Using RiverWare to Analyze the Impacts of High Frequency versus Low Frequency Climate Change Hydrology Sequences in the Truckee Carson Basin

Truckee-Carson River System (TCRS)

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Precision Water Resources Engineering

RiverWare User Group Meeting

August 28th, 2019

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Precision Water Resources Engineering

"Stewardship Through Technology"

- Founded in 2008, headquartered in Loveland, Colorado
- We develop and apply state-of-the-art technological water management tools in close collaboration with water managers of large, complex and contentious water systems
- Specialize in development and application of RiverWare modeling tools. (www.riverware.org)

- RiverWare modeling projects in :
  - Truckee-Carson River Basin
  - Colorado River Basin
  - Arkansas River Basin
  - Colorado-Big Thompson Project
  - San Juan River Basin
- Clients include:
  - Federal Agencies
  - State Agencies
  - Municipalities
  - Research Institutions

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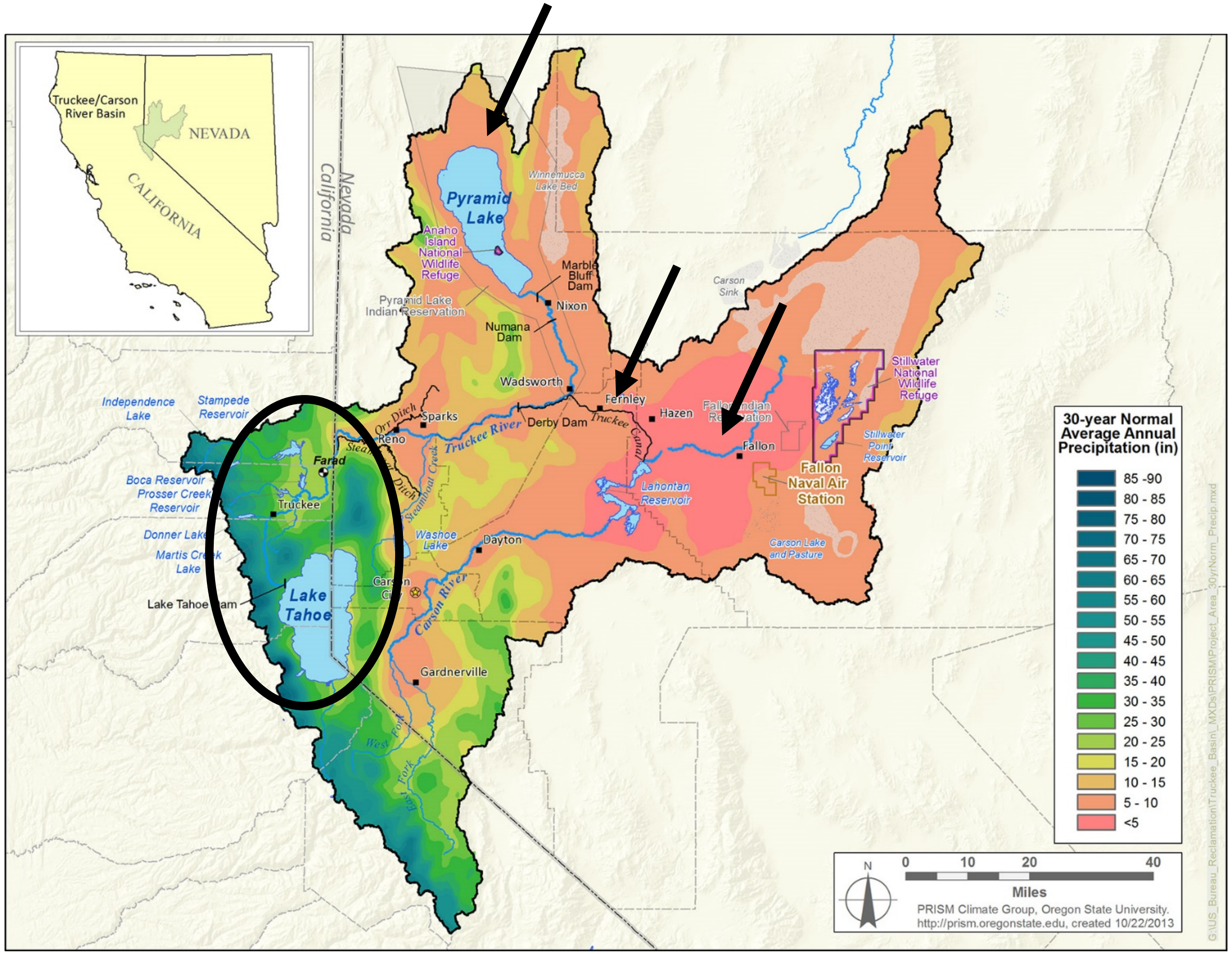
Truckee–Carson Basin Introduction

- Truckee River is ~100 miles long, flowing from Lake Tahoe to Pyramid Lake
- Seven upstream storage reservoirs regulate ~70% of the basin water supply
- Majority of the water originates in California (Sierra Nevada Mountains)
- Majority of the water usage is in Nevada
- Water is diverted from the Truckee Basin to the Carson basin via the Truckee Canal at Derby Dam
- The Newlands Project is served by the combined Truckee and Carson River in the lower Carson River basin
- The river ends in a desert terminal lake, Pyramid Lake in the Great Basin



Water for the Seasons

"A Program for Sustaining Water Resources in a Changing Climate"

- In 2014 a grant was offered jointly by the NSF and USDA to explore impacts of climate change in snow-fed arid lands
- An interdisciplinary team from Northern Nevada won the grant
  - University of Nevada at Reno
  - Desert Research Institute
  - United States Geological Survey
  - Precision Water Resources Engineering
- Project included
  - Development of an integrated system of models (climate models, hydrology models, system operation models, and groundwater models
  - Robust stakeholder interaction process whereby study team engaged water managers to develop climate scenarios and adaptation strategies
  - Characterization of impacts to the basin due to changing climate
  - Identification of potential adaptation strategies to address impacts

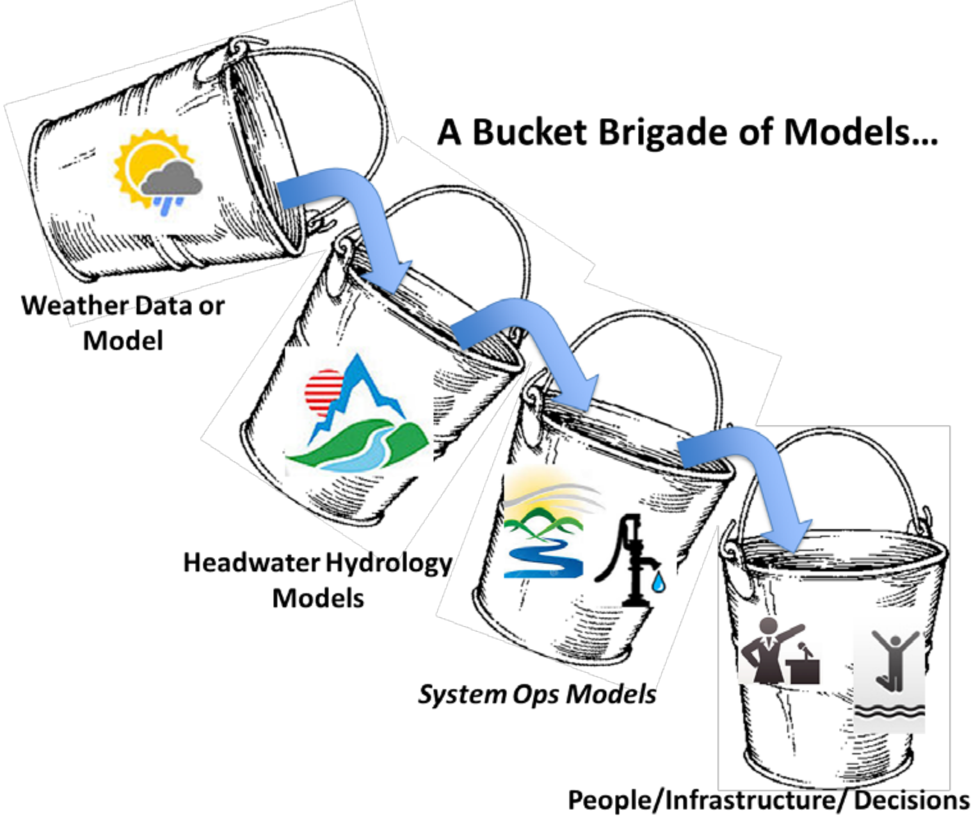


Figure courtesy of Mike Dettinger, USGS

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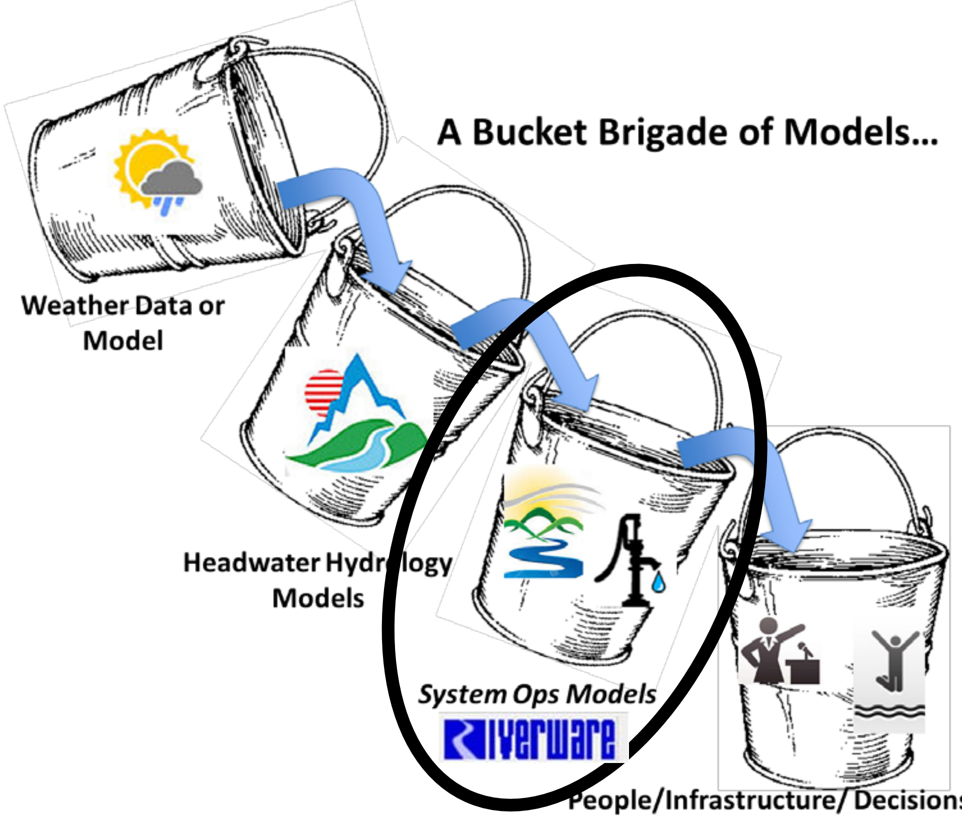
- Truckee RiverWare TROA Planning Model was the operations model for the Truckee river basin



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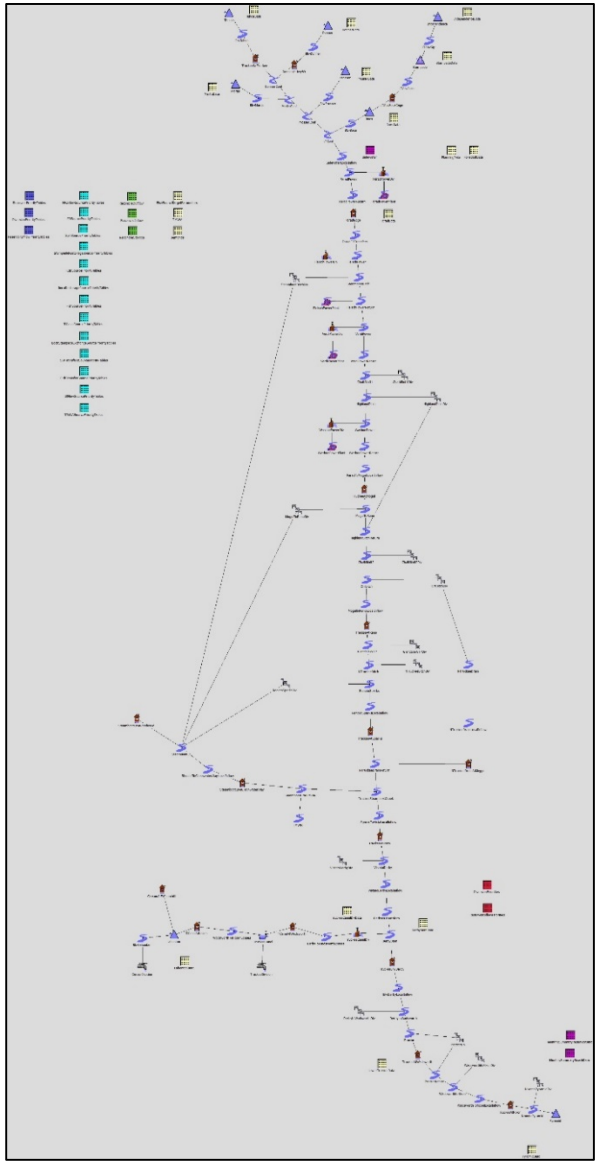
TROA Planning Model Summary

Truckee River Operations RiverWare Model



- Daily timestep RiverWare© model
- Under continuous collaborative development since 2009
- Capable of 100+ year runs
- Multiple hydrology and demand datasets available

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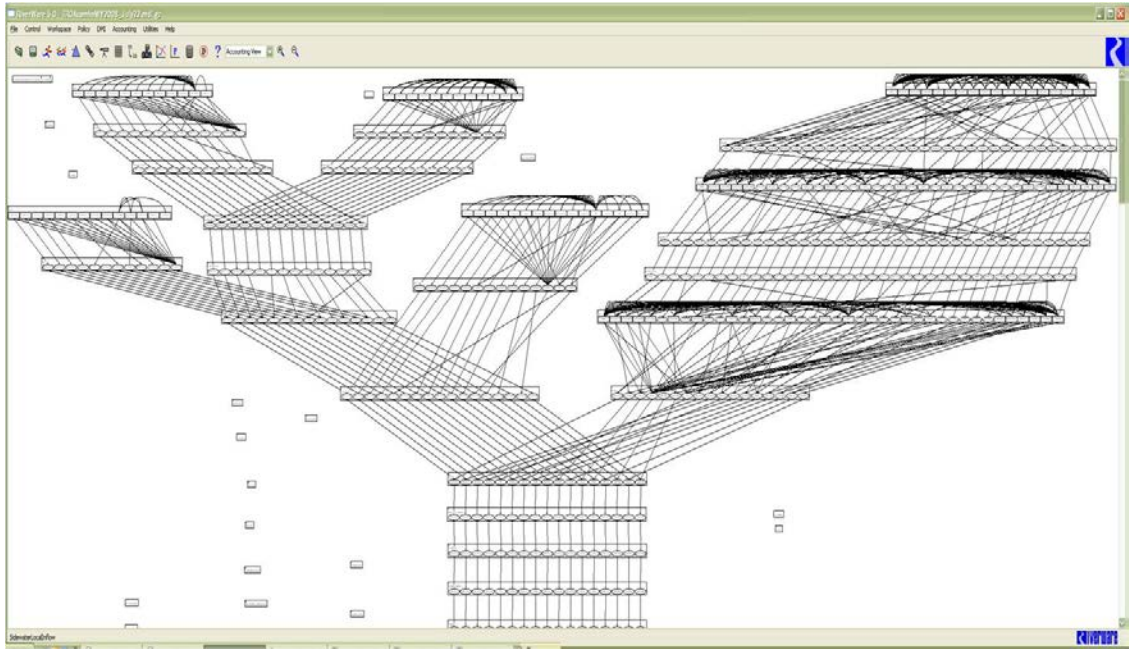
TROA Planning Model Summary

Truckee River Operations RiverWare Model

- Daily timestep RiverWare© model
- Under continuous collaborative development since 2009
- Capable of 100+ year runs
- Multiple hydrology and demand datasets available
- Simulates all reservoir operations and diversions/uses in the basin according to TROA policy
- Tracks TROA accounting in all reservoirs and reaches
- Performs TROA accounting transactions
- Includes baseline characterization of individual party's operational strategies under TROA
- USBR-LBAO is "gatekeeper" for the model, but it is available to and is used extensively by stakeholders throughout the basin



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Objective

- Often when considering current or future water supply conditions and whether it is "good", "bad", "wet", or "dry", water managers think primarily about annual inflow volumes .
- While annual inflow volume is probably the most impactful characteristic, it is certainly not the only significant characteristic of hydrology relative to water supply, and management systems functioning as designed.
- Water managers have increasingly become aware that the timing of inflows (runoff, winter storms, etc) is also an impactful characteristic.
- Management community seems to be less aware that there is another very significant characteristic of hydrology that impacts water supply on a longer time scale. This characteristic is the sequencing of hydrologic years, or what will be referred to as frequency.
- Objective is to examine the effects of frequency within existing GCM output on large water resource systems in snow-fed arid basins in the west.

Impactful Hydrologic Characteristics

1. Average Annual Volume
2. Timing
3. Frequency

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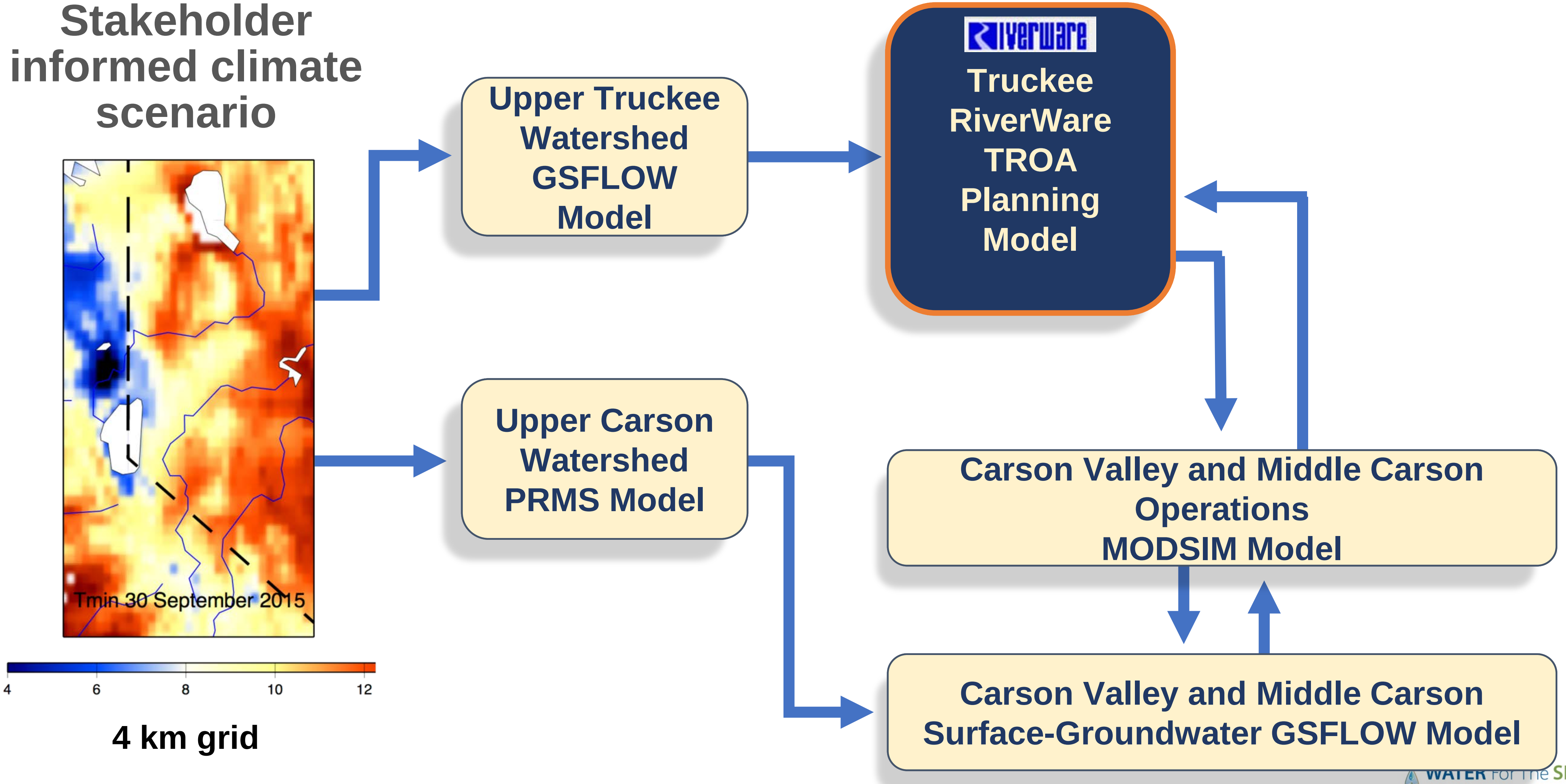
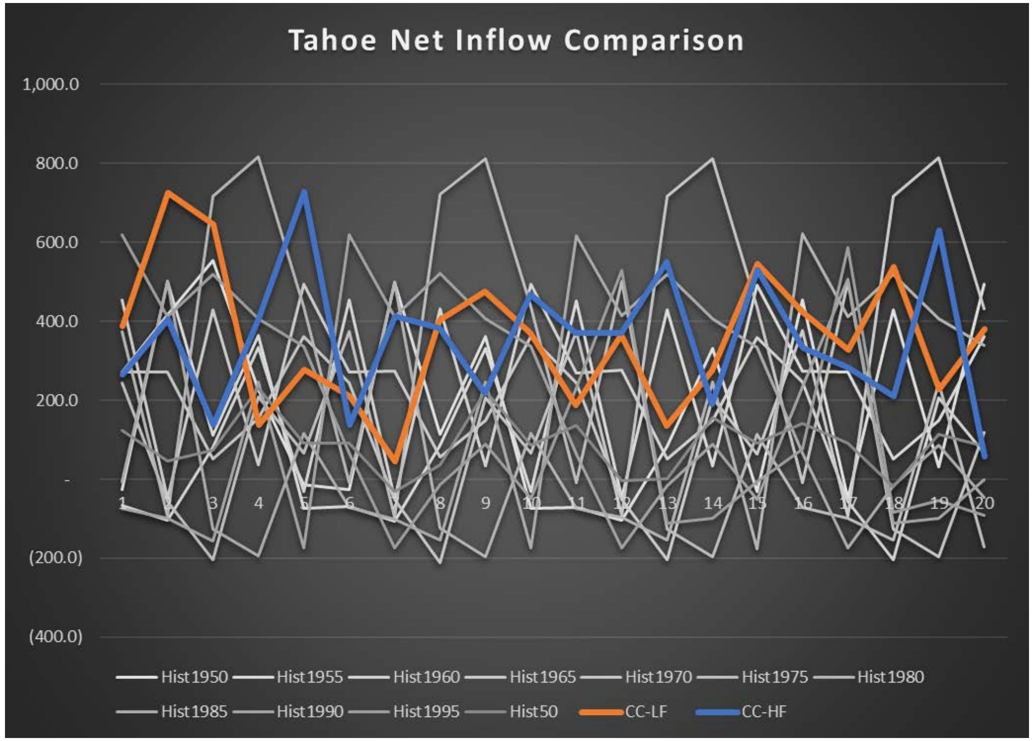
Water for the Seasons Integrated Models



WATER For The SEASONS

What is Frequency?

- If last year was wet, how likely is it that this year will be wet?...50%? … >50%?
- Do wet/dry years come in clusters or is each new year a fresh roll of the dice independent of what happened in the past?
- This is a difficult question
- Statistical analysis of the historical record seems to indicate there is "clustering"
- Anecdotally Truckee/Carson water managers recognize some degree of clustering of wet/dry years that would seem to be highly improbable if each year was independent of preceding years (1987-1994, 1995-1999, 2012-2015, 2017-???)
- WftS Project Team developed two climatic scenarios to explore the impacts of Frequency on the Truckee Carson system
  - The Low Frequency (LF) Scenario emphasizes this clustering effect
  - The High Frequency (HF) Scenario de-emphasizes this clustering effect



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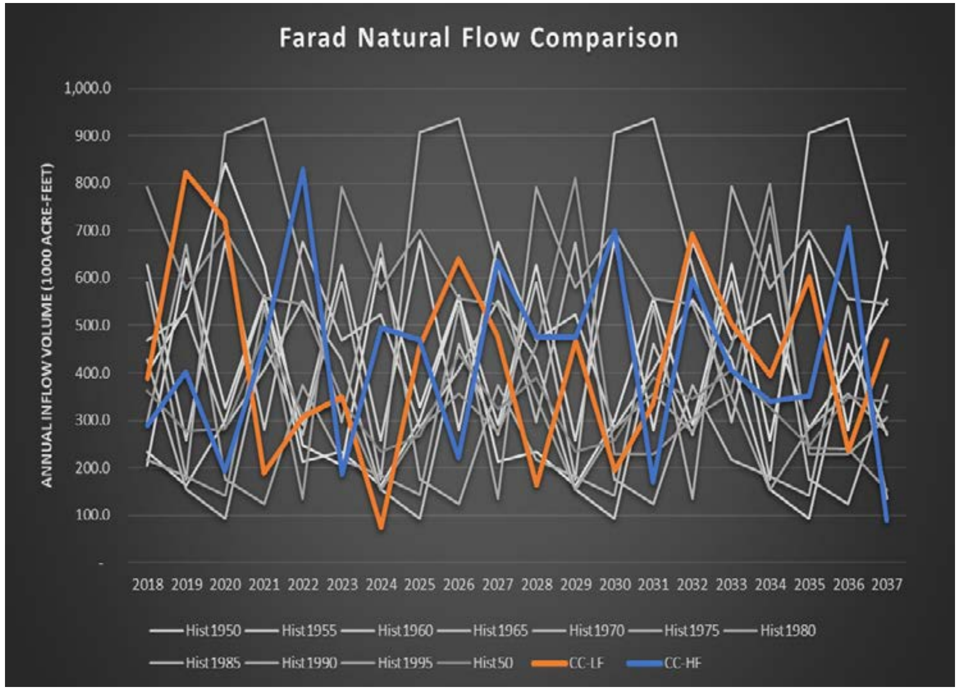
Climatic Scenarios Descriptions

- HF Scenario– 20-year sequence from each of a suite of 30 GCM's with highest ratio of the standard deviation of a high-pass 2-year mean precip to standard deviation of annual precip for that given model and scenario. Among these 30 sequences the one closest to historical average precip was selected (93% of historical average).
- LF Scenario – Same 20 years as above re-sequenced to have lower frequency variability - roughly 5 years. Average annual precipitation is the same as HF.
- Historical (Ensemble)- 10 "historical" scenarios were developed using 1950-2015 observed hydrology consisting of 20 years of historic hydrology beginning in years 1950, 1955, 1960, …, 1995.
    - Multiple historical series were developed because of the relatively short run period (20 years). Selecting one 20-year period to represent a historical scenario is problematic because of the high variability among 20-year periods in the recent past. The "ensemble" of 10 historical periods will collectively represent the historical basin conditions for the purpose of comparisons



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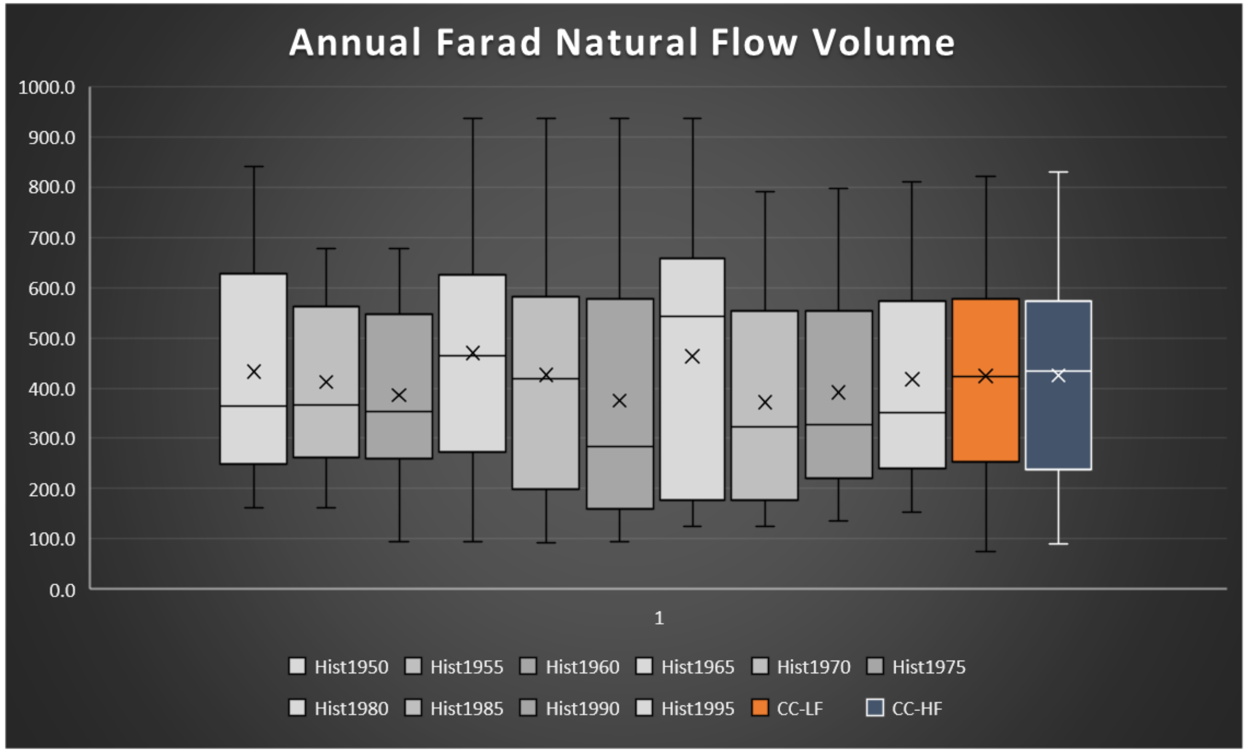
Hydrology Comparison - Volumes

- The climate scenarios were downscaled and run through the hydrologic model to generate hydrology for the RiverWare model
- Each hydrology scenario is 20-years (2018 – 2037)
- Each box and whisker shows the range of annual Truckee inflow volumes within that hydrologic scenario
- Annual Volumes of the LF and HF Scenarios are very similar to those of the Historical hydrology ensemble
- Driest historical scenario is ~50 AFA drier than the LF/HF scenarios
- Any observed impacts to the system and its users will be attributable to hydrologic characteristics other than annual inflow volume



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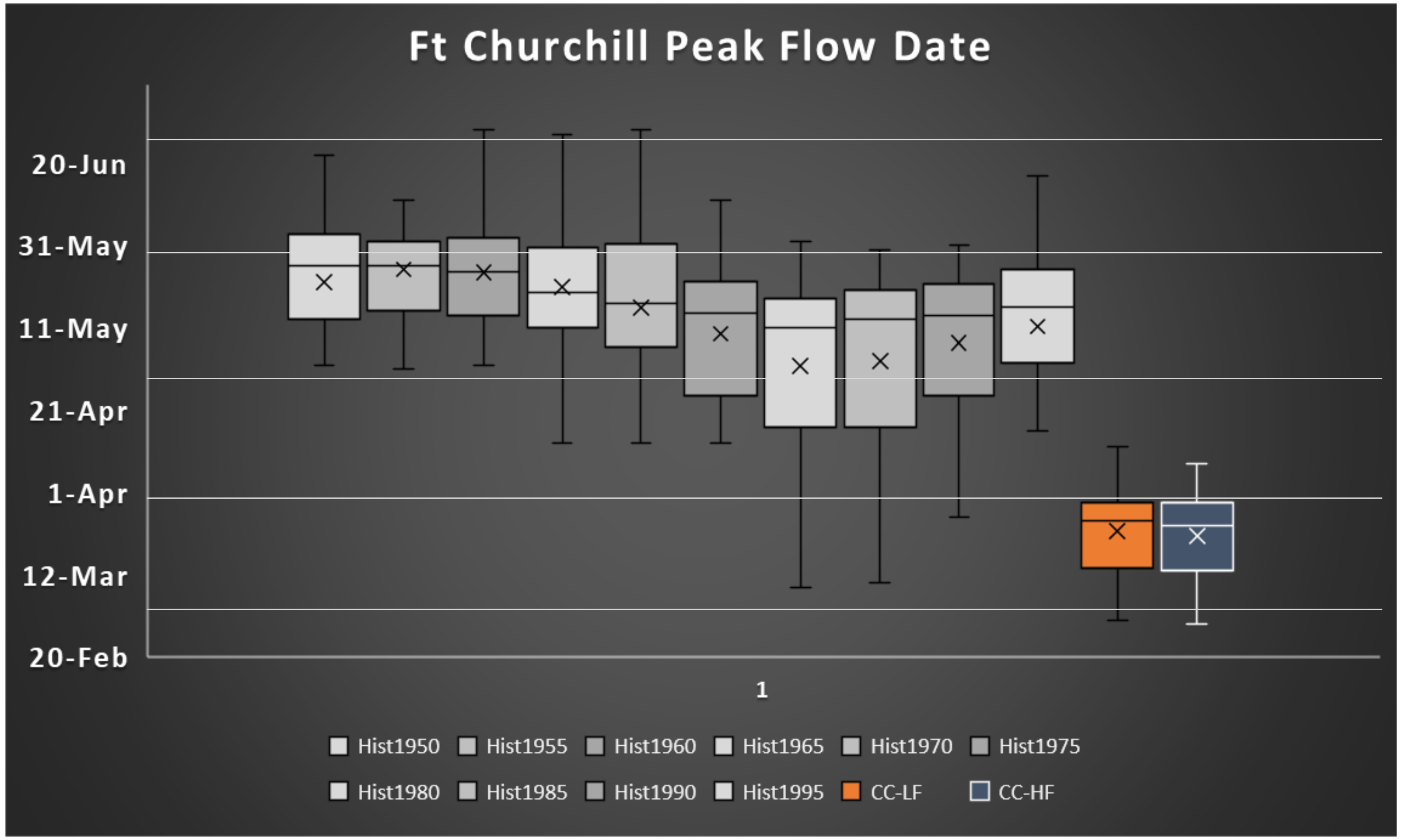
Hydrology Comparison - Timing

- Each box and whisker shows the range of peak inflow dates within that hydrologic scenario
- Note the apparent trend in the historical ensemble peak date ranges
- Peak runoff flows within the LF and HF scenarios are nearly two months earlier than those of the historical ensemble
- Note that timing was not considered in the selection of the LF/HF sequence within the GCM output. This timing is indicative of a consensus among GCM results
- The timing of the LF and HF inflow hydrology is significantly earlier than the historical hydrology. Impacts to the system due to runoff timing will be apparent in modeling results



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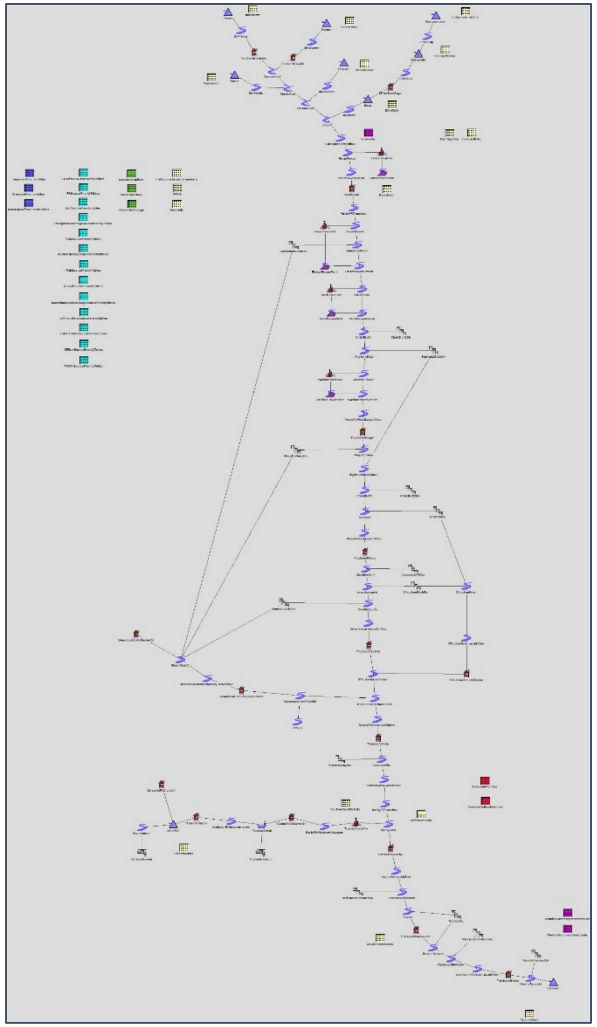
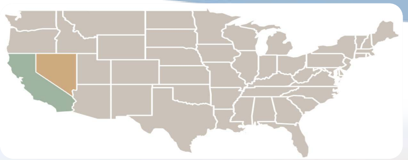
Modeling Results Survey

- Each of the hydrologic scenarios was input to the Truckee Planning Model to simulate basin operations and evaluate and characterize impacts across the whole system
- What follows is a survey of significant results from the RiverWare model runs.
- Results will be presented with some general observations that are appropriate based on the purpose of the effort – identify impacts to Tahoe/Truckee/Lower Carson system due to timing and frequency
- Detailed conclusions about specific users and locations would require a more detailed analysis. Model is configured to represent general operations of the system under TROA and current demand levels.

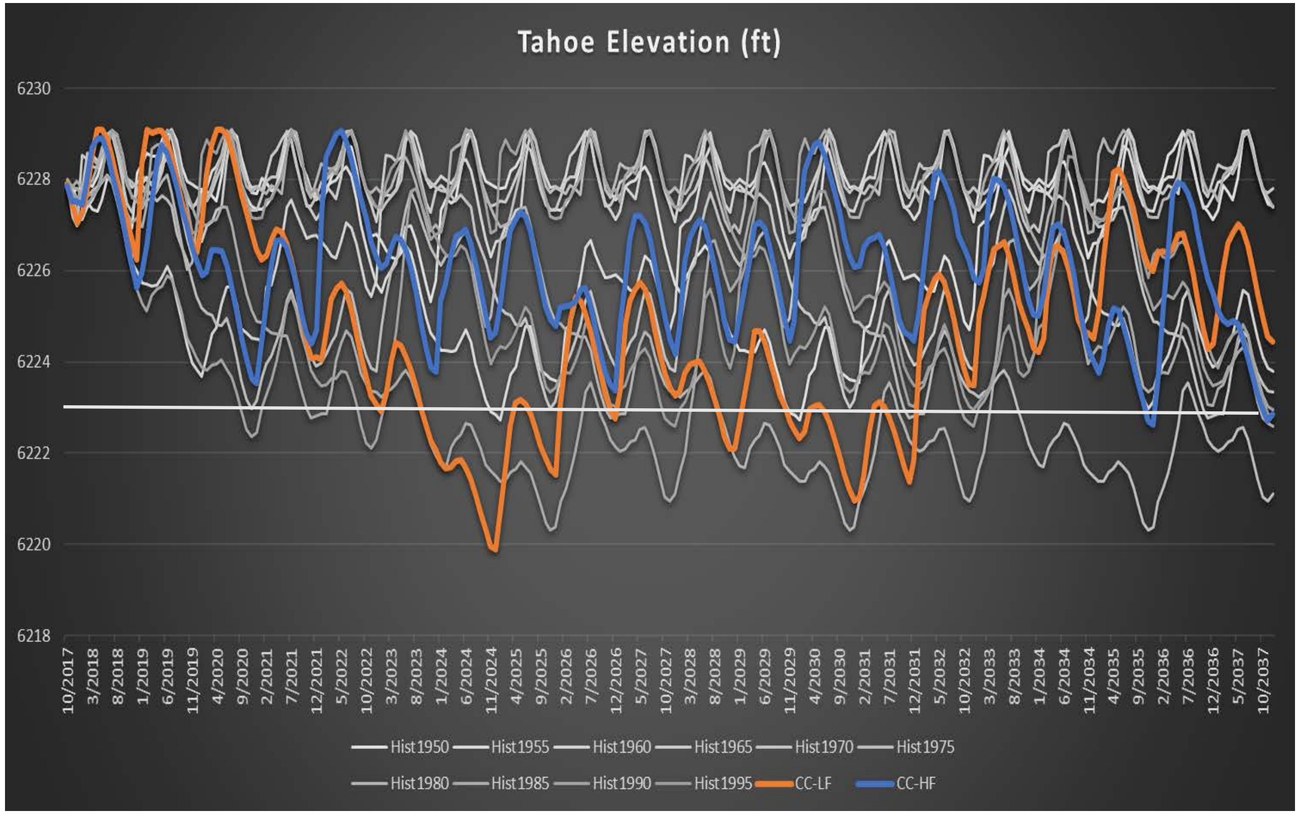




Lake Tahoe Elevation

Lake Tahoe Water Surface Elevation

- Longest time between fills in historical scenarios is 8 years
- LF Scenario goes 15 years between fills
- LF Scenario minimum elevation is 0.4 ft lower than historical scenarios' minimum elevation
- HF Scenario barely goes below the rim
- Average Elevation Comparison
  - Lowest average Historical Scenario elevation – 6225.19 ft
  - All Historical Scenarios – 6226.36 ft
  - HF Scenario – 6226.08 ft
  - LF Scenario – 6224.82 ft
- Timing of runoff has minimal effect on Lake Tahoe's elevation
- Frequency impacts Lake Tahoe's elevation significantly. Low frequency hydrology patterns negatively affect Lake Tahoe as a water supply source to the basin



Stampede Reservoir Storage

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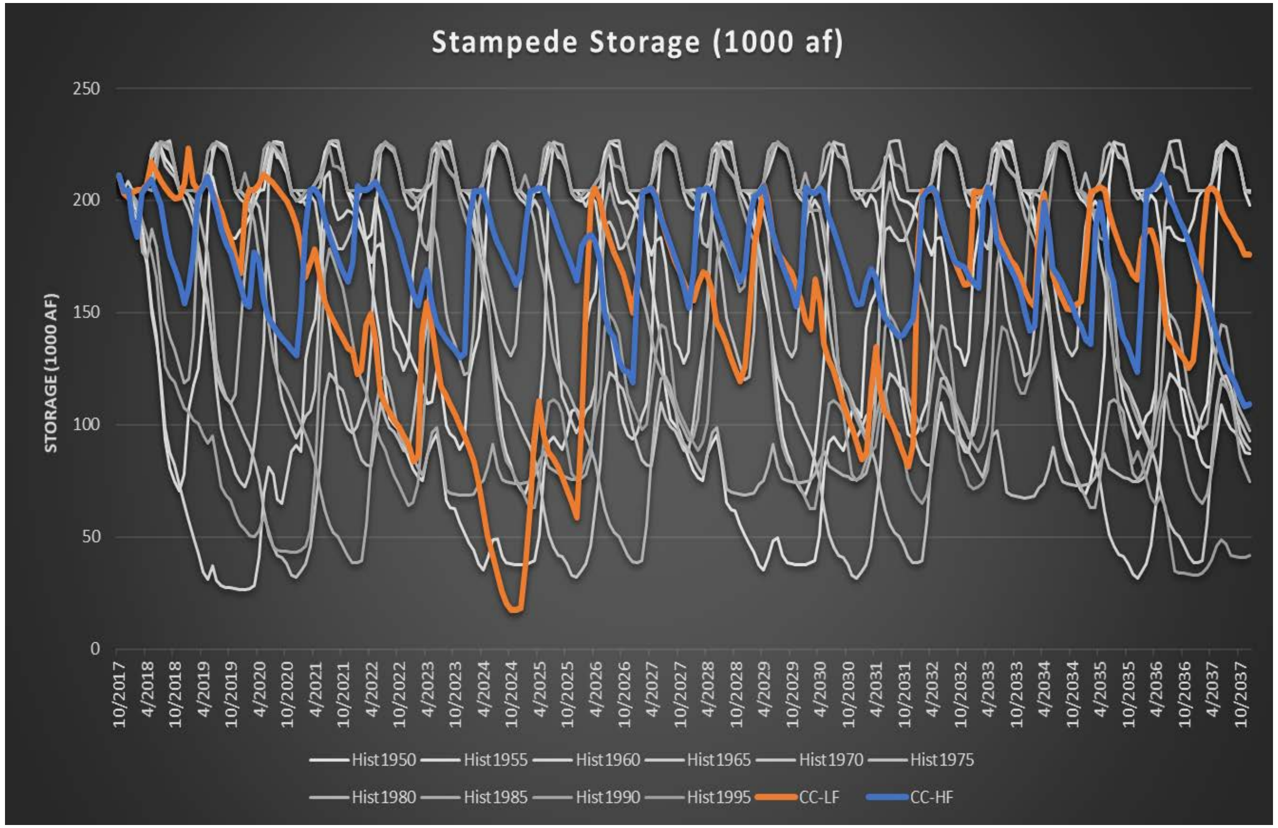
Stampede Reservoir Storage

- Note that in HF and LF scenarios the reservoir almost never fills to top due to early runoff's incompatibility with USACE flood control curves
- Average Storage Comparison
  - Lowest Historical Scenario – 138,000 AF
  - All Historical Scenarios – 153,000 AF
  - HF Scenario – 174,000 AF
  - LF Scenario – 155,000 AF
- HF Scenario is positive for Stampede Storage because when intervals between larger years are shorter, the reservoir cannot fall as far between fills. Stampede only fills in relatively wet years.
- LF Scenario minimum storage is lower than historical scenarios' minimum storage
- LF and early runoff both adversely affect Stampede Reservoirs performance as a water supply reservoir



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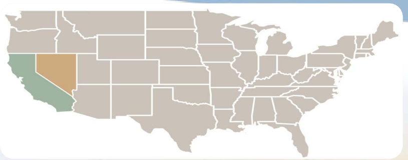

Truckee Meadows Agriculture

Truckee Meadows Agriculture

Annual Delivery Volume (1000 AF)												
	Hist1950	Hist1955	Hist1960	Hist1965	Hist1970	Hist1975	Hist1980	Hist1985	Hist1990	Hist1995	CC-LF	CC-HF
Average	23.4	23.4	23.4	23.4	23.2	21.6	21.6	21.5	22.7	23.4	18.8	23.0
Median	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4	21.7	23.4
Shortages	1	1	1	1	3	7	7	8	6	2	11	4
Shortage %	5%	5%	5%	5%	15%	35%	35%	40%	30%	10%	55%	20%
Min	21.7	21.7	21.8	21.7	20.3	9.5	9.3	9.3	19.0	21.7	3.0	19.1

- The worst historical scenario shows 8 shortage years or 40%
- The average number of historical scenario shortage years is 3.7
- The LF scenario shows 11 shortage years or 55%
- The LF scenario's minimum delivery volume is 3.0 kaf while the minimum historical scenario delivery is 9.3kaf
- The LF scenario is wetter than the driest historical scenario.
- LF hydrology results in significantly increased frequency and magnitude of shortages for agricultural users

- The average number of shortages in the historical scenarios is 3.7 or 18.9%
- The HF scenario shows 4 shortage years or 20%
- The lowest minimum historical scenario delivery volume is 9.3 kaf, the average minimum is 17.6kaf
- The HF scenario's minimum annual delivery volume is 19.1 kaf
- HF future hydrology does not have significant impact on agricultural deliveries in the Truckee system

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Pyramid Lake Elevation

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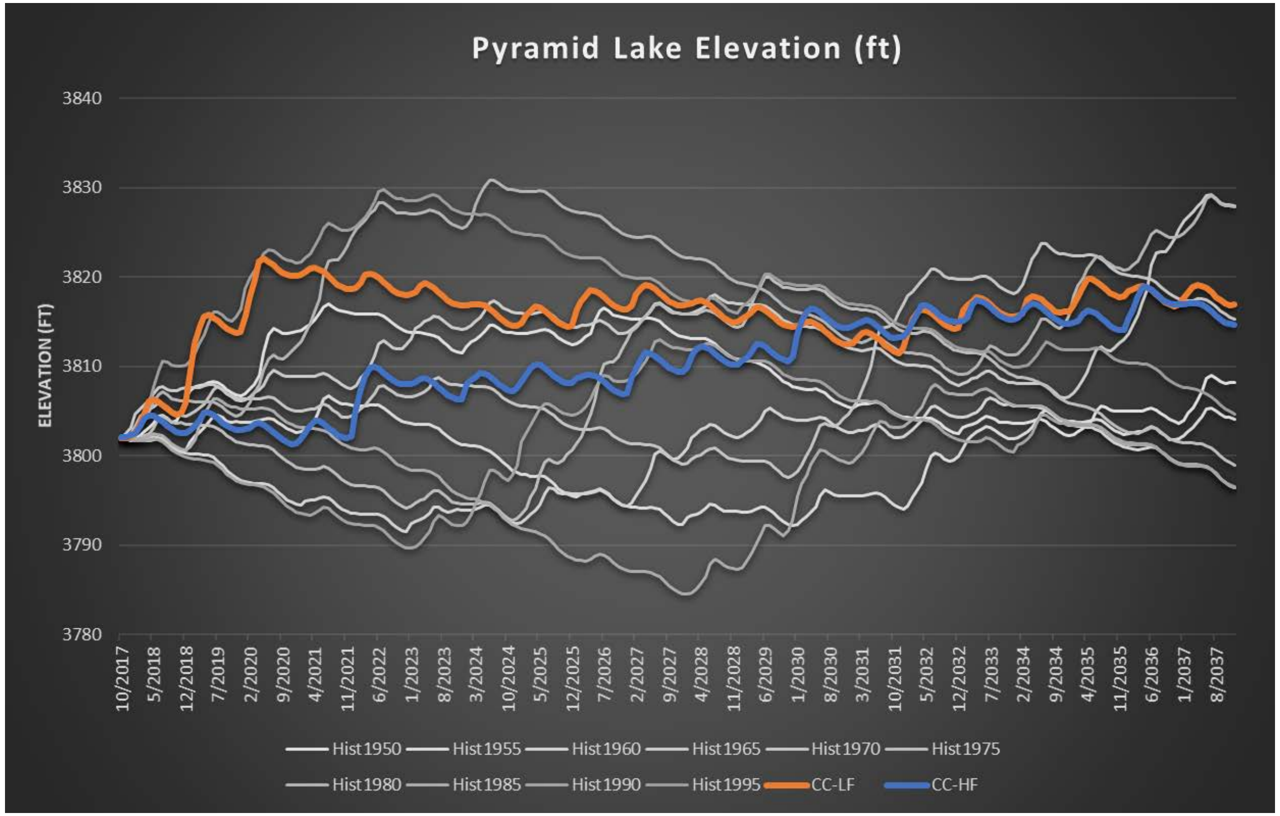
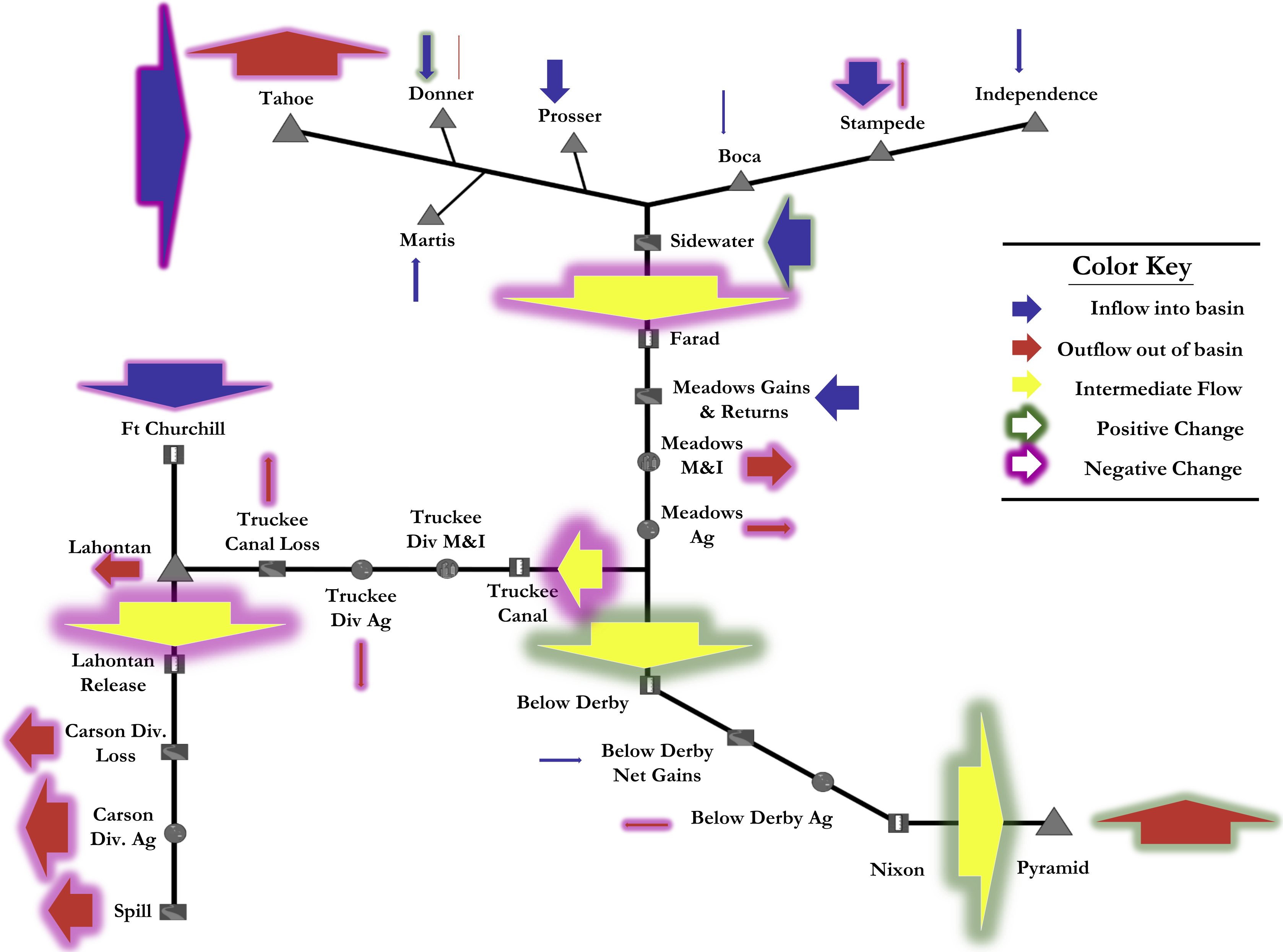
Pyramid Lake Elevation

- End of period (2037) Elevation Comparison
  - Ave All Historical Scenarios – 3807.6 ft
  - HF Scenario – 3814.7 ft
  - LF Scenario – 3816.9 ft
- LF and HF scenarios end a little higher than the average of the scenarios, but is within the bounds of the historical ensemble
- The change in timing of flows in the LF and HF scenarios results in more water making it to Pyramid Lake
- The LF scenario ends with higher elevation at Pyramid Lake due to less efficient storage of water in upstream reservoirs and use in the basin compared to the HF scenario



Truckee & Carson Water Balance

Comparison Run water balance of the entire calendar years of 2018-2037



	Baseline	Change	Abs. Diff.	Rel. Diff.
Reservoir Inflows				
Boca Inflow	10.4	10.4	0.0	0%
Donner Inflow	30.7	31.0	0.3	1%
Independence Inflow	18.4	18.5	0.1	0%
Martis Inflow	19.4	19.3	-0.1	-1%
Prosser Inflow	61.5	61.3	-0.2	0%
Stampede Inflow	111.6	111.1	-0.5	0%
Tahoe Inflow	520.7	519.5	-1.2	0%
Reservoir Evap				
Boca Evap	1.3	1.2	-0.1	-10%
Donner Evap	2.7	2.7	0.0	0%
Independence Evap	2.0	2.0	0.0	-1%
Lahontan Net Evap	63.4	62.7	-0.6	-1%
Martis Evap	0.2	0.2	0.0	0%
Prosser Evap	0.8	0.9	0.0	2%
Pyramid Net Evap	357.0	364.2	7.2	2%
Stampede Evap	9.3	8.5	-0.8	-9%
Tahoe Evap	400.4	399.1	-1.2	0%
Other Inflows				
Sidewater Inflow	183.3	184.8	1.6	1%
Meadows Gains & Return Flow	95.4	95.3	-0.1	0%
Below Derby Gains & Return Flow	12.4	12.4	0.0	0%
Ft. Churchill Inflow	376.1	375.7	-0.4	0%
Outflows				
Meadows M&I Outflow	77.3	71.2	-6.1	-8%
Meadows Ag Outflow	22.9	18.8	-4.1	-18%
Below Derby Ag Outflow	10.1	8.3	-1.8	-18%
Truckee Div M&I Outflow	0.0	0.0	0.0	-
Truckee Div Ag Outflow	12.3	9.9	-2.4	-20%
Truckee Canal Loss Outflow	17.1	13.9	-3.2	-19%
Carson Div Loss Outflow	111.7	107.1	-4.6	-4%
Carson Div Ag Outflow	198.6	190.5	-8.1	-4%
Spill Outflow	131.1	120.5	-10.6	-8%
Intermediate Flows				
Farad Gauge	570.1	556.2	-13.9	-2%
Truckee Canal Gauge	152.7	128.2	-24.5	-16%
Below Derby Gauge	428.0	448.7	20.7	5%
Nixon Gauge	434.7	456.4	21.7	5%
Lahontan Release	441.5	418.2	-23.3	-5%

*All table values are in thousands of acre-feet.

Conclusions

- Timing and Frequency are characteristics of Tahoe/Truckee/Carson basin hydrology that have a significant impact on water supply and system operations for managers and users, and are likely indicative of similar impacts in other basins
- Early runoff timing impacts the basin in part because basin policy was designed/evolved based on historical runoff timing.
- Hydrologic Timing shows more significant impacts on the Carson River primarily due to lack of storage in the upper basin
- LF hydrology results generally in negative impacts on the upstream reservoirs and users along the Truckee River. This is because the reservoirs were designed to "bridge the gap" between years of surplus (wet). As these gaps lengthen, the ability of the reservoirs to compensate is strained.
- Further, when the system experiences extended wet periods, all of the surplus water cannot be stored for subsequent dry periods
- LF hydrology is beneficial to Pyramid Lake due to the inability of the reservoirs and users along the Truckee River to efficiently use the water
- HF hydrology is beneficial to the upstream reservoirs and users along the Truckee River. HF allows the system to more effectively perform as designed, even with significantly different timing of runoff

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Thank You!

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