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IMPACT OF NAVAJO GENERATING STATION RETIREMENT AND REPLACEMENT WITH RENEWABLE ENERGY

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DEPARTMENT OF MECHANICAL ENGINEERING

ENERGY AND COMPUTATIONAL MODELING LAB

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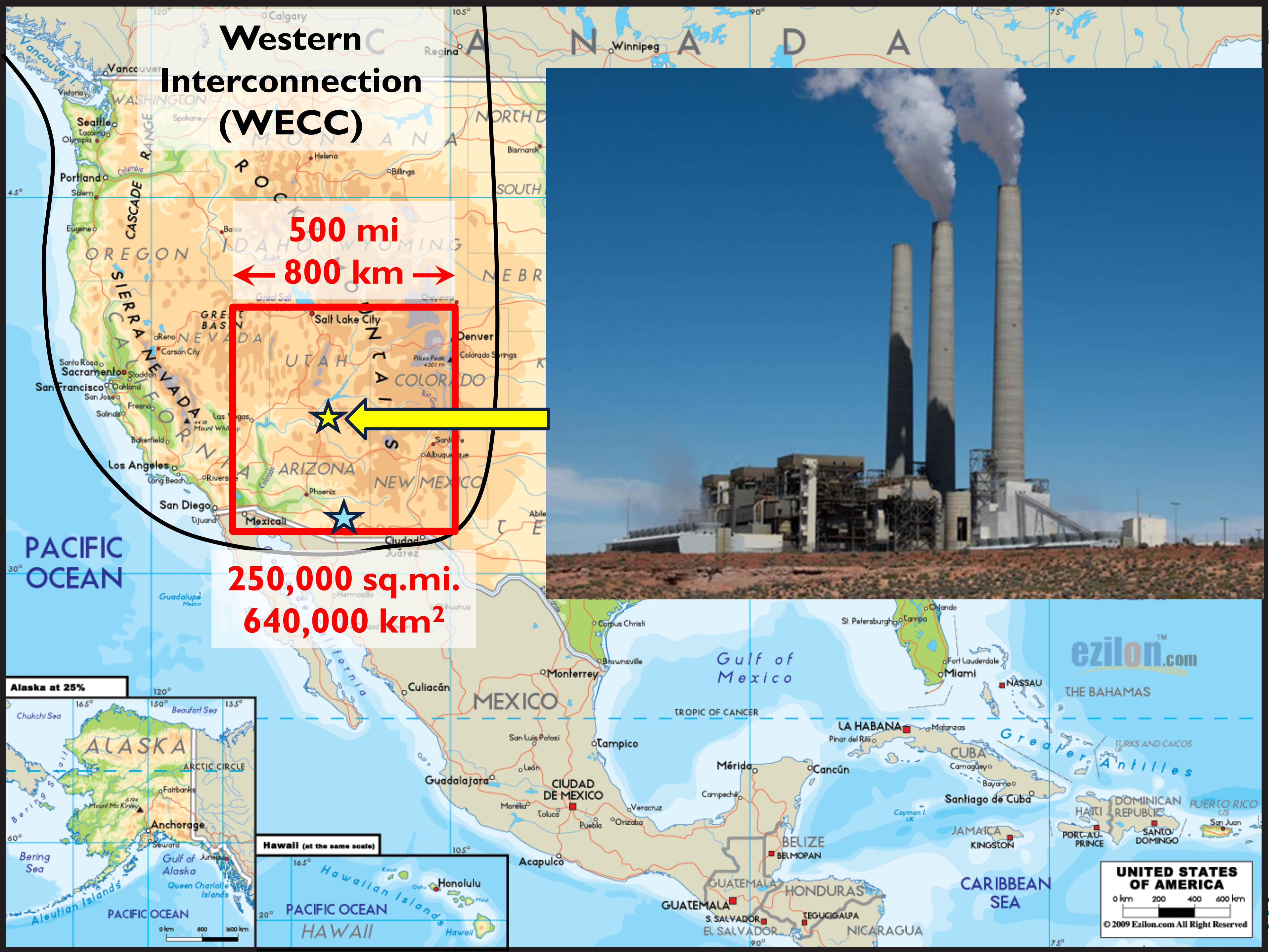
Western Interconnection (WECC)
500 mi
800 km
250,000 sq.mi.
640,000 km^2
PACIFIC OCEAN
CANADA
MEXICO
Gulf of Mexico
CARIBBEAN SEA
THE BAHAMAS
CUBA
Alaska at 25%
ALASKA
Hawaii (at the same scale)
HAWAII
OREGON
NEVADA
UTAH
COLORADO
ARIZONA
NEW MEXICO
CALIFORNIA
Salt Lake City
Denver
Los Angeles
San Diego
San Francisco
Sacramento
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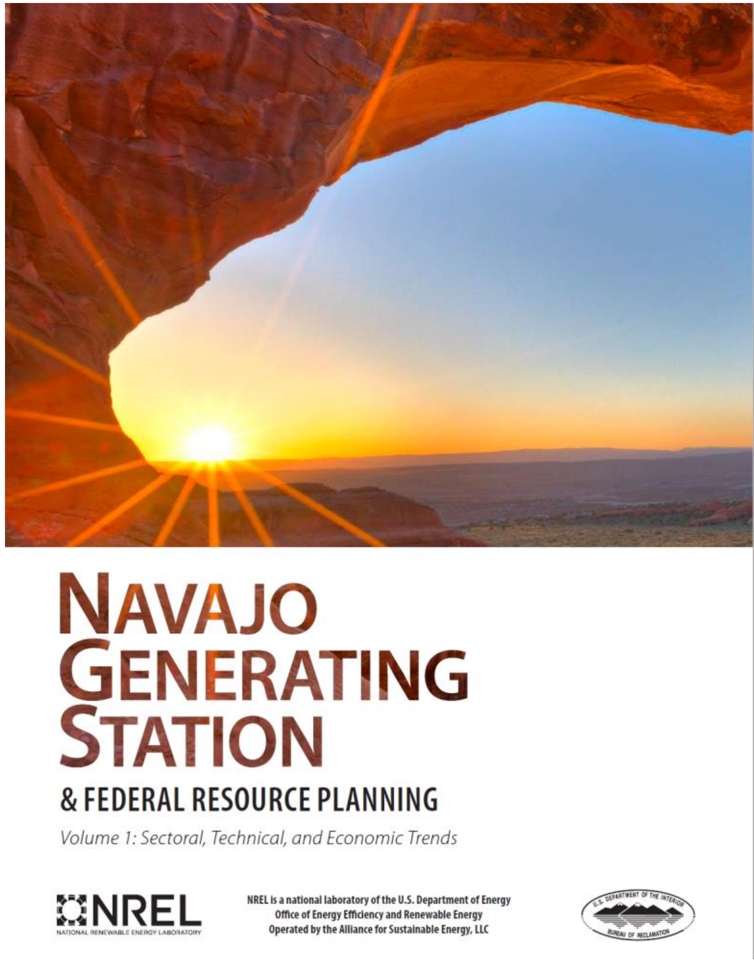
BACKGROUND

- Future retirement of the Navajo Generating Station (NGS) in 2019
  - Supercritical coal-fired steam plant 2,250 MW
  - 24.3% Federal Share which is 547 MW
  - Mainly used for Central Arizona Project pumps
- *"Closure of NGS would eliminate nearly 1,000 high-paying jobs and about $98.8 million in annual payroll, in addition to eliminating an average of $37.2 million in annual coal royalties, payments and fees paid to the Navajo Nation and $14 million in annual coal royalties, payments and fees paid to the Hopi Tribe"*

BACKGROUND

- The Department of the Interior, Department of Energy, and the Environmental Protection Agency… a broad set of long-term goals for *"producing clean, affordable, and reliable power, affordable and sustainable water supplies, and sustainable economic development, while minimizing negative impacts on those who currently obtain significant benefits from NGS, including tribal nations."*
- "…the completion of a comprehensive study by NREL to identify low-emitting energy alternatives to replace the federal shares in NGS."



BACKGROUND AND OBJECTIVES

- From the NREL study:
  - The capacity expansion modeling suggests that reduced operation at NGS appears to have little effect on the market fundamentals driving new generator investments in WECC. Even when simulating full NGS retirement in 2019, trends for adding new capacity did not change significantly.
  - A number of regions of WECC appear to have generating capacity well in excess of peak reserve margin requirements, which could persist at least in the short term. Large reserve margins dampen the economic need to build new generation capacity.
- *Investigate resilience of electrical system in the face of extreme drought*
- *Considers three options for NGS replacement to mitigate impacts*
- *Value of hydropower*

COLORADO RIVER SYSTEM

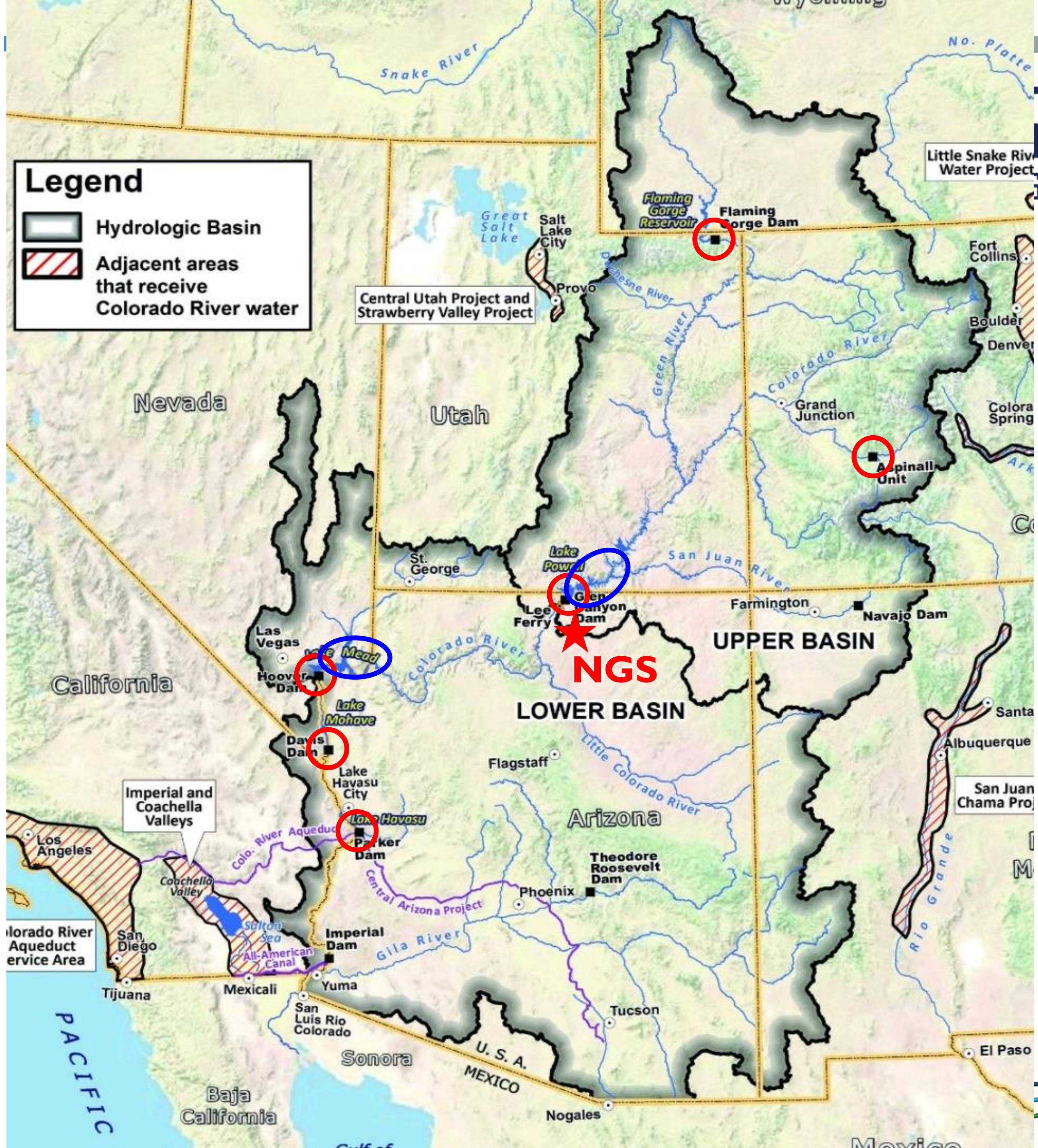
Municipal water
~ 30,000,000 people

Farmland irrigation
~ 3,500,000 acres

Annual Inflow
~ 13 to 18 maf

<u>Annual allocation (maf)</u>:

Upper Basin 7.5
Lower Basin 7.5
California 4.4
Arizona 2.8
Nevada 0.3
Mexico 1.5



COLORADO RIVER HYDROPOWER

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Maximum Capacity ~ 4,225 MW
Annual Generation ~ 10 TWh

Dam	Reservoir Name	Water Storage (million acre-feet)	Installed Capacity (MW)	10-year rolling average energy (GWh)
Hoover	**Lake Mead**	**29.0**	**2,078**	**3,741**
Glen Canyon	**Lake Powell**	**27.0**	**1,320**	**3,805**
Davis	Lake Mohave	1.8	255	1,116
Parker	Lake Havasu	0.65	120	444
Blue Mesa*	Blue Mesa	0.94	86.4	233
Morrow Point*	Morrow Point	0.12	173	305
Crystal*	Crystal Reservoir	0.026	31.5	143
Flaming Gorge	Flaming Gorge	3.8	151.5	390
Fontenelle	Fontenelle Reservoir	0.35	10	49

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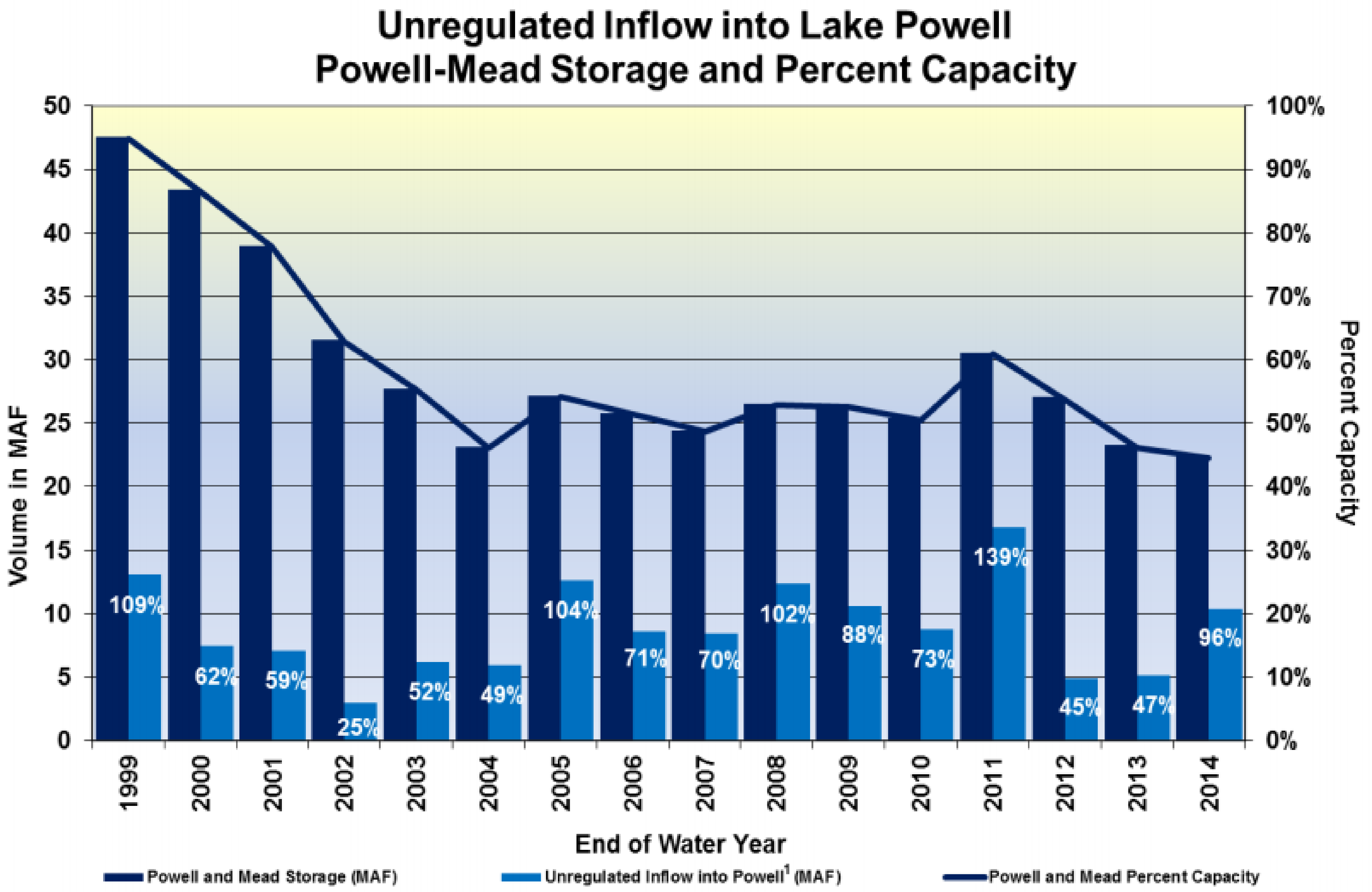
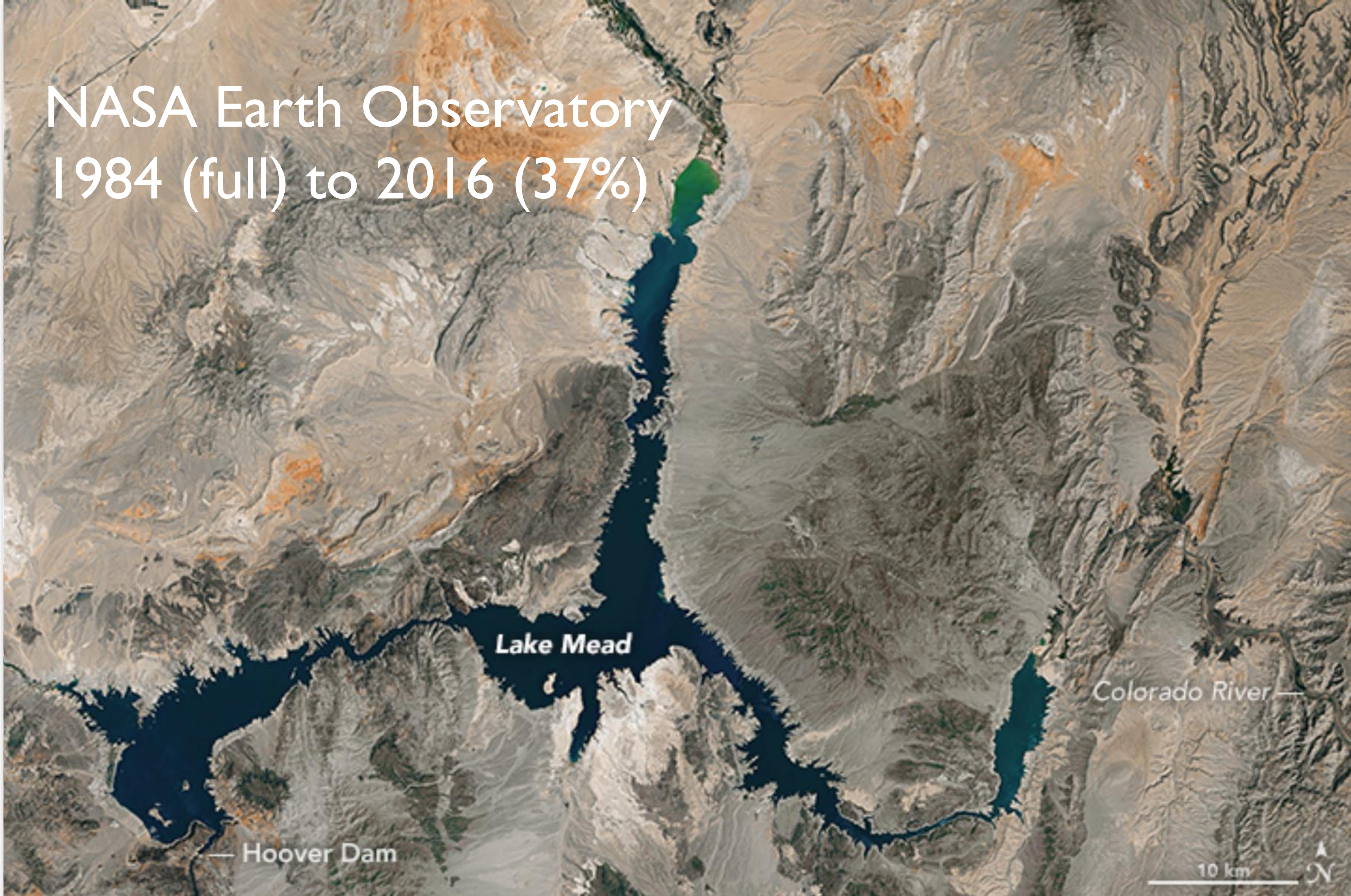
https://www.usbr.gov/uc/rm/crsp/gallery/gc-gallery/pages/pg6.html

http://www.inetours.com/Las_Vegas/Photos/Hoover-Dam-aerial.html



[1]Percentages at the top of the light blue bars represent percent of average unregulated inflow into Lake Powell for a given water year. Water years 1999-2011 are based on the 30-year average from 1971 to 2000. Water years 2012-2014 are based on the 30-year average from 1981-2010.

NASA Earth Observatory 1984 (full) to 2016 (37%)



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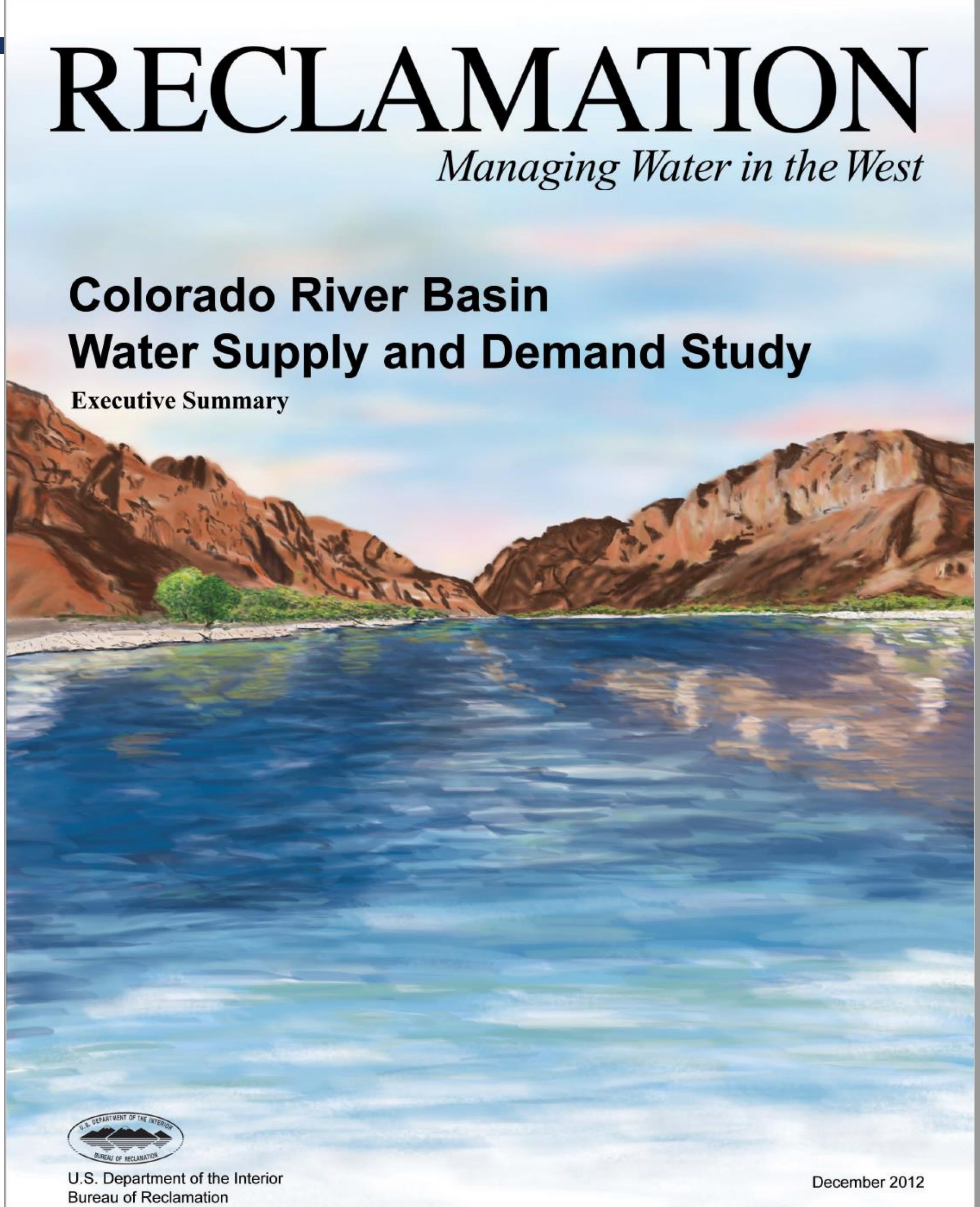

LAKE MEAD ELEVATION PREDICTIONS

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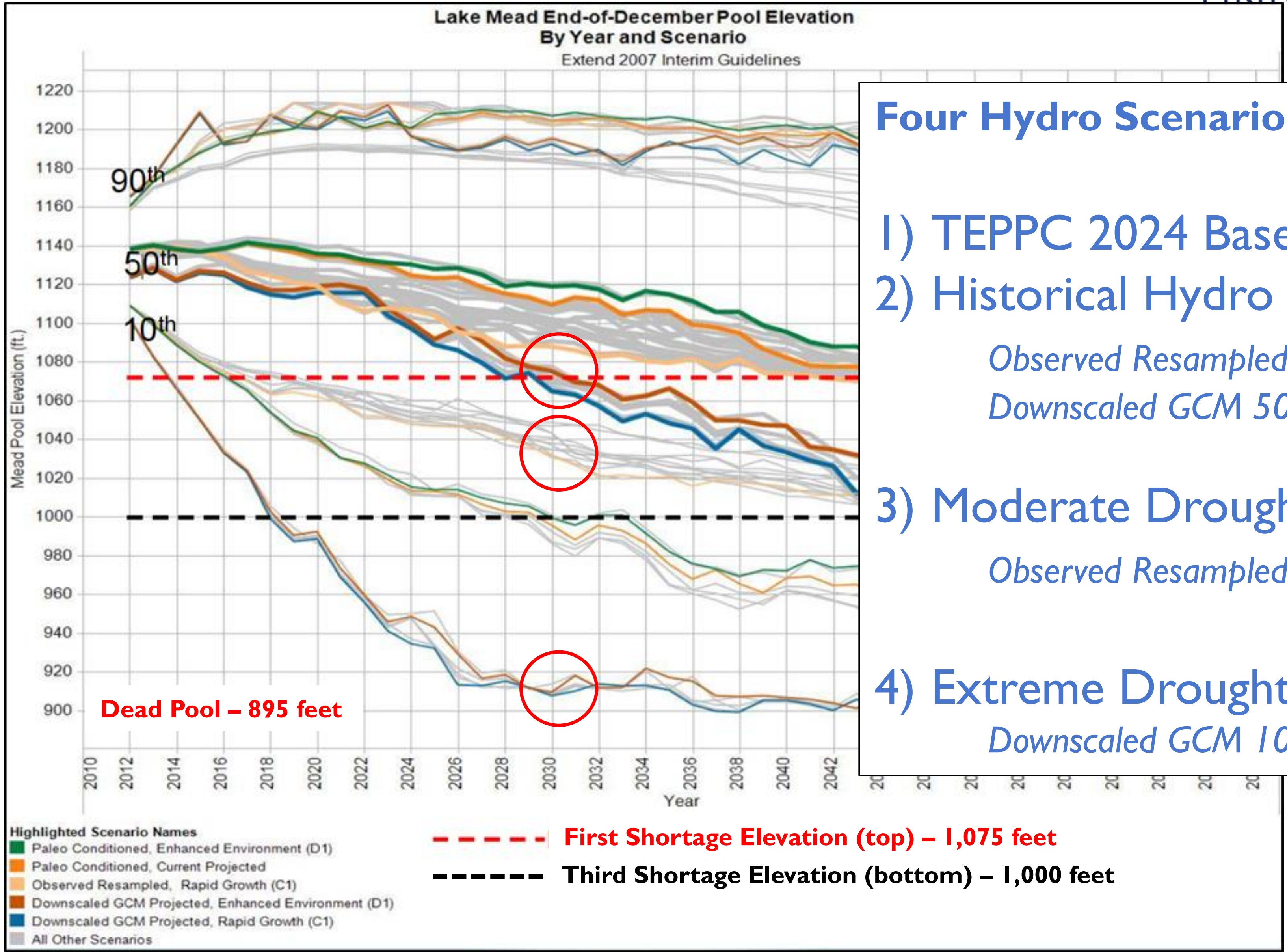

Four Hydro Scenarios Studied

1) TEPPC 2024 Base Case
2) Historical Hydro

   Observed Resampled 50% &
   Downscaled GCM 50%

3) Moderate Drought

   Observed Resampled 10%

4) Extreme Drought

   Downscaled GCM 10%

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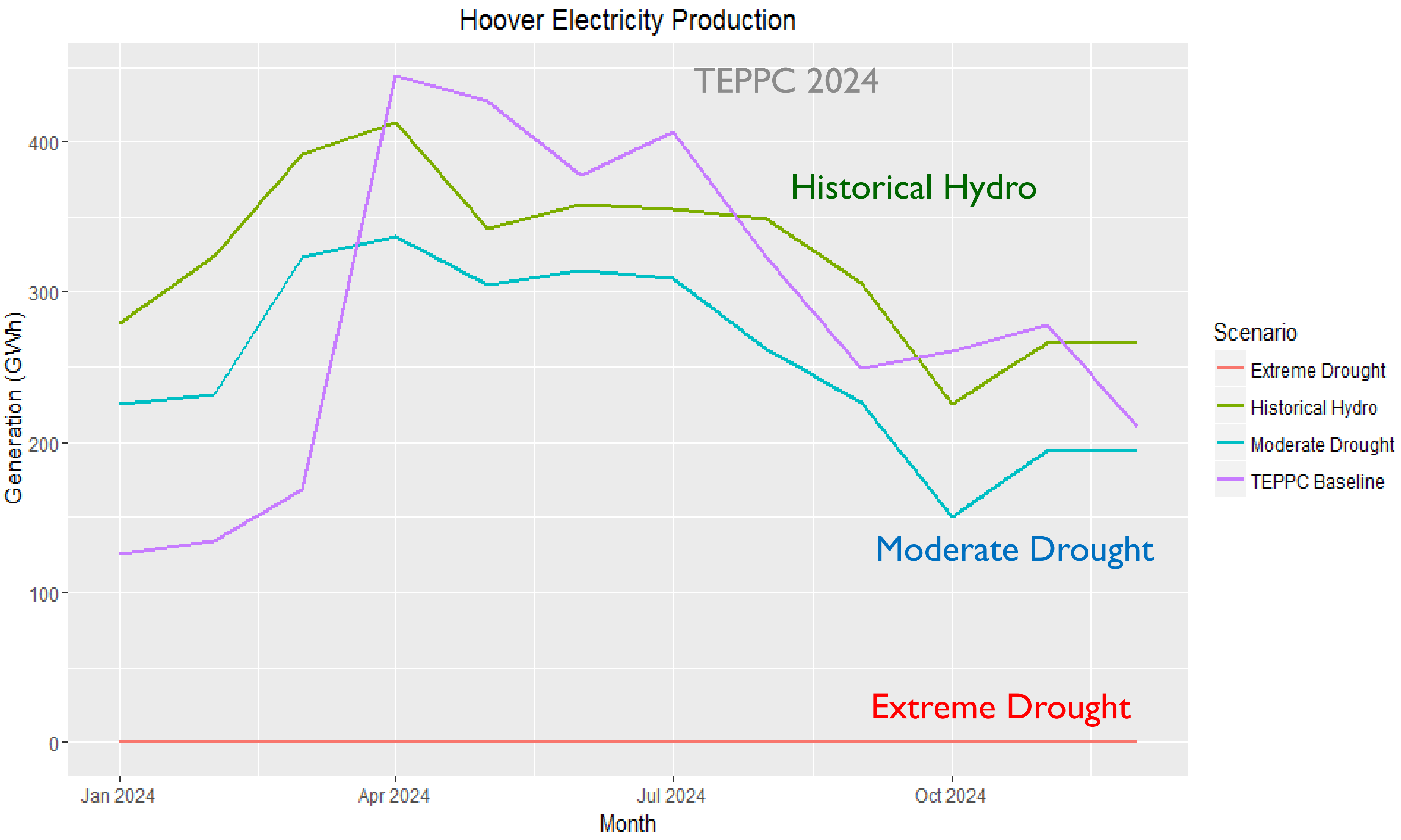
HOOVER PRODUCTION BY MONTH



NREL RESOURCE PLANNING MODEL (RPM)

- Capacity expansion model for a *regional* electric system over a utility planning horizon (10-20 years)
  - Includes hourly chronological dispatch and detailed system operation representation
  - High spatial resolution informs mid- to long-term generator (renewable and non-renewable) siting options
- This study considered three possible "glide paths" of future energy development in replacement of NGS

CAPACITY EXPANSION WITH GAS, WIND, SOLAR PV

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Scenario Basis	Transmission Point A Node: 14003_NAVAJO Page	Transmission Point B Node: 14002_MOENKOPI Cameron	Transmission Point C Node: 15011_KYRENE Phoenix	Transmission Point D Node: 16103_SOUTH Tucson	Transmission Point E Node: 16114_PINALWES
Solar	250 MW of PV	250 MW of PV	100 MW of PV	100 MW of PV	
Expanded Wind		500 MW of Wind 500 MW Of PV 250 MW of Natural Gas	100 MW of PV	100 MW of PV	1,000 MW of wind
Moenkopi		500 MW of Wind 500 MW of PV 750 MW of Natural Gas			

MODELING WITH PLEXOS

- Production Cost Model

  Inputs: generation, constraints, load, transmission system model

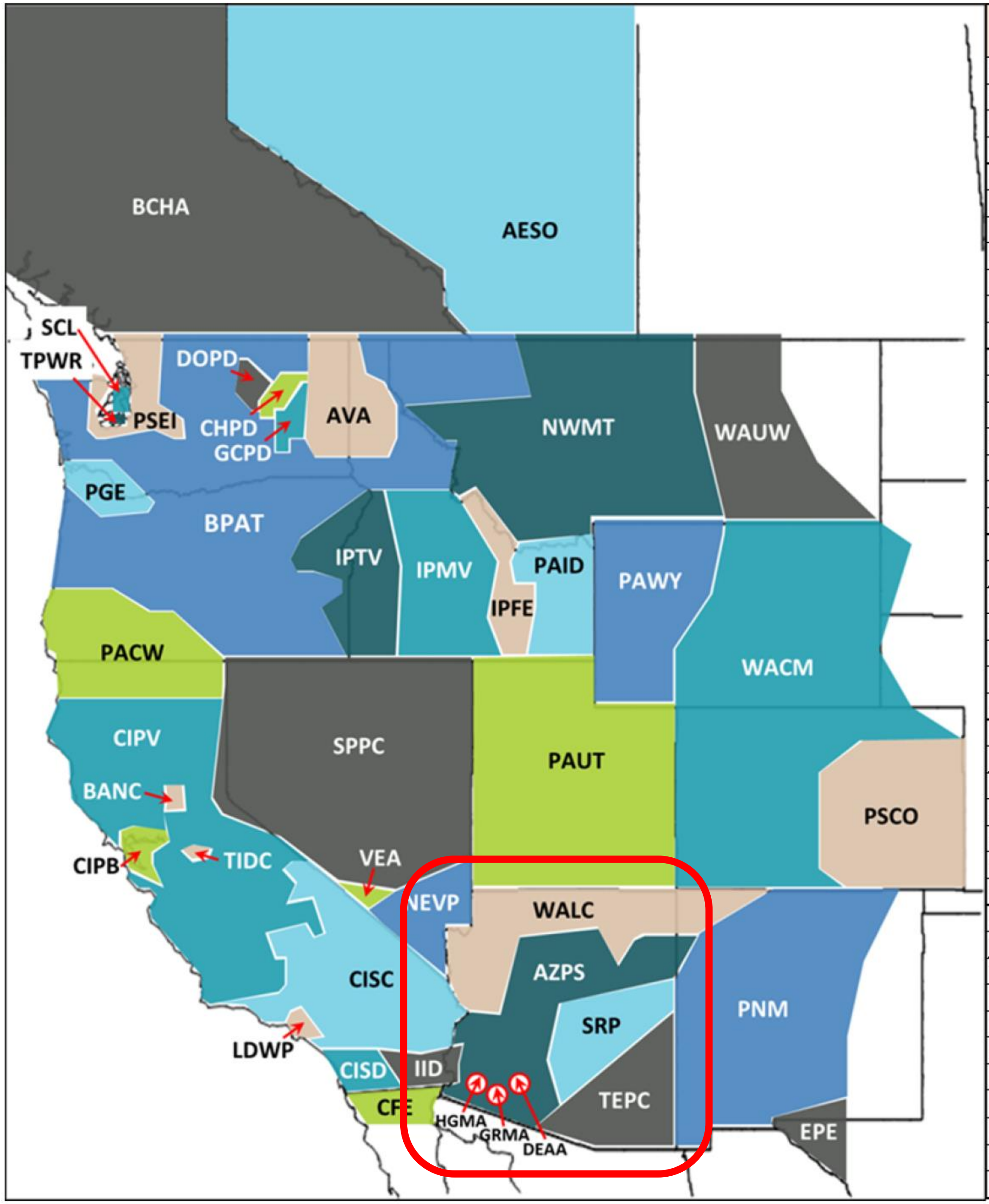
  Outputs: LMPs, total operating cost, imports, exports, dispatch stack, reserves, etc.

- Economic Dispatch of Colorado River hydro units
- Modeled all of the Western Interconnect
- High temporal and geographic resolution

  Hourly time step, Nodal in Arizona, Zonal elsewhere

- Transmission System Model

  WECC TEPPC 2024 loads, generation, transmission



TEPPC Area	Area Description
AESO	Alberta Electric System Operator
AVA	Avista
AZPS	Arizona Public Service
BANC	Sacramento Municipal District
BCHA	British Columbia Hydro
BPAT	Bonneville Power Administration
CFE	Comision Federal de Electricidad
CHPD	Chelan Co PUD
CIPB	Pacific Gas & Electric Bay Area
CIPV	Pacific Gas & Electric Valley Area
CISC	Southern California Edison
CISD	San Diego Gas & Electric
DOPD	Douglas Co PUD
EPE	El Paso Electric
GCPD	Grant Co PUD
IID	Imperial Irrigation District
IPFE	Far East (Idaho Power)
IPMV	Magic Valley (Idaho Power)
IPTV	Treasure Valley (Idaho Power)
LDWP	Los Angeles Dept of Water & Power
NEVP	Nevada Power
NWMT	Northwestern Montana
PACW	PacifiCorp West
PAID	PacifiCorp East – Idaho
PAUT	PacifiCorp East – Utah
PAWY	PacifiCorp East - Wyoming
PGE	Portland Gen Electric
PNM	Public Service New Mexico
PSCO	Public Service Colorado (Xcel)
PSEI	Puget Sound Energy
SCL	Seattle City Light
SPPC	Sierra Pacific Power
SRP	Salt River Project
TEPC	Tucson Electric Power
TIDC	Turlock Irrigation District
TPWR	Tacoma Power
VEA	Valley Electric Association
WACM	Western Area Power Admin Colorado/Missouri
WALC	Western Area Power Admin Lower Colorado
WAUW	Western Area Power Admin Upper Missouri
N/A	DECA, LLC - Arlington Valley (DEAA)
N/A	Gila River Maricopa Arizona (GRMA)
N/A	Harquahala L.L.C. (HGMA)

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DROUGHT RELATED RESULTS

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Scenario	WECC Total Generation Cost ($Billions)	Percent Change Compared to TEPPC
TEPPC	22.24	
Moderate Drought	22.25	+0.04 %
Extreme Drought	22.53	+1.30 %

- Unserved energy: no impact
- Coal capacity factors increase in AZ BA
- Price duration curves show small changes due to drought

LOCATIONAL MARGINAL PRICES

Water Scenario	Mean ($/MWh)	% diff mean compared to TEPPC
TEPPC Base Case	33.24	
Moderate Drought	33.32	0.24%
Extreme Drought	33.93	2.08%

Value of lost hydro in Moderate and Extreme drought cases (i.e. cost to replace each MWh of hydro):

~ $76/MWh

GLIDE PATHS – TOTAL GENERATION COST

Scenario	Total Generation Cost ($Billions)	Percent Difference Compared to TEPPC no drought
TEPPC, no drought	22.37	0
TEPCC, extreme drought	22.66	1.30
Solar, no drought	22.32	-0.22
Solar, extreme drought	22.60	1.03
Moenkopi, no drought	22.30	-0.31
Moenkopi, extreme drought	22.58	0.94
Wind, no drought	22.15	-0.98
Wind, extreme drought	22.43	0.27

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CONCLUSIONS

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- Extreme drought could increase cost of producing electricity by 1.3% to 2.0%
- In absence of other changes, NGS retirement and extreme drought tends to promote greater reliance on Arizona's remaining coal fleet
- All three glide path models tested have some ability to mitigate the effect of extreme drought
- A conservative estimate of the value of the lost hydropower was estimated at $76/MWh, over twice value of the average LMP

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THANK YOU

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EXTRA SLIDES

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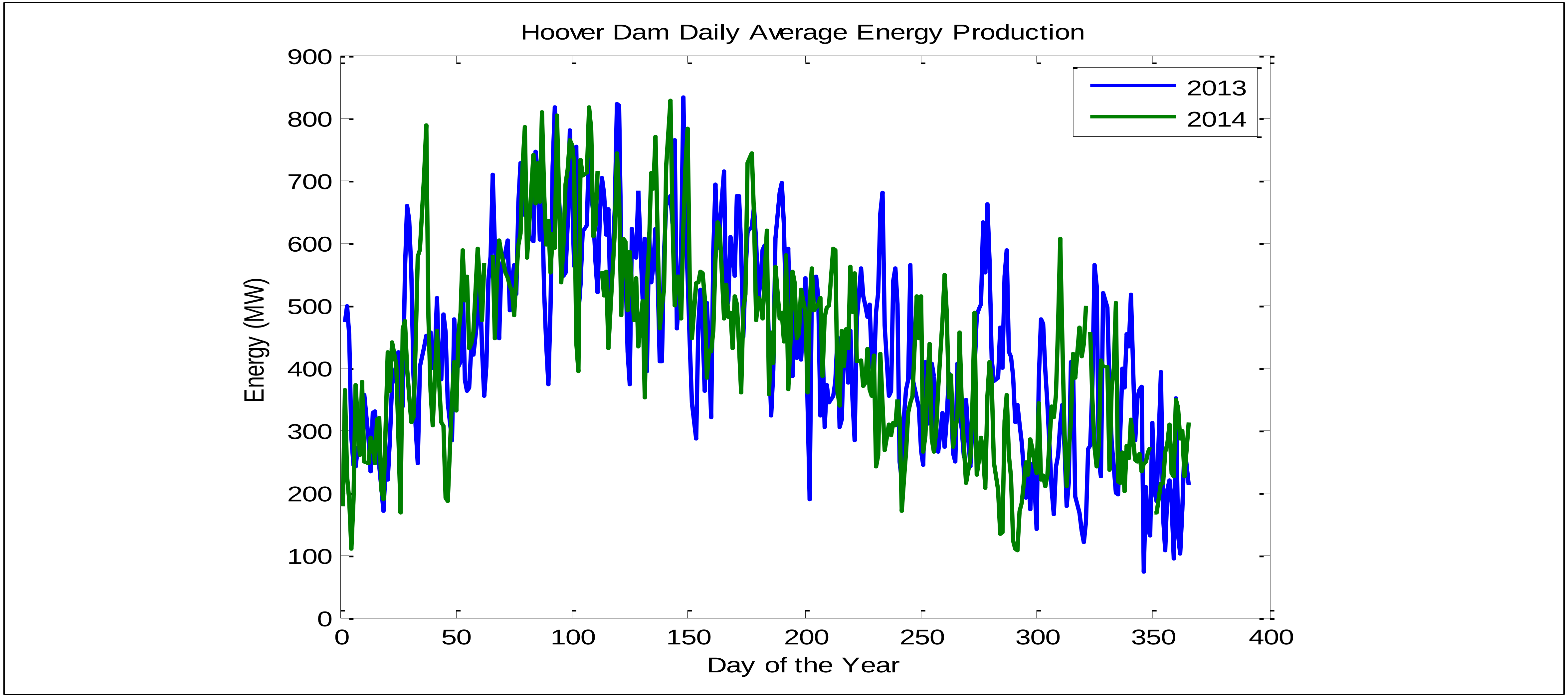
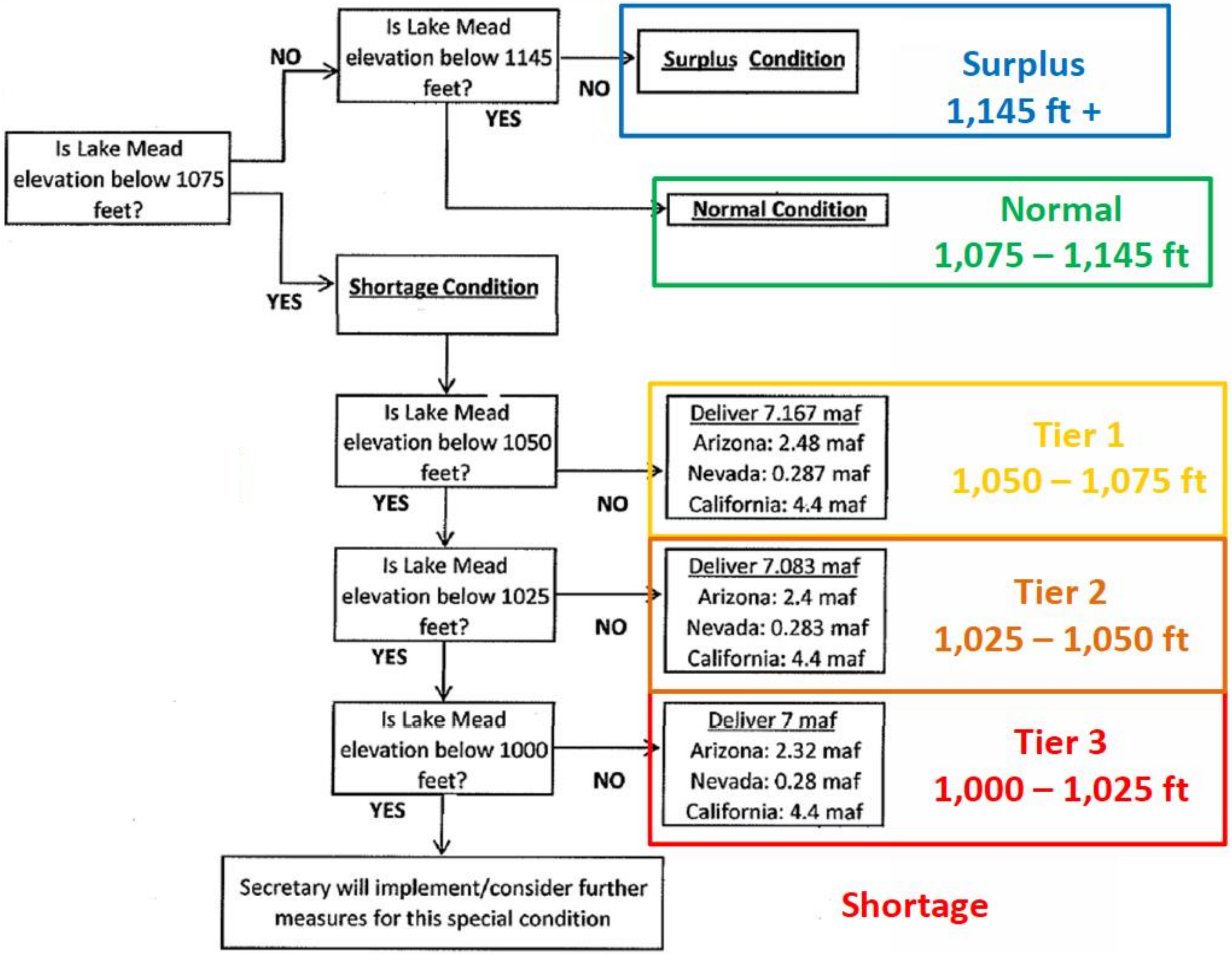
TABLE OF DAMS

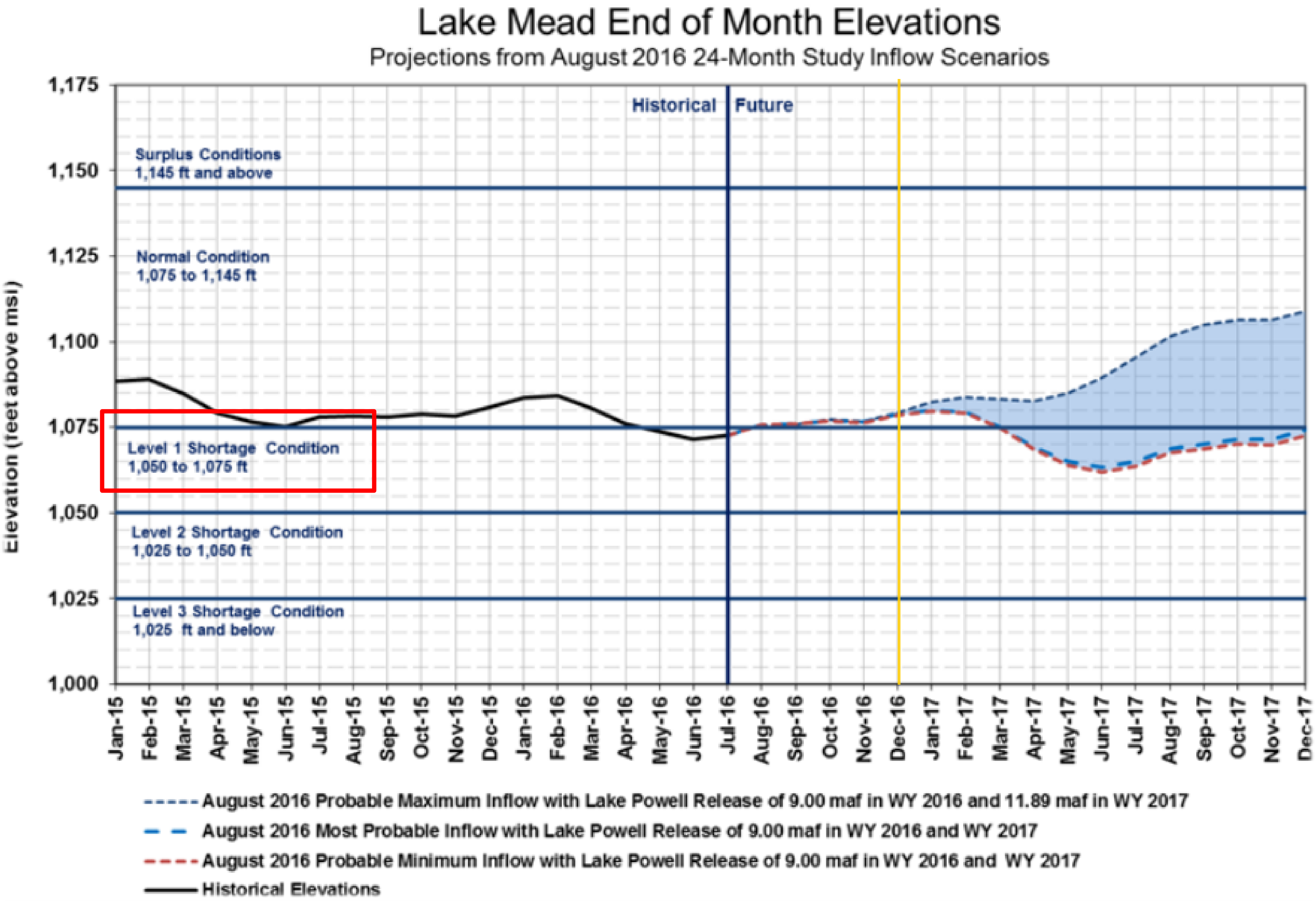
Dam	Reservoir Name	Region	State	Water Storage (acre-feet)	Installed Capacity (MW)	10 year rolling average (GWh)
Hoover	Lake Mead	Lower	Arizona/ Nevada	28,945,000 at 1221.4	2,078	3,741
Glen Canyon	Lake Powell	Upper	Arizona	27,000,000 at 3700	1,320	3,805
Davis	Lake Mohave	Lower	Arizona/ Nevada	1,800,000 at 647	255	1,116
Morrow Point*	Morrow Point	Upper	Colorado	117,190 at 7160	173	305
Blue Mesa*	Blue Mesa	Upper	Colorado	940,700 at 7519	86.4	233
Parker	Lake Havasu	Lower	Arizona/ California	646,200 at 450	120	444
Crystal*	Crystal Reservoir	Upper	Colorado	26,000 at 6755	31.5	143
Flaming Gorge	Flaming Gorge	Upper	Utah	3,788,700 at 6,040	151.5	390
Fontenelle	Fontenelle Reservoir	Upper	Wyoming	345,360 at 6513	10	49

HISTORICAL OPERATIONS FOR HOOVER

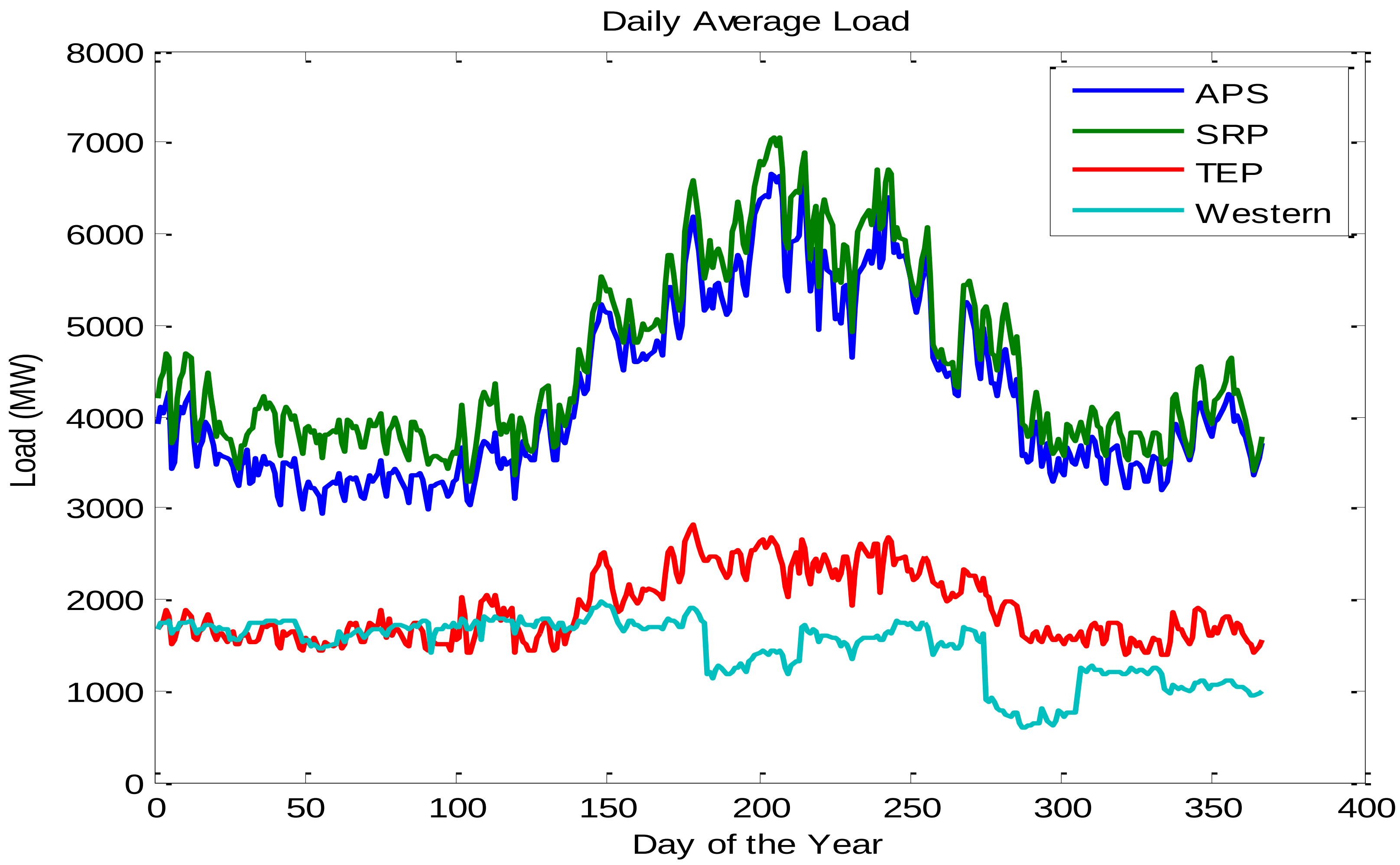




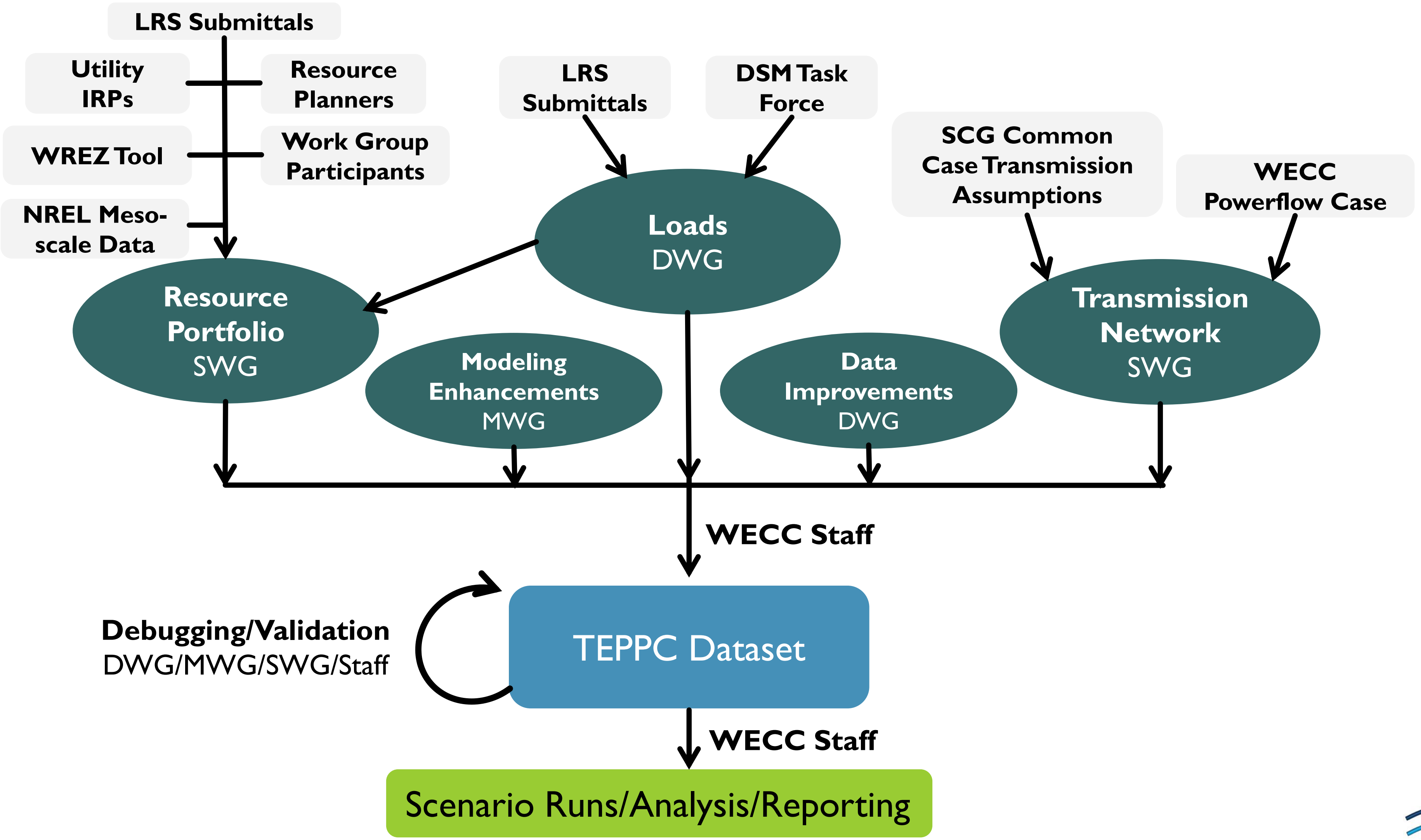
Is Lake Mead elevation below 1075 feet?
NO
Is Lake Mead elevation below 1145 feet?
NO
Surplus Condition
Surplus
1,145 ft +
YES
Normal Condition
Normal
1,075 – 1,145 ft
YES
Shortage Condition
Is Lake Mead elevation below 1050 feet?
NO
Deliver 7.167 maf
Arizona: 2.48 maf
Nevada: 0.287 maf
California: 4.4 maf
Tier 1
1,050 – 1,075 ft
YES
Is Lake Mead elevation below 1025 feet?
NO
Deliver 7.083 maf
Arizona: 2.4 maf
Nevada: 0.283 maf
California: 4.4 maf
Tier 2
1,025 – 1,050 ft
YES
Is Lake Mead elevation below 1000 feet?
NO
Deliver 7 maf
Arizona: 2.32 maf
Nevada: 0.28 maf
California: 4.4 maf
Tier 3
1,000 – 1,025 ft
YES
Secretary will implement/consider further measures for this special condition
Shortage


Lake Mead End of Month Elevations
Projections from August 2016 24-Month Study Inflow Scenarios
Elevation (feet above msl)
1,175
1,150
1,125
1,100
1,075
1,050
1,025
1,000
Historical
Future
Surplus Conditions
1,145 ft and above
Normal Condition
1,075 to 1,145 ft
Level 1 Shortage Condition
1,050 to 1,075 ft
Level 2 Shortage Condition
1,025 to 1,050 ft
Level 3 Shortage Condition
1,025 ft and below
Jan-15 Feb-15 Mar-15 Apr-15 May-15 Jun-15 Jul-15 Aug-15 Sep-15 Oct-15 Nov-15 Dec-15 Jan-16 Feb-16 Mar-16 Apr-16 May-16 Jun-16 Jul-16 Aug-16 Sep-16 Oct-16 Nov-16 Dec-16 Jan-17 Feb-17 Mar-17 Apr-17 May-17 Jun-17 Jul-17 Aug-17 Sep-17 Oct-17 Nov-17 Dec-17
August 2016 Probable Maximum Inflow with Lake Powell Release of 9.00 maf in WY 2016 and 11.89 maf in WY 2017
August 2016 Most Probable Inflow with Lake Powell Release of 9.00 maf in WY 2016 and WY 2017
August 2016 Probable Minimum Inflow with Lake Powell Release of 9.00 maf in WY 2016 and WY 2017
Historical Elevations

LOAD FOR AZ BA'S

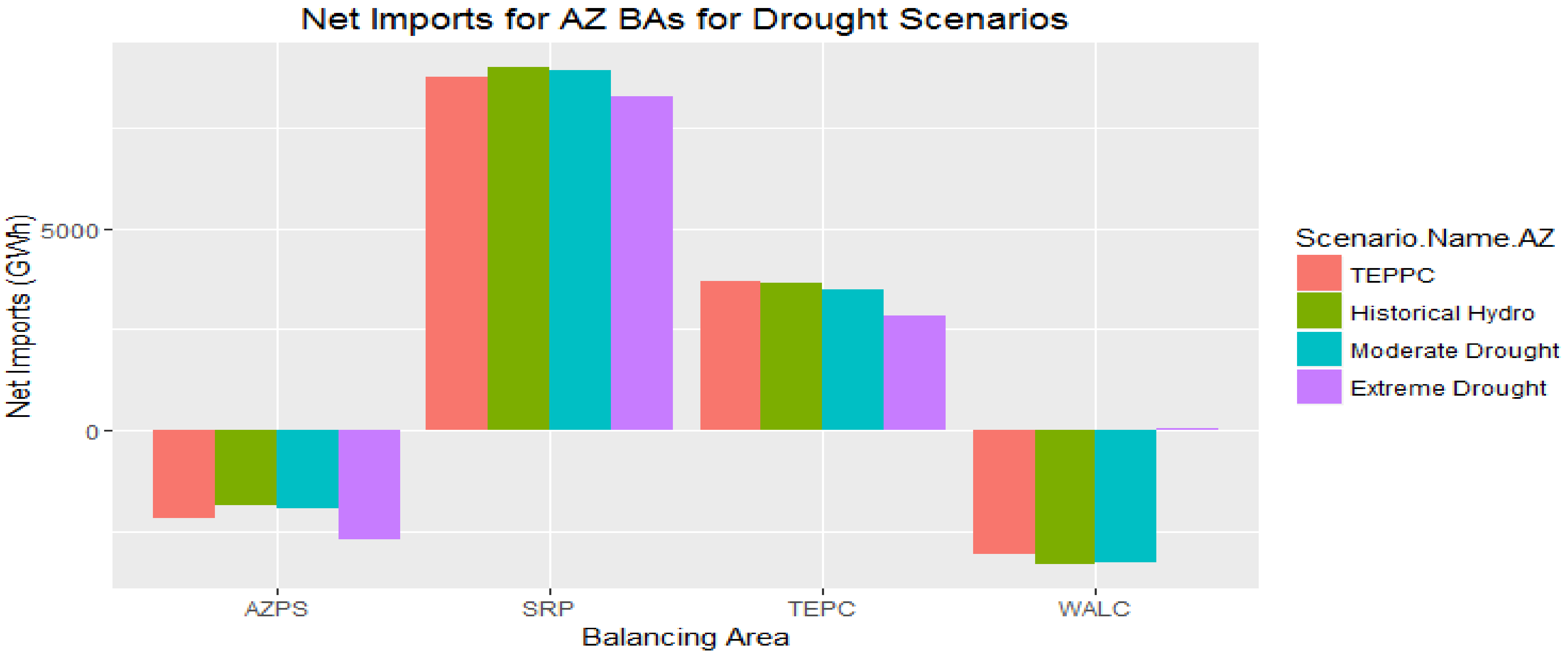


WECC DATASET BUILDING

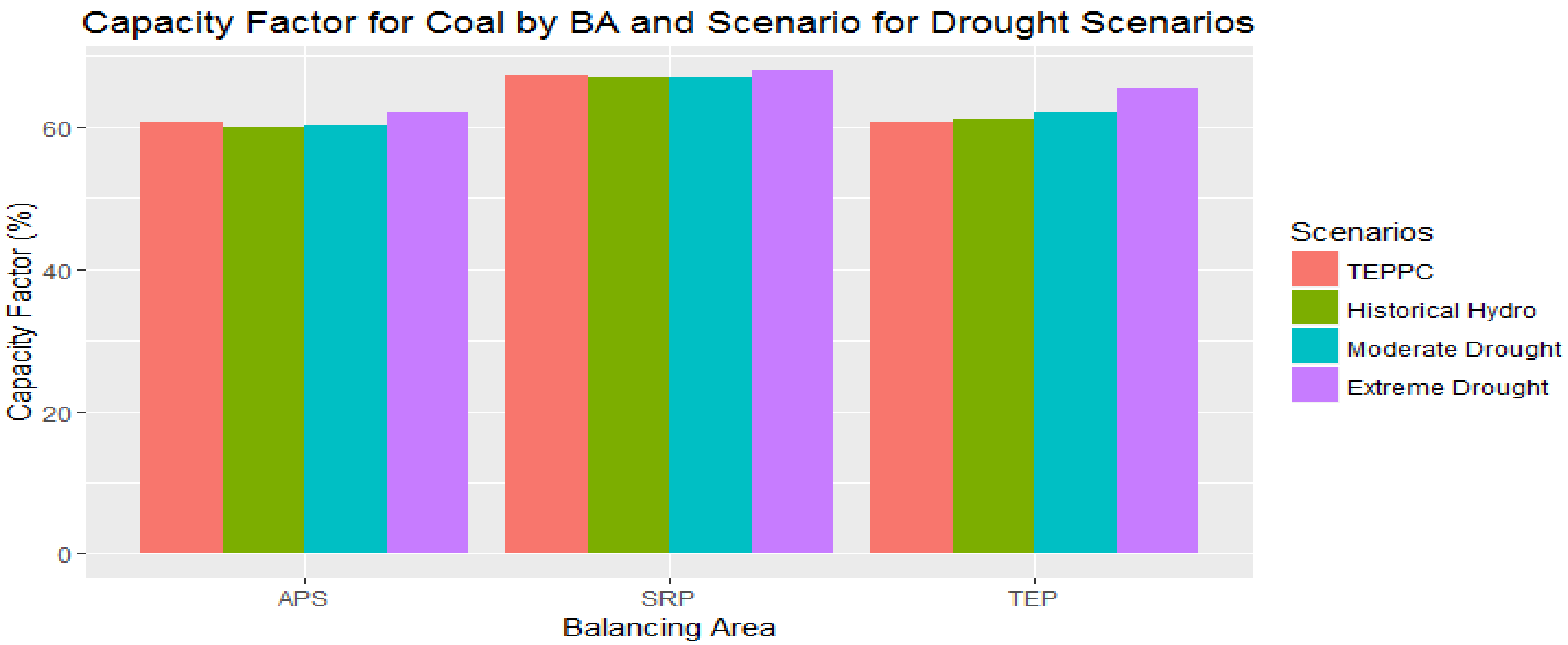


Source: Dan Beckstead, WECC

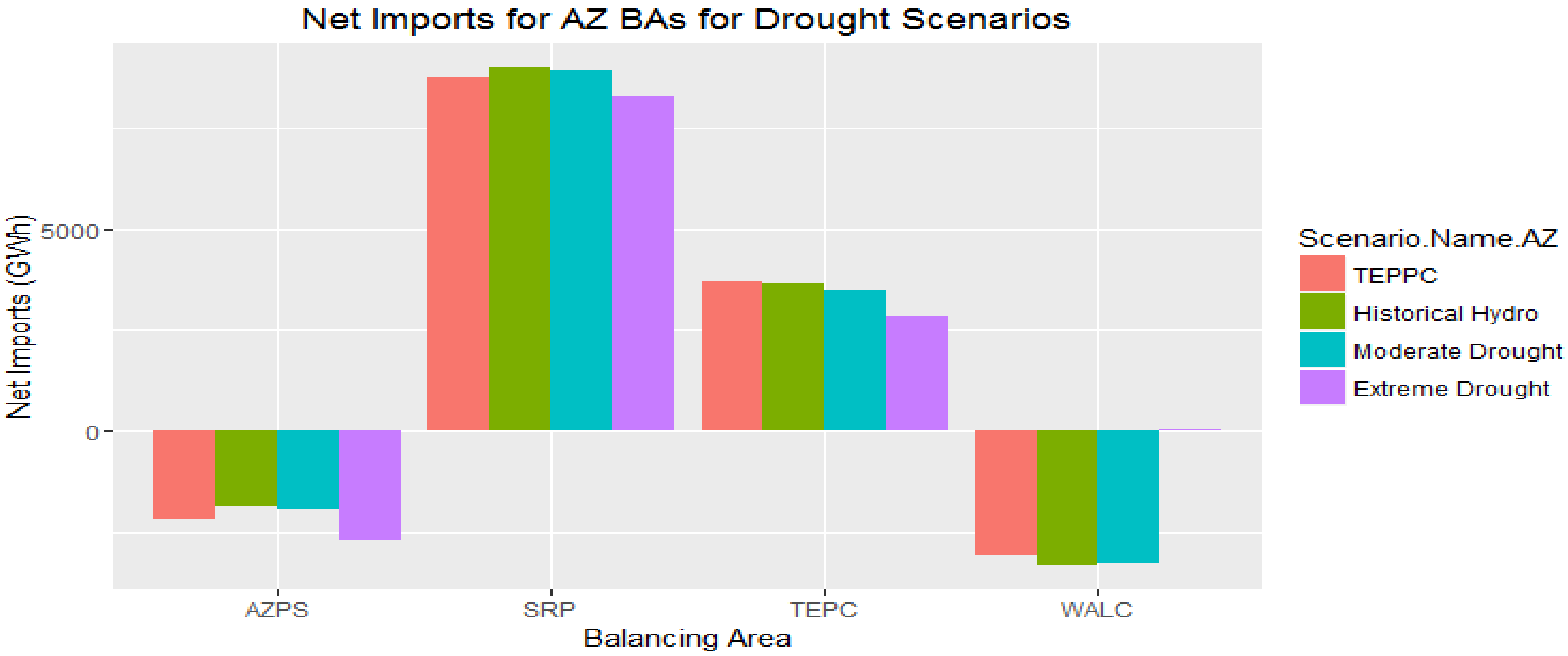
BASELINE – NET IMPORTS



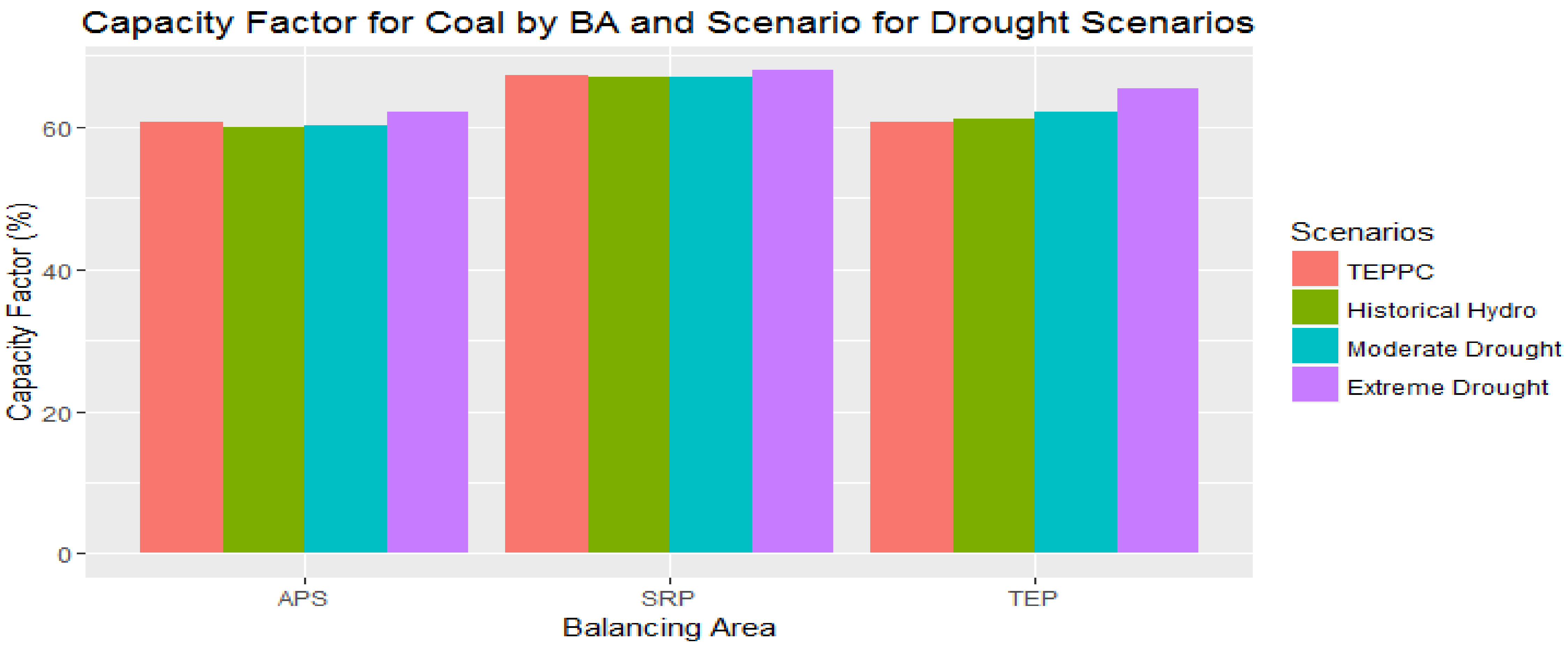
BASELINE- CAPACITY FACTOR



BASELINE – NET IMPORTS



BASELINE- CAPACITY FACTOR



NGS FUTURES – TOTAL GENERATION COST

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Scenario	Total Generation Cost ($Billions)	Percent Difference Compared to Accelerated, no drought
Central, no drought	22.24	-0.58
Central, extreme drought	22.53	0.72
Accelerated, no drought	22.37	0.00
Accelerated, extreme drought	22.66	1.30
Accelerated, high gas, no drought	25.61	14.48
Accelerated, high gas, extreme drought	25.95	16.0

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NGS FUTURES – PRICE DURATION CURVE

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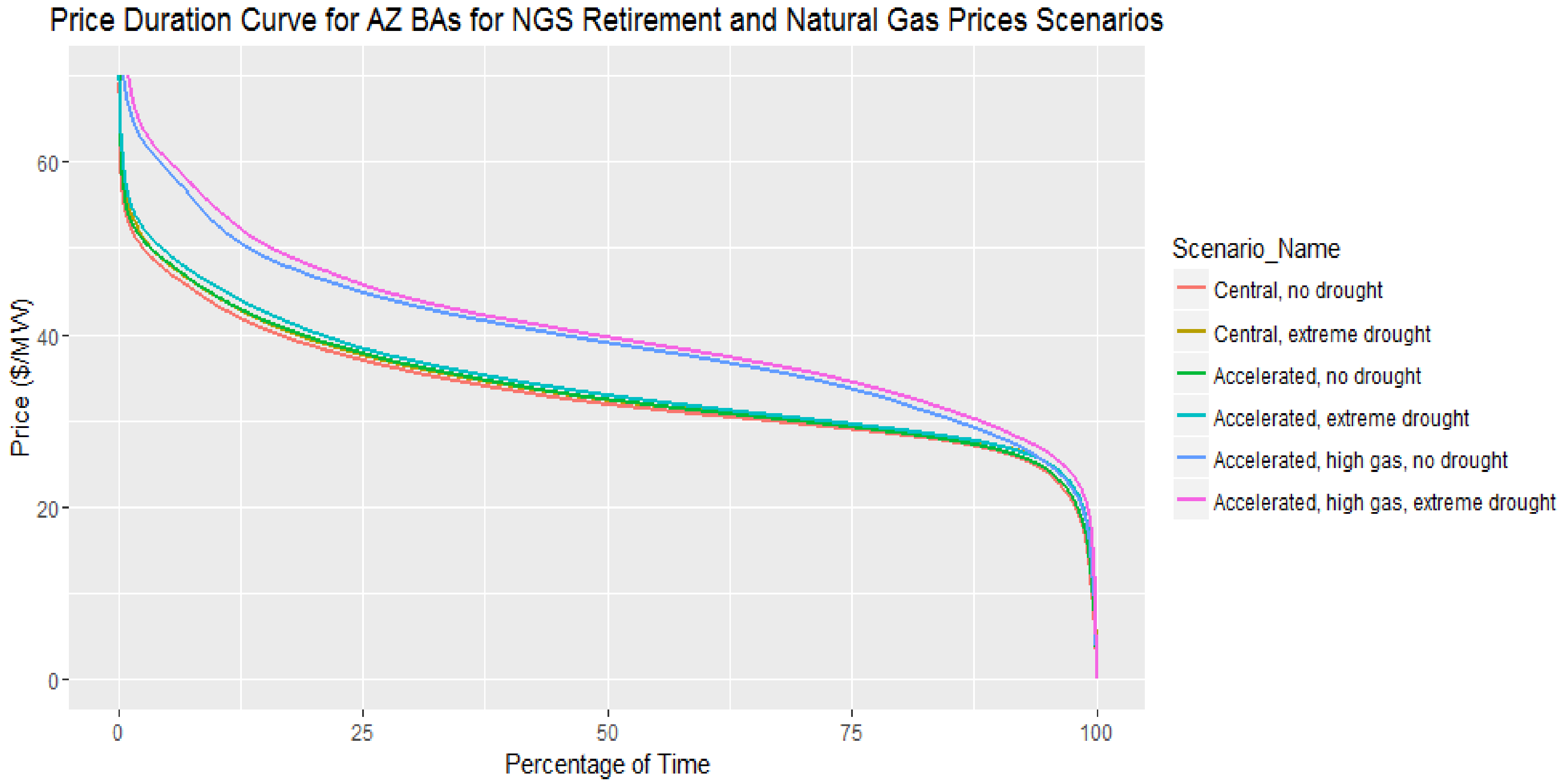

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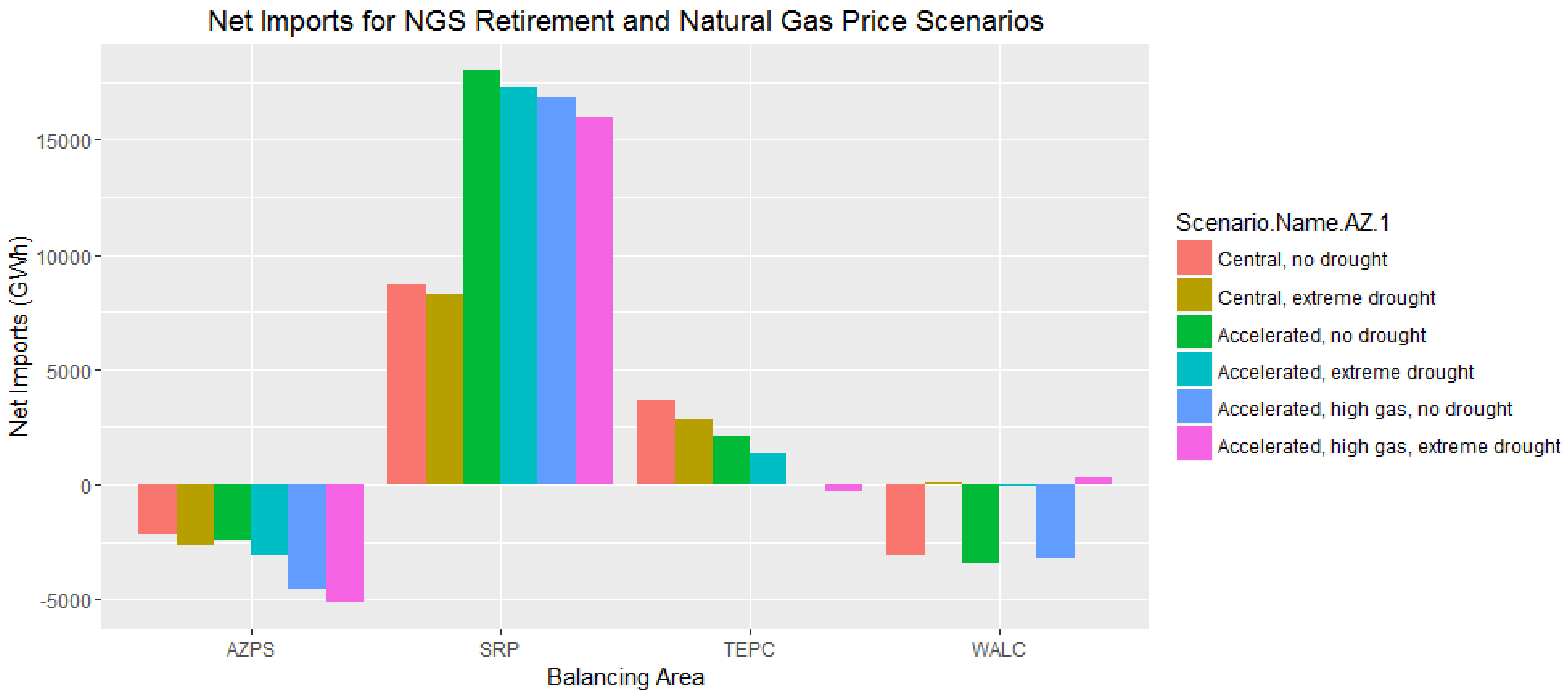
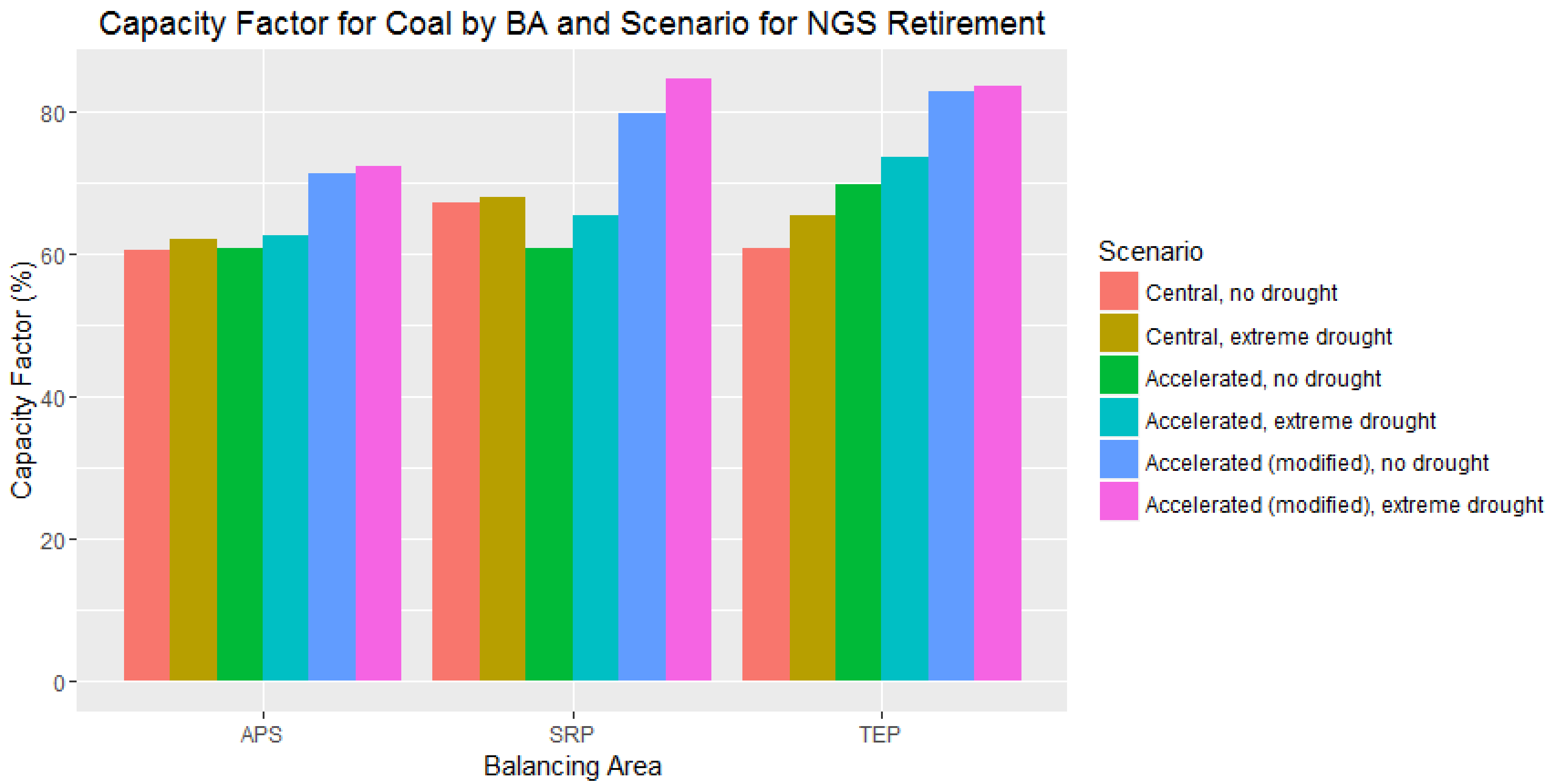
NGS FUTURES – NET IMPORTS



NGS FUTURES – COAL CF



GLIDE PATHS – CAPACITY FACTORS

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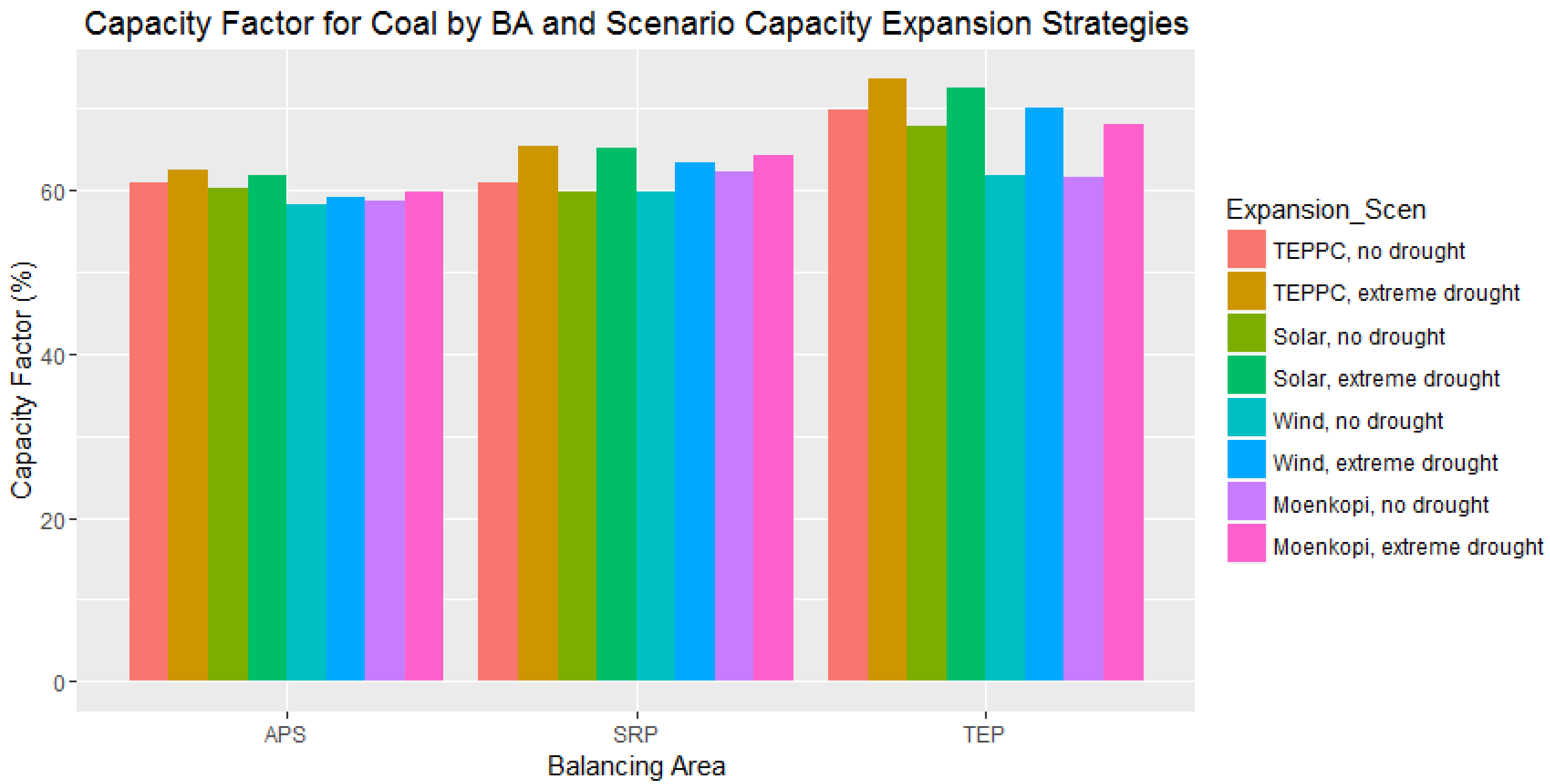
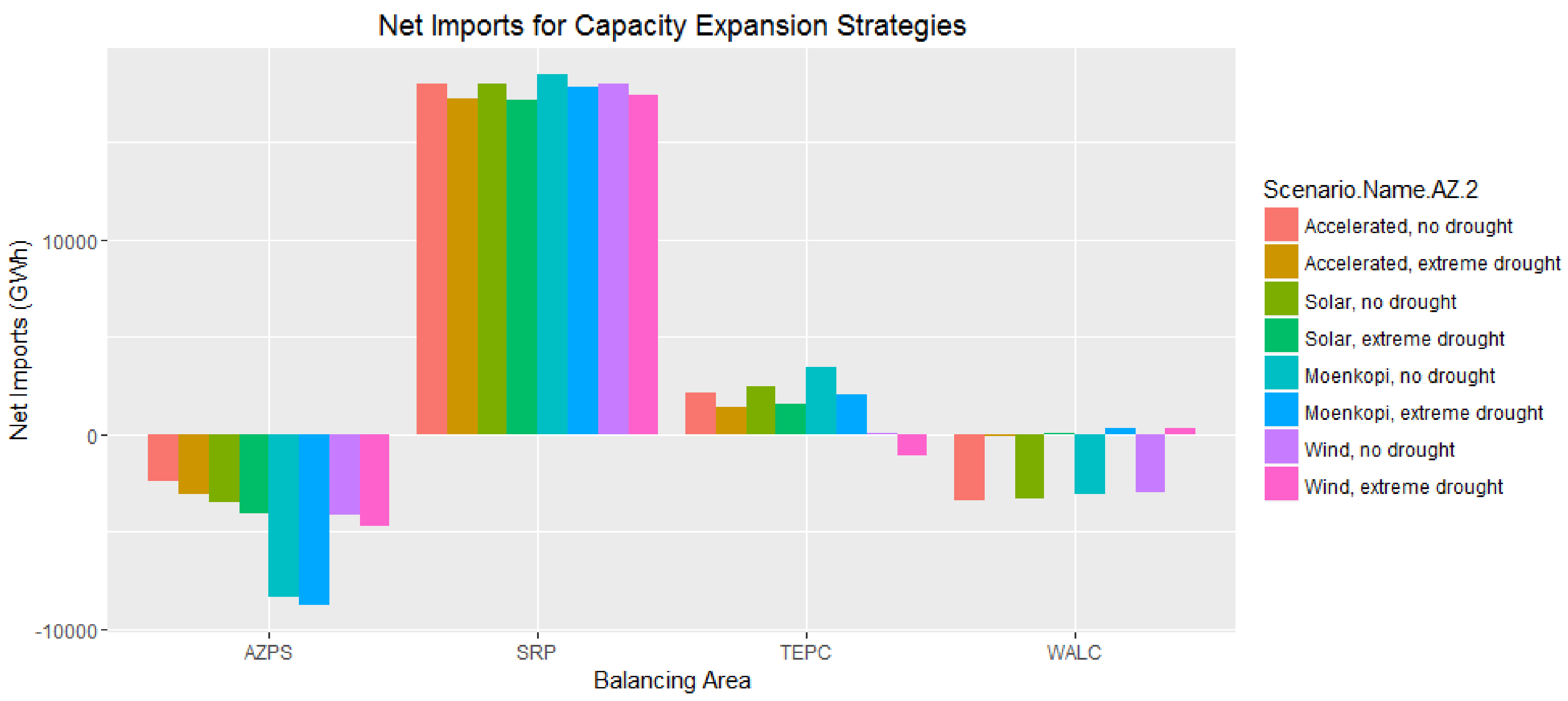


GLIDE PATHS – NET IMPORTS



https://www.britannica.com/place/La
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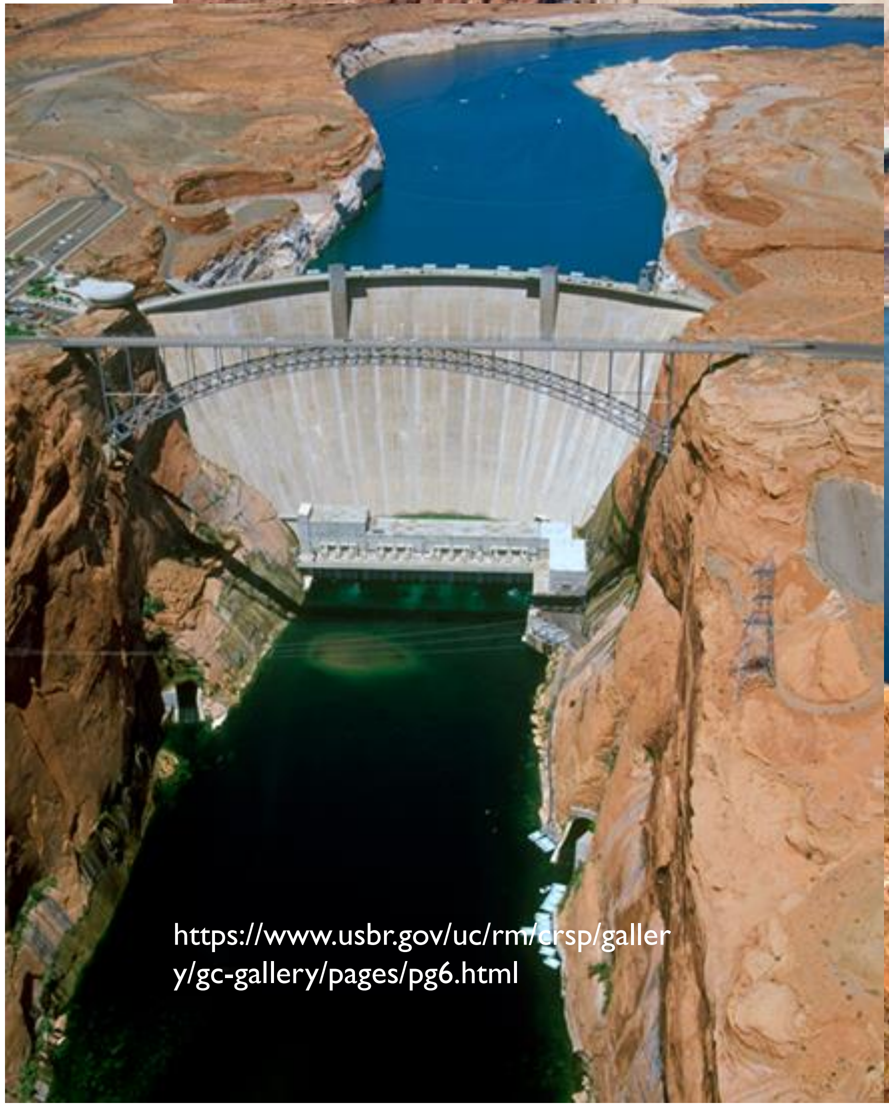

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