Methodology and Scientific Basis to Support the Delta Levee Investment Strategy

Report of the Independent Science Panel Review

To the Delta Science Program

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1. Introduction

a. Background

The California Delta provides many assets and services that are important at local, regional, statewide, and national scales. These assets and services include two major water diversion facilities with the capability to distribute water to other regions of the state, providing water for irrigation and food production, supporting local communities and historic towns within the Delta, siting of critical infrastructure including energy transmission and shipping, providing a multitude of recreational opportunities, and preserving habitats for plant and animal species of special concern.

The Delta contains over 1100 miles of levees that define more than 176 islands and tracts. The levee system was initiated in the 1850's, and has been enhanced and enlarged over time creating today's configuration of islands. The island soils, many containing organic peat, are susceptible to compression and oxidation, resulting in settlement so the ground surface is now below sea level, thus requiring the surrounding levee system for protection against flooding. Owing to *ad hoc* construction and aging, the levees require frequent maintenance to ensure their integrity. Events and factors that challenge the integrity of levees include daily tides, winter storms, burrowing mammals, seepage, slumping, earthquakes, floods, and sea level rise.

The Delta Plan was adopted by the Delta Stewardship Council (Council) in 2013, and provides a comprehensive long-term management plan for the Delta. A key aspect of the Delta Plan is the furthering of the state's coequal goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the ecosystem. These coequal goals are to be pursued in a manner that "…protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place (Delta as place)."

The Delta Reform Act directs the Council, in consultation with the Central Valley Flood Protection Board, to prioritize investments in support of operation, maintenance, repair, and improvement of the Delta levee system. To facilitate the development of a transparent, reproducible, and effective methodology to prioritize the State's funding for levee work, the California Department of Water Resources entered into an interagency agreement with the Council. The agreement calls for developing a methodology and Planning Tool that use existing data to quantify assets and other benefits associated with each island and tract in order to establish a basis to judge the effectiveness of State funds to accomplish State objectives. A competitive proposal solicitation was prepared, and a consulting team led by ARCADIS was awarded the contract for this project. The methodology is to be based on the best available science and modeling. The subsequent Planning Tool will be used to prioritize and classify islands to guide a long-term State levee investment strategy.

As part of the project, a science-based review of the methodology by an independent Scientific Review Panel (Panel) was to be convened by the Delta Science Program. The charge to the Panel was to review the scientific basis for the methodology developed to date by ARCADIS. This review is intended to ensure that the approach taken is transparent, robust, and sufficiently sensitive to quantify and prioritize the assets and risks to State interests associated with each leveed island and tract in the Delta. This document presents the results of the review of the methodology by the Panel.

b. Organization of this Report

The remainder of this report is organized as follows. The review process is described in part c. of this section. Section 2 contains a series of general statements that provide the foundation for how to view and interpret the Panel's comments. The review comments are presented in Sections 3 and 4. Section 3 is a discussion of seven overarching topics that in the Panel's view relate to critical issues about the scientific basis of the methodology. Section 4 contains our responses to the 18 charge questions given to the Panel by the Delta Science Program. We list all of our recommendations in Section 5. With the exception of some aspects of a few of them, as noted, the Panel urges that all of these recommendations be addressed before the methodology and Planning Tool are released. We end the report with a set of concluding remarks.

c. Review Process

The review process was designed and managed by the Delta Science Program. A review panel of seven experts, covering the areas of geotechnical/seismic engineering, integrated risk management, flood management/hydrology, human and social issues, economics, environmental/land use change, and integrated modeling, was selected by the Delta Science Program. The panel membership was: James Mitchell (Chair), Nathalie Asselman, John Bolte, Susan Cutter, Martin McCann, Ari Michelsen, and Kenneth Rose (report editor).

The Panel was provided with several documents to review in the form of Technical Memoranda (TM) prepared by ARCADIS. Many supplemental documents were also made available to provide additional background and explanatory information. The charge questions to the Panel are listed as part of Section 4. Several initial technical issues and fact-based questions were developed by the Panel through a conference call and passed, via the Delta Science Program, to ARCADIS to assist them in preparing for their presentations to the Panel at a public workshop. A two-day meeting (workshop) was then held in Sacramento (agenda is Appendix A to this report). The first day of the meeting included presentations by the ARCADIS team, question and answer exchanges between the Panel and ARCADIS, and public comment. The Panel then met in a closed session the morning of the second day. The afternoon of the second day consisted of initial reporting out of overall impressions by the Panel, further question and answer exchanges between the Panel and ARCADIS, and an opportunity for public comment. The Panel members met on the third day in a closed session to formalize their conclusions and recommendations, outline the report, and make writing assignments. The text for the report was then developed by the Panel members and synthesized into this report following conference call discussions to clarify outstanding issues and concerns. Additional information about the review process and meeting is at http://deltacouncil.ca.gov/event-detail/11868. Every Panel member has endorsed this report.

2. Timing and Constraints of the Review

a. Timing of this Review

This review was conducted in the middle of a two-year project and focused on information provided in the interim technical memos and obtained during question and answer sessions at the May 19 and 20, 2015 workshop. A major advantage of a mid-term review is that the timing allows for comments and issues to be addressed before the finalization, release, and application of the methodology and Planning Tool. A disadvantage of a mid-term review is that not all of the details of the methodology have been worked out and the documentation is understandably incomplete. Thus, the Panel evaluated the documentation provided, but acknowledges that some of the issues raised and recommendations offered may become more or less important as the methodology is adjusted and modified during its continued development towards finalization for release. Our comments and review are offered to help improve the methodology and to better ensure its scientific credibility to be useful as one part of the multi-faceted process of investment strategy planning for the California Delta levees. We emphasize that a premature application of the methodology and tool can jeopardize its credibility and acceptance.

b. Constraints

The ARCADIS team has accomplished an enormous amount of work in a short period of time. They accepted a challenging task; developing a methodology and Planning Tool within a short period of time, while being constrained to only using existing data. The Panel recognizes the constraints placed upon ARCADIS, and also acknowledges and appreciates their effort and willingness to engage the Panel as it progressed through this review. Despite these imposed constraints on the project (schedule, use of existing data), the charge to the Panel was to evaluate the scientific basis of the proposed methodology.

Another limitation on our review was that the results of example analyses using the entire methodology, with its linked components, were not yet available. Part of reviewing a methodology is assessing the quality of the input data and the behavior and performance of the fully-coupled and fully-functioning methodology. The lack of a comprehensive assessment of the quality and quantity of the available data, and the lack of a full demonstration of the methodology, constrained our ability to go into details in some of our recommendations.

3. Overarching Issues

The Panel identified seven overarching issues that cross many of the charge questions listed in Section 4. These overarching issues are: Definitions, Data, Uncertainty, Aggregation and Scale, Risk Methodology, Metrics, and Planning Tool.

a. Definitions

The foundation for any robust methodology is the definition of terms and concepts, followed by detailed descriptions of how those terms and concepts will be (or were) operationalized. Precise explanations of the definition and operationalization of all terminology is critical for clear understanding of the Delta Levee Investment Strategy (DLIS) methodology and proper interpretation of the results.

The TMs reviewed by the Panel require better documentation of many terms including, for example, water supply reliability, tolerable risk, indicators (versus metrics), beneficiaries, and levee rehabilitation. More significantly, the documentation must also define how such terms were operationalized and measured in the DLIS methodology being developed. For example, what is the scientific basis for operationalizing water supply reliability with a semi-quantitative indicator metric that is triggered by any degree of disruption? How would this affect the ranking of levees? Perhaps, disruption of water supply would be better operationalized in terms of quantitative measures such as the number of days without exporting water, the lost exported volume of water over some time period, or the lost revenue to the suppliers.

Another example of an important term that needs clear definition is tolerable risk. Tolerable risk is used throughout the documentation and underlies the general approach used in the methodology. Tolerable risk has multiple meanings in the literature and is a technical term that is not well understood outside of the risk experts. Some refer to tolerable risk at the individual level or scale, while others define it from a societal or broader social perspective. Tolerable risk has been operationalized in the DLIS methodology using a tolerable risk threshold based on dam failures that is then directly translated to the levee case. Is this appropriate and if so, what is the justification (and supporting literature) for doing so? The perception of risk of dam versus levee failures by the public is different, and such perceptions may influence the tolerance levels for risk at both the individual and societal scales. In the F-N curve (the dashed red line in Figure 3-6 (TM2.3)), the tolerance level for risk is expressed by both the height of the guidance line and by its steepness, which conveys a decreasing tolerance for events that lead to large numbers of fatalities. In the view of the Panel, the guidance adopted by the Corps of Engineers for dams should not be translated directly for application to the Delta levees. Rather, consideration should be given to (1) what risk is tolerable given the type of risk, and (2) how risk averse the guidance line should be; i.e., is an event with 10 times more fatalities 10 times more serious or severe, or does the severity increase by more or less than a factor of 10?

In the DLIS methodology, tolerable risk is defined in terms of “group risk” (i.e., the probability that a single, extreme event may lead to an intolerably high number of fatalities). However, for individuals living in the Delta, tolerable risk could probably better be defined as a maximum probability for dying because of a flood resulting from a levee breach. This could be expressed in terms of a maximum tolerable value for the flood fatality hazard. The flood fatality hazard indicates the probability that a person living in a certain area might die due to flooding. It is important to note that areas with a high flood fatality hazard do not necessarily contribute to a large number of fatalities. In fact, population densities often are low in these areas; thus, the contribution of these areas to the total number of flood fatalities during flood events can be relatively small.

How one measure is defined and operationalized can affect others. For example, island proximity to conveyance infrastructures is important to the indicator of water supply reliability. How is island proximity itself operationalized (e.g., distance measure in km from the centroid of the island or tract to the pumping stations) and how is this compatible with the definition of water supply reliability? Another term that requires some precision in its operationalization is beneficiaries, especially those beyond the local scale and present time period.

The Panel suggests that the operationalization of many of the indicators used in the DLIS methodology appears too much driven by whatever data was available, and thus the list of indicators used can appear *ad hoc* to the reader. This lack of sufficient definitions and explanation of why certain variables were selected can be interpreted as a lack of due consideration of the science underlying the selection and implementation of some of the key indicators (e.g., water supply reliability). While the Panel recognizes the constraints of the project, the selection of individual variables to represent the broader concepts should be based on the scientific literature, and then the logic and rationale for the actual operationalization in the DLIS methodology should be explained.

The ways in which the primary terms and concepts are defined and operationalized in the methodology will affect the transparency and credibility, and therefore the usefulness, of the Planning Tool. It is therefore critical that care be taken so that terminology is well articulated and used consistently throughout the document. This is more than just providing a glossary. There are many opportunities for misinterpretation of terms and concepts and why certain measures were operationalized in seemingly arbitrarily ways. In summary, utilizing readily available data to operationalize concepts is appropriate, but only when it makes theoretical or conceptual sense and the reasons and rationale for the operationalization and how it related to the other dependent measures are well described in the documentation.

b. Data

The DLIS methodology is a set of relatively simple (mostly linear) equations and calculations, and thus its accuracy and precision are heavily dependent on the quantity and quality of the available data. Two key types of data that are used as input are the raw data (e.g., island population; levee length) and data that resulted from the processing of raw data, such as through other models and analyses. As a result, documenting the quality of the input data (both types) used in the DLIS computations is complicated, but sufficient evaluation is critical to hav confidence in the results and for ensuring the results are properly interpreted. For example, as long as the assets per island as summarized in TM 2.1 are incorrect or raise questions, one can be sure that the results will be questioned too. The Panel found three data issues of concern in the DLIS methodology.

1. Evidence that the datasets employed are the most current and best available. ARCADIS is using existing datasets both directly as inputs and also as a basis for estimating parameters and deriving relationships used in the DLIS methodology. In both uses of the data, it is critical for transparency and credibility that the datasets used are as relevant and up-to-date as possible. For example, the role of salinity as influenced by hydrodynamics in the Delta has been extensively analyzed by DWR using a variety of models and datasets; however, there is no indication in the DLIS methodology documentation of whether these datasets were reviewed and, if used, details about how they were utilized in derivation of the water supply reliability measure.

Similarly, ARCADIS is using a USGS seismic hazard dataset with known limitations, without referencing a region-specific seismic hazard study completed by DWR (2007).[1] The USGS seismic hazard model is a regional scale study that is intended to provide a basis for the seismic loads that are used in building codes. It is not intended for site specific applications or for the evaluation of critical infrastructure response. It might be more reasonable to use the results of a site-specific seismic hazard assessment as input to the DLIS methodology.

In general, many of the datasets that were identified by ARCADIS are approaching 10 years old and should be assessed to determine if they are the best available and if they remain valid for use in the DLIS methodology. An example is the availability of more recent census data than what was used initially in the project.

[1] URS Corporation/Jack R. Benjamin & Associates, Inc., Delta Risk Management Strategy Phase 1: Technical Memorandum, Topical Area: Seismology, June 15, 2007.

A comprehensive list of datasets reviewed and/or used by ARCADIS, and the justification for their use or rejection, was not available to the Panel as part of this review. The Panel considers documentation of model inputs and formulation of model relationships a key part of the methodology. While the Panel realizes this effort is a work in process, it will be important to document the datasets reviewed and used for development of the methodology and in the Planning Tool and to provide the rationale for the decision to use or not use individual datasets.

2. Quality assurance/quality control procedures. Because establishing the quality of the input data is critical to the credibility of the DLIS methodology, clear quality assurance/quality control (QA/QC) procedures need to be identified and applied to all datasets used in the methodology. The Panel was provided a QA/QC plan that, if followed, is sufficient for this project; however, it is unclear from these materials whether the described QA/QC procedures have been applied rigorously and comprehensively to the datasets used to date in the DLIS methodology. The Panel also believes that some level of ground-truthing of key datasets, not by collecting new data, but by selectively confirming the existing data, would be beneficial to building confidence in the Planning Tool. For example, there were locations where there were no residential structures, yet the tract showed a population value. Is this a data problem, a definitional issue, or lack of a rigorous QA/QC procedure that would have caught the inconsistency?

3. Metadata. The QA/QC procedures described by ARCADIS include the development of metadata documenting the datasets used in the DLIS methodology. It is stated that they are using DWR and Federal Geographic Data Committee standards. The Panel emphasizes that these metadata are crucial to building confidence in the methodology and should be available from the Planning Tool interface. Too often, metadata are prepared late in the development process and not given proper attention. Proper metadata are especially critical to the DLIS methodology for credibility and proper interpretation of results, and also to ensure easy updating of information in the future.

c. Uncertainty

A critical issue in the DLIS methodology is the approach used to address the uncertainties in the data and modeling that is done in order to ensure the results are properly interpreted in terms of the prioritizations and their use in the formulation of investment alternatives. In the documentation provided to the Panel, including the discussions at the workshop, the issue of uncertainty is recognized by the ARCADIS team as an area that requires additional work. ARCADIS stated they planned on doing sensitivity and scenario analyses as part of this process. However, the documentation to date did not establish a framework for identifying sources of uncertainty or include a plan as to how uncertainties will be addressed and how the sensitivity of the levee prioritization to uncertainties will be evaluated. Presentation of such a plan is critical because there are many ways to assess uncertainty, and there is often confusion regarding the difference among sensitivity analysis, uncertainty analysis, and scenario analysis. The differences between these methods can lead to gaps (important analyses not done) and misinterpretation of the analyses that are performed.

One taxonomy for the identification of uncertainties that is used in risk studies recognizes there are differences between stochastic or random sources of uncertainty and uncertainties in models, and the estimation of model parameter values due to limited or uncertain data, or limited understanding of physical processes. These types of uncertainty are defined as aleatory and epistemic uncertainty, respectively. Aleatory uncertainty is attributed to the inherent randomness of events or properties. These events are predicted in terms of their frequency of occurrence or the fraction of the time an event or property (e.g., material strength, spatial variability of soils) is realized. Examples of sources of aleatory uncertainty are the frequency or rate of occurrence of future earthquakes on a fault, the magnitude of an earthquake, the performance of a levee given earthquake ground motion, the occurrence of a flood event, and the performance of a levee due to overtopping during a flood event.

Epistemic, or knowledge-based uncertainty, is attributed to lack-of-knowledge about events or physical processes that limits the ability to model these events and processes. Included in knowledge uncertainty are the limitations in available data (amount and quality) that impact the assessment of model parameters (parametric epistemic uncertainty). When data are limited, parameter estimates may be quite uncertain (i.e., statistical confidence intervals on parameter estimates are large).

We highlight in Box A some statements in the TMs that illustrate a variety of uses of the term "uncertainty" that do not have a clear meaning. In the absence of a clearly defined uncertainty framework, these statements illustrate how a lack of clarity (as it relates to uncertainty) can lead to confusion and misinterpretation. In each of these instances, it is unclear what the source of the uncertainty is and what type of uncertainty is being addressed. For example, the statement in TM 3.1, p. 13 seems to suggest the authors are referring to the randomness or aleatory uncertainty in earthquake events and levee breaches. Yet, the later part of this sentence seems to refer to the knowledge-based or epistemic uncertainty in estimating the probability (aleatory uncertainty) of earthquake and levee failure events. While both of these uncertainties are significant, it is unclear whether this or another interpretation is intended.

Often when uncertainty is mentioned, it is generally discussed, mixed in with sensitivity analysis and, in this project, with scenario analysis. The Panel notes there are fundamental differences between an analysis of uncertainties and performing sensitivity calculations. Uncertainty analysis examines how variation (uncertainty) in inputs or model formulation affects model predictions. Sensitivity analysis typically uses small changes in input values to determine how different inputs affect the calculations and prediction of the model. Sensitivity analysis often uses small changes (e.g., ±10%) in inputs varied one-at-a-time. Scenario analysis can mean many things, including how predictions are affected by changes in driving variables (e.g., water levels). It is the Panel's view that uncertainty, sensitivity, and scenario

Box A: Examples of text from the TMs that use the term "uncertainty" without clear meanings.

TM 2.2, p. 26 – "The monetary and non-monetary analyses described in this memorandum will be based on existing conditions as well as a range of possible future conditions to evaluate the effect on the magnitude and **uncertainty** of the predicted consequences and damage costs."

p. 27 – "Stage-damage relationships and the **uncertainty** of those relationships for residences and businesses are reasonably well established."

TM 3.1, p. 13 – "As another example, the likelihood of the magnitude, location, and timing of seismic events or levee breaches is **uncertain**: various studies suggest different plausible probabilities for these events."

p. 27 – "This accounts for **uncertainty** in the method, because islands / tracts assigned zero EFV may have a small chance of affecting water supply due to potential unknowns."

p. 30 – "The relationship between the flooding of an island and likelihood of water supply disruption is not well understood and so will be treated as a key **uncertainty** in our analysis."

analyses should each be an essential part of the DLIS methodology.

The Panel considers documentation of the strategy and methods (i.e., a plan) for uncertainty, sensitivity, and scenario analyses to be part of a scientifically sound methodology. The methodology should include a clear definition of the types of uncertainty that will be addressed in the analysis, how these uncertainties will be identified and evaluated, and how they will be propagated through the DLIS analysis to assess how they impact the levee prioritization. A plan for the uncertainty analysis should include:

- Definition(s) of uncertainty, sensitivity, and scenario analyses as used in the DLIS methodology.
- A framework for identifying and quantifying the sources of the uncertainties in the data, identifying key model assumptions, and what model inputs should be varied for scenarios to inform management. Very clear descriptions should be given of why and how each analysis will be done and how the results of each analysis should be interpreted.
- An approach for identifying and evaluating sources of uncertainties and assessing the effect of epistemic uncertainties on the island prioritization.

Given clear definitions for the types of uncertainty and a framework for their evaluation, the plan should describe how these uncertainties will be identified, evaluated, and considered in the levee prioritization analysis. It is the Panel's assessment that an evaluation that clearly addresses the sources of uncertainty that may impact the levee prioritization will strengthen the technical basis for the rankings that are produced and the investment strategies that are recommended.

d. Aggregation and scale

Three key aspects related to the scale of the DLIS methodology are: 1) the calculations and metrics are defined at the island level and, therefore, there is difficulty in treating interactions among islands, 2) the analysis focuses on local benefits and consequences and not also at the broader scales of the State and Nation, and 3) analyses for present day versus the future.

1. Interactions (responses and consequences) among islands. The DLIS methodology is based on calculations performed on a per island basis. Evaluation of individual island characteristics and conditions is necessary to meet the stated purpose of prioritization of investments for individual islands. However, simultaneous and concurrent failures of groups of islands must also be considered as part of the methodology. Groups of islands can fail together because of a major event, and the interconnectedness and interdependencies among islands can lead to amplified consequences (e.g., major disruptions of water supply and/or roadways; impacts to other infrastructure). The Panel considers this a major weakness in the present methodology. Dealing with these high consequence events is challenging but they must be addressed.

Accounting for multiple island failures can be especially important when looking at the scale of public safety consequences (fatalities), as well as the probability of these events as they relate to the generation of F-N curves and the comparison to tolerable risk criteria. TM 2.3 describes the development of F-N curves on a per island basis, which is valid for isolated island failures (so-called sunny day failures), but they need to be extended by considering the larger number of fatalities that can occur with multiple island failure based on a larger initiating event (e.g., earthquake or flood).

We recommend that ARCADIS explore existing methods for dealing with multiple island failures and accumulating the consequence of such events. An example of a method that can be applied to develop such F-N curves is given in De Bruijn et al. (2014)[2]. They discuss a method that provides an F-N curve to assess societal risk that is applicable to river deltas with levees. It takes into account the effect of breaches on downstream flood hazards[3], and it jointly considers all relevant threats (storm surges, river flows and, in their case, the functioning of storm surge barriers). The method is based on a Monte Carlo simulation for hydraulic load (storm surge and river discharge), levee vulnerability (expressed in fragility curves), and successful evacuation fraction (affecting the number of people present in the flooded areas). The F-N-curve that is obtained from the Monte Carlo approach does not automatically show the contribution of different islands or levees to the total number of fatalities. However, techniques exist to unravel this from the available results. Although the best results will be obtained with a Monte Carlo simulation, an approach that uses a series of systematic changes is more feasible in the short-term for the DLIS methodology and could be used to provide a first impression of the probability of multiple island failures, and also of the islands that are most likely to fail as a group. In addition, the Delta Risk Management Strategy study used a similar approach for the evaluation of public safety risks as well as economic consequences.

Accounting for multiple island failure also is of utmost importance when looking at the reliability of water supply. Failure of a single island is unlikely to result in long duration disruption of water supply. For example, the EAD or EAF of an individual island may be limited when compared to other islands, resulting in a low ranking. However, depending on its contribution to group risk (as indicated by the F-N curve), the ranking may change when failure of multiple islands is accounted for. Also, with respect to disruption of the water supply system, failure of individual islands may have little effect as long as they do not fail simultaneously (i.e. failure of 1 island every 2 years may have a different impact than failure of 5 islands at the same time). However, the concurrent failure of several islands could lead to multiple fatalities and long-term disruption of water supplies.

2. Local, regional, and national benefits and consequences. The present DLIS methodology focuses mainly on benefits and consequences on a local scale. An example of an event that has consequences on a scale broader than just local is water supply disruption. A more robust or reliable water supply system could generate benefits on a regional, state and even national scale. When costs are allocated to different beneficiaries, it is important to have insight into the consequences and benefits not only on a local, but also on these broader scales. What are the local benefits of a more secure water supply system? What are the benefits on a regional or even

[2] de Bruijn, K.M., F.L.M. Diermanse and J.V.L. Beckers (2014). An advanced method for flood risk analysis in river deltas, applied to societal flood fatality risk in the Netherlands, Nat. Hazards Earth Syst. Sci., 14, 2767-2781.

[3] To obtain a realistic estimate of the number and location of breaches (and the corresponding consequences), the hydrodynamic interaction between locations needs to be taken into account. Hydrodynamic interactions comprise the decrease of water levels at potential breach locations due to a breach elsewhere. This decrease of water levels may have a significant effect on the failure probabilities of (downstream) flood defenses.

on a national scale when water supply to agricultural areas in central and southern California becomes more secure? The analysis should be expanded to include consideration of these consequences and benefits on broader scales rather than just local and quantified in terms of quantity and quality of water in natural units (i.e. for export from the Delta in acre-feet and change in salinity) and then in monetary terms (obtained from resulting/avoided agricultural and, where applicable, urban losses/replacement values).

3. Present day versus future conditions. The available data (as mentioned above) contain uncertainties and these will be magnified by projections to 2030 and 2050. For example the vulnerability of the levees is expressed in the fragility curves. Making projections for the years 2030 and 2050 will increase the data uncertainties, not only in the vulnerability of the levees, but also in hydraulic loads and changes in land use. The Panel suggests that it would be better to devote effort to getting the best estimates for the present situation before stretching the effort to also predict rankings for 2030 and 2050. Hence, the method and the data should be documented and improved first; scenario analysis for 2030 and 2050 can be carried out later after the methodology has been fully evaluated for present-day conditions and uncertainties and sensitivities have been assessed.

e. Risk Methodology

The current documentation of the DLIS methodology describes the procedure that is being followed, without prior discussion and documentation of its underlying technical basis as an appropriate approach to assess the state's risks and to support decisions relative to levee investments. As stated in charge question (6), to the Panel, the methodology must be *valid and based on appropriate theories.* Documentation that makes this case is not provided in the current version of the TMs.

The following are examples of issues with the DLIS methodology as it relates to its scientific soundness and its basis on well-established theories and principles. Without sound grounding in theory, the methodology would appear as a somewhat *ad hoc* collection of calculations based on convenience rather than careful thought and consideration.

- The documentation must provide a complete description of the overall methodology that presents the theoretical foundation, the evaluation of uncertainties, the basis for the metrics that are used (specifically the indicators that have been developed), and their influence on investment strategies. As presented to the Panel, the methodology is a collection of "traditional" risk measures (such as expected annual damage) and indicator variables, without an overall foundation based in risk or decision science.
- A description of the approach that is used to estimate island recovery (levee repair and dewatering costs) is needed. This cost varies depending on the nature of the event (earthquake, flood, sunny day failure, etc.), the damage that is caused to the levees, and the size of the island. On a per island, per event basis, these costs are in the millions to possibly tens of millions of dollars.
- In the seismic risk analysis the vulnerability/fragility of an island is defined by the weakest levee reach on the island. This is an unconservative (overly optimistic) measure of island vulnerability. This approach implies that two islands with the same weak link have the same seismic reliability, even if the levee on one island is 5 times as long as that

on the other. The approach taken to date can underestimate the fragility of the islands and treats all islands with levees of like kind as equally vulnerable. This is a long-standing issue in these types of analyses, but it still needs to be addressed and the likely effects made clear to all users of the methodology.

- In the seismic risk analysis, the potential for non-breach damage and the cost of island recovery, which will include breach closure, repair of non-breach damage and island dewatering, are not considered. Levees can become structurally weakened from shaking but not breach immediately. This damage can be substantial since it could entail a considerable length of levee. If the methodology is going to address the cost of island recovery as part of the expected damages, then considering non-breach damage repair should be part of that cost.
- The methodology that is described in the tolerable risk TM for estimating fatality F-N curves is incorrect. Instead of estimating the frequency of exceedance of the number of fatalities, the methodology, as presented, estimates the frequency of exceedance of an **expected** number of lives lost. This result cannot be compared to an F-N tolerable risk criterion. In the case of the Delta, the expected value approach that is used does not consider the range in the possible loss-of-life from a single flooding event on an **island.** (Based on discussions at the public meeting it is our understanding the approach for estimating life safety risks is being revised.)
- A more rigorous case needs to be made for the relevance of adopting the Corps of Engineers tolerable risk criterion for dams for the DLIS methodology, or an alternative approach developed. While there are similarities between dams and Delta levees, there are also differences that would suggest the tolerable risk criterion for levees and dams should not be the same. Further, the implications of adopting the Corps of Engineers tolerable risk criterion for levees would indicate that, in some cases, the design standard for Delta levees would be more stringent than criteria recently adopted by the State.

The method used to quantify and represent the risks to the State associated with events in the Delta relies on expected value calculations on a per island/tract basis. The properties of the expected value of a random variable are such that many problems can be analyzed wherein basic events/components of the model can be quantified in terms of their expected value. These expected values can then be combined to determine a measure of risk. For many linear problems, the sum of the expected values of individual elements of a problem can be carried out to estimate exactly (or reasonably approximately) the expected value of the whole. For instance, in the case of the Delta, an argument can be made that the expected annual damages due to flooding on individual islands can be summed to determine the total expected annual damages for the Delta due to flooding. This approach allows the analyst to determine for a single island, on an event-by-event basis (e.g., different flood levels), the damage (direct damages due to flooding) from an event in terms of the expected value. Analytically, this is correct. However, from the perspective of providing a complete, and accurate representation of risk, the expected value approach may be problematic, and in some cases, incorrect.

This expected value issue is important because it underlies many of the calculations in the DLIS methodology, especially how information is passed among the component sub-models. Some limitations of the expected value approach that should be considered in the context of the calculations of the DLIS methodology include:

- The expected value approach can hinder incorporation of a systems approach (e.g., deal with interconnectedness of islands) to analyzing Delta risks, because calculations reduced to expected values early in the calculation process, limit how linkages and interactions between islands are incorporated.
- Multiple island failure in a single event may not be properly treated. In this circumstance, the scale of the risks to the State in terms of the number of lives that may be lost (F-N curve analysis) or the degree of water supply distribution are not estimated and, therefore, cannot be considered in the development of investment strategies. The State (public) may decide to make different decisions with respect to investments if they know the scale of fatalities or a major interpretation of water supply which might occur during a single event, as opposed to what might occur on average on individual islands. Society has decreasing tolerance for events that may have large consequences (see TM 2.1).
- The expected value approach will be incorrect in circumstances where the relationships among random variables that are input to the risk evaluation are non-linearly related.
- During discussions at the workshop, a characterization was offered that the risk analysis that is part of the levee prioritization methodology provides a relative measure of risks. This argument is typically made (and correctly so) when the results of the analysis are simply needed to establish a relative order of events, system risks, etc. Certainly, this is an objective of the levee prioritization methodology. However, as part of the methodology, absolute comparisons are made between public safety, tolerable risk criteria, and estimated fatality F-N curves. It is unclear, based on the available documentation (i.e., the case has not yet been made), as to whether a relative risk approach is appropriate for the Delta investment problem.

f. Metrics and Indicators

The DLIS definitions of terms and metrics, and the calculations that result in the reporting of impacts and rankings, should be more comprehensive and quantitative to provide transparency, adequate understanding of the resources at risk, and the impacts of levee failure or benefits of levee investments. In particular, there should be inclusion of social resources and vulnerable populations as metrics and quantitative measures of water supply reliability and disruption impacts. Also, water supply reliability is one of the two coequal goals of the Delta Stewardship Council and quantitative measurement estimates of water supply reliability is a critical part of the investment decision making process.

1. Metrics of the Impacts. In the DLIS methodology, water supply reliability is only measured qualitatively as an abstract index of probable “disruption” of water supply. Disruption is defined as the “expected annual water supply disruption risk score” (unitless). Conducting analyses and reporting results in this form of indices does not provide a sufficiently adequate measure of risk to the State in the form of a readily understandable measure required to evaluate investment decisions. Not all disruptions are the same or relevant in terms of the impact to the State’s water supply, and water supply disruptions can potentially affect the ranking of islands. Specifically, impacts on water supply export reliability, both quantity and quality (e.g. salinity), should be expressed in quantitative units such as acre-feet or millions of gallons of water and salinity concentration (NTUs) changes in export water, and include a temporal duration component.

These values can then be used to develop quantified monetary estimates of agricultural and/or municipal and industrial water supply impacts and avoided damages resulting from levee investments.

From the information provided in the Technical Memorandums, it would appear there are existing studies and data which could be used to develop water supply reliability quantitative and qualitative impacts. For example, in TM 3.1, page 27, a Sigmoid Disruption Curve for Expected Annual Water Supply Disruption Risk is presented in Figure 3-1. This figure shows the relationship between the Likelihood of Disruption and Effective Flooded Volume (EFV) of Delta tracts. While there are only two fit points used in developing this curve above the probability value of 0.1, the Island Group data points shown on the curve highlight the importance of evaluating groups of islands associated with a given objective metric. TM 3.1 (pages 25-26) also references the DWR report "Draft Long-term Salinity Impacts from Permanently Flooding Delta Islands"[4] and Public Policy Institute of California report "Delta Hydrodynamics and Water Salinity with Future Conditions"[5] These existing studies should be investigated for providing information on expanding the metric for water supply reliability, and such information can be carried through to other consequences such as impacts on crop yields. It is recognized that development of quantitative water supply reliability estimates will require extrapolations of existing data and the use simulation modeling output; however, this is one of the more important goals and should be evaluated using quantitative metrics.

2. Lack of Transparency and Limited Variation in Metrics. The DLIS methodology lacks sufficient transparency in the development of index metrics and their subsequent normalization, aggregation, and weighting. While the Panel understands this is a mid-stream evaluation and further documentation is coming, the Panel wanted to be clear that the interim TMs (which likely will be the basis of further documentation) are severely lacking in key information.

One key aspect related to the use of aggregated sets of weighted index results is whether the results will provide valid and distinguishable differences between the combined sets of impacts of individual tract or groups of tract investments. For example, while loss of life is of great concern and should be evaluated, historical observation of no previous experience in the Delta of fatalities occurring as a result of levee failure would seem to indicate that this metric will have very little variation across strategies and, therefore, it would result in very small or negligible additional information to influence the rankings. Another example of an aggregated metric

Box B: Examples of literature on dealing with indices.

Organization for Economic Co-operation and Development and Joint Research Center, European Commission. 2008. Handbook on Constructing Composite Indicators: Methodology and User Guide. OECD, ISBN 978-92-64-04345-9.
Stewart, T.J. 2015. A critical survey on the status of multiple criteria decision making theory and practice. Omega, Volume 20, Issues 5–6, September–November 1992, Pages 569–586.
Dyer, J.S., P.C. Fishburn, R.E. Steuer, J. Wallenius and S. Zionts. 1992. Multiple Criteria Decision Making, Multiattribute Utility Theory: The Next Ten Years. Management Science, Vol. 38, No. 5. (May, 1992), pp. 645-654.
Aruldoss, M., T.M. Lakshmi and V.P. Venkatesan. 2013. A Survey on Multi Criteria Decision Making Methods and Its Applications. American Journal of Information Systems 1.1: 31-43.
Department for Communities and Local Government. 2009. Multi-criteria analysis: a manual. Eland House, London, UK.
International Society on Multiple Criteria Decision Making (and MCDM journal) http://www.mcdmsociety.org/facts.html.

[4] California Department of Water Resources (2013). *Draft Long-term Salinity Impacts from Permanently Flooding Delta Islands,* Delta Modeling Section, Bay-Delta Office.
[5] Public Policy Institute of California (PPIC) (2008). *Delta Hydrodynamics and Water Salinity with Future Conditions: Technical Appendix C.* http://www.ppic.org/content/pubs/other/708EHR_appendixC.pdf

which may have questionable utility to show sufficient differences to impact interpretations among similarly ranked islands is related to ecosystem habitat. This is important because people can misinterpret the results as saying that habitat has been realistically considered in the rankings, whereas the way it was calculated (e.g., limited information on habitat and on an island by island basis) resulted in insufficient variation to appropriately influence the overall indices and thus the rankings.

There is a large body of literature on the development, normalization, weighting, and aggregation of indices and multi-criteria decision making methodology. However, references supporting the proposed methodologies were not included in the TMs. Box B shows a few examples (not endorsements) of and sources for such literature. Careful consideration must be given to how metrics and their companion indicators, are formulated, and combined in the effort to generate a simple, single ranking of islands.

3. Metrics in the Planning Tool. The data and information for informing Delta levee investments should be transparent and easily understandable, not only in the methodology but also in the Planning Tool. This is not the case with the use of individual metric indices, and especially not with the use of aggregated index metrics. One method that was proposed in the workshop is to present the results of the objective metrics in the form of relative values of aggregated, normalized, weighted indices in bar graph form. Whether graphically or numerically presented, aggregated, weighted indices do not provide transparent or sufficient information about the actual impacts or the individual weights of objective indices. We strongly recommend that, in addition to aggregated indicators, the Planning Tool metrics also be presented in their natural units. Having drill-down access to this information is one method, but admittedly adds another layer (more effort) for users to understand the outputs of the Planning Tool.

While there are many methods that could be used to provide metric information reported in natural units for alternative strategies, one simple method which could be used would be to present metric impact results in table form. See below as an example.

										Investment	
Island/ Group	Event	Water Supply Reliability - Export		Restore Ecosystem		"Place"	Agricultural Impacts		Fatalities	Total	State
		Quantity AF	Salinity ppm	Habitat acres	Channel margin miles	Historic buildings number	acres	$		$	$
#		Xxx	xxx	Xxx	Xxx	Xxx	Xxx	Xxx	Xx	Xxx	xxx

Another approach to presenting results of strategies and objective metrics could be to do it geographically. This could be particularly useful for evaluating strategies related to groups of islands.

4. Under-represented or Missing Metrics. In addition to inadequate quantification of water supply reliability, the measures related to ecosystem habitat and beneficiaries require further explanation. Finally, the lack of any measures related to "Delta as Place" needs to be addressed.

The information provided about ecosystem impacts was based on changes in habitat, which is a practical approach to the data-limited situation of island failures on fish, plants, and wildlife. However, the method was described as a general series of calculations. Like some other aspects of the DLIS methodology, the Panel could not evaluate the habitat method without more details and an evaluation and assessment of the availability and quality of the data. The general approach of assessing habitat changes is scientifically sound, but we are unsure of how well the specific calculations will perform relative to capturing important habitat changes with sufficient certainty to allow accurate and appropriate influencing of the overall results from the DLIS methodology.

There is little enumeration of beneficiaries beyond the local area. More consideration of beneficiaries beyond the immediate Delta area (state, region, and nation) should be part of the cost/benefits allocation. This can be done by quantifying changes in export water quantity and quality and then calculating monetary estimates of the water export changes on agricultural production and municipal and industrial losses/water replacement costs as noted above under the section entitled “Metrics of the Impacts.”

Overall, there is little if any mention of the social consequences of levee failures, such as the loss of livelihoods to certain groups (e.g., migrant farm workers or Native Americans), or the impacts of levee failures on socially vulnerable populations. Similarly, there is no mention of the beneficiaries, some of whom might be socially vulnerable populations. One of the two coequal goals is "protecting, restoring and enhancing the Delta ecosystem", and both coequal goals are to be achieved in "a manner that protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place" (California Water Code Article 85054). While metrics for these protections and enhancements were stated as being part of the proposed planning and decision making processes, they were not represented in the metrics used in the DLIS methodology. There seem to be data already collected in the asset database that could be used in developing an indicator to represent these “Delta as Place” considerations (e.g., number of historic structures, parks, landmarks, scenic highways), while others could be gathered (e.g., traffic counts on cross-delta transportation routes, diversity of crops, economic benefits of recreation, length of time at current residence, cultural meanings). Rather than work from the data, the team would need to define what Delta as Place means, how they operationalize it, and then what data are used to measure it. This could start out as a relatively simple metric based on readily available data, and then be expanded over time as the concept is broadened and more data become available, such as social surveys on the meaning and attributes of the Delta that the community (Delta, region, state) find desirable and which differentiate the Delta from other places.

g. Decision and Planning Tool

The Panel examined the use of the datasets and methodology in the Planning Tool vis-à-vis its overall potential for informing Delta levee investments in a transparent manner. We distinguish here between the methodology, and the Planning Tool, which is the implementation of the methodology to allow repeated calculations to occur. We list our issues below, recognizing that some of our comments on the Planning Tool overlap with comments we made earlier in the context of the methodology. For clarity, they are repeated here but in the context of the Planning Tool.

1. Consistent reporting of metrics in their natural units. The Planning Tool as described relies heavily on various indicators that are expressed as normalized, non-dimensional values. While useful for comparing across metrics with different fundamental units in their non-normalized forms, normalized values are highly dependent on the specific normalization process used, and the normalization process loses information related to the natural units describing the original (non-normalized) variable. Therefore, it is critical to report the metrics both in their natural units (e.g. acres of land converted to habitat) and in terms of any subsequent normalization and weighting used in the aggregate rankings. Reporting metrics in natural units where appropriate will provide more transparent, easily interpreted results and rankings.

2. "Drill-down" capabilities when exploring particular rankings. To facilitate interpretation of metrics and indicators, the Planning Tool needs to provide "drill-down" capabilities when reporting ranked results. Because of the inherent limitations of aggregate indicators, it is critical to build confidence both in the Planning Tool and in interpreting results, so that when these results are reported, the user has the ability to access the information and methodologies used to calculate the rankings. For example, the values of metrics expressed in their natural units (see Table in section f above) and access to the supporting data and metadata must be part of the drill-down capabilities.

3. Examination of particular groupings of islands/tracts in aggregate. Because levee investments may be targeted towards groups of islands, rather than single, disconnected islands, the Panel suggests adding a capability to the Planning Tool that allows the arbitrary groupings of islands to be ranked as aggregate groups. Such a capability would allow for the examination of investment portfolios that span multiple islands.

4. Codes used in the Planning Tool. ARCADIS has documented procedures for establishing that the codes used in the Planning Tool correctly operate according to specifications, primarily relying on parallel implementations for key algorithms by independent groups within ARCADIS. The Panel emphasizes the importance of such tests in establishing the credibility of the Planning Tool, and encourages ARCADIS to continue to apply code verification testing throughout the development of the Planning Tool. The Panel also recommends that the testing be documented for reference and future use if errors are discovered or if the methodology or data are modified and the Panning Tool must be updated.

5. User engagement. As with any software product, the value of the Planning Tool will depend on how well it addresses user needs, in terms of both the usability of the tool and the types of outputs generated by the tool. ARCADIS indicated they have had significant stakeholder engagement in the development of the approach for the DLIS methodology, but no indication of the degree of user involvement and beta-testing of the Planning Tool itself were provided to the Panel. As the Planning Tool is developed, the Panel encourages ARCADIS to engage potential users in usability tests of the tool to ensure it provides relevant information transparently to users through an accessible user interface.

4. Answers to Charge Questions

We provide Panel responses to the DSC Science Program's charge questions below. While the answers to most questions are short and direct, the discussions of the overarching issues in the preceding section provide additional explanations, amplifications and justifications for many of them.

Relevance

1. *Does the methodology require each and all leveed Delta islands and tracts to be treated as separate and distinct entities?*

Yes, the proposed methodology requires that each and all islands and tracts be evaluated separately. Evaluation of individual island characteristics and conditions is necessary to meet the stated purpose of prioritization of investments on a per island basis. However, the risks to the State and the roles that individual islands play that may be realized as a result of simultaneous and concurrent failures of groups of islands are not addressed. The interconnectedness and interdependencies among islands, and the potential for a multiple island failure, can have large consequences and must be considered as part of the methodology. This could be important, for example, in situations involving large numbers of fatalities or prolonged loss of water supply reliability. A systems-based approach could be included in the methodology to allow for inclusion of a group effect into the individual island risk and consequences ratings. For example, how often does Sherman Island show up as failing in 1000 realizations of a 100-year storm? Are there groups of islands that tend to fail simultaneously? Which islands disproportionately contributed to the various metrics being considered?

2. *Does the methodology account for the contribution of individual leveed islands and tracts to the interconnectedness and function of the Delta and the levee system as a whole?*

No, the methodology does not consider the interconnectedness and its role in a functioning Delta. The per island calculations do not consider dependencies among the islands or multiple island failures. As noted in the response to Question 1, the methodology should include a risk model that has this capacity.

3. *Does the methodology consider appropriate economic and environmental factors and beneficiaries to accurately quantify assets and risks?*

A number of important and appropriate economic and environmental factors and beneficiaries are considered. However, the methodology fails to incorporate some others that should be taken into account. For example, the methodology is deficient in its consideration of the Delta as place, and in metrics related to crop diversity, recreational facilities (e.g., parks and marinas), and the diversity of economic activities.

Water supply reliability is evaluated in terms of the disruption to water exports; a metric that is not sufficiently defined in the TMs. The current metric does not reasonably measure water supply reliability, the scale of disruptions to the state’s economy, and does not identify beneficiaries and impacts.

4. *Will the flexibility included in the methodology allow for updates based on changing environmental conditions, new data, changes in the physical configuration of the Delta, shifting policy objectives, etc.?*

The approach appears to offer flexibility from the perspective of being able to update basic data and revise weights that reflect user perspectives. From the perspective of future users, this flexibility will be available if the data, software, and the Planning Tool are well documented. The use of a relational database with geo-referencing, and the relative simplicity of the calculations in the methodology should allow for updating the data and re-running the model. If shifting policy objectives only require changing the weights of inputs, then the methodology will be capable of handling them. Incorporation of additional metrics (e.g., metrics related to Delta as place), would require some adjustments in the Planning Tool. Providing well-developed metadata (data documenting the data) would facilitate future updates to the methodology and Planning Tool.

It is not clear to what extent the risk analysis methodology offers flexibility to consider changes to the physical configuration of the Delta or shifting policy objectives (aside from revising weights that are input by the user). For instance, it is unclear if changes in the physical configuration of the Delta or changes in policies with respect to water exports can be assessed with respect to the impact on water supply reliability and the resulting economic impact to the state.

5. *Will this methodology contribute to achieving the coequal goals and support the Delta as place?*

In its present form, the methodology falls short of contributing to achieving the coequal goals and supporting the Delta as place. Water supply reliability is not adequately represented, and the Delta as place is not represented at all. The approach for evaluation of habitat seems reasonable, but better documentation of the data and calculations is needed in order for further review and evaluation. The methodology and Planning Tool can be modified and augmented to achieve the coequal goals and consideration of “Delta as place”.

Credibility

6. *Is the methodology valid and based on appropriate theories and technical literature?*

The overall methodology of using existing data, identifying important metrics, aggregating results, and making comparisons across islands is conceptually sound. A defensible conceptual framework, however, should include: (1) a theoretical basis, (2) description of how the methodology is implemented, (3) a guidance document (user’s manual) for the Planning Tool, and (4) illustrated examples that demonstrate the Planning Tool, the sensitivity of the results to alternative inputs, and the limits of its applicability. At present, it appears that only (2) is well-along, but it was stated that work on (4) is now in progress. An expansion of the flowchart presented in Figure 4-1 of TM 3.1 would be useful for summarizing the complete methodology.

There are some concerns in the implementation of the methodology, however, especially in the details of the use of metrics, developing indices, aggregation and summing of indices, normalization, and establishing objective rankings. Further discussion and documentation is needed on several points, including:

- The approach used to estimate life-loss risks appears incorrect in how expected values are computed (see Section 3e.)
- A risk analysis framework

- An approach to address systems-related aspects of the Delta (e.g., multiple island failures)
- An approach to identify, evaluate and model sources of uncertainty
- The use of tolerable risk and how criteria should be established
- How the various components of the methodology all fit together
- How the methodology can use multi-criteria decision-making concepts and methods
- Use of general principles about defining, determining, and interpreting indices

7. *Are the assets, risks, social considerations, and boundary conditions appropriately assigned and weighted?*

In its present form, the methodology includes little consideration of social factors. Possible candidates include: legacy towns as assets, Delta as place, vulnerable populations, migrant workers, and recreational activities. In addition, there are assets that are considered that are not adequately represented in the current methodology. For instance, the water supply reliability is not adequately represented and the volume of water export disruptions (fresh water asset) is not considered.

The present mix of assets, and associated metrics, include some expressed in dollars and others expressed in other units. This complicates how to weight them when they are combined into indicators. Too much reliance on normalization and aggregation, without considering the metrics in their native units, limits the interpretability of the results.

8. *Do the data, assumptions, and literature employed by this process provide practical thresholds and appropriate recommendations while identifying important data gaps and uncertainties?*

[The Panel does not understand what is meant by “practical thresholds.”]

The process that is being used to develop the methodology can identify important data gaps, such as the fact that there are fragility curves for only 15 percent of the islands. It is anticipated that the evaluation of uncertainties and results of the planned uncertainty and sensitivity analyses will reveal which input data or assumptions in the methodology result in the largest uncertainties in model predictions. It is important to get these critical data as correct and complete as possible.

9. *Is the technical basis of different components clearly defined?*

At a high level, the technical bases for the components of the methodology are defined. However, for a number of model components, clear definitions and details of the methodology are not sufficiently described. Components such as rehabilitation costs, ecosystem habitat impacts, and disruption to water supply are not sufficiently well-defined; these (and others) should be reviewed and augmented as necessary to be sure that they are all defined and technically supported. There are also examples of processes not included that need to be considered. For example, the costs associated with seismic-induced non-breach damage to levees (e.g., cracking, slumping, and erosion) should be considered as part of the island recovery costs.

10. Are the uncertainty and information sensitivity of the methodology for island prioritization relative to the assumptions clearly addressed?

Uncertainty and sensitivity analyses were not discussed in the TM's sent to the Panel for review. The documentation that has been provided to the Panel does not provide a methodological framework and a roadmap for the identification and evaluation of uncertainties and their potential impacts on the island prioritization. The Panel understands the methodology is evolving and additional evaluations such as uncertainty and sensitivity analyses are being discussed. A detailed plan for conducting the uncertainty and sensitivity analyses is needed.

11. Are the results sufficiently sensitive and robust to changing conditions, inputs, and scenarios to distinguish between different islands?

There were no results presented to the Panel concerning the sensitivity and robustness of the results generated by the methodology. We offer the following comments to consider about uncertainty, sensitivity, and robustness:

- Uncertainties in the predictions may be large relative to differences in island rankings that result from the methodology. This highlights a potential limitation of how detailed one should interpret the results of the methodology and a potential danger of treating similarly ranked islands as actually being differently ranked.
- Some of the metrics, and the measures proposed for these metrics, are likely not to vary much across islands resulting in little or no distinction of impacts between different islands or scenarios.
- Robustness needs to be addressed because of the use of existing data without complete knowledge of their uncertainties and the progression from metrics to indices to rankings.

Transparency

12. Is the methodology clearly defined, described and documented?

[It is important in addressing this question to keep in mind that the Panel is reviewing a project and report that is a work in progress.]

The clarity of definitions and documentation of the methodology varies greatly across components. Some parts, such as the flood frequency methodology are described and documented clearly, and others are not. Examples needing further documentation and explanation include: metrics for water supply reliability, data and calculations for ecosystem consequences, the methodology for describing the Delta as place, the approach to estimate the cost of island repair and recovery when there is a breach, and the basis for the use of a weak link approach to characterize the vulnerability of an island. Ultimately, a separate volume that provides a complete description of the risk and decision analysis framework, the approach for identifying and evaluating sources of uncertainty, and the theoretical basis for the elements of the methodology such as the indices, risks, and methods of interpretation may be needed. Additional topics that might be included are a description of meta-data, data uncertainties, calculation methods, software, and a glossary of relevant terms.

13. Are the rationale, assumptions, and supporting information used in this methodology clearly identified across all major steps of the development process?

The TM's are useful for documenting the mid-point progress on this project. As might be anticipated for a complex study involving inputs from several sources and investigators, they are somewhat uneven and incomplete at this stage. The Panel does not have sufficient information to evaluate the inputs and other supporting information to the methodology.

14. Are factors and interactions clearly defined and weighted?

The factors driving the methodology and that are used to determine the predictions are reasonably well described. Not all potential interactions among islands are identified, and many terms and phrases related to the methodology and the metrics are not sufficiently defined. For example, the interactions and dependencies between islands, as they would affect the metrics or interact under a multiple island failure, are not identified or considered in the methodology. While the weighting procedures are clearly defined, the results by themselves are likely to be insufficient for decision making, and the need for subjective inputs and "apples to oranges" comparisons in the decision making process is inevitable. Nonetheless, it should be possible to rank order the islands in terms of each of the dimensions considered important (e.g., EAF, EAD, agricultural land, water supply disruption, habitat, recovery, and Delta as place).

15. Are weightings adjustable and sensitive to varying conditions?

Yes, the weightings appear to be adjustable, and it is our understanding the Planning Tool will allow for the user to adjust the weightings. However, the sensitivity to the adjustments is unknown at this point and we caution against relying too much on final aggregated and normalized rankings without considering the metrics in their natural units.

16. Will the subsequent tool be usable and understandable?

It is premature to answer this question, given that the review was focused on the methodology and the fact that the Planning Tool was not presented to the panel because it is still a work in progress.

Additional Perspectives

17. Overall, will this tool provide staff and decision makers the objective analysis needed to prioritize islands for receipt of State funding assistance and guide a long-term levee investment strategy?

This question cannot be answered at this time because all details of the methodology and the Planning Tool are not yet in place. However, the Panel offers several comments for consideration by ARCADIS and the Delta Stewardship Council:

- Although the methodology will enable generation of rankings of individual islands and tracts, the ability to distinguish among similarly ranked islands may be limited by the methodology as it is currently described and the quality of available data.
- Knowing the relative risks to determine island and tract rankings may be useful for allocation of a fixed amount of resources. However, drilling down into the details to understand which of the risk factors are driving the composite values may be necessary to enable informed decisions concerning individual island prioritization.
- The users of the methodology and Planning Tool will need complete knowledge and understanding of their basis and details, and should receive training in the use of the Planning Tool.
- Further consideration of possible and likely changes in input variables for application of the methodology in the medium term (2030) and the long term (2050) is needed.

18. *Please provide any additional comments related to the suitability, robustness and sensitivity of this innovative methodology.*

    Please refer to the Panel's comments and recommendations presented in the other section of this report.

5. Recommendations

The Panel offers the following recommendations that, if implemented by the ARCADIS team, will help them achieve the goals of (1) providing a well-documented, sound methodology that is (2) incorporated in a Planning Tool, and that (3) will be ready for initial release and, when all aspects of the recommendations are addressed, (4) will be useable into the future. These recommendations are distilled from the comments, concerns, and suggestions given in the discussion of the overarching issues in Section 3. These recommendations must be addressed before a credible and useful Planning Tool is released, even for initial use. When issues can be addressed after the initial release, these are noted as part of the recommendations. The recommendations are not listed below in any priority order.

1. Finalize development of the DLIS methodology addressing the issues raised in this review, and exercise it to a level such that confidence in its technical veracity and stability of the island ranking is achieved and responsiveness to the variation in critical risk metrics is clear and transparent. As part of finalization, prepare comprehensive documentation of the methodology and Planning Tool, including the theoretical foundation, the evaluation of uncertainties, data sources used and QA/QC results, and consistent descriptions of the calculations within and between components.

2. Expand and complete the documentation of the DLIS methodology, including definitions of uncertainty, tolerable risk, water supply disruption, relative risk, and of the all metrics and indicators.

3. Provide the scientific basis for the selection of all metrics, avoiding the appearance that their selection and operationalization were selected simply based on what information was considered available.

4. State what datasets were examined and provide documentation for why they were used or rejected. Ensure and document that, at least for the critical data sets and information sources, the most up-to-date and relevant versions are being used. Examples include the seismic hazard input to the risk analysis, data used for estimating fatalities, and justification for adopting the risk tolerances used by the Corps of Engineers for dams.

5. Document the QA/QC procedures applied to the datasets employed in the methodology and the Planning Tool. Perform limited ground-truthing of key datasets by checking both internal consistency (e.g., residents but not residential housing) and consistency with other datasets.

6. Provide metadata for all primary datasets used in the Planning Tool.

7. Provide a mechanism in the Planning Tool for accessing primary data and meta-data by the user.

8. Define, operationalize, and implement measures for ranking water supply disruption that accounts for duration, water quality, and volume of export disruption. This is one of the few measures for which regional and national consequences and benefits need to be considered.

9. Define, operationalize, and implement metrics for assessing and ranking "Delta as place."

10. Verify that the Planning Tool (and associated code) has faithfully implemented the methodology.

11. Document a more formal and traceable presentation of the logic and rationale for the components in the DLIS methodology and their integration (i.e., theoretical foundation and conceptual model).

12. Document the approach and calculations being used to estimate island recovery and dewatering costs (i.e., rehabilitation). The methodology and cost estimation procedures for evaluating and comparing island rehabilitation (i.e., dewatering and repairs; abandonment) should be described.

13. Initially, a framework and plan should be prepared to guide uncertainty, sensitivity, and scenario analyses of the DLIS methodology. This should include the basis for identifying, characterizing, and quantifying the key uncertainties in the data and methodology, a plan for the specific analyses to be done, and how the data inputs will be varied and the results will be interpreted. The key before first release is to show recognition of the uncertainties and to have a plan for going forward to quantify the effects of uncertainties on DLIS methodology results. The initial results will be useful in the short-term to help with interpretation of the results. It is not critical to propagate these uncertainties through the calculations in a formal uncertainty analysis before the initial release. In the near future, fully implement the uncertainty framework and plan in order to quantitatively examine the effects of uncertainty on the DLIS methodology results.

14. Report metric results in their natural units. This is essential for transparency and understanding impacts and investment benefits.

15. Further evaluate the data and metrics related to how ecosystem consequences are calculated. Several examples should be provided and used to demonstrate how the ecosystem metrics respond to several types of failure scenarios.

16. Develop and apply a formal method for identifying critical data gaps using experience gained from the first release version of the methodology in conjunction with the uncertainty framework. This can be done after the first release.
17. Incorporate methods for characterizing interactions (responses and consequences) among islands and multiple island failure scenarios into the methodology and Planning Tool.
18. Develop (using existing methods from the literature) a sound approach to combine different metrics into normalized and aggregated indicators, and adapt these methods to the methodology and the Planning Tool for implementation.
19. Concentrate current efforts on the data, documentation, and methodology for present day calculations. The extension of the analyses to 2030 and 2050 scenarios can be investigated later.

6. Concluding Remarks

The Panel considers the proposed methodology and Planning Tool to have worthwhile potential in assisting the decision-making of investment priorities for levees. Much effort and work has been done to date, and the development of the methodology and Planning Tool appears to be on a good path going forward. However, a substantial amount of effort remains in order for the methodology, and associated Planning Tool, to be scientifically sound and ready for application. As part of this review, we discussed overarching issues and listed recommendations to address these issues. We flagged recommendations that the Panel considered necessary to address before release of methodology and Planning Tool, and additional recommendations that were also critical but could be addressed in the longer-term. We caution that, from a scientific point of view, premature release and application of the methodology and Planning Tool can lead to major credibility issues and greatly diminish the usefulness of the Planning Tool in the short and long term.

7. Appendix A – Meeting Agenda

DELTA STEWARDSHIP COUNCIL
A California State Agency

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HTTP://DELTACOUNCIL.CA.GOV
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April 21, 2015

– MEETING NOTICE –

LEVEE INVESTMENT STRATEGY REVIEW MEETING

Delta Science Program Review

Tuesday, May 19, 2015 - 8:30 a.m. – 4:50 p.m. (PDT)

Wednesday, May 20, 2015 – 1:30 p.m. – 5:00 p.m. (PDT)

Meeting Location:
980 9th Street, Second Floor
Park Tower Conference Center
Sacramento, CA 95814

As a courtesy, access to this meeting will be provided through WebEx.

May 19, 2015
https://deltascienceprogram.webex.com/deltascienceprogram/onstage/g.php?MTID=e9566c63965eaeb2608e8ccf391d2fbcd
Event Number/Access Code: 622 584 512   Password: Levee
Call-in Line for Audio: 1-650-479-3207

May 20, 2015
https://deltascienceprogram.webex.com/deltascienceprogram/onstage/g.php?MTID=e3cc45aa1bb0fdcb1ccf6bc56a35dcec3
Event Number/Access Code: 628 496 339   Password: Levee
Call-in Line for Audio: 1-650-479-3207

No public comment will be taken via the WebEx service. The WebEx access is limited to 100 participants at a time.

Purpose: The Delta Reform Act (2009) directed the Delta Stewardship Council (Council), in consultation with the Central Valley Flood Protection Board, to prioritize investments in support of the operation, maintenance, repair, and improvement of the Delta levee system. In 2014, the Council contracted with the consulting firm ARCADIS to help develop an investment strategy for State investments in Delta levees.

"Coequal goals" means the two goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem. The coequal goals shall be achieved in a manner that protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place."
– CA Water Code §85054

On May 19–20, 2015, the Levee Investment Strategy Independent Scientific Review Panel will meet to discuss its review of the methodology developed by ARCADIS and the supporting scientific basis. ARCADIS will present the components of the Levee Investment Strategy Methodology on May 19, 2015, and the panel members will provide initial feedback to ARCADIS on May 20, 2015. The Independent Scientific Review Panel's recommendations will provide objective feedback for ARCADIS to consider in the development of the Delta Levees Investment Strategy.

AGENDA

Order of agenda items and listed times are subject to change

May 19, 2015 (8:30 a.m. – 4:50 p.m. PDT)

8:30 a.m.	Opening Remarks Marina Brand, Program Manager, Delta Science Program
8:35 a.m.	Reason for the request for Scientific Review – Requesting Agencies Delta Stewardship Council: Cindy Messer, Deputy Executive Officer, Planning California Department of Water Resources (DWR): David Mraz, Chief Principle Engineer, Delta Levees and Environmental Engineering
9:00 a.m.	Review Panel Member Self Introductions
9:15 a.m.	Science Overview Rainer Hoenicke, Deputy Executive Officer, Delta Science Program
9:25 a.m.	Risks in the Delta David Mraz, Chief Principle Engineer, Delta Levees and Environmental Engineering, DWR
9:35 a.m.	Baseline Information on Islands and Tracts, Assets, Hazards, and Beneficiaries Presentation Jessica Ludy, Water Resources Planner, ARCADIS Levee Hazards, Risks and Consequences Presentation Hollie Ellis, Senior Vice President, Shannon & Wilson
10:25 a.m.	**Break**
10:35 a.m.	Tolerable Risk Presentation Larry Roth, Principal Engineer, ARCADIS Methodology Presentation Nidhi Kalra, Director, RAND Center for Decision Making Under Uncertainty

David Groves, Co-director, RAND Water and Climate Resilience Center
Alex Trahan, Senior Technical Support, ARCADIS
Ramona Swenson, Senior Restoration Ecologist, ESA

Define Methodology for Cost Allocation Presentation
George McMahon, Vice President, ARCADIS

12:30 p.m.	**Lunch**
1:50 p.m.	Q & A Session between panel members and presenter
3:40 p.m.	**Break**
3:50 p.m.	Public Comment on the Science Review *Public comment may be limited to 3 minutes per speaker*
4:50 p.m.	**Adjourn**

May 20, 2015 (1:30 p.m. – 5:00 p.m. PDT)

1:30 p.m.	Recommendations from the Review Panel and Discussion
3:00 p.m.	**Break**
3:10 p.m.	Q & A Session between ARCADIS and the Panel
4:00 p.m.	Public Comment on the Science Review *Public comment may be limited to 3 minutes per speaker*
5:00 p.m.	**Adjourn**

NOTE: Times listed on the agenda are approximate only

- If you have any questions, please contact Jiro Ariyama at (916) 445- 5398 or jiro.ariyama@deltacouncil.ca.gov.
- Members of the public are encouraged to visit the Delta Science Program website for the meeting materials. A limited number of copies of these materials will be available at the meeting.
- Reasonable time limits may be established for public comments (Government Code Sections 11125.7).
- If you have questions or need reasonable accommodation due to a disability, please contact Human Resources, Delta Stewardship Council (916) 445-5511, or TDD (800) 735-2929.