Evaluating Response Packages for the California Water Plan Update 2013: Plan of Study

1 Introduction

California faces significant challenges ensuring that its water resources successfully meet the diverse needs across the state in the coming decades. Increasing 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 (DWR, 2009).

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 during 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 Update 2013 (CWP 2013) will build upon the scenario planning begun in previous plans and include an analysis of the effects of different resource management strategies and response packages for the Central Valley under different assumptions about uncertain future conditions. A wide range of scenarios will reflect uncertainty about future population growth, agricultural land use, climate conditions, water use rates, and other factors.

This analysis will use a water management and planning model for the Central Valley developed within the Water Evaluation And Planning (WEAP) modeling environment (WEAP Central Valley). WEAP Central Valley simulates how the water management system could evolve over time in response to future scenarios and resource management strategies. It computes a wide range of outputs, such as urban and agricultural reliability, instream flows, and groundwater levels, that can be used to assess how well a response package, comprised of specific resource management strategies, would perform in the future.

The CWP 2013 analysis will use Robust Decision Making (RDM) to identify and characterize the vulnerabilities of the currently planned management approach and then to compare and develop robust water management response packages that can ameliorate the vulnerabilities. A Proof-of-Concept study demonstrated how RDM could be applied to the CWP 2013 analysis (Groves and Bloom, *forthcoming*).

This document describes the plan of study for implementing this analysis during 2012 and 2013.

2 Methods

2.1 Scenario Planning

The CWP Update 2005 began using a scenario planning approach to help describe a range of future water management conditions in California. The 2005 and 2009 updates described three narrative scenarios of water demand conditions reflecting demographic and land use trends, background conservation and water use rates, and dedication of water to unmet environmental water demand. These scenarios are described as Current Trends, Slow & Strategic Growth, and Expansive Growth (DWR, 2009):

- **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 concerning issues raging from flood damages to water quality and endangered species protection. 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 resource intensive than under current conditions. Population growth is slower than currently projected—about 45 million people live in California. 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.

The CWP 2009 included additional scenarios reflecting future climate conditions. Specifically, it used 12 different sequences of monthly temperature and precipitation derived from downscaled general circulation model global long-term climate forecasts. The 2009 Update then evaluated future water demand for California's ten hydrologic regions for each demand scenario and climate sequence (DWR, 2009).

2.2 Robust Decision Making

The CWP 2013 will use a new quantitative, scenario-planning approach, called Robust Decision Making (RDM) that is increasingly being applied to water management applications. RDM can be employed as a method for decision support, with a particular focus on helping decision makers identify and design new decision strategies that may be more robust than those they had originally considered. Often, these more robust strategies represent adaptive decision strategies designed to evolve over time in response to new information. In addition, RDM can be used to facilitate group decision making in contentious situations where parties to the decision have strong disagreements about assumptions and values.

The basic flow of an RDM analysis is iterative, beginning with a participatory scoping exercise. In the next step, the analysis begins with the evaluation of leading strategies against a large ensemble of plausible futures. The results are analyzed to define vulnerable decision-relevant scenarios—conditions in which the strategy performs poorly. These scenarios provide insight into how to make the strategy or strategies more robust to these vulnerabilities through mitigation and adaptation measures. The enhanced strategy or strategies are then re-evaluated through the preceding sequence of steps. Successive iterations lead to increasingly robust strategies along with key information about their vulnerabilities. In the last step, decision makers review the performance tradeoffs for the most robust strategies accounting for their vulnerabilities. This step often is informed by scientific or expert assessments of the likelihoods of the key vulnerabilities. For more detail on RDM, please see Appendix A.

3 Scope of Analysis

This plan of study describes the quantitative analysis of resource management strategies and response packages to support the CWP 2013. The scope for the CWP 2013 analysis was developed through numerous meetings and workshops from October 2011 through March 2012. It also builds on the Proof-of-Concept analysis performed in spring 2011 (Groves and Bloom, *forthcoming*).

This section describes the scope of the analysis in terms of the key uncertain scenario factors, performance metrics, resource management strategies and response packages, and relationships. An XLRM matrix (Lempert et al., 2003) summarizes these elements and is designed to clearly distinguish among the uncertain factors (X) that are used to develop the uncertain scenarios; the water management strategies (L) that comprise the response packages; the performance metrics (M) that are used to evaluate and compare response packages; and the relationships (R) among these elements that are reflected in the planning models. DWR used this matrix when developing the scoping of the analysis and communicating it to stakeholders (Table 3-1).

Table 3-1: Summary of Uncertain Factors, Resource Management Strategies, Relationships, and Performance Metrics

Uncertain factors (X)	Resource management strategies (L)
Demographics Urban and agricultural footprint Climate conditions Costs of resource management strategies	Currently planned management Additional water management strategies: • Urban water use efficiency • Agricultural water use efficiency • Recycled municipal water • Conjunctive management and groundwater storage • Surface storage • System reoperation • Meet new instream flow objectives • Groundwater overdraft recovery
Relationships (R)	**Performance metrics (M)**
Water Evaluation And Planning system (WEAP) Central Valley Model U-Plan urban growth model Statewide Agricultural Production model (SWAP) Demographic analysis Costs and economic impact tools	Urban supply reliability Agricultural supply reliability Instream flow reliability Groundwater levels Sacramento-San Joaquin River Delta exports (Central Valley Project and State Water Project) Cost of implementing response packages Economic impacts of unmet water demand

3.1 Uncertain Scenario Factors

The 2013 CWP analysis will develop scenarios reflecting several uncertain factors as summarized in Table 3-2. Each uncertain factor will be represented in the planning models using specific parameters. Different values or levels for these parameters will be evaluated.

Table 3-2: Uncertain Factors, Model Parameters, and Number of Scenarios

Uncertain Factor	Model Parameter	Levels (number of scenarios)
Demographics	Population growth rates; urban water use rate factors	Low, current trends, high (3)
Urban and agricultural footprint	Urban density parameter	Compact urban development, current trends, distributed development (3)
Climate conditions	Sequence of monthly temperature and precipitation	Subset of 17 climate model-derived sequences (CEC+BDCP) + four derived from historical data
Costs of management strategies	Levelized costs of management strategies	Range between 50% of expectations and 200% of expectations (TBD)

3.1.1 Demographics

The CWP will define three scenarios of demographic conditions, reflecting the following three factors:

- Projections of the number of urban water users by sector (single-family homes, multi-family homes, commercial employees, industrial employees, and total population for public sector use)
- Water use rate elasticity factors (e.g. income, household size, and water price)
- Water use rate reductions due to naturally occurring conservation.
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The scenarios of water users will correspond to a California population ranging from 45 million to 70 million by 2050 (Johnson, 2008). These scenarios will be applied at the planning area scale within the Central Valley.

3.1.2 Urban and agricultural footprint

The CWP will develop three new urban and agricultural footprint scenarios reflecting different assumptions about urban growth density and how population growth leads to changes in housing stock and reductions in agricultural irrigated land area. These scenarios will vary different values for urban density parameters within the U-Plan model (see section 3.3.2), representing strategic, high-density growth; growth consistent with current trends; and uncontrolled, low-density expansive growth.

The U-Plan model will then estimate nine different projections of urban and agricultural land footprint based on the three demographic scenario projections together with the three estimates of urban growth density. For each projection, the CWP Planning team will use the Statewide Agricultural Production (SWAP) model to develop estimates of cropping patterns over time (see Section 3.3.3). These nine projections will replace the three more narrow demographic scenario developed for the CWP 2009.

3.1.3 Climate conditions

Uncertain future climate conditions are represented by diverse sequences of temperature and precipitation applied to geographically-disaggregated catchment areas in the WEAP model (see 3.3.1). Some sequences will be based upon projections of temperature and precipitation from global climate models (Atmosphere-Ocean General Circulation Models—GCMs). Others will be based on historical observations and will be designed to test the effects of drought conditions experienced in the recent past at different times in the future. The Climate Change Technical Advisory Group (Climate TAG) will provide guidance about which specific sequences to evaluate that reflect a wide range of plausible climatic conditions and include periods of droughts similar to those experienced in recent decades.

3.1.3.1 Climate change scenarios

The CWP Update 2012 will use a subset of climate sequences used by the CWP Update 2009 and the Bay Delta Conservation Plan (BDCP) analysis.

The CWP Update 2009 evaluated 12 sequences of downscaled global predictions of temperature and precipitation, corresponding to the 12 model-emissions scenario combinations selected by the Governor's Climate Action Team (Maurer and Hidalgo, 2008). The GCMs used were:

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 were 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).

Downscaled monthly temperature and climate projections were obtained from the downscaled climate dataset jointly developed by the Lawrence Livermore National Laboratory (LLNL), the U.S. Department of the Interior, Bureau of Reclamation (Reclamation), and Santa Clara University (SCU), available at http://gdo-dcp.ucllnl.org. These data were derived from the World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3) multi-model dataset, and include data from 112 different global climate simulations of 16 global models evaluated for three global emissions scenarios. The projections are available from 1950 to 2099.

The Bay Delta Conservation Plan (BDCP) analysis took a different approach to developing climate scenarios. They created five synthetic sequences of temperature and precipitation (Q1 – Q5) by resampling data from subsets of 112 different GCM-derived sequences:

- Drier, less warming (Q1)
- Drier, more warming (Q2)
- Wetter, more warming (Q3)
- Wetter, less warming (Q4)
- Central tendency (Q5)

3.1.3.2 Historical climate conditions

Historical climate conditions are derived from a gridded historical data set from 1950 to 1999 (Maurer, 2002). The historical temperature and precipitation estimates will be used to evaluate future management under sequences of climate that include the drought conditions experienced from 1976-1977 and from 1987-1992. A simplified indexed sequential method (ISM) approach will test how the timing of these droughts would affect evaluations of different management responses. For one scenario, the first year of the historical record (1950) will be assigned to the first year of the simulation—2005. Three other scenarios will offset the historical year used for the first year of the simulation by 15 years and loop the first historical year to follow the last historical year to ensure a continuous 45-year sequence of climate data.

3.1.4 Costs of resource management strategies

Scenarios will reflect uncertainty about the cost of implementing different management strategies. Scenario factors will be based upon percentage deviations from a baseline estimate of costs. Each scenario will group the cost scenario factors into unique combinations to reflect plausible costs across the different management strategies. For example, one scenario could consider upper-bound estimates for surface storage strategies. Another could consider upper-bound estimates for water use efficiency strategies.

3.2 Performance Metrics

Performance metrics are used to concisely describe the modeled condition of the water management system for a specific response package and scenario across time. The analysis focuses on the Sacramento River, San Joaquin River, and Tulare hydrologic regions and evaluates water management conditions on a monthly time step from 2005 to 2050. See Section 3.3 for descriptions of the models.

Some metrics are calculated by considering model outcomes compared to a particular *metric threshold.* A supply reliability metric, for example, is calculated as the percentage of years in which unmet demand is below the metric threshold. The metrics provide the quantitative basis for evaluating the vulnerabilities for the planned management strategy and comparing different response packages. As described in Section 4, *vulnerability thresholds* are used to determine if performance of the management system is acceptable per the specific metric.

3.2.1 Urban supply reliability

This metric provides a measure of how much urban demand is unmet across a given time sequence. Urban supply reliability is calculated as the percent of years that supply is less than a specific metric threshold percentage of demand (e.g. 95% of demand met). This metric will be calculated for each hydrologic region.

3.2.2 Agricultural supply reliability

This metric provides a measure of how much agricultural demand is unmet across a given sequence. Agricultural supply reliability is calculated as the percent of years that supply is less than a given metric threshold percentage of demand. This metric will be calculated for each hydrologic region.

3.2.3 Instream flow reliability

This metric measures the reliability of river flows through particular river reaches, expressed in terms of the time frequency in which desired flow rates (i.e. instream flow targets) are not met across a given sequence. Two types of instream flow reliability metrics will be calculated: (1) flow targets which are already legally required, and (2) new instream flow needs or additional deliveries to managed wetlands that have been identified by regulatory agencies or pending court decisions, but are not yet required by law. New instream flow targets include:

- American (Nimbus)
- American (Nimbus) Department of Fish and Game Values
- Stanislaus (Goodwin)
- Ecosystem Restoration Program #1, Delta Flow Objective
- Ecosystem Restoration Program #2, Delta Flow Objective
- Ecosystem Restoration Program #4, Freeport
- Trinity below Lewiston
- Ecosystem Restoration Program #3 San Joaquin River at Vernalis
- San Joaquin River below Friant
- Level 4 Refuges

A single metric is calculated for each flow target and will be summarized over those that are legally required and those that are new.

3.2.4 Groundwater levels

This metric summarizes modeled groundwater levels mid-way through and at the end of the simulation (e.g. 2035 and 2050). The groundwater metrics will aggregate all groundwater basins within the three hydrologic regions.

3.2.5 Sacramento-San Joaquin River Delta exports

This metric summarizes how much water supply is exported from the Bay-Delta through the Central Valley Project and State Water Project. A metric threshold will be based on the long-term historic average export amount. A vulnerability threshold will be used to define sequences that have an unsatisfactory number of years below the historic average.

3.2.6 Cost of implementing response packages

This metric will represent estimates of implementing each management strategy. The cost estimate will include both fixed costs of implementing a management strategy, (e.g. the fixed capital costs of building a recycling plant), and the annual variable costs of utilizing the strategy (e.g. the cost per acre-foot of water recycled). This cost metric will be summarized by a single average annual cost.

These cost estimates will be necessarily rough due to significant uncertainty about costs in the future and due to how water management strategies are modeled. In many instances the model does not reflect specific policy choices to achieve objectives, but rather reflects system-wide performance if an objective is achieved. The cost metric will be used only to compare strategies and establish when one response package may be preferable to another—they are not estimates the actual costs that would be incurred to implement a response package.

3.2.7 Economic impacts of unmet water demand

Calculating the economic impacts of unmet demand will require additional data and modeling than is currently available. This section will be updated in the future.

3.3 Relationships

Relationships refer to the interconnections among the different components of the climate and hydrologic systems, facilities, and operational rules and management practices. For the CWP Update 2013, these relationships will be expressed in mathematical terms using three models:

- Water Evaluation And Planning (WEAP) Central Valley Model
- U-Plan urban growth model
- Statewide Agricultural Production model (SWAP)

3.3.1 WEAP Central Valley Model

The WEAP Central Valley model is described in detail in Joyce et al. (2009). To support the CWP 2013 analysis, a variety of improvements are being implemented:

- Adding representation of the Tulare Lake hydrologic region
- Improving calibration of the major reservoirs
- Improving calibration of the major catchment areas
- Updating urban water use, agricultural water use, and climate scenario data
- Incorporating calculations of water use rates (section 3.3.1.1)
- Representing additional resource management strategies (section 3.3.1.2 and section 3.4)

- Revising of system priorities for meeting each water demand node and the water supply preferences for each water demand node (section 3.3.1.3)

Details for some of these items are provided below.

3.3.1.1 Calculations of urban water use rates

The CWP Update 2009 used a WEAP model of the state's ten hydrologic regions to estimate future water use rates for households, commercial and industrial employees, and public uses for each region. The household water use rates were based on standard econometric equations that consider how demand responds to household size, household income, water price—i.e. elasticity factors—and naturally occurring conservation. Water use rates for commercial and industrial users were based on the number of future employees as well as water price and naturally occurring conservation. Water use rates for public use were based on population and water price only. Different water use rates were developed for each of the three narrative scenarios described in Section 2.2. Each scenario reflected different number of households, employees, and total people, and different elasticity parameters.

For the 2013 analysis these calculations will be implemented directly into the WEAP Central Valley model to support the direct estimate for water use rates at the planning area level for each demographic scenario.

3.3.1.2 Representing resource management strategies

Section 3.4 describes the resource management strategies that will be evaluated within the WEAP Central Valley model and how they will be implemented.

3.3.1.3 Revising priorities for meeting demand and preferences for supplies

WEAP allocates water supplies to water demand nodes using a set of demand node priorities and supply preferences for supply for each node. For example, demand nodes with lower priority may not receive all needed water under conditions in which supplies are limited. The POC analysis used the priority order for different demand nodes shown in Table 3-3.

Table 3-3: Current Demand Priorities in WEAP Central Valley Model

Priority Level	Demand Node Types
1	• Urban indoor demand • Delta exports • Instream Flow Requirements (Under Slow and Strategic land use scenario)
2	• Instream Flow Requirements (Under Current Trends and Expansive Growth land use scenarios)
3	• Agricultural demand • Urban outdoor demand

In this model development step, the current priorities and corresponding supply preferences will be updated.

3.3.2 UPlan urban growth model

UPlan is a GIS-based model of the spatial footprint of urban development developed by UC Davis researchers. UPlan uses simple rules to calculate the acreage for each urban land use type based on urban population growth projections, urban density assumptions, and spatially-assigned scores indicating the net attractiveness (based on user input) and suitability of different types of development. The agricultural footprint is estimated to decline proportionately to increases in the spatial extent of the urban footprint.

For the CWP 2013 Update, UPlan will calculate future urban footprints for scenarios that vary by both population growth assumptions and urban density assumptions. The calculated future urban footprint will be compared with estimates of the current footprint of irrigated agricultural land to determine the future spatial footprint and acreage of irrigated land available for crop production.

3.3.3 Statewide Agricultural Production model (SWAP)

The Statewide Agricultural Production model (SWAP), developed by UC Davis researchers, projects future cropping patterns, land use, and water use by considering land and water availability and their costs, market conditions, and production costs. The model selects those crops, acreage, and water supplies that maximize profits subject to certain constraints, such as availability of land, labor, water and supplies.

SWAP uses the Positive Mathematical Programming (PMP) technique to incorporate both marginal and average economic conditions when maximizing profit. To obtain a market solution, the model's objective function maximizes the sum of producers' surplus (net income) and consumers' surplus (net value of the agricultural products to consumers) subject to the following relationships and restrictions:

- Exponential marginal cost functions estimated using the PMP technique—these functions incorporate acreage response elasticities that relate changes in crop acreage to changes in expected returns and other information
- Commodity demand functions that relate market price to the total quantity produced.
- A variety of constraints involving land and water availability and other legal, physical, and economic limitations.

For the CWP Update 2013, SWAP will forecast future crop acreage for most regions in California with significant irrigated crops including portions of the Sacramento River, San Joaquin River, Tulare Lake, Central Coast and Colorado River hydrologic regions. SWAP will use the agricultural footprint developed from the UPlan urban growth model to forecast the future cropping pattern and acreage for 20 unique crop categories.

3.4 Resource Management Strategies

Volume 2 of the CWP Update 2009 describes 27 different resource management strategies for California. The WEAP Central Valley model can represent a subset of these water strategies. Table 3-4 lists each of the Water Plan strategies and describes to what extent and how each strategy could be implemented in the WEAP Central Valley model.

Table 3-4: Resource Management Strategies and details for implementation in the WEAP Central Valley Model

RESOURCE MANAGEMENT STRATEGY	CAN BE SIMU-LATED IN WEAP?	IMPLEMENTATION IN WEAP CENTRAL VALLEY 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 meeting demands or storage objectives, and 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 changes in supply preferences for demands
Surface Storage -- Regional/Local	YES	
STRATEGIES TO IMPROVE WATER QUALITY		
Drinking Water Treatment and Distribution	PARTIALLY	To the extent that distribution modifications increase capacity 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 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 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.

The CWP 2013 analysis will evaluate response packages comprised of the following strategies:

- Urban water use efficiency (section 3.4.1)
- Agricultural water use efficiency (section 3.4.2)
- Recycled municipal water (section 3.4.3)
- Conjunctive management and groundwater storage (section 3.4.4)
- Surface storage (section 3.4.5)

- System reoperation (section 3.4.6)
- Meet new instream flow objectives (section 3.4.7)
- Groundwater overdraft recovery (section 3.4.8)

3.4.1 Urban water use efficiency

Urban water use efficiency can be achieved through technological and behavioral improvements that decrease indoor and outdoor residential, commercial, industrial, and institutional water use. A broad array of individual and local actions can increase urban water use efficiency. The state has a number of policies that aim to provide incentivizes for those actions. Policies include:

- Standards, such as the 20x2020 regulation requiring urban water agencies to reduce per capita water use by 20 percent by 2020
- Funding mechanisms, such as requiring water agencies to implement urban best management practices to be eligible for loans and grants

Update 2009 described different statewide policies, which could be implemented to create technological and behavioral changes. For evaluating the effect of urban water use efficiency on the system for Update 2013, the WEAP model will simulate percentage reductions in demand rather than the implementation of specific programs.

Urban water use efficiency is represented in the WEAP model separately for indoor and outdoor urban demand nodes. For indoor urban demand sites, WEAP includes a parameter called “demand management.” The user specifies a percentage decrease in demand due to demand management activities and indoor urban demand is decreased by this factor. For outdoor urban demand, WEAP has irrigation thresholds for soil moisture; when soil moisture drops below the lower threshold, irrigation flows to the crop area until the upper threshold is reached. To approximate a decrease in demand due to efficiency, these thresholds are recalibrated to achieve specified percentage decreases in demand.

3.4.2 Agricultural water use efficiency

Agricultural water use efficiency is the use and application of scientific processes to control agricultural water delivery and achieve a beneficial outcome. Improvements in agricultural water use efficiency primarily occur from three approaches:

- Hardware: Improving on-farm irrigation systems and water supplier delivery systems
- Water management: Improving management of on-farm irrigation and water supplier delivery systems
- Crop water consumption: Reducing non-beneficial evapotranspiration

For evaluating the effect of agricultural water use efficiency on the system for Update 2013, the WEAP model will simulate percentage reductions in agricultural demand rather than the implementation of specific efficiency approaches.

WEAP estimates the irrigation requirement for different crops through the use of irrigation thresholds for soil moisture; when soil moisture drops below the lower threshold, irrigation flows to the crop area until the upper threshold is reached. These thresholds are based on current demand conditions for each crop in the local area. To approximate a decrease in demand due to efficiency, these thresholds are recalibrated to achieve specified percentage decreases in demand. This calibration has been completed under historic climate conditions, for one representative planning area in each hydrologic region, separately for each crop.

3.4.3 Recycled municipal water

Developing and using recycled municipal water can serve several purposes:

- As a water source for outdoor irrigation that offsets the need for other freshwater supplies
- As a water source for groundwater replenishment
- As a means to enhance environmental features, such as wetlands
- As an alternative to treatment and disposal of wastewater
- As a source of nutrients for crops or landscape plants

For the Update 2013, this strategy is evaluated with respect to the use of recycled municipal water as an alternative source for outdoor irrigation. This is represented using wastewater treatment nodes in WEAP. These nodes reroute runoff from demand nodes to outdoor urban and agricultural demand nodes within the same planning area. These wastewater treatment nodes are set to take a specified percentage of water supplied from their source node.

3.4.4 Conjunctive management and groundwater storage

Conjunctive management and groundwater storage is the coordinated and planned use and management of surface water and groundwater resources to maximize the availability and reliability of water supplies in a region to meet various management objectives. A simple form of conjunctive use is to intentionally recharge a groundwater basin from surplus surface water supplies and additional pumping of groundwater during periods of need.

For the CWP 2013 Update, this type of conjunctive use will be represented in WEAP through additional linkages between surface supplies and groundwater basins. Demand nodes are used to represent the monthly maximum volume that could be pumped into the basins. They are set to consume none of the surface water supplied to them. All water supplied is directed to the groundwater basins. These demand nodes are set at the lowest priority, so that only after urban, agricultural, environmental, and other water demands are met, would water be banked.

3.4.5 Surface storage

The CWP Update 2013 will evaluate two surface storage sites: one north of the Delta and one south of the Delta. They will be roughly based upon two of the five storage sites identified for the CALFED Bay-Delta Program (CALFED) surface storage investigations—Sites Reservoir (north of the Delta) and Temperance Flat (south of the Delta) (DWR, 2010).

The north of the Delta surface storage site will be represented by a surface storage node, sized at 2.0 million acre-feet (MAF), located off the Sacramento River in the Sacramento River hydrologic region. Its operation would be set such that during high flow months, water would be conveyed to the reservoir. Flows back into the Sacramento would then be permitted during lower flow months. The WEAP model would be calibrated such that the average annual yield during historical hydrologic conditions would be about 500 thousand acre-feet per year (TAF/year).[1]

The south of the Delta surface storage site will be represented through an instream reservoir node, sized at 1.25 MAF, on the San Joaquin River, above Millerton Lake. Its operational logic would be set similar to that of Millerton Lake and would be calibrated to yield on average 150 TAF/year during average historical conditions.[2]

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[1] DWR's 2010 progress report on CALFED Surface Storage Sites evaluated a north of Delta facility, Sites Reservoir, sized at 1.8 MAF with an estimated average yield of 560 TAF/year.

[2] DWR's 2010 progress report on CALFED Surface Storage Sites evaluated a San Joaquin River-based facility at Temperance Flat sized at 1.26 MAF with an estimated average yield of 140 TAF/year.

3.4.6 System reoperation

There are many approaches for re-operating the water management system to achieve improved outcomes. For the CWP Update 2013, this will be represented by the strategies to conjunctively manage surface and groundwater resources (section 3.4.5), meet new instream flow objectives (see section 3.4.7), and to recover groundwater overdraft (section 3.4.8). Additional system reoperation strategies will be considered for inclusion in future analyses.

3.4.7 Meet new instream flow objectives

Several new instream flow objectives are represented in the WEAP model, as described in section 3.2.3. This strategy would require that these objectives are met and would be implemented in WEAP by increasing the prioritization specified for these objectives to a higher level than other demand nodes (e.g. agricultural, indoor urban, and outdoor urban).

3.4.8 Groundwater overdraft recovery

Groundwater overdraft recovery is a strategy designed to purposefully reduce groundwater extractions so that groundwater levels in the Central Valley groundwater basins increase. This option would be implemented within the WEAP model by incrementally increasing the minimum groundwater levels for each basin. Without this option, the minimum groundwater levels is set to the lowest level for the period 1970-2005, by basin.

4 Uncertain Futures and Response Packages

To evaluate different management strategies in an uncertain future, the WEAP Central Valley Model will evaluate *response packages*, comprised of different combinations of strategies, under different *futures*, each characterized by a combination of different scenario factors.

4.1 Uncertain Futures

The Water Plan team will construct between 50 and 200 different futures for the analysis by grouping the different demographic, urban and agricultural footprint, and climate condition scenarios. For the baseline evaluation, the analysis will evaluate futures reflecting all combinations of these factors (Table 4-1). The analysis may evaluate a smaller subset of futures for the response packages evaluation.

Table 4-1: Scenarios and Futures for Evaluating the Vulnerabilities of Currently Planned Management

Scenarios						**Futures**
Demographics		Urban and Agricultural Footprint		Climatic conditions		
3	x	3	x	to be determined*	=	**Between 50 and 200**

*Note: * The specific climate sequences to be used will be determined per guidance of Climate Change Technical Advisory Group.*

4.2 Management Response Packages

A comprehensive solution to current and future water management challenges will require the implementation of multiple water management strategies. The CWP 2013 Update will develop and evaluate several management response packages, each comprised of different water management strategies that are implemented at specific levels, amounts, and locations. For example, a response package could include improvements in urban water use efficiency this is specified to increase to 20 percent savings by 2020 for each hydrologic region in the Central Valley and to 30 percent by 2030 for one of the hydrologic regions. These response packages will not represent a definitive set of alternatives, rather they will be illustrative of different types of approaches that could be taken to address water management challenges.

The initial response packages will be developed by the CWP planning team and regional offices. To facilitate their development, each management strategy is grouped into one of four *strategy categories*—water use efficiency, reuse and conjunctive management, surface storage, and environmental flows and groundwater recovery. Each response package emphasizes one or more of the strategy categories. Table 4-2 lists a preliminary proposal for the relative levels of strategy emphasis by category for six response packages. The corresponding implementation specifics for each strategy are under development. Note that the first response package—currently planned management—is considered the baseline condition.

Additional response packages may be developed that are specifically tailored to address the vulnerabilities of currently planned management (see Section 5).

Table 4-2: Potential Response Packages

Response Package	Resource Management Strategy Category			
	Water use efficiency	**Reuse and conjunctive management**	**Additional environmental flows and groundwater recovery**	**New Surface storage**
Currently planned management*	currently planned	currently planned	currently planned	none
Diversification Level 1	aggressive	moderate	moderate	none
Diversification Level 2	aggressive	aggressive	moderate	none
Diversification Level 3	aggressive	aggressive	aggressive	none
Diversification Level 4	aggressive	aggressive	aggressive	two facilities

** The currently planned management response package is used for the baseline analysis. The descriptive levels for each management strategy are ordered from least to greatest as follows: none, currently planned, moderate, and aggressive. For some categories (e.g. new surface storage) none is representative of what is currently planned.*

5 Vulnerability and Response Package Analysis

The analysis will proceed in two main stages. First, the WEAP Central Valley model will evaluate the performance of the currently planned management response package under all the futures defined in Table 4-1. This vulnerability analysis will address the following two questions:

- How will the currently planned management approach perform under different plausible futures?
- What are the key drivers of the currently planned management's vulnerabilities?

Next, an analysis of the response packages will address these additional questions:

- Which management response packages could reduce the key vulnerabilities?
- What are the key tradeoffs among response packages?
- How likely would the vulnerabilities need to be to justify different response packages?

The following subsections briefly describe each of these analytical steps. The POC study provides detailed examples of these analyses.

5.1 Vulnerability Assessment of Currently Planned Management

5.1.1 Evaluate Currently Planned Management for Plausible Futures

The WEAP Central Valley Model will first evaluate the currently planned management response package for each future defined in Table 4-1. Next, the performance metrics will be calculated using the outputs from the model at each year and location. The outputs of this step will be a database containing a record for each simulation consisting of the following details:

- Scenario factors used as inputs
- Values for each performance metrics over time and across the spatial domain of the WEAP Central Valley Model

5.1.2 Identify Vulnerabilities of Currently Planned Management

In this step, each future will be classified with respect to each performance metric as leading the currently planned management to be vulnerable or not. The classification will be based on a comparison of the performance metric value and the *vulnerability thresholds* developed as part of the analysis scoping (see section 3.2). The output of this step will be an additional element in the database that will indicate to which futures currently planned management is vulnerable for each performance metric.

5.1.3 Characterize Vulnerabilities of Currently Planned Management

In this step, statistical methods will identify the scenario conditions (or factors) that consistently lead the currently planned management to perform poorly (or be vulnerable) for each performance metric. For example, this analysis will summarize the demographic, land use, and climatic conditions that result in low agricultural reliability. The outputs of this step are concise definitions, in terms of the scenario factors, of each of the *vulnerabilities* of currently planned management. The analysis of response packages will be designed to compare how different response packages alleviate the identified vulnerabilities.

5.2 Analysis of Robust Water Management Response Packages

5.2.1 Evaluate Water Management Response Packages for Plausible Futures

This analysis first uses the WEAP Central Valley Model to evaluate each water management response package for each future. As with Step 5.1.1, the model outputs will be used to calculate each performance metric. The outputs of this step will be additional records in the database containing the results of each response package for each future.

5.2.2 Identify Remaining Vulnerabilities of Water Management Response Packages for Plausible Futures

Next, the residual vulnerability of the Central Valley for each response package will be defined using the same methods as in 5.1.2. The outputs of this step will be additional elements in the database that will indicate to which futures each response package remains vulnerable for each performance metric.

5.2.3 Compare Response Packages and Describe Key Tradeoffs

This last step will present information for the comparison of response packages in terms of how much different vulnerabilities are alleviated and estimates of the comparative cost of the different response packages (reflecting uncertainties about these costs as described in section 3.1.4). This analysis will *not* identify a preferred response package, but instead will articulate the key tradeoffs associated with each. For example, one key tradeoff to be shown will be reduction of vulnerabilities across the different performance metrics. These results will show how different response packages favor the alleviation of some vulnerabilities over others. Another key tradeoff to be shown will be a comparison of the relative cost of the response packages to the amount of vulnerability reduction that they provide.

5.3 Interactive Results

The CWP 2013 analysis will generate a large amount of quantitative results. To support broad comprehension of these results, the CWP 2013 Update will develop two interactive, graphical environments for the viewing and interrogation of the results. For example, such an environment would enable a user to see key results, in terms of the performance metrics, corresponding to a single or small subset of the hundreds of futures evaluated. Other displays would show how the distribution of results across all the futures changes when different response packages are implemented. This task will build upon the interactive visualization environment developed in support of the POC Analysis and used with stakeholders during meetings in 2011.[3]

Two different visualization environments will be developed. The first would include all the data and results used to develop the specific findings of the analysis that is described in the CWP 2013 Update. This environment would be tailored for water managers and technical stakeholders. It would be run locally on a user's personal computer and will require the download of a free Microsoft Windows-based application.

Another, more streamlined version, would be developed for broad dissemination to all interested parties. This version would be made available through the Water Plan website and would not require specific software to use it.

[3] The POC analysis used the Tableau visualization environment (www.tableausoftware.com).

6 Implementation Schedule

The CWP 2013 analysis will be performed during 2012. Implementation is divided into six key phases as show in Figure 6-1.

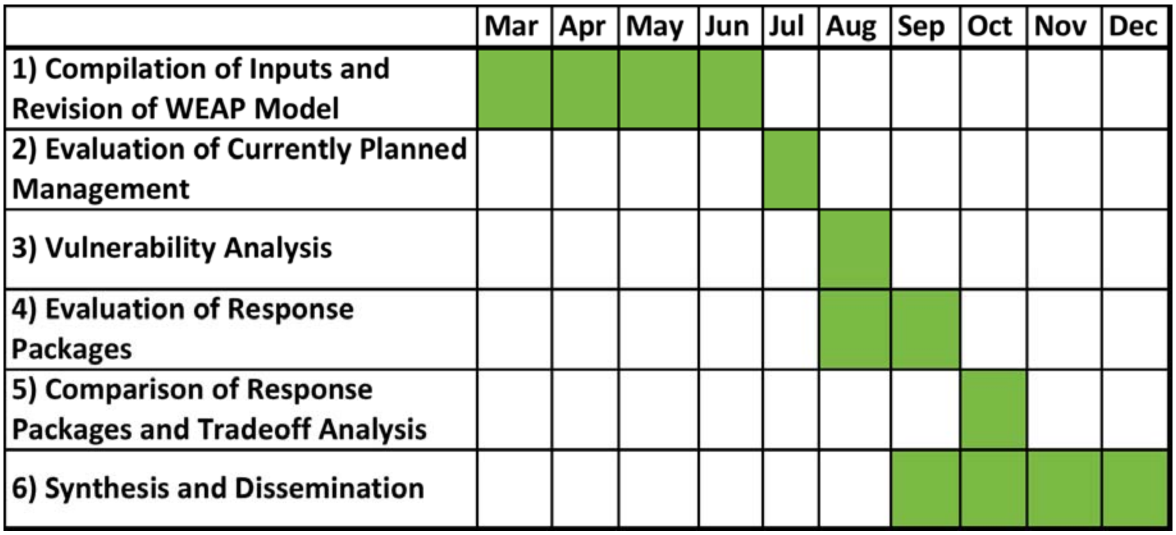

Figure 6-1: Analysis Schedule Overview

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Appendix A: Description of Robust Decision Making

Traditional scenario analyses typically consider only a small number of handcrafted scenarios to identify potential vulnerabilities of different strategies and compare alternatives for ameliorating these vulnerabilities. For complex water management systems, however, planners are developing increasingly more scenarios to reflect wider ranges of future hydrologic, demand, and regulatory conditions, to name a few.

Stakeholder processes that develop these scenarios can rarely develop consensus probabilities of these scenarios (Lempert and Popper, 2005), as uncertainty about the drivers of these scenarios are poorly understood or contentious. Without clearly specified probabilistic information about the scenarios, planners can no longer employ traditional systems reliability analysis. As a result, planning processes typically rely on ad hoc processes to reduce the number of scenarios to a manageable number to support planning.

Robust Decision Making (RDM), in contrast, provides an analytic method for developing a small number of decision-relevant scenarios that emerge directly from the analysis and provide tailored information about specific strategies and decisions facing planners. To do this, RDM evaluates many thousands of different assumptions about plausible future conditions (or futures) and stores these results in a database. RDM then analyzes the database of cases 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.

B.1 Background

RDM is a quantitative, decision analytic approach that supports decision making under conditions of deep uncertainty (Lempert, Popper and Bankes, 2003). RDM has been applied with increasing frequency to water management applications (Groves and Lempert, 2007; Groves et al., 2008; Lempert and Groves, 2010; Means, 2010; Schwarz et al., 2011).[4]

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[4] Current RAND RDM applications include work with the Metropolitan Water District of Southern California; U.S. Bureau of Reclamation, Lower Colorado Division; El Dorado Irrigation District; Colorado Springs Utilities; New York City Department of Environmental Protection; the U.S. Environmental Protection Agency; and the World Bank.

In brief, RDM offers a novel approach to understanding the vulnerabilities of proposed strategies and identifying factors under the control of planners and resource managers that could make a strategy more robust against a wide range of possible future conditions. In more technical terms, RDM is an iterative, analytic decision support methodology—sophisticated statistical and software tools embedded in a process of participatory stakeholder engagement. In the context of water management, the application of RDM facilitates the evaluation of management strategies under a wide range of futures—conditions reflecting uncertainty in future climate, economic, regulatory, and other uncertainties.

RDM helps water managers iteratively identify and evaluate *robust* strategies—those that perform well in terms of management objectives over a wide-range of plausible futures but may perform less well under an assumption that one future may be most likely to occur. Trading off optimality for adequacy across many possible conditions is referred to as "satisficing" (Simon, 1956). Often, the robust strategies identified by RDM are adaptive and thus designed to evolve over time in response to new information. RDM also can be used to facilitate group decision making in contentious situations where parties to the decision have strong disagreements about assumptions and values (Groves and Lempert, 2007; Lempert and Popper, 2005).

RDM helps resource managers develop adaptive strategies by iteratively evaluating the performance of leading options against a wide array of plausible futures, systematically identifying the key vulnerabilities of those strategies using statistical "scenario discovery" algorithms (Bryant and Lempert, 2010; Groves and Lempert, 2007), and using this information to suggest responses to the vulnerabilities (Lempert and Collins, 2007; Lempert, Popper and Bankes, 2003; Means, 2010). Successive iterations develop and refine strategies that are increasingly robust. Final decisions among strategies are made by considering a few robust choices and weighing their remaining vulnerabilities.

B.2 Iterative Process of RDM

RDM follows an interactive series of steps consistent with the "deliberation with analysis" decision support process described by the National Research Council (NRC, 2009) (Figure B-1). Deliberation with analysis begins with the participants to a decision working together to define the policy questions and develop the scope of the analysis to be performed. Subsequent steps involve expert data collection, modeling, and analysis, along with deliberations based on this information in which choices and objectives are revisited.

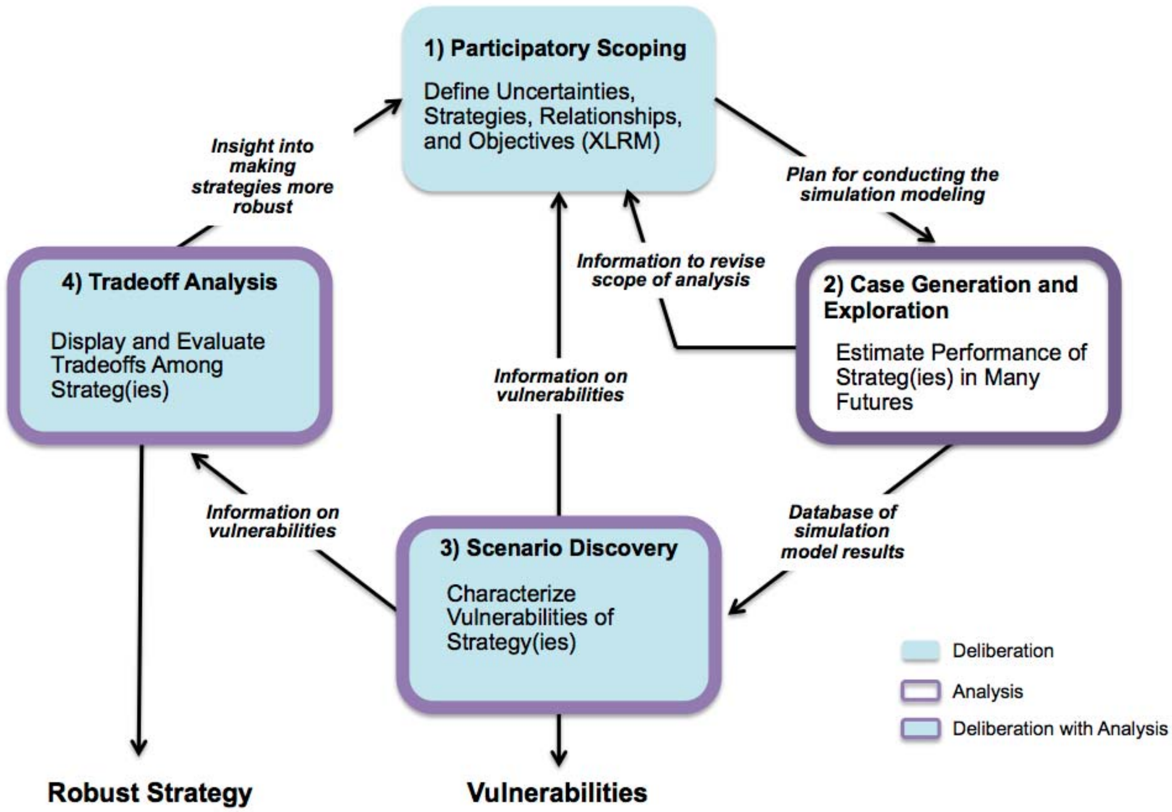

Figure B-1: Iterative Steps of a Robust Decision Making (RDM) Analysis

The RDM process begins at the top of Figure B-1 with a participatory scoping activity in which stakeholders and decision makers define the objectives and metrics, strategies that could be used to meet these objectives, the uncertainties that could affect the success of these strategies, and the relationships that govern how strategies would perform with respect to the metrics (Step 1). This scoping activity often uses a framework called "XLRM" and provides the information needed to organize the simulation modeling which captures the response of the water system to an assumed set of external conditions related to, for example, climate, economics, regulatory requirements, and demand projections.

In Step 2, analysts use the simulation model or models to evaluate the strategy or strategies in each of many plausible futures. This step in the analysis generates a large database of simulation model results (or cases). In Step 3 analysts and decision makers use visualizations and "scenario discovery" analysis to explore the data and identify the key combinations of future conditions where one or more candidate strategy might not meet the agency's objectives.

The information on potential vulnerabilities that comes out of the RDM analysis can be quite useful for decision makers. It also provides the foundation for evaluating potential modifications of the candidate strategy or strategies that might reduce these vulnerabilities (Step 4). Based on this tradeoff analysis, decision makers may decide on a robust strategy, or they may decide that none of the strategies under consideration is sufficiently robust and return to the scoping exercise, this time with deeper insight into the strengths and weaknesses of the strategies initially considered.

There are also other paths through the RDM process. For instance, information in the database of model results may be used to identify the initial candidate strategy. In other situations, information about the vulnerabilities of the candidate strategy may lead directly to another scoping exercise to revisit objectives, uncertainties, or strategies.

B.3 Vulnerability Analysis

Step 3 of RDM—characterizing vulnerabilities of strategies—often employs statistical methods called *Scenario Discovery*. In some applications it may be useful to refer to this step as *Vulnerability Analysis*. This analysis provides concise descriptions of the combination of future conditions that lead a strategy to fail to meet its objectives. These descriptions of conditions can usefully be considered as decision-relevant scenarios in a decision support process because they can help focus decision makers' attention on the uncertain future conditions most important to the challenges they face and help facilitate discussions regarding the best ways to respond to those challenge (Bryant and Lempert, 2010; Groves and Lempert, 2007). In other words, decision-relevant scenarios arise from a systematic analysis of performance under a wide range of future conditions. In contrast, analysts handcraft traditional scenarios based on intuition about the important factors driving performance.

Scenario discovery begins with the database of simulation model results (or cases) generated in Step 2 of the RDM analysis. Users define minimally acceptable outcomes or satisficing thresholds for one or more performance metric. These thresholds distinguish among cases where a strategy does or does not meet the objectives.

In this analysis, we then use the Patient Rule Induction Method (PRIM) (Friedman and Fisher, 1999) to identify decision-relevant scenarios.[5,6] Three measures of merit help guide this process:

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[5] Scenario discovery can similarly be used to identify scenarios in which a strategy performs especially well.

[6] Other algorithms such as CART or principal component analysis have also been used.

- **Coverage**: the fraction of all the vulnerable cases in the database that are contained within the scenario. (A vulnerable case is one where the strategy does not meet its objectives.) Ideally, the scenario would contain all the vulnerable cases in the database and coverage would be 100%.
- **Density**: the fraction of all the cases within the scenario that are vulnerable. Ideally, all the cases within the scenario would be vulnerable and density would be 100%.
- **Interpretability:** the ease with which users can understand the information conveyed by the scenario. The number of uncertain conditions used to define the scenario serves as a proxy for interpretability. The smaller the number of parameters, the higher the interpretability.

These three measures are generally in tension with one another. For instance, increasing density may decrease coverage and interpretability. PRIM thus generates a set of decision-relevant scenarios and allows the users to choose the one with the combination of density, coverage, and interpretability most suitable for their application.

Scenario discovery is most useful in situations in which some combinations of uncertain factors are significantly more important than others in determining whether or not a strategy meets its goals. In such situations, the analysis can help decision makers recognize those combinations of uncertainties that require their attention and those they can more safely ignored.