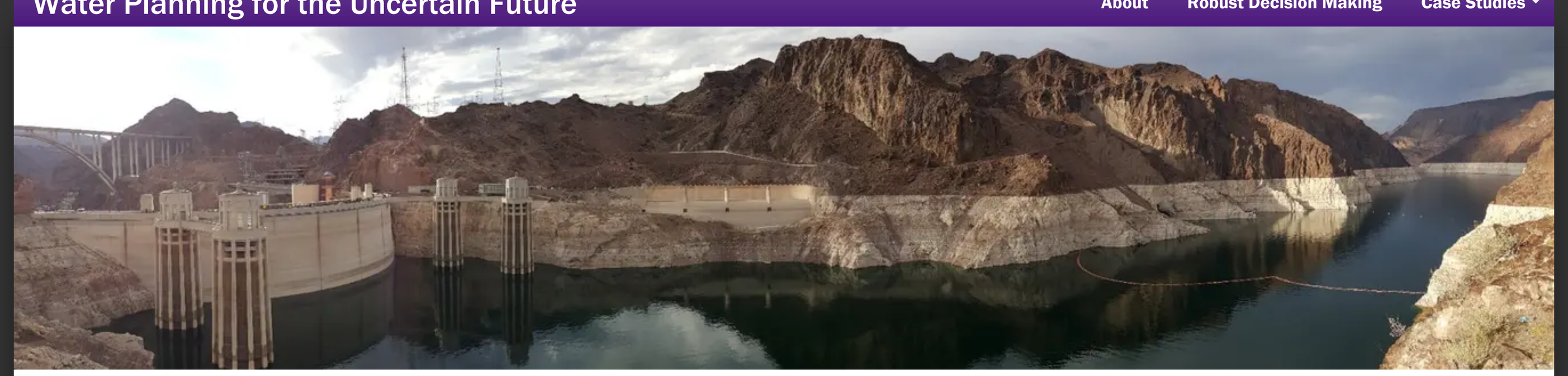


An Interactive Guide to the Use of Methods for Decisionmaking Under Deep Uncertainty (DMDU) for U.S. Bureau of Reclamation Water Resources Planning

In Collaboration with

BUREAU OF RECLAMATION

Water Resources Planning Is Changing

Water resources planning is becoming more challenging as the era of simply expanding supply to meet demand is replaced by integrated resources management, which must account for limits on new sources, variability or changes in supply and demand outside historical ranges, and competing needs from different users and uses (such as environmental and recreational needs).

Although water resources managers have always considered variability in their planning, uncertainty about future variability is increasing. Recent climatic shifts are likely to continue to affect water resources management in significant—but uncertain—ways. Degradation of species habitat and associated policy responses add further considerations for water resource managers.

At the same time, technological advances are making water use more efficient and upending traditional water-demand forecasting approaches. To ensure that water needs are met in the coming decades, traditional planning methods based on historical system characteristics must be augmented by forward-looking approaches that stress-test assumptions and plans in a wide range of conceivable futures. In other words, approaches and methods need to account for deep uncertainty—uncertainty that cannot be predicted or well understood using standard statistical methods.

Fortunately, new planning methods can evaluate how water management systems would perform across different assumptions about future supply availability, changes in demand, regulations, and other factors.

Robust Decision Making Approach

This tool provides information about Decisionmaking Under Deep Uncertainty (DMDU) methods and case studies that demonstrate various aspects of one particular DMDU approach: Robust Decision Making (RDM).

The goal is to help users gain sufficient familiarity with the methodology and techniques so that they can

- **determine** whether RDM (or another DMDU variant) is warranted for their own respective water-management studies
- **decide** which specific techniques are most appropriate
- **understand** the requirements and challenges for implementing RDM
- **assemble** the needed technical team and stakeholders to successfully apply RDM to their respective contexts.

This tool is designed to inform water managers at the U.S. Bureau of Reclamation and other agencies, but managers of other resources might find the information useful as a demonstration of how DMDU methods work to support planning under deep uncertainty. The tool can be used at any time in the water resource management planning process, but it is perhaps most helpful in the beginning stages of a new planning cycle, when the DMDU techniques described in the tool can be directly applied.

Importantly, applying DMDU techniques takes practice and training, and, therefore, the tool is not intended to substitute for experience; rather, the tool is intended to guide water managers to develop this experience for themselves. The Guidance on How Best to Apply DMDU section in the discussion of RDM describes how such experience can be cultivated.

This tool is best viewed on a desktop or laptop browser and is not intended for mobile or handheld devices.

Decisionmaking Under Deep Uncertainty

The challenge of planning in the face of deeply uncertain future conditions has given rise to a growing collection of concepts, tools, and techniques that have been termed *Decisionmaking Under Deep Uncertainty* (DMDU) methods. Rather than predicting the most likely future or deriving a plan or strategy that would perform best on average, these approaches seek robust strategies (i.e., strategies that perform well across a wide range of plausible assumptions about the future). These approaches are generally adaptive and include near-term investments and policies, signposts to monitor, and deferred investments and policies. The identification and implementation of robust strategies (1) ensures that planners do not make irreversible and regrettable choices today, such as investing to develop a new supply that does not provide expected yields or is unnecessary, and (2) establishes an iterative approach for adapting as the future unfolds.

DMDU methods differ from traditional planning and decisionmaking approaches in that they explicitly account for the fact that many decision drivers cannot be characterized statistically either because of their complexity or their newness. For example, recent global climate conditions are different from those observed over the previous century and are expected to change further in response to the accumulation of greenhouse gasses in the atmosphere. Other drivers of uncertainty include the introduction of water-saving technologies, such as smart meters or irrigation controllers, and future regulations aimed at managing scarcity and the environmental impacts of water use.

DMDU in Action

DMDU methods are actively being developed by numerous research groups across the world and include such approaches as

- RDM
- Many-Objective RDM (MORDM)
- Dynamic Adaptive Policy Pathways (DAPP)
- Decision Scaling
- Info-Gap.

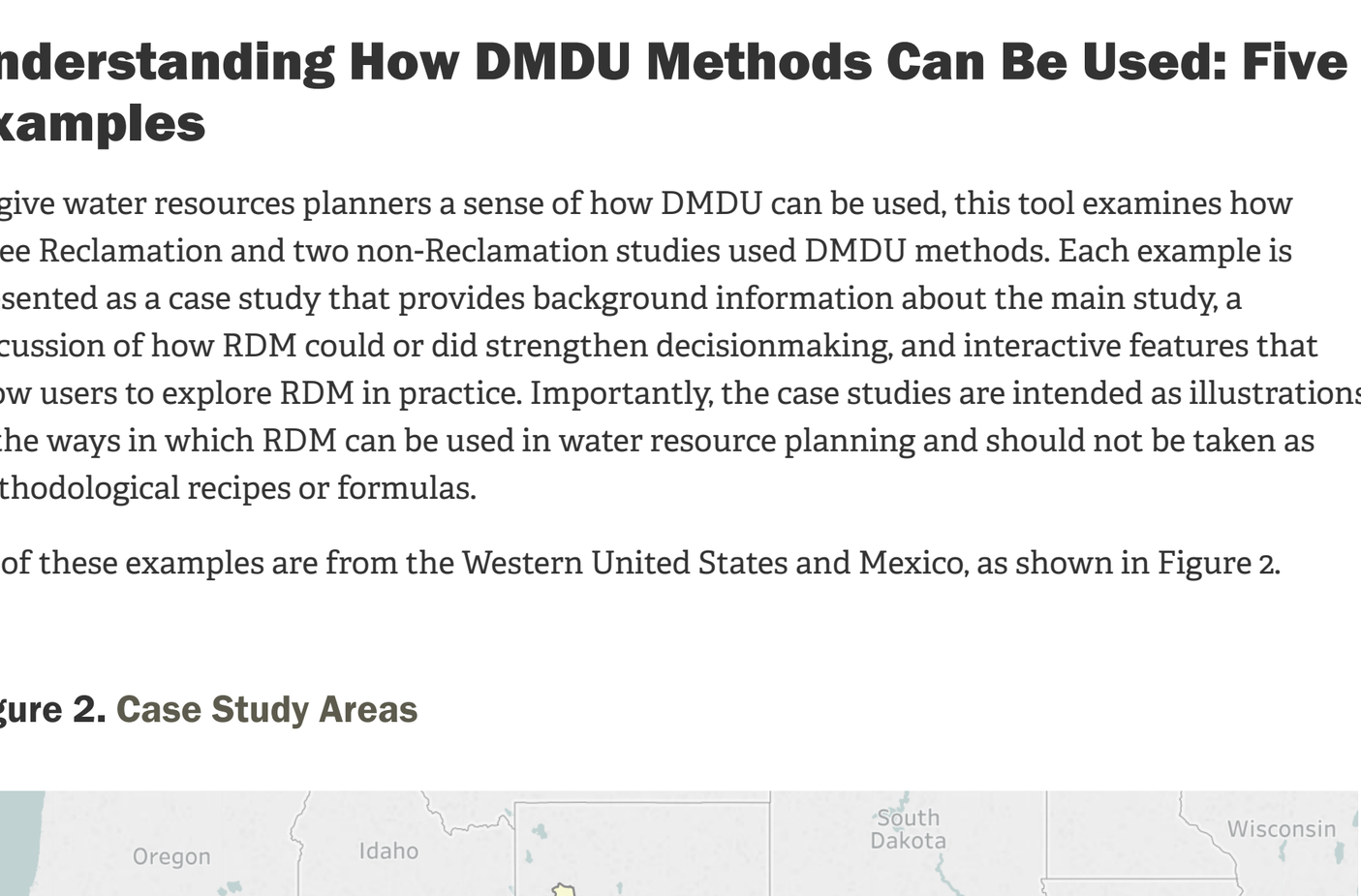
There are also several software tools to help implement DMDU methods, including

- Exploratory Modeling and Analysis (EMA) Workbench
- OpenMORDM (see also Hadka et al., 2015)
- SDToolkit.

A General and Customizable Approach to DMDU

RDM, which originally was developed by RAND Corporation researchers and now is advanced by researchers worldwide, is a fairly general framework that can be tailored to incorporate aspects of different DMDU methods. At the heart of RDM, and all DMDU methods, is an iterative, participatory, sequence of steps, as shown in Figure 1. Hover over each box to see a short description of each step, or review a more detailed description of RDM.

Figure 1. Iterative Steps of Robust Decision Making

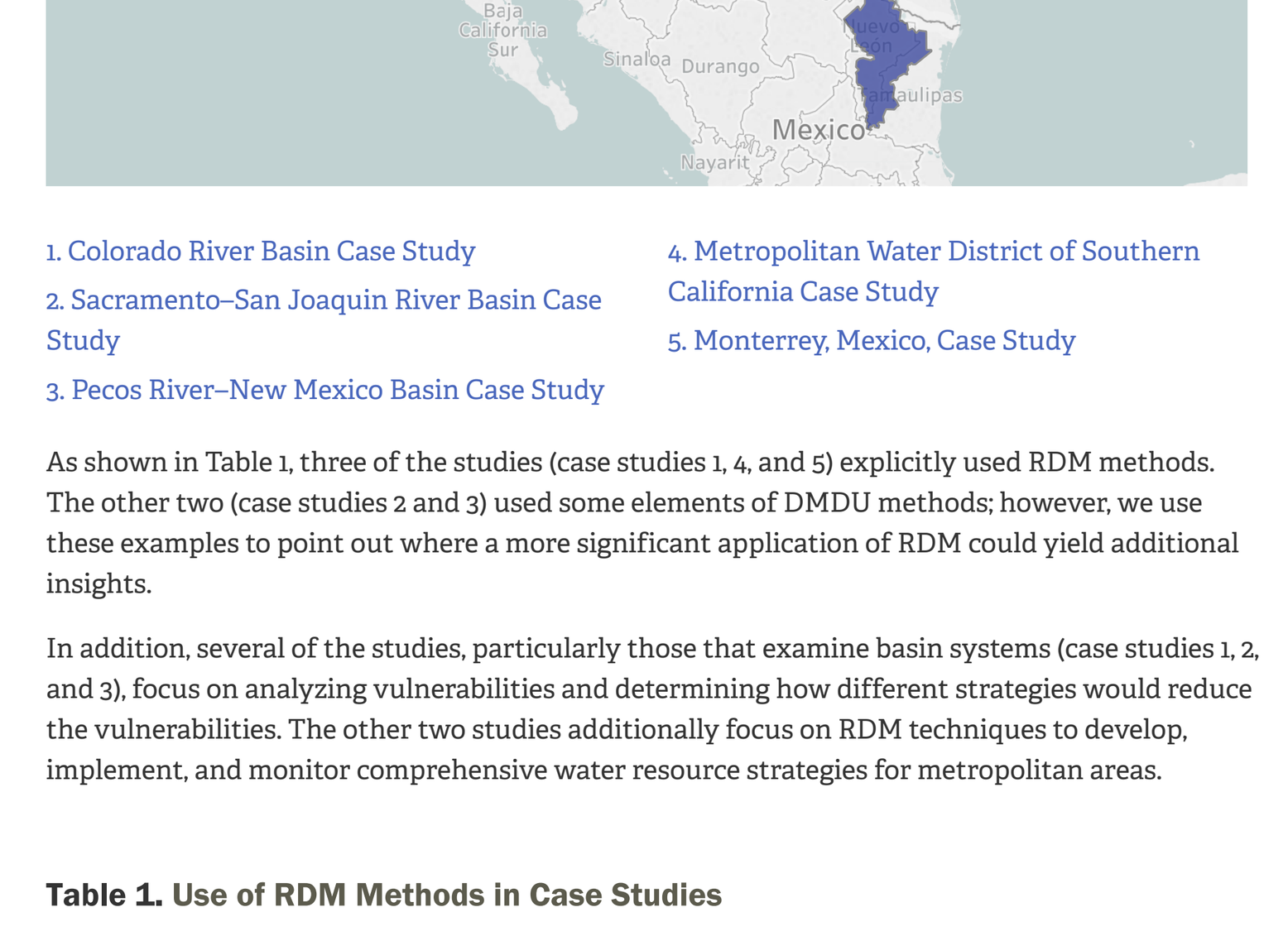


Understanding How DMDU Methods Can Be Used: Five Examples

To give water resources planners a sense of how DMDU can be used, this tool examines how three Reclamation and two non-Reclamation studies used DMDU methods. Each example is presented as a case study that provides background information about the main study, a discussion of how RDM could or did strengthen decisionmaking, and interactive features that allow users to explore RDM in practice. Importantly, the case studies are intended as illustrations of the ways in which RDM can be used in water resource planning and should not be taken as methodological recipes or formulas.

All of these examples are from the Western United States and Mexico, as shown in Figure 2.

Figure 2. Case Study Areas



1. Colorado River Basin Case Study
2. Sacramento–San Joaquin River Basin Case Study
3. Pecos River–New Mexico Basin Case Study
4. Metropolitan Water District of Southern California Case Study
5. Monterrey, Mexico, Case Study

As shown in Table 1, three of the studies (case studies 1, 4, and 5) explicitly used RDM methods. The other two (case studies 2 and 3) used some elements of DMDU methods; however, we use these examples to point out where a more significant application of RDM could yield additional insights.

In addition, several of the studies, particularly those that examine basin systems (case studies 1, 2, and 3), focus on analyzing vulnerabilities and determining how different strategies would reduce the vulnerabilities. The other two studies additionally focus on RDM techniques to develop, implement, and monitor comprehensive water resource strategies for metropolitan areas.

Table 1. Use of RDM Methods in Case Studies

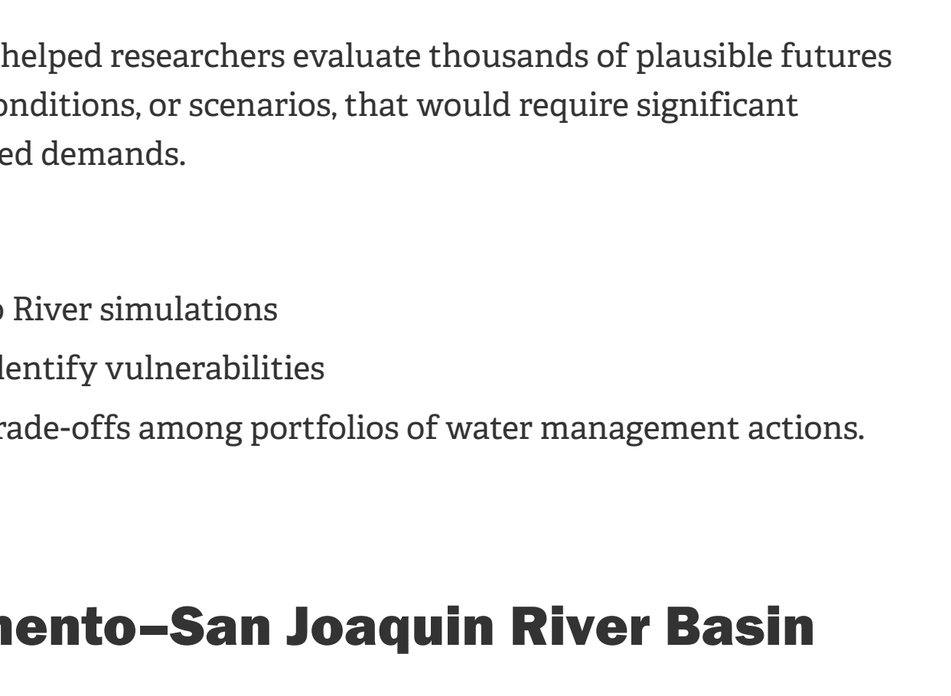
	Decision Framing	Evaluate Strategies Across Futures	Vulnerability Analysis	Trade-Off Analysis	New Futures and Strategies
1. Colorado River Basin Case Study	Explicit	Explicit	Explicit	Explicit	Explicit
2. Sacramento–San Joaquin River Basin Case Study	Implicit	Implicit	Notional	Implicit	Implicit
3. Pecos River–New Mexico Basin Case Study	Implicit	Implicit	Notional	Notional	Notional
4. Metropolitan Water District of Southern California Case Study	Explicit	Explicit	Explicit	Not included	Other
5. Monterrey, Mexico, Case Study	Explicit	Explicit	Explicit	Explicit	Explicit

Explicit: The original study explicitly undertook this step as part of a formal RDM analysis, and it aligns closely with the RDM methodology.
Implicit: The original study implicitly undertook this step; it was not formally part of an RDM analysis but serves the purpose of this step in an RDM analysis.
Notional: The original study did not involve this step. We have developed notional data or provided a notional discussion to illustrate how it could have been used.
Not included: Neither the original study nor the case study includes this step.

Different case studies use different kinds of visualizations, such as scatter plots, bar graphs, heat maps, tables, and decision trees. These choices reflect differences among the case studies in the kinds of information that needs to be communicated to facilitate stakeholder deliberations. Although a discussion of data visualization is beyond the scope of this tool, there are several good resources on data visualization that might be helpful.

Each case study is briefly described below, and links are provided to interactive pages where users can explore the studies in more detail.

Case Study 1. Colorado River Basin Case Study



The Colorado River Basin Water Supply and Demand Study (CRBS), which was published in 2012, was one of the first of a series of Reclamation-led basin studies examining water management conditions and adaptation options over the next five decades (through 2060). Working with representatives from the seven U.S. Colorado River Basin states and a consulting team, the CRBS team explicitly used RDM to support its evaluation of the Colorado River Basin's supply-and-demand imbalance and compare portfolios of management options under a variety of plausible future climate, demand, and operations conditions.

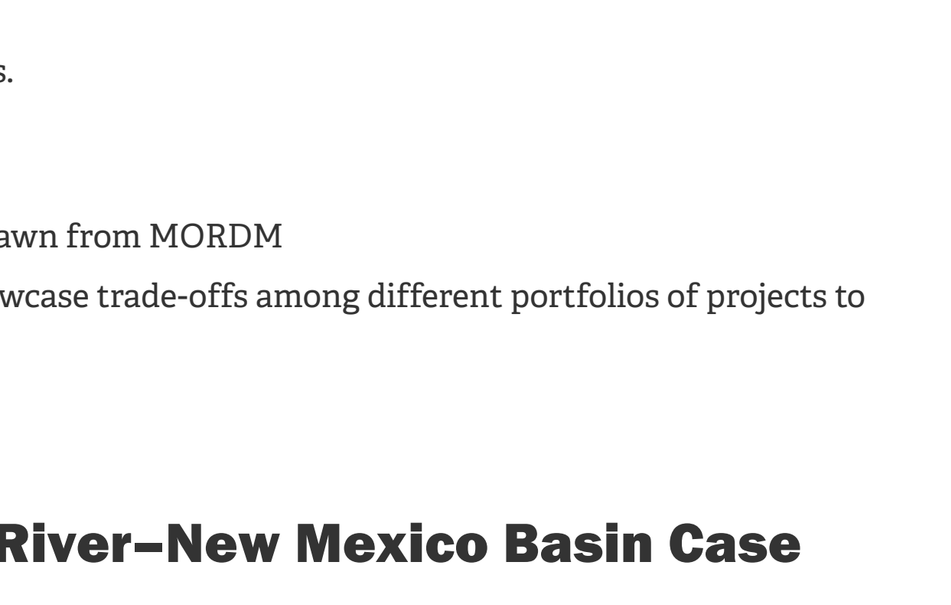
This case study focuses on how RDM helped researchers evaluate thousands of plausible futures and concisely define the key future conditions, or scenarios, that would require significant investments in new supplies or reduced demands.

Use this case study to

- explore a subset of the Colorado River simulations
- experiment with tools used to identify vulnerabilities
- interact with visualizations of trade-offs among portfolios of water management actions.

Explore case study →

Case Study 2. Sacramento–San Joaquin River Basin Case Study



Reclamation's Sacramento and San Joaquin Rivers Basin Study (SSJRBS) examined California's largest watershed and a key source of water throughout the Central Valley, Bay Area, and Southern California. The study, which was completed in 2014, took a comprehensive look at the potential impacts of climate change and mitigation strategies to the system. It used many elements of DMDU but in a different way than the CRBS. For this case study, the project team worked with staff from Reclamation's Mid-Pacific Regional Office to explore how some specific RDM techniques could be used to derive additional information about key vulnerable conditions, potential benefits across multiple objectives, and multiobjective trade-offs of different adaptations. Specifically, the case study focuses on the following three aspects of RDM:

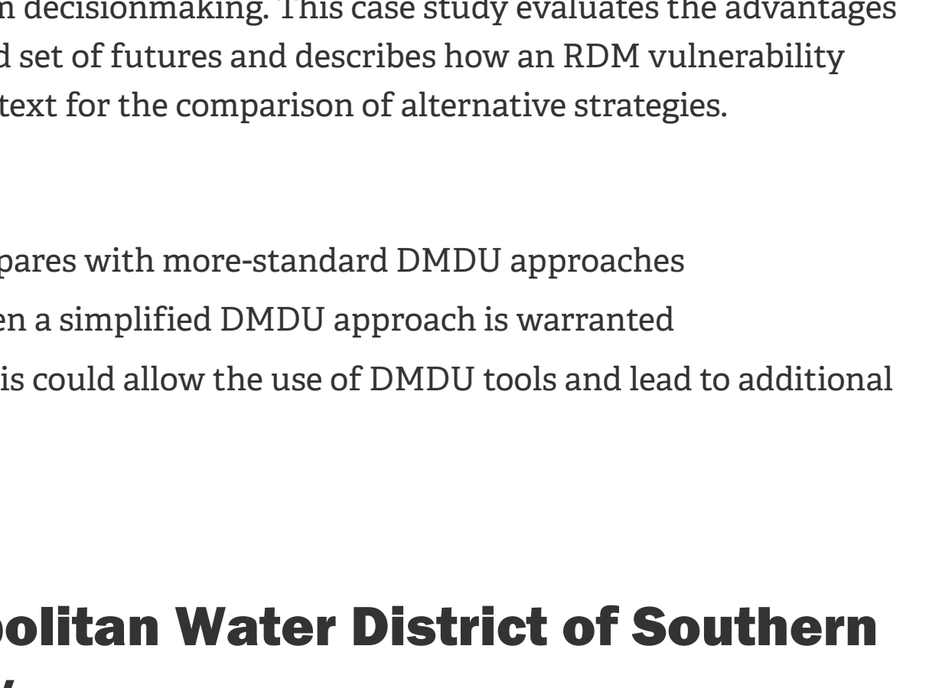
1. evaluating plausible futures
2. identifying vulnerabilities
3. comparing alternative strategies.

Use this case study to explore

- multiobjective visualizations drawn from MORDM
- interactive visualizations to showcase trade-offs among different portfolios of projects to reduce vulnerabilities.

Explore case study →

Case Study 3. Pecos River–New Mexico Basin Case Study



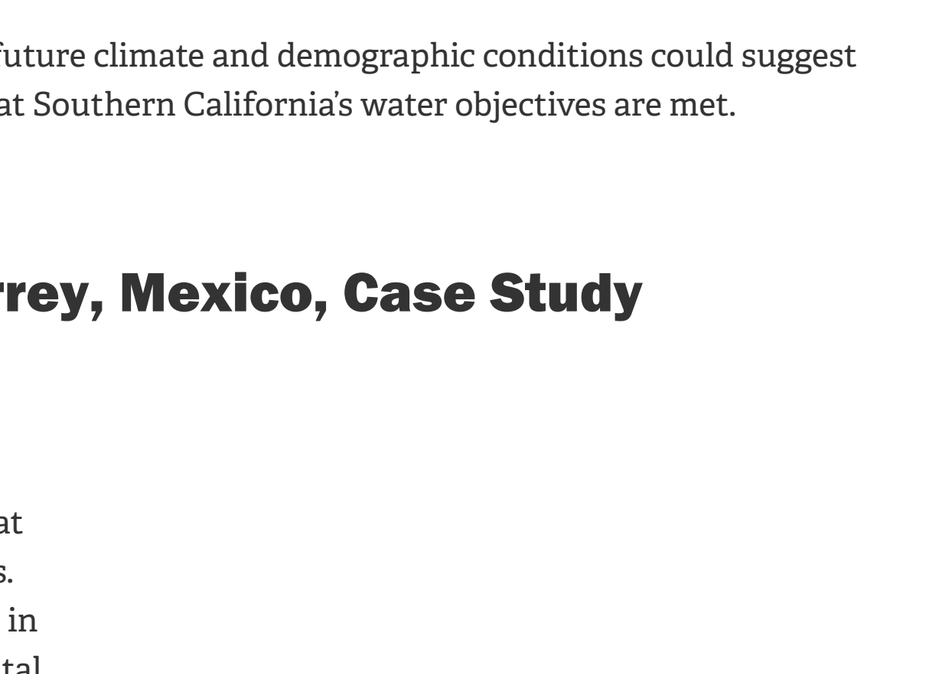
The Pecos River–New Mexico Basin Study (PRNMBS) is the most recent Reclamation basin study described in this tool. The PRNMBS used a scenario-planning approach that included many of the main elements of DMDU best practices. The PRNMBS team simplified some of the more complex analytical tasks of a standard RDM study by selecting five scenarios to represent uncertainty before evaluating the performance of the system. By doing so, the study team reduced the computational burden of evaluating the water management system across hundreds of different, plausible climate conditions. This approach led to results that are straightforward—how different adaptations would perform under the five scenarios. However, by using only a small set of scenarios, it is not easy to identify the thresholds that would help inform decisionmaking. This case study evaluates the advantages and limitations of exploring a reduced set of futures and describes how an RDM vulnerability analysis could provide additional context for the comparison of alternative strategies.

The case study also

- describes how this method compares with more-standard DMDU approaches
- develops some guidance for when a simplified DMDU approach is warranted
- describes how additional analysis could allow the use of DMDU tools and lead to additional insights.

Explore case study →

Case Study 4. Metropolitan Water District of Southern California Case Study



The Metropolitan Water District of Southern California (Metropolitan) 2015 Integrated Resources Plan (IRP) describes how Metropolitan could meet water demands over the next 25 years (through 2040) (Metropolitan, 2016a). A Metropolitan-funded study used RDM to evaluate the robustness of Metropolitan's 2015 IRP to a wide range of uncertain future trends. The findings were used to propose a monitoring approach that Metropolitan can use to adapt the IRP to future conditions. In addition to summarizing the RDM analysis, this case study examines how the results from the vulnerability analysis can inform an approach for monitoring IRP implementation.

Use this case study to game out how future climate and demographic conditions could suggest modifications to the IRP to ensure that Southern California's water objectives are met.

Explore case study →

Case Study 5: Monterrey, Mexico, Case Study

Planners in growing metropolitan regions in Latin America face many challenges in developing water resources–management strategies that will support current and future needs. These issues are particularly relevant in Monterrey, Mexico, the economic capital of northern Mexico and an important player in the economic industrial cluster across Mexico's border with the United States. A recent study, funded by Fondo de Agua Metropolitano de Monterrey (FAMM), used DMDU methods—specifically, RDM—to structure an analysis of water management vulnerabilities and develop a robust, adaptive water management strategy for Monterrey, Mexico. This case study summarizes the project and focuses on describing the identified robust, adaptive water management strategy.

Use this case study to

- compare strategies that emphasize different water management approaches in the near term
- explore how a robust strategy adapts over time to evolving hydrological conditions and water demand.

Explore case study →

About

This tool was developed as part of a collaborative U.S. Bureau of Reclamation and RAND Corporation project titled *Building Capacity for Addressing Climate Uncertainty in Long Term Planning and Decision Making*.

The project was overseen by Kenneth Nowak (of Reclamation's Research and Development Office) and managed by David Groves (RAND). Nidhi Kalra, Edmundo Molina-Perez, James Syme, and Chandra Garber contributed to the development of the case studies.

RAND Project Lead

No Results Found

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