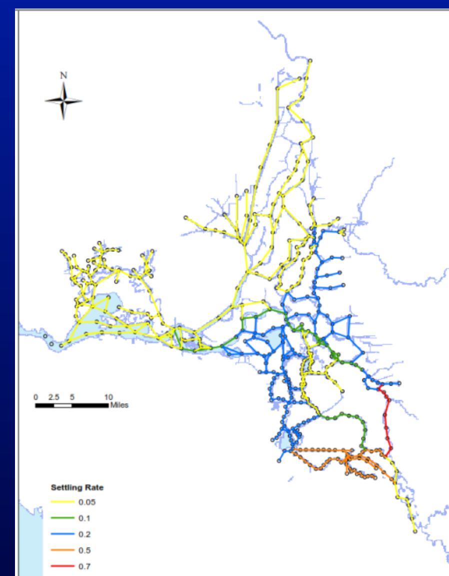
Modeling Delta Flow-Turbidity Relationships

with Artificial Neural Networks



CWEMF Annual Meeting

April 16, 2012
Paul Hutton, Ph.D., P.E.

Acknowledgements

Dr. Sujoy Roy, Tetra Tech

Dr. Limin Chen, Tetra Tech

Sanjaya Seneviratne, DWR

Summary Findings

- Additional review is needed before firm conclusions can be reached.
- ANNs appear to faithfully emulate DSM2 turbidity fate and transport during the season of interest (i.e. Dec-Feb).
- ANNs appear to provide a promising foundation for representing turbidity-based regulations in CalSim.

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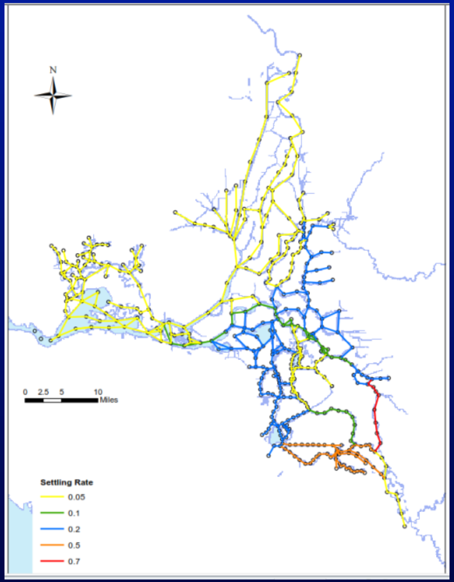
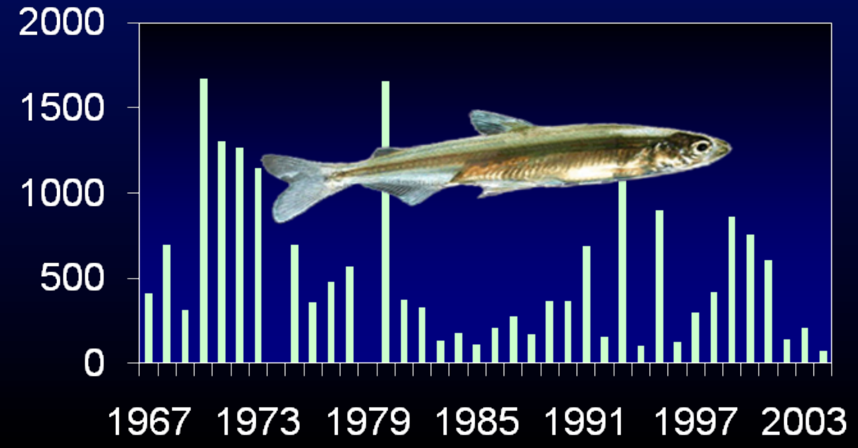


- Background
- Model Development
- Results
- Next Steps

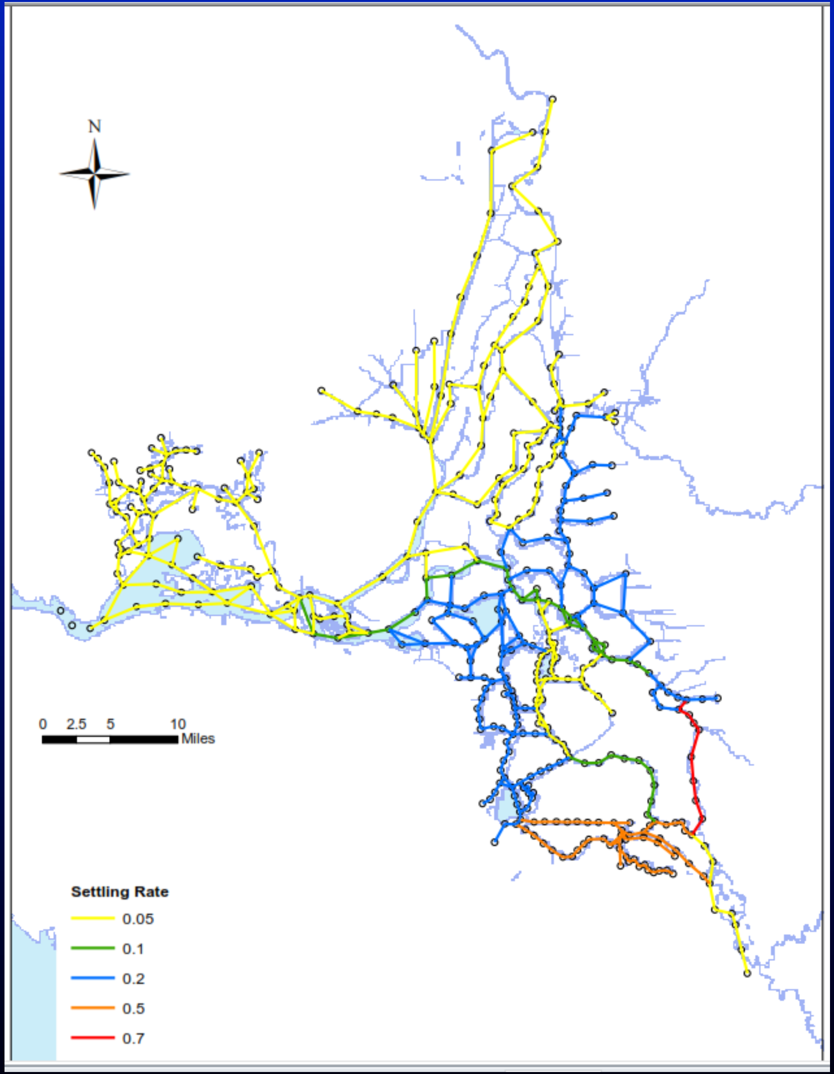
RPA Component 1:
Protection of Adult Delta Smelt Life Stage

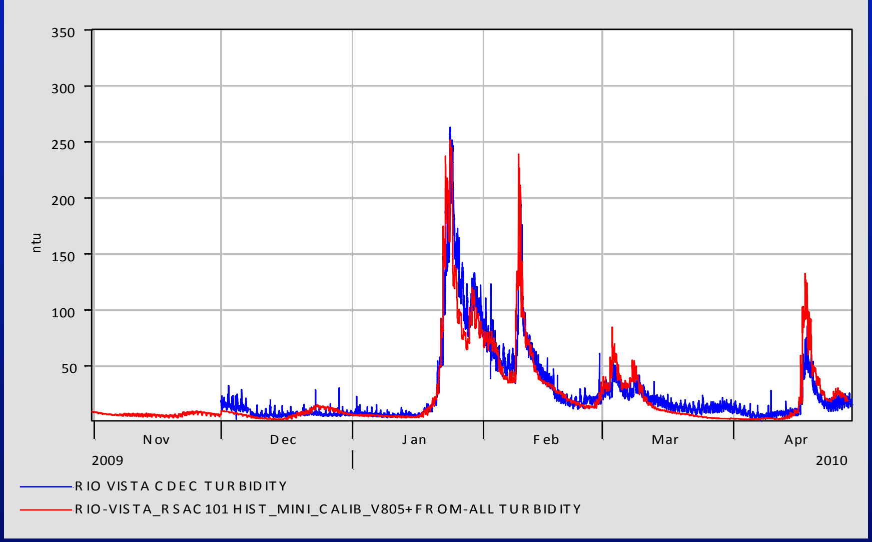
… delta smelt have historically been entrained when first flush conditions occur in late December. In order to prevent or minimize such entrainment, Action 1 shall be initiated on or after December 20 if the 3 day average turbidity at Prisoner's Point, Holland Cut, and Victoria Canal exceeds 12 NTU… Action 1 shall require the Projects to maintain OMR flows no more negative than -2000 cfs…

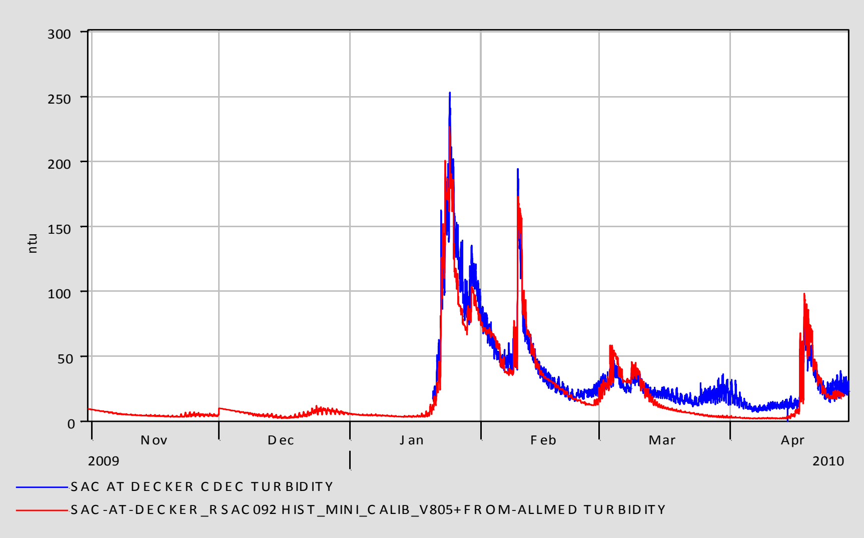
Source: Remanded USFWS 2008 Biological Opinion



DSM2 Turbidity Fate & Transport







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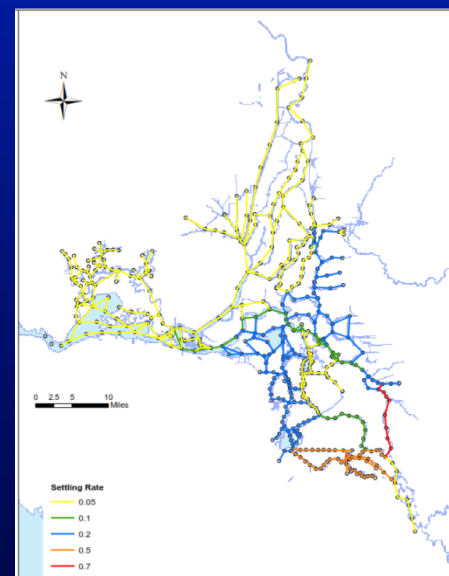


Background

Model Development

Results

Next Steps

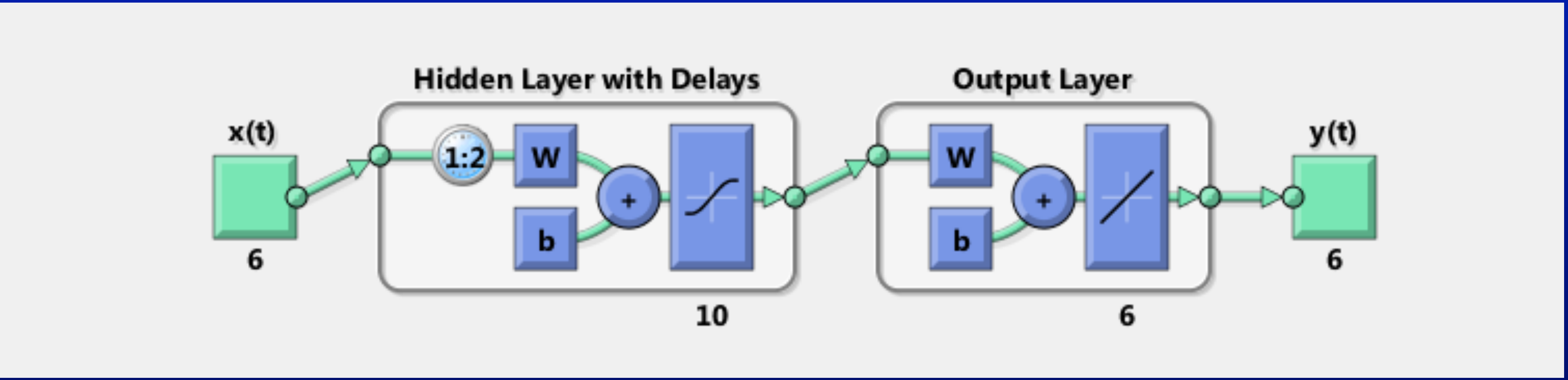
ANN Training Data
DSM2 Simulations

Run	Hydrology & Operations	Turbidity Boundary Conditions					
		Freeport	Vernalis	Yolo	Cosumnes	Mokelumne	Calaveras
1	Historical	Low	Low	Low	Low	Low	Low
2	Historical	Mid	Low	Mid	Mid	Mid	Mid
3	Historical	High	Low	High	High	High	High
4	Historical	Low	High	Low	Low	Low	Low
5	Historical	Mid	High	Mid	Mid	Mid	Mid
6	Historical	High	High	High	High	High	High
7	Historical w/o Exports	Low	Low	Low	Low	Low	Low
8	Historical w/o Exports	Mid	Low	Mid	Mid	Mid	Mid
9	Historical w/o Exports	High	Low	High	High	High	High
10	Historical w/o Exports	Low	High	Low	Low	Low	Low
11	Historical w/o Exports	Mid	High	Mid	Mid	Mid	Mid
12	Historical w/o Exports	High	High	High	High	High	High

Notes: (1) DCC gates closed; (2) South Delta barriers not installed; (3) Constant Martinez & agricultural return turbidity boundary conditions

ANN Model Structure

Matlab Feed Forward



$y(t) = f(x(t-1), \ldots., x(t-d))$

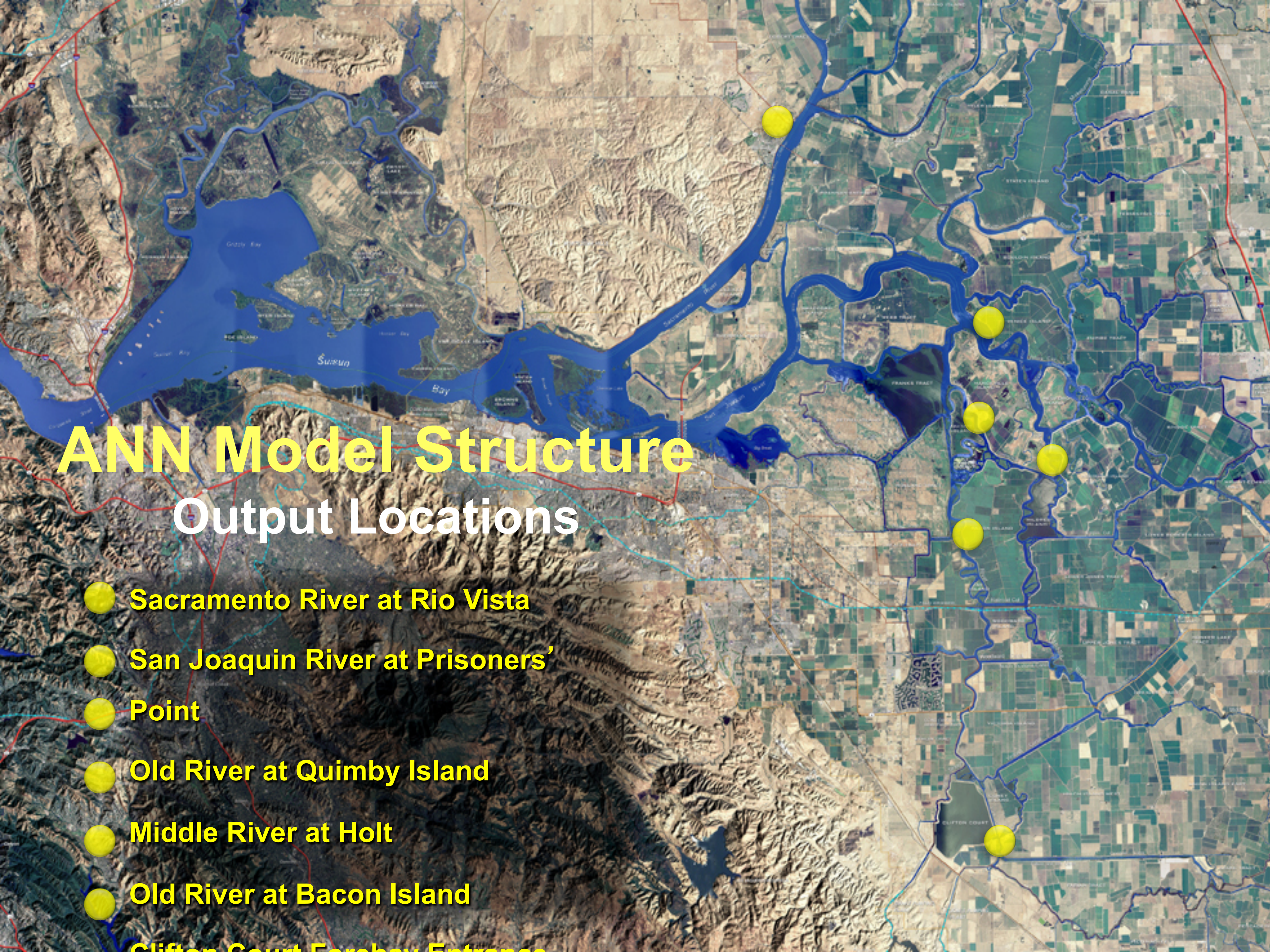
Inputs = 6 boundaries (3 flow & 3 turbidity)
Hidden Neurons = 10
Time delay = 1-2 days
Outputs: turbidity at 6 locations

ANN Model Structure
Boundary Input (Daily Averages)

- Flow
  - North Delta (Freeport + Yolo)
  - East Side Streams
  - Calculated Old & Middle Rivers
- Turbidity (Flow-weighted)
  - North Delta (Freeport + Yolo)
  - East Side Streams
  - Vernalis

ANN Model Structure

Output Locations



- Sacramento River at Rio Vista
- San Joaquin River at Prisoners' Point
- Old River at Quimby Island
- Middle River at Holt
- Old River at Bacon Island
- Clifton Court Forebay Entrance

ANN Model Structure
Training Process

- DSM2 data points are randomly assigned:
  - Training 60%
  - Validation 20%
  - Testing 20%
- Training data are used to compute network parameters. Intermediate results are iteratively compared with validation data until residual error is minimized.
- Testing data are independent of training and validation data and are used to evaluate network predictive power.

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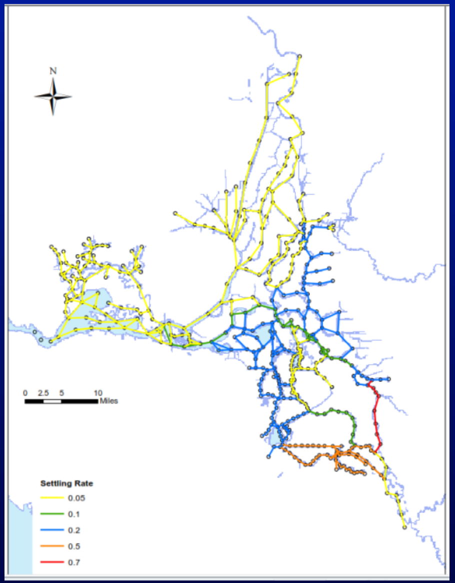


Background

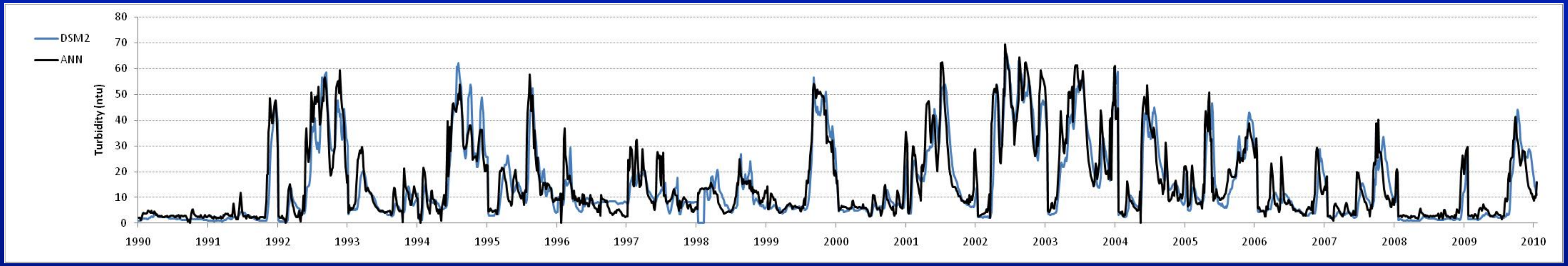
Model Development

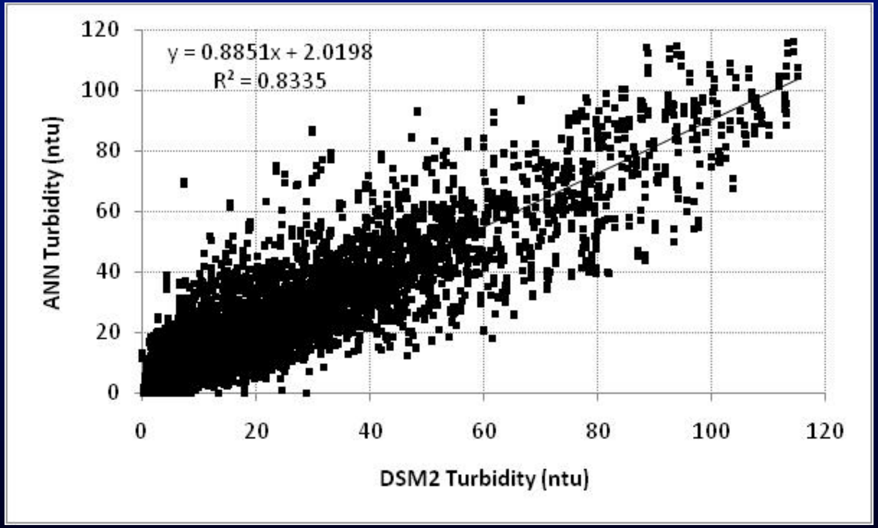
Results

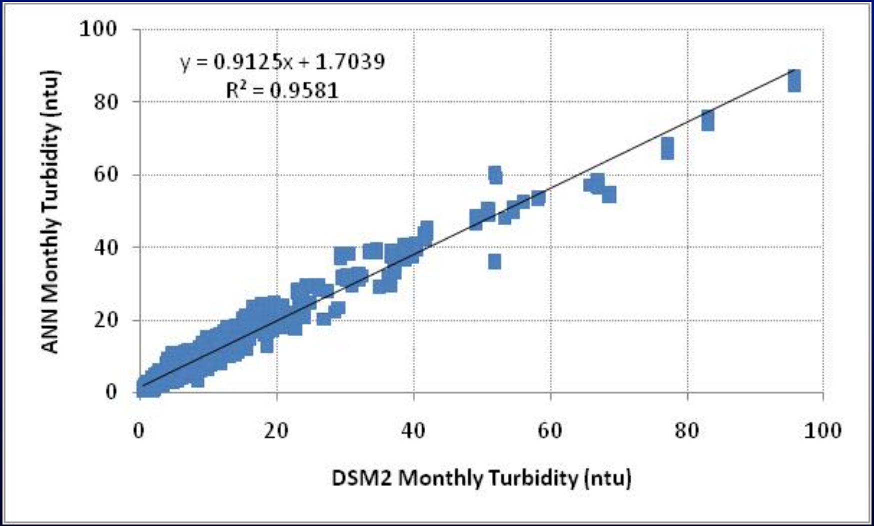
Next Steps

Model Results

Old River @ Quimby Island (Dec-Feb)





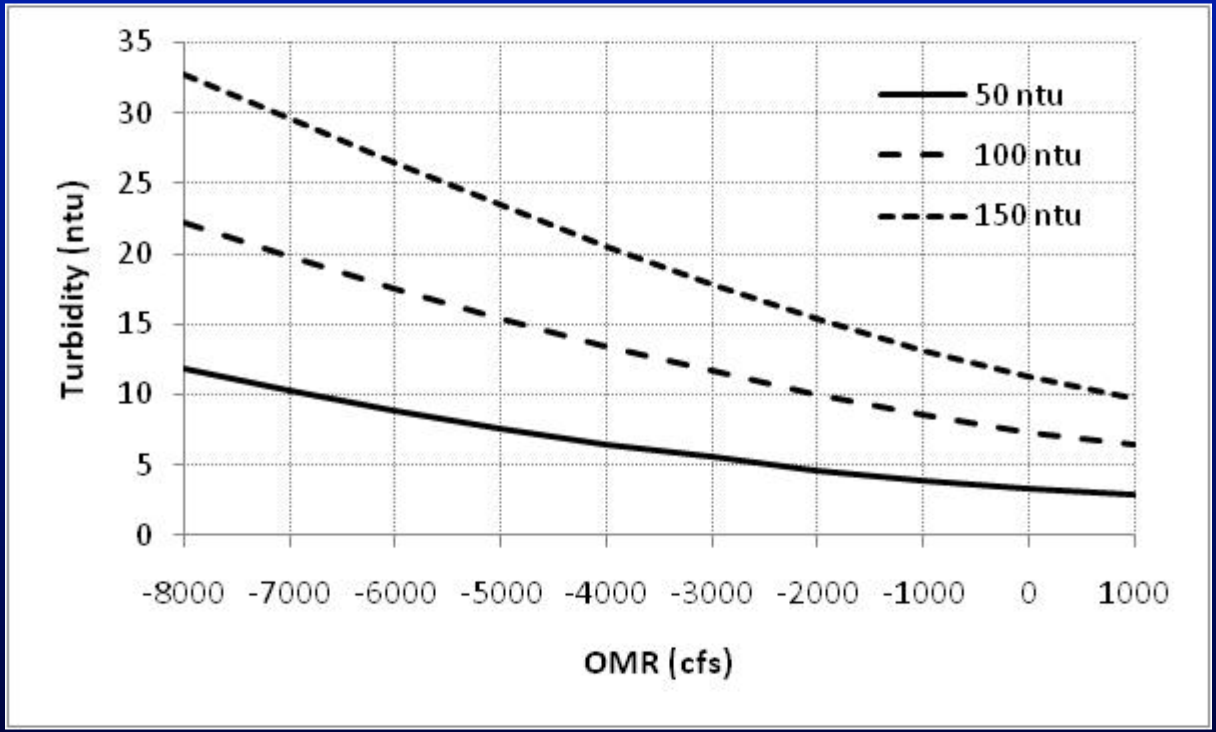


Model Results: Summary Statistics

ANN Turbidity (ntu) = $\Phi_1 + \Phi_2$ * DSM2 Turbidity (ntu)

Location	Daily			Monthly		
	Φ_1	Φ_2	R^2	Φ_1	Φ_2	R^2
Sacramento River @ Rio Vista	3.5	0.97	0.94	1.1	1.01	0.99
Old River @ Quimby Island	2.0	0.89	0.83	1.7	0.91	0.96
Old River @ Bacon Island	1.8	0.82	0.78	1.5	0.85	0.93
San Joaquin River @ Prisoner's Point	3.7	0.81	0.76	3.0	0.87	0.92
Middle River @ Holt	2.0	0.76	0.69	1.7	0.82	0.89
Clifton Court Forebay Entrance	3.1	0.75	0.73	1.3	0.90	0.91

Steady State Flow-Turbidity Relationship
as a Function of North Delta Turbidity
Old River @ Quimby Island



<u>Steady State Assumptions</u>
North Delta Flow = 30,000 cfs
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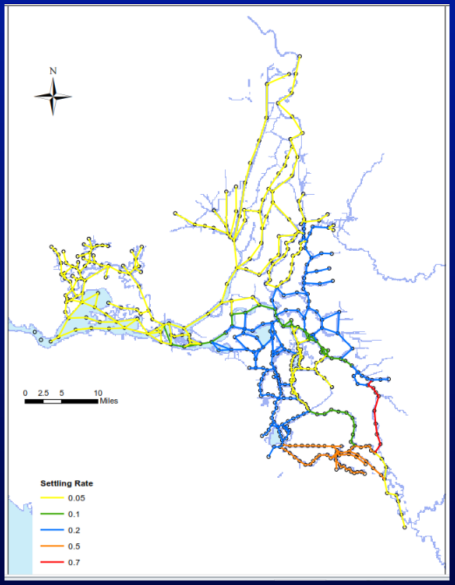

- Background
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Next Steps

- Evaluate auto-regressive networks
- Explore tidal input variable
- Implement methodology in CalSim

Next Steps (cont’d)

CalSim Implementation

- Decision statement: Reduce pumping as needed to increase OMR flows, thereby controlling turbidity levels as defined by existing or alternative regulations.
- Develop 82-year turbidity time series for Delta inflows
- Integrate information into monthly time step
- Refine ANN training (and associated data) as needed

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EXTRA SLIDES

Turbidity Boundary Conditions

Freeport

Flow Range (cfs)	Low (50%)	Mid (75%)	High (90%)
< 10,000	10	15	20
12,500	20	30	40
17,500	30	40	70
22,500	40	60	100
27,500	60	100	160
32,500	70	140	280
37,500	90	160	**320**
45,000	100	170	350
55,000	100	175	300
65,000	**100**	140	240
>70,000	100	140	180

Turbidity Boundary Conditions (cont'd)

Vernalis

Flow Range (cfs)	Low (50%)	High
<2,000	15	100
2,750	20	100
4,250	25	100
7,500	25	90
15,000	20	60
>20,000	15	60

Turbidity Boundary Conditions (cont’d)

Calaveras

Flow Range (cfs)	Low	Mid	High
<50	20	20	20
100	30	30	40
>1,000	40	70	100

Yolo Bypass

Flow Range (cfs)	Low	Mid	High
<100	20	20	20
1,000	30	40	60
5,000	60	120	200
10,000	100	200	300
>30,000	100	150	200

Turbidity Boundary Conditions (cont'd)

Cosumnes River

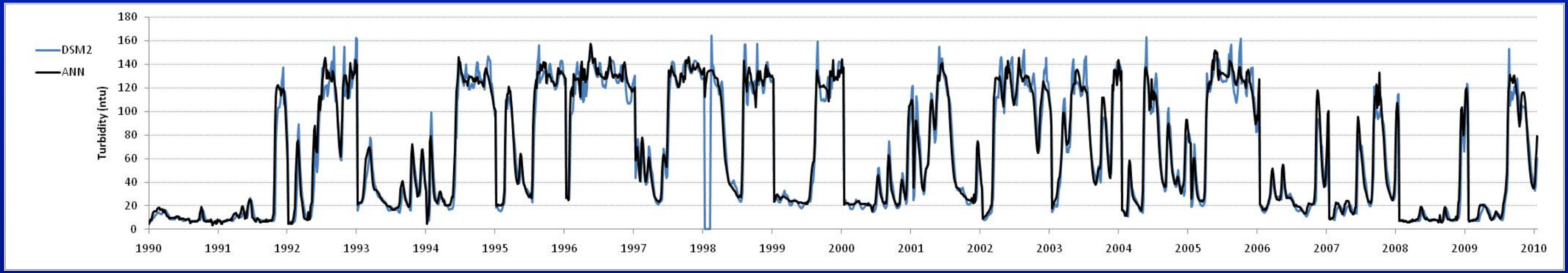
Flow Range (cfs)	Low	Mid	High
<100	10	10	10
500	30	50	80
1,000	50	100	180
2,000	80	200	280
>3,000	100	300	300

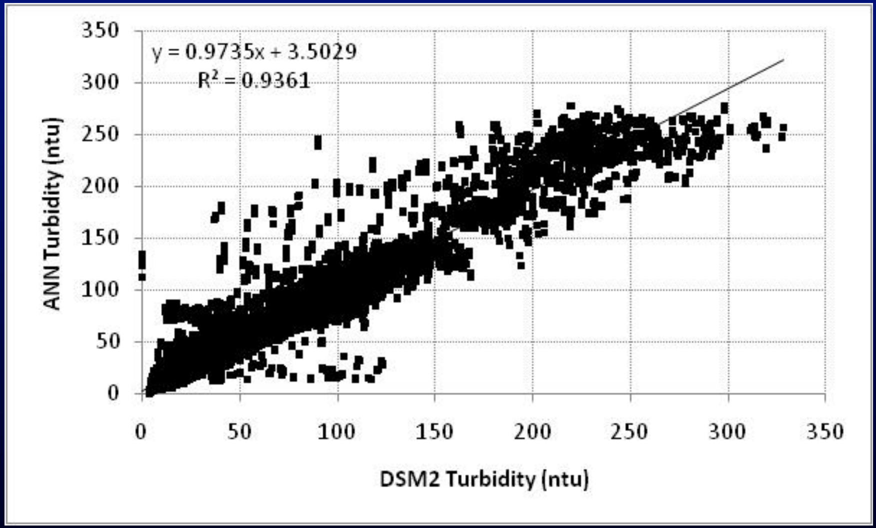
Mokelumne River

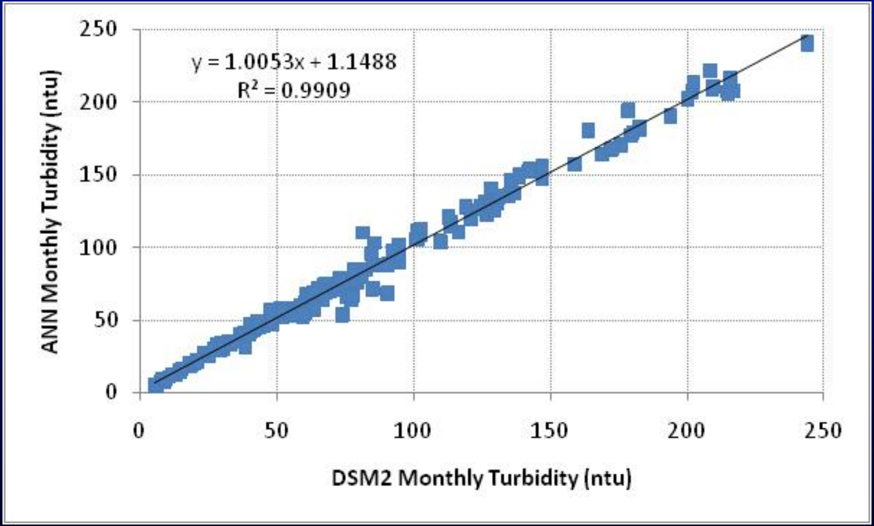
Flow Range (cfs)	Low	Mid	High
<100	20	20	20
500	30	50	80
>1,000	40	70	100

Model Results

Sacramento River @ Rio Vista (Dec-Feb)

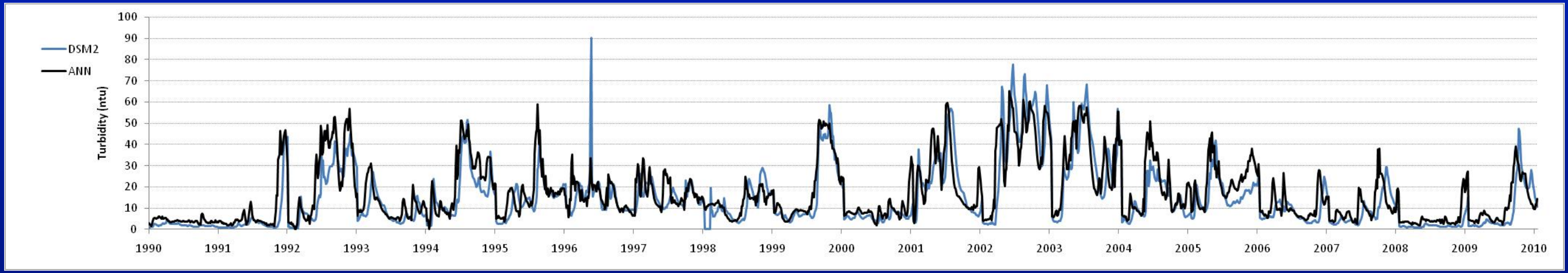


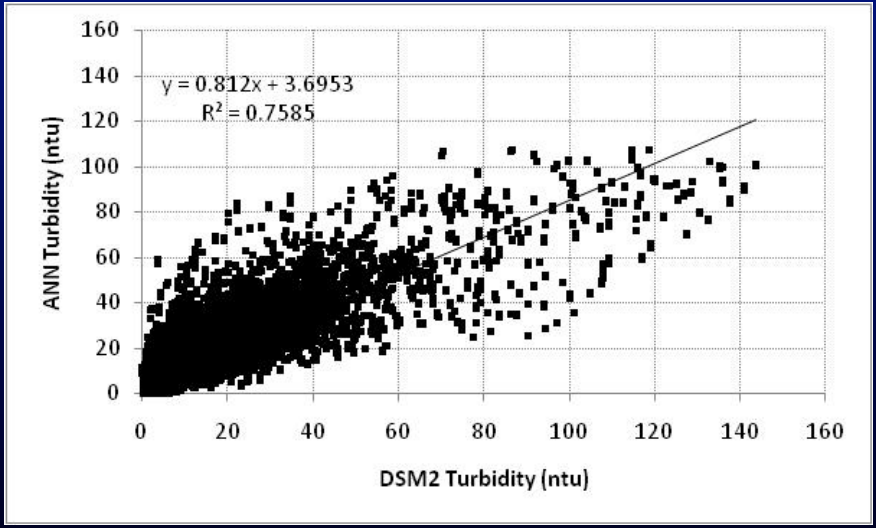


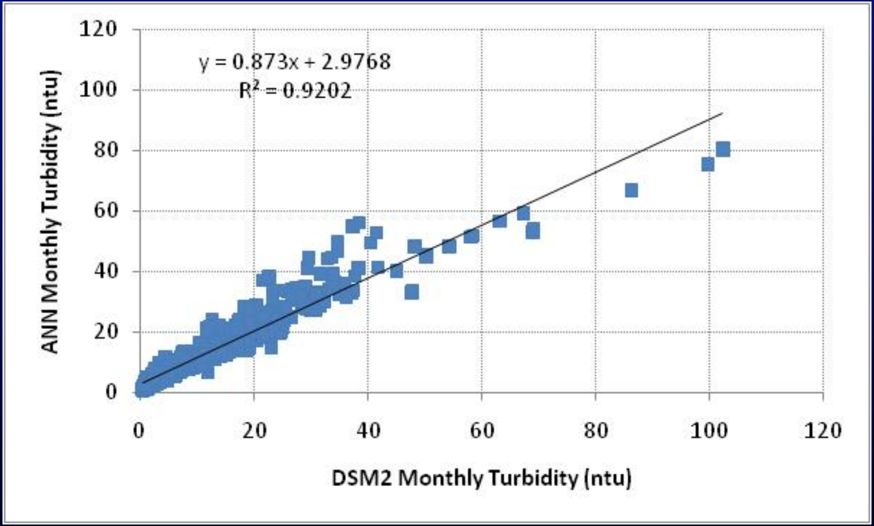


Model Results

Old River @ Prisoner's Point (Dec-Feb)

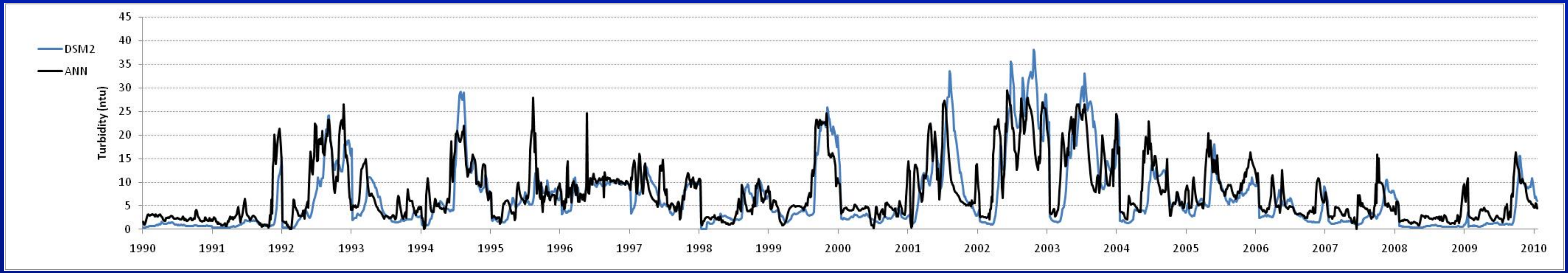


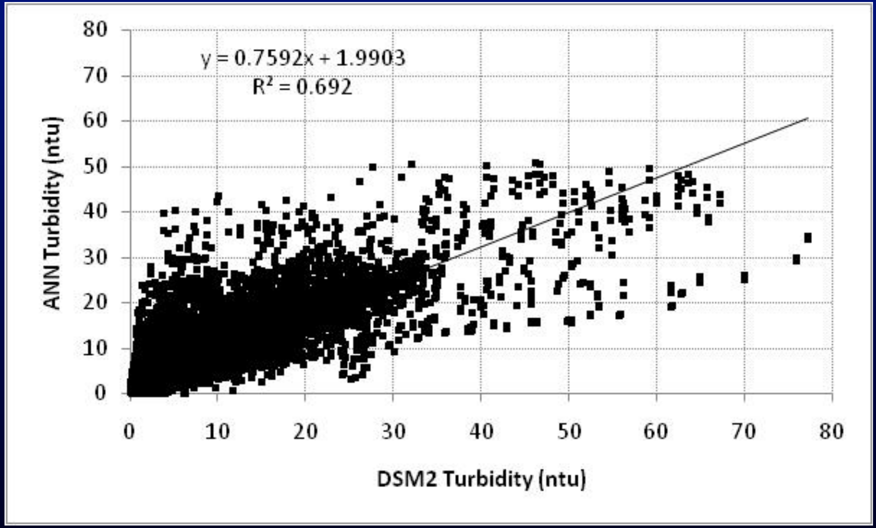


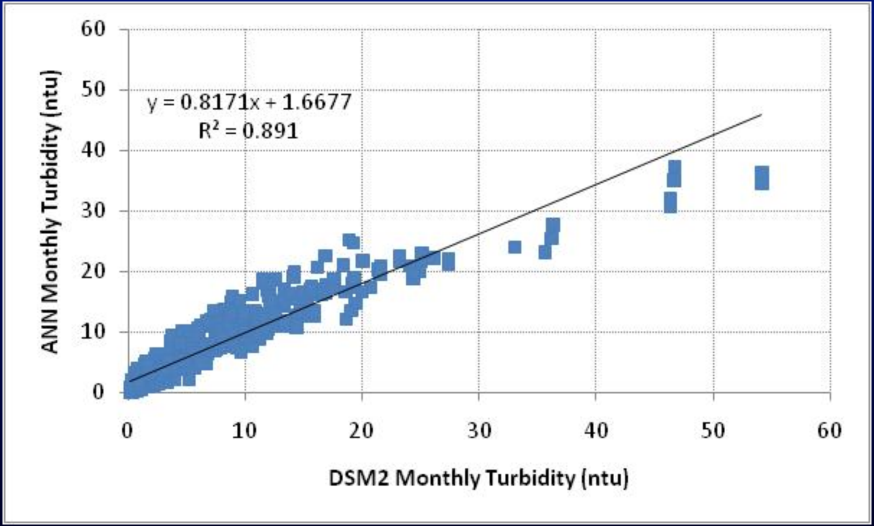


Model Results

Middle River @ Holt (Dec-Feb)

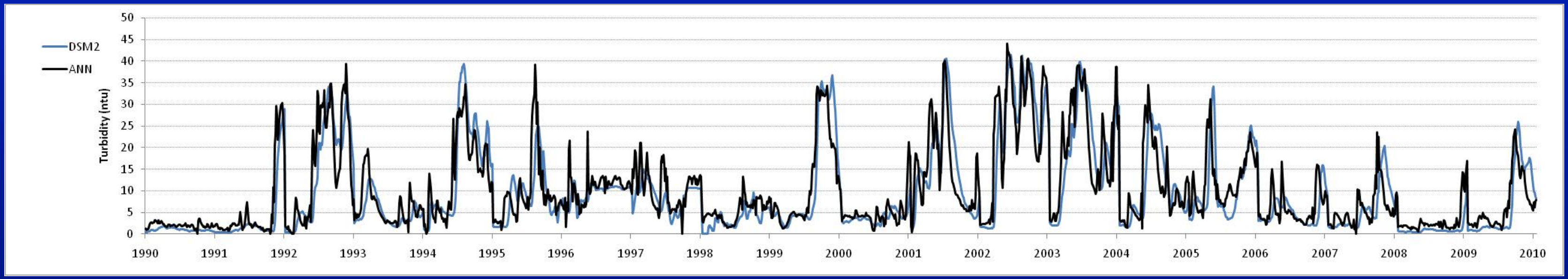


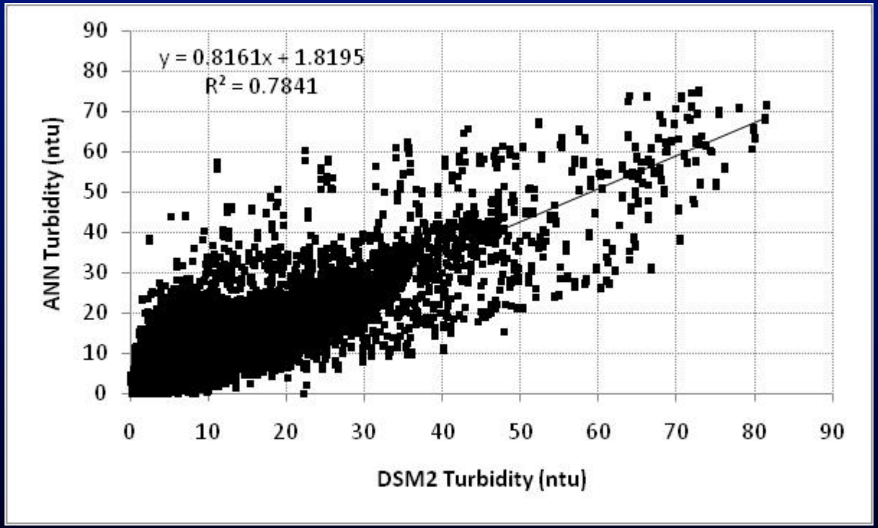


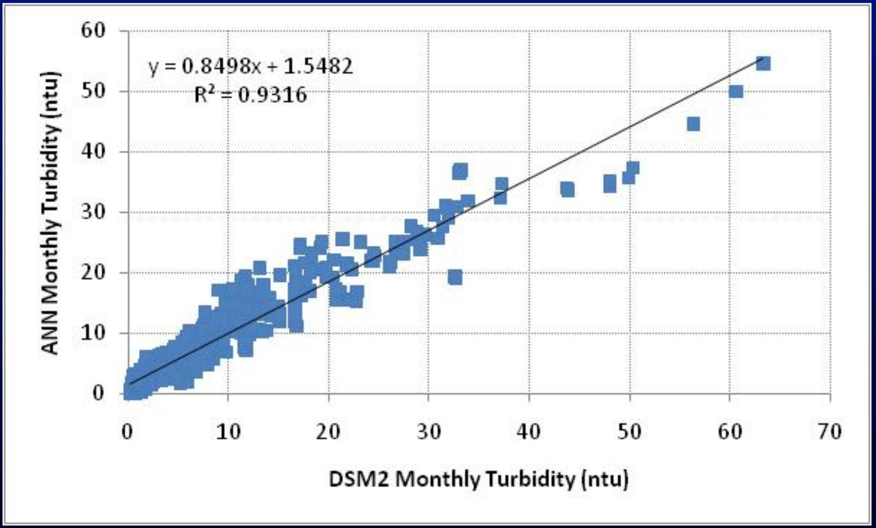


Model Results

Old River @ Bacon Island (Dec-Feb)

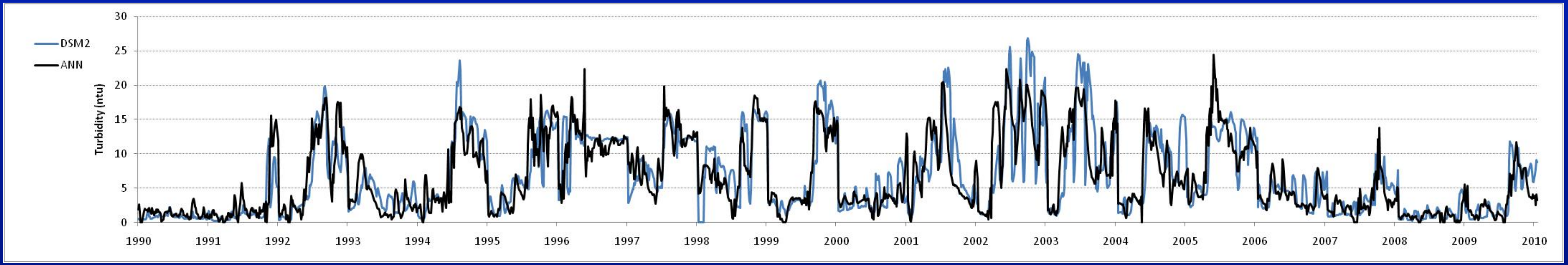


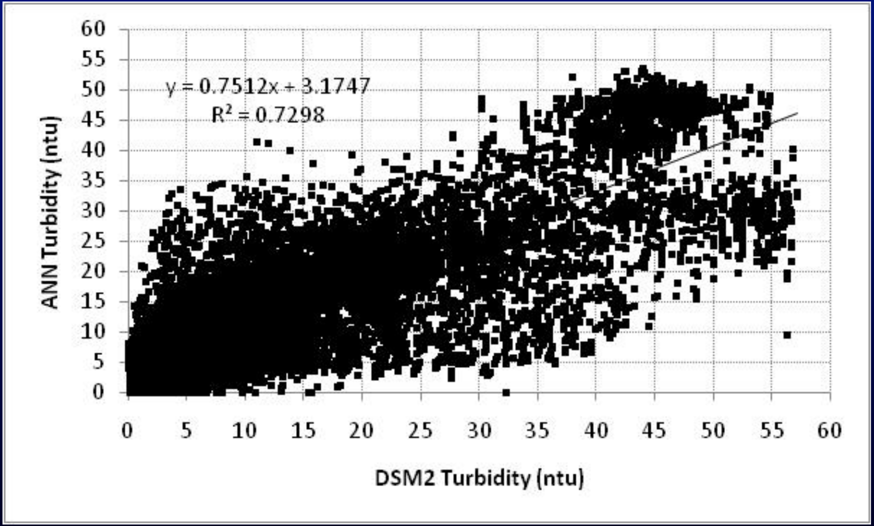


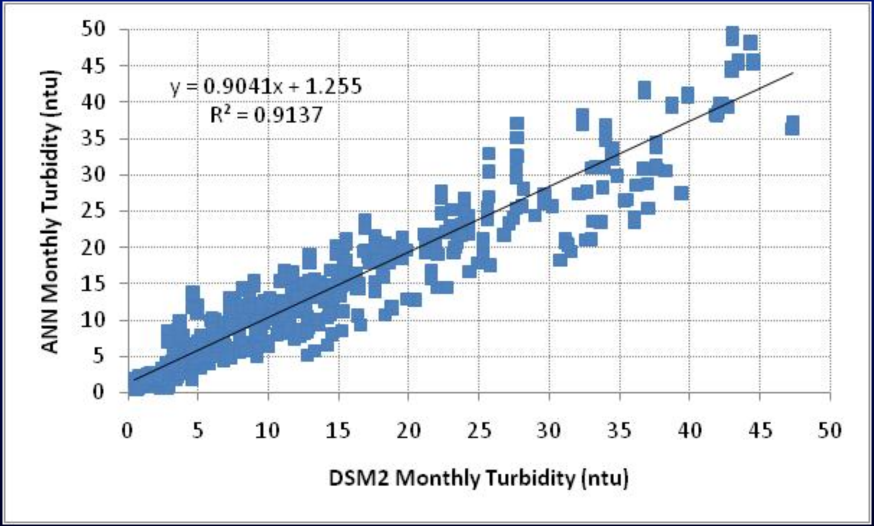


Model Results

Clifton Court Forebay Entrance (Dec-Feb)

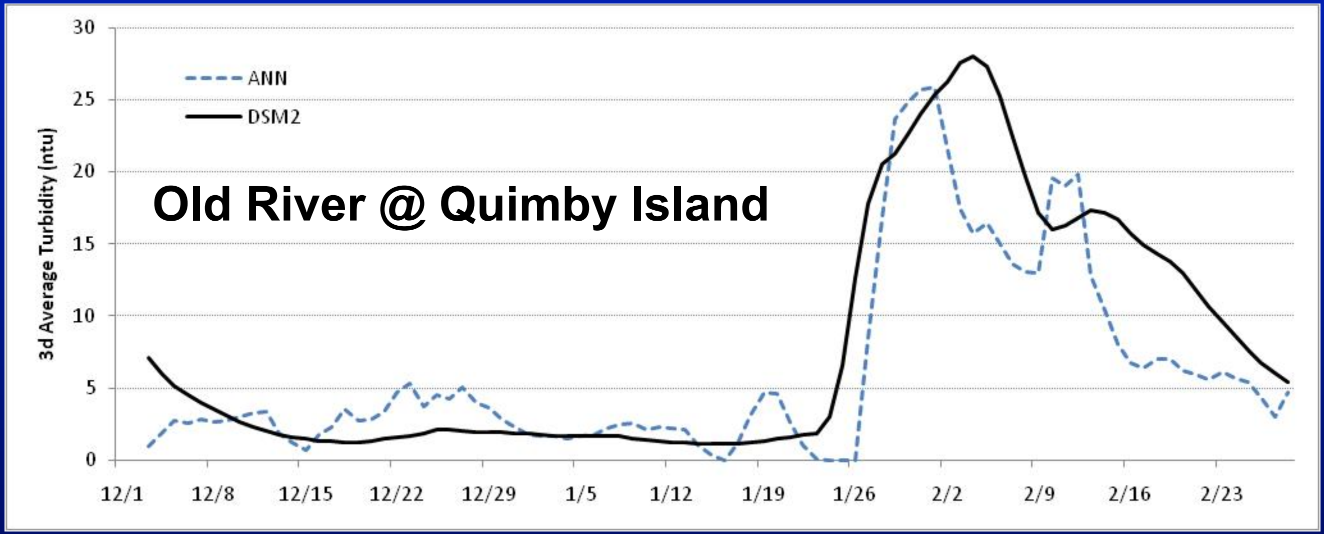


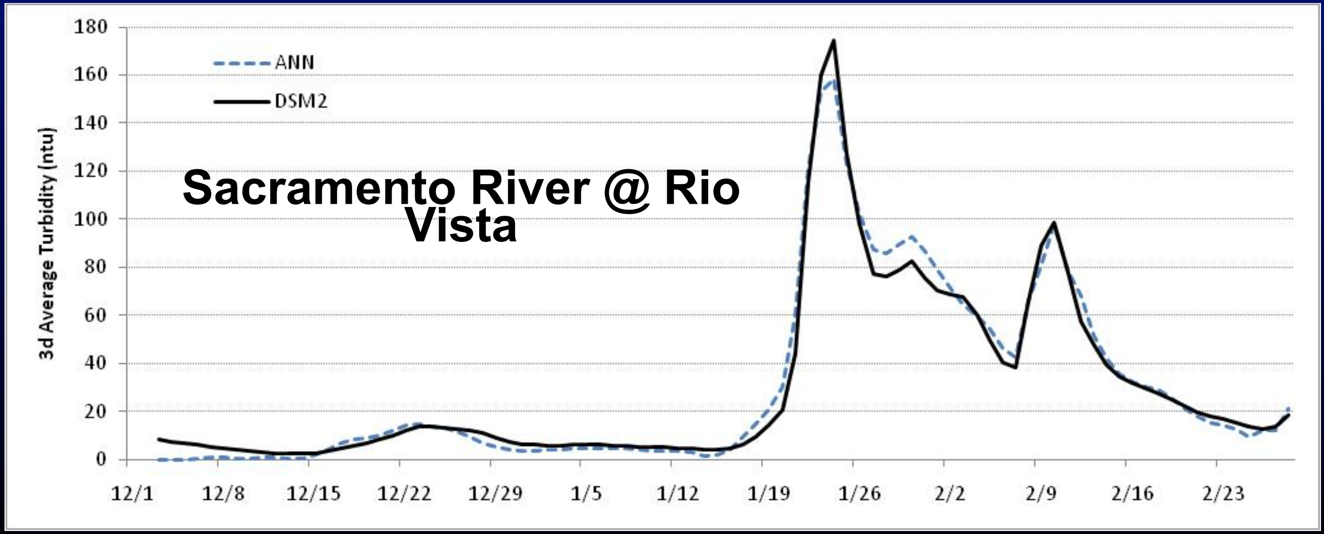




Model Results

2009-10 Historical Conditions





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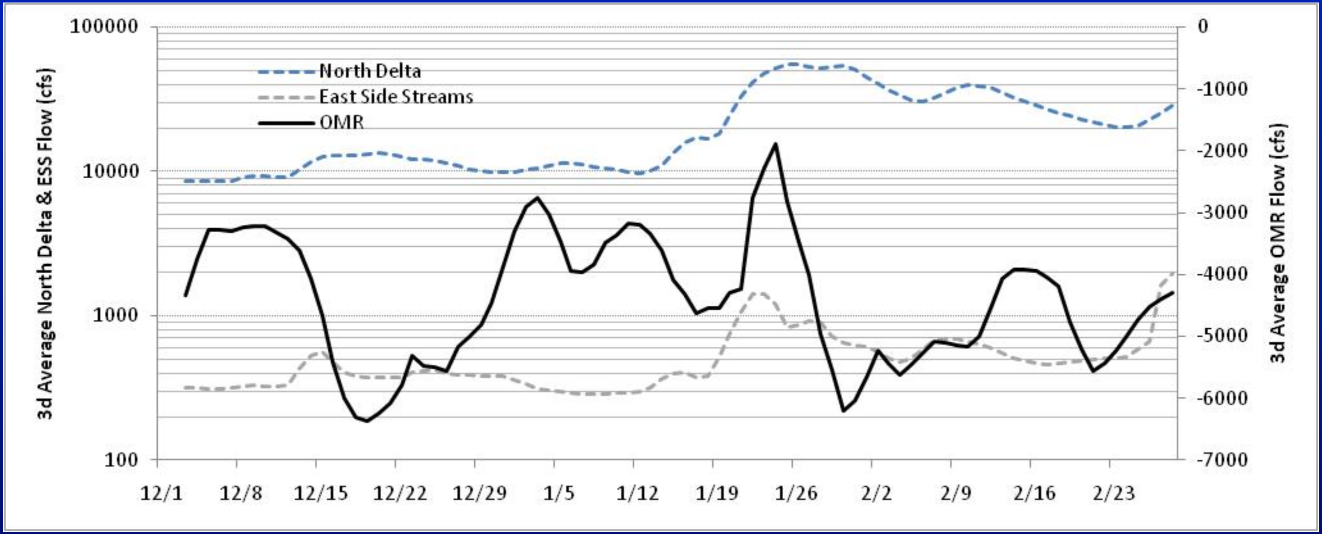
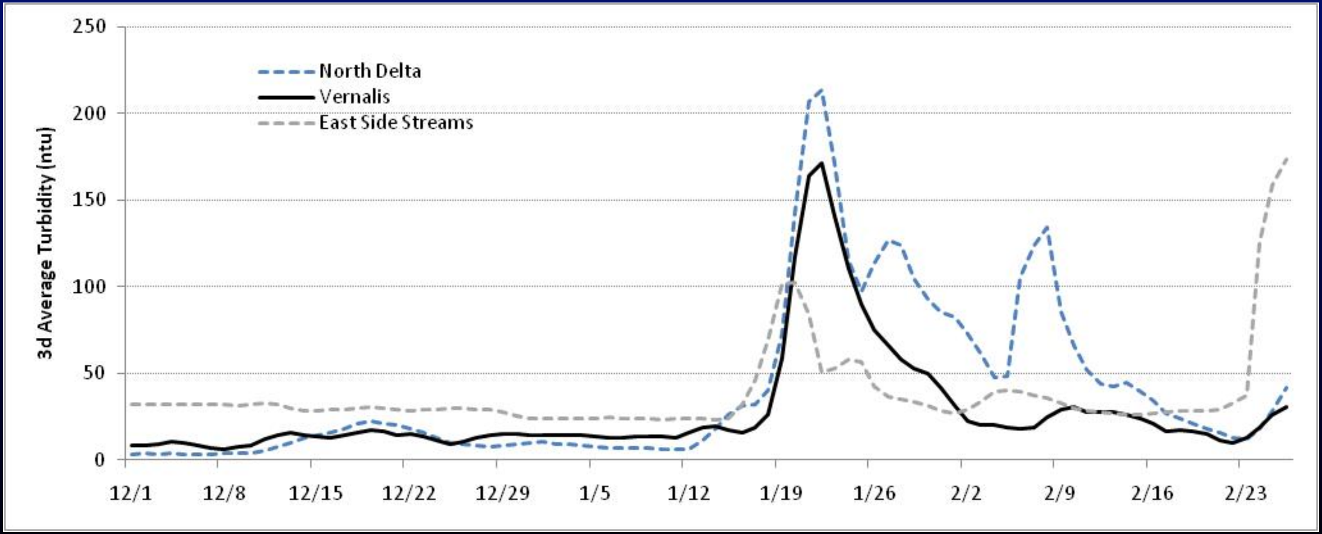
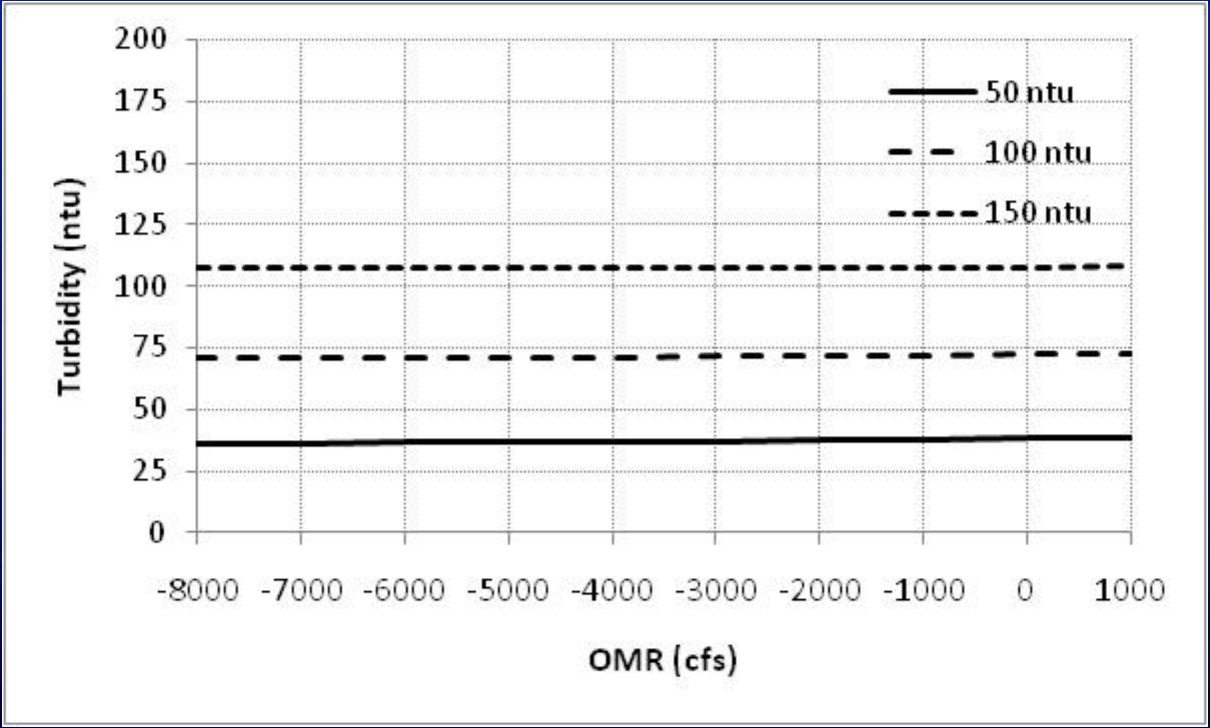




Steady State Flow-Turbidity Relationship
as a Function of North Delta Turbidity
Sacramento River @ Rio Vista



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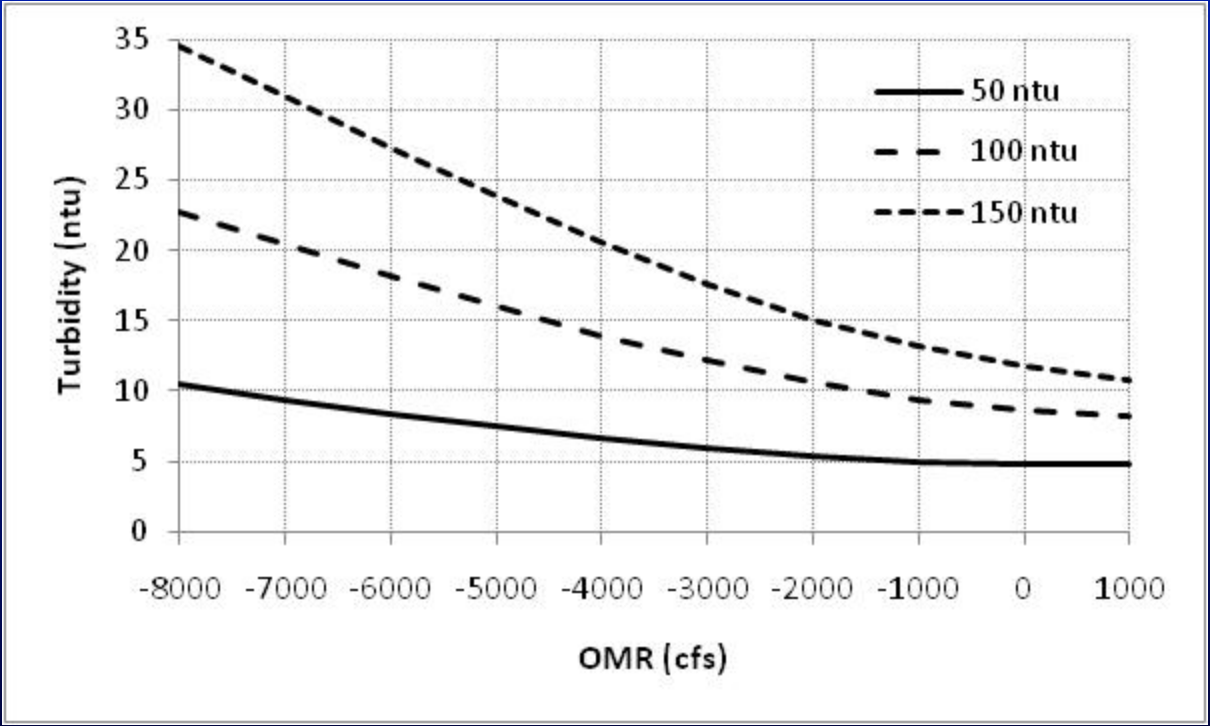
San Joaquin River @ Prisoner's Point



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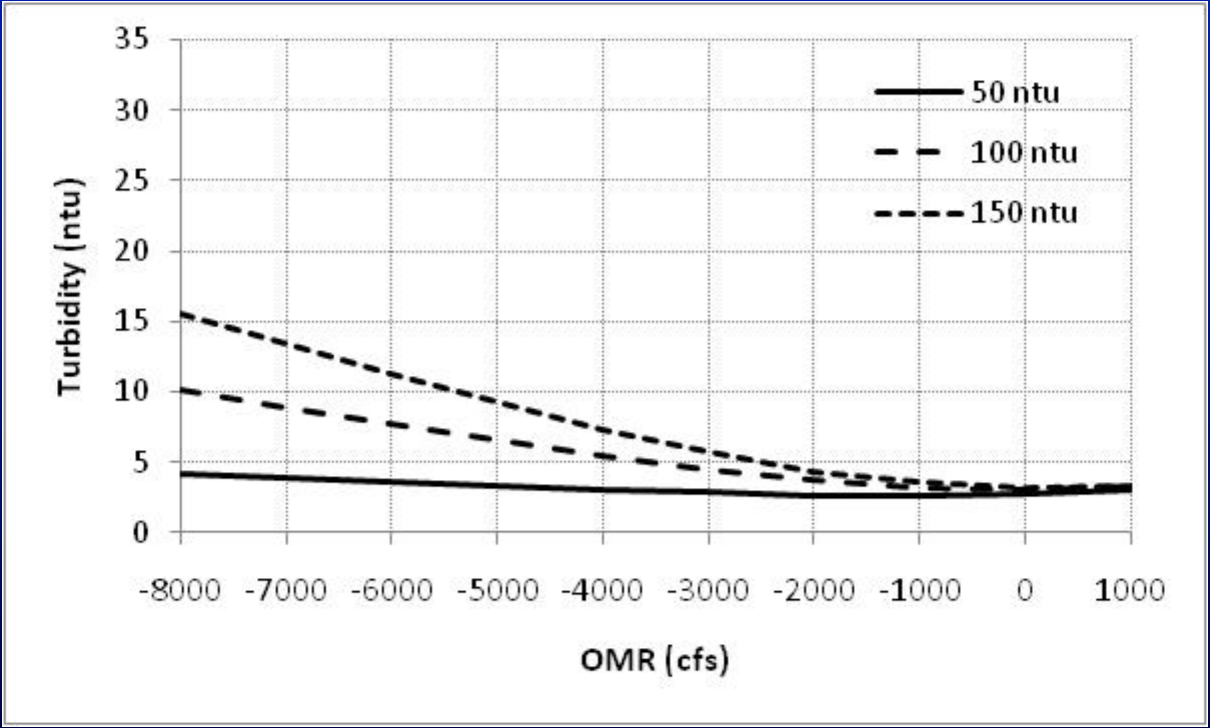
Middle River @ Holt



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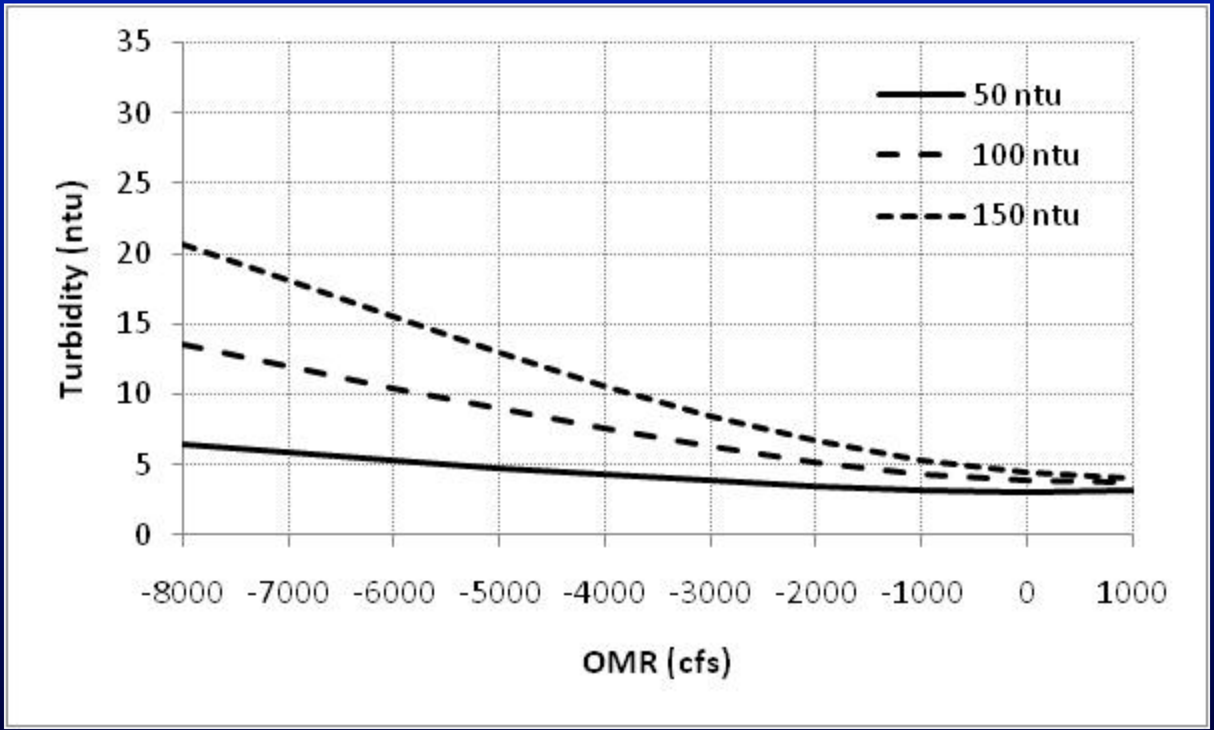
Old River @ Bacon Island



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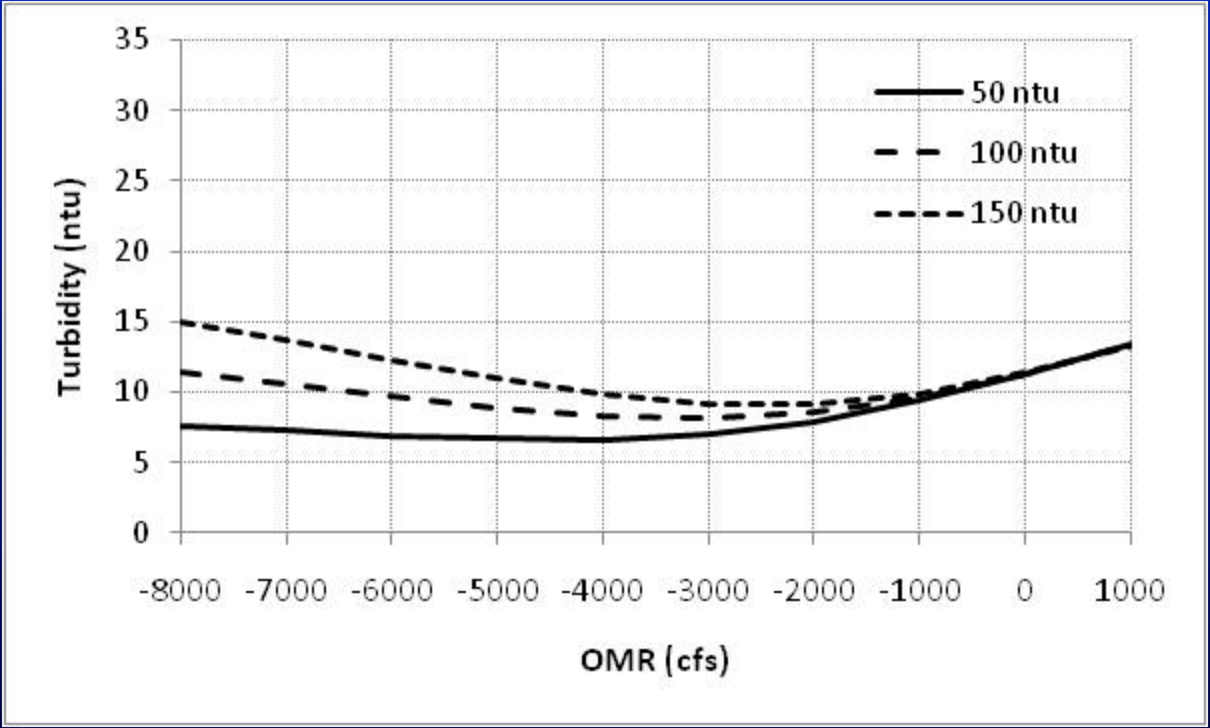
Clifton Court Forebay Entrance



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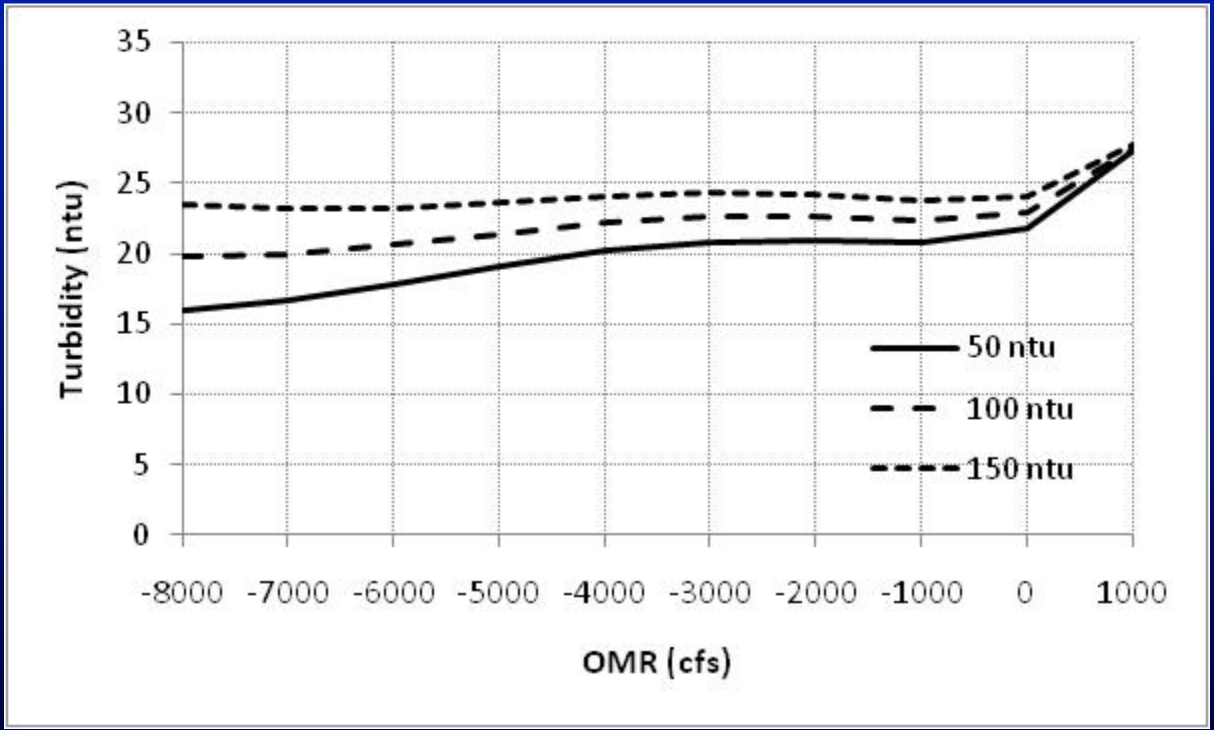

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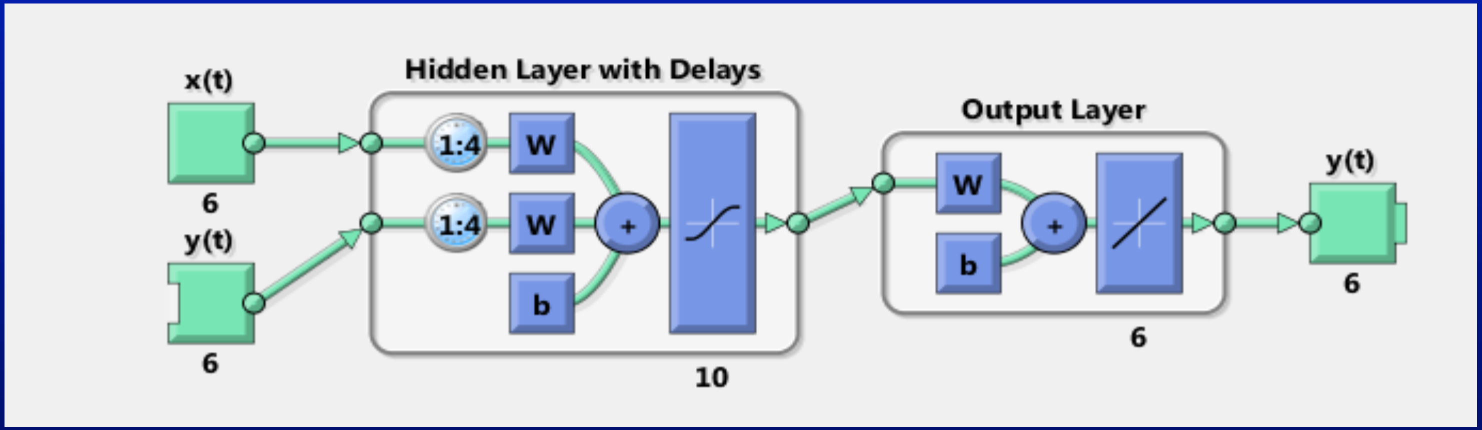
ANN Model Structure

Matlab Autoregressive



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Boundary Inputs = 6 (3 flow & 3 turbidity)
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Spring-Neap Effect on Turbidity

Clifton Court Forebay Entrance 1994-95