# Application of TensorFlow Trained Artificial Neural Network (ANN) Model to Estimate Salinity and X2 in the Sacramento-San Joaquin Delta

**Malinda Wimalaratne**

Hamed Zamanisabzi
Yiwei Chen
Zachary Roy

CalSim 3 Development Team

# Outline

- What/Why ANN in CS3?
- Key Components in ANN Development
- ANN architecture, training and full circle analysis
- Performance evaluation and results
- Conclusion

# What's ANN Why it's in CalSim 3?

**What is an Artificial Neural Network (ANN)?**

- Computational Model inspired by the structure and functioning of the human brain

**Why ANN for Salinity Prediction in CS3?**

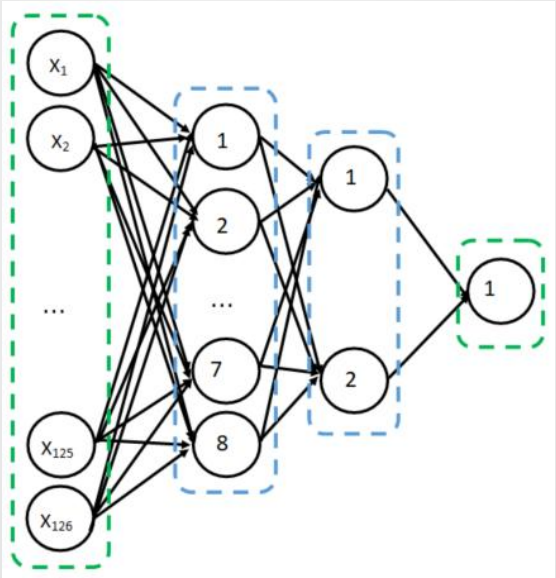
- **Need salinity/X2 calculation component for regulatory purposes**
  - DSM2 (practically not viable, and can not do reverse calculation)
- **Planning studies (CALSIM 3)**
  - Known: salinity standards
  - Unknown: flows, salinity
- **Need a salinity model allowing**
  - Specify a location in the delta
  - Specify the corresponding salinity standard
  - Provide an inflow-export-salinity relationship that allows compliance with salinity standard

# Key Components in EC/X2 ANN Development for a given station

**Inputs/ predictors from Models/Field measurements**

- •CalSim3
- •DCD
- •Planning Astronomical SF Tides

**Neural Network**




**Targets (Model/Field Measurements)**

- •EC (DSM2)
- •X2 (DSM2 interpolate)

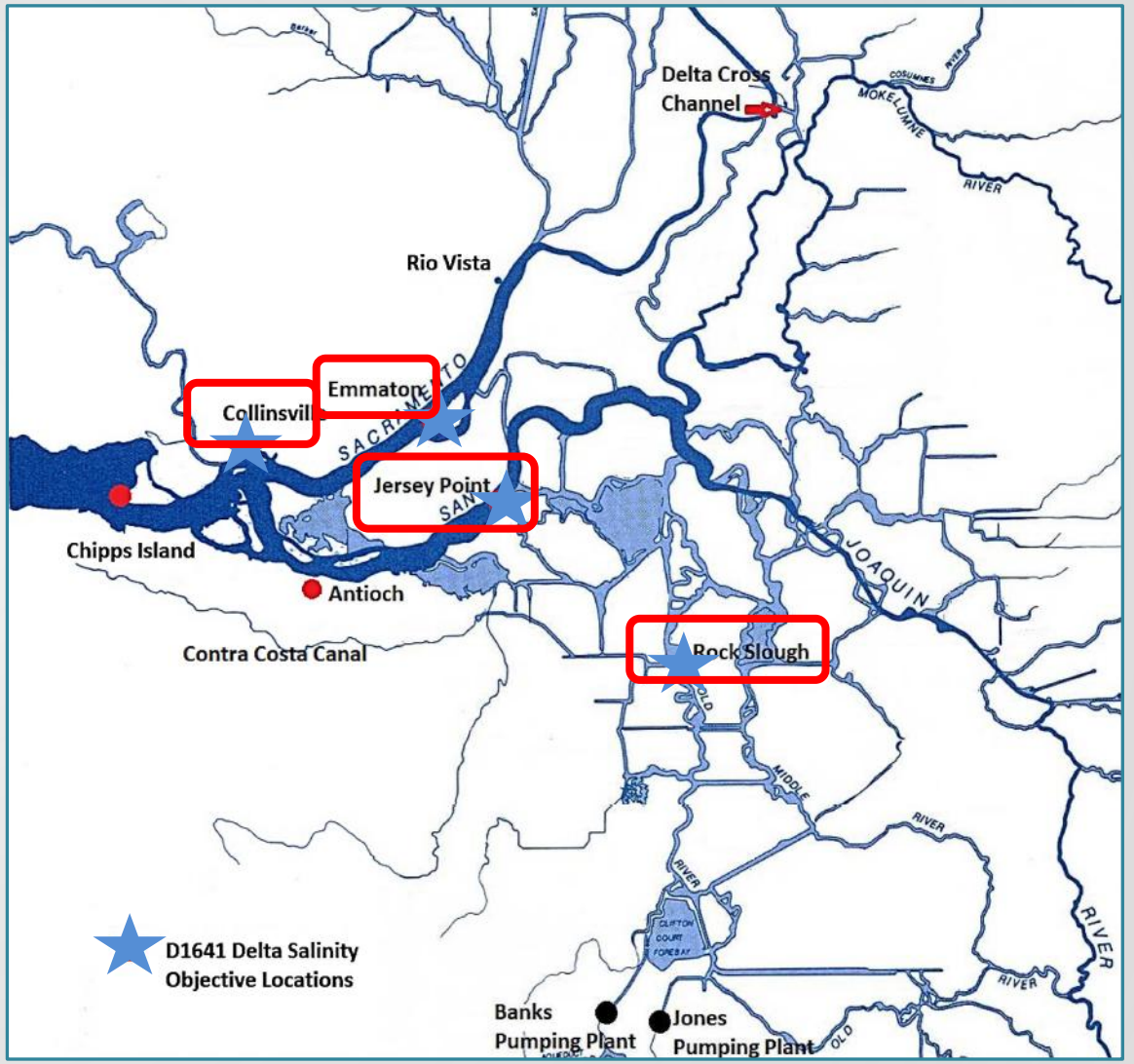
# EC/X2 predictions for CalSim 3

**Regulatory requirements D1641**

- Emmaton: Apr-Aug, 0.45-2.78 mmhos/cm EC
- Jersey Point: Apr-Aug, 0.45-2.20 mmhos/cm EC
- Rock Slough: year-round, 130-225 mg/l Cl
- Collinsville: Oct-May, 8.0-19.0 mmhos/cm EC

**Operational requirements**

- Triggering gate operations (Suisun Marsh Salinity Control Gate SMSCG tidally operation)

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# Data Processing and Model Structure

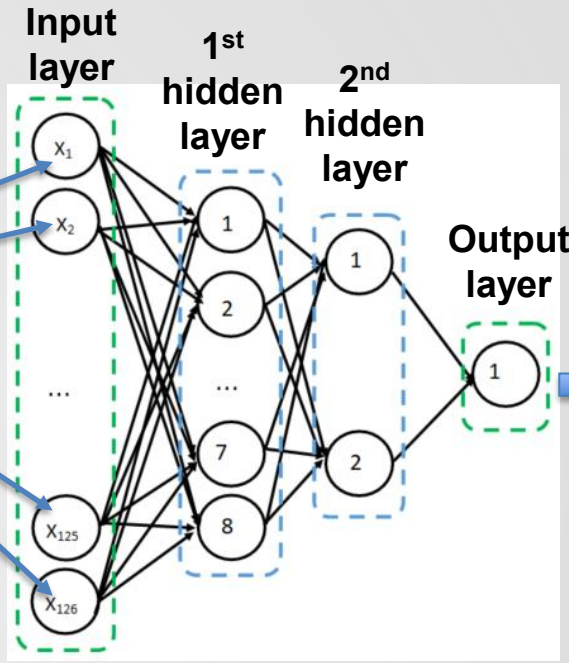
**EC Inputs – 7**

Delta Cross Channel Operations
Exports
Northern Flow
San Joaquin Flow
Asto Planning Tidal Range
Delata Channel Depletion
Suisun Marsh Salinity Gate

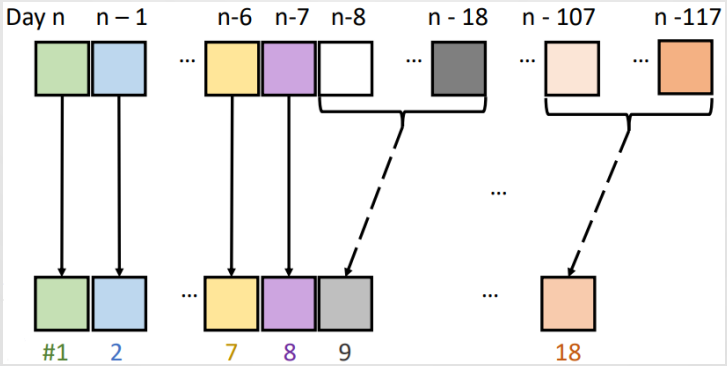
**X2 Inputs – 3**

Net Delta Outflow Index (NDOI)
Astrological Planning Tide
Suisun Marsh Salinity Control Gate

Pre-processing
7 input parameters convert from monthly to daily and considered antecedent conditions




Schematic of ANN Structure for EC




Predicted EC

Predicted X2

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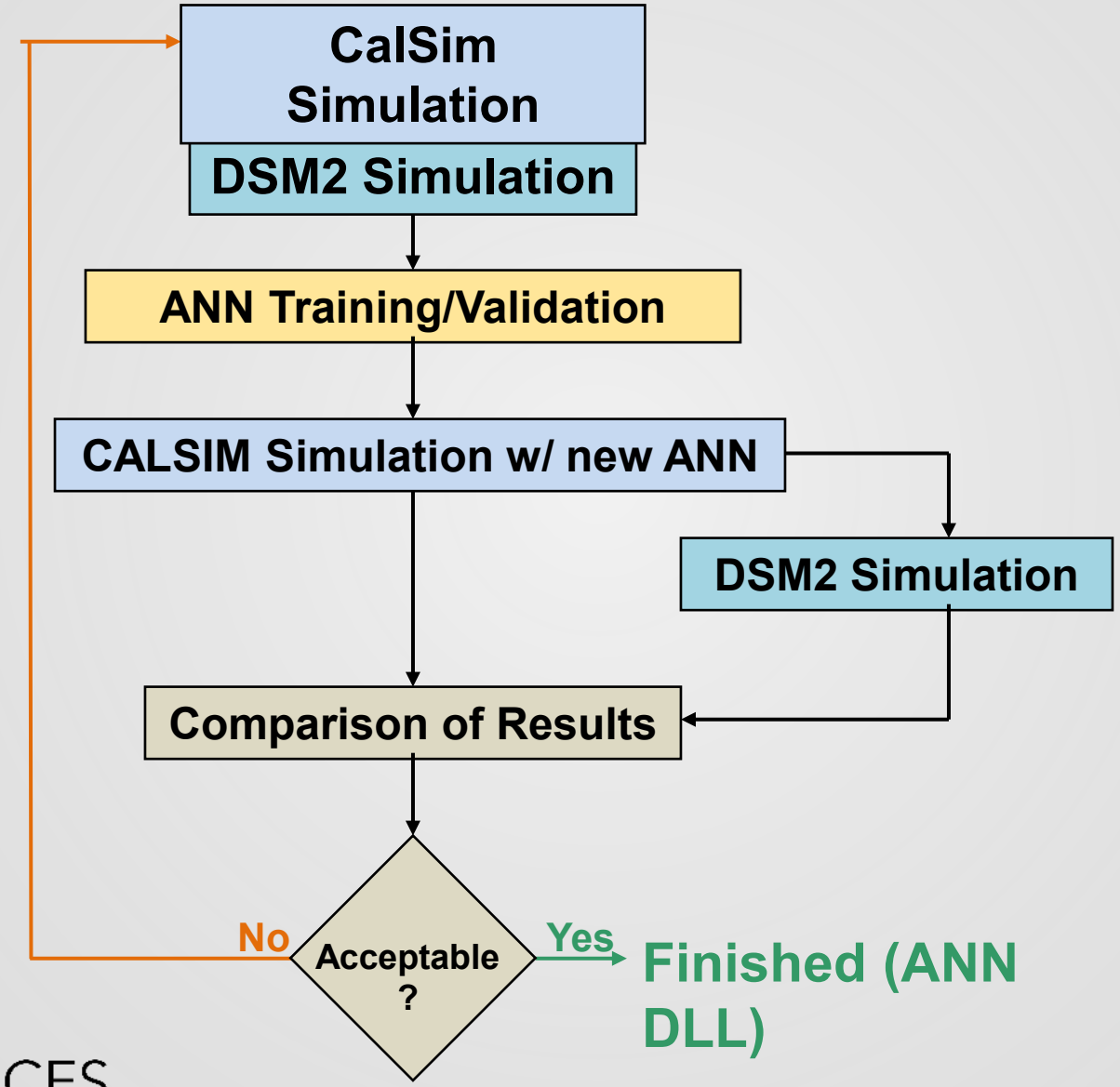
(sources: Adapted from Jayasundara et al., 2020, Qi et al., 2021)

# ANN Training and Full Circle Analysis

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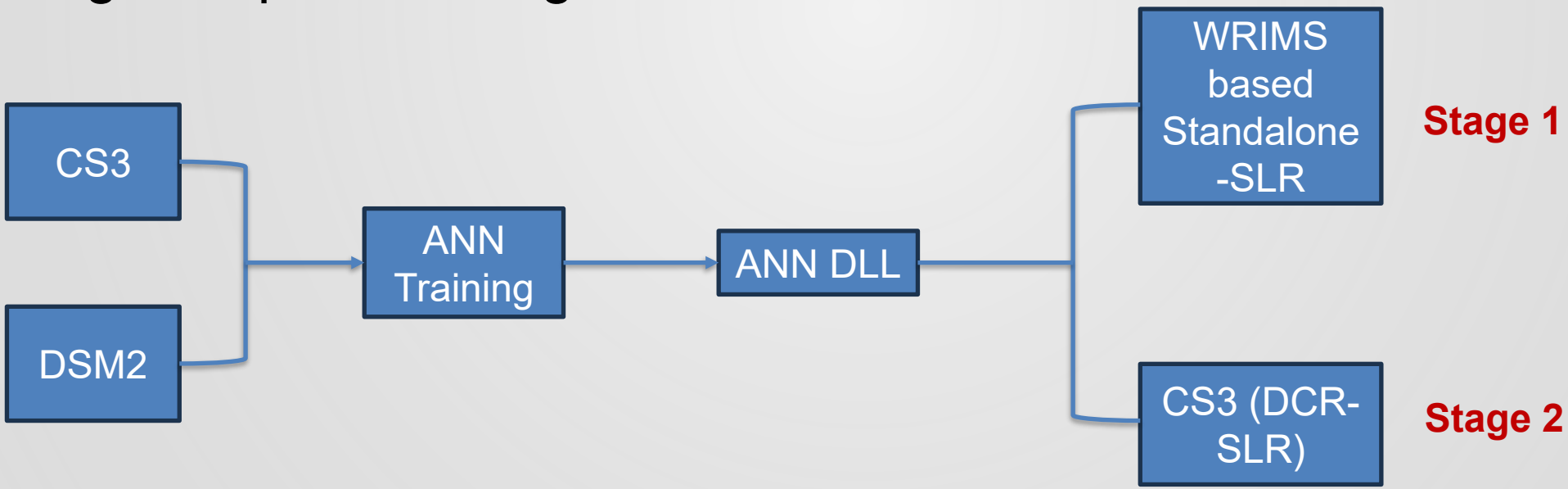
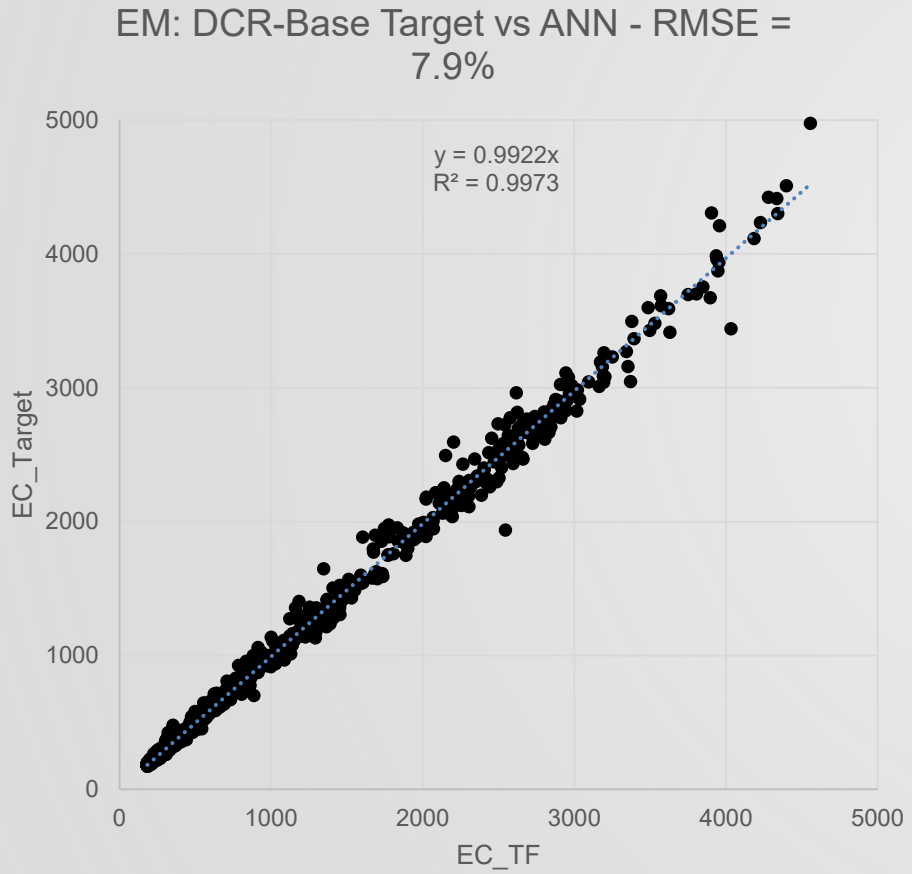
# Performance Comparisons With and Without CS3 Operations

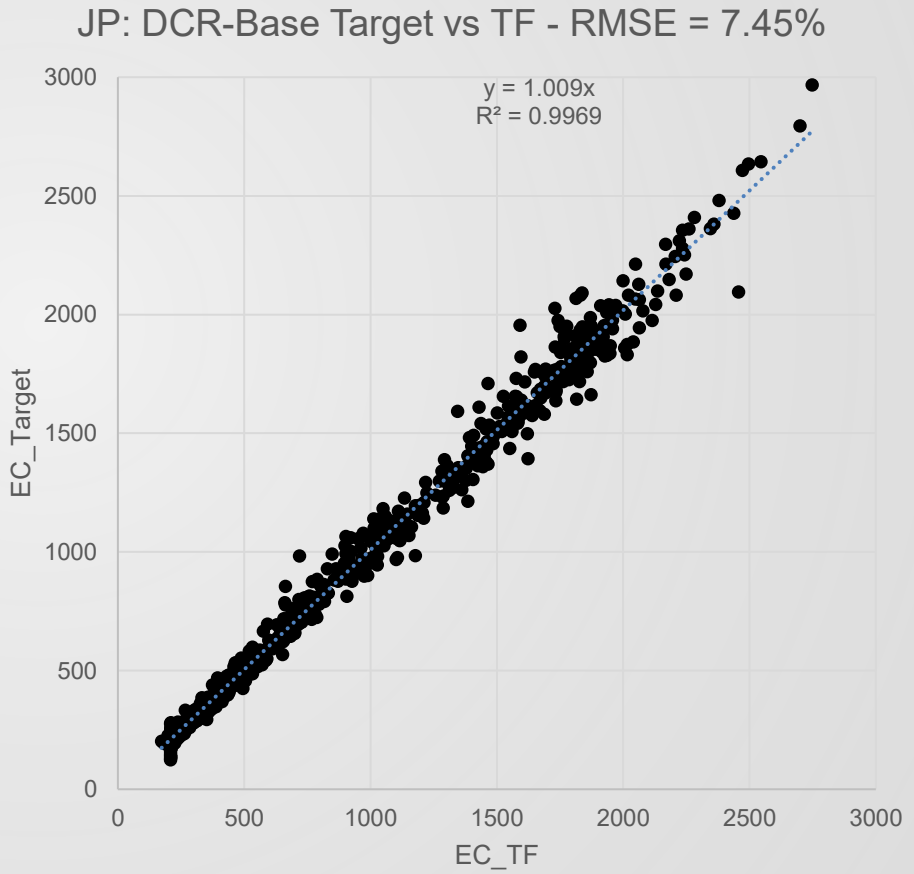
- Stage 1: ANN Performance excluding CalSim operations, comparison against target EC/X2 used for training
- Stage 2: Complete Process Flow Performance Comparison, against post training CS3 DSM2 results



# Stage 1 Results: Comparison out of ANN training and validation

**Monthly EC comparisons from ANN training and validation (for the period of Oct1921 – Sep2021)**

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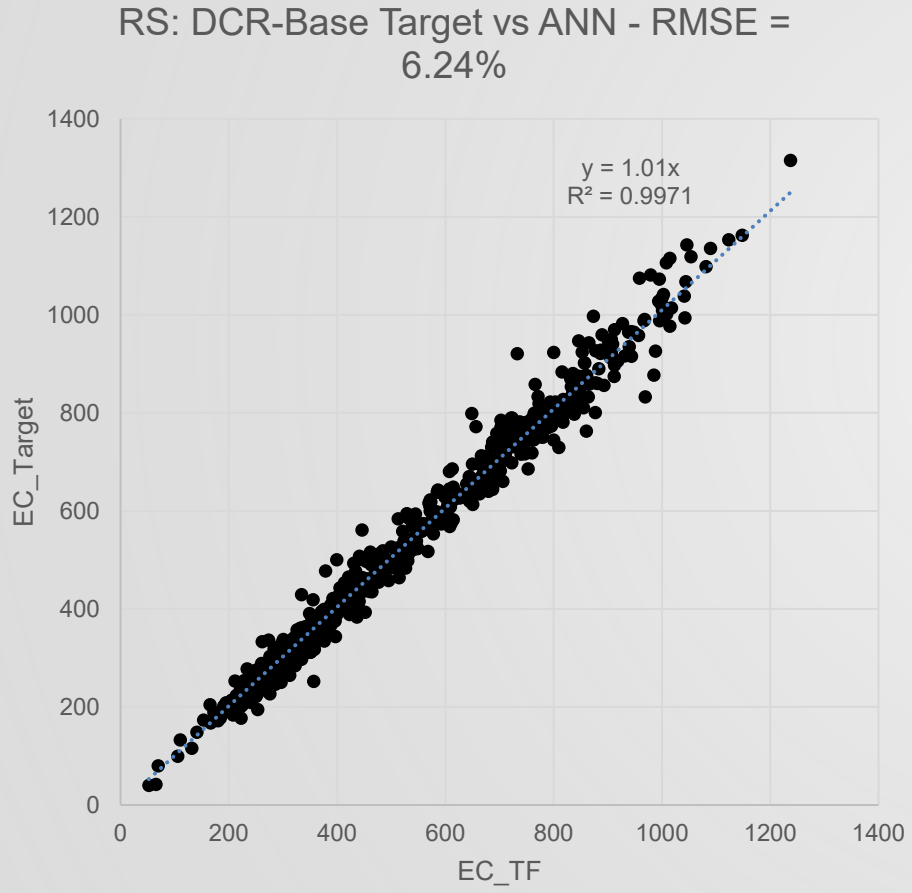


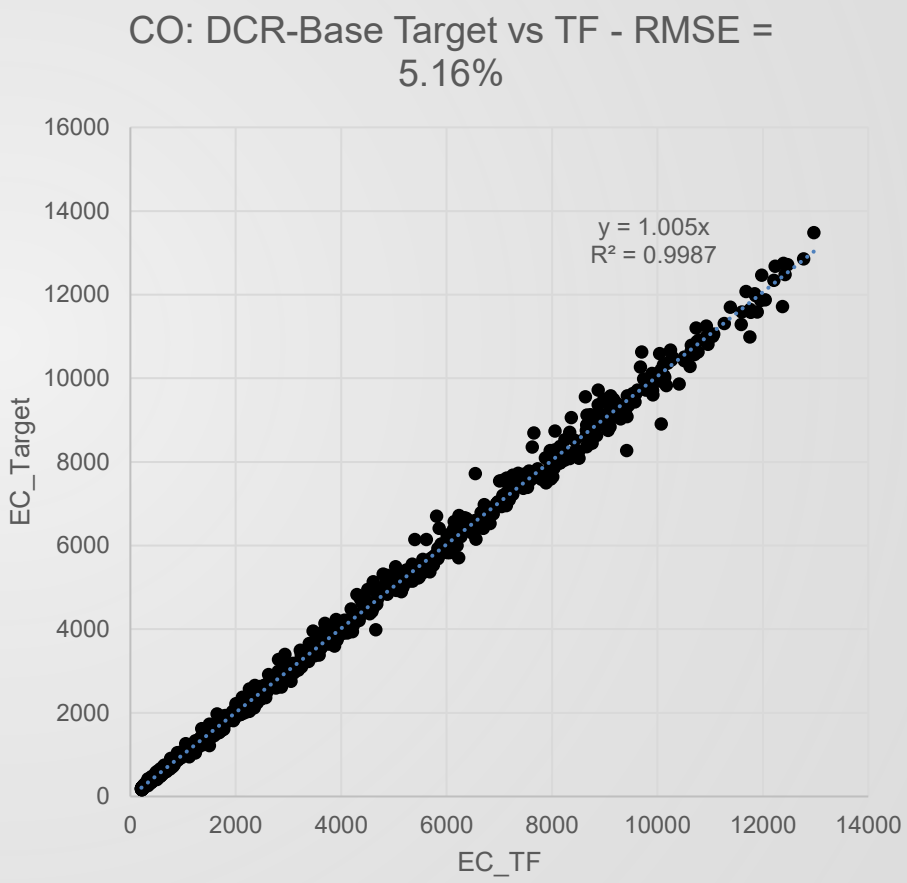


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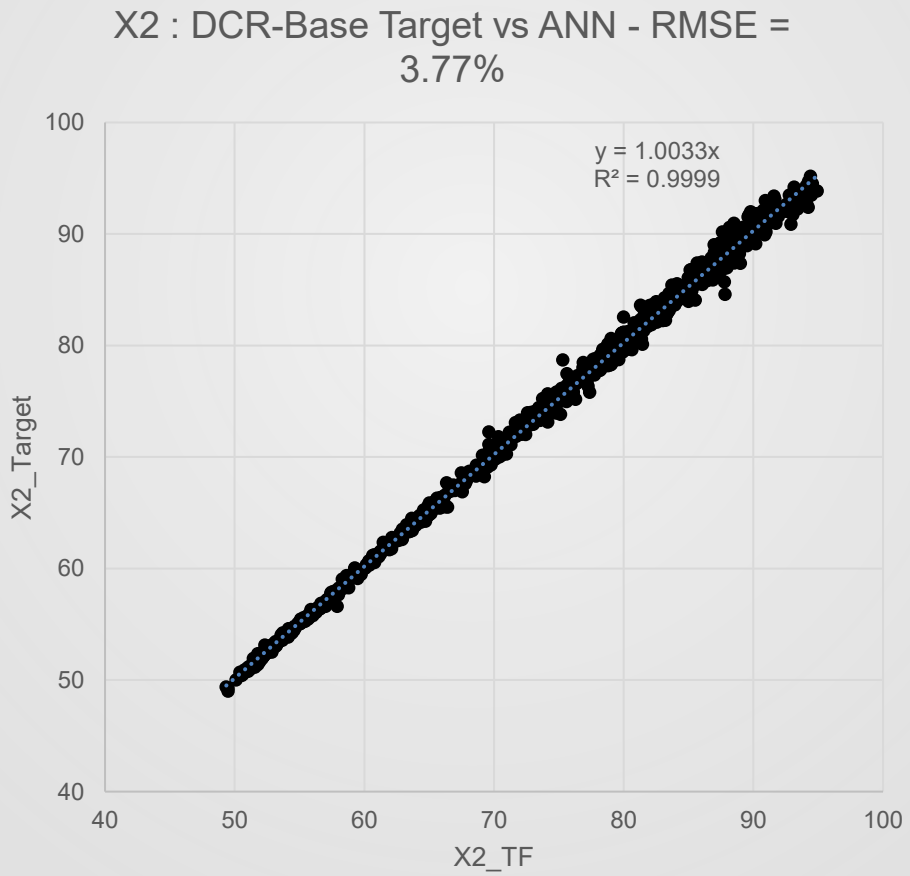


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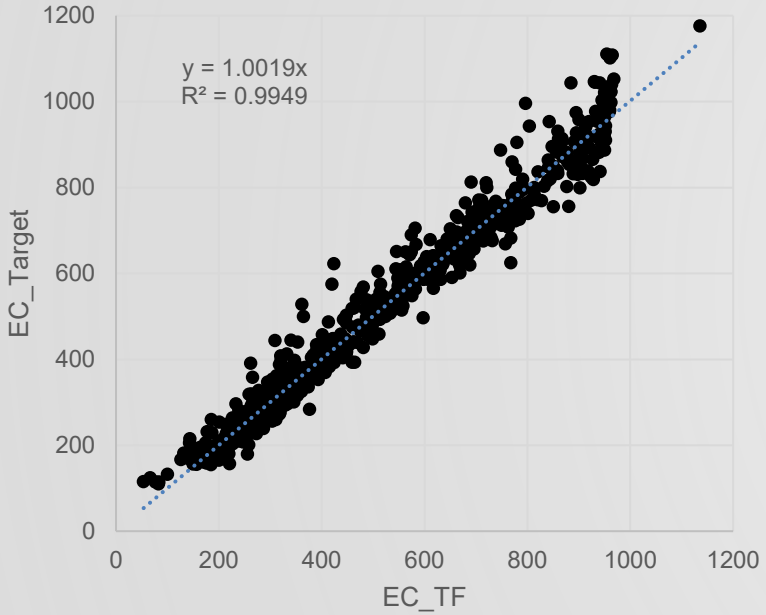
# Stage 1 Results: Comparison out of ANN training and validation

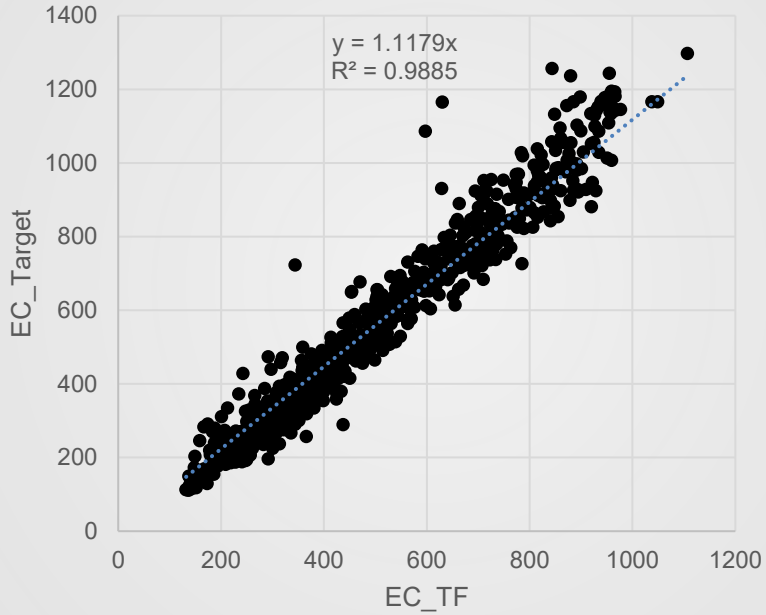
| Sea Level Rise | Station Code | Prior Version(DCR23) | Current Version(DCR23) |
|---|---|---|---|
| 0cm | EMM | 7.9% | 9.4% |
| | JP | 7.5% | 8.0% |
| | RS | 6.2% | 6.0% |
| | CO | 5.2% | 6.0% |
| | X2 | 3.7% | 3.7% |
| 15cm | EMM | 8.0% | 8.0% |
| | JP | 10.6% | 16.6% |
| | RS | 7.9% | 9.2% |
| | CO | 4.8% | 4.6% |
| | X2 | 3.7% | 3.7% |
| 30cm | EMM | 9.9% | 9.2% |
| | JP | 13.8% | 11.1% |
| | RS | 6.3% | 7.4% |
| | CO | 4.5% | 5.0% |
| | X2 | 3.7% | 3.7% |

# Stage 2 Results: Comparison out of ANN training and validation

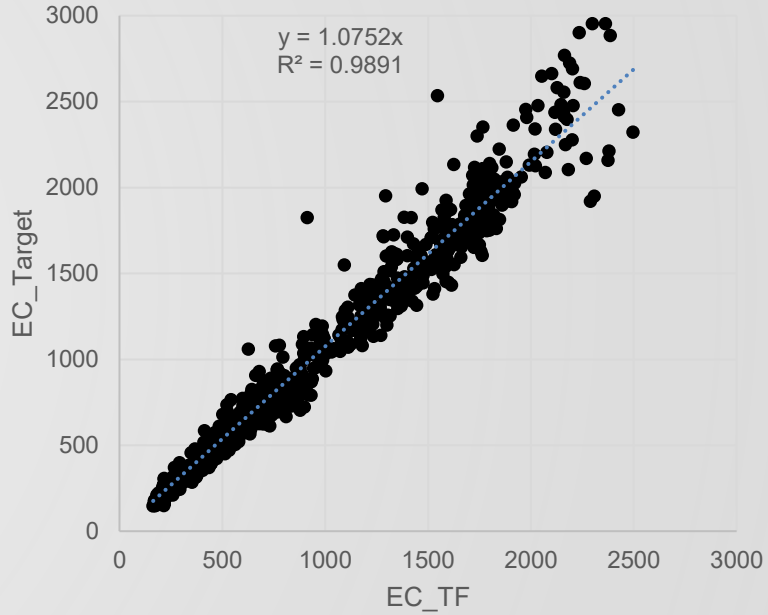
RS: DCR-Base Target vs TF
RMSE = 8.12%




RS: DCR-50cc15cm SLR Target vs TF
RMSE = 17.33%




RS: DCR-95cc30cm SLR Target vs TF
RMSE = 15.54%

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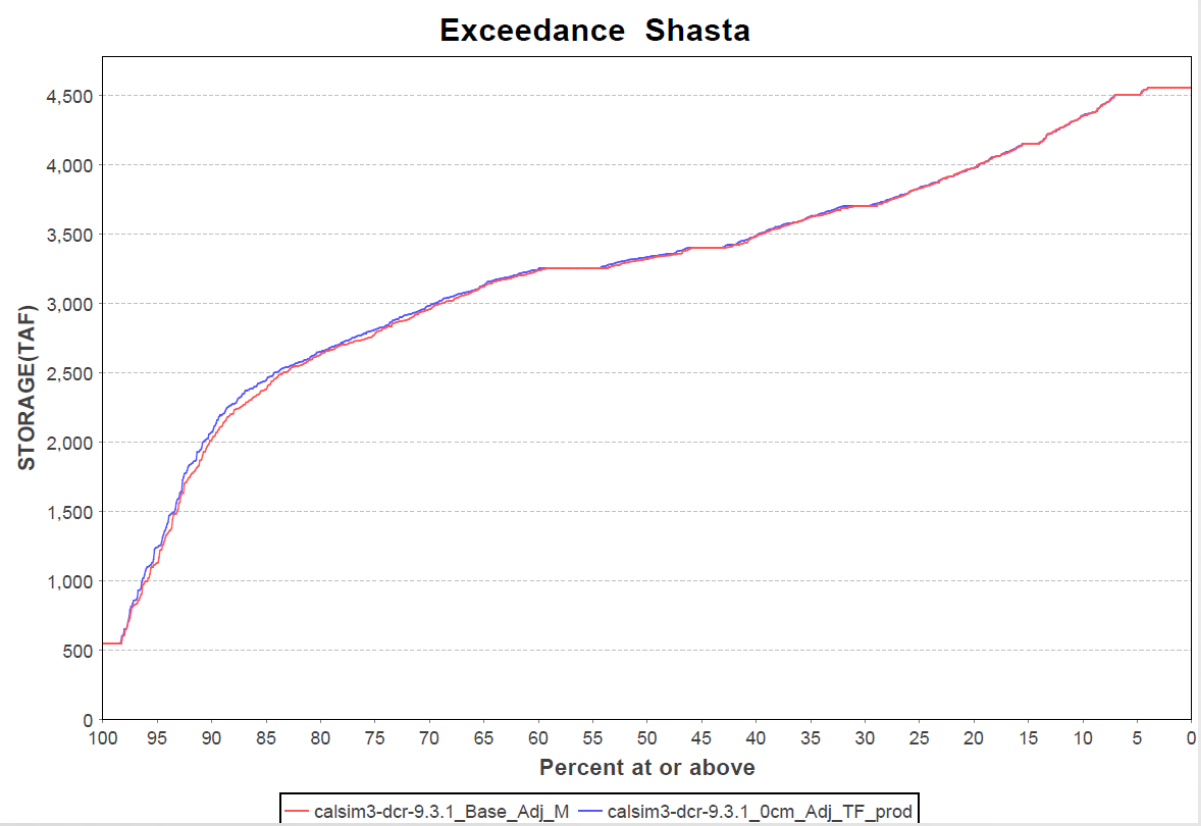
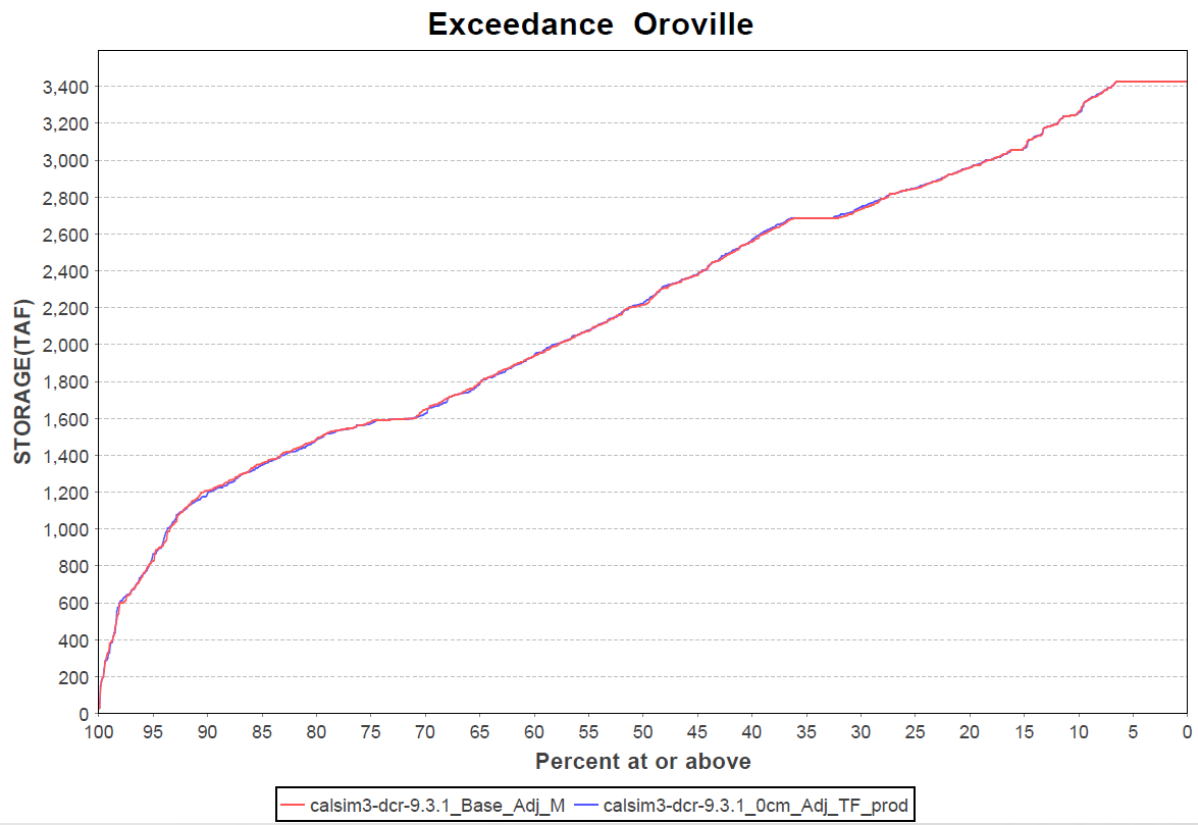
# Stage 2 Results: Comparison of CS3 Key System Variables

| | 1922-2021 | | | |
|---|---|---|---|---|
| | calsim3-dcr-9.3.1_0cm_Adj_TF_prod | calsim3-dcr-9.3.1_Base_Adj_M | Diff | % Diff |
| **River Flows** | | | | |
| Trinity R blw Lewiston | 745 | 744 | 1 | 0 |
| Trinity Export | 500 | 501 | -1 | 0 |
| Clear Cr blw Whiskeytown | 147 | 147 | 0 | 0 |
| Sacramento R @ Keswick | 6161 | 6162 | -2 | 0 |
| Sacramento R @ Wilkins Slough | 6078 | 6089 | -11 | 0 |
| Feather R blw Thermalito | 3027 | 3026 | 1 | 0 |
| Feather R at Sac R confluence | 5252 | 5251 | 1 | 0 |
| Yuba R @ Marysville | 1517 | 1517 | 0 | 0 |
| Sacramento R @ Verona | 12731 | 12737 | -6 | 0 |
| American R blw Nimbus | 2514 | 2514 | 0 | 0 |
| American R at Sac R confluence | 2446 | 2446 | 0 | 0 |
| GW Pumping Inflow | 21438 | 21438 | 0 | 0 |
| Sac Rim Inflow | 21438 | 21438 | 0 | 0 |
| SJR Rim Inflow | 7635 | 7635 | 0 | 0 |
| Friant-Kern Diversion | 888 | 888 | 0 | 0 |
| Sac WBA Runoff | 2193 | 2193 | 0 | 0 |
| SJR WBA Runoff | 212 | 212 | 0 | 0 |
| Sac Stream Gain/Loss | -482 | -483 | 1 | 0 |
| SJR Stream Gain/Loss | -566 | -570 | 4 | -1 |
| Sac Closure Terms | 247 | 247 | 0 | 0 |
| SJR Closure Terms | 397 | 397 | 0 | 0 |
| | | | | |
| **Delta Inflow** | **21883** | **21881** | **2** | **0** |
| Sacramento R @ Hood | 15392 | 15398 | -7 | 0 |
| Yolo Bypass | 2783 | 2778 | 6 | 0 |
| Mokelumne R | 897 | 897 | 0 | 0 |
| Calaveras R | 116 | 116 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| **NDOI** | **15718** | **15747** | **-29** | **0** |
| Min Outflow | 5154 | 5073 | 81 | 2 |
| Additional Outflow | 10564 | 10673 | -110 | -1 |
| Delta Outflow - ANN | 318 | 369 | -50 | -14 |
| Delta Outflow - CVP | 5565 | 5586 | -21 | 0 |
| Delta Outflow - SWP | 4599 | 4634 | -36 | -1 |
| Delta Outflow - SJRR | 64 | 65 | -1 | -2 |
| Delta Outflow - VA | | | | |
| Delta Outflow - WHLCV | 10 | 11 | -1 | -7 |
| Delta Outflow - WHLJP | 0 | 0 | 0 | |
| Delta Outflow - WTS | 8 | 8 | 0 | -4 |

# Stage 2 Results: Comparison of CS3 Key System Variables

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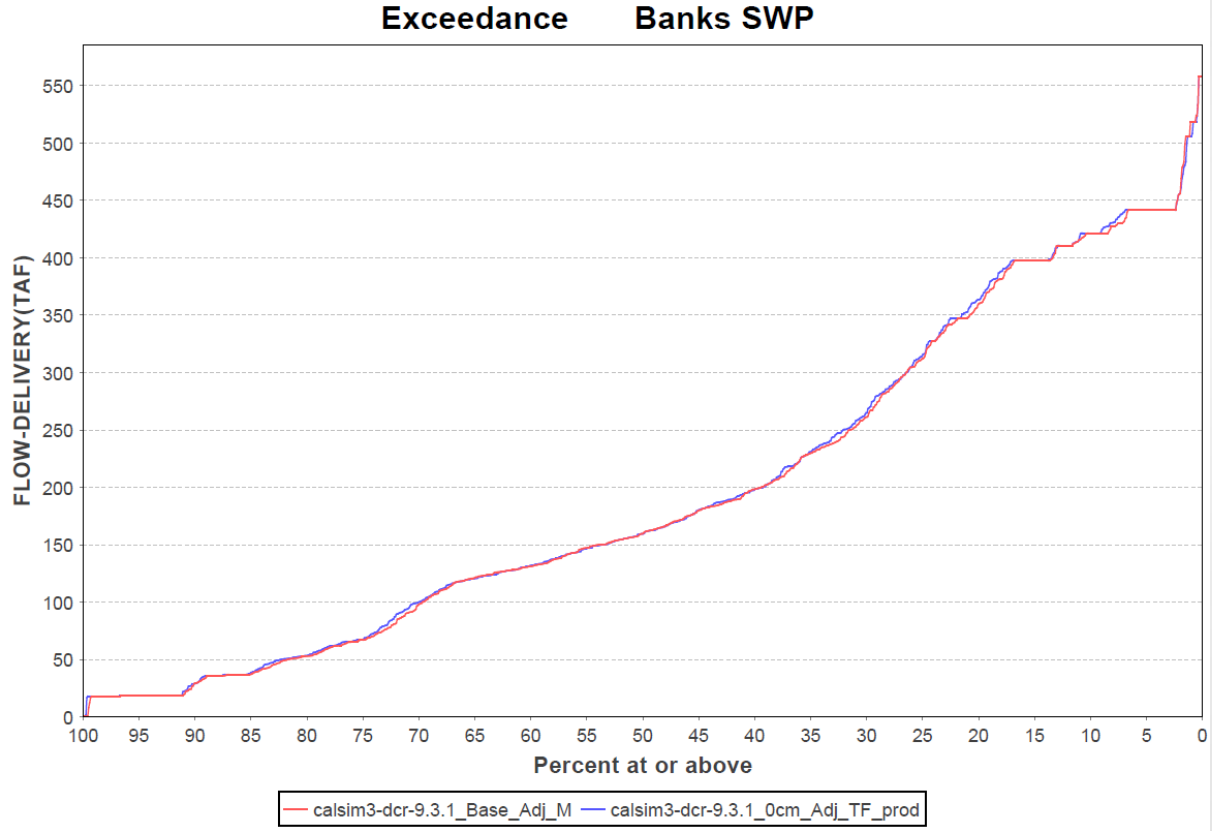


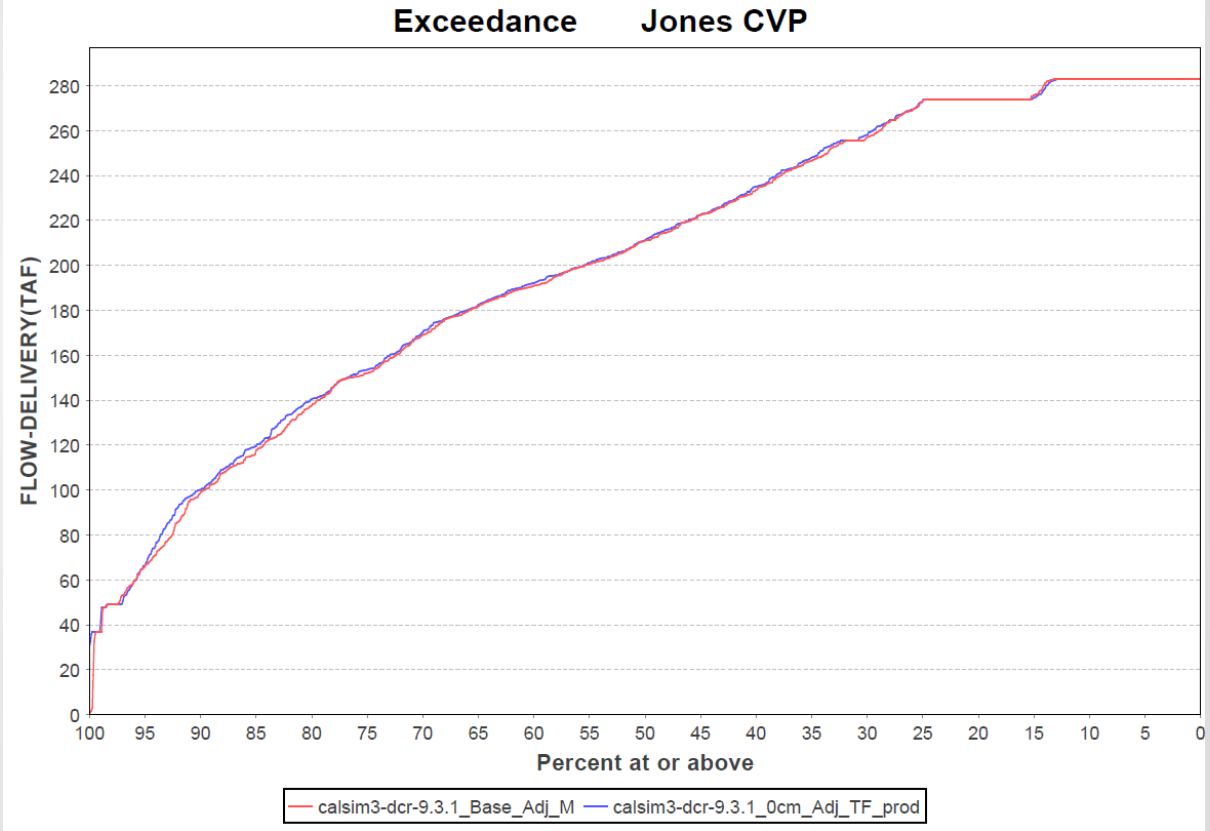


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# Stage 2 Results: Comparison out of ANN training and validation

| Sea Level Rise | Station Code | R2 | Normalized - RMSE |
|---|---|---|---|
| 0cm | EMM | 0.996 | 9.7% |
| | JP | 0.995 | 8.9% |
| | RS | 0.995 | 8.1% |
| | CO | 0.998 | 6.1% |
| | X2 | 0.999 | 1.0% |
| 15cm | EMM | 0.994 | 12.0% |
| | JP | 0.991 | 21.6% |
| | RS | 0.989 | 17.3% |
| | CO | 0.998 | 6.7% |
| | X2 | 0.999 | 0.9% |
| 30cm | EMM | 0.975 | 23.0% |
| | JP | 0.945 | 22.9% |
| | RS | 0.989 | 15.5% |
| | CO | 0.998 | 6.0% |
| | X2 | 0.999 | 0.9% |

# Conclusion

•**Successful Transition to TensorFlow**: The transition of ANN training from MATLAB-based (ML) to TensorFlow-based (TF) estimation for salinity (EC) and X2 has successfully streamlined and tested.

•**Comparison Studies**: Two stage comparisons (without CalSim operations and full blown CalSIm) shows excellent ANN training performances in stage I and  and similar level CalSim 3 performances for  the base case and good comparisons on other cases. Further, a thorough CalSim 3 operational analysis are in progress.

**Model and Data Sharing:** Model codes (committed to GitHub - Private) and data will be available after thorough CS3 evaluation . (potentially with DCR25?)

# Questions???

# Thank you!