Colorado River Simulation System (CRSS)

Overview and Use in Planning and Operation in the Colorado River Basin

Donald J. Gross, P.E.
Colorado River Management

CRSS Overview

Presentation Topics

- Overview of the Colorado River Basin
- Background on CRSS Development
- Overview of CRSS Model
- How is CRSS Used in the Colorado River Basin
    - Planning
    - Operations
    - Arizona

Overview of the Colorado River Basin

Colorado River Basin Overview

- Colorado River Basin
  Covers an area of over 252,000 square miles

- Supplies water to:
  - Over 40 million people
  - Irrigation of nearly 5.5 million acres

- 22 federally recognized tribes
  7 National Wildlife Refuges
  11 National Parks
  4 National Recreation Areas
  also rely on the Colorado River

- More than 4,200 megawatts of electricity generated

Colorado River Basin

Colorado River Basin Overview

Colorado River Reservoir Storage

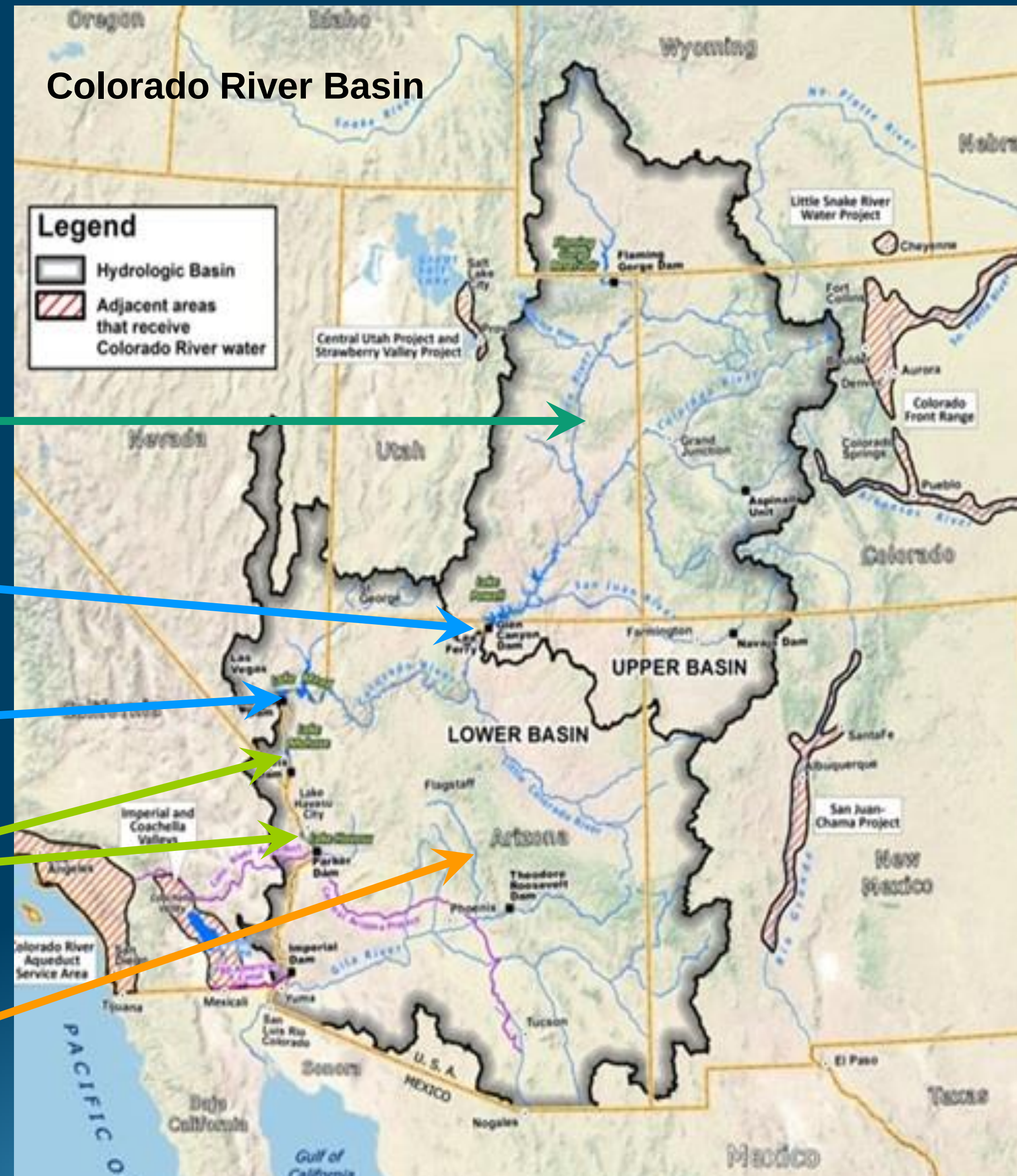
Upper Basin - 10 MAF

Lake Powell - 24 MAF

Lake Mead - 26 MAF

Lakes Mohave and Havasu – 2.5 MAF

(Arizona Tributaries – 5.6 MAF)



Colorado River Basin Overview

Colorado River Allocations

1922 Colorado River Compact established Upper and Lower Basin States' allocations

UPPER BASIN STATES - 7.5 MAF

1948 Upper Colorado Basin Compact established the Upper Basin States' apportionment

LOWER BASIN STATES - 7.5 MAF

California – 4.4 MAF

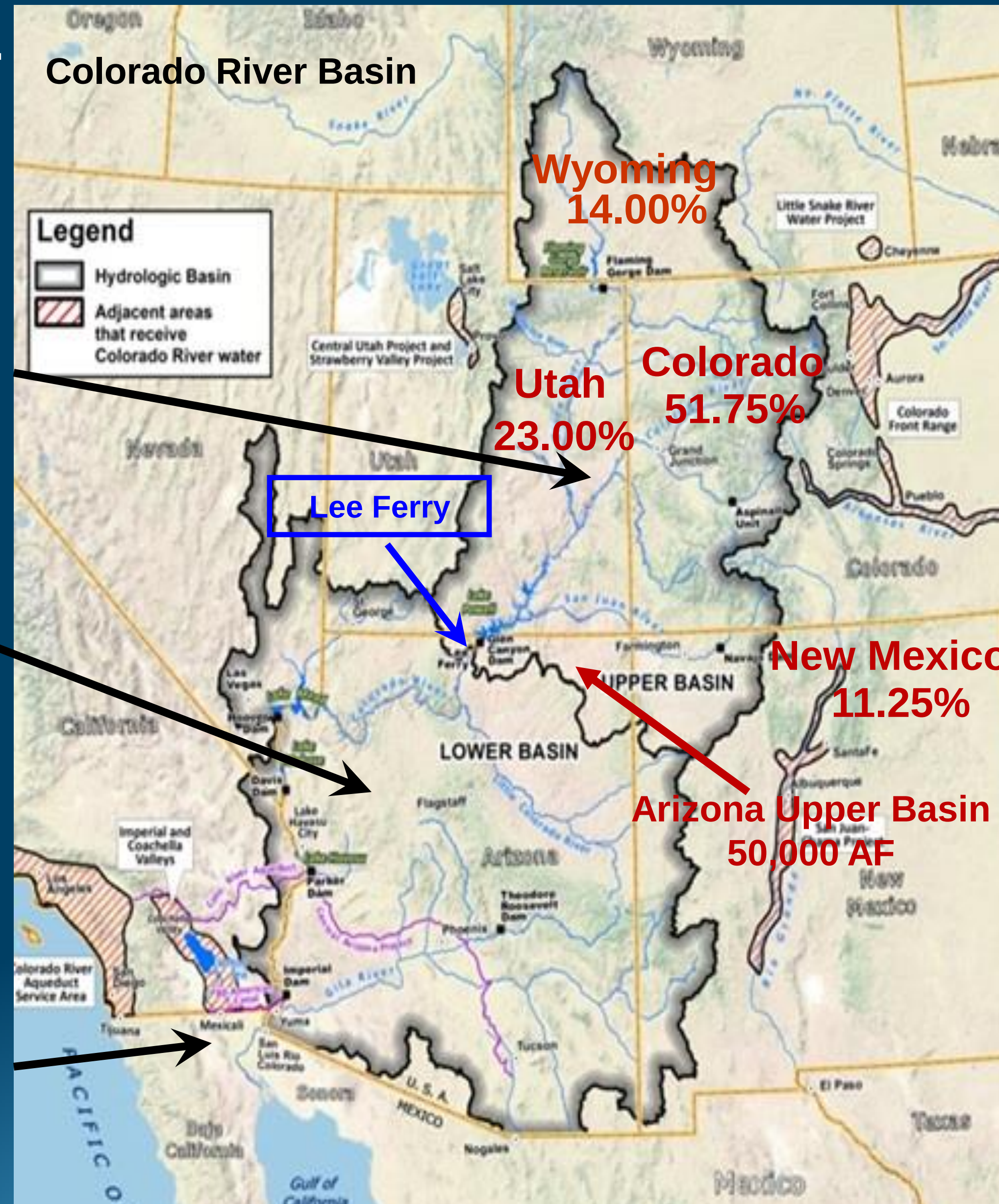
Arizona – 2.8 MAF

Nevada – 0.3 MAF

1928 Boulder Canyon Project Act established the Lower Basin States' apportionment

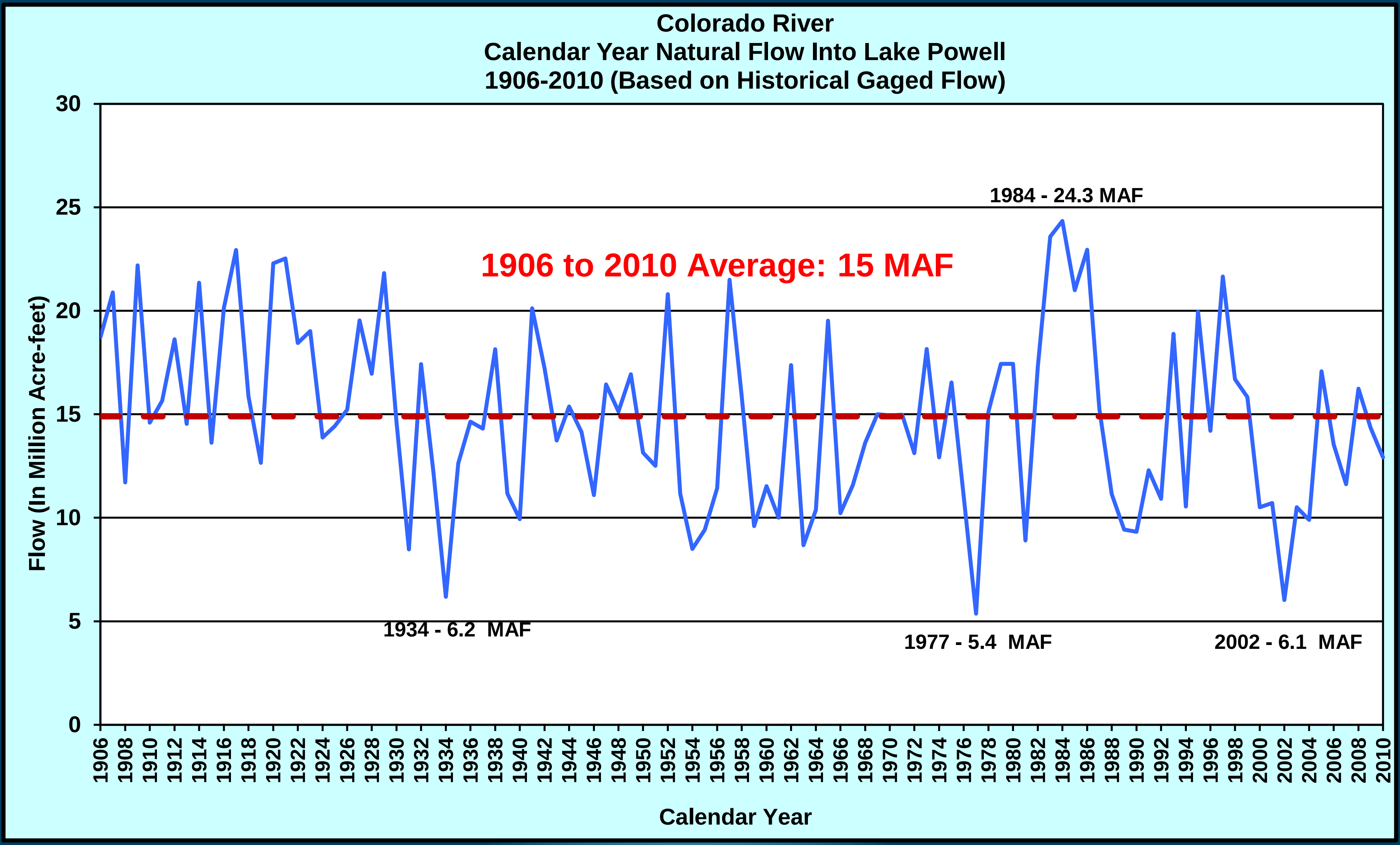
MEXICO - 1.5 MAF

1944 Treaty with Mexico established Mexico's treaty deliveries



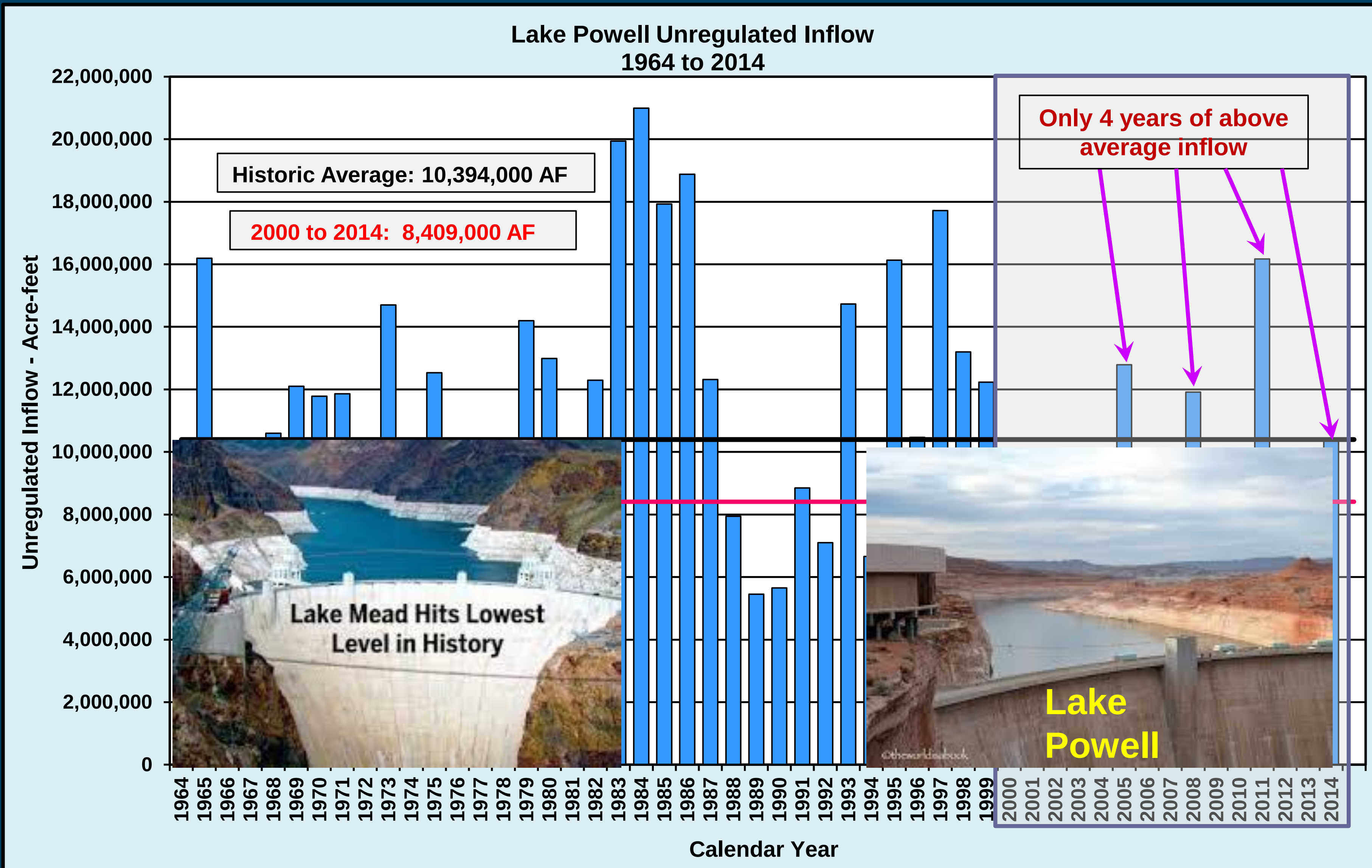
Colorado River Basin Overview

- Flows are highly variable



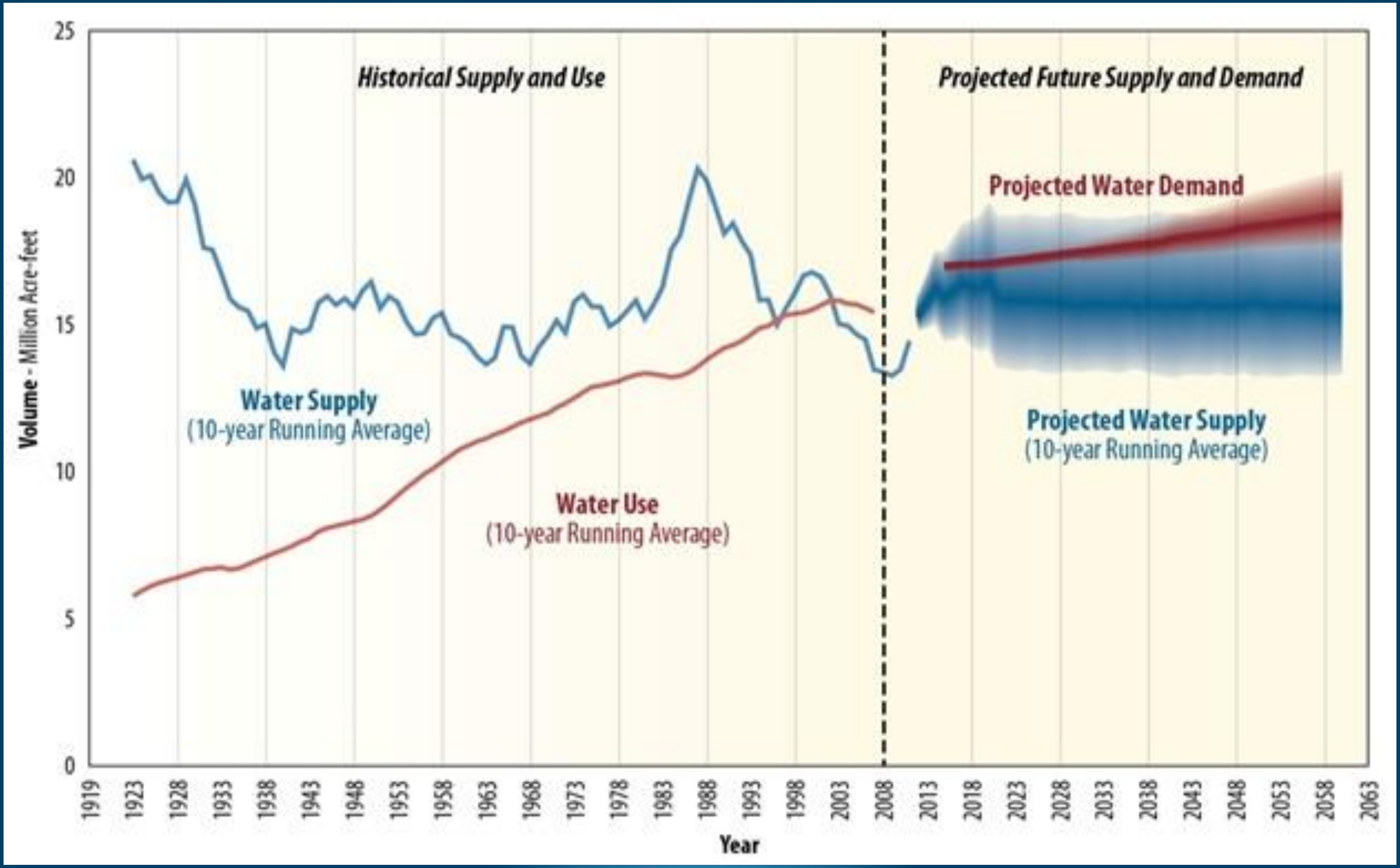
Colorado River Basin Overview

- Colorado River Basin is currently in its 15th year of drought.



Colorado River Basin Overview

- **Future supplies and demands are uncertain.**



Colorado River Basin Overview

Law of the River – Major Compacts, Treaties, and Laws

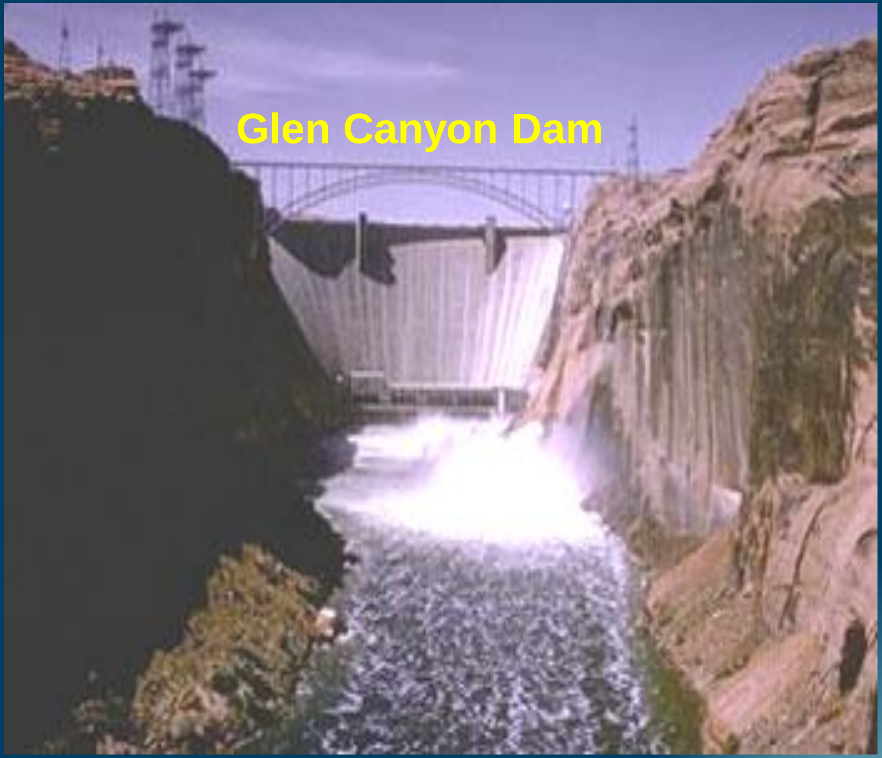
- 1922 - Colorado River Compact
- 1928 - Boulder Canyon Project Act
- 1929 and 1931 - California Limitation Act and Seven Party Agreement
- 1944 - Mexican Water Treaty
- 1948 - Upper Colorado River Compact
- 1956 - Colorado River Storage Project Act
- 1964 - *Arizona v. California* – 1964 (Consolidated in 2006)
- 1968 - Colorado River Basin Project Act
- 1973 - Mexican Treaty Amendment (Minute No. 242)
- 1974 - Salinity Control Act
- 1986 - Colorado River Floodway Act
- 1992 - Grand Canyon Protection Act
- 2007 - Interim Guidelines for Lower Basin Shortage and Coordinated Reservoir Operations ("2007 Interim Guidelines")
- 2012 - Minute No. 319

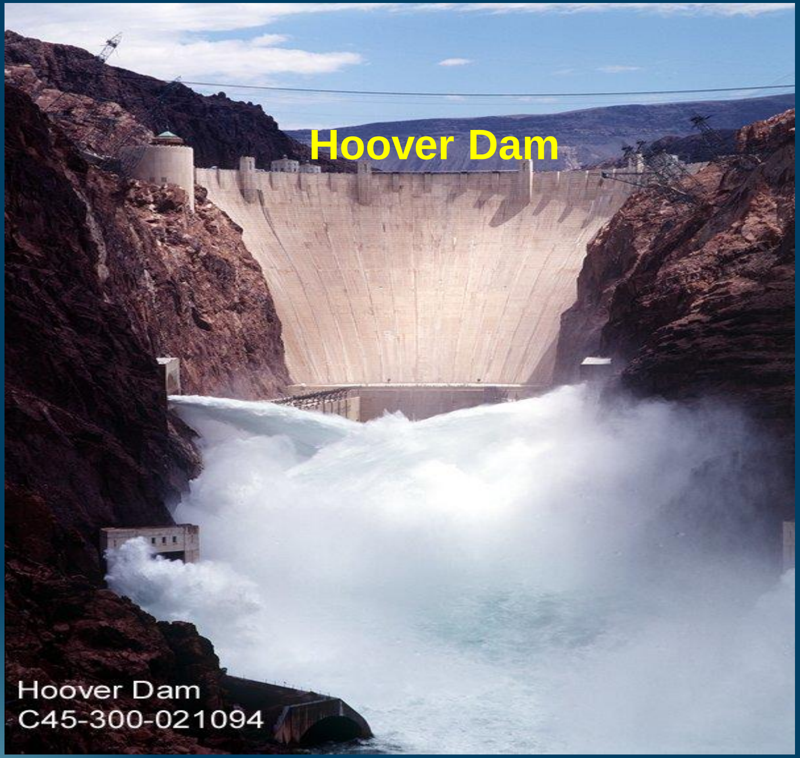
NOT ALL INCLUSIVE !!!

Overview
of the
Colorado River Simulation System

CRSS Overview

- Background and Configuration
- Operating Policies





CRSS Overview

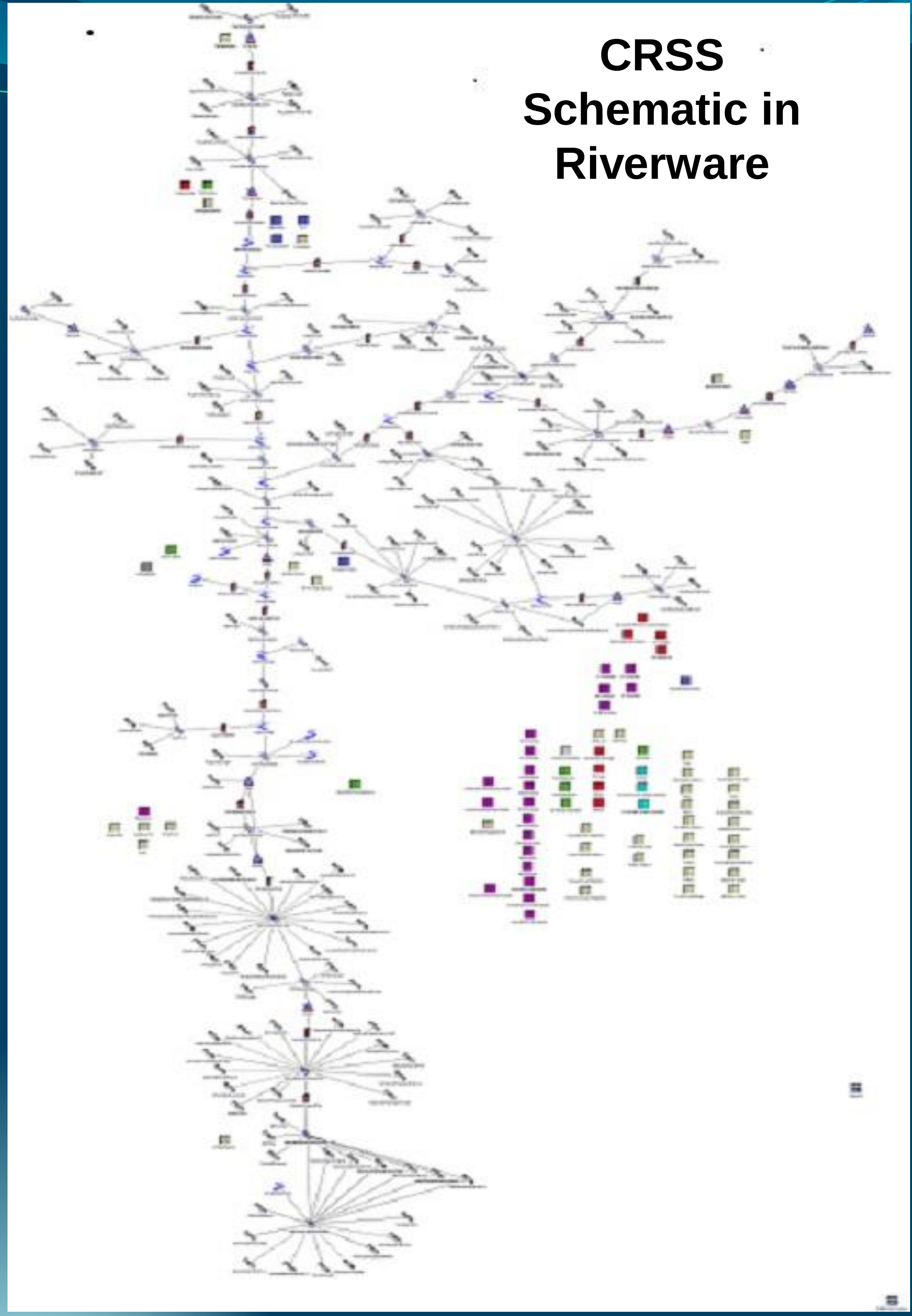
Background

- Comprehensive model of the Colorado River Basin
  - Developed by Reclamation in the early 1970s (in Fortran)
  - Implemented in RiverWare™ in 1996 (funding for development by Reclamation and the Tennessee Valley Authority to CADSWES, originally called PRYSM – Power and Reservoir System Model)
  - Primary tool for river operations and analysing projected development and hydrology
  - Used in a number of environmental compliance studies and Bi-National negotiations with Mexico
- Updated and maintained continually by Reclamation's Colorado River Modeling Work Group
- Run by stakeholders in Colorado River Stakeholder Modeling Work Group
- Two "official" simulations are made each year (January and August)

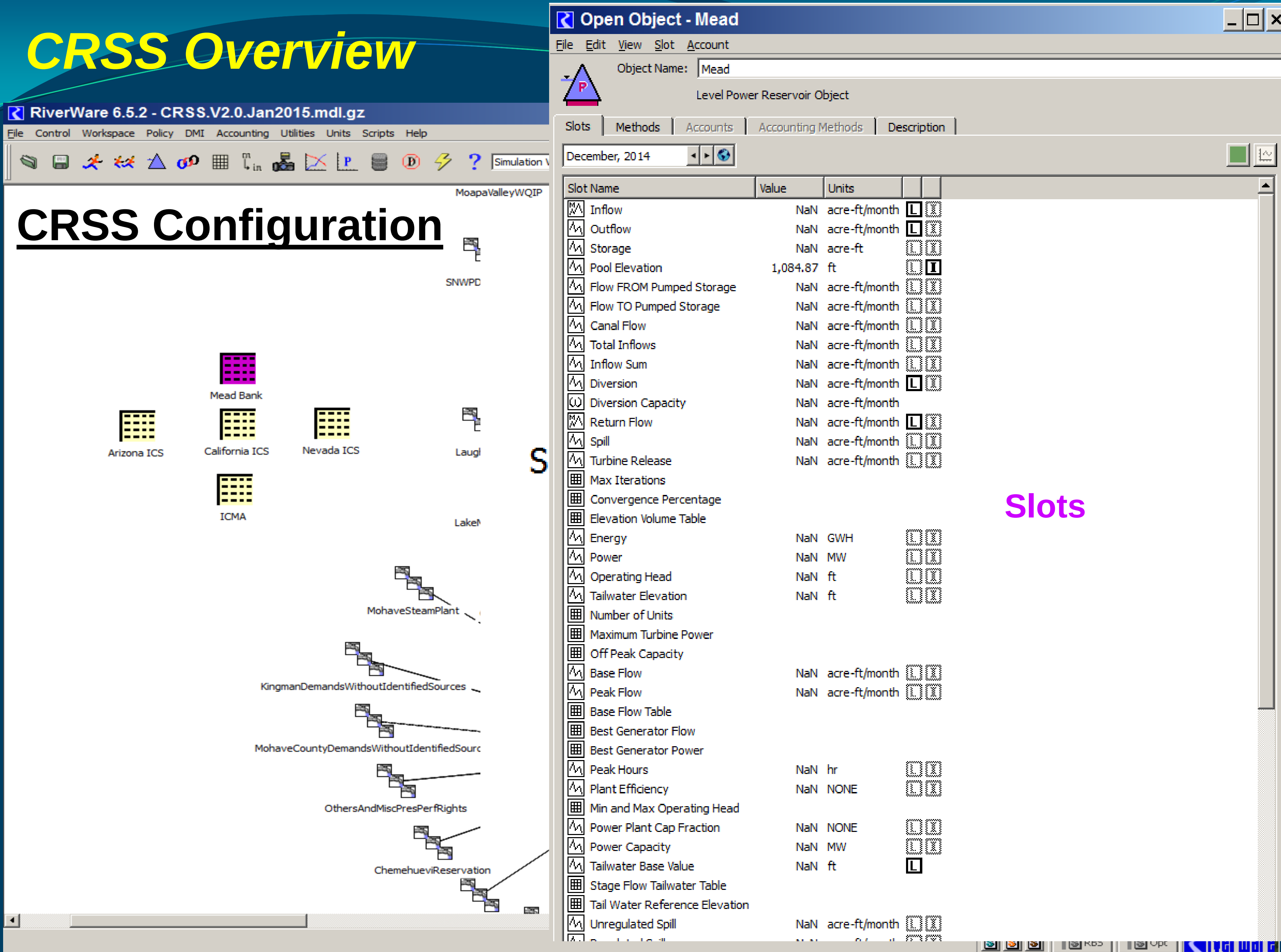
CRSS Overview

- A basin-wide, long-term planning and policy Model
- Also used for day-to-day operations
- Simulates operations at 12 reservoirs and deliveries to over 500 individual water users
- Excellent for comparative analysis
  - Hold most variables constant between model runs
  - Compare the differences due to changing the variables of interest
- Gives a range of potential future system conditions
- Examples:
  - Reservoir levels
  - Releases
  - River flows

CRSS Schematic in Riverware



CRSS Overview



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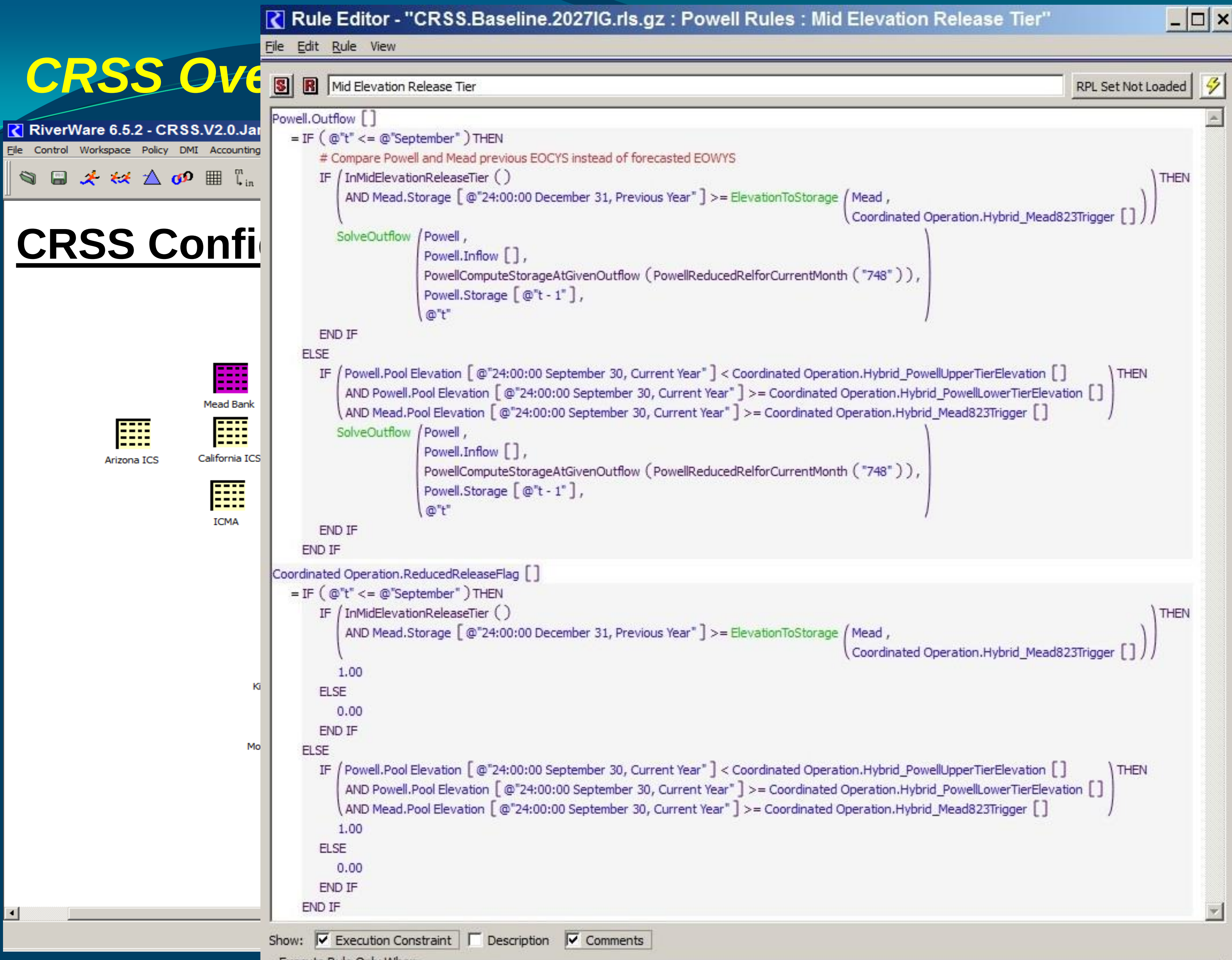
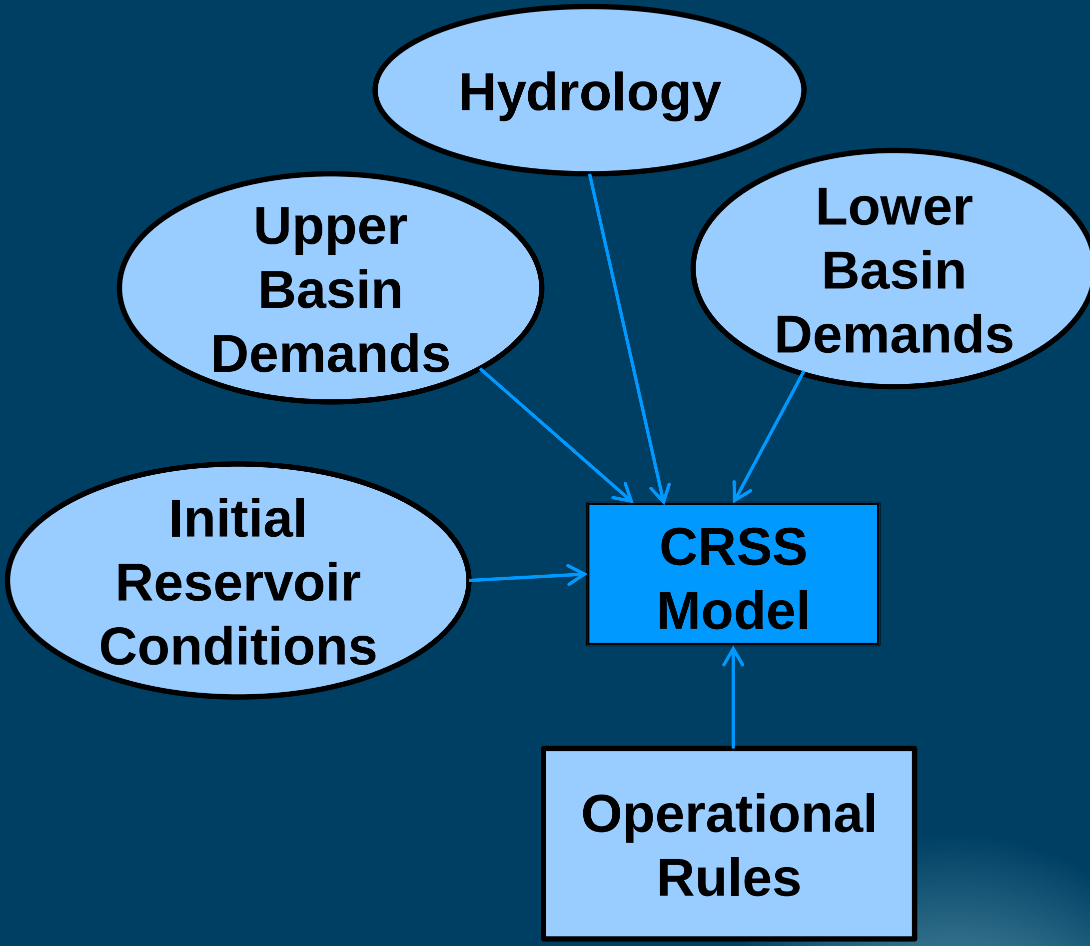
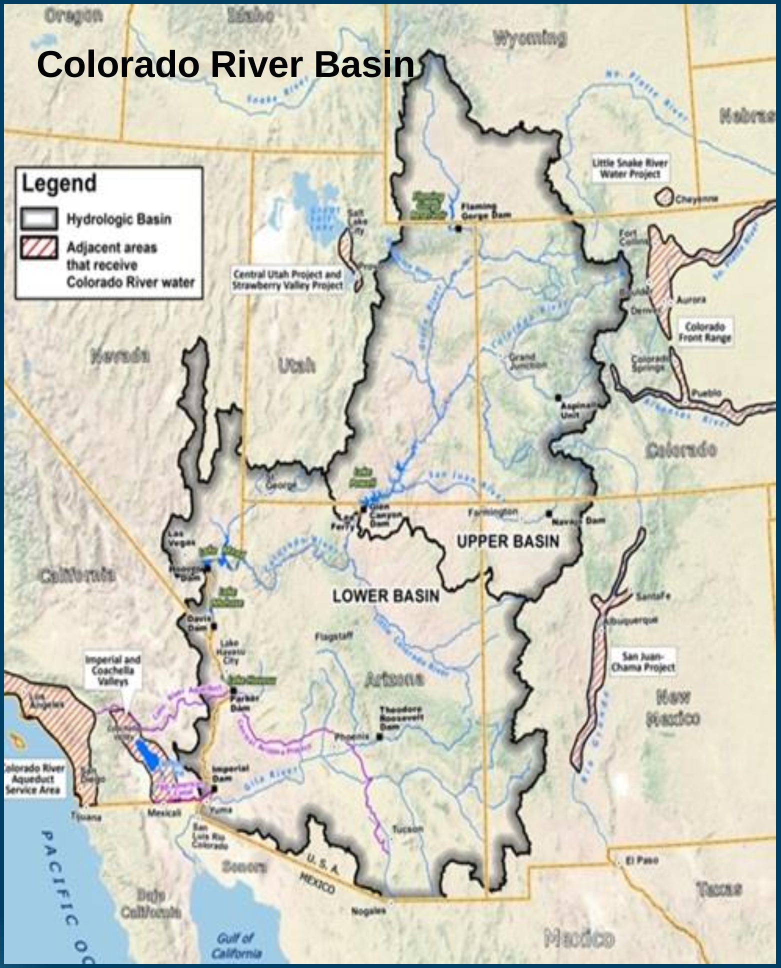

RiverWare 6.5.2 - CRSS.V2.0.Jar
File Control Workspace Policy DMI Accounting
CRSS Confi
Mead Bank
Arizona ICS
California ICS
ICMA
Rule Editor - "CRSS.Baseline.2027IG.rls.gz : Powell Rules : Mid Elevation Release Tier"
File Edit Rule View
Mid Elevation Release Tier
RPL Set Not Loaded
Powell.Outflow [ ]
= IF (@"t" <= @"September") THEN
# Compare Powell and Mead previous EOCYS instead of forecasted EOWYS
IF (InMidElevationReleaseTier ( )
AND Mead.Storage [@"24:00:00 December 31, Previous Year"] >= ElevationToStorage (Mead ,
Coordinated Operation.Hybrid_Mead823Trigger [ ])) THEN
SolveOutflow (Powell ,
Powell.Inflow [ ] ,
PowellComputeStorageAtGivenOutflow (PowellReducedRelforCurrentMonth ("748")) ,
Powell.Storage [@"t - 1"] ,
@"t")
END IF
ELSE
IF (Powell.Pool Elevation [@"24:00:00 September 30, Current Year"] < Coordinated Operation.Hybrid_PowellUpperTierElevation [ ]
AND Powell.Pool Elevation [@"24:00:00 September 30, Current Year"] >= Coordinated Operation.Hybrid_PowellLowerTierElevation [ ]
AND Mead.Pool Elevation [@"24:00:00 September 30, Current Year"] >= Coordinated Operation.Hybrid_Mead823Trigger [ ]) THEN
SolveOutflow (Powell ,
Powell.Inflow [ ] ,
PowellComputeStorageAtGivenOutflow (PowellReducedRelforCurrentMonth ("748")) ,
Powell.Storage [@"t - 1"] ,
@"t")
END IF
END IF
Coordinated Operation.ReducedReleaseFlag [ ]
= IF (@"t" <= @"September") THEN
IF (InMidElevationReleaseTier ( )
AND Mead.Storage [@"24:00:00 December 31, Previous Year"] >= ElevationToStorage (Mead ,
Coordinated Operation.Hybrid_Mead823Trigger [ ])) THEN
1.00
ELSE
0.00
END IF
ELSE
IF (Powell.Pool Elevation [@"24:00:00 September 30, Current Year"] < Coordinated Operation.Hybrid_PowellUpperTierElevation [ ]
AND Powell.Pool Elevation [@"24:00:00 September 30, Current Year"] >= Coordinated Operation.Hybrid_PowellLowerTierElevation [ ]
AND Mead.Pool Elevation [@"24:00:00 September 30, Current Year"] >= Coordinated Operation.Hybrid_Mead823Trigger [ ]) THEN
1.00
ELSE
0.00
END IF
END IF
Show: Execution Constraint Description Comments
Execute Rule Only When

CRSS Overview

Major Inputs to Model





CRSS Overview

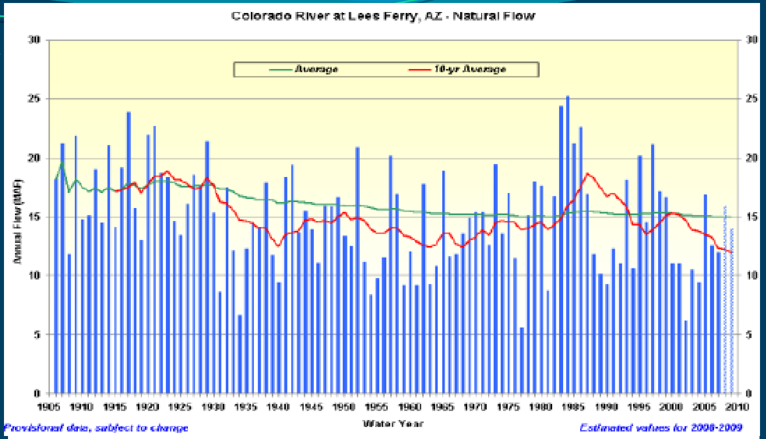
Major Inputs to Model

- **Initial Reservoir Conditions**
  - Historical or projected by the Mid-Term 24-Month Study
- **Operating Policy**
  - 2007 Interim Guidelines in effect through 2026
  - Assumption needed to run past 2027, e.g. operations revert to Final EIS No Action Alternative
  - Other aspects from the "Law of the River" (e.g., Minute #319, 1922 Compact delivery requirements)
- **Hydrology**
  - Hydrologic uncertainty is modelled by using historical, paleo, and/or down-scaled global climate models flow sequences
- **Demands**
  - Upper Basin Demands from the Upper Colorado River Commission
  - Lower Basin Demands from each state, including Intentionally Created Surplus (ICS) schedules
  - Colorado River Basin Water Supply and Demand Study also explored alternative demand scenarios

Modeling Hydrologic Variability

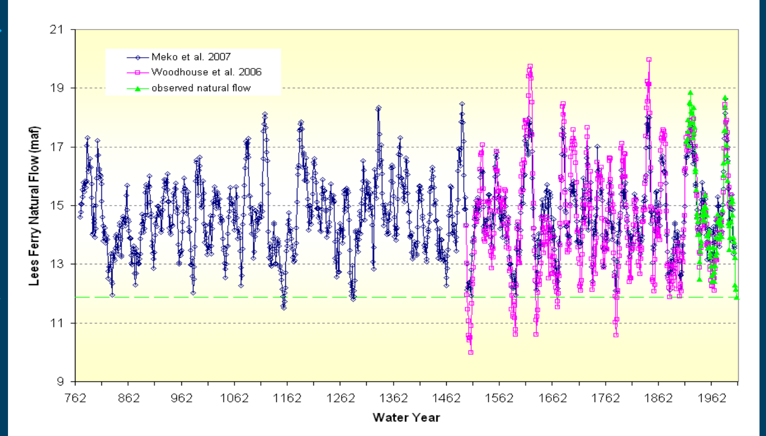
Observed Resampled

- Future hydrologic trends and variability will be similar to the past 100+ years (1906 – 2010, 105 sequences)



Paleo Resampled

- Future hydrologic trends and variability are represented by the distant past (762 A.D to 2005, approximately 1,250 years)

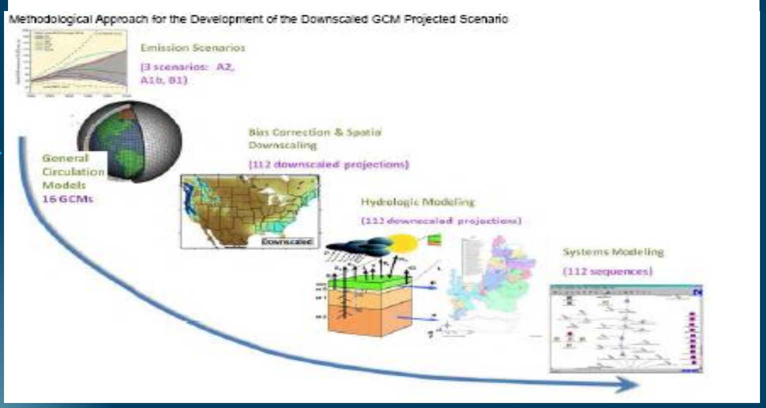


Paleo Conditioned

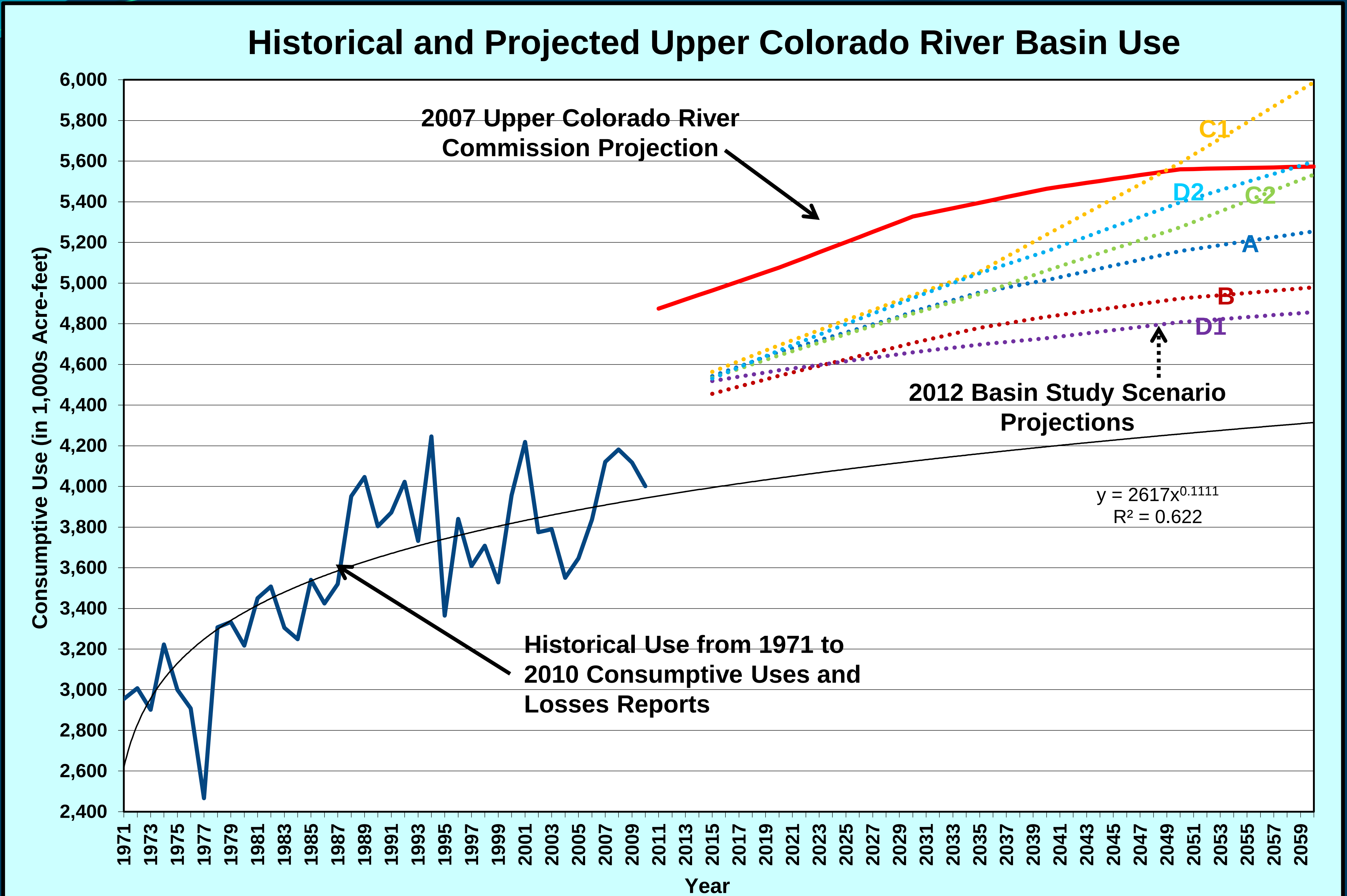
- Future hydrologic trends and variability are represented by a blend of the wet dry states of the paleo-climate record but magnitudes are more similar to the observed period (1,000 sequences)

Downscaled GCM Projected

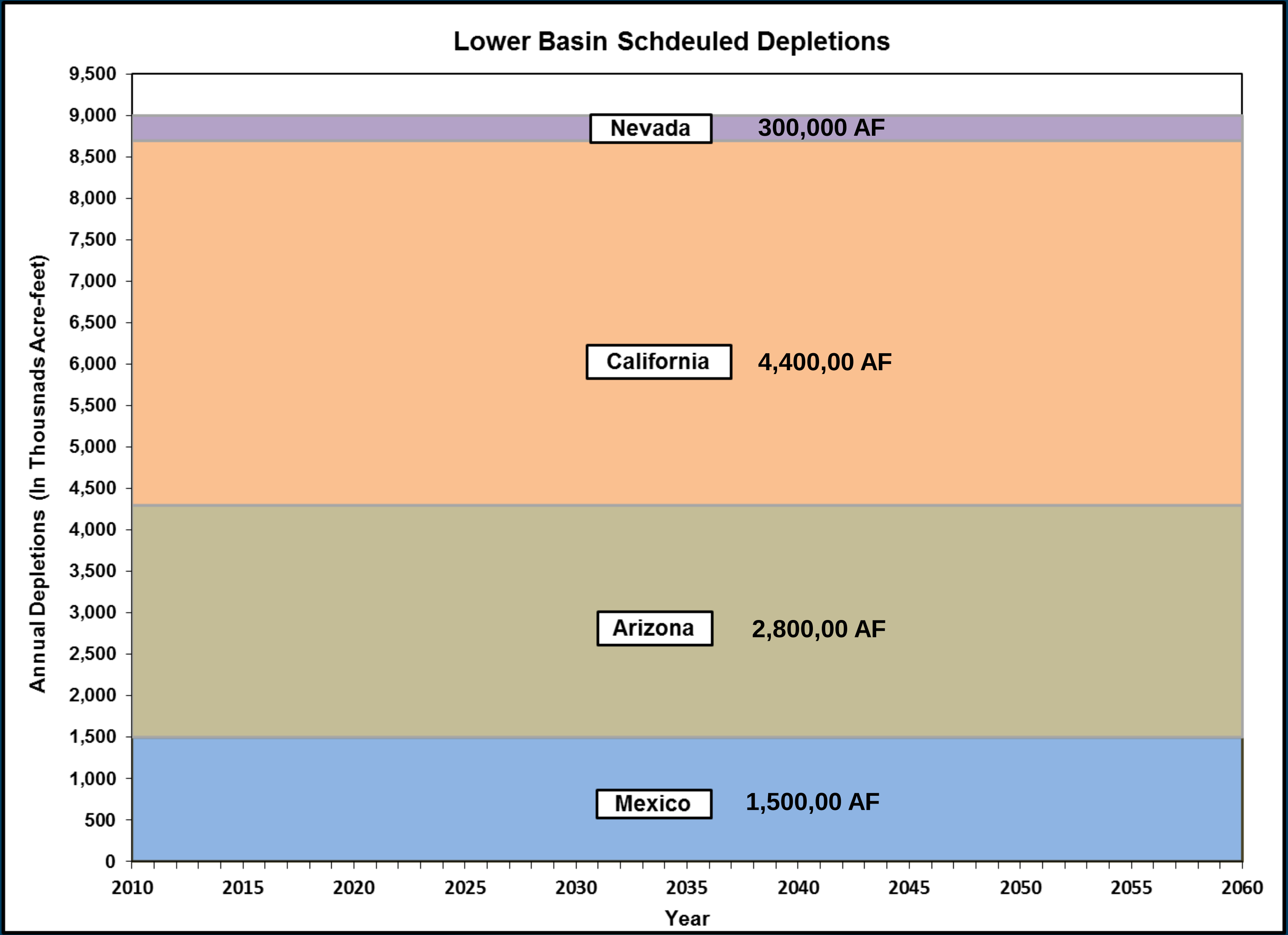
- Future climate will continue to warm with regional precipitation trends represented through an ensemble of future GCM projections (16 models and 112 sequences) [Reclamation is updating with latest projections]



Upper Basin Demands

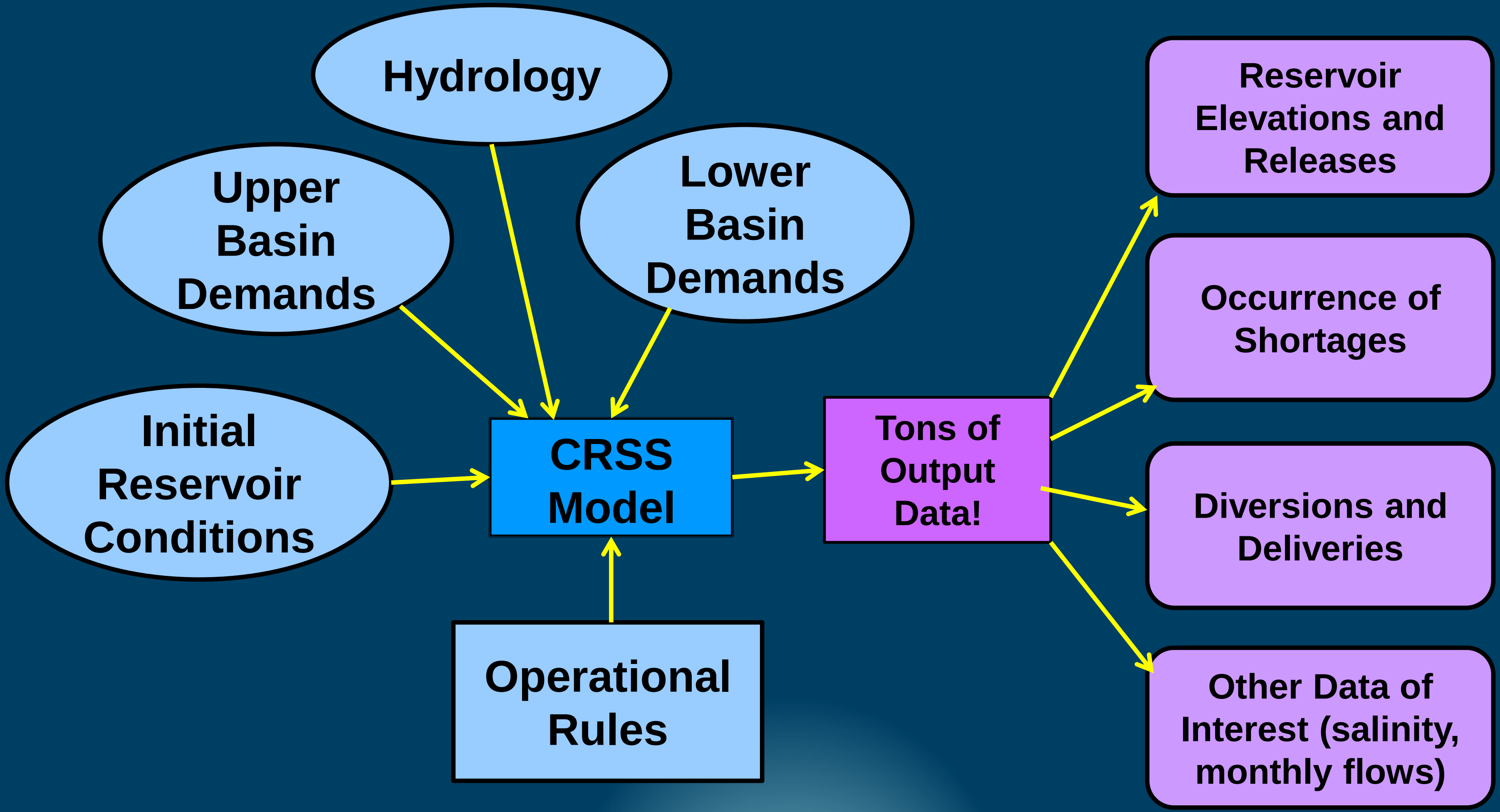


Lower Basin Demands



CRSS Overview

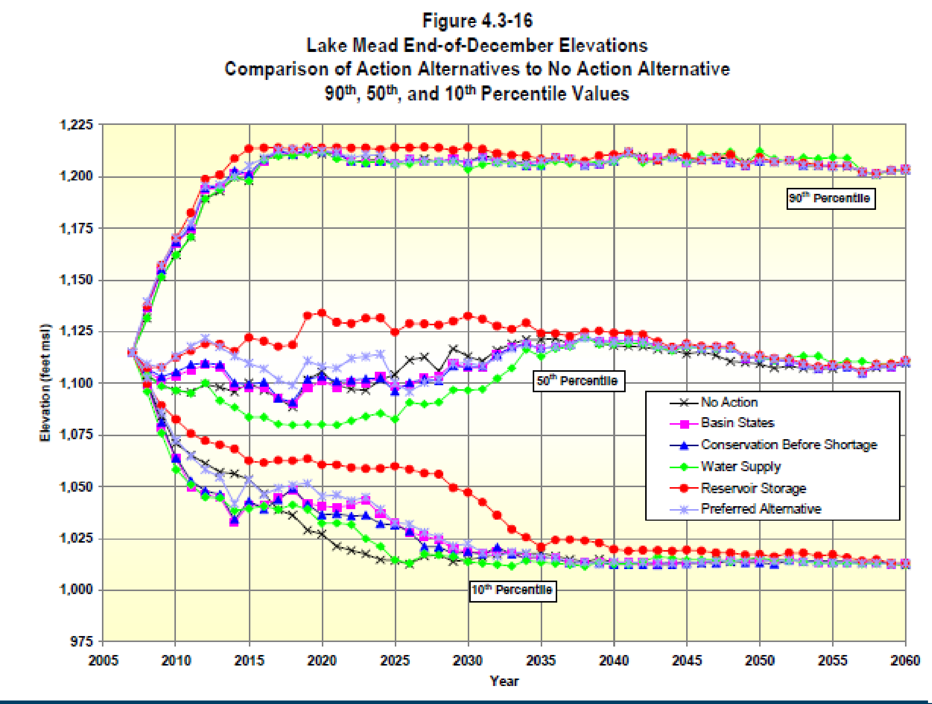
CRSS Model Outputs

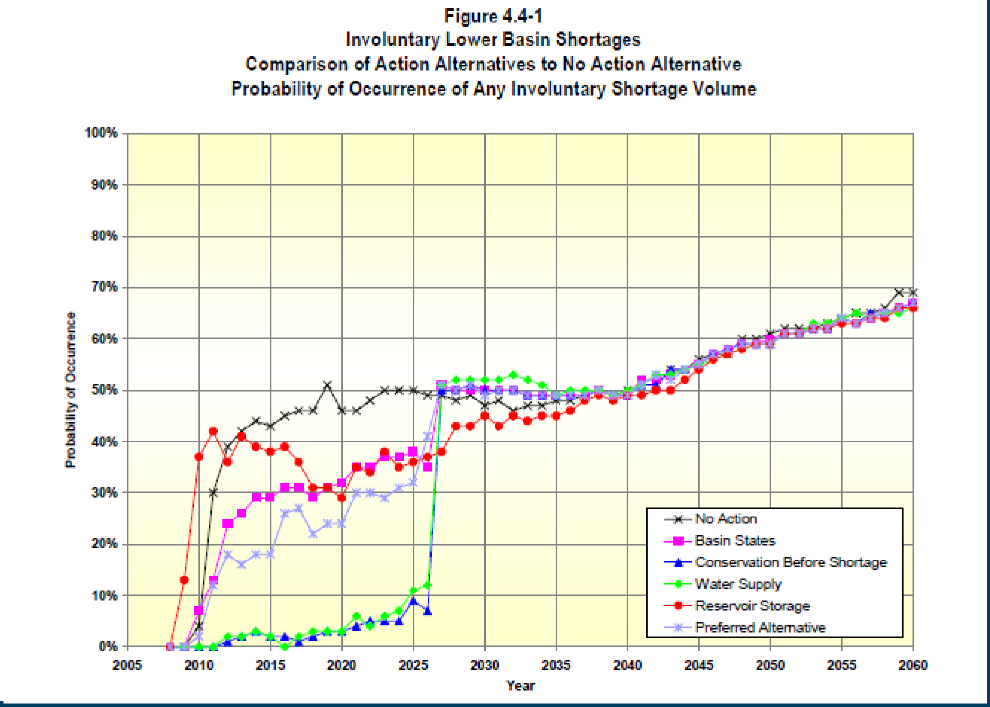


CRSS Overview

CRSS Model Outputs

Illustrative Examples





CRSS Overview

Model Use Activity	Spatial Resolution / Time Horizon	Primary Models
Long-term Planning	Basin-Wide over Decades	Monthly CRSS With Operational Rules
Mid-term Operations	Basin-Wide over 1-2 Years	"24-Month Study" Monthly CRSS With Operational Rules and Input from Operators
Short-term Operations	Sub-basin over 1-6 weeks	Daily Sub-model of CRSS
Short-term Operations	Single Project over 1-2 days	Hourly Sub-model of CRSS

CRSS Overview

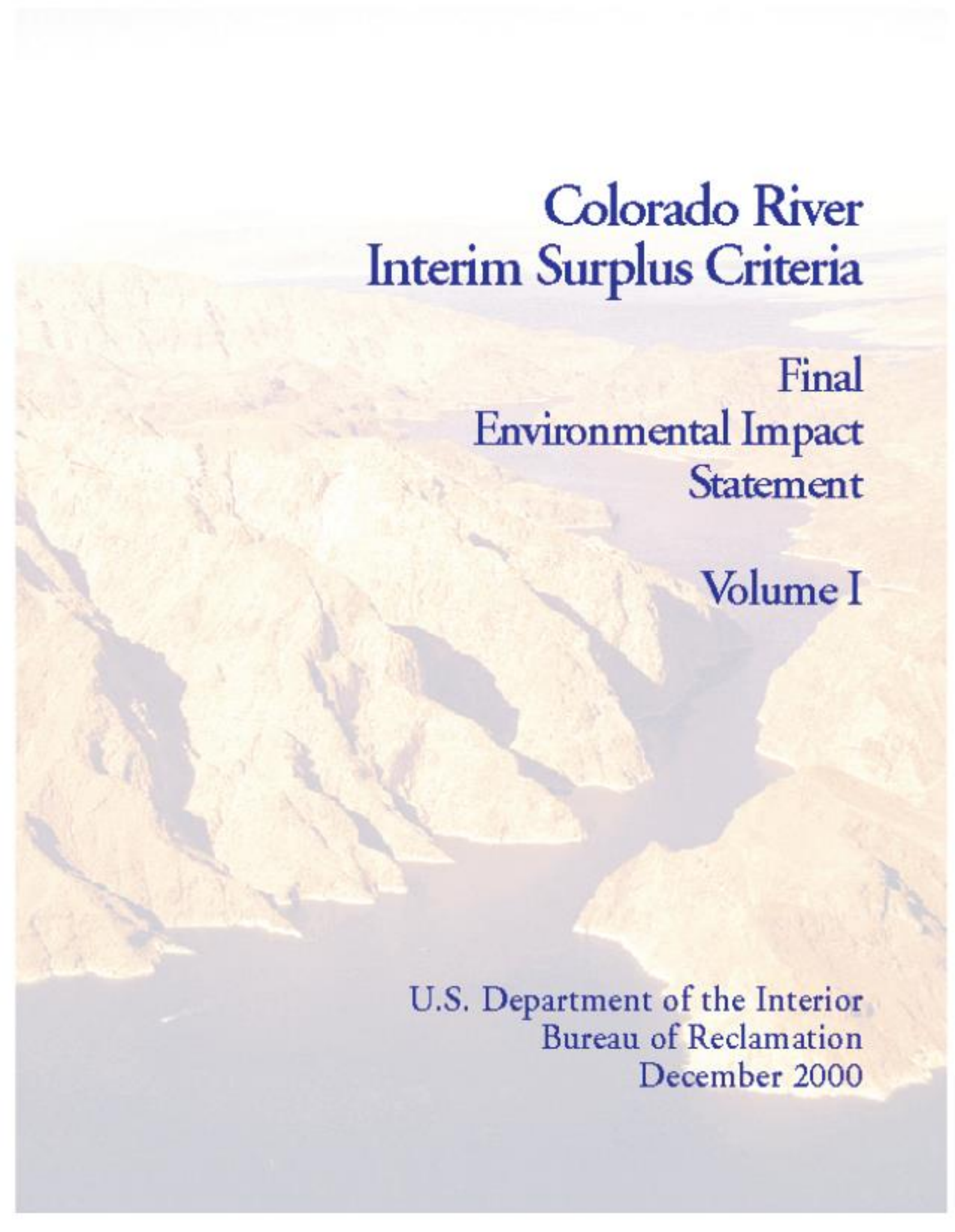
CRSS Long-Term Planning

- **CRSS has been used for many planning and environmental studies related to different reservoir operational and resource management options throughout the Colorado River Basin.**
  - **1980s Various Basin–wide Studies (i.e., Westwide Water Studies, Alternative Operating Strategies for Distributing Surplus Water and Avoiding Spills)**
  - **1995 Operation of Glen Canyon Dam**
  - **2001 Interim Surplus Guidelines** ✓
  - **2006 Navajo Reservoir Operations**
  - **2006 Flaming Gorge Operations**
  - **2006 Lower Colorado River Multi-Species Conservation Program**
  - **2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead**
  - **2012 Aspinall Unit Operations**
  - **2010–2012 Bi-National Negotiations with Mexico**
  - **2012 Colorado River Basin Water Supply and Demand Study** ✓
  - **2015 Long-term Experimental and Management Plan for Glen Canyon Dam (On-going)**
  - **2014 – 2015 Drought Contingency Planning (On-going)**

CRSS Overview

CRSS Long-Term Planning

Colorado River Interim Surplus Criteria

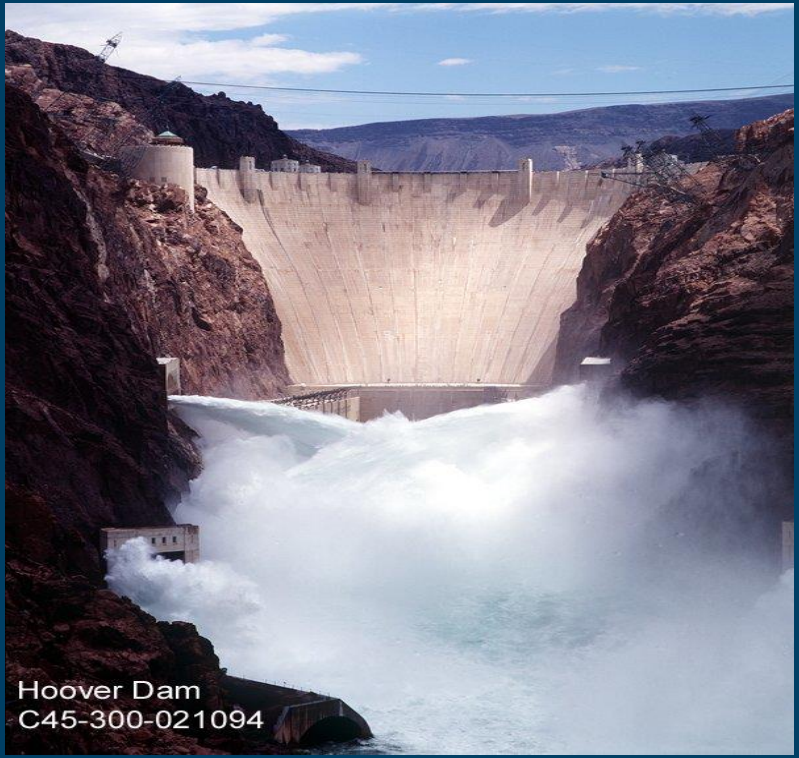


CRSS Overview

CRSS Long-Term Planning – Interim Surplus Guidelines

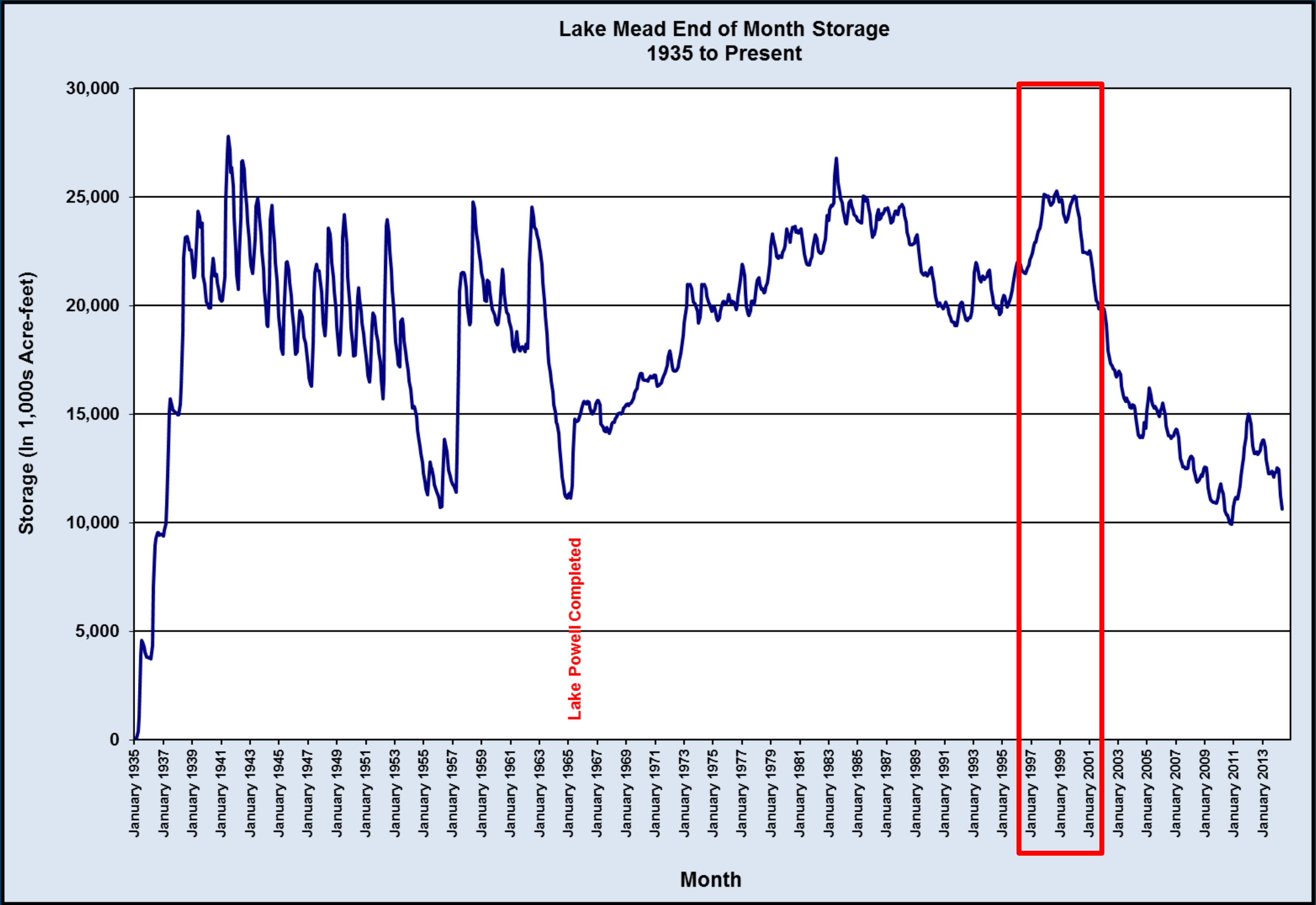
Need for the Guidelines

- There was need for the Secretary of the Interior to have more specific criteria to make decisions regarding demands for surplus water
- California was using more than its apportionment of 4.4 million acre-feet (MAF) and was urged to reduce its use to 4.4 MAF
- Arizona and Nevada were approaching full use of their apportionments



CRSS Overview

CRSS Long-Term Planning – Interim Surplus Guidelines

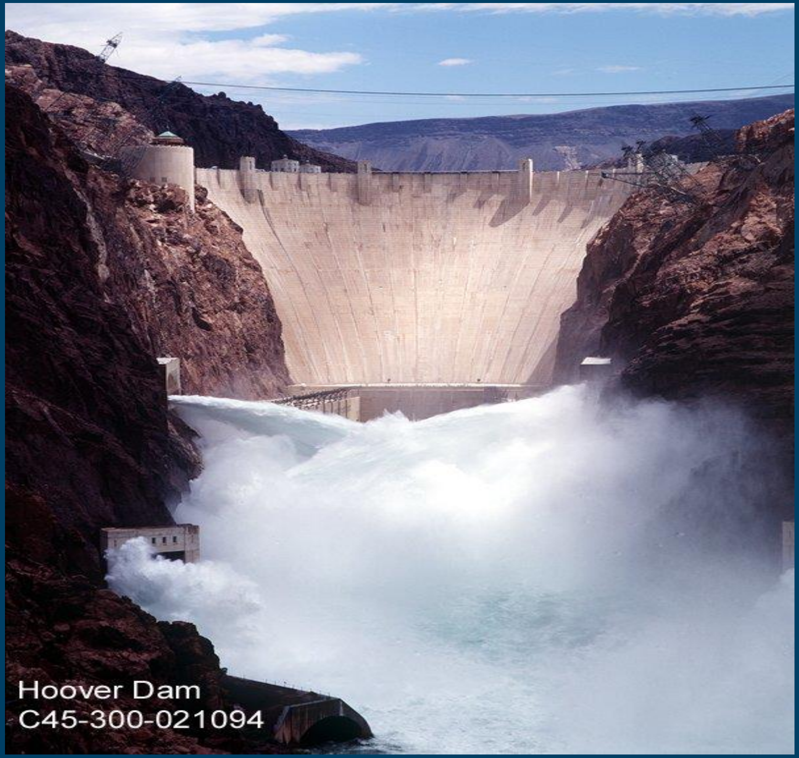


CRSS Overview

CRSS Long-Term Planning – Interim Surplus Guidelines

Alternatives Considered

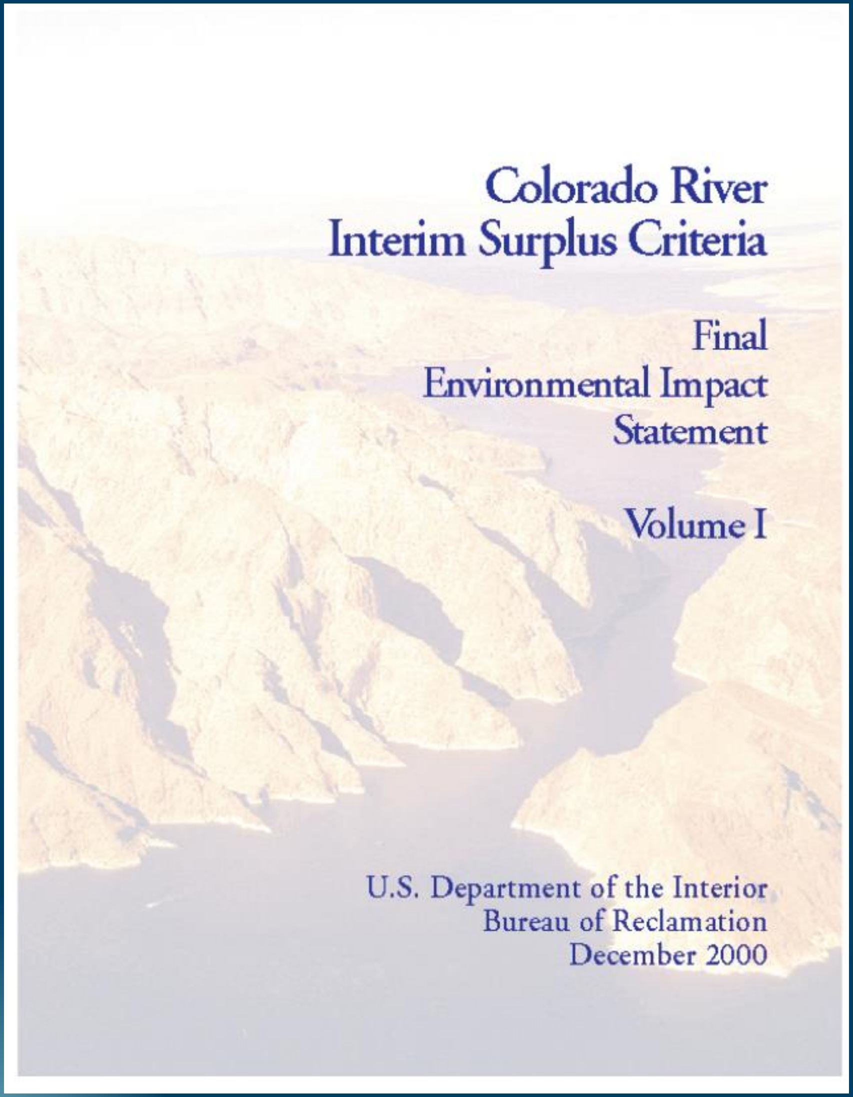
- No Action
  70R trigger (70% runoff into Lake Mead, the elevation rises from 1,199 feet to 1,201 feet in 2050 due to increase in Upper Basin depletion)
- Basin States Triggers
  3 tiers in Lake Mead
- Six States Triggers (different volumes of surplus than Basin States)
  3 tiers in Lake Mead
- California Triggers (higher trigger elevations than Basin States or Six States)
  3 tiers in Lake Mead
- Flood Control Surplus
  Secretary declares a surplus when flood control releases are required



CRSS Overview

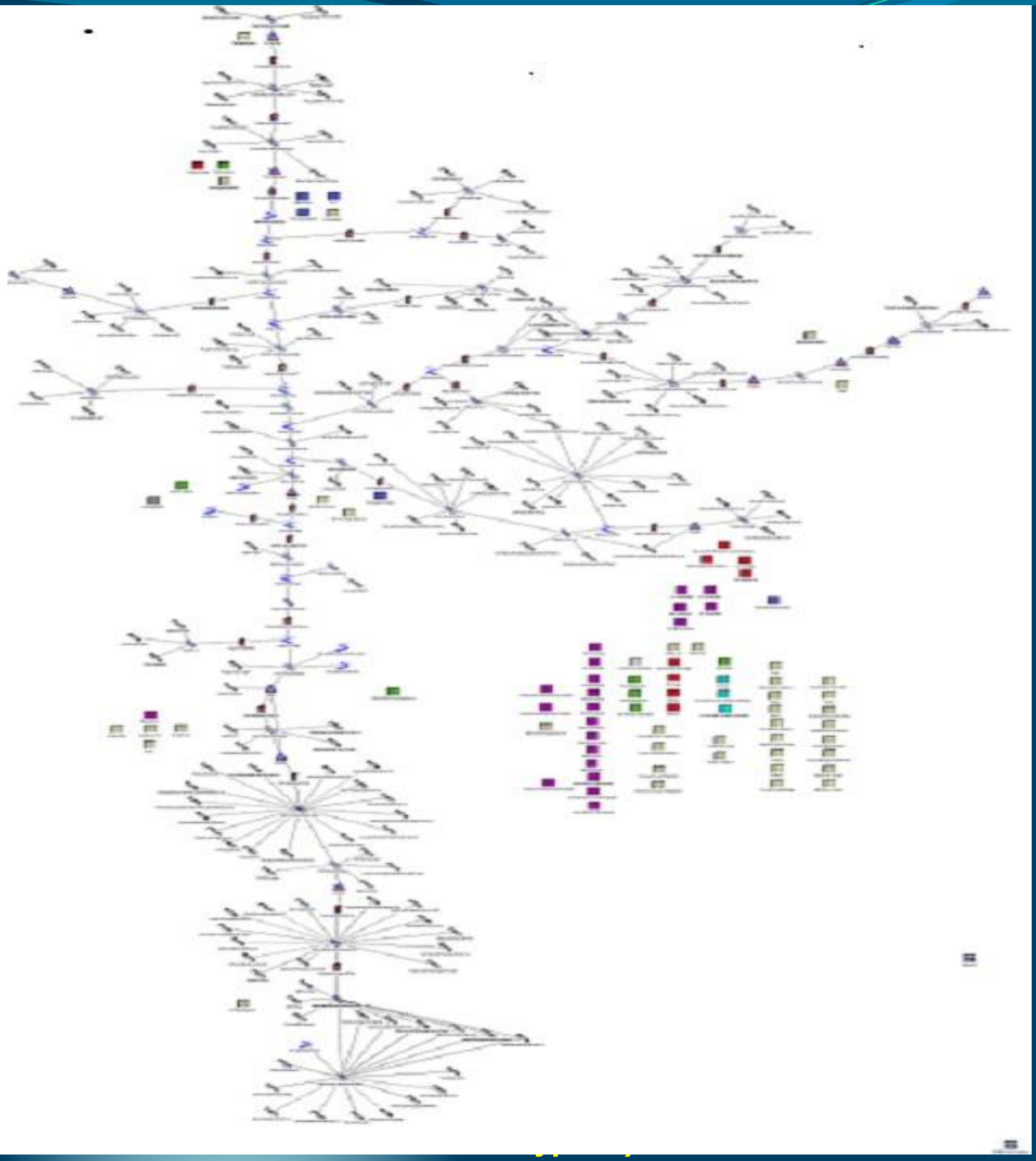
CRSS Long-Term Planning – Interim Surplus Guidelines

- CRSS not available or used by Basin States stakeholders
- CRSS model runs were long due (8-hours +) computing power at the time
- CRSS-EZ developed by Reclamation to quickly screen alternatives
- Policies hardwired into CRSS-EZ
- Any changes to CRSS-EZ had to be requested and made by Reclamation
- CRSS was used to evaluate EIS alternatives



CRSS Long-Term Planning – Interim Surplus Guidelines

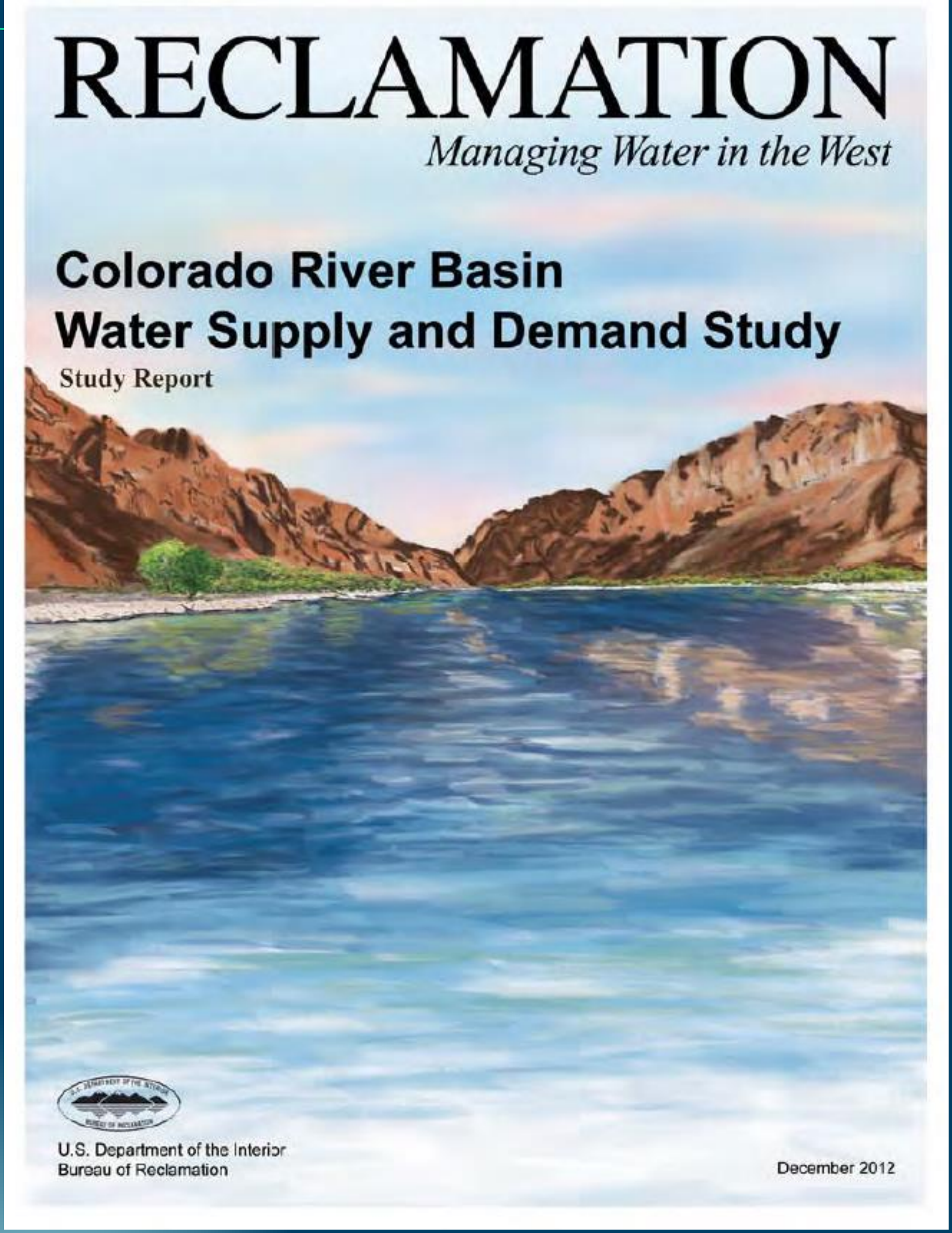
CRSS Schematic in Riverware



CRSS Overview

CRSS Long-Term Planning

Colorado River Basin
Water Supply and Demand Study
"Basin Study"



CRSS Overview

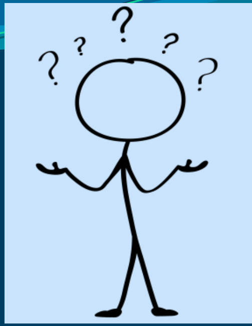
CRSS Long-Term Planning – "Basin Study

Objectives of the Study

- Assess current and future imbalances in water supply and demand for the period 2010 to 2060
- Assess the system reliability and risks to all Basin Resources (water supply, hydropower, water quality, fish and wildlife, flood control, recreation)
- Develop and evaluate opportunities or strategies for resolving imbalances
- Study began in January 2010 and completed in December 2012

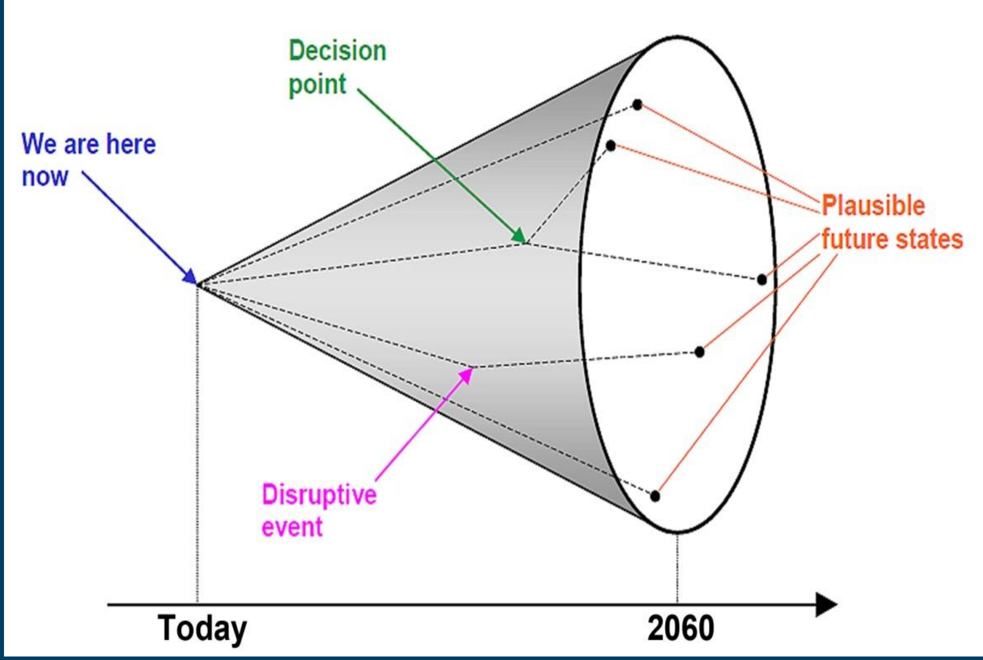
CRSS Overview

CRSS Long-Term Planning – “Basin Study”



Scenario Planning: Addressing an Uncertain Future

- **The path of major influences on the Colorado River system is uncertain and can not be represented by a single view.**
- **An infinite number of plausible futures exist.**
- **A manageable and informative number of scenarios - water supply and water demand - were developed to explore the broad range of futures.**



(adapted from Timpe and Scheepers, 2003)

CRSS Overview

CRSS Long-Term Planning – Basin Study

Water Supply Scenarios

Observed Resampled: 15.0 MAF Mean
- future hydrologic trends and variability will be similar to the past 100 years

Paleo Resampled: 14.7 MAF Mean
- future hydrologic trends and variability are represented by the distant past (approximately 1250 years)

Paleo Conditioned: 14.9 MAF Mean
- future hydrologic trends and variability are represented by a blend of the wet dry states of the paleo-climate record but magnitudes are more similar to the observed period 1,000 sequences

Downscaled GCM Projected: 13.7 MAF
- future climate will continue to warm with regional precipitation trends represented through an ensemble of future GCM projections

112 sequences from 16 GCMs

Water Demand Scenarios

Current Projected (A):
- growth, development patterns, and institutions continue along recent trends

Slow Growth (B):
- low growth with emphasis on economic efficiency

Rapid Growth (C1 and C2):
- economic resurgence (population and energy) and current preferences toward human and environmental values
  - C1 – slower technology adoption
  - C2 – rapid technology adoption

Enhanced Environment (D1 and D2):
- expanded environmental awareness and stewardship with growing economy
  - D1 – with moderate population growth
  - D2 – with rapid population growth

Higher water use efficiencies

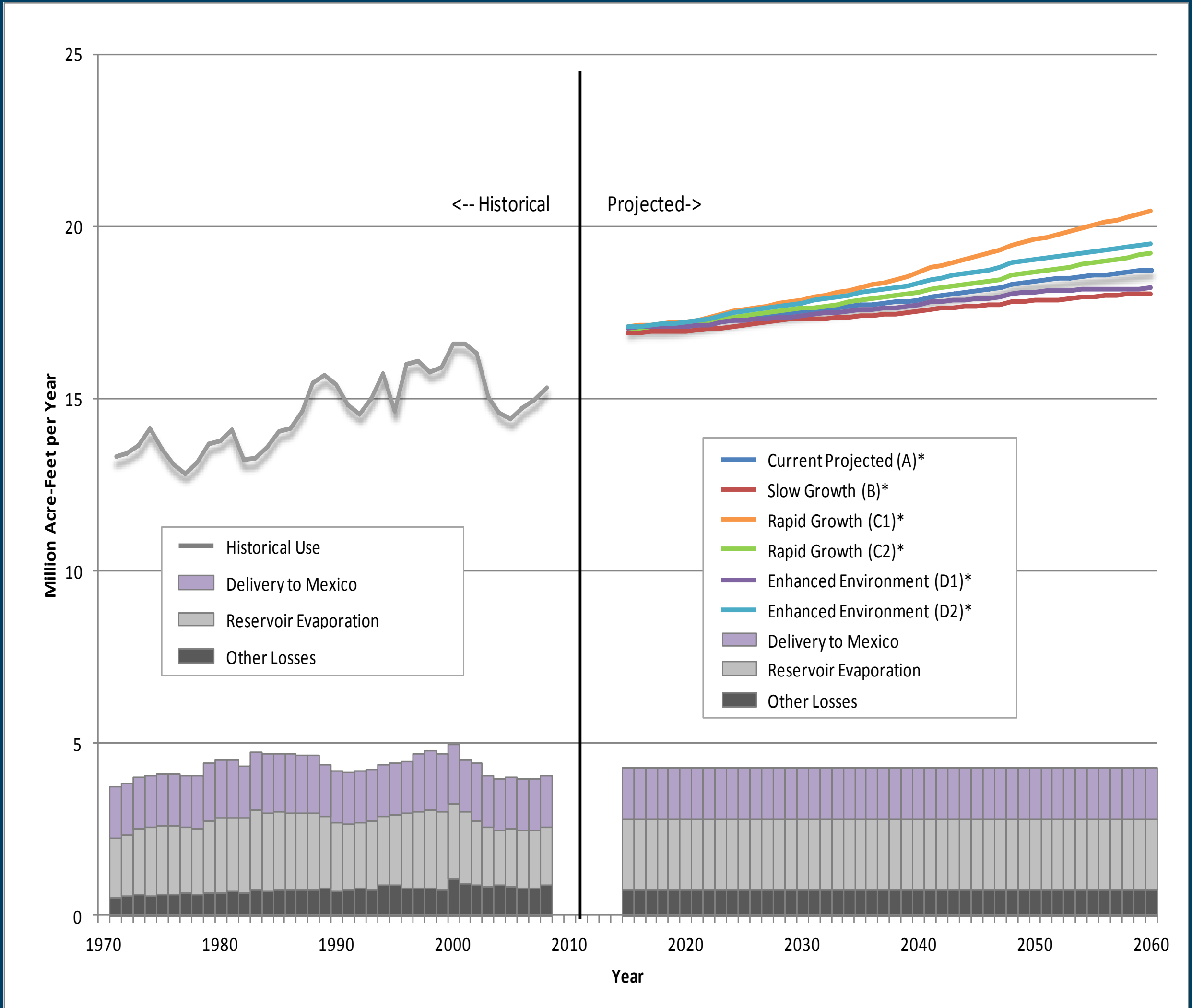
CRSS Overview

CRSS Long-Term Planning – "Basin Study

Water Demand Scenarios Summary

- Demand for consumptive uses ranges between 13.8 and 16.2 maf by 2060 (including Mexico and losses 18.1 and 20.4 maf by 2060)
- Approximately a 20% spread between the lowest (Slow Growth) and highest (Rapid Growth – C1) demand scenarios

Colorado River Basin Historical Use and Future Projected Demand



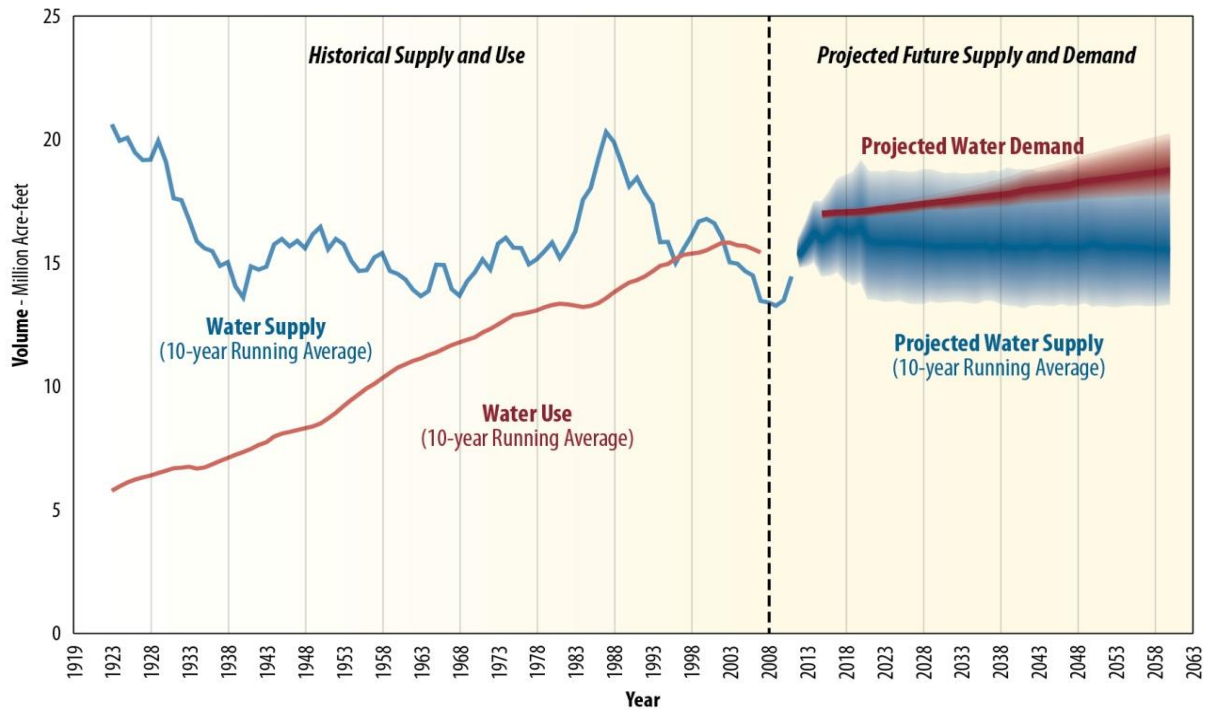
*Quantified demand scenarios have been adjusted to include Mexico's allotment and estimates for future reservoir evaporation and other losses.

CRSS Overview

CRSS Long-Term Planning – “Basin Study

Projected Future Colorado River Basin Water Supply and Demand

- Median supply-demand imbalances by 2060 are approximately 3.2 million acre-feet (MAF)
- Arizona portion of imbalance is about 1 MAF
- This imbalance may be more or less depending on the nature of the particular supply and demand scenario
- Imbalances have occurred in the past, but deliveries have been met due to reservoir storage



Notes:

Water Supply represents natural flow as measured at the Colorado River above Imperial Dam, Arizona

Water Use and Demand include deliveries to Mexico in accordance with the 1944 Treaty with Mexico and losses such as those due to reservoir evaporation, native vegetation, and operational inefficiencies.

Projected Water Supply is computed as the average 10th, 50th (median), and 90th percentiles of the Study's 4 water supply scenarios. The average of the medians is indicated by the darker shading.

Projected Water Demand is represented by the Study's 6 water demand scenarios. The median of the scenarios is indicated by the darker shading.

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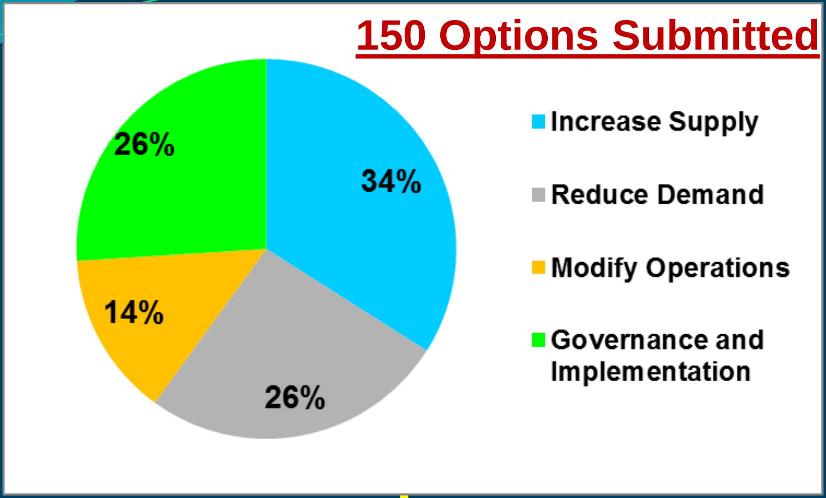
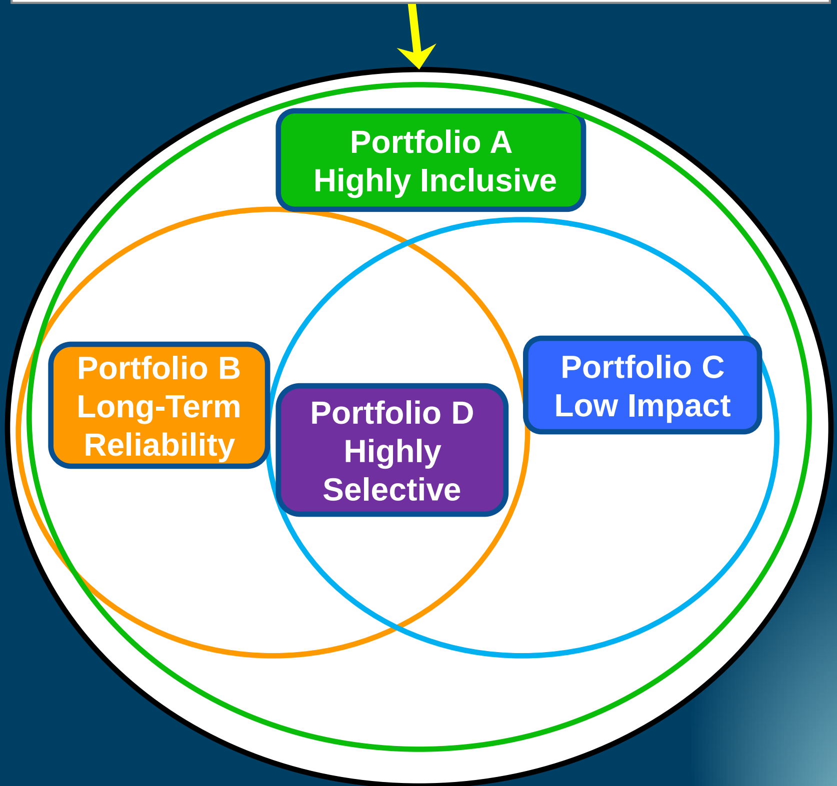
CRSS Overview

CRSS Long-Term Planning – "Basin Study



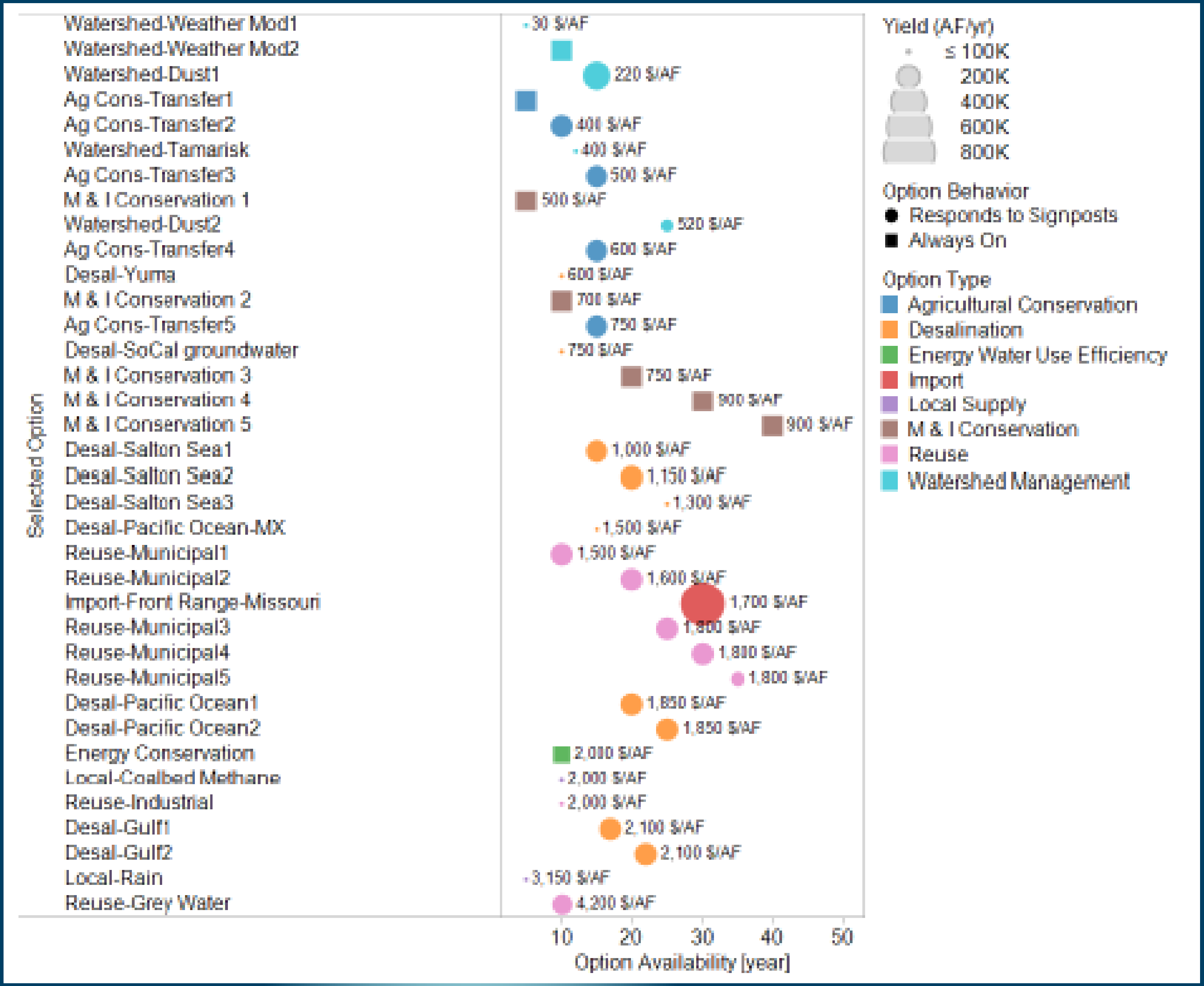


Portfolio	Which Options?
<u>Portfolio A</u> Highly Inclusive *Ordered by least-cost, but higher risk strategy*	• Most cost effective • Highly inclusive set of option preferences • Considers the <u>largest set</u> of options
<u>Portfolio B</u> Long-Term Reliability *High feasibility and long-term reliability*	• Low risk strategy in the long-term with high reliability • High technical feasibility • Excludes options with high permitting, legal, and policy risks
<u>Portfolio C</u> Low Impact *Low environmental impact*	• Prioritizes options that have low environmental impacts and log-term flexibility • Excludes options with high permitting risk
Portfolio D Highly Selective" *An intersection of high feasibility, high long-term reliability, and low environmental impact*	• High technical feasibility and long-term reliability • Low energy intensity • Excludes options with high permitting, legal, and policy risks • Considers <u>smallest set</u> of options

CRSS Overview

CRSS Long-Term Planning – "Basin Study

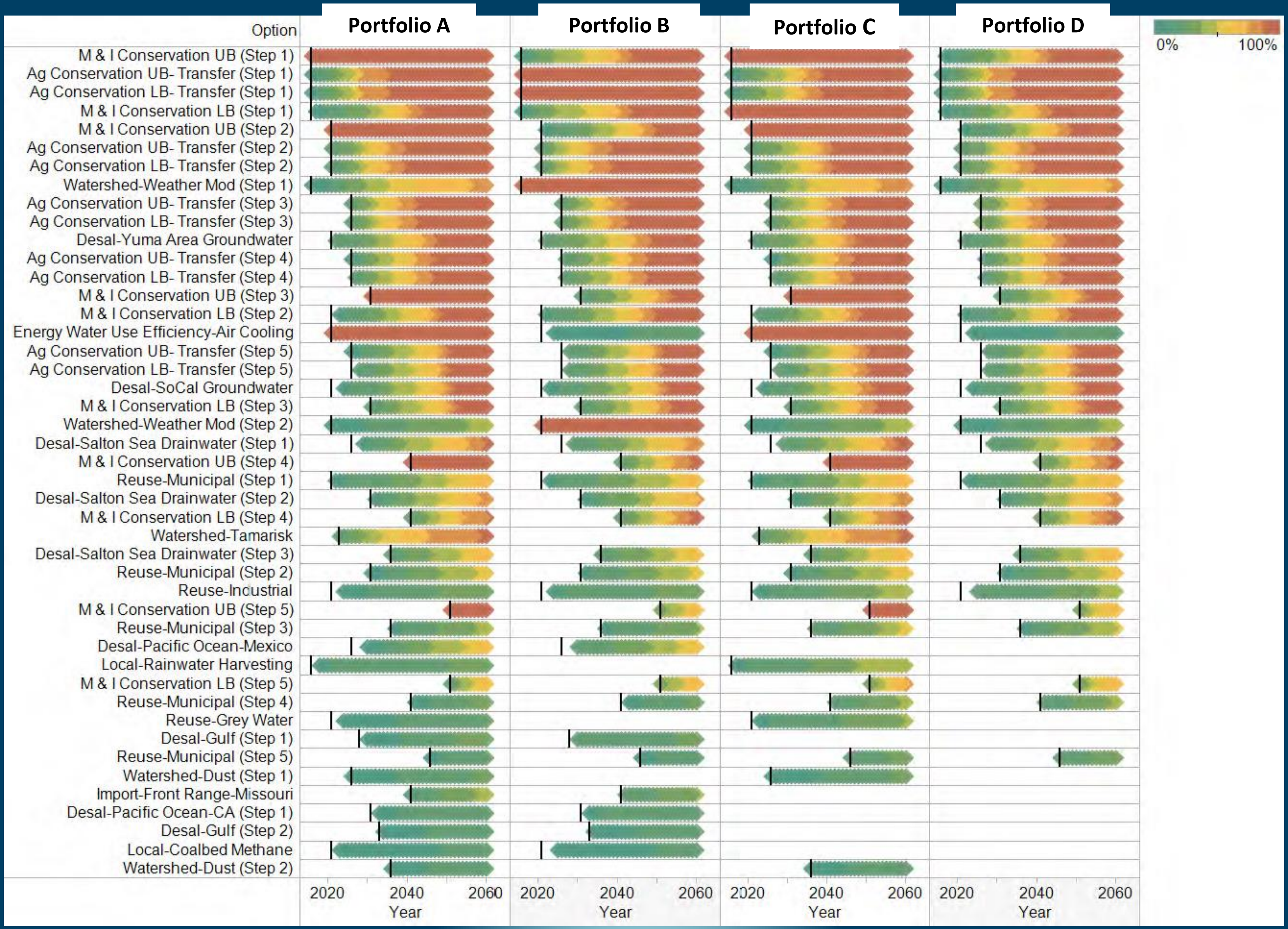
Portfolio A Option List



CRSS Overview

CRSS Long-Term Planning – "Basin Study

Frequency of Portfolio Option Implementation



CRSS Overview

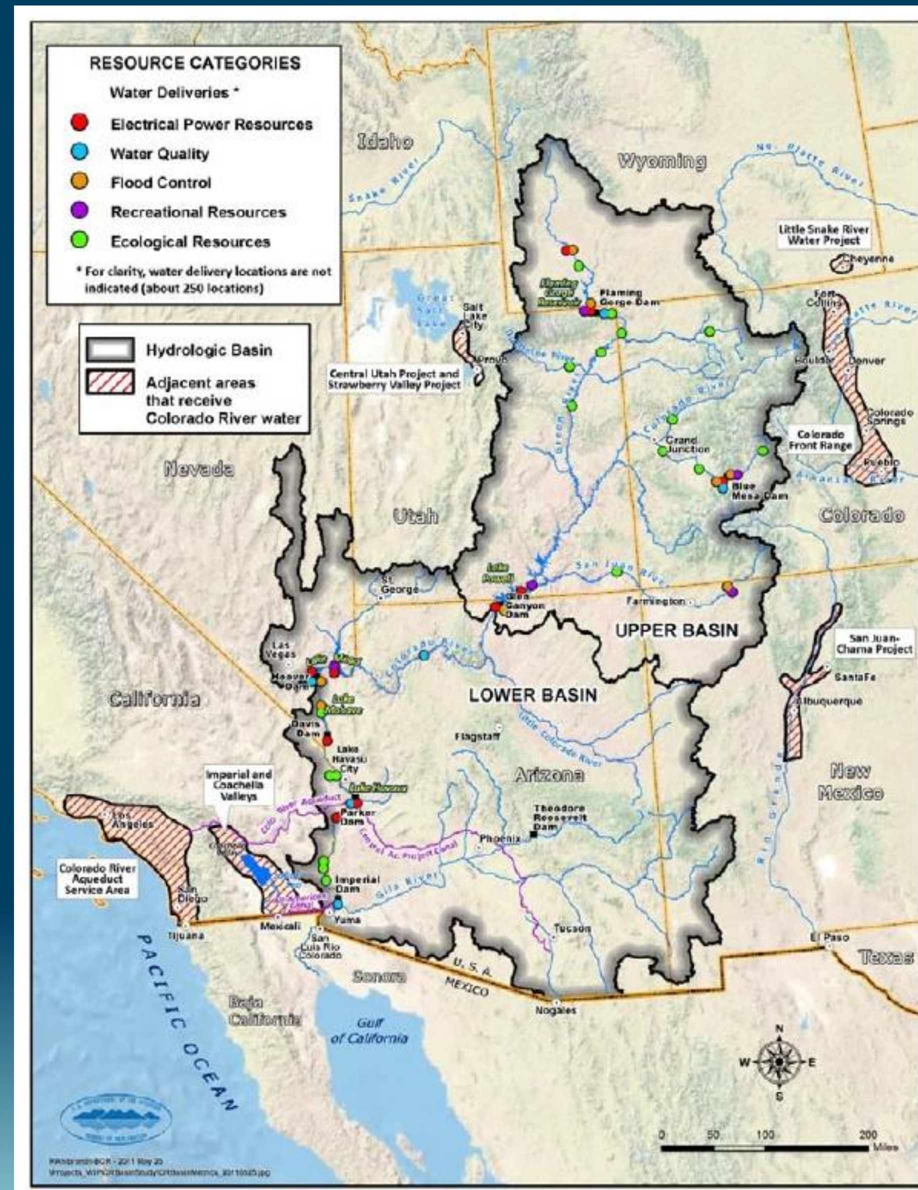
CRSS Long-Term Planning – “Basin Study

System Reliability Analysis

- Simulate the state of the system on a monthly time step over the next 50 years for each scenario, with and without options and strategies

- Metrics and vulnerabilities used to quantify impacts to Basin Resources

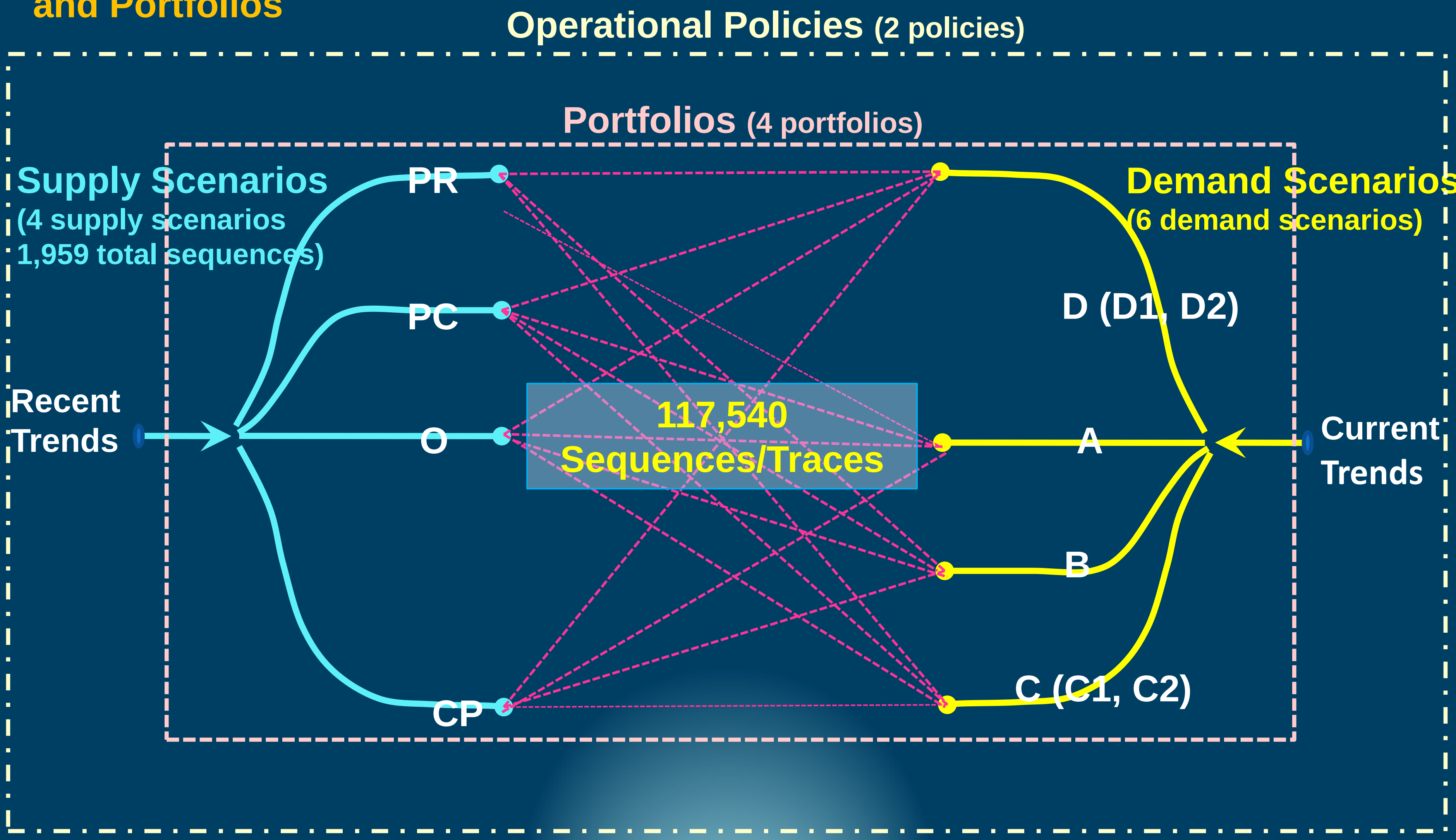
- *Resource Categories*
  - Water Deliveries
  - Electrical Power Resources
  - Water Quality
  - Flood Control
  - Recreational Resources
  - Ecological Resources

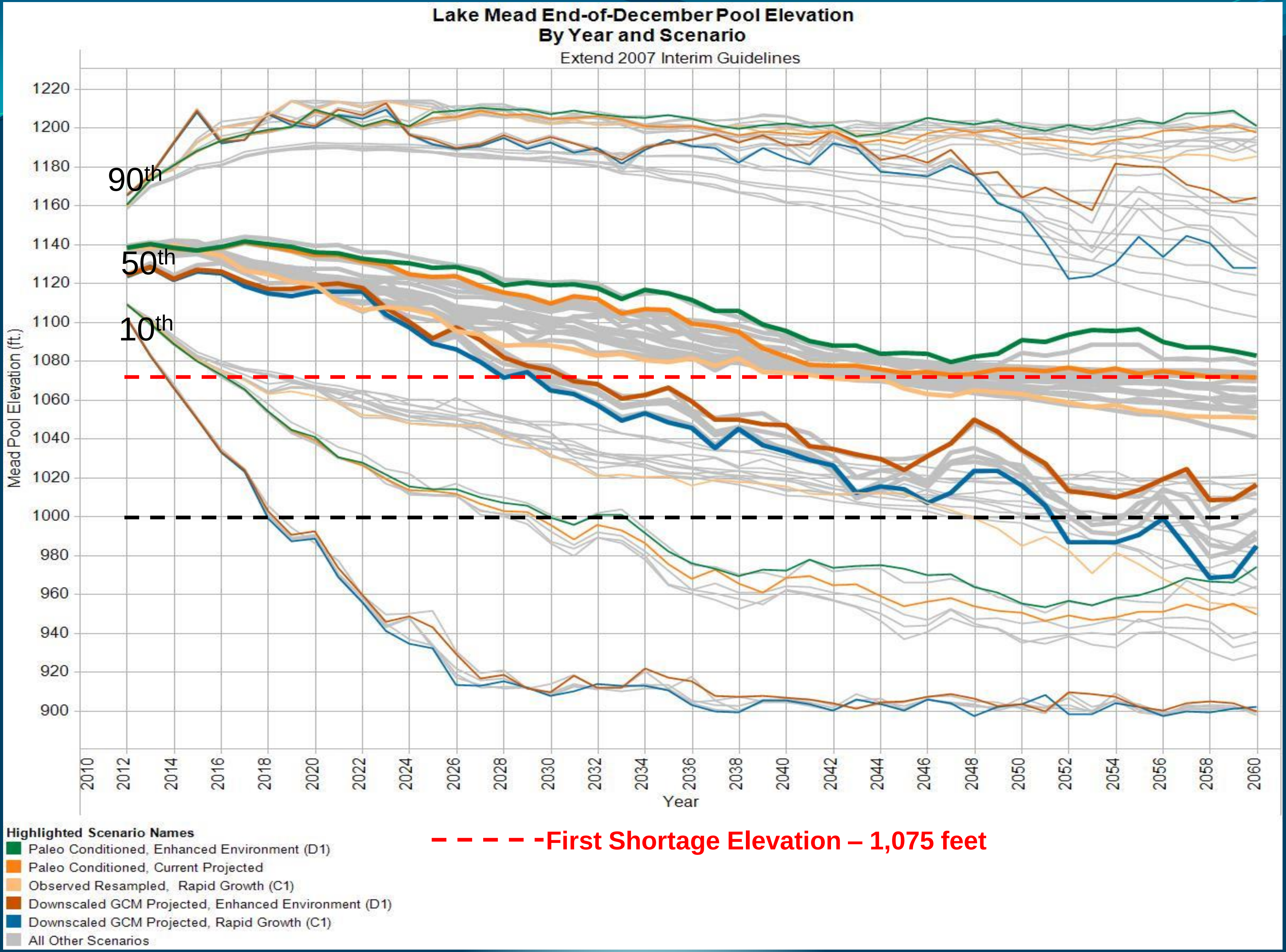


CRSS Overview

CRSS Long-Term Planning – "Basin Study

Integration of Supply and Demand Scenarios, Operational Policies and Portfolios




Lake Mead End-of-December Pool Elevation
By Year and Scenario
Extend 2007 Interim Guidelines
Mead Pool Elevation (ft.)
Year
90th
50th
10th
Highlighted Scenario Names
Paleo Conditioned, Enhanced Environment (D1)
Paleo Conditioned, Current Projected
Observed Resampled, Rapid Growth (C1)
Downscaled GCM Projected, Enhanced Environment (D1)
Downscaled GCM Projected, Rapid Growth (C1)
All Other Scenarios
First Shortage Elevation – 1,075 feet

CRSS Overview

CRSS Long-Term Planning – "Basin Study

Water Delivery Indicator Metrics – Portfolio Performance

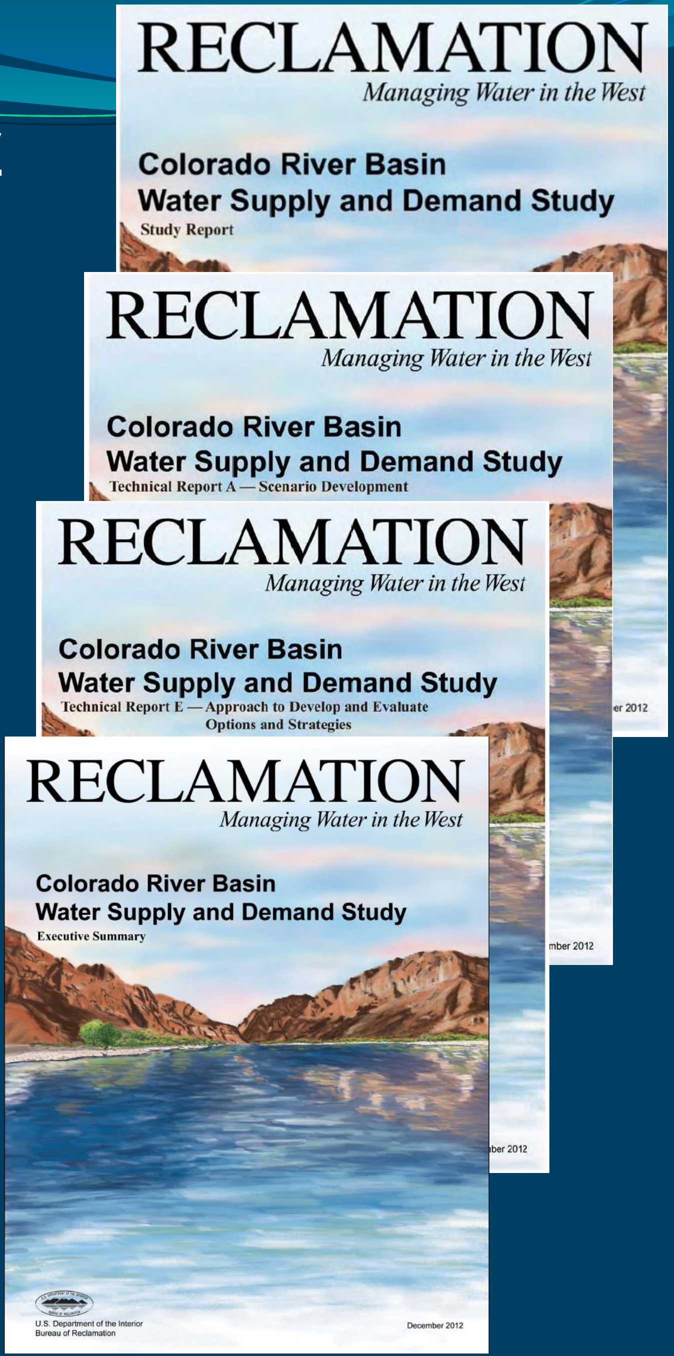
Vulnerable Years	Time Period	Baseline	Portfolio A	Portfolio B	Portfolio C	Portfolio D
Upper Basin Shortage (exceeds 25% of requested depletion in any one year)	2012-2026	4%	3%	3%	3%	3%
	2027-2040	5%	3%	3%	3%	3%
	2041-2060	7%	2%	2%	3%	3%
Lee Ferry Deficit (exceeds zero in any one year)	2012-2026	0%	0%	0%	0%	0%
	2027-2040	3%	1%	2%	1%	2%
	2041-2060	6%	1%	2%	1%	3%
Lake Mead Pool Elevation < 1000 feet (below 1000 feet in any one month)	2012-2026	4%	4%	4%	4%	4%
	2027-2040	13%	7%	7%	8%	8%
	2041-2060	19%	3%	3%	5%	6%
Lower Basin Shortage (exceeds 1 maf over any two year window)	2012-2026	7%	5%	5%	5%	5%
	2027-2040	37%	22%	19%	23%	23%
	2041-2060	51%	10%	10%	13%	14%
Lower Basin Shortage (exceeds 1.5 maf over any five year window)	2012-2026	10%	9%	9%	9%	9%
	2027-2040	43%	35%	30%	36%	36%
	2041-2060	59%	23%	23%	26%	28%
Remaining Demand Above Lower Division States' Basic Apportionment (exceeds moving threshold in any one year)	2012-2026	0%	0%	0%	0%	0%
	2027-2040	40%	2%	1%	1%	2%
	2041-2060	93%	5%	5%	7%	5%
		0% 50% 100% Percent Years Vulnerable	0% 50% 100% Percent Years Vulnerable	0% 50% 100% Percent Years Vulnerable	0% 50% 100% Percent Years Vulnerable	0% 50% 100% Percent Years Vulnerable

CRSS Overview

CRSS Long-Term Planning – “Basin Study

❖ The Final Basin Study is a collection of nine reports

Executive Summary
Final Study Report
Technical Report A – Scenario Development
Technical Report B – Water Supply Assessment
Technical Report C – Water Demand Assessment
Technical Report D – System Reliability Metrics
Technical Report E – Approach to Develop and Evaluate Opportunities to Balance Supply
Technical Report F – Development of Options and Strategies
Technical Report G– System Reliability Analysis and Evaluation of Options and Strategies



Overview
of
Colorado River Operations and CRSS

CRSS Overview

Colorado River Operations – Mid-Term Operations Models

Model Comparisons

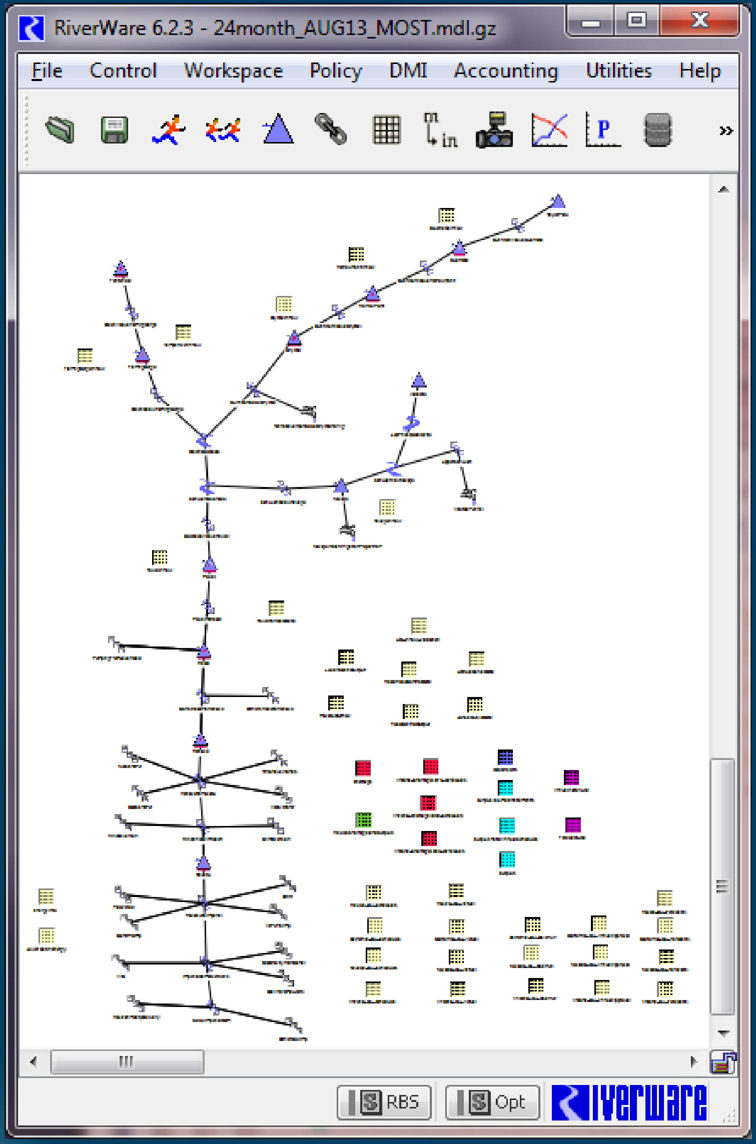
	CRSS	24-Month Study
Hydrology	Natural/Observed, Paleo, Downscaled GCM	Unregulated inflow from the Colorado Basin Forecast Center
Upper Basin Demands	2007 Upper Colorado River Commission	In unregulated inflow forecast
Lower Basin Demands	Lower Basin States and Mexico are using their apportionments	Official approved diversions
Probabilistic / Deterministic	Probabilistic – 105 (or more) sequences	Deterministic
Rule-Driven / Manual Operations	Rule-Driven	Rule-Driven plus input from reservoir operators
Time Horizon	Long-range – 15 years or more	2 years from current month

CRSS Overview

Colorado River Operations

For mid-term operations, Reclamation uses the "24-Month Study" CRSS Model

- Annual Operating Plan model
- Incorporates the 2007 Interim Guidelines to determine operating tiers of Lake Powell and Lake Mead
- 2-year projection updated monthly
- Hydrology projection based on "most probable" inflow forecast from the Colorado Basin River Forecast Center (4 times a year a maximum and minimum probable inflow forecast are modeled)
- Contains12 major reservoirs (9 Upper Basin, 3 Lower Basin)



CRSS Overview

Colorado River Operations – 24_Month Study

OPERATION PLAN FOR COLORADO RIVER SYSTEM RESERVOIRS

RECLAMATION
Managing Water in the West

January 2015 24-Month Study

Most Probable Inflow*

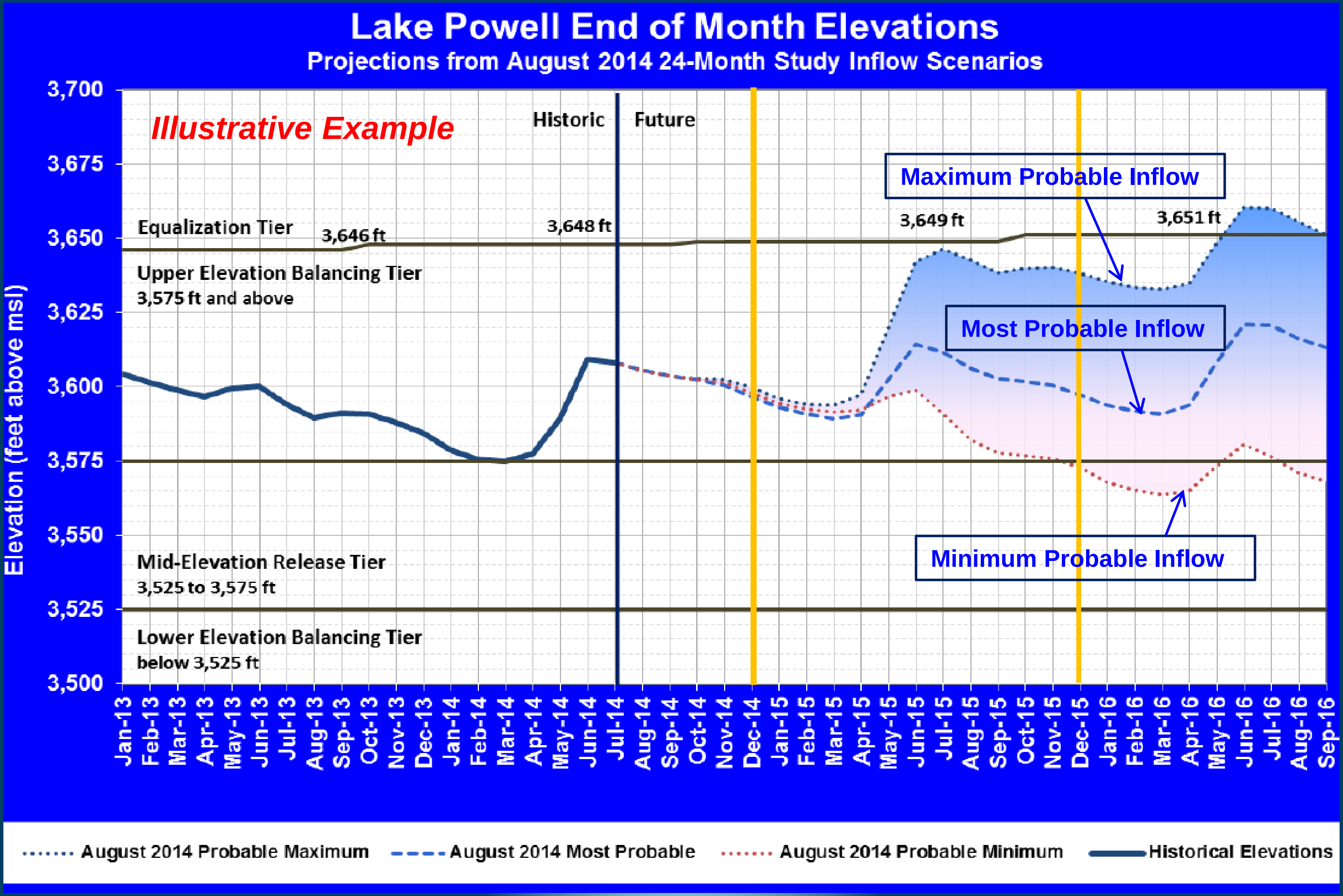
Hoover Dam - Lake Mead

Illustrative Example

	Date	Glen Release (1000 Ac-Ft)	Side Inflow Glen to Hoover (1000 Ac-Ft)	Evap Losses (1000 Ac-Ft)	Total Release (1000 Ac-Ft)	Total Release (1000 CFS)	SNWP Use (1000 Ac-Ft)	Downstream Requirements (1000 Ac-Ft)	Bank Storage (1000 Ac-Ft)	Reservoir Elev End of Month (Ft)	EOM Storage (1000 Ac-Ft)
*	Jan 2014	800	45	33	605	9.8	8	605	815	1108.75	12531
H	Feb 2014	599	76	31	717	12.9	8	716	810	1107.94	12456
I	Mar 2014	504	29	34	1090	17.7	13	1087	773	1101.71	11888
S	Apr 2014	502	17	41	1134	19.1	20	1130	731	1094.55	11254
T	May 2014	493	13	46	1086	17.7	30	1084	692	1087.46	10639
O	Jun 2014	598	10	54	959	16.1	28	958	665	1082.66	10233
R	Jul 2014	800	54	67	943	15.3	27	941	654	1080.60	10061
I	Aug 2014	801	113	71	735	12.0	23	727	659	1081.55	10140
C	Sep 2014	604	140	58	686	11.5	19	684	658	1081.33	10121
	WY 2014	**7480**	**677**	**567**	**9759**		**216**	**9716**			
A	Oct 2014	598	68	43	472	7.7	21	461	666	1082.79	10244
L	Nov 2014	777	43	43	695	11.7	12	692	670	1083.57	10309
*	Dec 2014	864	67	37	493	8.0	7	492	693	1087.79	10667
	Jan 2015	860	75	31	789	12.8	8	789	700	1088.97	10768
	Feb 2015	600	78	28	642	11.6	7	642	700	1088.98	10769
	Mar 2015	650	68	31	1013	16.5	15	1013	679	1085.22	10448
	Apr 2015	600	80	38	1165	19.6	21	1165	646	1079.11	9937
	May 2015	700	60	43	1044	17.0	29	1044	624	1075.00	9601
	Jun 2015	800	23	52	918	15.4	30	918	613	1072.95	9436
	Jul 2015	1050	64	65	907	14.8	31	907	620	1074.24	9540
	Aug 2015	800	116	69	819	13.3	29	819	620	1074.23	9539
	Sep 2015	701	97	57	744	12.5	16	744	619	1074.01	9520
	WY 2015	**9000**	**839**	**537**	**9702**		**228**	**9687**			
	Oct 2015	600	52	41	451	7.3	21	451	627	1075.62	9651
	Nov 2015	600	52	42	572	9.6	11	572	629	1075.94	9678
	Dec 2015	800	95	36	529	8.6	8	529	649	1079.63	9980
	Jan 2016	800	75	30	710	11.5	9	710	656	1081.07	10100
	Feb 2016	650	78	27	626	10.9	8	626	661	1081.82	10162
	Mar 2016	650	68	31	1020	16.6	16	1020	639	1077.87	9835
	Apr 2016	600	80	37	1104	18.6	22	1104	610	1072.28	9381
	May 2016	650	60	42	992	16.1	30	992	588	1068.09	9049
	Jun 2016	800	23	50	910	15.3	30	910	578	1066.09	8891
	Jul 2016	1000	64	63	878	14.3	32	878	584	1067.18	8977
	Aug 2016	1050	116	67	795	12.9	30	795	600	1070.44	9235
	Sep 2016	800	97	56	730	12.3	17	730	606	1071.56	9323
	WY 2016	**9000**	**861**	**522**	**9316**		**232**	**9316**			
	Oct 2016	600	55	41	488	7.9	21	488	612	1072.78	9422
	Nov 2016	600	54	41	635	10.7	12	635	610	1072.39	9390
	Dec 2016	800	95	36	567	9.2	8	567	628	1075.69	9657

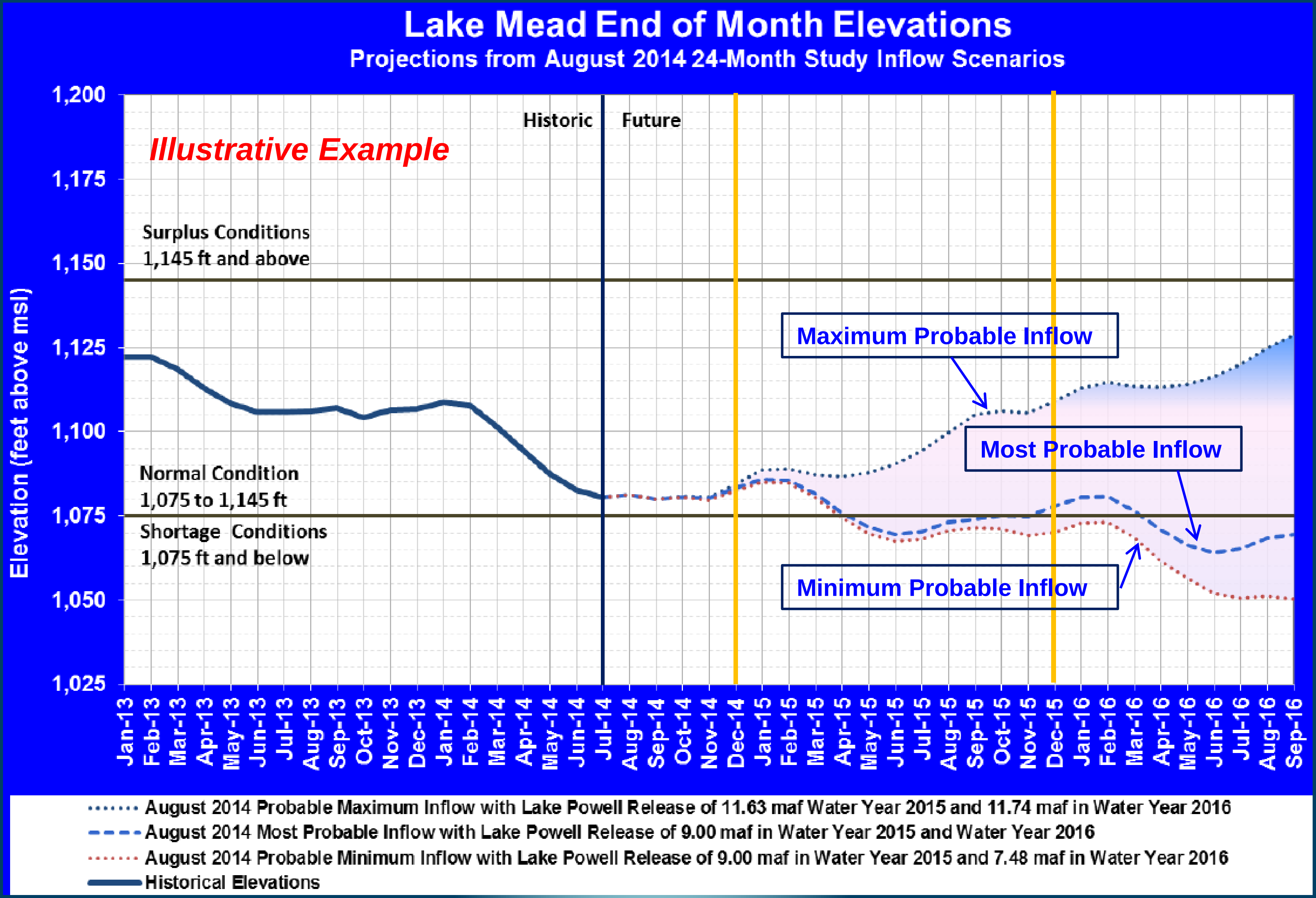
CRSS Overview

Colorado River Operations – 24_Month Study



CRSS Overview

Colorado River Operations – 24_Month Study



CRSS Overview

Colorado River Operations – 24_Month Study

Lake Powell & Lake Mead Operational Table

Operational Tiers for Water/Calendar Year 2015 determined with the August 2014 24-Month Study

Lake Powell

Elevation (feet)	Operation According to the Interim Guidelines	Live Storage (maf)[1]
3,700	**Equalization Tier** Equalize, avoid spills or release 8.23 maf	24.3
3,636 - 3,666 (2008-2026)	**Upper Elevation Balancing Tier[3]** Release 8.23 maf; if Lake Mead < 1,075 feet, balance contents with a min/max release of 7.0 and 9.0 maf	15.5 - 19.3 (2008-2026)
3,575	**Mid-Elevation Release Tier** Release 7.48 maf; if Lake Mead < 1,025 feet, release 8.23 maf	9.5
3,525	**Lower Elevation Balancing Tier** Balance contents with a min/max release of 7.0 and 9.5 maf	5.9
3,490		4.0
3,370		0

3,596.62 ft Jan 1,2015 projection

Lake Mead

Elevation (feet)	Operation According to the Interim Guidelines	Live Storage (maf)[1]
1,220	**Flood Control Surplus or Quantified Surplus Condition** Deliver > 7.5 maf	25.9
1,200 (approx.)[2]	**Domestic Surplus or ICS Surplus Condition** Deliver > 7.5 maf	22.9 (approx.)[2]
1,145	**Normal or ICS Surplus Condition** Deliver ≥ 7.5 maf	15.9
1,105		11.9
1,075	**Shortage Condition** Deliver 7.167[4] maf	9.4
1,050	**Shortage Condition** Deliver 7.083[5] maf	7.5
1,025	**Shortage Condition** Deliver 7.0[6] maf Further measures may be undertaken[7]	5.8
1,000		4.3
895		0

1,083.37 ft Jan 1, 2015 projection

CRSS Overview

Colorado River Operations – Mid-Term Operations Models

Model Comparisons

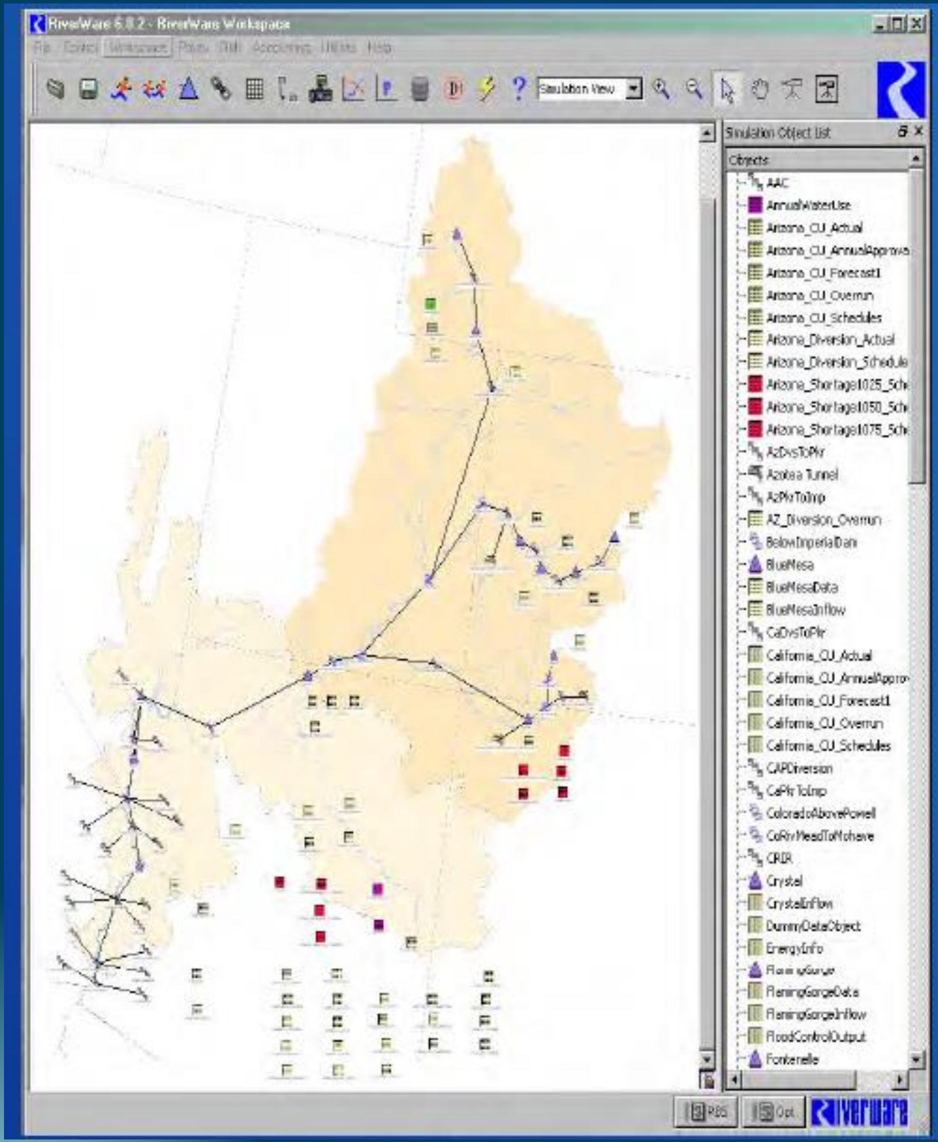
	CRSS	24-Month Study	Mid-Term Operations Model
Hydrology	Natural/Observed, Paleo, Downscaled GCM	Unregulated inflow from the Colorado Basin Forecast Center	Unregulated inflow from the Colorado Basin Forecast Center, from the 1981 through 2010 period
Upper Basin Demands	2007 Upper Colorado River Commission	In unregulated inflow forecast	In unregulated inflow forecast
Lower Basin Demands	Lower Basin States and Mexico are using their apportionments	Official approved diversions	Official approved diversions
Probabilistic / Deterministic	Probabilistic – 105 (or more) sequences	Deterministic	Probabilistic – 30 (or more) sequences
Rule-Driven / Manual Operations	Rule-Driven	Rule-Driven plus input from reservoir operators	Rule-Driven
Time Horizon	Long-range – 15 years or more	2 years from current month	3 to 10 years

CRSS Overview

Colorado River Operations – Mid-Term Operations Model

For mid-term operations between 3 to 10 years ahead, Reclamation is developing the Mid-Term Operations Model or "MTOM"

- **To better quantify range of possibilities for the mid-term future of the Colorado River Basin**
- **Used to estimate potential risks and provide a platform for mid-term planning**



Overview
of
Arizona Modeling and CRSS

CRSS Overview

Arizona Colorado River Modeling

Why the Arizona Department of Water Resources does modeling using CRSS.

- Arizona assumes a lower ultimate Upper Colorado River Basin depletion by 2060 –

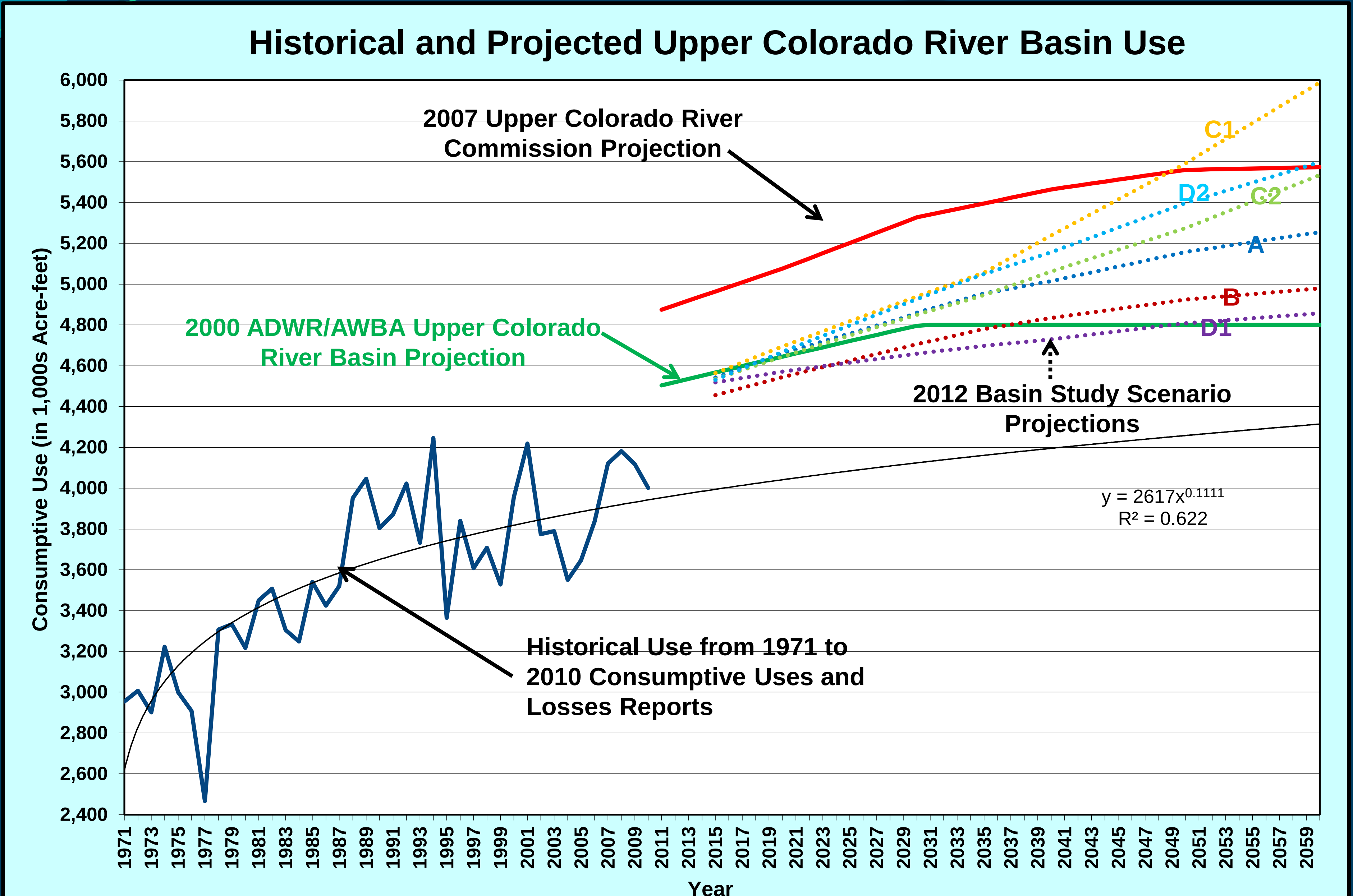
  Arizona: 4.8 MAF, Reclamation: 5.4 MAF
- Arizona model timeframe is longer than Reclamation –

  Arizona: 100 years, Reclamation; the present to 2060
- Arizona uses different depletion schedules for mainstem Colorado River Tribes –

  Arizona: moderate growth in Tribal depletions,

  Reclamation: uses the "Ten Tribes Partnership" depletion schedules (about 135,000 AF greater at full use)
- Arizona assumes a more moderate growth of mainstem non-Tribal depletions
- Arizona can assume that the Yuma Desalter Plant operates – which adds about 80,000 AF to the system and reduces releases from Lake Mead

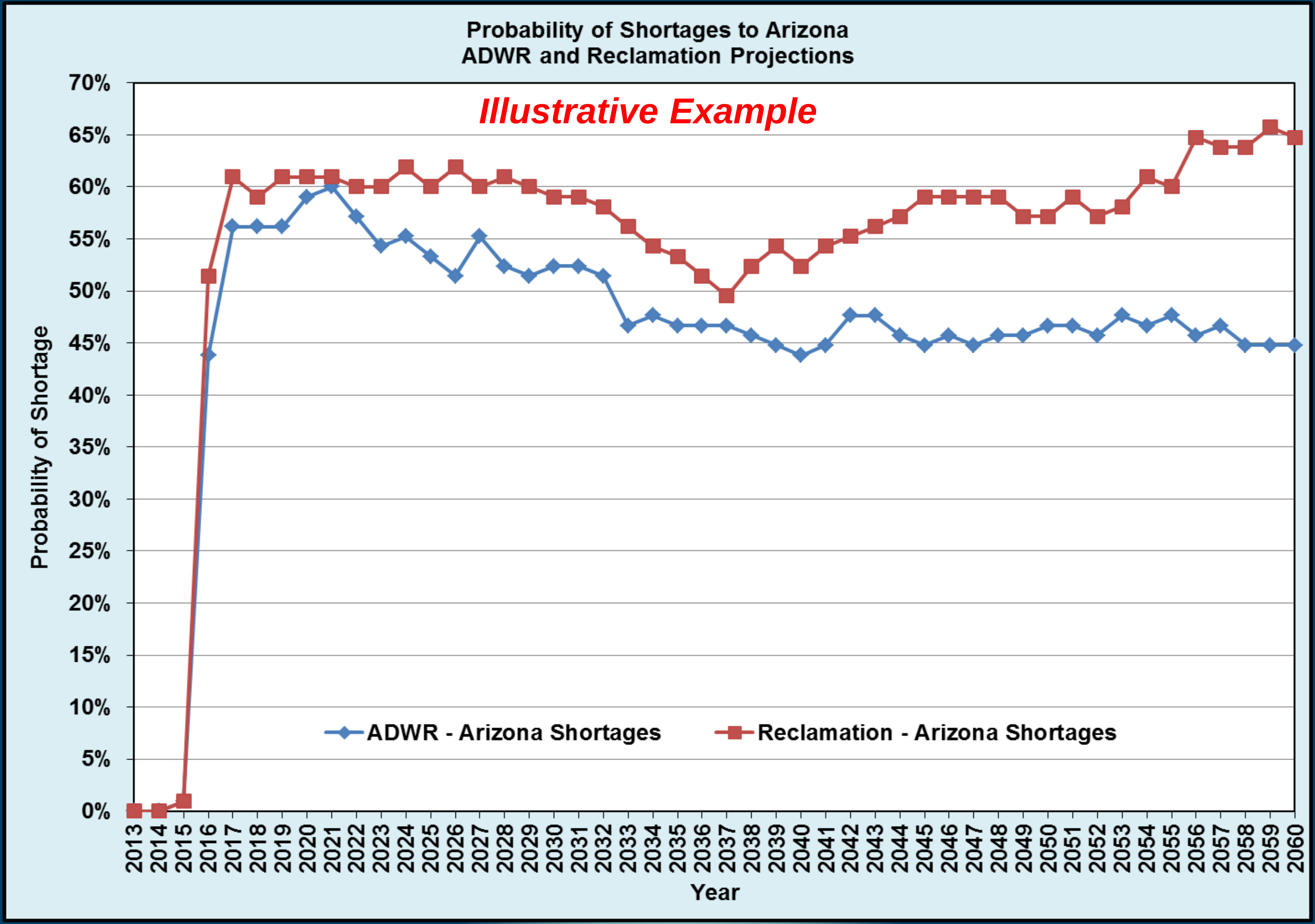
Upper Basin Demands



CRSS Overview

Arizona Colorado River Modeling

Probability of Shortages



CRSS Overview

Arizona Colorado River Modeling

ADWR performs Colorado River modeling for the following purposes:

- **Determine the probability and duration of shortages and the occurrence of the first shortage**
- **Update firming requirements for the Arizona Water Banking Authority (AWBA)**
- **Assured and Adequate Water Supply Re-designations**
- **Active Management Area Assessment Reports**
- **Assess impacts of various Colorado River reservoir operational strategies to Arizona water users**
- **Central Arizona Project Relinquished Non-Indian Agricultural (NIA) Priority Water Re-allocation**

CRSS Overview

Arizona Colorado River Modeling

Update Firming Requirements for the Arizona Water Banking Authority

Modeling Scenarios

Case 1

- Arizona Demand Schedules (CAP Full Build-up by 2045)
- 2007 Interim Guidelines Extended
- Arizona Recommended Shortage Sharing Formula for Priority 4 On-River Users and CAP

Case 2

- Arizona Demand Schedules (CAP Full Build-up by 2045)
- 2007 Interim Guidelines Followed by 80P1050
- Pro-rata Arizona Shortage Sharing Formula after 2026 for Priority 4 On-River Users and CAP

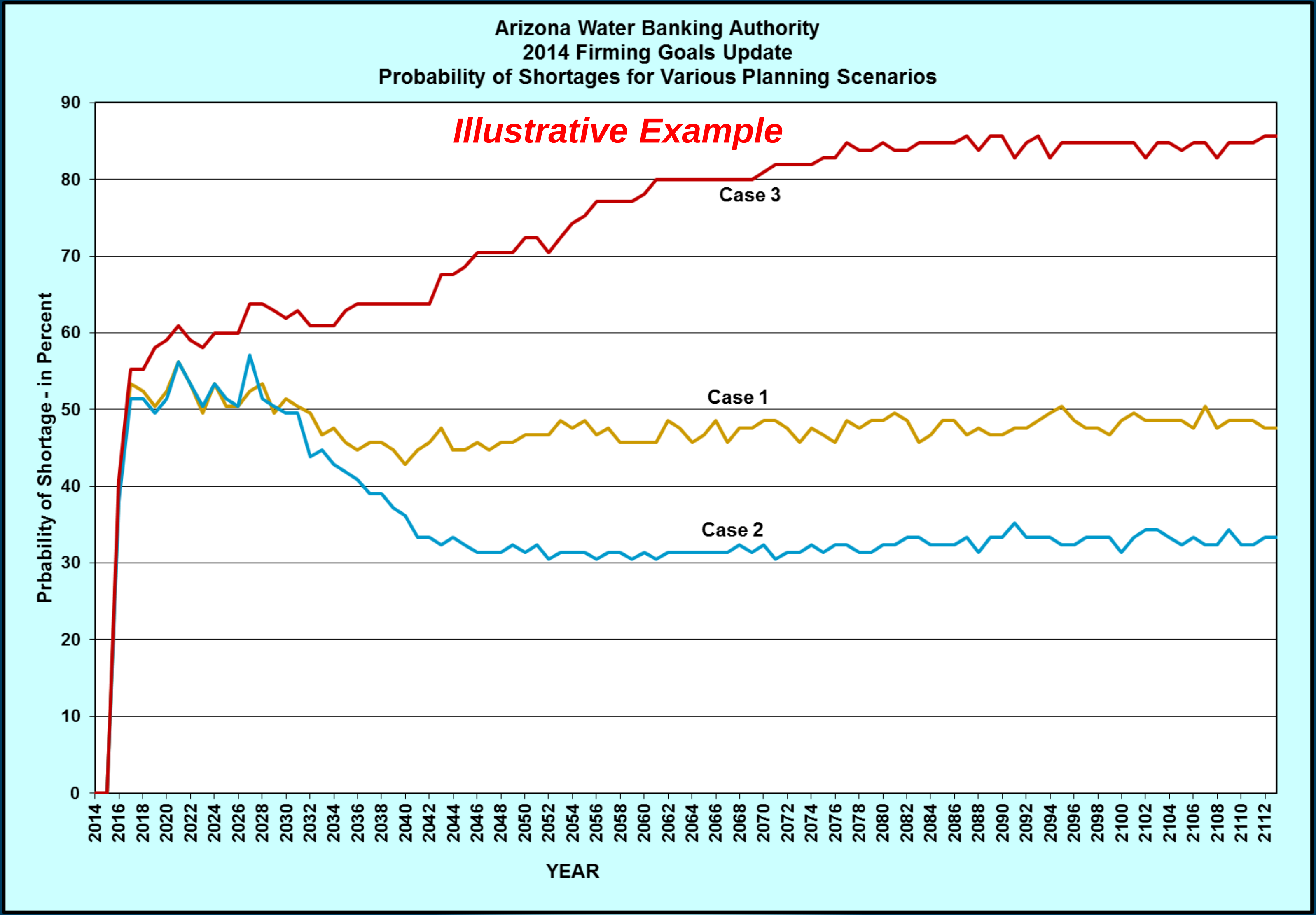
Case 3

- 2007 Upper Colorado River Commission and Ten Tribes Demand Schedules
- 2007 Interim Guidelines Followed by 80P1050
- Pro-rata Arizona Shortage Sharing after 2026 or Priority 4 On-River Users and CAP
- CAP Full Build-out by 2035

CRSS Overview

Arizona Colorado River Modeling

Update Firming Requirements for the Arizona Water Banking Authority



CRSS Overview

Arizona Colorado River Modeling

Update Firming Requirements for the Arizona Water Banking Authority

Case	OnRiver Firming Goal (kAF)	CAP M&I Priority Firming Goal Limited to 20% of 639 or 686 kaf (kAF)	CAP NIA Priority Indian Firming Obligation (kAF)	(kAF)
1997 [1]	420	2,673	550	3,643
1	134	385	778	1,297
2	468	2,540	544	3,552
3	948	6,911	1,298	9,157
Trace 95 [2]	196	853	926	1,975

1) Does not include Hohokam transfer to cities

2) Trace 95 for Run 1 starts in with Water Year 2000

CRSS Overview

Arizona Colorado River Modeling

CAP NIA Priority Water Re-allocation (per the 2004 Arizona Water Settlements Act

NIA Water Supply Analysis Modeling Assumptions

Basin Hydrology --------------------------- ***Observed Record (1906–2008)***

Upper Basin Depletions)----------------- ***4.8 MAF***

Operation of YDP -------------------------- ***No***

Mexico Shortage Sharing --------------- ***No***

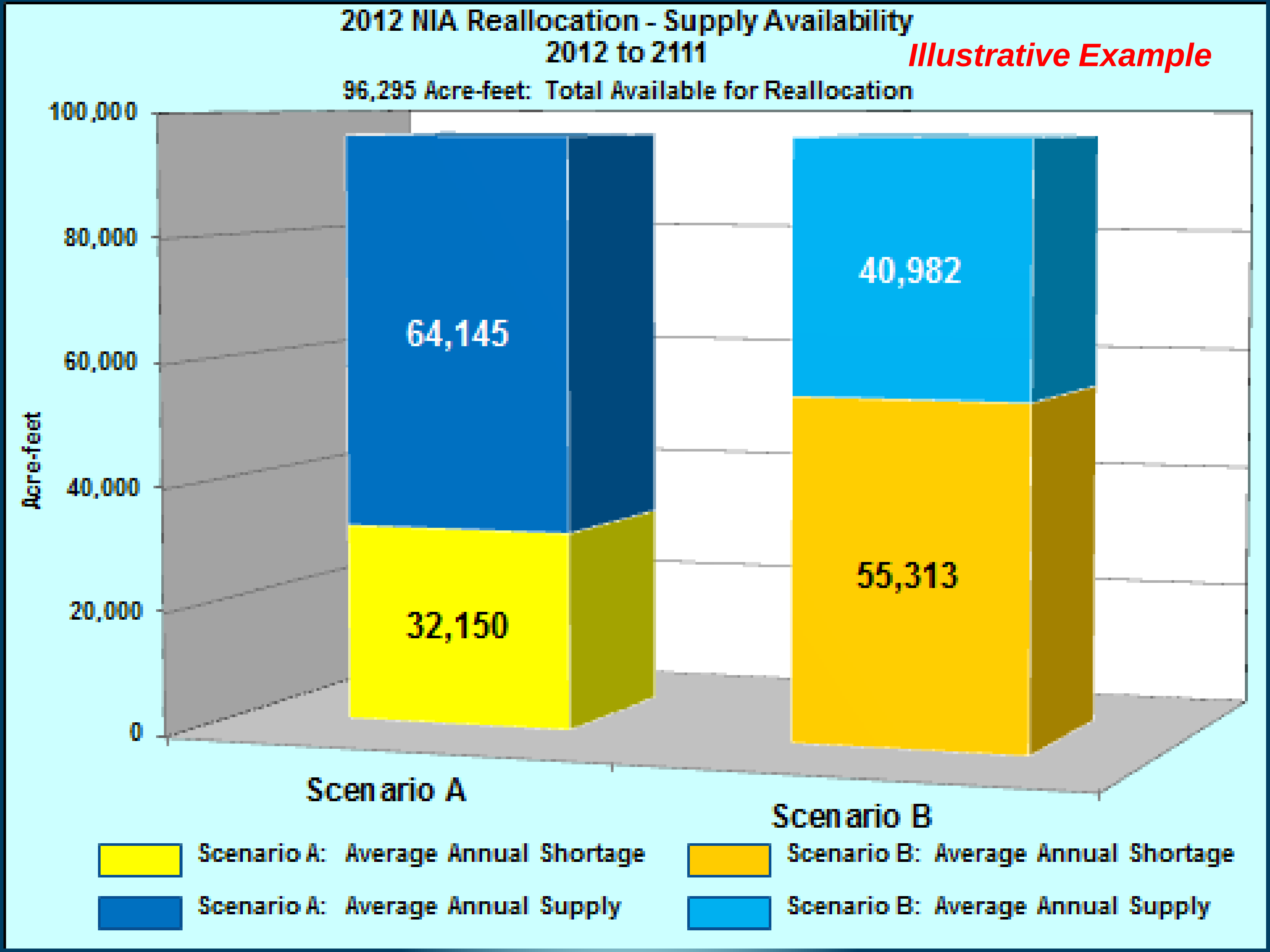
Reservoir and Shortage Operations- ***2007 Interim Guidelines***

Mainstem Use Projections ------------- ***Two Scenarios :***
Moderate Growth
Full Use of Entitlements

CRSS Overview

Arizona Colorado River Modeling

CAP NIA Priority Water Re-allocation



CRSS Overview

Arizona Colorado River Modeling

CAP NIA Priority Water Re-allocation