

# The Use of System Dynamics Model to Enhance Integrated Resources Planning Implementation

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**Abstract** Elsinore Valley Municipal Water District (EVMWD), like many other water agencies in southern California, relies heavily on imported water supply. The uncertainty associated with reliable imported water supplies due to drought conditions and climate change, and the increasing cost of imported water are areas of concern for EVMWD. Considering these conditions, EVMWD, which serves one of the fastest growing regions within Riverside County, embarked upon the development of its first Integrated Resources Plan (IRP) – a long term strategy for providing reliable water supplies to its growing customer base. The IRP’s evaluation methodology consists of three steps: Identification of potential water supply projects, project evaluation, and recommendation of a water supply portfolio comprised of the specific projects. A System Dynamics (SD) Water Resources Decision Support System (WRDSS) was used to evaluate different scenarios and examine EVMWD’s vulnerability to risks such as water supply shortage, and changes to water quality and/or water demand

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projections. Even though SD has been extensively applied to many water resources planning modeling efforts, based on our literature review, there is not a documented case of SD modeling applied to an IRP project. The recommended water supply portfolio represents the most cost effective option. It meets the forecasted long term deficit and provides the best reliability while providing good quality water supplies to EVMWD's customers. The recommended water supply portfolio will be implemented using an adaptive management approach to adjust to changing conditions, coupled with long-range resource management policies that optimize water supply and storage assets in times of both drought and surplus.

**Keywords** Integrated resources planning · Decision support system · System dynamics · Elsinore Valley Municipal Water District · Imported water

## 1 Introduction

Current population within Elsinore Valley Municipal Water District (EVMWD)'s service area is approximately 40% of build out conditions and significant growth is expected to occur during the next 25 years. This growth is expected to pose significant strain on EVMWD's water resources. EVMWD, like many other water agencies in the region, relies heavily on imported water supply. Consequently, the uncertainty associated with reliable imported water supplies due to climate change and drought conditions, and the increasing cost of imported water are areas of concern for EVMWD. In light of these conditions, EVMWD, which serves one of the fastest growing regions within Riverside County, embarked upon the development of its first Integrated Resources Plan (IRP) – a long term strategy for providing reliable water supplies to its growing customer base.

IRP's are used by many large water resources management agencies in the United States to understand current and future water supply conditions in a holistic manner in order to make optimal operational and financial policy decisions. Metropolitan Water District of Southern California (MWDSC) has continued to prepare and implement IRPs since the historic drought lasting from the late 80s – early 90s, which prompted rethinking of water resources planning in Southern California (The Metropolitan Water District of Southern California 2015). The City of Pasadena prepared an IRP to address critical water supply challenges and to improve water supply reliability and decrease dependence on Imported Water Supply (Pasadena Water and Power 2011).

The key elements of an IRP can be summarized as a comprehensive planning approach that incorporates least-cost analysis under a participatory decision making process (American Water Resources Association 2001; Boonin 2011; Palmer and Lundberg 2003). An IRP identifies and considers supply and demand management alternatives and includes analyses of economic, societal, scientific, and environmental concerns that balance the needs and objectives of competing resource users. Integrated resource planning also attempts to identify and manage risk and uncertainty (Gastelum et al. 2013).

For practical purposes, EVMWD's IRP methodology uses a collaborative approach to define a set of water resources goals and projects, which will enable EVMWD to accomplish its core mission: "To provide reliable, cost effective, high quality water and wastewater services that are dedicated to the people we serve." More specifically, the IRP considers six core goals: decrease dependence on imported water, create new water supply, increase supply reliability, promote reuse, improve water quality, and promote conservation.

In order to facilitate the IRP evaluation process and simulate different water supply scenarios, EVMWD implemented the use of a System Dynamics (SD)-Decision Support System (DSS) model. The first application of SD in water resources management, the Stanford Watershed Model, dates back almost 60 years (Forrester 1958; Winz et al. 2009). The Stanford Watershed Model was a comprehensive hydrological response process to simulate water flows and storage (Crawford and Linsley 1966). Winz et al. (2009) made a comprehensive review of SD application to water resources management. They emphasized the value of applying SD to integrated water resources regional analysis at different levels: regional (Cartwright and Connor 2003; Den Exter 2004; Guo et al. 2001; Leal Neto et al. 2006; Passell et al. 2003; Sehlke and Jacobson 2005; Xu et al. 2002), national (Simonovic and Fahmy 1999; Simonovic and Rajasekaram 2004), and global (Simonovic 2002). Long-term applications of river basin and watershed management aimed to evaluate the complexity of water resources components, including effects of population growth (Costanza and Ruth 1998; Ford 1996; Gastelum Perez 2006; Huerta 2004; Leal Neto et al. 2006; Peterson et al. 2004; Tidwell et al. 2004). Complex modeling of urban water resources management implemented to evaluate immediate and more problematic concerns (Bagheri 2006; Grigg and Bryson 1975; Passell 2004; Stave 2002; Wallace et al. 1988).

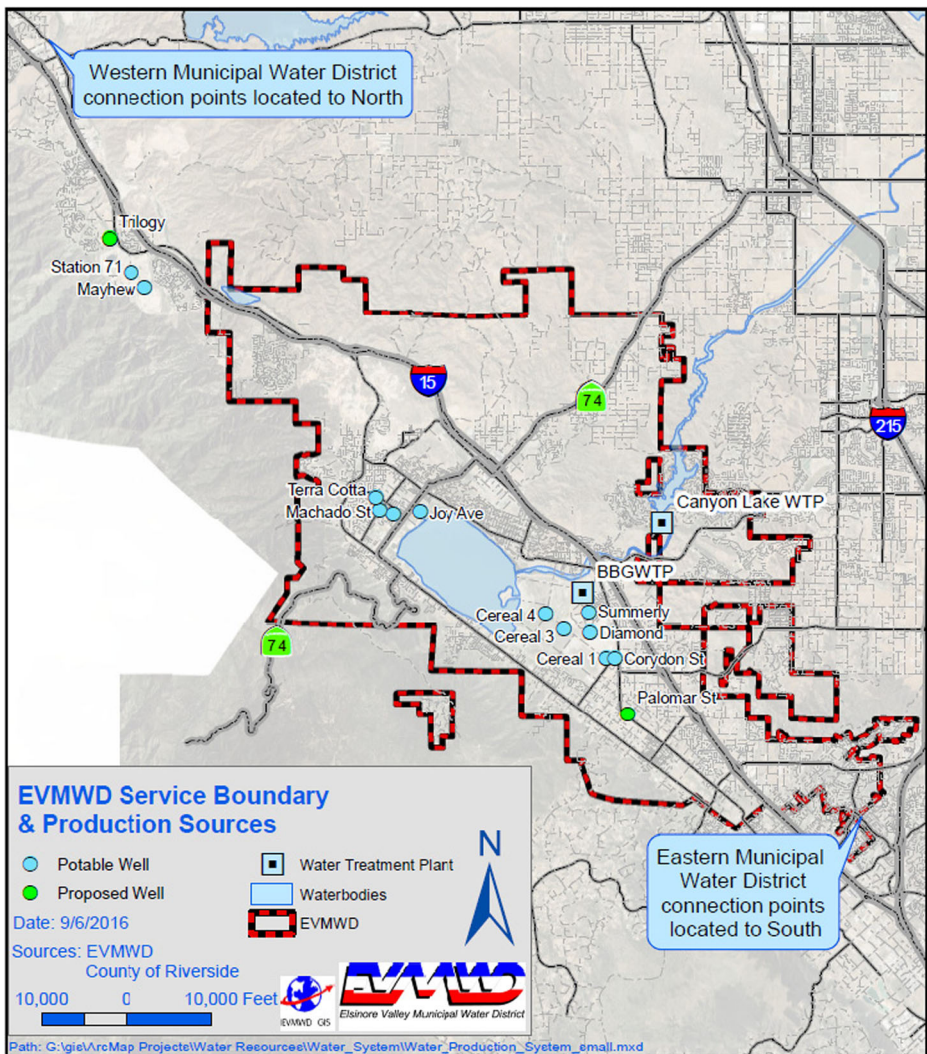
Even though SD has been extensively applied to many water resources planning modeling efforts, based on our literature review, there is not a documented case of SD modeling applied to an IRP project. As discussed by Winz et al. (2009), SD is emerging as a modeling tool to address the complexities of water resources systems dealing with multiple objectives, stakeholder participation and the efficient use of limited water supplies. The combined application of SD and IRP will better address the complexity of water resources systems, particularly in southern California where many water utilities are embracing the application of IRP and modeling techniques given the adverse impacts on water supply from droughts experienced in the region.

## 2 Background: EVMWD Service Area, Historical Water Use, and Future Water Requirements

EVMWD is located in Southern California in the western portion of Riverside County, one of the fastest growing areas in California (Fig. 1). EVMWD provides water and wastewater services to 148,587 residential customers, and to 3767 institutional, commercial, and industrial users in the cities of Lake Elsinore, Canyon Lake, Wildomar, and parts of Murrieta, Corona, and unincorporated areas of Riverside County. The current water demand is approximately 31.4 million of cubic meter per year (MCM/yr) (25,500 acre-feet per year (AFY)). The water demand is expected to double by 2040.

Local groundwater, extracted from Elsinore Valley Groundwater Basin (EVGB) and Coldwater Basin, accounts for approximately 22% of EVMWD's water supply (considering the period 2011 to 2015). Surface water from Canyon Lake Reservoir is treated at the Canyon Lake Water Treatment Plant (CLWTP) and accounts for approximately 8% of the current water supply portfolio. Imported water purchased from MWDSC through Western Municipal Water District (WMWD), accounts for approximately 70% of EVMWD's water supply.

By 2040, population in the EMWD's service area will approach 238,300, representing an increase of more than 100,000 inhabitants (60% increase, as compared to current population).



**Fig. 1** EVMWD service boundary

At the end of the planning horizon (2040), the estimated water demand will be around 63.6 MCM/yr. (51,600 AFY) (MWH 2015). The current total water supply is 43.8 MCM/yr. (35,486 AFY). Based on demand projections, the total water supply deficit in 2040 would be 19.9 MCM/yr. (16,114 AFY). The IRP considers several supply alternatives to overcome the projected water supply deficit and more specifically, recommends a preferred water supply portfolio.

### 3 Methodology

The process to identify the most optimal water supply portfolio is composed of three main areas: IRP, ranking and weighting factors for evaluation criteria, and the Water Resources Decision Support System (WRDSS) model. The IRP is the core component of the

methodology. Ranking and weighting factors are the key quantitative elements used in the IRP to select the best water supply portfolio. The WRDSS model was used as part of IRP as a quantitative tool to enhance the identification of the best water supply portfolio. The following paragraphs provide further detail for each of these discussed three main areas.

### 3.1 IRP

The initial phase of the IRP process involved collaboration with both internal and external stakeholders, including the EVMWD Board of Directors (Board). A workshop was held with the Board to describe the IRP's purpose and process; and engage the Board in meaningful dialogue regarding current water resource management issues, such as drought and climate change. Through a series of questions and directed discussion, the Board set the following objectives to be met by the IRP: create new water, improve water quality, increase supply reliability, improve groundwater management, decrease dependence on imported water supply, promote conservation, and promote reuse.

Each objective contributes to improved water supply reliability for the Elsinore Valley by ensuring that adequate supplies are available to meet current and future water demands. The ultimate outcome of the IRP process is to identify an optimal and cost-effective supply portfolio that guarantees a reliable water supply to meet future water demands.

IRP's evaluation methodology consists of three steps: Identification of potential water supply options, project evaluation, and recommendation of water supply portfolio. The first step considers all potential water supply options. In this step, 44 new water supply source alternatives, with a total yield of 71.2 MCM/yr (57,713 AFY) were defined. The potential project list is comprised of projects identified in previous water supply studies, and as a result of feedback from staff, the Board, and consultants.

The second step consists of the project evaluation and eliminating mutually exclusive projects. The projects are quantitatively evaluated using a methodology that combines ranking and weighting factors for specific evaluation criteria: Average Year Supply Capacity, Water Supply Reliability, Water Quality, Cost, Implementability, and Environmental Impacts.

The evaluation criteria and ranking associated with each alternative are presented in Table 1. The rankings for capacity, water quality and cost were linearly interpolated between the maximum and minimum values for those particular criteria. Individual project scores were then developed, taking into account the rankings as well as the relative importance of each evaluation criteria. This approach allowed EVMWD to identify the top ranked projects based on source.

**Table 1** Supply alternative evaluation criteria and ranking

Evaluation criteria	Ranking			
	1	2	3	4
Average year supply capacity MGD	Minimum			Maximum
Water supply reliability	Low			Higher
Water quality: TDS (mg/L)	Maximum			Minimum
Cost (\$/acre-ft)	Maximum			Minimum
Implementability (Regulatory/Technical/Financial/Public process constraints)	Severe	Multiple	Some	None
Environmental impacts	Major	Moderate	Minor	None



The third step evaluated a series of water supply portfolios or scenarios to determine the sensitivity of the combination water supply projects. The evaluation of these scenarios considers the same methodology to eliminate mutually exclusive projects. Also, by using EVMWD’s WRDSS model, the following additional criteria was used to evaluate performance of each scenario: Salinity expressed in terms of Total Dissolved Solids (TDS) in mg/L, Unit Cost of water, Reliability under historical hydrologic conditions, and Projected cumulative supply deficit under historical hydrologic conditions. This approach allowed EVMWD to identify the optimum portfolio that would meet the overarching objectives of this IRP.

### 3.2 Ranking and Weighting Factors for Evaluation Criteria

Weighting factors were developed for the evaluation criteria based on feedback obtained in workshops with EVMWD’s executive management and its Board. Evaluation criteria were ranked on a scale from 1 to 6, with 1 being the highest and 6 being the lowest. The ranking results are shown in Table 2. It is important to highlight that each member provided his or her ranking preference independently and anonymously.

By using this ranking preference, the weighting factors for each of the criteria were estimated. Weighting factors range from 1 to 20 with 20 being the highest. Water supply reliability has the highest preference (18.1), followed by capacity and cost with a weighting factor of 13.6 and 13.3 respectively. Water quality, implementability, and environmental criteria received the lowest preference with weighting factors of 11.2, 10.9, and 5.6, respectively.

The project scores, used to identify the highest ranked projects, are calculated by multiplying the criteria ranking by the weighting factor, which is dependent on the importance of the particular criteria.

$$PS_k = \sum_l \left( PSmin_l + \left( \frac{p_{kl} - pmin_{kl}}{pmax_{kl} - pmin_{kl}} \right) (PSmax_l - 1) \right) Wf_l + \sum_m \left( PSmax_m + \left( \frac{p_{km} - pmin_{km}}{pmax_{km} - pmin_{km}} \right) (PSmax_m - 1) \right) Wf_m + \sum_n PSsub_n (PSmin_n : PSmax_n) Wf_n \tag{1}$$

Where:  $PS_k$ = Score value for project k;  $PSmin_l$ = minimum value for evaluation criteria l (capacity and reliability);  $PSmin_m$ = minimum value for evaluation criteria m (water quality and cost);  $PSmin_n$ = minimum value for evaluation criteria n (implementability and environmental);  $PSmax_l$ = maximum value for evaluation criteria l;  $PSmax_m$ = maximum value for evaluation criteria m;  $PSmax_n$ = maximum value for evaluation criteria n;  $p_{kl}$ = value of evaluation

**Table 2** Ranking preferences for project evaluation criteria

Criteria	Ranking preference												
	M1	M2	M3	M4	M5	M6	M7	B1	B2	B3	B4	B5	
Capacity	3	2	4	5	5	3	3	2	3	2	3	1	
Reliability	2	1	1	1	1	2	1	1	5	1	1	2	
Water quality	4	4	5	3	6	5	2	3	1	3	5	4	
Cost	1	5	2	2	4	4	4	4	2	4	2	3	
Implementability	5	3	3	4	2	1	5	2	6	6	4	5	
Environmental	6	6	6	6	3	6	6	6	4	5	6	6	

M = Executive Management Participant; B = Board of Directors Participant

criteria  $l$  for project  $k$ ;  $p_{km}$  = value of evaluation criteria  $m$  for project  $k$ ;  $p_{min_{kl}}$  = minimum value of evaluation criteria  $l$  among all projects  $k$ ;  $p_{min_{km}}$  = minimum value of evaluation criteria  $m$  among all projects  $k$ ;  $p_{max_{kl}}$  = maximum value of evaluation criteria  $l$  among all projects  $k$ ;  $p_{max_{km}}$  = maximum value of evaluation criteria  $m$  among all projects  $k$ ;  $W_{f_l}$  = weighting factor for evaluation criteria  $l$ ;  $W_{f_m}$  = weighting factor for evaluation criteria  $m$ ;  $W_{f_n}$  = weighting factor for evaluation criteria  $n$ ; and  $PS_{sub_n}$  = subjective ranking assigned to evaluation criteria  $n$  between  $PS_{min_n}$  and  $PS_{max_n}$ .

### 3.3 WRDSS Model

Because of its usefulness in understanding future performance of complex economic and social systems, such as water resources systems, and given its graphical-friendly and object-oriented simulation tools that allows to represent these systems in a series of components or submodels, several authors have emphasized the importance of using an SD approach to derive at sound model business policy and strategy (Smith and Van Ackere 2002; Xu et al. 2002; Gastelum Perez 2006; Gastélum et al. 2010). The use of SD has provided traction for resource managers in two main areas: 1) Integration of water resources planning scenarios to better understand their quantitative impacts in the system and 2) Educate and facilitate group discussions in efforts associated with water resources management and planning (Gastélum et al. 2013).

In 2009, EVMWD developed a SD based WRDSS to optimize short-term potable water supply operations with different supply sources (groundwater, surface water, and imported water) (MWH 2009). This WRDSS is a lumped semi-distributed model operating on a daily time step basis created using Goldsim Software. The main elements of SD simulation models are: causal loops, which are used to represent the positive or negative feedback structure existing among the different elements of the system and stocks and flows, which are used to symbolize the different variables (elements) forming the system (Smith and Van Ackere 2002).

Given that the model was created around five years ago and considering the current IRP goals, the DSS model was updated to incorporate changed conditions of the water resources system and re-design of certain components of the model in order to execute long-term scenario simulations; in addition to the current model's short-term simulation capability. The updated DSS model will be capable of evaluating different scenarios to examine EVMWD's vulnerability to different risks (e.g. impacts of imported water shortage conditions, future costs of imported water supplies, etc.), water demand (evaluating different, plausible, water demand scenarios), and water quality (variation of TDS due to different blends of water supplies and potential implementation of desalters). Figure 2 provides a schematic of EVMWD's water resources system represented in the WRDSS model. The model also captures constraints within EVMWD's water distribution system such as capacity constraints, water quality constraints, etc.

With the development of the IRP to assist project scenario evaluation, the WRDSS model was recently updated to include new programs such as MWD's Conjunctive Use Program. The WRDSS model allows EVMWD to evaluate different scenarios and examine EVMWD's vulnerability to risks such as water supply shortages, water quality and changing water demand conditions.

The Daily Water Demand subcomponent is the most relevant WRDSS model subcomponent used for the estimation of water supplied from each evaluated alternative. The daily demand subcomponent minimizes the cost of supplying users' daily demand subject to different constraints: maximum daily capacity of each water supply, maximum yearly allocation of each water supply, etc.

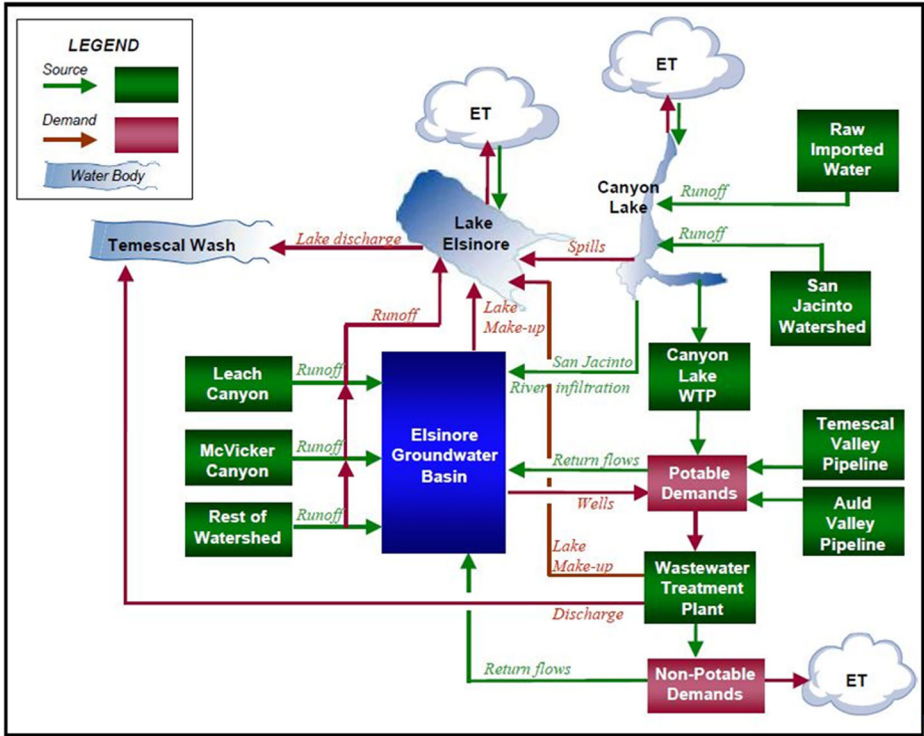


Fig. 2 EVMWD's water resources system

$$\text{Min } \sum_i UC_i DWP_i \text{ in US Dollars} \tag{2}$$

Subject to:

$$\sum_i DWP_i \leq DW \tag{3}$$

$$DWP_i \leq \text{MaxDC}_i \tag{4}$$

$$\sum_j DWP_{ij} \leq \text{MaxYW}_i \tag{5}$$

Where:  $UC_i$ = Unit cost of water supply  $i$ ;  $DWP_i$ = Daily Production from Water Supply  $i$ ;  $DW_i$ = Total Daily Water Demand;  $DWP_i$ = Daily Production from Water Supply  $i$ ;  $\text{MaxDC}_i$  = Maximum Daily Capacity Production from Water Supply  $i$ ;  $\sum_j DWP_{ij}$ = Daily (j) Cumulative Production through the year from Water Supply  $i$ ; and  $\text{MaxYW}_i$ = Maximum yearly allocation or availability from water supply  $i$ .

#### 4 Analysis: Selection of Water Supply Portfolio

In order to offset the deficit of approximately 19.9 MCM/yr. (16,114 AFY) by 2040, the IRP considered 44 supply alternatives covering different supply sources such as untapped



groundwater basins, indirect potable reuse, seawater desalination, water exchanges and transfers, continued water conservation, etc. Each alternative was given a score for each category (with applied weighting based upon its relative importance), and then ranked based upon the sum of all its scores (Eq. 1). The supply alternative evaluation is aimed to eliminate mutually exclusive projects and select the top ranked projects based on sources which are then utilized to develop scenario based portfolios to offset the supply deficit identified for the planning horizon (year 2040).

Seven scenarios, each targeting a specific goal as outlined in the objectives of the IRP, were developed for further analysis. The goal of this final step was to identify EVMWD's water supply portfolio for the next 25 years.

**Scenario 1 – Status Quo.** This scenario represents no change to the current dependence on imported water supply to meet future water demands. Approximately 70% of the total water supply is imported water delivered via a proposed expansion of the Temescal Valley Pipeline (TVP).

**Scenario 2 – Other Imported Water.** This scenario considers other water supplies in lieu of imported water such as that obtained by desalinating ocean water. Approximately 75% of the total water supply would be delivered via seawater desalination.

**Scenario 3 – Maximize Local Resources.** This scenario considers local water supply projects intended to maximize EVMWD's groundwater and surface water assets. Approximately 49% of the water in this scenario is made up of local supplies.

**Scenario 4 – Minimize Salinity (TDS).** This scenario minimizes total salinity levels (represented by TDS concentrations) in EVMWD's composite water supply. These projects represent 89% of the total water supply in this scenario.

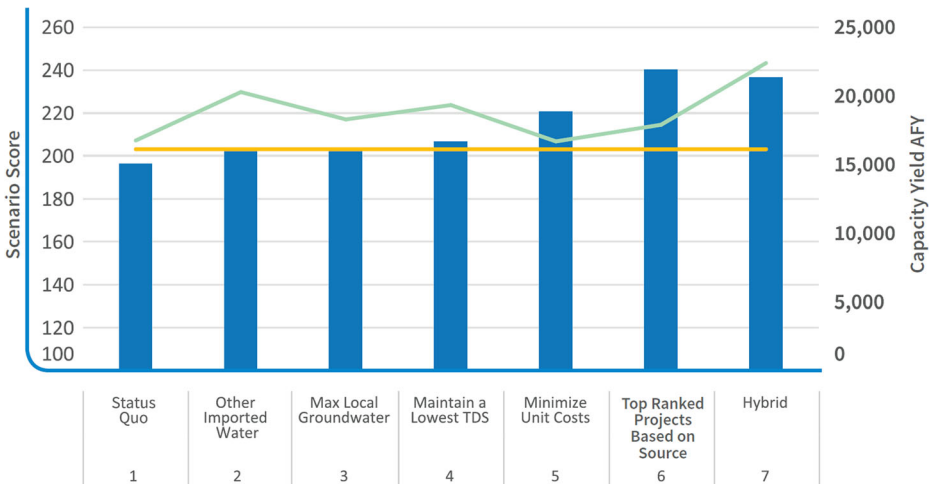
**Scenario 5 – Minimize Unit Costs.** This scenario considers a water supply portfolio that has the lowest unit cost.

**Scenario 6 – Top ranked projects based on source.** This scenario represents the top ranked projects based on source (elimination of mutually exclusive projects) from the 44 projects considered to offset EVMWD's future water supply deficit based on weighting factor.

**Scenario 7 – Hybrid.** This scenario considers a supply portfolio that offers the greatest reliability at a reasonable cost. This is accomplished by modifying the supply portfolio identified as part of Scenario 6 to include additional local supply projects.

Figure 3 shows the scores for each scenario, along with their total water supply yield. Each scenario generates sufficient yield to satisfy the long-term water supply deficit of 19.9 MCM/yr. (16,114 AFY). Scenarios 5, 6 and 7 have the highest scores. The performance metrics associated with each scenario are presented in Table 3, which were obtained by running EVMWD's Water Resources Decision Support System (WRDSS) model by implementing a probabilistic simulation.

Based on the WRDSS model results (Table 3), Scenario 7 has the highest water supply reliability relative to the other scenarios. This scenario also optimizes the use of EVMWD's local water supply assets, has a competitive unit cost relative to current and forecasted imported water costs, and has one of the lowest TDS values – a critical factor for EVMWD given the regulatory and financial implications of TDS management in the groundwater basins. Given these results, Scenario 7 (Hybrid) represents the recommended water supply portfolio (Table 4) for implementation.



**Fig. 3** Scenario comparison by rank

The recommended supply portfolio will be implemented in three phases: short- (low hanging fruit), medium-, and long-term. Phasing for the implementation of the supply projects is flexible to adapt to water supply uncertainties inherent to California.

## 5 Discussion: Water Supply Portfolio Implementation and Adaptive Management

In order to address uncertainty, EVMWD will implement a multi-faceted approach by implementing an adaptive management approach to adjust to changing conditions, coupled with long-range resource management policies that optimize water supply and storage assets in times of both drought and surplus. Adaptive management includes two main components: Core Resources Strategy and Adaptive Resources Plan.

**Core Resource Strategy:** EVMWD will focus on implementing the recommended portfolio, increasing long-term water supply reliability by reducing reliance on imported water supplies. This core resource strategy includes a 10% supply buffer to meet future uncertainties.

**Adaptive Resource Plan:** EVMWD's resources management strategies will focus on the following areas: Long-term groundwater storage in the Elsinore Basin, Drought management and response, continued water conservation, and acquiring strategic water assets. The implementation of certain programs will be initiated by certain triggers that indicate a change in conditions. EVMWD's WRDSS model will be used to evaluate change conditions and establish the implementation and timing for these predefined programs.

**Long-Term Groundwater Storage in the Elsinore Basin:** Since 2010, EVMWD has stored approximately 9.9 MCM (8000 AF) of imported water during wet periods and extracted the same amount during the periods of drought. Given the success of this program and the large storage potential in the Elsinore Basin, long-term groundwater storage will be a key component of EVMWD's adaptive management strategy. EVMWD may utilize a combination

**Table 3** Performance metrics for each scenario

	1. Status Quo	2. Other imported water	3. Maximum local groundwater	4. Maintain the lowest TDS	5. Minimize unit costs	6. Highest rank	7. Hybrid
TDS (ppm)	518	524	508	478	546	500	506
Cost (\$/AF)	\$912	\$3616	\$768	\$950	\$630	\$1265	\$1110
Reliability	0.95–0.99	0.97–1	0.98–1	0.98–1	0.99–1	0.99–1	1
Deficit (AFY)	44,798	22,788	16,982	21,123	12,424	5389	710

of imported water supplies and local Canyon Lake surface water for the purposes of groundwater storage. EVMWD may also choose to expand the existing conjunctive use program with MWDSC or participate in regional dry-year-yield programs with the intent of storing water in the Elsinore Basin.

For planning purposes, water management experts assume that a 10-year hydrologic cycle in California is comprised of three wet years, four normal years, and three dry years. A 10-year storage program would consider recharging a total of 12.36 MCM (10,000 AF (2.5 MCM (2000 AF) each wet year, and 1.2 MCM (1000 AF) each normal year). This volume was defined considering that during the dry years EVMWD will experience a water shortage condition of around 10% of current water consumption. Consequently, extraction of stored water will be implemented during each of the three dry years at rate of 4 MCM (3333 AFY).

**Table 4** Summary of recommended portfolio

Projects	Capacity (mgd)	Average yield (AFY)	Dry year yield (AFY)	Reliability	Capital cost (Million dollars)	Annual O&M cost (\$)	Unit cost (\$/AF)	TDS (mg/L)
1 J. Transfer Bunker Hill Basin Groundwater via Riverside and Corona	5.56	6223	6223	1.00	30.6	3,547,000	847	400
2A-1. Pump Lee Lake Basin Groundwater via the TVP. No Salt Removal Treatment	0.89	1000	500	0.50	11.3	227,000	593	800
2A-2. Pump Bedford Groundwater via the TVP. No Salt Removal Treatment	1.37	1300	1045	0.80	6.6	345,000	542	800
3D. Palomar Well Replacement	0.50	560	560	1.00	3.1	106,000	496	400
4A. Extract Groundwater from Warm Springs Basin - No Salt Removal Treatment	0.89	1000	1000	1.00	6.9	428,000	794	1000
5E. Modify Operation of Canyon Lake	2.5	1500	1125	0.75	5.9	502,000	589	800
10B. Indirect Potable Reuse at Regional WRF. Injection/Extraction with AWT	6.00	5700	5415	0.95	132.1	5,707,000	2515	100
11. Temecula-Pauba Groundwater	1.79	2000	2000	1.00	7.8	328,000	375	725
12B. Implement Increased Water Conservation Measures - Enhanced	0.00	3100	3100	1.00	–	1,240,000	400	450
Total	24	22,383	20,968	0.93	203.5	12,778,000	1110	506

**Drought Management and Response:** In 2015, EVMWD updated its existing Water Shortage Contingency Plan (WSCP) in order to make it consistent with that of regional water suppliers. The WSCP establishes triggers for the implementation of demand reduction measures based on regional water shortages. The WSCP also empowers EVMWD to implement surcharges and penalties to promote conservation and penalize waste during regional shortages.

**Continued Water Conservation:** The success of EVMWD's water conservation program is demonstrated by the overall reduction in per capita water use since 2007. EVMWD will continue to enhance its on-going conservation program by continuing its robust outreach, partnering with developers to promote water efficiency, and incentivizing water conservation as approved by EVMWD's Board of Directors.

**Acquiring Strategic Water Assets:** On a pro-active basis, EVMWD will review on-going and proposed regional and statewide water programs. As part of this effort, EVMWD will work closely with WMWD and may participate in groundwater banking programs outside its service area, purchase permanent water rights on the open market, participate in regional desalination programs etc.

While the effects of climate change cannot be accurately predicted, EVMWD's core resource strategy as well as its adaptive resource framework will assist EVMWD in reliably meeting the long-term water demands within its service area.

## 6 Conclusions

The recommended portfolio shown on Table 4 represents the most cost effective option. It meets the forecasted long term deficit and provides the best reliability while providing good quality water supplies to EVMWD's customers. EVMWD's goal of maximizing its local water supply assets to offset the gap between supply and demand is a responsible approach from a local, regional, and statewide perspective. Investments in innovative projects such as the Indirect Potable Reuse will diversify EVMWD's water supply portfolio. In addition, expanding EVMWD's existing conjunctive use program and participating in regional conjunctive use projects will allow EVMWD to adapt to the uncertainties associated with climate change.

While uncertainties such as climate change, economic cycles, environmental issues associated with the Delta, and emerging water quality concerns will continue to affect Southern California's water landscape, the water supply strategy set-forth in this IRP will ensure that EVMWD is able to successfully meet its mission of providing reliable, cost-effective, high quality water and wastewater services within its service area.

Separately, both IRP and SD methods have been extensively applied to many water resources planning and managing efforts. This research effort focused on combining the two methods to provide a more robust water supply portfolio selection, by leveraging a collaborative decision-making process with the use of sophisticated benefit cost and uncertainty analysis techniques. These methods will continue to be an invaluable tool for evaluating a variety of plausible water resources scenarios, and will provide a framework to address uncertainty. The combined application of IRP and SD will increase in relevance, particularly in the Southwestern United States, a region prone to extensive drought conditions and potential climate change.

## Compliance with Ethical Standards

**Conflict of Interest** None.

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