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TECHNICAL REPORT

Presenting Uncertainty About Climate Change to Water-Resource Managers

A Summary of Workshops with the Inland Empire Utilities Agency

David G. Groves, Debra Knopman, Robert J. Lempert, Sandra H. Berry, Lynne Wainfan

Sponsored by the National Science Foundation

Environment, Energy, and Economic Development

A RAND INFRASTRUCTURE, SAFETY, AND ENVIRONMENT PROGRAM

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APPENDIX A

Workshop Presentations

This appendix contains the slides shown during the workshop presentations.

Workshop 1

Climate Change in the Inland Empire: How to Best Address the Uncertainties

First of Three Workshops
Sponsored by
RAND and IEUA

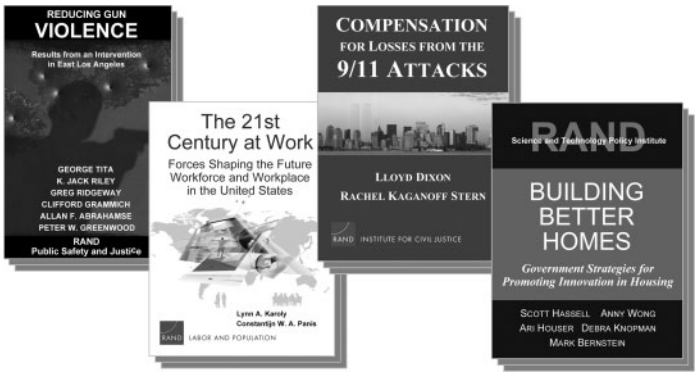
September 28, 2006

What Is RAND?

- **An independent, nonprofit research institution**
- **RAND's mission is to help improve policy and decisionmaking through research and analysis**
- **RAND's strength is in its more than 750 professional, multidisciplinary research staff in the U.S. and abroad**
- **RAND's clients include government agencies, private firms, and other nonprofits**

workshop1-2 9/06

Recent RAND Research Addresses Many Critical Societal Issues



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Today's Agenda

- **Workshop purpose**
- **Computer model and its representation of the 2005 Urban Water Management Plan (UWMP)**
- **Break**
- **Discuss challenges facing 2005 UWMP assuming current climate**
- **Discuss implications of potential future changes in climate**
- **Next steps**

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What Information About Climate Change Uncertainty Is Most Useful for Decisionmakers?

- **Decisionmakers must often make decisions under significant amounts of uncertainty**
- **Decisions about climate change are a key example**
- **These workshops are**
  - **Funded by the National Science Foundation**
  - **Part of a larger effort researching how to best characterize climate change information and associated uncertainties for decisionmakers**

workshop1-5 9/06

We Will Conduct Three Workshops That Explore Different Characterizations of Uncertainty

- **We have developed a model that can assess IEUA 2005 UWMP across a wide range of futures**

workshop1-6 9/06

We Will Conduct Three Workshops That Explore Different Characterizations of Uncertainty

- **We have developed a model that can assess IEUA 2005 UWMP across a wide range of futures**
- **We will use model to demonstrate potential strengths/weaknesses of plan with different characterizations of climate**
  - **Workshop 1 (today): current climate conditions**
  - **Workshop 2 (10/20): the best probabilistic estimate of future climate**
  - **Workshop 3 (11/3): a wide range of plausible climate scenarios**

workshop1-7 9/06

We Will Conduct Three Workshops That Explore Different Characterizations of Uncertainty

- **We have developed a model that can assess IEUA 2005 UWMP across a wide range of futures**
- **We will use model to demonstrate potential strengths/weaknesses of plan with different characterizations of climate**
  - **Workshop 1 (today): current climate conditions**
  - **Workshop 2 (10/20): the best probabilistic estimate of future climate**
  - **Workshop 3 (11/3): a wide range of plausible climate scenarios**

We will solicit and use your input and comments at each step along the way

workshop1-8 9/06

The Workshops Should Prove Valuable

- **These workshops will:**
  - **Provide regional water managers and other policymakers with useful information about system performance under climate change**
  - **Contribute to the scientific communities' understanding of how to best characterize uncertainty for decisionmakers**
- **IEUA is an ideal host for these workshops**
  - **Has been proactive in assembling a plan that greatly improves the region's water outlook**
  - **Now aims to systematically consider potential impacts of climate change on the region's plans**

We very much appreciate your participation!

workshop1-9 9/06

RAND Hopes to Improve Approaches for Managing Deep Uncertainty

- **Decisionmakers in many areas increasingly face rapid, consequential, and hard-to-predict change**
- **Promising advances by RAND and others may help them meet these challenges**
  - **New technology can collect, summarize, and display key information**
  - **New scientific understanding of decisions under ambiguity suggests what information is most useful**

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

www.rand.org

workshop1-10 9/06

Today's Agenda

- **Workshop purpose**
- **Computer model and its representation of the 2005 Urban Water Management Plan (UWMP)**
- ***Break***
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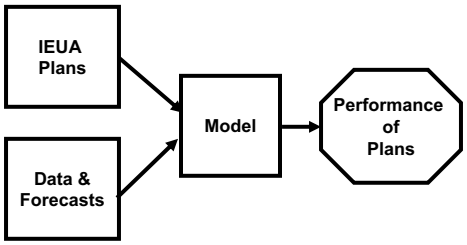
- **Discuss implications of potential future changes in climate**
- **Next steps**

workshop1-11 9/06

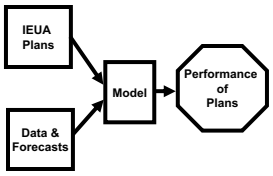
RAND Model Compares Performance of IEUA Water Management Plans in Variety of Futures



- **Approximates future water needs, supplies, and management**
- **Base-case replicates 2005 UWMP**
- **Explores other plans under other future conditions**

workshop1-12 9/06

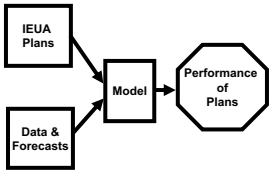
Model Draws on Regional Data



- **Recent projections of factors driving water demand**
- **Land use projections**
- **Climate data drive**
  - **Irrigation needs**
  - **Groundwater natural recharge**
  - **Availability of imports and local surface supplies**

workshop1-13 9/06

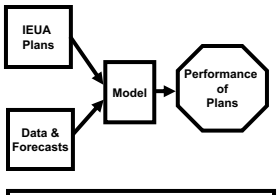
Model Considers Key Components of Water Management Plans



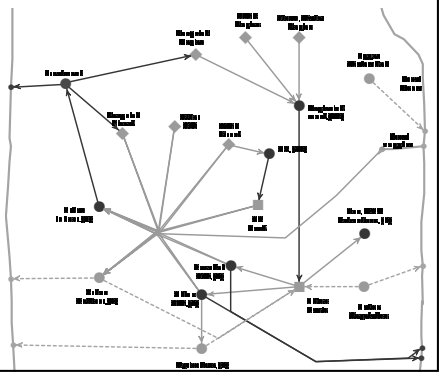
- **Chino Basin Optimum Basin Management**
  - **Replenishment**
  - **Hydrologic control (via desalting)**
  - **Conjunctive use**
- **Recycling**
- **Imports**
- **Water use efficiency**
- **Additional measures suggested by workshops and analysis**

workshop1-14 9/06

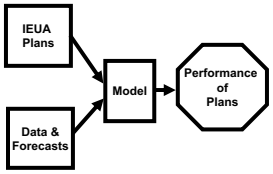
Given the Inputs, Model Represents Key Components of the IEUA System



Uses Water Evaluation And Planning (WEAP) platform



Model Produces Key Outputs Used to Assess the Effectiveness of Plans



- **Gap between supply and demand**
- **Frequency of shortages**
- **Costs of alternative management (later workshops)**

workshop1-16 9/06

We Have Discussed the Model with Experts

- **IEUA staff**
  - **Martha Davis and colleagues**
- **Wildermuth Environmental Inc.**
  - **Treatment of Chino Basin**
- **California Department of Water Resources**
  - **Outdoor water use**
- **Natural Heritage Institute**
  - **Model construction**

workshop1-17 9/06

IEUA 2005 UWMP Incorporates Many Progressive Water Management Strategies

- **Increased Chino Basin groundwater production**
  - **Improvement of recharge basins ($50 million)**
  - **Hydrologic control through desalting ($150 million)**
  - **Conjunctive Use / Dry Year Yield Program ($27 million)**
- **Aggressive recycling and reuse program**
  - **Nine-fold increase to 69 taf by 2025 ($110 million)**
- **Conservation**
  - **Conservation of up to 10% during drought years ($20 million)**

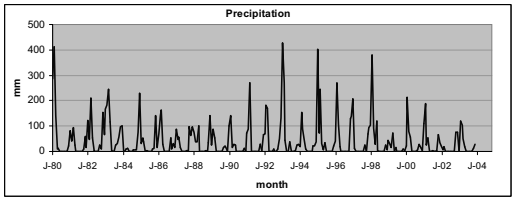
workshop1-18 9/06

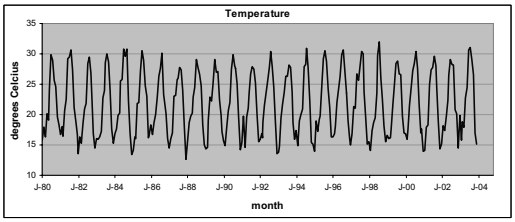
We Begin By Comparing IEUA's Pre-2000 Plan and 2005 UWMP

Management Action	Pre-2000 Plan	2005 UWMP
Water use efficiency	4%	10% (2015)
Direct recycled use	6 taf	30 taf (2010) 69 taf (2025)
GW desalting	6.3 taf	14+ taf (2010)
Dry-year Yield Program	0 taf	30 taf
Imports (direct use)	60 taf 120 taf*	60 taf (2005) 82 taf (2025)

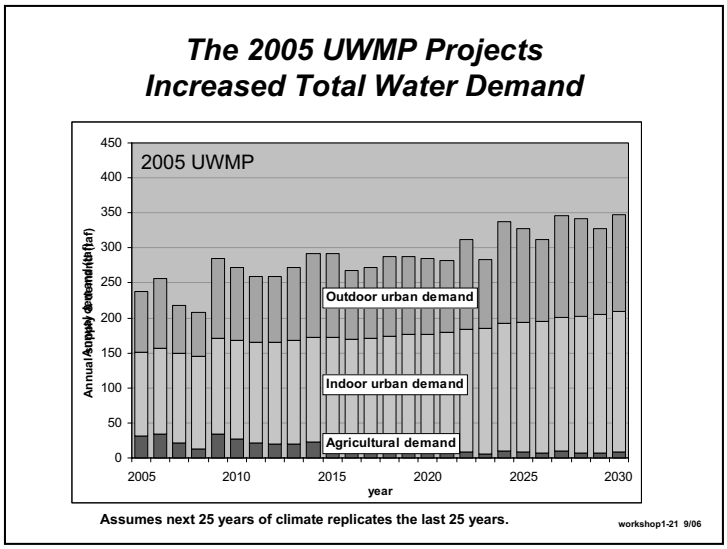
workshop1-19 9/06

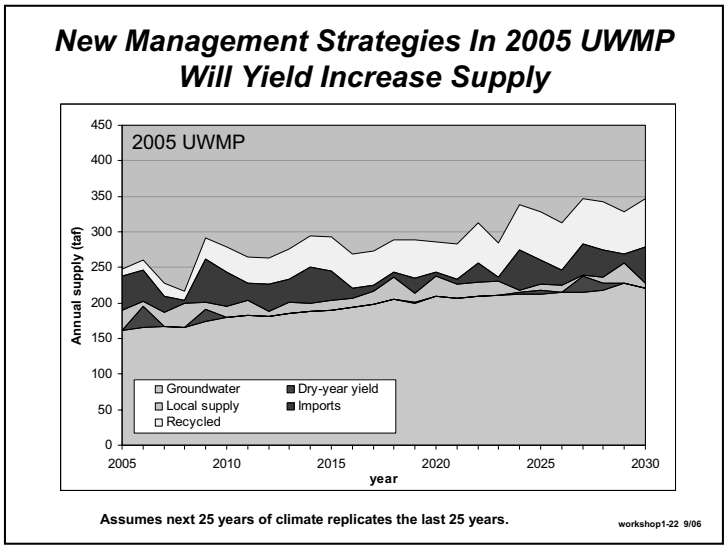
Today's Results Assume Future Climate Replicates Historical Monthly Weather Data



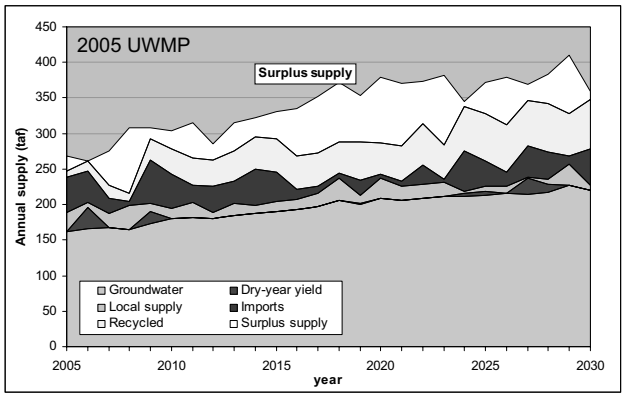


workshop1-20 9/06


The 2005 UWMP Projects
Increased Total Water Demand
2005 UWMP
Annual supply or demand (taf)
Outdoor urban demand
Indoor urban demand
Agricultural demand
year
Assumes next 25 years of climate replicates the last 25 years.
workshop1-21 9/06


New Management Strategies In 2005 UWMP
Will Yield Increase Supply
2005 UWMP
Annual supply (taf)
Groundwater
Local supply
Recycled
Dry-year yield
Imports
year
Assumes next 25 years of climate replicates the last 25 years.
workshop1-22 9/06

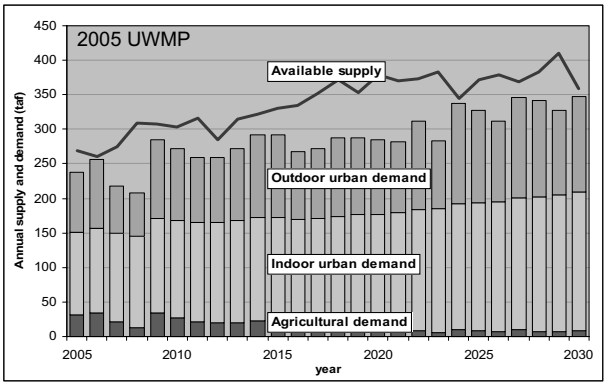
The 2005 UWMP Is Likely To Yield Surplus Supply



Assumes next 25 years of climate replicates the last 25 years.

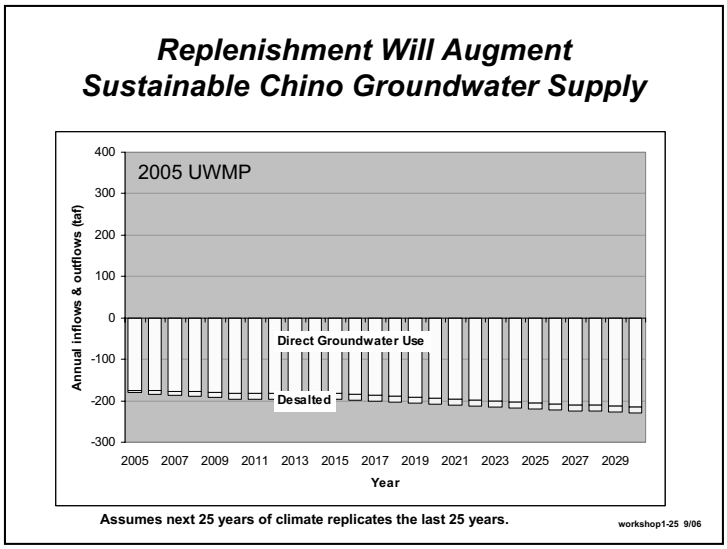
workshop1-23 9/06

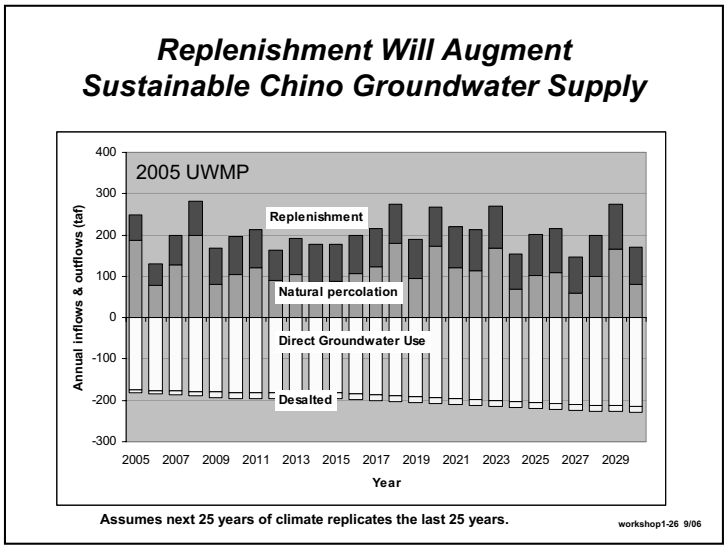
Total Available Supply Is Projected to Exceed Demand



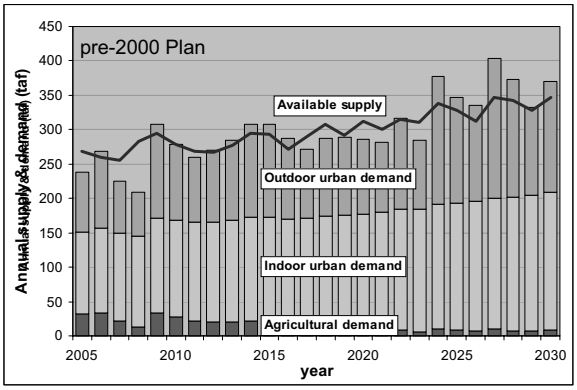
Assumes next 25 years of climate replicates the last 25 years.

workshop1-24 9/06


Replenishment Will Augment
Sustainable Chino Groundwater Supply
2005 UWMP
Annual inflows & outflows (taf)
400
300
200
100
0
-100
-200
-300
Direct Groundwater Use
Desalted
2005 2007 2009 2011 2013 2015 2017 2019 2021 2023 2025 2027 2029
Year
Assumes next 25 years of climate replicates the last 25 years.
workshop1-25 9/06


Replenishment Will Augment
Sustainable Chino Groundwater Supply
2005 UWMP
Annual inflows & outflows (taf)
400
300
200
100
0
-100
-200
-300
Replenishment
Natural percolation
Direct Groundwater Use
Desalted
2005 2007 2009 2011 2013 2015 2017 2019 2021 2023 2025 2027 2029
Year
Assumes next 25 years of climate replicates the last 25 years.
workshop1-26 9/06

The Pre-2000 Plan Would Have Led to Frequent Shortages

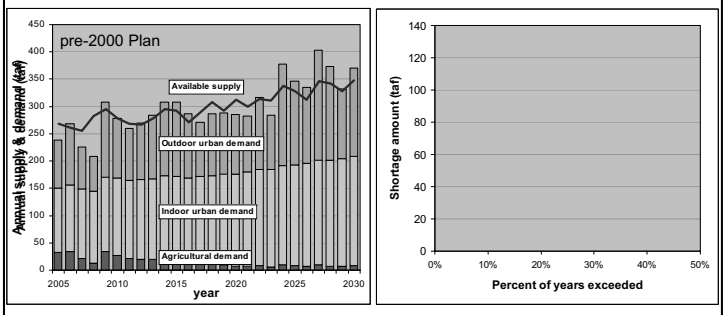


Assumes next 25 years of climate replicates the last 25 years.

Assuming 2005 UWMP projected imports

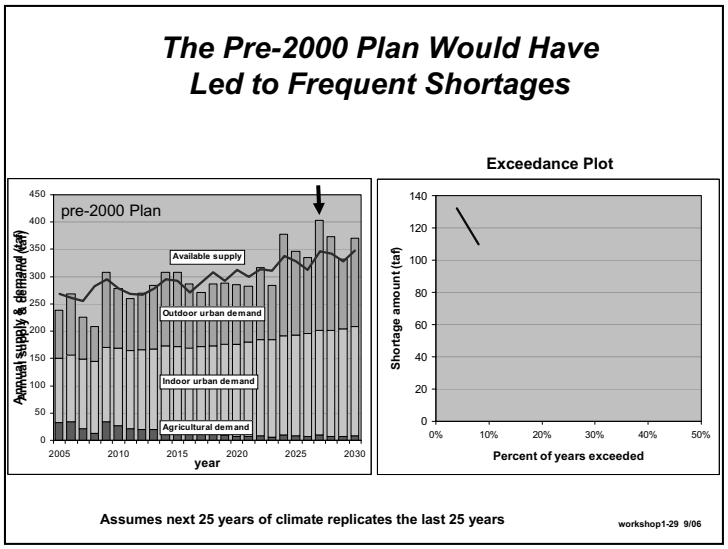
workshop1-27 9/06

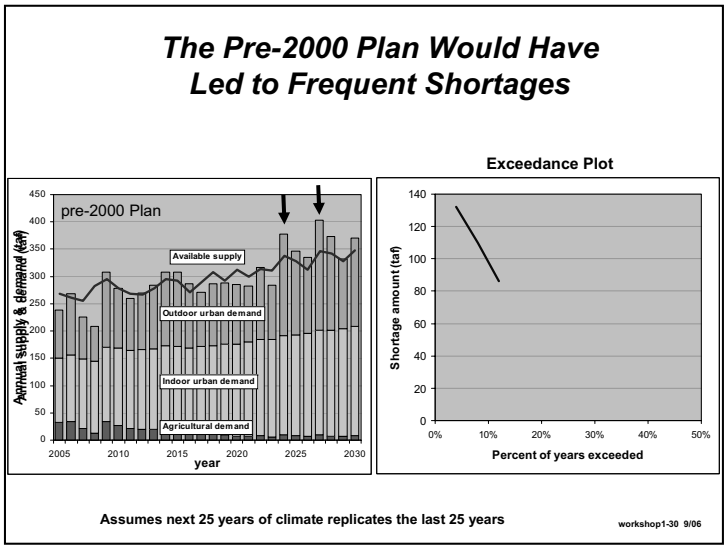
The Pre-2000 Plan Would Have Led to Frequent Shortages



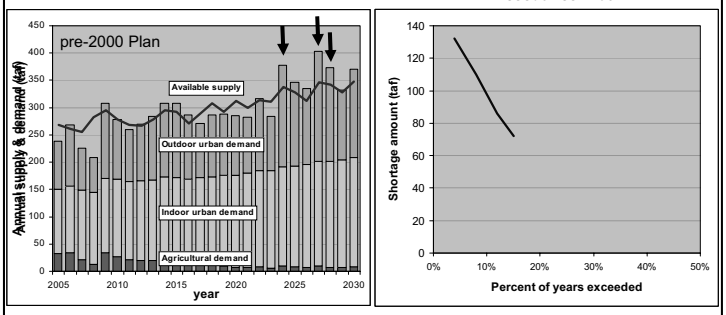
Assumes next 25 years of climate replicates the last 25 years

workshop1-28 9/06


The Pre-2000 Plan Would Have Led to Frequent Shortages
Exceedance Plot
pre-2000 Plan
Available supply
Outdoor urban demand
Indoor urban demand
Agricultural demand
Annual supply & demand (taf)
year
Shortage amount (taf)
Percent of years exceeded
Assumes next 25 years of climate replicates the last 25 years
workshop1-29 9/06


The Pre-2000 Plan Would Have Led to Frequent Shortages
Exceedance Plot
pre-2000 Plan
Available supply
Outdoor urban demand
Indoor urban demand
Agricultural demand
Annual supply & demand (taf)
year
Shortage amount (taf)
Percent of years exceeded
Assumes next 25 years of climate replicates the last 25 years
workshop1-30 9/06

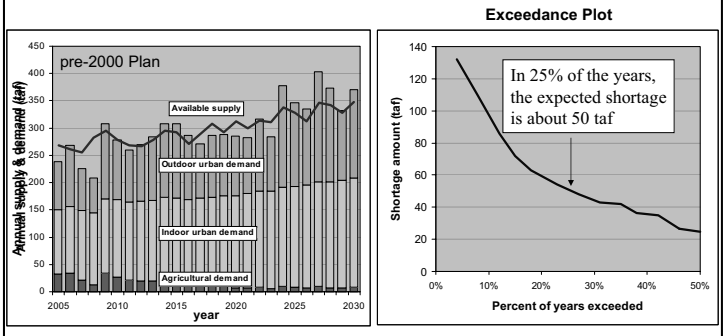
The Pre-2000 Plan Would Have Led to Frequent Shortages



Assumes next 25 years of climate replicates the last 25 years

workshop1-31 9/06

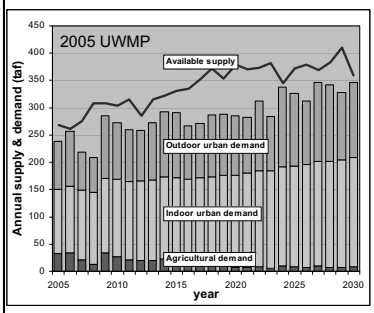
The Pre-2000 Plan Would Have Led to Frequent Shortages



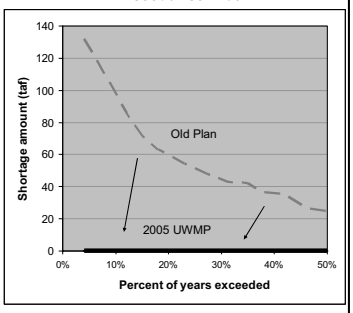
Assumes next 25 years of climate replicates the last 25 years

workshop1-32 9/06

If the Region Meets the 2005 UWMP Goals, It Would Face No Shortages



Exceedance Plot



Assumes next 25 years of climate replicates the last 25 years

workshop1-33 9/06

Some Key Assumptions Underlie Favorable Performance of the 2005 UWMP

- **The plan includes aggressive goals for:**
  - **Recycling**
  - **Increased groundwater pumping through replenishment and conjunctive use**
  - **Expanded imports for direct use and replenishment**
- **The model assumes these goals are met**

workshop1-34 9/06

Today's Agenda

- **Workshop purpose**
- **Computer model and its representation of the 2005 Urban Water Management Plan (UWMP)**
- ***Break***
- **Discuss challenges facing 2005 UWMP assuming current climate**
- **Discuss implications of potential future changes in climate**
- **Next steps**

workshop1-35 9/06

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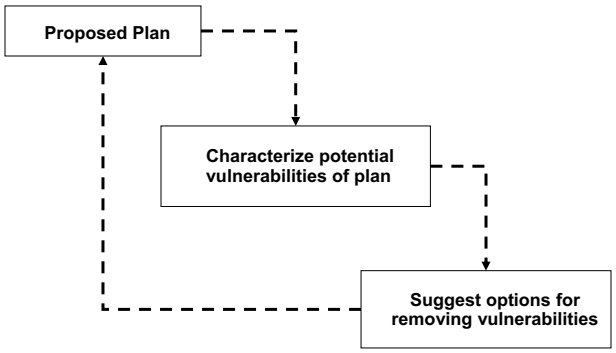
- **Next steps**

workshop1-36 9/06

A Plan Can Be Strengthened by Identifying And Addressing Its Potential Vulnerabilities



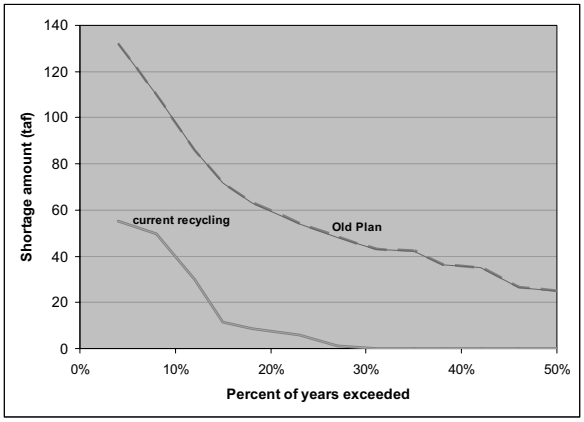
workshop1-37 9/06

Vulnerabilities To The 2005 UWMP Include Not Meeting Its Goals

Potential Vulnerability	Current Level (2005)	Goal
Recycling	7.5 taf	49 taf (2015) 69 taf (2025)
Chino Basin Replenishment	68 taf	91 taf (2015) 107 taf (2025)
Imports (direct use)	60 taf	74 taf (2015) 83 taf (2025)

workshop1-38 9/06

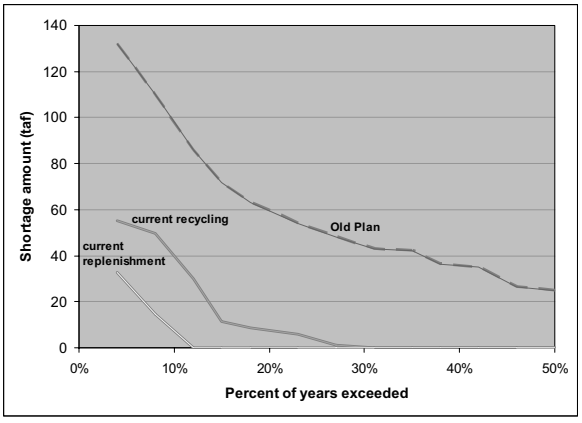
Failure to Meet Goals Leads to Shortages



Assumes next 25 years of climate replicates the last 25 years.

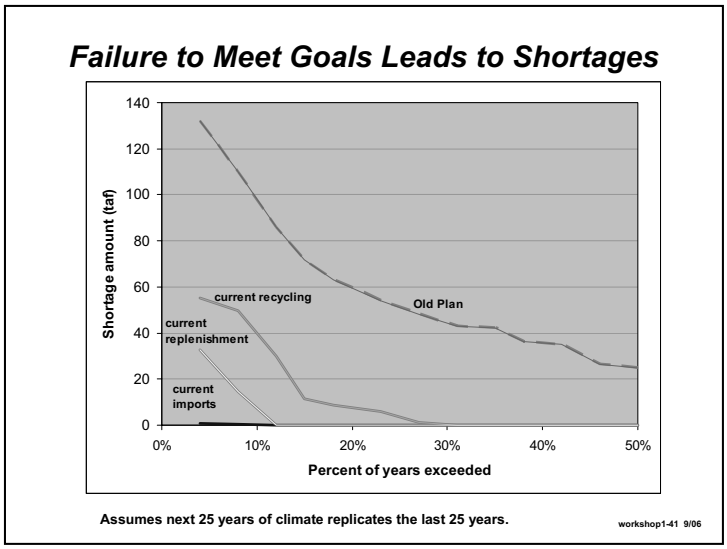
workshop1-39 9/06

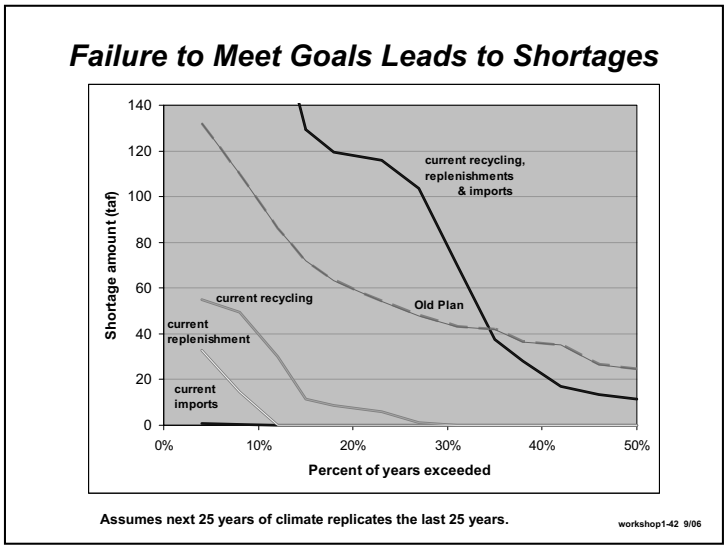
Failure to Meet Goals Leads to Shortages



Assumes next 25 years of climate replicates the last 25 years.

workshop1-40 9/06


Failure to Meet Goals Leads to Shortages
Shortage amount (taf)
140
120
100
80
60
40
20
0
0%
10%
20%
30%
40%
50%
Percent of years exceeded
current recycling
Old Plan
current replenishment
current imports
Assumes next 25 years of climate replicates the last 25 years.
workshop1-41 9/06


Failure to Meet Goals Leads to Shortages
Shortage amount (taf)
140
120
100
80
60
40
20
0
0%
10%
20%
30%
40%
50%
Percent of years exceeded
current recycling, replenishments & imports
current recycling
Old Plan
current replenishment
current imports
Assumes next 25 years of climate replicates the last 25 years.
workshop1-42 9/06

In the next workshop, we will show exceedance plots for 2005 UWMP based on

- **Likelihood of achieving plan goals**
- **Risks of future climate change**

We would now like your input on likelihood of achieving plan goals

workshop1-43 9/06

What Are The Main Challenges, and the Likelihood, of Achieving These Goals?

Potential Vulnerability	Current Level	Goal	Likelihood of Achieving the Goal
Recycling	7.5 taf	49 taf (2015) 69 taf (2025)	?
Chino Basin Replenishment	68 taf	91 taf (2015) 107 taf (2025)	?
Imports (direct use)	60 taf	74 taf (2015) 83 taf (2025)	?

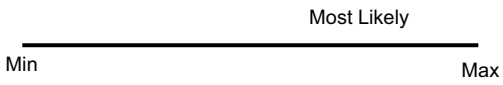
workshop1-44 9/06

By 2015 or 2025, for each of recycling, replenishment, and imports:

workshop1-45 9/06

By 2015 or 2025, for each of recycling, replenishment, and imports:

- **What is the most likely level reached?**



workshop1-46 9/06

By 2015 or 2025, for each of recycling, replenishment, and imports:

- **What is the most likely level reached?**
- **What is the likelihood the goal will be reached or exceeded?**

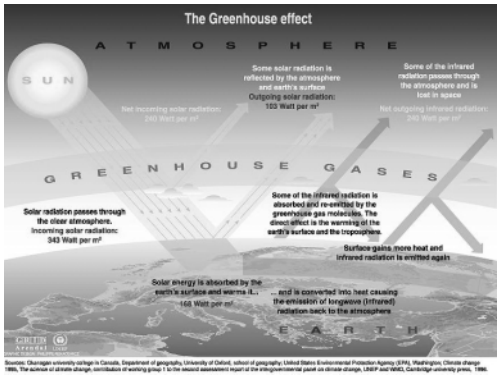
workshop1-47 9/06

Today's Agenda

- **Workshop purpose**
- **Computer model and its representation of the 2005 Urban Water Management Plan (UWMP)**
- ***Break***
- **Discuss challenges facing 2005 UWMP assuming current climate**
- **Discuss implications of potential future changes in climate**
- **Next steps**

workshop1-48 9/06

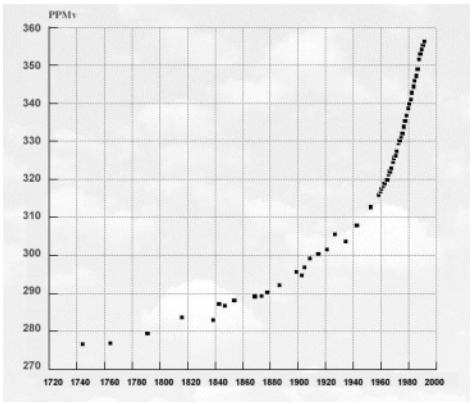
Greenhouse Gases Keep the Earth Warm



Source: National Academy of Sciences

workshop1-49 9/06

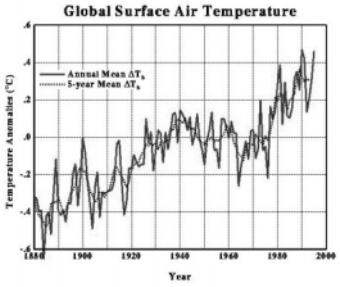
Atmospheric Concentrations of Greenhouse Gases Have Been Rising Over the Last Century



Source: US Department of Energy

workshop1-50 9/06

Concurrently, the Earth's Average Observed Surface Temperature Has Increased

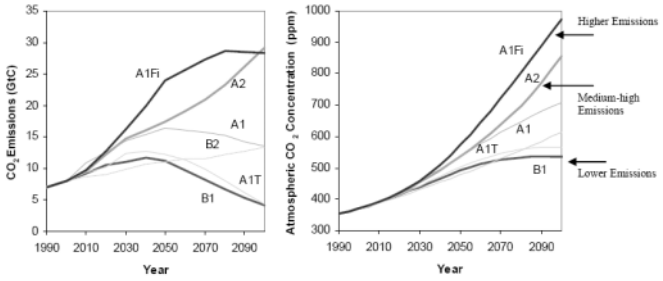


Source: Intergovernmental Panel on Climate Change (IPCC)

workshop1-51 9/06

Global Emissions and Concentrations Will Likely Increase Over the 21st Century

Heavy lines represent scenarios used by California Climate Change Center

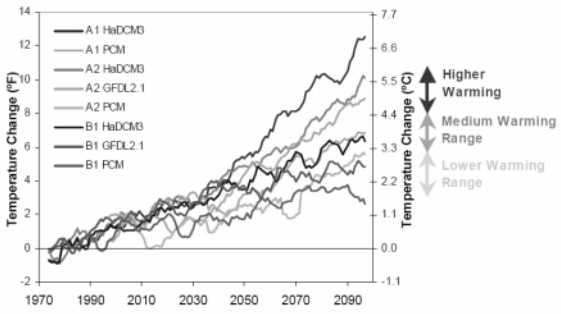


Intergovernmental Panel on Climate Change (IPCC) Scenarios

Source: California Climate Change Center

workshop1-52 9/06

California Climate Center Projects a Wide Range of Future Temperature Increases

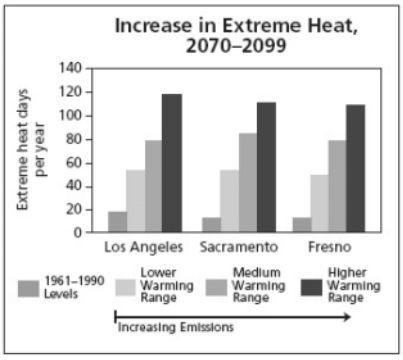


Change in California mean temperature relative to 1961-1990 average

Source: California Climate Change Center

workshop1-53 9/06

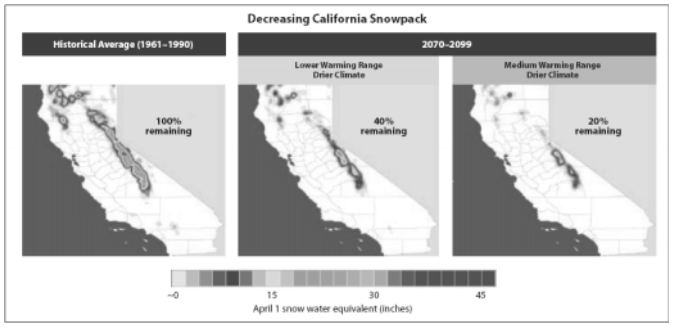
Increased Average Temperatures Could Increase Frequency of Extreme Events



Source: California Climate Change Center

workshop1-54 9/06

California Snow Pack May Significantly Decline

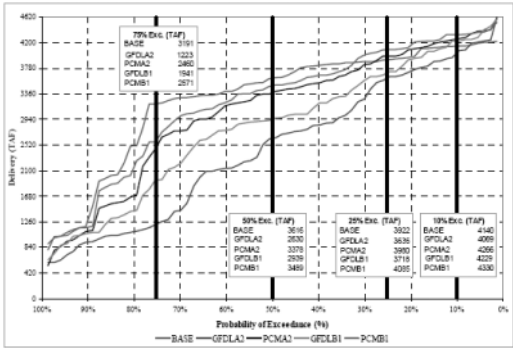


Source: California Climate Change Center

workshop1-55 9/06

Water Available for Imports May Also Decline

SWP 2070–2099

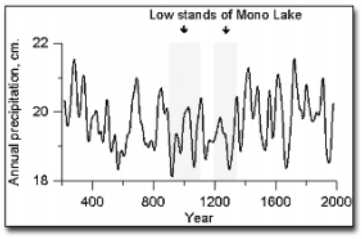


Source: California Climate Change Center

workshop1-56 9/06

Prior to Modern Human Influence, California's Climate Exhibited Significant Changes

- **Records suggest severe droughts (40% or larger decrease in available water) lasting for many decades**
- **Unclear the extent to which future climate may exhibit such extreme variability**



Source: NOAA

workshop1-57 9/06

What actions, if any, should IEUA take in the near-term to address potential climate change?

We will use your suggestions to inform the modeling for the next two workshops

workshop1-58 9/06

Today's Agenda

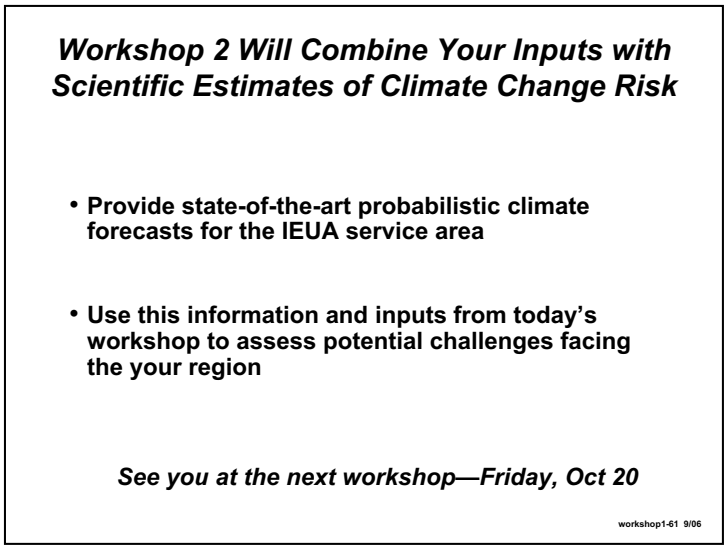
- **Workshop purpose**
- **Computer model and its representation of the 2005 Urban Water Management Plan (UWMP)**
- ***Break***
- **Discuss challenges facing 2005 UWMP assuming current climate**
- **Discuss implications of potential future changes in climate**
- **Next steps**

workshop1-59 9/06

What Happens Next?

- **Today's workshop focused on current climate conditions**
- **The next two workshops will increasingly relax assumptions about the future**
  - **Workshop 2 (Oct 20) will focus on best probabilistic estimate of future climate**
  - **Workshop 3 (Nov 3) will focus on a wide range of plausible climate scenarios**

workshop1-60 9/06


Workshop 2 Will Combine Your Inputs with Scientific Estimates of Climate Change Risk
• Provide state-of-the-art probabilistic climate forecasts for the IEUA service area
• Use this information and inputs from today's workshop to assess potential challenges facing the your region
See you at the next workshop—Friday, Oct 20
workshop1-61 9/06

Workshop 2

Climate Change in the Inland Empire: How to Best Address the Uncertainties

Second of three workshops sponsored by RAND and IEUA

October 20, 2006

What Is RAND?

- **RAND is an independent, nonprofit research institution**
- **Its mission is to help improve policy and decisionmaking through research and analysis**
- **Its strength is in its more than 750 professional, multidisciplinary research staff in the United States and abroad**
- **RAND's clients include government agencies, private firms, and other nonprofits**

Workshop2 2 10/06

What Information About Climate Change Uncertainty Is Most Useful to Decisionmakers?

- **Decisionmakers must often act under conditions of deep uncertainty**
- **Decisions about climate change are a key example**
- **These workshops are**
  - **funded by the National Science Foundation**
  - **presented in cooperation with IEUA**
  - **part of a larger effort studying ways to best characterize climate change information and associated uncertainties for decisionmakers**

Workshop2 3 10/06

We Are Conducting Three Workshops That Explore Different Characterizations of Uncertainty

- **We have developed a model to assess water management plans for the IEUA region across a wide range of futures**
- **We will use the model to demonstrate potential strengths and weaknesses of plans with different characterizations of climate**
  - **Workshop 1 (Sept 28) presented current climate conditions that continue in the future**
  - **Workshop 2 (today) will emphasize traditional scenarios and best probabilistic representations of future climate**
  - **Workshop 3 (Nov 3) will present a wide range of climate scenarios**

We will solicit and use your input at each step along the way

Workshop2 4 10/06

Today We Consider Some Standard Approaches for Taking Uncertainty into Account in the Planning Process

Uncertainties

Climate change

Ability to meet goals

Approaches

Traditional scenarios

Probability distribution

Workshop2 5 10/06

The Workshops Should Prove Valuable

- **These workshops will**
  - **provide regional water managers and other policymakers with useful information about system performance under climate change**
  - **contribute to the scientific understanding of how to best characterize uncertainty for decisionmakers**
- **IEUA is an ideal host for these workshops**
  - **Has been proactive in assembling a plan that greatly improves the region's water outlook**
  - **Now aims to systematically consider potential impacts of climate change on the region's plans**

We very much appreciate your participation!

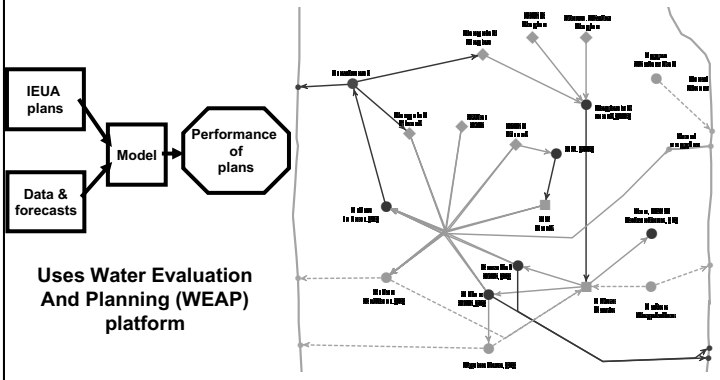
Workshop2 6 10/06

Today's Agenda

- **Review of previous workshop**
- **Forecasting climate change in the Chino Basin**
- **Using scenarios to assess IEUA responses to climate change**
- **Lunch**
- **Using probabilities to assess IEUA responses to climate change**
- **Next steps**

Workshop2 7 10/06

In the Previous Workshop, We Introduced a Water Management Model to Evaluate Performance of Plans Under Various Future Conditions



Uses Water Evaluation And Planning (WEAP) platform

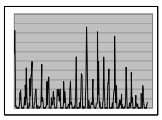
Workshop2 8 10/06

We Considered IEUA's Pre-2000 Plan and the 2005 UWMP

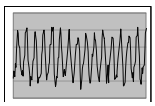
Management action	Pre-2000 plan	2005 UWMP
Water use efficiency	4%	10% (2015)
Direct use of recycled water	6 taf	30 taf (2010) 69 taf (2025)
GW desalting	6.3 taf	14+ taf (2010)
Dry-year yield program	0 taf	30 taf
Imports (direct use)	60 taf 120 taf*	60 taf (2005) 82 taf (2025)

Workshop2 9 10/06

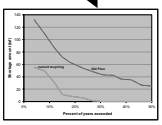
Last Time We Assumed Future Climate Will Be Similar to Past Climate



Past Chino climate

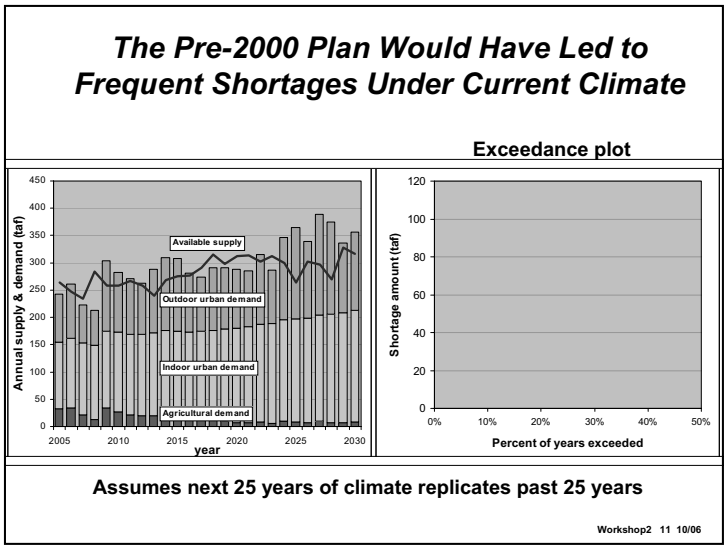


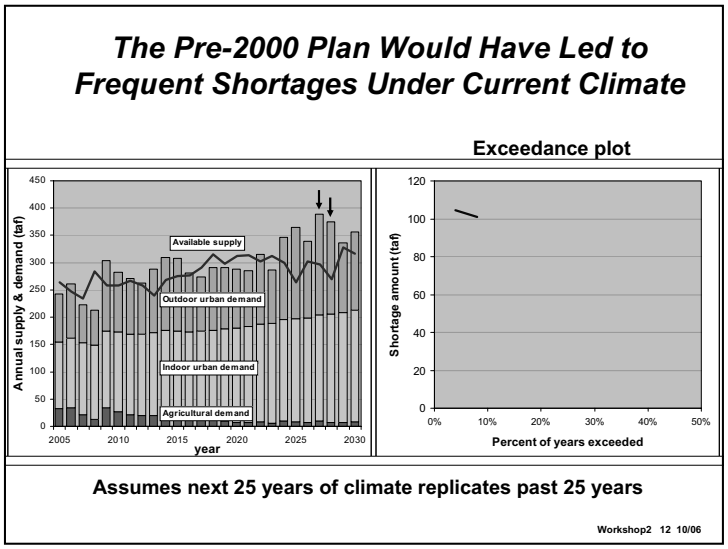
Model of IEUA system



Performance of IEUA plans

Workshop2 10 10/06


The Pre-2000 Plan Would Have Led to Frequent Shortages Under Current Climate
Exceedance plot
Annual supply & demand (taf)
Available supply
Outdoor urban demand
Indoor urban demand
Agricultural demand
year
Shortage amount (taf)
Percent of years exceeded
Assumes next 25 years of climate replicates past 25 years
Workshop2 11 10/06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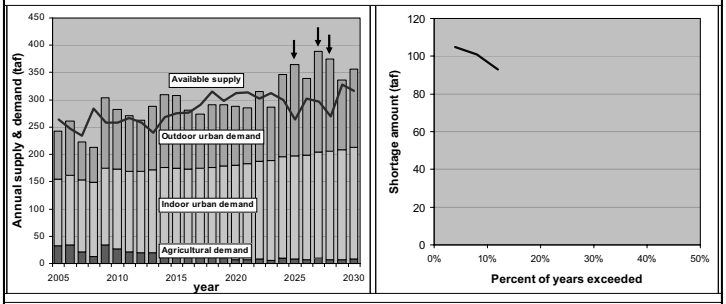
Outdoor urban demand
Indoor urban demand
Agricultural demand
year
Shortage amount (taf)
Percent of years exceeded
Assumes next 25 years of climate replicates past 25 years
Workshop2 12 10/06

The Pre-2000 Plan Would Have Led to Frequent Shortages Under Current Climate

Exceedance plot

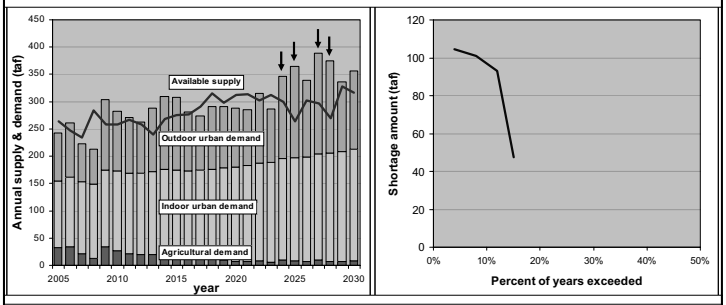


Assumes next 25 years of climate replicates past 25 years

Workshop2 13 10/06

The Pre-2000 Plan Would Have Led to Frequent Shortages Under Current Climate

Exceedance plot

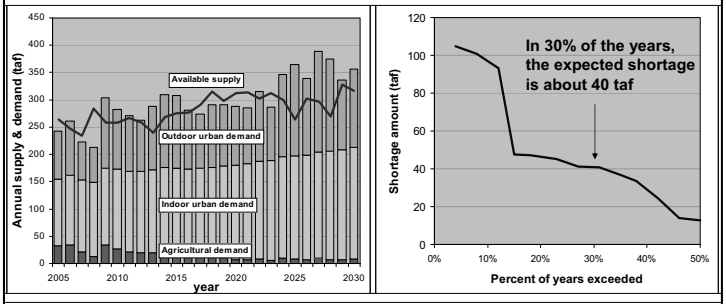


Assumes next 25 years of climate replicates past 25 years

Workshop2 14 10/06

The Pre-2000 Plan Would Have Led to Frequent Shortages Under Current Climate

Exceedance plot

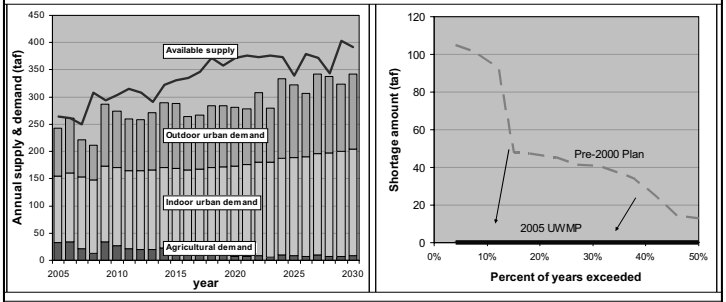


Assumes next 25 years of climate replicates past 25 years

Workshop2 15 10/06

If the Region Successfully Implements the 2005 UWMP, It Will Face No Shortages Under the Current Climate

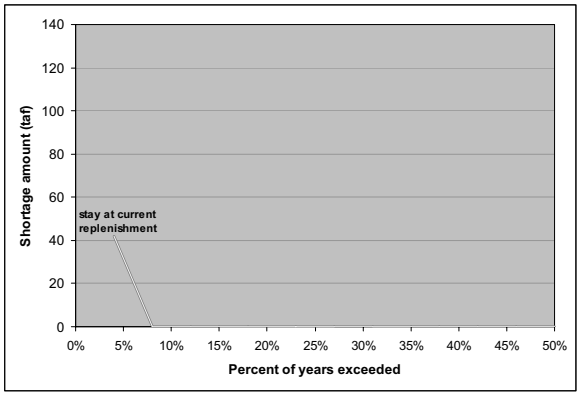
Exceedance plot



Assumes next 25 years of climate replicates past 25 years

Workshop2 16 10/06

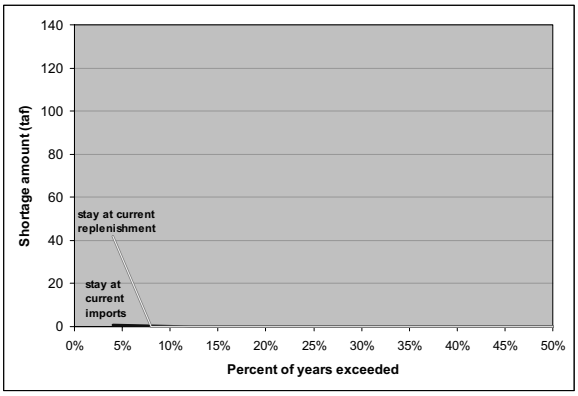
We Discussed the Importance of Meeting 2005 UWMP Goals



Assumes next 25 years of climate replicates past 25 years

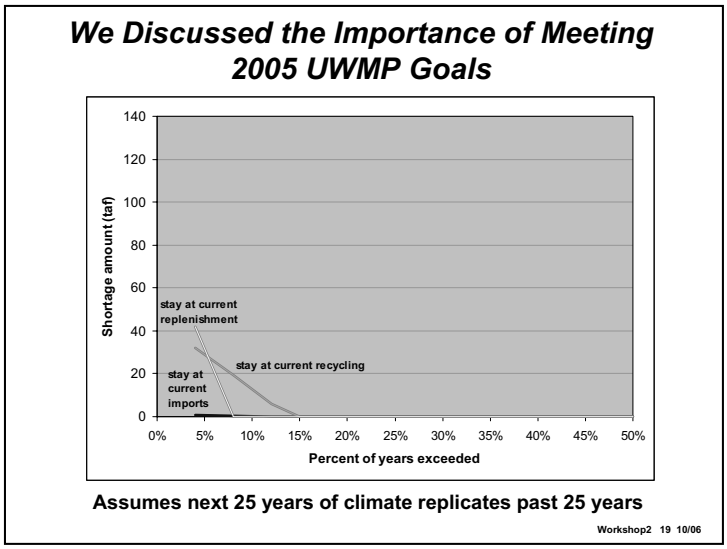
Workshop2 17 10/06

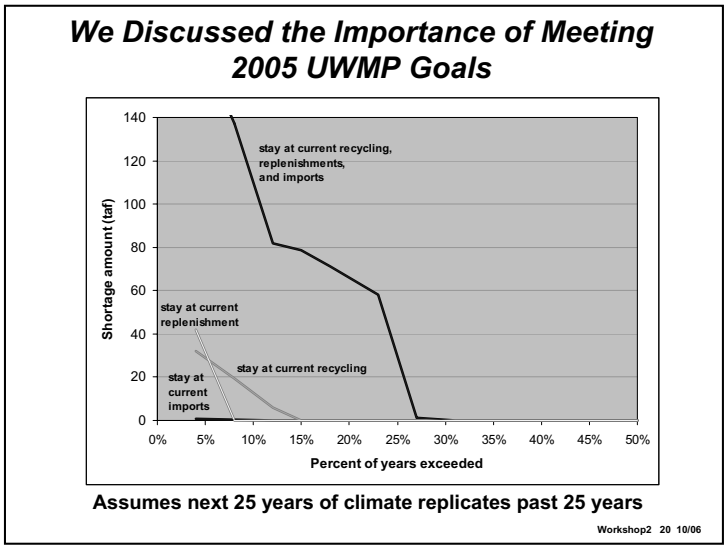
We Discussed the Importance of Meeting 2005 UWMP Goals



Assumes next 25 years of climate replicates past 25 years

Workshop2 18 10/06


We Discussed the Importance of Meeting 2005 UWMP Goals
Shortage amount (taf)
140
120
100
80
60
40
20
0
stay at current replenishment
stay at current recycling
stay at current imports
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
Percent of years exceeded
Assumes next 25 years of climate replicates past 25 years
Workshop2 19 10/06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stay at current recycling, replenishments, and imports
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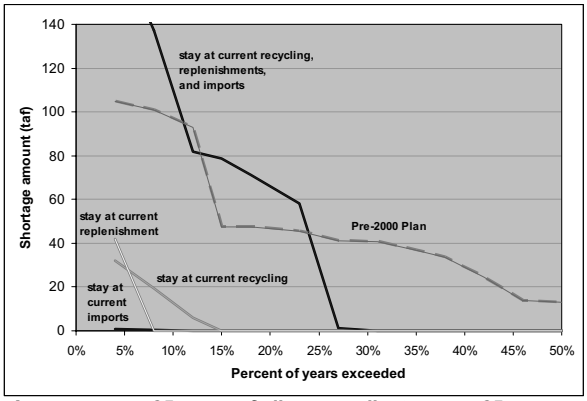
50%
Percent of years exceeded
Assumes next 25 years of climate replicates past 25 years
Workshop2 20 10/06

We Discussed the Importance of Meeting 2005 UWMP Goals



Assumes next 25 years of climate replicates past 25 years

Workshop2 21 10/06

Participants Provided Information about the Likelihood of Reaching Goals

Management action	Goal	Chance reached 2015	
Recycling	49 taf (2015)	72%	
Chino Basin replenishment	91 taf (2015)	79%	
Imports (direct use)	74 taf (2015)	75%	

Workshop2 22 10/06

Participants Provided Information about the Likelihood of Reaching Goals

Management action	Goal	Chance reached 2015	Chance reached 2025
Recycling	49 taf (2015) 69 taf (2025)	72%	69%
Chino Basin replenishment	91 taf (2015) 107 taf (2025)	79%	73%
Imports (direct use)	74 taf (2015) 83 taf (2025)	75%	67%

Workshop2 23 10/06

We Discussed the Climate Change Threat and Participants Suggested Strategies for Addressing It

- **Moderate demand growth**
  - **Increase indoor and outdoor efficiency**
  - **Use conservation pricing strategies**
- **Increase usability of local resources**
  - **Use more recycled water for replenishment**
  - **Increase basin permeability for greater recharge**
  - **Develop more groundwater recharge basins**
  - **Expand recycled water distribution network**

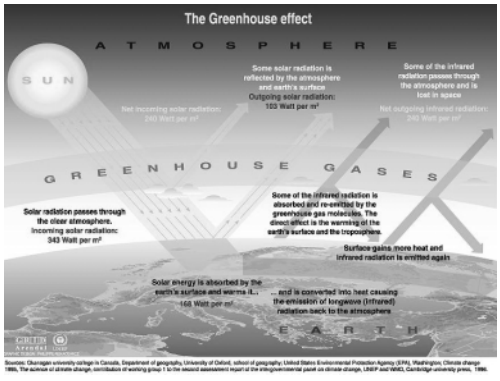
Workshop2 24 10/06

Today's Agenda

- **Review of previous workshop**
- **Forecasting climate change in the Chino Basin**
- **Using scenarios to assess IEUA responses to climate change**
- **Lunch**
- **Using probabilities to assess IEUA responses to climate change**
- **Next steps**

Workshop2 25 10/06

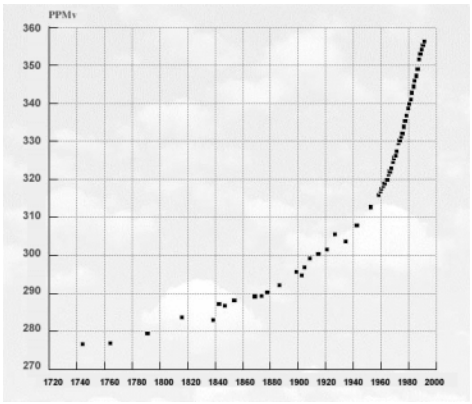
Greenhouse Gases Keep the Earth Warm



Source: National Academy of Sciences

Workshop2 26 10/06

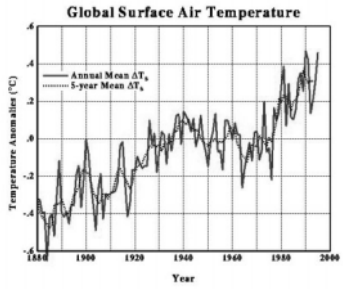
Atmospheric Concentrations of Greenhouse Gases Have Been Rising Over the Last Century



Source: US Department of Energy

Workshop2 27 10/06

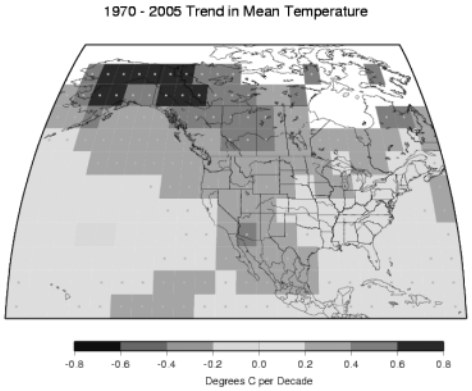
Concurrently, the Earth's Average Observed Surface Temperature Has Increased



Source: Intergovernmental Panel on Climate Change (IPCC)

Workshop2 28 10/06

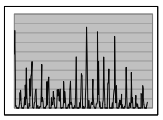
Temperatures Have Also Increased Across North America



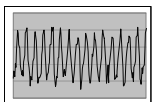
Source: National Academy of Sciences

Workshop2 29 10/06

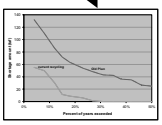
Last Time We Assumed Future Climate Will Be Similar to Past Climate



Past Chino climate



Model of IEUA system



Performance of IEUA plans

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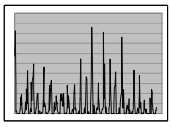
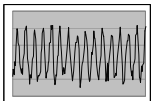
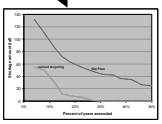
Now We Want to Use Forecasts of Future Climate



Future projections of Chino climate



Model of IEUA system



Performance of IEUA plans

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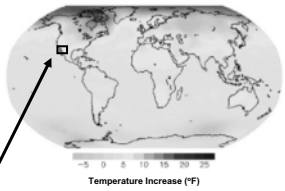
We Use General Circulation Models (GCMs) to Forecast Future Global Climate

- Climate represents the time and space average of weather
- GCMs are similar to models used for weather prediction; Both
  - divide the atmosphere into boxes (grids) and
  - track flow of air and heat among them
- But to predict climate, GCMs
  - have larger grid cells than weather models
  - model changes in ocean and land surface properties (coupled ocean-atmosphere models)



What do GCMs say about the Chino Basin?

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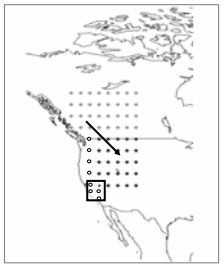
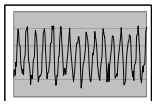
Then We Use a Climate Model to Forecast Future Weather Patterns in the Chino Basin

- **Create future weather sequences with**
  - **daily and monthly variability that matches historic Chino climate**
  - **overall temperature and precipitation trends that match climate model forecasts**



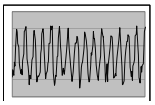
Source: National Center for Atmospheric Research (NCAR)

Regional trends from GCM



Local weather patterns

Future projection of Chino climate



Past Chino climate

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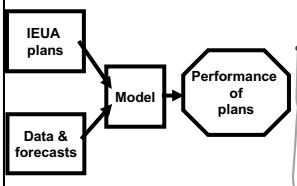
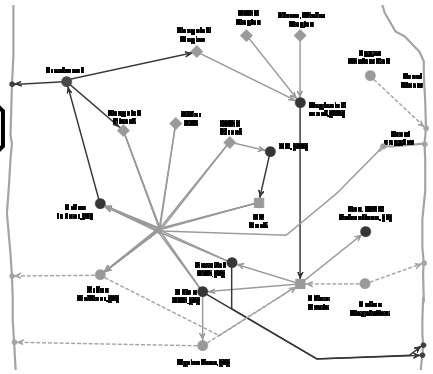
IEUA System Model Evaluates Performance of Plans Under Different Water Management Conditions



Uses Water Evaluation And Planning (WEAP) platform



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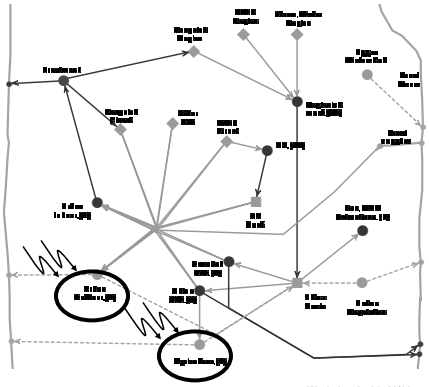
Climate Change Affects Urban Outdoor and Agricultural Demand

- **Soil moisture model estimates irrigation demand based on monthly weather data**
- **Hotter and drier conditions increase irrigation demand**



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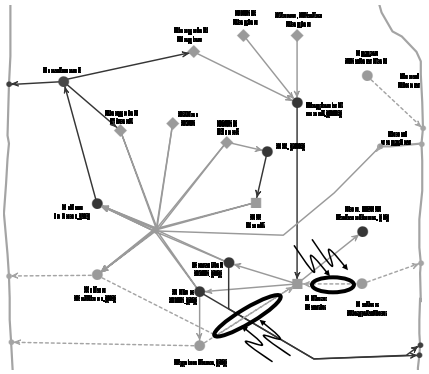
Climate Change Affects Natural Groundwater Recharge

- **Soil moisture model estimates deep percolation of precipitation and irrigation**
- **Hotter and drier conditions decrease groundwater recharge**



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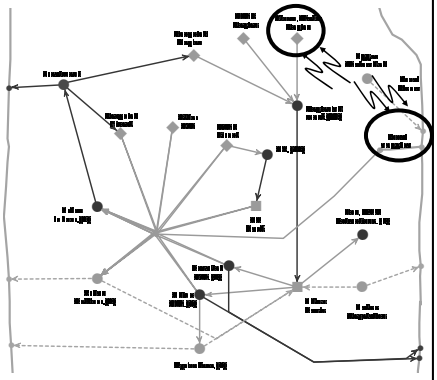
Climate Change Affects Local Surface Supplies

- **Local surface supply responds to precipitation in upper watershed**
- **Storm water availability for groundwater replenishment limited in dry years**



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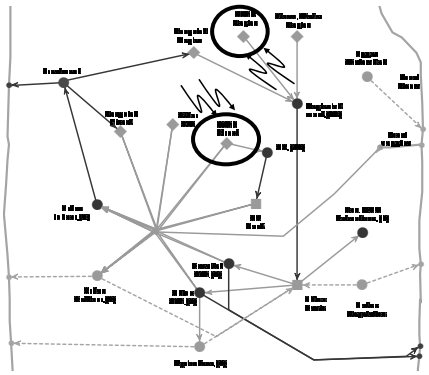
Climate Change Affects Reliability of Imported Supply

- **Imports provided by MWD systematically decrease under drier climate conditions**



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But how credible are the climate forecasts?

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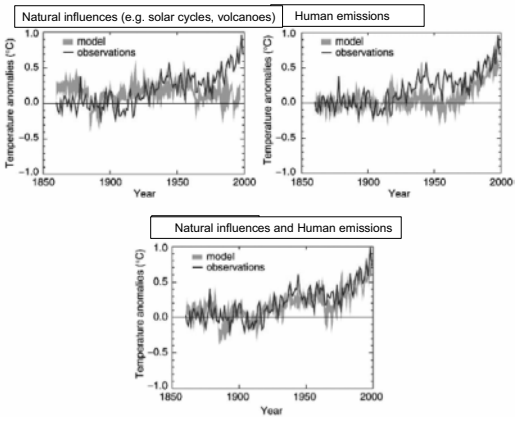
Climate Models Can Explain Recent Trends

Simulated annual global mean surface temperatures



Source: National Academy of Sciences

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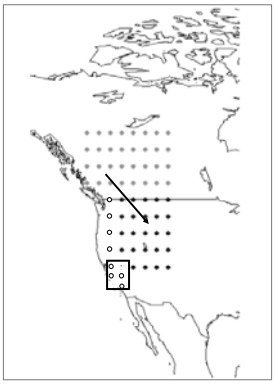
Grid Size Is One Limit On Predictive Power

- **GCM grid size (~ 250 km)**
  - **remains larger than many important atmospheric processes**
  - **requires that those processes be represented through complicated physical and chemical calculations**
- **The representations**
  - **introduce uncertainty**
  - **increase the difficulty of predicting important local phenomenon such as**
    - **precipitation amount**
    - **intensity of storms**



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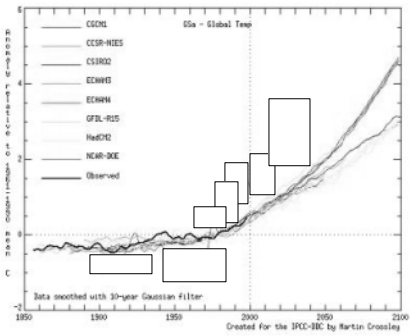
Climate Models Give Differing Predictions



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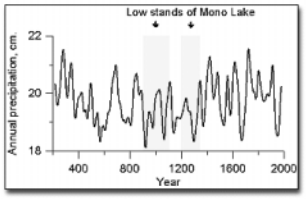
Climate Models Have Trouble Explaining Large Or Abrupt Changes

Last 100,000 years

Last 2,000 years



Source: NOAA

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How Can You Use This Uncertain Information to Inform Your Planning?

Uncertainties

Climate change

Ability to meet goals

Approaches

Traditional scenarios

Probability distribution

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Today's Agenda

- **Review of previous workshop**
- **Forecasting climate change in the Chino Basin**
- **Using scenarios to assess IEUA responses to climate change**
- **Lunch**
- **Using probabilities to assess IEUA responses to climate change**
- **Next steps**

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Use Several Scenarios to Represent Uncertainty

- **Regional planning often assumes a single scenario of future climate (e.g., the past climate)**
  - **Today we will present four scenarios**
- **Scenarios**
  - **provide carefully constructed descriptions of alternative futures**
  - **help decisionmakers assess how their plans might perform in a wide array of contingencies**
- **Scenarios are often created by**
  - **identifying decision challenge**
  - **ranking key driving forces**
  - **representing different combinations of these driving forces**

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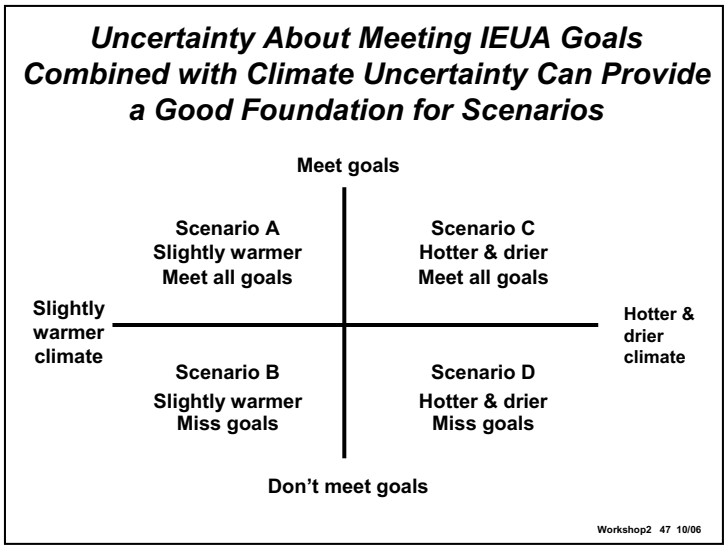
Uncertainty About Meeting IEUA Goals Combined with Climate Uncertainty Can Provide a Good Foundation for Scenarios
Meet goals
Scenario A
Slightly warmer
Meet all goals
Scenario C
Hotter & drier
Meet all goals
Slightly warmer climate
Hotter & drier climate
Scenario B
Slightly warmer
Miss goals
Scenario D
Hotter & drier
Miss goals
Don't meet goals
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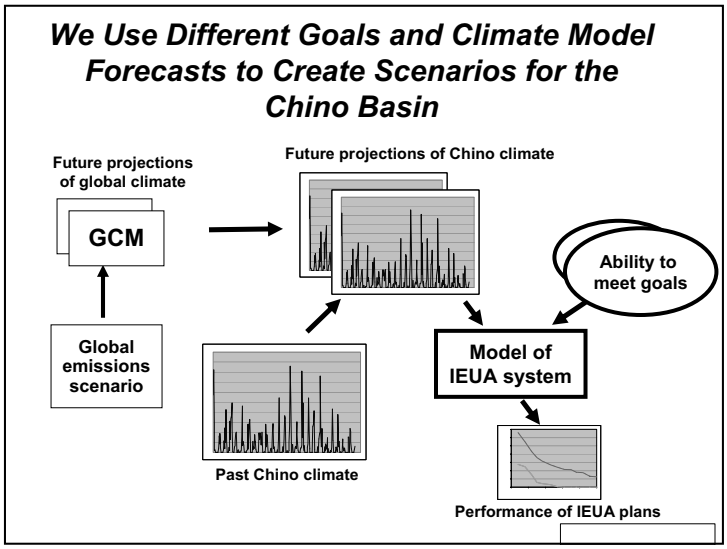
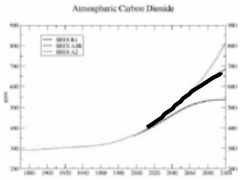

We Use Different Goals and Climate Model Forecasts to Create Scenarios for the Chino Basin
Future projections of global climate
GCM
Global emissions scenario
Future projections of Chino climate
Past Chino climate
Ability to meet goals
Model of IEUA system
Performance of IEUA plans

Two Estimates of Climate Span a Wide Range of Plausible Futures



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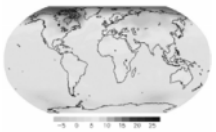

1 emissions scenario (A1B)

High and low estimate from several GCMs

Climate parameters

Slightly warmer — Hotter & drier — Temperature change

0 +.7C +1.6C

Hotter & drier — Slightly warmer — Precipitation change

-10% 0 +3%

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Two Estimates for Goals Were Drawn from Participant Input

Direct use of recycled water

6 taf 30 taf 39 taf 50 taf 69 taf — Meet goals / Miss goals

2005 2010 2025

Chino Basin replenishment

68 taf 90 taf 92 taf 107 taf — Meet goals / Miss goals

2005 2010 2025 2025

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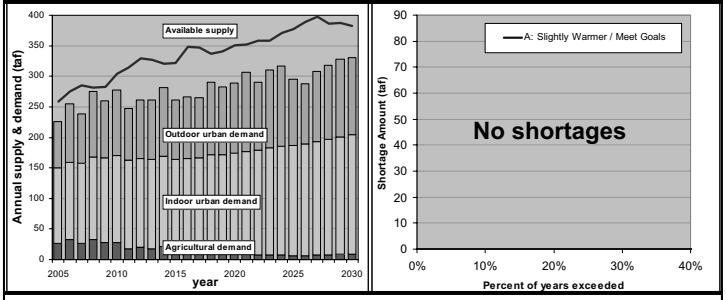
Performance of IEUA 2005 Plan Depends Upon the Scenario

Scenario A – Slightly warmer, meet goals



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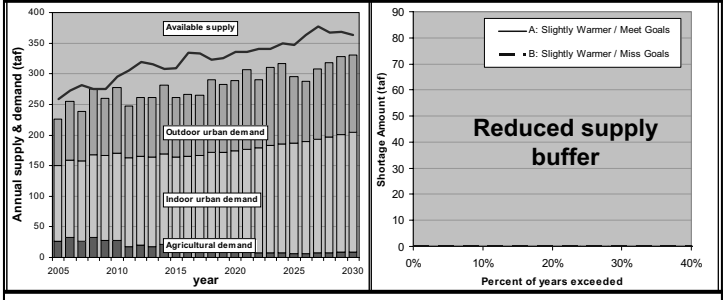
Performance of IEUA 2005 Plan Depends Upon the Scenario

Scenario B – Slightly warmer, miss goals



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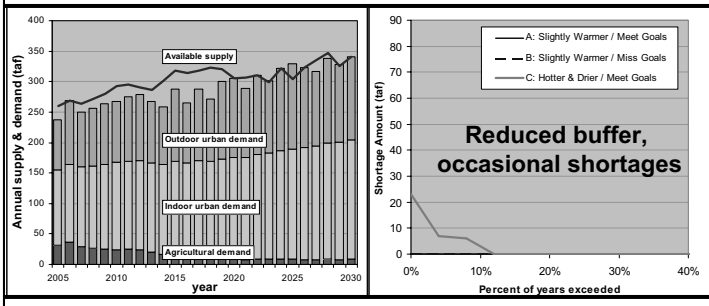
Performance of IEUA 2005 Plan Depends Upon the Scenario

Scenario C – Hotter & drier, meet goals



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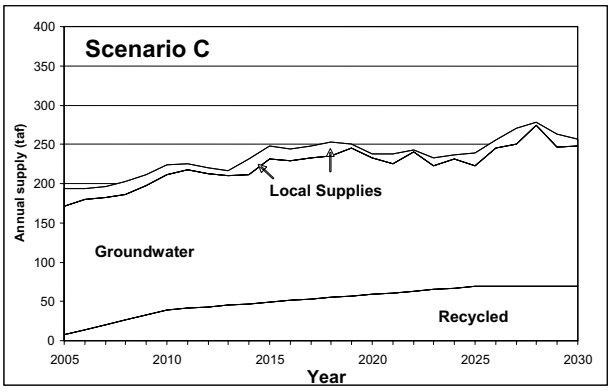
Scenario C Would Produce Reduced Buffer and Occasional Shortages



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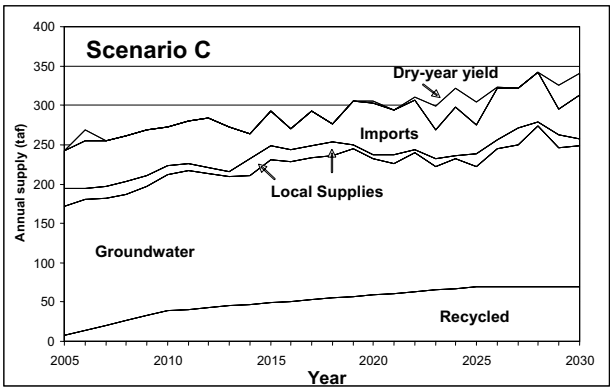
Scenario C Would Produce Reduced Buffer and Occasional Shortages



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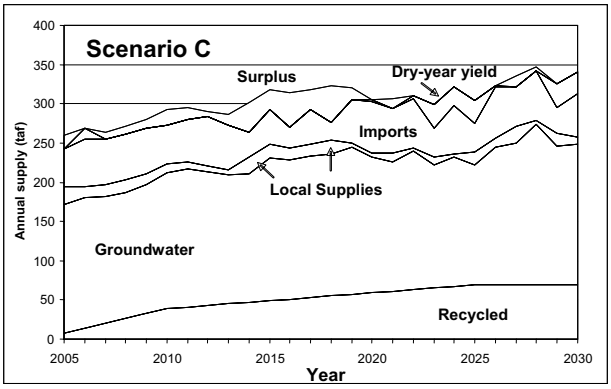
Scenario C Would Produce Reduced Buffer and Occasional Shortages



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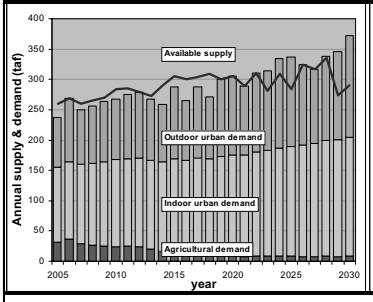
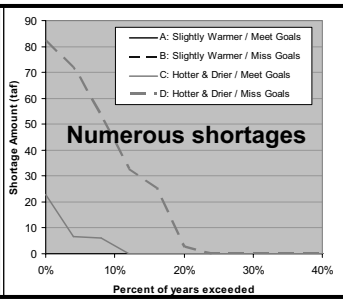
Performance of IEUA 2005 Plan Depends Upon the Scenario

Scenario D – Hotter & drier, miss goals





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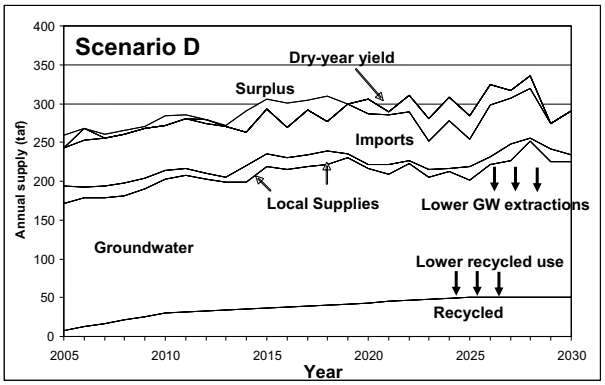
Scenario D Would Lead To Numerous Shortages



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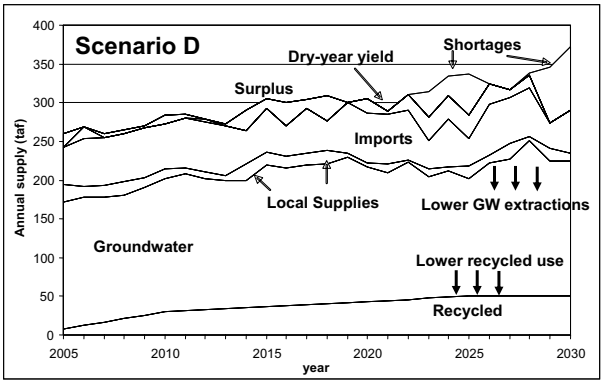
Scenario D Would Lead To Numerous Shortages



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Scenario Maps Summarize Performance of Plans

Percent of years with shortages	A: Slightly warmer, meet goals	B: Slightly warmer, miss goals	C: Hotter & drier, meet goals	D: Hotter & drier, miss goals
2005 UWMP	0%	0%	19%	42%

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Based On Participants' Input, We Modeled Two Enhancements to the 2005 UWMP

- **Moderate demand growth**
  - **Increase indoor and outdoor efficiency**
  - **Use conservation pricing strategies**
- **Increase usability of local resources**
  - **Use more recycled water for replenishment**
  - **Increase basin permeability for greater recharge**
  - **Develop more groundwater recharge basins**
  - **Expand recycled water distribution network**

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We Constructed Three New Plans Based On These Enhancements

	2005 UWMP actions	+ Increased efficiency	+ Increased recycled replenishment
Plan 1	✓		
Plan 2	✓	✓	
Plan 3	✓		✓
Plan 4	✓	✓	✓
		+ 15% (2015) + 20% (2020)	+ 20% allowable recycled replenishment

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All Plans Perform Well In Scenario A

Percent of years with shortages	A: Slightly warmer, meet goals	B: Slightly warmer, miss goals	C: Hotter & drier, meet goals	D: Hotter & drier, miss goals
Plan 1 (2005 UWMP)	0%			
Plan 2 (+ Efficiency)	0%			
Plan 3 (+ Recycled replenishment)	0%			
Plan 4 (+ Efficiency & recycled replenishment)	0%			

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Enhanced Plans Perform Better Under More Difficult Scenarios

Percent of years with shortages	A: Slightly warmer, meet goals	B: Slightly warmer, miss goals	C: Hotter & drier, meet goals	D: Hotter & drier, miss goals
Plan 1 (2005 UWMP)	0%	0%	19%	42%
Plan 2 (+ Efficiency)	0%	0%	4%	27%
Plan 3 (+ Recycled replenishment)	0%			
Plan 4 (+ Efficiency & recycled replenishment)	0%			

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Enhanced Plans Perform Better Under More Difficult Scenarios

Percent of years with shortages	A: Slightly warmer, meet goals	B: Slightly warmer, miss goals	C: Hotter & drier, meet goals	D: Hotter & drier, miss goals
Plan 1 (2005 UWMP)	0%	0%	19%	42%
Plan 2 (+ Efficiency)	0%	0%	4%	27%
Plan 3 (+ Recycled replenishment)	0%	0%	12%	42%
Plan 4 (+ Efficiency & recycled replenishment)	0%			

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Enhanced Plans Perform Better Under More Difficult Scenarios

Percent of years with shortages	A: Slightly warmer, meet goals	B: Slightly warmer, miss goals	C: Hotter & drier, meet goals	D: Hotter & drier, miss goals
Plan 1 (2005 UWMP)	0%	0%	19%	42%
Plan 2 (+ Efficiency)	0%	0%	4%	27%
Plan 3 (+ Recycled replenishment)	0%	0%	12%	42%
Plan 4 (+ Efficiency & recycled replenishment)	0%	0%	0%	15%

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Enhanced Plans Carry Risk of Over Investment

Percent of years with shortages	A: Slightly warmer, meet goals	B: Slightly warmer, miss goals	C: Hotter & drier, meet goals	D: Hotter & drier, miss goals	Cost
Plan 1 (2005 UWMP)	0%	0%	19%	42%	
Plan 2 (+ Efficiency)	0%	0%	4%	27%	++
Plan 3 (+ Recycled replenishment)	0%	0%	12%	42%	++
Plan 4 (+ Efficiency & recycled replenishment)	0%	0%	0%	15%	+++

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To what extent would scenarios like these provide water planners with sufficient information to assess and possibly modify current plans?

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Today's Agenda

- **Review of previous workshop**
- **Forecasting climate change in the Chino Basin**
- **Using scenarios to assess IEUA responses to climate change**
- **Lunch**
- **Using probabilities to assess IEUA responses to climate change**
- **Next steps**

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Today's Agenda

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Probabilities Help Quantify Risk

- **Probabilities offer a powerful framework for quantifying and ranking risks**

  Risk = Probability x Impact

- **Probability can be estimated from**
  - **quantitative models and data**
  - **expert opinion**

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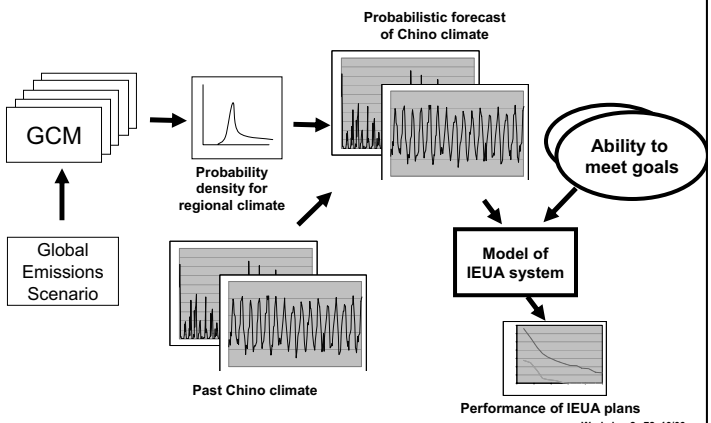
We Used Climate Models and Your Input to Create a Probabilistic Forecast for the Chino Basin



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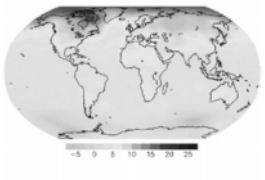
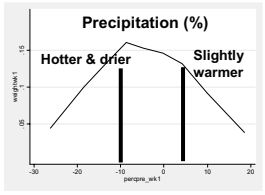
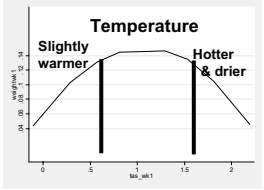
Models Yield Probabilistic Forecast For Climate







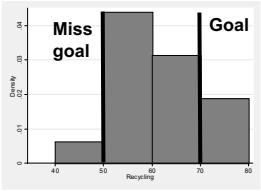
- **Weight models according to**
  - **how well they reproduce past climate**
  - **how well they agree with forecasts of other GCMs**

Probability Density for Regional Climate

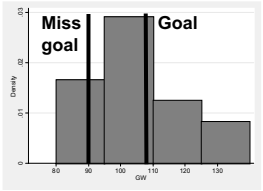
Workshop2 73 10/06

Participants' Input Provided a Probabilistic Forecast For Meeting Goals

Recycling

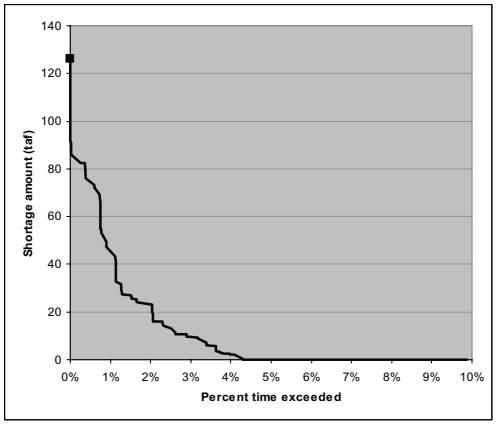


Replenishment



Workshop2 74 10/06

The 2005 UWMP Performs Reasonably Well Given Our Probabilistic Forecast



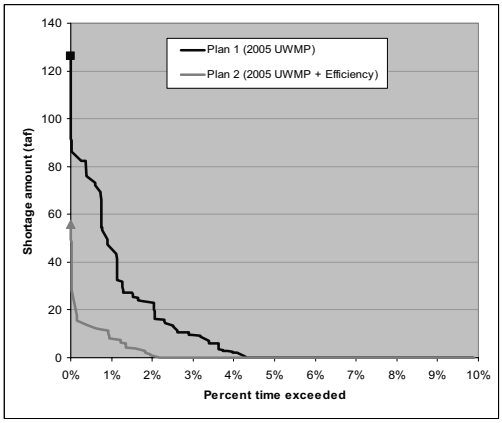
Workshop2 75 10/06

Consider the Alternative Plans Again

	2005 UWMP actions	+ Increased efficiency	+ Increased recycled replenishment
Plan 1	✓		
Plan 2	✓	✓	
Plan 3	✓		✓
Plan 4	✓	✓	✓
		+ 15% (2015) + 20% (2020)	+ 20% allowable recycled replenishment

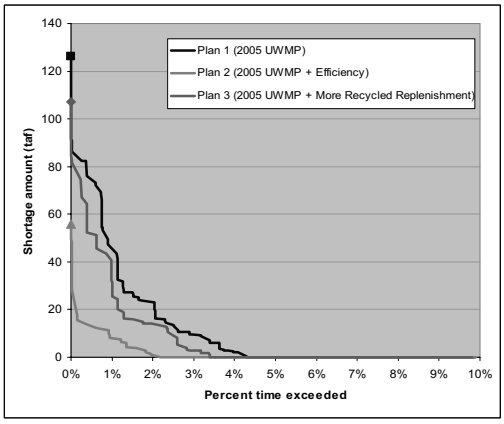
Workshop2 76 10/06

Enhanced Plans Perform Even Better



Workshop2 77 10/06

Enhanced Plans Perform Even Better



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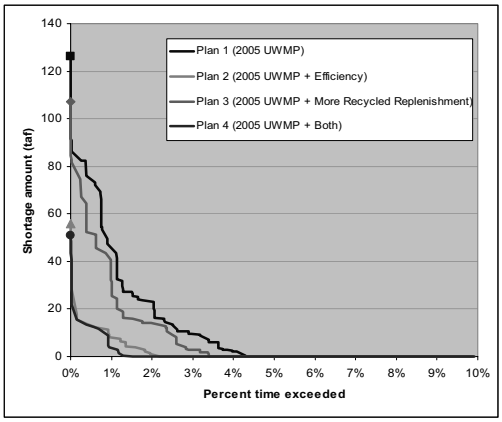
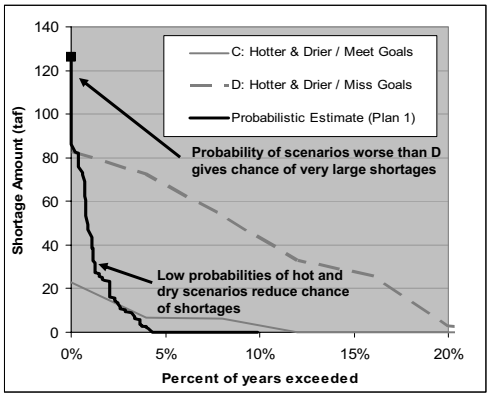
Enhanced Plans Perform Even Better



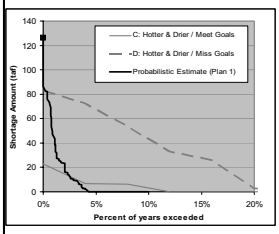
Workshop2 79 10/06

Probability Distribution Summarizes Information Contained in Many Scenarios



Workshop2 80 10/06

Given a Probabilistic Forecast, All Plans Perform Relatively Well



Probability of shortage	Probabilistic climate & goals forecast	COST
Plan 1 (2005 UWMP)	**4.4%**	
Plan 2 (+ Efficiency)	**2.1%**	**++**
Plan 3 (+ Recycled replenishment)	**3.3%**	**++**
Plan 4 (+ Efficiency & recycled replenishment)	**1.1%**	**+++**

Workshop2 81 10/06

To what extent would probability-weighted results like these provide water planners with sufficient information to assess and possibly modify current plans?

Workshop2 82 10/06

Today's Agenda

- **Review of previous workshop**
- **Forecasting climate change in the Chino Basin**
- **Using scenarios to assess IEUA responses to climate change**
- **Lunch**
- **Using probabilities to assess IEUA responses to climate change**
- **Next steps**

Workshop2 83 10/06

Today We Explored Two Ways to Characterize Climate and Other Uncertainties

- **Four traditional scenarios suggest that 2005 UWMP**
  - **performs well under some conditions but**
  - **can have significant shortages under hot and dry climate conditions**
- **Probability distributions suggest 2005 UWMP**
  - **has small chance of significant shortages**
  - **performs well on average**

Workshop2 84 10/06

What Happens Next?

- **The final workshop (Nov 3) will present a new approach for identifying plans that perform well over a wide range of climate scenarios**
- **Help us evaluate which of the approaches presented in these workshops are most useful for your planning**

See you at the next workshop—Friday, Nov 3

Workshop2 85 10/06

Workshop2 86 10/06

Workshop 3

Climate Change in the Inland Empire: How to Best Address the Uncertainties

Last of three workshops
funded by the National Science Foundation and
sponsored by RAND and IEUA

November 3, 2006

What Is RAND?

- **RAND is an independent, nonprofit research institution**
- **Its mission is to help improve policy and decisionmaking through research and analysis**
- **Its strength is in its more than 750 professional, multidisciplinary research staff in the United States and abroad**
- **RAND's clients include government agencies, private firms, and other nonprofits**

Workshop 3 11/03/06 2

What Information About Climate Change and Other Uncertainties Is Most Useful to Decisionmakers?

- **Potential climate change confronts IEUA with difficult decision challenges**
  - **Substantial scientific evidence suggests climate change may be an important concern**
  - **But the evidence is not as solid as that typically used in planning and engineering judgments**
- **How should IEUA respond to uncertain but potentially serious information about climate and other factors?**
- **How can these uncertainties be presented in ways that help IEUA respond most effectively?**

Workshop 3 11/03/06 3

The Three Workshops Explore Different Representations of Uncertainty

- **We will use a model of the IEUA system and the best available climate science to demonstrate potential strengths and weaknesses of different representations of uncertainty**
  - **Workshop 1 (Sept 28) presented current climate conditions that continue in the future**
  - **Workshop 2 (Oct 20) presented traditional scenarios and best probabilistic representations of future climate**
  - **Today's workshop will use the model to construct the scenarios most important to IEUA plans**

Workshop 3 11/03/06 4

The Workshops Will Make Valuable Contributions to Policy Formulation and to Science

- **Provide regional water managers and other decisionmakers with useful information about system performance under climate change**
- **Contribute to scientific understanding of how to best analyze and represent uncertainty for decisionmakers**

Workshop 3 11/03/06 5

IEUA Is an Ideal Host for the Workshops

- **Has been proactive in assembling a plan that greatly improves the region's water outlook**
- **Now aims to systematically consider potential impacts of climate change on the region's plans**

We very much appreciate your participation!

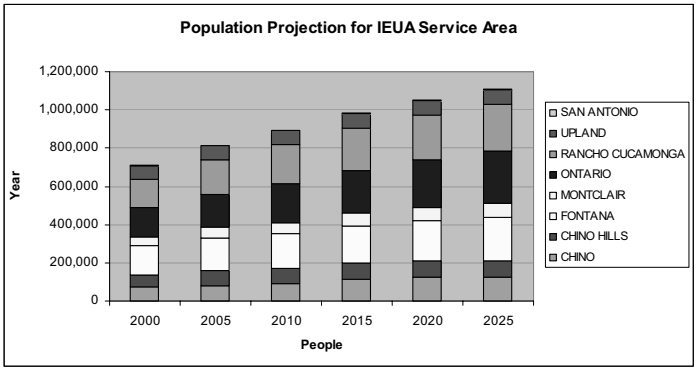
Workshop 3 11/03/06 6

Today's Agenda

- **Review key information from previous workshops**
- **Use traditional scenarios to assess IEUA responses to climate change**
- **Use probabilities to assess IEUA responses to climate change**
- **Consider scenarios most important to IEUA responses to climate change**
- **Discuss how you would use these ideas in your own planning**

Workshop 3 11/03/06 7

IEUA And Member Agencies Must Prepare for Strong Growth in the Chino Basin



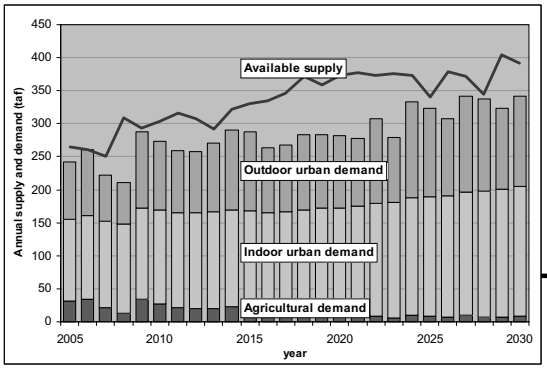
Workshop 3 11/03/06 8

IEUA Has an Ambitious Plan to Supply Water for the Region's Growth

Management action	Current (2005)	2005 UWMP
Water use efficiency	4%	10% (2015)
Direct use of recycled water	7.5 taf	30 taf (2010) 69 taf (2025)
GW Replenishment	68 taf	91 taf (2015) 107 taf (2025)
GW desalting	6.2 taf	14+ taf (2010)
Dry-year yield program	n/a	33 taf/year (2008)
Imports (direct use)	60 taf	82 taf (2025)

Workshop 3 11/03/06 9

If the Region Successfully Implements the 2005 UWMP, It Will Face No Shortages Under the Current Climate



Assumes next 25 years of climate replicates past 25 years

Workshop 3 11/03/06 10

Climate Change May Affect IEUA's Plans

- Climate models predict that by 2030, the Chino climate
  - is virtually certain to become warmer (0°C to 2°C)
  - may be wetter (precipitation increases 10%) or significantly drier (decreases by 30%)
- These results reflect the best available scientific information, but they are uncertain
  - Storms may be more intense than in the past
  - Climate changes may be either more or less abrupt than predicted

How should IEUA use this information in its planning?

Workshop 3 11/03/06 11

To Address These Challenges, IEUA Might Choose to Enhance the 2005 UWMP

- Reduce demand growth
  - Increase indoor and outdoor efficiency
  - Use conservation pricing strategies
- Increase usability of local resources
  - Use more recycled water for replenishment
  - Increase basin permeability for greater recharge
  - Develop more groundwater recharge basins
  - Expand recycled water distribution network

Workshop 3 11/03/06 12

Based On Participants' Input, We Modeled Two Enhancements to the 2005 UWMP

- **Reduce demand growth**
  - **Increase indoor and outdoor efficiency**
  - **Use conservation pricing strategies**
- **Increase usability of local resources**
  - **Use more recycled water for replenishment**
  - **Increase basin permeability for greater recharge**
  - **Develop more groundwater recharge basins**
  - **Expand recycled water distribution network**

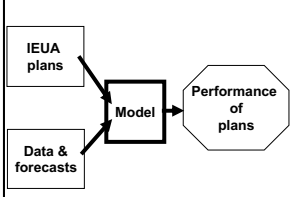
Workshop 3 11/03/06 13

We Also Constructed Three Additional Plans Based On These Enhancements

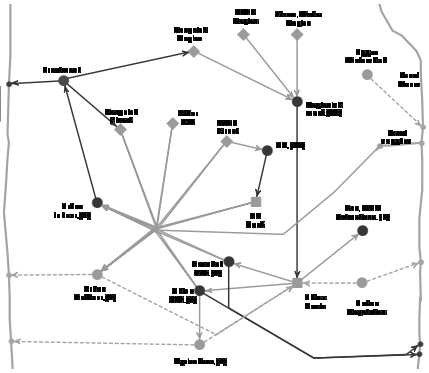
	2005 UWMP actions	+ Increased efficiency	+ Increased recycled replenishment
Plan 1	✓		
Plan 2	✓	✓	
Plan 3	✓		✓
Plan 4	✓	✓	✓
		+ 15% (2015) + 20% (2020)	+ 20% allowable recycled replenishment

Workshop 3 11/03/06 14

IEUA System Model Suggests How Climate Change Might Affect the Region's Plans



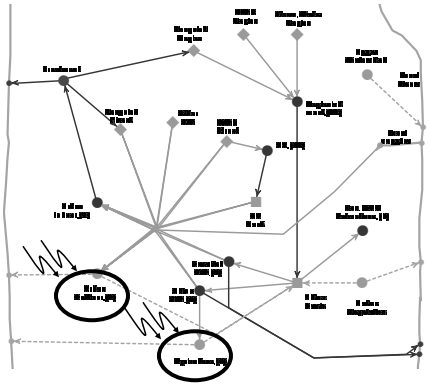
IEUA system model evaluates performance of plans under different water management conditions



Workshop 3 11/03/06 15

Climate Change May Affect Urban Outdoor and Agricultural Demand

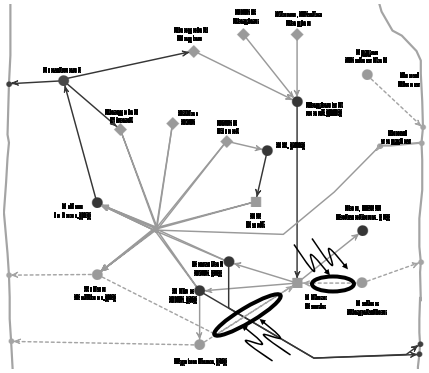
- **Soil moisture model estimates irrigation demand based on monthly weather data**
- **Hotter and drier conditions increase irrigation demand**



Workshop 3 11/03/06 16

Climate Change May Affect Natural Groundwater Recharge

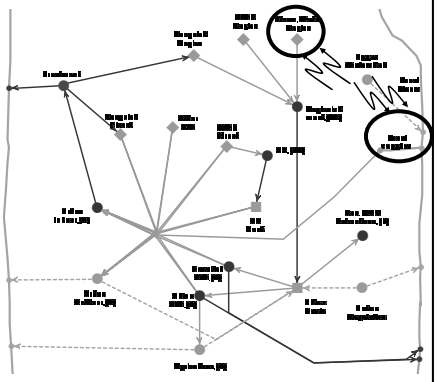
- **Soil moisture model estimates deep percolation of precipitation and irrigation**
- **Hotter and drier conditions decrease groundwater recharge**



Workshop 3 11/03/06 17

Climate Change May Affect Local Surface Supplies

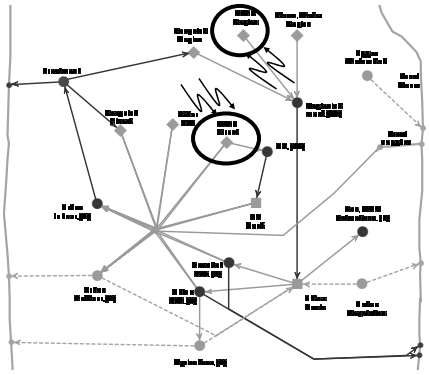
- **Local surface supply responds to precipitation in upper watershed**
- **Storm water availability for groundwater replenishment is limited in dry years**



Workshop 3 11/03/06 18

Climate Change May Affect Reliability of Imported Supply

- **Imports provided by MWD systematically decrease under drier climate conditions**



Workshop 3 11/03/06 19

Climate Change Is Not the Only Potentially Important Uncertainty Facing the 2005 UWMP

Management action	Goal	Chance reached 2015	
Recycling	49 taf (2015)	72%	
Chino Basin replenishment	91 taf (2015)	79%	
Imports (direct use)	74 taf (2015)	75%	

Workshop participants provided Information about the likelihood of reaching goals

Workshop 3 11/03/06 20

Climate Change Is Not the Only Potentially Important Uncertainty Facing the 2005 UWMP

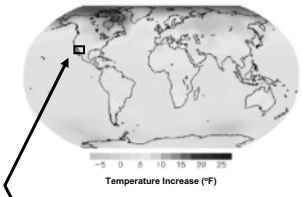
Management action	Goal	Chance reached 2015	Chance reached 2025
Recycling	49 taf (2015) 69 taf (2025)	72%	69%
Chino Basin replenishment	91 taf (2015) 107 taf (2025)	79%	73%
Imports (direct use)	74 taf (2015) 83 taf (2025)	75%	67%

Workshop participants provided Information about the likelihood of reaching goals

Workshop 3 11/03/06 21

What Can Science Tell IEUA About Future Climate Change?

- General circulation models (GCMs) forecast future global climate
- GCMs are similar to models used for weather prediction; Both
  - divide the atmosphere into boxes (grids) and
  - track flow of air and heat among them
- But to predict climate, GCMs
  - have larger grid cells than weather models
  - model changes in ocean and land surface properties (coupled ocean-atmosphere models)

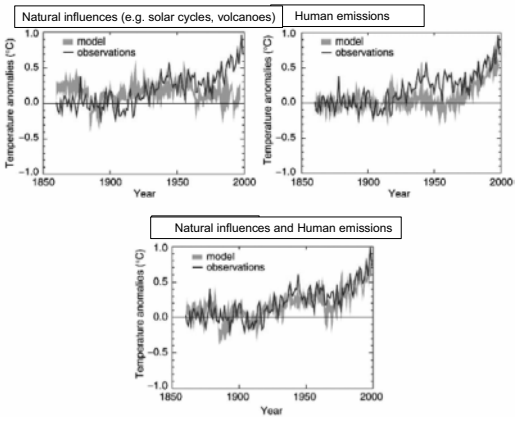


What do GCMs say about the Chino Basin?

Workshop 3 11/03/06 22

Climate Models Can Explain Recent Trends

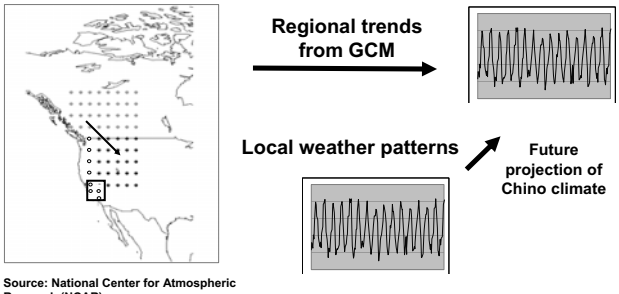
Simulated annual global mean surface temperatures



Source: National Academy of Sciences

How Do Scientists Make Forecasts of Future Climate in the Chino Basin?

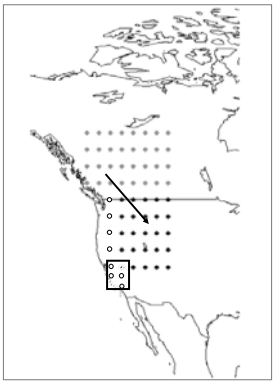
- **Create future weather sequences with**
  - **daily and monthly variability that matches historic Chino climate**
  - **overall temperature and precipitation trends that match climate model forecasts**



Source: National Center for Atmospheric Research (NCAR)

Grid Size Is One Limit on Predictive Power

- **GCM grid size (~ 250 km)**
  - **remains larger than many important atmospheric processes**
  - **requires that those processes be represented through complicated physical and chemical calculations**
- **The representations**
  - **introduce uncertainty**
  - **increase the difficulty of predicting important local phenomenon such as**
    - **precipitation amount**
    - **intensity of storms**



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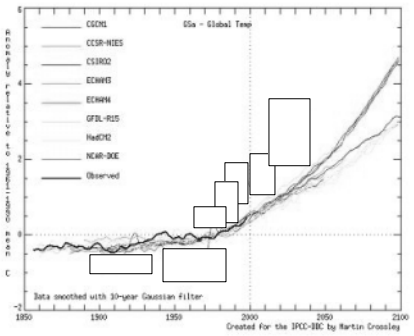
Climate Models Give Differing Predictions

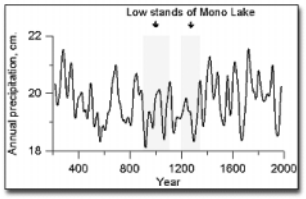


Workshop 3 11/03/06 26

Climate Models Have Trouble Explaining Large or Abrupt Changes

Last 100,000 years

Last 2,000 years



Source: NOAA

Workshop 3 11/03/06 27

What Means of Characterizing Climate and Other Uncertainties Work Best for IEUA?

Uncertainties

Climate change | **Other uncertainties** | **Ability to meet goals**

⇩

We consider three approaches

Traditional scenarios | **Probability distribution** | **Most policy-relevant scenarios**

Workshop 3 11/03/06 28

Today's Agenda

- **Review key information from previous workshops**
- **Use traditional scenarios to assess IEUA responses to climate change**
- **Use probabilities to assess IEUA responses to climate change**
- **Consider scenarios most important to IEUA responses to climate change**
- **Discuss how you would use these ideas in your own planning**

Workshop 3 11/03/06 29

Use Several Scenarios to Represent Uncertainty

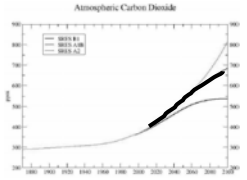
- **Scenarios**
  - **provide carefully constructed descriptions of alternative futures**
  - **help decisionmakers assess how their plans might perform in a wide array of contingencies**
- **Scenarios are often created by**
  - **identifying decision challenge**
  - **ranking key driving forces**
  - **representing different combinations of these driving forces**

Workshop 3 11/03/06 30

Uncertainty About Meeting IEUA Goals Combined with Climate Uncertainty Can Provide a Good Foundation for Scenarios

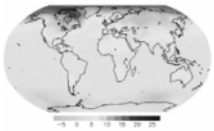
Workshop 3 11/03/06 31

Two Estimates of Climate Span a Wide Range of Plausible Futures

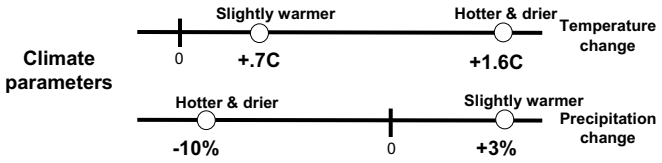


1 emissions scenario (A1B)

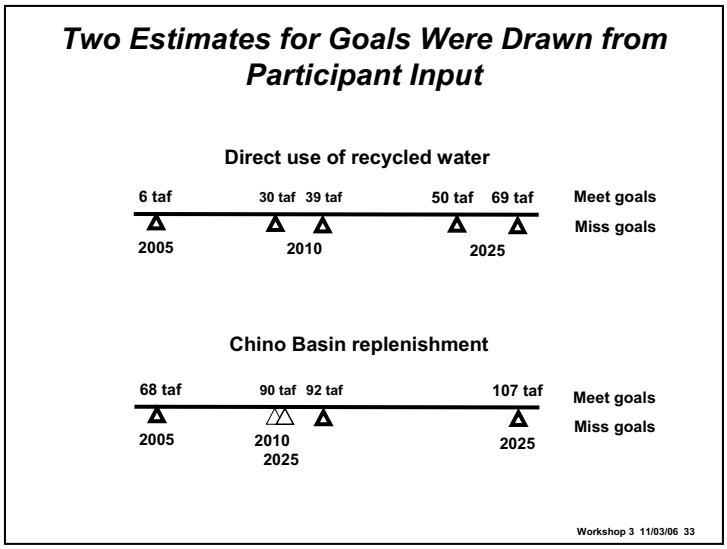
+

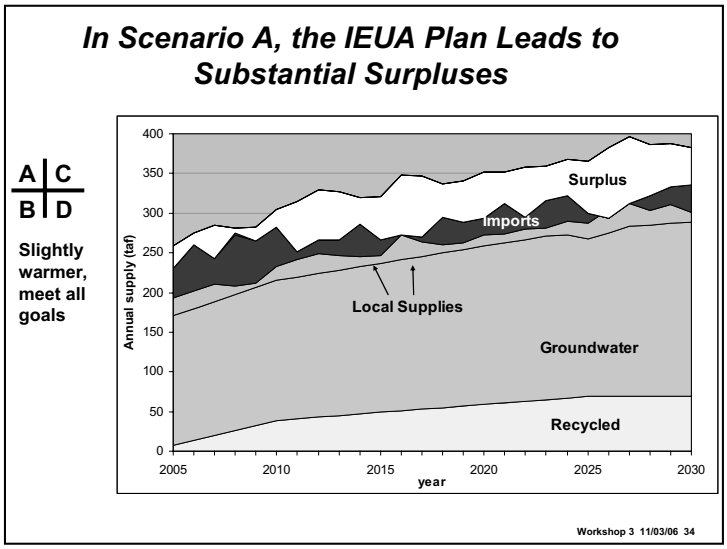


High and low estimate from several GCMs



Workshop 3 11/03/06 32

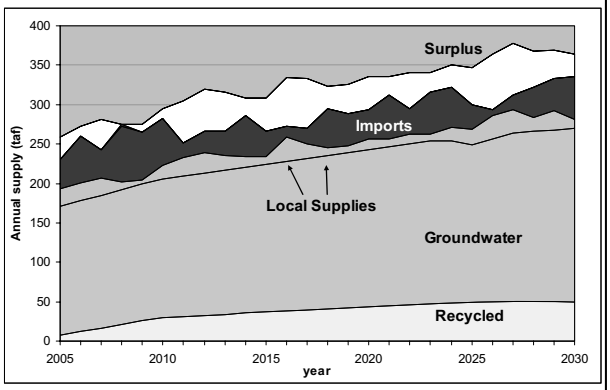

Two Estimates for Goals Were Drawn from Participant Input
Direct use of recycled water
6 taf
30 taf
39 taf
50 taf
69 taf
Meet goals
Miss goals
2005
2010
2025
Chino Basin replenishment
68 taf
90 taf
92 taf
107 taf
Meet goals
Miss goals
2005
2010
2025
2025
Workshop 3 11/03/06 33


In Scenario A, the IEUA Plan Leads to Substantial Surpluses
A C
B D
Slightly warmer, meet all goals
Annual supply (taf)
400
350
300
250
200
150
100
50
0
2005
2010
2015
2020
2025
2030
year
Surplus
Imports
Local Supplies
Groundwater
Recycled
Workshop 3 11/03/06 34

In Scenario B, the IEUA Plan Performs Well Also

A | C
B | D

Slightly warmer, miss goals

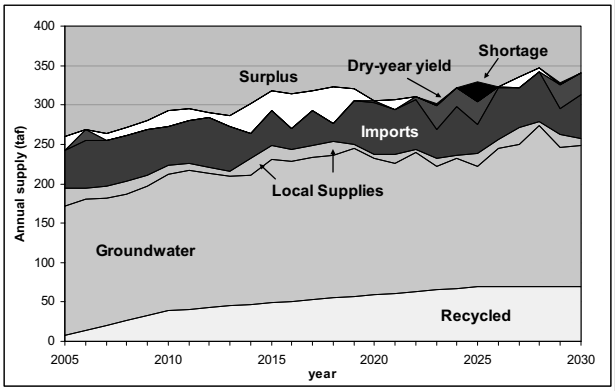


Workshop 3 11/03/06 35

In Scenario C, the IEUA Plan Has Limited Surpluses and Might Experience Shortages

A | C
B | D

Hotter & drier, meet all goals



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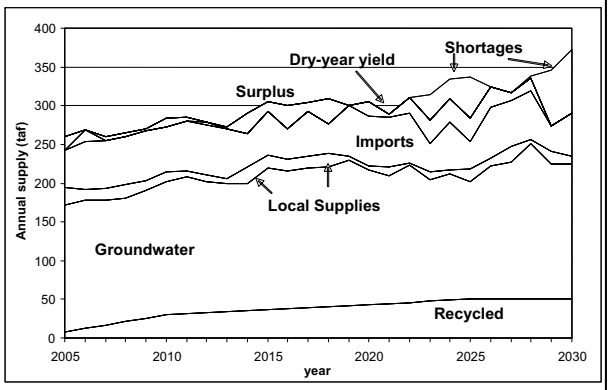
In Scenario D, the IEUA Plan Experiences Significant Shortages

A | C
B | D

Hotter & drier, miss goals



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Compare Performance of Four Plans

	2005 UWMP actions	+ Increased efficiency	+ Increased recycled replenishment
Plan 1	✓		
Plan 2	✓	✓	
Plan 3	✓		✓
Plan 4	✓	✓	✓
		+ 15% (2015) + 20% (2020)	+ 20% allowable recycled replenishment

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Last Time We Compared Plans Based on Percentage of Years with Shortages

Percent of years with shortages	A: Slightly warmer, meet goals	B: Slightly warmer, miss goals	C: Hotter & drier, meet goals	D: Hotter & drier, miss goals
Plan 1 (2005 UWMP)	0%	0%	19%	42%
Plan 2 (+ Efficiency)	0%	0%	4%	27%
Plan 3 (+ Recycled replenishment)	0%	0%	12%	42%
Plan 4 (+ Efficiency & recycled replenishment)	0%	0%	0%	15%

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But Planners Are Concerned With Over-Investment As Well-As Under-Investment

Average Surplus (2006 - 2030)	A: Slightly warmer, meet goals	B: Slightly warmer, miss goals	C: Hotter & drier, meet goals	D: Hotter & drier, miss goals
Plan 1 (2005 UWMP)	39 taf	26 taf	11 taf	6 taf
Plan 2 (+ Efficiency)	51 taf	35 taf	17 taf	9 taf
Plan 3 (+ Recycled replenishment)	43 taf	27 taf	14 taf	8 taf
Plan 4 (+ Efficiency & recycled replenishment)	52 taf	36 taf	19 taf	11 taf

Underinvestment leads to shortages

Overinvestment leads to excessive surpluses

>40 <40 <20 <10

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Today's Agenda

- **Review key information from previous workshops**
- **Use traditional scenarios to assess IEUA responses to climate change**
- **Use probabilities to assess IEUA responses to climate change**
- **Consider scenarios most important to IEUA responses to climate change**
- **Discuss how you would use these ideas in your own planning**

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Probabilities Help Quantify Risk

- **Probabilities offer a powerful framework for quantifying and ranking risks**

  Risk = Probability x Impact

- **Probability can be estimated from**
  - **quantitative models and data**
  - **expert opinion**

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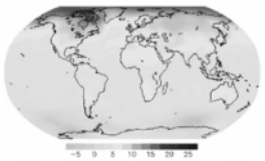
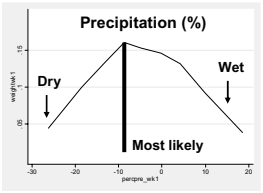
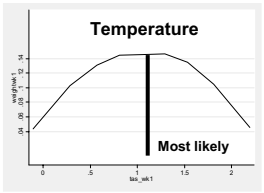
Models Yield Probabilistic Forecast For Climate





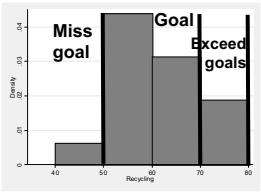


- **Weight models according to**
  - **how well they reproduce past climate**
  - **how well they agree with forecasts of other GCMs**

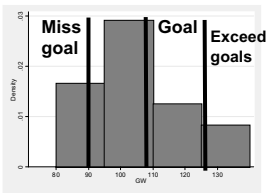
Probability Density for Regional Climate

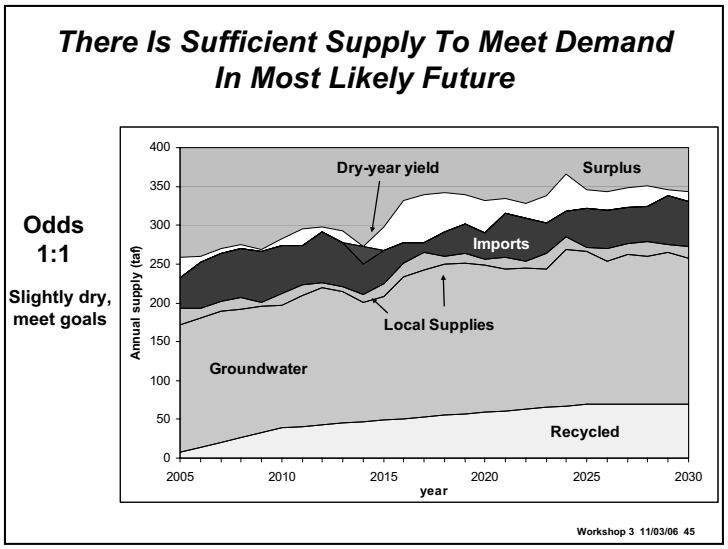
Participants' Input Provided a Probabilistic Forecast For Meeting Goals

Recycling



Replenishment




There Is Sufficient Supply To Meet Demand In Most Likely Future
Odds 1:1
Slightly dry, meet goals
Annual supply (taf)
400
350
300
250
200
150
100
50
0
2005
2010
2015
2020
2025
2030
year
Dry-year yield
Surplus
Imports
Local Supplies
Groundwater
Recycled
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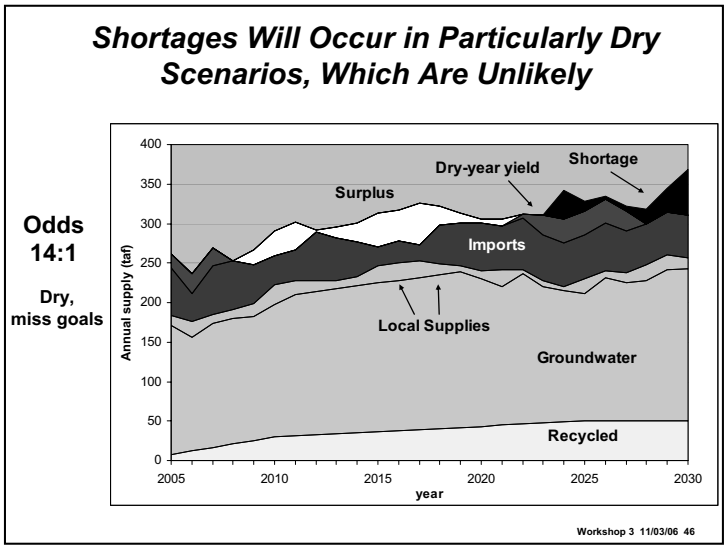
Shortages Will Occur in Particularly Dry Scenarios, Which Are Unlikely
Odds 14:1
Dry, miss goals
Annual supply (taf)
400
350
300
250
200
150
100
50
0
2005
2010
2015
2020
2025
2030
year
Dry-year yield
Shortage
Surplus
Imports
Local Supplies
Groundwater
Recycled
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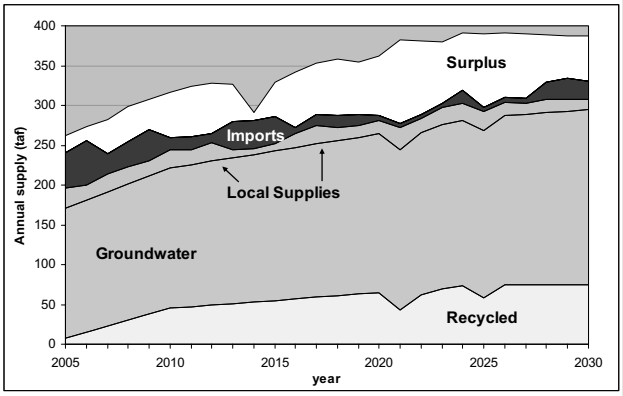
Large Surpluses Occur in Particularly Wet Scenarios, Also Unlikely

Odds 31:1

Wet, exceed goals



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We Consider Four Alternative Plans

	2005 UWMP actions	+ Increased efficiency	+ Increased recycled replenishment
Plan 1	✓		
Plan 2	✓	✓	
Plan 3	✓		✓
Plan 4	✓	✓	✓
		+ 15% (2015) + 20% (2020)	+ 20% allowable recycled replenishment

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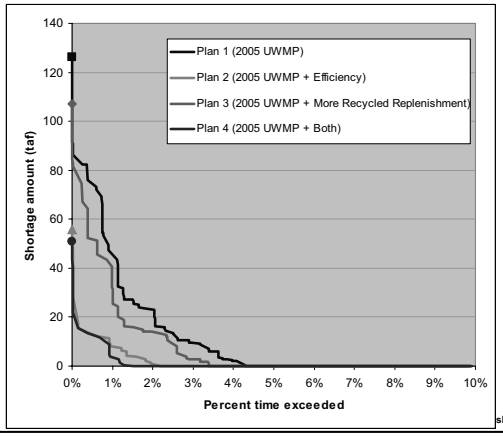
Probabilistic Forecasts Weight Most-Likely Conditions Leading to Favorable Performance of the IEUA 2005 UWMP



Given a Probabilistic Forecast, All Plans Perform Relatively Well

Probabilistic climate & goals forecast	Probability of shortage	Average surplus (2006-2030)
Plan 1 (2005 UWMP)	4.4%	28 taf
Plan 2 (+ Efficiency)	2.1%	37 taf
Plan 3 (+ Recycled replenishment)	3.3%	30 taf
Plan 4 (+ Efficiency & recycled replenishment)	1.1%	39 taf

Today's Agenda

- **Review key information from previous workshops**
- **Use traditional scenarios to assess IEUA responses to climate change**
- **Use probabilities to assess IEUA responses to climate change**
- **Consider scenarios most important to IEUA responses to climate change**
- **Discuss how you would use these ideas in your own planning**

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Robust Decision Making Can Help Identify Plans That Are Insensitive to Uncertainties

- **Robust Decision Making (RDM) is an iterative, analytic process for**
  - **identifying strategies that, compared to the alternatives, perform reasonably well across a very wide range of plausible futures**
  - **characterizing a small number of irreducible tradeoffs inherent in the choice among such robust strategies**

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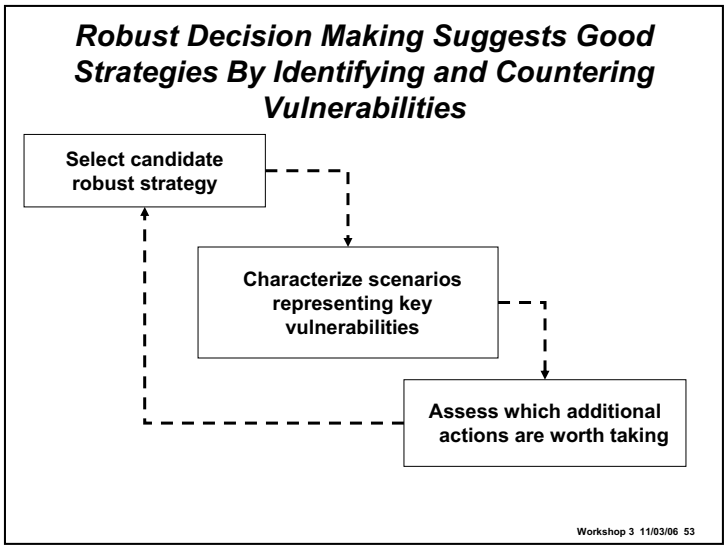
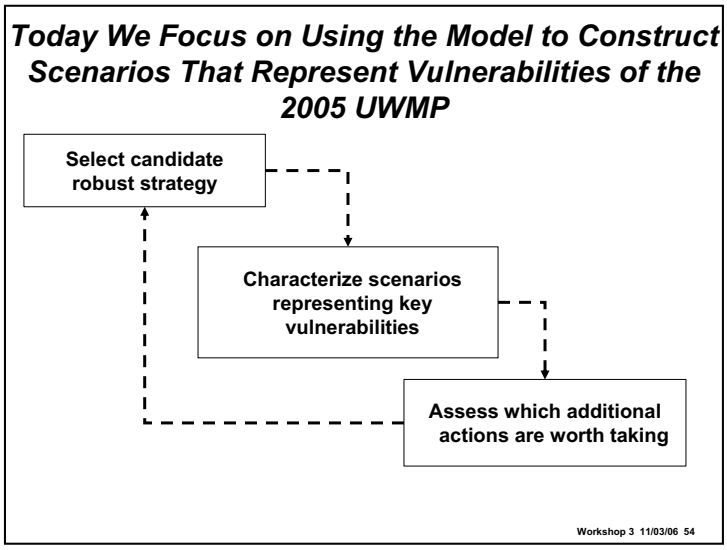

Robust Decision Making Suggests Good Strategies By Identifying and Countering Vulnerabilities
Select candidate robust strategy
Characterize scenarios representing key vulnerabilities
Assess which additional actions are worth taking
Workshop 3 11/03/06 53


Today We Focus on Using the Model to Construct Scenarios That Represent Vulnerabilities of the 2005 UWMP
Select candidate robust strategy
Characterize scenarios representing key vulnerabilities
Assess which additional actions are worth taking
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Previous Assessments Considered a Small Number of Uncertain Factors

Considered previously

- **Future climate from global models**
- **Ability to meet replenishment goal**
- **Ability to meet recycling goal**

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RDM Facilitates Exploration of Uncertainties That Are Less Well Understood

Considered previously

- **Future climate from global models**
- **Ability to meet replenishment goal**
- **Ability to meet recycling goal**

Potentially important but poorly understood

- **Efficiency associated with new growth**
- **Percolation rates under changed climate**
- **Impact of climate change on imports**

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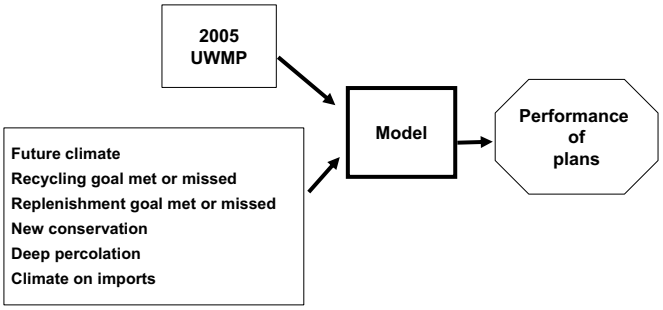
Model Can Explore Performance of 2005 UWMP over Many Combinations of the Uncertainties



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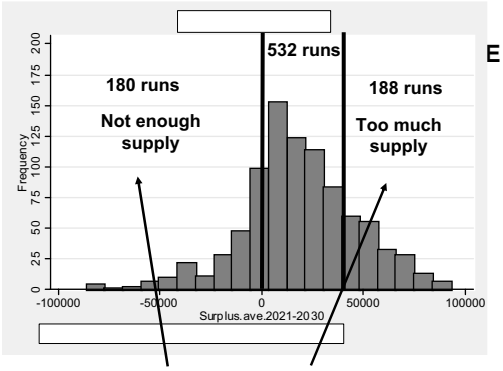
We Examined the 2005 UWMP Plan over 900 Different Model Runs



What factors contribute most to these undesirable outcomes?

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What Factors Most Consistently Suggest Severe Shortages for the 2005 UWMP?

- **Conduct statistical, cluster-finding analysis over all the model runs to identify the factors most strongly associated with 2005 UWMP shortages**

Call this the dry, flashy, low-recycling scenario

Meet recycling goal	Miss	Meet	Exceed
Meet replenishment goal	Miss	Meet	Exceed
Future climate	Drier		Wetter
New conservation	-5%		+20%
Percolation decrease	-20%		0%
Climate on imports	Weak		Strong

Explains 127 (of 180) low surplus cases

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The Model Suggests Only Three Uncertainties Are Most Important in Causing Shortages for the 2005 UWMP

Dry, flashy, low-recycling scenario

Meet recycling goal	Miss	Meet	Exceed
Future climate	Drier		Wetter
Percolation decrease	-20%		0%

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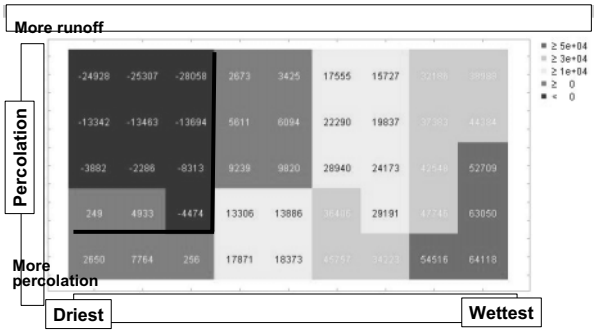
These Few Uncertainties Capture Most Futures With Severe Shortages



Future Climate

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A Second Scenario Also Yields Surpluses That Are Consistently Too Large

	Dry, flashy, low-recycling scenario	Wet, effective-recycling scenario
Meet recycling goal	Miss Meet Exceed	Miss Meet Exceed
Meet replenishment goal	Miss Meet Exceed	Miss Meet Exceed
Future climate	Drier Wetter	Drier Wetter
New conservation	-5% +20%	-5% +20%
Percolation decrease	-20% 0%	-20% 0%
Climate on imports	Weak Strong	Weak Strong
	127 (of 180) low surplus cases	*126 (of 188) too much surplus cases*

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We Consider Four Alternative Plans…

	2005 UWMP actions	+ Increased efficiency	+ Increased recycled replenishment
Plan 1	✓		
Plan 2	✓	✓	
Plan 3	✓		✓
Plan 4	✓	✓	✓
		+ 15% (2015) + 20% (2020)	+ 20% allowable recycled replenishment

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… in Three Scenarios

Average surplus (2021-2030)	Favorable conditions	Dry, flashy, low-recycling	Wet, effective recycling
Plan 1 (2005 UWMP)			
Plan 2 (+ Efficiency)			
Plan 3 (+ Recycled replenishment)			
Plan 4 (+ Efficiency & recycled replenishment)			

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2005 UWMP Performs Well Under Favorable Conditions

Average surplus (2021-2030)	Favorable conditions	Dry, flashy, low-recycling	Wet, effective recycling
Plan 1 (2005 UWMP)	27 taf		
Plan 2 (+ Efficiency)	42 taf		
Plan 3 (+ Recycled replenishment)	29 taf		
Plan 4 (+ Efficiency & recycled replenishment)	46 taf		

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2005 UWMP Performs Poorly In Dry, Flashy, and Low-Recycling Scenario

Average surplus (2021-2030)	Favorable conditions	Dry, flashy, low-recycling	Wet, effective recycling
Plan 1 (2005 UWMP)	27 taf	-0.3 taf	
Plan 2 (+ Efficiency)	42 taf	16 taf	
Plan 3 (+ Recycled replenishment)	29 taf	5 taf	
Plan 4 (+ Efficiency & recycled replenishment)	46 taf	20 taf	

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2005 UWMP Has Least Excessive Surplus In Wet and Effective-Recycling Scenario

Average surplus (2021-2030)	Favorable conditions	Dry, flashy, low-recycling	Wet, effective recycling
Plan 1 (2005 UWMP)	27 taf	-0.3 taf	53 taf
Plan 2 (+ Efficiency)	42 taf	16 taf	68 taf
Plan 3 (+ Recycled replenishment)	29 taf	5 taf	55 taf
Plan 4 (+ Efficiency & recycled replenishment)	46 taf	20 taf	72 taf

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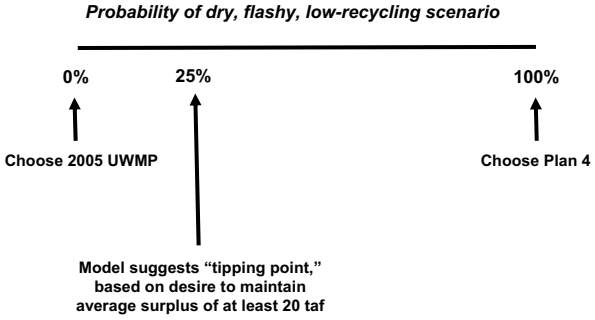
How Might You Use This Information?

- **Choice of plan may depend on your judgments about the (uncertain) likelihood of the dry, flashy, & low-recycling scenario**



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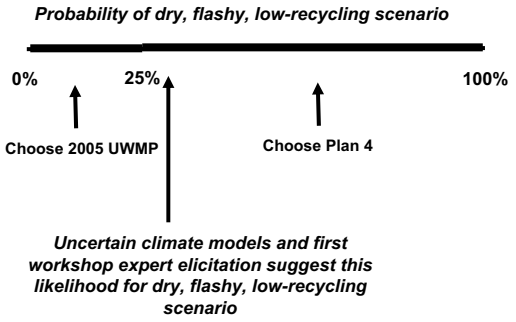
How Might You Use This Information?

- **Choice of plan may depend on your judgments about the (uncertain) likelihood of the dry, flashy, & low-recycling scenario**



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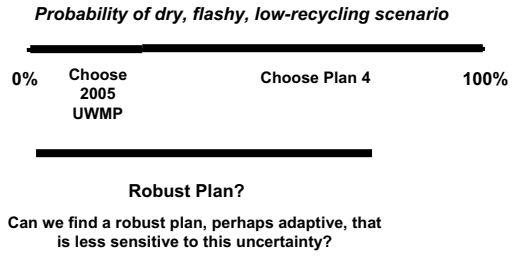
How Might You Use This Information?

- **Choice of plan may depend on your judgments about the (uncertain) likelihood of the dry, flashy, & low-recycling scenario**



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Choice of Plan May Depend on How You Represent Uncertainty

- **Traditional scenarios**
  - **Suggest that the 2005 UWMP can be vulnerable, and meeting goals at least as important than potential climate change**
- **Probabilities**
  - **Suggest that, on average, the 2005 UWMP performs well**
- **Robust Decision Making**
  - **Suggests that IEUA might consider augmenting the 2005 UWMP**

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What Is Different About These Approaches?

- **Traditional scenarios**
  - **Uses judgments to suggest a small number of interesting scenarios**
  - **Must believe these scenarios are sufficiently informative about range of uncertain futures**
- **Probabilities**
  - **Uses objective probabilities and expert judgments to rank desirability of alternative plans**
  - **Must believe probabilities are sufficiently accurate and that excluded factors are not important**
- **Robust Decision Making**
  - **Uses model to identify critical tradeoffs**
  - **Must be comfortable using own judgment to choose among these tradeoffs**

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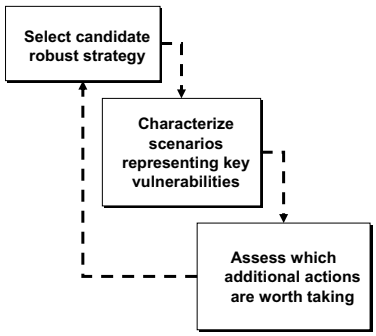
Discussion

Today's Agenda

- **Review key information from previous workshops**
- **Use traditional scenarios to assess IEUA responses to climate change**
- **Use probabilities to assess IEUA responses to climate change**
- **Consider scenarios most important to IEUA responses to climate change**
- **Discuss how you would use these ideas in your own planning**

A Full Analysis Would Seek Robust, Adaptive Strategies for Any Augmentation of the 2005 UWMP



- Use agency's models and/or work more closely to develop "scenario generator"
- Iterate with agency to identify and test robust, adaptive strategies that evolve over time

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Thank you for your participation!

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