activities are planned, a less comprehensive group of indicators would be derived, but would follow the same logic.)

Step 2. Determine the essential ecological attributes that should be assessed for all components in order to accurately diagnose integrity. The conceptual framework provides for a discrete set of indicators for each of the components of the typology (i.e., each box in the diagram). The sum of all the sets of indicators (including the set for the integrated landscape) provides the big picture of ecological integrity, while the set of indicators for one of the smaller subunits provides a more detailed picture of the integrity of that particular piece.

In order to help assure that each component is assessed accurately, and also to facilitate the integration of the

Table 1. Ecological Attributes of the Watershed

For practical reasons, ecosystem-level attributes were organized into five broad categories, each of which reflects essential aspects of ecosystem structure/function:

A. General Hydrologic Attributes

Rationale: Ensuring the integrity of natural hydrology is an essential aspect of restoring/maintaining healthy ecological structure and function. In rivers and streams for example, minimal flow levels are necessary to assure viability of all life stages of all native aquatic organisms, and to maintain adequate groundwater levels in support of riparian vegetation. Sufficient seasonal shifts in stream level are essential to flushing, groundwater and other river-riparian exchange processes. Seasonal velocity ranges and timing must be compatible with viability of all life stages of aquatic organisms and with the maintenance of sediment delivery/deposition processes. Periodic flooding is necessary to maintain diversity and succession within riparian zone, and for the exchange of materials between riverine and riparian habitats.

Example: Representative Hydrologic Attributes:

* flows and floods (hydrograph/hydroperiod)
* water movement patterns/circulation
* salinity distribution
* groundwater exchange

B. General Geomorphic Attributes

Rationale: Ensuring the integrity of major geomorphic features and processes is an essential aspect of restoring/maintaining healthy ecological structure and function. For example, altered local topography may cause habitat fragmentation. Physical barriers may prevent or inhibit natural water, sediment and/or animal movement, and/or prevent reestablishment of riparian zone even if hydrologic restoration is successful. In-stream structure, sinuosity of channel, and cross-sectional profile interact with flow to determine sediment deposition, distribution, and substrate composition.

Example: Representative Geomorphic Attributes:

* topography
* sediment budget
* sediment composition

C. Habitat Attributes

Rationale: Among-habitat attributes define essential aspects of system structure and function at the landscape and ecosystem-levels. For example, the disconnection of nearby habitats (through construction of barriers or alteration of natural topography) may prevent full community development and/or restrict the distribution and viability of some populations. More specialized (***within-habitat***) attributes that distinguish habitat-types are being addressed elsewhere (habitat-level of the typology). Both within and among habitat attributes are essential to the support of native biological communities and natural ecological processes in these ecosystems.

Example: Representative Habitat Attributes (Among- Habitat/Landscape and Ecosystem-levels):

* habitat extent and distribution
* connectivity
* habitat diversity
* water and sediment quality

D. Native Biological Community Attributes

Rationale: Restoration and protection of natural community attributes is an essential aspect of restoring and protecting ecosystem integrity. The various ecosystem-types of the watershed each harbor distinctive biological communities, distributed within and among their component habitat-types. The maintenance of overall biodiversity and fundamental aspects of community structure are primary goals of most restoration/management programs. Biodiversity and community structure are important determinants of habitat structure and of many fundamental ecosystem processes, including primary production, nutrient cycling and exchange.

Example: Representative Community Attributes:

* species composition
* abundance/dominance relationships
* species diversity
* trophic structure
* threatened or endangered species
* exotics

E. Community Energetics/Nutrient Cycling Attributes

Rationale: The acquisition, cycling and fate of energy and nutrients are critical aspects of ecosystem function, and essential to the support of native biological communities. Ecosystem attributes related to energy/nutrient movement are a combination of both abiological (e.g., water movement and circulation) and biological (e.g., trophic dynamics and decomposition) factors.

Example: Representative Attributes:

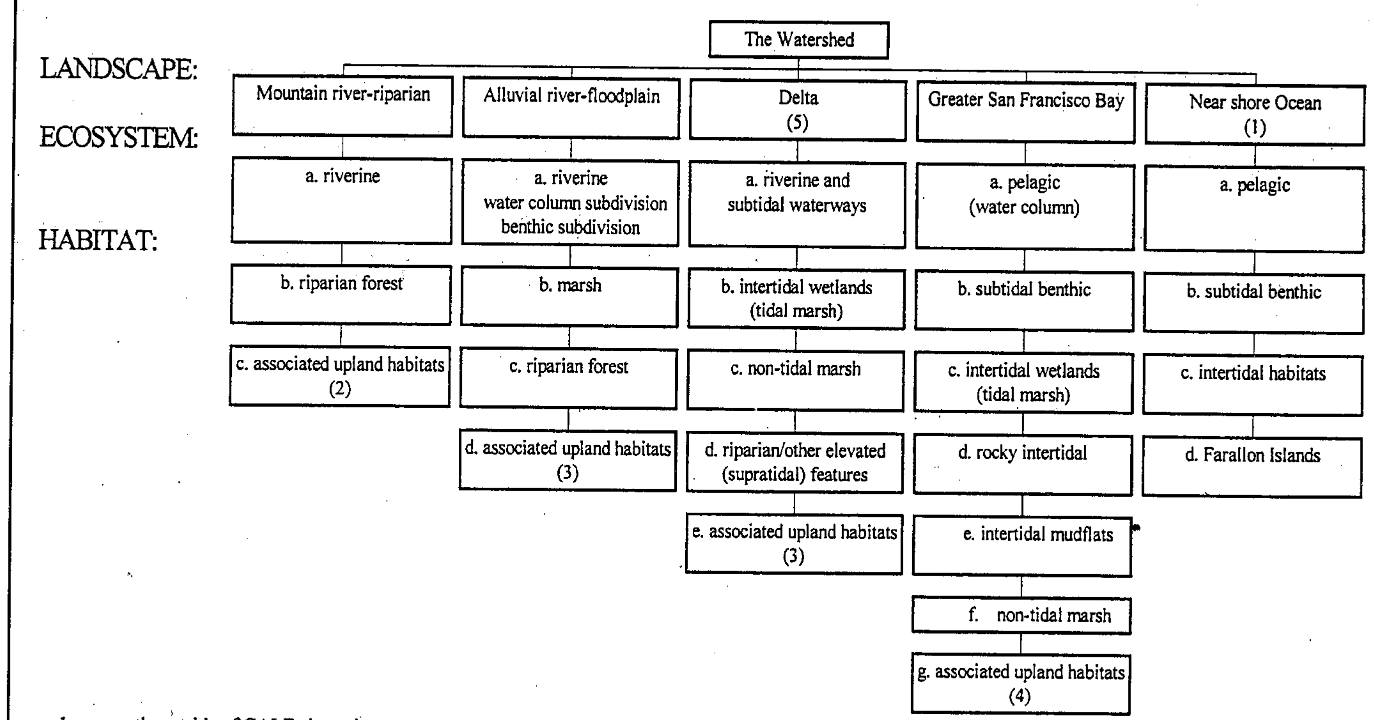
* nutrient sources and sinks
* carbon budget
* trophic dynamics
* food webs and nutrient cycling

information into a coherent picture, we have derived a list of generic ecological attributes that should be addressed in the set of indicators derived for each component (Table 1). This list of attributes is based on our understanding of (i.e., our hypotheses about) natural system structure and function. The five generic attributes are similar to a set derived independently by a group of scientists for the South Florida system (Harwell in prep.), for the Trinity River system (Trinity River Mainstem Fishery Restoration EIS/EIR, 1997), and by a group of environmental professionals during a workshop on restoration performance criteria convened by the Society of Ecological Restoration (Read *et al.* in prep.), which suggests that the approach is relatively robust.

In many cases, the individual indicators that are chosen to represent each generic attribute will be the same for different components of the typology (e.g., habitat extent). In other cases, the same attribute will require indicators that differ for different locations, yet still convey the same type of information (e.g., habitat quality). In either case, using a consistent list of attributes for different parts of the system provides a mechanism for assembling and integrating the information for useful interpretation and reporting.

Step 3: For each component of the typology, determine which specific attributes should be assessed in each of the generic categories. A preliminary list of the attributes for four of the five generic ecosystem categories has been developed by the agency/stakeholder group and is available for review from CALFED. Attributes for the landscape as a whole and for habitat types have not yet been developed, but would reflect the same five generic categories.

Attributes for each of the system's ecosystem-types were generated by assessing available information on (1) the historical state of these systems, (2) "pristine" remnant sites within this watershed, and (3) similar types of systems at other locations. They represent our best current evaluation of the condition of the system in its natural or pristine state, which may differ from a desired (or attainable) "target state" of a restoration or rehabilitation program. "Stressors" noted for the attribute group-



1. currently outside of CALFed purview
2. including mountain meadows, upslope conifer forests, and oak woodlands
3. including valley oak woodland, native grassland, chapparal, wildflower fields, and vernal pools
4. including valley oak woodland, native grassland, chapparal, wildflower fields, vernal pools and riparian forest
5. the legal Delta

Figure 1. A Bay/Delta Watershed Ecological Typology

ings represent those anthropogenic factors believed most influential in altering attribute states over the last few centuries. The attributes presented are most applicable to the broader, ecosystem level of restoration/rehabilitation planning. They represent common, fundamental ecological features of these types of systems. It is emphasized that application of these attributes (and their indicators) at particular sites will require refinement by experts familiar with the unique properties and environmental conditions found at those sites, as well as the specific goals and objectives of the particular restoration project.

It is important to note that conceptual models will also be derived for each component of the typology. The conceptual models should incorporate each of the generic attributes listed in Table 1, show how they interrelate, and be derived from the same working hypotheses regarding natural system structure and function used to generate the attribute lists. In short, the conceptual models provide a qualitative description of causal links in the system (NRC 1990), including those between stressors and attributes. The indicator framework and the conceptual models are therefore complementary: the generic attributes provide a checklist for the derivation of conceptual models; and the conceptual models help to determine which individual indicators will best reflect the improvements that the CALFED program has committed to effect.

Step 4: Determine the best indicators to use for each of the specific attributes. While attributes represent essential ecological characteristics that should be assessed, they are not always directly measurable. For this reason, ecological indicators—parameters that are directly measurable—must be developed that correspond to each attribute. In some cases, such as water temperature, the attribute and indicator are the same. In other cases, such as habitat continuity, the attribute may be assessed by combining several individual indicator measurements.

In order to be selected for use in the program, we recommend that individual indicators meet two rigorous tests: they must be both ecologically relevant and scientifically defensible. These two criteria are explained in greater detail, and an additional list of useful criteria are presented in Levy *et al.* (1996).

Once the indicator list is developed, we suggest that it be reviewed to determine whether some indicators can be consolidated without losing information, to determine whether some indicators should be revised to facilitate aggregation across levels of hierarchy within the typology and across different geographic regions, and to assure that the essential criteria for indicator selection have been met.

Step 5: Determine optimal numerical ranges, current values, short-term milestones (with schedule), and long-term targeted numerical ranges for each indicator. The methods and criteria that may be used to derive optimal numerical ranges for the indicators have not yet been addressed by the agency/stakeholder group, although considerable background research is underway.

Step 6:Assure that the monitoring program includes the measurements required for each indicator. The monitoring program currently being developed by a consortium of CALFED and other agencies (the Integrated Environmental Monitoring and Research Program) will, we assume, include not only measurement of each of the indicators, but also other components required to implement and adaptively manage the program , as well as conduct focused research projects, provide compliance information, and the like.

Step 7: Assess the results. Evaluating the indicator measurements will require considerable scientific expertise, even with the most transparent and logical system for indicator development. Interpretation of conflicting results also may be necessary, particularly in the early years of the restoration program. One way to address these difficult issues is to convene a standing scientific panel to evaluate indicator results, report to the public, and determine when certain indicators would be updated to reflect advances in ecological science. The panel would be composed of scientists independent of agencies and other parties with a direct stake in the implementation of the restoration program.

References

Harwell, M.A., S. Appelbaum, J. Barko, A. Bartuska, B. Causey, N. Gassman, J. Gentile, C. Harwell, C. Johnson, A. McLean, V. Myers, P. Templet, S. Tosini, T. Yount. In prep. A framework for an ecosystem health report card.

Levy, K., T. F. Young, R. M. Fujita, W. Alevizon. *Restoration of the San Francisco Bay-Delta-River System: Choosing Indicators of Ecological Integrity.* University of California. Berkeley, California. 66 pp.

National Research Council (NRC). 1986. *Ecological Knowledge and Environmental Problem Solving: Concepts and Case Studies.* National Academy of Sciences. Washington, D.C. 388 pp.

——. 1990. *Managing Troubled Waters: The Role of Marine Environmental Monitoring.* National Academy of Sciences. Washington, D.C. 125 pp.

Read, E., *et al.* (in prep). Proceedings of the Workshop on Ecological Restoration Performance Criteria. Society of Ecological Restoration, California Chapter. March 9-10, 1998, San Diego, CA.

Trinity River Mainstem Fishery Restoration EIS/EIR, Public Meeting of October 28-30, 1997

Water Year 1997-98

By Maurice Roos

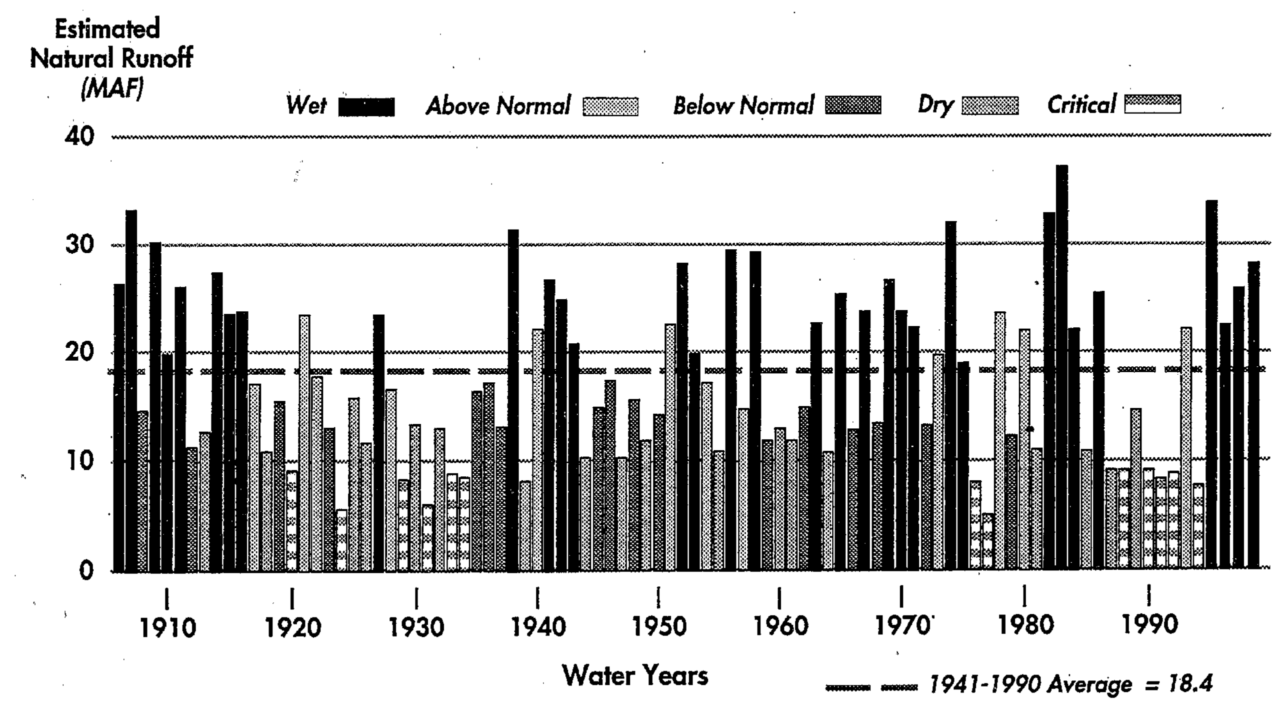
Water year 1997-98 was wet, but a marked contrast to water year 1996-97. Last year saw some extreme flooding from a couple of concentrated storm events. This year saw frequent storms, which generally kept moving with moderate snow levels. As a result, the total rainfall and runoff are expected to be more than last year once the April 1 (160 percent of average) snowpack melts. This year will mark the fourth wet year in a row, a rather unusual string of wet years which has only happened once or twice before this century. One of the century's stronger El Niño events strengthened the southern jet stream track to push storm after Pacific storm into California, especially the coastal region.

Total runoff this year will probably be the fourteenth wettest this century in the Central Valley, less than either 1983 (the last strong El Niño year) or 1995, but more than 1997. See Figure 1 for the history of Sacramento River system runoff. The forecasted 1997-98 amount will rank 12th wettest for Sacramento River unimpaired runoff.

After a slow start in December this winter turned wet. A series of El Niño driven storms delivered twice normal statewide precipitation during January and three times normal precipitation in February. Runoff statewide during February was 250 percent of average, following a January that produced about 160 percent of the monthly average amount.

Most major Central Valley foothill reservoirs operated in the flood control mode during February and March with excess waters released in a controlled manner into the Sacramento and San Joaquin River systems. All Sacramento system fixed weirs flowed most of February and 16 of 48 gates in the Sacramento Weir were opened in early February. The Paradise Cut weir near Tracy on the San Joaquin River also flowed for about three weeks. The San Joaquin River near Vernalis reached within one-third foot of its 29-foot flood stage about mid-February then fluctuated around the 28-foot level as reservoir operations controlled much of the storm runoff.

Most of the winter storms were fairly rapid movers with short breaks between rain events. As such, no



NOTE: The Sacramento River runoff is the sum of unimpaired runoff from the Sacramento River at Bend Bridge, Feather River Inflow to Oroville, Yuba River at Smartville and American River Inflow to Folsom. Categories are based on the 40-30-30 formula.

Figure 1. Sacramento River Unimpaired Runoff Since 1906