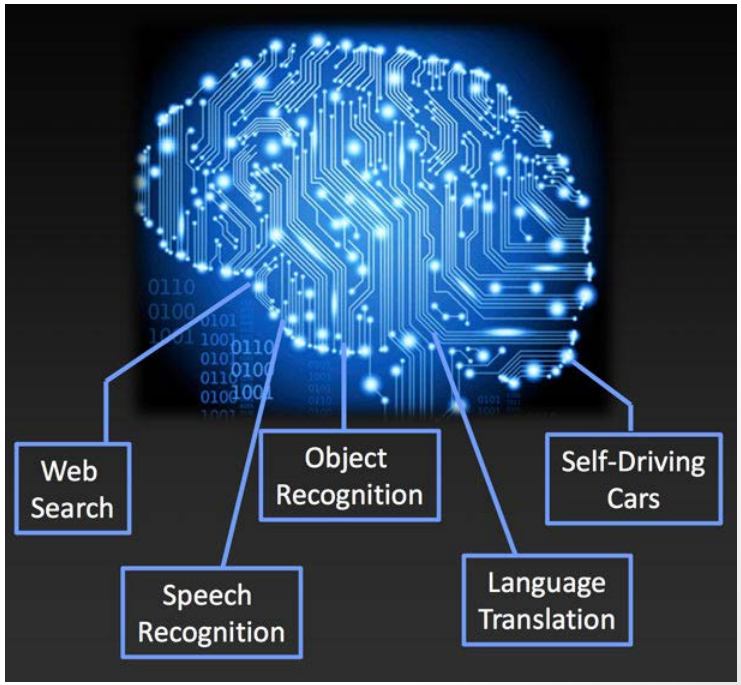
Artificial Neural Network (ANN)

California Department of Water Resources

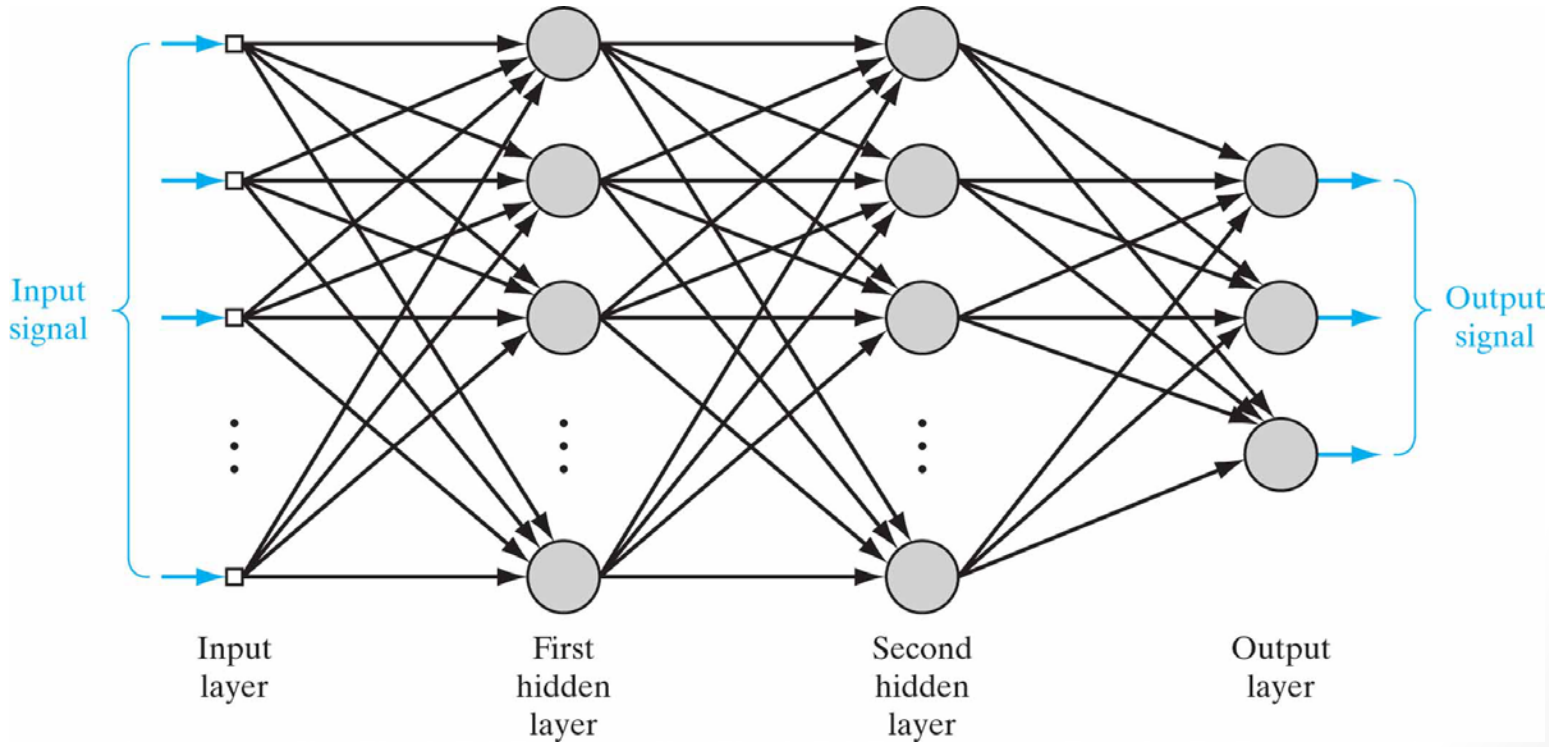
United States Bureau of Reclamation

ANN Background

- An **artificial neural network** (ANN) is a network inspired by **biological** neural networks which are used **to estimate or approximate functions** that can depend on a large number of inputs.
- ANN resembles brain in two respects:
  - Network acquires knowledge through a learning process.
  - Neuron connection are used to store the acquired knowledge.

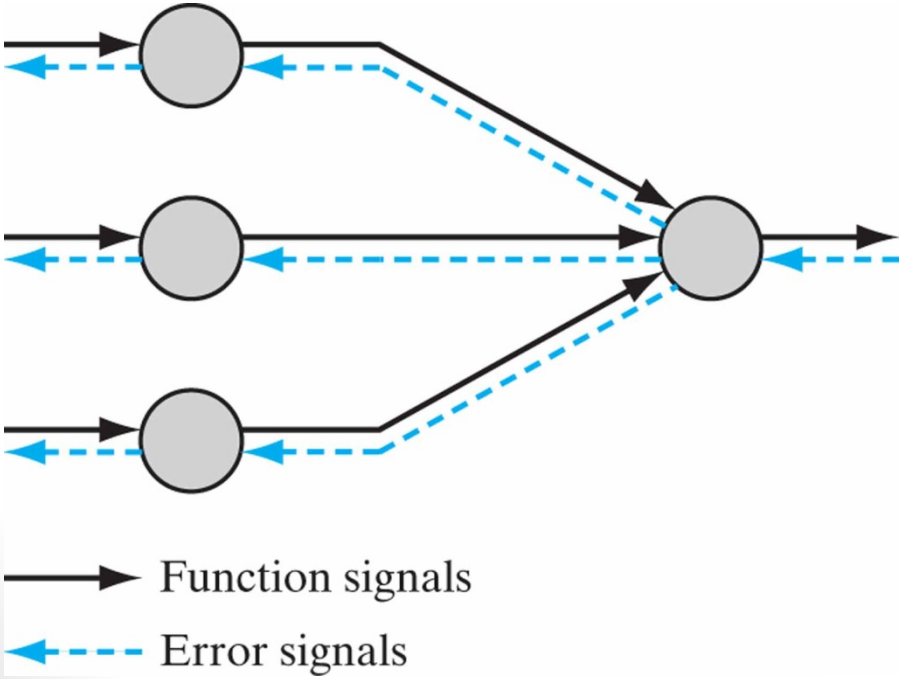


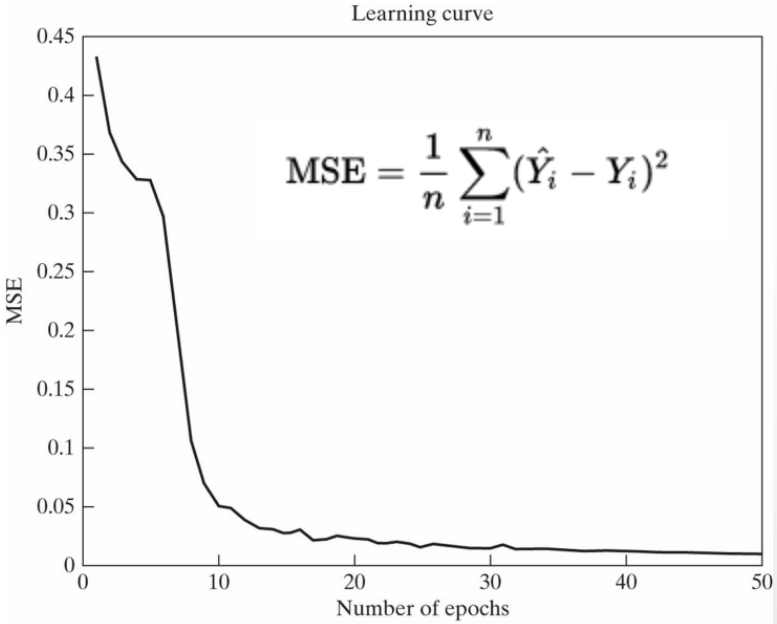
ANN Architecture multilayer perceptron (neuron)



ANN learning

- Directions of two basic signal flows in a multilayer perceptron:
  - forward propagation of function signals and
  - back propagation of error signals.





Mean-Squared Error (MSE) with training

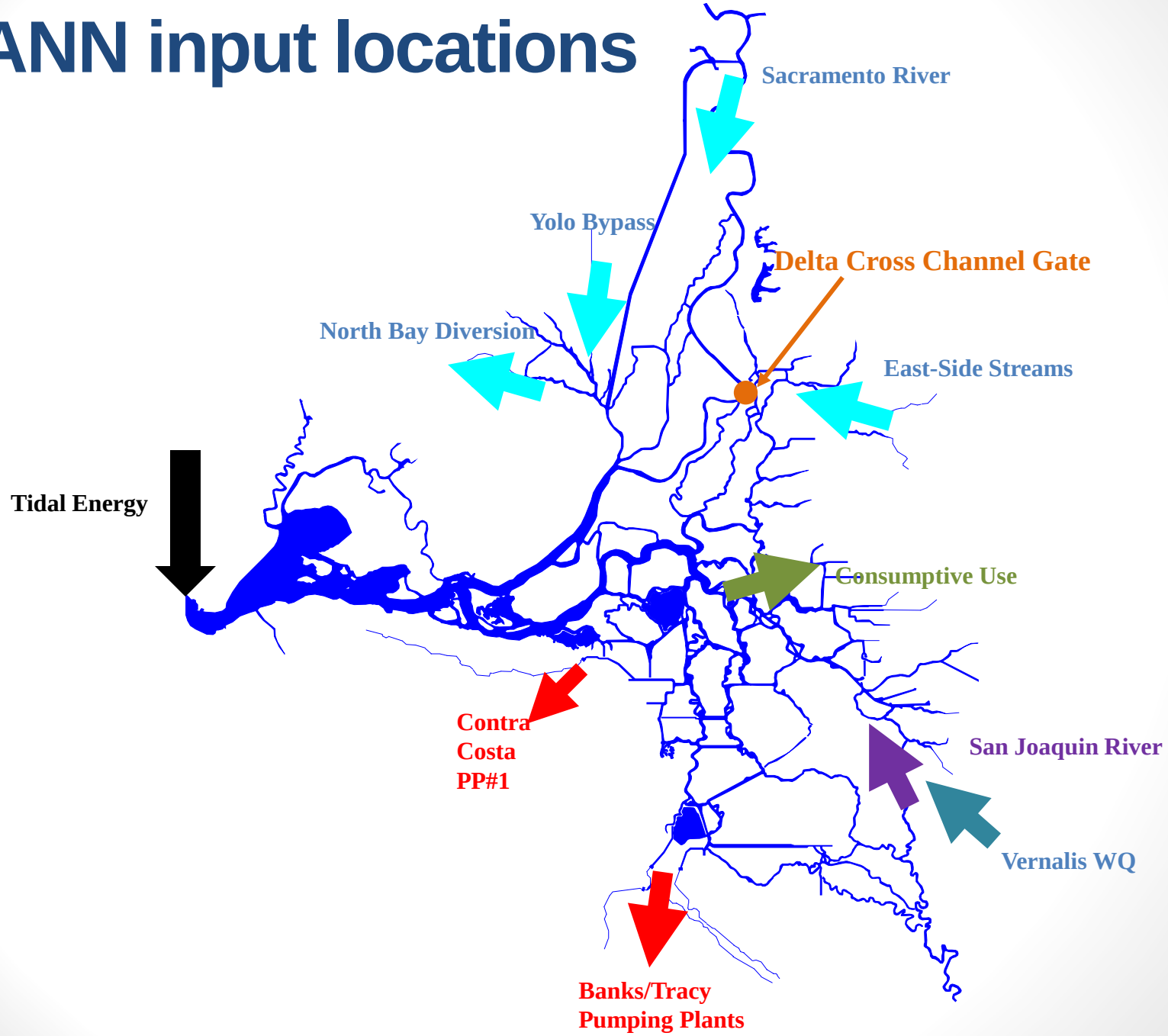
Why ANN in CalSim II?

- CALSIM model
  - Known: Salinity standards
  - Unknown: Flow requirements, Salinity
- Purpose of ANN :
  - Provide an **inflow-export-salinity relationship** that allows compliance with salinity standard
    - **Specify flows** given a salinity standard (Inverse application of ANN)
    - Provide for carriage water calculations (Post processing)
  - **Estimate salinity** for a location in the delta (Direct application of ANN)

ANN input for salinity

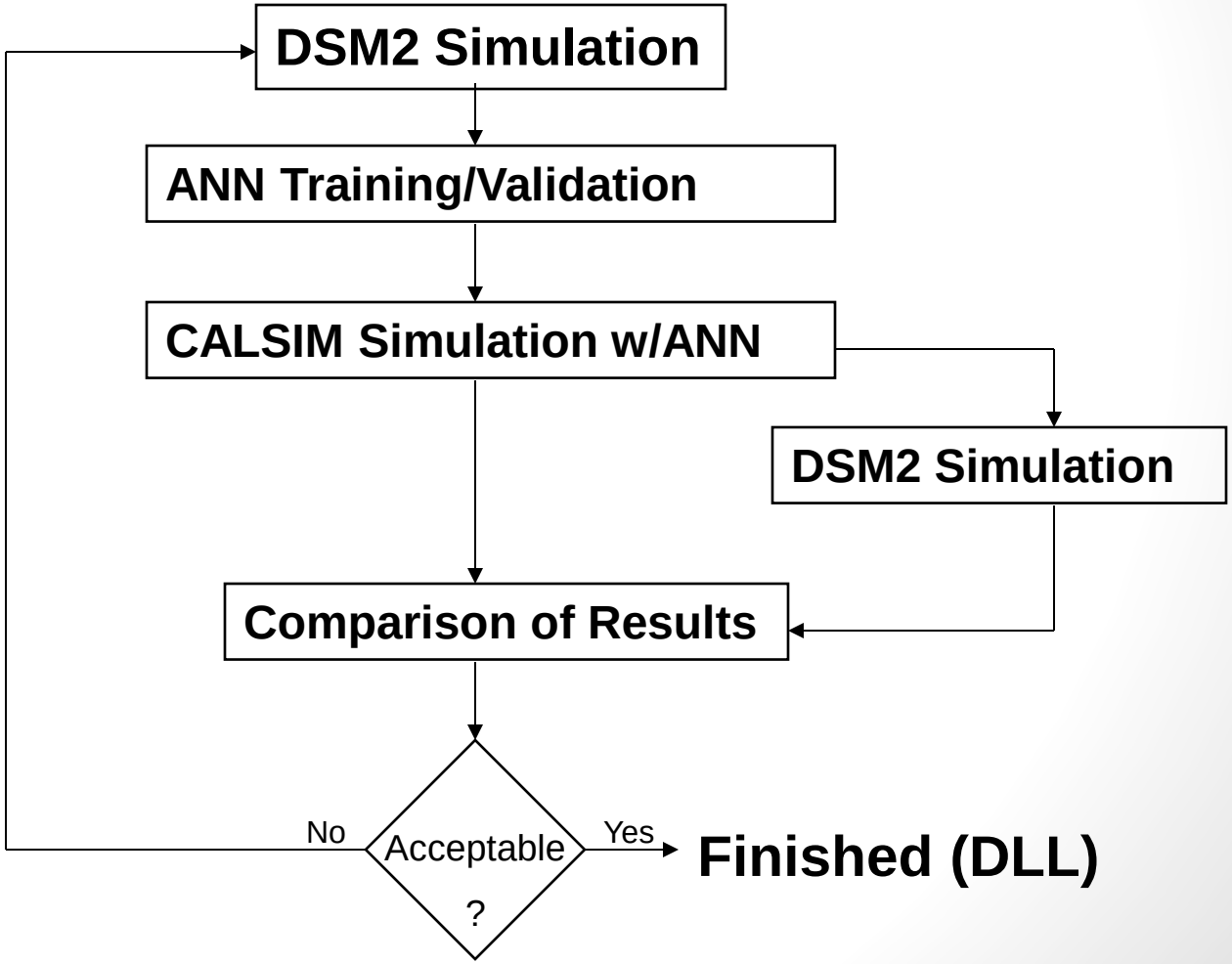
- Input Parameters (7)
  - Northern flows: Sacramento River +Yolo Bypass + East streams + Calaveras - North Bay & Vallejo Exports
  - San Joaquin River Flow
  - Exports: Banks, Tracy, Contra Costa Exports
  - Delta Cross Channel Gate
  - Net Delta Consumptive Use
  - Vernalis water quality
  - Tidal Energy (daily maximum – minimum hourly astronomical tide)
- 117 days antecedent conditions

ANN input locations



ANN training and Full circle analysis

- ANN Training and Validation: 16 years of DSM2 simulation data (10 years training and 6 years validation)

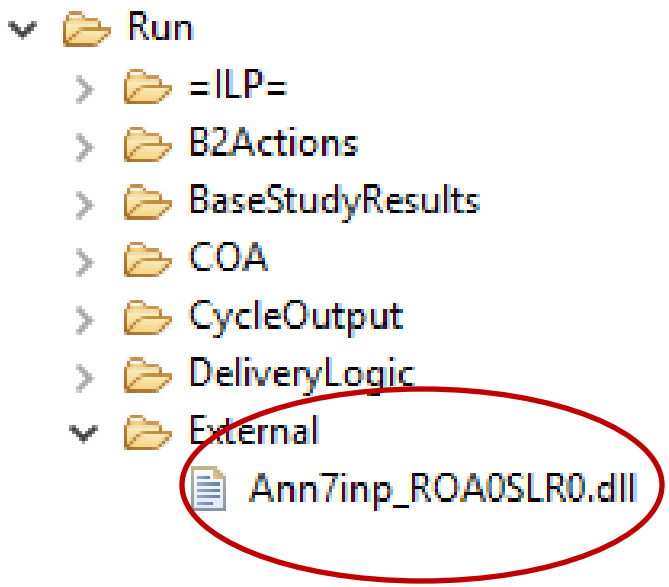


ANN DLL (Dynamic Link Library)

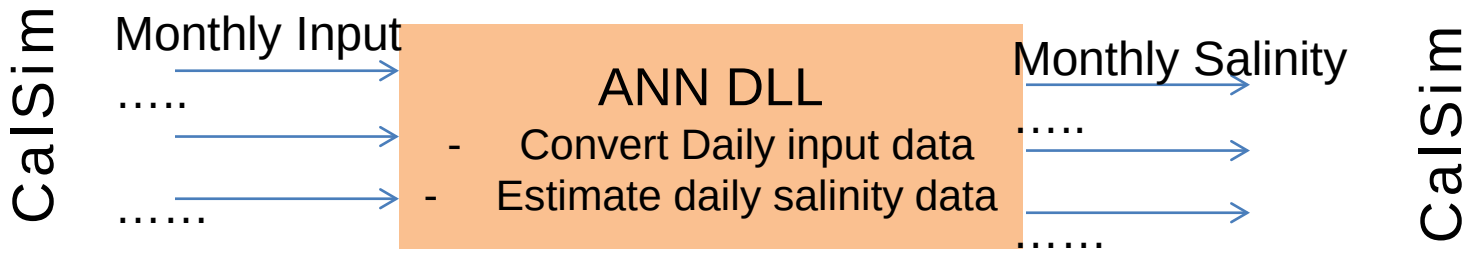
Functions:

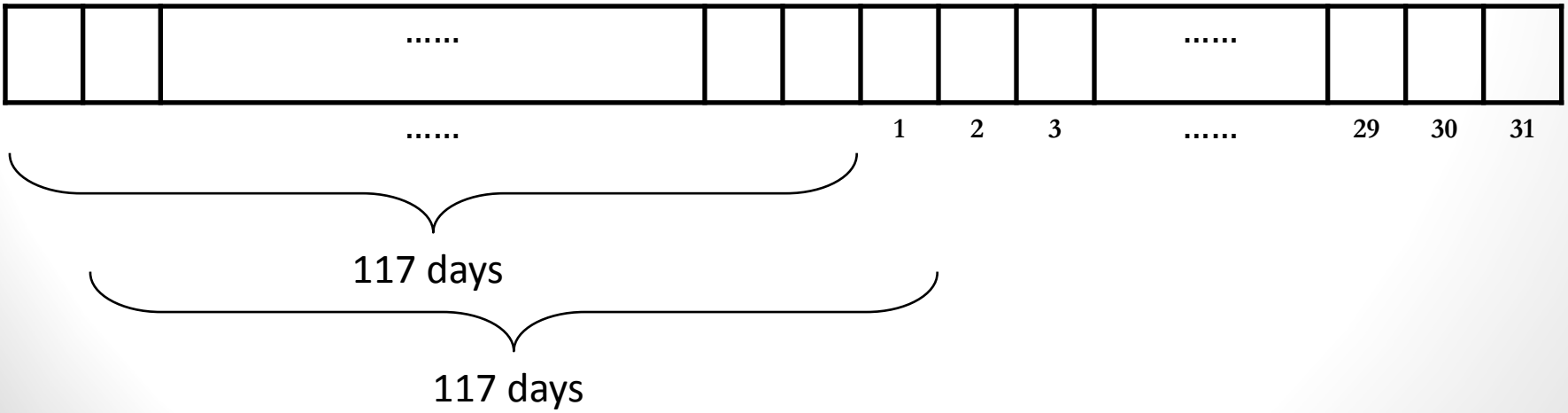
- EM_EC_Month_sv = Function of (input) → Salinity previous month

- ANNLineGen = Function of (input) → Flow requirement



ANN input and output salinity - Implementation





Why not DSM2?

- Delta Simulation Model 2 (DSM2)
  - Hydro: 1-D hydrodynamic model
- Lacks ability to specify flows given a salinity standard
- Run time vs Accuracy

Recap

What does ANN provide in CalSim II?

(A) Flow requirements given salinity standard

(B) Allocation of water supply

(C) Salinity of the previous month given the flow and exports.

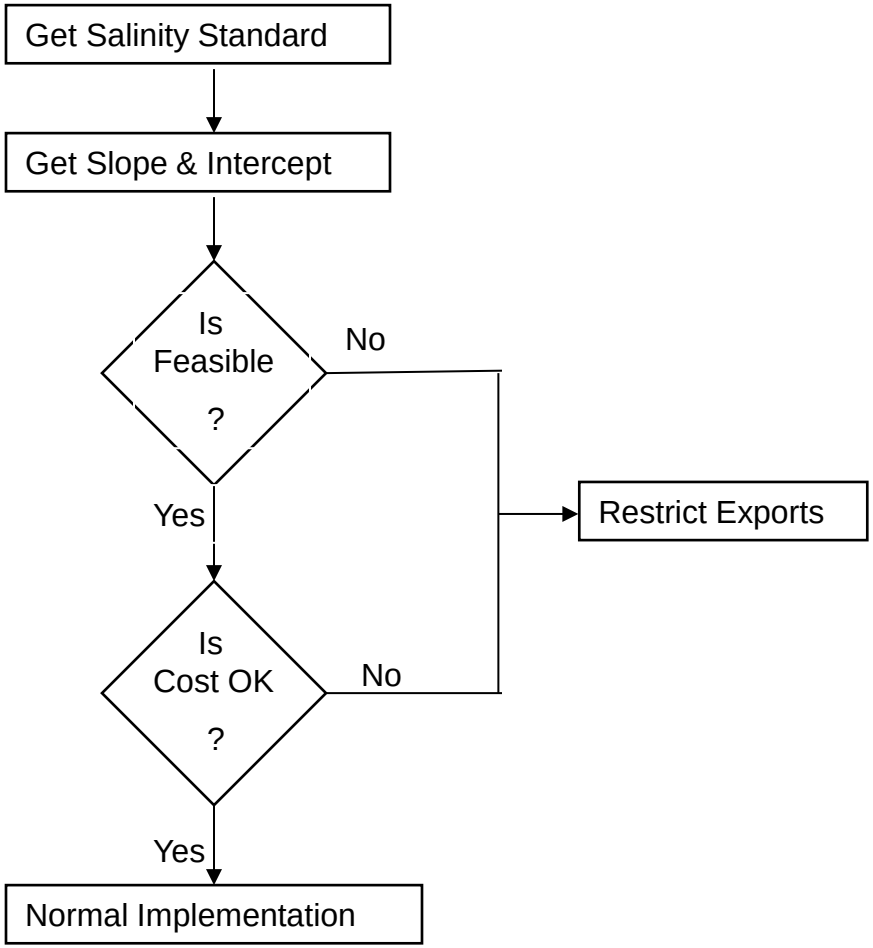
(D) Both A and B

ANN files – CalSim implementation

- DCR2015
  - common
    - B2Actions
    - CAAFramework
    - CCWD
    - cvp_dellogic
    - CycleOutput
    - DailyDeltaInput
    - Delta
      - Ann
      - IsolatedFacility
      - Mrdo
      - Riovista
      - SoDeltaChannels
      - SpecProjects
      - Vallejo
      - Xchannel
      - Delta_ANN_Reduced_Calls.wresl
      - Delta_ANN.wresl
      - DeltaExtFuncs_7inpANN.wresl

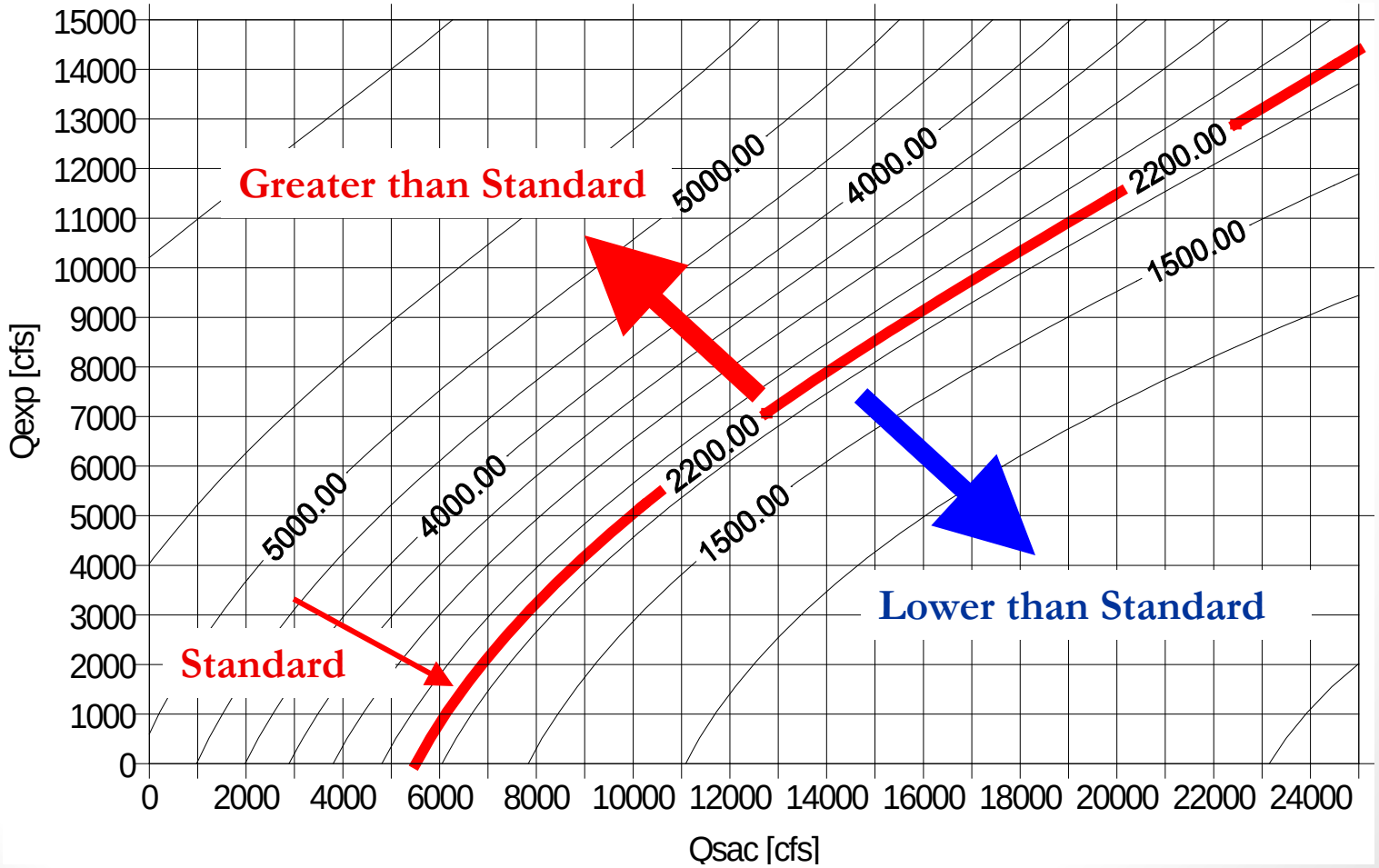
- Ann
  - ANN_COA_MRDO.wresl
  - Ann_wyt_D1641.wresl
  - AnnCommon1.wresl
  - AnnCommon2.wresl
  - AnnCommon3.wresl
  - AnnSacFlow.wresl
  - Antioch_constrain.wresl
  - Antioch_data_reduced_calls.wresl
  - Antioch_data.wresl
  - Antioch_est.wresl
  - Antioch_output.wresl
  - CCFB_data_reduced_calls.wresl
  - CCFB_data.wresl
  - CCFB_intake_data_reduced_calls.wresl
  - CCFB_intake_data.wresl
  - Chipps_constrain.wresl
  - Chipps_data_reduced_calls.wresl
  - Chipps_data.wresl
  - Chipps_est.wresl
  - Chipps_output.wresl

AnnlineGen – CalSim implementation



Flow-Salinity Relationship

- ANN Line Generation: $\mathbf{Q_{EXP} \leq m\ Q_{SAC} + b}$
  - m & b are determined by ANN



Sac flow requirements for Emmaton salinity

```
!Get the required Sac flow for ESTIMATED exports
define EMReqSac {
  case NoSalinityControlPossible{
    condition abs(EM_m_sv) <= 0.001 .and. int(EM_b_sv) == 0
    value 0.}
  case NegSlope{
    condition EM_m_sv <= 0.0
    value 0.}
  case highcost{
    condition EM_Sac_ZeroExp_sv2 >= ANNcap
    value 0.}
  case control{
    condition month >= Apr .and. month <= Aug
    value max(0., (EstTotExpTD-EM_b_sv)/EM_m_sv)}
  case other {
    condition  always
    value 0.}
}
```

File name: Emmaton_constrain.wresl

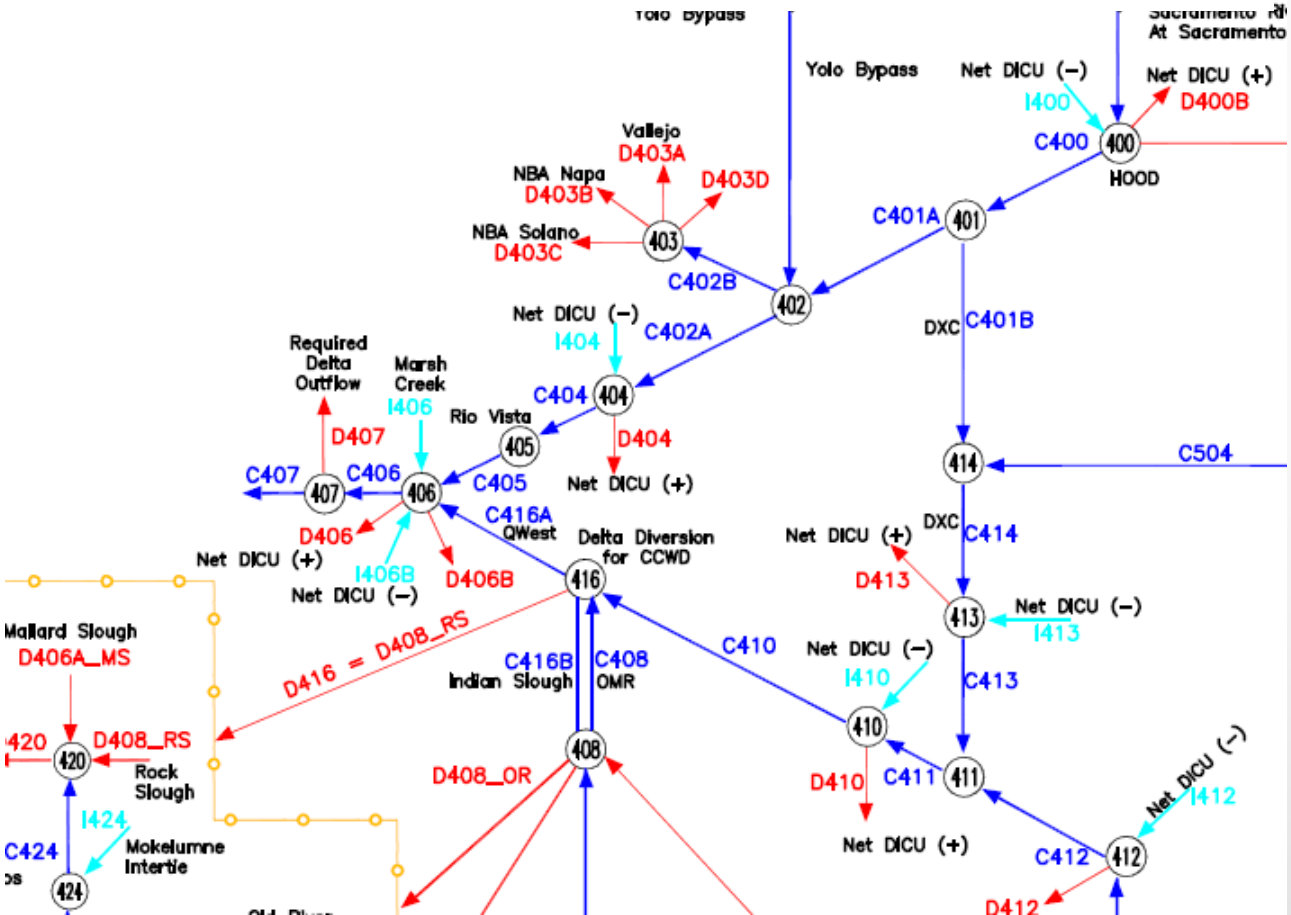
How Sac flow requirements are met?

- ExportEstimate2.wresl
  - Estimate target export for this month (**EstTotExpTD**)
- *Station*_est.wresl
  - What Sac flow is necessary to provide the target
    - EstTotExpTD = m * Sac_req + b
    - **Sac_req** = (EstTotExpTD – b)/m
- AnnSacFlow.wresl – use Sac req’ts from station estimates to inform flow at Hood

How Sac flow requirements are met?

```
!required sac flow for estimated exports considering all ann stations:
define AnnSacReq_max {value max(0.0,RSReqSac,JPReqSac,EMReqSac,COReqSac)}
define AnnSacReqmaxdv {alias AnnSacReq_max kind 'FLOW' units 'CFS'}

define AnnSacReq {value min(AnnSacReq_max,EstTotExpTD/0.65+7000.)}
define AnnSacReqdv {alias AnnSacReq kind 'FLOW' units 'CFS'}
```



Restrict exports - *Station*_constraint.wresl

- Goal meetST

  LHS EXP_TD + D408_P

  RHS ST_m_sv*C_SACtot_ANN + ST_b_sv

Restrict Exports to meet the standard

```
goal meetEM {
  lhs D409 + D408_P
  case NoSalinityControlPossible{
    condition abs(EM_m_sv) <= 0.001 .and. int(EM_b_sv) == 0
    rhs ExportCap
    lhs<rhs penalty 0}
  case NegSlope{
    condition EM_m_sv <= 0.0
    rhs 999999.
    lhs<rhs penalty 0}
  case HighCost{
    condition EM_Sac_ZeroExp_sv2 >= ANNcap
    rhs ExportCap
    lhs<rhs penalty 0}
case Normal {
    condition always
    rhs EM_m_sv*c400_ANN + EM_m_sv*c157 + EM_b_sv
    lhs<rhs penalty 0}
}
```

File name: Emmaton_constrain.wresl

ANN output salinity

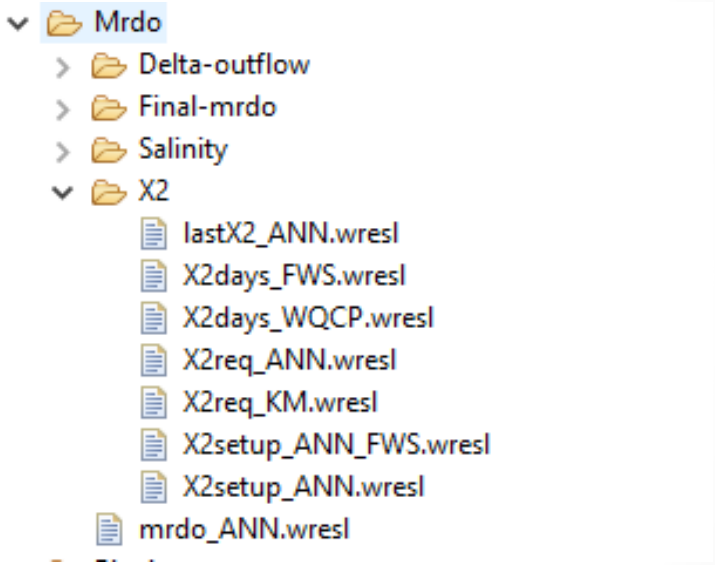
- Monthly EC data for a station

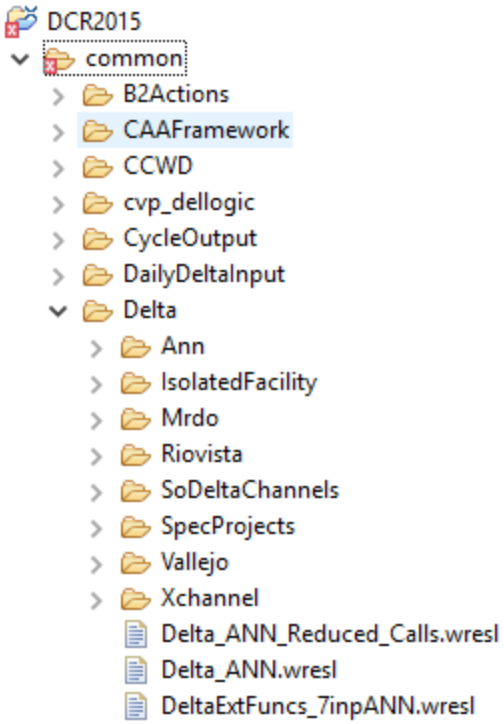
```
define EM_EC_Month_sv {
condition always
      value  AnnEC(C400(-5),C400(-4),C400(-3),C400(-2),C400(-1),
               D409(-5),D409(-4),D409(-3),D409(-2),D409(-1),
               C639(-5),C639(-4),C639(-3),C639(-2),C639(-1),
               DXC(-5),DXC(-4),DXC(-3),DXC(-2),DXC(-1),
               net_DICU(-5),net_DICU(-4),net_DICU(-3),net_DICU(-2),net_DICU(-1),
               sac_oth(-5),sac_oth(-4),sac_oth(-3),sac_oth(-2),sac_oth(-1),
               exp_oth(-5),exp_oth(-4),exp_oth(-3),exp_oth(-2),exp_oth(-1),
               VERNWQFINAL(-5),VERNWQFINAL(-4),VERNWQFINAL(-3),VERNWQFINAL(-2),VERNWQFINAL(-1),
               int(daysindv(-5)),int(daysindv(-4)),int(daysindv(-3)),int(daysindv(-2)),int(daysindv(-1)),
               int(EM),int(monthly_ave),(month-1),wateryear)}
}
```

File name: Emmaton_data.wresl

ANN X2 Input and output

- ANN X2 input (3 input instead of 7 input)
  - NDO
  - Previous months X2
  - Tide energy



- ANN X2 output
  - Delta outflow to maintain X2 standard
  - X2 position

Swap ANN DLL files