Operational Inflow Forecasting and Water Management

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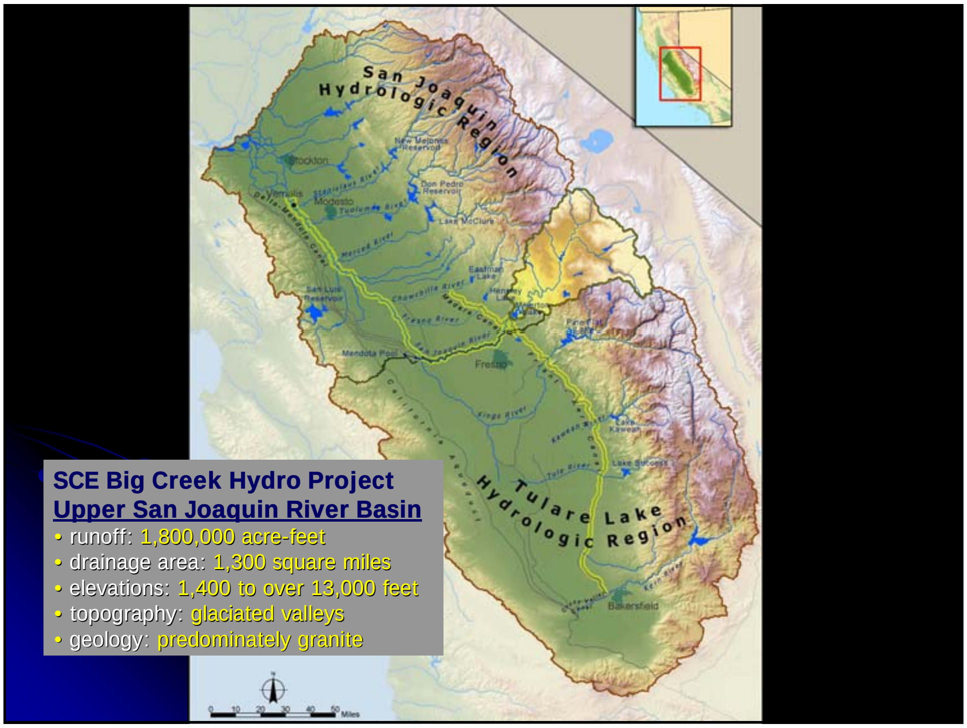
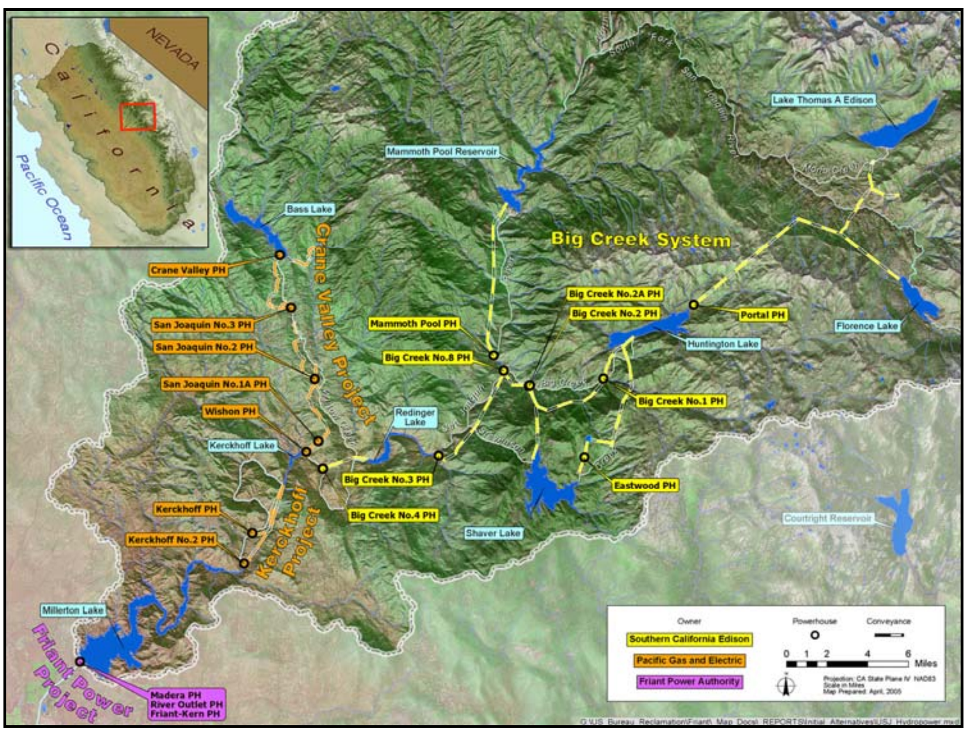

SCE Big Creek Hydro Project
Upper San Joaquin River Basin
• runoff: 1,800,000 acre-feet
• drainage area: 1,300 square miles
• elevations: 1,400 to over 13,000 feet
• topography: glaciated valleys
• geology: predominately granite
San Joaquin Hydrologic Region
Tulare Lake Hydrologic Region
Stockton
Modesto
Fresno
Bakersfield
Mendota Pool
Miles


NEVADA
California
Pacific Ocean
Lake Thomas A Edison
Mammoth Pool Reservoir
Bass Lake
Big Creek System
Crane Valley Project
Crane Valley PH
San Joaquin No.3 PH
San Joaquin No.2 PH
San Joaquin No.1A PH
Wishon PH
Kerckhoff Lake
Redinger Lake
Mammoth Pool PH
Big Creek No.8 PH
Big Creek No.2A PH
Big Creek No.2 PH
Portal PH
Huntington Lake
Florence Lake
Big Creek No.1 PH
Big Creek No.3 PH
Big Creek No.4 PH
Eastwood PH
Shaver Lake
Courtright Reservoir
Kerckhoff PH
Kerckhoff No.2 PH
Kerckhoff Project
Millerton Lake
Friant Power Project
Madera PH
River Outlet PH
Friant-Kern PH
Owner
Southern California Edison
Pacific Gas and Electric
Friant Power Authority
Powerhouse
Conveyance
0 1 2 4 6
Miles
Projection: CA State Plane IV NAD83
Scale in Miles
Map Prepared: April, 2005

Big Creek Hydro Engineering Milestones

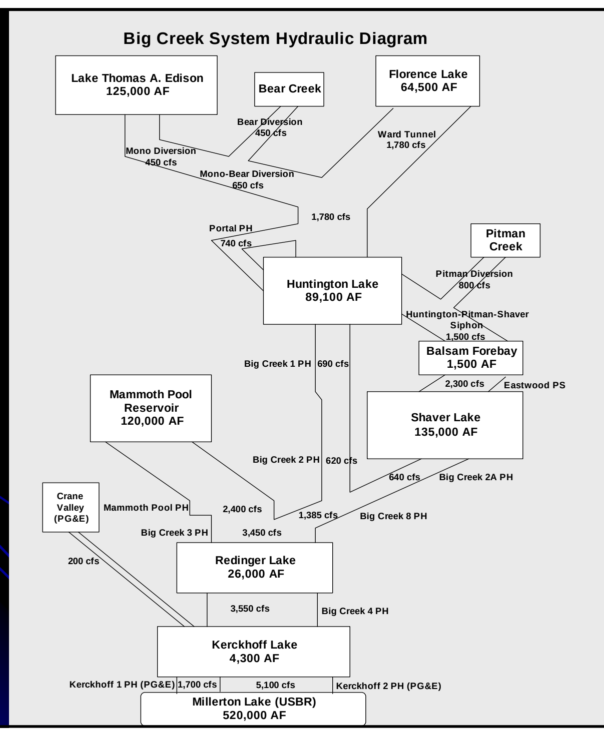
9 powerhouses, 23 generating units, 1015 MW, 560,000 AF storage, 6 Major Dams

"The hardest working water in the world"

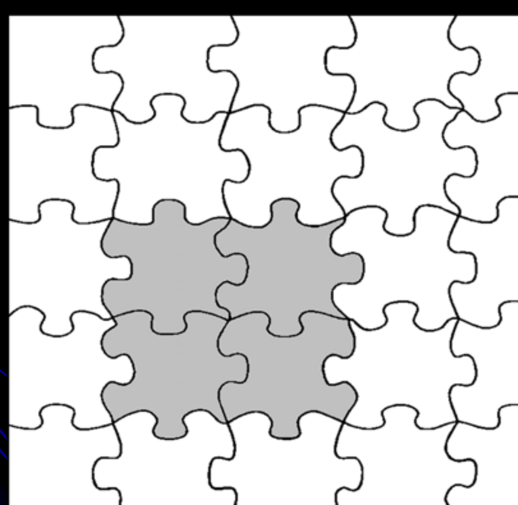
- 1st large scale integrated hydroelectric project in the world
- Construction began in 1911 – *said to be a greater challenge than building the Panama Canal*
- Longest water tunnel in the world
- Largest multiple arch dam in the world
- Highest head penstocks in the world
- Longest and Steepest Penstock in the World
- Largest water turbines in the world
- Longest & highest voltage transmission line in the world

May, 1910
SCE surveyors prepare to measure the flow of Big Creek

October, 1913
SCE workmen install the final segment of the Big Creek No. 1 penstock

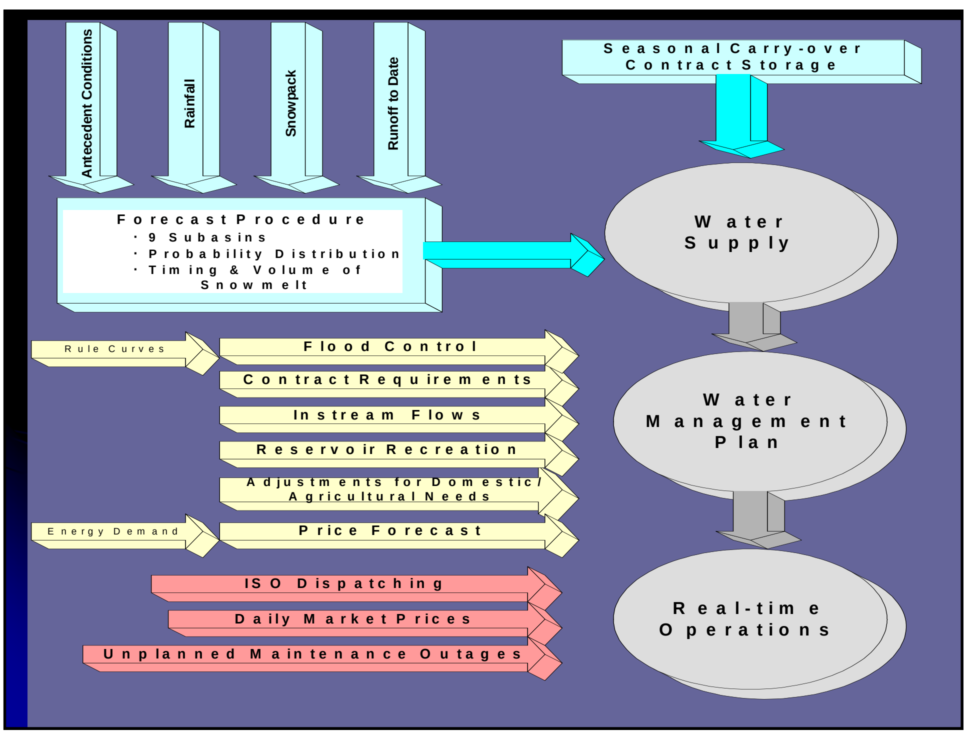


Big Creek Hydroelectric Project Water Management



Who We *Actively* Collaborate With

- DWR
- USGS
- FERC
- PG&E
- USBR
- DSOD
- USFS
- NPS
- Cal Tech (Siesmic)
- Whitewater Community
- Local Vendors and Communities

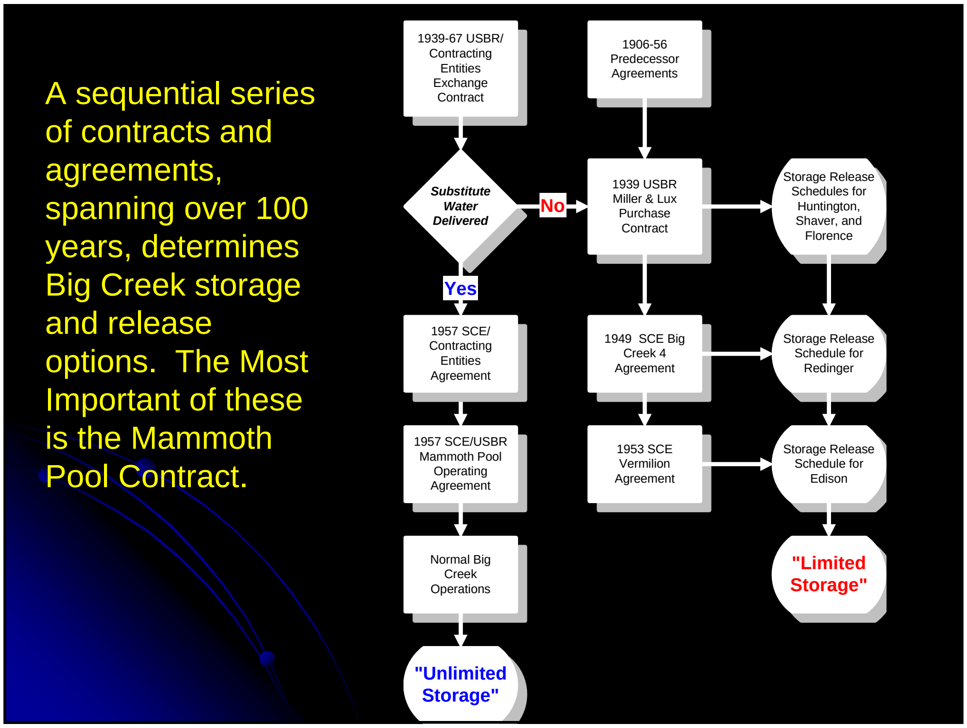


Big Creek Project Water Management Operations: *General Strategy*

- **Avoid spill** (flood control; water conservation)
  - Exceptions for pre-scheduled ISO days with negative energy bids
  - Exceptions for years with big snowpack (e.g., consider mid canyon controlled spills, such as BC2)
  - Plan for Portal bypass, as needed
- **Maintain Functional Reservoir Head**
  - Huntington outlets to BC1 & Eastwood
  - Shaver pump storage
  - Edison fishwater turbine
  - Mammoth Pool P/H efficiency (incl. winter months)
  - Florence Dam winter freeze-thaw deterioration (limit to below arches)

Big Creek Project Water Management Operations: *General Strategy*

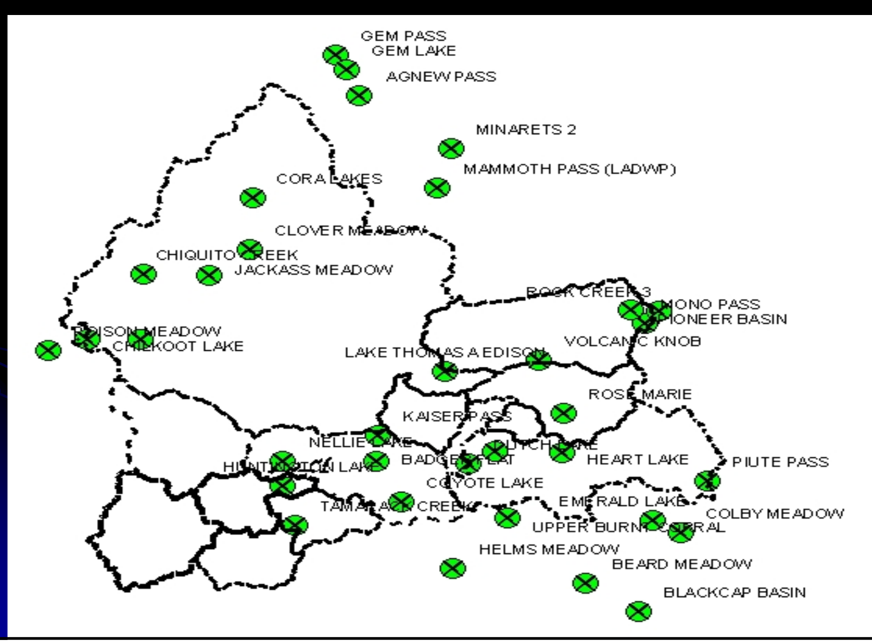
- **Comply with Mammoth Pool Operating Contract requirements**
  - March 1 reservoir storage criteria
  - March reservoir release criteria
  - September 30 (seasonal carryover) reservoir storage criteria
  - Work with USBR/FWUA on mutually beneficial contract deviations, as necessary
  - [USBR can not store from Aug 1 to Nov 1 (Aug 15 to Oct 15)]
  - **Meet Unusual Contract Obligations (Schedule 1 Substitute Water)**
- **Comply with FERC/USFS Recreation Requirements**
  - Minimum pool & seasonal storage levels (all reservoirs)
  - Meet Minimum In stream Release Requirements
  - Schedule pre-spill rafting releases (Mammoth Pool reservoir)
  - Write letters to local community and business interests re. estimated seasonal storage levels (all reservoirs


A sequential series of contracts and agreements, spanning over 100 years, determines Big Creek storage and release options. The Most Important of these is the Mammoth Pool Contract.
1939-67 USBR/ Contracting Entities Exchange Contract
1906-56 Predecessor Agreements
Substitute Water Delivered
No
Yes
1939 USBR Miller & Lux Purchase Contract
Storage Release Schedules for Huntington, Shaver, and Florence
1957 SCE/ Contracting Entities Agreement
1949 SCE Big Creek 4 Agreement
Storage Release Schedule for Redinger
1957 SCE/USBR Mammoth Pool Operating Agreement
1953 SCE Vermilion Agreement
Storage Release Schedule for Edison
Normal Big Creek Operations
"Limited Storage"
"Unlimited Storage"

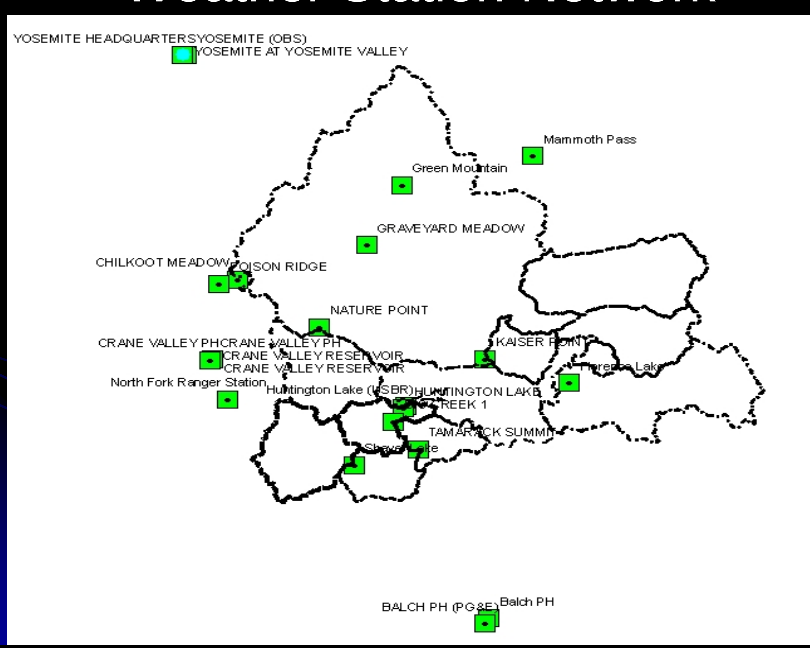

Water Rights - First in Time = First in Right
1890
Central Valley agriculture
1910
Central Valley agriculture
May, 1910
SCE surveyors prepare to measure the flow of Big Creek
October, 1913
SCE installs the final segment of the Big Creek No. 1 penstock
February, 1925
SCE miners blast the final section of the Ward Tunnel thru Kaiser Mtn.

The San Joaquin Basin – High Country

Snow Courses and Sensors



Weather Station Network



SCE - Huntington Weather Station Elevation – 7050 ft.

Basin and Data Collection Characteristics

- Elevation range from 1400 feet to over 13000 feet above sea level w/ 50+% of basin above 7500 feet
- 80% of data collected is from sources above 7000 ft

Types of Data Collected

- Temperature and Precipitation
- Snow Surveys (including snow pillow verification)
- In stream Flow Releases and Reservoir Spill Flows
- Powerhouse Flows
- Water Movement Through diversion pipes and tunnels
- Reservoir Elevation / Storages
- Dam Surveillance / Dam Safety Data
- Seismic Data

Typical Gauging Station

Elevation – 7600 ft.

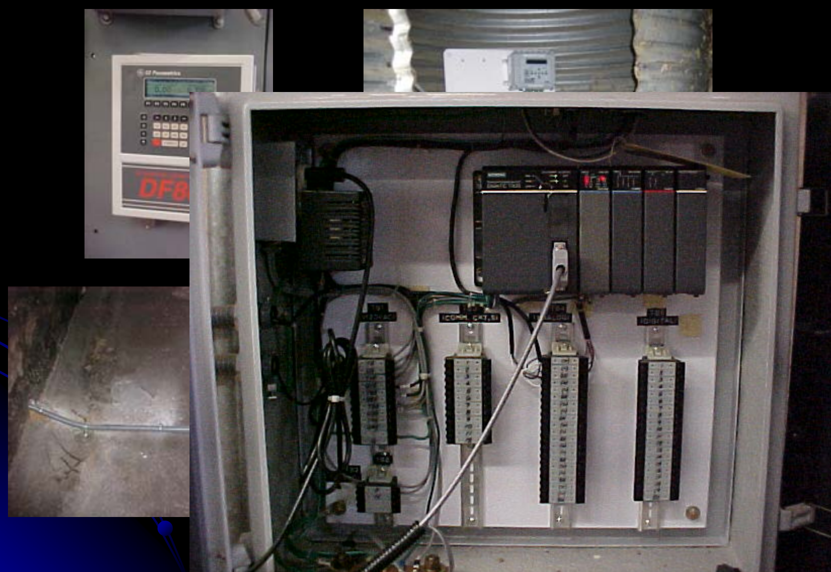
Data Collection Challenges

- Access (USFS under pressure to limit)
- Permits for Maintenance and New Sites
- Terrain
- Weather
- Proximity
- Power Consumption
- Equipment & PLC compatibility/flexibility
- Frequency of collection at Non Automated sites
- Communications

Data Tools Used

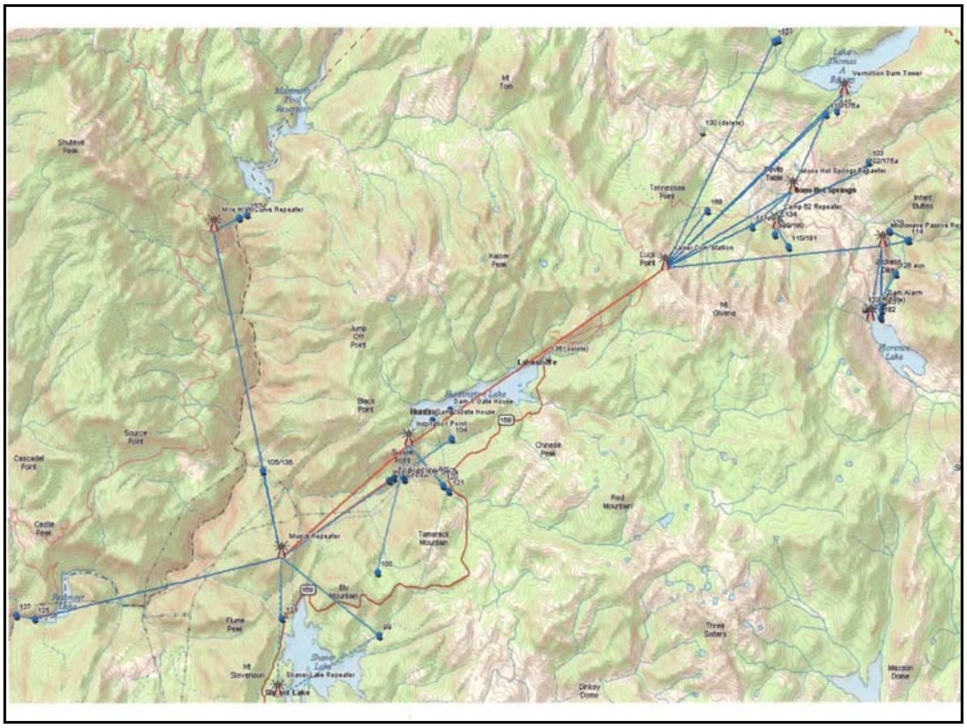
- Ovation DCS collects data from communication / collection system for operational decision making.
- Hydstra – Hydrographic Database QA/QC.
- Sierra Hydrotech – Forecast Model.
- Excel – Legacy Strategic Water Management Tool.
- Synexus Global / Vista – Model with some short range predictive forecasting capabilities. Integrates Hydrology model with operational model and market price forecast.

Data Collection Platforms



Communications Network

- New unlicensed 900 MHz Ethernet radio system with control capability (uses line of site)
- Remote Microwave voice and data collection system.
- Land Lines - %$#&^@!
- Future – Satellite Communication of non sensitive data to web (i.e. Weather)
- T-1 Lines carry DCS data to the secure web servers in Rosemead for integration into Synexus Global Model
- Web scraping of Non – SCE Sites



Modeling Challenges

- Weather network is limited – not enough High Country
- Snow Pillows – not enough of them
- Need more real time SWE data – new technologies (tech and access has not kept up with the data needs). Wilderness ACT restricts new technology implementation
- Data often out of date a day or two after collection due to “New Weather”
- Filtering “Bad” Data – the amount of effort required to QA/QC the data is substantial especially with new models. Knowing the capabilities of personnel, agencies, equipment is important
- Good at determining seasonal volume, less so at timing
- Line restrictions and emergency maintenance outages create outflow forecast issues
- Need Sub basin level QPF’s daily
- Stations are often “down” and not collecting data
- Current Model only considers previous 2 years antecedant conditions

Legacy Forecasting and Scheduling Tools

- Prior water management
  - spreadsheet simulation tools to schedule generation & minimize spill, but no market signals
- Prior inflow forecasting
  - model for seasonal emphasis of hydro operations
  - predated the real-time Independent System Operator (deregulated bidding market)
  - limited to monthly forecasting of stream flows, and for only the current water year
  - uses monthly precipitation, snowpack, & runoff measurements to compute indices that predict the volume and timing of snowmelt, based on pattern matching of previous years within a long-term database
  - a new model was needed to enhance the forecasting ability to include smaller time steps of days & hours, w/ the ability to project out for more than 12 months

New Scheduling and Forecasting Tools (Experimental)

- Optimization tools for both long-term (1-2 years) and short-term (1-4 weeks) scheduling and planning.
  - reservoir and channel routing handled in modules,
  - need forecasts of natural or local inflow
- Inflow forecasting integrated with scheduling tools
  - short-term forecast generated automatically
  - seamless transfer of inflow forecasts to optimization routing tools

Components of New Operational Forecasting System

- Successful implementation of an operational flow forecast system requires a number of essential components to collect the required data, generate forecasts and disseminate results. The main components of an operational forecast system include:
  - Inflow forecast model or engine
  - real-time data collection and data transmission for obtaining both weather data and forecasts
  - data base management
  - Data and forecast monitoring and trend analysis

Inflow Forecast Engine

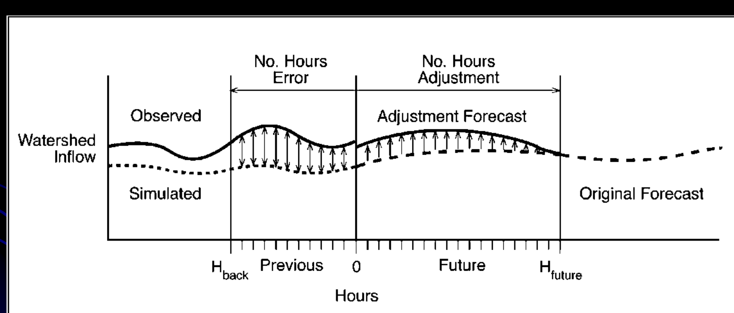
- Inflow Vista includes a number of forecast engines and a basin process (rainfall-runoff) models was implemented for Big Creek. The basin process model consists of a suite of models, including
  - Mean Areal Input Estimator
  - Snowmelt mode, referred to as HYDRO-17 (Snow Accumulation and Ablation Model, Anderson, 1973)
  - Abstraction model , Sacramento Soil Moisture Model (soil moisture accounting and runoff determination, Burnash, 1973)
  - Watershed routing model
  - Forecast updating function

- The models translate actual and forecast hourly values of precipitation (either as rain or snow) and temperature to runoff entering the river at specified locations. The models continuously simulates watershed storage variables snow pack, soil moisture and groundwater conditions.

Inflow Forecast Updating

- An important feature of operational forecasting is that observations of the forecast variable (stream flow), become available in real-time. This creates the opportunity to adjust (correct) subsequent forecasts in light of the most recent information.
- This adjustment is referred to as updating and is essentially an attempt to correct for forecast errors that result from errors in input data, such as estimated mean areal precipitation as well as from the model's inability to totally capture the runoff generating dynamics.
- Inflow forecast model includes a simple function to adjust the forecasts for the next n hours based on the simulation error for previous m hours.

Inflow Forecast Updating



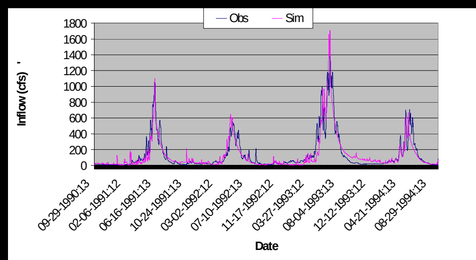
Mean Areal Data

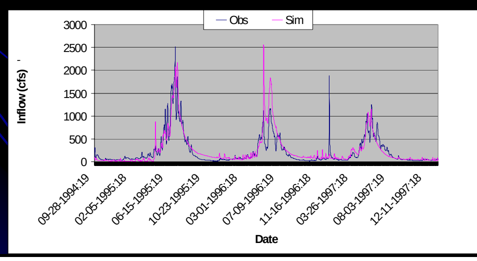
- The mean areal precipitation (MAP), temperature (MAT) and snow water equivalent (MAS), are estimated as a weighted average of observations from representative stations (or snow courses).
- Determining the weighting of stations requires considerable analysis, a number of analytical methods can be employed, that rely on the location of gauging station relative to watershed boundaries. In mountainous areas, the elevation and the orientation of the stations are also quite important, complicating the determination of weights.
- In operational forecasting, stations may not always report on-time and can be down for some period due to equipment problems.
- To estimate real-time MAP/MAT/MAS, the met stations are defined in multiple groups. This ensures that mean areal data can be processed even if some met stations do not report at a particular time. Each group contains different combinations of the met stations.

Calibration and Verification

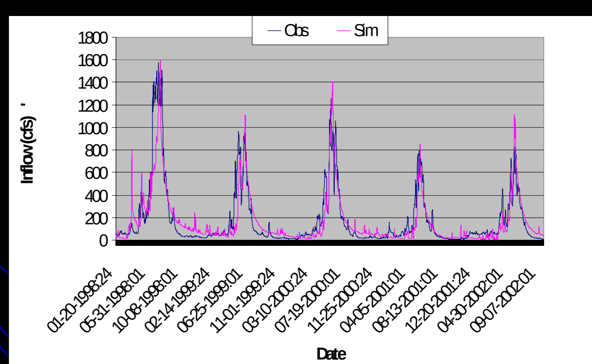
- For calibration purposes a 20 year history of both meteorological data and hydrometric data was assembled. The data was divided into a 15 year calibration set and an independent verification set (the remaining years).
- The model includes over 20 parameters per watershed element. In-depth knowledge of the model and the application watershed is required to achieve a good calibration.
  - calibration of the inflow forecast models is work intensive and has to be approached very methodically.
  - some are derived from observing historic stream flows and meteorological conditions and the remainder are derived from adjustments of standard values.
  - The inflow forecast tool includes an automatic parameter search function, and once initial values and a feasible parameter range were established, this parameter search function was used to aid in the calibration.
- Calibration results quite good

Calibration Results: L.T. Edison





Verification Period Results



Operational Data Processing

Data Service runs continuously and performs the following tasks once per hour

- Acquires real-time data from CDEC ftp site, processes and stored in the database
- Acquires SCADA data from corporate DB
- Calculates actual inflow using the calculated plant and spill flow and the change in reservoir storage

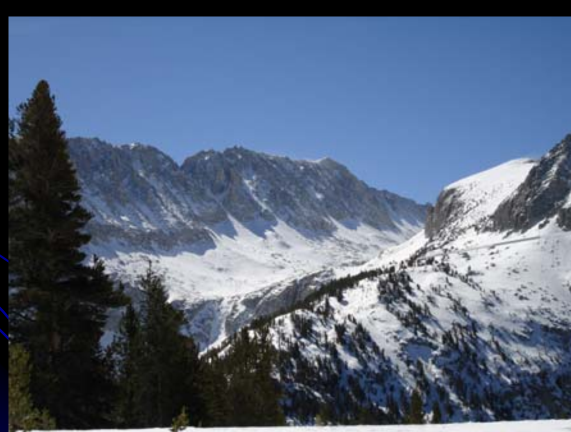
Weather Forecasts

- To forecast inflow up to two weeks into the future requires a forecast of hourly precipitation and temperature.
- Watershed divided into a number of regions.

  SCE has contracted with a forecast vendor to provide site specific forecasts, at least once and day.

Automated-Customized WRF-Based Quantitative Precipitation Forecast Model

Rick Stone, RHS Consulting, Reno, NV
Weather Decision Technologies Inc., Norman, OK

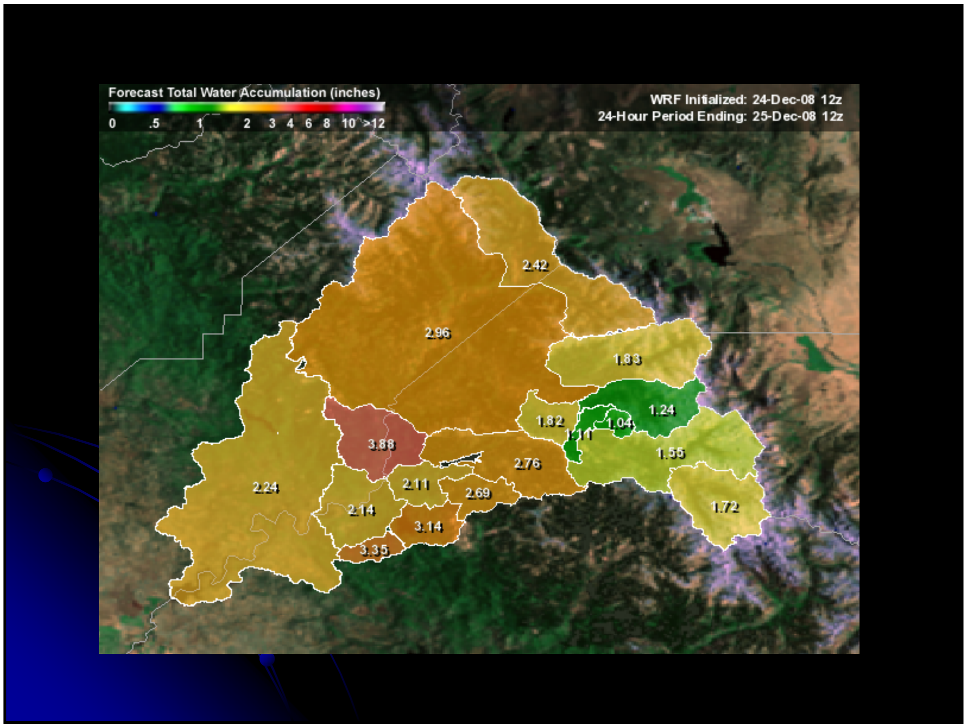


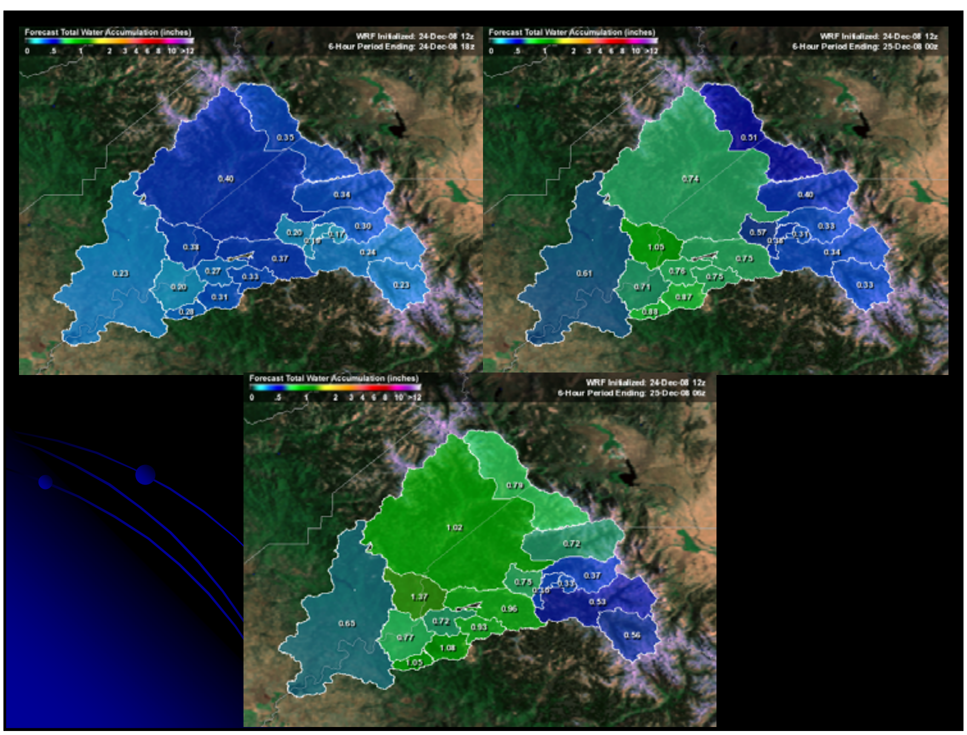
Overview of WRF Model

- state-of-the-science automated quantitative precipitation forecast system
- to support SCE hydro and cloud seeding operations
- *sub-basin resolution*
- based on the WRF-ARW model currently in use by NCAR, NOAA, NCEP, USAF, and the academic community
- more advanced microphysics options
- 36-hour forecast generated *continuously* every 6 hours
- high-resolution grids (outer spacing 6-km; inner spacing 1-km)
- mechanisms for forecast interval & total precip accumulation

WRF Model Primary Forecast Products

- Surface Winds, Rel. Hum., Pressure, Temps
- 700 mb Winds, Rel. Hum., Pressure, Temps (10,000')
- 500 mb Winds, Rel., Hum, Pressure, Temps (18,000')
- Precip Accumulation
- Precip Rate
- Radar Echo & Cloud Cover
- Turbulence (4,000 - 20,000')
- Vertical Cross Sections


Forecast Total Water Accumulation (inches)
0 .5 1 2 3 4 6 8 10 >12
WRF Initialized: 24-Dec-08 12z
24-Hour Period Ending: 25-Dec-08 12z
2.42
2.96
1.83
1.82
1.24
1.04
1.11
1.56
3.88
2.76
2.24
2.11
2.69
1.72
2.14
3.14
3.35


Forecast Total Water Accumulation (inches)
0 .5 1 2 3 4 6 8 10 >12
WRF Initialized: 24-Dec-08 12z
6-Hour Period Ending: 24-Dec-08 18z
Forecast Total Water Accumulation (inches)
0 .5 1 2 3 4 6 8 10 >12
WRF Initialized: 24-Dec-08 12z
6-Hour Period Ending: 25-Dec-08 00z
Forecast Total Water Accumulation (inches)
0 .5 1 2 3 4 6 8 10 >12
WRF Initialized: 24-Dec-08 12z
6-Hour Period Ending: 25-Dec-08 06z

Operational Forecasting

Short-Term Forecasting Process

- Hourly forecasts of local inflow are generated automatically several times a day.
- Staff manually check and correct data several times a day.
- Inflow forecast model can also be executed in interactive mode.

Long-Term Forecasting

- The long-term planning tool is designed to use a number of plausible future inflows to capture to uncertainty in inflows. SCE will use the following sources,
  - Forecasts from existing forecast model
  - Selected historic inflow sequences
  - Extended inflow forecast generated by the new inflow forecast model.
- The extended inflow forecasts are generated using the current state of watershed (snow water equivalent, wetness etc.), a short-term weather forecast, and rainfall and temperature data from user selected historic years.

What is Driving Us to do All of This?

- Energy Services and Marketing
  - The need for real time forecast and operations Data
  - Smaller time steps needed but also needed the ability to predict farther than 12 months
  - MRTU (Market Restructuring Tech Upgrade)
  - Importance of Hydro to the Ancilliary Services Market
  - More value per AF as required by CEC to use best management practices
- New F.E.R.C. License Requirements
- Climate Change Issues

Summary

- Climate Change, Market Forces and additional Federal Energy Regulatory Commission license requirements dictate that development of new inflow forecast and Water Management tools be developed with smaller time steps but……………

Beware of Precision without Accuracy

- More analysis of new models performance is needed which will take several years before we have confidence in the process and tools
- Still rely heavily on the monthly State Forecasts for comparative purposes
- Collaboration with USBR is also very important to SCE

The current weather forecast…

Front porch forecasters

Questions and Comments?

Contact Info

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