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# Robust Water-Management Strategies for the California Water Plan Update 2013

Proof-of-Concept Analysis

David G. Groves, Evan Bloom

The research described in this report was prepared for the California Department of Water Resources and conducted in the Environment, Energy, and Economic Development Program within RAND Justice, Infrastructure, and Environment.

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## Summary

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California faces significant challenges in ensuring that its water resources successfully meet diverse needs across the state in the coming decades. Escalating needs due to population and economic growth, potentially increasing agricultural irrigation requirements, and growing desires to dedicate more water to the environment will put a strain on a system that is near or exceeds capacity. These challenges are exacerbated by potential declines in available water supply due to natural variability and climatic changes. How these long-term changes will unfold and affect California's water system is highly uncertain. It is unlikely that all future water needs can be met at all times. Addressing the future uncertainty and diversity of needs requires a planning approach that is flexible and can support deliberations over different approaches, rather than a single prescription for how to move forward.

The California Water Plan (CWP) Update 2013 analysis will use Robust Decision Making (RDM), an analytic approach to decisionmaking under uncertainty, to identify and characterize the vulnerabilities of the currently planned management approach in the Central Valley of California (the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions). The analysis will then develop and compare robust water-management response packages that could ameliorate the vulnerabilities identified. The CWP Update 2013 analysis will use a water management and planning model for the Central Valley, developed within the Water Evaluation and Planning (WEAP) modeling environment.

This report summarizes a proof-of-concept analysis developed in 2010 and 2011 and presented to the California Department of Water Resources' (DWR's) Statewide Water Analysis Network (SWAN) in May 2011.<sup>1</sup> The geographic scope of the proof-of-concept analysis covers a portion of the Central Valley and tributary watersheds representing the Sacramento River and San Joaquin River hydrologic regions. The CWP Update 2013 analysis will also include the Tulare Lake hydrologic region to more fully represent the Central Valley and tributary watersheds and use more-thoroughly vetted assumptions. The results shown in this report were generated to illustrate the methodology only and should not be used to draw policy conclusions.

### Robust Decision Making

Traditionally, water agencies have estimated future system performance, such as reliability and cost, by using trends based on historical statistics of hydrology and best-estimate forecasts of other important factors, such as demand, regulatory conditions, and the likely increases in new

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<sup>1</sup> SWAN serves as the voluntary technical advisory group for the California Water Plan and is made up of technical experts from local, state, and federal agencies; universities; nongovernmental organizations; and consulting firms.

supply from investments. Given increasing recognition that past climate is no longer a good predictor of future climate and of the large uncertainty in most planning factors, many agencies have increasingly incorporated handcrafted paths, called *scenarios*, into their analyses.

RDM, in contrast, provides an analytic method for developing a small number of composite scenarios that are decision relevant for a wide range of potential futures. These composite scenarios emerge directly from the analysis and provide tailored information about specific strategies and decisions that planners face. To generate these composite scenarios, RDM evaluates many thousands of different assumptions about plausible future conditions (or *futures*) and stores these results in a database. Researchers then use RDM to analyze the database to identify the key combinations of assumptions most important to determining whether or not a particular strategy meets its goals. These combinations of assumptions represent decision-relevant scenarios that can help planners to better understand the strengths and weaknesses of different management strategies and, hence, the specific conditions to which an adaptive management plan may need to respond.

## Vulnerability and Response Package Analysis

Building on work performed for the CWP Update 2009, the proof-of-concept analysis presented in this report seeks to address some of the key questions that are to be answered for the CWP Update 2013, with a focus on the Central Valley:

- How would the region's current management approach perform under different plausible futures?
- What are the vulnerabilities of the current management approach?
- Which supply augmentation options could improve the performance of the current management approach?
- How would additional augmentation reduce the key vulnerabilities of the current management approach?
- What are key trade-offs among response packages?
- How does this analysis inform decisionmaking?

Researchers developed 36 future scenarios by combining three different sets of assumptions about future land use and 12 different future climate sequences derived from global climate models. The water-management model, built in the WEAP modeling environment, evaluates future management conditions for the Sacramento River and San Joaquin River hydrologic regions in terms of three key performance metrics: urban supply reliability, agricultural supply reliability, and the frequency of meeting in-stream flow requirements (IFRs). The WEAP model evaluated the current management baseline and five other response packages made up of different water-management strategies. The proof-of-concept analysis considers the notional costs of these strategies in order to support a comparison and trade-off analysis. Table S.1 summarizes the key elements of the proof-of-concept analysis.

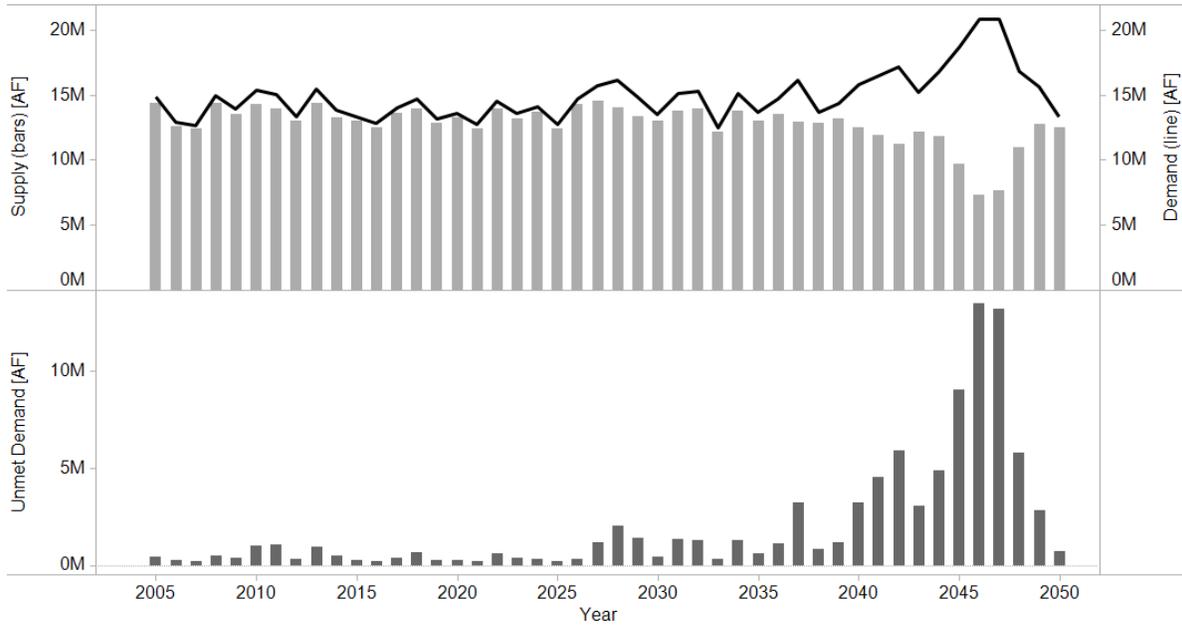
**Table S.1. Summary of Uncertainties, Policy Levers, Relationships, and Metrics Identified in the Study**

<b>Uncertainties or Scenario Factors (X)</b>	<b>Management Strategies and Response Packages (L)</b>
Demographic and land-use scenarios, which describe changes in <ul style="list-style-type: none"> <li>• population</li> <li>• household factors</li> <li>• employment factors</li> <li>• climate sequences, which describe changes in temperature and precipitation</li> </ul>	Current management baseline Additional management strategies: <ul style="list-style-type: none"> <li>• agricultural water-use efficiency</li> <li>• urban water-use efficiency</li> <li>• conjunctive management and groundwater storage</li> <li>• recycled municipal water</li> </ul>
<b>Relationships or Systems Model (R)</b>	<b>Performance Metrics (M)</b>
WEAP Central Valley Model (Sacramento River and San Joaquin River hydrologic regions)	Urban supply reliability Agricultural supply reliability IFRs Notional costs

*How Would the Region’s Current Management Baseline Perform Under Different Plausible Futures?*

We began the proof-of-concept analysis by evaluating the current management baseline across the 36 different future scenarios. In a SWAN workshop held in 2011, we showed a wide range of model outputs corresponding to individual simulations of the WEAP Central Valley Model. Figure S.1 shows an example of annual supply, demand, and unmet demand in the agricultural sector for one simulation. In this simulation, supply is adequate to meet nearly all demand until about the year 2027. At that point, rising demand and declining supply lead to significant shortages and unmet demand.

**Figure S.1. Annual Supply, Demand, and Unmet Demand for the Agricultural Sector in the Study Region for One Simulation**



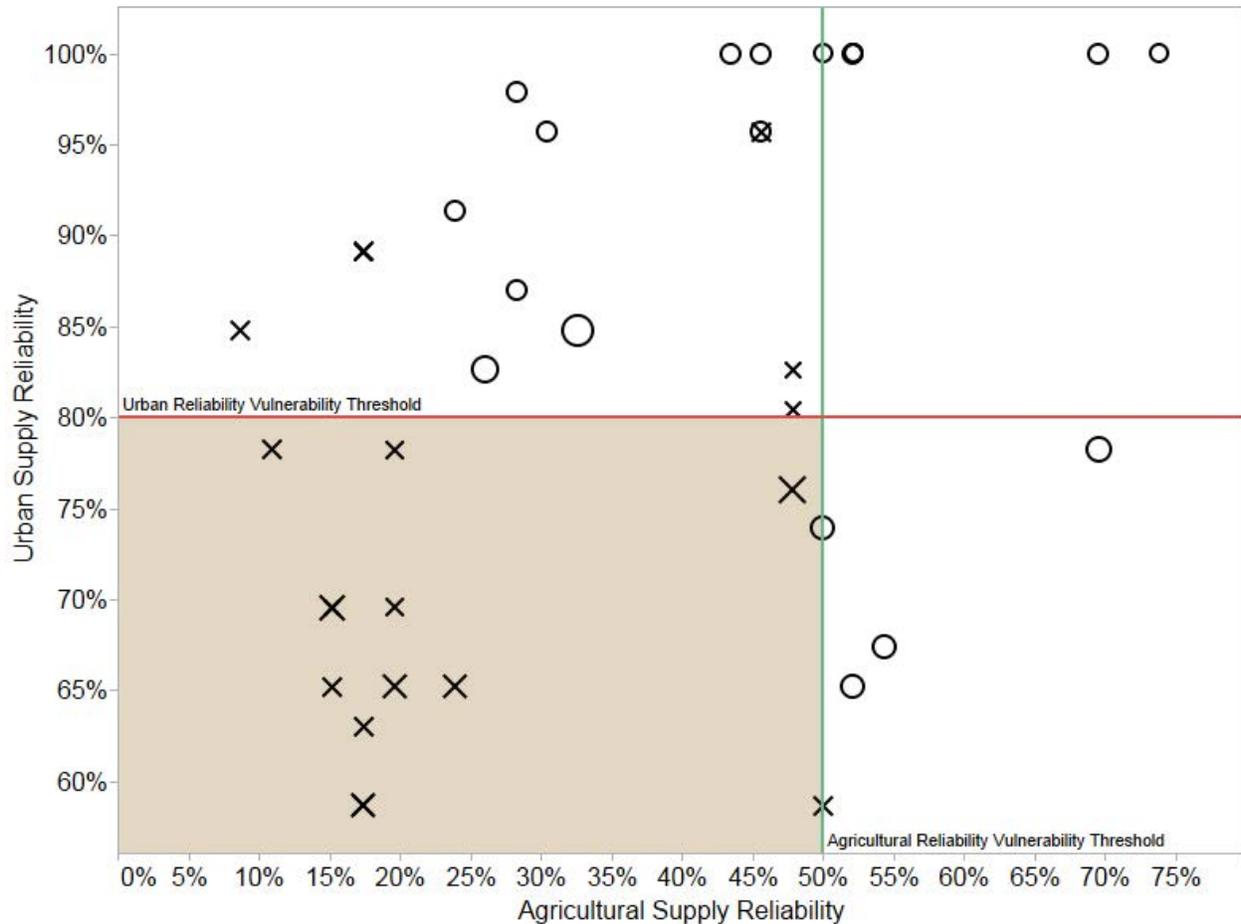
NOTE: In the upper part of the figure, the black line indicates demand and vertical bars indicate annual supply. AF = acre-foot.

***What Are the Vulnerabilities of the Current Management Baseline?***

We next determined which of the simulations meet the region’s goals in terms of urban and agricultural supply reliability and IFRs. Using definitions of acceptable performance set by the research team, we calculated that the current management baseline would be vulnerable in 15 of the 39 scenarios (38 percent).

Figure S.2 shows the results for urban supply reliability (vertical axis), agricultural supply reliability (horizontal axis), and percentage of years in which IFRs are not all met (size of symbols). The symbol shapes indicate whether the current management strategy is vulnerable (i.e., does not meet the thresholds for acceptable performance for two of the three metrics). All points that are to the left of the agricultural supply reliability threshold and below the urban supply reliability threshold (i.e., the shaded area) are vulnerable. In addition to those within the shaded area, some points above the shaded region in the graph are vulnerable because of poor performance on the IFR metric.

**Figure S.2. Vulnerable Urban and Agricultural Supply Outcomes Across Scenarios Under the Current Management Baseline**

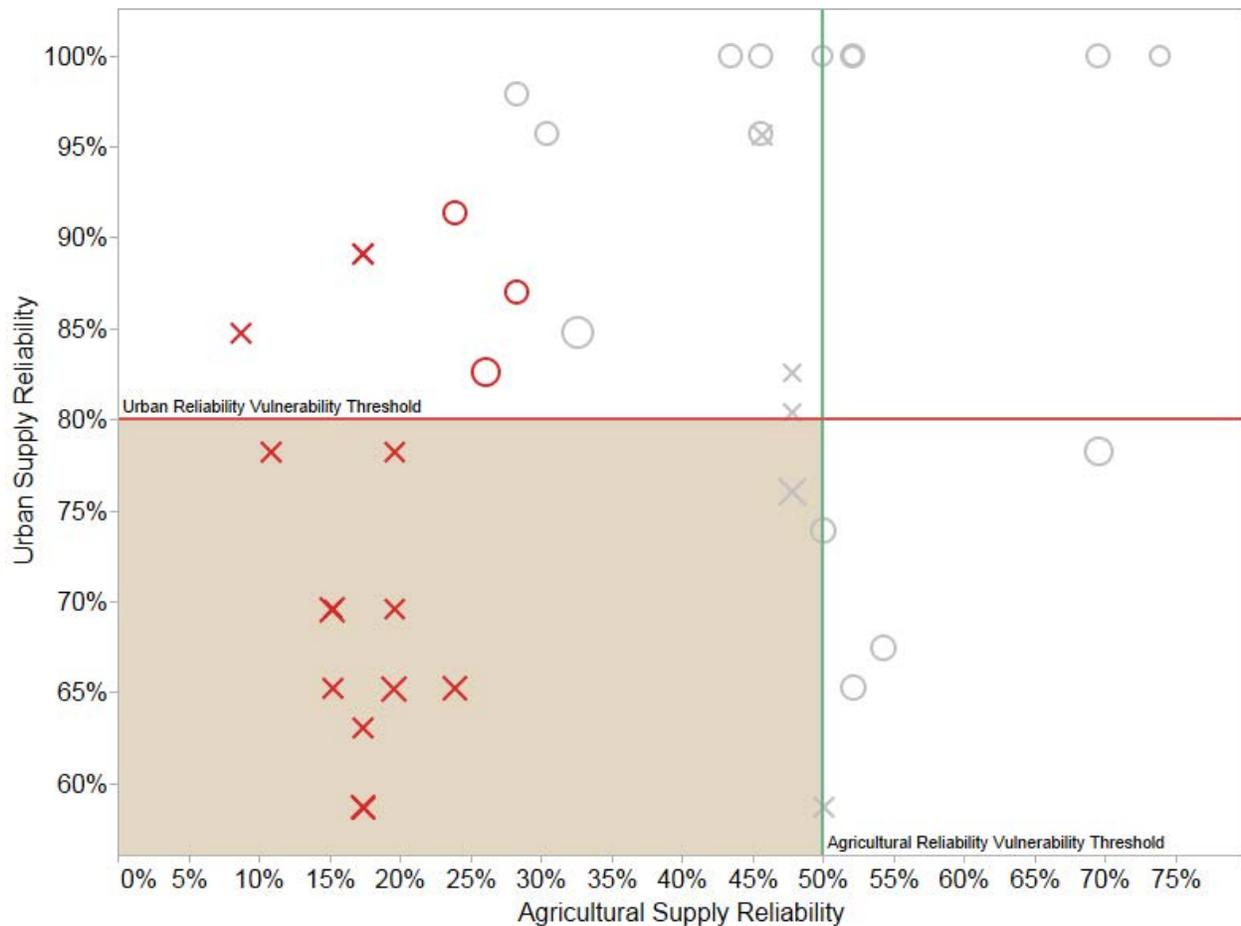


NOTE: Each point represents one future under current management conditions. The Xs represent futures in which policy objectives are not met; circles represent futures in which policy objectives are met. The size of each symbol represents the number of IFRs missed, ranging between 4.8 percent and 15.6 percent. Smaller symbols represent higher percentages of unmet requirements.

We next defined a composite *decision-relevant* scenario—those conditions that lead the current management strategy to perform poorly—using statistical scenario discovery techniques. This composite scenario is defined solely by the projected temperature trend and average annual precipitation, and we call this composite scenario the Hot and Dry composite scenario. This composite scenario accounts for 75 percent of the vulnerable futures, and 100 percent of the futures making up this scenario are vulnerable.

Figure S.3 shows the definition of the Hot and Dry composite scenario in relationship to the three performance metrics. The red symbols are those results that are described by the Hot and Dry composite scenario. One can see that the Hot and Dry composite scenario encompasses the majority of vulnerable cases but not most nonvulnerable cases.

**Figure S.3. Vulnerable and Nonvulnerable Urban and Agricultural Supply Outcomes Described by the Hot and Dry Composite Scenario Across Futures Under the Current Management Baseline**



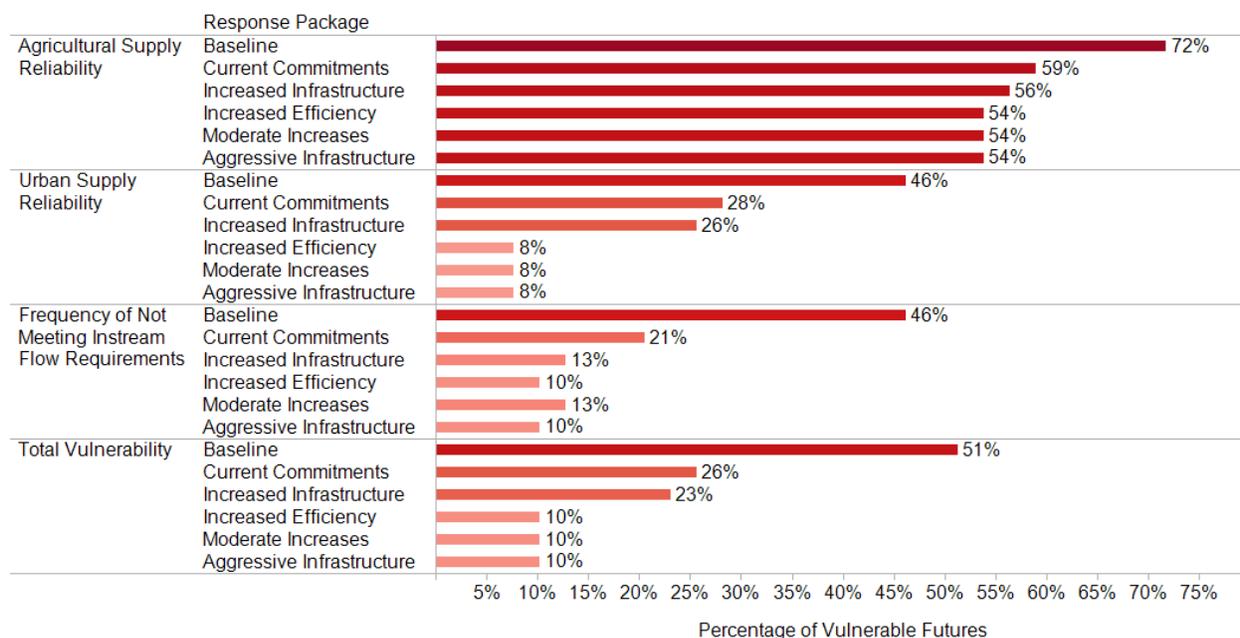
NOTE: Each point represents one future for the current management baseline. The Xs represent futures in which policy objectives are not met, and circles represent futures in which policy objectives are met. The size of each symbol represents the number of IFRs missed, ranging between 4.8 percent and 15.6 percent. Smaller symbols represent higher percentages of unmet requirements. Red symbols represent outcomes that are described by the Hot and Dry composite scenario; gray symbols represent outcomes that are not.

### *How Would Additional Management Strategies Reduce Vulnerabilities of the Current Management Baseline?*

We next evaluated how the implementation of five different response packages would improve outcomes and reduce vulnerabilities (see Chapter Three). Figure S.4 summarizes the effect that each of the response packages has on the three performance metrics and a total reliability metric. For agricultural supply reliability, the percentage of vulnerable futures declines from 72 percent to around 55 percent for three of the five response packages—those in which agricultural efficiency improves to the greatest extent. Urban supply reliability also improves the most for the three response packages in which agricultural efficiency improves the most—declining to less than 10 percent of the futures examined. All response packages have positive

effects on the metric measuring frequency of not meeting IFRs. Across all response packages, the best outcomes are achieved for the Increased Efficiency, Moderate Increases, and Aggressive Infrastructure response packages—reducing total vulnerability from 51 percent to about 10 percent.

**Figure S.4. Percentage of Vulnerable Futures for the Current Management Baseline and Five Augmentation Strategies, by the Four Reliability Metrics**



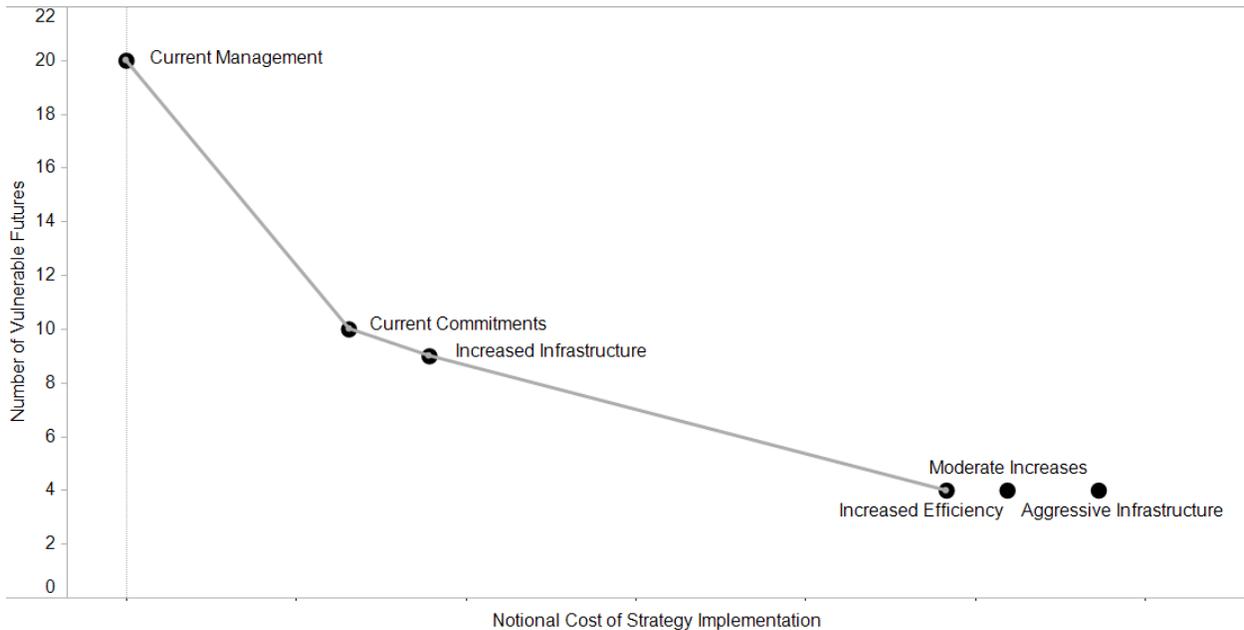
NOTE: Darker red bars indicate higher percentages of vulnerable futures.

### *What Are Key Trade-Offs Among Response Packages?*

If level of effort and other effects of the augmentation strategies not captured by this analysis were not a consideration, the Increased Efficiency, Moderate Increases, and Aggressive Infrastructure response packages would clearly be equally preferred options. When costs of the management strategies are factored in, a trade-off emerges.

Figure S.5 plots each response package by the percentage of futures that are vulnerable for the metrics for total vulnerability (vertical axis) and notional cost of strategy implementation (horizontal axis). In general, the more-effective response packages cost more. However, additional efforts beyond the Increased Efficiency response package do not further reduce vulnerabilities. Thus, Increased Efficiency is always preferable to Moderate Increases or Aggressive Infrastructure. The line on the graph traces out a simple trade-off curve that one could consider when choosing among strategies. Note that a more involved RDM analysis would consider the cost uncertainty along with the other uncertainties when defining vulnerabilities.

**Figure S.5. Trade-Off Curve of Notional Cost of Strategy Implementation and Number of Vulnerable Futures**



## Discussion

This analysis demonstrates how RDM might be applied to the CWP Update 2013 analysis of vulnerabilities and response packages. It shows how the WEAP Central Valley Model could be used to generate different scenarios of future conditions and how these results can be used to define those conditions that would lead to poor performance in the current management baseline. Next, the report shows how the implementation of response packages could reduce vulnerabilities and lead to a more resilient system. Then it shows one example of how the trade-off between reductions in vulnerabilities and cost for the different response packages can be used to inform long-term planning for the Central Valley.

Because of its focus on methodology, the proof-of-concept analysis was not designed to provide policy recommendations, nor does it demonstrate all aspects of RDM. The analysis under way for the CWP Update 2013 will address some but not all of these issues. Specifically, it will evaluate a larger set of scenarios to span a wider range of plausible future conditions, including climate. The WEAP model will report on a larger set of performance metrics, and the vulnerability analysis will define vulnerable conditions for each of these performance metrics. The final trade-off analysis will compare outcomes not just between reductions in total vulnerability and cost but also between reductions in vulnerability for the different performance metrics. Lastly, the final trade-off analysis will be based on improved estimates of implementation costs.