Delta ISB Thematic Review Matrix

Draft (June 19, 2019)

Purpose:

During the planning retreat in July 2017, the Delta Independent Science Board (ISB) discussed the idea that each new major thematic review should consider including the following topics: climate change impacts, connections upstream and to the Bay, modeling and forecasting capabilities, state of science integration, broad science vision on the topic, uncertainty, and science and social system linkages. The purpose of this document is to document how these seven different topics were discussed in the past six Delta ISB thematic reviews in order to inform topics that future reviews may focus on. Each table covers one topic and contains a row for each of the past reviews that discussed the topic to some extent. Eventually, these topics may become independent reviews. The topic with the least coverage in past reviews was "broad science vision on the topic," which was mentioned in one review.

Thematic reviews covered in this matrix include Habitat Restoration (2013), Fish and Flows (2015), Adaptive Management (2016), Levee Hazards (2016), Delta as an Evolving Place (2017), and Water Quality (2018).

Climate change impacts:

Review	Relevant content
2013 Habitat Restoration	Climate change needs to be considered when planning restoration projects, especially with regard to sea-level rise. Related quotes: 1) pg 3: "We found widespread awareness that modifications of climate [and sea level]... affect the design, implementation, and outcomes of restoration projects." 2) pg 4: recommendation: "Consider the effects of climate change, sea-level rise, land-use change, and other environmental changes in planning and modeling efforts." 3) pg 14: "sea level rise was the primary focus [when considering how climate change will affect restoration projects]. Little attention was given to ... altered hydrology and temperature." 4) pg 14: "restoration plans must incorporate approaches and alternatives that are resilient and adaptable to both anticipated and unintended changes associated with climate change and sea-level rise."
2015 Fish and Flows	Climate change will affect flows and water levels and lead to more climatic variability and difficulty in predicting the effects of these variables on fish. Related quote:

Review	Relevant content
2015 Fish and Flows (Continued)	1) pg 5: "Interannual extremes of climate, such as the current drought, also affect flows and regulatory restrictions on flows. Substantial future changes in Delta flow volumes, pathways, and dynamics are expected... The Delta also will be subjected to interannual variations in water supply through changes in the patterns of precipitation and evaporation, sea level rise caused by climate change...The need to understand and predict how these evolving changes will affect fishes will become even more important."
2016 Adaptive Management	Climate change is bringing about a period of rapid and unpredictable change. Adaptive management is an effective management solution to deal with this change due to its flexibility and its design to anticipate change. Related quotes: 1) pg 28: "Looking ahead is important not just so one can gauge the effectiveness of an action and make changes before it is too late, but also because the Delta, like the rest of California and most of the world, is undergoing massive change. All coastal areas will be affected by sea-level rise, and models of future climate change predict higher temperatures and altered rainfall and snowfall patterns, with changed hydrologic flows in the Delta... If the system changes rapidly and unpredictably, an action may not produce the desired outcomes or it may be difficult to determine whether a change in the system is due to the action itself or to changes in other factors... [Some] suggest that adaptive management is the best approach to deal with rapid changes because of its management flexibility, which is an essential element of decision-making in a changing world. Adaptive management also provides a way to formally anticipate and prepare for changes through modeling and monitoring... It may be useful to develop “anticipatory adaptive management,” in which the management actions are designed for future conditions, when the actions will be completed and the outcomes are expected, rather than for the conditions existing at the time the actions are planned or initially implemented." 2) pg 37: "The novel ecosystems of the future will require novel approaches—helping species move to new locations, accepting some non-native species as part of the new nature, restoring landscapes rather than bits of habitat... and coming to grips with the inevitability that some species will be lost."

Review	Relevant content
2016 Levee Hazards	Climate change may exacerbate the risk of levee failure due to increasing sea levels and storm events. Related quote: 1) pg 4: "Present-day Delta water levels were shown to rise with riverine floods, wind surge, and tides. Sea level has been rising at the Golden Gate and is predicted to rise more with time... floods and winds in the Delta are projected to become more severe with global warming…"
2017 Delta as an Evolving Place	Climate change was not discussed aside from mentioning Michelaina Johnson's senior thesis at UCB on the history of floodplains of the Cosumnes River which flows into the Delta. Related quote: 1) pg 7: "[Johnson's] epilogue emphasizes the challenges of climate change, increasing urbanization, and the planting of less wildlife friendly crops adjacent to the Cosumnes River Preserve, which protects the lower Cosumnes River watershed today."
2018 Water Quality	More frequent and intense storms and droughts associated with climate change will alter the flow of contaminants and pathogens due to increasing runoff and residence time. Warmer temperatures may also facilitate harmful algal blooms. Related quotes: 1) pg 8: "Proposed changes in water conveyance and changes in hydrology, coupled with climate change, are likely to affect water quality, providing further impetus and relevance for continued review of this topic." 2) pg 10-11: "Climate change, including sea level rise, is expected to lead to more frequent and extended periods of drought as well as more frequent and intense floods and changes in salinity (Lund 2016 and references therein). These events will influence water quality both by altering the delivery of contaminants and pathogens, and by changing the residence time of water quality constituents. Storms and floods have been shown to increase runoff of sediment, organic matter, nutrients and contaminants from land to adjacent water bodies, and increase eutrophication (Sinha et al. 2017). Drought leads to less dilution of contaminant point sources in receiving waters and lengthens water residence time, which may reduce water quality in regions with poor circulation. Drought periods also affect groundwater and water quality in wells used for drinking water."

Review	Relevant content
2018 Water Quality (Continued)	pg 24-25: discussion of harmful algal blooms: "...as warm water temperatures extend later in the season, this may extend the ability of *Microcystis* to remain actively growing in the water column for longer periods of the year... Given that the known triggers of *Microcystis* blooms, which include warm, slow, and clear waters, are likely to become more prominent with climate change, it is important to address cyanoHAB formation and identify mitigation actions as a short-term management priority."

Connections upstream and to the Bay:

Review	Relevant content
2013 Habitat Restoration	Restoration projects are often not considered or planned within the context of the greater landscape, which often includes how they are connected upstream and to the Bay. Related quotes: 1) pg 3: "many restoration projects in the Delta are being planned and implemented largely independently of one another and their landscape context." 2) pg 4: recommendation: "Include the potential impacts of other management activities in the Delta, such as water diversions and levee alterations, in the design of restoration projects." 3) pg 13: "planning and implementation of individual restoration projects should occur within a landscape framework over multiple scales."
2015 Fish and Flows	Flows in the Delta are greatly affected by both natural and anthropogenic processes. Development upstream, including dams, has greatly altered flows within the Delta and can restrict the movement of fish. Related quotes: 1) pg 8: "At any point in the Delta, the bulk flow regime is determined by a combination of natural processes and management decisions. Current conditions of land-use and cover, channel morphology, dams, and levees set the morphologic framework. Precipitation, evaporation, basin runoff, snowmelt, and tides are natural processes that affect the flow (hydrologic) regime which can be modified through management decisions." 2) pg 8: "Overall flow dynamics directly affect fish movement by defining viable routes and pathways, restricting movements (e.g., dams), providing upstream homing (e.g., olfactory) cues to direct fish migrations to spawning grounds, providing currents through which fishes must swim, and through passive transport downstream."

Review	Relevant content
2016 Adaptive Management	Some topics related to the Bay were discussed, including salt pond restoration in the South Bay, but not in relation to how AM in the Bay and in the Delta are coordinated or related.
2016 Levee Hazards	Earthquakes downstream in the Bay Area produce more shaking than earthquakes in the Delta itself. However, some predictions may overestimate their transmission to the Delta and need more research to substantiate them. Related quotes: 1) pg 1: "Earthquake hazards in the Delta were described in terms of ground motions from Bay Area earthquakes..."
2016 Levee Hazards (Continued)	2) pg 3: "Discussion in the earthquake session focused largely on Bay Area earthquakes as sources of strong ground motions. Bay Area faults produce earthquake shaking in the Delta more often than faults beneath the Delta itself. How strongly a Bay Area earthquake affects the Delta, however, depends on attenuation—on how abruptly the ground motions diminish as the seismic waves advance eastward from the Bay Area into the Delta. A DRMS study a decade ago used attenuation equations that were considered state of the art at the time. These equations have now been found to overestimate Bay Area transmission of ground motions by factors of two to four in the case of the 2014 South Napa earthquake of magnitude 6.0, and also for smaller Bay Area earthquakes." 3) pg 5: "It was shown that ground motions from certain Bay Area earthquakes diminished with distance more rapidly than had been expected. It was proposed that more accelerometers be deployed to measure Delta ground motions before the next moderate or large earthquake on a Bay Area fault."
2017 Delta as an Evolving Place	The reviews discusses Michelaina Johnson's senior thesis focused on the Cosumnes River which flows into the Delta. Related quote: 1) pg 7: "The Cosumnes is the only river of the 20 that drain the western Sierra Nevada and eventually flow into the Delta that is free of large dams… [She] documents the early indigenous management of the floodplain and the subsequent diking and draining by settlers in the late 19th century... [and] demonstrates how the river's unregulated flooding unintentionally enabled the preservation of some of the best examples of native habitat remaining in California... Her epilogue emphasizes the challenges of climate change, increasing urbanization, and the planting of less wildlife friendly crops…"

Review	Relevant content
2018 Water Quality	The Sacramento and San Joaquin Rivers are a substantial source of nutrients in the Delta, and large concentrations of selenium are an issue for the both the SF Bay and Delta. Related quotes: 1) pg 5: "Water quality is also influenced by materials from the atmosphere and the surrounding landscape..." 2) pg 12: "The largest loads of nutrients to the Delta derive from the Sacramento and San Joaquin rivers, with agricultural and municipal discharge providing the main sources." 3) pg 12: "In combination with upstream and in-Delta sources, Publicly Owned Treatment Works account for about 25% of the total nitrogen and 20% of the total phosphorous loads to the Delta." 4) pg 22: Discussion of selenium monitoring done for fish in the Bay: "Many questions are not resolved, and more monitoring of selenium and the testing of cause-effect relationships on biota in the Delta are needed in the Delta and San Francisco Bay, especially given the movement of fish across these connected habitats... [S]elenium may be an increasing problem in the Delta. It is clearly a problem in the North San Francisco Bay, which receives water from the Delta."

Modeling and forecasting capabilities:

Review	Relevant content
2013 Habitat Restoration	Modeling is a crucial tool for restoration projects as it reduces uncertainties and predicts outcomes. However, it is underused in the Delta and resources are not available to scientists and agencies to create complex models. Related quotes: 1) pg 3: "models were not being used to assess the potential outcomes of restoration activities or to connect restoration activities at local sites to restoration goals and processes for the Delta as a whole." 2) pg 5: recommendation: "Use conceptual modeling, simulation or scenario modeling, and risk analysis to assess uncertainties and the potential costs and benefits of restoration actions." 3) pg 10: "Modeling is essential in design and evaluation [of restoration activities.]" 4) pg 15: regarding information conveyed in interviews: “we [Delta ISB] only saw one example (one of the DRERIP models) where conceptual models had been developed, despite the fact that conceptual modeling is supposedly the first step in adaptive management.” 5) pg 17: "development and management of modeling capability in the Delta remains highly decentralized." 6) pg 17: “developing, testing, and disseminating more advanced 3-D modeling capabilities… will require substantial development of common digital geomorphic, bathymetric, hydrologic, and water-quality data sets...development of a model library for use by Delta scientists and agencies [is endorsed by the ISB]." 7) pg 23: recommendation: "Use conceptual modeling, simulation or scenario modeling, and risk analysis to assess uncertainties and the potential costs and benefits of restoration actions."
2015 Fish and Flows	Modeling is useful in predicting flows and fish populations and how they relate and while some successful models do exist, more work should be done to link 3-D water flows to fish models. Related quotes: 1) pg ii: recommendation: "Link quantitative fish models with three-dimensional models of water flows… develop a 3-D, open-source, hydrodynamic model that can be more widely adopted and integrated with generic and species-specific models of fish growth, movement, mortality, and reproduction and with food-web models." 2) pg 13: "models will need to be more related to the habitat requirements for fish species and the proximal causes that affect fish reproduction, mortality, and individual growth rates." In depth summary of future model needs on pg 15-16.

Review	Relevant content
2016 Adaptive Management	Modeling is a critical step in the adaptive management process and is important in anticipating outcomes, even if just a conceptual model is used. However, some individuals see modeling as a barrier to adaptive management and projects due to the cost and time required. Related quotes: 1) pg 15: "There is also a general recognition of the need to develop quantitative modeling expertise and tools to implement adaptive management and balance long-term benefits against short-term costs. Even when quantitative models are used, however, there is often little follow-up and no adjustment of models based on new information. Developing quantitative models that capture the complexity of Delta systems requires staff well-versed in systems thinking, data analysis and management, and modeling. Such staff are difficult to attract and retain... While most respondents use conceptual models and recognize at least the desirability of more quantitative systems models, others question the value of modeling in addressing problems in the Delta, particularly when the ecological or physical processes are well known... we [Delta ISB] believe that conducting adaptive management in a complex, multivariate system must at a minimum entail the development of a comprehensive conceptual model, organized in relation to the overall problem being addressed, the goals and objectives, the uncertainties involved, and the desired or anticipated outcomes." 2) pg 16: "Because such models are demanding of expertise, time, and money, they should be developed in a collaborative framework... fostering inter-agency collaboration, which in turn may reveal insights or knowledge gaps apparent to one agency but not to others." 3) pg 27: "Step 3 (modeling) is often considered a barrier [to completing adaptive management], but this depends on the kind and level of modeling required. It should not take much time or effort to assemble enough of what is known about a system to develop a reasonable conceptual model, which can quickly reveal unrecognized linkages and critical knowledge gaps and can suggest alternative actions. The impediments to such modeling are more institutional than intrinsic to the modeling process."

Review	Relevant content
2016 Levee Hazards	There is a need to document all levee failures in the Delta for accurately modeling future levee failures. Related quote: 1) pg 7: (from a 2008 DRMS report) "'The Delta offers numerous case histories (although with incomplete details) for calibrating the levee flood-induced failure model. These case histories helped groundtruth the model used in the results. We observed that not all the details of historical flood events are recorded or available. It is recommended that failures in the Delta be fully documented in a formal and comprehensive way that covers the necessary details to reconstruct the events and verify them numerically. This documentation will provide increased validity to future modeling exercises.'"
2017 Delta as an Evolving Place	N/A
2018 Water Quality	The Sacramento and San Joaquin Rivers are a substantial source of nutrients in the Delta. The review discusses the use of models in methylmercury research and the need for models to better predict and understand drivers of chemical contaminants and HABs. Related quotes: 1) pg 5-6: "A more comprehensive view of the multiple elements that comprise water quality in the Delta is needed among stakeholders. Improved development and use of numerical and conceptual models of water quality in the Delta could help the community move towards this goal." 2) pg 19-20: Regarding hypotheses on why methylmercury concentrations are higher in the Delta's periphery than the center: "Windham-Myers et al. (2016) incorporated various factors related to these hypotheses into the CASCaDE hydrodynamic model to determine whether the model can reflect concentrations in the central Delta compared to the peripheral Delta... [and] used available information to develop a set of conceptual models that can be used to assess what types of processes and associated risks are most important in a particular habitat or system... models can be used by managers to assess potential actions to control mercury bioaccumulation... Other modeling efforts have been used for developing TMDLs."

Review	Relevant content
2018 Water Quality (Continued)	3) pg 25: The Southern California Coastal Water Research Project produced a white paper which recommends a monitoring and special study program for CyanoHABs in the Delta: "The monitoring program would develop an ecological model to better understand drivers and controls on primary production and phytoplankton assemblage in the Delta. These results would be useful in determining what triggers *Microcystis* bloom initiation and development, and what determines the size of the final bloom and thus the geographical extent of concern after the bloom dies off." 4) pg 27: (from survey response) "'there does not appear to be sufficient information for regulatory agencies to prioritize aquatic ecosystem health over anthropogenic interests. This may require numerical models to show that seemingly minor sublethal and indirect impacts to individual organisms can result in major population declines. Both numerical and conceptual models are needed to help understand how sources, pathways, transport, mechanisms (e.g., biological, chemical, and physical), and other management actions (e.g., land use and sediment management) affect water quality.'"

State of science integration:

Review	Relevant content
2013 Habitat Restoration	Although coordination among scientists from different disciplines is important for successful restoration projects, science integration is often not done enough during the restoration process. Related quotes: 1) pg 4: "A greater degree of coordination among project administrators, scientists, planners, and implementers is needed." 2) pg 4 "Habitat restoration rests on a solid foundation of information and experience from multiple scientific disciplines." 3) pg 5: recommendation: "Enhance collaboration among scientists in different organizations." 4) pg 17: "NRC report calls for scientific integration and notes that more than coordination is needed for the Delta... the intent to cooperate is clearly there." 5) pg 18: "lack of linkages among projects is exacerbated by the overall lack of coordination among the multiple entities involved in planning, conducting, monitoring, or regulating the restoration." 6) pg 23: "Coordinate scientific research with restoration planning, and synthesize and communicate the findings to those responsible for planning and implementation... Enhance collaboration among scientists in different organizations."

Review	Relevant content
2015 Fish and Flows	There needs to be a strong coordination among scientific fields in order to understand how flows affect fish populations. This coordination is necessary for modeling this relationship as well. Related quotes: 1) pg ii: recommendation: "Expand integrative science approaches… Strategies that strengthen interagency and interdisciplinary work can speed and solidify scientific discoveries and their application." 2) pg iii: recommendation: “Improve understanding among ecologists, hydrologists, hydrodynamicists and across the various institutions where they work. Interdisciplinary, interagency understanding can be facilitated through implementing the Delta Science Plan." 3) pg 11: "There have been several successful models of interagency science collaboration in the Delta.” Examples given are the Interagency Ecological Program, Collaborative Adaptive Management Team and the Collaborative Science and Adaptive Management Program, California Water and Environmental Monitoring Forum, and the Management Analysis and Synthesis Team. 4) pg 13: "An integrative approach is essential for developing flow management tools that also ensure the health of fish populations." 5) pg 16: "Hydrodynamic modelers must work directly with fish and lower food web experts as well as decision-makers so essential model parameters and necessary time and space scales are employed and the best biophysical understanding is incorporated." 6) pg 18: "A wealth of knowledge exists from other ecosystems. To accelerate and improve scientific insights and reduce their costs, agency scientists need access to these other studies and scientists through expanded access to the recent scientific literature and opportunities for travel..."
2016 Adaptive Management	The topic of integrating different areas of science was not really covered, but there was some discussion on improving inter-agency collaboration. Related quote: 1) pg 7: Factors that limit the use of adaptive management: "Understanding complex systems requires multiple disciplines that are typically housed in different agencies and have different responsibilities, different priorities, and different approaches; transcending these boundaries is difficult."

Review	Relevant content
2016 Levee Hazards	There is somewhat of a rift between scientific research and engineering, mostly due to different time scales. Related quotes: 1) pg 4: "The workshop exhibited a tension that often arises between scientific research and its practical application. While focused on research problems and opportunities, the workshop included reminders that Delta levees have received hundreds of millions of dollars spent for maintenance and upgrades in recent decades. This engineering work is slated to continue, and it is unlikely to await solution of research problems." 2) pg 8: "Scientists and engineers working on Delta levees, as a community, have been minimally represented in the biennial Bay-Delta Science Conference and in the annual Interagency Ecological Program Workshop."
2017 Delta as an Evolving Place	N/A
2018 Water Quality	There should be collaboration among agencies and different scientific fields for successful water quality monitoring. Related quotes: 1) pg 6: "The management of chemicals of emerging concern and harmful algal blooms requires greater vigilance and coordination between agencies." 2) pg 29: (from survey responses) "Agencies and programs tend to naturally be siloed. It takes time and effort to coordinate and integrate. The way to counter this is to present cohesive strategies on answering priority management questions in the Delta. This requires buy-in and agency or entity management commitment to the process. This can be done by addressing and prioritizing regulatory information needs, then grouping like purposes and missions. Work teams or study groups are then formed based on the grouping. Within each work team, individual program's mandates and needs are discussed and recognized... Work teams need to include the appropriate multidisciplinary members, such as biologists, geologists, water quality experts, and data management resources.'"

Broad science vision on the topic:

Review	Relevant content
2013 Habitat Restoration	All reviews should have a framework of success for their given topic: pg 9: "Reviews are best accomplished when there is a frame of reference for what a successful or 'ideal' project or program should include… we suggest that successful habitat restoration projects in the Delta will include the following attributes: 1. Goals are clearly articulated. 2. Spatial context is part of the design. 3. Temporal context is part of the design. 4. Adaptive management and flexibility are part of the design. 5. Monitoring is part of the design. 6. Modeling is essential in design and evaluation. 7. Planning and implementation are coordinated among project. 8. The necessary scientific expertise is available. 9. Stakeholders are involved early and often."
2015 Fish and Flows	N/A
2016 Adaptive Management	N/A
2016 Levee Hazards	N/A
2017 Delta as an Evolving Place	N/A
2018 Water Quality	N/A

Uncertainty:

Review	Relevant content
2013 Habitat Restoration	There is a considerable amount of uncertainty in relation to restoration, especially in regards to outcome and climate change. Modeling is one method to reduce uncertainty. Related quotes: 1) pg 2: "We found considerable ambiguity about overall restoration goals for the Delta as an ecosystem." 2) pg 14: "Uncertainties in projections of regional climate changes and their effects means that restoration plans will need to incorporate flexibility to adapt as projections improve." 3) pg 15: "ongoing changes in the Delta's biological and physical environment and the anticipated prospects of increased changes, extreme events, and thresholds in the future will increase uncertainty, making it difficult to predict the outcomes of specific habitat-restoration activities."
2015 Fish and Flows	There is significant uncertainty surrounding how different stressors affect flows, and subsequently how flows affect fish populations. There is a need for a better understanding of these stressors, such as the use of models, which should incorporate uncertainty. Related quotes: 1) pg 6: "Specific reasons for the declines in abundances of native species in the Delta remain unclear but are likely caused by multiple drivers (or stressors) and the interactions thereof … the relative contributions of these drivers and significance of their interactions are inadequately known." 2) pg 12: recommendation: "Deeper understanding of the causal mechanisms by which water flows affect fishes is critical for effective adaptive management, identifying and reducing uncertainty and risks, and for creating specific outcome expectations for management actions." 3) pg 16: "development [of models] must be done in the context of assessing uncertainty..."
2016 Adaptive Management	The adaptive management process can reduce uncertainty and identify gaps through the use of past outcomes to predict the results of future management actions and projects. Related quotes: 1) pg 4: "Adaptive management is most powerful in reducing uncertainty when management actions are thought of as experiments. By using a design that includes appropriate controls, monitoring, and replication, the factors that produced the observed outcomes can be disentangled from a variety of potentially confounding factors. As a result, one can have a good idea of why a management action did or did not work as expected."

Review	Relevant content
2016 Adaptive Management (Continued)	2) pg 5: "Adaptive management is most likely to be useful and effective when: • There is considerable uncertainty, making it difficult to predict with confidence the outcomes of management actions but actions must nonetheless be taken (i.e., waiting for better knowledge is not an option); • The system is complex and nonlinear, which means that many direct and indirect pathways can affect outcomes, identifying cause(s) and effect(s) is difficult, and the system being managed may veer in unexpected directions in response to management actions and other factors; • There is potential to learn (and reduce uncertainty) by observing and recording what happens in response to management actions." 3) pg 7: Factors that limit the use of adaptive management: "Uncertainty about the response of complex systems to multiple factors often leads to a hesitancy to move forward on adaptive management once a management decision is made." 4) pg 11: The survey revealed that Delta scientists and managers broadly recognize that "adaptive management can aid in identifying knowledge gaps and sources of uncertainty..." 5) pg 22: On why adaptive management is not more common in the Delta: "A manager or decision-maker must manage the risks of investing in projects with uncertain results, even when the stakes are high. Explaining such risks to administrators, politicians, or the public may be difficult. Perhaps these constraints and anxieties encourage managers to believe that it is better to err on the side of caution and be conservative in modifying original actions."
2016 Levee Hazards	Levee failures are a realm of great uncertainty because seismic events that bring about failures are largely unpredictable, and their level of transmission to the Delta is uncertain. Related quote: 1) pg 1: "Large uncertainties attend all these seismic elements of levee hazard (ground motions from Bay Area earthquakes, infrequent earthquake recurrence on faults beneath the Delta, and levee fills prone to earthquake-induced liquefaction). Those uncertainties, according to presentations in the workshop, include whether the Delta ground motions previously computed for Bay Area earthquakes were too large."

Review	Relevant content
2017 Delta as an Evolving Place	The actual uncertainties on the Delta as an evolving place were not identified but the need to allocate research and funding priority to these uncertainties was stated. Related quotes: 1) pg 2: "[Delta scientists'] research effort [on the values of the Delta as an evolving place] should be directed to those areas where the lack of information and uncertainties are greatest." 2) pg 10: "funders and researchers [undertaking research on the Delta as an evolving place] should give priority to projects that: ... are directed at reducing the greatest uncertainties in understanding."
2018 Water Quality	Several uncertainties were listed in the "General Findings and Recommendations" section, covering water quality science and monitoring overall, effects of nutrients and contaminants, and interactions between contaminants and other ecosystem components or stressors. Related quotes: 1) pg 5: "A more comprehensive view of the multiple elements that comprise water quality in the Delta is needed among stakeholders" 2) pg 6: "there is still much uncertainty about the effects of nutrients and some contaminants on the Delta ecosystem, especially those of emerging concern." 3) pg 6: "Little attention has been paid to interactions among chemical contaminants, as well as interactions between contaminants and other stressors." 4) pg 6: "Increased research is needed on the effects of nutrients on the Delta's food web and on the growth of aquatic weeds." 5) pg 6: "how contaminants affect ecosystem processes needs more attention from monitoring programs." 6) pg 7: "An understanding of spatial and temporal variability in contaminant delivery and the role of key events (e.g., first flush, floods, and tides) will contribute to better understanding and management of contaminants." 7) pg 20: "The potential for mercury to affect human health in the Delta is not well understood."

Science and social system linkages:

Review	Relevant content
2015 Fish and Flows	Human population growth and increased urbanization will affect water flows and supply, and subsequently fish in the future. Related quotes: 1) "Delta also will be subjected to interannual variations in water supply through... continued growth of the human population and increased urbanization [and] changes in land-use..." 2) pg 6: [From the NRC 2010 report] "Nobody disagrees that [among other drivers]... the general effects of an increasing human population have contributed to the fishes decline."
2016 Adaptive Management	1) pg 30: [Implementing adaptive management] "will require a change in the culture of management in the Delta. Managers and decision-makers must become more willing to take risks. Not managing adaptively entails the risk that, by following a traditional approach, better options are ignored." 2) pg 37: “But stewardship of the Delta and its way of life will require more... novel approaches… balancing the needs of people and the environment.”
2016 Levee Hazards	The workshop included few residents of the Delta whose lives and homes depend on effective levees. Related quote: 1) pg 8: "Few who attended the July workshop brought first-hand experience with maintaining, patrolling, or living behind non-urban levees of the Delta."
2017 Delta as an Evolving Place	There is a strong sense of place in the Delta which centers on the land as an agricultural region and a relatively unaltered landscape with concern for future changes. There have been negative effects from past racial injustices and the view of people as a nuisance to environmental causes, and more research is needed to understand cultural values and history in the Delta. Related quotes: 1) pg 4: "...Gambirazzio’s 2009 PhD dissertation considers the politics and processes of place-making in Locke, CA, during the urban redevelopment and preservation project conducted by the County of Sacramento and the State of California. This transformed governance and land ownership patterns in the town as part of an attempt to remedy past injustices committed against Chinese and other Asian groups."

Review	Relevant content
2017 Delta as an Evolving Place (Continued)	2) pg 4: "The Delta as a place evolved in a great leap with the construction of levees starting in the later 19th century. Its serious development as an agricultural region followed. The Delta as a place as we now know and value it is dependent on the levees and their continued maintenance." 3) pg 5: "Smith found that Delta residents valued their agricultural heritages, were pleased that the physical landscape had not been altered significantly during the past two decades, and were concerned about future potential changes in the Delta from proposals of water conveyance." 4) pg 6-7: "Environmental research on Delta landscapes has either ignored the presence and influence of people or documented environmental reasons why people are a nuisance. Milligan and Kraus-Polk take the perspective that people are a part of the landscape and that an understanding of human uses can lead to better landscape outcomes... better to work with and develop people's understandings to achieve better outcomes...human uses need to be factored into management of Delta landscapes." 5) pg 9: recommendation: "We recommend establishing an ongoing research program on the Delta as an evolving place. We recommend that this area of research become substantial and integrated with Delta research in other areas such as flows, water quality, or at risk populations." 6) pg 10: recommendation: "contribute more to cultural and historical knowledge and the understanding of the Delta's cultural, recreational, natural resource, and agricultural values... identify natural processes that protect and could be manipulated to enhance the values of the Delta as an evolving place...Research involving Native Californians who have lived in and/or used the Delta..."
2018 Water Quality	The link between water quality and societal issues was discussed briefly in parts, including the effect of mercury and the need for more research on drinking water and human health in the Delta. Related quotes: 1) pg 6: "agricultural pesticides and nitrates in groundwater may contribute to unsafe drinking water for some Delta residents." 2) pg 8: "There is a perception, especially among Delta residents, that water quality is impaired in the Delta."

Review	Relevant content
2018 Water Quality (Continued)	3) pg 20: "The potential for mercury to affect human health in the Delta is not well understood. Shilling et al. (2010)... reported that Delta subsistence anglers and their families... are likely bioaccumulating substantially more mercury than is safe... little research is being conducted on human activities in the Delta, and critical follow up research has not been conducted" 4) pg 34: "The Delta ISB also recognizes the need for more studies that consider interactions between water quality and societal issues, including human health, economic considerations, and social justice."