DELTA STEWARDSHIP COUNCIL

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January 26, 2011

To: Phil Isenberg, Chair, Delta Stewardship Council
Members of the Delta Stewardship Council

From: Delta Independent Science Board

Re: Addressing Multiple Stressors and Multiple Goals in the Delta Plan

On August 18, 2010, some members of the California Legislature wrote to you requesting that the Delta Science Program and the Delta Independent Science Board (Delta ISB) "…conduct an assessment of stressors on populations of native fish species in the Delta, the Sacramento and San Joaquin rivers, and the tributaries of those rivers below the rim dams of the central valley." In your response dated September 15, 2010, you stated, "It is my intent to ask our science team, including the Independent Science Board, to develop a list of 'stressors' to the Delta and then prioritize the stressors."

Based on the members' experience, a quick survey of key environmental management efforts around the world, and information gleaned from a one-day workshop organized by the Delta Science Program, the Delta ISB notes that environmental planners, managers, and scientists worldwide are struggling with the assessment and prioritization of multiple stressors. Given the clear urgency around developing an approach to handling multiple stressors for the Delta Plan, the Delta ISB notes and advises:

1. The Council's decisions will necessarily blend scientific and political judgment. There is at present no broadly agreed upon objective methodology for prioritizing multiple stressors, but there are scientific tools, discussed in the attached supporting material, that can add rigor to subjective prioritization.
2. The Council, with the help of the Science Program and review by the Delta ISB, needs to make sure that there are strong causal connections between the stressors addressed in the Delta Plan and particular objectives within the broad coequal goals of the Plan. Sound science and improved modeling can help further ensure these causal connections as the Plan is implemented.
3. A large number of stressors need to be addressed. The Delta ISB has found no reason to think that reducing one stressor, or several stressors, will solve even a particular problem such as the pelagic organism decline (POD). The Delta ISB has prepared a list of key stressors, provided as Attachment 2 to this memo. These are organized under the following four categories:
    a. Global drivers that cannot be controlled by the Delta Plan but whose impacts can be reduced through adaptation,
    b. Legacy stressors resulting from past actions in the Delta watershed that cannot be undone,
    c. Anticipated stressors that can be foreseen resulting from present or future activities, and

   d. Current stressors that result from ongoing activities such as water management practices, agricultural practices, and waste discharges.

4. The Council should plan around the long-term drivers that are producing multiple stressors effecting the major changes in the Delta for the foreseeable future. Climate change, population growth, and pollution are driving numerous particular stressors causing unwanted impacts. Some of these drivers and their associated stressors cannot be mitigated by local action (e.g. temperature increase and changes in precipitation patterns from climate change) and the main planning response must be adaptation. Informed planning can mitigate other drivers and stressors (e.g. patterns of urban expansion from population growth).
5. The success of the Delta Plan depends on the strength of the system of environmental monitoring and adaptive management it establishes. The response of the Delta to management actions is uncertain and will be more so as climate change and other drivers shift the Delta system into new states. The Delta Plan needs to support substantially more intensive monitoring, strong ecological analytical capability, and clear mechanisms for review and updating all aspects of policy and management over time.
6. The implementation of the Delta Plan can improve over time through better integration of Delta science. The Delta Science Program and the prior efforts under CALFED provide the primary journal, conference venue, research support, and shared modeling efforts integrating the scientific understanding of the Delta. This coordinating role needs to be strengthened and expanded. The DRERIP (Delta Regional Ecosystem Restoration Implementation Plan) models, developed as part of CALFED, provide the most relevant set of scientific tools for assessing the significance of different stressors in the Delta, but the models need further development to be useful as dynamic tools for policy and planning.

The supporting material attached elaborates on the findings of the Delta ISB. The content of this memo and supporting material was approved for transmittal to the Council by a quorum of the Delta ISB on January 24, 2011.

Attachment 1

Supporting Material

The implementing legislation for the Delta Stewardship Council and Delta Plan, SBX7-1, specifies in Section 83502(c) that: "The Delta Plan shall include measures that promote all of the following characteristics of a healthy ecosystem" including (4) "reduced threats and stresses on the Delta ecosystem." Thus, threats and stressors and their reduction must be addressed in the Delta Plan.

Members of the Delta ISB, with assistance from the Delta Science Program, reviewed the approaches used for classifying and prioritizing stressors in a wide variety of environmental planning and management efforts in the United States and around the world. A list of key stressors was also developed. Then, the Delta Science Program and Delta ISB organized a workshop held in Sacramento on January 12, 2011, at which invited experts, members of the Delta ISB and the Science Program Lead Scientist addressed two questions: 1) Is it feasible to classify stressors in terms of their importance to the goals of Delta management; and 2) What methods could be used to accomplish that classification? The workshop also helped the Board assess the available science for use in Delta planning and recommend sustaining the science for future needs.

We elaborate on the key points of our discussion about multiple stressors and best available science as follows:

1. *There is no broadly agreed upon methodology for classifying and prioritizing multiple stressors*

In the collective experience of the Delta ISB, the issues of multiple stressors and multiple objectives are pervasive, are of considerable concern to scientists, and are still being evaluated in the Delta, as they are for ecosystem planning and management worldwide. For a variety of reasons noted below, the ranking of stressors is especially difficult. With present understanding, it is not possible to identify a small number of key stressors preventing the achievement of the coequal goals. Nonetheless, the Board finds that there are several approaches that can be used to assist in classifying and prioritizing stressors. Council decisions about which stressors to address at which time will involve a blend of science and political judgment. The scientific tools that can help with this process are discussed further in the following sections.

2. *The importance of a stressor depends on the importance of the management objective it impedes*

The Delta Reform Act of 2009 specifies four basic goals for the Delta (section 29702) and further identifies a number of subgoals and characteristics of the Delta ecosystem and reliable water supply that the Delta Plan shall address (section 85302). These goals, subgoals and characteristics suggest an integrated set of objectives that the Delta Plan must try to address. Stressors can be considered as variables or aspects of the Delta system that are obstacles to meeting the objectives. Thus, stressors and objectives are tightly linked in the sense that objectives define the important stressors and stressors affect the difficulty, or even possibility, of reaching the objectives.

Because of this tight linkage between policy and management objectives and stressors, the relative importance of stressors cannot be assessed, or prioritized, independent of the relative importance of the objective that is stressed. Scientists rarely address the relative values of different social objectives explicitly, and, as a consequence, the scientific literature provides little information about the relative importance of stressors.

3. *Assessing, or ranking, stressors is very complex for many reasons*

For example:

a) Multiple stressors typically affect an objective in complex, interactive ways that can make it very difficult to ascertain that one stressor is more important than another.
b) Objectives can also be interconnected.
c) A stressor that impedes reaching one objective may have positive effects on achieving another objective.
d) The action and importance of a stressor can vary over seasons or from year to year, or from place to place.
e) Objectives and stressors can vary in importance, for example, as they are assessed at different spatial and temporal scales.
f) There are two broad categories of stressors, those that can be mitigated and those to which the Delta Plan must adapt, and prioritizing across these categories is probably counterproductive.

In developing the Delta Plan, it will be important for the Council to look closely at the relationship between stressors and objectives to ensure that the most important stressors are identified and addressed in the Plan. At the same time, for the reasons noted in a-f above, this will be difficult and will require interactive scientific and political judgment.

4. *The terminology for describing and classifying stressors is not standardized*

Some environmental scientists use quite elaborate terminology to describe how systems respond to stressors and how stressed ecosystems can be managed, splitting terms that other scientists lump together. Even when referring to the same phenomenon, such as something that has a negative effect on an ecosystem attribute, some scientists refer to them as stressors, others call them threats. The inconsistent terminology can be quite frustrating, but this is the state of the science available for crafting The Delta Plan.

The DPSIR (Driver, Pressure, State, Impact and Response) framework has been adopted by the European Environment Agency for describing the challenges of environmental management.[1] We have modified the DPSIR terminology slightly to tailor it to the needs of planning in the Delta (the relationships among these components are shown in the conceptual model of section 5):

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[1] http://enviro.lclark.edu:8002/rid=1145949501662_742777852_522/DPSIR%20Overview.pdf).

- *Drivers* are the sources or creators of stress that exert pressure on the ecosystem; for example, altered flows through the Delta.
- *Pressures* are the *stressors*, the factors that act to determine the condition of a system attribute of interest; for example, altered flows result in increased salinity as well as other stressors (temperature, currents, etc.).
- *Key system attributes* are the components of the system that are of interest or concern; for example, the condition (e.g., physiology, reproduction, productivity) of wetland vegetation. Other examples of key system attributes might include the specific life-history stage of a species that is affected by a particular stressor, the population size of a listed species, or the availability of irrigation water for agricultural crops.
- *Responses* are the actions that are taken to maintain or improve the condition of key system attributes. For example, this could be changing the flow regime to reduce salinity stress at critical times of the year. Responses can be directed at the drivers or the stressors, to remove or mitigate their effects, or at the key system attributes, to facilitate adaptation to the stressors. For example, one response would be to manage flows—the driver, to reduce salinity—the stressor. Other management actions could be directed at the wetland vegetation (e.g., protecting critical areas or vegetation restoration), but management directed at the stressor itself, in this case salinity, is less likely.
- *Objectives* describe preferred outcomes of management actions on key system attributes; for example, restoring or improving wetland functioning.
- *Performance measures* are metrics describing the state of key system attributes that can be used to assess progress in meeting objectives; for example, progress might be evaluated by monitoring measures of productivity, biomass, or biodiversity.
- All elements of this conceptualization – the linkages among drivers, stressors, key system attributes, responses, objectives, and performance measures – are parts of an ongoing, dynamic process of *adaptive management*.

Note that, depending on the key system attributes of interest, what is a driver of stressors in one case can be a stressor in another. This has led some scientists to lump drivers and stressors together. This is the situation for the DRERIP (Delta Regional Ecosystem Restoration Implementation Plan), in which a driver-linkage-outcome terminology is used.[2] The DRERIP approach also underlies the POD (Pelagic Organism Decline) studies and BDCP (Bay Delta Conservation Plan).[3] The U.S. Environmental Protection Agency has developed the "Causal Analysis/Diagnosis Decision Information System" or CADDIS that uses source, stressor, outcome terminology.[4] Each of these approaches has different strengths and weaknesses. It is important to recognize, however, that the different approaches and terminologies are conceptually rather similar. Mainly, they differ in the degree to which they may aggregate causal

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[2] see: http://www.dfg.ca.gov/delta/erpdeltaplan/

[3] http://science.calwater.ca.gov/pod/pod_index.html (http://baydeltaconservationplan.com/Home.aspx).

[4] http://www.epa.gov/caddis

factors and in the labels they apply to different aspects of the system linking causes to outcomes. It is important to distinguish between what is stressing a system attribute (e.g., a species population, water quality) and what is producing or driving the stress, because this could affect the likelihood of successfully realizing goals and objectives. However, management actions can target different levels in the chain of causation depending on circumstances.

5. *Ecosystem management models are a critical element in the characterization and assessment of stressors*

The Delta ISB believes that defining and delineating stressors is best accomplished by developing a conceptual model that clearly specifies the relationships between cause and effect with respect to the attributes of interest. Such models have been successfully used as a template for structuring an ecosystem-management approach in numerous regional assessments. For example, they have been used as a basis for management programs in the Everglades of south Florida[5] (Gentile et al. 2001) and Alaska[6] and are the foundation of conservation planning in The Nature Conservancy[7] and the Conservation Measures Partnership.[8] In these programs, the conceptual models have been used to identify risks and develop performance criteria as well as to provide a clear understanding of stressors in the systems. Conceptual models also are a prominent part of DRERIP, which includes both species life-history models and ecosystem-component models. Because they are specific to the Delta, the DRERIP models provide a valuable resource for characterizing causal linkages between stressors and objectives and for prioritizing stressors.

The following diagrams illustrate (on the left) a conceptual model of the pathways linking drivers to outcomes and objectives and how stressors fit into this causal chain and provide a hypothetical example (on the right, described in section 4) to clarify the components and linkages of this conceptualization. The elements within the oval are the components linking drivers and stressors to system attributes, management responses, and objectives. The box below the oval indicates how all of these components feed into the monitoring and performance assessment that are at the core of adaptive management, and the arrows encircling the oval indicate that adaptive management is a continuous, ongoing process.

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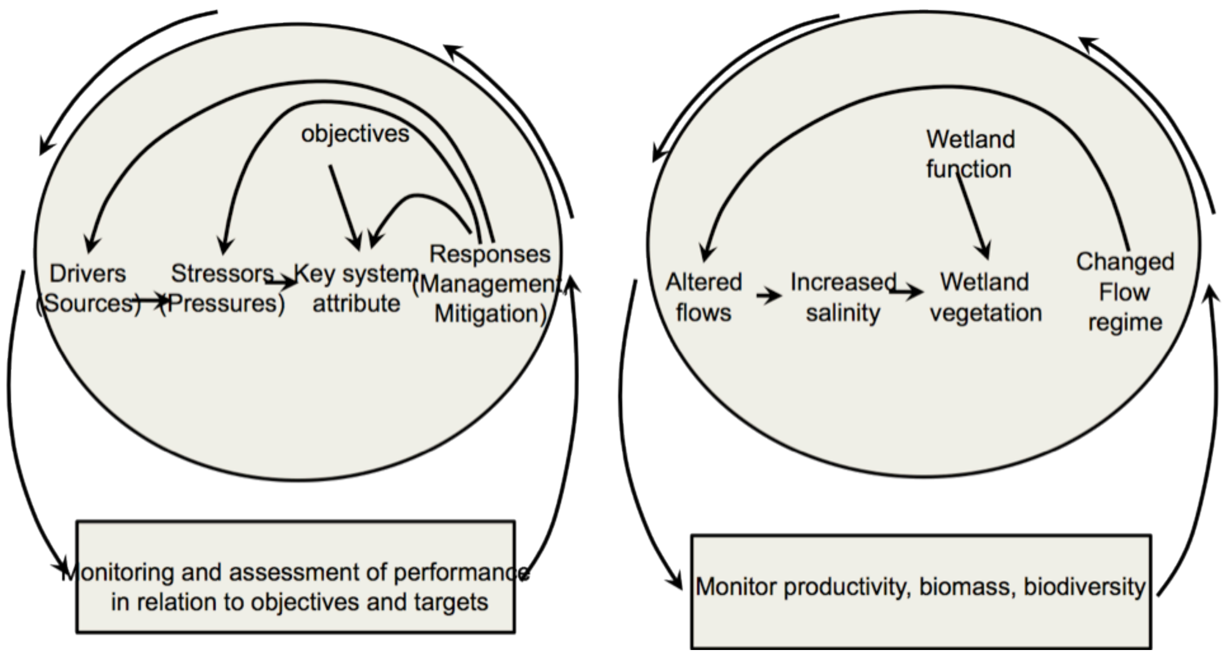
[5] Gentile, J.H., M.A. Harwell, W. Cropper Jr., C.C. Harwell, D. DeAngelis, S. Davis, J.C. Ogden, and D. Lirman. 2001. Ecological conceptual models: a framework and case study on ecosystem management for South Florida sustainability. *Science of the Total Environment* 274: 231-253.

[6] Harwell, M.A., J.H. Gentile, K.W. Cummins, R.C. Highsmith, R. Hilborn, C.P. McRoy, J. Parrish, and T. Weingartner. 2010. A conceptual model of natural and anthropogenic drivers and their influence on the Prince William Sound, Alaska, ecosystem. *Human and Ecological Risk Assessment* 16: 672-726.

[7] see http://conserveonline.org/workspaces/cbdgateway/cap/index_html

[8] see http://www.conservationmeasures.org/



This conceptual model is derived from the DPSIR approach and generally follows the approach of Gentile et al. (2001). The DRERIP models, in general, represent the left three steps within the large oval (Drivers, Stressors, Key ecosystem attribute, which in DRERIP terms are Drivers, Linkages, Outcomes).

Understanding how particular factors fit into this conceptualization – as drivers, stressors, or key system attributes – and developing scientifically sound conceptual models of the causal relationships is critical because it affects where management actions can be most effective and what to expect (and monitor) as a result of the actions. In general, actions directed at a driver (e.g., water flow) will affect multiple stressors (e.g., water temperature, seasonality, chemistry, as well as salinity), whereas actions directed at stressors will have more targeted effects. Importantly, **a stressor should be defined in terms of its effect on a key system attribute and an objective for that attribute**. In the above example, increased salinity may be a widespread or frequent consequence of altered flows, but it will differ in its effects (i.e., its status as a stressor) on different species or system components. Furthermore, there are temporal and spatial dimensions to the presence of a stressor; salinity levels may vary seasonally and be dependent on location in the Bay-Delta system. Finally, stressors are scale-dependent – some stressors may act broadly, others only in localized situations. Proper assessment of stressors requires consideration of temporal and spatial variation and the operating scales at which drivers are linked to stressors and attributes. Management actions need to be commensurate with the scale of the stressor.

6. *Different kinds of stressors call for different kinds of responses*

Stressors can be classified in various ways; in terms of origin, mode of action, spatial and temporal breadth of impact, whether or not managers have the ability to affect their action, and so on. Classifying stressors is an essential step toward understanding, and eventually to assessing them. The Delta ISB found the following four categories of stressors to be helpful in our own discussions of the Delta:

- Globally determined stressors—stressors, like the effects of climate change or human population growth, which cannot be eliminated or mitigated within the purview of the Delta Plan. Management actions must adapt to the continued effects of these stressors in the Delta.
- Legacy stressors—stressors that result from past actions in the Delta watershed that cannot be undone. These include stressors such as the continuing effects of sediment and mercury discharge during the gold mining era. Infrastructure that causes stress on the Delta and is not likely to be significantly altered, such as upstream dams and the network of levees, can also be treated as legacy stressors. Although these stressors cannot be eliminated, management actions can reduce their effects on the Delta.
- Anticipated stressors—stressors that scientists can anticipate will result from present or future activities. The Delta Plan can modify these stressors in such a way as to prevent or reduce the stressor or better adapt to the stressor.
- Current stressors—stressors that result from ongoing activities, such as water management practices, agricultural practices, waste discharges, etc. Management actions can either change those practices, take steps to reduce their effects on the Delta, or both.

Note that the legacy stressors exist because of an historic failure by Californians to anticipate and prevent or mitigate the long-term effects of human activity. They serve as a good reminder to us of the importance of anticipating stressors and reducing them through planning.

We list "current stressors" last because The Delta Plan needs to take the long temporal view. To the extent that current stressors are expected to carry on into the future, including how water is managed, the DSC should address them.

In preparing for the workshop on January 12, the Delta ISB compiled a list of stressors affecting the Delta. These are organized in relation to the categories above in Attachment 2. The list of stressors is not comprehensive, nor has it as yet been vetted in terms of how the various stressors relate to the objectives, subobjectives and characteristics listed in SBX7-1. However, the list serves to illustrate the broad range of kinds of stressors that must be considered in developing the Delta Plan and some of the constraints on opportunities to mitigate their effects.

Some long-term stressors, such as sea level rise, cannot be mitigated and must be adapted to. In some cases, when confronted with such stressors, objectives will have to be modified to fit the reality of the stressor. In other cases, the objective might be reached, or partially reached, through adaptation, for example, by improving levees. Where adaptation is necessary, the stressor requires us to reconsider the objective.

Where mitigation is possible, specific objectives are needed simply to identify what the stressors are. For example, section 83502(c)(1) specifies the objective of having "viable populations of native resident and migratory species." To determine which stressors are preventing viable populations of native species, one typically must look at particular species – Chinook salmon, Sandhill crane, etc. – and what has been stressing them. In the process of identifying stressors, one might logically overlook less valued species or less valued states of the environment except to the extent they are important to valued species or valued states of the environment. A focus on particular species (listed species, for example) may lead to management measures that are detrimental to other species. Thus, even where a stressor can be mitigated, the outcome may not be universally positive. Trade-offs will be necessary as will vigilance in assessing the broad consequences of stressor reduction.

7. Pay attention to the long-term drivers

Decision-makers need to plan management in the context of the directional changes that are occurring in the Delta as well as the potential for catastrophic change if Delta levees fail. Decision-makers need to be looking 30-50 years into the future as they develop policy. Experience has shown that the development and implementation of major policies can take more than a decade and response times to policy change are also on the order of a decade or more. In essence, policies to manage for the coequal goals will need to be flexible and nimble enough to succeed in the context of continual but uncertain long-term directional change.

Climate change is driving directional change in several key variables affecting the coequal goals. Although total precipitation is not changing much, less is falling as snow so that the winter snowpack is decreasing. Because the snowpack is the major storehouse of water for spring and summer irrigation, loss of snowpack strongly affects the amount of water that is available for human and other uses. With warming temperatures, snowpack is melting earlier and winter flows are less stable. Consequently, peak flows occur earlier and over a shorter period of time. Air temperatures are also increasing so that both patterns of inflow to the Delta and water temperature are changing over time. Rising sea level is changing the salinity of the Delta and also increasing the risk to Delta levees. In addition to changes resulting from climate change, the likelihood of an earthquake within this century that will cause catastrophic breaks in Delta levees is high. Thus, there is significant risk that a number of Delta islands may be flooded in the future. Economic considerations will influence any decision about restoration of the levees, so that the future Delta may include a number of flooded islands as large deep lakes. Such flooding of islands will have important implications for the hydrodynamics and salinity of the Delta, will affect the quality of water exported from the Delta, and will impact Delta land use. New species continue to be introduced to the Delta so scientists expect that the biological community will continue to change with uncertain implications for native species. These kinds of broad-scale changes will also affect terrestrial ecosystems; changing habitat conditions for plants and wildlife, particularly migratory birds. Exotic species are also invading terrestrial habitats, with effects on productivity and food webs for native species. Processes of continual change also derive from population growth, urban expansion, agricultural practice and a host of other human activities in and around the Delta.

These continual processes of change greatly complicate development of effective management policy to protect, restore and enhance the Delta and maintain reliable water supply. Indeed, some analysts suggest that the Delta has entered a new ecological regime significantly different from its historic regime or even the recent past. This may not be a stable regime but rather a transitory condition that will continue to change as climate change and other unmanageable stressors continue to change the Delta. As changing climate increases stress on listed species, conservation may demand more water for environmental protection, further reducing the flows available for other uses.

8. Policies to deal with multiple stressors have highly uncertain consequences

Although the Delta is a relatively well-studied environmental system, our ability to predict the Delta of the future is not strong. Scientific inferences are quite uncertain because the ongoing, serial change that is occurring in the Delta makes future states difficult to predict. Relationships that appear relatively well developed at one point in time (e.g., the relationship between abundance of four species in the Pelagic Organism Decline, and X_2 (The distance upstream from Golden Gate of the isopleth of two practical salinity units)) tend to break down as additional years of data are accumulated. Another consequence of change and non-linear responses to stressors is that even in circumstances where there is a clear dose/response relationship between change in a stressor and response of the system in the past, removing the stressor may not result in a reversal of the observed dose response relationship. A consequence of this uncertainty is that simply relieving stressors may not lead to desired outcomes. This fact speaks strongly to the need to implement policy as adaptive management experiments in which there is a clearly developed process for gathering information on the effectiveness of the policy and a mechanism for review and updating of all aspects of the policy over time. This need includes problem definition, conceptual model, indicator variables, and policy response.

SBX7 defines adaptive management in section 85052. "'Adaptive management' means a framework and flexible decision-making process for ongoing knowledge acquisition, monitoring, and evaluation leading to continuous improvement in management planning and implementation of a project to achieve specified objectives." This definition is a fairly standard one. In applying adaptive management to the Delta, however, it is not reasonable to assume that the system is stable over time. The directional change that is occurring in the Delta means that the adaptive approach cannot assume that uncertainty will decline as more information is gathered. Planning and management must include rigorous programs of data gathering to assess the effectiveness of policy, but it needs also to recognize that policies may fail not only because of uncertainty in system behavior but because the system is actually changing over time in fundamental ways. In practical terms this makes monitoring programs and timely analysis of the data generated more important. There will also need to be ongoing research in the Delta to identify and anticipate the emergence of conditions that could undermine the effectiveness of policy.

9. *Support Delta science*

The Delta ISB is impressed with the variety and depth of past scientific study and ongoing research in the Delta. The Delta Science Program plays a central role in communicating and coordinating Delta science as well as funding and publicizing critical scientific initiatives. But the Delta ISB is also concerned that Delta science needs stronger integration and coordination. In this sense, the Delta ISB found the DRERIP models and approach to be an especially good start with considerable potential for further development. Although designed to evaluate restoration actions, the DRERIP models also provide an objective, science-based set of tools for evaluating stressors. The models do not, as yet, cover all the aspects that are of concern to the Council and at present they are static models that require staff to work out the effects of varying a stressor qualitatively. The usefulness of these models would be greatly enhanced if they were made dynamic and interactive. Support to accomplish this through the Delta Science Program would give the Science Program and the Council a powerful, locally designed set of tools for assessing stressors now and in the future.

10. *Expect surprises*

As noted earlier, the Delta is changing over time. Some changes, like the effects of changing hydrology and sea level rise due to climate change, can be anticipated and modeled. In addition to changing climate, the 21st century Delta faces the likelihood of earthquakes that may leave a number of islands permanently flooded. Other changes are more contingent on unforeseeable circumstances, like species invasion or levee failure by decay. Regardless, uncertainty virtually guarantees that large, unexpected events will occur from time to time. From the perspective of analysis and prioritization of drivers and stressors, this has several implications. First, scientists and managers need to be continually alert for the emergence of new drivers and stressors. Second, the governance process needs to be nimble enough to adjust policy and management to respond to emerging problems. Third, even if management is focused on a subset of stressors, monitoring should continue to gather information on a broad spectrum of stressors as a means to monitor the “pulse” of the Delta. Such broad scale monitoring also has the potential to identify emerging issues and stressors before their effects are irreversible.

Attachment 2

Some Key Drivers and Stressors Demonstrating a Possible Classification

As noted in section 6 of Attachment 1, the Delta ISB has found the following categorization of drivers and stressors to be helpful.

- **Globally Determined stressors (Global)** - stressors, like the effects of climate change or human population growth, which cannot be eliminated or mitigated within the purview of the Delta Plan. Management actions must adapt to the continued effects of these stressors in the Delta.
- **Legacy stressors (Legacy)** - stressors that result from past actions in the Delta watershed that cannot be undone. These include stressors such as the continuing effects of sediment and mercury discharge during the gold mining era. Infrastructure that causes stress on the Delta and is not likely to be significantly altered, such as upstream dams and the network of levees, can also be treated as legacy stressors. Although these stressors cannot be eliminated, management actions can reduce their effects on the Delta.
- **Anticipated stressors (Anticipated) -** stressors that scientists can anticipate will result from present or future activities. The Delta Plan can modify these stressors in such a way as to prevent or reduce the stressor or better adapt to the stressor.
- **Current stressors (Current)** - stressors that result from ongoing activities, such as water management practices, agricultural practices, waste discharges, etc. Management actions can either change those practices, take steps to reduce their effects-on the Delta, or both.

The Delta ISB also prepared a list of drivers and stressors for the Delta. We present these under the categories suggested above with notes with respect to each stressor's impact.

Table of Some Key Drivers and Stressors in the Bay-Delta [Notes include both changes in state of the ecosystem as well as examples of impacts.]

PLEASE NOTE THAT THE FOLLOWING LIST OF DRIVERS AND STRESSORS IS NOT TO BE CONSIDERED A COMPLETE LISTING OF ALL POTENTIAL DRIVERS AND STRESSORS IN THE SYSTEM. THE ORDER OF THEIR OCCURRENCE ON THIS TABLE IS NOT INTENDED TO DENOTE ANY FORM OF PRIORITIZATION.

Type	Whether Driver (D) or Stressor (S)	Notes
Global		
	D Climate change	
	S Reductions in inflow and outflow	Possibly lower water yield
	S Alterations in hydrograph	Changes in seasonal patterns (earlier, smaller freshest)
	S Higher temperatures	Seasonal temperature variation; altered phenology (e.g., timing mismatch between predators and prey, flower and pollinator); species and biogeochemical processes impacted

Type	Whether Driver (D) or Stressor (S)	Notes
		by temperature
	S Sea level rise	Salinity intrusion, levee breaches, altered rates of erosion and deposition. Shifting species distribution and food web dynamics
	S Changes in ocean conditions	Many Delta species spend part of their lives living or feeding in the ocean
Global		
	D Earthquakes	Levee and highway damage
	D Population growth	Places increasing pressure on land and water resources
	D California economy	Patterns of development, agriculture, recreation are driven by economics
Legacy		
	S Habitat loss and alteration	Loss or reduction of seasonal and tidal wetlands, riparian habitats, gallery forests and native grasslands; simplified system of leveed agricultural islands separated by deep channels with leveed shorelines; small, unconnected fragments of natural habitat; channels unconnected to floodplain; uplands less connected to Delta; channels dredged, interconnected, and simplified; terrestrial diversity reduced; impacts include: changing competition and predation, loss of access to breeding sites
	S Changed pattern of flow	Channel simplification and interconnection changed flow velocity and pattern; infrequent floodplain inundation; impacts include: migration barriers, altered migration corridors, improved water conveyance to south Delta, salt entrainment affects domestic water supply, loss of access to breeding sites, greater tidal excursion and salt penetration into Delta
	S Methyl-mercury from released mercury	Changing Delta conditions can affect the methylation of mercury stored in sediments; impacts include mercury bioaccumulation in the foodweb
	S Selenium	Past practices resulting in residual toxins in the food web
	S Subsidence	Loss of peat soils in islands; impacts include increased risk of levee breaks with loss of structures and habitat
	S Changing sediment loads	Sediment delivery increased with European colonization and is now declining; impacts include: turbidity declines, altered erosion and deposition, SAV expansion, smelt distribution
	S Artificial levees	Isolated land and water ecosystems that made possible the development of the Delta's cultural and economic character

Type	Whether Driver (D) or Stressor (S)	Notes
	D Water management infrastructure	Increases reliability of water delivery; habitat loss; altered migration corridors
	S Levee breaks	Permanent flooding of multiple islands would likely raise salinity in the south Delta; native fish may not use deeply flooded islands
Legacy		
	D Upstream dams	Loss of access to breeding sites; existence and operation affect virtually every aspect of Delta environment, society and economy
	D Federal-state agricultural policies	Ag subsidies affect land use and habitation patterns
	D Development, zoning, building codes	Affects land use, lifestyle choices and many other human decisions affecting the Delta
	S Invasive species	Low prey; changes food web; changing competition; higher predation; agricultural pests
Anticipated		
	S Subsidence	Loss of peat soils in islands; impacts include increased risk of levee breaks with loss of structures and habitat
	D Landscape change	Delta's habitat mosaic is constantly changing as human land and water use evolves
	D Urban expansion	Affects the Delta in many ways that threaten native species and ecosystems, water quality and demand, unique Delta attributes
	D Upstream land use	Affects the quantity and quality of water entering the Delta, sediment load, habitat for species migrating through Delta
	D Upstream dams	Existence and operation affect virtually every aspect of Delta environment, society and economy
	D Lifestyle choices	Decisions about where and how to live affect species, habitats, water demand
	D Urban-rural migration patterns	Dominant human migration patterns are rural to urban and inland to coastal
	S Invasive species	Low prey; changed food web; changing competition; higher predation
Current		
	S Changed hydrograph; reduced inflow and outflow	Upstream water withdrawals; water project and in-Delta withdrawals reduce flow through Delta; reduced seasonal flow variation; improved seasonal availability of water for agriculture; impacts include: salinity intrusion, less salinity variability, seasonal temperature changes, water residence time more uniform, stranding, low DO and thermal migration barriers
	S Entrainment at pumps & other diversions	Effect of OMR flows on fish movement and water supply; in-Delta withdrawals for agriculture, domestic water, power plants. Mortality of

Type	Whether Driver (D) or Stressor (S)	Notes
		entrained fishes, including threatened species
	S More nitrate, ammonium and less phosphorus	Excess nutrients from agriculture and domestic waste; altered N/P ratios; impacts include: low DO, SAV expansion, *Microcystis* blooms, reduced phytoplankton production, can favor invasive species
Current		
	S Selenium release	Releases by agriculture and industry can be toxic through the food web
	S Pesticide release	Agriculture, industry, and residential use (pyrethroids and organophosphates of concern)
	S Other trace metals and toxics	Lead, chromium, copper, surfactants, endocrine mimics and disruptors introduced from agriculture, industry, domestic waste, and storm water
	S Dredging	Channel dredging mobilizes sediment and toxins; impacts benthic organisms
	S Legal harvest	Incidental take of threatened species
	S Illegal harvest	Illegal take of threatened species
	D Hatchery impacts	Alters genetic makeup affecting ability to perform in the wild and the wild conspecifics with which they breed. Introduction of diseases to wild populations
	D Federal-state agricultural policy	Ag subsidies affect land use and habitation patterns
	D Development, zoning, building codes	Affects land use, lifestyle choices and many other human decisions affecting the Delta