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Impacts of Long-term Drought on Power Systems in the U.S. Southwest

Prepared for:

U.S. Department of Energy
Office of Electric Delivery and Energy Reliability

Infrastructure Security and Energy Restoration Division

U.S. DEPARTMENT OF
ENERGY

Outline of Presentation

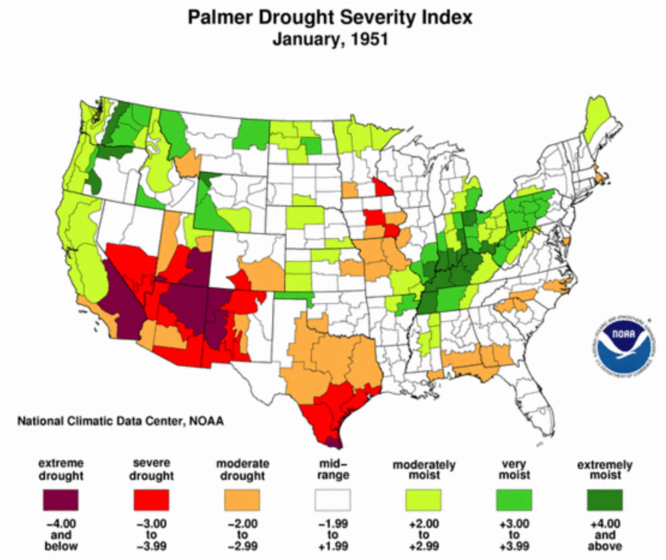
1. Background, Objectives, and Assumptions
2. Methodology and Data
3. Analysis and Results

Study Background

- **DOE-OE has a responsibility to promote a resilient energy infrastructure in which continuity of business and services are maintained through secure and reliable information sharing, coordinated response capabilities, and trusted relationships between public and private partners at all levels of industry and government.**

- **This analysis is intended to provide an opportunity for utilities to receive information from subject matter experts in industry and government.**

- **Argonne was engaged by DOE-OE in May 2012 to develop a drought scenario to elicit discussion with sector partners.**



Palmer Drought Severity Index
January, 1951

National Climatic Data Center, NOAA

Purposes of the Study

- **Develop a hypothetical but plausible drought scenario involving the U.S. Southwest**
- **Assess the impacts of the drought scenario on the power systems comprising the U.S. Southwest:**
    - supply-demand balance
    - thermal and hydro capacity losses
    - reserve margin reductions
    - overall system reliability and vulnerability
- **Analysis results presented at two levels: *Regional* and *Per-State***
- **Analysis is high-level and is more of a screening analysis representing a first-cut attempt based on limited time**
- **Provide pertinent drought and power–related information for educational purposes**

General Impacts of Drought and High Temperatures on Power Systems

- **Reductions in Power Generation and Transmission:**
  - Thermo-electric plants:
    - * Use surface water for cooling, fuel processing, and emission control
    - * Low water level limits the amount of water that can be withdrawn (Min water elevation limits)
    - * Intake structures could be exposed (above water level)
    - * Higher water temperature at intake may lead to violation of water discharge regulations
    - * High temperatures lowers plant heat rate (efficiency)
  - Hydro-electric plants:
    - * Lower inflows means low power output (run-of-river)
    - * Lower reservoir levels mean less water available for power generation and degraded water-to energy conversion factors
  - Gas-fired plants:
    - * High ambient temperatures limit cooling ability of air-cooled systems
    - * High temperatures decrease efficiency and capacity
  - Photovoltaic Cells:
    - * High temperatures reduce efficiency and outputs of PV units
  - Transmission lines:
    - * High temperatures lower the thermal limits of transmission lines and circuit breakers
    - * High temperatures increase transmission loss and operational cost
    - * High ambient temperatures lower throughputs of transformers

- **Increased Production Cost of Electric Power and Increased Emissions:**
  - Purchased power from spot market tend to cost more
  - More expensive natural gas is used as less-efficient gas turbine output is increased
  - Output from low-risk thermal plants is increased leading to elevated CO_2 emissions

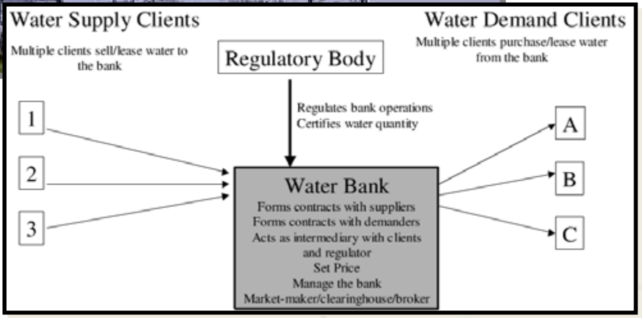
General Impacts of Drought and High Temperatures on Power Systems (Contd.)

- **System reliability:**
  - High deterioration rates of system components
  - Lower reserve margins
  - Increased susceptibility to faults and cascading failures
  - High probability of longer and more wide-spread blackouts

- **Recent examples of reduced power production from drought:**
  - *Southeast U.S. in 2007* – nuclear and coal-fired plants in TVA system were forced to shutdown or curtail operations. Intake water exceeded 90 F for 24 hours.
  - *Mississippi River in 2006* – affected nuclear plants in Illinois and Minnesota. Drought and heat wave warmed intake water.
  - *France in 2003* – loss of 7% to 15% of nuclear capacity for 5 weeks; loss of 20% of hydro generation capacity.

General Response Strategies Pertaining to Drought

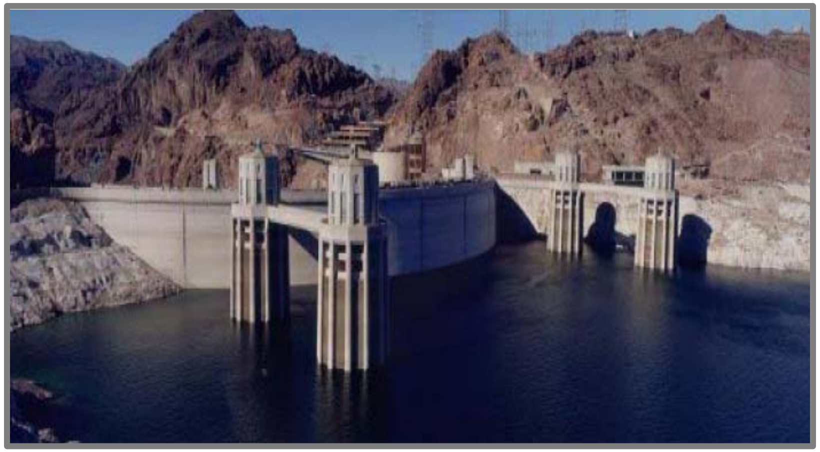
- **Electric Supply Alternatives**
  - Spot market Purchases
  - Option or Firm Purchases
  - Power Exchanges (“credit line”)
  - Subject to transmission constraints
- **Electricity Demand Response**
  - Interruptible-load Contracts
  - Demand Exchange or Management
  - Energy Efficiency and Conservation
- **Alternative Water Supplies**
  - Water Banks
  - Water Supply Contracts
  - Groundwater Wells
  - Processed waste water for cooling
- **Water Demand Response**
  - Education and Conservation Campaigns
  - Water Use Restrictions
  - Rate Surcharges



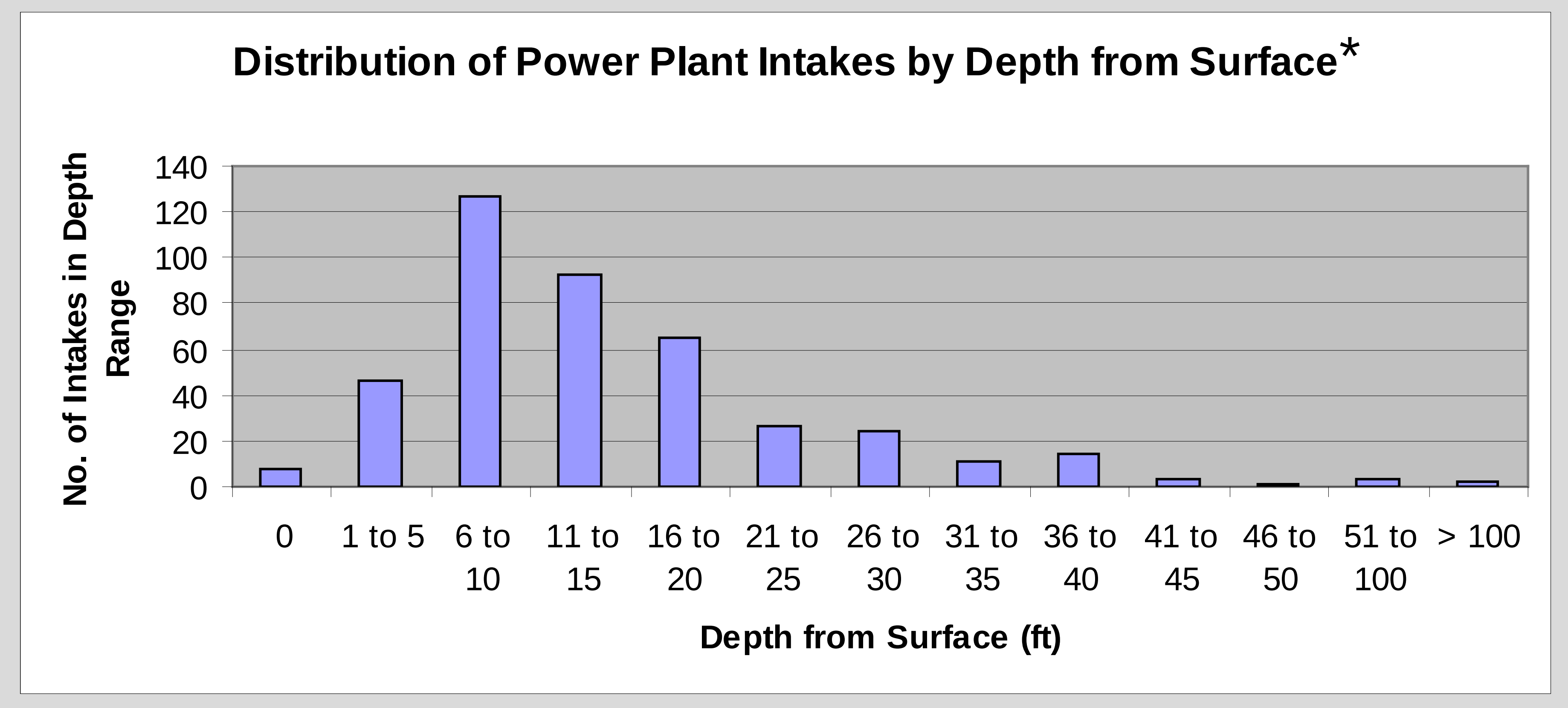
SOURCE: *Harto, C.B and E. Yan, “Analysis of Drought Impacts on Electricity Production in the Western and Texas Interconnection”, Environmental Science Division, Argonne National Laboratory, Dec 2011*

Reservoir Management as a Strategic Response

- **Reservoirs allow for storage of water which is crucial for managing impacts of drought. Reservoirs permit the controlled release of water to maximize benefits.**
- **Reservoirs are traditionally managed through heuristic regulation policies based on historical system response.**
- **Reservoir operation faces many constraints including:**
  - Minimum flow requirements
  - Limits on ramp rates
  - Environmental consideration such as fish life and support of ecosystems
  - Irrigation and domestic water use
  - Industrial use and plant cooling
  - Recreational and navigational use
- **At times, power generation is lowest priority; environmental is top priority.**
- **Computer models are employed to optimally manage reservoirs to maximize usage and minimize risk.**

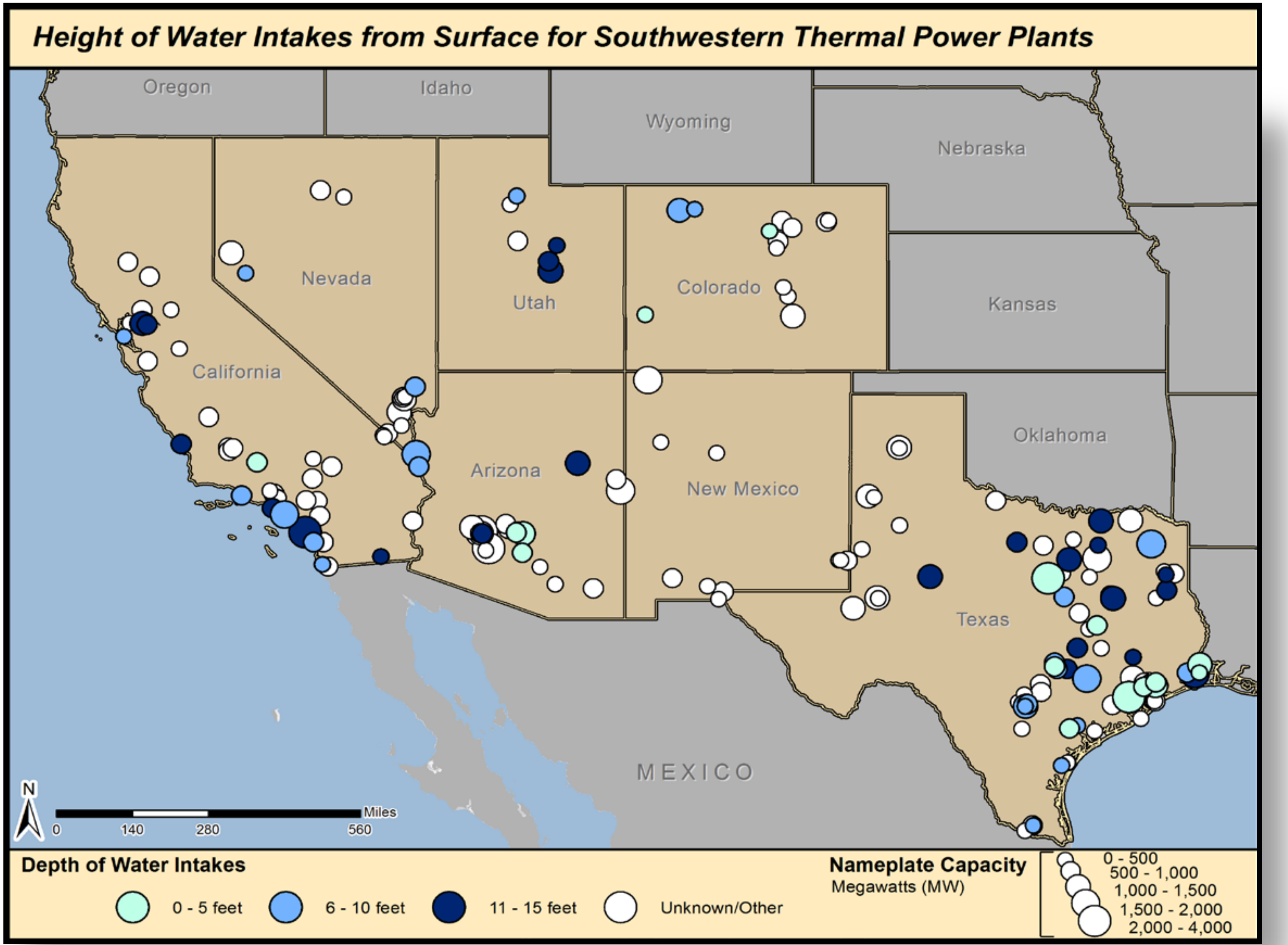


Depth of Intake Below Surface of Power Plants in the U.S.



** SOURCE: Kimmel, T. and J. Veil, "Impact of Drought on U.S. Steam Electric Power Plant Cooling Water Intakes and Related Water Resource Management Issues" Argonne National Laboratory, April 2009.*

Location of Thermal Plants with Depth of Intake Information

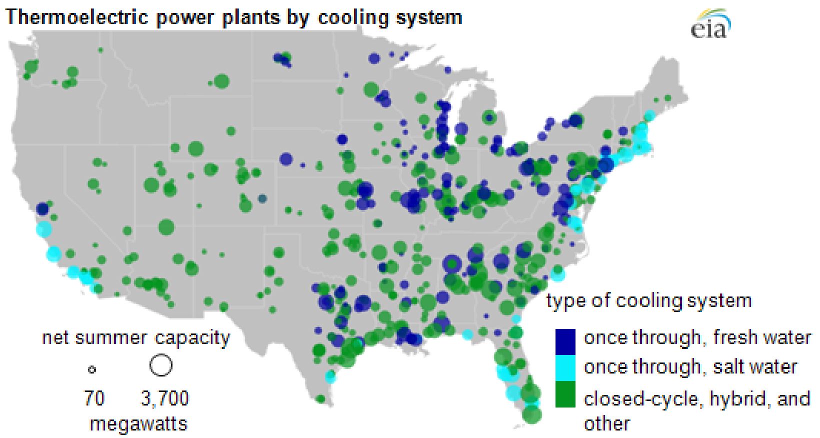


SOURCE: EIA Form 860

Recent Incidents Affecting Power Plant Operation

- **Power plant operations have historically been affected by both drought and heat wave conditions.**

- **Low water levels affect coal-fired and nuclear power plants' operations:**
  - The Millstone nuclear plant in Waterford, CT had to shut down one of its reactors in mid-August 2012 because the water it drew from the Long Island Sound was too warm to cool critical equipment outside the core.
  - A twin-unit nuclear plant in Braidwood, IL needed to get special permission to continue operating this summer because the temperature in its cooling-water pond rose to 102 degrees, four degrees above its normal limit.
  - Another Midwestern plant stopped operating temporarily because its water-intake pipes ended up on dry ground from the prolonged drought.
  - Another power plant in Illinois had to shut down because it was overheating due to its cooling water intake pipe being blocked with dead fish killed by low water levels.
  - In July 2012, US nuclear-power production hit its lowest seasonal levels in nine years as drought and heat forced nuclear power plants from Ohio to Vermont to slow output.

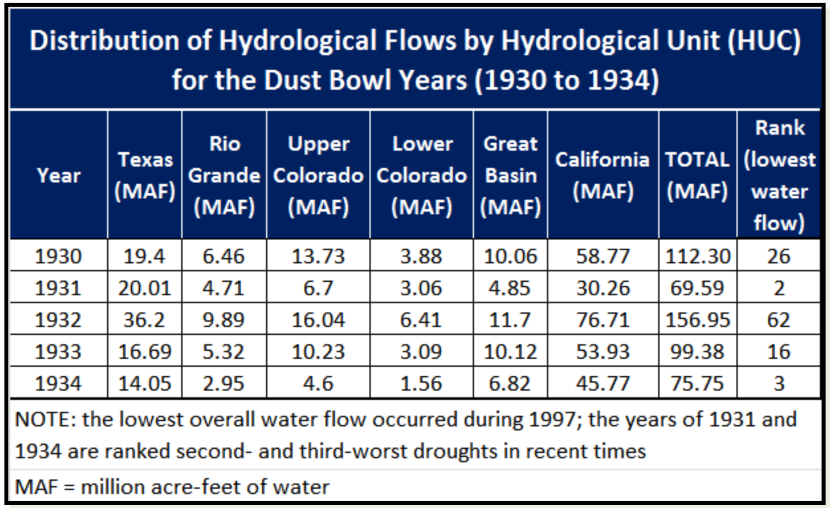


Source: U.S. Energy Information Administration forms EIA-923, Power Plant Operations Report, and EIA-860, Annual Electric Generator Report.

- **Low water levels impede the passage of coal barges along the Mississippi River:**
  - This summer's drought disrupted the transport of coal delivered by barges on the Mississippi, and the U.S. Army Corps of Engineers had to use dredges to deepen the navigation channel.

Major Assumptions for Scenario Development

- **The Southwest Region (SW) is defined as the U.S. western area encompassing the states of CA, AZ, NM, TX, NV, UT and CO**
- **A five-year drought period is assumed with stream flow level variations following conditions experienced during 1930 to 1934 (Dust Bowl years):**



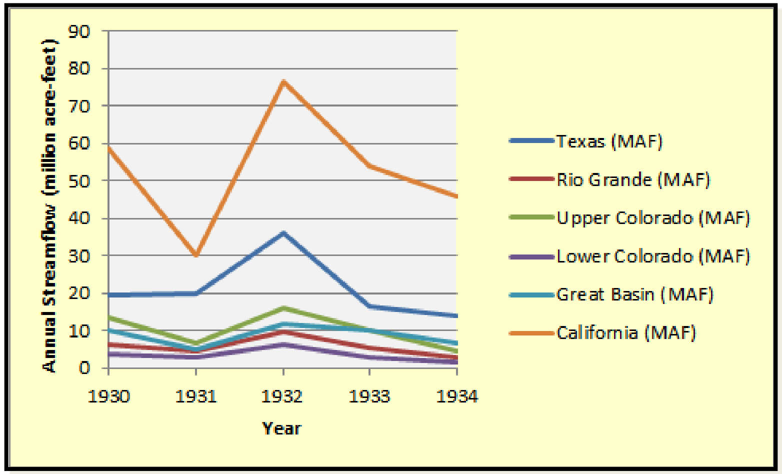
Distribution of Hydrological Flows by Hydrological Unit (HUC) for the Dust Bowl Years (1930 to 1934)

Year	Texas (MAF)	Rio Grande (MAF)	Upper Colorado (MAF)	Lower Colorado (MAF)	Great Basin (MAF)	California (MAF)	TOTAL (MAF)	Rank (lowest water flow)
1930	19.4	6.46	13.73	3.88	10.06	58.77	112.30	26
1931	20.01	4.71	6.7	3.06	4.85	30.26	69.59	2
1932	36.2	9.89	16.04	6.41	11.7	76.71	156.95	62
1933	16.69	5.32	10.23	3.09	10.12	53.93	99.38	16
1934	14.05	2.95	4.6	1.56	6.82	45.77	75.75	3

NOTE: the lowest overall water flow occurred during 1997; the years of 1931 and 1934 are ranked second- and third-worst droughts in recent times

MAF = million acre-feet of water

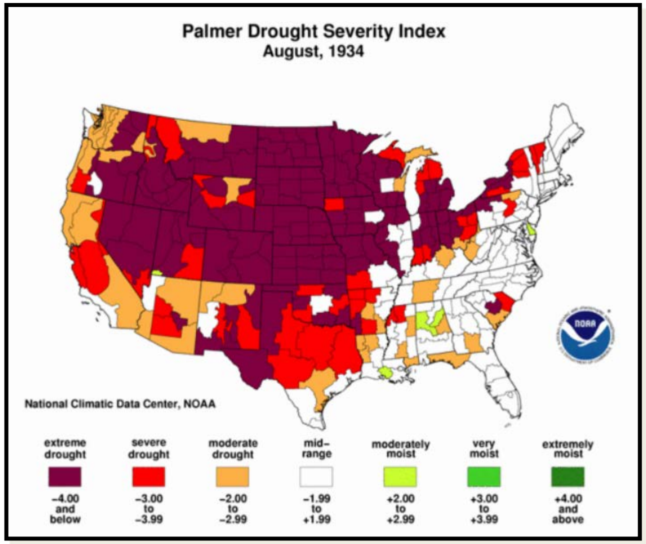
Highlighted States in Southwest Region



- **Drought conditions would occur in areas within the SW region**
- **Analysis considers impacts to surface water**
- **The reference normal average year would be 2010**
- **Wind capacity assumed available during peak periods**
- **No plant maintenance during peak summer months**

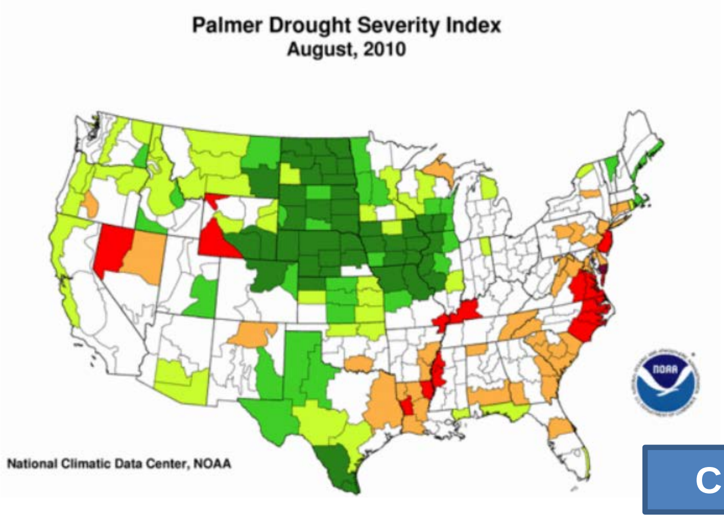
Dust Bowl Years of 1930 to 1934

- **The 1930s are remembered as the driest and warmest decade for the U.S.:**
  - The drought events of the 1930s are widely considered to be the “drought of record” for the Nation
- **During the Dust Bowl years of 1930 to 1934, severe drought struck the Great Plains region:**
  - In the summer of 1931, the rain stopped coming and a drought that would last for most of the decade descended on the region
  - Drought conditions during 1934 covered 79.9 percent of U.S. land area
- **Dust Bowl drought of the 1930s was arguably one of the worst environmental disasters of the 20th century:**
  - The Dust Bowl affected 100,000,000 acres, centered on the panhandles of Texas and Oklahoma, and adjacent parts of New Mexico, Colorado, and Kansas
  - Lack of precipitation affected wildlife and plant life, and created water shortages for domestic needs
- **Many proactive measures taken after the 1930s drought reduced rural and urban vulnerability to drought, including new or enlarged reservoirs and improved domestic water systems**



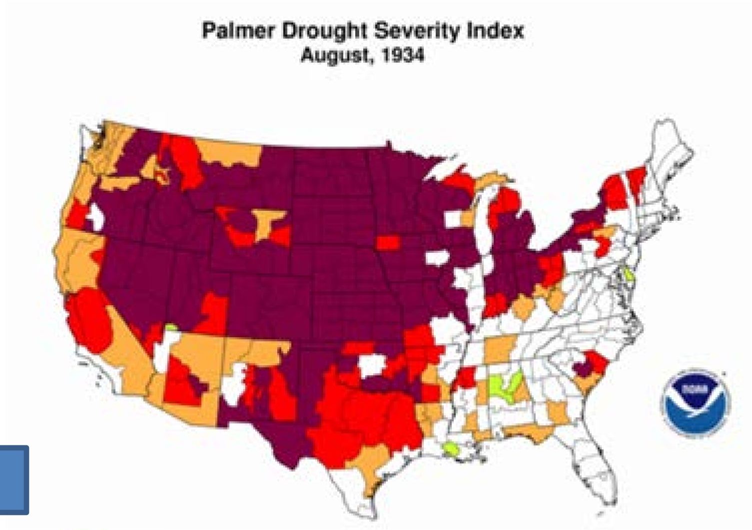
Comparison: Normal versus Assumed Drought Scenario

Normal Reference Year (2010)

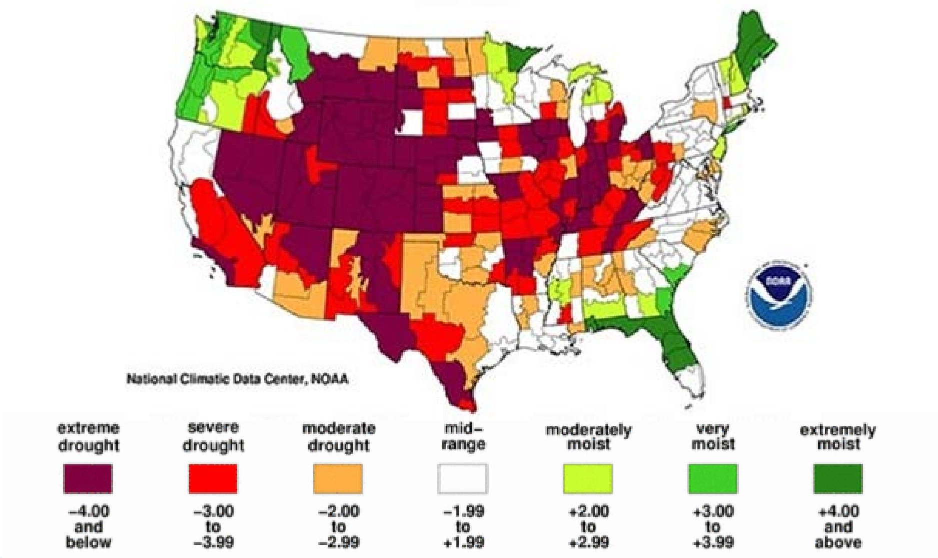

Palmer Drought Severity Index
August, 2010

National Climatic Data Center, NOAA

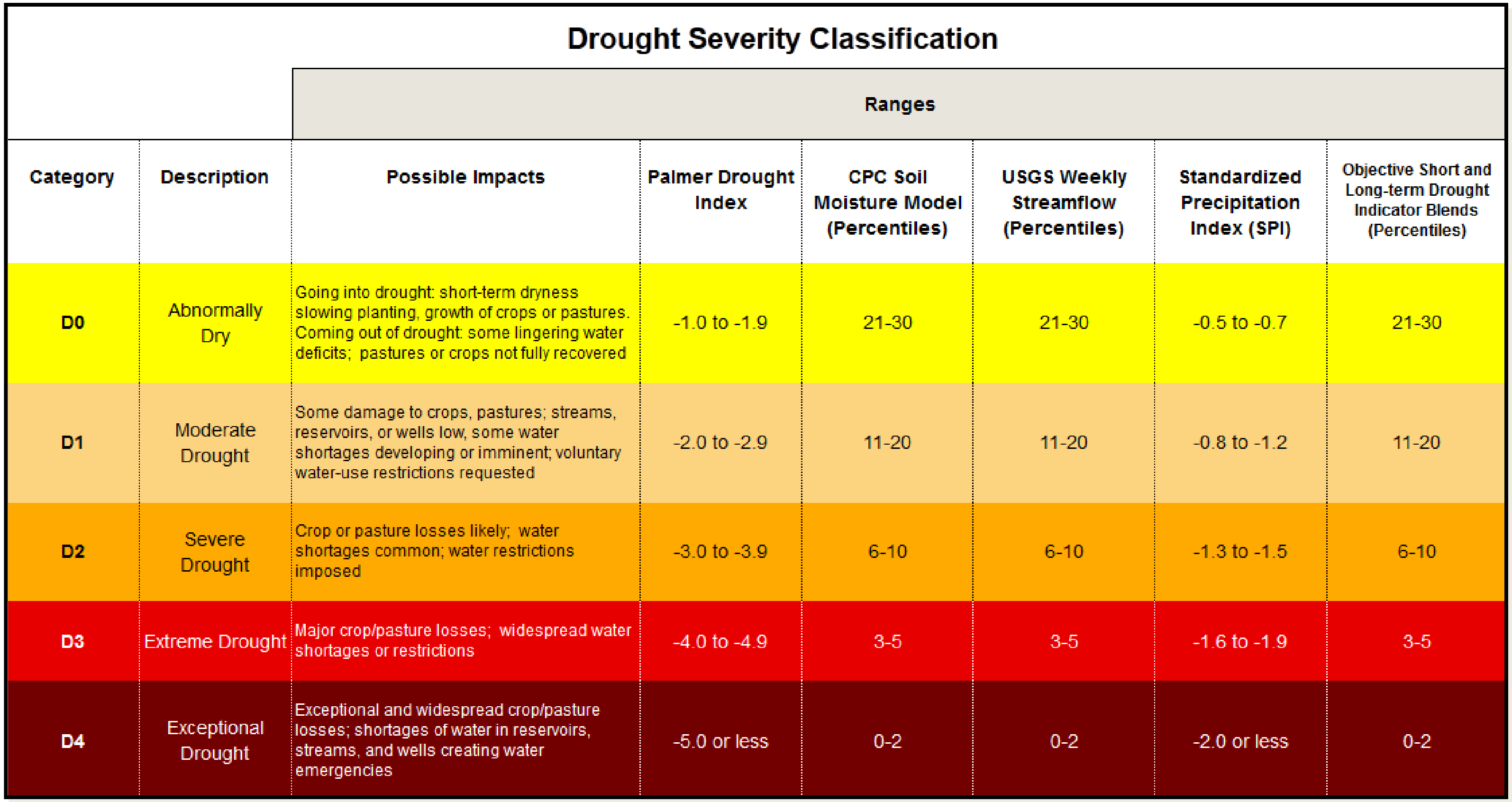
Assumed Drought Scenario (5-years)


Palmer Drought Severity Index
August, 1934

Current Conditions


National Climatic Data Center, NOAA

Drought Index Translation Across Selected Severity Indices



Drought Severity Classification

		Ranges					
Category	**Description**	**Possible Impacts**	**Palmer Drought Index**	**CPC Soil Moisture Model (Percentiles)**	**USGS Weekly Streamflow (Percentiles)**	**Standardized Precipitation Index (SPI)**	**Objective Short and Long-term Drought Indicator Blends (Percentiles)**
D0	Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered	-1.0 to -1.9	21-30	21-30	-0.5 to -0.7	21-30
D1	Moderate Drought	Some damage to crops, pastures; streams, reservoirs, or wells low, some water shortages developing or imminent; voluntary water-use restrictions requested	-2.0 to -2.9	11-20	11-20	-0.8 to -1.2	11-20
D2	Severe Drought	Crop or pasture losses likely; water shortages common; water restrictions imposed	-3.0 to -3.9	6-10	6-10	-1.3 to -1.5	6-10
D3	Extreme Drought	Major crop/pasture losses; widespread water shortages or restrictions	-4.0 to -4.9	3-5	3-5	-1.6 to -1.9	3-5
D4	Exceptional Drought	Exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less	0-2	0-2	-2.0 or less	0-2

Increasing Drought Severity

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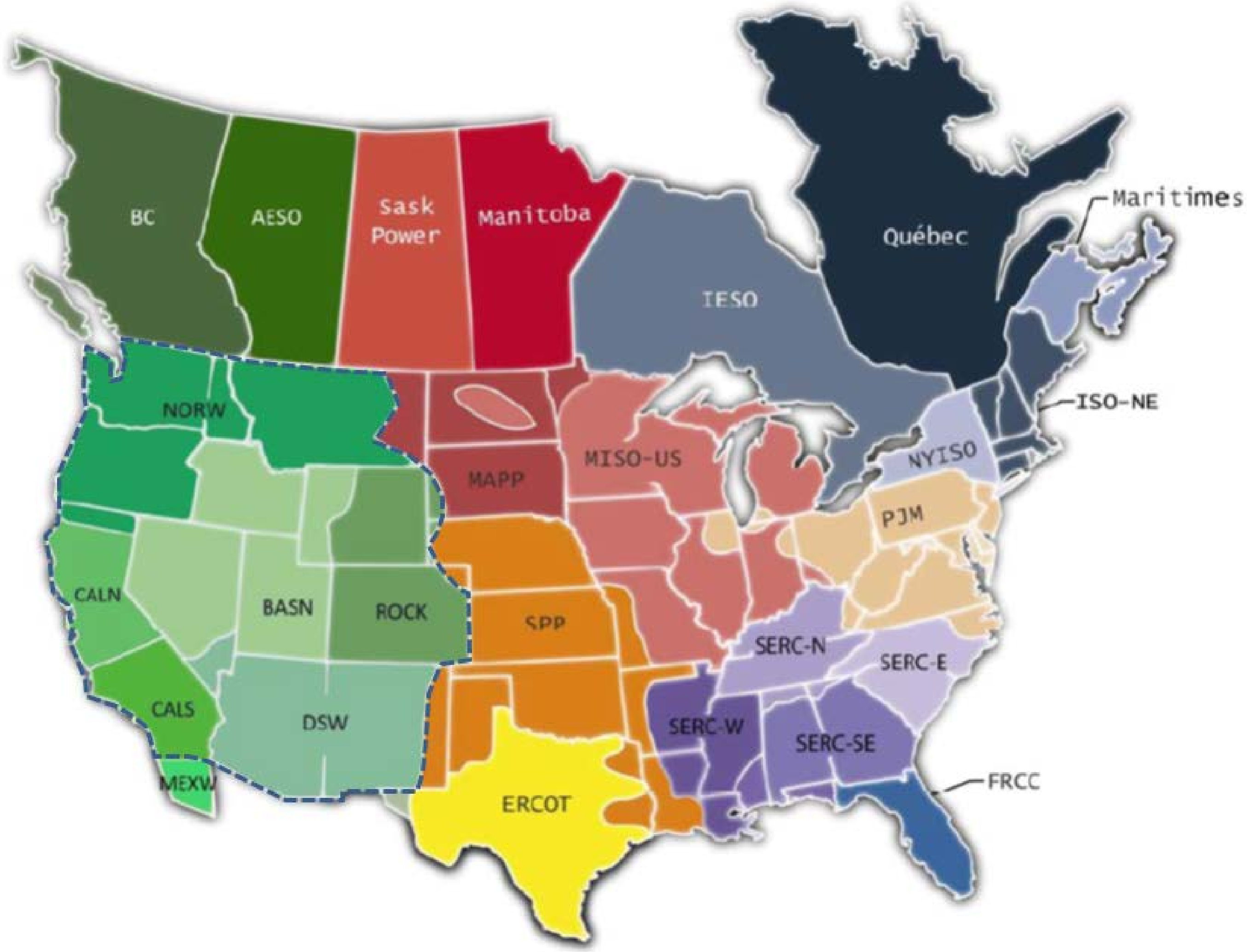
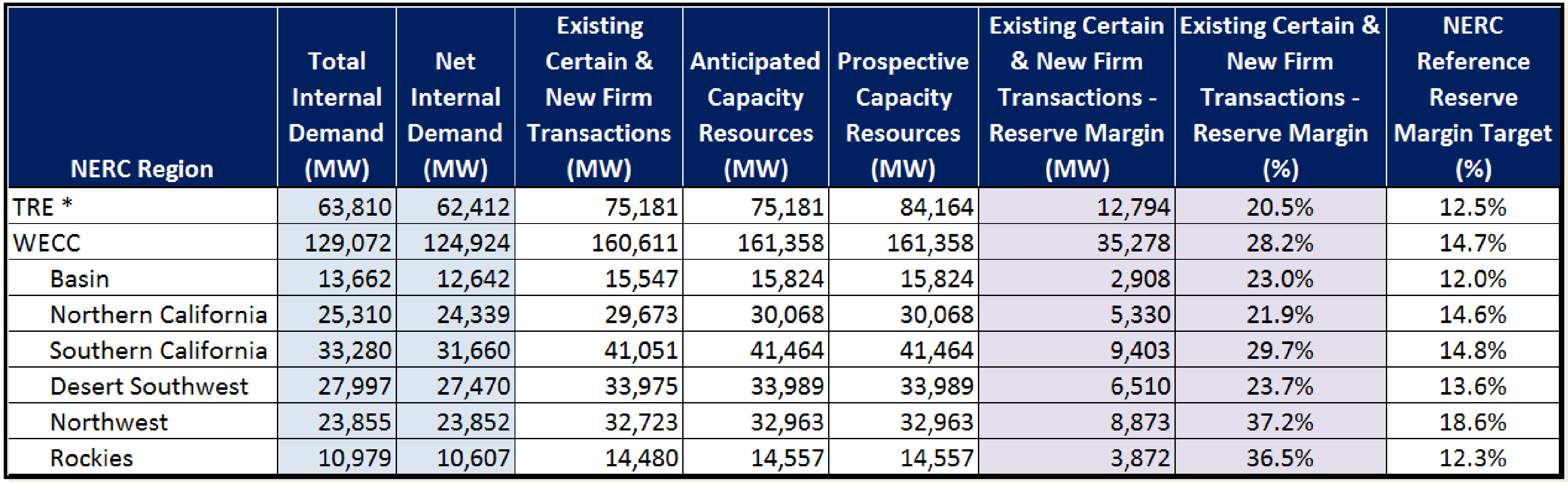
SOURCE: National Drought Mitigation Center

WECC Sub-Regions defined by NERC



Typical Demand Levels and Reserve Margins for Normal Year in the SW (Peak Summer Case)

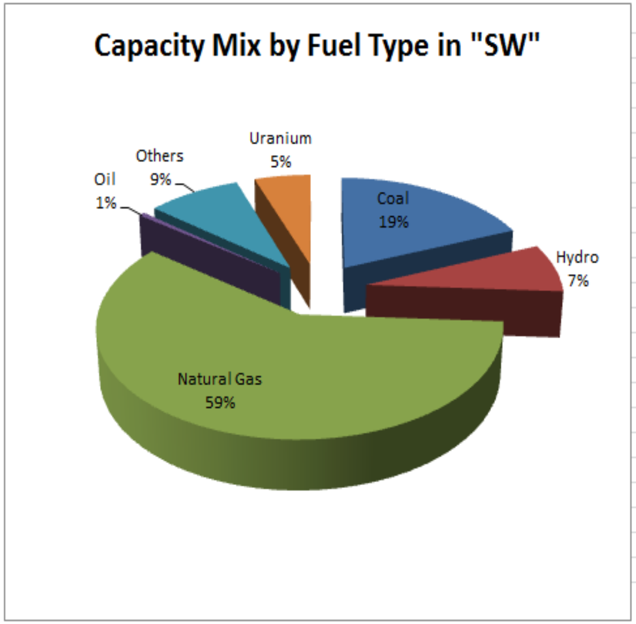


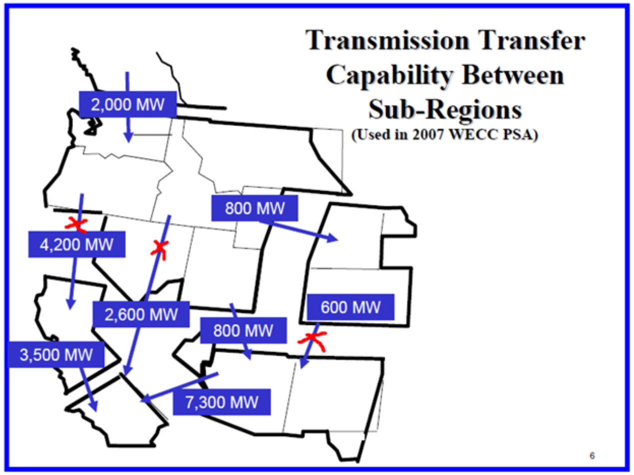
NERC Region	Total Internal Demand (MW)	Net Internal Demand (MW)	Existing Certain & New Firm Transactions (MW)	Anticipated Capacity Resources (MW)	Prospective Capacity Resources (MW)	Existing Certain & New Firm Transactions - Reserve Margin (MW)	Existing Certain & New Firm Transactions - Reserve Margin (%)	NERC Reference Reserve Margin Target (%)
TRE *	63,810	62,412	75,181	75,181	84,164	12,794	20.5%	12.5%
WECC	129,072	124,924	160,611	161,358	161,358	35,278	28.2%	14.7%
Basin	13,662	12,642	15,547	15,824	15,824	2,908	23.0%	12.0%
Northern California	25,310	24,339	29,673	30,068	30,068	5,330	21.9%	14.6%
Southern California	33,280	31,660	41,051	41,464	41,464	9,403	29.7%	14.8%
Desert Southwest	27,997	27,470	33,975	33,989	33,989	6,510	23.7%	13.6%
Northwest	23,855	23,852	32,723	32,963	32,963	8,873	37.2%	18.6%
Rockies	10,979	10,607	14,480	14,557	14,557	3,872	36.5%	12.3%

**TRE = Texas Reliability Entity (now Electric Reliability Council of Texas [ERCOT]). ERCOT is more vulnerable system relative to WECC because ERCOT is an isolated system while WECC is more interconnected.*

Methodology

- **Define scope of U.S. SW affected by drought**
- **Establish base case power system to represent normal year:**
  - Supply-demand balance summer case
  - WECC-sub-regions and exchange capabilities
  - Energy and capacity mix
  - Reserve margins and reliability status
  - Critical transmission corridors
- **Define extent and severity of drought:**
  - Based on 1930 to 1934 historic stream flows levels
  - Derive corresponding hydro-thermal capacity loss factors using HUC-2 and HUC-4 water basin flows
- **Identify low- and high-risk thermal and hydro plants:**
  - *Low risk*: renewables and groundwater- or seawater-dependent
  - *High-risk*: surface water-dependent and hydro plants
- **Calculate amount of reduction in capacity:**
  - Use Harto and Yan's 1st order formula for capacity loss calculation
  - Depict reduction regionally and per-state
  - Examine impact on inter-state transfer capability
- **Consider transmission line failures and assess further effects on reliability.**





Note: "X"s indicate possible line failures due to wild fires

Data Sources

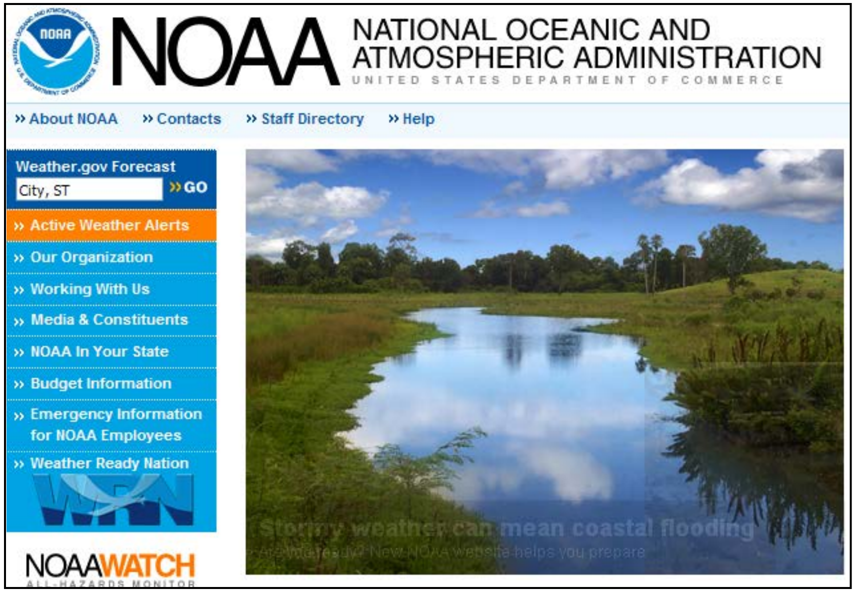
- **Hydrologic Data:**
  - Harto and Yan Files*
  - U.S.G.S. website
- **Power Plant Capacity and Technical Characteristics:**
  - *Platts* PowerMap
  - EIA 860, 767, and 923
  - FERC 715
  - EPA website
- **Plant and Transmission Operational Data:**
  - 2010 Transmission Atlas by Energy Visuals
  - FERC 715 April 2010 Filings
  - EIA website (Form 860, 423)
  - WECC website (path rating studies)
- **Drought Severity data:**
  - Drought Monitor website
  - NOAA website -
- **System Reliability and Reserve Margin Data:**
  - NERC website
  - ERCOT Reports
  - WECC Reports

* SOURCE: *Harto, C.B and E. Yan, "Analysis of Drought Impacts on Electricity Production in the Western and Texas Interconnection", Environmental Science Division, Argonne National Laboratory, Dec 2011*


NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

2011 Long-Term Reliability Assessment

November 2011


NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

Stormy weather can mean coastal flooding
Are you ready? New NOAA website helps you prepare

Harto and Yan* 1st Order Formula for Hydro Capacity Loss Factor Calculation

Loss of Hydro Gen (MWH) = Ave Annual Hydro Gen (MWH)x (1-HGF)

Where:

HGF (Fraction) = Hydro Gen Factor

= Drought Flow/Average Flow

* SOURCE: *Harto, C.B and E. Yan, "Analysis of Drought Impacts on Electricity Production in the Western and Texas Interconnection", Environmental Science Division, Argonne National Laboratory, Dec 2011*

Harto and Yan* 1st Order Formula for Thermal Capacity Loss Factor Calculation

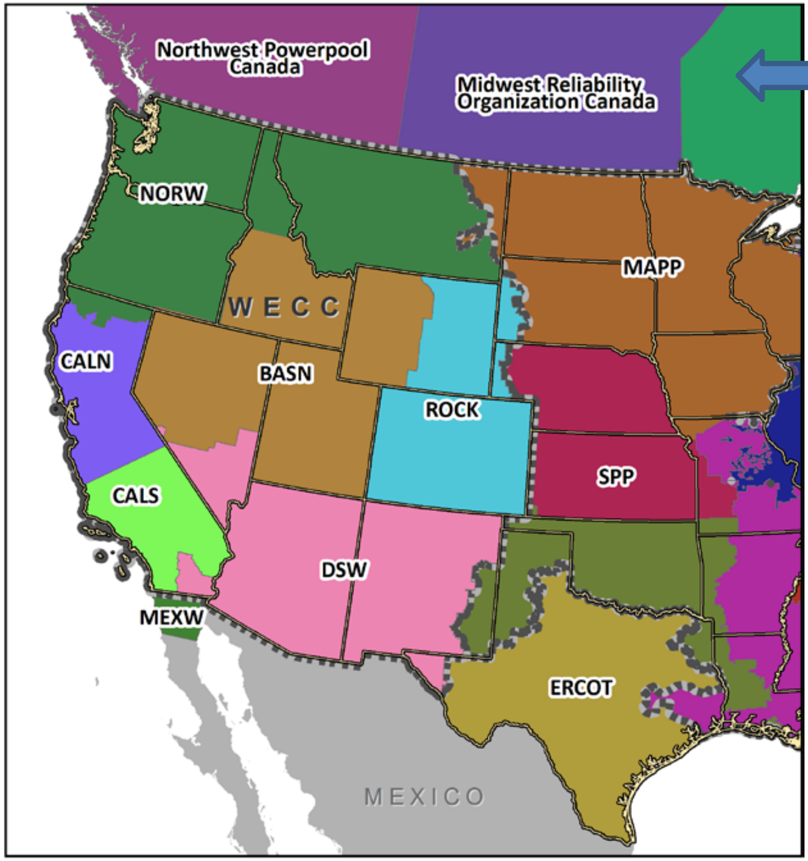
Loss of Thermal Gen (MWH) = At Risk Thermal Gen (MWH) x (1-TGF)

Where:

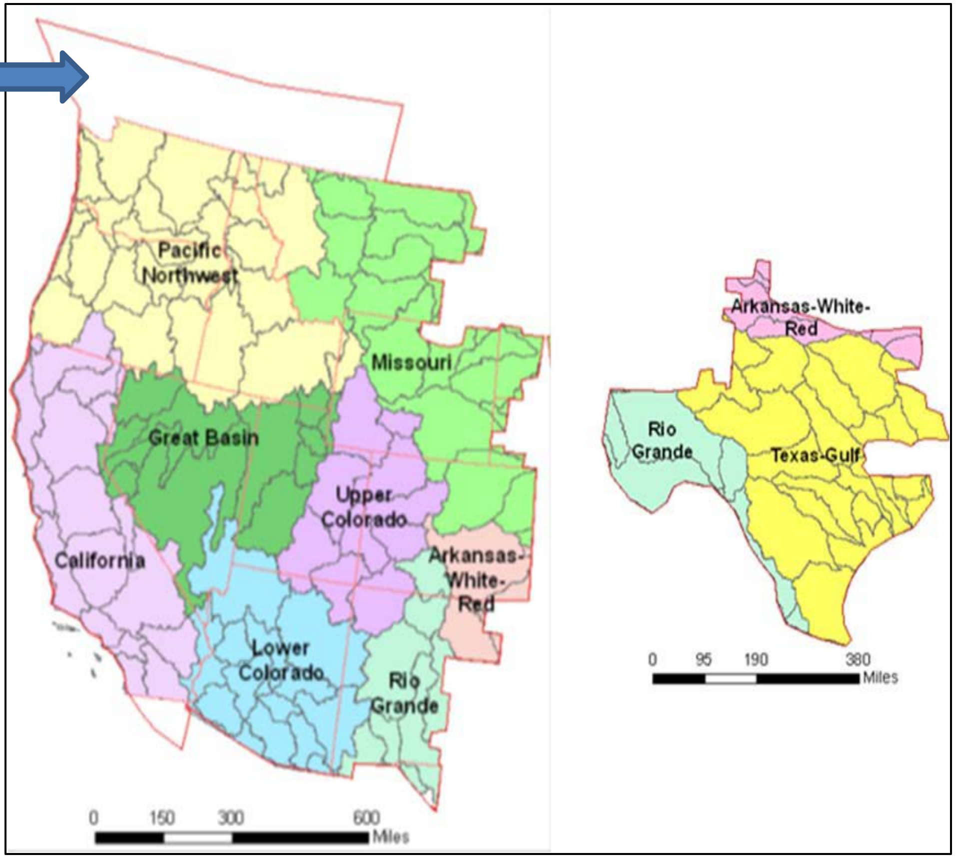
TGF(Fraction) = Thermal Gen Factor
= Drought Flow/(Min [Ave Flow: 2010 Water Demand])

* SOURCE: *Harto, C.B and E. Yan, "Analysis of Drought Impacts on Electricity Production in the Western and Texas Interconnection", Environmental Science Division, Argonne National Laboratory, Dec 2011*

Comparison of NERC Sub-Regions and HUC Water Basins



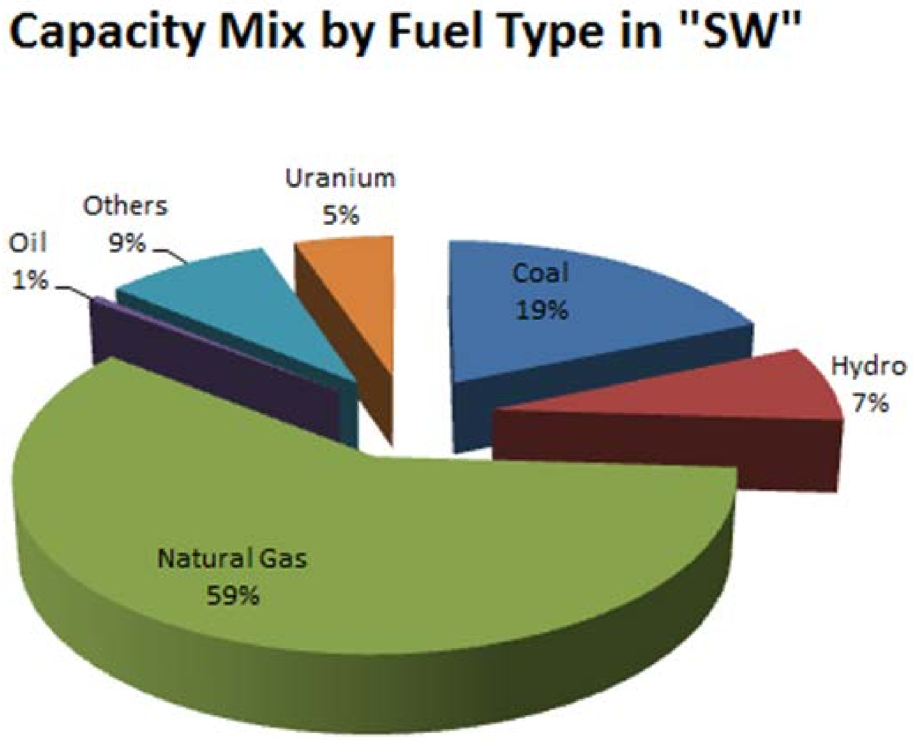
NERC Sub-Regions



HUC-2 Water Basins

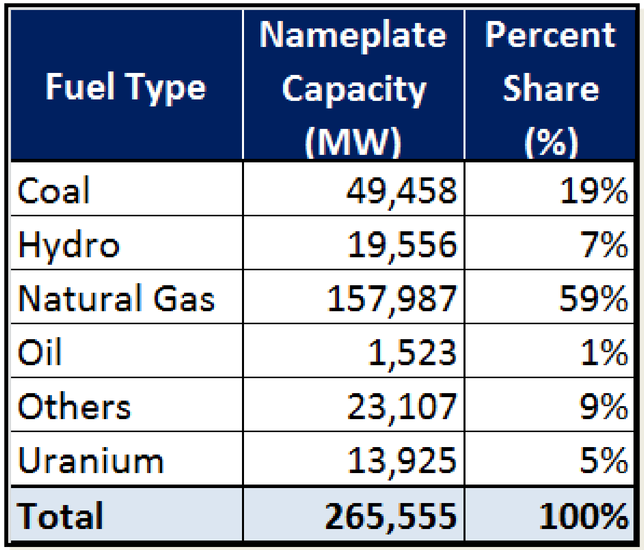
Analysis Results: Characteristics of the Southwest Region

Installed Capacity Mix by Fuel Type in the “SW”
(including ERCOT)



Capacity Mix by Fuel Type in "SW"

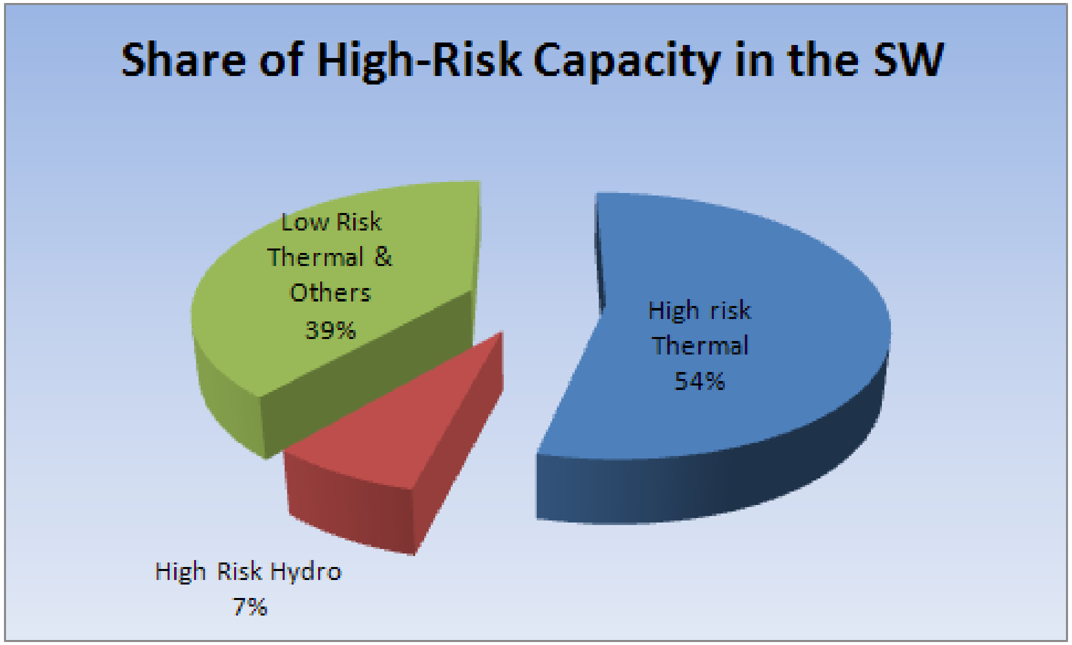
Total Installed Capacity : 265,555 MW

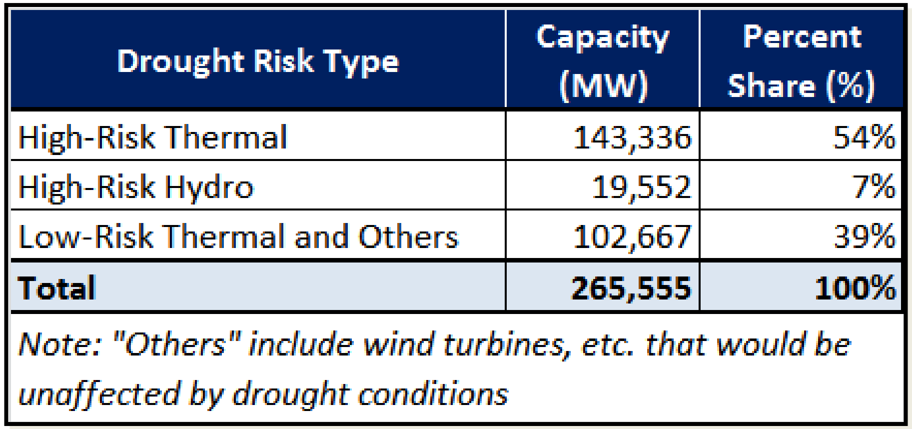


Fuel Type	Nameplate Capacity (MW)	Percent Share (%)
Coal	49,458	19%
Hydro	19,556	7%
Natural Gas	157,987	59%
Oil	1,523	1%
Others	23,107	9%
Uranium	13,925	5%
Total	**265,555**	**100%**

Note: **The high dependence of the region on natural gas presents a unique vulnerability to natural gas disturbance. A long-term disruption of a major gas pipeline serving the region could spell disaster especially during drought season.**

Share of High-Risk Capacity in the Southwest (SW)

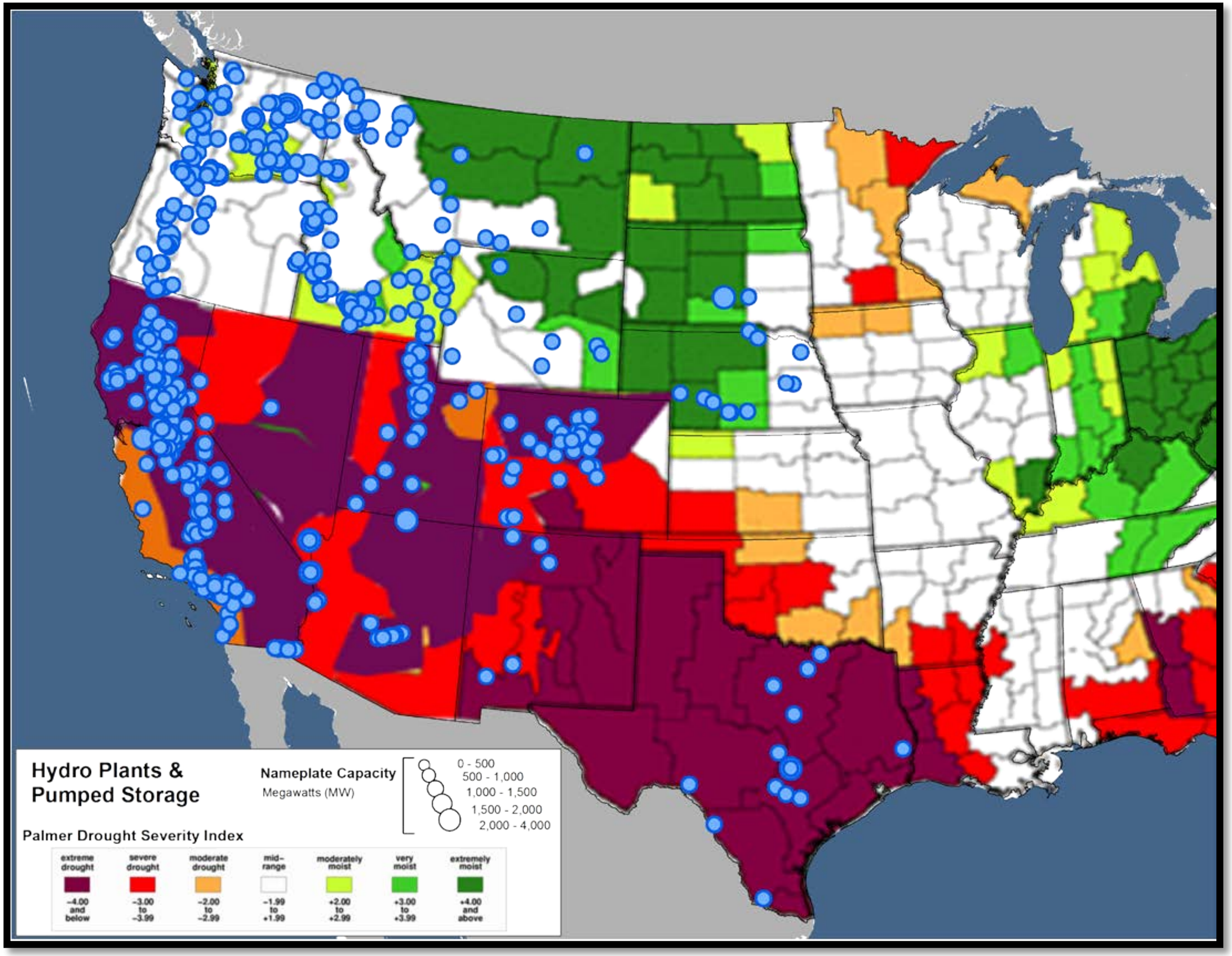




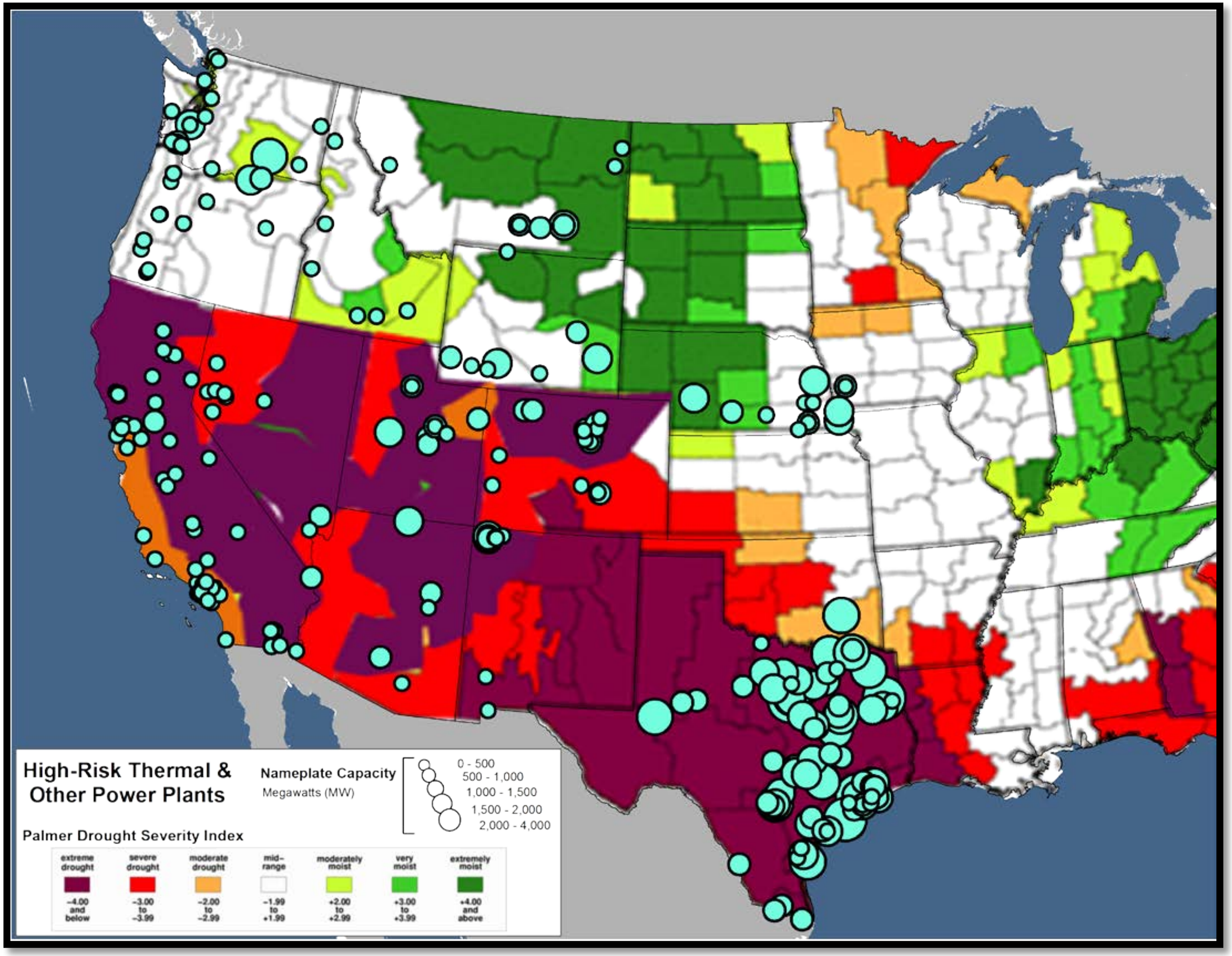
Drought Risk Type	Capacity (MW)	Percent Share (%)
High-Risk Thermal	143,336	54%
High-Risk Hydro	19,552	7%
Low-Risk Thermal and Others	102,667	39%
Total	**265,555**	**100%**

Note: "Others" include wind turbines, etc. that would be unaffected by drought conditions

Dispersal Pattern of High-Risk Hydro Plants within WECC and ERCOT

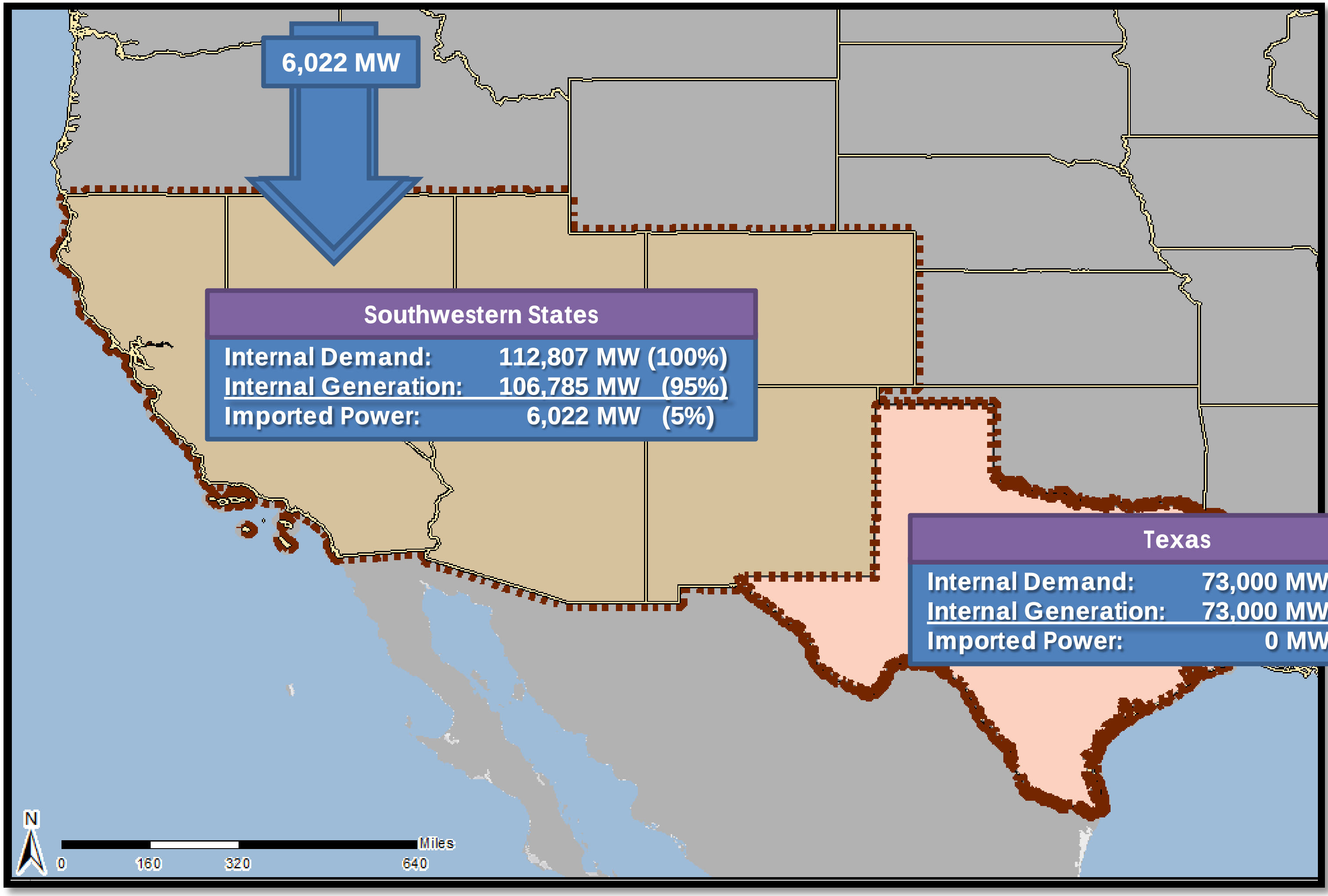


Dispersal Pattern of High-Risk Thermal Plants within WECC and ERCOT



U.S. DEPARTMENT OF ENERGY

Supply Demand Balance in the Southwest
(2010 Summer Peak FERC 715)



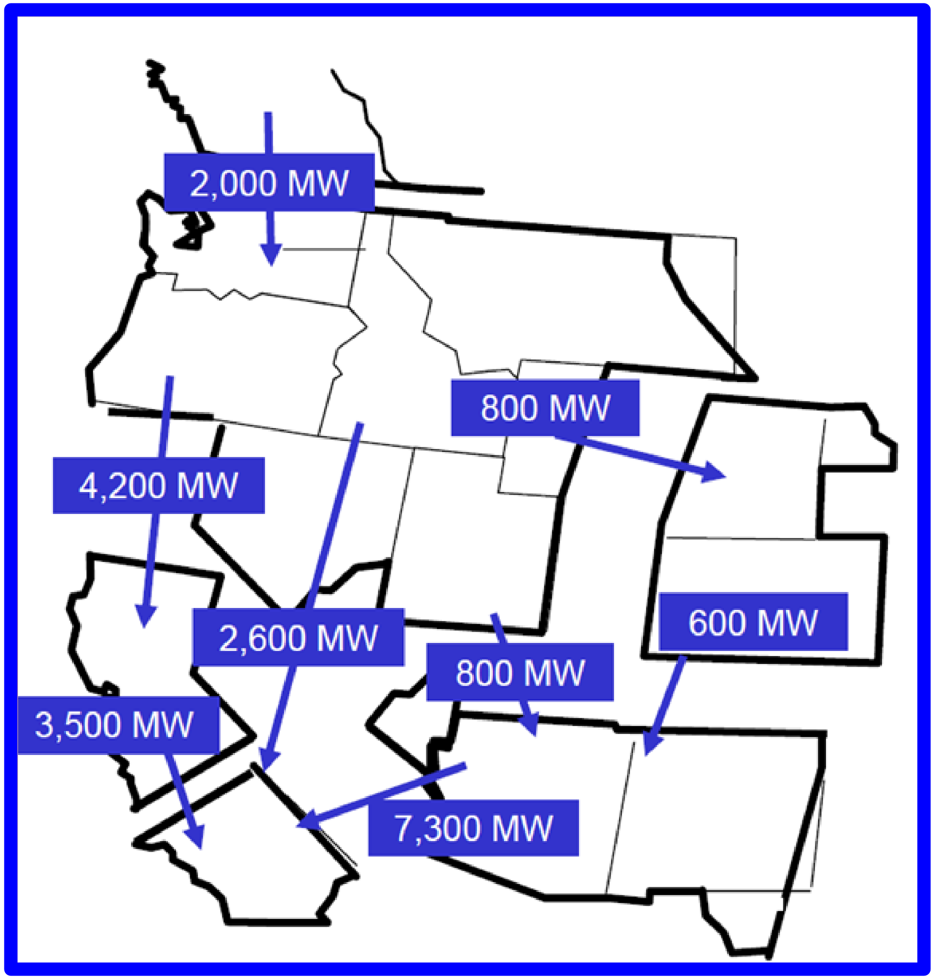
Southwestern States

Internal Demand:	112,807 MW (100%)
Internal Generation:	106,785 MW (95%)
Imported Power:	6,022 MW (5%)

Texas

Internal Demand:	73,000 MW (100%)
Internal Generation:	73,000 MW (100%)
Imported Power:	0 MW (0%)

Assumed Transmission Transfer Capability Between WECC Sub-Regions



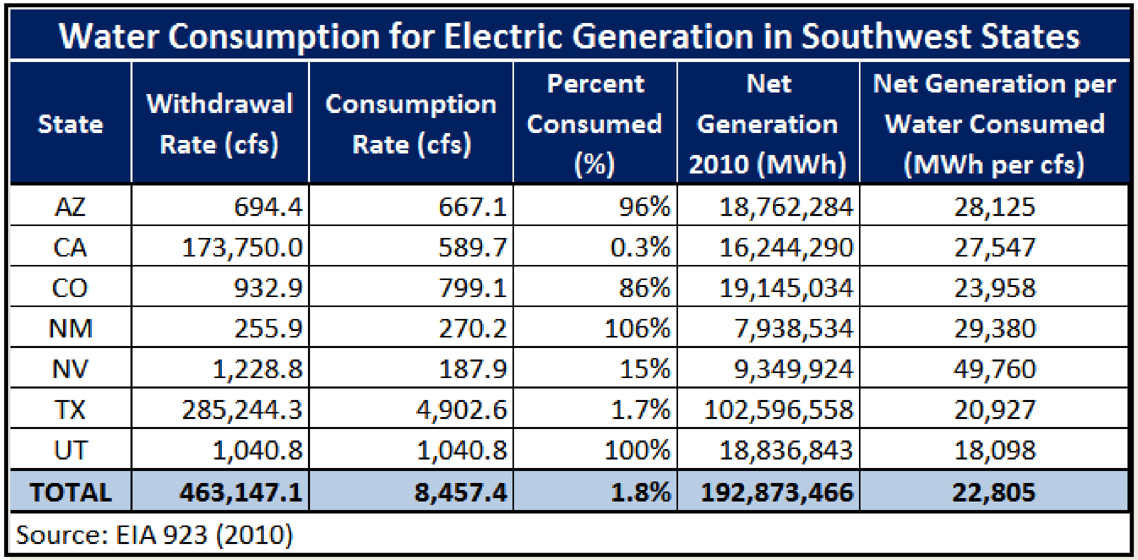
Major 500-kV and DC Transmission Lines Serving the SW

Water Consumption for Electric Generation

- Water withdrawn is the total volume removed from a water source such as a lake or river. Often, a portion of this water is returned to the source and is available to be used again

- Electric power plants account for more than 40 percent of water withdrawal in the U.S., but consume only a fraction of that amount

- Electric generation in the Southwest States consumes less than 2-percent of the total amount of water withdrawn:



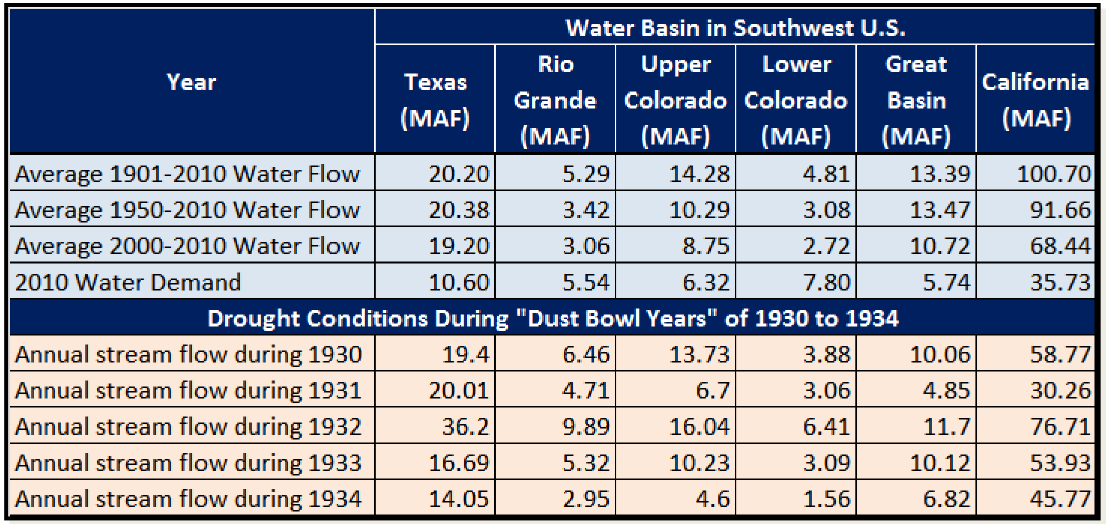
Water Consumption for Electric Generation in Southwest States

State	Withdrawal Rate (cfs)	Consumption Rate (cfs)	Percent Consumed (%)	Net Generation 2010 (MWh)	Net Generation per Water Consumed (MWh per cfs)
AZ	694.4	667.1	96%	18,762,284	28,125
CA	173,750.0	589.7	0.3%	16,244,290	27,547
CO	932.9	799.1	86%	19,145,034	23,958
NM	255.9	270.2	106%	7,938,534	29,380
NV	1,228.8	187.9	15%	9,349,924	49,760
TX	285,244.3	4,902.6	1.7%	102,596,558	20,927
UT	1,040.8	1,040.8	100%	18,836,843	18,098
TOTAL	**463,147.1**	**8,457.4**	**1.8%**	**192,873,466**	**22,805**

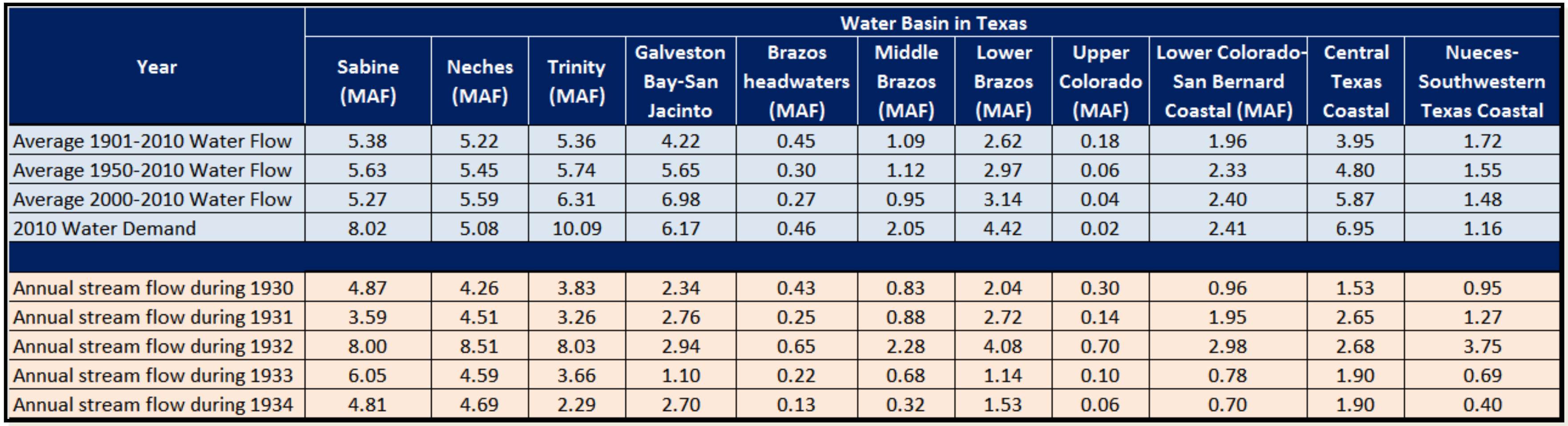
Source: EIA 923 (2010)

Analysis Results: Hydrological Data and Drought-Driven Capacity Loss Factors

Stream Flow Levels During Drought

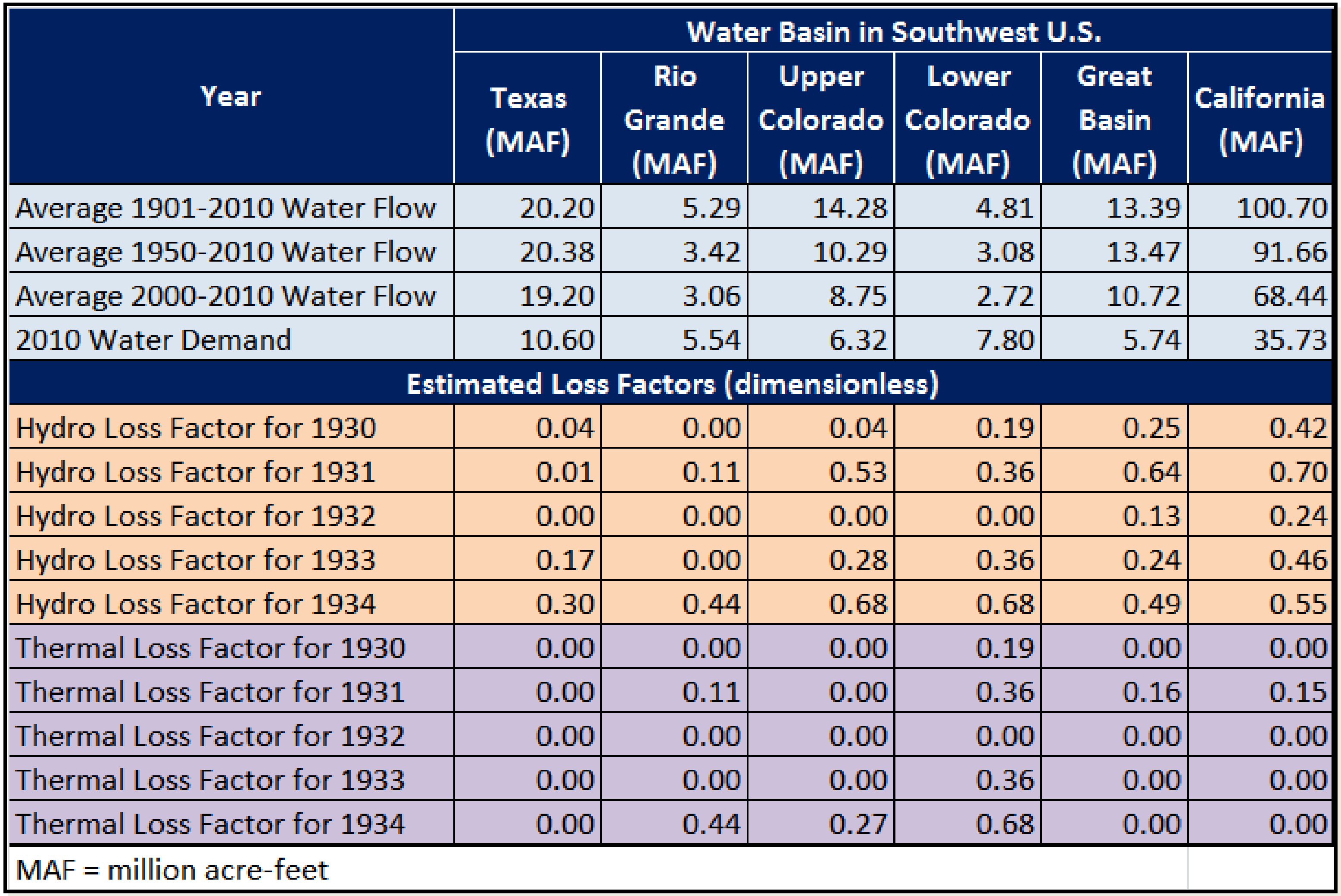


Year	Water Basin in Southwest U.S.					
	Texas (MAF)	Rio Grande (MAF)	Upper Colorado (MAF)	Lower Colorado (MAF)	Great Basin (MAF)	California (MAF)
Average 1901-2010 Water Flow	20.20	5.29	14.28	4.81	13.39	100.70
Average 1950-2010 Water Flow	20.38	3.42	10.29	3.08	13.47	91.66
Average 2000-2010 Water Flow	19.20	3.06	8.75	2.72	10.72	68.44
2010 Water Demand	10.60	5.54	6.32	7.80	5.74	35.73
Drought Conditions During "Dust Bowl Years" of 1930 to 1934						
Annual stream flow during 1930	19.4	6.46	13.73	3.88	10.06	58.77
Annual stream flow during 1931	20.01	4.71	6.7	3.06	4.85	30.26
Annual stream flow during 1932	36.2	9.89	16.04	6.41	11.7	76.71
Annual stream flow during 1933	16.69	5.32	10.23	3.09	10.12	53.93
Annual stream flow during 1934	14.05	2.95	4.6	1.56	6.82	45.77



Year	Water Basin in Texas										
	Sabine (MAF)	Neches (MAF)	Trinity (MAF)	Galveston Bay-San Jacinto	Brazos headwaters (MAF)	Middle Brazos (MAF)	Lower Brazos (MAF)	Upper Colorado (MAF)	Lower Colorado-San Bernard Coastal (MAF)	Central Texas Coastal	Nueces-Southwestern Texas Coastal
Average 1901-2010 Water Flow	5.38	5.22	5.36	4.22	0.45	1.09	2.62	0.18	1.96	3.95	1.72
Average 1950-2010 Water Flow	5.63	5.45	5.74	5.65	0.30	1.12	2.97	0.06	2.33	4.80	1.55
Average 2000-2010 Water Flow	5.27	5.59	6.31	6.98	0.27	0.95	3.14	0.04	2.40	5.87	1.48
2010 Water Demand	8.02	5.08	10.09	6.17	0.46	2.05	4.42	0.02	2.41	6.95	1.16
Annual stream flow during 1930	4.87	4.26	3.83	2.34	0.43	0.83	2.04	0.30	0.96	1.53	0.95
Annual stream flow during 1931	3.59	4.51	3.26	2.76	0.25	0.88	2.72	0.14	1.95	2.65	1.27
Annual stream flow during 1932	8.00	8.51	8.03	2.94	0.65	2.28	4.08	0.70	2.98	2.68	3.75
Annual stream flow during 1933	6.05	4.59	3.66	1.10	0.22	0.68	1.14	0.10	0.78	1.90	0.69
Annual stream flow during 1934	4.81	4.69	2.29	2.70	0.13	0.32	1.53	0.06	0.70	1.90	0.40

Hydrological Data and Drought-Driven Capacity Loss Factors



Year	Water Basin in Southwest U.S.					
	Texas (MAF)	Rio Grande (MAF)	Upper Colorado (MAF)	Lower Colorado (MAF)	Great Basin (MAF)	California (MAF)
Average 1901-2010 Water Flow	20.20	5.29	14.28	4.81	13.39	100.70
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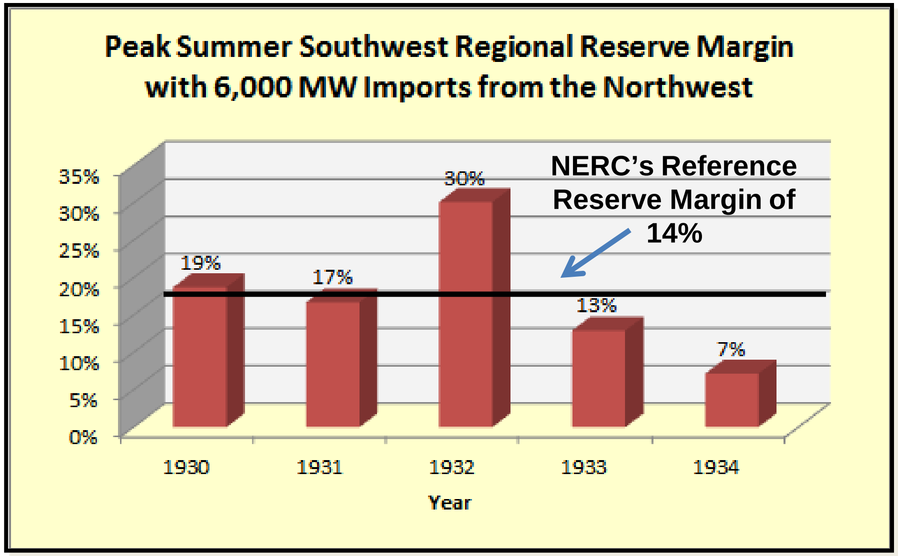
Average 2000-2010 Water Flow	19.20	3.06	8.75	2.72	10.72	68.44
2010 Water Demand	10.60	5.54	6.32	7.80	5.74	35.73
Estimated Loss Factors (dimensionless)						
Hydro Loss Factor for 1930	0.04	0.00	0.04	0.19	0.25	0.42
Hydro Loss Factor for 1931	0.01	0.11	0.53	0.36	0.64	0.70
Hydro Loss Factor for 1932	0.00	0.00	0.00	0.00	0.13	0.24
Hydro Loss Factor for 1933	0.17	0.00	0.28	0.36	0.24	0.46
Hydro Loss Factor for 1934	0.30	0.44	0.68	0.68	0.49	0.55
Thermal Loss Factor for 1930	0.00	0.00	0.00	0.19	0.00	0.00
Thermal Loss Factor for 1931	0.00	0.11	0.00	0.36	0.16	0.15
Thermal Loss Factor for 1932	0.00	0.00	0.00	0.00	0.00	0.00
Thermal Loss Factor for 1933	0.00	0.00	0.00	0.36	0.00	0.00
Thermal Loss Factor for 1934	0.00	0.44	0.27	0.68	0.00	0.00

MAF = million acre-feet

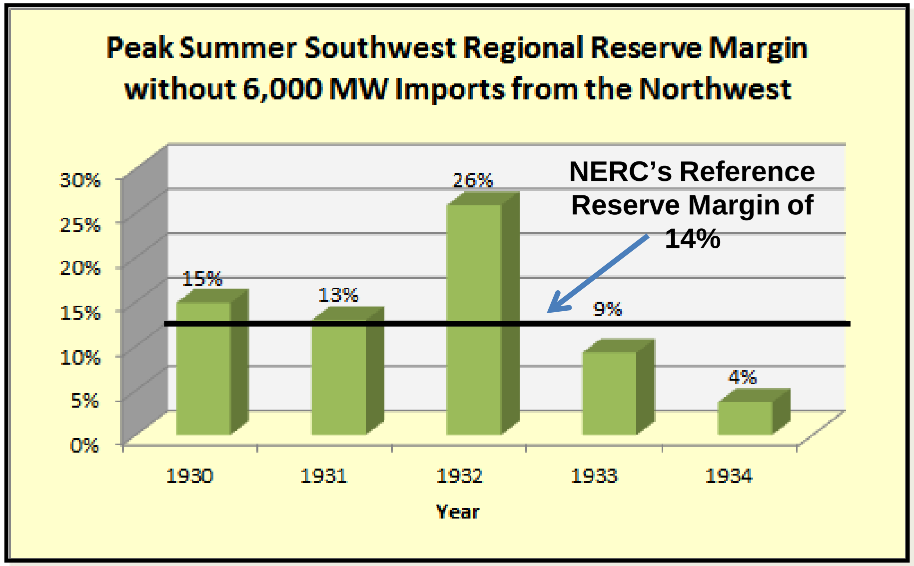
Analysis Results: Impacts on Region-Wide Power Supply Capability and Reserve Margins

Regional Reserve Margins as Affected by Drought Conditions (Plant Maintenance not considered)



Peak Summer Southwest Regional Reserve Margin with 6,000 MW Imports from the Northwest

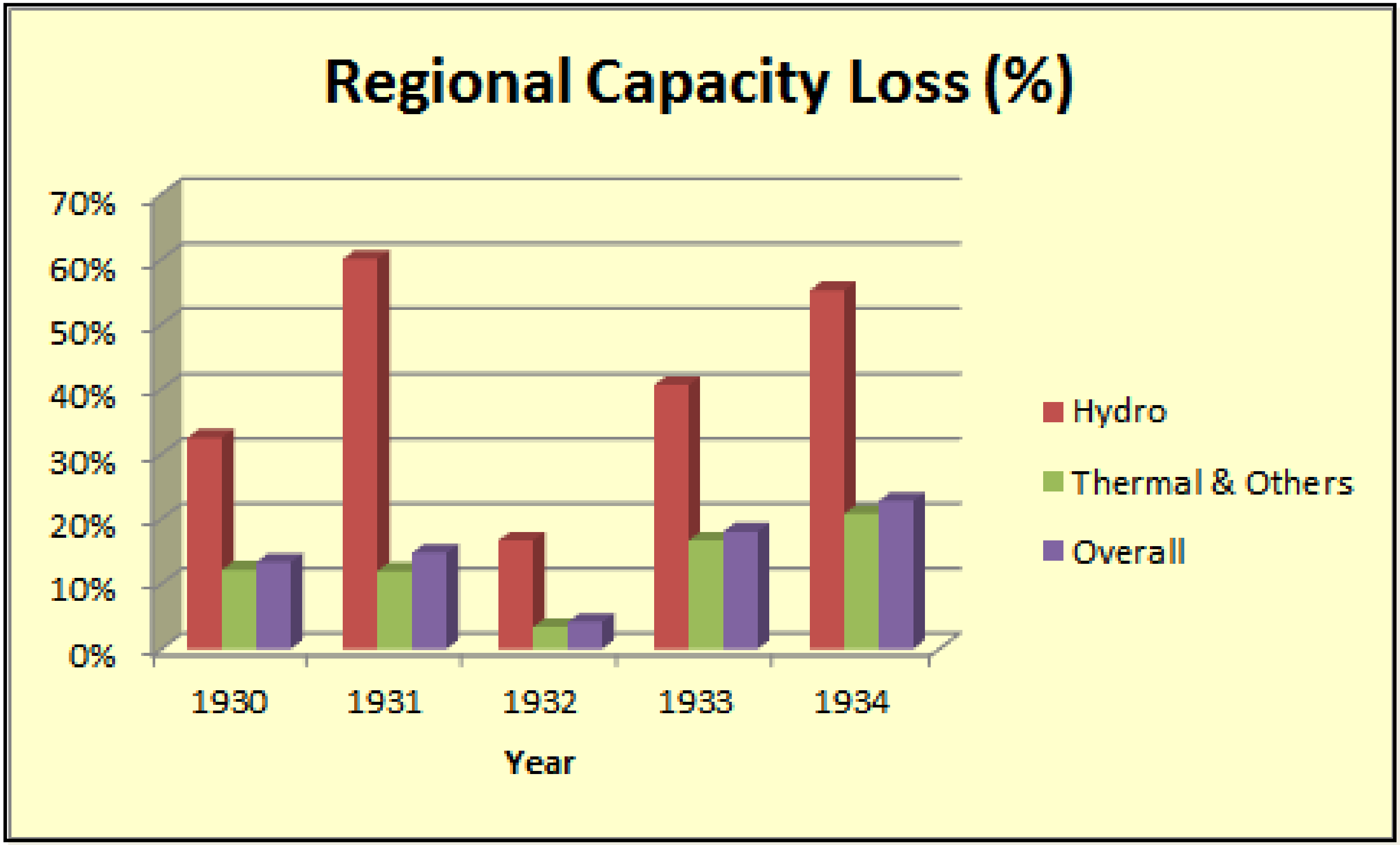
NERC's Reference Reserve Margin of 14%



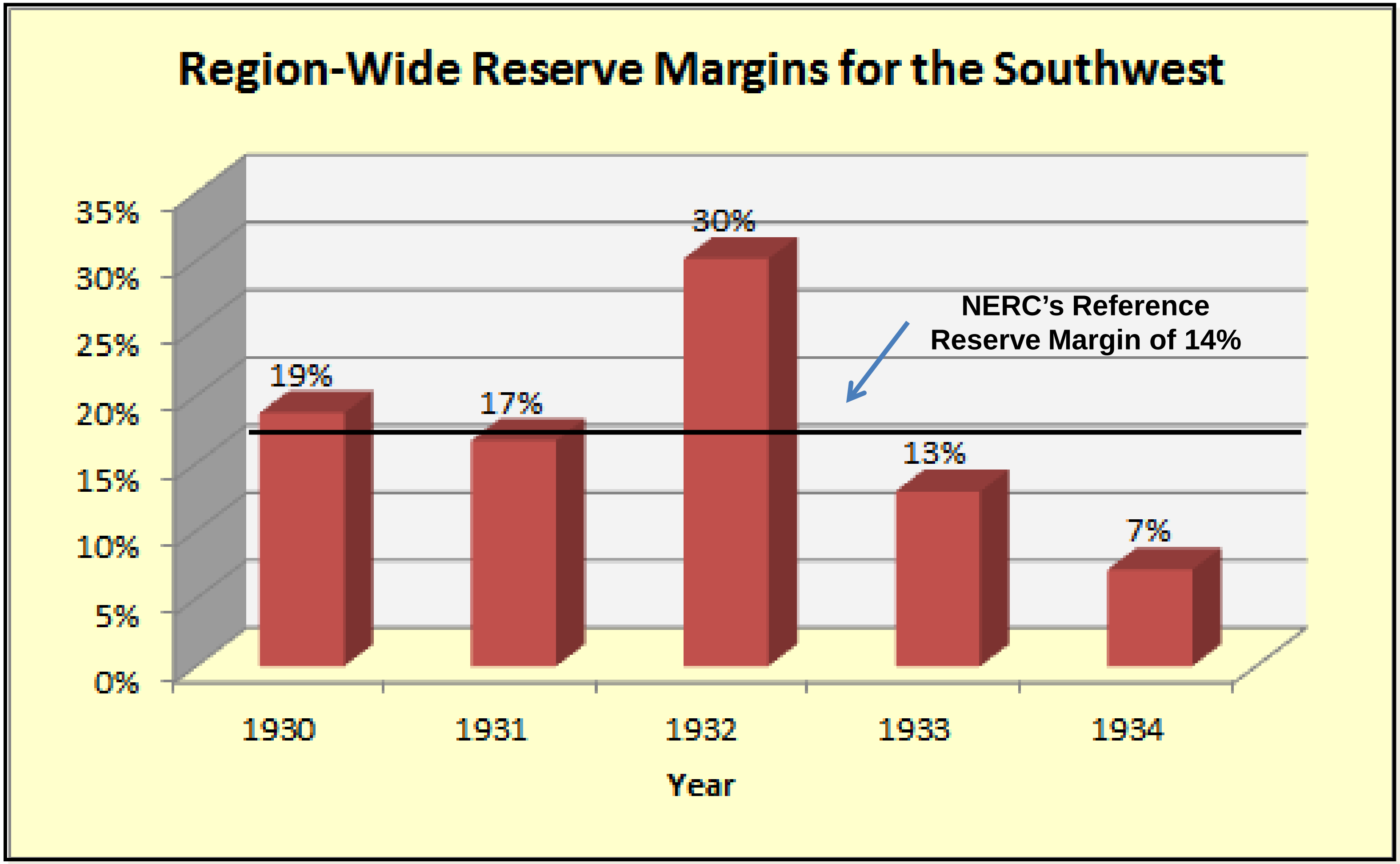
Peak Summer Southwest Regional Reserve Margin without 6,000 MW Imports from the Northwest

NERC's Reference Reserve Margin of 14%

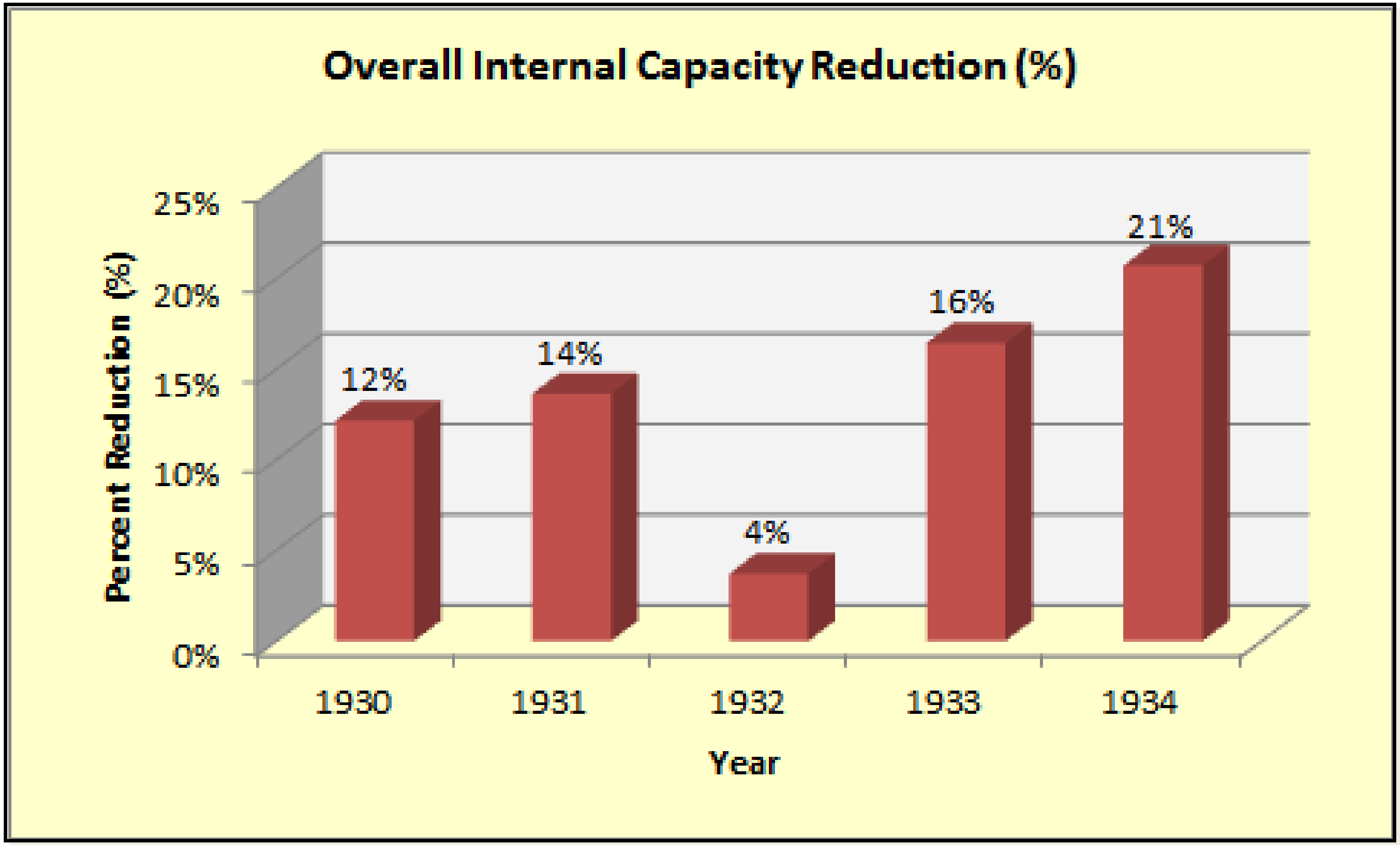
Percent Capacity Reduction in Hydro, Thermal and Other Capacity as Affected by Drought Conditions in the Southwest



Impact on Regional Reserve Margins over Five-Year Drought Scenario

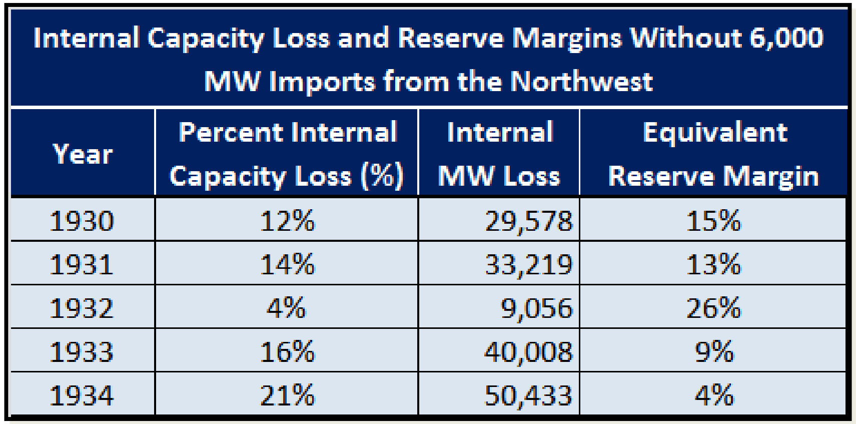


Impact on Regional Supply Capability over Five-Year Drought Scenario



Summary of Impacts: Regional Level

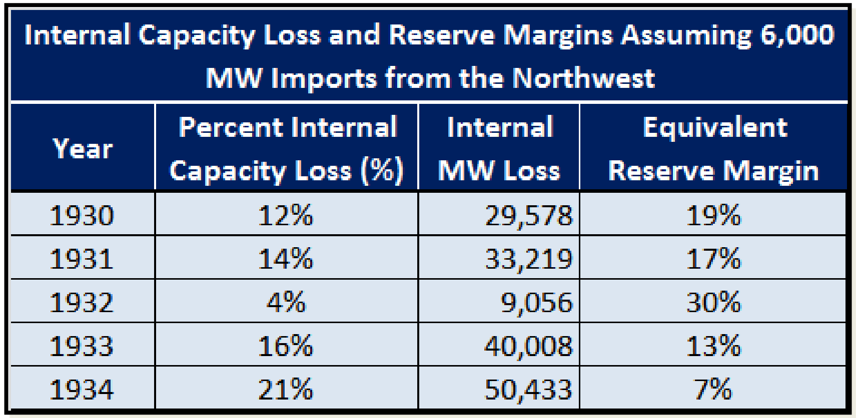
- The five year drought sequence will result in a region-wide capacity loss and new reserve margin levels (without imported power) as follows:



Internal Capacity Loss and Reserve Margins Without 6,000 MW Imports from the Northwest

Year	Percent Internal Capacity Loss (%)	Internal MW Loss	Equivalent Reserve Margin
1930	12%	29,578	15%
1931	14%	33,219	13%
1932	4%	9,056	26%
1933	16%	40,008	9%
1934	21%	50,433	4%

- Regional-wide reliability indices (with 6,000 MW imports) are as follows:

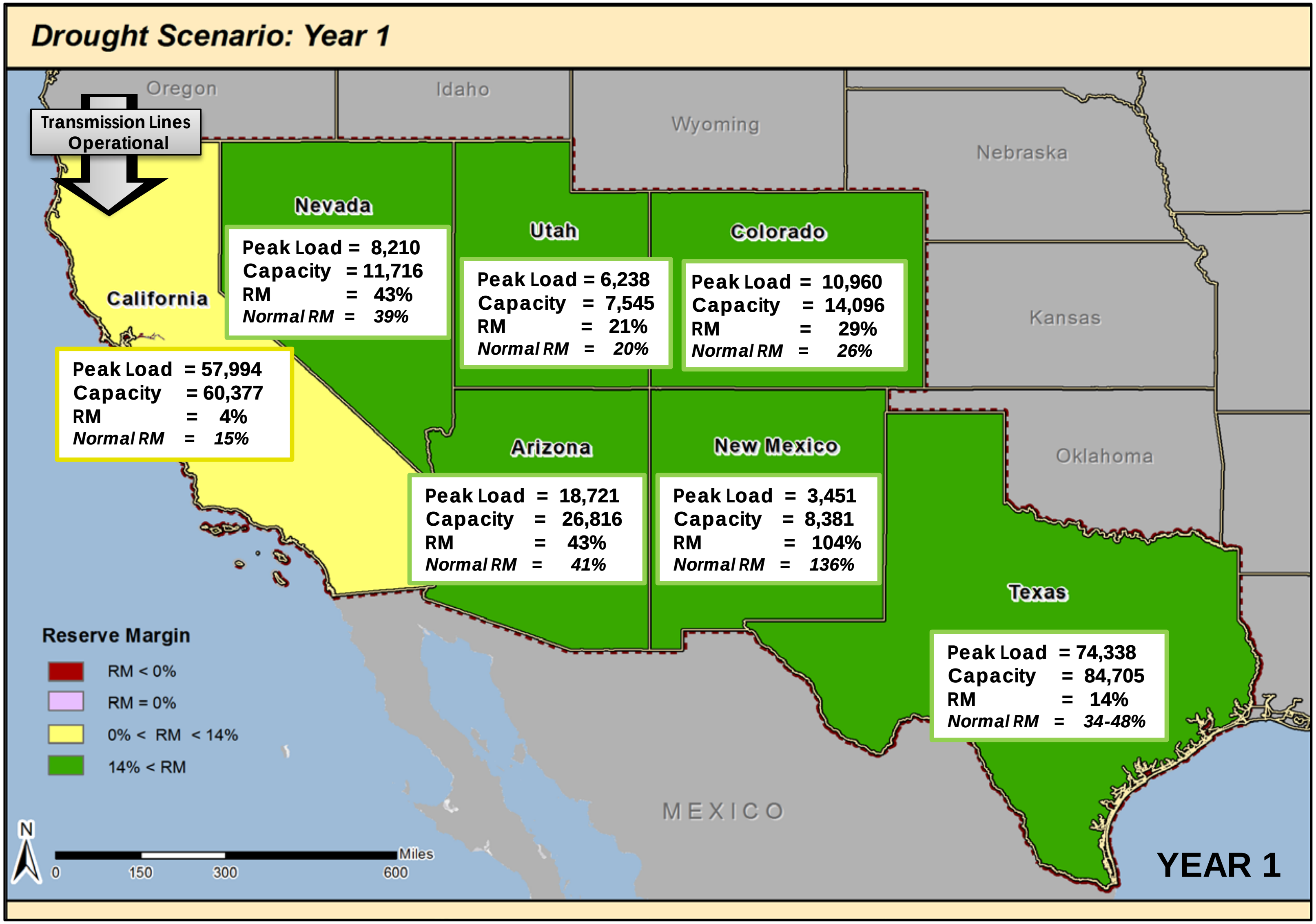


Internal Capacity Loss and Reserve Margins Assuming 6,000 MW Imports from the Northwest

Year	Percent Internal Capacity Loss (%)	Internal MW Loss	Equivalent Reserve Margin
1930	12%	29,578	19%
1931	14%	33,219	17%
1932	4%	9,056	30%
1933	16%	40,008	13%
1934	21%	50,433	7%

Analysis Results:
Impacts on Per-State Reserve Margins

Supply-Demand Conditions and Reserve Margin Levels in Year 1 (based on 1930 stream flow) of Drought Scenario in the Southwest



Nevada
Peak Load = 8,210
Capacity = 11,716
RM = 43%
Normal RM = 39%

Utah
Peak Load = 6,238
Capacity = 7,545
RM = 21%
Normal RM = 20%

Colorado
Peak Load = 10,960
Capacity = 14,096
RM = 29%
Normal RM = 26%

California
Peak Load = 57,994
Capacity = 60,377
RM = 4%
Normal RM = 15%

Arizona
Peak Load = 18,721
Capacity = 26,816
RM = 43%
Normal RM = 41%

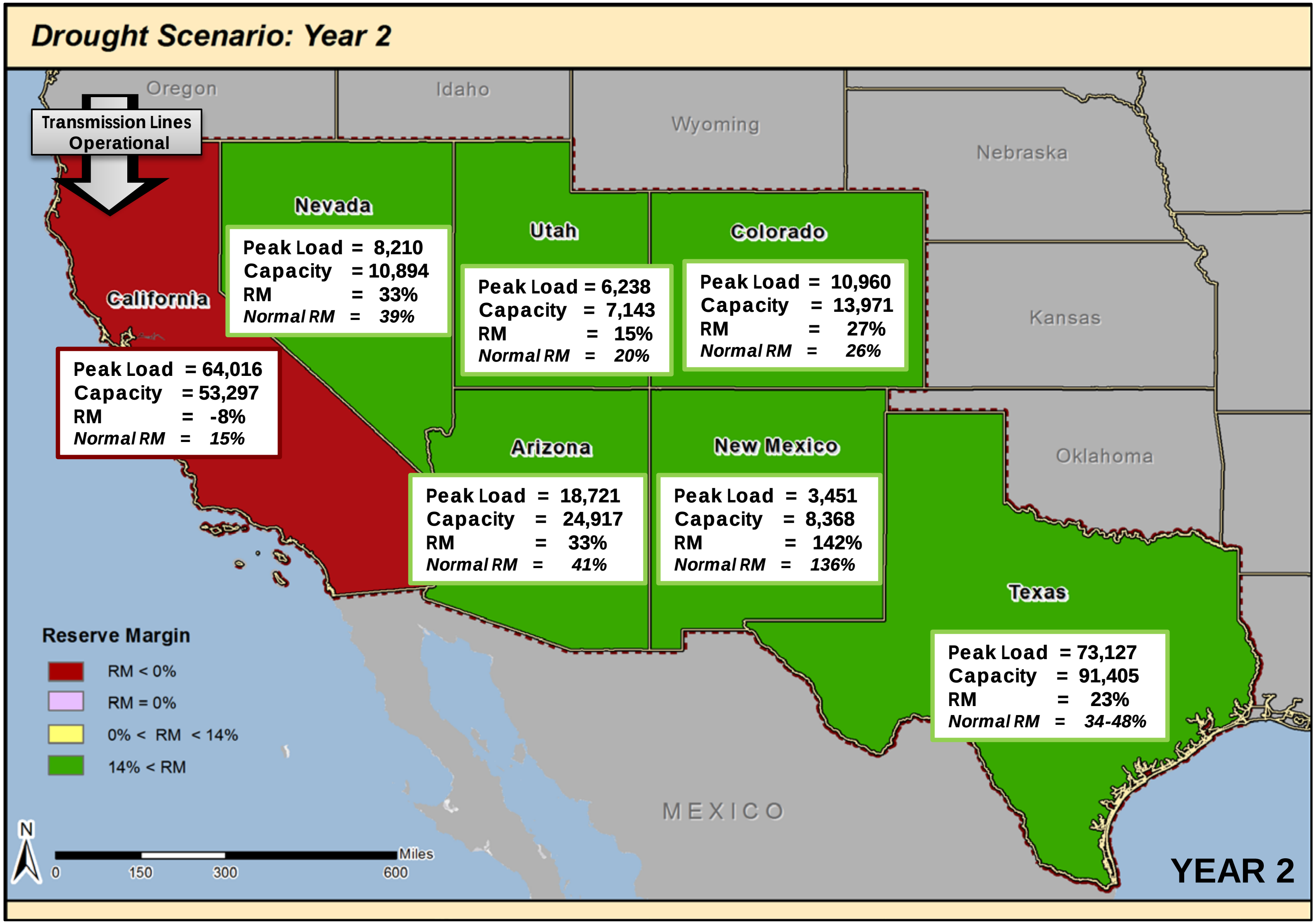
New Mexico
Peak Load = 3,451
Capacity = 8,381
RM = 104%
Normal RM = 136%

Texas
Peak Load = 74,338
Capacity = 84,705
RM = 14%
Normal RM = 34-48%

Reserve Margin

- 🟥 RM < 0%
- 🟪 RM = 0%
- 🟨 0% < RM < 14%
- 🟩 14% < RM

Supply-Demand Conditions and Reserve Margin Levels in Year 2 (based on 1931 stream flow) of Drought Scenario in the Southwest



Drought Scenario: Year 2

Transmission Lines Operational

California
Peak Load = 64,016
Capacity = 53,297
RM = -8%
Normal RM = 15%

Nevada
Peak Load = 8,210
Capacity = 10,894
RM = 33%
Normal RM = 39%

Utah
Peak Load = 6,238
Capacity = 7,143
RM = 15%
Normal RM = 20%

Colorado
Peak Load = 10,960
Capacity = 13,971
RM = 27%
Normal RM = 26%

Arizona
Peak Load = 18,721
Capacity = 24,917
RM = 33%
Normal RM = 41%

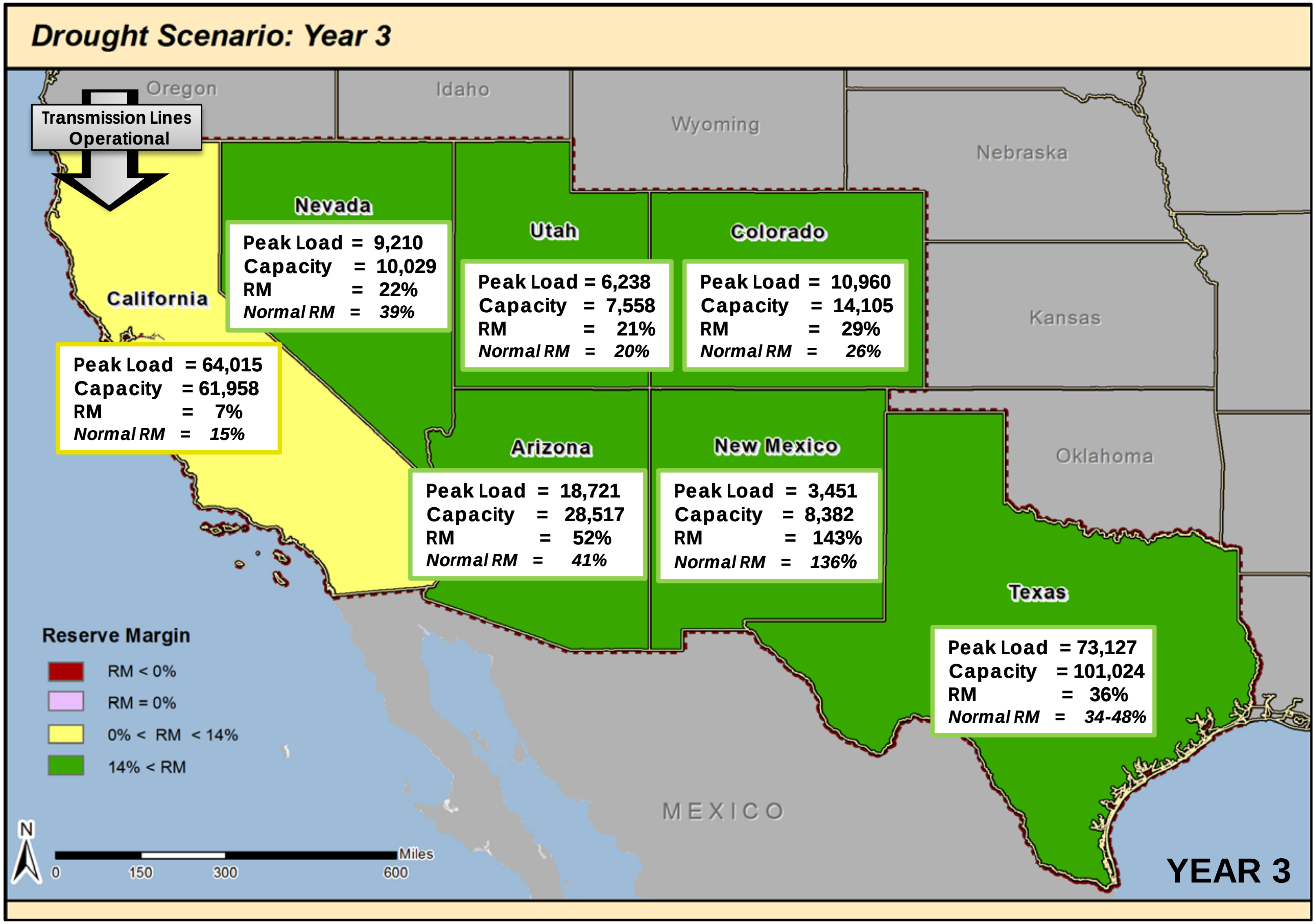
New Mexico
Peak Load = 3,451
Capacity = 8,368
RM = 142%
Normal RM = 136%

Texas
Peak Load = 73,127
Capacity = 91,405
RM = 23%
Normal RM = 34-48%

Reserve Margin
🟥 RM < 0%
🟪 RM = 0%
🟨 0% < RM < 14%
🟩 14% < RM

YEAR 2

Supply-Demand Conditions and Reserve Margin Levels in Year 3 (based on 1932 stream flow) of Drought Scenario in the Southwest



Drought Scenario: Year 3

Transmission Lines Operational

Nevada
Peak Load = 9,210
Capacity = 10,029
RM = 22%
Normal RM = 39%

Utah
Peak Load = 6,238
Capacity = 7,558
RM = 21%
Normal RM = 20%

Colorado
Peak Load = 10,960
Capacity = 14,105
RM = 29%
Normal RM = 26%

California
Peak Load = 64,015
Capacity = 61,958
RM = 7%
Normal RM = 15%

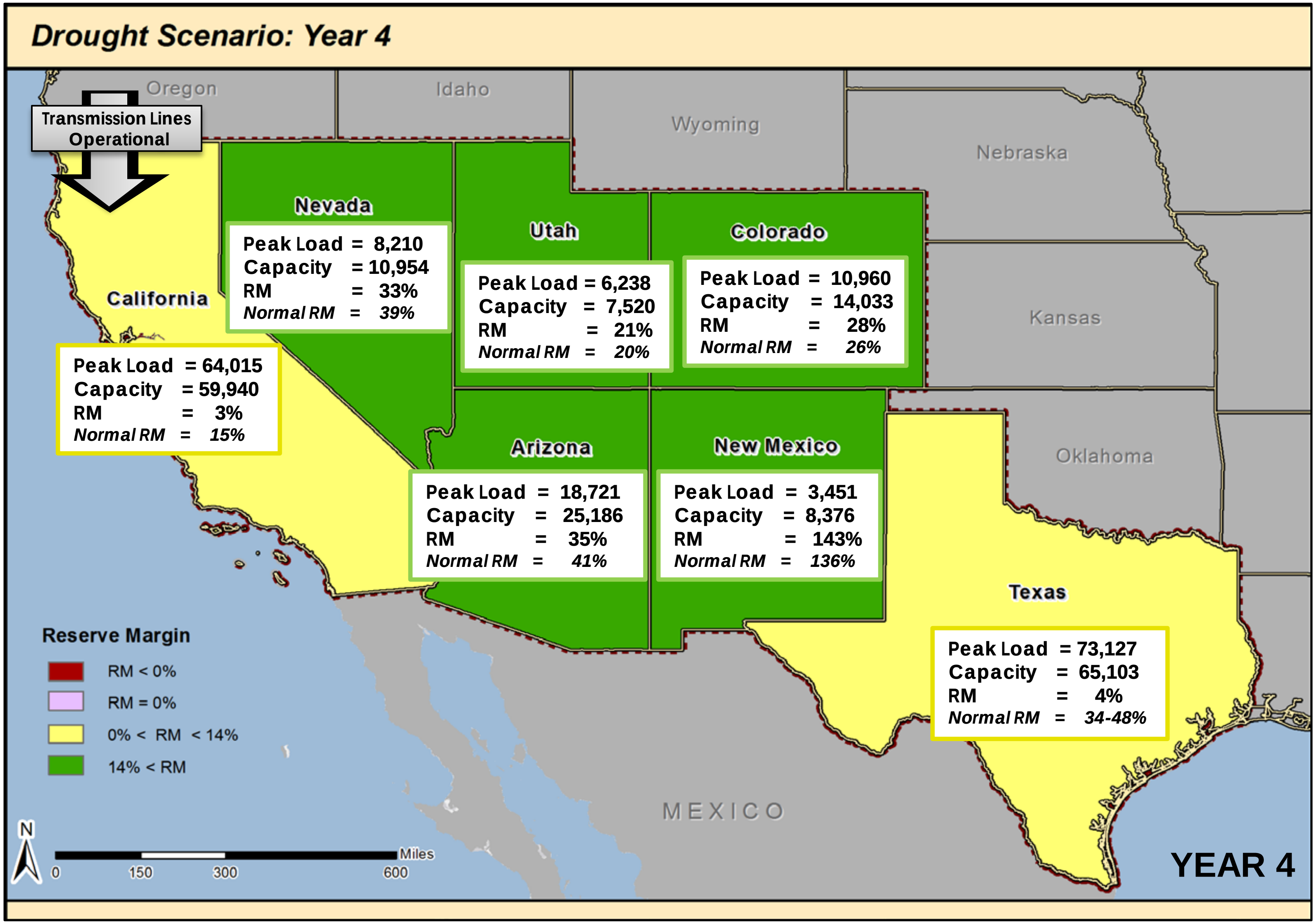
Arizona
Peak Load = 18,721
Capacity = 28,517
RM = 52%
Normal RM = 41%

New Mexico
Peak Load = 3,451
Capacity = 8,382
RM = 143%
Normal RM = 136%

Texas
Peak Load = 73,127
Capacity = 101,024
RM = 36%
Normal RM = 34-48%

Reserve Margin
🟥 RM < 0%
🟪 RM = 0%
🟨 0% < RM < 14%
🟩 14% < RM

Supply-Demand Conditions and Reserve Margin Levels in Year 4 (based on 1933 stream flow) of Drought Scenario in the Southwest



Nevada
Peak Load = 8,210
Capacity = 10,954
RM = 33%
Normal RM = 39%

Utah
Peak Load = 6,238
Capacity = 7,520
RM = 21%
Normal RM = 20%

Colorado
Peak Load = 10,960
Capacity = 14,033
RM = 28%
Normal RM = 26%

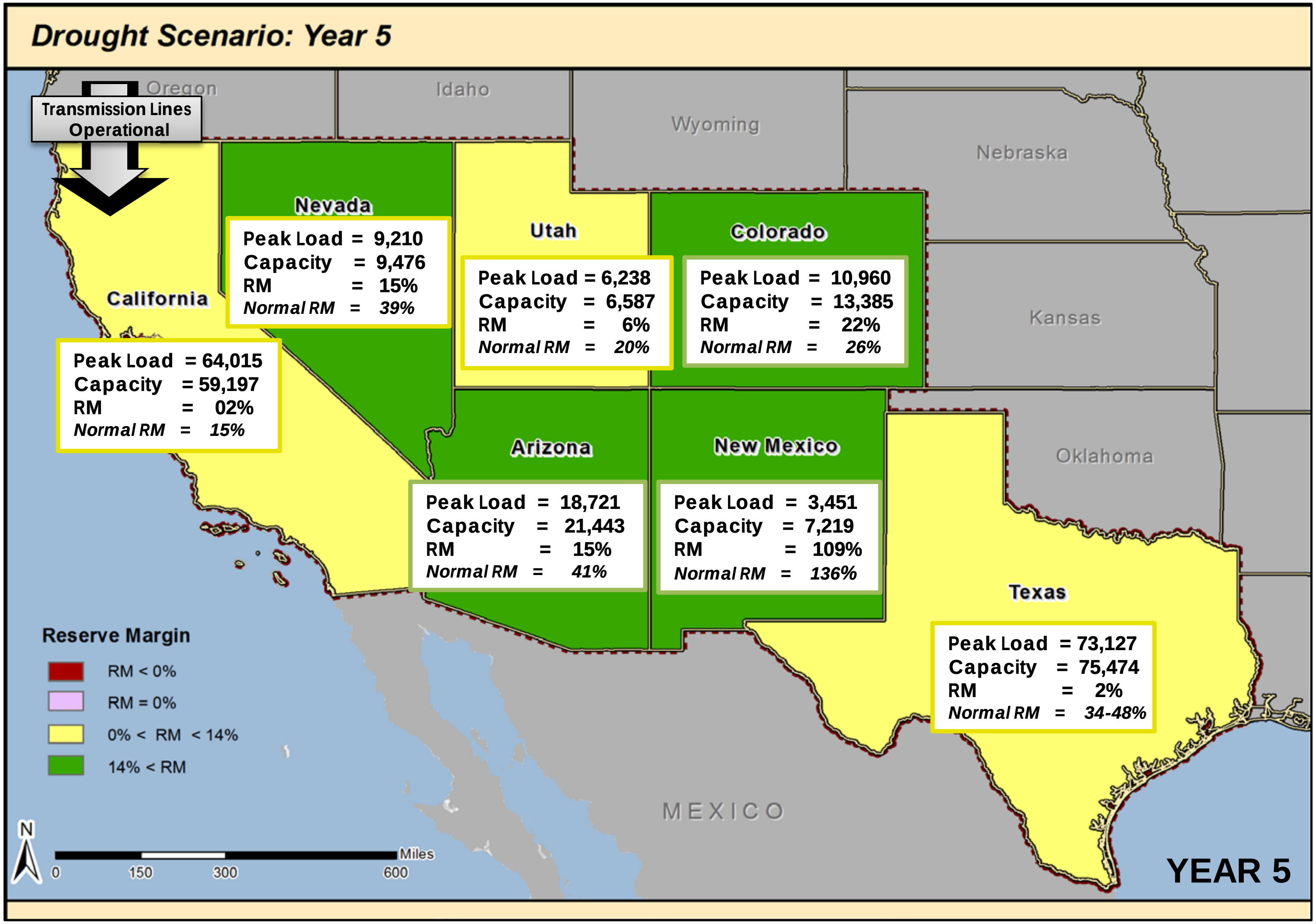
California
Peak Load = 64,015
Capacity = 59,940
RM = 3%
Normal RM = 15%

Arizona
Peak Load = 18,721
Capacity = 25,186
RM = 35%
Normal RM = 41%

New Mexico
Peak Load = 3,451
Capacity = 8,376
RM = 143%
Normal RM = 136%

Texas
Peak Load = 73,127
Capacity = 65,103
RM = 4%
Normal RM = 34-48%

Supply-Demand Conditions and Reserve Margin Levels in Year 5 (based on 1934 stream flow) of Drought Scenario in the Southwest



Drought Scenario: Year 5

Transmission Lines Operational

Nevada
Peak Load = 9,210
Capacity = 9,476
RM = 15%
Normal RM = 39%

Utah
Peak Load = 6,238
Capacity = 6,587
RM = 6%
Normal RM = 20%

Colorado
Peak Load = 10,960
Capacity = 13,385
RM = 22%
Normal RM = 26%

California
Peak Load = 64,015
Capacity = 59,197
RM = 02%
Normal RM = 15%

Arizona
Peak Load = 18,721
Capacity = 21,443
RM = 15%
Normal RM = 41%

New Mexico
Peak Load = 3,451
Capacity = 7,219
RM = 109%
Normal RM = 136%

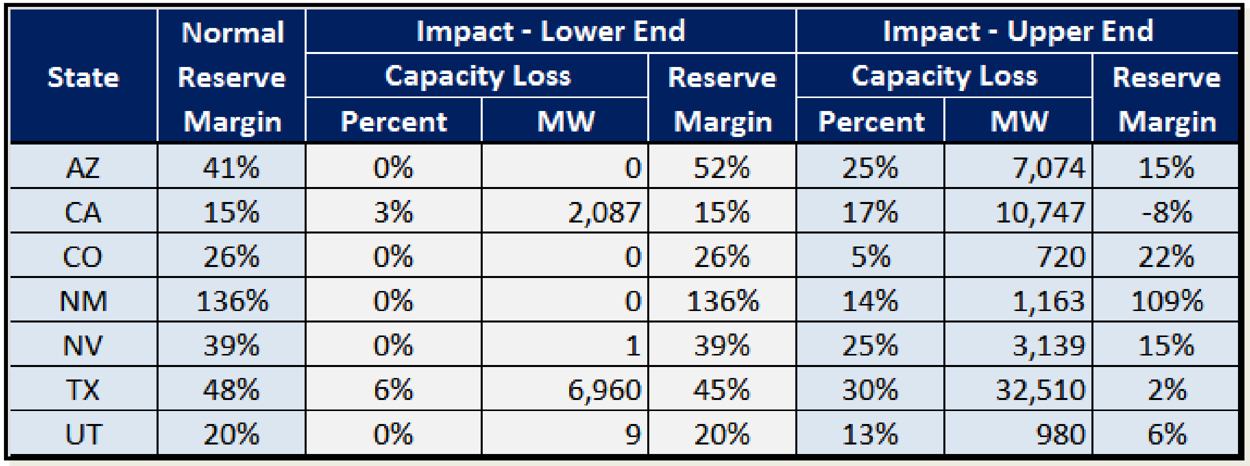
Texas
Peak Load = 73,127
Capacity = 75,474
RM = 2%
Normal RM = 34-48%

Reserve Margin
- 🟥 RM < 0%
- 🟪 RM = 0%
- 🟨 0% < RM < 14%
- 🟩 14% < RM

YEAR 5

Summary of Impacts: State Level

- The five-year drought would have a range of impacts on the power system reliability of the various states as follows:



State	Normal Reserve Margin	Impact - Lower End			Impact - Upper End		
		Capacity Loss		Reserve Margin	Capacity Loss		Reserve Margin
		Percent	MW		Percent	MW	
AZ	41%	0%	0	52%	25%	7,074	15%
CA	15%	3%	2,087	15%	17%	10,747	-8%
CO	26%	0%	0	26%	5%	720	22%
NM	136%	0%	0	136%	14%	1,163	109%
NV	39%	0%	1	39%	25%	3,139	15%
TX	48%	6%	6,960	45%	30%	32,510	2%
UT	20%	0%	9	20%	13%	980	6%

Note: RM calculation assumes no units under maintenance or forced outage.
It further assumes limited availability of wind power during peak.

- CA exhibited highest vulnerability to drought in terms of MW due to its water-dependent thermal units.
- TX showed the largest capacity reduction among the states in the region with capacity loss of up to 30% during the last year (based on 1934 conditions) when stream flows were very low.
- However, TX exhibited reserve margins for years 2 and 3 (1931 and 1934) higher than the NERC reference level of 14%.

Summary of Impacts: State Level

- Without imported power, CA was found to be most susceptible to capacity shortfall with RM raging from -3 % to -17% over all years.

- Even with imported power from the northwest, CA was still susceptible to serious capacity shortfall with RM ranging from -8% to 7% in all drought years of the scenario. It needs additional import power from AZ.

- CO, NV, AZ, and NM appear impervious to all drought events even with 1930 and 1934 stream conditions. These four states maintain positive reserve margins during all drought years.

- CO, NV, AZ, and NM, in particular, exhibited RM consistently above or equal to NERC’s reference RM of 14% throughout the drought period. As such, CO, NV, AZ and NM are the only states within SW region that could export power (although at reduced levels) to more supply-deficient states even during 1930 and 1934 stream flow drought conditions.

Summary of Impacts: Other Effects

- **During summer months, heat index through out most of the region hover at 100 degrees Fahrenheit or greater.**

- **High temperatures cause power system stress in many respects**:
  - Lowers power-carrying capability of system elements such as transmission lines, transformers, circuit breakers, etc.
  - Accelerate deterioration of dielectric materials, operating mechanism, supporting structures, and cooling/insulating liquids used in power apparatus
  - Induces greater overall wear and tear impacts on apparatus which leads to increased vulnerability to faults and cascading failures.
  - Shortens life of batteries that are crucial in supporting UPS and emergency response systems.
  - Significantly reduces the efficiency of PV solar panels
  - Reduces capacity and efficiency of gas and combustion turbines

- **Drought (affected by climate change) combined with possible exhaustion of aquifers could lead to population and power use shifts that could change electrical load patterns.**

Contact Information

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Stewart.Cedres@hq.doe.gov

Supplemental Slides

Potentially-Relevant Technical Papers

Milazi, Dominic and L Pratson, 2009, *The Impact of Drought on Electric Supply in North Carolina,* Master's Thesis, Nicholas School of Environment, Duke University 2009.

Benenson, Peter, et al,1977, *Effects of Drought on California Electricity Supply and Demand,* Lawrence Berkeley Laboratory, University of California Berkeley, June 1977.

Harto, C.B., and Y.E. Yan 2011, *Analysis of Drought Impacts on Electricity Production in Western and Texas Interconnections of the U.S*., Environmental Science Division, Argonne National Laboratory, December 2011.

GoldStein, R, 2006, *Framework to Evaluate Water Demands and Availability for Electrical Power Production Within Watersheds Across the United States: Development and Applications,* Electric Power Research Institute (EPRI), Palo Alto, CA, December 2005.

GoldStein, R, 2003, *A Survey of Water Use and Sustainability in the United States With a Focus on Power Generation* , Electric Power Research Institute (EPRI), Palo Alto CA , November 2003.

Poch, Les, et al, 2009, *Analysis of the Effects of Drought Conditions on Electric Power Generation in the Western United States*, Argonne National Laboratory, Sponsored by National Energy Technology Laboratory (NETL-DOE), April 2009.

Kimmell, Todd, and Jophn Veil, 2009, *Impact of Drought on U.S. Steam Electric Power Plant Cooling Water Intakes and Related Water Resource Management Issues*, Argonne National Laboratory, Sponsored by National Energy Technology Laboratory (NETL-DOE), April 2009.

Potentially-Relevant Technical Papers (contd.)

Alvarado, AL, and Karen Griffin 2006, *Revised Methodology To Estimate Generation Resource Mix of California Electricity Imports, Electricity Analysis Office*, California Energy Commission, San Francisco California, April 12, 2007.

Smith Paul, 2008, *Regional Capacity and New Projects*, Generation Market Analysis and Planning, Western Electricity Coordinating Council (WECC), March 2008.

Feldman, David, 2008, *Freshwater Availability and Constraints on Thermoelectric Power Generation in the Southeast U.S.,* The Southern States Energy Board, Norcross, GA, June 2008.

Tarboton, David, 1994, *The Source Hydrology of Severe Sustained Drought in the Southwestern U.S*., Utah State University, January 1994.

GoldStein, R and W. Smith, 2002, *Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production - The Next Half Century,* Electric Power Research Institute (EPRI) Technical Report, March 2002.

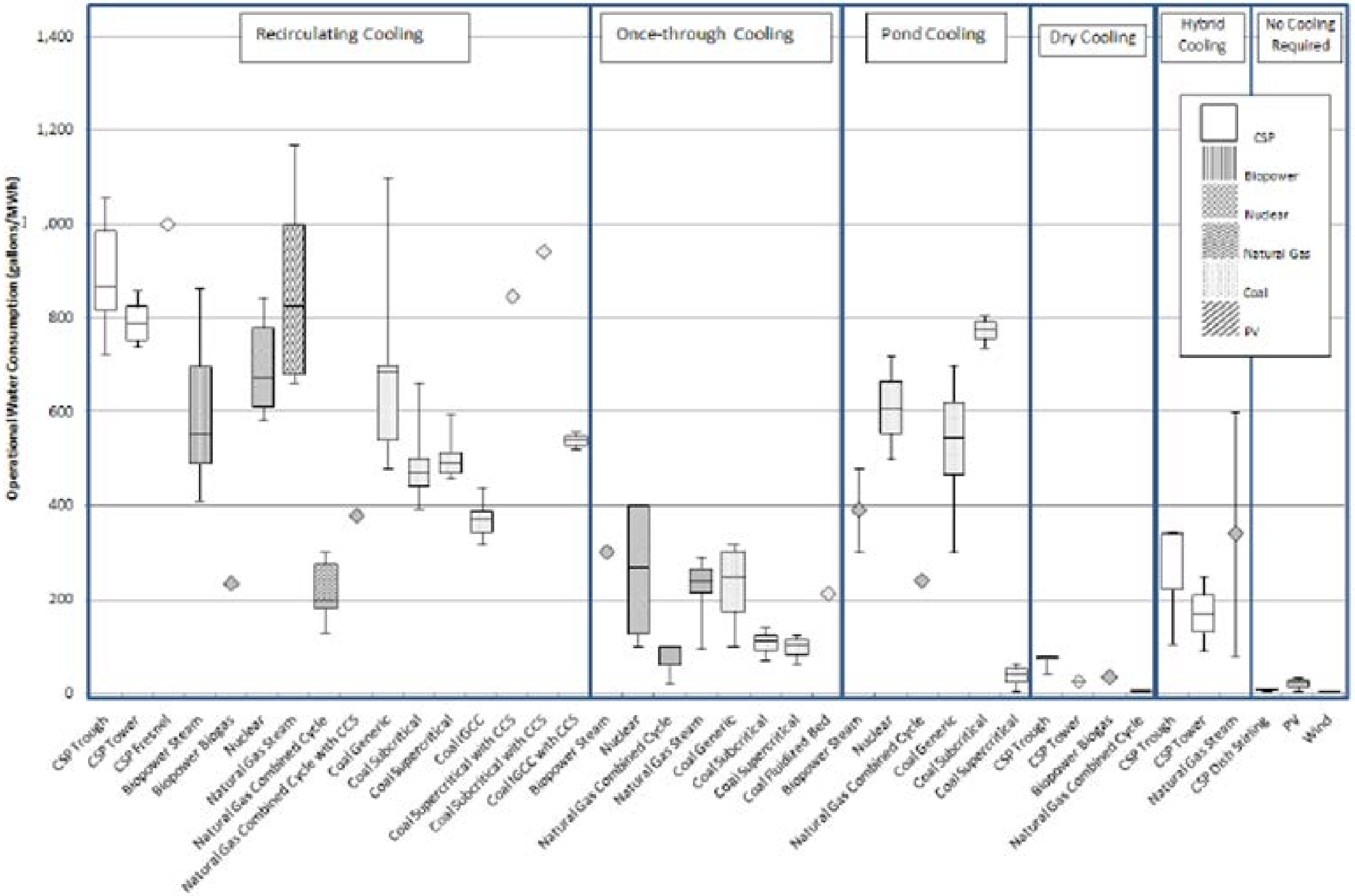
NERC 2011, *2011 Long-Term Reliability Assessment,* North American Electric Reliability Corporation, Atlanta GA (www.nerc.com,) November 2011.

NERC 2012, Summer Reliability Assessment 20102, North American Electric Reliability Corporation, Atlanta GA (www.nerc.com,) November 2011.

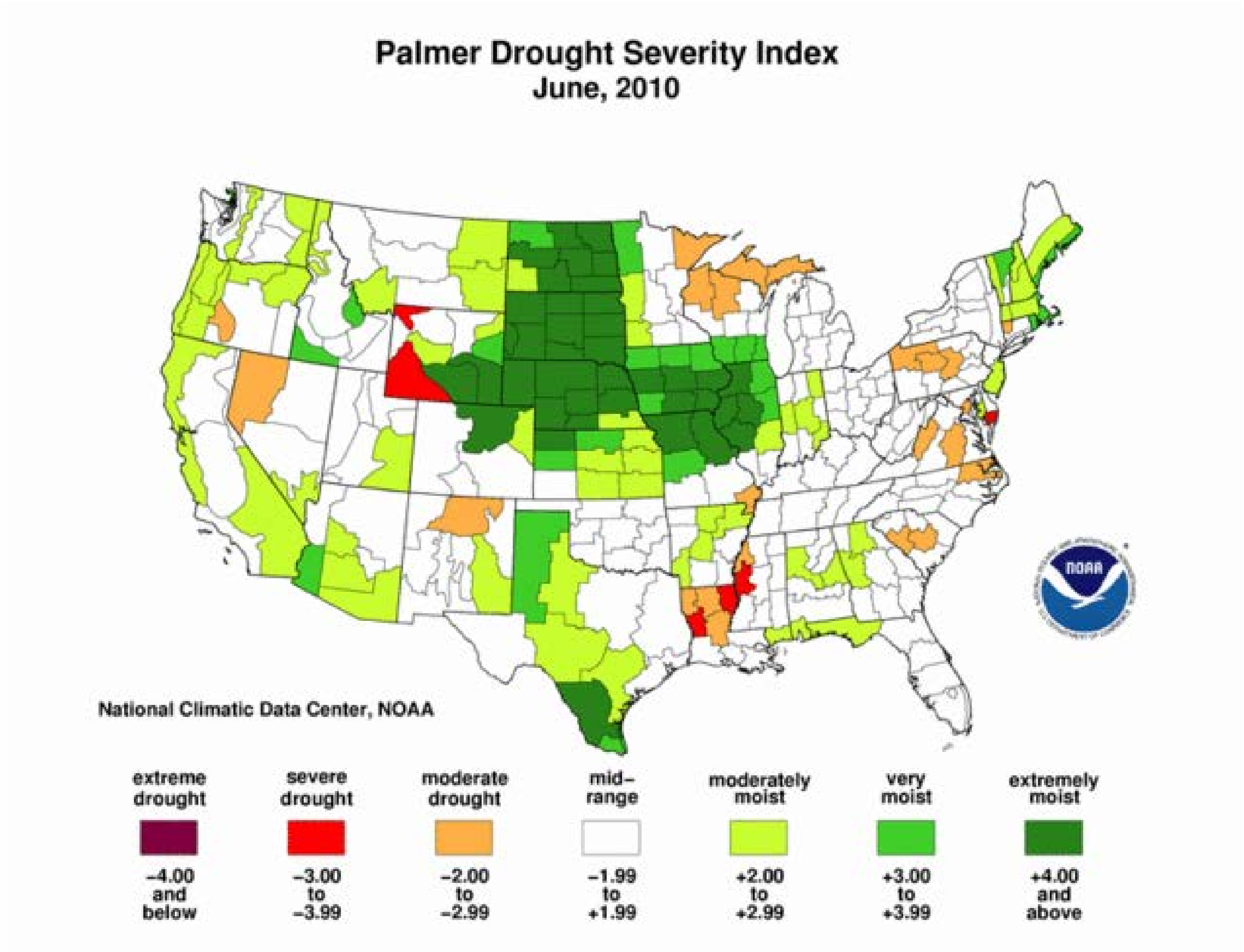
WECC 2011, *Path Rating Studies* 2011

U.S. DEPARTMENT OF ENERGY

Operational Water Consumption Factors for Electricity Generating Technologies



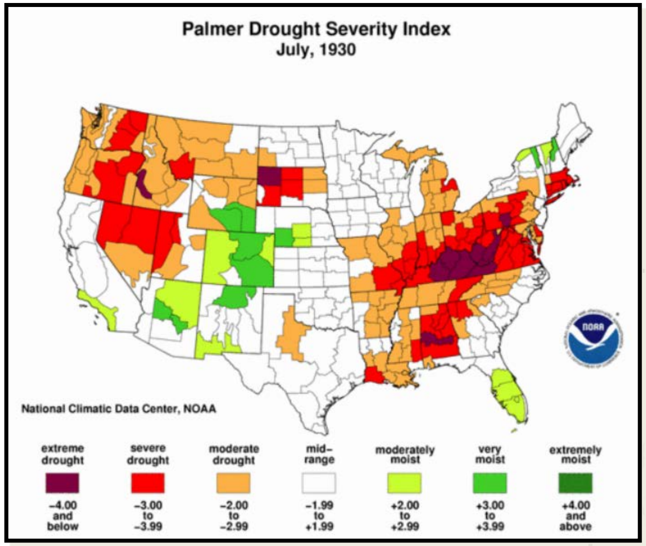
Normal Year Depiction of Drought Index



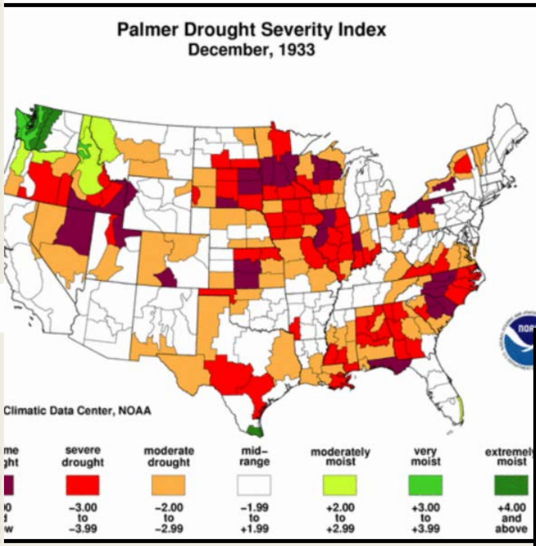
Palmer Drought Severity Index
June, 2010

National Climatic Data Center, NOAA

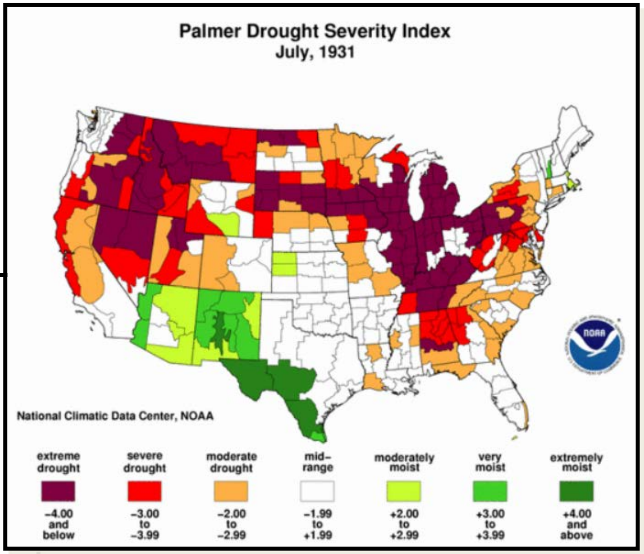
Spatial Extent of Assumed Drought Scenario


Palmer Drought Severity Index
July, 1930

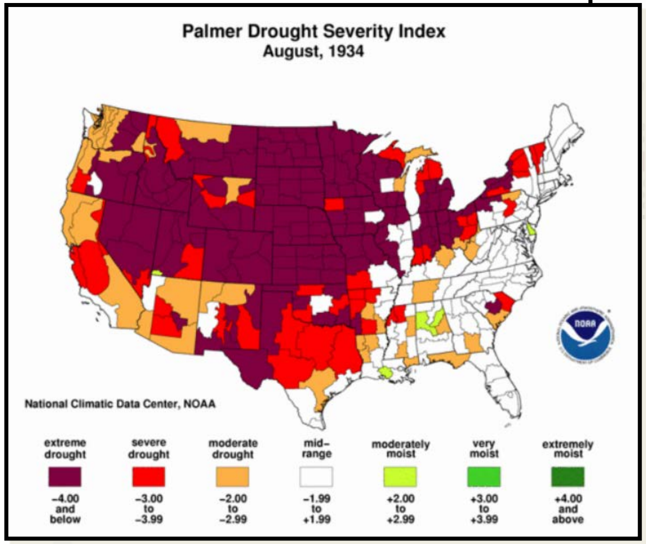
National Climatic Data Center, NOAA


Palmer Drought Severity Index
December, 1933

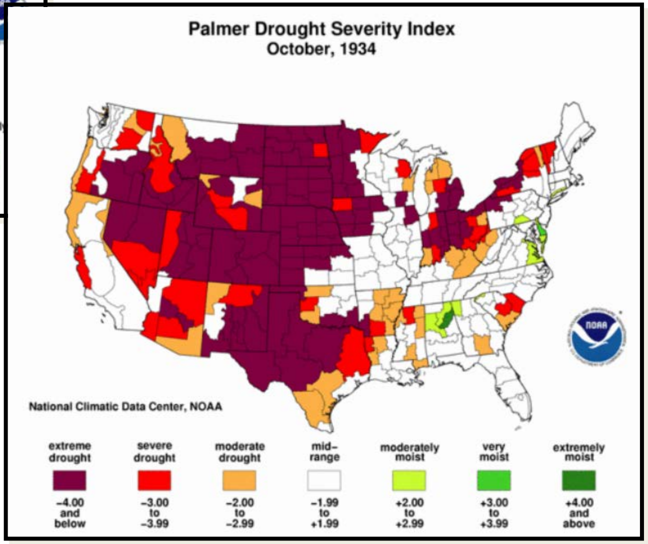
Climatic Data Center, NOAA


Palmer Drought Severity Index
July, 1931

National Climatic Data Center, NOAA


Palmer Drought Severity Index
August, 1934

National Climatic Data Center, NOAA

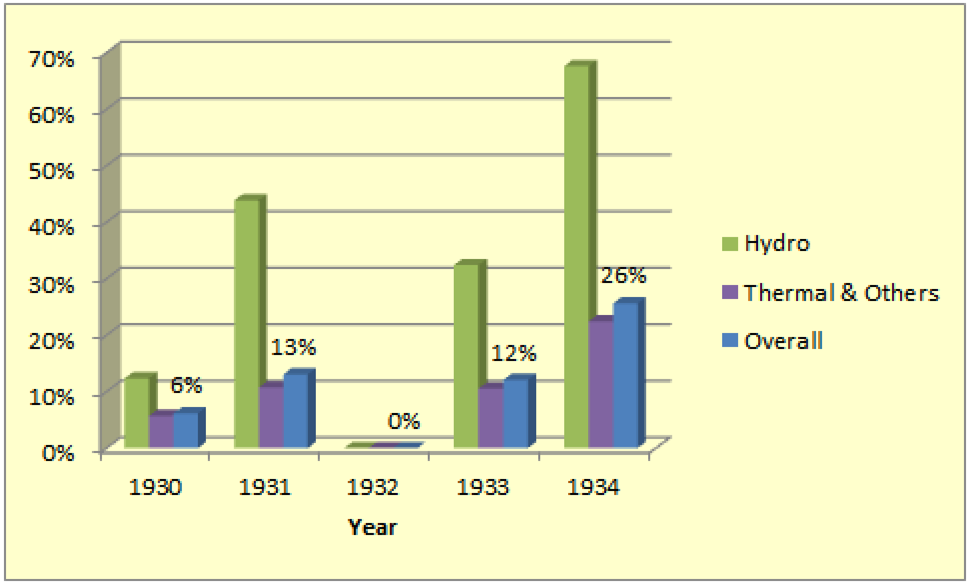

Palmer Drought Severity Index
October, 1934

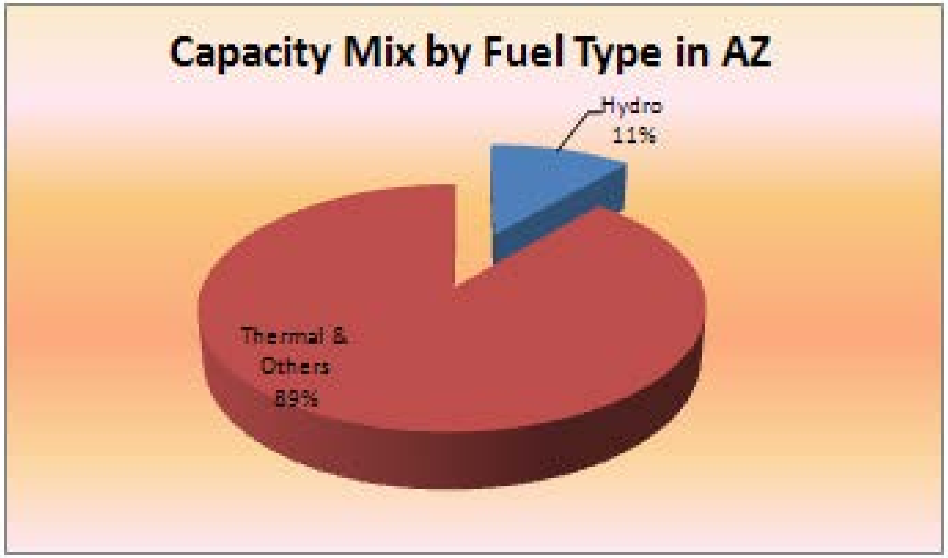
National Climatic Data Center, NOAA

Percent Capacity Reduction in Hydro, Thermal, and Others Capacity as Affected by Drought Conditions in AZ

ARIZONA

Summer Cap: 26,400 MW
Estimated Load: 18,721 MW
Reserve Margin: 41%



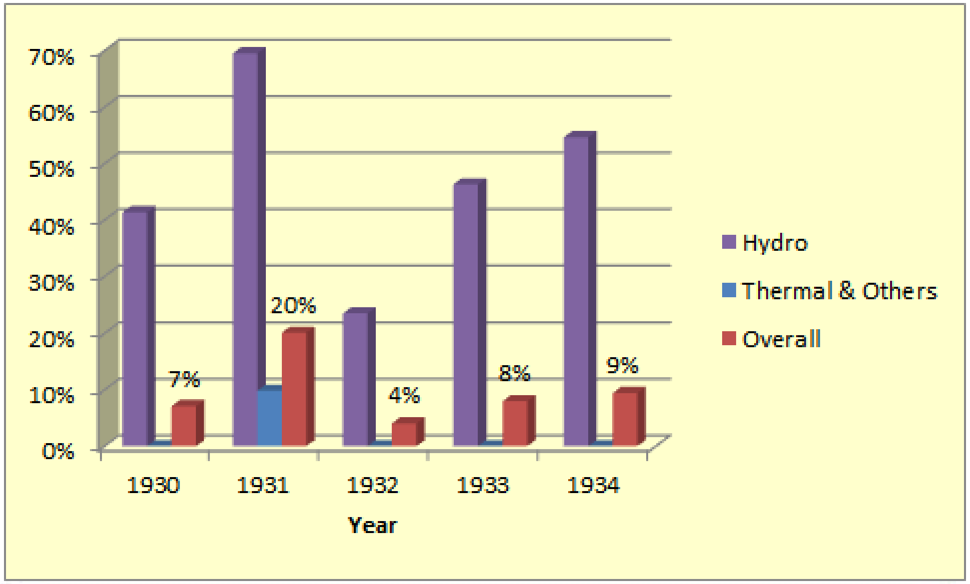


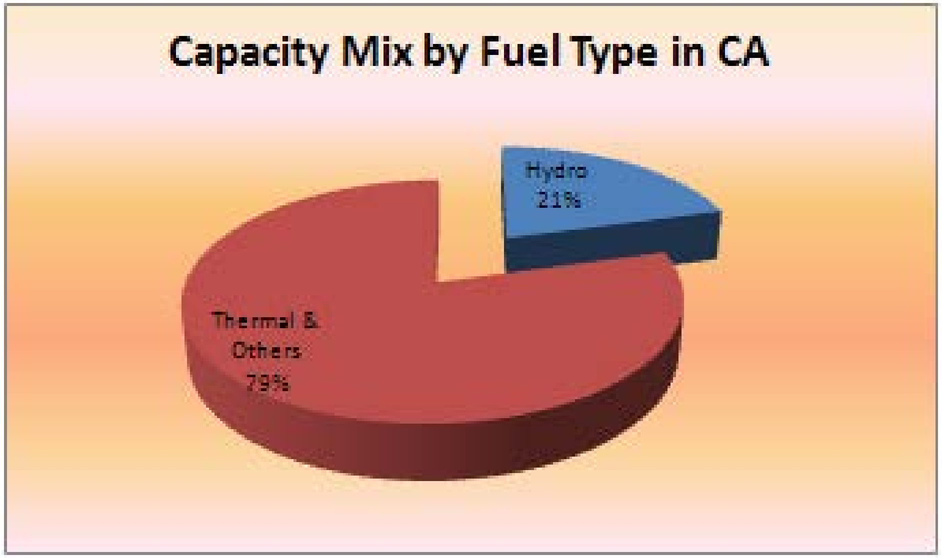
Percent Capacity Reduction in Hydro, Thermal, and Others Capacity as Affected by Drought Conditions in CA

CALIFORNIA

Summer Cap: 73,300 MW
Estimated Load: 64,015 MW
Reserve Margin: 15%

Needs additional imported power from AZ, NM, and NV

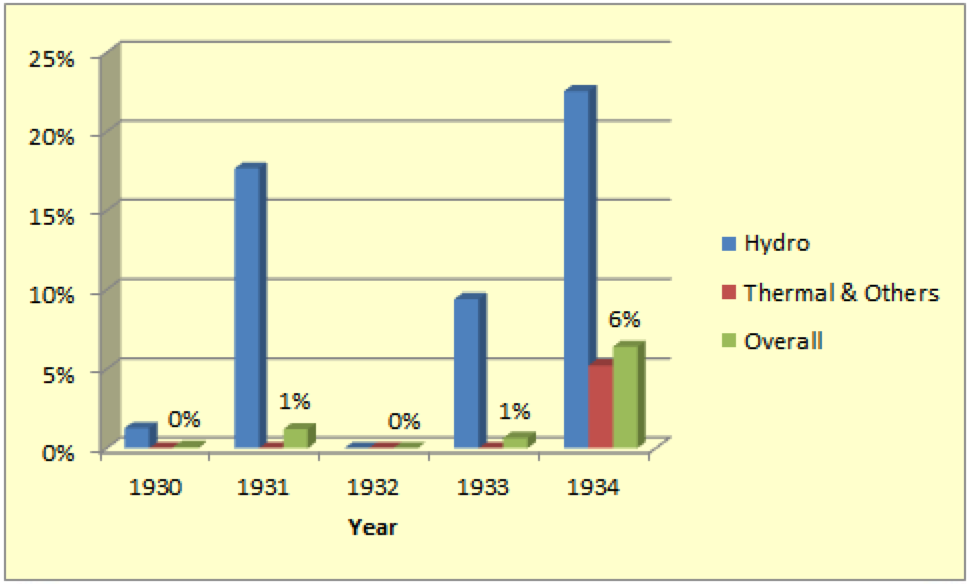


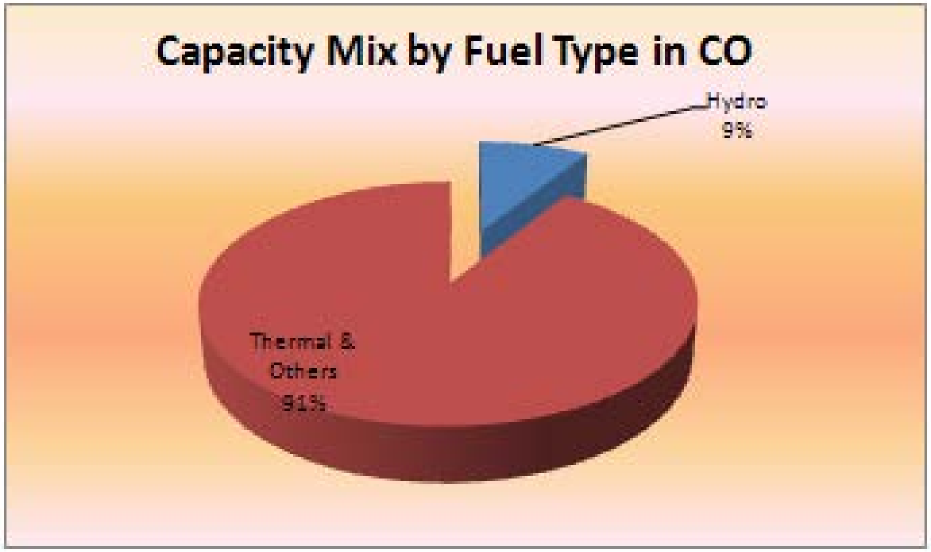


Percent Capacity Reduction in Hydro, Thermal, and Others Capacity as Affected by Drought Conditions in CO

COLORADO

Summer Cap: 13,800 MW
Estimated Load: 11,000 MW
Reserve Margin: 26%

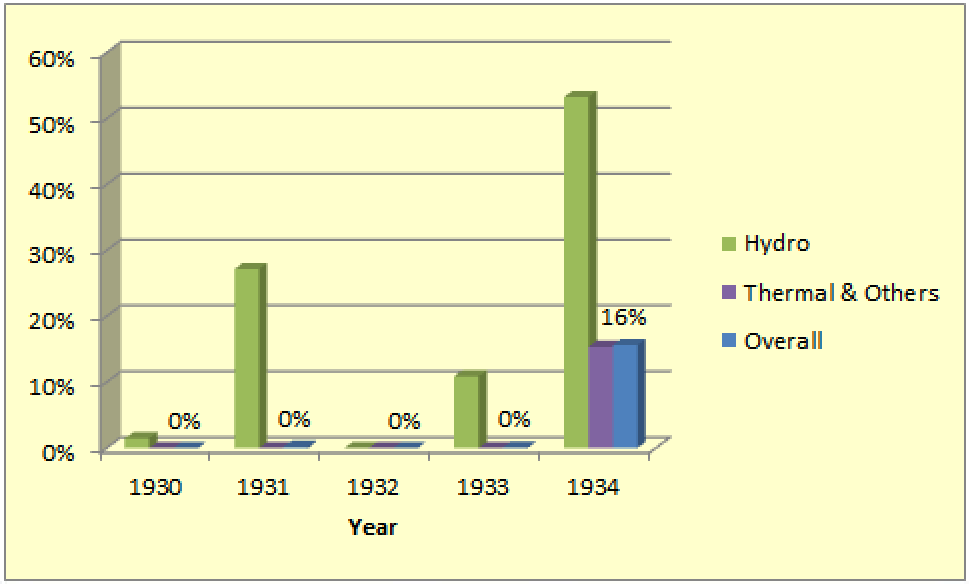


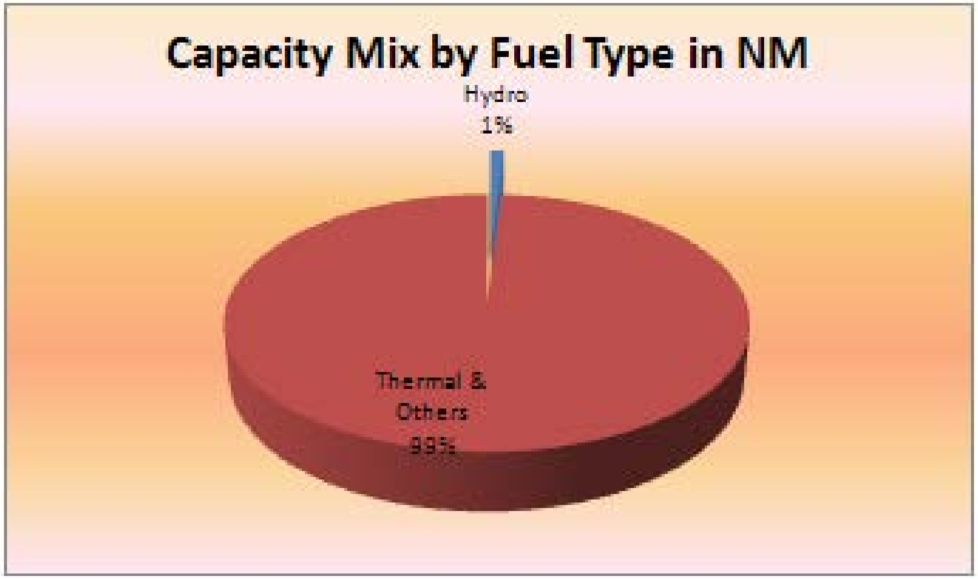


Percent Capacity Reduction in Hydro, Thermal, and Others Capacity as Affected by Drought Conditions in NM

NEW MEXICO

Summer Cap: 8,100 MW
Estimated Load: 3,450 MW
Reserve Margin: 136%

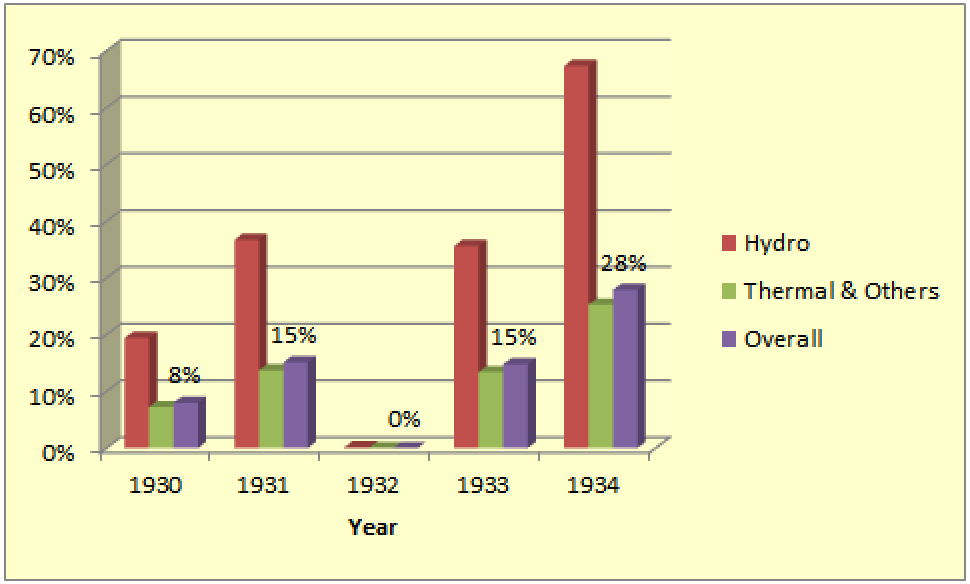


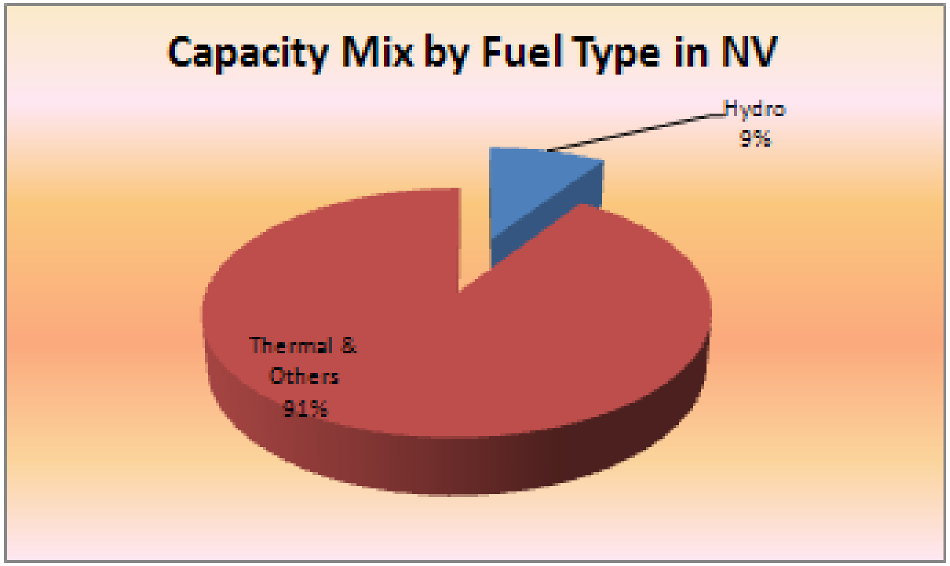


Percent Capacity Reduction in Hydro, Thermal, and Others Capacity as Affected by Drought Conditions in NV

NEVADA

Summer Cap: 11,420 MW
Estimated Load: 8,200 MW
Reserve Margin: 39%



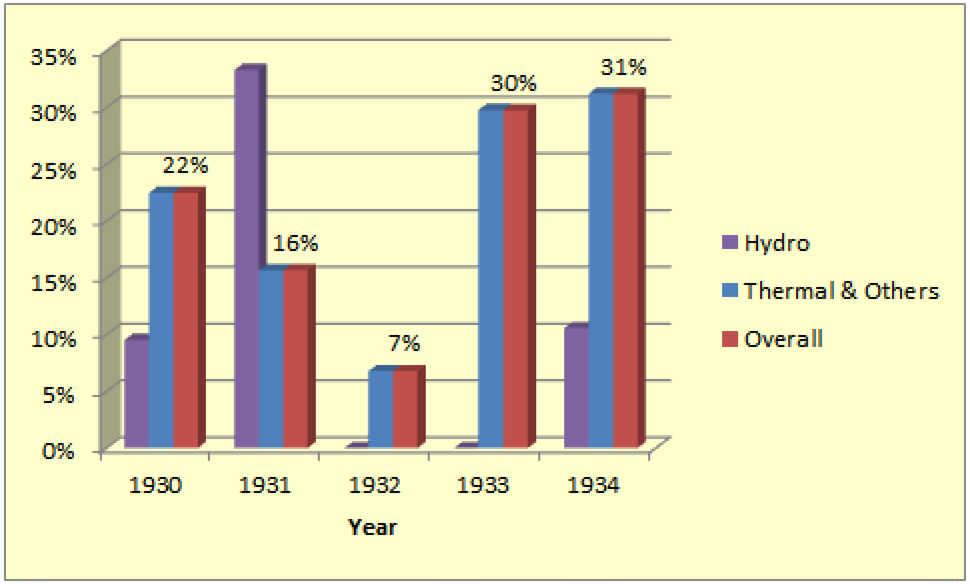


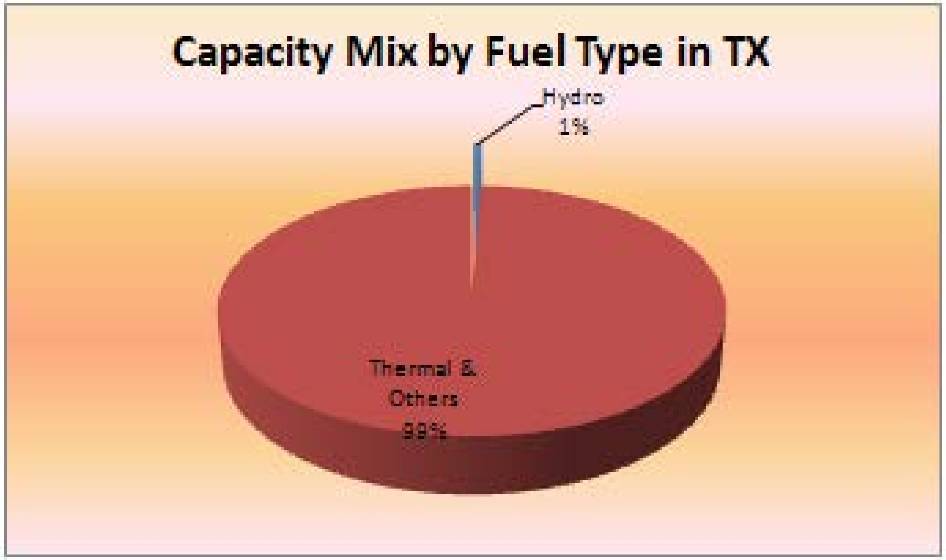
Percent Capacity Reduction in Hydro, Thermal, and Others Capacity as Affected by Drought Conditions in TX

TEXAS

Summer Cap: 108,300 MW
Estimated Load: 73,000 MW
Reserve Margin: 48%

Note: Reserve Margin (RM) calculation assumes that wind power capacity of about 9,000 MW is available. If wind capacity is assumed unavailable RM drops to about 34 %.

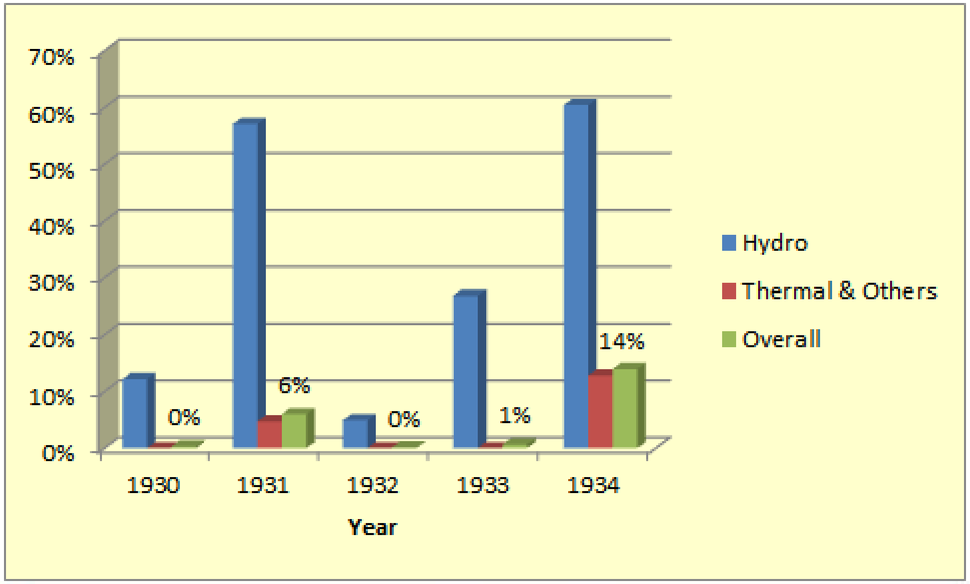


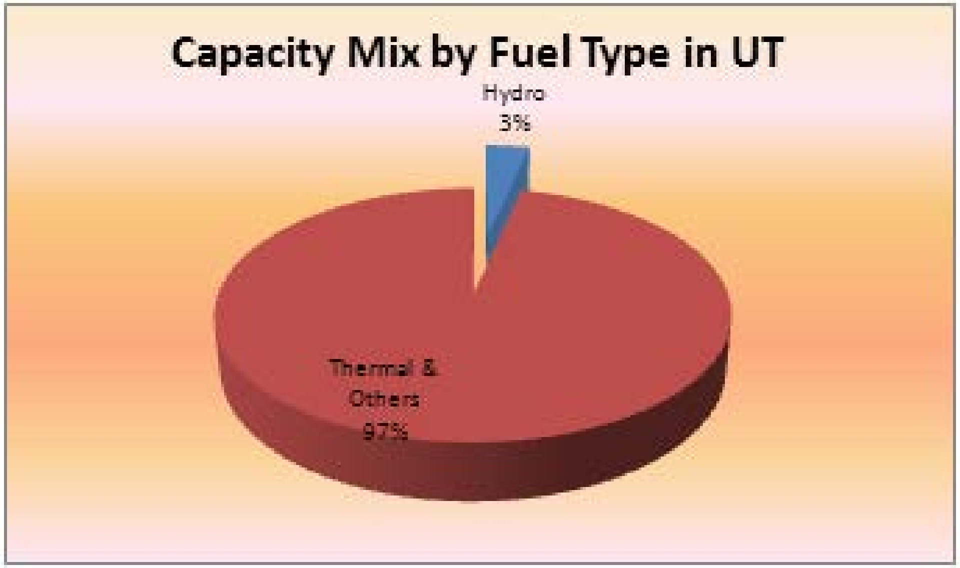


Percent Capacity Reduction in Hydro, Thermal, and Others Capacity as Affected by Drought Conditions in UT

UTAH

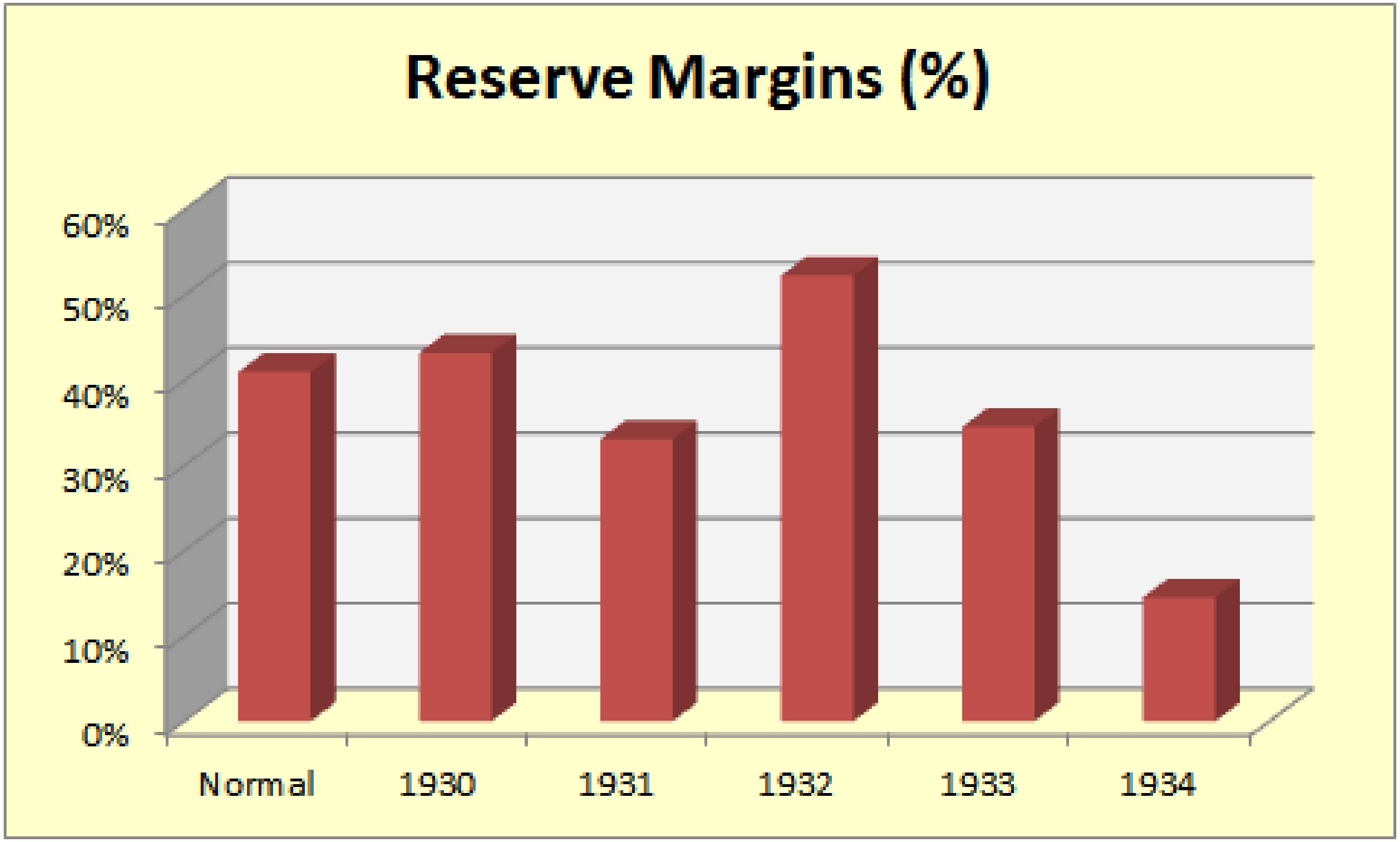
Summer Cap: 7,500 MW
Estimated Load: 6,200 MW
Reserve Margin: 20%





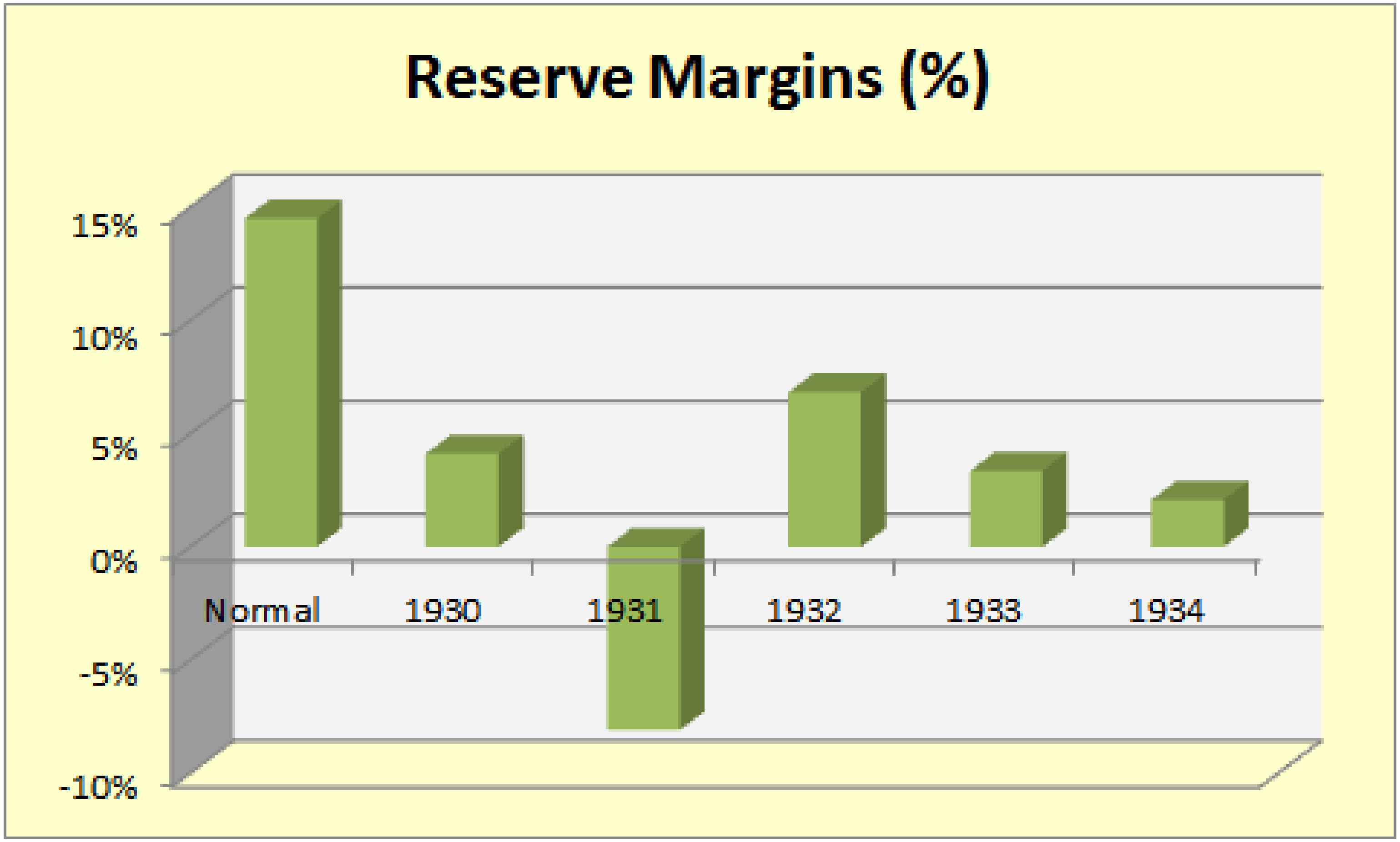
State-wide Reserve Margins as Affected by Drought Conditions in Arizona

ARIZONA



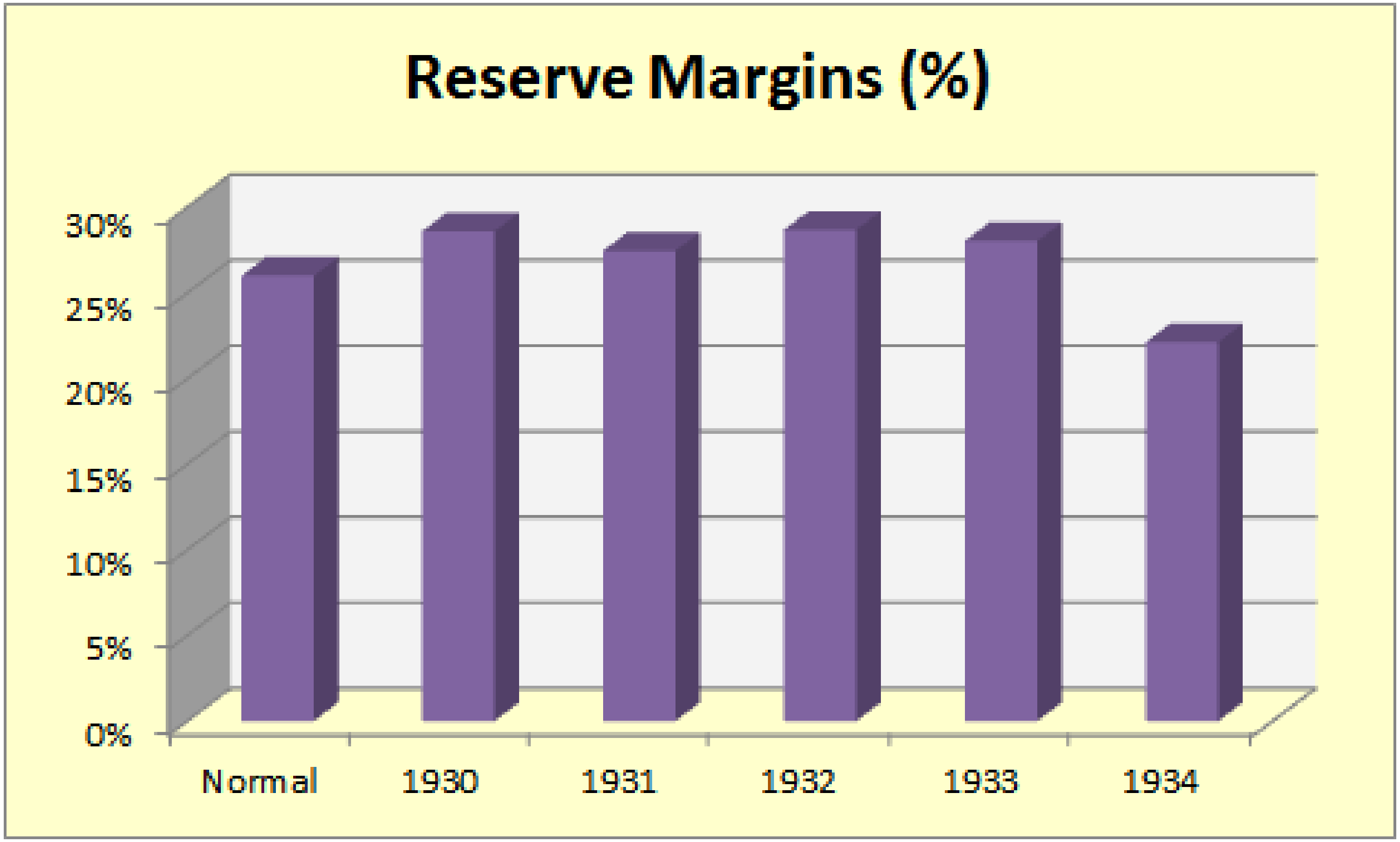
State-wide Reserve Margins as Affected by Drought Conditions in California (with Imports from NW only)

CALIFORNIA



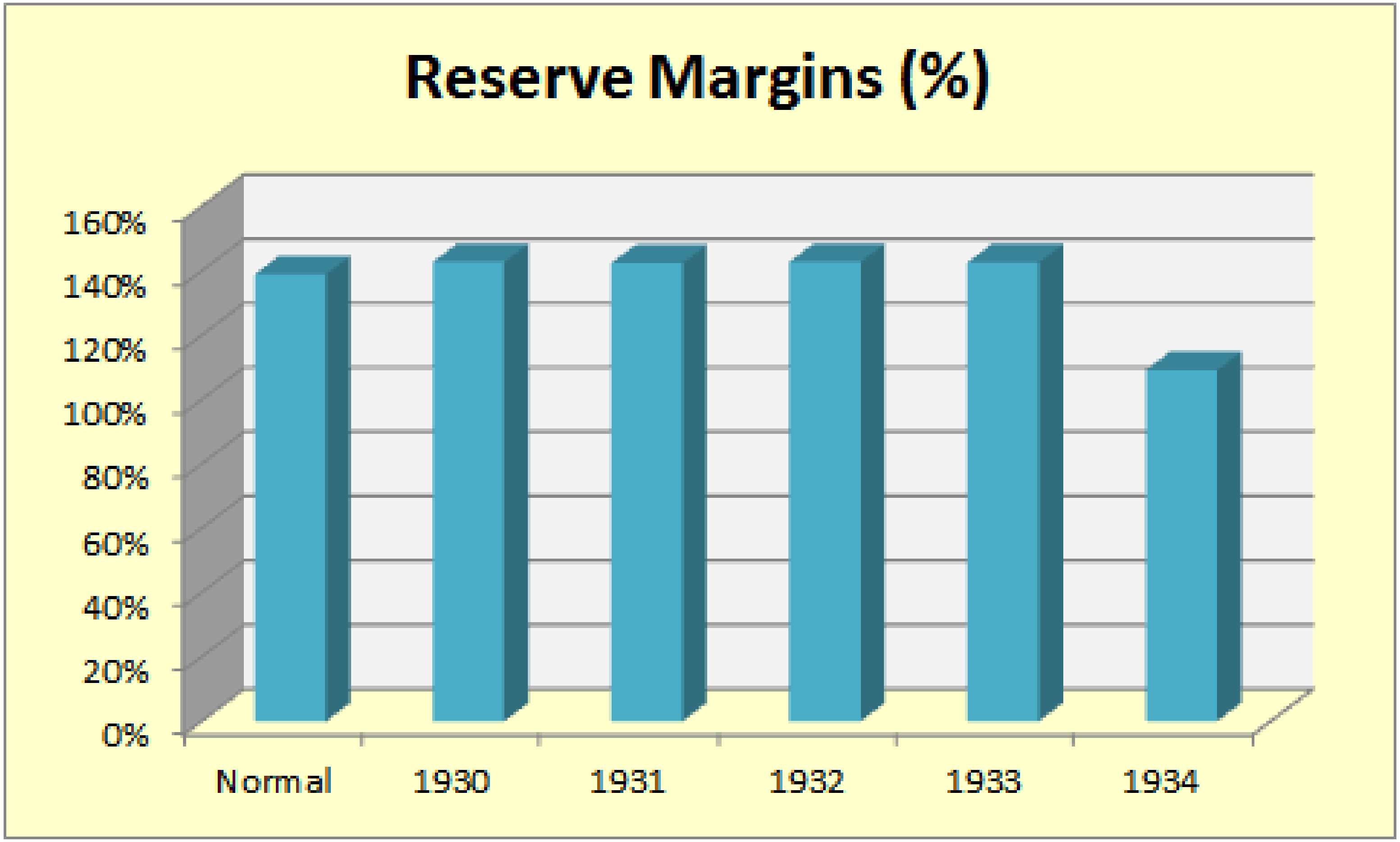
State-wide Reserve Margins as Affected by Drought Conditions in Colorado

COLORADO



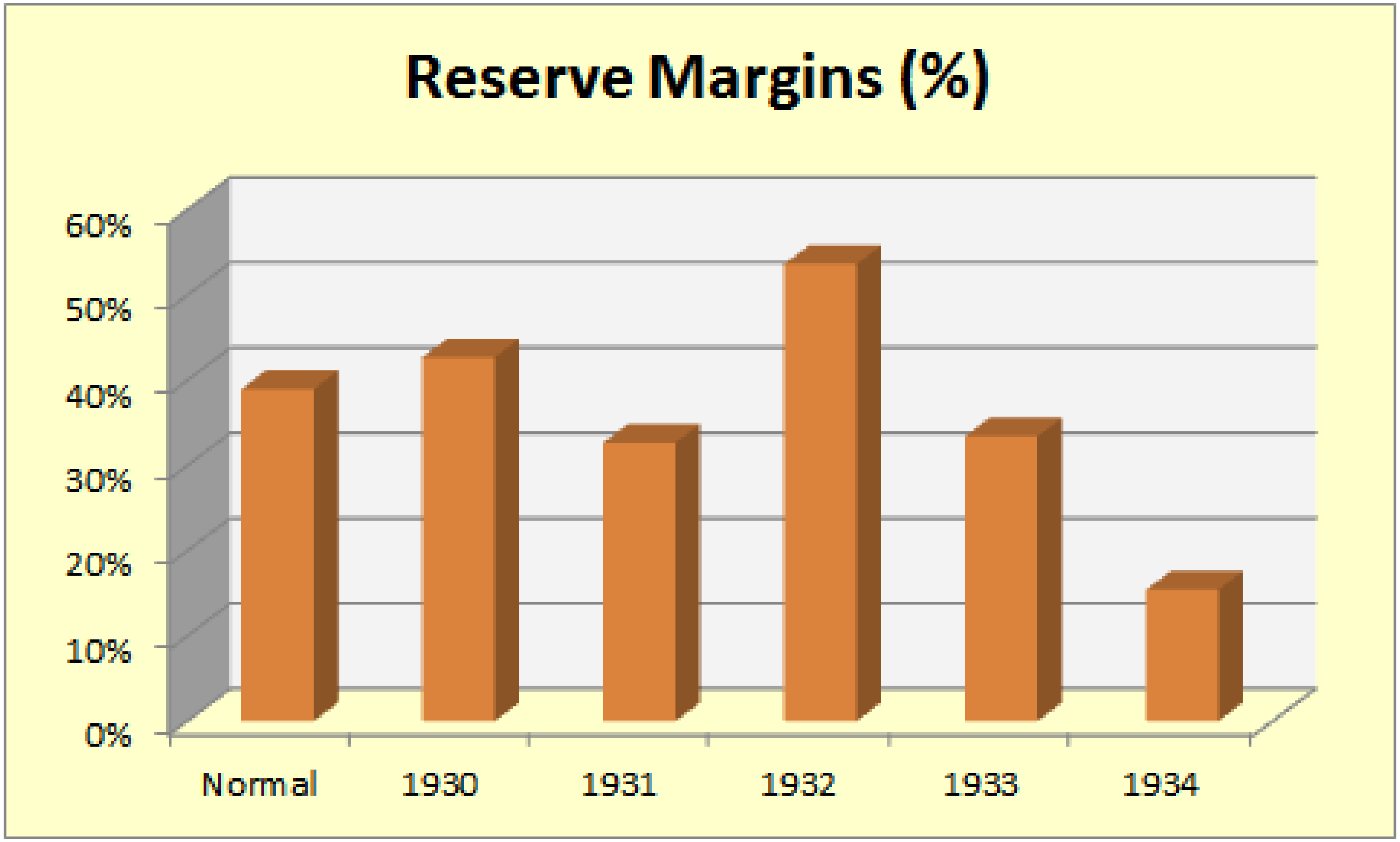
State-wide Reserve Margins as Affected by Drought Conditions in New Mexico

NEW MEXICO



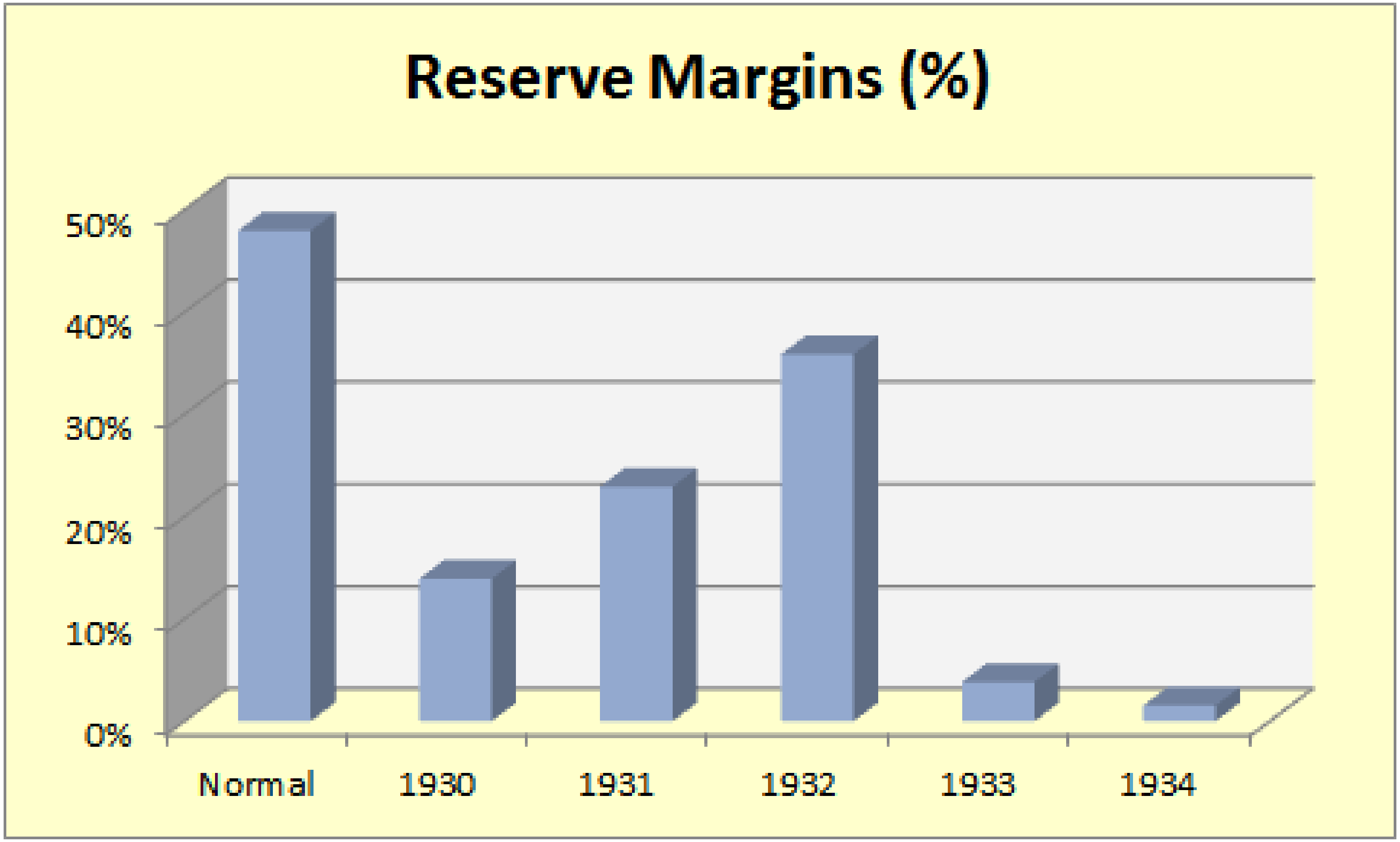
State-wide Reserve Margins as Affected by Drought Conditions in Nevada

NEVADA



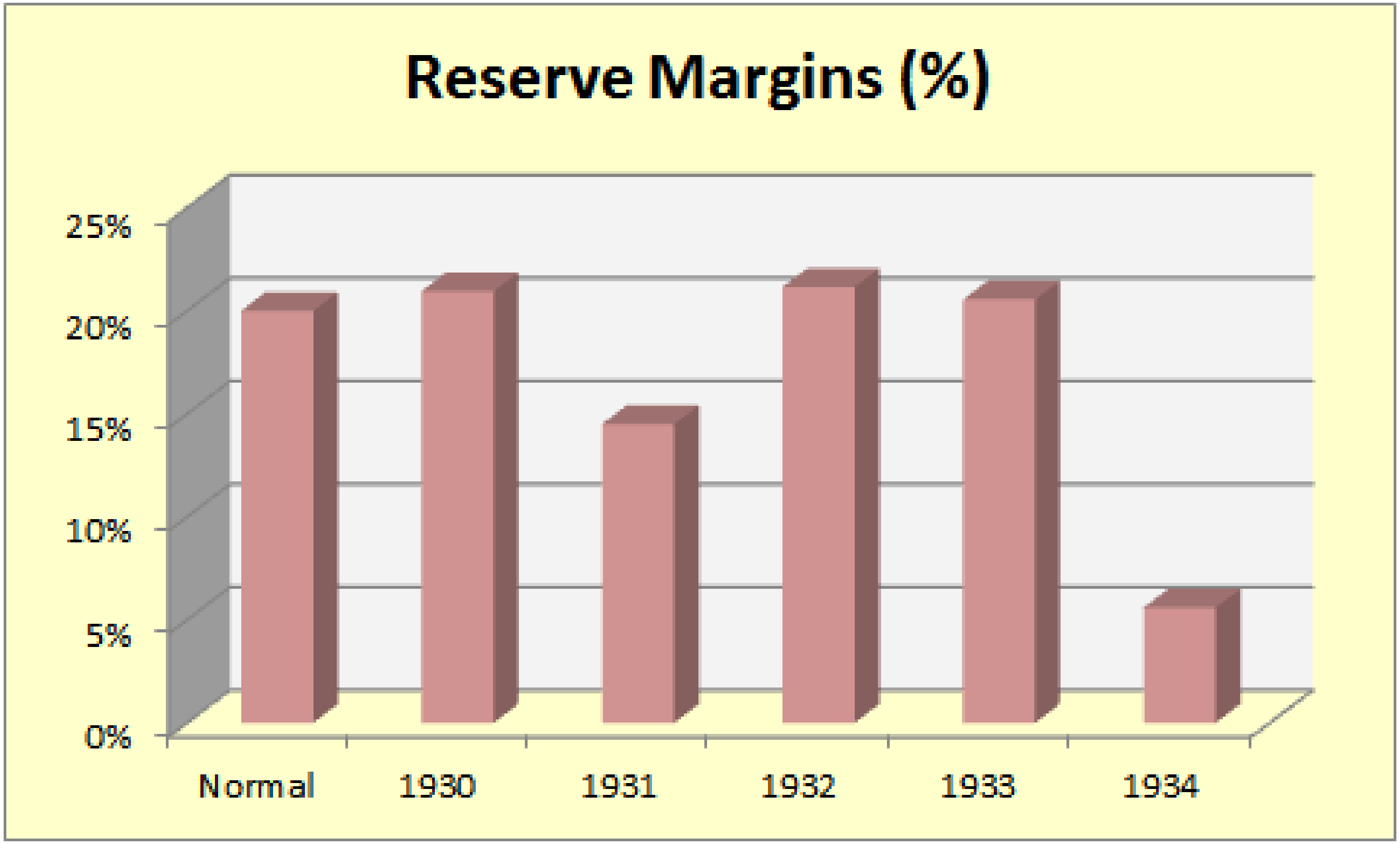
State-wide Reserve Margins as Affected by Drought Conditions in Texas

TEXAS



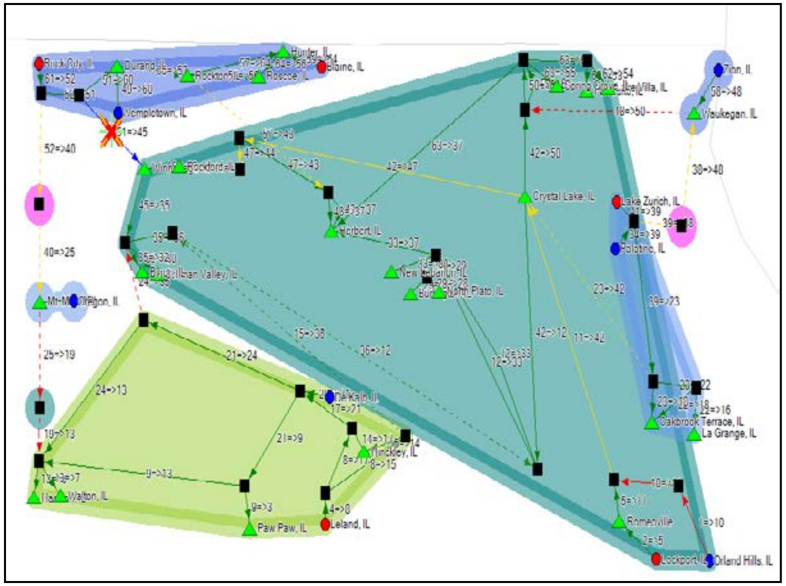
State-wide Reserve Margins as Affected by Drought Conditions in Utah

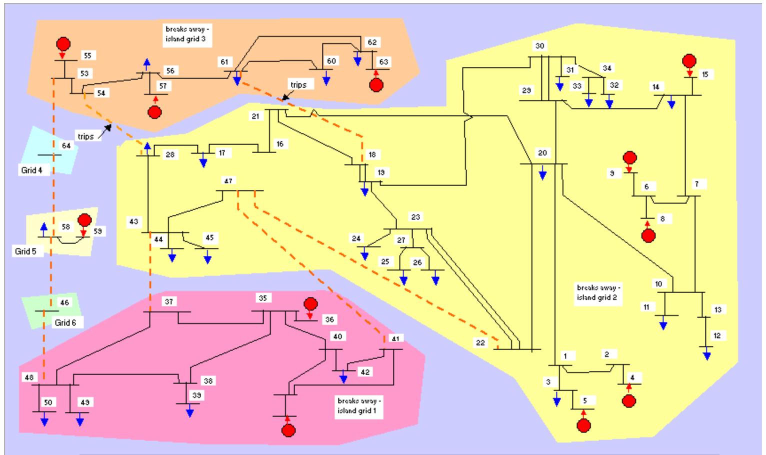
UTAH



EPFast: Model for Uncontrolled Islanding and Load Flow Analysis

- Linear, steady-state model provides a quick estimate of impacts on downstream substations due to:
  - Uncontrolled islanding
  - Single or multiple transmission line outages
  - Plant siting and line reinforcement studies
- Can handle regional size networks:
  - Up to 60,000 nodes and 70,000 lines
  - WECC, ERCOT and Eastern Interconnection
- User-friendly graphical user interface (GUI)
  - Point-and-click technology
- Graphical and tabular HTML – formatted outputs
  - Amount of load reduction per substation
  - Number and size of island grids formed
- Applications
  - FEMA-DOE/OE New Madrid Study
  - DHS Regional Resiliency Studies
  - General seismic and hurricane analysis
  - Others– BLM Solar Energy Zone Transmission Study





SEQUENCE 4. As Line nine lines trip, the splinters into 6 island grids. Each grid will be assessed for sufficeincy of supply; islands that have no source will be considered outage areas.