# Statewide Impacts of Climate Change on Hydroelectric Generation and Revenues in California

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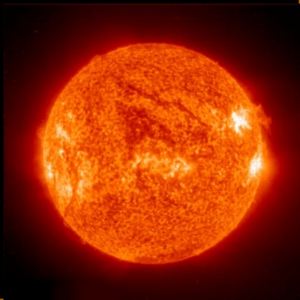


September 2008

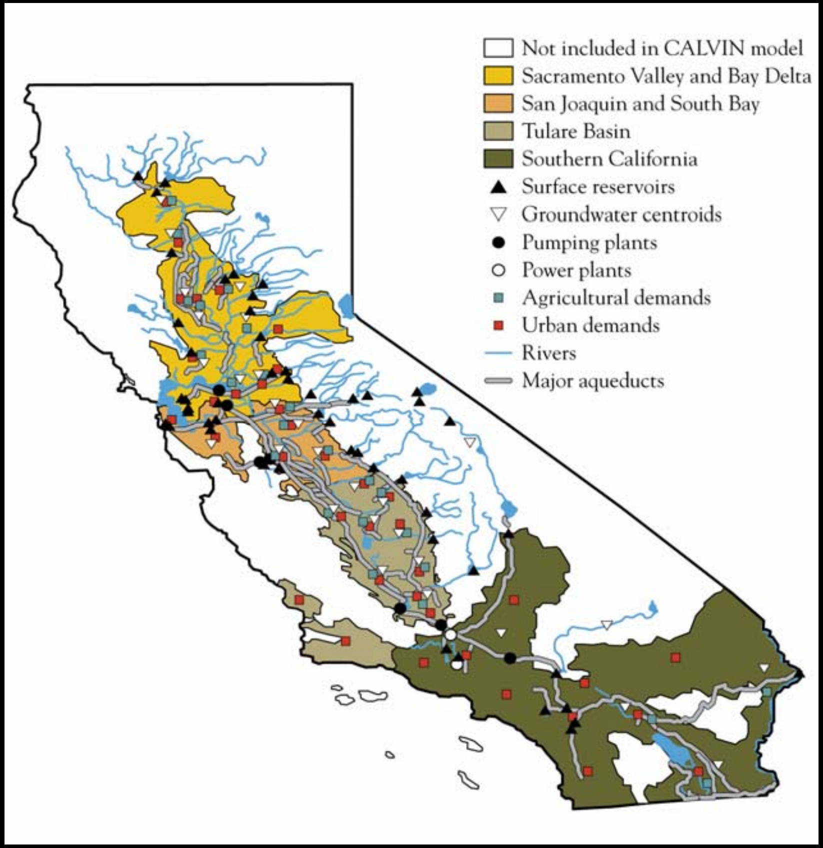
# Outline

- CALVIN updates
- Hydropower in California
- Effects on Low Elevation System (CALVIN)
- Effects on High Elevation System (EBHOM)
- Results
- Limitations!
- Next Step?
- Conclusions

# Water Management Adaptation to Climate Warming using CALVIN

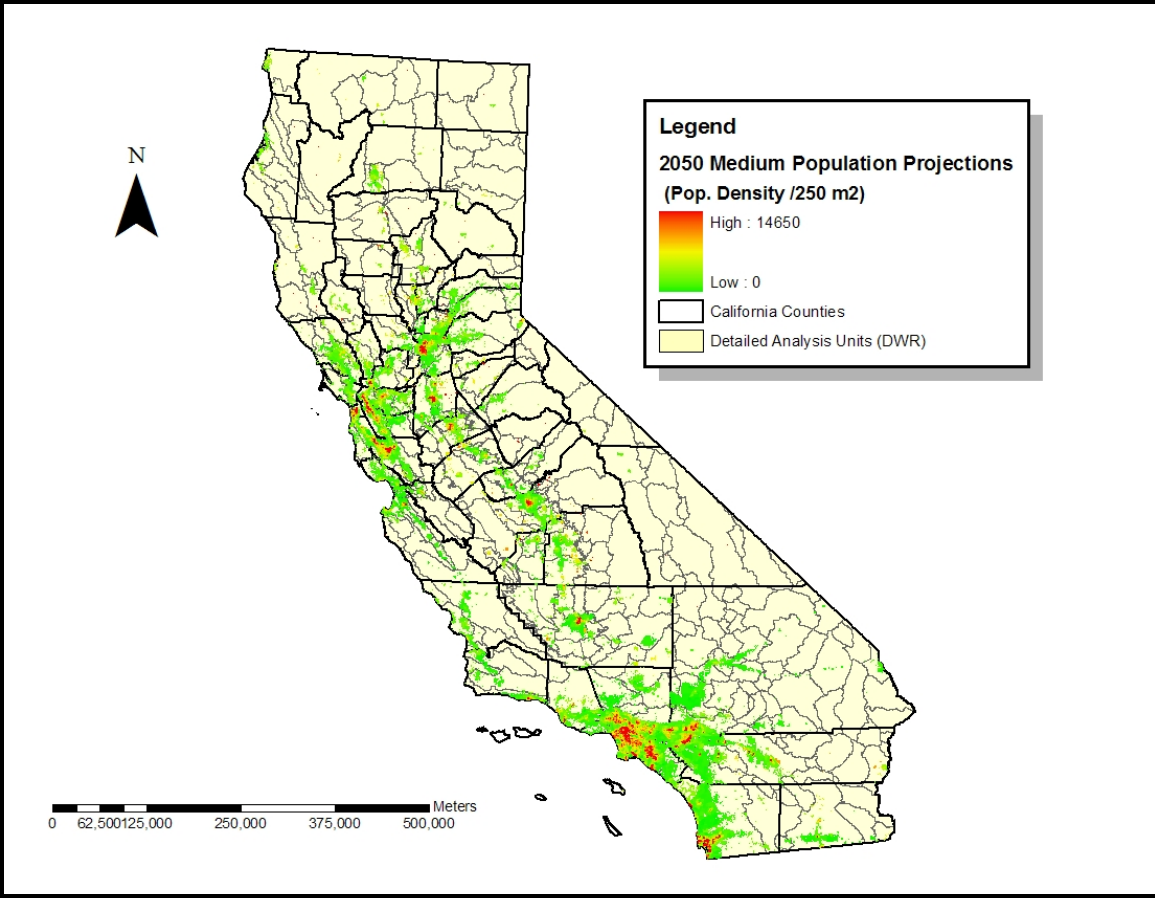
# The CALVIN model

- An hydro-economic model for water resources management in California
- Applications
  - Conjunctive use and water markets
  - Climate change
  - Alternatives for the Sacramento-San Joaquin Delta.



# The CALVIN model

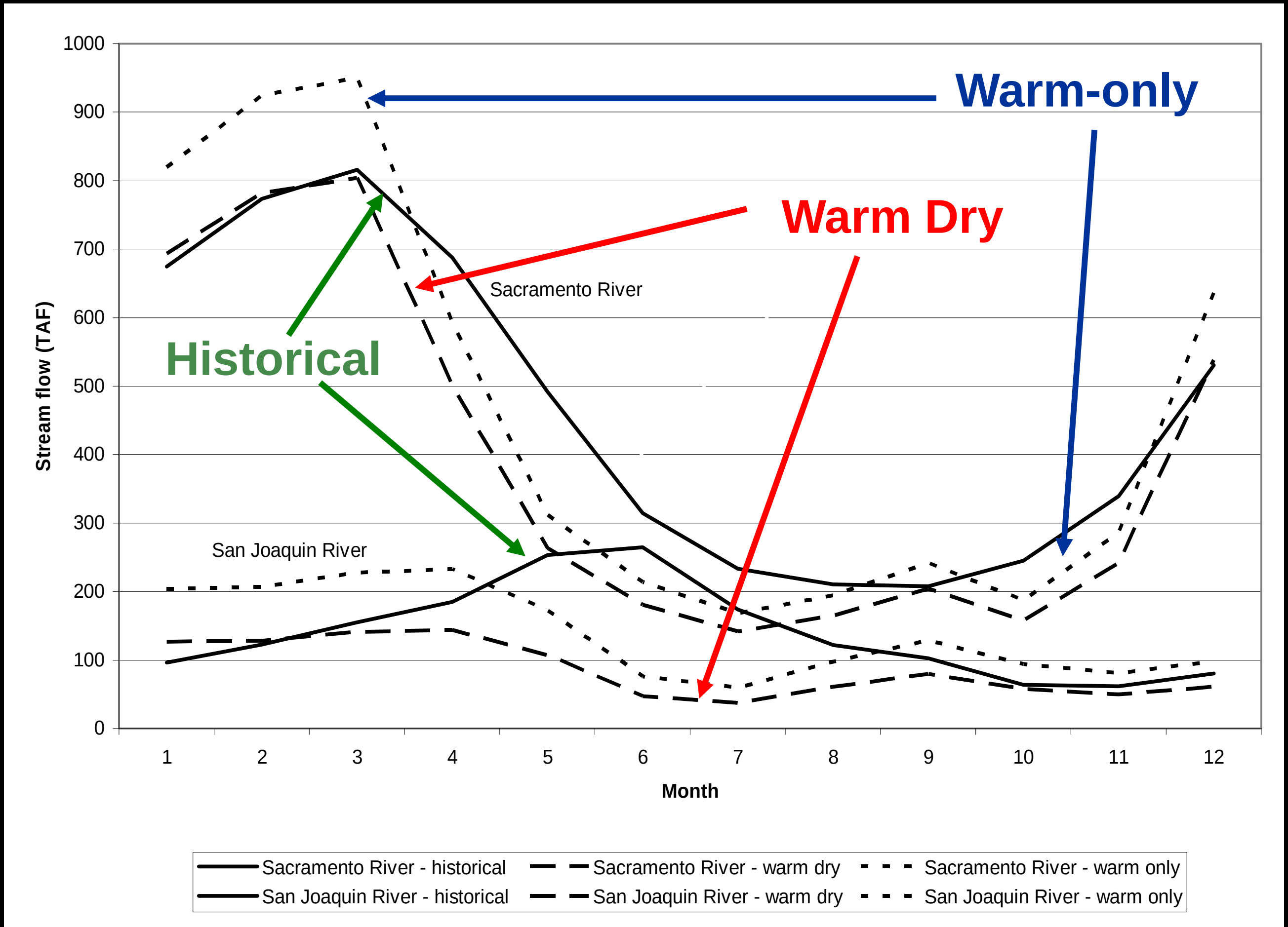
- GIS-based land use for the agricultural demand Model (DWR surveys)
- Population projections for year 2050



# Climate Change Scenarios

- Historical Hydrology (1921-1992)
- Warm-Dry Climate (GFDLCM1 A2)
- An estimated warm-only hydrology
  - Historic mean annual flow
  - Warm-dry patterns of early snowmelt and dryer summers
- Compared use of 6 versus 18 index basins to obtain perturbed rim flows

# Preliminary Results




**Rimflows in the Sacramento and San Joaquin Rivers**

# Preliminary Results

- Shortages of 15% of the target demands for agriculture are expected under the warm-dry scenario

- Historical and warm only scenario only vary slightly in terms of water deliveries and shortages

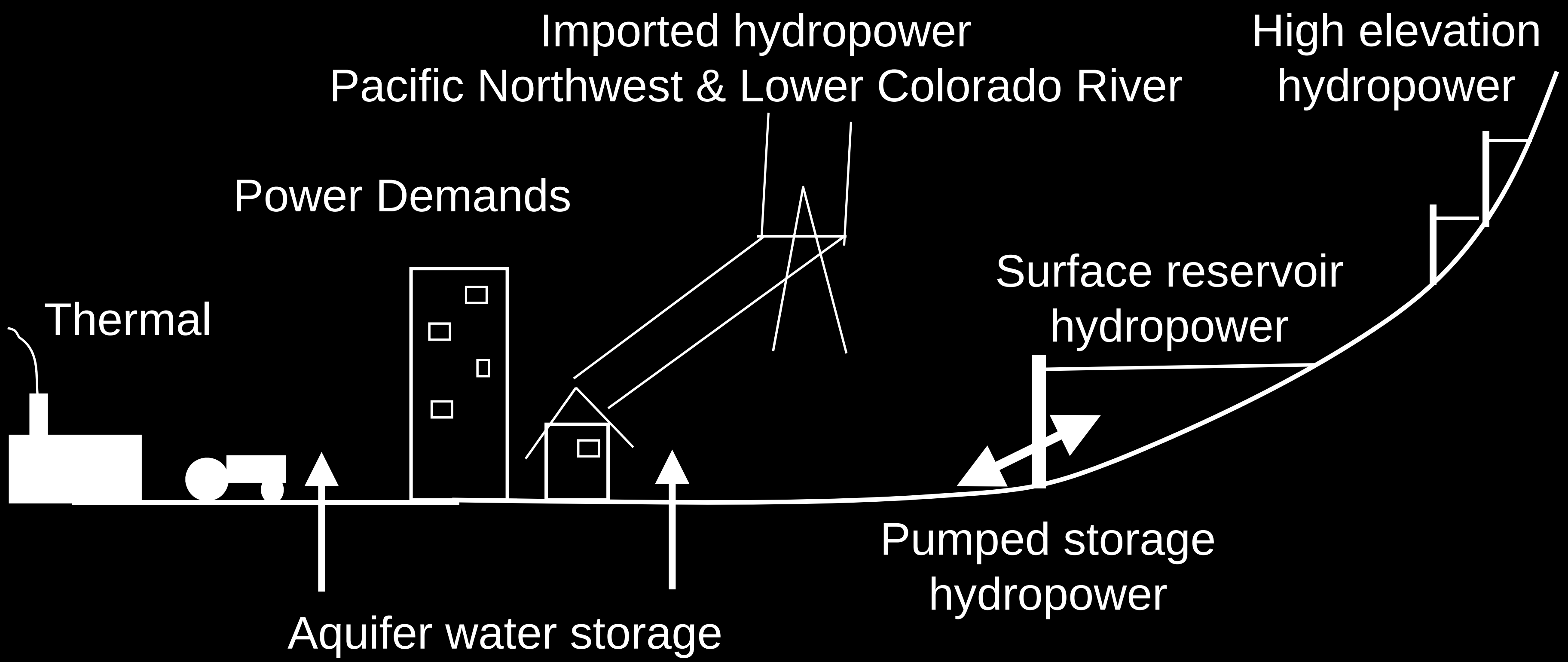
# Conclusions

- Agriculture remains vulnerable to shortages in the climate scenarios

- Water scarcity in California is more sensible to changes in precipitation rather than temperature

- Similar reductions in dry rim flows are expected using 18 versus just 6 index basins

# Hydropower Systems



# Hydropower and California

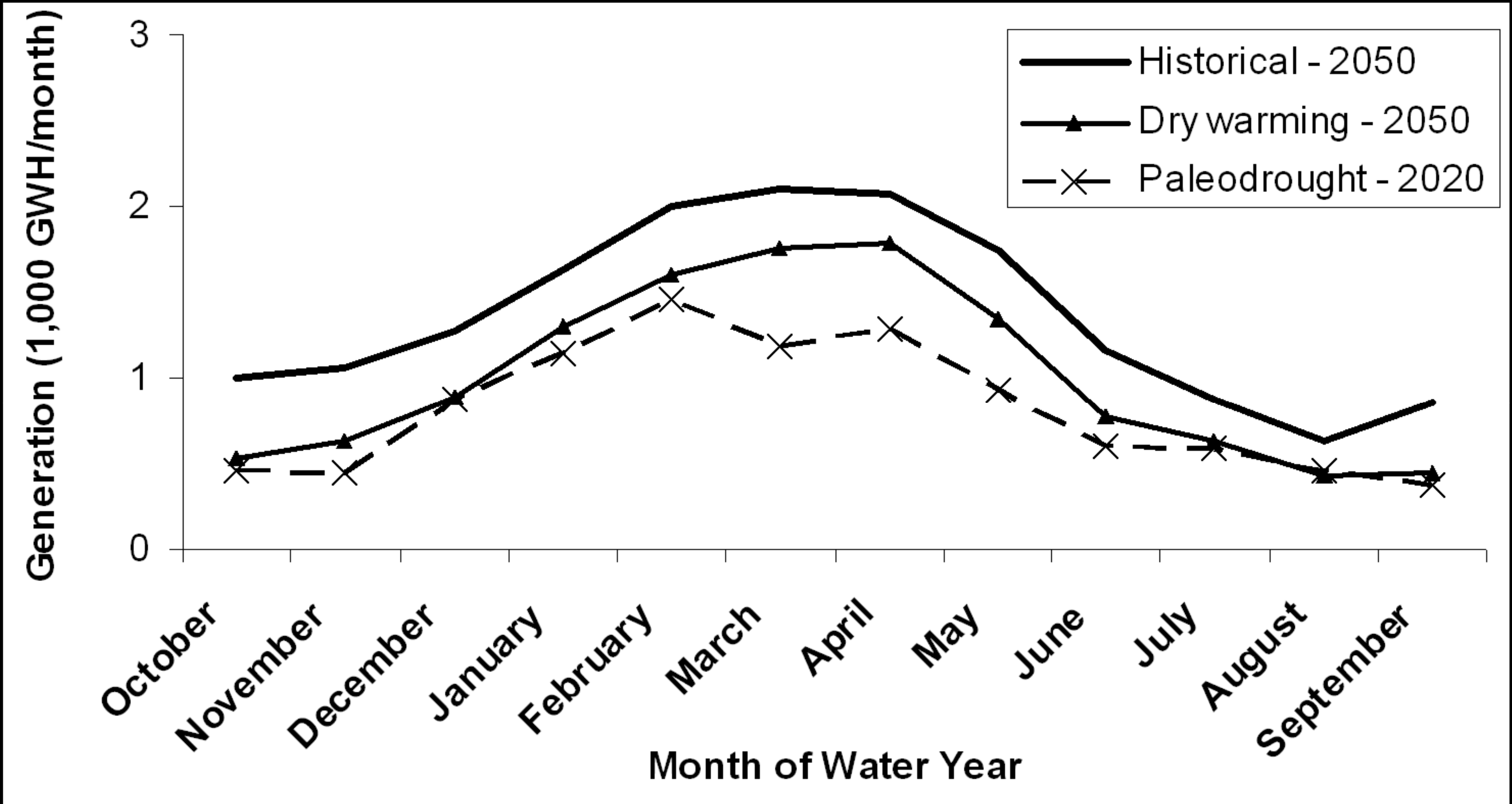
| | 1,000 GWH/yr, 2004 |
|---|---|
| Hydropower Total | 45.4 |
| In-state Hydropower | *34.4* |
| High Elevation* | 25.3 |
| Low Elevation* | 9.1 |
| Pumped Storage | ? |
| Imported Hydropower | *11* |
| PNW | 9.5 |
| LCR | 1.5 |
| Thermal | 205.2 |
| Other renewables | 24.5 |
| **Total** | **275.1** |

* Estimated     Sources: CEC; McCann 2005

# Climate Effects on Hydropower

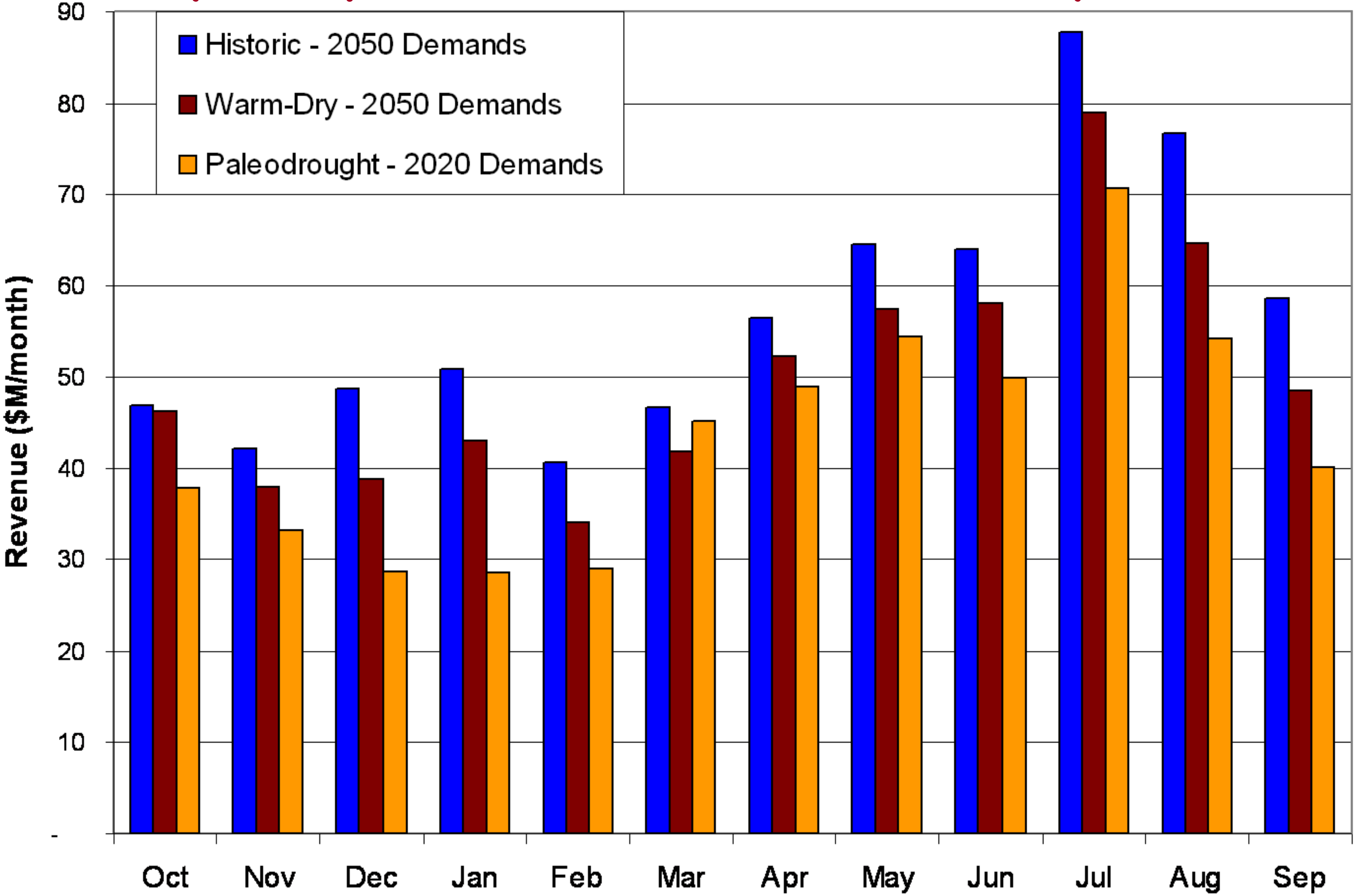
1. Energy demand
2. Timing of water availability
3. Quantity of water available
4. Availability of hydropower to import
5. Thermal generation efficiency
6. Sensitivity of environment to hydro operations

# Water Supply Dam Hydropower Seasonal Generation Changes

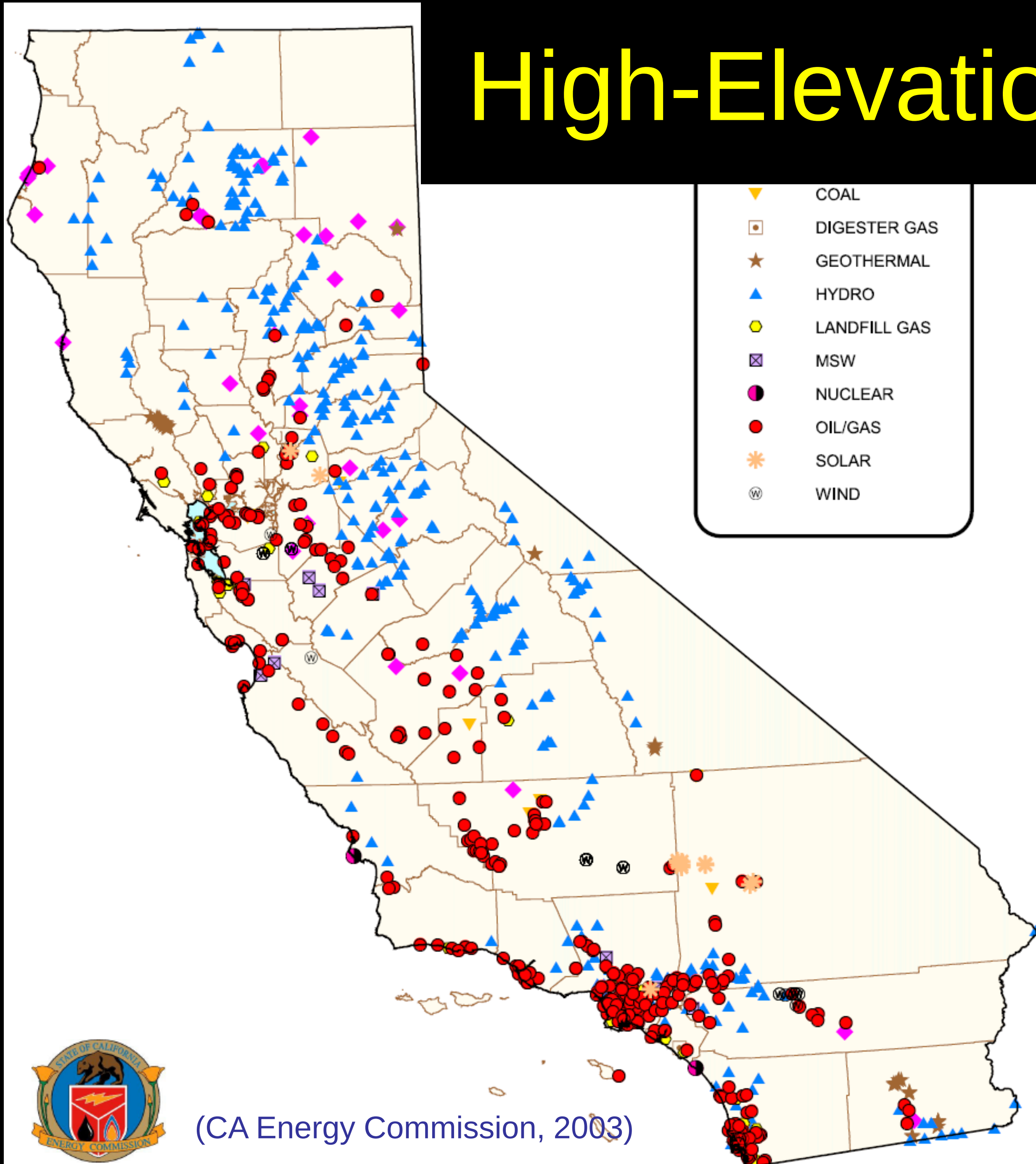



Major water supply reservoirs in CALVIN system optimization model

# Average Water Supply Reservoir Hydropower Benefits ($M/year)



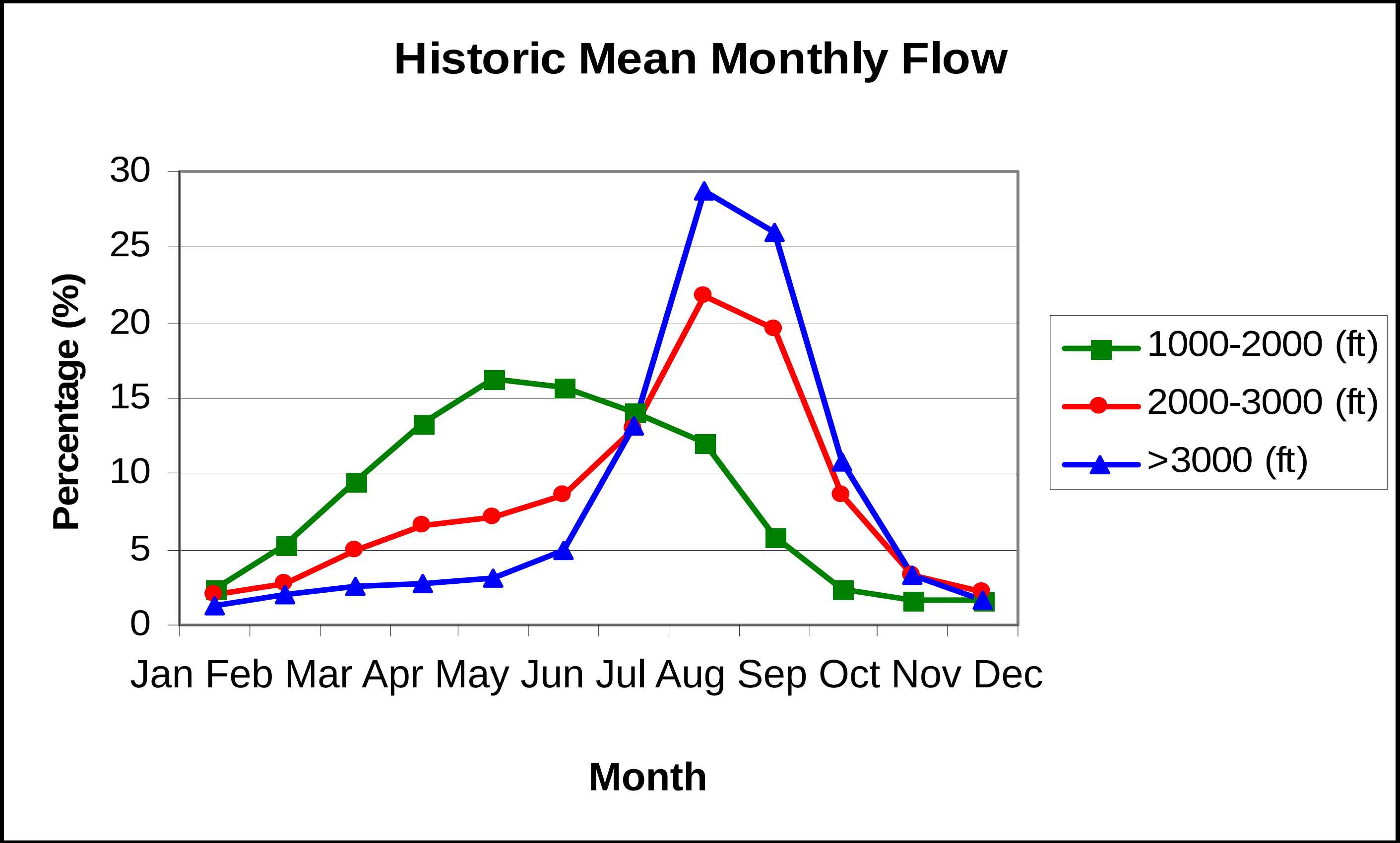
# High-Elevation System




(CA Energy Commission, 2003)

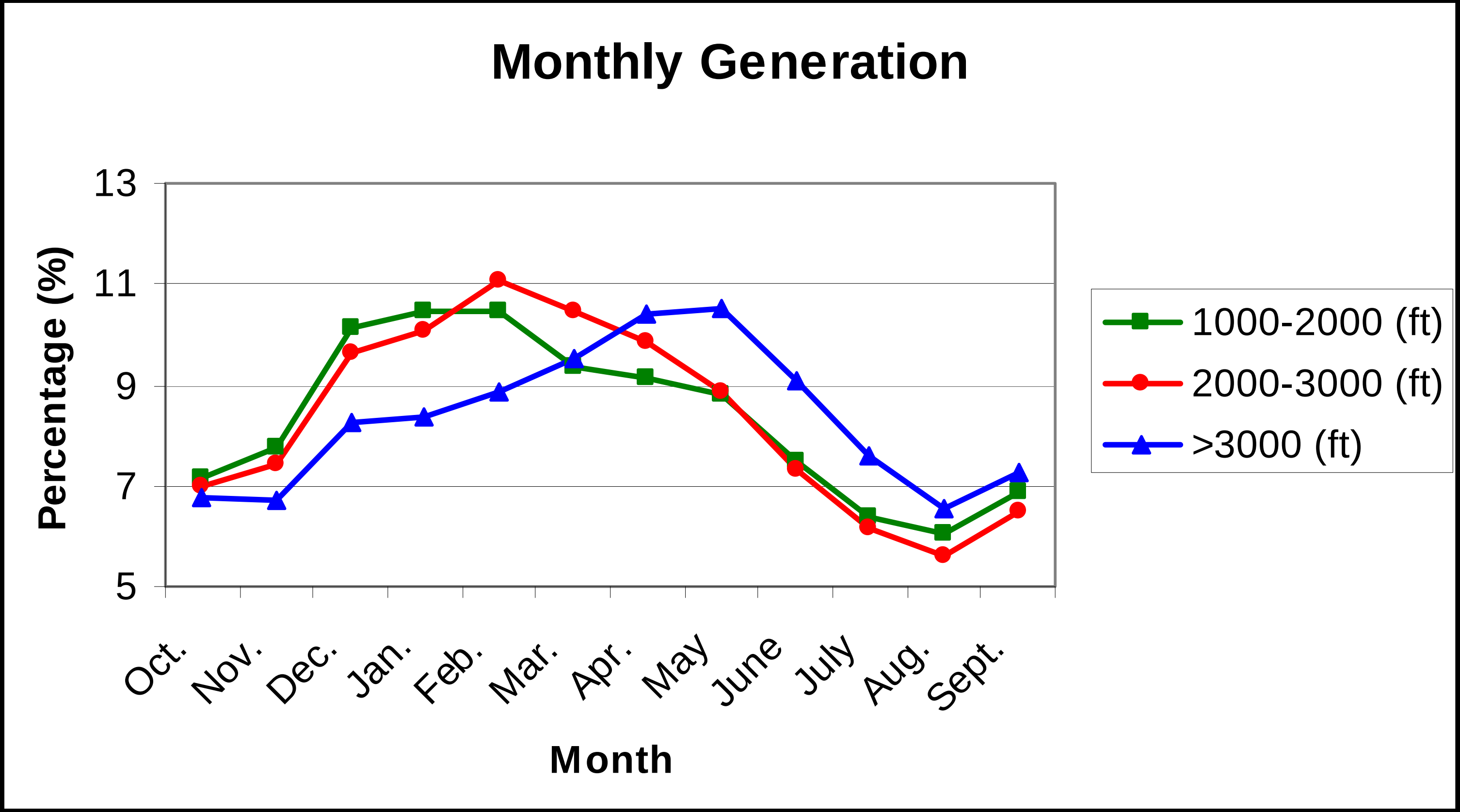
- 156 High-elevation power plants
- Snowpack dependant
- High-head, little head-storage effect
- Limited storage or flow data!!

# High-Elevation Runoff (Snowpack Effect)



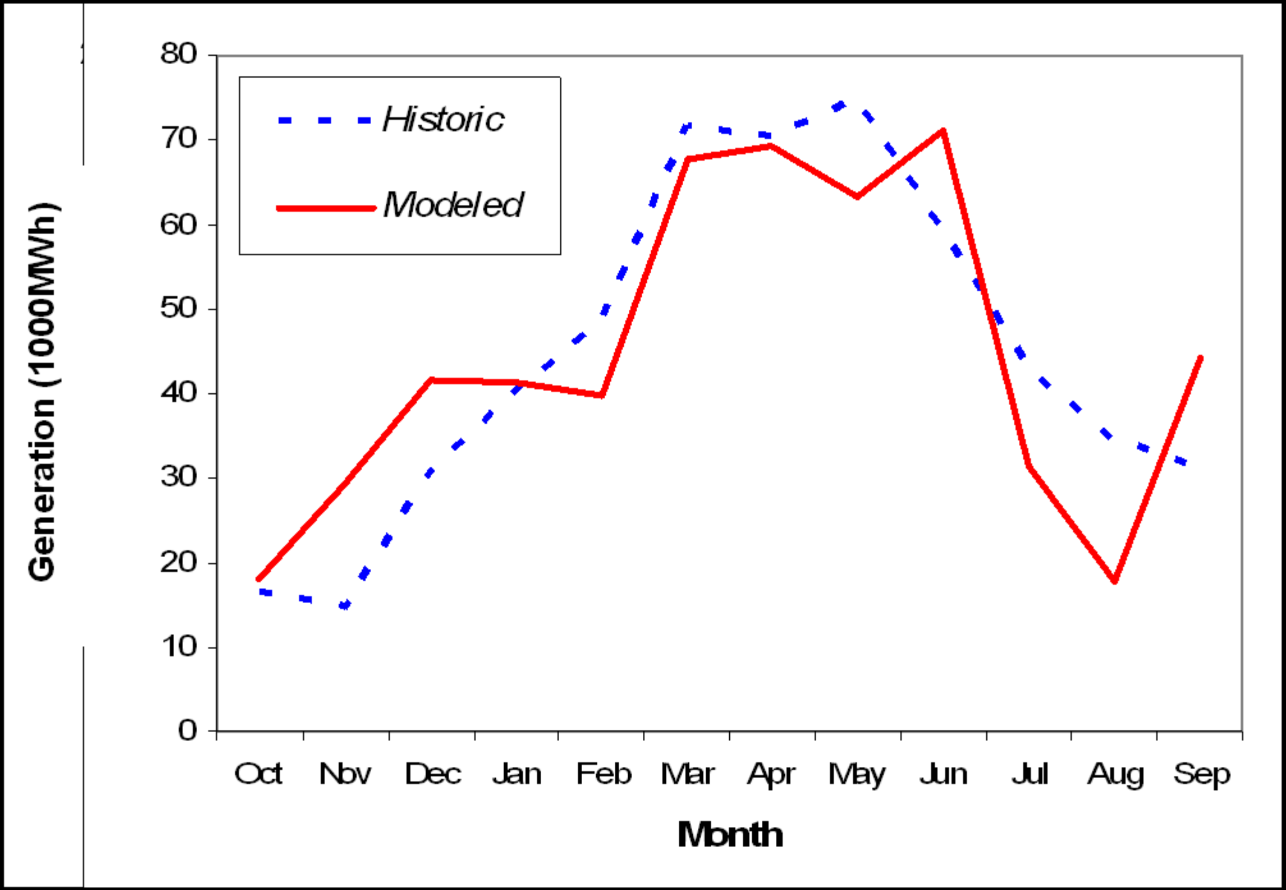

$$runPercent(i) = \frac{average\_Runoff(i)}{average\_Annual\_Runoff}$$

# High-Elevation Generation (Snowpack Effect)



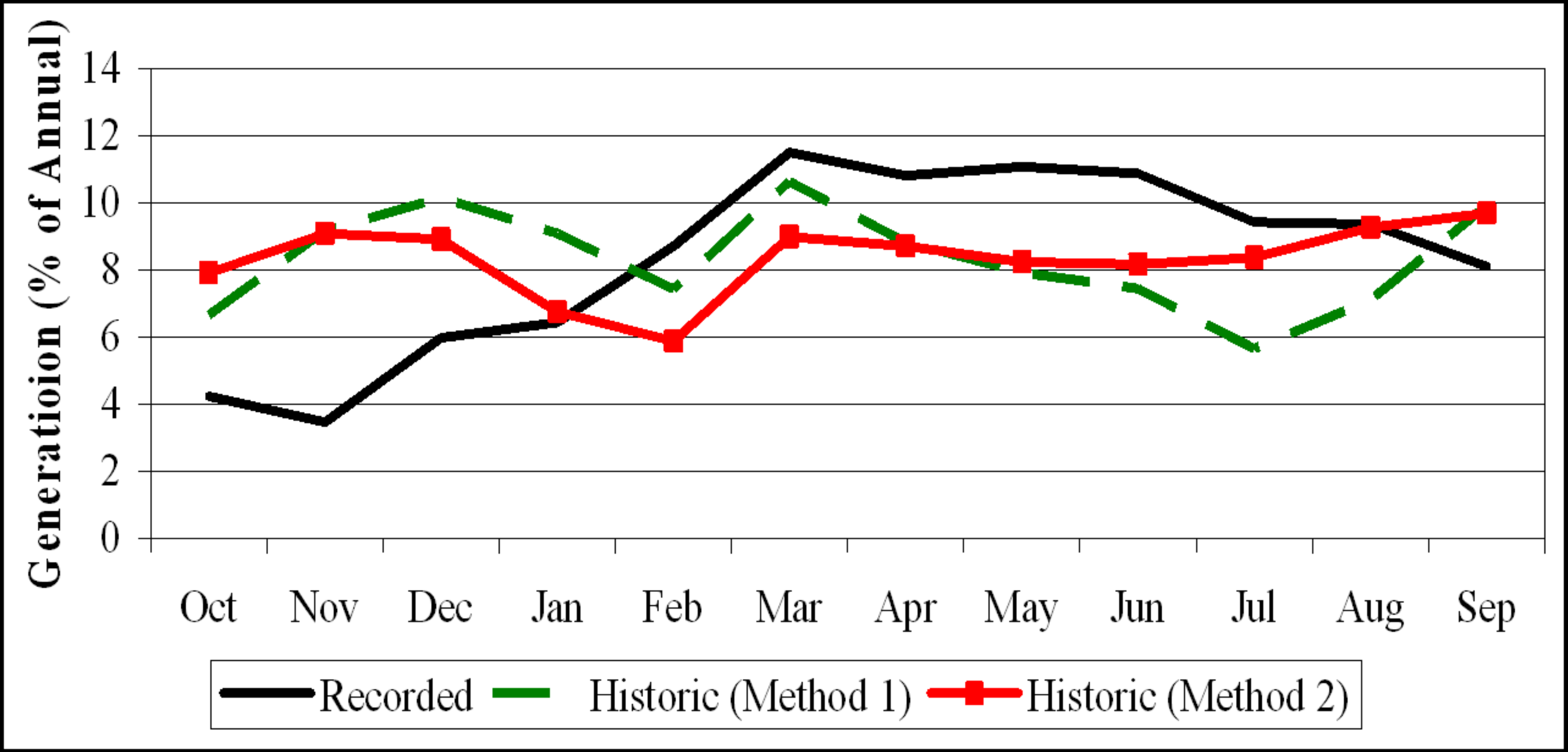

$$genPercent(i) = \frac{average\_generation(i)}{average\_Annual\_generation}$$

# White Rock




Historic monthly electricity generation and optimized monthly electricity generation (by EBHOM) in an average year

# SMUD System



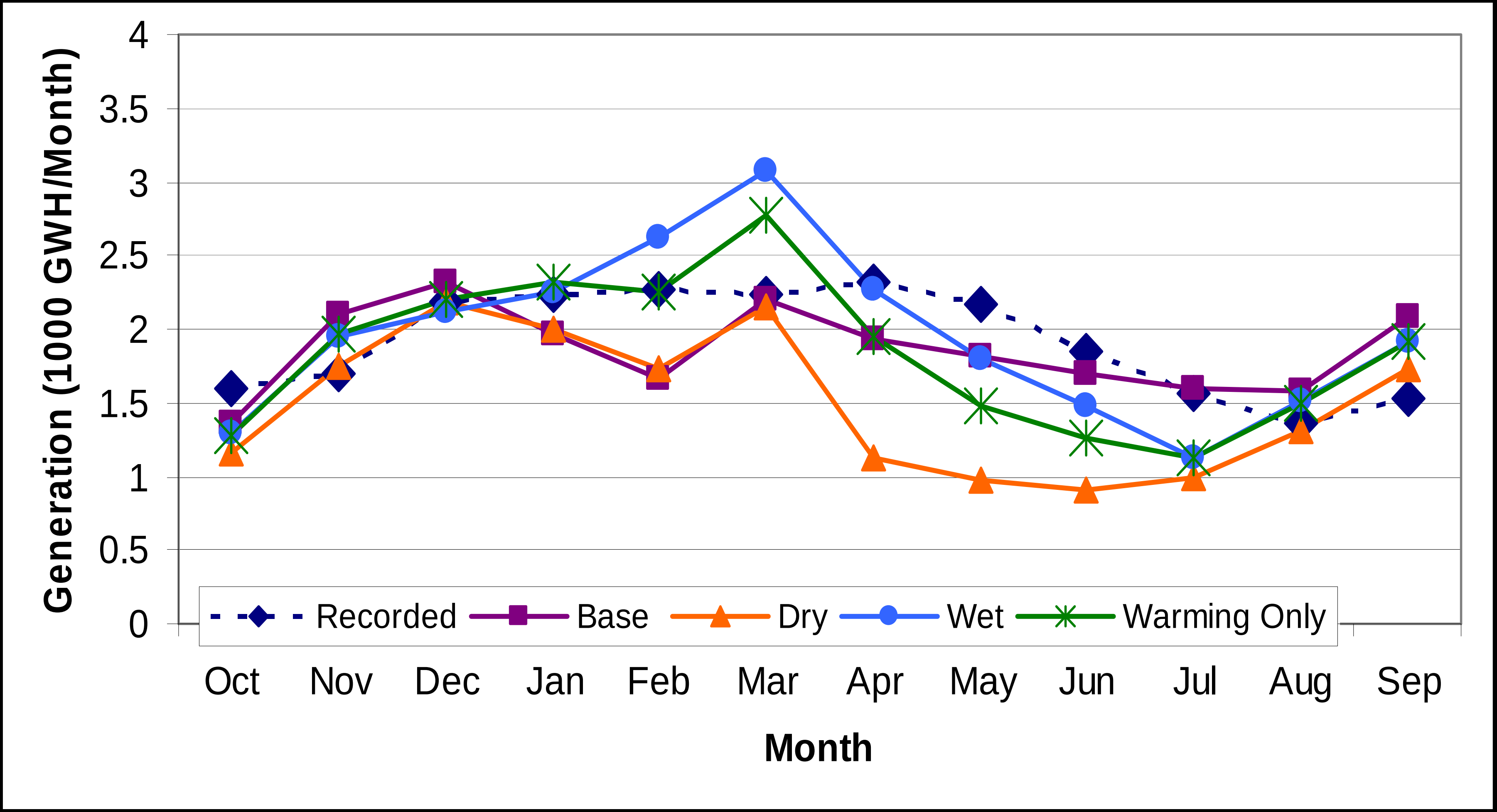

Comparison of EBHOM and traditional optimization applied to SMUD system

# High-Elevation Model Results

137 of 156 hydropower plants

1984 – 1998 period

# Monthly Generation

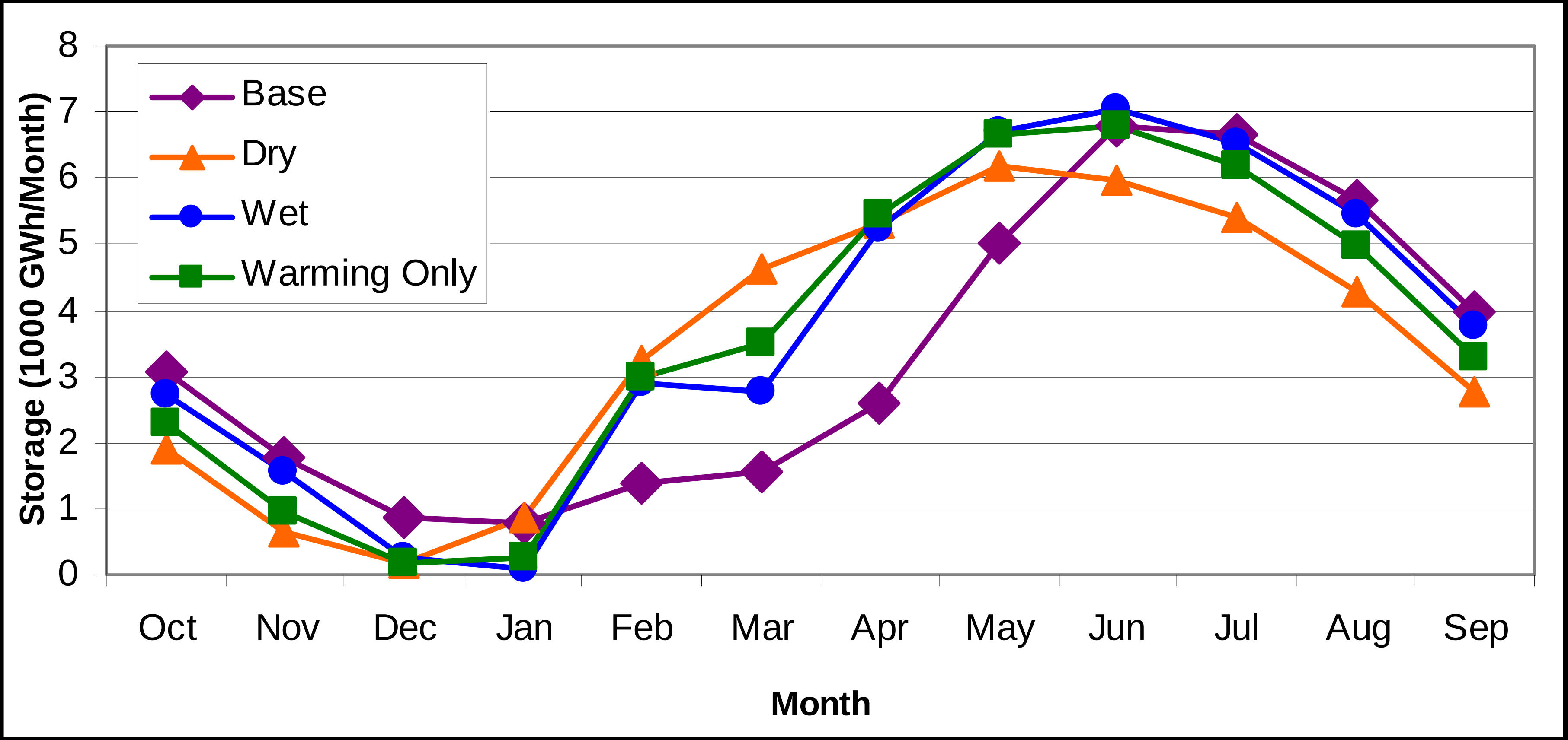


# Model Results

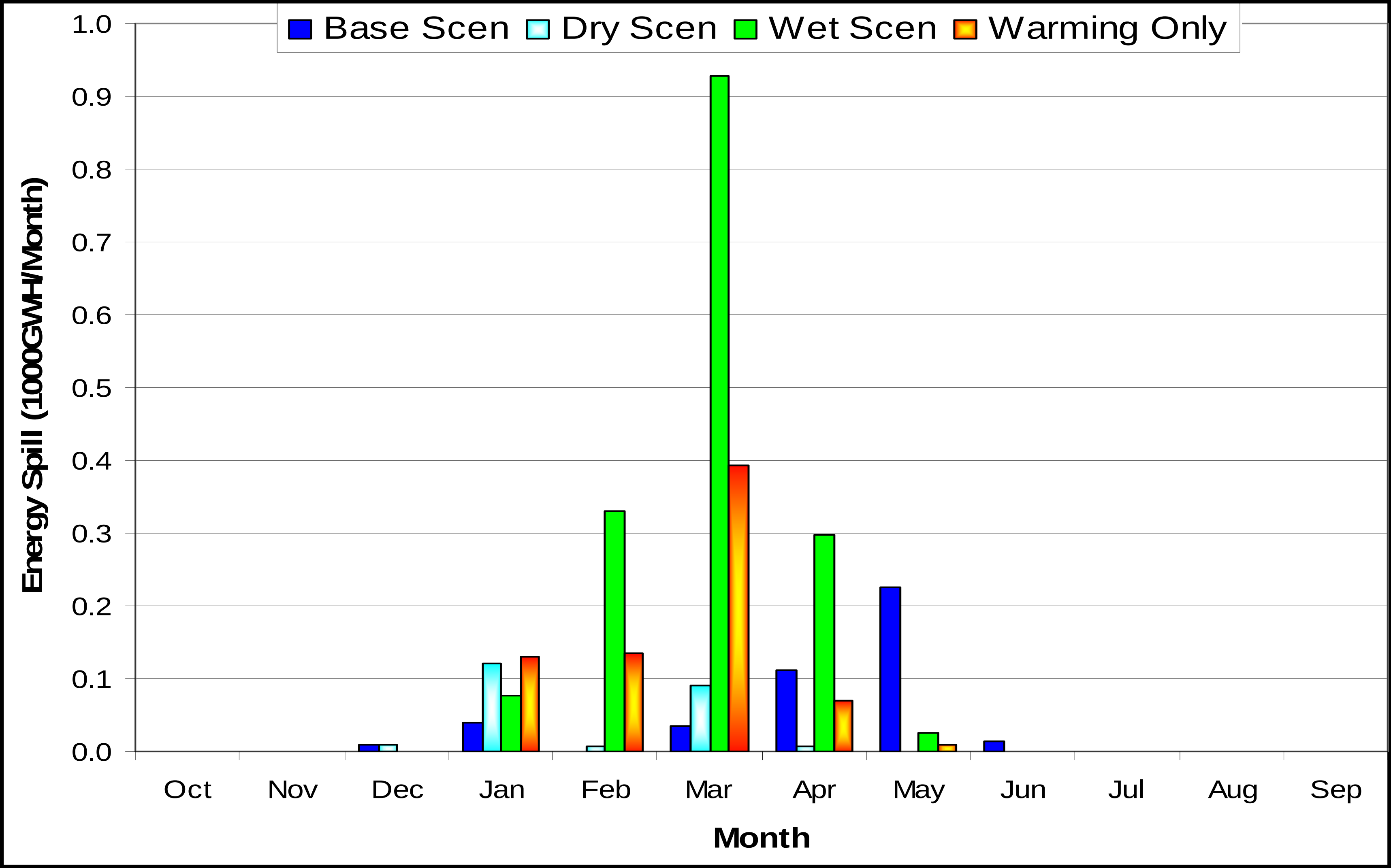
| | Scenario | | | |
|---|---|---|---|---|
| | ***Base*** | ***Dry*** | ***Wet*** | ***Warming-Only*** |
| **Generation (1000 GWH/yr)** | 22.3 | 18.0 | 23.4 | 22.0 |
| Generation Change with Respect to the Base Case (%) | | - 19.3 | + 4.8 | - 1.4 |
| **Spill (MWH/yr)** | 433 | 224 | 1,661 | 735 |
| Spill Change with Respect to the Base Case (%) | | - 46.0 | + 283.9 | + 58.8 |
| **Revenue (Million $/yr)** | 1,449 | 1,271 | 1,483 | 1,435 |
| Revenue Change with Respect to the Base Case (%) | | - 12.3 | + 2.3 | - 0.9 |

**average of results over 1984-1998 period**

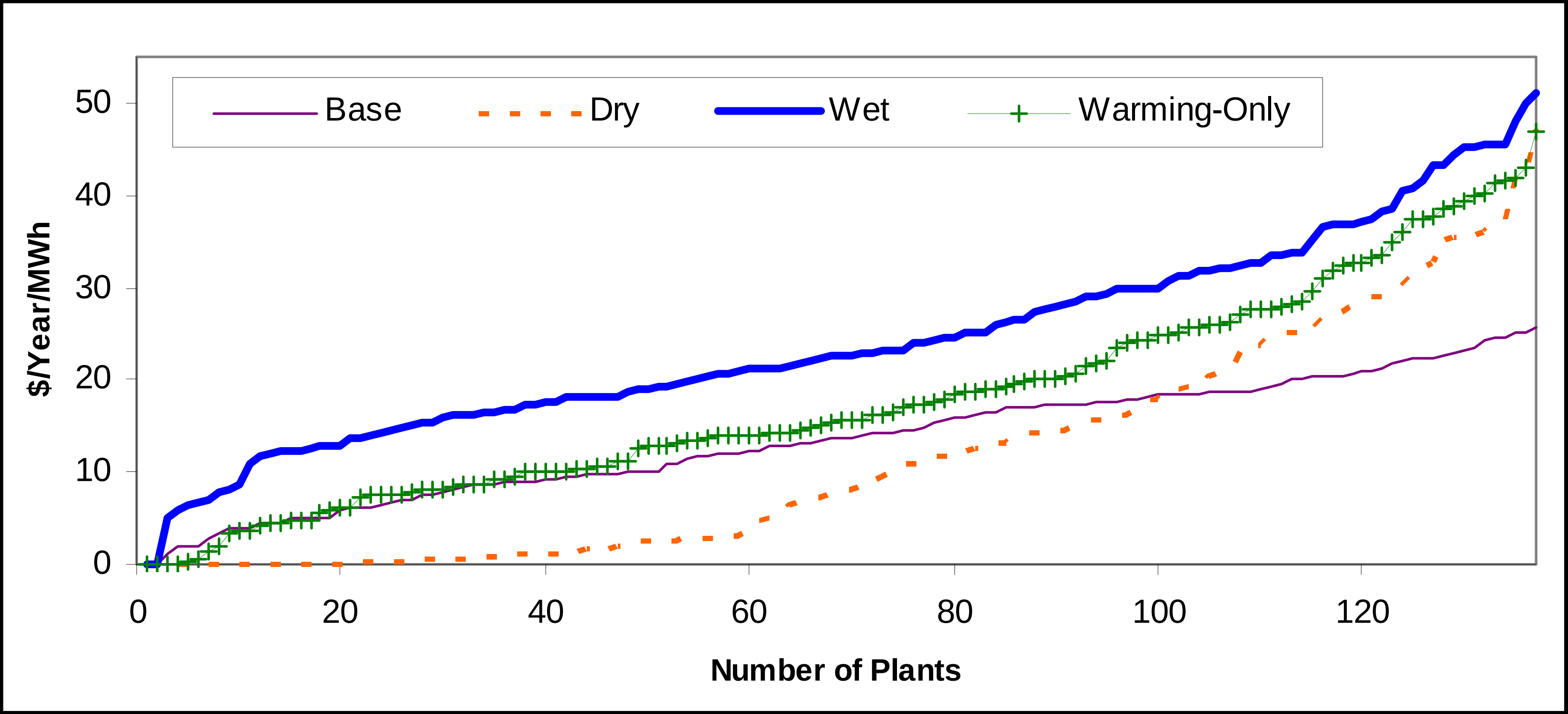
# Average total end-of-month energy storage (1984-1998)



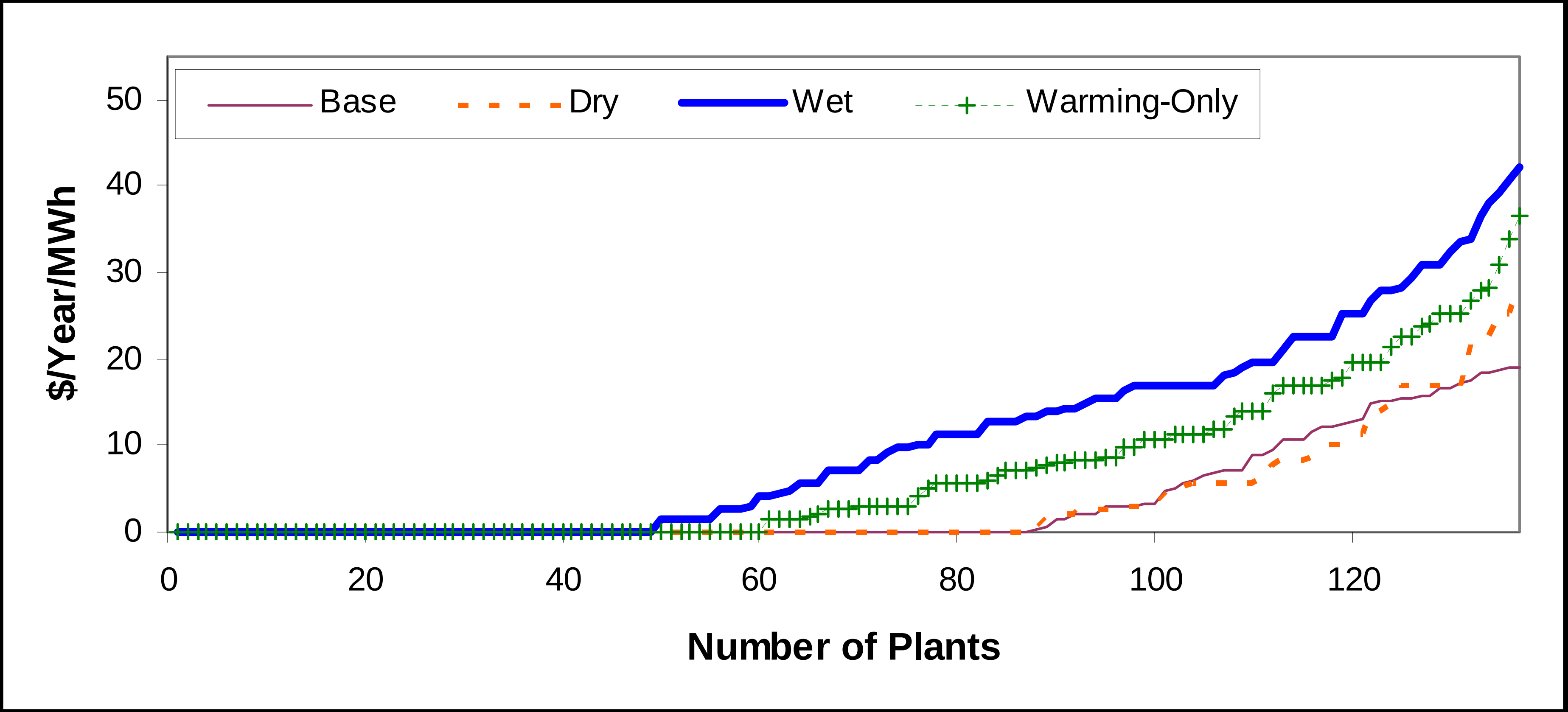
# Average monthly energy spill (1984-1998)



# Benefit of Storage Capacity Expansion



# Benefit of Generation Capacity Expansion



# Limitations of EBHOM

- NSM Limitations
- Few stream gauges
- Coarse elevation ranges
- Hydrologic variability
- Perturbation ratios
- Energy demand/price changes
- Deterministic (perfect foresight)
- No Environmental Constraints

# Overall Conclusions

- Sierra loses snowpack, the natural reservoir.
- Storage works.  Generation changes more with total runoff than seasonal runoff shift.
- Problems for smaller high-elevation reservoirs - more spills even without change in total runoff
- Drier climate causes more problems than wetter climate causes benefits.
- Revenue reduction may be economically insufficient to justify expanding storage or generation capacity.

# Next Steps?

- Climate change effects on energy demand/ price
- More detailed high-elevation studies

# Acknowledgements

- Supported by CA Energy Commission (PIER) and the Resources Legacy Fund Foundation
- Maury Roos, CA DWR
- Omid Rouhani, UC Davis
- Marcelo Olivares, UC Davis
- Sebastian Vicuna, UC Berkeley

# Water SISWEB

- Social Bookmarking Website dedicated to the Water Community
- SISWEB= Scientific Information Syndication WEBsite

www.watersisweb.org