GROUNDWATER MODELING – A PRIMER FOR THE COMMUNITY

Public Orientation Session #4

Presenter: Cameron Tana, HydroMetrics Water Resources Inc.

SANTA CRUZ MID-COUNTY
GROUNDWATER AGENCY

Thursday, December 7, 2017

Objectives and Outline

Objectives

1. *Provide introduction to groundwater models*
2. *Describe how groundwater model will be used for GSP*
3. *Describe model of the Mid-County Basin*
4. *Outline plans for simulating future groundwater management in the Mid-County Basin*

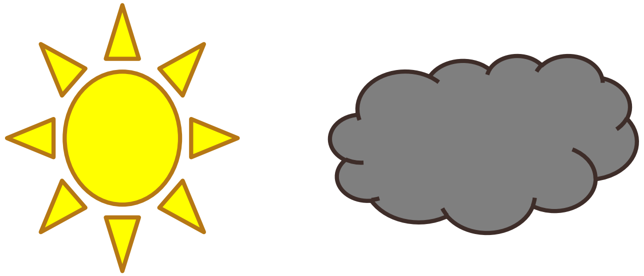
Outline

- Introduction
  - Groundwater Flow Modeling
  - Uses of Model for GSP
  - Modeling Platform for Mid-County Basin
- Modeling Mid-County Basin Climate and Watershed and Estimating Water Use
- Modeling Mid-County Basin Groundwater Flow
- Simulating Future Projects, Actions, and Climate Change

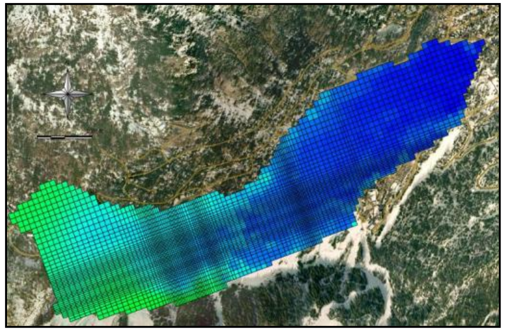
Introduction

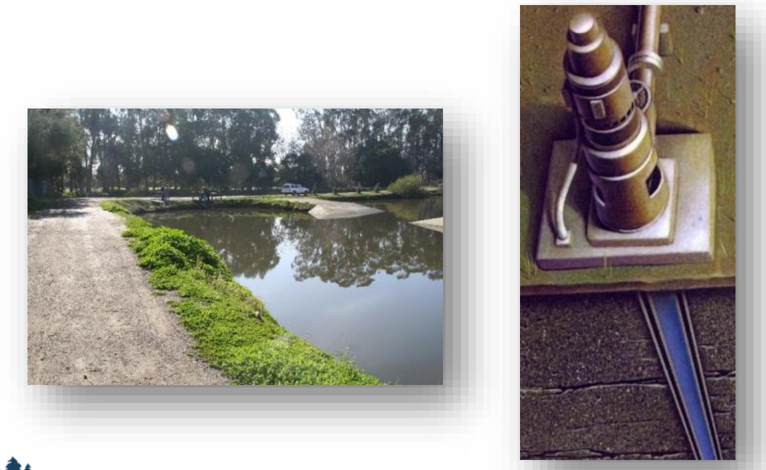
What Groundwater Flow Models Do

Climate

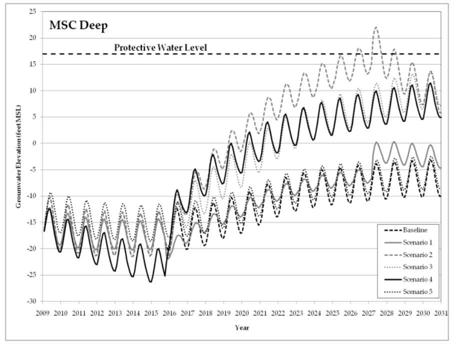


Model

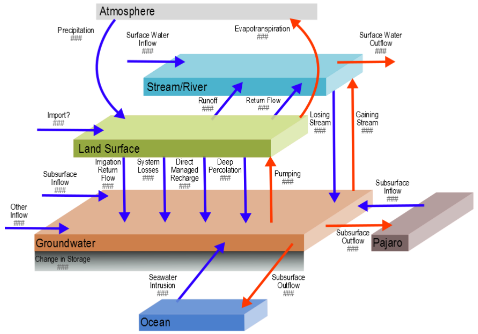




Use and Management



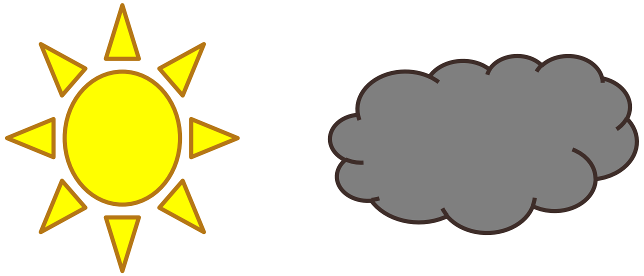
Levels



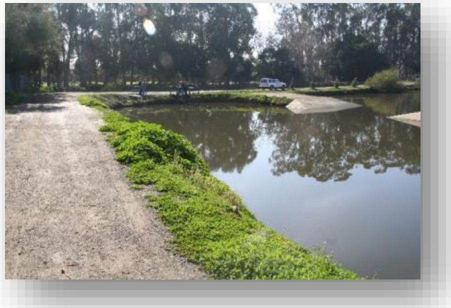
Flows

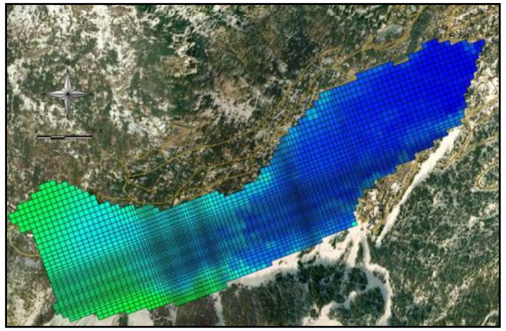
Tracking

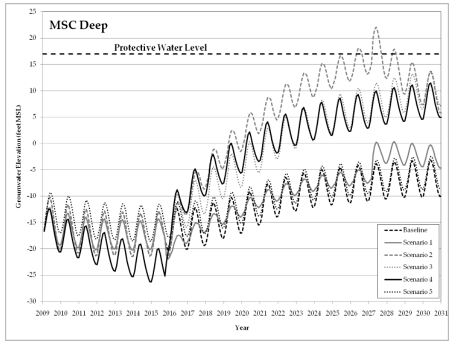
Why Use Models for Planning

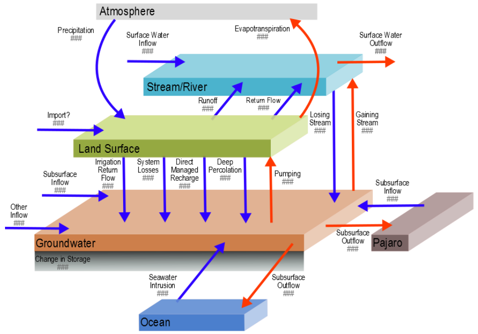


Future Changes









Model

Projections

Inform

Plans

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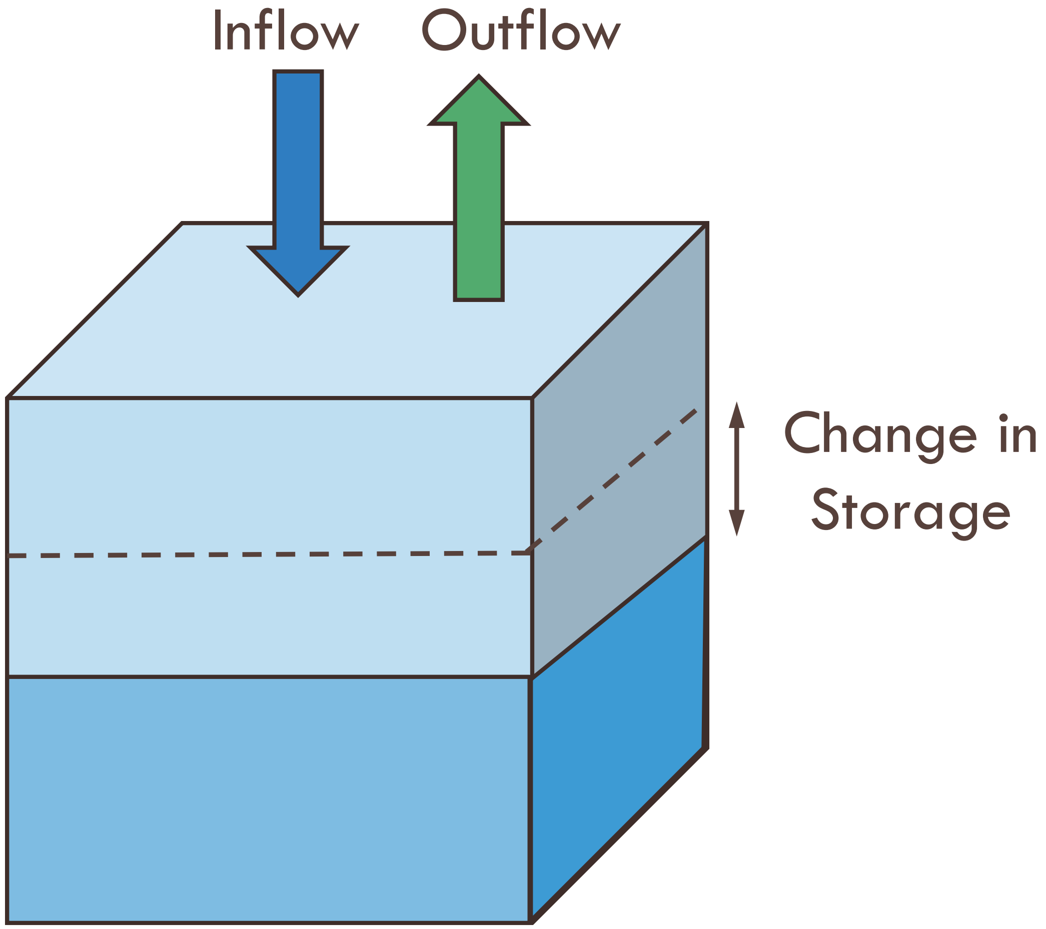
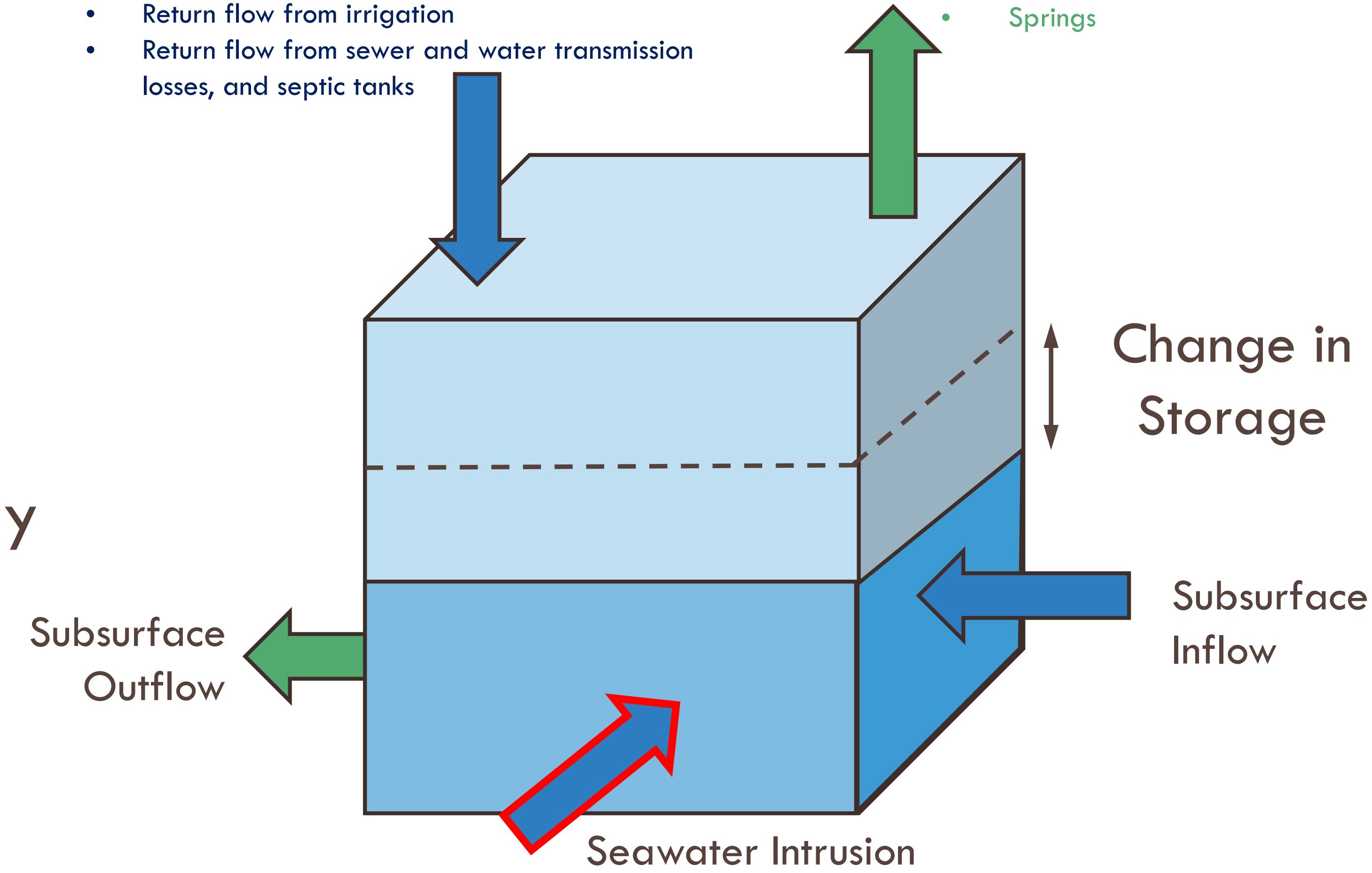
How Models Calculate Outputs from Inputs

- Models Calculate Water Budgets
- Inflow – Outflow = Change of Storage
- Change of Storage ~ Change in Groundwater Level



Why Model with a Computer, Part 1

- Many flows to track
- Some flows are inter-dependent
- Difficult and complex to estimate all items accurately



Inflow (Intermittent)

- Direct percolation of precipitation
- Streambed percolation
- Managed aquifer recharge
- Return flow from irrigation
- Return flow from sewer and water transmission losses, and septic tanks

Outflow (Continuous)

- Evapotranspiration
- Well pumping
- Streams and Creeks
- Springs

Change in Storage

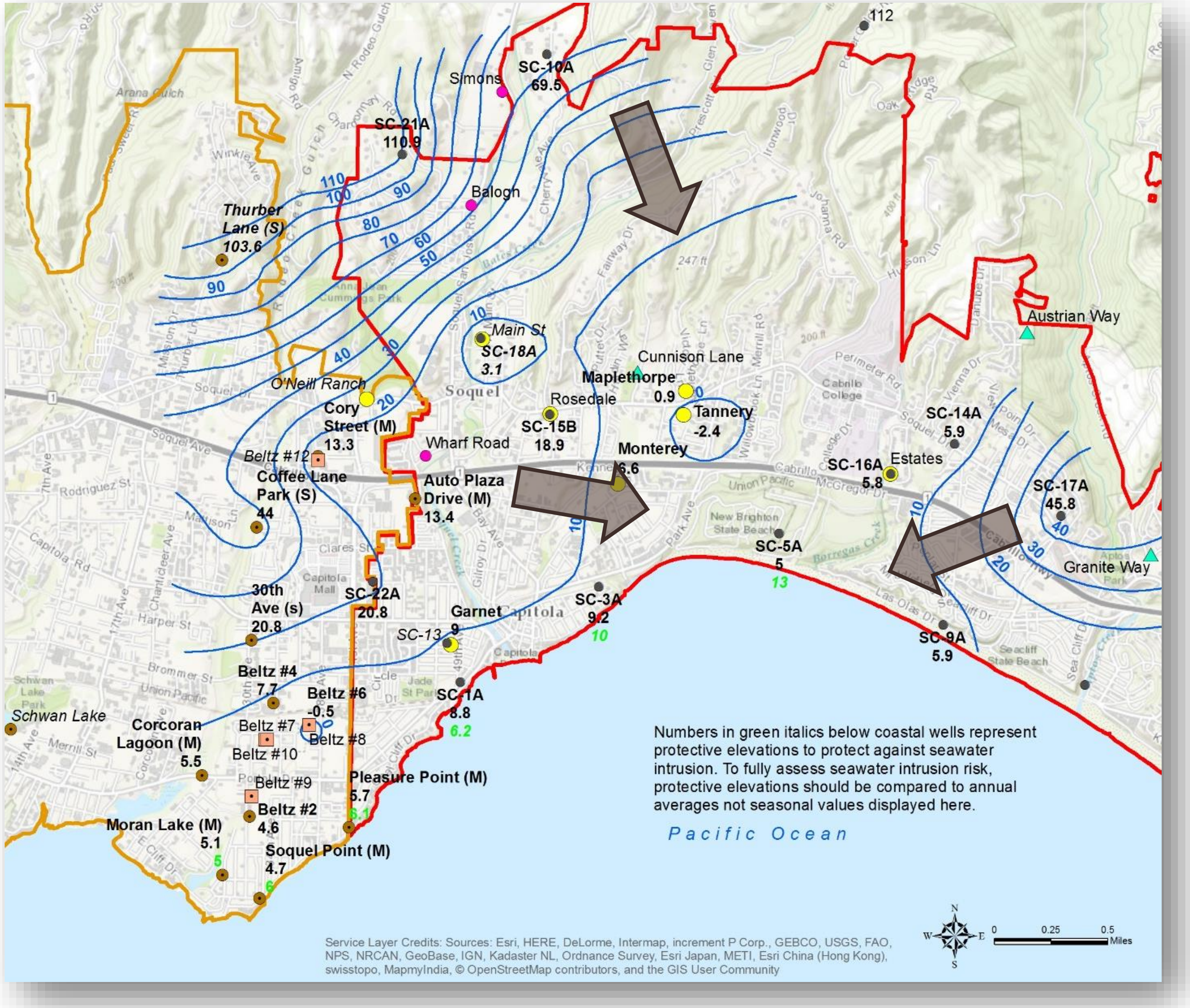
Subsurface Inflow

Subsurface Outflow

Seawater Intrusion

Why Model with a Computer, Part 2

- Water flows from high to low elevations
- Models represent groundwater flow with equations
- Numerical models usually used for basinwide models
  - Large area
  - Multiple aquifers (3D)
  - Many equations



Numbers in green italics below coastal wells represent protective elevations to protect against seawater intrusion. To fully assess seawater intrusion risk, protective elevations should be compared to annual averages not seasonal values displayed here.

Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Models Solve Flow Equations Like Darcy's Law

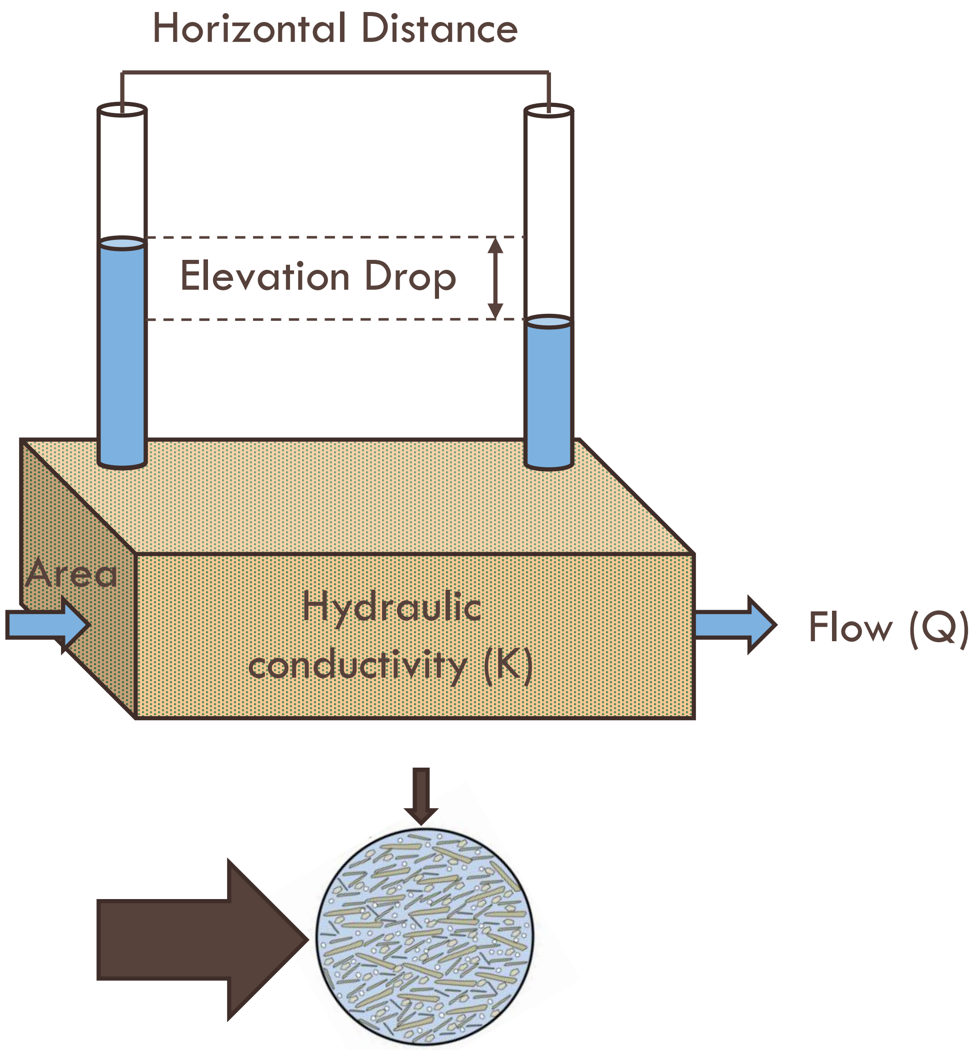
Groundwater Flow (Q)

depends on:

1. Hydraulic conductivity (K)
2. Hydraulic gradient (i)
3. Cross-sectional area

$$Q = KiA$$

4. For 3-D flow, models apply equations horizontally and vertically



Flow Equations Include Storage Properties

- Storage – how much water can be released from the pores of an aquifer
- Storage properties help describe how groundwater levels change over <u>time</u>
- Specific Yield is the amount of water that drains from an unconfined aquifer
- Specific storage/storativity is amount of water released with pressure changes in a confined aquifer

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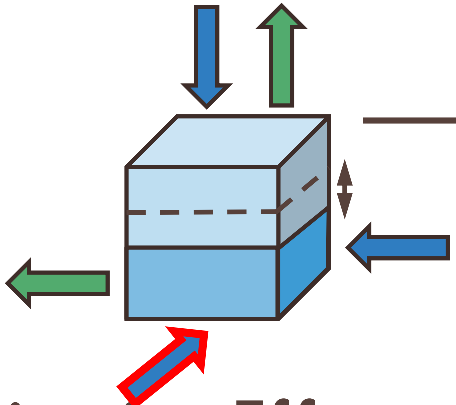
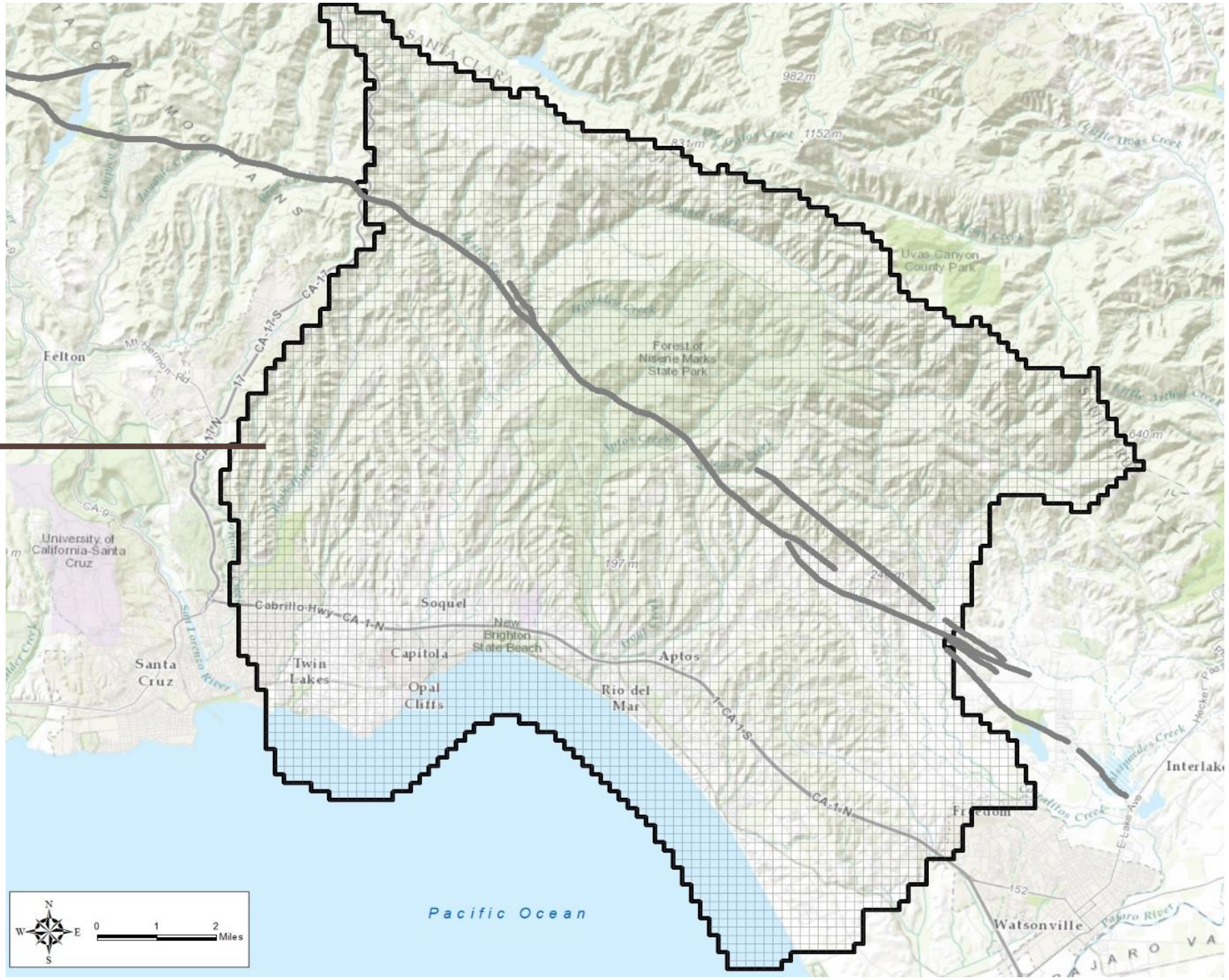
How a Numerical Model Represents Space

- Grid or mesh
- Calculations at each cell
  - Water Budget
  - Flow equations between cells





- Discretization Effects
  - Model run time
  - What results can be used for

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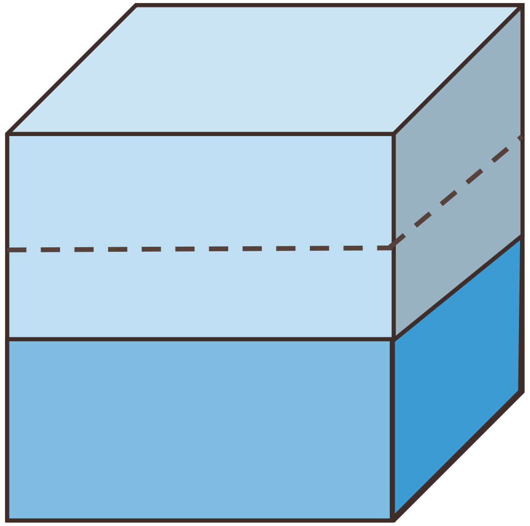
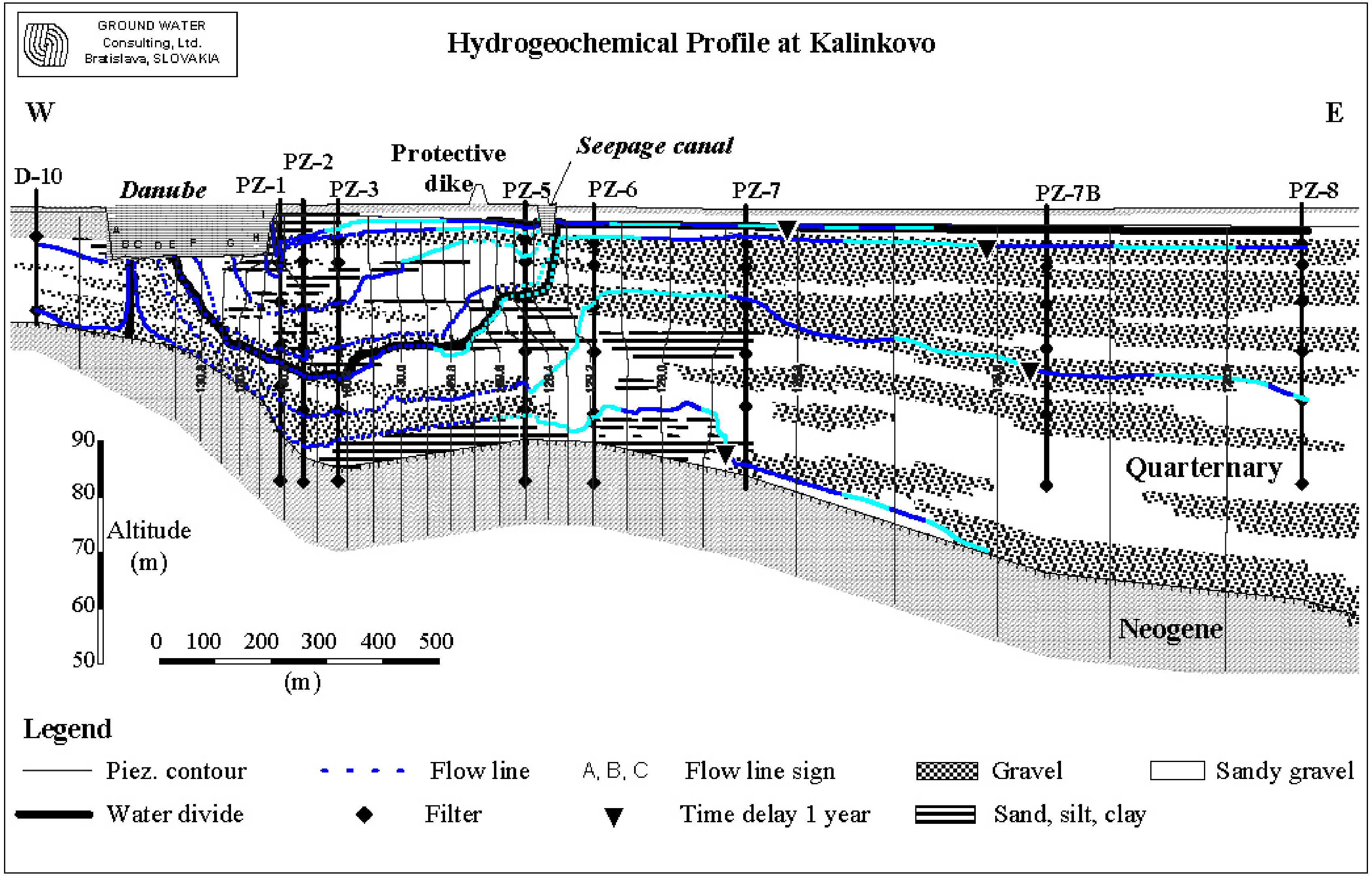
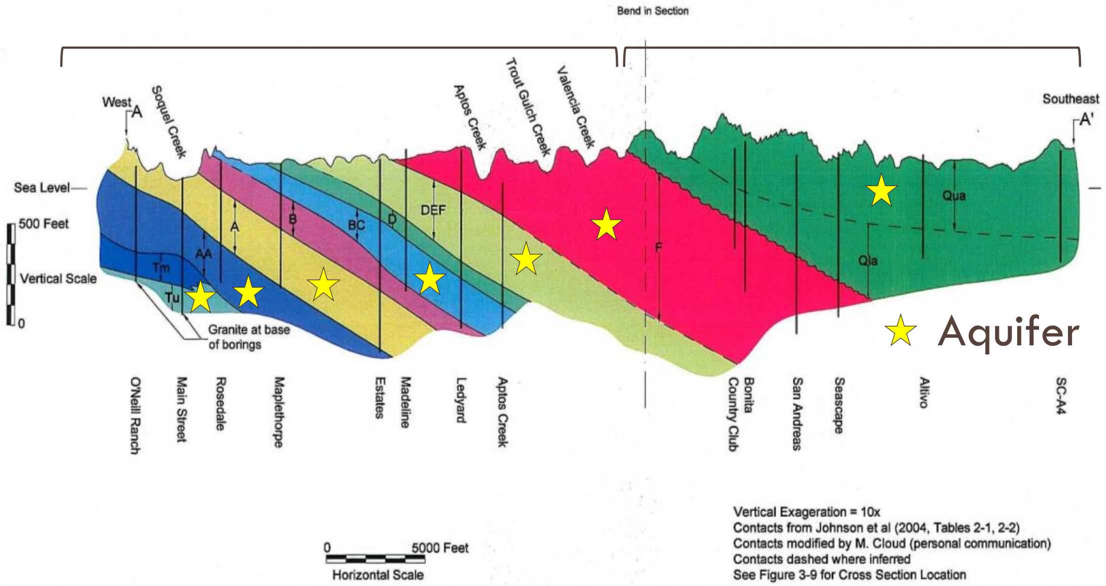
Numerical Models Can Include Lateral Variability

Each model cell can have different hydraulic conductivity and storage properties

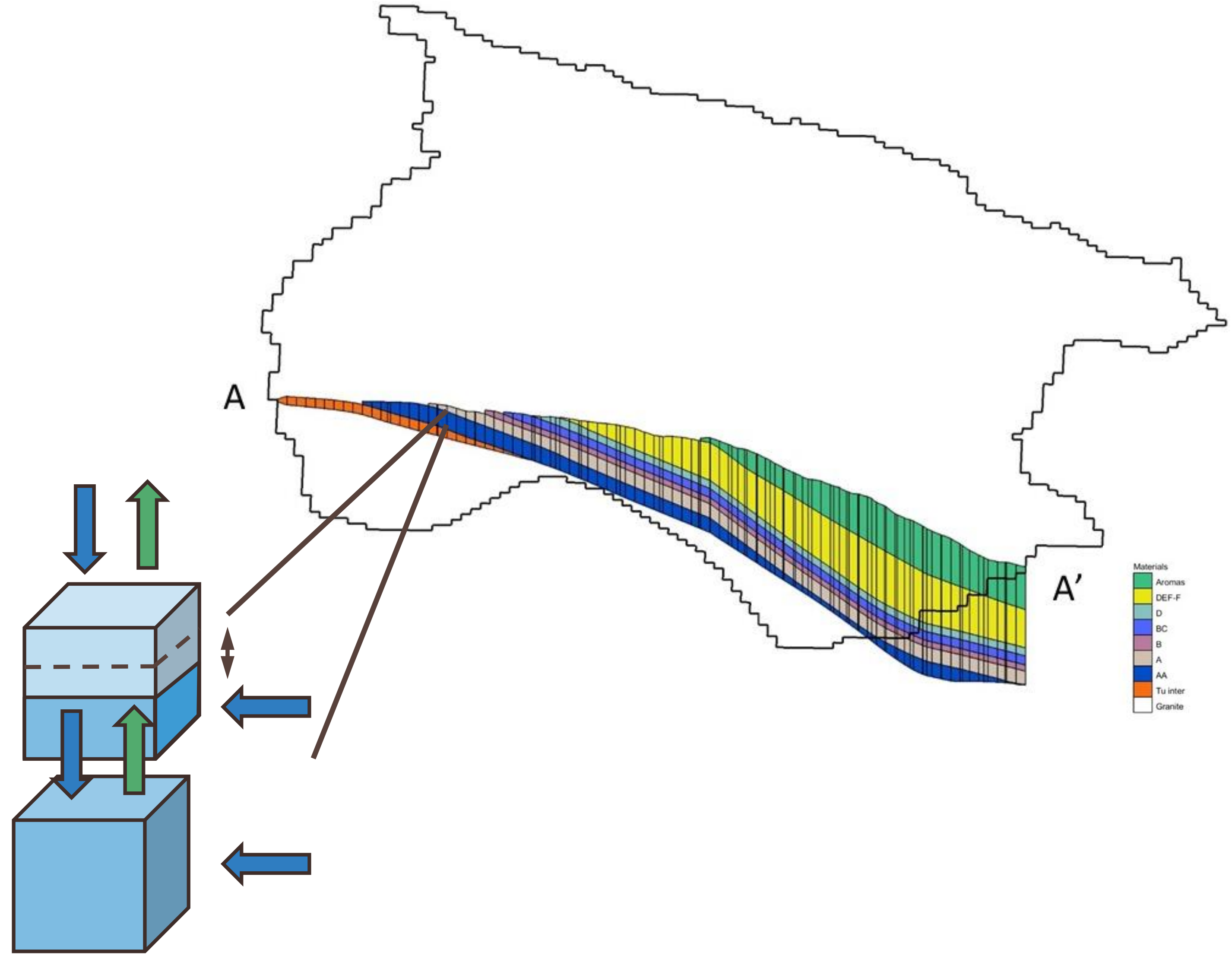




Aquifers and Aquitards Modeled as Layers

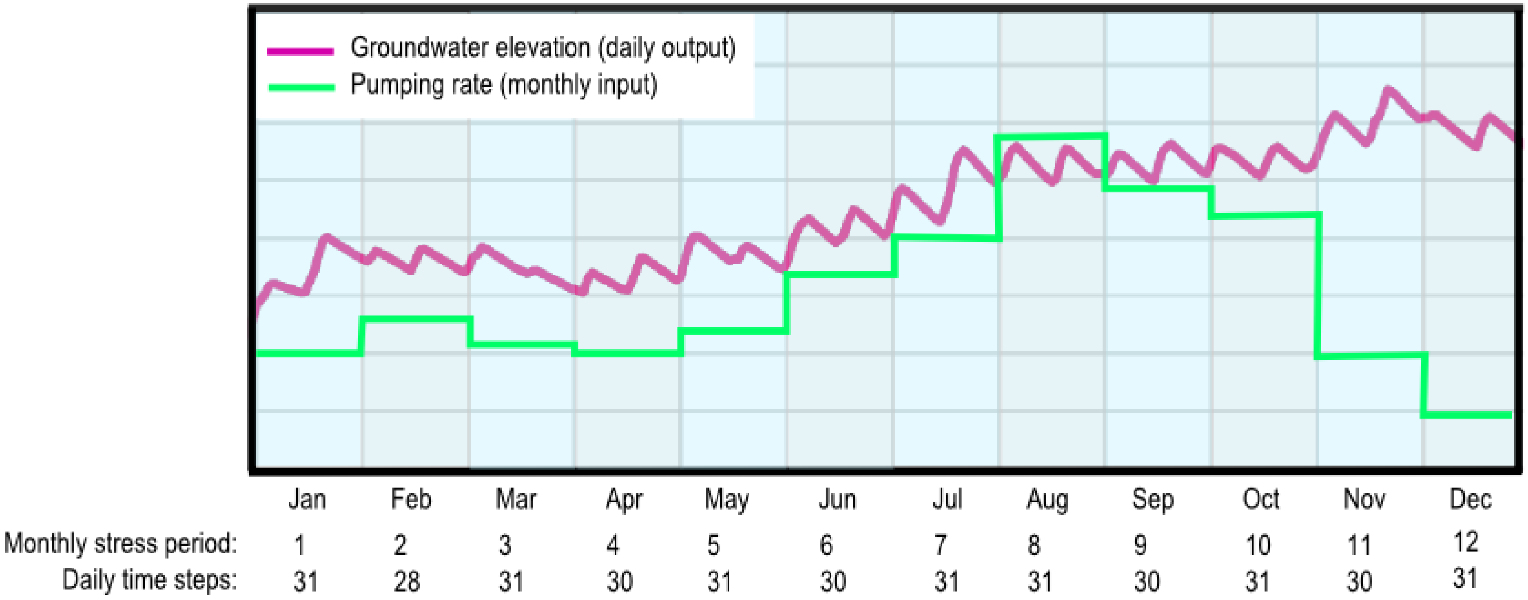


Calculate vertical and horizontal flows between cells

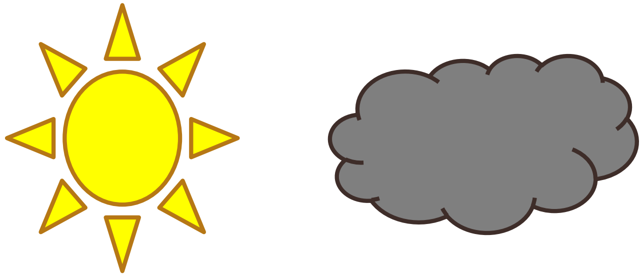


How a Numerical Model Represents Time

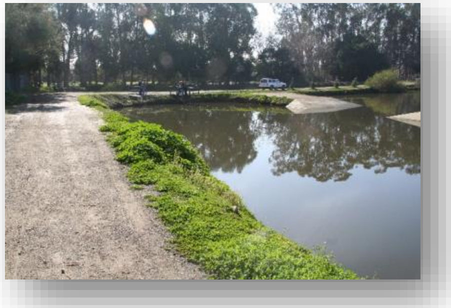
- Calculations performed at each time step
  - Flow equations solved iteratively to estimate groundwater levels and flows
- Inputs provided for stress periods

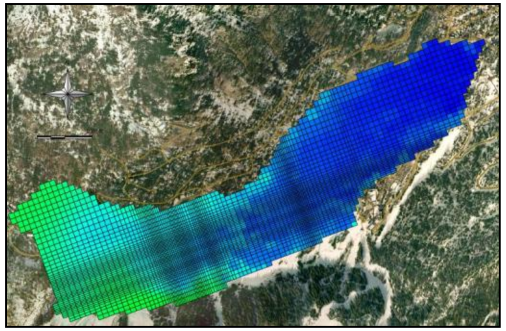


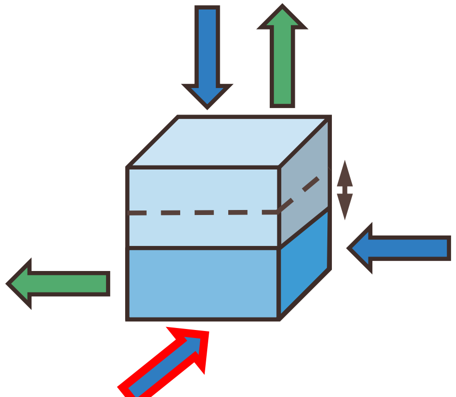
How Models Represent Reality: Calibration



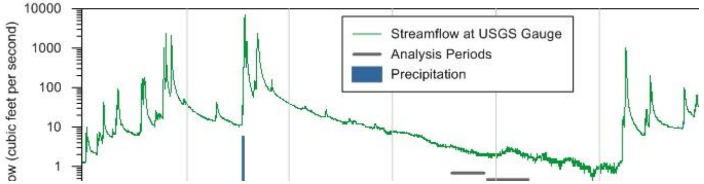
Historical Data







Historical Observations



Adjust model hydraulic conductivity and storage properties so that model outputs from model inputs to approximate historical observations

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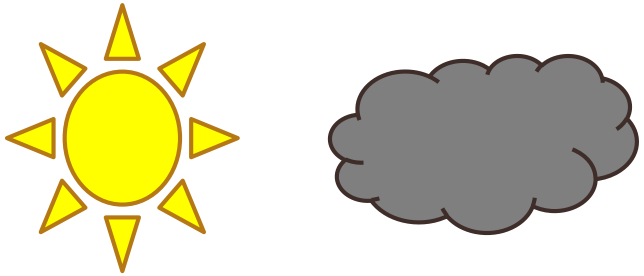
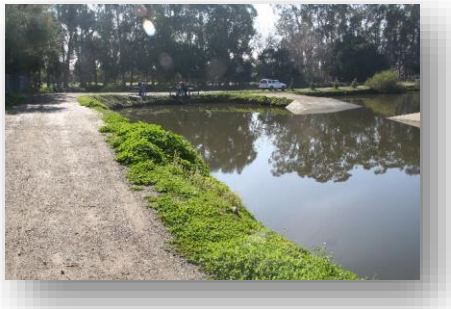
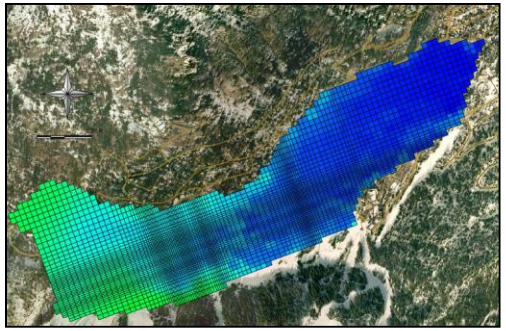
Calibration Provides Level of Confidence



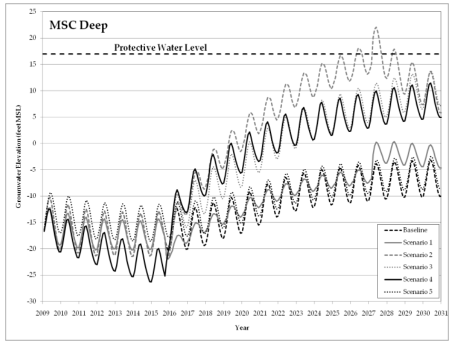
Future Changes

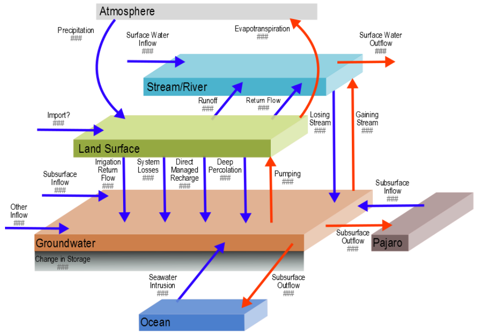


Calibrated Model



Evaluate Uncertainty within Calibration



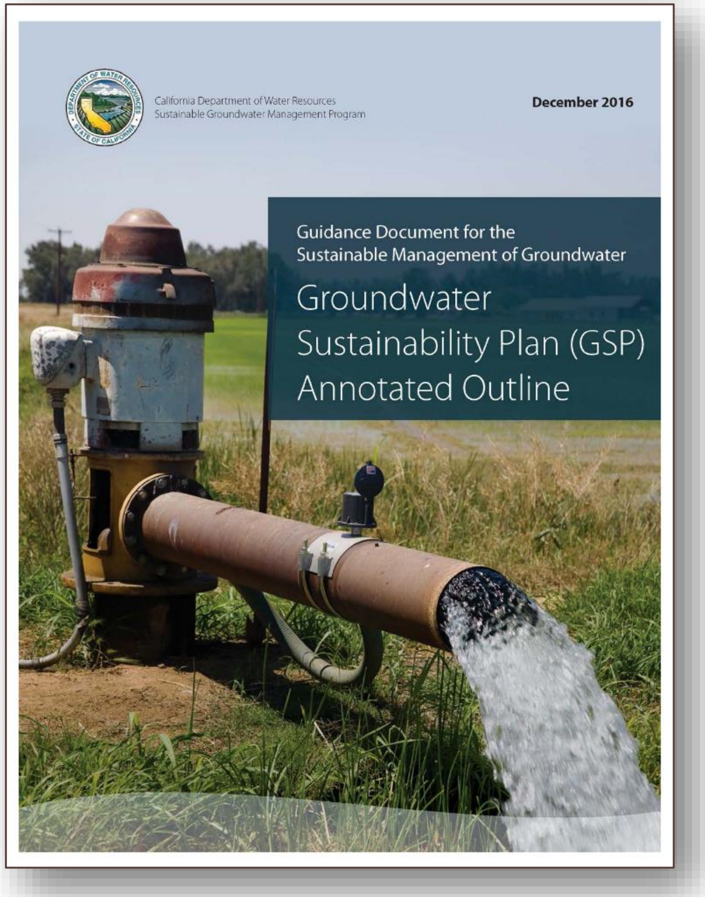


Model Projections & Uncertainty Inform Plans

GSP Parts that Use the Model

- Part 1: Describe who you are
- Part 2: Describe the basin's geology and hydrogeology (with sustainable yield)
- Part 3: Define how you will measure sustainability
- Part 4: Identify programs and projects that get you to sustainability
- Part 5: Implementation information

DWR's Example GSP Outline



California Department of Water Resources
Sustainable Groundwater Management Program

December 2016

Guidance Document for the Sustainable Management of Groundwater

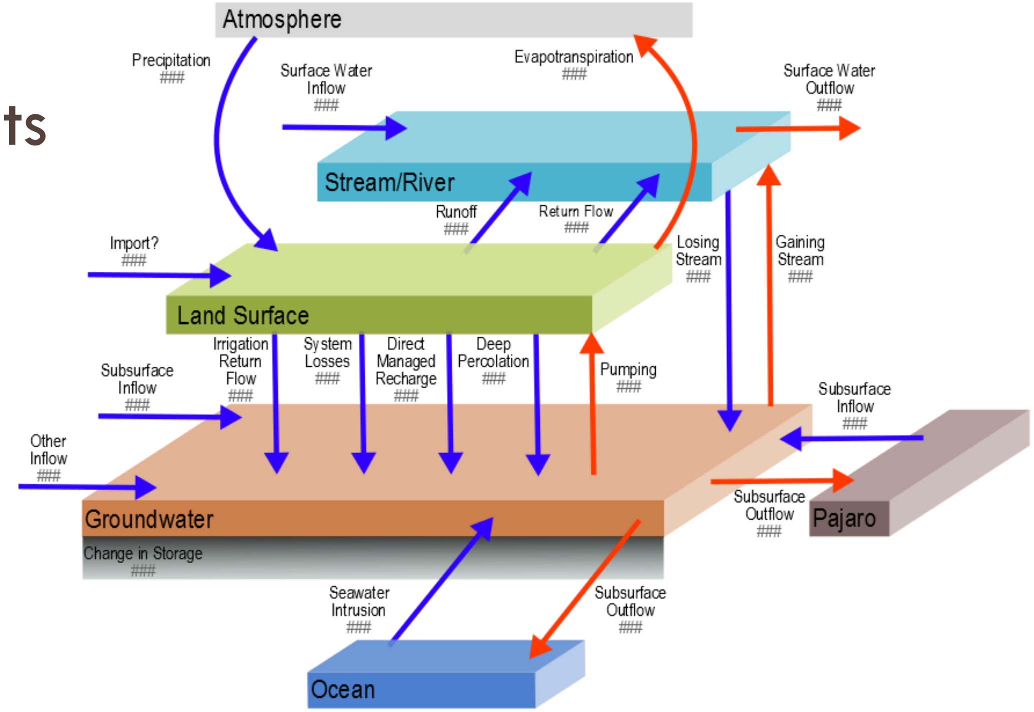
Groundwater Sustainability Plan (GSP) Annotated Outline

Part 2: Groundwater Budgets from Model

- Largely technical section with relatively low controversy
- Geology
  - At least 2 geologic cross-sections per basin
- Historical and current groundwater budgets
  - Groundwater recharge
  - Groundwater pumping
  - Change in storage
  - Estimate of Sustainable Yield

Part 3

- Future groundwater budget
  - Include effects of climate change
- Existing monitoring programs



Part 3: Sustainable Management Criteria

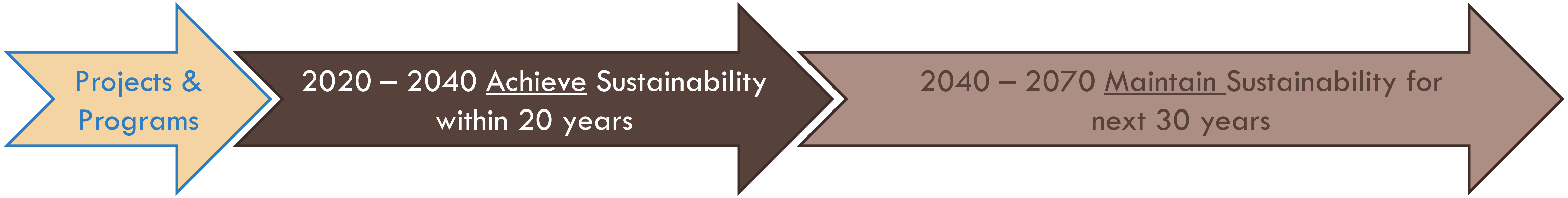
- Undesirable Results and Minimum Thresholds Set by Policy Likely Independent of Model
- Measurable Objectives May Be Informed by Model
  - Defined by Operational Flexibility
- Interim Milestones Likely Based on Model
  - Based on Planned Projects and Programs

Part 4

DWR, Draft BMP, Nov 2017

Part 4: Demonstrating Plan to Achieve Sustainability

- Both technical and policy aspects to this section
- Opportunity for public input and review
- Demonstrate your projects and programs achieve sustainability in 20 years
- Demonstrate you will maintain sustainability for 30 years thereafter
- Agree on who pays for these programs, and who benefits (negotiations)
- You may need backup or supplemental plans if your preferred projects and programs are not adequate



Projects & Programs

2020 – 2040 Achieve Sustainability within 20 years

2040 – 2070 Maintain Sustainability for next 30 years

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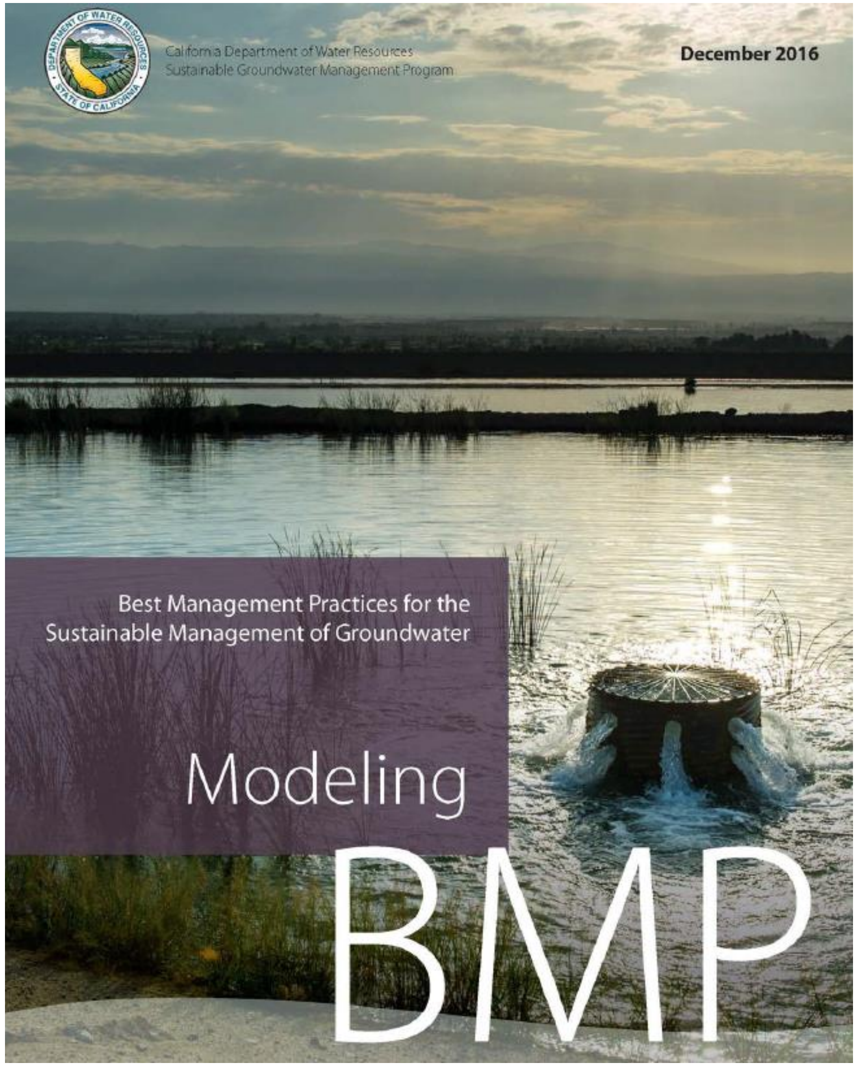
DWR on Using Models for GSPs

- Numerical groundwater and surface water model set as standard for tool to evaluate projected water budget conditions §354.18(e)
- Model standards §352.4(f)
  - Public supporting documentation
  - Based on field or laboratory measurements and calibrated against site-specific field data
  - Public domain open-source software.
- Best Management Practices (Dec 2016)


California Department of Water Resources
Sustainable Groundwater Management Program

December 2016

Best Management Practices for the
Sustainable Management of Groundwater

Modeling

BMP

GSFLOW Selected for Mid-County Basin

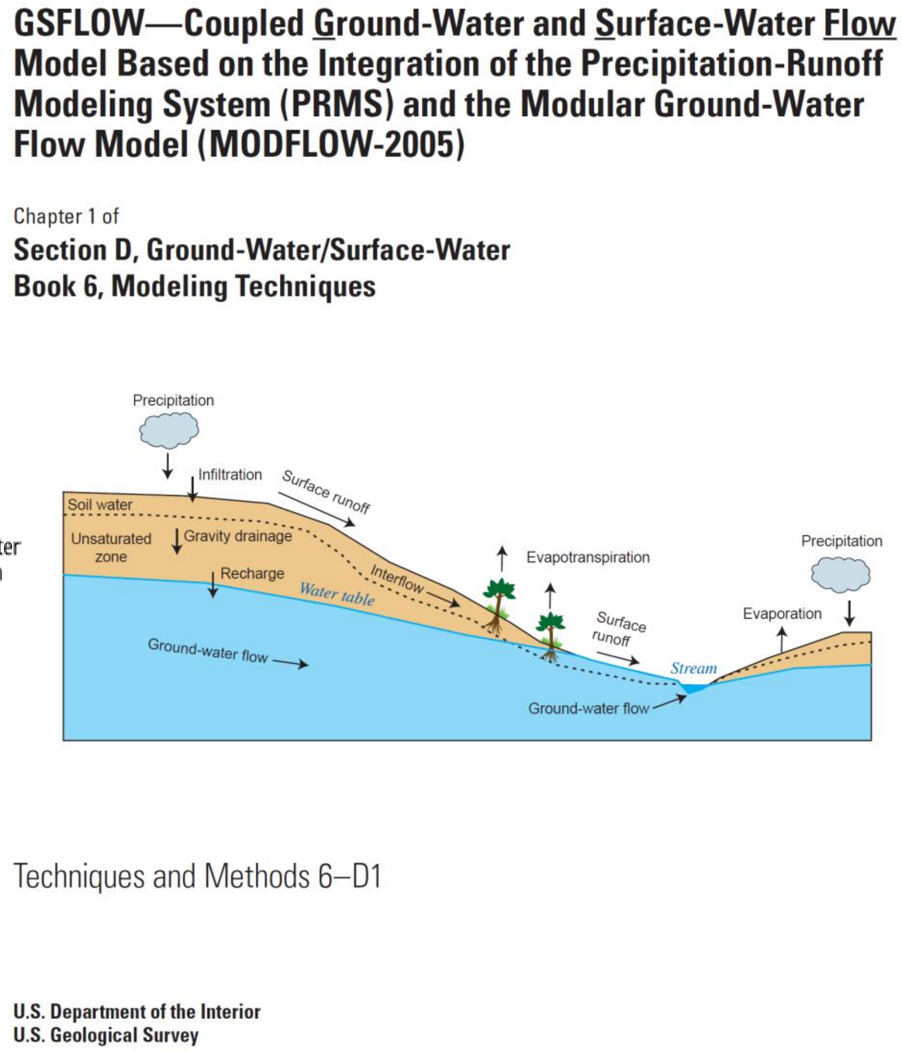
- Integrated groundwater-surface water model
- Developed by US Geological Survey
  - Public documentation
  - Public domain code
- BMP: Commonly Used in California
- MODFLOW SWI2 Package Added
- Dan McManus, DWR: “I like the watershed approach”
- Calibration challenges

Lowering GW Levels

Reduction of Storage

Surface Water Depletion

Seawater Intrusion



GSFLOW—Coupled Ground-Water and Surface-Water Flow Model Based on the Integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005)

Chapter 1 of

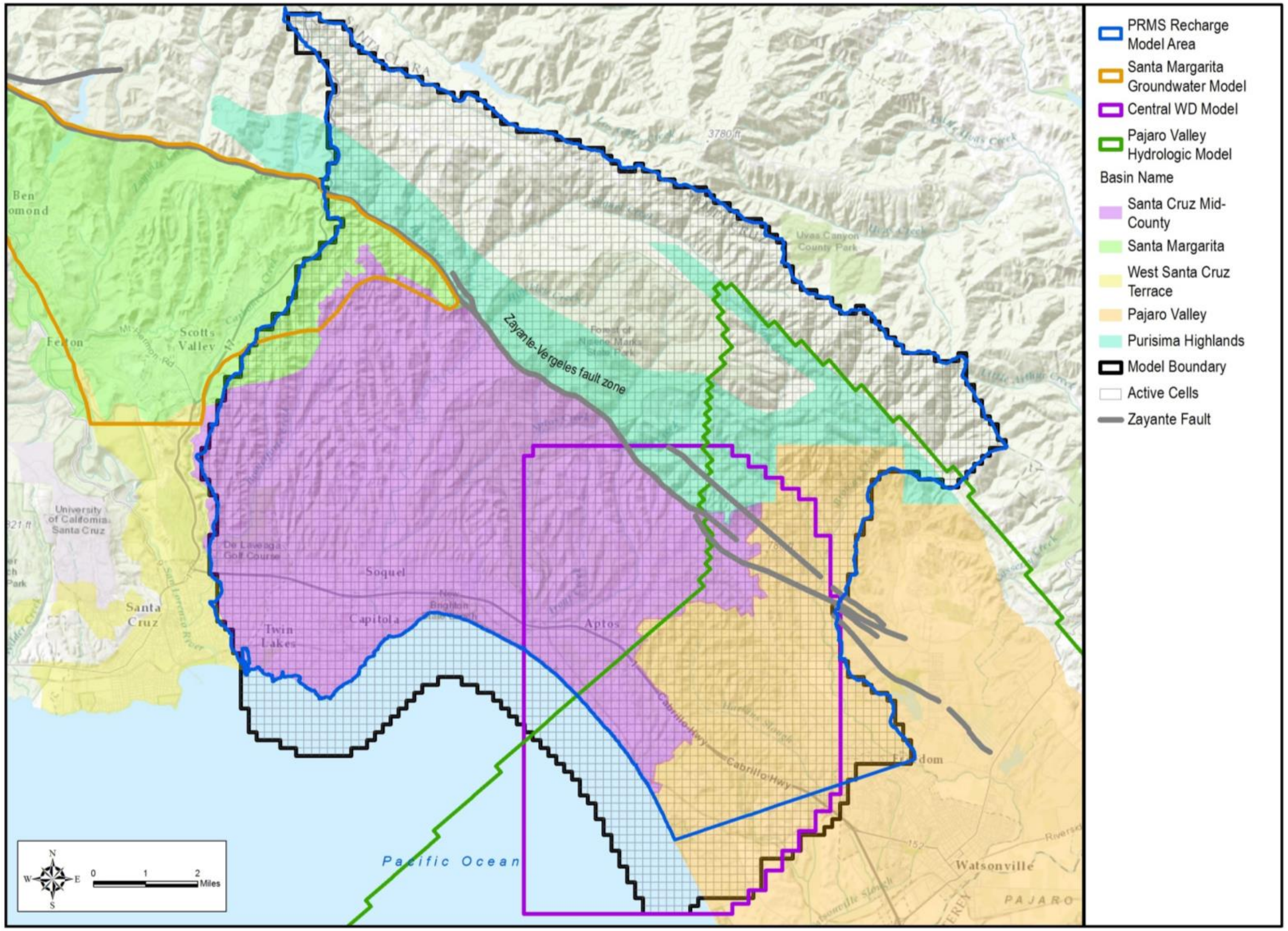
Section D, Ground-Water/Surface-Water
Book 6, Modeling Techniques

Techniques and Methods 6–D1

U.S. Department of the Interior
U.S. Geological Survey

Other Models in Area Informed Development

- Central Water District
  - ☐ Aromas structure
- Pajaro Valley
  - ☐ Crop coefficients
- Santa Margarita
  - ☐ Layer 9 granitic divide
- 2011 PRMS Recharge
  - ☐ Calibration setup



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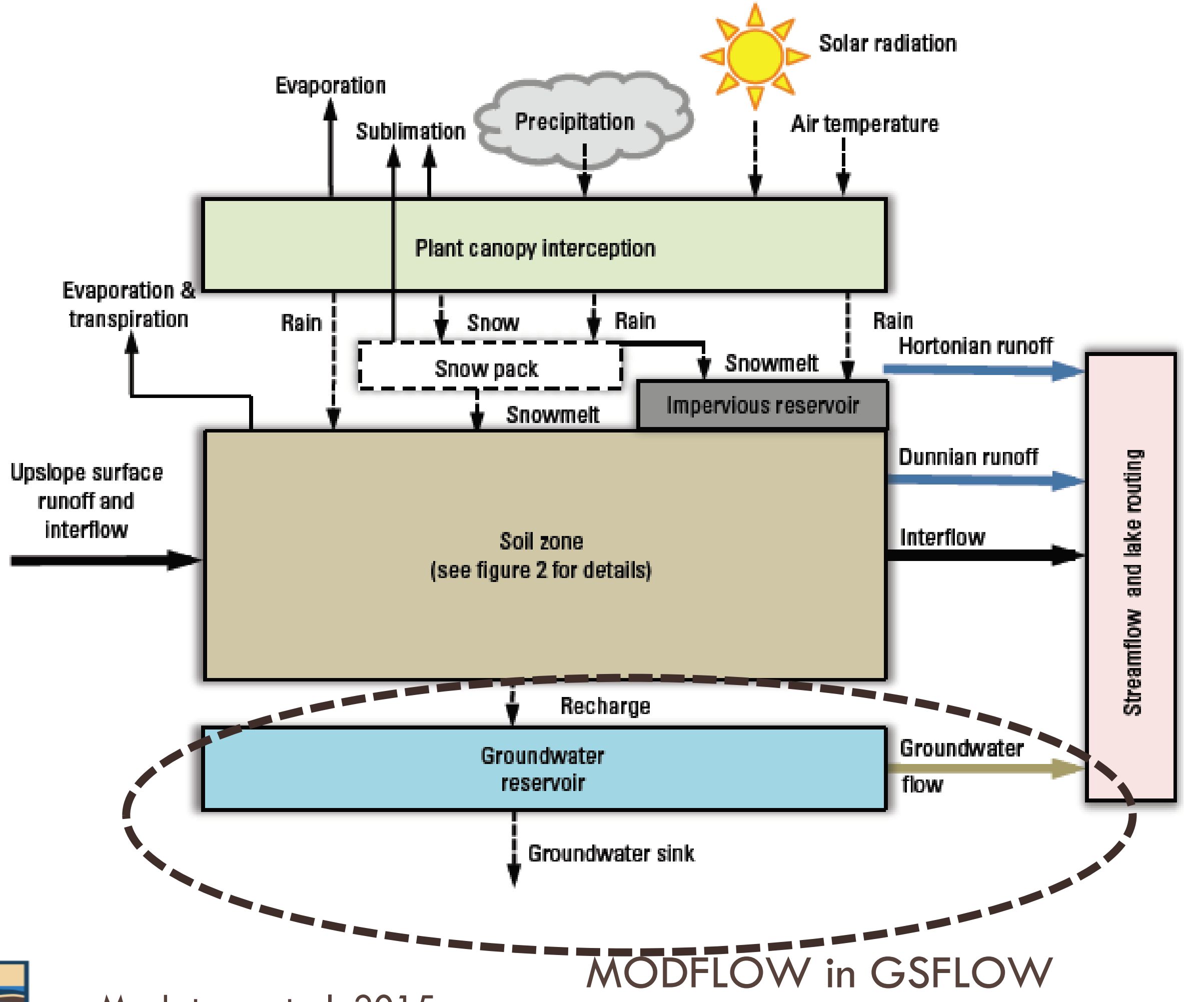
Questions on Model Introduction?

Modeling Basin Climate, Watershed, and Water Use

PRMS Watershed Model

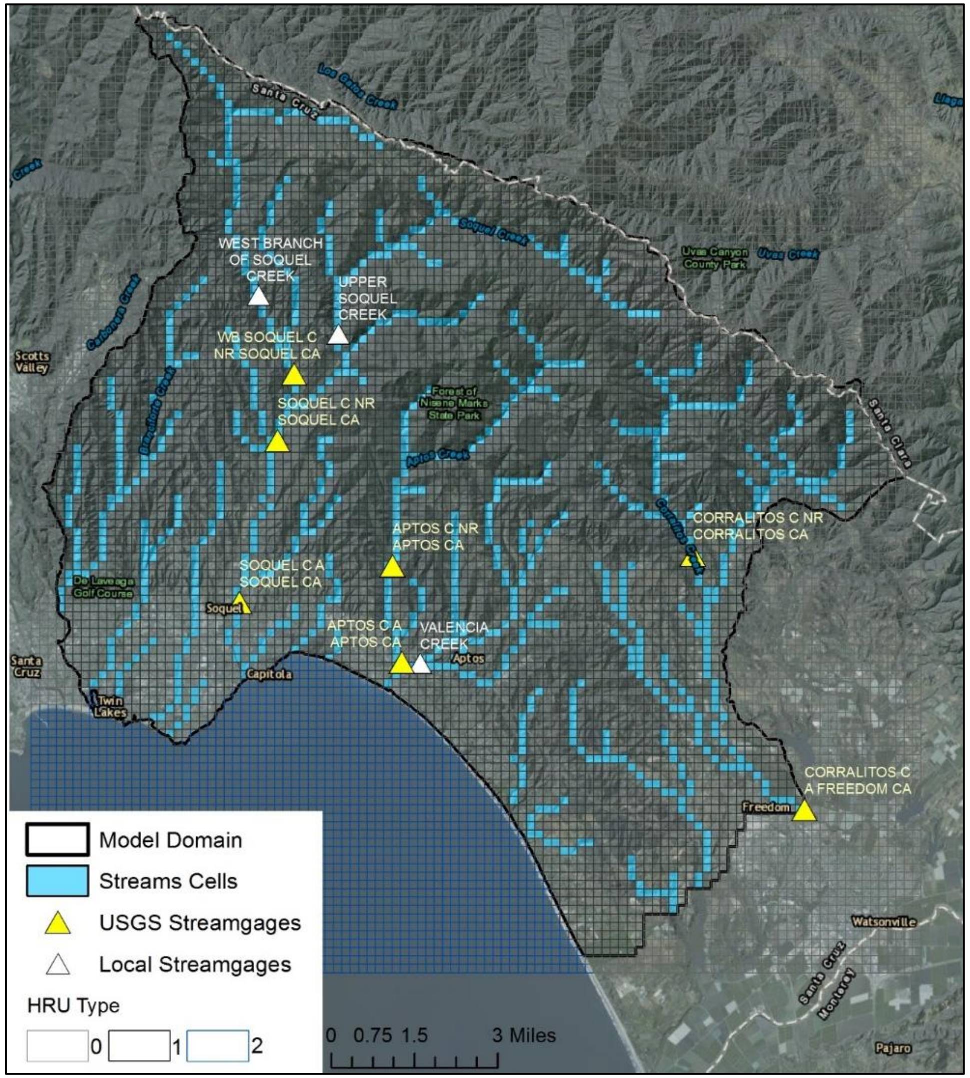


Markstrom et al, 2015

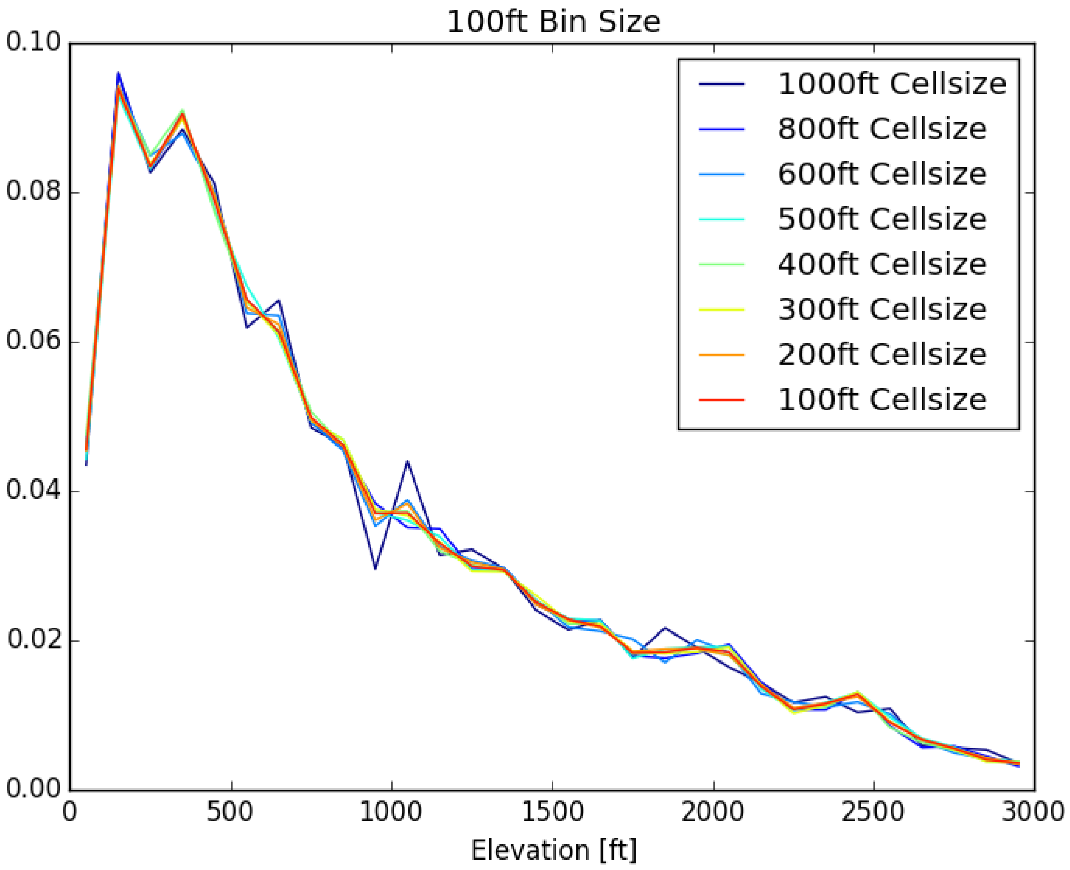
- Physical process model
- Distributed parameters
- Simulates watershed response from climate effects
- Select PRMS modules for distributing climate data
- Daily time steps

Hydrologic Response Units (HRUs)

- Assigned physical characteristics such as slope, aspect, elevation, vegetation type, soil type, land use, and precipitation
- Water and energy balances calculated for each HRU
- Sum of area weighted responses for all HRUs = daily watershed response for the model area



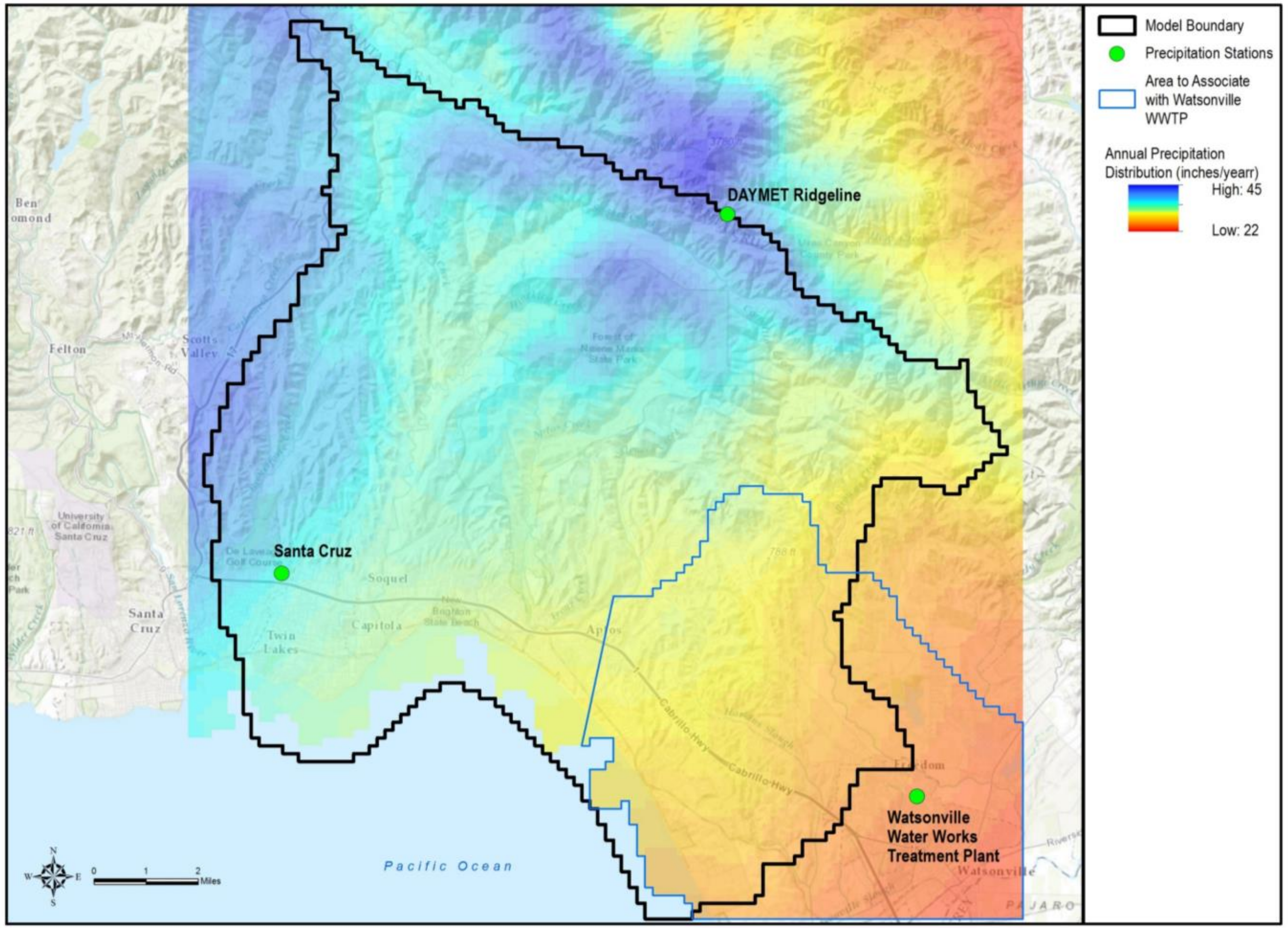
Selecting Grid Cell Size



- 800 feet x 800 feet
- Largest grid cell size that best preserves finer scale elevation distributions across the study area
- Smaller grid cell size would increase run times

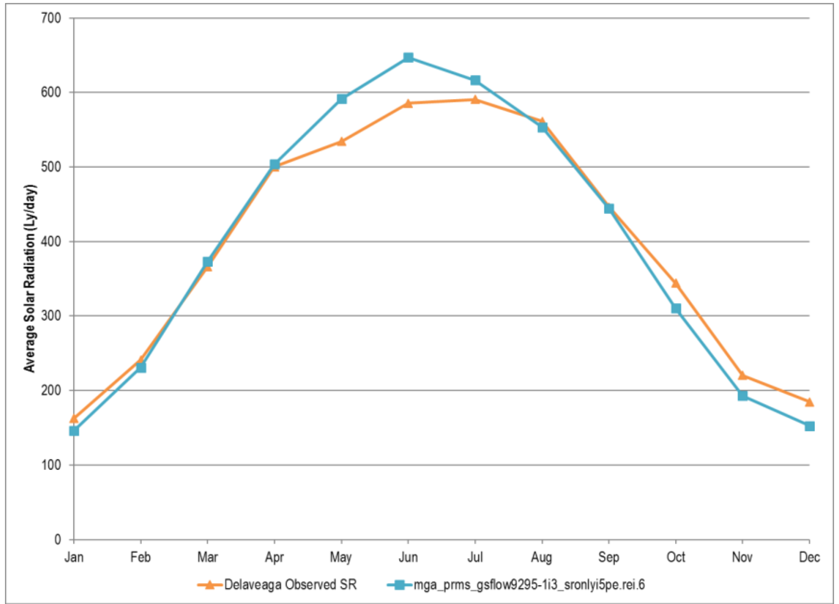
Climate Input Data

- Precipitation
  - ☐ Spatial distribution from DAYMET
  - ☐ Daily data from Santa Cruz and Watsonville stations
- Temperature
  - ☐ Lapse rates
  - ☐ Daily max and min data from Santa Cruz and DAYMET values in upper watershed

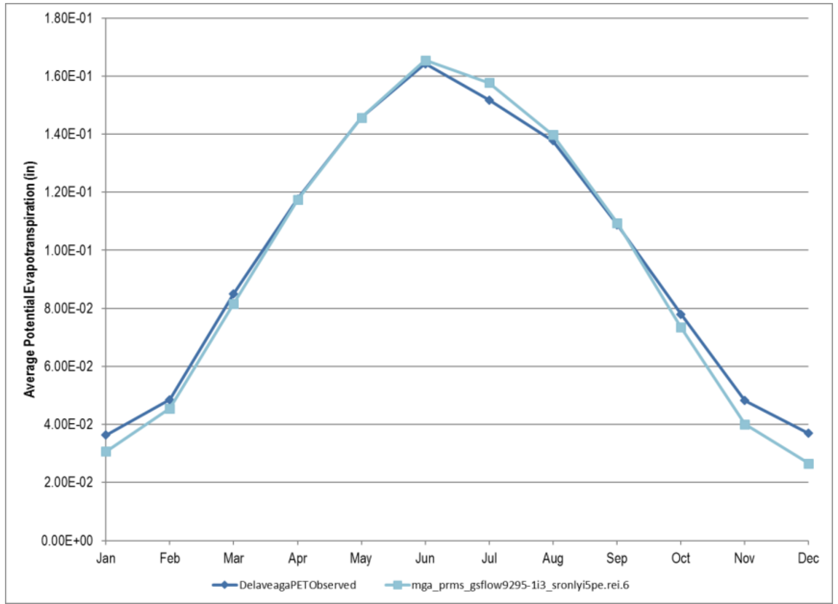


Calibrate Potential Evapotranspiration

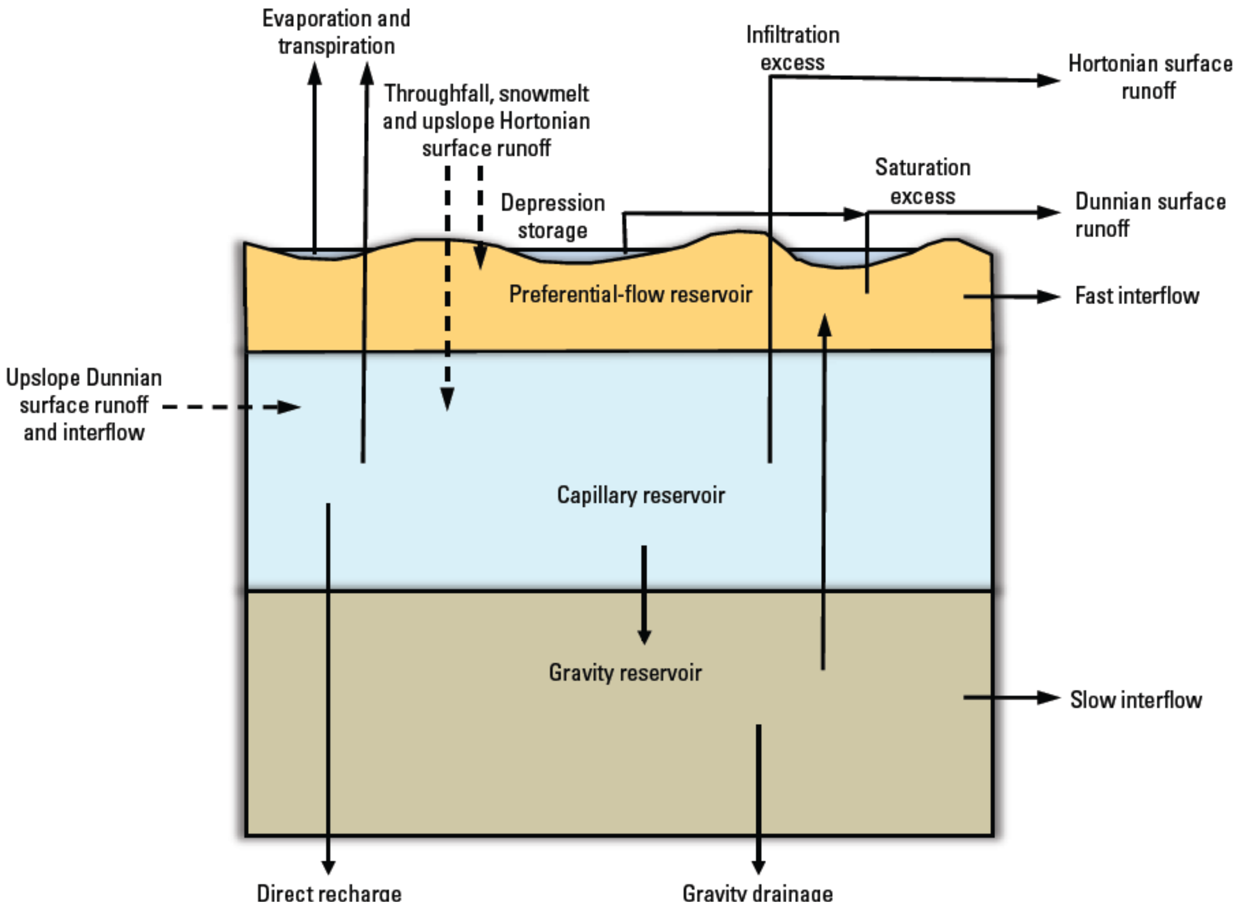
- Calibrate Solar Radiation
  - Function of temperature
  - Monthly parameters

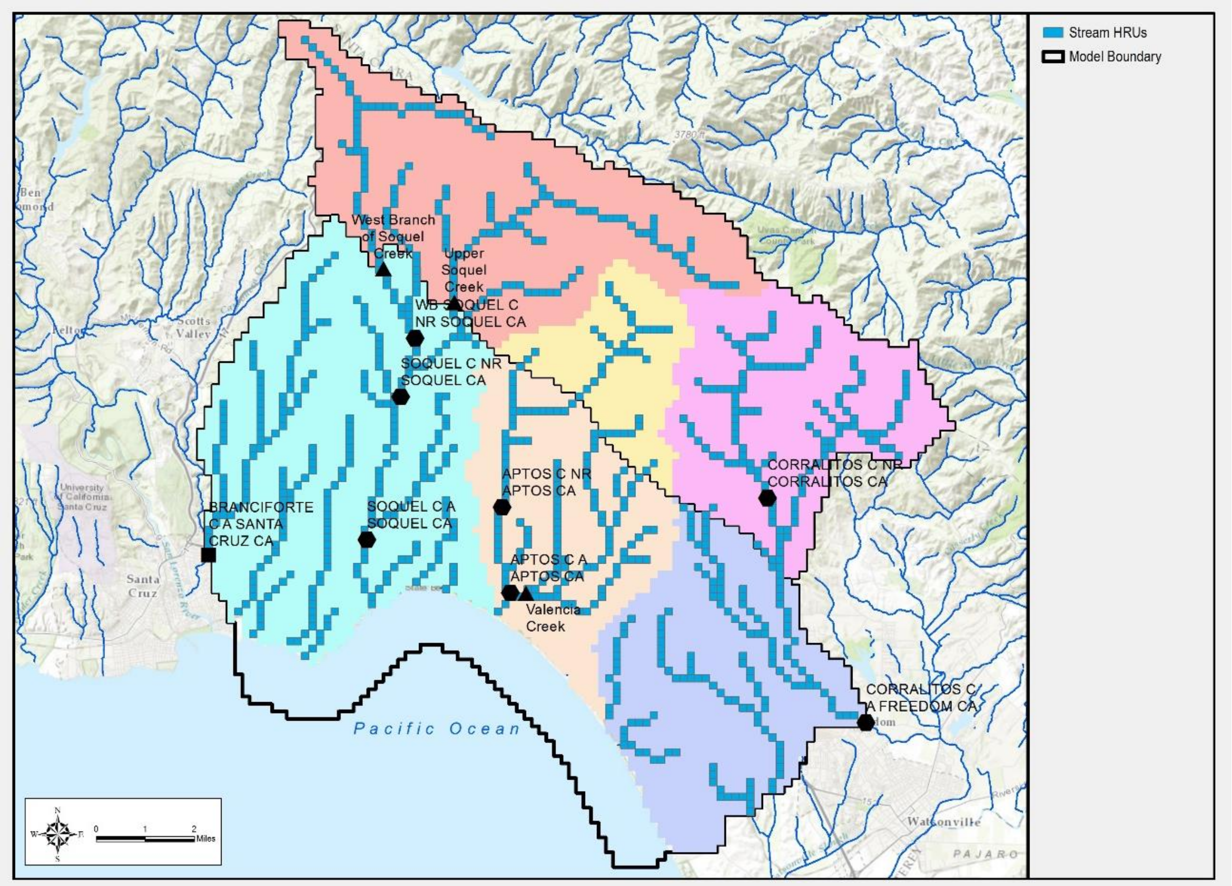


- Calibrate Potential Evapotranspiration (PET)
  - Function of solar radiation
  - Monthly parameters
  - Jensen-Haise and Priestly-Taylor



Calibrate Watershed Parameters to Streamflow

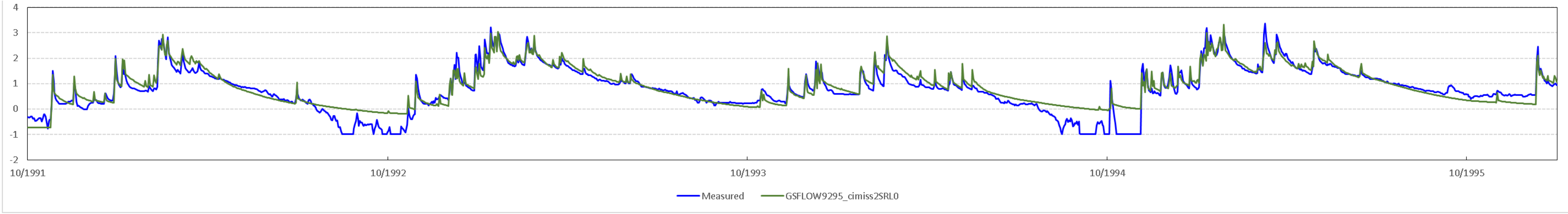




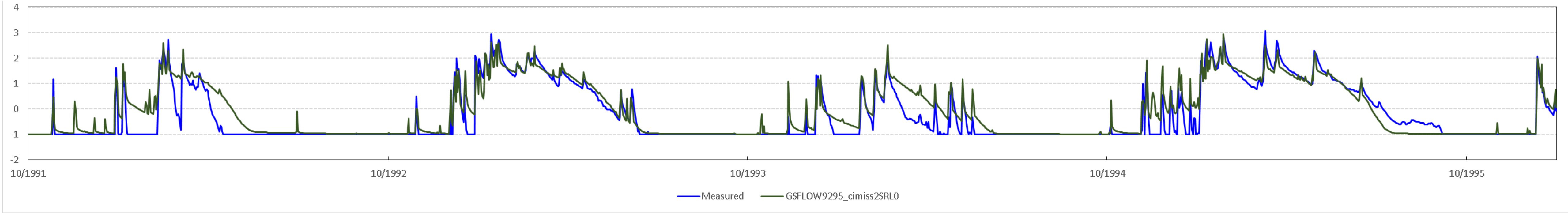
Markstrom et al, 2015

Streamflow Calibration

Soquel at Soquel



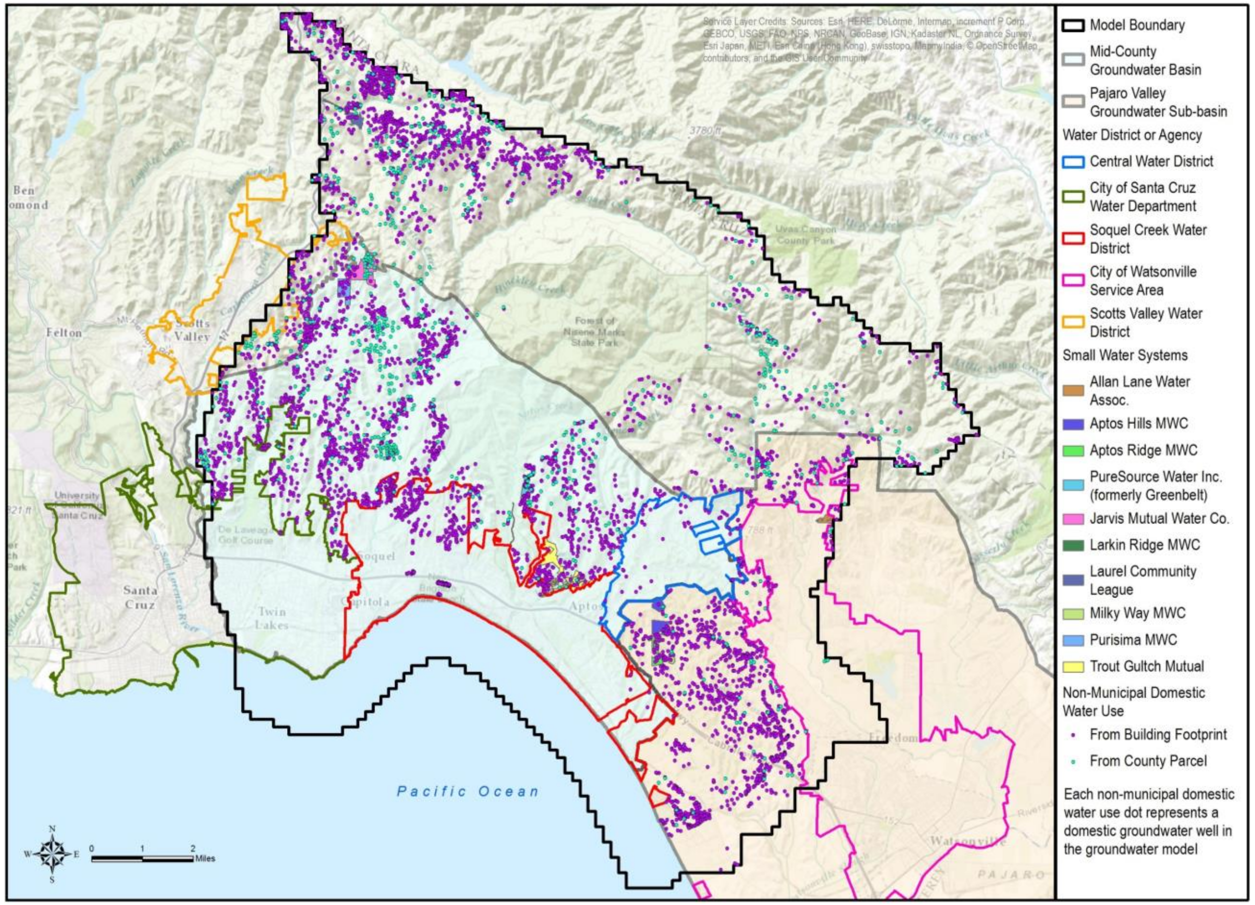
Corralitos at Freedom



Preliminary Model, Subject to Revision

Estimated Water Use for Residential Private Wells

- Based on Building Footprints and Residential Parcels
- Water Use Factor Declines Over Time
  - 1985: 0.46 afy (~410 gpd)
  - 2005: 0.41 afy (~400 gpd)
  - 2013: 0.35 afy(~310 gpd)
  - 2015: 0.23 afy (~210 gpd)
- Monthly variation based on PRMS ET Demand

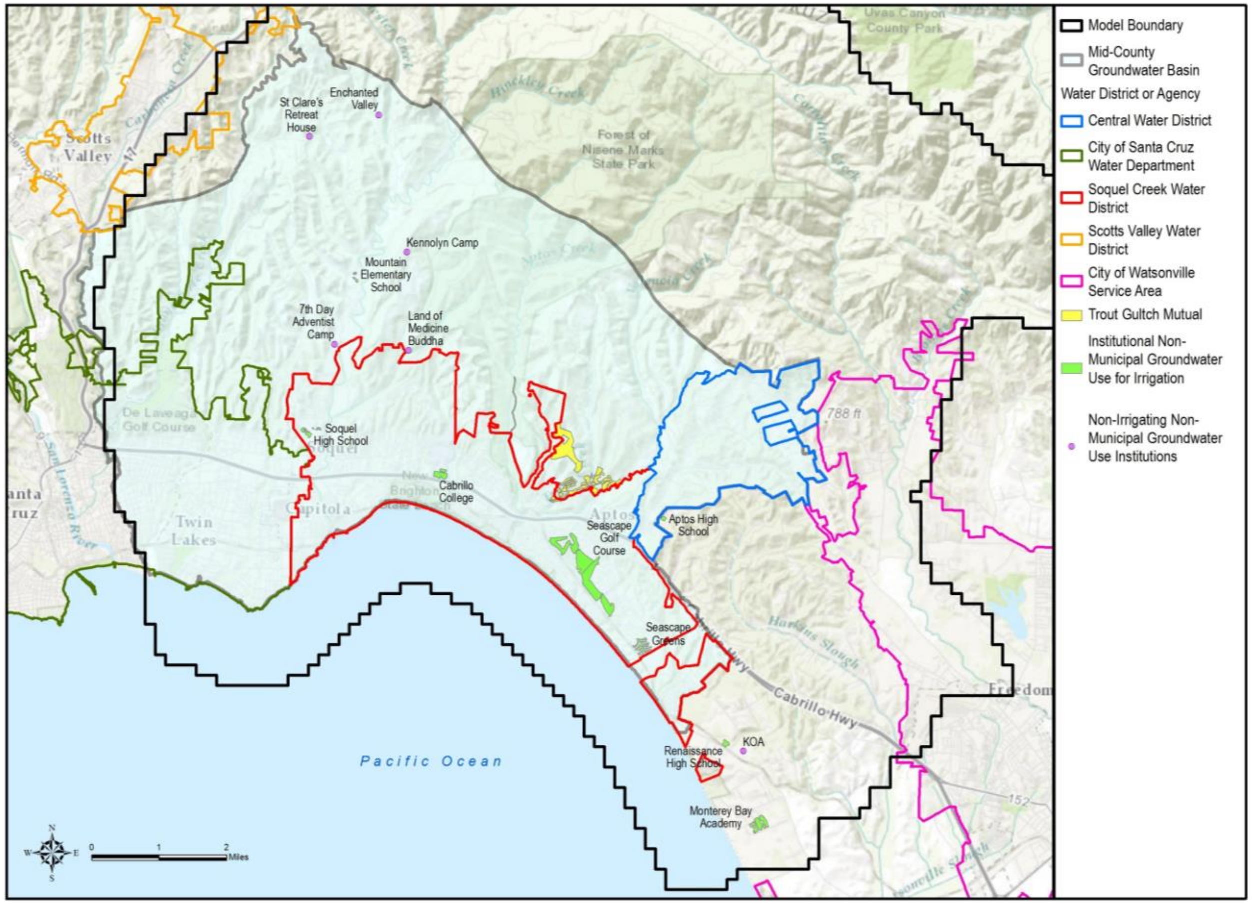


Each non-municipal domestic water use dot represents a domestic groundwater well in the groundwater model

afy= acre-feet per year (per household)
gpd= gallons per day (per household)

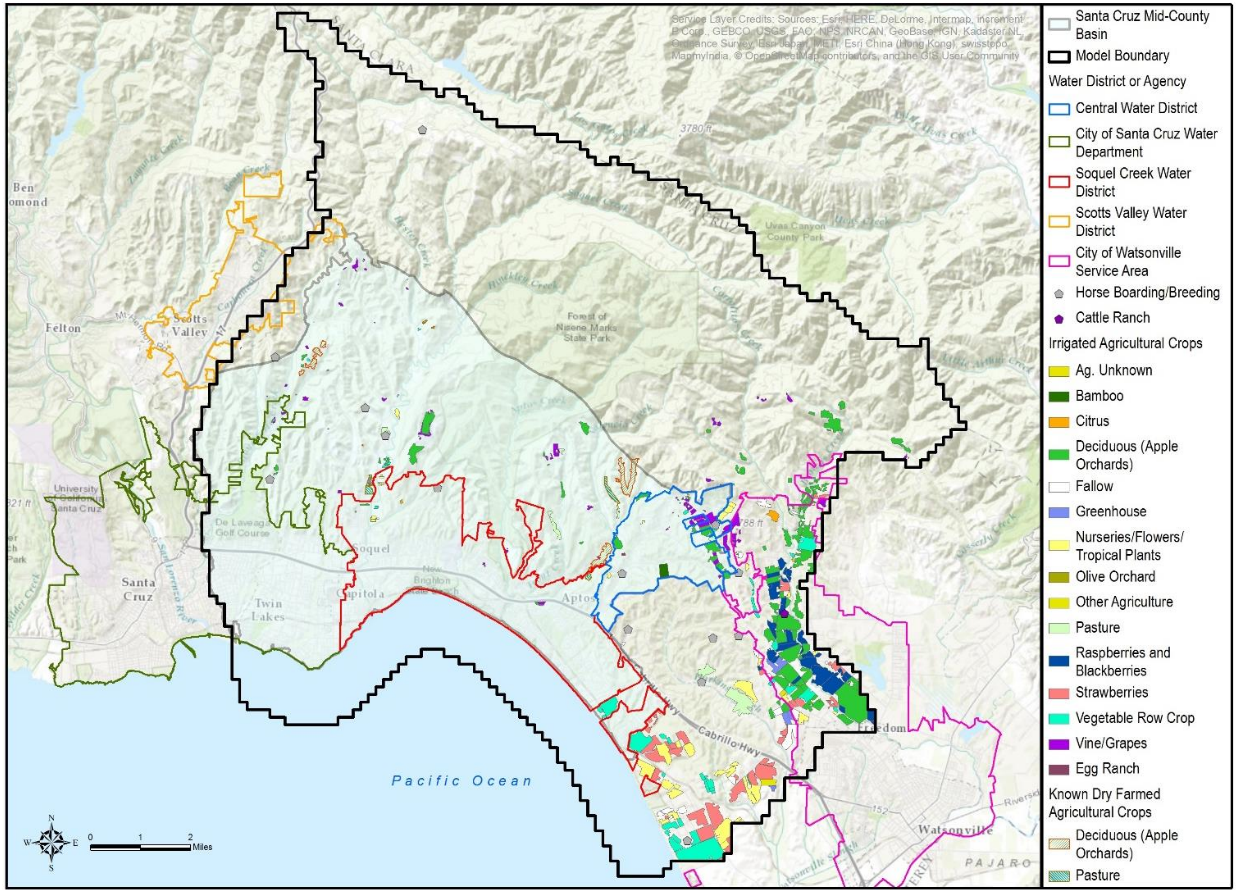
Estimated Non-Municipal Institutional Water Use

- Estimates for indoor water use
- Estimate for outdoor water use
  - PRMS calculation of ET Demand
  - Crop coefficient for turfgrass
  - 10% inefficiency
- Trout Gulch Mutual data for 2008-2015
- County now has metered usage for most small water systems



Estimated Non-Municipal Agricultural Water Use

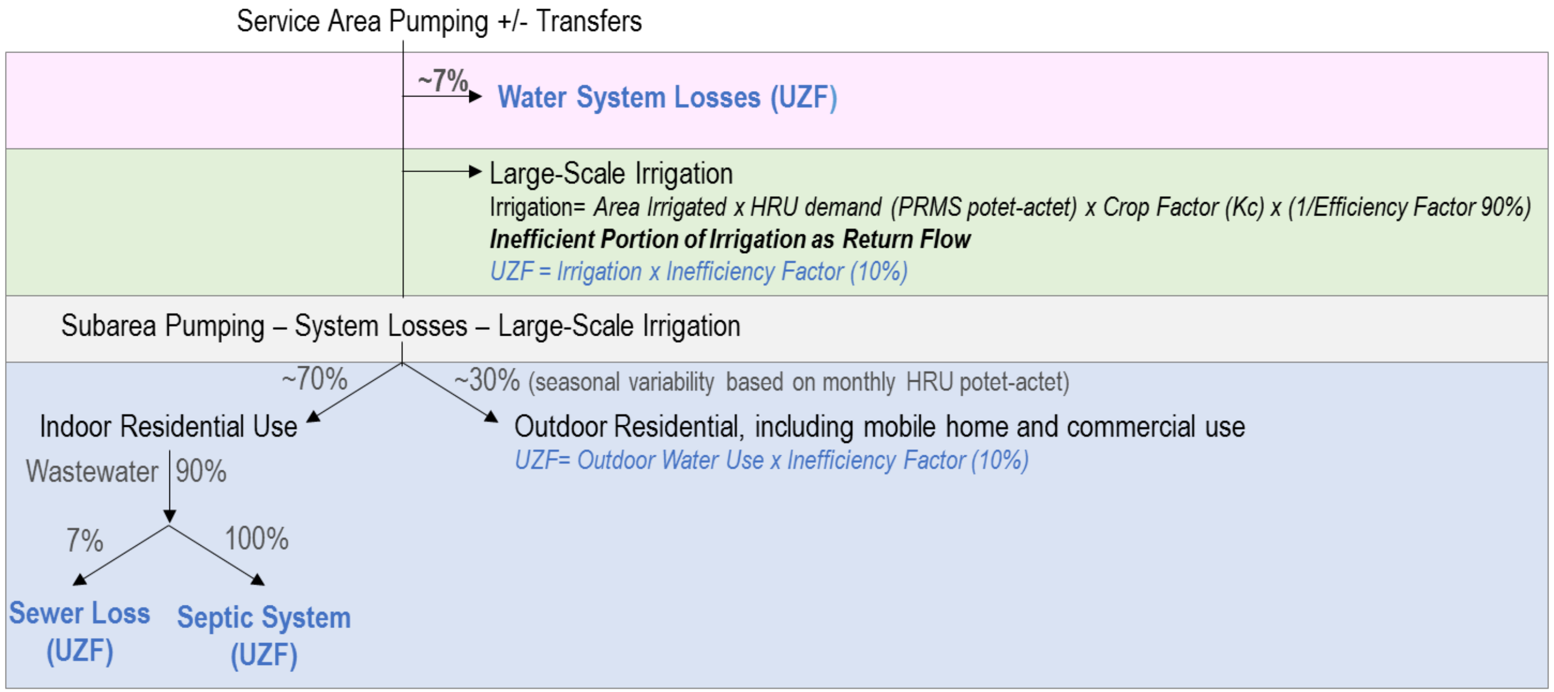
- Crop land use map
- Estimate for irrigation demand
  - PRMS calculation of ET Demand
  - Crop coefficients
- 10% inefficiency



Estimating Return Flow

- Water System Losses
- Sewer Losses
- Septic System Losses
- Inefficient Irrigation
- Applied below Soil Zone as Recharge (UZF)

Example of Return Flow Calculation: Municipal Use



Service Area Pumping +/- Transfers

~7% Water System Losses (UZF)

Large-Scale Irrigation

Irrigation= *Area Irrigated x HRU demand (PRMS potet-actet) x Crop Factor (Kc) x (1/Efficiency Factor 90%)*

Inefficient Portion of Irrigation as Return Flow

UZF = Irrigation x Inefficiency Factor (10%)

Subarea Pumping – System Losses – Large-Scale Irrigation

~70% Indoor Residential Use

~30% (seasonal variability based on monthly HRU potet-actet) Outdoor Residential, including mobile home and commercial use

UZF= Outdoor Water Use x Inefficiency Factor (10%)

Wastewater 90%

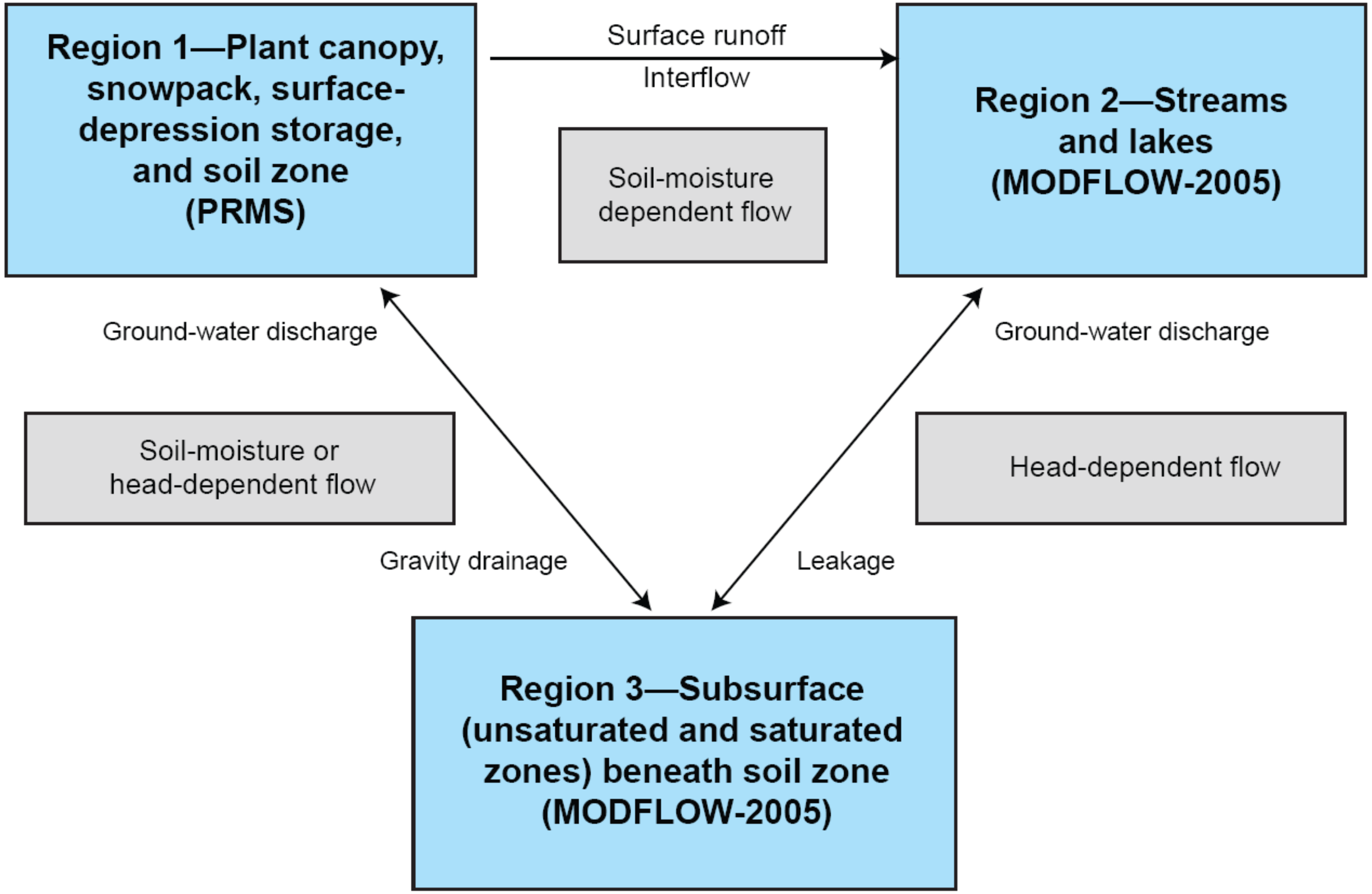
7% Sewer Loss (UZF)

100% Septic System (UZF)

Questions on Watershed Model?

Modeling Groundwater Flow

GSFLOW = PRMS + MODFLOW



Region 1—Plant canopy, snowpack, surface-depression storage, and soil zone (PRMS)

Surface runoff

Interflow

Soil-moisture dependent flow

Region 2—Streams and lakes (MODFLOW-2005)

Ground-water discharge

Ground-water discharge

Soil-moisture or head-dependent flow

Head-dependent flow

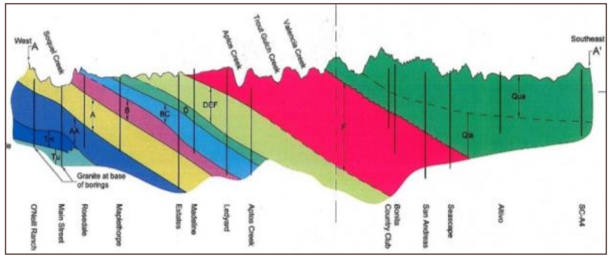
Gravity drainage

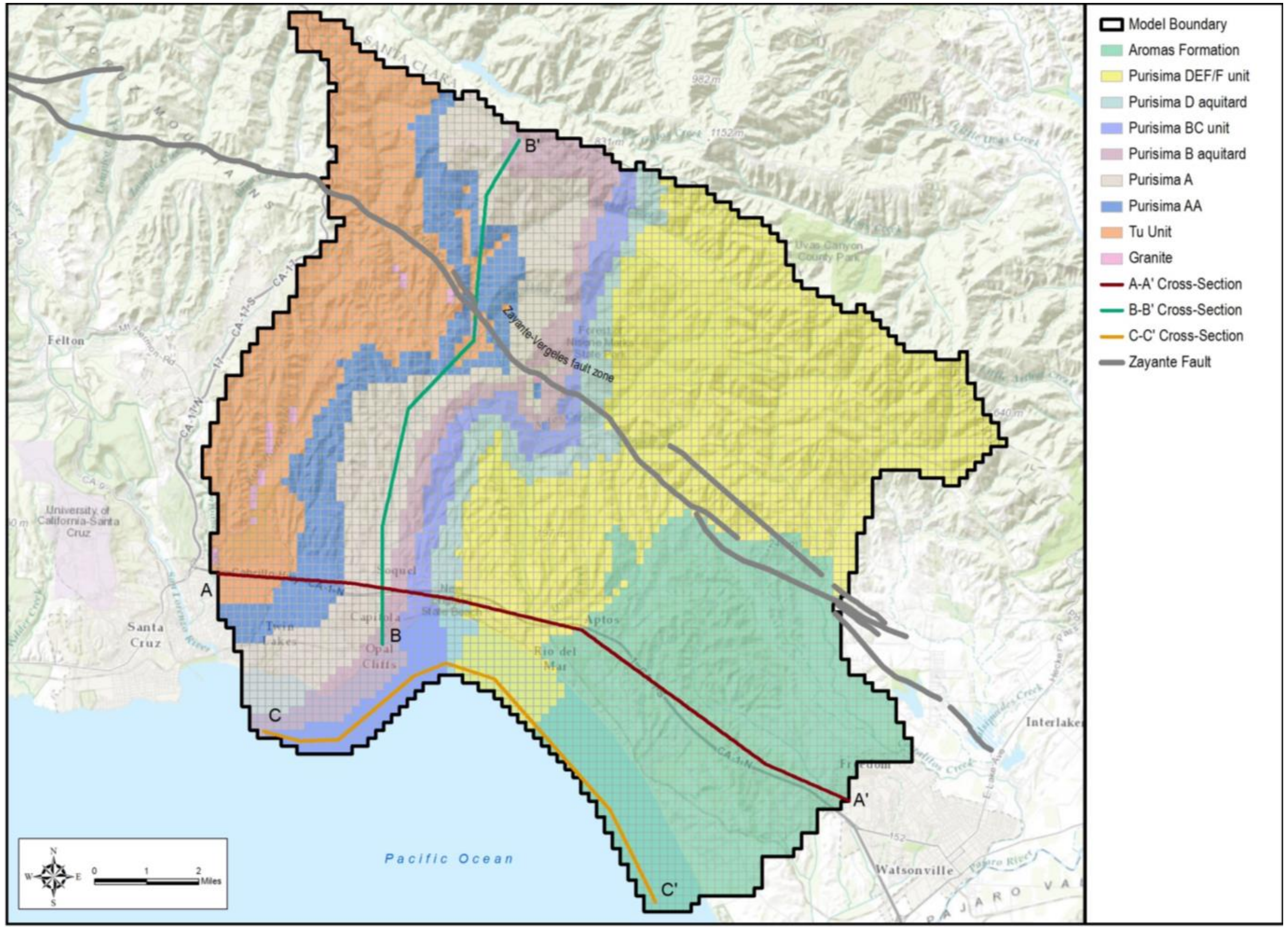
Leakage

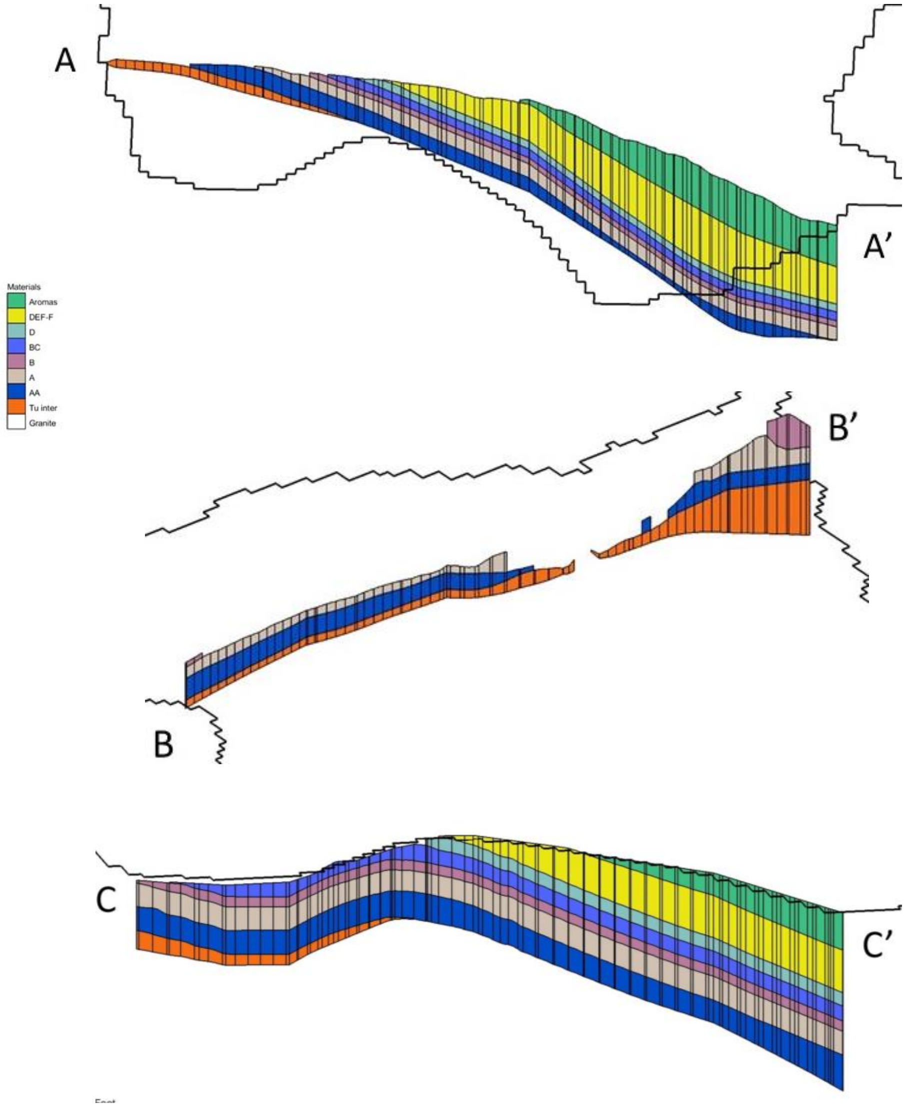
Region 3—Subsurface (unsaturated and saturated zones) beneath soil zone (MODFLOW-2005)

SANTA CRUZ MID-COUNTY GROUNDWATER AGENCY

Modeled Stacked Aquifer Units



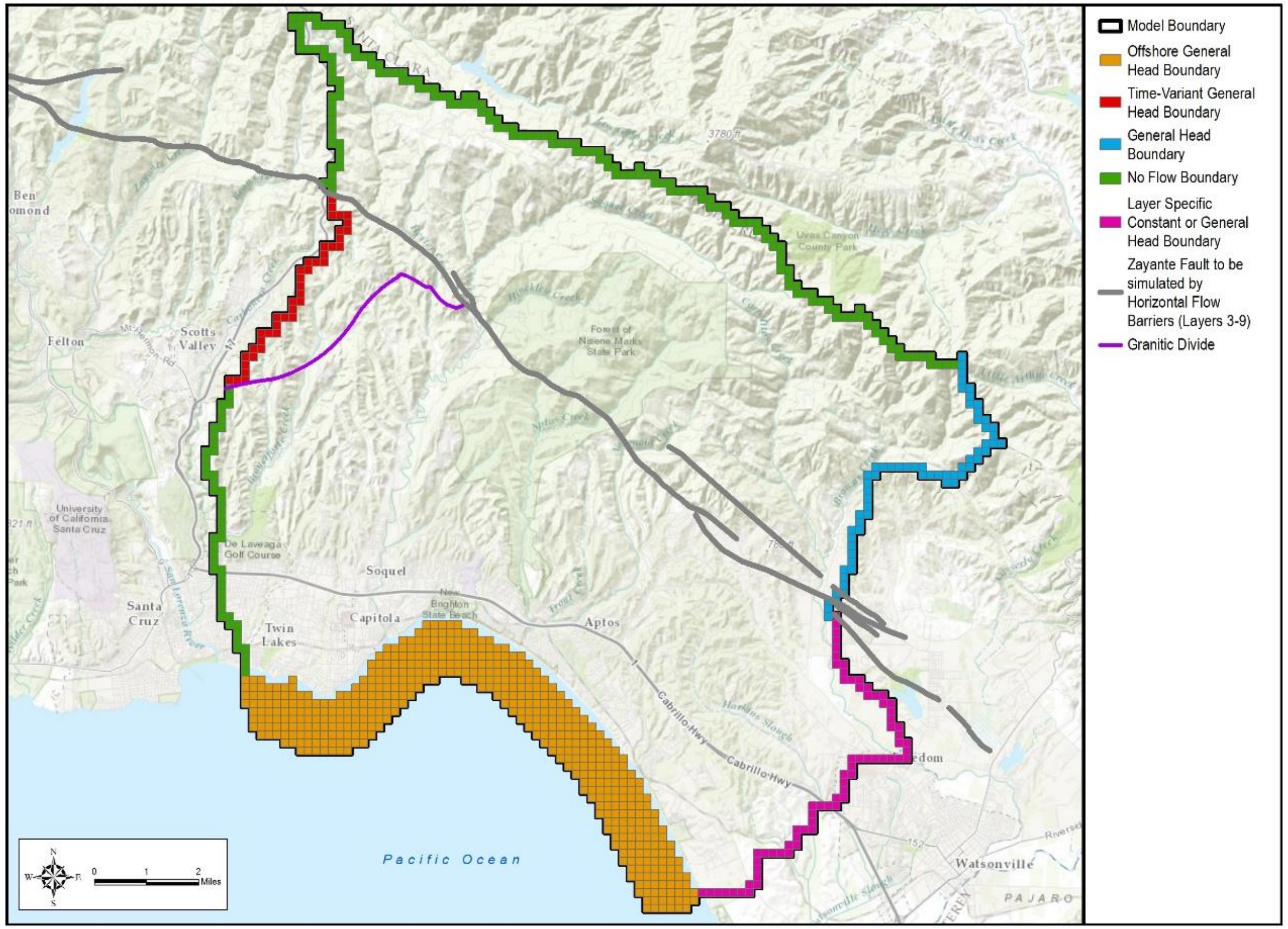




SANTA CRUZ MID-COUNTY GROUNDWATER AGENCY

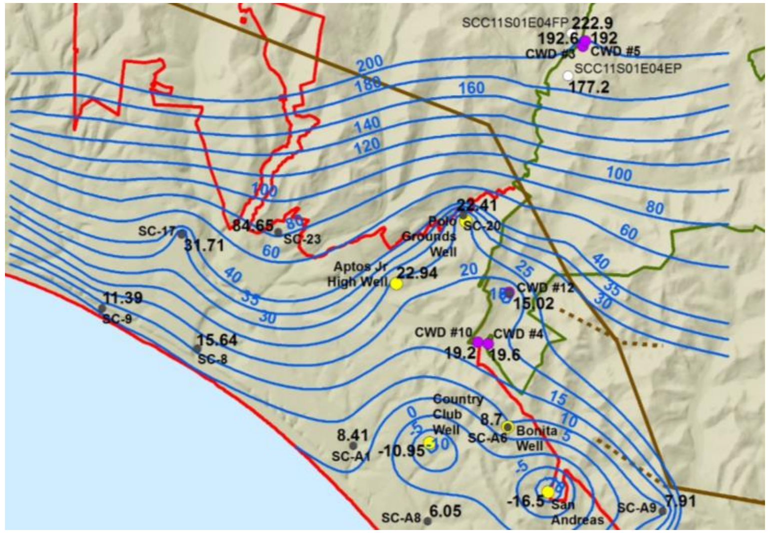
Boundary Conditions

- Offshore General Heads
  - Outcrop vs. Model Edge
  - Salt Density Corrected
- Pajaro Valley Subbasin
  - Aromas and Purisima F Based on Data
- Santa Margarita Basin
  - Tu Based on Data
- Purisima Highlands
  - Flow to Southeast



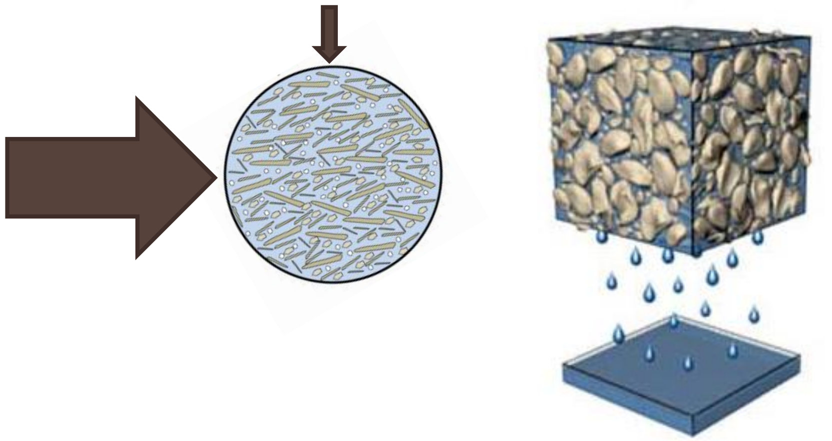
Conceptual Model Change: Aptos Fault

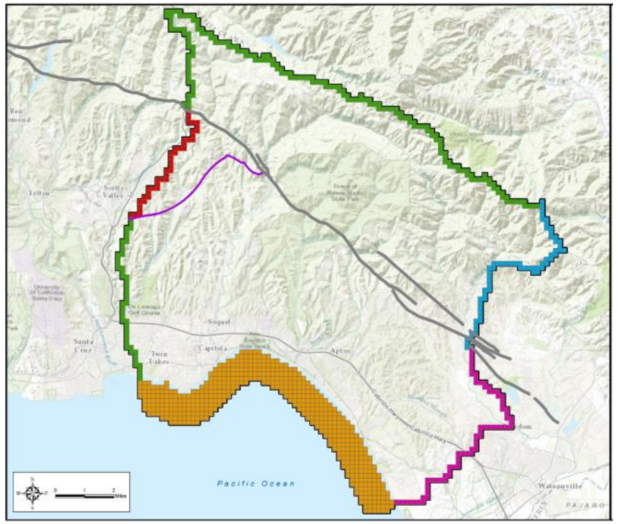
- Steep Groundwater Gradients
- USGS Seismicity Data of Faulting South of Zayante Fault
- Add Horizontal Flow Barrier (HFB) like Zayante Fault

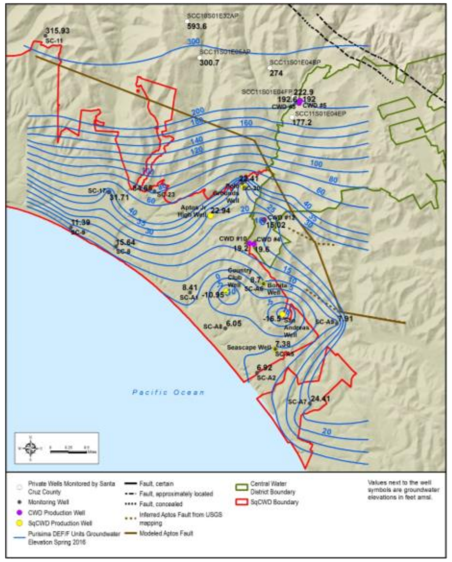


Groundwater Flow Calibration Parameters

- Horizontal and Vertical Hydraulic Conductivity
- Specific Storage and Specific Yield
- General Head Boundary Conductance
  - Offshore Outcrop Represents Seafloor
  - Model Boundary Represents Distance to Head
- Fault Conductance

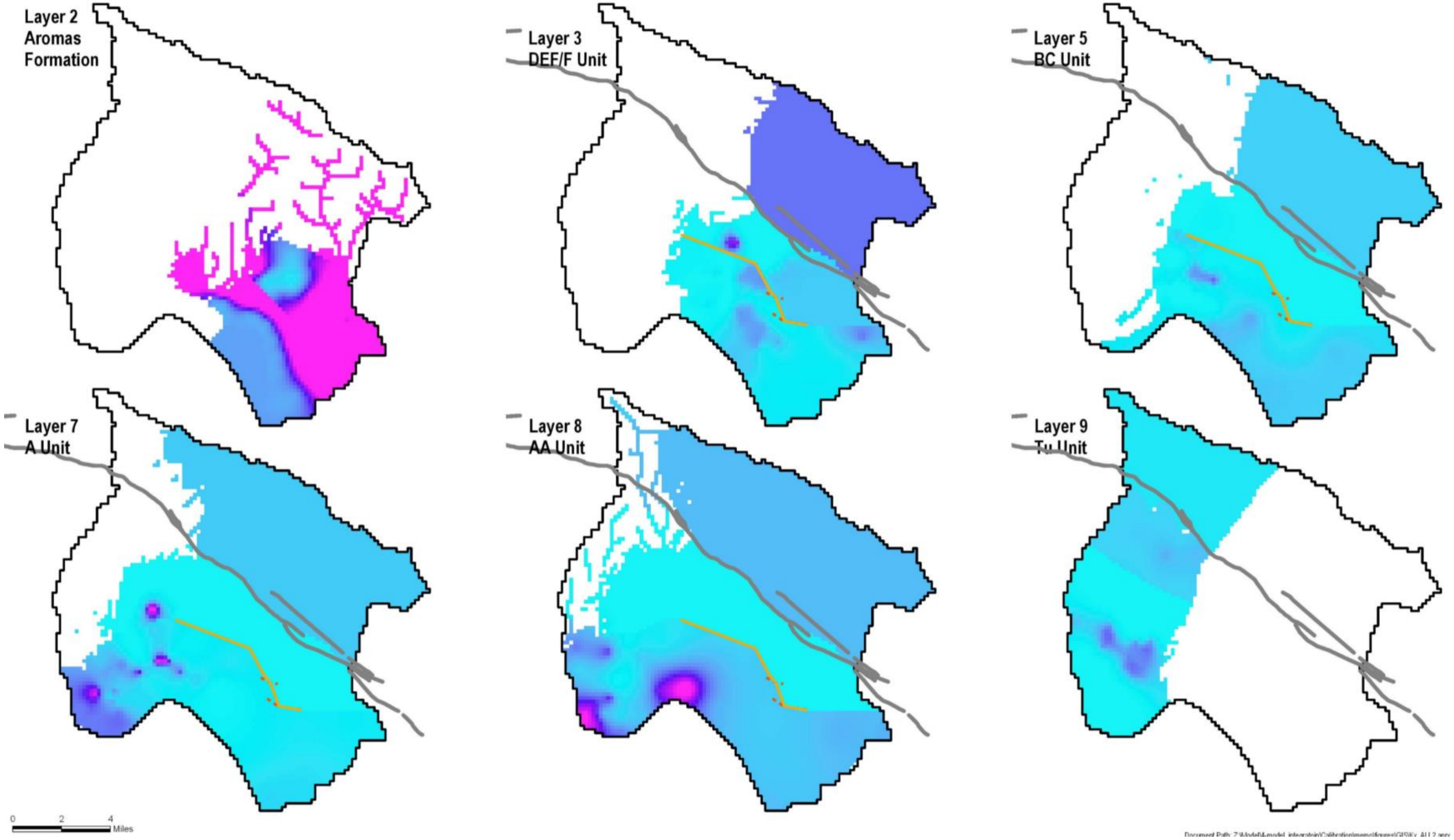






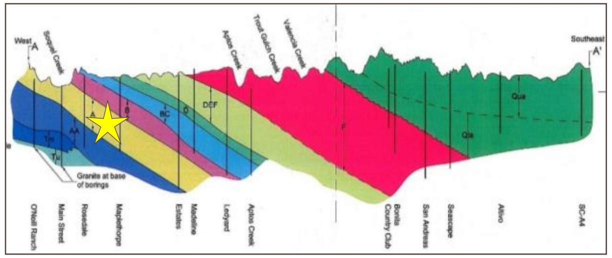
Spatial Heterogeneity of Conductivity, Storage

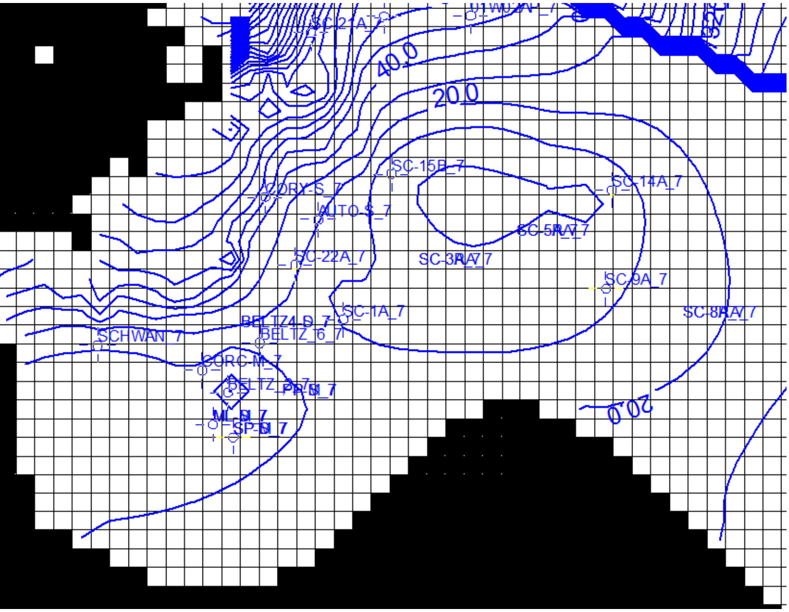
Horizontal Hydraulic Conductivity



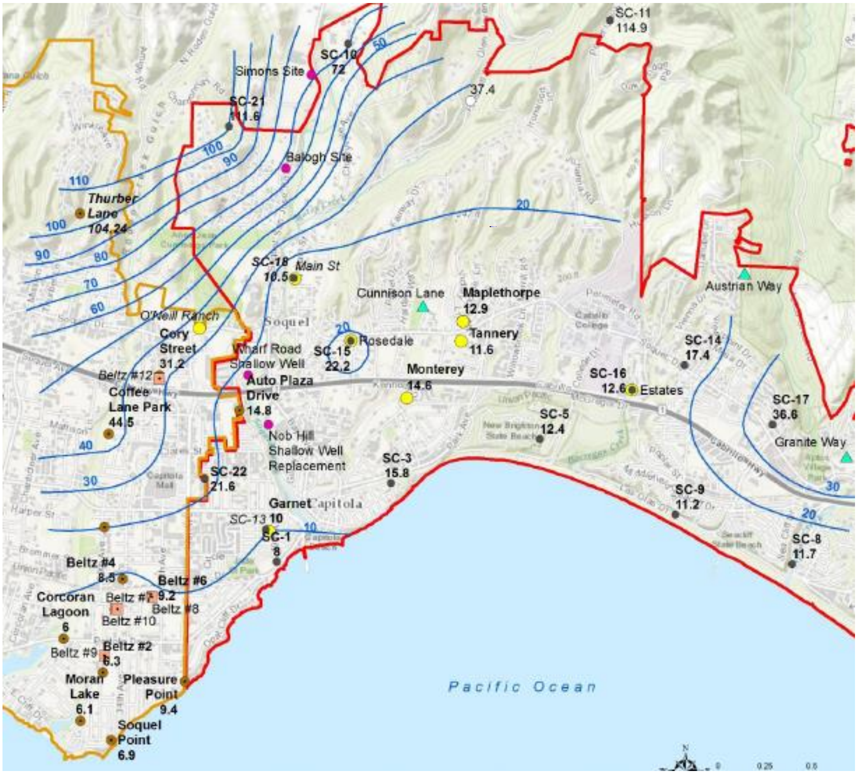
Preliminary Model, Subject to Revision

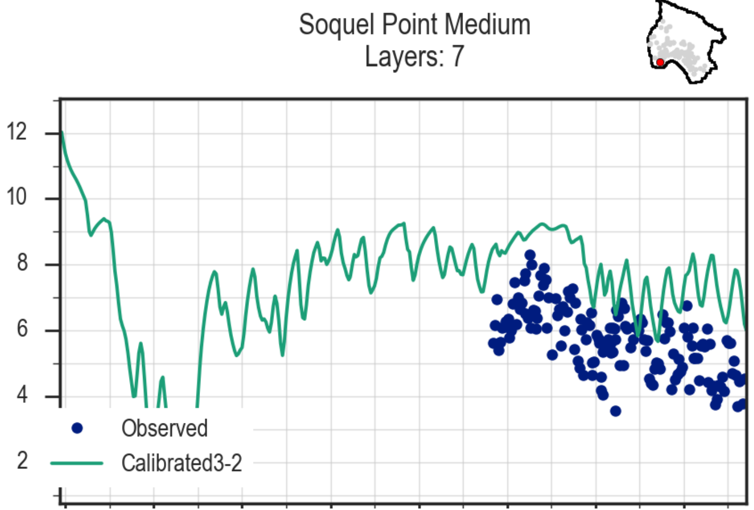
Calibration Example – Purisima A

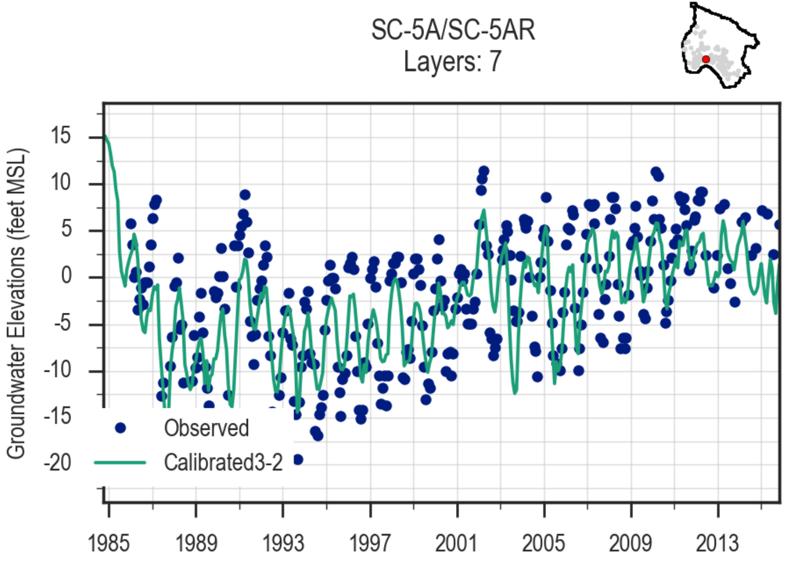




BRR, Spring 2016

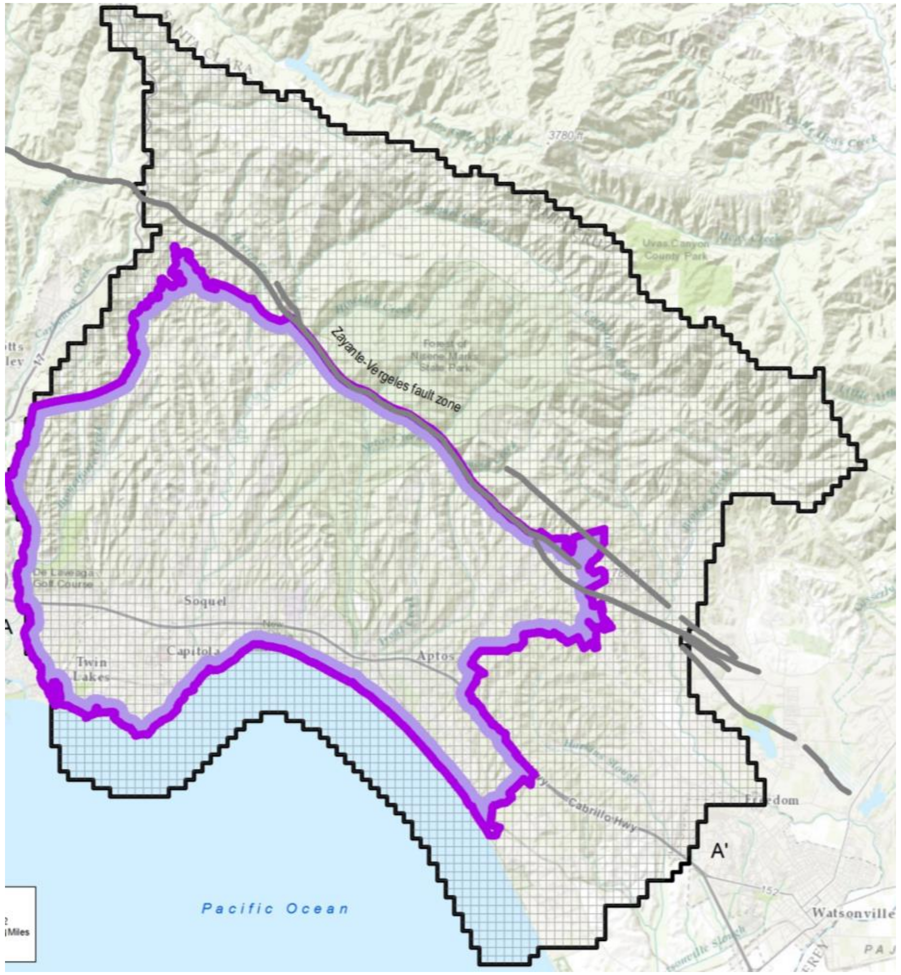


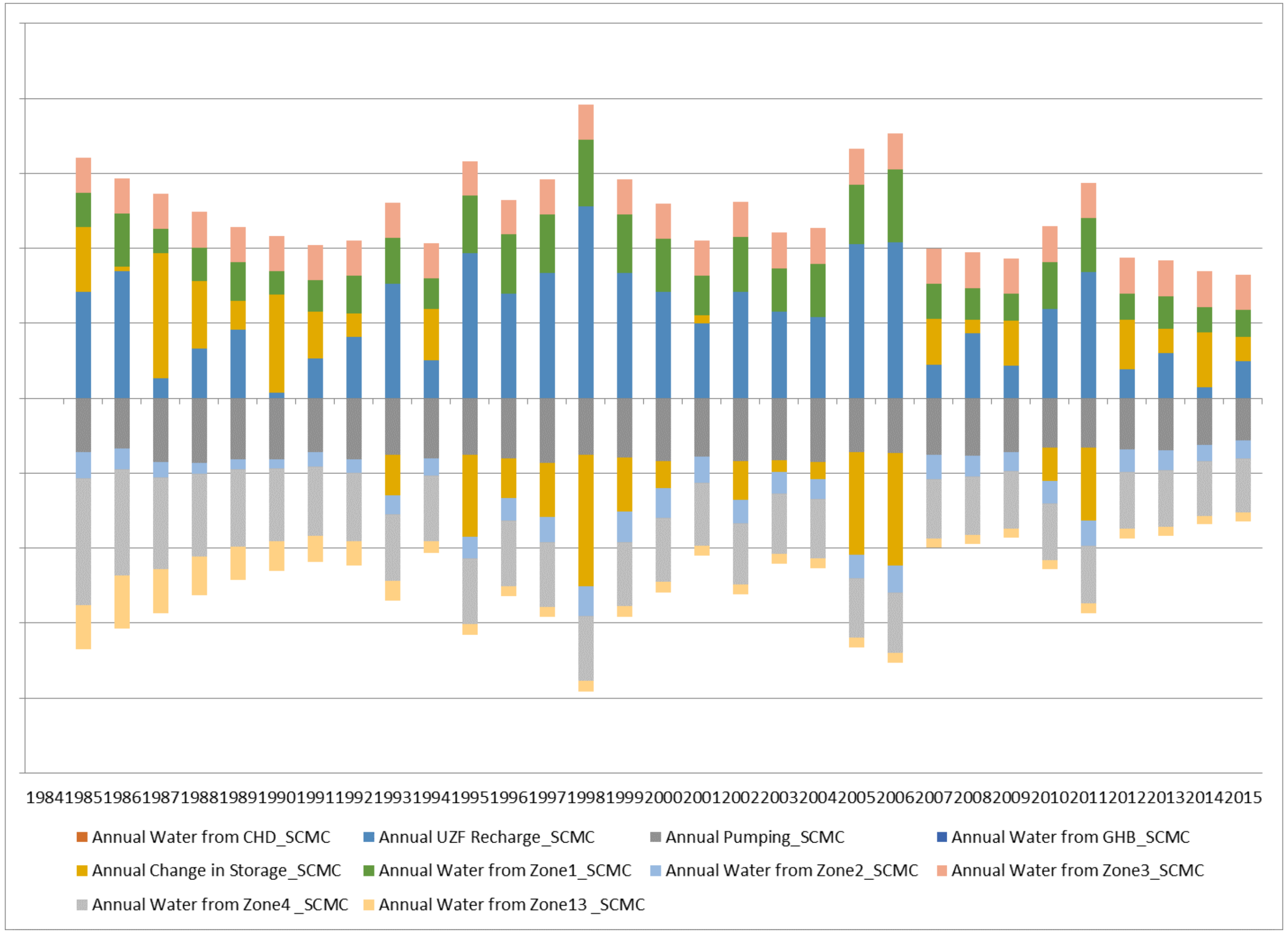




Preliminary Model, Subject to Revision

Groundwater Budget Example





SANTA CRUZ MID-COUNTY GROUNDWATER AGENCY

Preliminary Model, Subject to Revision

Questions on Groundwater Model?

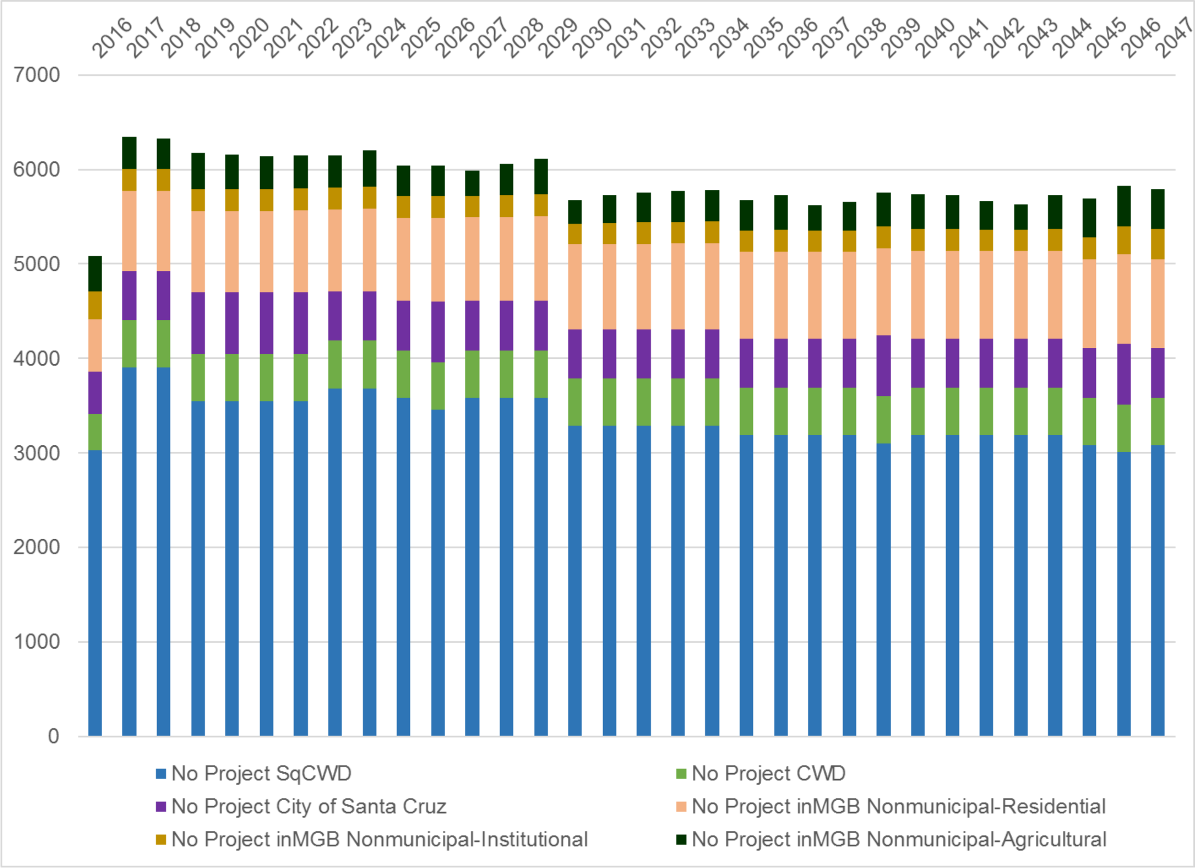
Modeling Future Projects and Climate Change

Groundwater Management Strategies

- No Projects
- Reduced pumping
  - Conservation
  - Transfer of Treated Surface Water
- Replenish basin with highly purified water
  - Evaluation for SqCWD's Pure Water Soquel EIR
- Aquifer Storage and Recovery (ASR) of Treated Surface Water
  - Evaluation for City of Santa Cruz ASR Study
- MGA likely to evaluate variations of Pure Water Soquel and ASR
  - Focus on basinwide sustainability

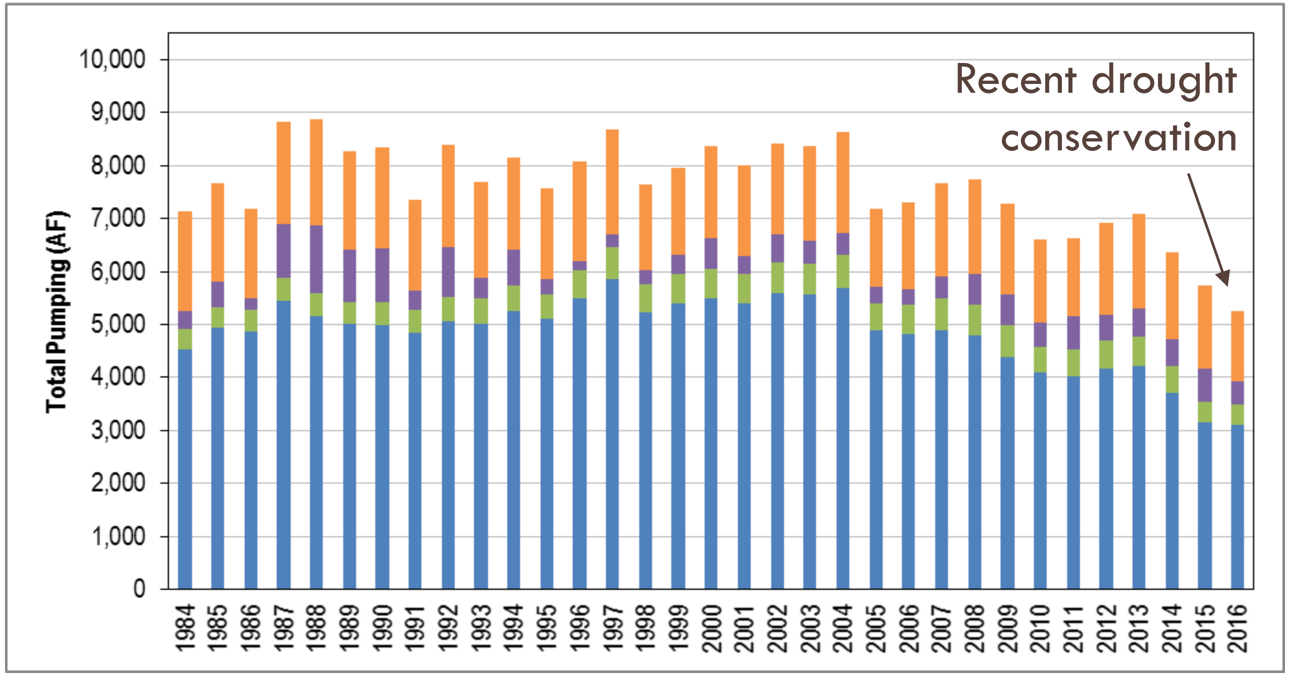
Groundwater Pumping Demand Assumptions

- CWD pre-drought average 2008-2011
- SqCWD Urban Water Management Plan projections
- City of Santa Cruz cooperative agreement
- Pre-drought estimates for non-municipal pumping


No Project Projected Pumping in Basin

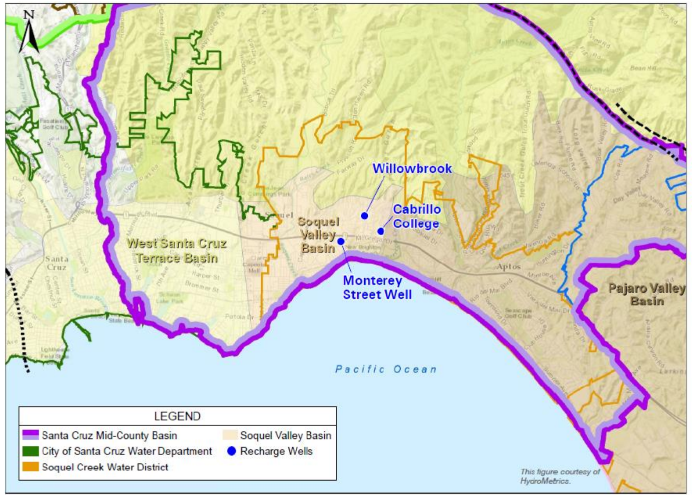
Reduced Pumping Simulation

- Demand based on conservation achieved or estimated in recent drought throughout basin
- Transfer of treated surface water from City to SqCWD



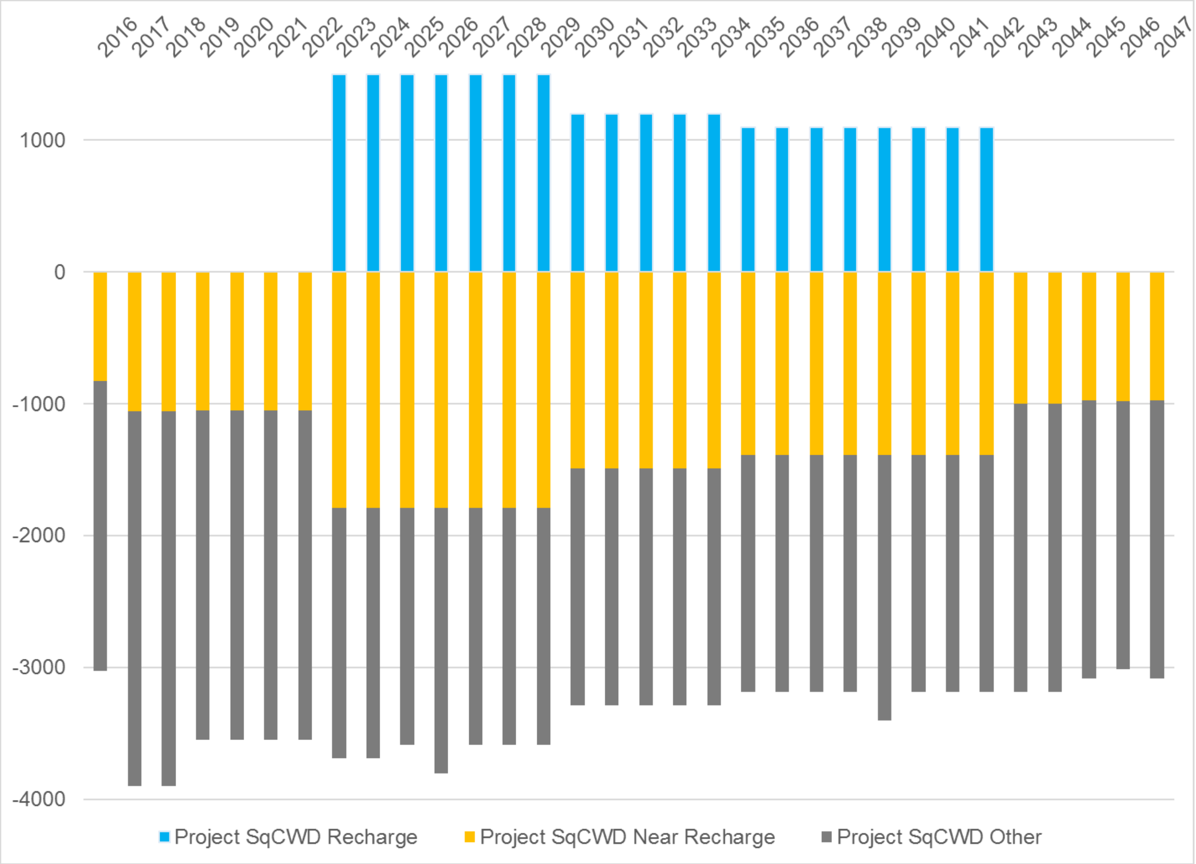
Pure Water Soquel

- Recharge into Purisima
- Redistribution of pumping
  - Increase pumping near recharge
  - Decrease pumping away from recharge
  - Decrease pumping near coast



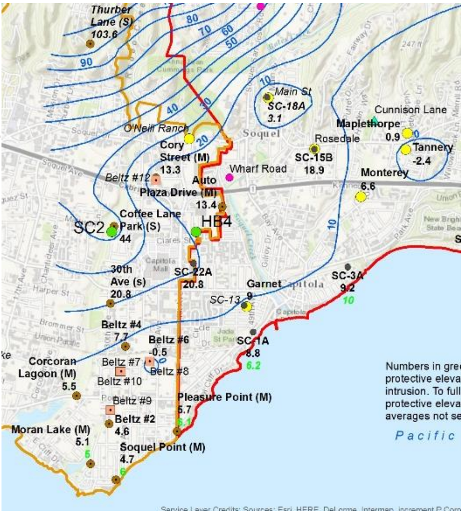
This figure courtesy of HydroMetrics.

SqCWD Replenishment and Pumping with Pure Water Soquel

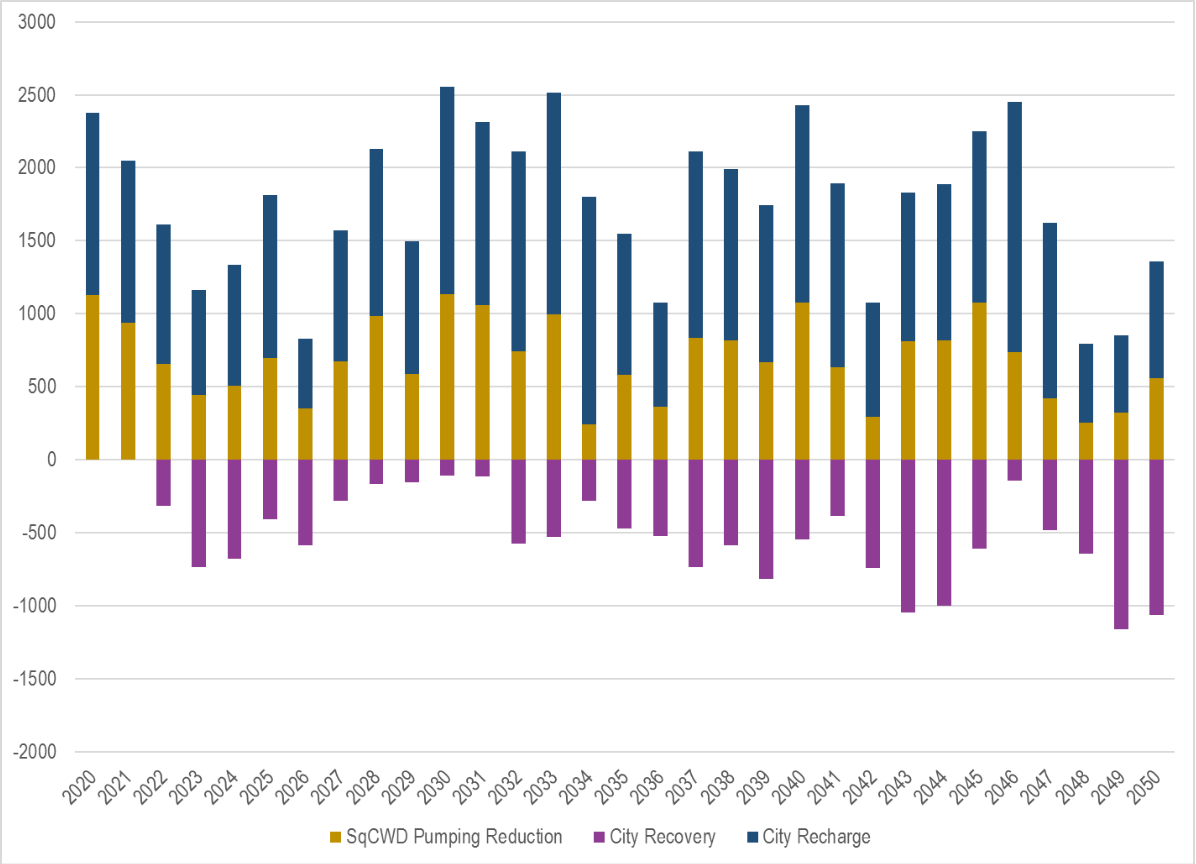


City of Santa Cruz Aquifer Storage Recovery

- Recharge in Purisima as storage to be extracted to meet surface water shortfalls
- 3 Scenarios
  - ☐ In-Lieu (reduce pumping at existing wells)
  - ☐ ASR (well recharge and extraction)
  - ☐ ASR + In-Lieu

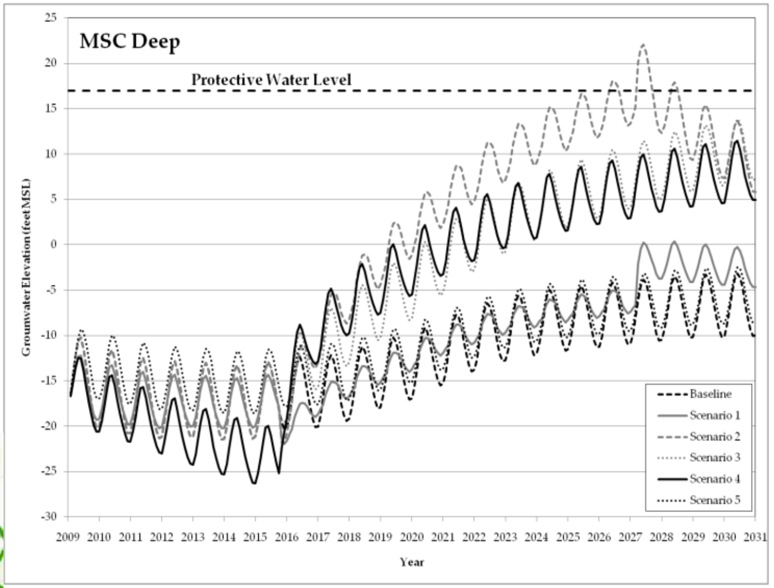


ASR + In-lieu Recharge and Recovery



Model Results Evaluation

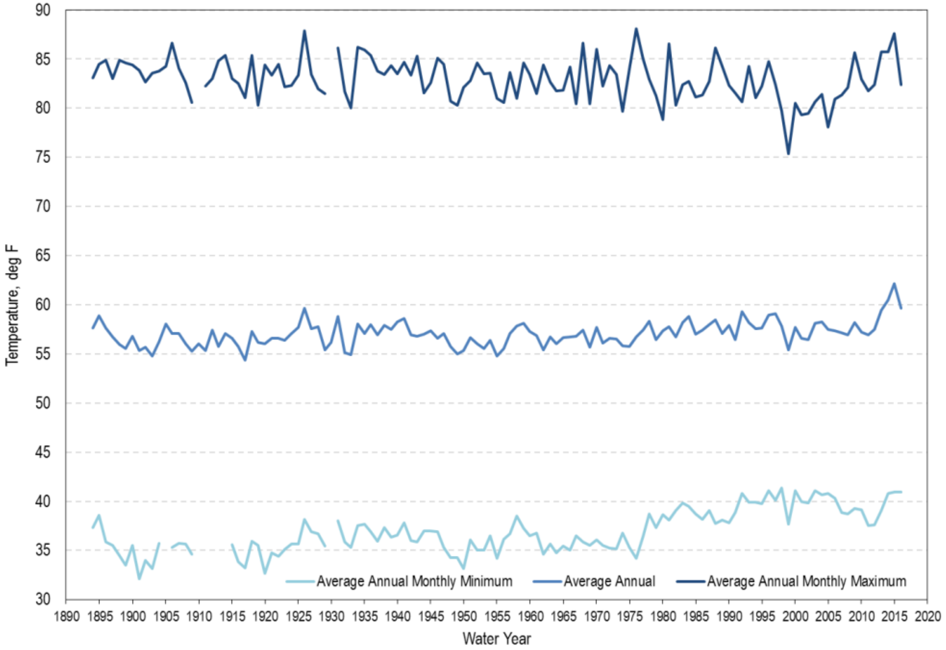
- Groundwater levels vs. sustainable management criteria proxies
- Water budget components like streamflow
- Particle tracking for Pure Water Soquel
- Seawater interface movement (2018)

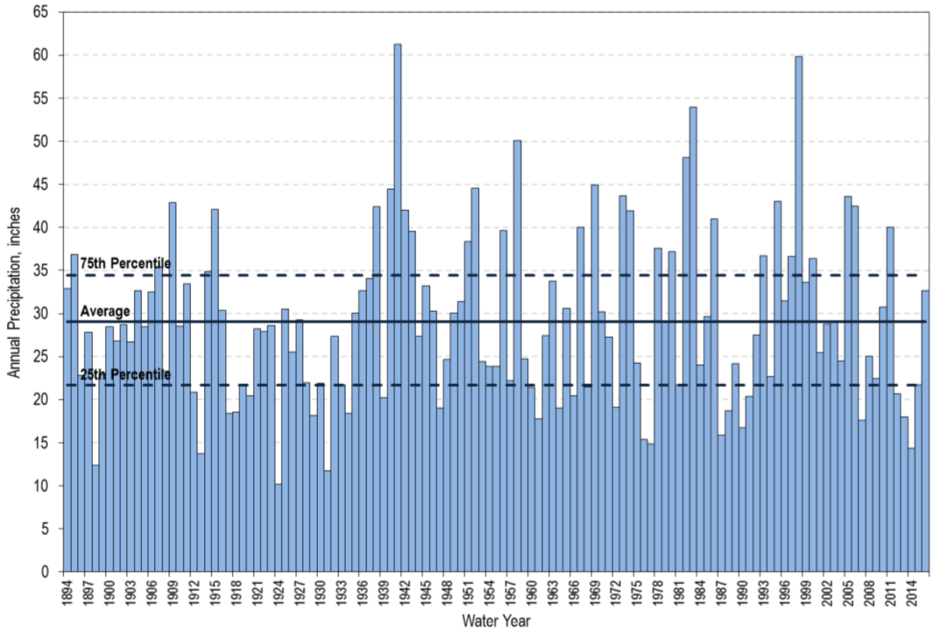


Examples from Seaside Basin

Future Climates

- Water Years 1985-2015
  - Calibration Period
- Water Years 1969-1984
  - Drought shortfall for City of Santa Cruz ASR
- Catalog Climate
  - Select mostly warm years from 1909-2016
- Downscaled Global Circulation Model GFDL2.1-A2
  - City of Santa Cruz WSAC
- Evaluate Ensemble of Global Circulation Models (GCM)

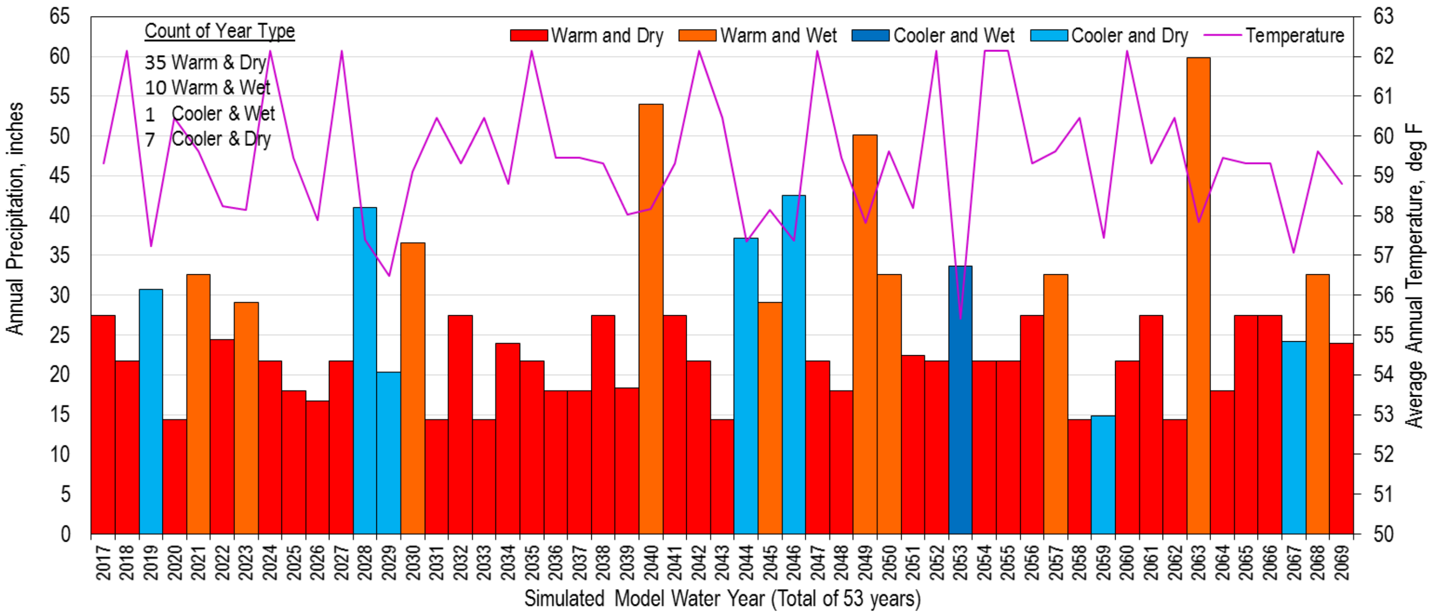




Catalog Climate

- Use historical data
- Suggested by Prof. Andy Fisher, UC Santa Cruz
- Approach followed by So. Cal. Metropolitan WD
- Weight selection of years based on temperature

Exceedance Probability Category	Weight
< 5%	0.5
5 – 25%	0.3
>=25 – 50%	0.1
> = 50%	0.1



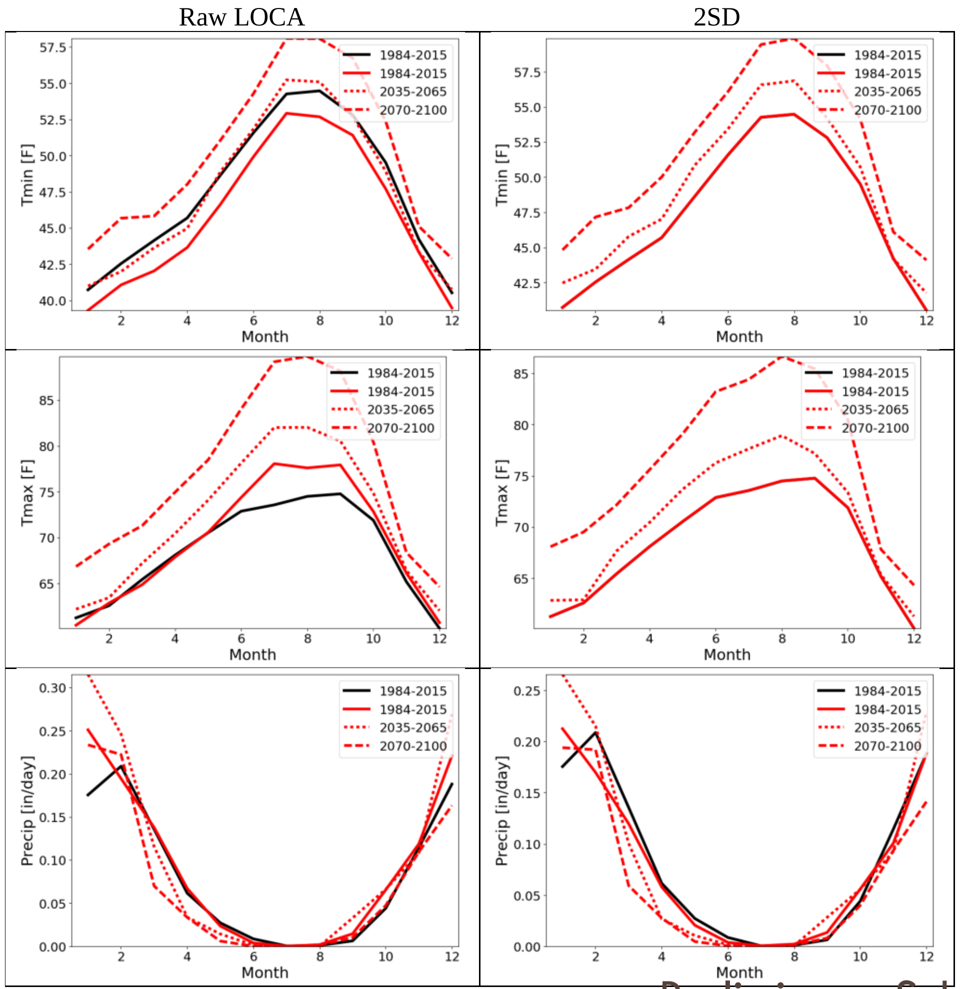
Annual Temperature, deg F	
Scenario Average	59.4
1985-2015 Average	57.9
1977-2016 Average	57.8
Pre-1977 Average	56.6
1894-2016 Average	57.0

Annual Precipitation, inches	
Scenario Average	26.0
1985-2015 Average	29.0
1977-2016 Average	29.9
Pre-1977 Average	28.7
1894-2016 Average	29.1

Downscaling GFDL2.1-A2

- Use Double Statistical Approach to Downscale temperature and rainfall from 6 km grid to stations used in PRMS
- Scoped for City of Santa Cruz ASR evaluations

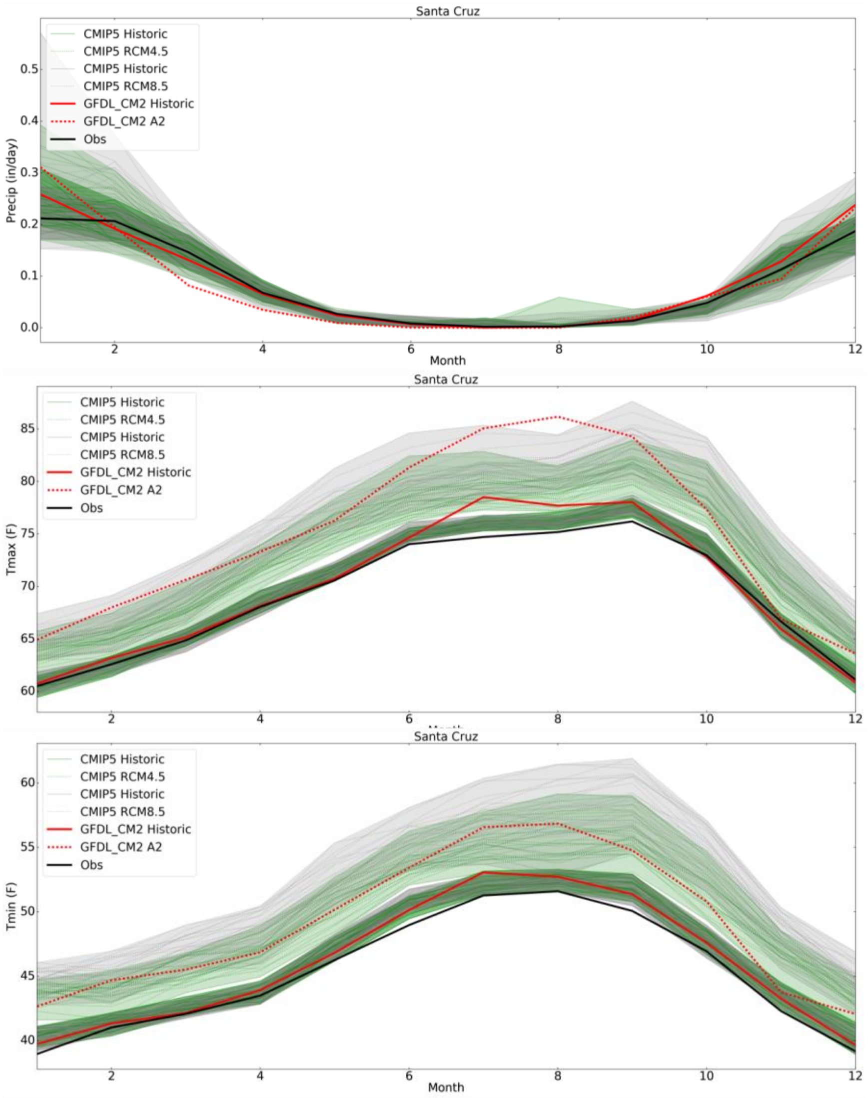
Downscaling at City of Santa Cruz



Preliminary, Subject to Revision

Evaluation of GCM Ensemble

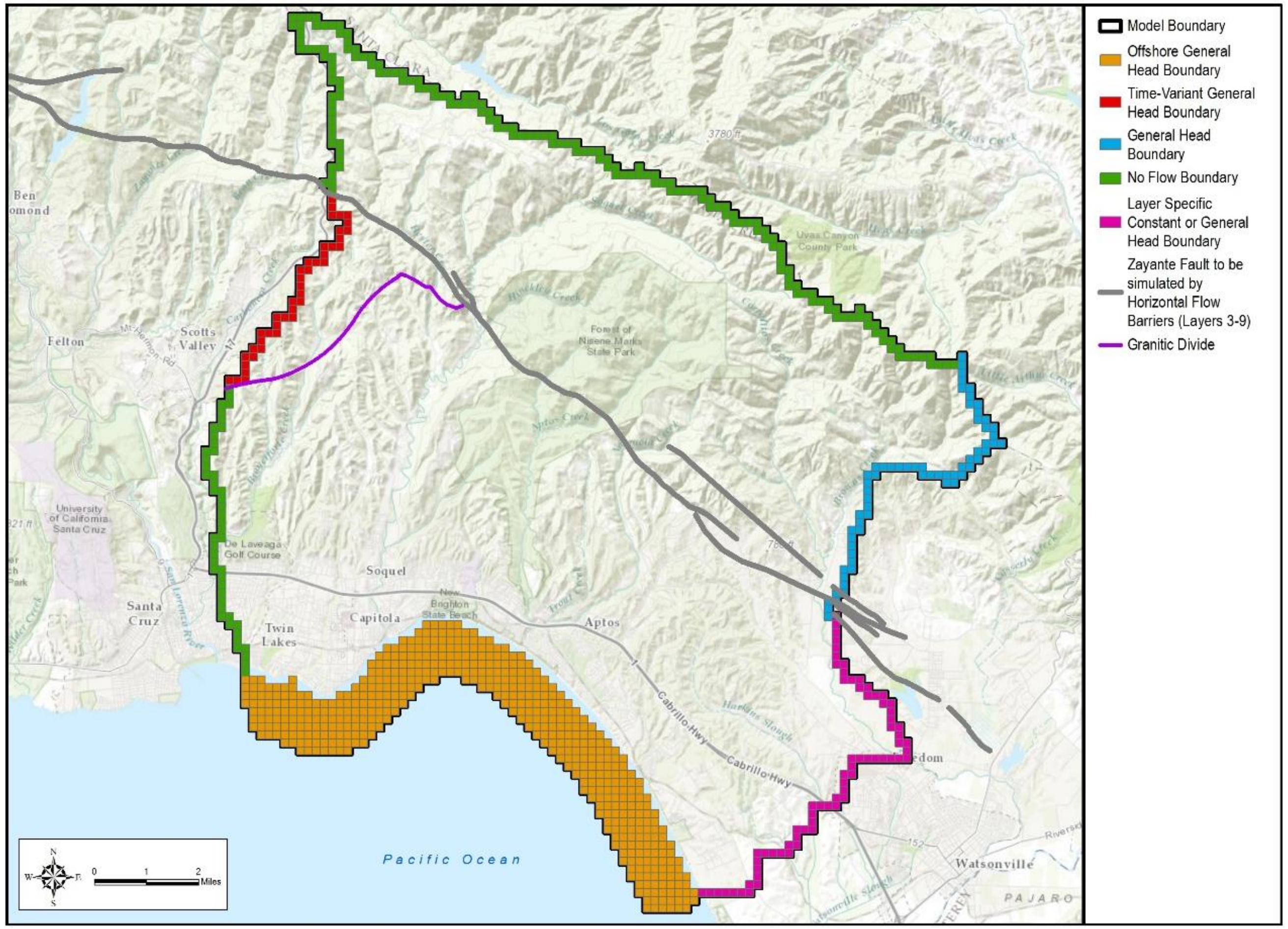
- GSP Regulations Require Evaluating Future Climate
- DWR Guidance Based on Water Storage Investment Program (WSIP)
  - Uses ensemble average
  - More conservative than ensemble average acceptable for GSP
- Evaluate ensemble to decide whether additional GCM should be downscaled for simulation



Preliminary, Subject to Revision

Sea Level Rise

- Based on mean projections from National Research Council 2012 report
  - Similar to WSIP
- 2070 vs 2000: +1.5 feet
- Applied at offshore General Head Boundary
- Sea level rise may propagate inland in confined aquifers resulting in little net effect (Chang et al, 2011)



Next Steps for MGA

- Document calibration for Technical Advisory Committee
  - Andy Fisher, PhD, UC Santa Cruz (Earth and Planetary Sciences)
  - Barry Hecht, PG, CEG, CHg, Balance Hydrologics, Inc.
  - Brian Lockwood, PG, CHg, Pajaro Valley Water Management Agency
  - Bruce Daniels, PhD (hydroclimatology), Soquel Creek Water District Board
  - Robert Marks, PG, CHg, Pueblo Water Resources Inc.
- Groundwater management simulations
  - Reduced pumping
  - Develop runs based on results of Pure Water Soquel and City ASR studies
- Evaluate climate change ensemble
- Model runs to evaluate effects of different groups of pumpers

Questions on Modeling Future Projects and Climate?

Thank you!