

Technical Meeting: Integrated Surface Water and Groundwater Modeling of the Shasta River Watershed

Presented By:

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S.S. Papadopoulos & Associates, Inc.
Environmental & Water Resource Consultants

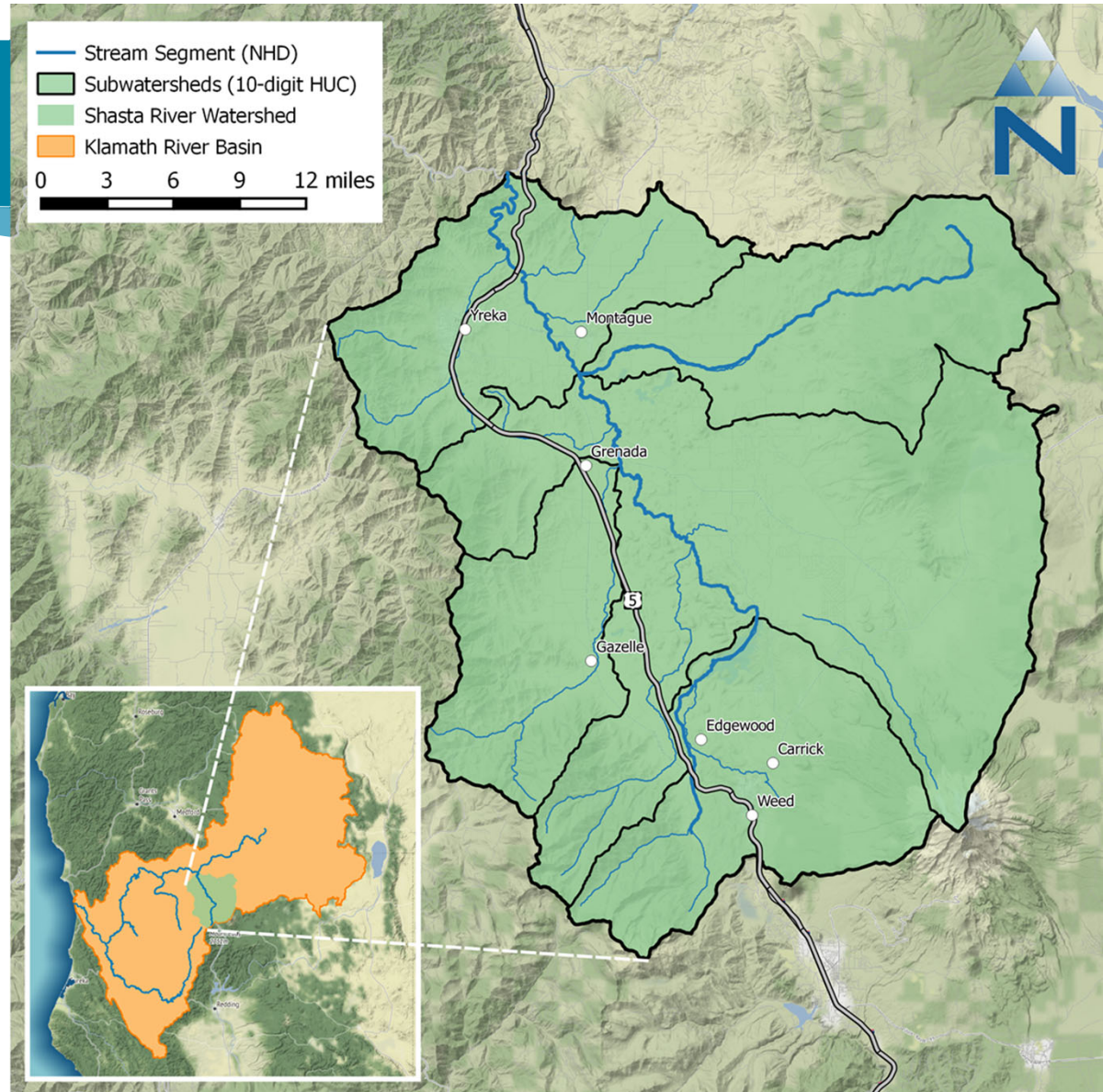


Flow of the Presentation

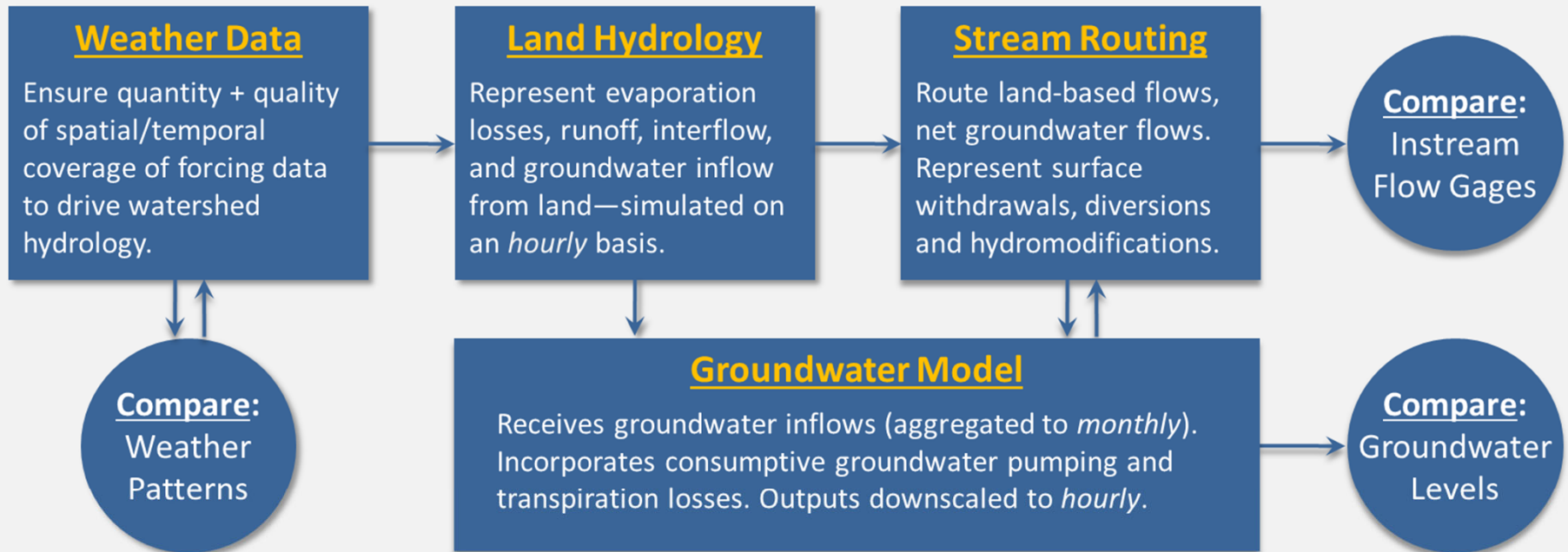
- Overview of the integrated model
- Explanation of LSPC-MODFLOW integration
- Concise description of scenarios and inputs
- Instructions for executing the model

Shasta River Watershed

- Drains 794 mi²
- Flows north to Klamath River
- Originates as snowmelt from southern portion
- Geology/Topography
 - East: Younger Volcanic
 - West: Older Metamorphic
 - Low-gradient floor
 - Surrounding mountains
- Water diversion:
 - Agriculture
 - Municipal supply
 - Recreation
 - 227 cfs (SW Irrigation demand)



Integrated Modeling Approach



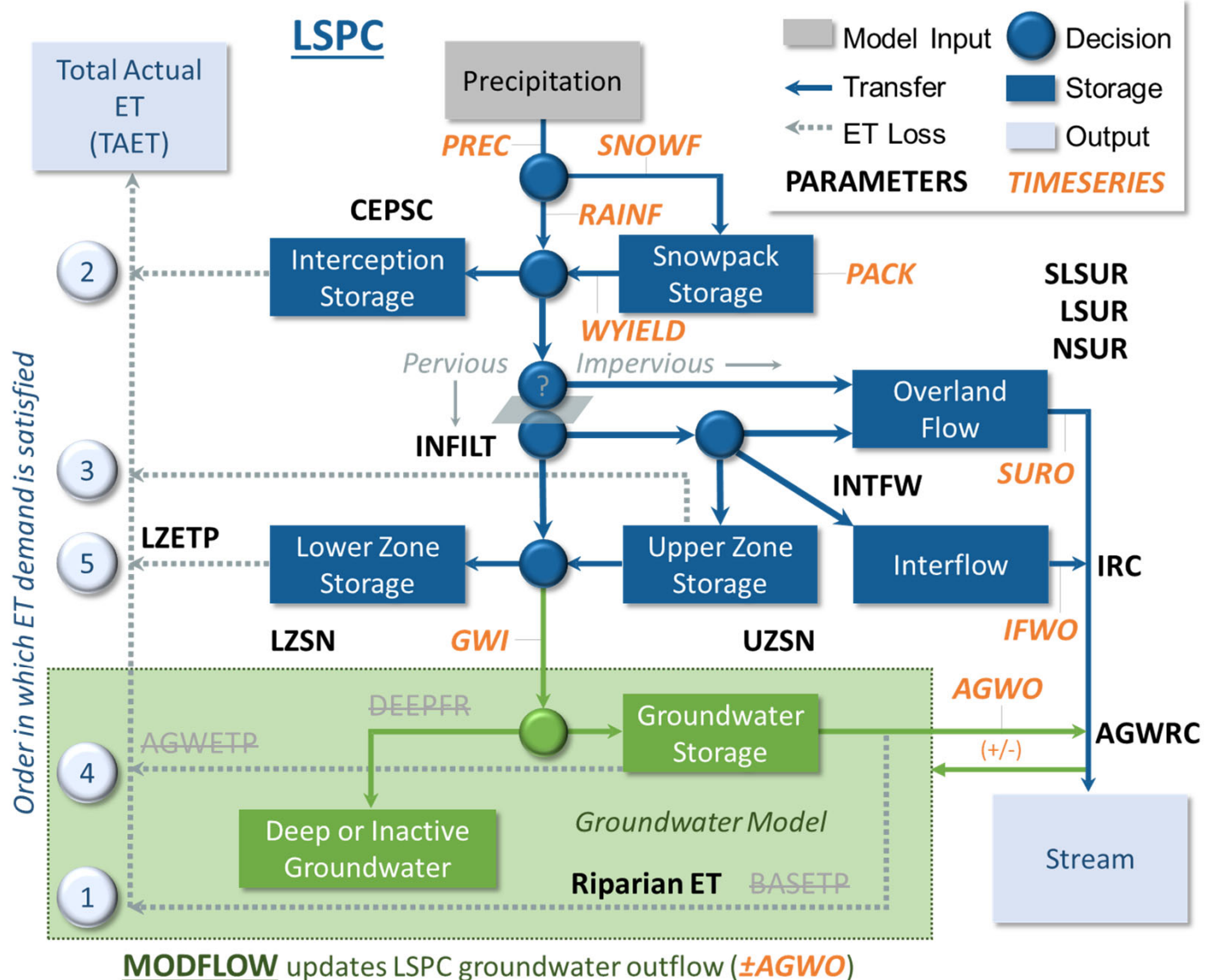
Calibration Objective:

Minimize Residual

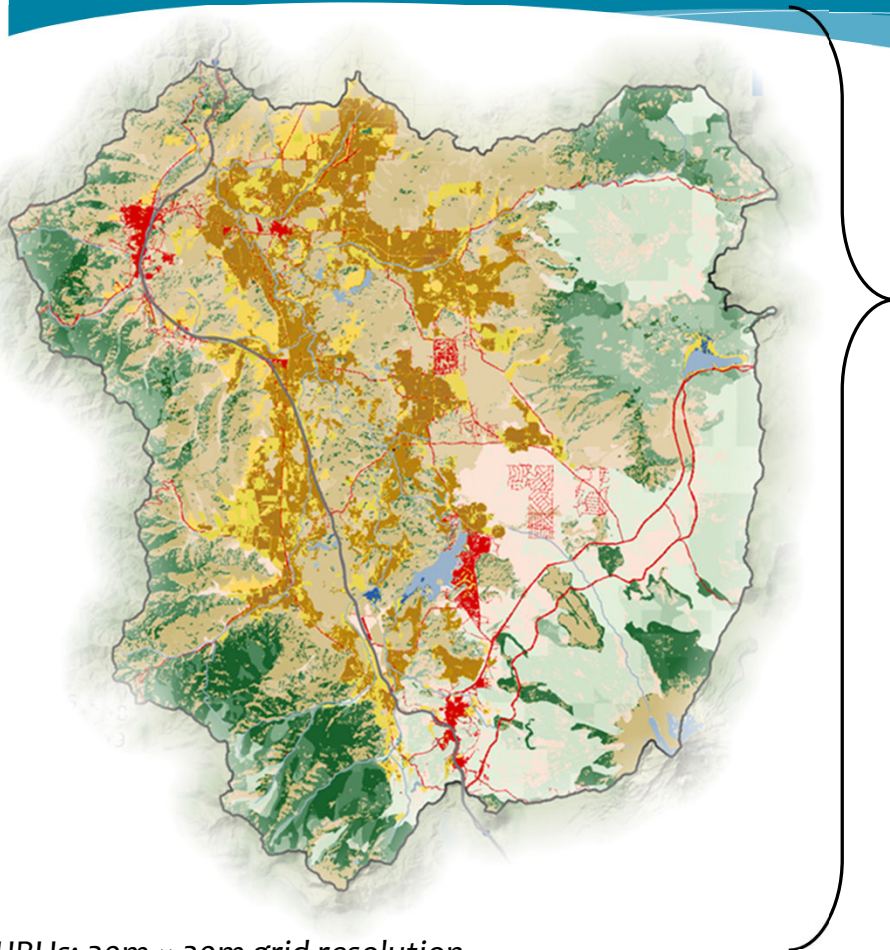
Integrated SW-GW Model

LSPC & MODFLOW

- MODFLOW replaces **Groundwater Layer** in LSPC
- AGWO volumes adjusted (+/-) to match MODFLOW monthly volumes
- Linkage occurs at edge-of-stream to AGWO, prior to reach routing



Hydrologic Response Units (HRU) Representation



HRUs: 30m × 30m grid resolution

Land Use/Land Cover

NLCD 2011

×

Crop Layer

(Irrigation Source Areas)

DWR 2019

×

Hydrologic Soils Group

USDA SSURGO 2019

×

Slope

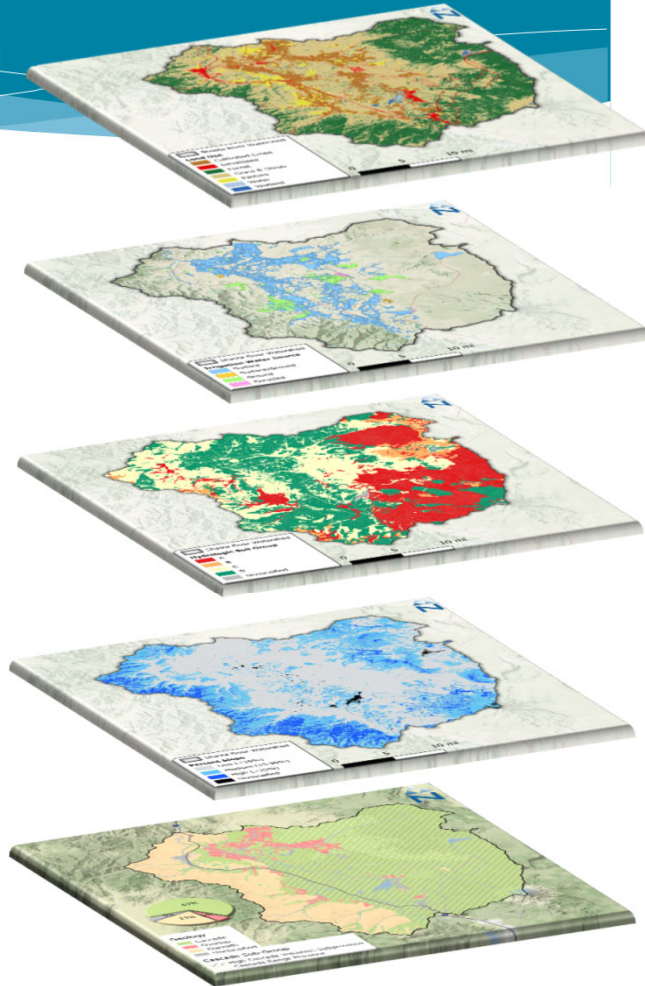
USGS

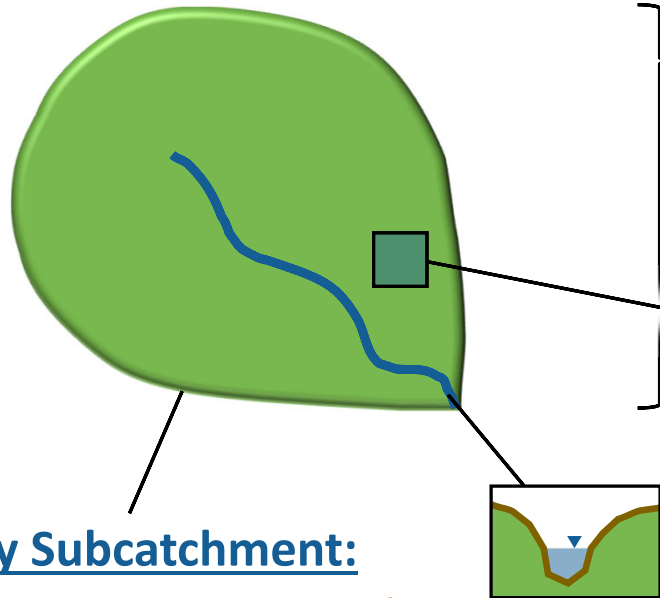
×

Geology

Holtz, 1977

Wagner & Saucedo 1987





By Subcatchment:

- **Parameter Group***
- HRU Area Distribution
- Weather Data
- Average Elevation
- Reach or Lake Segment

By HRU × Subcatchment (Physical):

- Slope of HRU
- Length of Overland Flow
- Imperviousness

By Individual HRU (Processes):

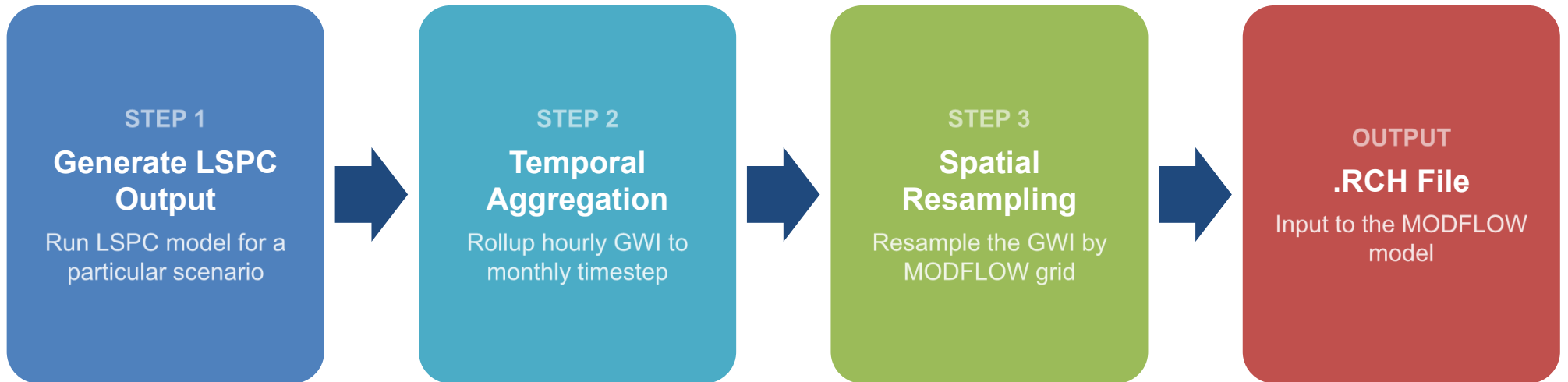
- Interception Storage Capacity
- Subsurface Storage Capacity
- All other Hydrological Parameters, Rates, and Constants

By Reach/Lake Segment:

- **Reach Group ***
- Geometry
- Transport Rates and Constants

* **Parameter/Reach Groups** can be used to differentiate features with distinct characteristics.

LSPC to MODFLOW: Main Input



Python script: GWI_to_RCH.py

LSPC to MODFLOW: Additional Inputs

- Water Budget Components (SURO/IFWO/IRWD)
- Riparian Evapotranspiration
- Non-irrigation consumptive use time-series
- Parks Creek diversion flow time-series
- Dwinnell Reservoir (seepage and environmental flow) time-series
- Groundwater pumping for irrigation
- Pacey and Flying L wells
- Canal leakage time-series (for MWCD and Edson-Foulke Yreka Ditch)

Python scripts: water_balance_summary.py & AdditionalData.py

MODFLOW Workflow Overview

- 1 Receive LSPC exports** GWI, pumping, streamflow components (SURO/IFWO/IRWD, diversions, canal leakage, environmental flows, riparian ET)
- 2 Run package preprocessors** RCH, WEL, SFR, LAK scripts/workbooks create package files or PEST templates
- 3 Copy to PEST/MODFLOW** RCH_*.dat and WEL.wel to PEST/mf; sfr.tpl and LAK.tpl to PEST
- 4 Execute MODFLOW** “*pest.exe Shasta_2024.pst*” runs MODFLOW-NWT within the PEST framework
- 5 Return groundwater feedback to LSPC** AGWO_MODFLOW.dat and DRN_RATES.OUT are generated with MODFLOW execution

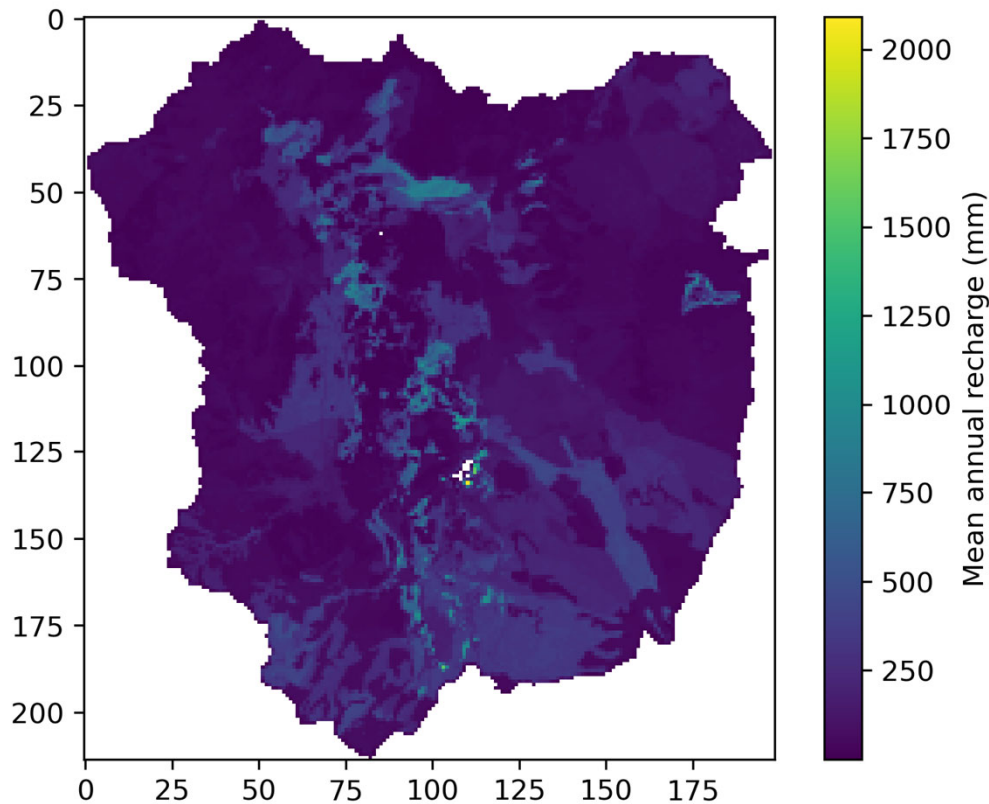
Note: Model length unit is meters, model time unit is days

LSPC-MODFLOW Process Mapping

LSPC/MODFLOW Flow Term	MODFLOW Package	Conceptual Representation	Preprocessing Source
GWI	RCH	Monthly recharge arrays; first stress period uses mean steady-state recharge	addSStoRCH_1980.py
Irrigation pumping	WEL	Cell-by-cell extraction rates; pumping rates are area-weighted from subbasins/HRU-cell intersections	PumpingData_InchAcres.csv_sspa_2026_01_05.xlsx; write_wel_V4.py; WEL_2026_01_05.wel
Additional well pumping	WEL	Additional Pumping include Pacey Well and Flying L Well	AdditionalPumping.xlsx; AdditionalPumping.txt; CalcPumping.exe; CalcPumping.in
Canal leakage	WEL	Canal leakage is distributed to 76 Yreka Ditch cells and 18 Montague Canal cells	AdditionalPumping.xlsx tabs EdsonFoulke_YrekaDitch_CanalLea and Montague_Canal_Leakage; AdditionalPumping.txt; CalcPumping.exe
SURO + IFWO	SFR / LAK	Routed overland inflow to stream segments; and Lake Shastina	createSFR_v4.py; LAK workbook
IRWD, non-irrigation use, Riparian ET, diversions	SFR	Segment inflow/outflow terms; Diversions	createSFR_v4.py
Dam leakage + environmental releases + surface water diversion from SFR	LAK / SFR	Lake withdrawals and routed streamflow from SFR	write_LAKE_withdrawal_LakeRunoff_Grass_PrecipET.py + createSFR_v4.py
AGWO, Spring flow, and shallow groundwater discharge	SFR + DRN	SFR used for AGWO and in-stream spring flow; DRN used for off-stream spring flow and shallow groundwater discharge	MODFLOW package outputs

MODFLOW RCH package Represents LSPC GWI

MODFLOW Groundwater Recharge

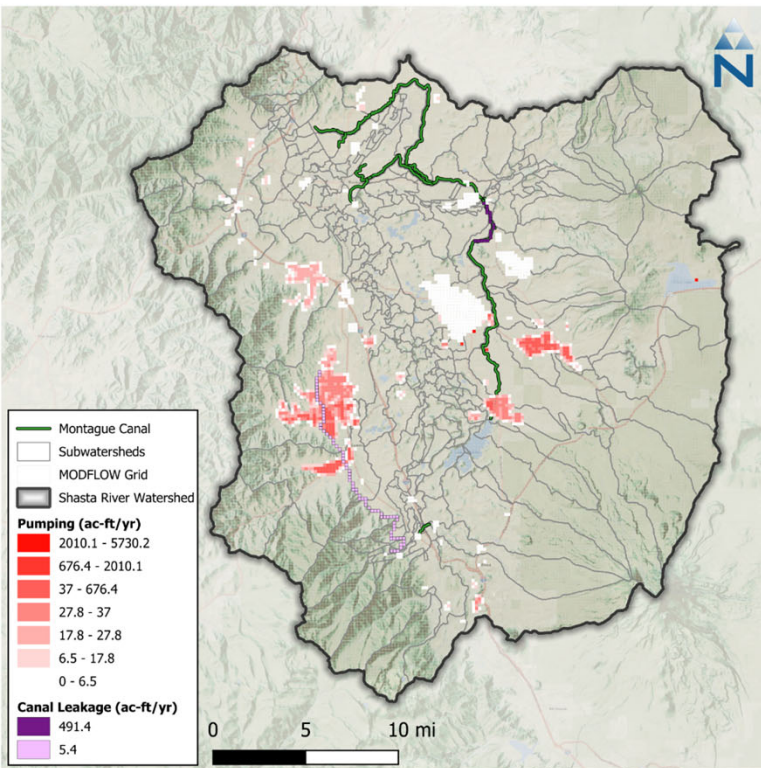


Mean recharge is used for the initial steady-state stress period.

For all transient stress periods, GWI from LSPC is applied as RCH in MODFLOW.

MODFLOW WEL package Represents Irrigation Demand and Canal Leakage in LSPC

MODFLOW Pumping Conceptualization:



Irrigation pumping: negative WEL rates

Pumping is area-weighted by HRU x MODFLOW cell intersections. Write_wel_V4.py creates base irrigation pumping from PumpingData_InchAcres.csv_sspa_2026_01_05.xlsx. Additional Pumping adds specific pumping from Pacey Well and Flying Well using CalcPumping.exe.

Canal leakage: positive WEL rates

AdditionalPumping.xlsx tabs has Canal Leakage from Edson/Foulke/Yreka Ditch and Montague Canal leakage.

AdditionalPumping.txt distributes leakage to 76 YrekaDitch MODFLOW cells and 18 Montague Canal MODFLOW cells in model layer 1.

Irrigation pumping
layer 3 extraction

Additional specific wells
layer 2 extraction

Canal leakage
layer 1 inflow

CalcPumping.exe
combines all terms

Final WEL.wel
Add SPECIFY -0.5

MODFLOW SFR package Represents SURO+IFWO+Riparian ET+Diversion+Environmental Flows + Dam Leakage in LSPC

MODFLOW Streamflow Conceptualization:

- Streams act as head-dependent boundaries tied to the Groundwater Model Layer 1.
- SFR simulates flow within the stream network using channel slope, width, and Manning roughness.
- Stream-aquifer exchange depends on the stream stage, gw head, streambed elevation, and conductance.
- This exchange (AGWO) is provided back to LSPC.

Process Step	Function
Load LSPC water balance	Reads Streams_WaterBalanceParams_* with SURO, IFWO, IRWD by segment/date
Convert monthly volume to rate	Divides by days in month (ft ³ to m ³ where needed)
Intermediate catchments	Push SURO/IFWO to next downstream segment
Build diversion series	Combines IRWD, non-irrigation use, riparian ET, Parks Creek, dam leakage, environmental flows, Flying L Well, Pacey Wells
Write template	Writes REACHINPUT and monthly segment records with FLOW, RUNOFF, roughness, width
Update template file	Open sfr.tpl; copy REACHINPUT.dat; replace the REACHINPUT section in sfr.tpl, rows 2-1521

MODFLOW LAK package

MODFLOW Lake Shastina Conceptualization:

Lake Water Balance:
stage-volume-area bathymetry in
MODFLOW LAK

Lake Inflows:
stream inflow, groundwater seepage,
precipitation, LSPC SURO/IFWO

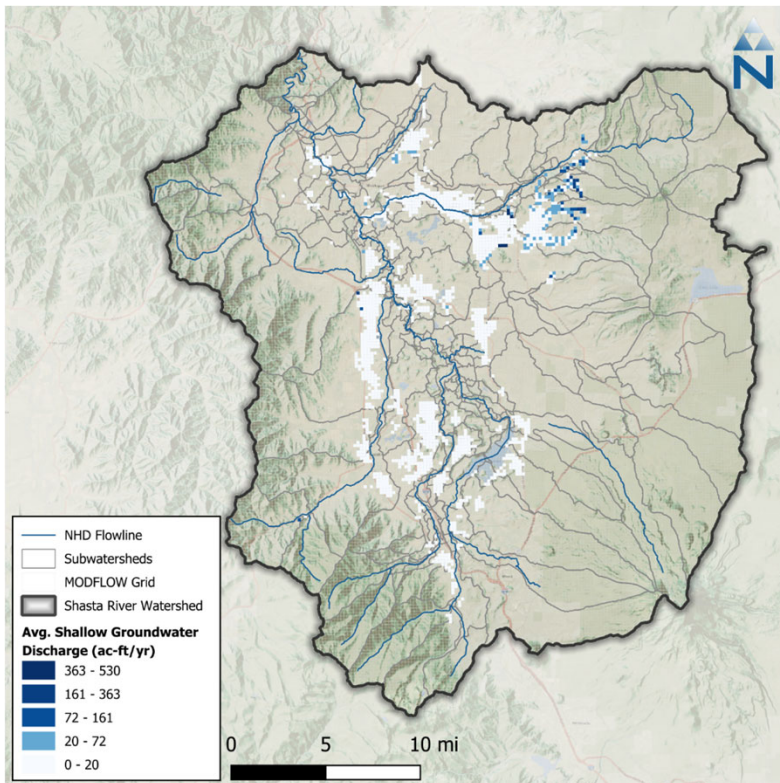
Lake Outflows:
reservoir releases, dam leakage,
environmental releases, evaporation,
diversions, outflow to groundwater

MODFLOW LAK Setup

- DamLeakage_CubicFeetperMonth and EnvironmentalFlows_CubicFeetperMonth update the WITHDRAW tab.
- Lake Shastina and Lake Grass runoff are updated in lake runoff tabs; RUNOFF tab values feed LAK runoff terms, which are generated by createSFR_v4.py
- Write_LAKE_withdrawal_LakeRunoff_Grass_PrecipET.py updates Base.tpl and writes LAK.tpl.
- For stress period 2 and beyond, the script updates the 3rd boundary term with Total_SURO_IFWO_m3_per_day and the 4th boundary term with Total_DAM_ENVIRON_m3_per_day.

MODFLOW DRN + SFR package Output to LSPC

MODFLOW Spring and Shallow Groundwater Discharge



SFR

- Stream-groundwater interaction simulated with SFR, is provided to LSPC. This flow component includes baseflow and spring flow, i.e., AGWO.

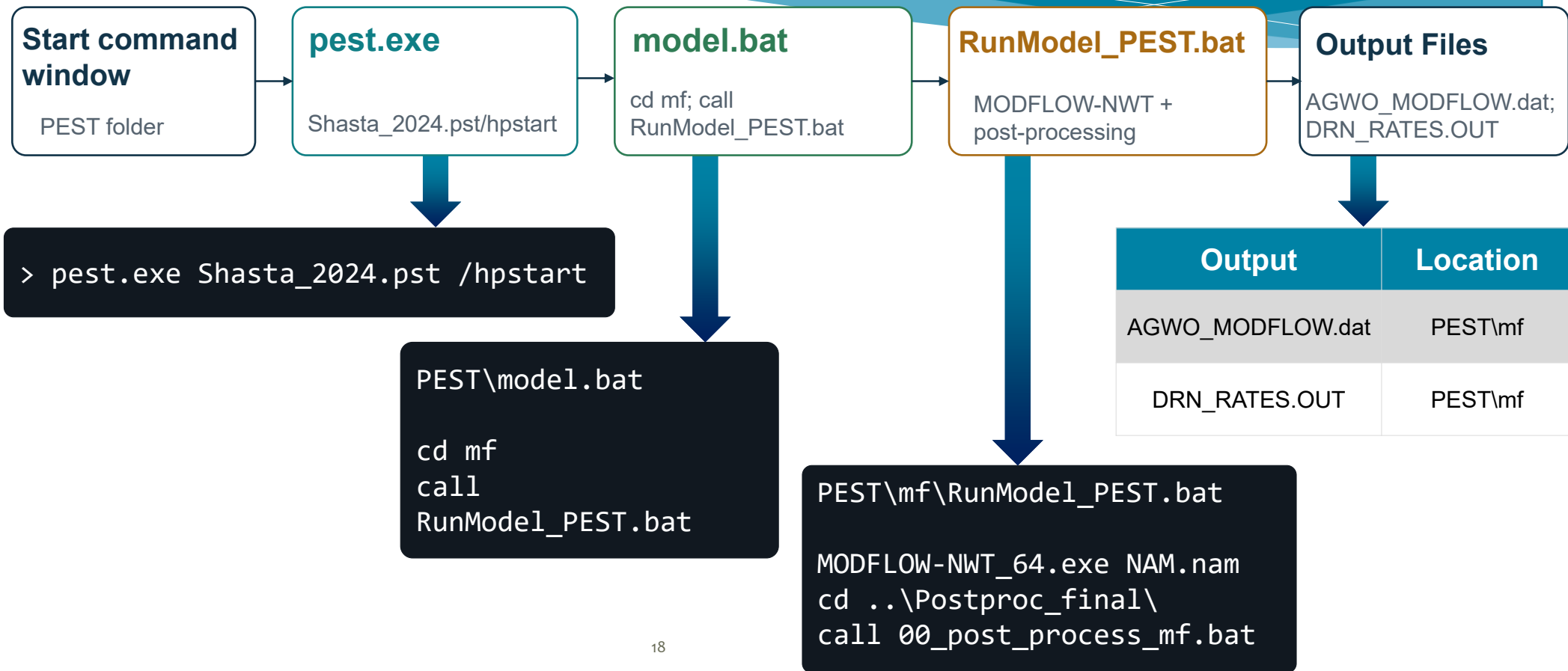
DRN

- DRN package represents known spring flow and shallow groundwater discharge.
- Where springs are far from reaches, DRN simulates the spring flow.
- DRN flow terms are provided to LSPC for routing to streams.

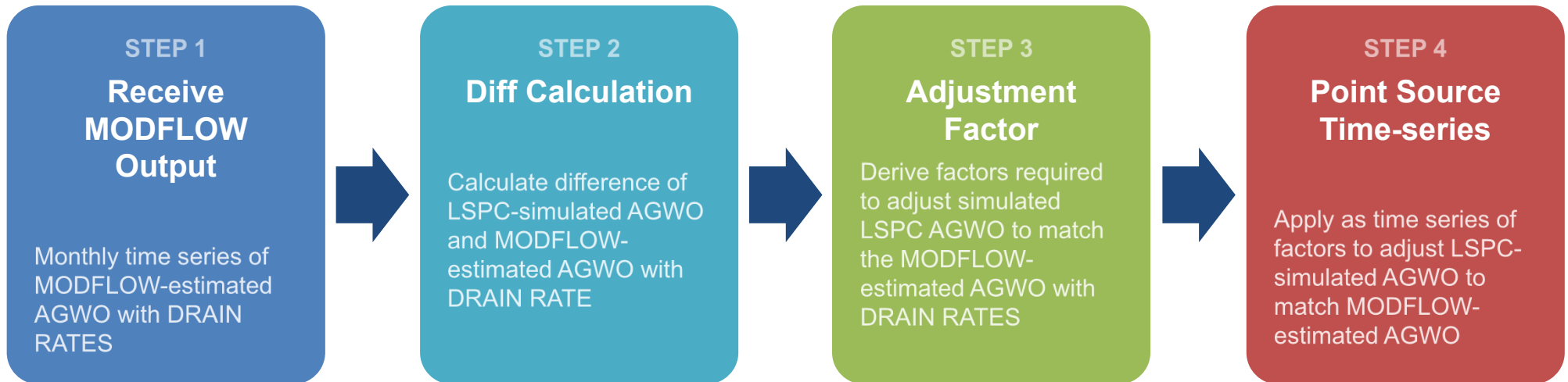
Reference Files for Pre- and Post-processing For MODFLOW

Source	Information
README.txt	Folder structure, package update workflow, run command, return files
README_Scenario.txt	Scenario 1 unimpaired-flow assumptions
preprocessor_for_MF/update_RCH/addSStoRCH_1980.py	RCH reshape, trim, steady-state mean, MeanRCH.png
preprocessor_for_MF/update_WEL/write_wel_V4.py	WEL area weighting and pumping rate conversion
preprocessor_for_MF/update_SFR/.../createSFR_v4.py	SFR routing, special diversions, segment/reach template writing
preprocessor_for_MF/update_LAK/write_LAKE_withdrawal_LakeRunoff_Grass_PrecipET.py	LAK runoff and withdrawal template updates

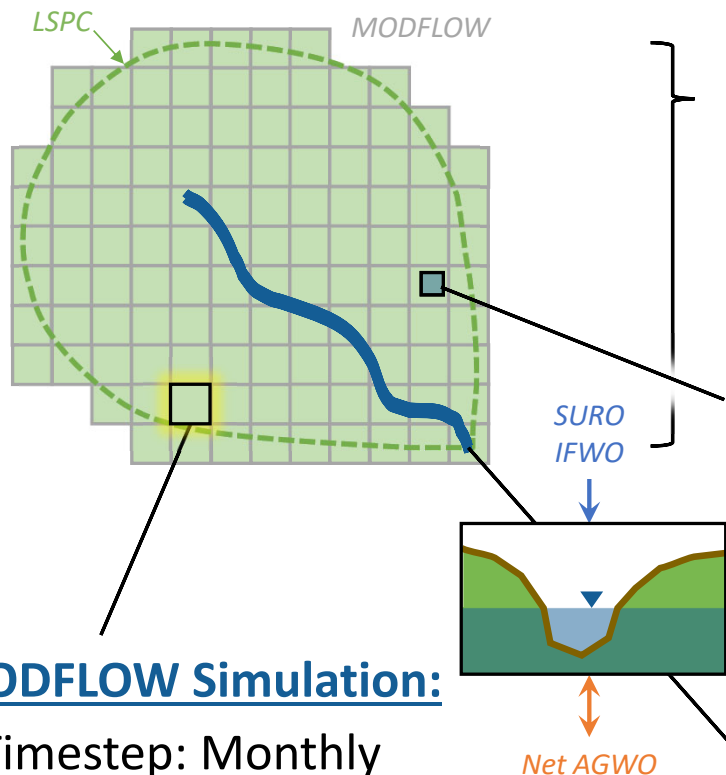
Running MODFLOW and Post-Processing



MODFLOW to LSPC



Python script: MODFLOW2LSPC_StepWise.py



LSPC Simulation (Hourly):

- Diversions + Irrigation + Return Flows
- Runoff (SURO) + Interflow (IFWO)
- **Groundwater Outflow (AGWO) iteratively adjusted w/ MODFLOW***

HRU Combinations:

- Resampled by MODFLOW grid
- **Groundwater Inflow (GWI)*** from LSPC aggregated monthly by MODFLOW grid (unique by grid)

MODFLOW Simulation:

- Timestep: Monthly
- Inflow: **GWI** * + Canal Leakage
- Withdrawals: Pumping
- **Net Outflow: AGWO** *

By Reach/Lake Segment:

- **AGWO "Deltas"** * derived to match monthly **MODFLOW Net Outflow**
- **AGWO** adjusted to close linkage

* MODFLOW Linkages: **Inflow (GWI)** and **Net Outflow (AGWO)**

Model Scenarios

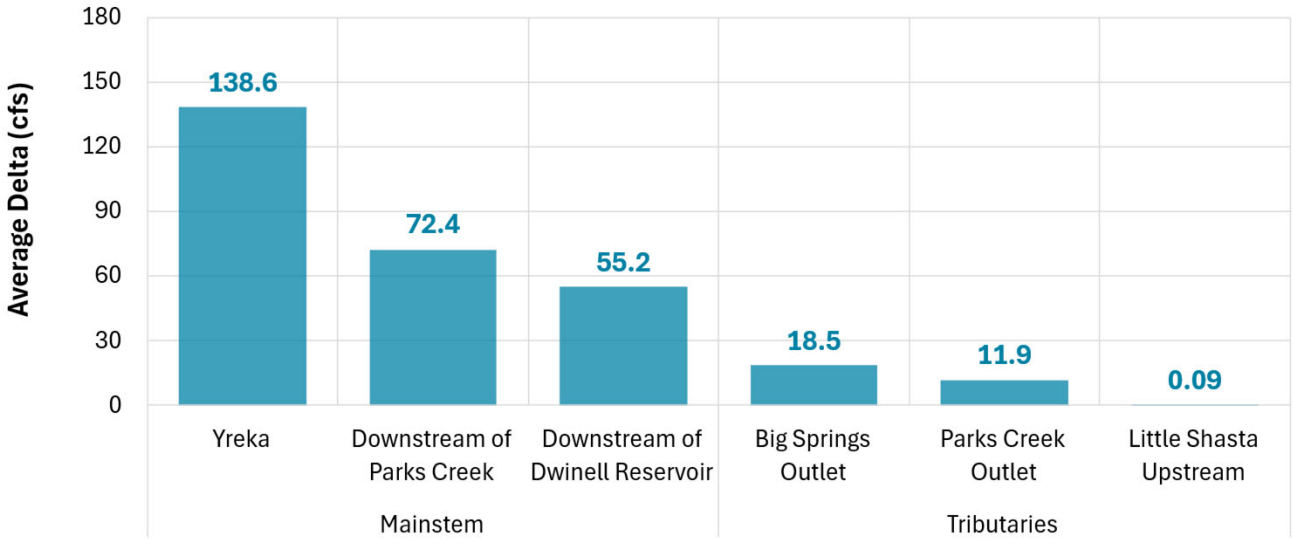
Base Case or Baseline Scenario

- Historical Climate Forcing Inputs
- Surface Diversions (including Parks Creek Diversion)
- Irrigation (both surface water and groundwater, canal leakage)
- Groundwater pumping (includes pacity and flying L wells)
- Reservoir storage (lake/dam seepage, environmental flows and overspill)
- Non-irrigation consumptive uses

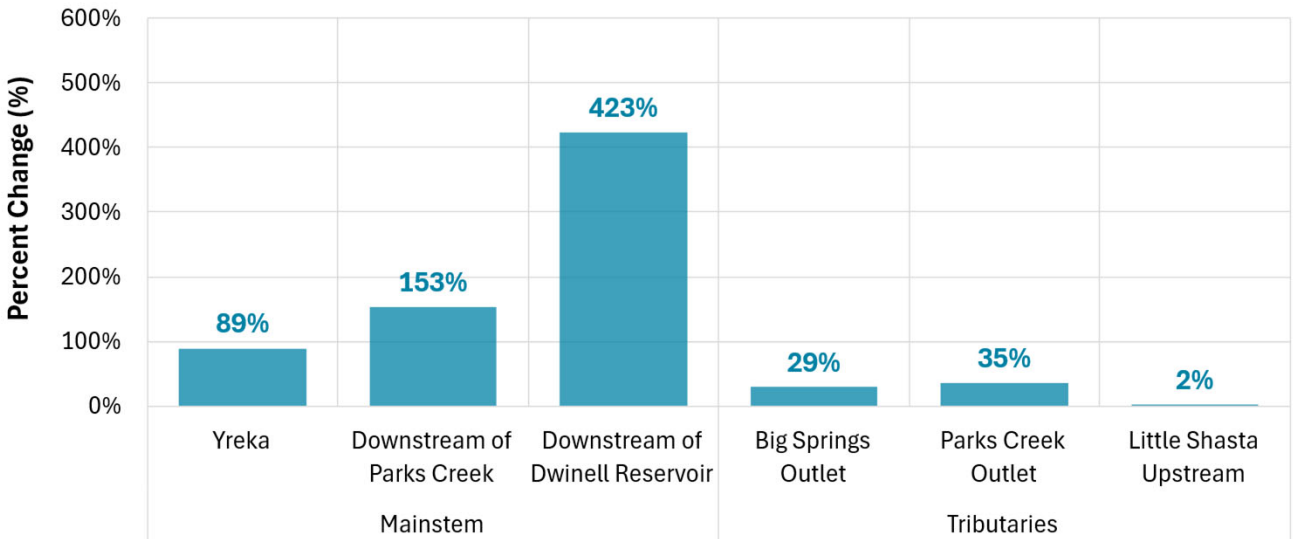
Unimpaired Scenario

- Using calibrated baseline model as a starting point
- Historical Climate Forcing Inputs
- Turn off everything else that listed above in 'Base case'.

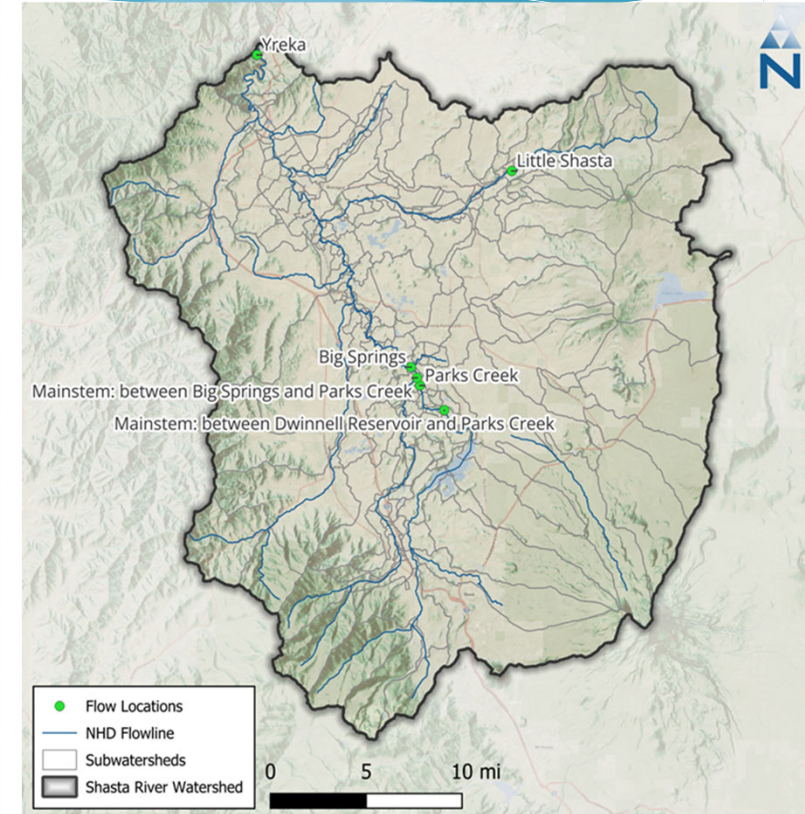
Delta Streamflow (Unimpaired - Baseline): Water years 1991-2023



Percent Change, (Unimpaired - Baseline)/Baseline: Water years 1991-2023



Unimpaired Flow vs. Baseline Flow Δ at Selected Outlets



Inputs for Model Execution

Items required to run the model

1. Model executable (LSPCModel_v6.33.exe)
2. Climate Forcings (Weather.zip)
3. Model Database:
 - Baseline scenario: SHASTA_BASELINE_Scenario_v633.accdb
 - Unimpaired scenario: SHASTA_UNIMPAIRED_Scenario_v633.accdb

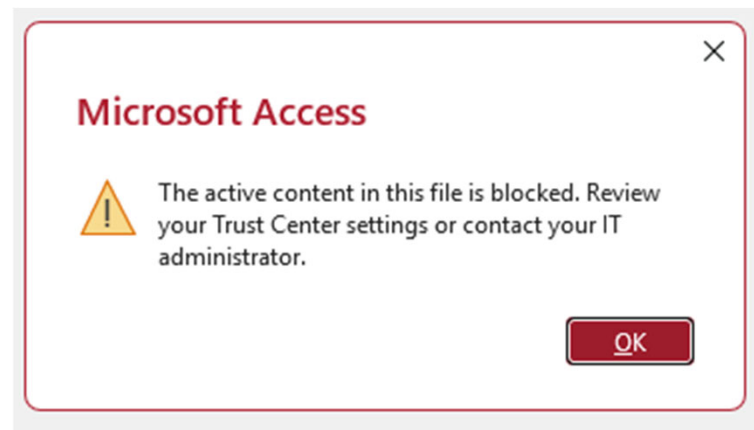
- LSPC is the **Primary Model**; MODFLOW linkage updates AGWO in LSPC
- The “Baseline” and “Unimpaired” scenario results presented in the report are based on the coupled LSPC-MODFLOW model
- Simulated **Groundwater Levels** are the only unique MODFLOW outputs

Instructions for Model Execution

1: Unzip the "Weather.zip" folder.

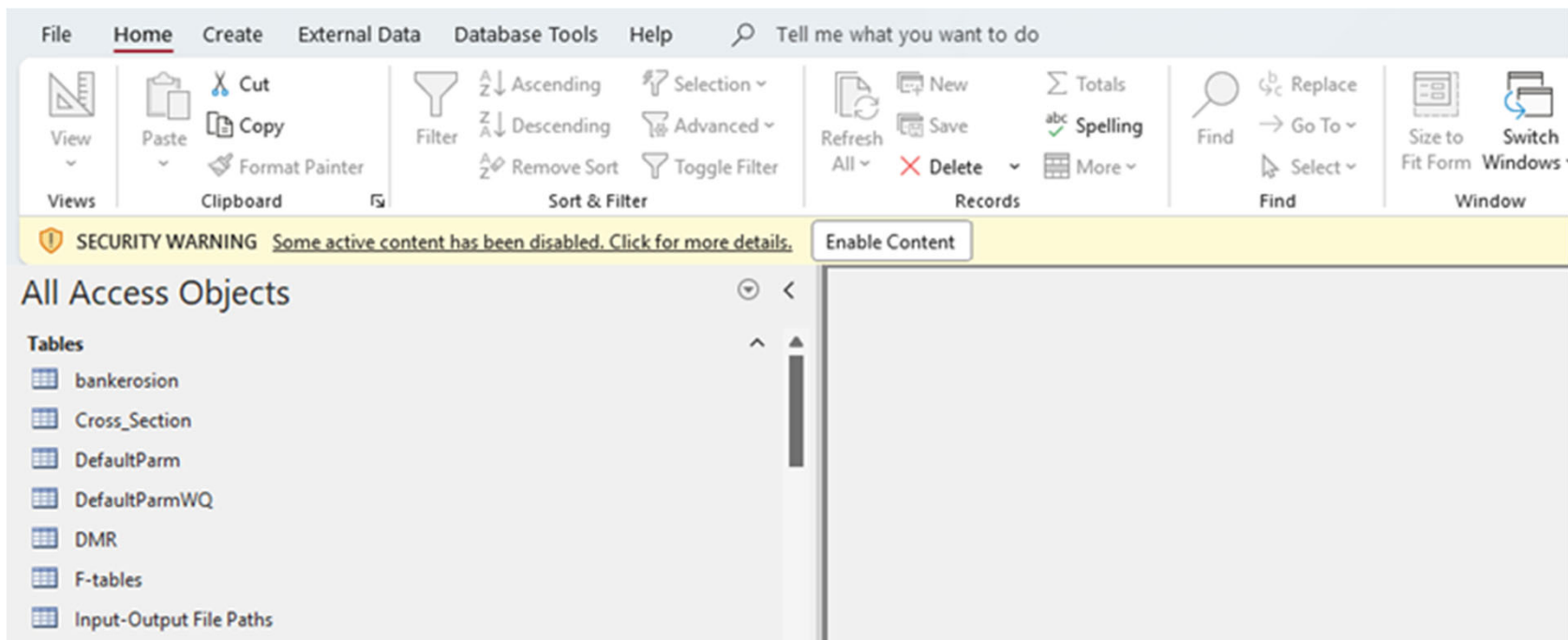
2: Update the paths for the weather and output files in the model databases.

- Open the Model Database in Microsoft Access.
- Depending on your Microsoft/Windows settings, you may see a pop-up window (as shown below). If prompted, click 'OK' to proceed.



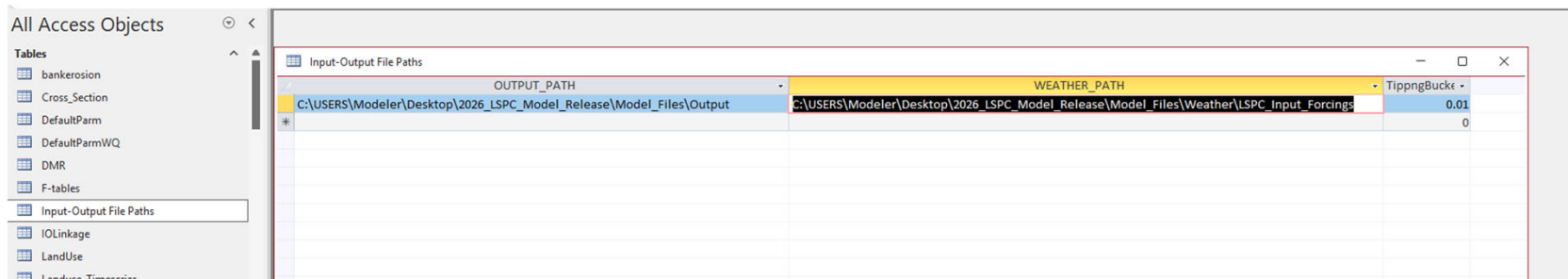
Instructions for Model Execution

- If macros are not enabled, a security warning may appear. In such cases, please select "Enable Content" to proceed.



Instructions for Model Execution

- Go to the "Input-Output File Paths" table as illustrated below.

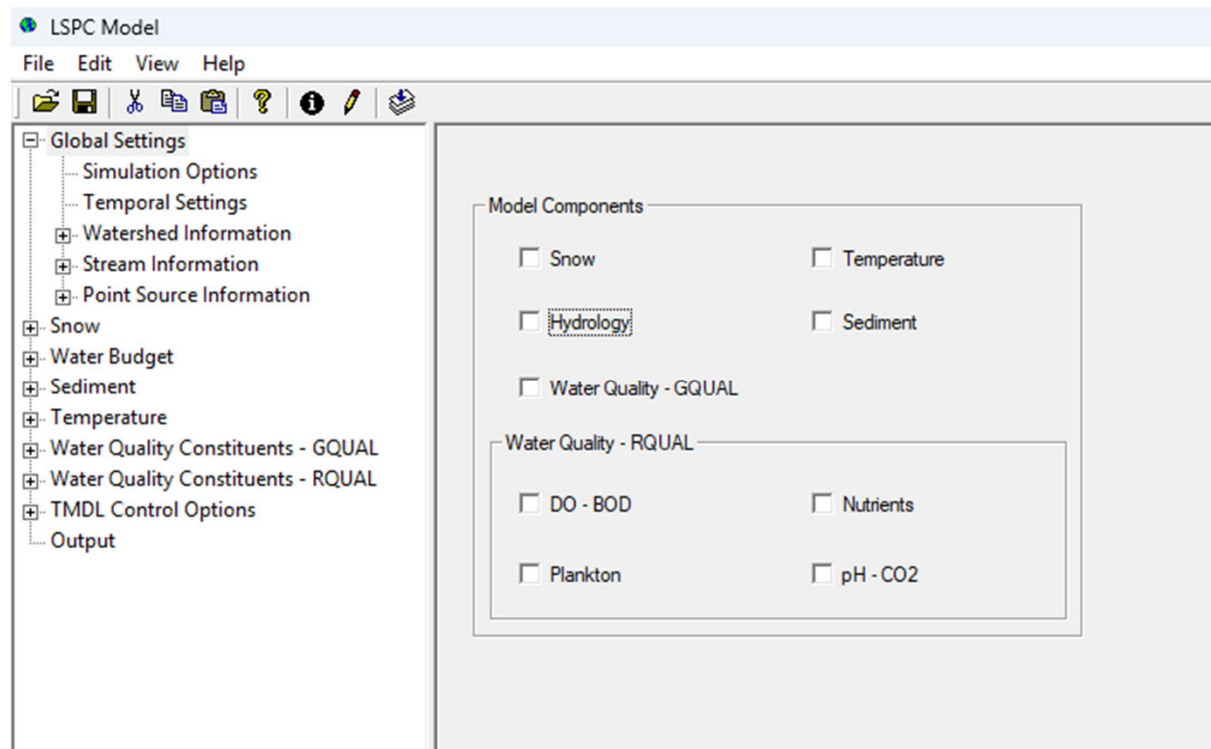


OUTPUT_PATH	WEATHER_PATH	TipngBucke
C:\USERS\Modeler\Desktop\2026_LSPC_Model_Release\Model_Files\Output	C:\USERS\Modeler\Desktop\2026_LSPC_Model_Release\Model_Files\Weather\LSPC_Input_Forcing	0.01
*		0

- Modify the "OUTPUT_PATH" and "WEATHER_PATH" columns in the table:
OUTPUT_PATH: Enter the location where the model output is to be stored.
WEATHER_PATH: Specify the directory of the unzipped weather folder.
(Recommended: Ensure that these file paths do not include any spaces.)
- Exit the Microsoft database.

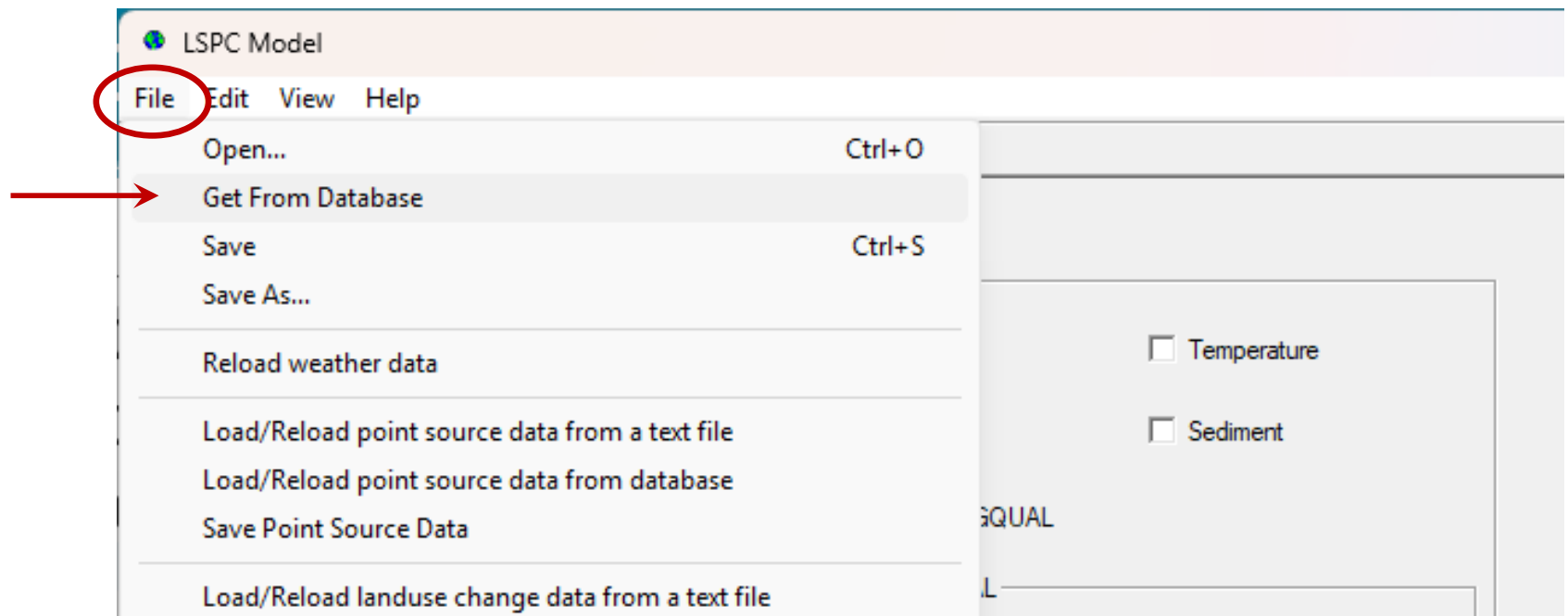
Instructions for Model Execution

- Double-click “LSPCModel_v6.33.exe” to open the program window



Instructions for Model Execution

- Click on the “File” tab in the upper-left corner of the window, then select “Get From Database.” A new window will appear where you can choose the database. Find the folder containing the updated database from the previous steps and click “Open.”



Instructions for Model Execution

- Next, a window will display the Model options. These may differ depending on the scenario and should not be modified—simply click ‘OK’.

Irrigation is turned off

The screenshot shows the 'Option Selection' dialog box with the following options:

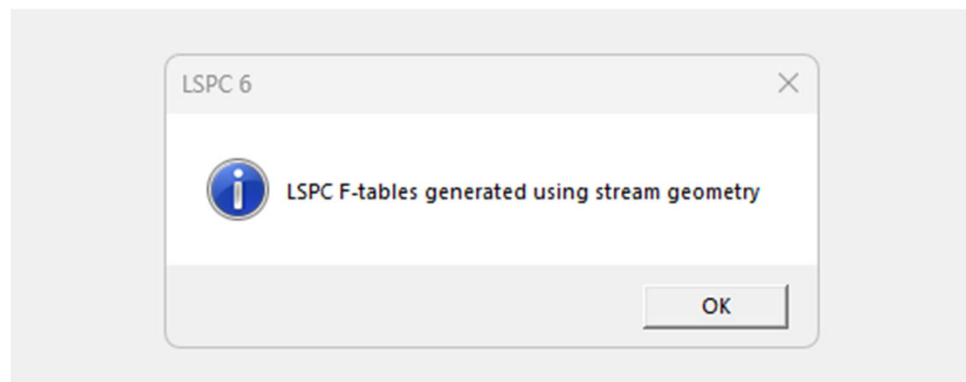
- Hydrology Controls:** Hydrology, Snow, Temperature
- Irrigation Controls:** Irrigation (circled in red), Monthly ETC, Constant PET
- Sediment Controls:** Sediment, Monthly cover, Monthly NVSI, Stream BER
- Water Quality Controls:** GQUAL, Nutrients, DO - BOD, Plankton, pH - Carbon
- Monthly Hydrology Controls:** Interception storage capacity (vcsfg), Upper zone nominal storage (vuzfg), MANNING'S N for the overland flow plane (vnnfg), Interflow inflow parameter (vifwfg), Interflow recession constant (vircfg), Lower zone evapotranspiration parameter (vlefg), Ftable conversion factor (convf)
- Monthly Water Quality Controls:** Accumulation, Surface flow concentration, Interflow concentration, Groundwater concentration, Atm. dry deposition on land, Atm. wet deposition on land, Atm. dry deposition on reach, Atm. wet deposition on reach
- Monthly Soil Temperature Controls:** Surface flow temperature, Interflow temperature, Ground water temperature
- Monthly DO CO2 Controls:** DO concentration in interflow, CO2 concentration in interflow, DO concentration in ground water, CO2 concentration in ground water

Buttons: OK, Cancel

This is the screen grab for Unimpaired Scenario

Instructions for Model Execution

- Additional dialog boxes related to F-Tables may appear. Simply click 'OK' when prompted.



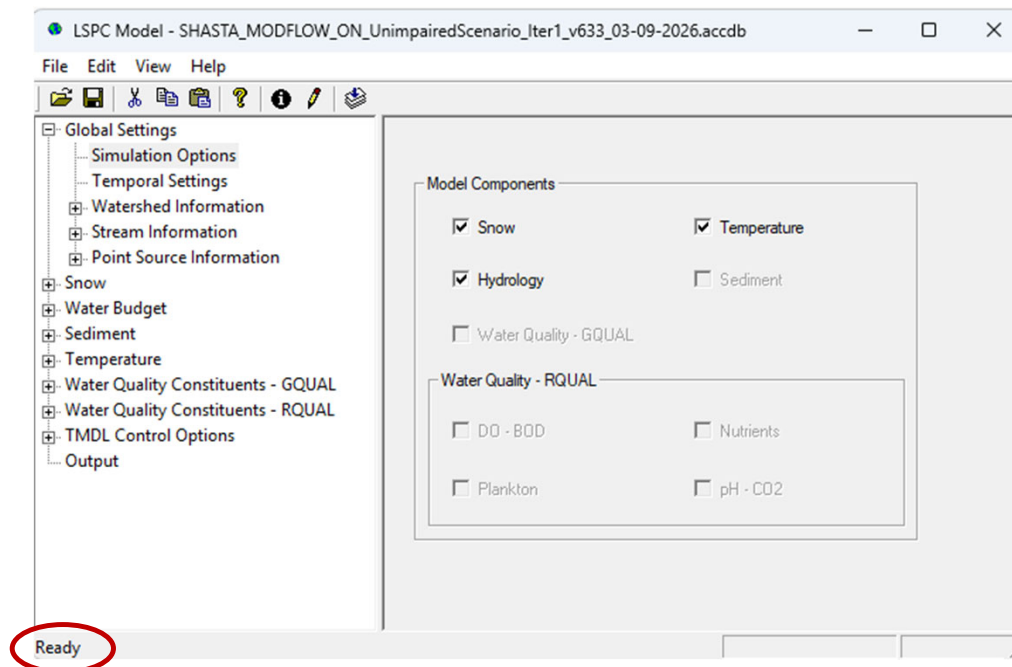
This is the
screen grab for
Unimpaired
Scenario

*(FTABLE geometry for
Dwinell Reservoir has
been removed)*

Note that the message in these dialog boxes may vary depending on your model options, so it might not match the example shown above.

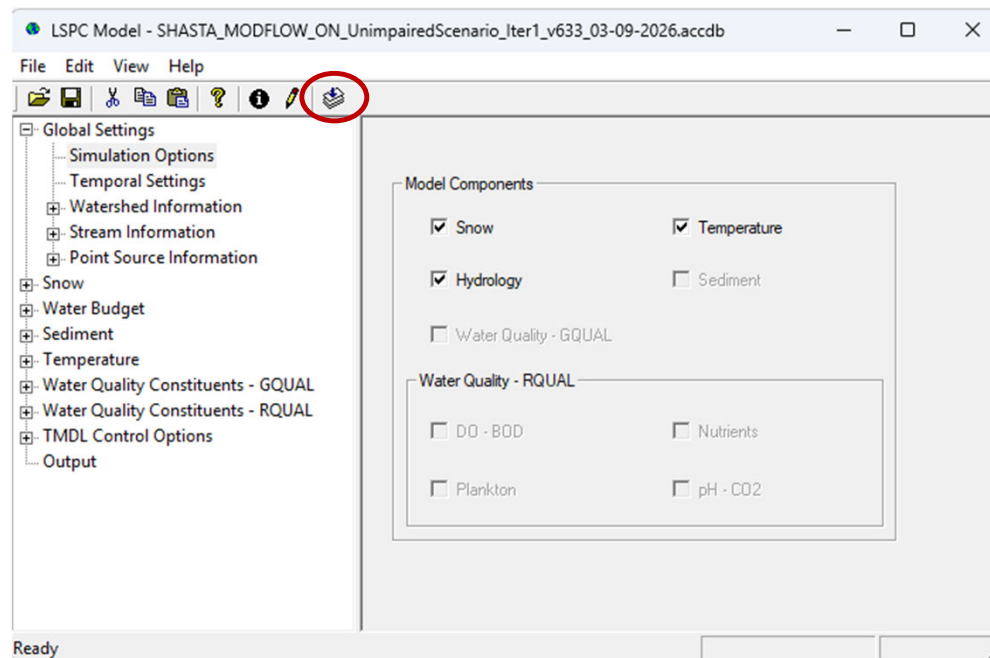
Instructions for Model Execution

- When the database loads successfully, you'll notice "Ready" displayed in the lower-left corner of the model screen, and the main area will show checked boxes under 'Model Components,' as illustrated in the figure below:



Instructions for Model Execution

- Click the “Run the Model” button



Sample Output

1. .OUT files

- Generated for each subwatershed (configured by default at a daily time step)
- A header listing all output variables is included

2. Summary Files

- Landuse
- Stream
- WaterBudget

```
-----  
TT LSPC -- Loading Simulation Program, C++  
TT Version 6.33 (64-bit) - February 2026  
TT  
TT Created through code updates by:  
TT Paradigm Environmental, Inc.  
TT San Diego, California, USA  
TT www.paradigmh2o.com  
TT  
TT Based upon LSPC version 5.0 (Mar 2018), originally developed by :  
TT United States Environmental Protection Agency  
TT with support by Tetra Tech, Inc.  
TT https://github.com/USEPA/LSPC-Loading-Simulation-Program  
TT  
-----  
TT LSPC MODEL OUTPUT FILE  
TT This output file was created at 08:26:18pm on 02/23/2026  
TT Time interval: 60 min      Output option: day  
TT Label  
TT PREC      precipitation (rain + snow) volume (in-acre/day)  
TT AIRTMP_MIN  minimum air temperature (degree F)  
TT AIRTMP_MAX  maximum air temperature (degree F)  
TT AIRTMP     air temperature (degree F)  
TT SNOTMP     snow temperature (degree F)  
TT SNOWF     precipitation (snow) volume (in-acre/day)  
TT RAINF     precipitation (rain) volume (in-acre/day)  
TT PRIN     rainfall entering snow pack (in-acre/day)  
TT MELT     snow melt from the snow pack (in-acre/day)  
TT SNOWE     evaporation from pack (in-acre/day)  
TT WYIELD    water yield from pack (in-acre/day)  
TT PACK     total contents of pack (water equiv) (in-acre/day)  
TT PACKF    frozen contents of pack, ie. snow + ice (water equiv) (in-acre/day)  
TT PACKW    liquid water in pack (in-acre/day)  
TT PACKI    ice in pack (water equiv) (in-acre/day)  
TT PDEPTH    pack depth (in-acre/day)  
TT CEPS     average volume of interception storage (in-acre)  
TT SURS     average volume of surface storage (in-acre)  
TT UZS     average volume of upper zone storage (in-acre)  
TT LZS     average volume of lower zone storage (in-acre)  
TT AGWS     average volume of groundwater storage (in-acre)  
TT SURO     surface outflow volume (in-acre/day)  
TT IFWO     interflow outflow volume (in-acre/day)  
TT AGWO     groundwater outflow volume (in-acre/day)  
TT PSIF     point source inflow (in-acre/day)  
TT PSWD     point source outflow (in-acre/day)  
TT PSDT     point source diverted inflow (in-acre/day)  
TT MODFLOW  modflow point source (in-acre/day)  
TT IRWD_AGWS irrigation withdrawal volume from the active groundwater storage (in-acre/day)  
TT IRWD     irrigation withdrawal volume including the IRWD_loss volume (in-acre/day)  
TT IRWD_loss loss of irrigation withdrawal from a reach through an irrigation canal system (in-acre/day)  
TT PERO     total outflow volume (SURO+IFWO+AGWO) (in-acre/day)
```

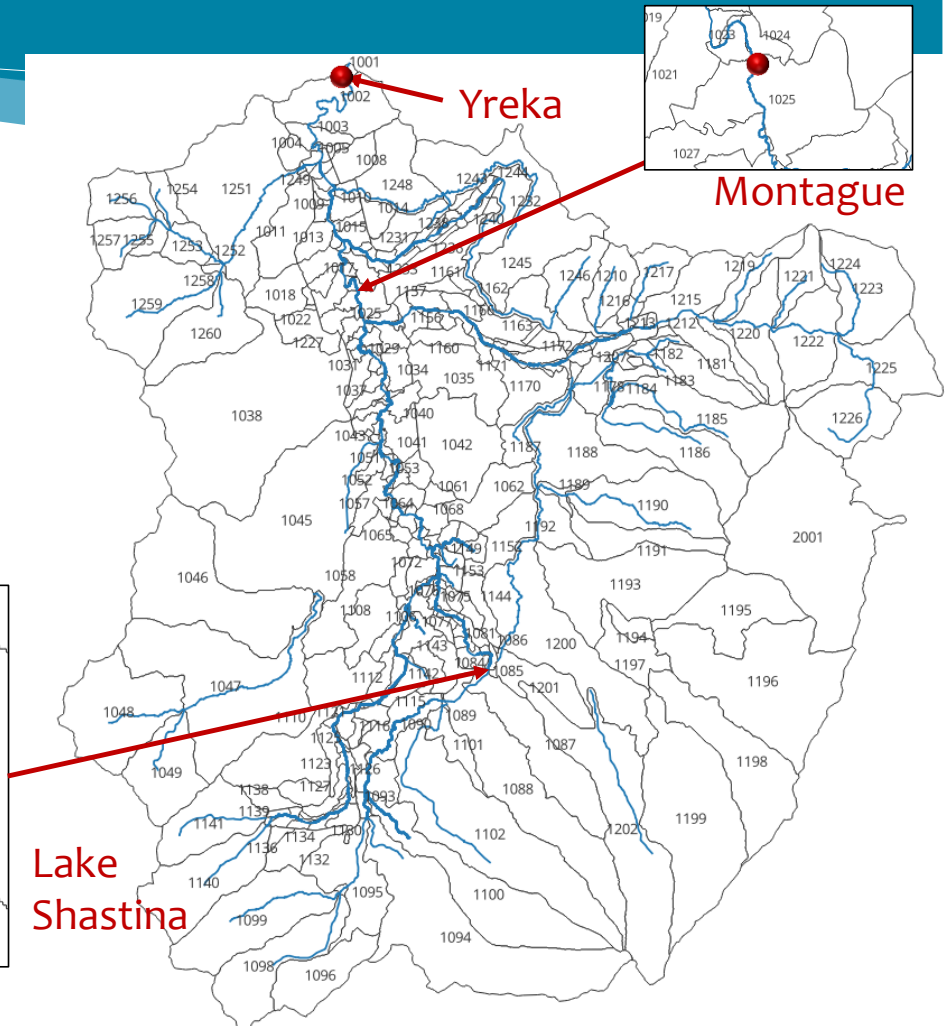
Sample Output: .OUT Files

.OUT files are generated for each sub-watershed

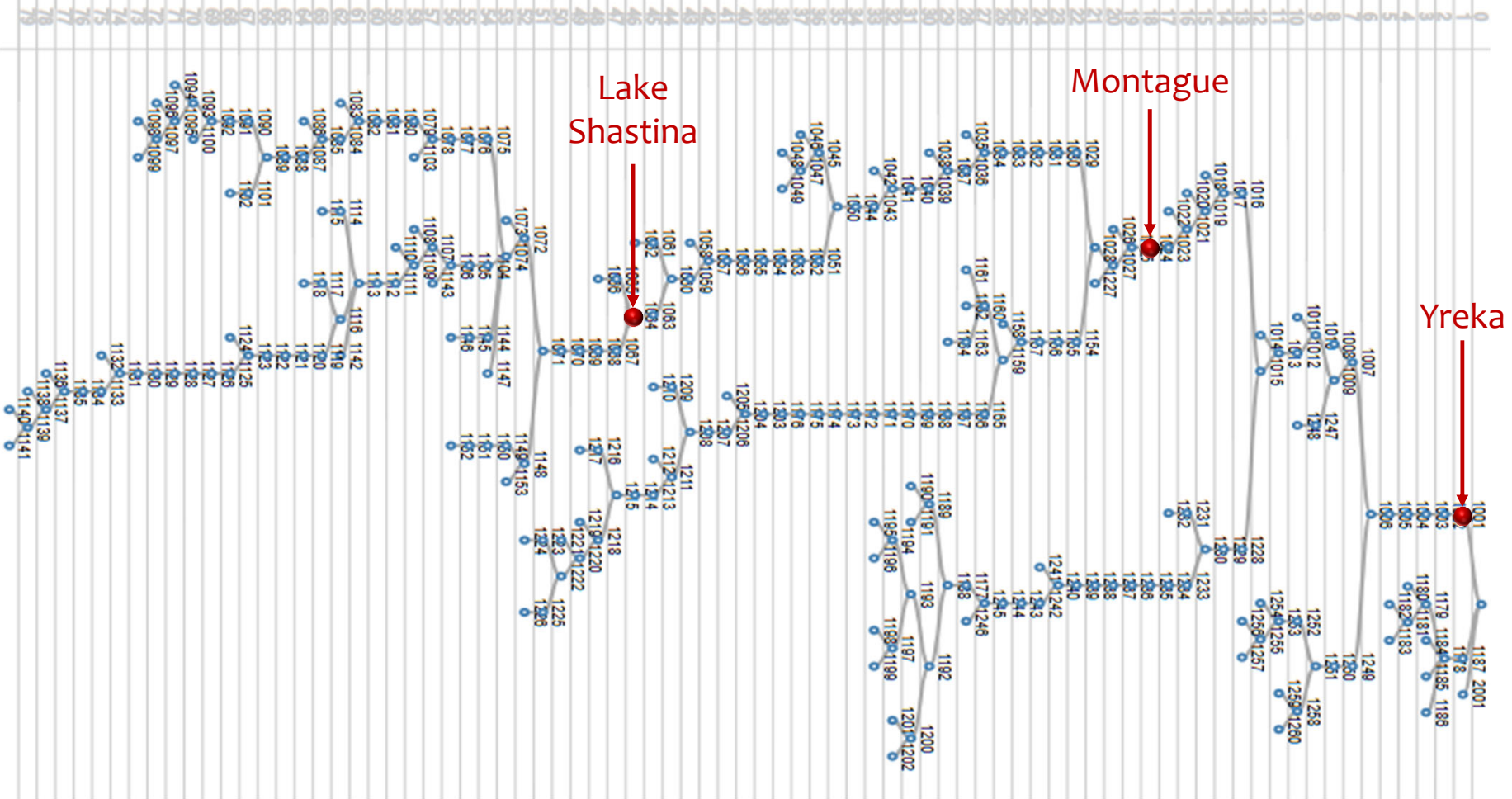
Yreka gage: 1002.out

Montague gage: 1025.out

Lake Shastina/Dwinnell Reservoir: 1087.out



Reach Network Schematic



System Requirements and Run Time

LSPC-MODFLOW Integrated Model

- Disk/storage space required: ~7.8 GB
- Simulation runtime: ~ 4- 6 hours
- Varies for different operating systems and scenarios
(Simulation period: 1/1/1981 – 09/30/2023)

MODFLOW Model

- Disk/storage space required: 1.2 GB
- Simulation runtime: 1 hour

LSPC-MODFLOW MODEL DOCUMENTATION

Author: [John Riverson; Ashish Kondal]
Organization: [Ulteig]
Date: [04/23/2026]
Contact: [john.riverson@ulteig.com; ashish.kondal@ulteig.com]

1. FOLDER CONTENT

The model directory structure is organized as follows:

```
/2026_04_LSPC-MODFLOW_Model_Release/Data_Processing|
├── README.txt # This documentation file
├── LSPC_to_MODFLOW/ # Data processing scripts and input files. Generating MODFLOW Inputs From LSPC Outputs.
│   ├── MODFLOW_Linkage_Inputs/ # LSPC to MODFLOW linkage/mapping files
│   │   └── [LSPC to MODFLOW Mapping data files]
│   ├── GWI_to_RCH.py # Script to generate RCH file
│   ├── water_balance_summary.py # Script to generate water balance summary file
│   └── AdditionalData.py # Script to generate additional csvs required for MODFLOW
├── MODFLOW_Model_Public_Release/ # MODFLOW model files
│   ├── README.txt # MODFLOW documentation file. Please read this for more details.
│   ├── PEST/ # Main PEST calibration and MODFLOW execution folder
│   │   ├── mf/ # MODFLOW input/output files
│   │   │   └── [MODFLOW data files]
│   │   ├── Postproc_final/ # Post-processing scripts and outputs
│   │   │   ├── *.tpl # PEST template files (DRN.tpl, LAK.tpl, Rch.tpl, etc.)
│   │   │   ├── *.ins # PEST instruction files (*.ins)
│   │   │   └── shasta_2024.* # PEST control and output files (.pst, .par, .rec, .res, etc.)
│   │   └── pest.exe # PEST executable
│   ├── preprocessor_for_ME/ # Preprocessing scripts for MODFLOW inputs
│   │   ├── update_LAK/ # Lake package update scripts
│   │   ├── update_RCH/ # Recharge package update scripts
│   │   ├── update_SER/ # Stream Flow Routing package update scripts
│   │   └── update_WEL/ # Well package update scripts
├── MODFLOW_to_LSPC/ # Data processing scripts and input files. Generating LSPC Inputs From MODFLOW Outputs.
│   ├── MODFLOW2LSPC_StepWise.py # Script to generate LSPC point source input from MODFLOW outputs
│   └── [Template data files]
└── ../Model_Files # Final Model files (this folder is in the same parent directory as the 'Data_Processing' folder)
    └── README.docx # Read the "README.docx" for more details
```

README
file for
Data
Processing
Steps

README
file for
model
execution
steps

Stay Informed

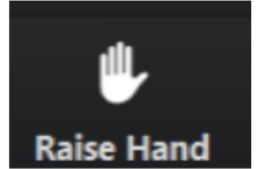
Additional Information

- State Water Board's Scott River and Shasta River Watersheds Emergency Regulation website
 - https://www.waterboards.ca.gov/drought/scott_shasta_rivers/

How to Receive Email Updates

- To receive email updates related to Scott and Shasta regulation and flow efforts visit:
 - https://www.waterboards.ca.gov/resources/email_subscriptions/
 - Sign up under “State Water Resources Control Board” and “Water Rights” for the “Scott-Shasta Drought & Flow Efforts” email subscription list

How to Participate



1. Provide questions:

Raise your hand (click on react tab) to be placed in the speaker queue. When it is your turn, the facilitator will call your name and invite you to unmute yourself. **Please introduce yourself with your name and title/affiliation.**

Telephone callers:

- Press *9 to raise hand
- Press *6 to unmute when prompted

Submit questions in Chat

- Send questions in chat directly to Dan Shultz

2. Email written comments to:

ScottShastaFlows@waterboards.ca.gov



(written comments due June 12th)

Email comments to: ScottShastaFlows@waterboards.ca.gov