METHODOLOGIES TO ESTIMATE
BASELINE (CURRENT) AZ WATER DEMANDS BY COUNTY

Current, or baseline, water demands will be established statewide by county for the most recent year with complete water use data (2006?). Current demands will be established for Municipal and Domestic, Industrial, Agriculture and Indian demands.

Municipal and Domestic

1. AMA

Municipal - 2006 municipal demands from AMA Assessments – will require some dividing of data by county. ***ADWR***

Domestic – For domestic uses not served by a water provider:

a. Query the WELLS55 database to count the number of exempt and non-exempt domestic wells. ***ADWR***
b. Plot well locations on land use maps that distinguish rural/unincorporated from urban/incorporated areas (SWGAP or Census GIS covers) ***ADWR/Reclamation***
c. Estimate domestic use based on a water use per exempt and non-exempt well (could be different for urban and rural water users). ***Municipal Subcommittee***

2. Non-AMA

Municipal – 2006 municipal demands from Community Water System (CWS) reports – these data are already stored by county. ***ADWR***

Domestic - For domestic water uses not served by a water provider:

a. Query the WELLS55 database to count the number of exempt and non-exempt domestic wells. ***ADWR***
b. Plot well locations on land use maps that distinguish rural/unincorporated from urban/incorporated areas (SWGAP or Census GIS covers) ***ADWR/Reclamation***
c. Estimate domestic use based on a water use per exempt and non-exempt well (could be different for urban and rural water users). ***Municipal Subcommittee***

3. Identify which water sources (groundwater vs. surface water vs. CAP vs. effluent) are used to meet municipal/domestic demands.

Industrial

1. **AMA** - 2006 industrial demands from AMA assessments – will require some dividing of data by county. ***ADWR***

2. **Non-AMA** – 2006(?) industrial demands from the AZ Water Atlas – should not be a major effort to regroup data by basin. ***ADWR***
   a) Power plants

b) Major mines
c) Sand and gravel operations
d) Feedlots/dairies
e) Golf courses

3. Identify which water sources are used to meet industrial demands.

Agriculture

1. **AMA** - 2006 agricultural demands from AMA assessments – will require some dividing of data by county. ***ADWR***

2. **Non-AMA** – 2006 agricultural demands outside of the AMAs based on GIS data collected and compiled by the USGS and ADWR for the AZ Water Atlas and by the Reclamation for its appraisal studies. ***USGS/ADWR/BOR***
   a. Field boundaries
   b. Crop types
   c. Irrigation system
   d. Consumptive uses and system efficiencies

3. Identify which water sources are used to meet agricultural demands.

Indian

1. **AMA** - 2006 tribal municipal, industrial and agricultural water demands from AMA assessments – will require some dividing of data by county. ***ADWR***

2. **Non-**AMA Average Year 2001-05 (no 2006?) tribal water demands outside of the AMA based on AZ Water Atlas. ***ADWR***

3. Identify which water sources are used to meet Indian demands.

METHODOLOGIES TO ESTIMATE
PROJECTED (FUTURE) AZ WATER DEMANDS BY COUNTY

Future demands will be established based on projected population and assumptions for Municipal and Domestic, Industrial, Agriculture, and Indian Demands. Assumptions for future demands will be established by the appropriate sub-committee and reviewed and approved by the Water Supply/Demand Working Group and the Water Resource Development Commission (WRDC).

.

Future demands will be projected for 2035, 2060, 2085 and 2110.

Recent studies provide guidance on selecting future demand assumptions:

a) *AMA Assessments*
b) *BOR Appraisals*
c) *Colorado River Basin Study*
d) *Water provider plans (CAP, SRP, City of Phoenix, Tucson Water, etc)*
e) *Reservation master plans.*

Municipal and Domestic Demands (Subcommittee)
Based on population estimates by WRDC Population Committee, estimate future Gallons per Capita per Day (GPCD) values (may be different for rural and urban areas.

Considerations: Will GPCD decrease over time through conservation and/or use of effluent?

Agricultural Demands (Subcommittee)
Estimate whether cropped acreage will expand from baseline or decline through retirement.

Considerations: Will water demands decrease through improved irrigation efficiencies and/or seed technology?

Industrial Demands (Subcommittee)
Estimate future industrial needs and uses.

Considerations:

1. *Will new power plants be needed to meet an increased AZ population and, if so, what water demands are likely (wind vs. solar vs. nuclear vs. fossil fuel)?*
2. *In which counties would new power plants be most likely?*
3. *In what counties are major ore deposits currently undeveloped and how might technology decrease future water demands for ore processing?*
4. *Which counties have existing mines that will run out of ore and close?*
5. *Will feedlots and dairies increase in AZ or move out of state?*
6. *Which counties are expected to have new golf courses and will water demands be decreased through improved turf irrigation technology?*

7. *How many new sand and gravel mines are expected to meet the demands of new population centers?*

Indian Uses (Subcommittee)
Estimate future tribal demands.

Considerations:

1. *How will recent and future Indian water right settlements affect reservation water use?*
2. *Which sector (municipal, industrial, or agriculture) is expected to grow most quickly on each reservation?*
3. *Which tribes are most likely to change their water use?*

Identify the most likely sources of water to meet these future demands.

Eastern Plateau Planning Area accounting for 49% of the demand and in the Central Highlands Planning Area at 22%. Elsewhere, industrial sector demand ranges from 0.5% to 13% of the planning area total (Figure 1-30).

Planning area industrial demand by industrial category is listed in Table 1-15. The primary industrial user in the Eastern Plateau and Lower Colorado River planning areas is power plants. Mining is the predominant industrial user in the Central Highlands, Southeastern Arizona and Upper Colorado River planning areas. Golf courses are the largest industrial use in the AMA and Western Plateau planning areas. Groundwater meets most of the industrial demand in every planning area, although 28% of the industrial demand in the AMA Planning Area is met with effluent delivered to the Palo Verde Nuclear Generating Station. Information on industrial basin and industrial category demand is found in Volumes 2-8.

Tribal Demand

Tribal water demand is included in the totals described above and varies significantly throughout the state although it is a relatively small component of planning area demands. As listed in Table 1-16, most tribal water demand is for agricultural irrigation. As Indian water right claims have been settled, several tribes including the Gila River Indian Community (Phoenix

Table 1-15 Average annual planning area industrial demand by category

	1991-1995	1996-2000	2001-2005
Type/*Planning Area*	Water Use (acre-feet)		
Power Plant			
Eastern Plateau	52,918	56,943	63,279
Southeastern Arizona	6,000	5,200	5,700
Upper Colorado River	0	0	4,900
Lower Colorado River	285	700	7,670
Active Management Areas	52,200	61,700	69,410
Turf[1]			
Eastern Plateau	1,266	1,326	1,596
Southeastern Arizona	1,596	1,806	2,316
Upper Colorado River	0	440	530
Central Highlands	2,910	3,010	3,334
Western Plateau	920	920	920
Lower Colorado River	440	440	440
Active Management Areas	53,300	70,100	77,800
Dairy/Feedlot			
Eastern Plateau	472	524	546
Southeastern Arizona	262	272	502
Upper Colorado River	0	0	80
Central Highlands	790	790	790
Western Plateau	30	30	30
Lower Colorado River	3,400	3,500	3,700
Active Management Areas	10,370	13,600	19,200
Mining[2]			
Eastern Plateau	11,144	11,445	6,241
Southeastern Arizona	48,195	47,085	25,831
Upper Colorado River	16,740	17,800	16,610
Central Highlands	17,900	14,100	14,160
Lower Colorado River	350	380	550
Active Management Areas	54,900	53,700	45,800
Other[3]			
Eastern Plateau	17,092	15,530	11,452
Southeastern Arizona	290	290	290
Lower Colorado River	2,600	2,900	1,200
Active Management Areas	16,900	18,000	21,620

Source: ADEQ 2005, ADWR 2008 f,g, and USGS 2007

[1] In the AMA Planning Area turf-related facilities include golf courses, schools, parks, cemeteries and common areas of subdivisions. Water use outside of the AMAs is predominately by golf courses.

[2] Mining uses include both hard rock mines and sand and gravel operations.

[3] Other category includes large cooling facilities, new large landscape, paper mills and other industrial users.

AMA) and Tohono O'odham Nation (Pinal and Tucson AMAs) have expanded their irrigated agricultural acreage with a commensurate increase in water demand. Information on tribal water demand is found in Volumes 2-8.

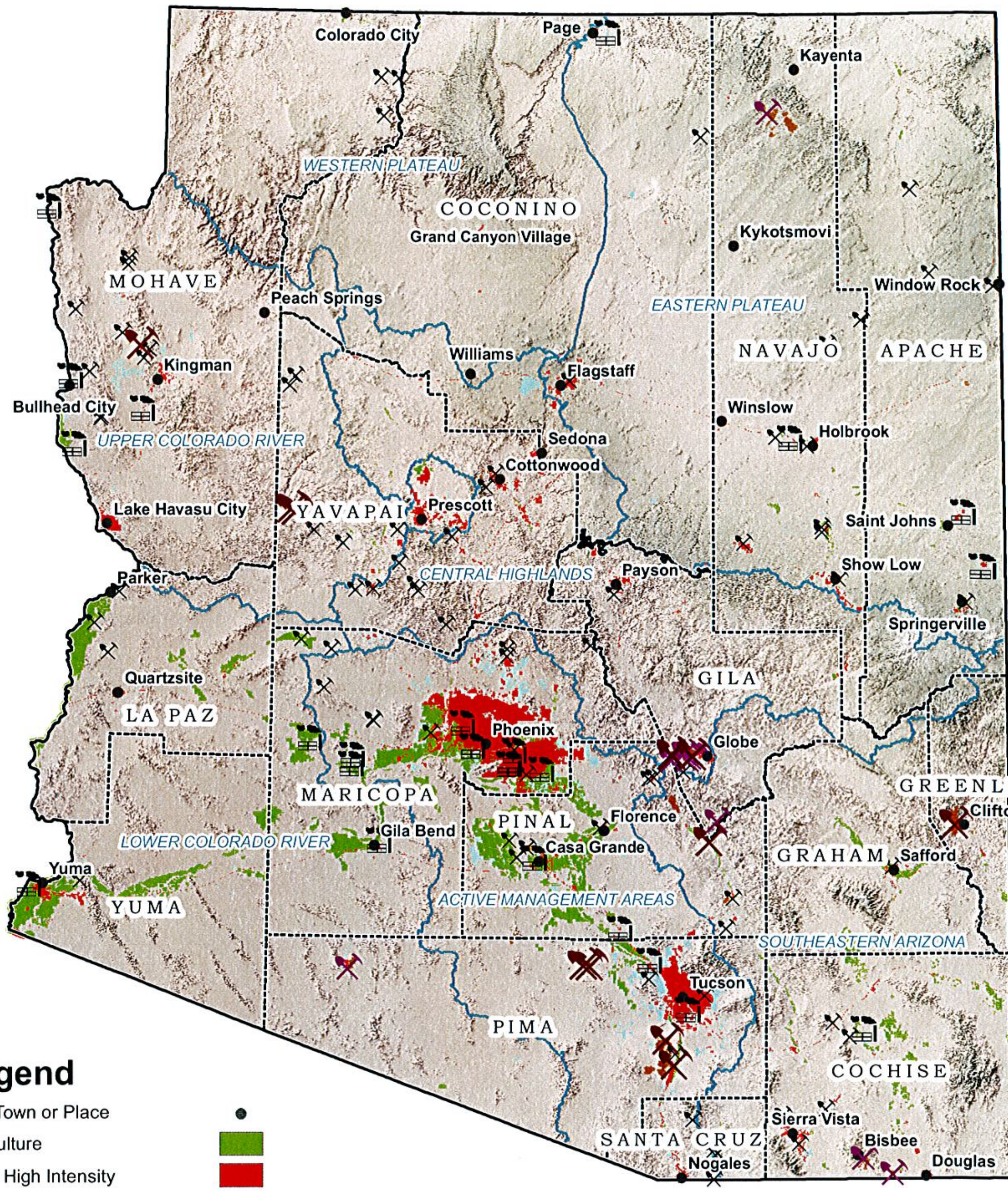
1.4.8 Water Resource Issues

A number of issues face communities and regions in Arizona including population growth and associated concerns about sustainable water supplies, lack of sufficient data to make informed water management decisions, drought, legal questions related to surface water availability, aging water delivery infrastructure, insufficient financial resources, water level declines, environmental protection, and Endangered Species Act (ESA) implications. These concerns have resulted in groundwater studies, regional planning, legislation, establishment of conservation easements and other activities. Issues vary from area to area and are discussed

Table 1-16 Average annual water demand on Arizona Indian Reservations (2001-2005)

Planning Area/*Reservation*	Population (2000 Census)	Groundwater/Surface Water (acre-feet)		
		Agricultural	Municipal	Industrial
Eastern Plateau	**111,800**	0/1,550[1]	11,040/160	0[2]
Navajo	*104,600*			
Hopi	*6,900*			
San Juan Southern Paiute	*300*			
Zuni	*NA*			
Southeastern Arizona	**8,300**	~5,300		0
San Carlos Apache	*8,300*			
Upper Colorado River	**2,200**	NA	~300	0/4,000
Fort Mojave	*800*			
Hualapai	*1,400*			
Central Highlands	**21,200**	200/3,750	700/60	0
Fort Apache	*20,400*			
Tonto Apache	*100*			
San Carlos Apache	*NA*			
Yavapai-Apache	*700*			
Western Plateau	**3,950**	46	310	0
Havasupai	*650*			
Kaibab-Paiute	*200*			
Navajo	*3,100*			
Lower Colorado River	**10,850**	658,000		0
Cocopah	*1,000*			
Colorado River Indian Tribes	*3,400*			
Gila Bend	*600*			
Fort Yuma (Quechan)	*50*			
Tohono O'odham	*5,800*			
Active Management Areas	**34,730**	135,600/131,600[3]	8,900/200	1,300/0
Ak-Chin	*750*			
Fort McDowell Yavapai	*900*			
Gila River	*14,000*			
Pascua Yaqui	*7,700*			
Salt River Pima-Maricopa	*6,200*			
Tohono O'odham	*5,000*			
Yavapai-Prescott	*180*			

Sources: ACC (2005); ADWR (1992, 2007, 2008f,g,h,i); BIA (1998); BOR(2006), CAP (2008); ITCA (2008); Truini and others (2005); USGS (2007, 2008b)
NA = Not Available
[1] Navajo irrigated acreage estimated based on 2005 aerial imagery. Does not include dryland farming by the Hopi Tribe and Navajo Nation.
[2] Does not include water withdrawn from tribal lands leased by Peabody Energy for use at the Black Mesa Mines
[3] Includes CAP water



Baseline Water Demands By County
Adapted from
From Atlas Vol 1, Figure 1-31
Cultural Water Demand Centers
in Arizona

Scenario Approach for Incorporating Uncertainty in the Colorado River Water Supply and Demand Study

August 13, 2010

Introduction

Uncertainties in the factors influencing long-term assessments of the water resources of the Colorado River Basin have become more apparent in the recent decades. Hydroclimatic variability and the potential impacts of climate change, changes in water demand within the basin, both for consumptive and non-consumptive uses, and many other factors represent areas of considerable future uncertainty. The Colorado River Basin Water Supply and Demand Study (Study) is focused on evaluating the water supply-demand imbalances in the Basin through 2060, assessing the risks to Basin resources, and developing and analyzing mitigation and adaptation options and strategies to resolve those imbalances. Recognition of the key future uncertainties is critical to the robust assessment of future imbalances and system reliability and the thorough assessment of options and strategies. This paper summarizes the approach for incorporation of uncertainty in the Study.

Scenario Approach

Management of the water resources of the Colorado River is a complex interplay between natural and human systems, driven by forces such as climate, demographic, economic, social, institutional, political, and technological changes. The precise trajectory of this interplay over time, and the resulting state of the Colorado River system over time, is uncertain and cannot be represented by a single view of the future (Figure 1). A scenario approach will be used to consider and portray the broad range of plausible futures in a manageable number of scenarios.

Scenarios are *alternative views* of how the future might unfold and are used to assist in evaluating the effect of the driving forces on future system reliability. Scenarios are **not** predictions or forecasts of the future. Rather, a set of well-constructed scenarios represent a range of plausible futures that assist in the assessment of future risks and development of mitigation and adaptation options and strategies.

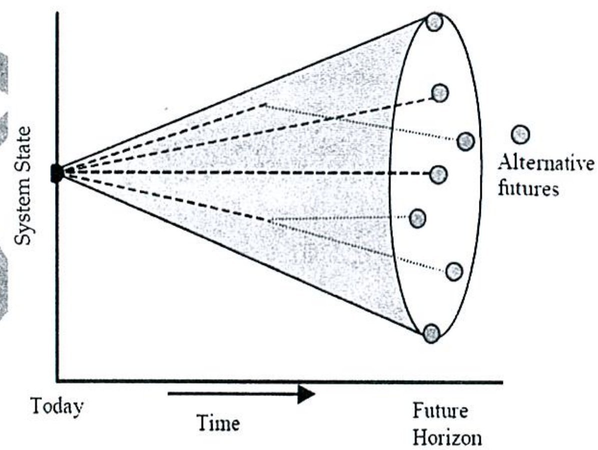


Figure 1. The scenario funnel (adapted from Timpe and Scheepers, 2003).

Scenario approaches have been widely applied in water planning and management, from global to regional scales, although specific methodologies have varied considerably. The scenario approach used this Study consists of the following major steps:

1. Frame the question or focal issue being addressed by the Study

2. Identify and rank (in order of importance and degree of uncertainty) the *driving forces* likely to influence the focal issue of the Study
3. Prioritize and select *critical uncertainties* relating to the driving forces
4. Develop scenario narratives (*storylines*) that weave the critical uncertainties into descriptions of plausible future trajectories
5. Develop *scenarios* that quantify (where possible) the effect of the storylines

These steps are graphically depicted in Figure 2.

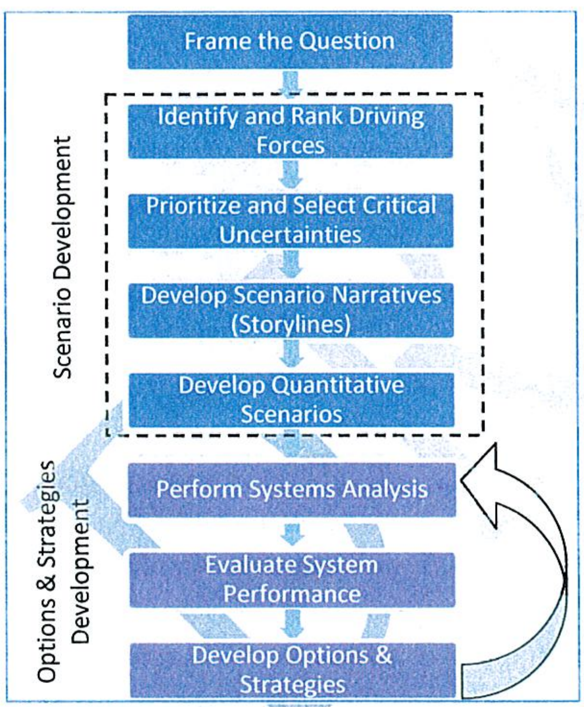


Figure 2. General steps involved in the scenario planning process.

The scenario development process will include stakeholder and other expert input to ensure a broad perspective of the possible future uncertainties is considered. The process will result in a manageable number of scenarios that capture the broad range of plausible future system conditions.

Framing the Question

The Plan of Study provides the purpose and objectives for this effort which can be expressed in terms of two fundamental questions: (1) *What is the future reliability of the Colorado River system to meet the needs of Basin resources?* and (2) *What are the options and strategies to mitigate future risks to these resources?*

The first question relates directly to incorporating uncertainty and is the focus of the scenario development process. The second question relates to management responses to the potential impacts under uncertain futures and is the focus of the water management option and strategy development. The distinction between what is included in a "scenario" versus an "option and strategy" is not always clear; however, those distinctions are important to ensure a structured analytical approach and will be made as part of the scenario development process.

Driving Forces

Driving forces represent the key factors that affect the performance of the system over time. While categorization within other water management studies has varied, the following categories of driving forces have generally been considered:

- Demographic
- Economic
- Technological
- Social
- Governance
- Natural Systems

These broad categories of driving forces lead to consideration of more specific factors. An initial list of the key driving forces contributing to future uncertainty has been developed (Table 1). Broad stakeholder input will be solicited to complete this list and when complete, this list will provide the initial framework for identifying critical uncertainties within the Study process.

Table 1. Example list of key driving forces influencing future Colorado River system reliability.

Example Key Driving Forces Contributing to Future Uncertainty

- Hydroclimate variability and change
- Population growth and distribution
- Changes to irrigated agricultural areas and crop mixes
- Changes in agricultural and urban land uses (conversion, density)
- Changes in watershed vegetation (diseases, species transitions, etc)
- Municipal, industrial, and agricultural water use efficiency
- Changes in watershed management
- Institution and regulatory conditions (laws, regulations on operations)
- Changes to organization or management structures (state, federal, and binational)
- Changes in water needs for energy generation (solar, oil shale)
- Adoption of new supply technologies (brackish desal, cloud seeding)
- Changes in ecosystems demands (endangered species)
- Changes in social values affecting water use
- Cost of water

The planning horizon of the Study is an important consideration which will help to focus the scenario development process. Therefore, the driving forces and related uncertainties will need to be assessed through 2060.

In addition, the concept of management control is an important consideration which will also help to focus the scenario development process. The driving forces and related uncertainties should be focused on the influences that are primarily external to the control of water management entities. This will help in separating the "external" uncertainties which will be considered in the scenarios from the "internal" uncertainties which will be considered in the options and strategies to be developed in a subsequent phase of the Study. In some cases, the influences may be partially under the control of the water management entities (e.g. watershed management, water use efficiency) and scenarios will need to be carefully crafted to separate out the effect of external components (e.g., "naturally occurring" water use trends) versus the internal components (e.g., a strategy to invest in technologies or programs to increase water use efficiency).

Critical Uncertainties

Not all driving forces influence the system to the same degree or contribute the same level of uncertainty. In the development of scenarios, it is useful to rank the driving forces based on their *importance* to the focus of the Study and the relative degree of *uncertainty* of occurring. *Critical uncertainties* are the key driving forces that are identified as both highly uncertain and highly important.

Stakeholder and other expert input is crucial for identifying these critical uncertainties, and can be structured to gage the relative "importance" and "uncertainty" of each of the driving forces. In this approach, stakeholders provide a relative score (1-5) relating to the importance of the driving force to the future reliability of the system, and a second relative score (1-5) relating to the perceived uncertainty of that driving force. There are no "correct" answers to this qualitative assessment. Rather, the process seeks to ensure that critical uncertainties are not overlooked and are representative of the views of those who best know the system.

The resulting stakeholder and other expert input will be displayed in an importance-uncertainty graph (Figure 3). The horizontal axis shows the relative importance and the vertical axis shows the relative degree of uncertainty, as determined by the ranking process described above.

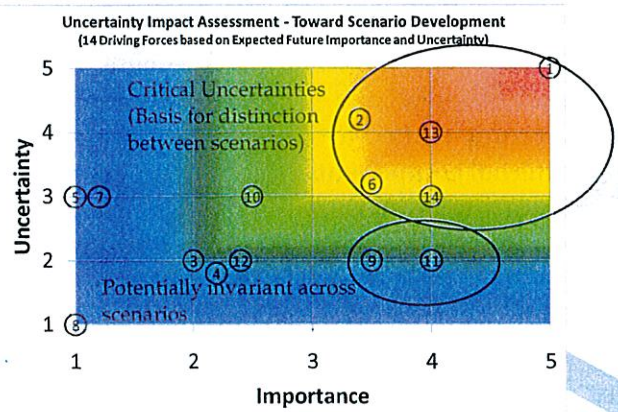


Figure 3. Conceptual importance-uncertainty graph for identifying critical uncertainties.

Driving forces that consistently score in the upper right represent critical uncertainties (highly important and highly uncertain). These forces and associated uncertainties will form the basis of the scenario development. Driving forces in the lower right are highly important, but the range of uncertainty is believed to be low. These forces are included in the scenario development, but may be invariant across scenarios. Driving forces to the left are of lesser importance to the study question and do not significantly influence scenario development, but may still be included as a component in the scenarios depending on the ability to quantify them. Sensitivity analysis may be used to quantify the potential impact to system reliability of changes in forces that are either less important, less uncertain, or both.

Storylines and Scenarios

Storylines are narrative descriptions of how the future may unfold, based on the driving forces and critical uncertainties, and provide the "plot" for describing the scenarios. Critical uncertainties are used to build storylines that provide a broad range of plausible futures. However, since the number of scenarios could increase exponentially with the number of critical uncertainties, groupings are commonly established. The relationship between critical uncertainties will be explored and groupings may emerge around similar themes. For example, demographic trends and water use efficiency are often paired into a demand-related theme. The goal in the storyline development is to seek outcomes that span the range of the funnel (Figure 1). Often, one storyline is selected toward the center of the funnel while the other storylines seek out the rim of the funnel. The final result of the process should be scenarios that are the most informative to the Study questions, not necessarily ones that are most probable.

Quantitative scenarios, as used in this Study, consist of both the narrative description (storyline) and a quantitative evaluation of the outcome of the storyline. Both the qualitative and quantitative assessments are developed with considerable input from stakeholders.

It is currently envisioned that separate scenarios will be developed for supply and demand, forming a "matrix" of scenarios for analysis (i.e., specific combinations of supply and demand scenarios will form the analytical scenarios that will be modeled).

Assessment of System Reliability Using Metrics

The Study will evaluate the imbalances between supply and demand as a primary test of the performance of the system.

Working with stakeholders, metrics are being developed for the following Basin resource categories:

- water allocations and deliveries,
- electrical power,
- water quality,
- flood control,
- recreation,
- environmental, and
- operational risk.

For many of the metrics, probabilistic assessments of performance will be developed based on model output (e.g., frequency, magnitude, and duration of shortages). For some metrics quantitative assessments will not be possible, and the assessment will be performed qualitatively.

Evaluation of Options and Strategies

One of the most challenging aspects of future water planning and this Study is evaluating options and strategies under broad future uncertainty. Many questions arise including: Are all futures equally plausible? Which future(s) should be used in the development of options and strategies? What if the options and strategies show dissimilar responses when measured against different futures?

These questions related to risk have not been rigorously addressed in traditional water resources planning. However, techniques from the security, financial, and environmental sectors, which have a broader resume in such risk-based planning, are now being applied to water resource planning.

One method that may prove useful in this Study is the evaluation of reliability versus risk for each water management option or strategy. For each water management option, model simulations will be performed for each of the combined supply-demand scenarios and metrics for the various resources will be used to measure their reliability. The result of a metric for a resource category can be summarized as the mean reliability across all plausible future scenarios. Similarly, the "risk" for the resource category can be computed as the standard deviation of the metric across all futures scenarios.

Plots such as Figures 6 (one metric category) and Figure 7 (across metric categories) can be generated that depict the reliability-risk performance of each water management option or strategy across the metric groups.

For example, an option that plots to the upper left of Figure 6 indicates high mean performance for that resource as measured by the metric (e.g., probability of full water delivery) and is relatively consistent in its performance for the range of future scenarios. Conversely, an option that plots to the lower right indicates low mean performance for that resource and a high degree of risk (or volatility) depending on the future scenario. Options that plot to the upper left on Figure 7 for various resources indicate that performance is maximized for those resources while risk is minimized. Conversely, options that plot to the lower right on Figure 7 indicate low performance and high risk.

Evaluating reliability and risk for Basin resources in these or other ways will help in prioritizing options and strategies for further consideration.

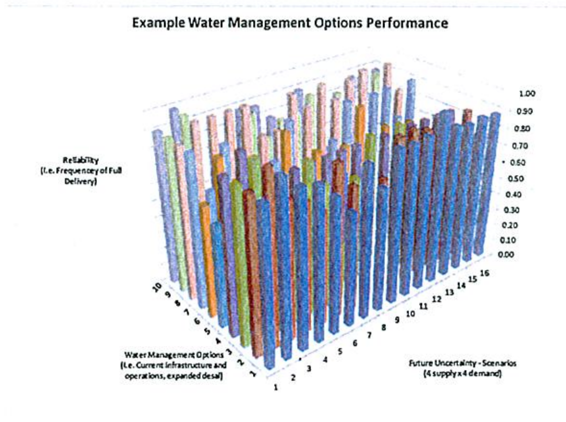


Figure 6. Conceptual performance chart for various water management actions for one resource category.

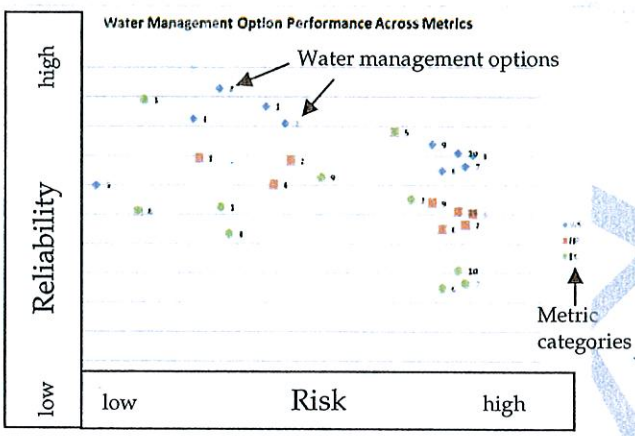


Figure 7. Conceptual performance chart for various water management actions across resource categories.

References

Alcamo and Gallopin, 2009. United Nations World Water Assessment Programme, Building a 2nd Generation of World Water Scenarios.

City of Tuscon Water. Water Plan: 2000-2050.

California Department of Water Resources 2009. Water Plan Update. Draft Scenarios (http://www.waterplan.water.ca.gov/scenarios/index.cfm).

Intergovernmental Panel on Climate Change 2001. Special Report on Emission Scenarios.

Lienert J, Monstadt J, and Truffer B. 2006. Future Scenarios for a Sustainable Water Sector: A Case Study from Switzerland.

Mahmoud M, Liu Y, Hartmann H, Stewart S, Wagener T, Semmens D, Stewart R, Gupta H, Dominguez D, Dominguez F, Hulse D, Letcher R, Rashleigh B, Smith C, Street R, Ticehurst J, Twery M, van Delden H, Waldick R, White D, and Winter L. 2009. A formal framework for scenario development in support of environmental decision-making. Environmental Modelling & Software 24: 798-808.

Mara R and Thomure T. 2009. Scenario Planning: Making Strategic Decisions in Uncertain Times. Southwest Hydrology May/June.

Metropolitan Water District of Southern California 2010. Integrated Resource Plan 2010, Draft.

National Park Service 2010. Scenario Planning Brief, A Tool for Decision-Making in an Era of Uncertainty.

Raskin, P.D. 2008. World Lines: A framewok for exploring global pathways. Ecological Economics 65: 461-470.

Timpe, C. and Scheepers, M.J.J 2003. SUSTELNET: A Look into the Future: Scenarios for Distributed Generation in Europe.

Van Notten 2006. Scenario Development: A Typology of Approaches. In Think Scenarios, Rethink Education. Organisation for Economic Co-Operation and Development.

Water Utility Climate Alliance 2010. Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning.

Water Services Association of Australia 2008. Real Options and Urban Water Resource Planning in Australia. WSAA Occasional Paper No. 20.

Attachment 1. Example Table of Driving Forces and Survey Relating to Importance and Uncertainty

	Importance (1-5): Rate the relative importance of the driving forces to the reliability of the Colorado River system to meet the needs of Basin resources through 2060			
	Uncertainty (1-5): Rate the relative uncertainty of the driving forces in the Colorado River Basin through 2060			
	Importance Ranking Guidance: 1=Relatively Unimportant, 3=Important, 5=Extremely Important			
	Uncertainty Ranking Guidance: 1=Relatively Certain, 3=Uncertain, 5=Highly Uncertain			
	NA=Enter "NA" if you are unfamiliar with the driving force (Note: will not be included in final ranking)			
No.	**Driving Forces**	**Importance**	**Uncertainty**	**Comment**
1	Hydroclimate variability and change			
2	Population growth and distribution			
3	Changes to irrigated agricultural areas and crop mixes			
4	Changes in agricultural and urban land use (i.e conversion, density)			
5	Municipal, industrial, and agricultural water use efficiency			
6	Changes in watershed conditions (diseases, species transitions, etc)			
7	Changes in watershed management			
8	Institutional and regulatory conditions (laws, regs on operations)			
9	Changes in water needs for energy generation (solar, oil shale)			
10	Changes to organization or management structures (state, federal and binational institutions)			
11	Adoption of new supply technologies (brackish desal, cloud seeding)			
12	Changes in ecosystems demands (endangered species)			
13	Change in social values affecting water use			
14	Changes in cost of water			