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
Outline of Presentation

1. Background, Objectives, and Assumptions

2. Methodology and Data

3. Analysis and Results
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.
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    * Low water level limits the amount of water that can be withdrawn (Min water elevation limits)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 CO₂ 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 widespread 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.
    - *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.
Distribution of Power Plant Intakes by Depth from Surface

Location of Thermal Plants with Depth of Intake Information

Source: EIA Form 860
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.

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):
  - 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

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

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

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
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)

Assumed Drought Scenario (5-years)

Current Conditions
## Drought Index Translation Across Selected Severity Indices

### Drought Severity Classification

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

**Increasing Drought Severity**

**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)

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TRE *</td>
<td>63,810</td>
<td>62,412</td>
<td>75,181</td>
<td>75,181</td>
<td>84,164</td>
<td>12,794</td>
<td>20.5%</td>
<td>12.5%</td>
</tr>
<tr>
<td>WECC</td>
<td>129,072</td>
<td>124,924</td>
<td>160,611</td>
<td>161,358</td>
<td>161,358</td>
<td>35,278</td>
<td>28.2%</td>
<td>14.7%</td>
</tr>
<tr>
<td>Basin</td>
<td>13,662</td>
<td>12,642</td>
<td>15,547</td>
<td>15,824</td>
<td>15,824</td>
<td>2,908</td>
<td>23.0%</td>
<td>12.0%</td>
</tr>
<tr>
<td>Northern California</td>
<td>25,310</td>
<td>24,339</td>
<td>29,673</td>
<td>30,068</td>
<td>30,068</td>
<td>5,330</td>
<td>21.9%</td>
<td>14.6%</td>
</tr>
<tr>
<td>Southern California</td>
<td>33,280</td>
<td>31,660</td>
<td>41,051</td>
<td>41,464</td>
<td>41,464</td>
<td>9,403</td>
<td>29.7%</td>
<td>14.8%</td>
</tr>
<tr>
<td>Desert Southwest</td>
<td>27,997</td>
<td>27,470</td>
<td>33,975</td>
<td>33,989</td>
<td>33,989</td>
<td>6,510</td>
<td>23.7%</td>
<td>13.6%</td>
</tr>
<tr>
<td>Northwest</td>
<td>23,855</td>
<td>23,852</td>
<td>32,723</td>
<td>32,963</td>
<td>32,963</td>
<td>8,873</td>
<td>37.2%</td>
<td>18.6%</td>
</tr>
<tr>
<td>Rockies</td>
<td>10,979</td>
<td>10,607</td>
<td>14,480</td>
<td>14,557</td>
<td>14,557</td>
<td>3,872</td>
<td>36.5%</td>
<td>12.3%</td>
</tr>
</tbody>
</table>

*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
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
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)

**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.

**Total Installed Capacity:** 265,555 MW

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Nameplate Capacity (MW)</th>
<th>Percent Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>49,458</td>
<td>19%</td>
</tr>
<tr>
<td>Hydro</td>
<td>19,556</td>
<td>7%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>157,987</td>
<td>59%</td>
</tr>
<tr>
<td>Oil</td>
<td>1,523</td>
<td>1%</td>
</tr>
<tr>
<td>Others</td>
<td>23,107</td>
<td>9%</td>
</tr>
<tr>
<td>Uranium</td>
<td>13,925</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>265,555</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>
Share of High-Risk Capacity in the Southwest (SW)

Share of High-Risk Capacity in the SW

<table>
<thead>
<tr>
<th>Drought Risk Type</th>
<th>Capacity (MW)</th>
<th>Percent Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-Risk Thermal</td>
<td>143,336</td>
<td>54%</td>
</tr>
<tr>
<td>High-Risk Hydro</td>
<td>19,552</td>
<td>7%</td>
</tr>
<tr>
<td>Low-Risk Thermal and Others</td>
<td>102,667</td>
<td>39%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>265,555</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Note: "Others" include wind turbines, etc. that would be unaffected by drought conditions
Dispersal Pattern of High-Risk Hydro Plants within WECC and ERCOT
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:

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

Source: EIA 923 (2010)
Analysis Results:
Hydrological Data and Drought-Driven Capacity Loss Factors
# Stream Flow Levels During Drought

<table>
<thead>
<tr>
<th>Year</th>
<th>Water Basin in Southwest U.S.</th>
<th>Water Basin in Texas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average 1901-2010 Water Flow</td>
<td>20.20</td>
<td>5.29</td>
</tr>
<tr>
<td>Average 1950-2010 Water Flow</td>
<td>20.38</td>
<td>3.42</td>
</tr>
<tr>
<td>Average 2000-2010 Water Flow</td>
<td>19.20</td>
<td>3.06</td>
</tr>
<tr>
<td>2010 Water Demand</td>
<td>10.60</td>
<td>5.54</td>
</tr>
</tbody>
</table>

## Drought Conditions During "Dust Bowl Years" of 1930 to 1934

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<tbody>
<tr>
<td>Annual stream flow during 1930</td>
<td>19.4</td>
<td>6.46</td>
<td>13.73</td>
<td>3.88</td>
<td>10.06</td>
<td>58.77</td>
</tr>
<tr>
<td>Annual stream flow during 1931</td>
<td>20.01</td>
<td>4.71</td>
<td>6.7</td>
<td>3.06</td>
<td>4.85</td>
<td>30.26</td>
</tr>
<tr>
<td>Annual stream flow during 1932</td>
<td>36.2</td>
<td>9.89</td>
<td>16.04</td>
<td>6.41</td>
<td>11.7</td>
<td>76.71</td>
</tr>
<tr>
<td>Annual stream flow during 1933</td>
<td>16.69</td>
<td>5.32</td>
<td>10.23</td>
<td>3.09</td>
<td>10.12</td>
<td>53.93</td>
</tr>
<tr>
<td>Annual stream flow during 1934</td>
<td>14.05</td>
<td>2.95</td>
<td>4.6</td>
<td>1.56</td>
<td>6.82</td>
<td>45.77</td>
</tr>
</tbody>
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Hydrological Data and Drought-Driven Capacity Loss Factors

<table>
<thead>
<tr>
<th>Year</th>
<th>Water Basin in Southwest U.S.</th>
<th></th>
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<tbody>
<tr>
<td>Average 1901-2010 Water Flow</td>
<td>20.20</td>
<td>5.29</td>
<td>14.28</td>
<td>4.81</td>
<td>13.39</td>
<td>100.70</td>
</tr>
<tr>
<td>Average 1950-2010 Water Flow</td>
<td>20.38</td>
<td>3.42</td>
<td>10.29</td>
<td>3.08</td>
<td>13.47</td>
<td>91.66</td>
</tr>
<tr>
<td>Average 2000-2010 Water Flow</td>
<td>19.20</td>
<td>3.06</td>
<td>8.75</td>
<td>2.72</td>
<td>10.72</td>
<td>68.44</td>
</tr>
<tr>
<td>2010 Water Demand</td>
<td>10.60</td>
<td>5.54</td>
<td>6.32</td>
<td>7.80</td>
<td>5.74</td>
<td>35.73</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Estimated Loss Factors (dimensionless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro Loss Factor for 1930</td>
</tr>
<tr>
<td>Hydro Loss Factor for 1931</td>
</tr>
<tr>
<td>Hydro Loss Factor for 1932</td>
</tr>
<tr>
<td>Hydro Loss Factor for 1933</td>
</tr>
<tr>
<td>Hydro Loss Factor for 1934</td>
</tr>
<tr>
<td>Thermal Loss Factor for 1930</td>
</tr>
<tr>
<td>Thermal Loss Factor for 1931</td>
</tr>
<tr>
<td>Thermal Loss Factor for 1932</td>
</tr>
<tr>
<td>Thermal Loss Factor for 1933</td>
</tr>
<tr>
<td>Thermal Loss Factor for 1934</td>
</tr>
</tbody>
</table>

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)

NERC’s Reference Reserve Margin of 14%

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

Year: 1930 - 19%  1931 - 17%  1932 - 30%  1933 - 13%  1934 - 7%

NERC’s Reference Reserve Margin of 14%

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

Year: 1930 - 15%  1931 - 13%  1932 - 26%  1933 - 9%  1934 - 4%
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

Region-Wide Reserve Margins for the Southwest

NERC’s Reference Reserve Margin of 14%
Impact on Regional Supply Capability over Five-Year Drought Scenario

Overall Internal Capacity Reduction (%)

<table>
<thead>
<tr>
<th>Year</th>
<th>Percent Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
<td>12%</td>
</tr>
<tr>
<td>1931</td>
<td>14%</td>
</tr>
<tr>
<td>1932</td>
<td>4%</td>
</tr>
<tr>
<td>1933</td>
<td>16%</td>
</tr>
<tr>
<td>1934</td>
<td>21%</td>
</tr>
</tbody>
</table>
The five year drought sequence will result in a region-wide capacity loss and new reserve margin levels (without imported power) as follows:

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

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

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

**Drought Scenario: Year 1**

- **Transmission Lines Operational**
  - California: Peak Load = 57,994, Capacity = 60,377, RM = 4%, Normal RM = 15%
  - 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%
  - Arizona: Peak Load = 3,451, Capacity = 8,381, RM = 104%, Normal RM = 136%
  - New Mexico: Peak Load = 18,721, Capacity = 26,816, RM = 43%, Normal RM = 41%
  - Texas: Peak Load = 74,338, Capacity = 84,705, RM = 14%, Normal RM = 34-48%

Legend:
- RM < 0%
- RM = 0%
- 0% < RM < 14%
- 14% < RM

YEAR 1
Supply-Demand Conditions and Reserve Margin Levels in Year 2 (based on 1931 stream flow) of Drought Scenario in the Southwest

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%

- 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

- **California**
  - Peak Load: 64,015
  - Capacity: 61,958
  - RM: 7%
  - Normal RM: 15%

- **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%

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

**Drought Scenario: Year 4**

- **California**
  - Peak Load: 64,015
  - Capacity: 59,940
  - RM: 3%
  - Normal RM: 15%

- **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%

- **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%

*Transmission Lines Operational*
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**

- **California**
  - Peak Load: 64,015
  - Capacity: 59,197
  - RM: 02%
  - Normal RM: 15%

- **Nevada**
  - Peak Load: 9,210
  - Capacity: 9,476
  - RM: 15%
  - Normal RM: 39%

- **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%

- **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%

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

Transmission Lines Operational

**Reserve Margin**
- RM < 0%
- RM = 0%
- 0% < RM < 14%
- 14% < RM
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:

<table>
<thead>
<tr>
<th>State</th>
<th>Normal Reserve Margin</th>
<th>Impact - Lower End</th>
<th>Impact - Upper End</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Capacity Loss</td>
<td>Reserve Margin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percent</td>
<td>MW</td>
</tr>
<tr>
<td>AZ</td>
<td>41%</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>CA</td>
<td>15%</td>
<td>3%</td>
<td>2,087</td>
</tr>
<tr>
<td>CO</td>
<td>26%</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>NM</td>
<td>136%</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>NV</td>
<td>39%</td>
<td>0%</td>
<td>1</td>
</tr>
<tr>
<td>TX</td>
<td>48%</td>
<td>6%</td>
<td>6,960</td>
</tr>
<tr>
<td>UT</td>
<td>20%</td>
<td>0%</td>
<td>9</td>
</tr>
</tbody>
</table>

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 ranging 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.
During summer months, heat index throughout 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
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Supplemental Slides
Potentially-Relevant Technical Papers


Potentially-Relevant Technical Papers (contd.)


WECC 2011, *Path Rating Studies 2011*
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

- extreme drought: $-4.00$ and below
- severe drought: $-3.00$ to $-3.99$
- moderate drought: $-2.00$ to $-2.99$
- mid-range: $-1.99$ to $+1.99$
- moderately moist: $+2.00$ to $+2.99$
- very moist: $+3.00$ to $+3.99$
- extremely moist: $+4.00$ and above
Spatial Extent of Assumed Drought Scenario
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
COLORADO

Summer Cap: 13,800 MW
Estimated Load: 11,000 MW
Reserve Margin: 26%
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%.
Percentage 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)
State-wide Reserve Margins as Affected by Drought Conditions in Colorado

COLORADO

![Reserve Margins (%)](chart)
State-wide Reserve Margins as Affected by Drought Conditions in New Mexico

NEW MEXICO

Reserve Margins (%)

- Normal
- 1930
- 1931
- 1932
- 1933
- 1934

- 160%
- 140%
- 120%
- 100%
- 80%
- 60%
- 40%
- 20%
- 0%
State-wide Reserve Margins as Affected by Drought Conditions in Nevada

NEVADA

![Bar graph showing Reserve Margins (%)](image)

- Normal: 30%
- 1930: 40%
- 1931: 30%
- 1932: 60%
- 1933: 40%
- 1934: 20%
State-wide Reserve Margins as Affected by Drought Conditions in Texas

Reserve Margins (%)

- Normal
- 1930
- 1931
- 1932
- 1933
- 1934

Margins decrease significantly from normal to the drought years.
State-wide Reserve Margins as Affected by Drought Conditions in Utah

UTAH

Reserve Margins (%)

- Normal
- 1930
- 1931
- 1932
- 1933
- 1934
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