California Water Plan Update – Response Package Evaluation Analysis Plan

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1 Introduction

The California Water Plan Update is evaluating the impacts of different water management response packages under different future scenarios (reflecting plausible future water management conditions) through the development and use of two new water planning models within the Water Evaluation And Planning (WEAP) modeling environment.

The first model is a low-resolution representation of monthly applied water demand and available supply for each of the 10 hydrologic regions (hereafter the “HR Model”). The second model is a higher-resolution representation of monthly hydrologic flows, demand, water use and return flow, and groundwater use and storage for the Sacramento River and San Joaquin River Hydrologic Regions. This model is generally organized around Department of Water Resources’ Planning Areas and is thus hereafter called the “PA Model”. Both models are calibrated against historical data and estimate future water management outcomes from 2005 to 2050 (see SEI interim project report).

These WEAP models are designed to evaluate a wide range of scenarios and response packages. In order to anchor the scenario analysis to concerns articulated by CWP stakeholders, three narrative scenarios were developed. Each scenario represents a specific story line of how conditions in California could evolve through 2050. These narrative scenarios generally do not include weather-related conditions, as these factors are to be considered by specified weather projections from a suite of downscaled global climate models. Specific model parameters have been developed for each WEAP model in order for them to develop quantitative projections consistent with the scenario narratives. This approach was used to quantify three scenarios of water demand for the CWP Update 2009. The model will also be used to evaluate a wider-range of scenarios.

Both models will reflect the implementation of different water management responses across California. For the HR Model, this is likely to be a coarse representation of how supplies and efficiency efforts may change due to different water management responses. Such an approach is demonstrated in Wilkinson and Groves (2006). For the PA Model the consulting team will work collaboratively with DWR staff and the Statewide Water Analysis Network (SWAN) to develop specific representations of alternative water management strategies. These strategies will be comprised of different combinations of management responses.

This document outlines an approach for evaluating water management response packages against numerous scenarios for the California Water Plan Update 2013 and describes the required model enhancements and data to perform this analysis. The approach will be demonstrated through a Proof-of-Concept (POC) analysis during 2010 (described in Section 7).

2 Water Management Scenarios

The HR Model and PA model will both evaluate different water management scenarios. These scenarios are constructed by combining scenario factors pertaining to demographic and land use scenarios with sequences of weather, consistent with different climate change projections. Additional scenario factors may also be included.

2.1 Narrative Demographic and Land Use Scenarios

The CWP staff developed three narrative scenarios: Current Trends, Slow & Strategic Growth, and Expansive Growth. These scenarios are described in the CWP Public Review Draft (Chapter 5) as:

- **Scenario 1 – Current Trends**. For this scenario, recent trends are assumed to continue into the future. In 2050, nearly 60 million people live in California. Affordable housing has drawn families to the interior valleys. Commuters take longer trips in distance and time. In some areas where urban development and natural resources restoration has increased, irrigated crop land has decreased. The state faces lawsuits on a regular basis: from flood damages to water quality and endangered species protections. Regulation lacks a comprehensive plan, creating uncertainty for local planners and water managers.
- **Scenario 2 – Slow & Strategic Growth**. Private, public, and governmental institutions form alliances to provide for more efficient planning and development that is less resources intensive than current conditions. Population growth is slower than currently projected—about 45 million people live here. Compact urban development has eased commuter travel. Californians embrace water and energy conservation. Conversion of agricultural land to urban development has slowed and occurs mostly for environmental restoration and flood protection. The State Legislature has enacted several comprehensive programs to improve water quality, protect fish and wildlife, and protect communities from flooding.
- **Scenario 3 – Expansive Growth**. Future conditions are more resource intensive than existing conditions. Population growth is faster than currently projected with 70 million people living in California in 2050. Families prefer low-density housing, and many seek rural residential properties, expanding urban areas. Some water and energy conservation programs are offered but at a slower rate than trends in the early century. Irrigated crop land has decreased significantly where urban development and natural restoration have increased. Protection of water quality and endangered species is driven mostly by lawsuits, creating a patchwork of regulations.

Note that these narrative scenario storylines primarily affect demographic conditions, lifestyle choices, land use parameters, trends in regulation and legislation, and legal actions. For our analysis, we reflect these three scenarios in the demand estimations only (hereafter called Growth Scenarios). These narrative scenarios are thus grouped with other scenario specifications of future climate, and other water system uncertainties to comprise complete water system scenarios (see section 2.3, below).

2.2 Climate Scenarios

Each growth scenario is paired with one climate scenario derived from downscaled general circulation model simulations. The downscaled climate information includes monthly temperature and precipitation data on a 1/8th degree grid. The current models use downscaled climate information derived from six climate models (GCMs) run under two global emissions scenarios—the same scenarios as selected by the Governor's Climate Action Team. The GCMs used are:

1. CNRM-CM3 (France)
2. GFDL-CM21 (USA)
3. Micro32med (Japan)
4. MPI-ECHAM5 (Germany)
5. NCAR-CCSM3 (USA)
6. NCAR-PCM1 (USA)

The two emissions scenarios used are the A2 and B1 scenarios:

> "The **A2 SRES global emissions scenario** represents a heterogeneous world with respect to demographics, economic growth, resource use and energy systems, and cultural factors. There is a de-emphasis on globalization, reflected in heterogeneity of economic growth rates and rates and directions of technological change. These and other factors imply continued growth throughout the 21st century of global GHG emissions.
>
> By contrast, **B1 is a "global sustainability" scenario**. Worldwide, environmental protection and quality and human development emerge as key priorities, and there is an increase in international cooperation to address them as well as to convergence in other dimensions. Neither scenario entails explicit climate mitigation policies. The A2 and B1 global emission scenarios were selected to bracket the potential range of emissions and the availability of outputs from global climate models" California Climate Action Team (2009).

In order to support comparisons to the analysis being performed in support of the CVP Operations Criteria and Plan (OCAP) and the Bay Delta Conservation Plan, we propose to include the four additional climate scenarios selected for these studies. Figure 1 shows the mean annual precipitation change (%, horizontal axis) and temperature change (°C, vertical axis) for the 12 CAT scenarios and 4 OCAP scenarios.

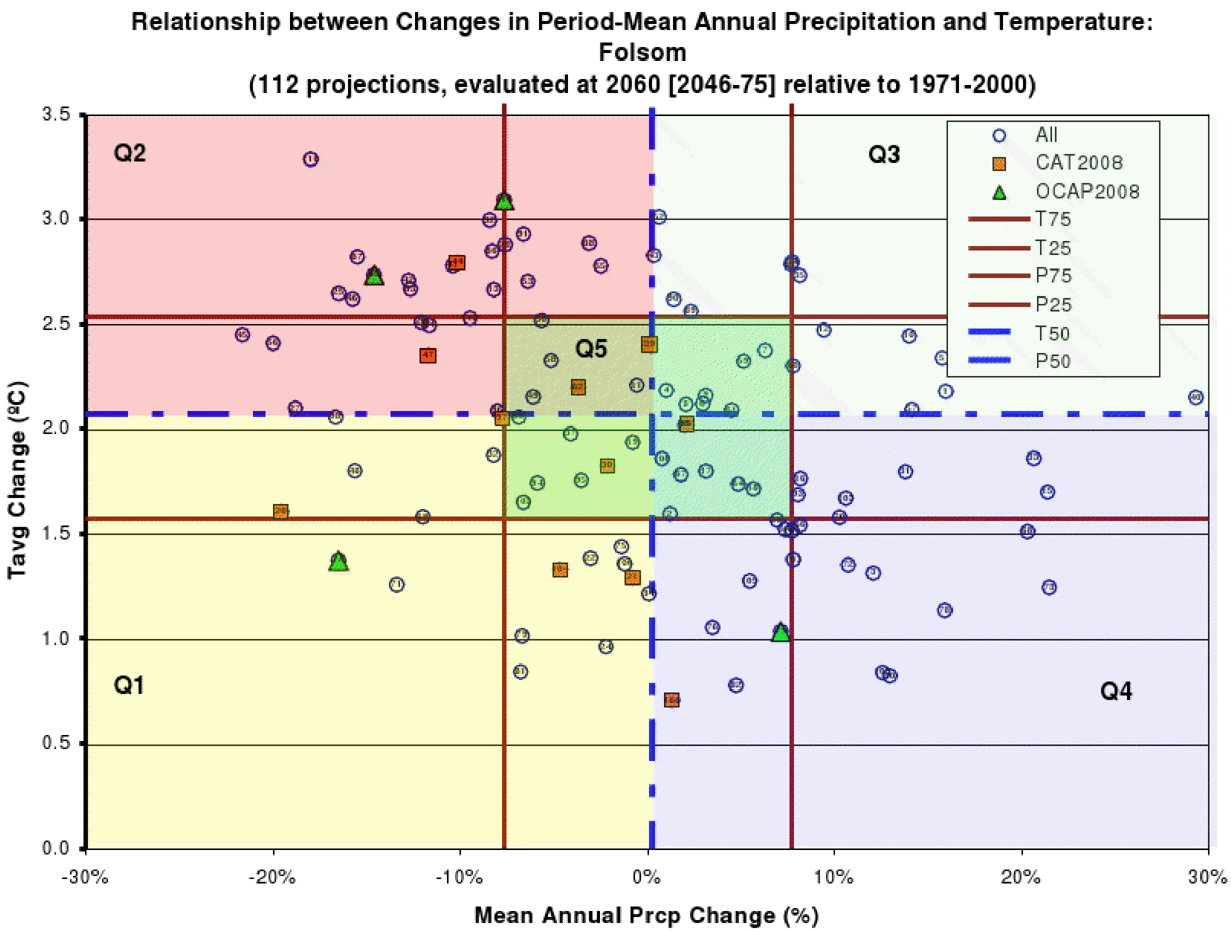

Figure 1: Mean annual precipitation change (%, horizontal axis) and temperature change (°C, vertical axis) between 2060 and recent historical conditions for the 12 CAT scenarios and 4 OCAP scenarios. Source: BDCP Physical Modeling Update, April 22, 2010.

2.3 Other Scenario Factors

The planning team is developing an expanded list of potential scenario factors to consider as part of the California Water Plan Update 2013. Currently, we anticipate adding a few new scenario factors to those described above:

- Costs and/or limits to groundwater pumping[1]
- Costs of resource management strategies (described below)

Other scenario factors will be included in the analysis after the first round analysis is completed and demonstrated to the stakeholder community.

[1] One option for accounting for the impact of rising energy costs on groundwater pumping would be to develop cost/groundwater level curves and introduce a cost constraint for each major groundwater basin.

3 Resource Management Strategies and Response Packages

3.1 Strategies

Volume 2 of the CWP Update 2009 includes 27 different resource management strategies for California. WEAP is able to quantify many of the water supply augmentation and demand reduction strategies identified by the Water Plan. WEAP can partial quantify many of the other strategies. Table 1 lists each of the Water Plan strategies and describes to what extent and how each strategy could be implemented in the PA Model.

Table 1: Resource Management Strategies and details for implementation in the PA Model. Strategies names preceded by * are recommended for implementation in the first round of analysis. Implementation of strategies preceded by † will require coordination with existing Delta and surface storage investigations.

WATER PLAN STRATEGIES	SIMULATE IN WEAP?	IMPLEMENATION IN PA Model
STRATEGIES TO REDUCE WATER DEMAND		
*** Agricultural Water Use Efficiency**	YES	Adjust crop/irrigation coefficients
*** Urban Water Use Efficiency**	YES	Adjust water use rates through efficiency parameter
STRATEGIES TO IMPROVE OPERATIONAL EFFICIENCY		
† Conveyance - Delta	YES	Modify schematic to reflect any structural changes. Adjust constraints on existing facilities to reflect any capacity expansions.
† Conveyance - Regional/Local	YES	
*** System Reoperation**	YES	Modify operational logic. May include adjusting reservoir rule curves, adjusting priorities of demands and/or storages, adjusting supply preferences
Water Transfers	YES	Adjust constraints as needed to permit contractual transfer of water. Adjust demands (as needed) by decreasing the sellers demand (presumably due to land retirement or efficiency improvement). Update supply preferences as needed.
STRATEGIES TO INCREASE WATER SUPPLY		
*** Conjunctive Management & Groundwater Storage**	YES	Adjust supply preferences to reflect a shift to relying more on groundwater in dry periods. Modify schematic to include groundwater recharge areas (using WEAP's reservoir object)
Desalination - Brackish & Seawater	YES	Modify schematic to include new sources. Specify capacity/production
Precipitation Enhancement	YES	Adjust precipitation time series to reflect expected increases.
*** Recycled Municipal Water**	YES	Allow return flows from waste water treatment plants to be used as a water supply source
† Surface Storage -- CALFED/State	YES	Modify schematic to include new facilities. Modify operational logic to reflect changes in water storage priorities for reservoirs and/or changes in supply preferences for demands
Surface Storage -- Regional/Local	YES	

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STRATEGIES TO IMPROVE WATER QUALITY		
Drinking Water Treatment and Distribution	PARTIALLY	To the extent that distribution modifications increase capacity and/or demand (by expanding service area), we can modify demands within WEAP
Groundwater Remediation/Aquifer Remediation	PARTIALLY	Presumably, groundwater remediation will have water supply implications by expanding usable groundwater resources. We can adjust groundwater pumping constraints to reflect this.
Matching Water Quality to Use	PARTIALLY	Modify system schematic to reflect changes in water supply sources
Pollution Prevention	NO	n/a
Salt and Salinity Management	NO	n/a
Urban Runoff Management	NO	n/a
STRATEGIES TO PRACTICE RESOURCE STEWARDSHIP		
Agricultural Lands Stewardship	NO	n/a
Economics Incentives Policy	PARTIALLY	New (and existing) economic policies can be included in the model. WEAP will calculate costs and benefits of associated policies, but will not optimize on economic outputs of the model.
Ecosystem Restoration	NO	n/a
Forest Management	NO	n/a
Land Use Planning and Management	YES	Land use is an input to the WEAP model, which influences rainfall-runoff and consumptive water usage. These inputs can be adjusted to reflect any new management strategies to protect, reclaim, or otherwise modify land use.
Recharge Area Protection	PARTIALLY	WEAP considers all of the factors in managing groundwater supplies - i.e. recharge, storage, flow to rivers, and pumping. However, the PA model represents large-scale groundwater basins. Whereas, protection of recharge areas is likely to occur at a much smaller scale.
Water-Dependent Recreation	NO	n/a
Watershed Management	PARTIALLY	WEAP can evaluate changes to the hydrologic response of a watershed that result from management actions that affect the vegetative and/or soil characteristics of a watershed.
STRATEGIES TO IMPROVE FLOOD MANAGEMENT		
Flood Risk Management	PARTIALLY	Adjust reservoir rule curves for flood control. Modify rules for bypass flow structures.

We propose to implement a subset of these strategies for the first iteration of the response package evaluation:

1. Agricultural water use efficiency
2. Urban water use efficiency
3. Conjunctive management and groundwater storage
4. Recycled municipal water
5. System reoperation

These options are the easiest of the list above to implement in WEAP and provide a wide enough range of options to support an evaluation of the methodology in the first round of analysis. In the longer term, we propose to implement Delta conveyance and new surface storage facilities to reflect on-going assessments by the Delta Stewardship Council and Surface Storage Investigations.

3.2 Response Packages

Each of these strategies can be implemented to varying degrees in each Planning Area and initiated at different periods in the future. They can also be implemented in different combination and be specified to be implemented only if specific conditions are estimated to occur within a model simulation. This approach thus enables the specification of countless alternative responses, even with just four types of strategies.

In the first round of analysis, the PA Model will evaluate **static** Response Packages defined by following for each Strategy:

- Level of implementation
- Year of implementation (or time schedule for various levels of implementation)

Initially, we propose to develop a small number of static Response Packages to bracket the range of broad-based management responses the State may choose to promote. One of these strategies will be designed to represent the minimum level of strategy implementation to be expected and thus comprise the “current approach” response package. For example, many agencies are planning to invest in additional urban water use efficiency and thus some level of efficiency will be included in the baseline. The other static Response Packages will be designed to evaluate additional management strategies above and beyond the current approach. DWR and stakeholders will also be able to suggest other combinations of strategies for evaluation.

The second round of Response Package evaluation will consider **dynamic** Response Packages. Dynamic packages are defined first by a set of near-term options as above. Next they will specify conditions that are simulated by the PA Model to monitor and thresholds for triggering additional strategies. For example, a dynamic Response Package may begin with modest efficiency goals but increase these goals if certain reliability goals are not met at each 5-year interval of the model run. Figure 2 illustrates how a dynamic Response Package would work in the PA Model.

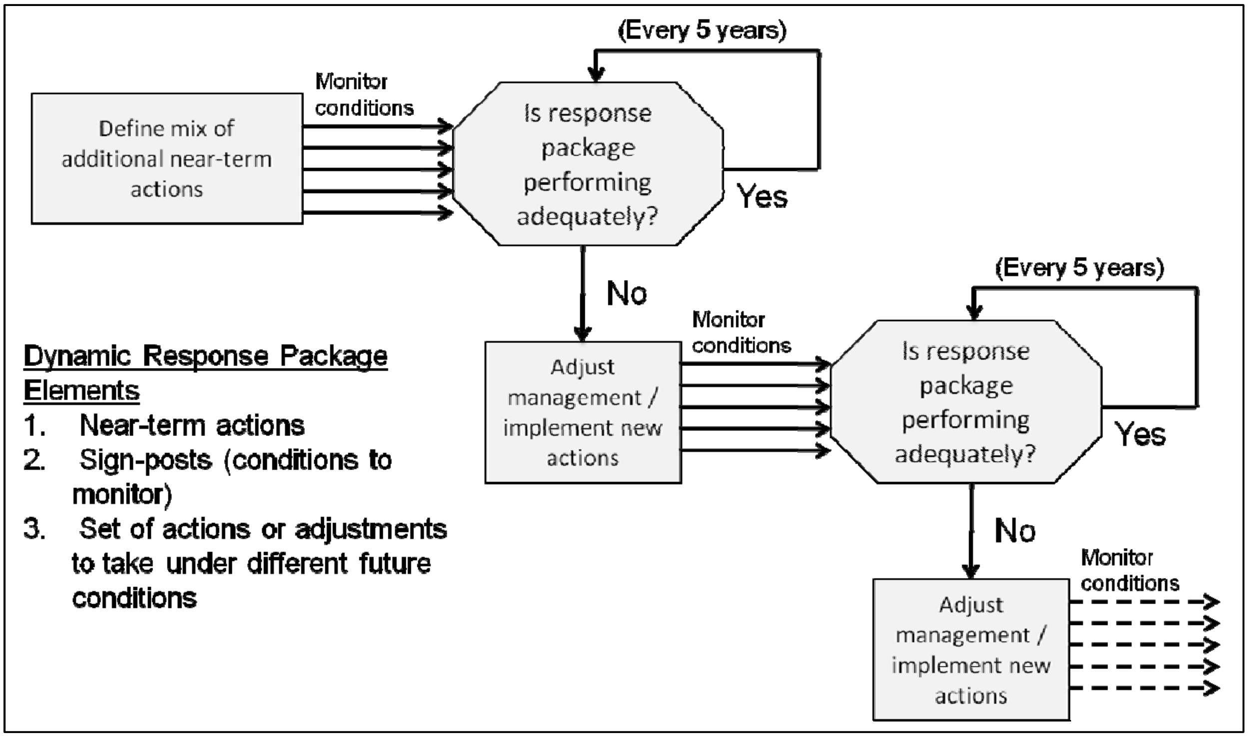


Figure 2: Schematic illustrating a dynamic Response Package.

4 Performance Metrics

The WEAP models can report on the projected state of the modeled water management system using a wide variety of metrics.

The HR Model provides output pertaining to annual water demand by sector for all 10 hydrologic regions and baseline supply estimates assuming current management and future climatic conditions. Although, it is not advisable to infer supply reliability or attainment of instream flow requirements or other environmental objectives using this model, the planning team is evaluating its use in stakeholder settings.

Due to a higher resolution and more complete representation of the hydrologic cycle, the PA model can provide projections at the planning level scale (or finer, in some cases) of monthly demand, supply, and unmet demand by sector. These data can then be used to calculate reliability at each demand node in the model, or in aggregate. The PA model resolves the major environmental flows and requirements in these HRs and can report out associated reliability statistics. The model can report on operational parameters of the built infrastructure. In particular storage volume over time of the five major reservoirs (Shasta, Oroville, Folsom, New Melones, and San Luis) and exports into the Delta Mendota and California Aqueduct can be reported. Conditions in the Bay-Delta, as summarized by the position of the X2 salinity standard, can be reported. Finally, with additional data the PA model could report cost of delivery estimates over time and hydropower generation.

Table 2 summarizes the performance metrics to be included in Response Package evaluation using the PA Model.

Table 2: Proposed performance metrics to consider in Response Package evaluation for the PA Model.

Performance Metric Category	Performance Metric	Additional model development or data required
Demand	- Monthly and annual demand by node (irrigated agriculture, indoor urban, outdoor urban)	Explicit inclusion of demand-related scenario factors – currently water use rates corresponding to each growth scenario are defined as an input.
Supply	- Surface supply delivered - Groundwater supply delivered	Aggregation across multiple supplies
Reliability	- Unmet demand by node - % of years with unmet demands	None
Environmental Objectives	- Anadromous Fish Restoration Programs flows (4) - Delta inflow - Delta outflow - X2 position - Water quality (temperature)	Water temperature data
System Operations	- Flows into major reservoirs - Storage volume for major dams (5) - Delta exports (Cal Aqueduct and Delta Mendota Aqueduct) - Groundwater levels	None
Financial	- Capital costs - Fixed costs - Variable costs	Cost data for all model elements
Hydropower	- Annual hydropower generation	Develop hydropower data
Economic impacts	- Economic impacts of shortages	Inclusion of LCPSIM functions into WEAP model.

5 PA WEAP Model Enhancements

The PA Model will require some modest enhancements to evaluate a wide range of management strategies and response packages under a wide range of scenarios.

To implement the scenarios described above, the following PA WEAP model enhancements are required:

- Adding uncertainty factors to the allowable pumping rates from key groundwater basins.
- Developing cost estimates and uncertainty ranges for the resource management strategies to be defined.

To evaluate the resource management strategies described in Section 3, the following enhancements are required:

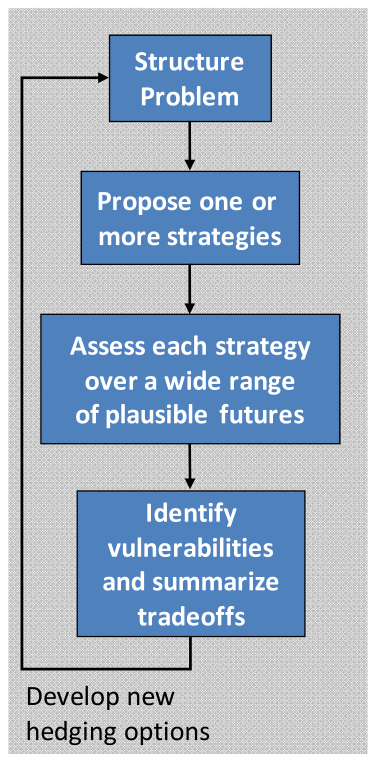
- Model agricultural and urban water use efficiency strategies
- Implement recycled municipal water systems
- Develop protocol for defining static Response Packages
- Model conjunctive use and groundwater storage
- Define alternative system operation rules

Logic to assemble management strategies into dynamic response packages is also required.

6 Analytic Process

The CWP Update 2013 will use Robust Decision Making (RDM) to evaluate the performance of water management response packages against the wide range of scenarios and identify those that are most robust.

RDM is an iterative, analytic process designed to identify strategies that are robust to a wide range of planning uncertainties. The sections below illustrate how the process will be executed.



6.1 Step 1 – Structure Problem

An RDM analysis can be viewed in five iterative steps as shown to the right. In the first step—Structure Problem—the consulting team and Water Plan staff will (1) define a set of scenarios to evaluate uncertainty (see Water Management Scenarios section, above); (2) define the different resource management strategies that the state might take to improve upon the current water management and compile into a set of response packages to analyze in the first iteration of the analysis (see Resource Management Strategies section, above); and (3) identify the key WEAP model outputs to use to evaluate the performance of each response package in each scenario (see Performance Metrics section, above).

6.2 Step 2 – Propose Strategies

RDM next focuses on evaluating a set of promising response packages. For the first iteration of the analysis, the team will develop a set of response packages as described in the Resource Management Strategies section, above.

6.3 Step 3 – Evaluate Strategies Over Many Futures

In the third step—Asses each strategy over a wide range of plausible futures—the WEAP PA model will be configured to reflect each Response Package and then will be evaluated for each of the scenarios (described above). To support this task, the consulting team will define an Experimental Design, that is, specify a set of scenarios that efficiently samples the range of plausible values for each of the key uncertain factors. For the POC, the experimental design will be a full factorial design of the 3 growth scenarios and 16 climate scenarios—yielding 48 scenarios (for each response package). As additional uncertainties are reflected in the model, the experimental design will expand accordingly for the 2013 Update.

As its end product, this task will produce a table or database of individual WEAP runs representing the performance of each response package run under each scenario. A convenient format for the results table for each Response Package is as follows:

Simulation #	Response Package	Scenario		Outputs		
		Growth Scenario	Climate Scenario	Output 1	…	Output *M*
1	Nominal Response Package	Current Trends	A (CNRM-CM3_A2)	{WEAP output value}	{WEAP output value}	{WEAP output value}
2	Nominal Response Package	Slow & Strategic Growth	A (CNRM-CM3_A2)	{WEAP output value}	{WEAP output value}	{WEAP output value}
…	…	…	…	…	…	…
36	Nominal Response Package	Expansive Growth	F (NCAR-PCM1 _B1)	{WEAP output value}	{WEAP output value}	{WEAP output value}

6.4 Step 4 – Identify Vulnerabilities

The consulting team will next analyze the data contained in the output table and identify and characterize those scenarios in which each of the response packages perform poorly across each of the performance metrics. This process, often called "Scenario Discovery" (Groves and Lempert 2007; Lempert et al. 2006) uses statistical algorithms to identify the combinations of ranges of a small number of uncertain WEAP input parameters that best predict the conditions where a strategy suffers poor outcomes. These clusters of cases represent key policy-relevant scenarios because if CWP stakeholders view them as sufficiently likely, the CWP staff may wish to consider alternative response packages. As part of this scenario discovery approach, the consulting team will work with CWP staff to define, for each of the metrics, what a "poor" outcome would be (also called a satisficing criterion (Simon 1959)).

The figure below illustrates the results of this approach as applied in a study with the Inland Empire Utilities Agency (IEUA) (Groves et al. 2008). Each dot represents the outcomes of IEUA's 2005 UWMP evaluated against one of 200 scenarios as measured by the present value shortage costs over the 35-year time period (x-axis) and the present value provisioning costs over the 35-year time period (y-axis). A satisficing threshold of $3.75 billon was used to define bad outcomes (to the upper-right of the red line). The Scenario Discovery process revealed an important policy-relevant scenario defined by the following restrictions on three uncertain parameters:

1) Climate change trends are significantly drying and warming
2) Groundwater percolation declines modestly or more
3) State Water Project imports decrease in response to climate change

The red triangles indicate those simulations in which each of these three conditions are met. Note that this policy-relevant scenario explains about half of the bad outcomes (about half the cases above the satisficing line are red triangles) and that almost all cases that are part of this scenario lead to bad outcome (almost all red triangles are above the satisficing line).

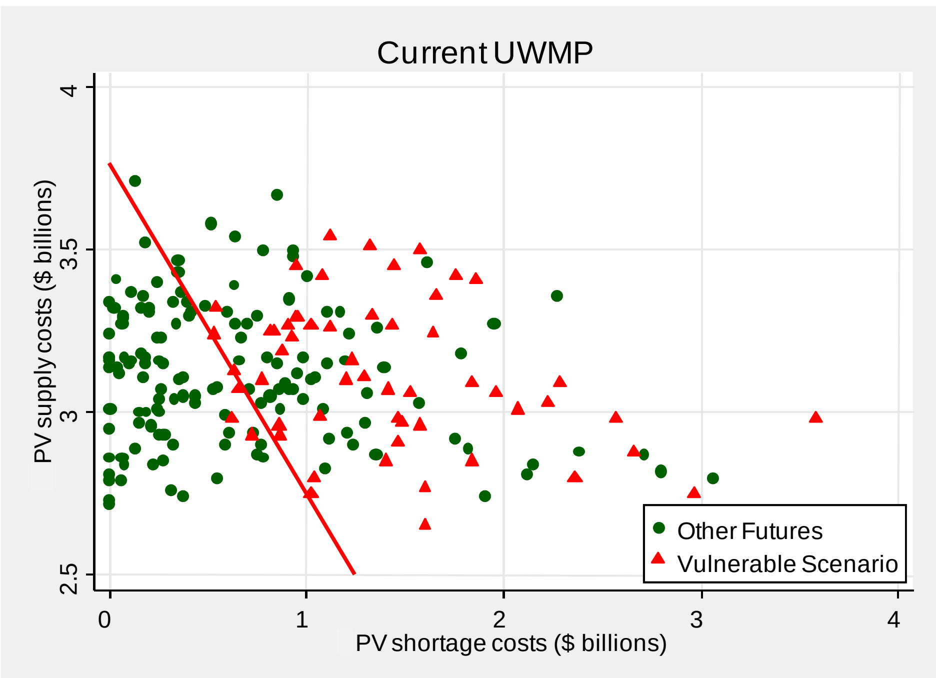


Figure 3: Scenario map showing outcomes for IEUA UWMP under 200 scenarios.

For the POC analysis and CWP Update 2013, a similar analysis will thus define a small number of scenarios that characterize the major ways in which each response package may perform poorly under each of the metrics. Some strategies may prove vulnerable to most, if not all, of the future conditions (e.g. the Current Management strategy). Others may prove sufficient under some metrics, such as reliability, but not other, such as environmental or cost. These "stress test" will thus provide insight into ways to develop a Response Package that both hedges against the key vulnerabilities and balances performance across each of the metrics.

6.5 Step 5 – Develop More Robust Strategies and Iterate

The RDM analysis next develops new strategies, evaluates them against the full set of plausible futures in the experimental design, and then identifies and characterizes any remaining vulnerabilities of the new strategies. Generally, these new strategies will have fewer and sometimes different vulnerabilities. Once the process has defined several alternative strategies, important tradeoffs can be identified, both in terms of how the different strategies perform against the different metrics and how they perform against each other.

The figures below illustrate how an evaluation of augmented and adaptive plans can lead to more robust plans and also present remaining tradeoffs. Figure 4 shows how the number of high cost outcomes declines under alternative strategies for the IEUA. Note that the results (marked with orange diamonds) indicate adaptive strategies. Figure 5 shows how these same strategies perform against both the metric of number of scenarios above the cost threshold (y-axis) and level of additional effort required to enact these policies (x-axis).[2] This graph thus reveals a trade-off curve ranging from low additional effort, but high vulnerabilities (current UWMP) to high effort, but low vulnerabilities (take all available near-term actions) (Lempert and Groves 2010).

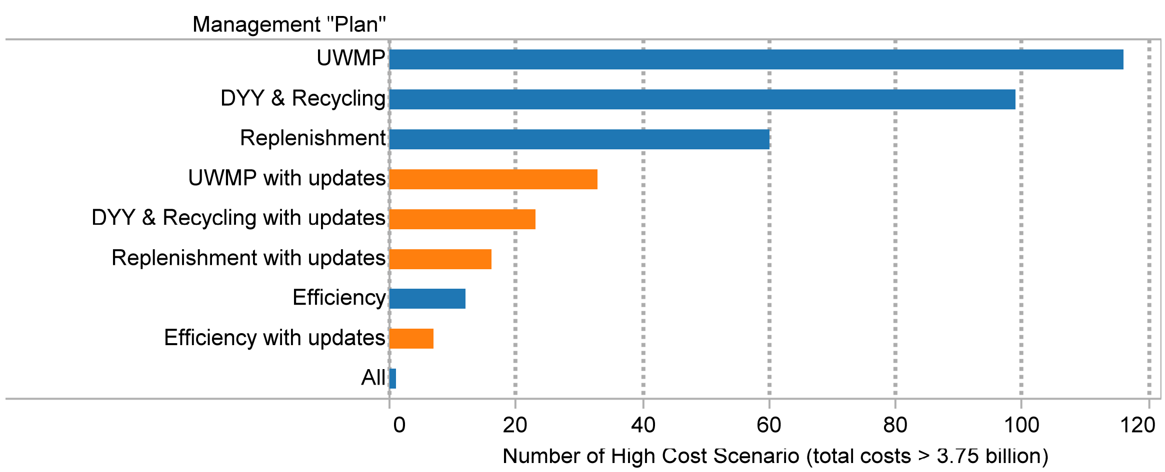


Figure 4: Number of high cost scenarios for different IEUA strategies.

[2] Note that the level of effort scores for each policy are notional in this example.

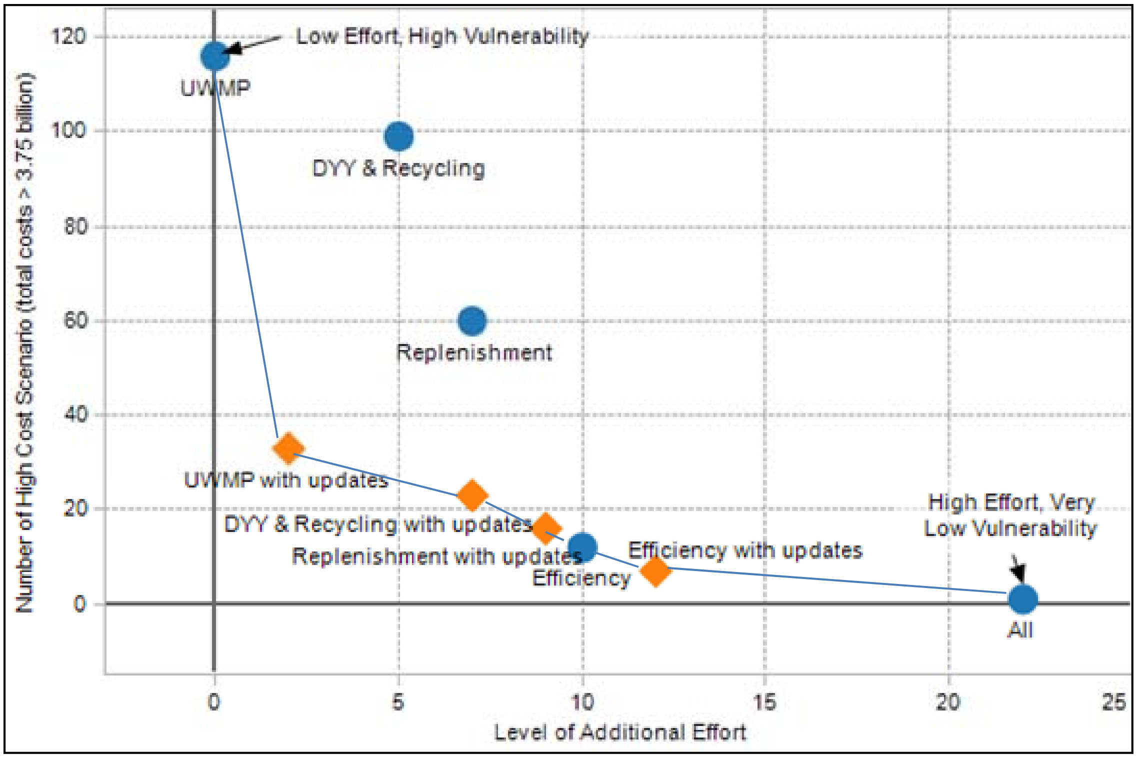


Figure 5: Tradeoff curve of number of high cost outcomes versus level of effort for alternative IEUA strategies.

For the POC and CWP Update 2013 the RDM analysis will likely involve some significant tradeoffs both in terms of how the strategies are expected to perform across the various performance criteria and inside and outside of the key vulnerabilities (or policy-relevant scenarios). The nature of the final results is thus not easy to define prior to analysis. They will likely to include the following elements:

- Scenario maps showing performance of plans under the each of the cases in the experimental design and summarizing the plans' performance in the vulnerable scenarios (see Figure 3).
- Tables describing the key vulnerabilities.
- Summary tables, stoplight charts, or bar charts showing how alternative plans perform both within and outside of the key vulnerabilities (see Figure 4).
- Tradeoff curves that show how evaluated plans perform under the range of scenarios by metric (see Figure 5).
- Tradeoff curves that show how expectations of different policy-relevant scenarios affect the expected performance of the various policies.

7 Implementing RDM for the California Water Plan Update 2013

The RDM procedure will be first implemented in a Proof-of-Concept (POC) analysis during 2010 using the current PA WEAP model (for Sacramento River and San Joaquin River hydrologic regions). After the completion of the POC analysis, the Water Plan staff, consulting team, SWAN, and other stakeholders, will determine how to best implement the RDM methodology for the CWP Update 2013.

The intent of the POC analysis is to:

1. demonstrate the application of RDM using the WEAP model developed for the CWP Update 2013,
2. help educate the water community of this new approach,
3. identify critical methodological issues to be resolved prior to application for the CWP Update,
4. help prioritize WEAP modeling enhancements for the CWP Update analysis , and
5. define application of RDM to the CWP Update 2013.

Implementation of the POC analysis will proceed in same steps described in Section 6 (above). Step 1 (Structure Problem) will be done through consultation with Water Plan staff and SWAN members during the August 2010 workshop. Step 2 (Propose Strategies) will evaluate static response packages (as described in Section 3.2) only. In Step 3, the static response packages will be evaluated against the scenarios defined in Step 1. In Step 4, key vulnerabilities will be identified according to the procedure described above. For the POC analysis, Step 5 will focus on evaluating tradeoffs in terms of performance of the various static response packages across different metrics and under the vulnerable scenarios. The results from the POC analysis, while realistic, will not be conclusive nor predictive of the results to be obtained through the more comprehensive application for the 2013 Update.

The POC analysis will be performed from August 2010 through January 2011. The final results will be presented in a workshop in January 2011. The application of RDM for the 2013 Update will be determined in the first few months of 2011.

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