Science Supporting Decision-Making Under Deep Uncertainty

Delta Independent Science Board

Final Prospectus

July 20, 2023

Motivation

Rapidly changing conditions and increasing uncertainty of future projections (e.g., atmospheric rivers) highlight how extreme and hard-to-predict conditions challenge effective management of the greater Bay-Delta system, including its watersheds. Similarly, changing social, policy, and economic conditions can alter resource use and desirable management approaches, sometimes substantially. When conditions change rapidly and unexpectedly, managers are forced to prioritize some goals at the expense of others and may not have time to consider all management options or elicit stakeholder preferences.

The Delta Independent Science Board (Delta ISB) will conduct a review to build understanding of scientific tools and concepts that can increase the capacity to anticipate and adapt to growing uncertainty of future conditions in the Bay-Delta system. Starting from the current planning assumptions, these approaches use decision science tools to compare performance of management options under extreme or unpredictable events, such as those related to changes in climate, ecosystem processes and human behavior. The benefits of applying these tools include agencies having opportunities to anticipate concerns and prepare by engaging stakeholders in problem-solving and by building plans and relationships to coordinate actions when unlikely events occur. The goal of using tools of anticipatory modeling and pre-planning for unlikely, but still plausible, conditions is to promote new insights about effective preparation for change, even if harms cannot be fully avoided. Anticipating unprecedented extreme conditions can also speed up response time to emergencies by providing an opportunity for managers to consider potential outcomes of various actions and plan procedures to increase the likelihood of more positive outcomes.

Scientific analysis can reduce some types of uncertainty to improve the accuracy and the time and space scales of those predictions, typically using well-calibrated simulation models. However, other types of change have unknown or unknowable likelihoods of occurrence and research cannot substantially improve predictability. For example, new research may not increase our ability to predict global pandemics, collapses in fish populations, or novel species invasions far in advance. These conditions exhibit *Deep Uncertainty,* which is defined here as unpredictable events or system variability that cannot be well characterized with existing data, models, and understanding. Often, there is little or no agreement among stakeholders on how systems are likely to behave or the probabilities of occurrence of such events, including the duration, sequence, and co-occurrence of events (Haasnoot et al. 2013; Hallegatte et al. 2012). For the purpose of the Delta ISB's review, these types of uncertainties include extreme, novel, and compounding events and conditions that are important for the Bay-Delta system.

Decision-making under deep uncertainty (DMDU) includes a set of tools for stakeholder participation, anticipatory planning, and forecasting, when feasible. Multiple approaches may be used to identify and evaluate a wide range of possible futures and pathways, assess the robustness of potential decisions under each scenario, and select the decision that addresses risks using criteria consistent with stakeholder preferences and financial feasibility. Risk may be defined in multiple ways and evaluated from multiple perspectives. Instead of planning for a single "best guess" future, DMDU approaches aim to evaluate varied conditions under which a policy or plan might fail, in order to understand if an alternative approach may be more robust to uncertainty. Some DMDU approaches emphasize adaptive planning in which management actions are modified in response to decision triggers or tipping points, which may be based on risk assessments. The result is that risk mitigation efforts can be sequenced in time to promote cost-effective and responsive management (e.g., Haasnoot et al. 2013).

These tools can be usefully applied to manage risk associated with low probability-high consequence events that impact flood protection, water supplies, ecosystems, and human well-being. Those events include extreme droughts, extreme floods, or wildfires that have some predictability but may not be captured well in management due to their perceived low probability of occurrence or the expectation that risk mitigation will be cost-prohibitive. Further, such events could occur in combination with less predictable events, particularly those unrelated to climate change such as earthquakes, tsunamis, or sudden mass human migration, which compound effects and management challenges. These events are being included here to direct attention to advance planning and to recognize that probabilities of future events that are based on historic conditions may no longer be accurate.

DMDU is not an appropriate tool for all types of decisions and deciding whether to use DMDU and how to implement the findings requires careful consideration. What level of management investment may ultimately be warranted as a result of analysis can be evaluated through many lenses, including the expected benefits relative to costs and social equity. In general, DMDU can be particularly helpful when long time horizons are needed for planning and when it is difficult to change plans once initiated. Other considerations for choosing DMDU are the complexity of the decision and the number and variety of available management responses.

One DMDU tool that is commonly used to support forward-looking, future-oriented thinking is scenario analysis. Scenario analysis is uniquely valuable among decision support tools in that it can be used to examine different risks and probe deep uncertainties that reach beyond those that have been estimated using existing data and models. The potential benefits of using scenarios that include extreme or highly uncertain conditions are exemplified by the ARkStorm (Atmospheric River 1000 Storm) tabletop exercise to model and plan for a hypothetical scenario of an extreme weather event , or “megastorm” (Porter et al. 2011). California agencies who participated in that exercise reported using results to improve preparations (Kaplan 2023), and to evaluate opportunities to consider using greener approaches to stormwater management (Smith 2022). However, ARkStorm also shows the limits of forecasting based on historic data since climate change is expected to intensify extreme weather events (e.g., Espinoza et al. 2018). According to one study, runoff in the future extreme storm scenario is 200 to 400% greater than historical values in the Sierra Nevada due to the influence of climate change (Huang and Swain 2022). Similarly, evaluating scenarios about earthquake effects on levees and water supply could lead to deeper understanding of vulnerabilities and opportunities to coordinate action. In general, scenarios can be used as part of “stress testing” an existing or proposed infrastructure or management plan (e.g., Lempert et al. 2004). Stress testing reveals how the performance of multiple objectives deteriorates or changes under alternative futures. Results can lead to new insights about plans that have superior performance across diverse futures.

Techniques have been developed in the interdisciplinary social sciences (especially decision science) to generate scenarios, informed by forecasting when feasible, that systematically account for uncertainties that can include many stressors, such as climate change, human behavior, and compounding events. The science of scenario development uses data-informed approaches to understand evidence of change and incorporates horizon-scanning activities that identify novel ways that the system may be changing in the future. These techniques are valuable for mitigating some of the common cognitive biases in decision-making that can limit our capacity to anticipate and effectively plan for potential future scenarios.

This Delta ISB review will draw on existing studies from the interdisciplinary sciences that support DMDU and synthesize insights from a seminar series on current applications, DMDU insights and methods. The review includes a dedicated effort to review the scenario-planning methods being used within the Delta or in regions relevant to the Delta. After evaluating the methods in use, the review will explore potential benefits and concerns of applying structured scenario development methods from DMDU or related disciplines. The scenario methods of DMDU are usually intended to evaluate what could plausibly occur, rather than normative scenarios of what should occur. The social aspects of scenario development and their communication to stakeholders will be explored in the associated seminar series. The ultimate goal of this Delta ISB review is to support planning and management of events that are largely unpredictable or of greater magnitude in outcomes than are typically prepared for in current management practices (e.g., long-term average conditions).

Audience

The intended audiences for this work are those who manage resources or design projects using intermediate-to-long planning horizons, along with scientific and technical staff at government agencies, research institutions, and environmentally focused public or private organizations. We expect the results will be of interest to a wide range of management applications, such as salinity management, water supply, fisheries management, and ecosystem restoration goals.

Inputs to the review

Inputs will include information gathered through 1) public seminars, 2) an inventory and synthesis of current and planned scenario-development processes affecting the Delta, and 3) interviews with those engaged in or influencing Delta policy decisions.

Seminars

A public seminar series introducing concepts from the decision sciences, futurism, and other relevant scientific fields will engage stakeholders, rights holders, and other interested and affected parties. The seminar series will feature experts speaking on the science of DMDU, scenario development methods, major sources of deep uncertainty affecting the Delta, and current efforts to address those deep uncertainties. The seminars will also be an opportunity to explore social science research that evaluates community responses and reactions to future scenarios, and potential approaches to mitigate concerns. The seminar series will be hosted by the Delta ISB with support from the Delta Science Program (DSP).

Inventory and analysis of scenarios

The Delta ISB DMDU review will include a synthesis of scenario design and development methods being applied in the region. Scenarios relevant to the Bay-Delta region will be compiled and examined to understand how they are being designed to explore future socio-ecological changes and how they are being applied to decision-making and addressing uncertainty. Scenario elements to be captured in the assessment will include the scope of drivers and outcomes considered, methods of incorporating historical data, types of stakeholders engaged, and how uncertainty was identified and incorporated. Examples of existing scenario analysis efforts relevant to the Delta include, “Sacramento-San Joaquin River Basin Robust Decision Making Case Study” (Kalra and Groves) and, “Future of Agriculture in the San Joaquin Valley” (Escriva-Bou et al. 2023; see Appendix A for draft list of scenarios). The information gathered will be relevant to understanding opportunities to apply deep uncertainty concepts or otherwise expand the usefulness of scenarios for different management goals in the Delta.

Interviews

Semi-structured interviews are planned with those engaged in or influencing Delta policy decisions to deepen understanding of how scenarios are or could be developed and applied to address uncertainty in Delta analysis and decision-making. These interviews will contribute to recommendations on the potential application of DMDU tools and concepts to management challenges in the Delta.

Timeframe

Target Date	Benchmark
July 2023	Prospectus finalized
Ongoing (Throughout 2023)	Hold public seminar series to: a) Introduce concepts of DMDU; b) Explore/identify deep uncertainties affecting the Delta as perceived from diverse individual and/or organizational perspectives; c) Identify some signals of future change; and d) Provide other useful background information.
Summer 2023	Scenario inventory and qualitative analysis to systematically characterize and critically evaluate existing scenario design and development processes relevant to the Bay-Delta region through an interdisciplinary decision science and futurism lens.
Summer-Fall 2023	Interviews with those engaged in or influencing Delta policy decisions to understand use of scenarios to address uncertainty in their decision-making processes.
Winter 2024	Release a draft report summarizing information gained through the seminar series, scenario inventory and analysis, and interviews, with recommendations to improve the science of scenario analysis to inform decision-making under deep uncertainty in the Bay-Delta system.
Spring 2024	Finalize summary report and findings.

Related Reviews

We are not aware of any similar in-depth investigation of DMDU in previous or current review efforts. However, the Water Supply Reliability Review emphasized the importance of long-term preparations and improving estimates of water reliability by increasing the range of water management portfolios represented in water supply reliability analyses. Furthermore, the Review highlighted the critical need to apply risk-based decision support and forecast-informed reservoir operations to manage the impact of extreme events on water management systems (Delta ISB 2022).

The Delta ISB review of DMDU is responsive to calls for DMDU made in the memo for the Delta Plan Interagency Implementation Committee (DPIIC) entitled, “Science Needs Assessment: Integrating Science for a Rapidly-Changing Delta, Principal Recommendation: Interagency Forecasting” (Delta ISB 2021). The article, “Preparing Scientists, Policy-Makers, and Managers for a Fast-Forward Future” by Delta ISB members discussed the importance of scenario analyses, horizon scanning, expert elicitation, and dynamic planning for anticipating and responding to rapid future changes (Norgaard et al. 2021). Other recommendations produced by the Delta ISB and the DSP that have noted the need for anticipatory management (Delta Independent Science Board 2022; Delta Stewardship Council, Delta Science Program 2019).

Expected Products and Outcomes

Results and insights gained through the inputs described above will be synthesized in a report and shared through public presentations and other methods. The Delta ISB review will provide an exploration of tools, techniques, and recommendations that could be applied to help the Delta science and management community better characterize, prepare for, and adapt to uncertainty for a range of management needs such as salinity management, water supply, and ecosystem goals. Recommendations could inform new analyses, simulations, and approaches for coordinating multi-agency responses to events, strategic scientific planning and collaboration by agencies, and other activities to anticipate and prepare for the future.

Appendix A: Draft List of Scenarios

This preliminary list represents scenarios identified to date that evaluate expected or plausible future conditions or develop visions of desirable futures using environmental, social, and/or policy elements. We expect to expand this list as we examine various ways that scenarios are used in the Delta or relevant areas, and we invite anyone to share additional scenarios that do not appear on this list.

If you use scenario analysis or conduct any type of anticipatory planning to account for future uncertainty to support decision-making and stakeholder engagement purposes in the Delta, please provide the information to disb@deltacouncil.ca.gov.

Below is a current list:

- Achete et al., 2017: How can climate change and engineered water conveyance affect sediment dynamics in the San Francisco Bay-Delta system
- ARkStorm 2.0
- Brown et al., 2013: Implications for Future Survival of Delta Smelt from Four Climate Change Scenarios for the Sacramento–San Joaquin Delta, California
- Brown et al., 2016: Coupled downscaled climate models and ecophysiological metrics forecast habitat compression for an endangered estuarine fish
- California Aqueduct Subsidence Program
- California Department of Water 2015: Perspectives and Guidance for Climate Change Analysis
- California Water Plan Update
- California Water Plan: Future Scenarios of Water Supply and Demand
- Central Valley Flood Protection Plan
- Cloern et al., 2011: Projected evolution of California's San Francisco bay-delta-river system in a century of climate change
- Decision Support Tool for SF Bay-Delta Levee Investment Strategy
- Delta Adapts Flood Analysis and Risk
- Delta Island Adaptations
- Delta Stewardship Council Delta Levee Investment Strategy planning process
- DredgeFest California
- Department of Water Resources: Climate Change Vulnerability Assessment
    - Decision Scaling Evaluation of Climate Change Driven Hydrologic Risk to the State Water Project
- Department of Water Resources SWP Delivery Capability Report 2021: Appendix B Future Condition with Climate Change and 55 cm Sea Level Rise Scenario
- Escriva-Bou et al., 2023: The Future of Agriculture in the San Joaquin Valley
- Flood-Managed Aquifer Recharge (MAR) Program
    - Merced River Basin Study and Technical Memorandum
- Forecast-Informed Reservoir Operations
- Franks Tract Futures

- Ganju et al., 2010: Decadal-timescale estuarine geomorphic change under future scenarios of climate and sediment supply
- Hanak and Bedsworth 2008: Preparing California for a Changing Climate
  - Luers and Mastrandrea 2008: Climate Change in California: Scenarios for Adaptation
- Hanak et al., 2007: Envisioning Futures for the Sacramento-San Joaquin Delta
- Hanak et al., 2008: Comparing Futures for the Sacramento-San Joaquin Delta
  - Fleenor et al., 2008: Delta Hydrodynamics and Water Salinity with Future Conditions Technical Appendix C
  - Medellín-Azuara et al., 2008: The Economic Effects on Agriculture of Water Export Salinity South of the Delta Technical Appendix I
  - Lund et al., 2008: Decision Analysis of Delta Strategies Technical Appendix J
- Knowles et al., 2018: Modeling managed flows in the Sacramento/San Joaquin watershed, California, under scenarios of future change for CASCaDE2
- Medellín-Azuara et al., 2012: Transitions for the Delta Economy
- Porter et al., 2011: Overview of the ARkStorm Scenario
- Prospect Island Tidal Restoration Modeling
- Reed et al., 2021: Toward improved decision-support tools for Delta Smelt management actions
- RMA Suisun Marsh Modeling
  - Presentation
  - Final EIR
- Sacramento Area Council of Governments: Envisioning the Future: Delta Agriculture Scenarios
- SFEI Resilient Staten Island
- Stern et al., 2020: The future of sediment transport and streamflow under a changing climate and the Implications for long-term resilience of the San Francisco Bay-Delta
- Swanson et al., 2015: Modeling Tidal Freshwater Marsh Sustainability in the Sacramento–San Joaquin Delta Under a Broad Suite of Potential Future Scenarios
- Turbidity and Delta Smelt Forecasting Modeling
- Underwood et al., 2017: Quantifying Trade-Offs Among Ecosystem Services, Biodiversity, and Agricultural Returns in an Agriculturally Dominated Landscape Under Future Land-Management Scenarios
- United States Bureau of Reclamation: Sacramento and San Joaquin Rivers Basin Study

- Vicuña, Hanemann, and Dale 2006: ECONOMIC IMPACTS OF DELTA LEVEE FAILURE DUE TO CLIMATE CHANGE: A SCENARIO ANALYSIS
- Wagner et al., 2011: Statistical models of temperature in the Sacramento-San Joaquin Delta under climate-change scenarios and ecological implications
- Winter-run Chinook Salmon Lifecycle Model

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