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One-Dimensional Model Simulation of Aquifer-System Deformation at the PX and MVWD-28 Sites

October 21, 2021

Scope-of-work to develop a subsidence management plan for Northwest MZ-1 (2021/22)

1. Construct and calibrate 1D compaction models in Northwest MZ-1.
   - Characterize the current (2018) pre-consolidation stress throughout the aquifer system.
   - Conduct GLMC meeting to review
   - Prepare TM to document
2. Run a “baseline” scenario using the 1D models to estimate future subsidence.
   - Use Chino Valley Model results from Safe Yield Reset simulation as 1D model input
   - Evaluate 1D Model results → Determine the need for subsidence management strategies
     - Possible strategies? → Recharge and/or modified pumping patterns
   - Recommend a “subsidence management” scenario
3. Run a “subsidence management” scenario using CVM and 1D Models
   - Evaluate 1D Model results → Determine the need for additional scenarios

Agenda

- Model Configuration
- Model Calibration
- Simulated Compaction and Critical Head
- Next Steps

Agenda

Model Configuration

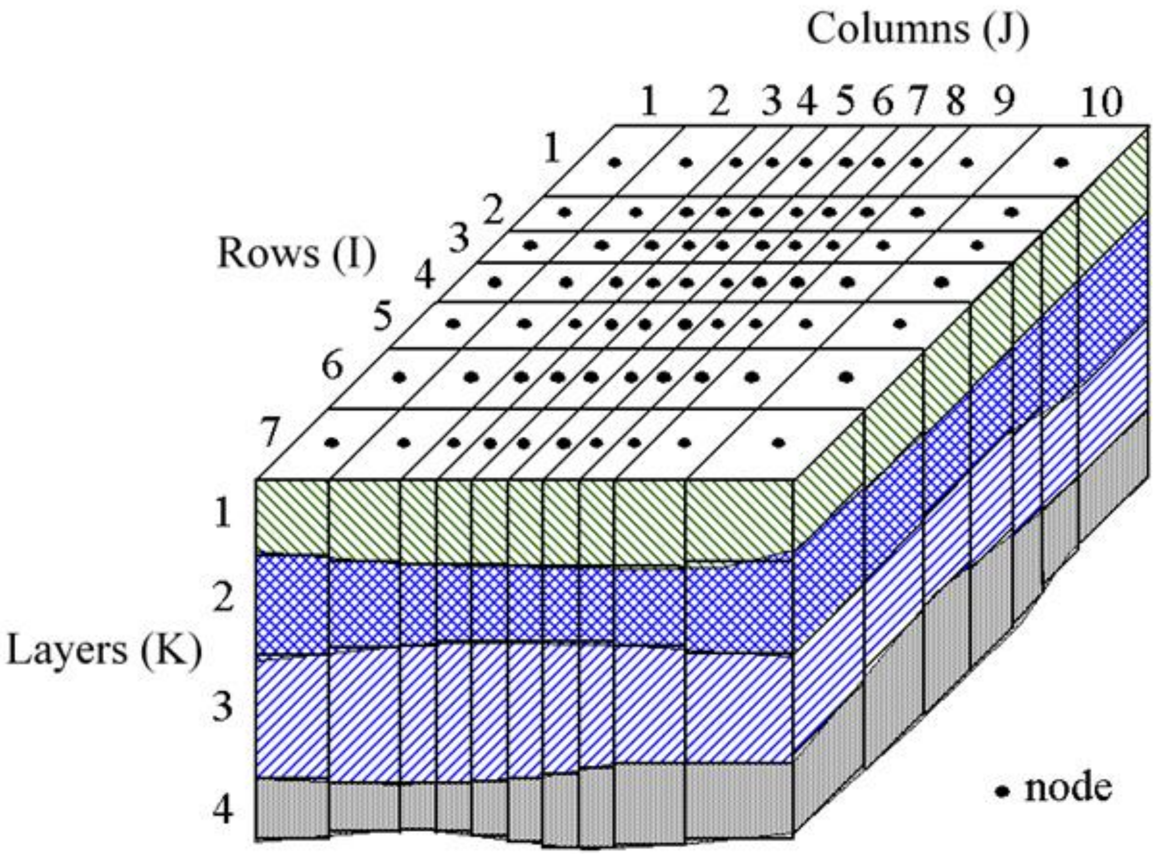
- How does a 3D groundwater model work and why 1D model?
- Simulation of land subsidence with a 1D model.

Calibration

Compaction and Critical Head

How does a groundwater flow model work?

A Discretized Hypothetical Aquifer System



- Each block is a model cell.
- Head values at cell centers (nodes) are unknown and are calculated as follows:
  1. A water balance equation is formulated for each cell.
  2. Each equation involves the hydraulic conductivity, specific storage, cell geometry, and the unknown head values at the cell and its neighbors.
  3. The set of all equations are solved simultaneously for the unknown head values.
- Calculated heads are used to determine compaction, flows between cells, etc.

Water Balance for a Saturated Cell

$$\Sigma Q = S_s \cdot \frac{\Delta h}{\Delta t} \cdot V + S' \cdot \frac{\Delta h}{\Delta t} \qquad \text{(equation 1)}$$

Sum of all fluxes = storage change.

ΣQ: Sum of all fluxes across cell faces, pumping, recharge, etc.

S_s: Specific storage of the cell. Accounts for the compressibility of water. Volume of water that can be released per unit volume of aquifer material per unit change in head.

S' : Elastic or inelastic storage factor of the cell. Accounts for the skeleton compressibility of soil matrix.

Δh: Change in head in the cell over a time interval of length Δt

V: Volume of the cell

Skeleton Storage Coefficient

$$S' = S_{fe} \quad \text{if } h > h_c$$

$$S' = S_{fv} \quad \text{if } h \le h_c$$

(equation 2)

S_{fe} is the elastic skeleton storage coefficient.

S_{fv} is the inelastic skeleton storage coefficient.

h is the hydraulic head.

h_c is the preconsolidation/critical head (i.e., previous lowest hydraulic head).

Usually, $S_{fv} >> S_{fe}$

Computing the Deformation in a Model Cell

Elastic $\Delta b = S_{fe} \cdot \Delta h \quad if\ h > h_c$ (equation 3)

Inelastic $\Delta b = S_{fv} \cdot \Delta h \ \ if\ h \leq h_c$

Δb is the (elastic or inelastic) deformation/compaction over a time interval.

Δh is the change in hydraulic head over a time interval.

Challenges of 3D Models:

Inadequate Vertical Resolution – CVM has only five layers.

Agenda

Model Configuration

How does a 3D groundwater model work and why 1D model?

Simulation of land subsidence with a 1D model.

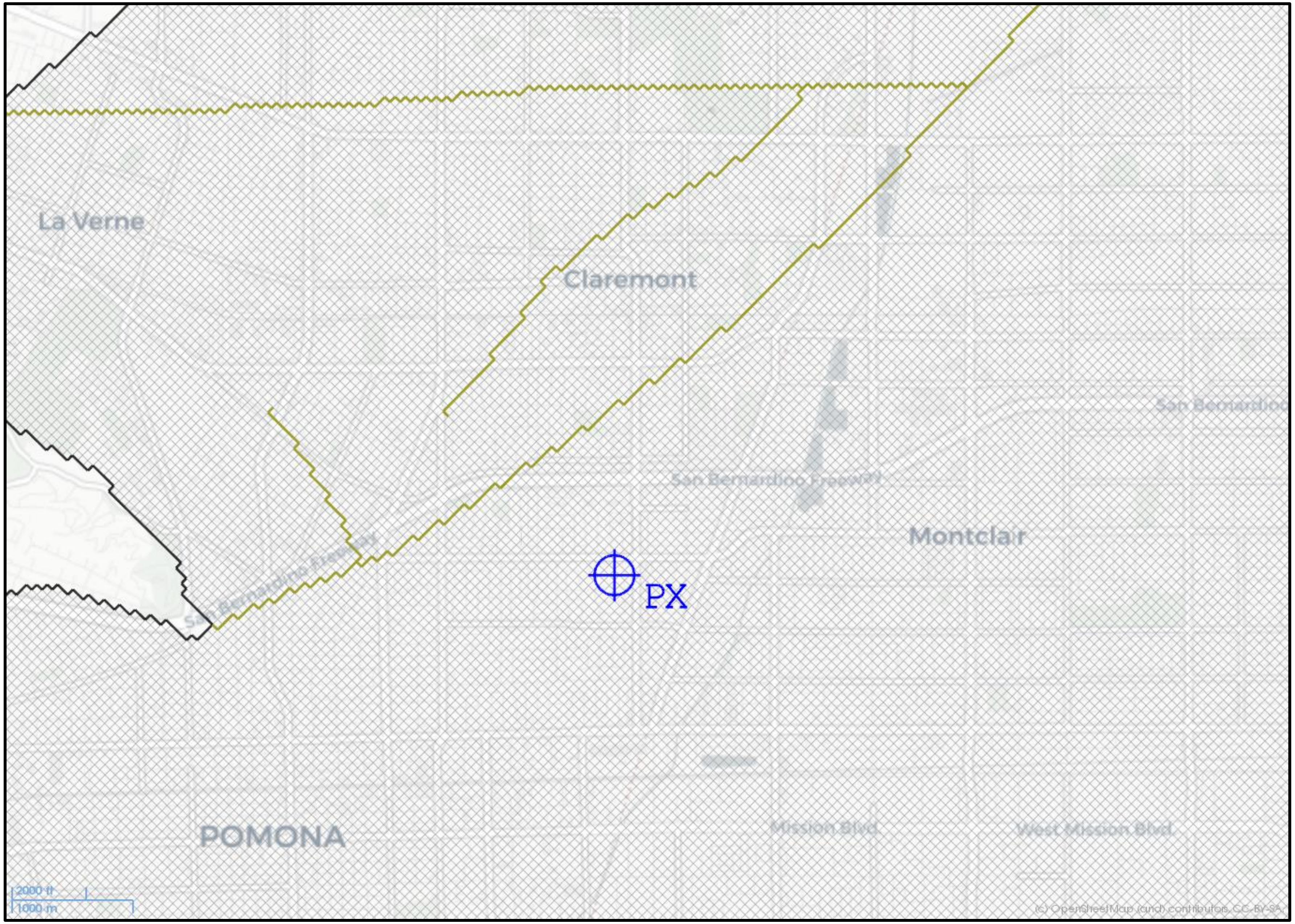
Model Calibration

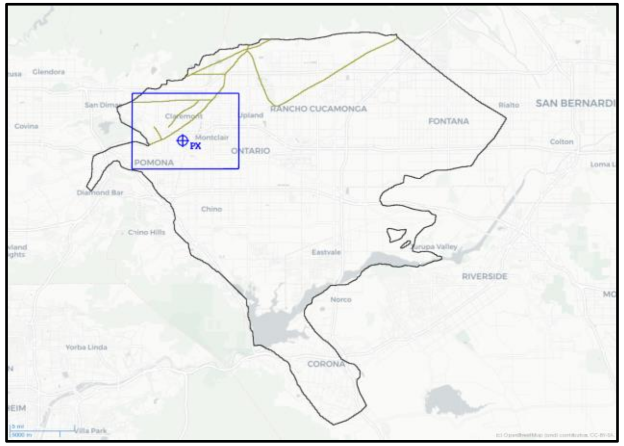
Simulated Compaction and Critical Head

Steps for the Simulation of Aquifer-System Deformation With a 1D Model

1. A 3D groundwater flow model is developed (without the skeleton compressibility terms).
2. Within the 3D model domain, a site with lithological log is chosen for the 1D model.
3. A 1D model with a vertical stack of cells is constructed. The model cells are categorized into either Sand (for coarse grain materials) or Clay (for fine grain materials) based on the lithological log.
4. Initial model parameters of Sand and Clay are assigned to the cells accordingly.
5. Heads from the 3D model are assigned as prescribed heads to the corresponding Sand cells in the 1D model.
6. The 1D model simulation is executed and the time-series of compaction of the cells are computed.

Locations of the PX-Site





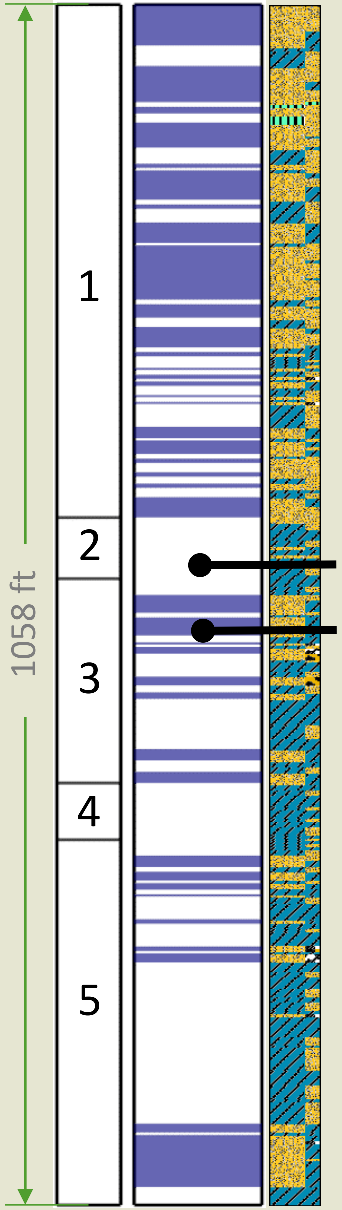
Configuration of the One-Dimensional Aquifer-System Deformation Model at the PX-Site

Three-Dimensional Chino Valley Model:

Five Layers

From 1930 to 1977, observed or model simulated heads in each of the 5 layers were assigned to the corresponding sand cells in the 1D model.

From 1977 to 2018, simulated heads of the CVM were assigned to the corresponding sand cells in the 1D model.



One-Dimensional Model:

Starting Head = 750 ft

Simulation Time: 1930-2018

Discretization: 529 Cells

Each Cell = 2ft thick

Agenda

Model Configuration

Model Calibration

Adjust model parameters to minimize the differences between the modeled and observed land subsidence values.

Simulated Compaction and Critical Head

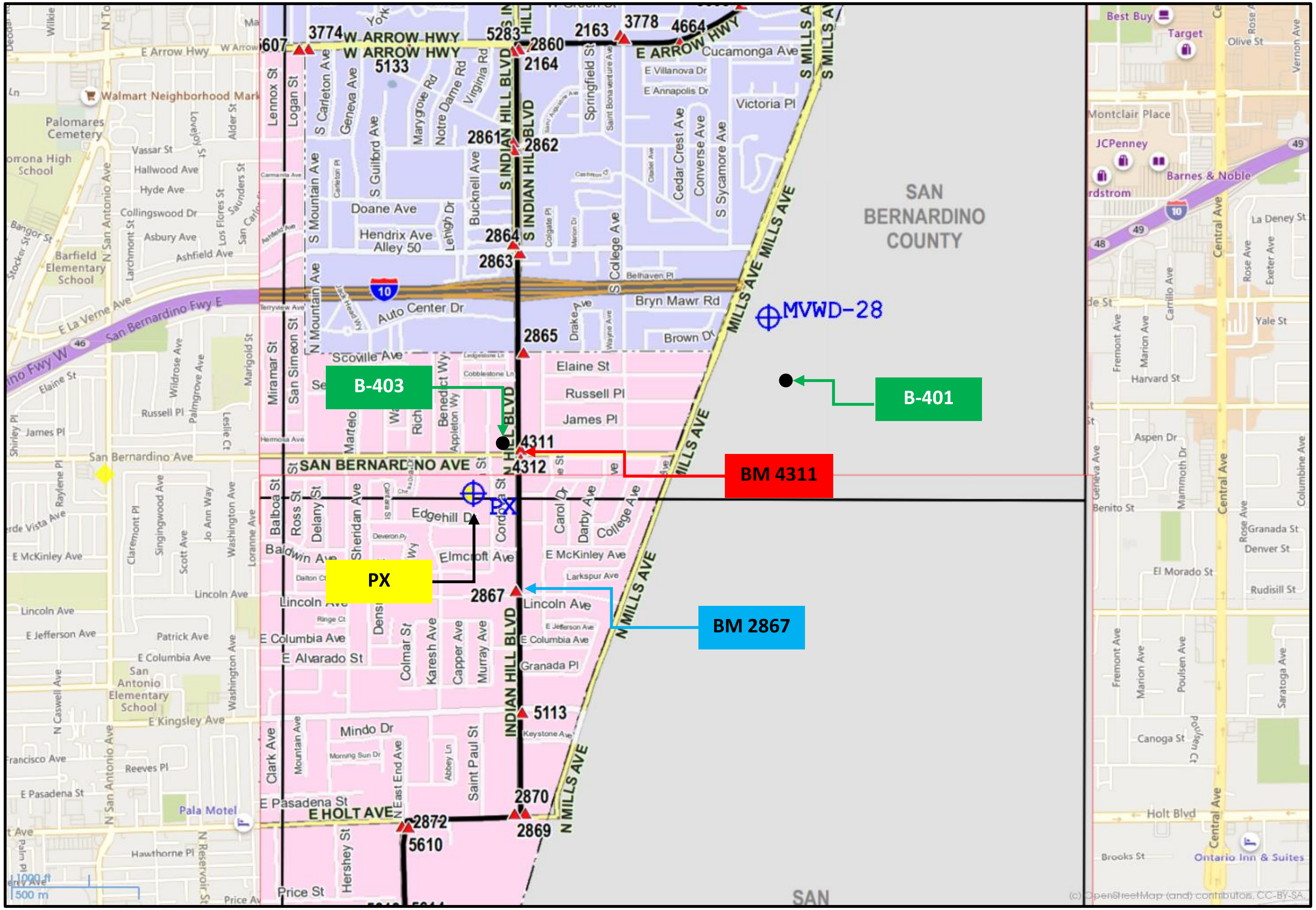
Observed Land Subsidence Values

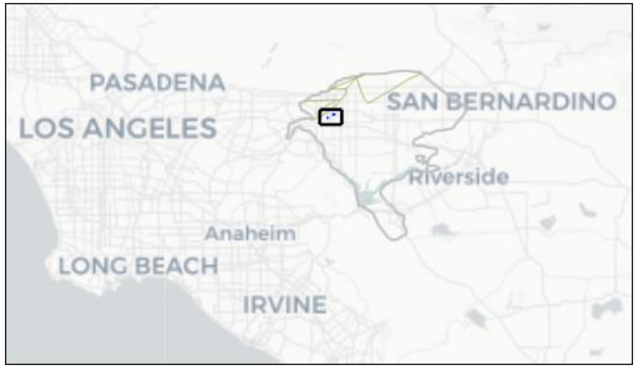
InSAR at PX and MVWD-28: 1992 to 1999, 2005 to 2020

LADPW Benchmarks 2687 and 4311: 1990 to 2013

Benchmarks B-401 and B-403: 2013 to 2021

Locations of the PX Site, MVWD-28, and Nearby Benchmarks





Model Parameters Adjusted During Calibration

VK: Vertical hydraulic conductivity.

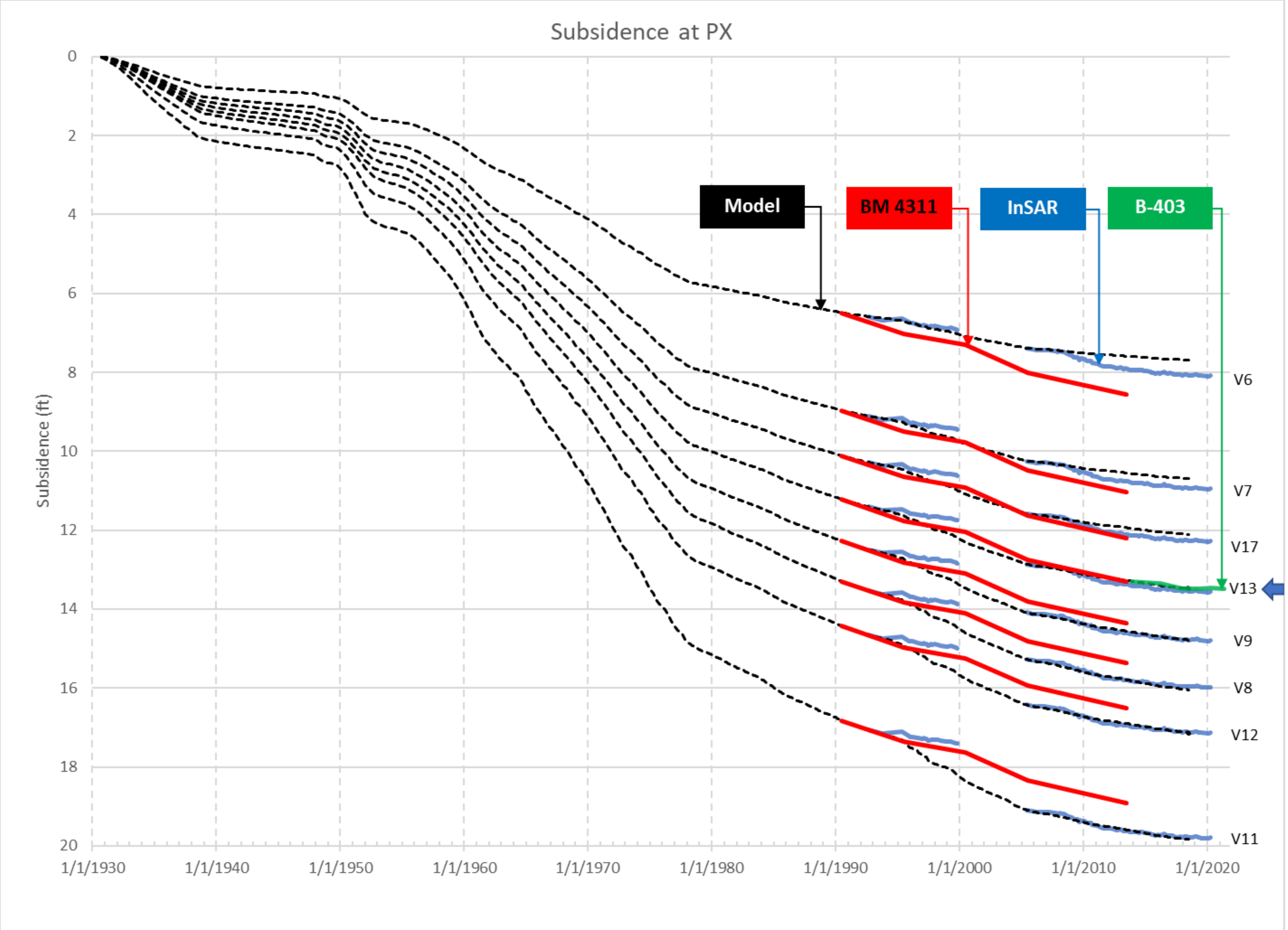
S_s: Specific storage.

S_{fe}: Elastic storage coefficient.

S_{fv}: Inelastic storage coefficient.

Model Parameters Adjusted During Calibration

Model Versions	Sand				Clay			
	VK [ft/day]	Ss [1/ft]	Sfv [-]	Sfe [-]	VK [ft/day]	Ss [1/ft]	Sfv [-]	Sfe [-]
V1 (baseline)	5.000E-01	1.830E-06	1.000E-06	1.000E-06	2.000E-05	1.140E-05	1.650E-04	4.500E-06
V2	5.000E-01	1.830E-06	1.000E-06	1.000E-06	1.000E-05	1.140E-05	1.650E-04	4.500E-06
V3	5.000E-01	1.830E-06	1.000E-06	1.000E-06	1.000E-06	1.140E-05	1.650E-04	4.500E-06
V3a	5.000E-01	1.830E-06	1.000E-06	1.000E-06	1.000E-06	5.000E-06	1.650E-04	4.500E-06
V3b	5.000E-01	1.830E-06	1.000E-06	1.000E-06	1.000E-06	7.000E-06	1.650E-04	4.500E-06
V4	5.000E-01	1.830E-06	1.000E-06	1.000E-06	2.000E-05	1.140E-05	1.000E-04	4.500E-06
V5	5.000E-01	1.830E-06	1.000E-06	1.000E-06	2.000E-05	1.140E-05	2.000E-04	4.500E-06
V6	5.000E-01	1.830E-06	1.000E-06	1.000E-06	1.000E-06	1.140E-05	2.000E-04	4.500E-06
V7	**5.000E-01**	**1.830E-06**	**1.000E-06**	**1.000E-06**	**1.000E-06**	**1.140E-05**	**3.000E-04**	**8.000E-06**
V8	5.000E-01	1.830E-06	1.000E-06	1.000E-06	1.000E-06	1.140E-05	5.000E-04	8.000E-06
V9	5.000E-01	1.830E-06	1.000E-06	1.000E-06	1.000E-06	1.140E-05	4.500E-04	4.500E-06
V10	5.000E-01	1.830E-06	1.000E-06	1.000E-06	5.000E-06	1.140E-05	4.500E-04	8.000E-06
V11	5.000E-01	1.830E-06	1.000E-06	1.000E-06	5.000E-06	5.000E-05	4.500E-04	8.000E-06
V12	5.000E-01	1.830E-06	1.000E-06	1.000E-06	2.000E-06	1.140E-05	4.500E-04	4.500E-06
V13	**5.000E-01**	**1.830E-06**	**1.000E-06**	**1.000E-06**	**1.000E-06**	**1.140E-05**	**4.000E-04**	**4.500E-06**
V14	5.000E-01	1.830E-06	1.000E-06	1.000E-06	1.000E-06	7.000E-06	4.000E-04	4.500E-06
V15	5.000E-01	1.830E-06	1.000E-06	1.000E-06	6.000E-07	1.140E-05	4.500E-04	4.500E-06
V16	5.000E-01	1.830E-06	1.000E-06	1.000E-06	8.000E-07	1.140E-05	4.500E-04	4.500E-06
V17	5.000E-01	1.830E-06	1.000E-06	1.000E-06	1.000E-06	1.140E-05	3.500E-04	8.000E-06
V18	5.000E-01	1.830E-06	1.000E-06	1.000E-06	1.000E-06	1.140E-05	4.000E-04	2.000E-06
V19	5.000E-01	1.830E-06	1.000E-06	1.000E-06	4.000E-05	1.140E-05	1.000E-04	4.500E-06
Notes	VK = Vertical Hydraulic Conductivity [ft/day] Ss = Specific Storage[1/ft] Sfv = Inelastic Storage Factor [-] Sfe = Elastic Storage Factor [-]				Representative Values of VK: 7.5E-8 to 8.6E-4 [ft/day]	Representative Values of Storage Factor: 2.8E-4 to 6.2E-3		



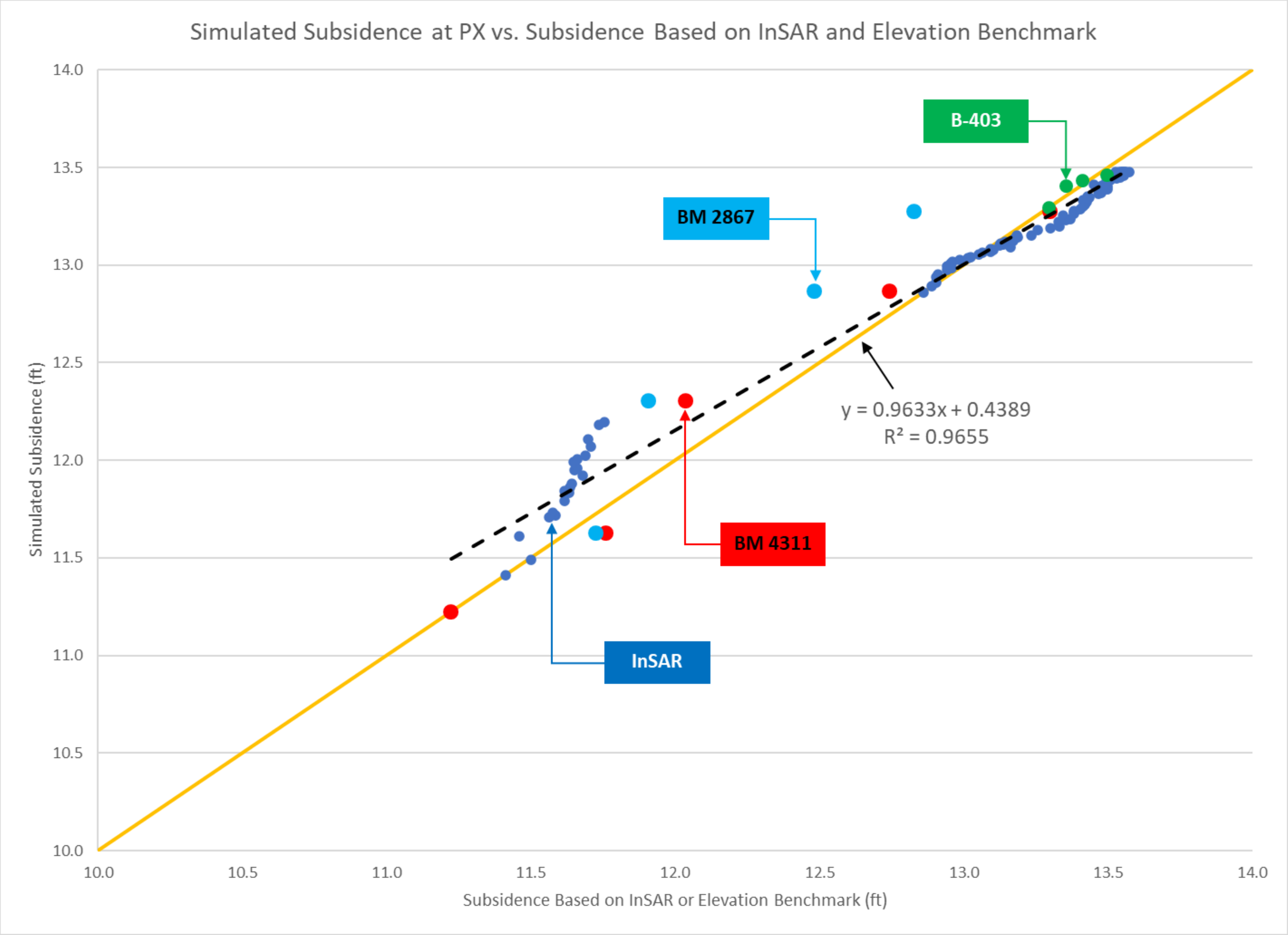
At PX Site

Simulated vs. Measured Land Subsidence

InSAR data: 1992 to 2020.

BM 2867 and BM 4311: 1990 to 2013.

B-403: 2013 to 2021



At PX Site

Simulated vs. Measured Land Subsidence

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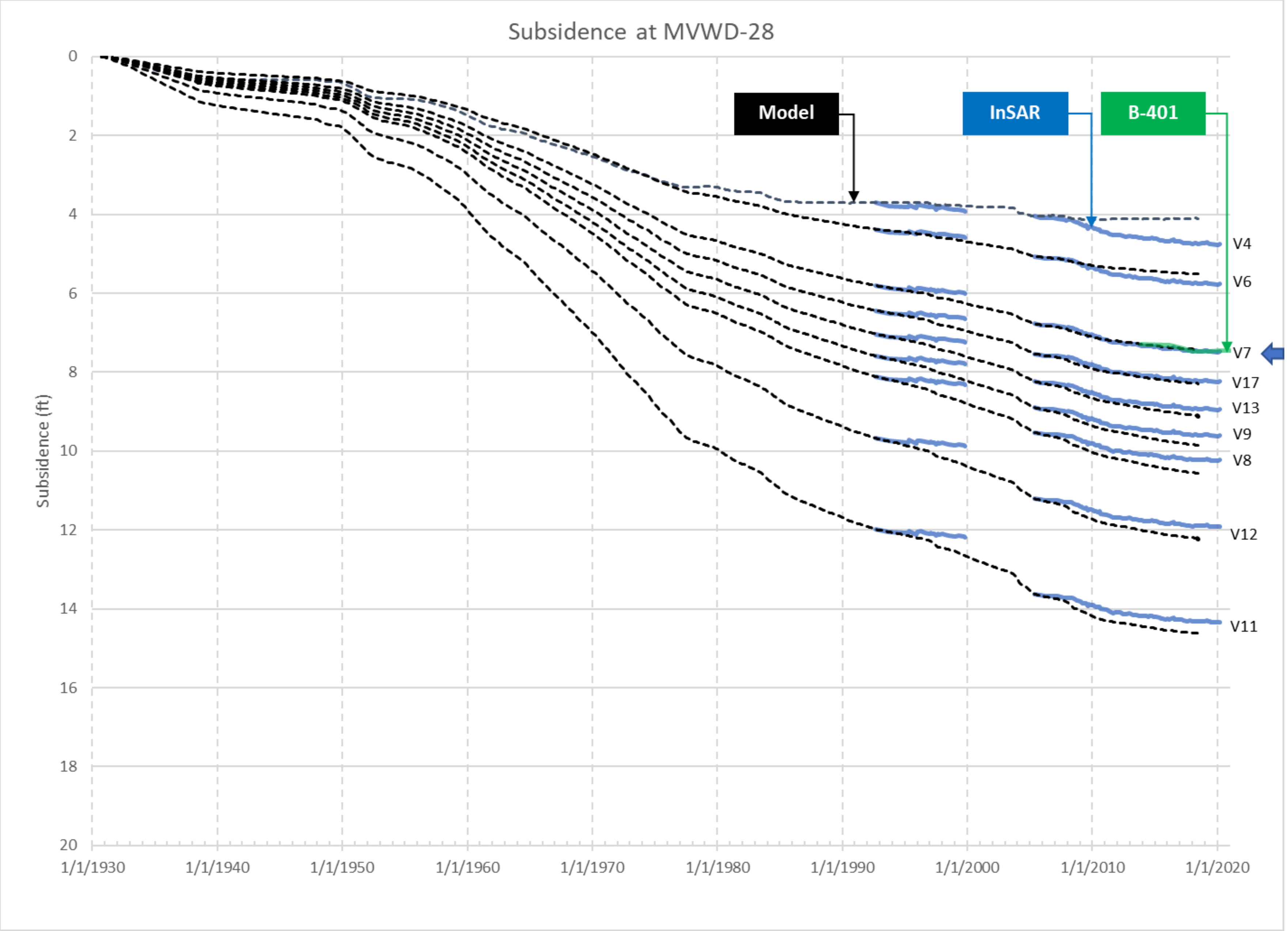
At MVWD-28

Simulated vs. Measured Land Subsidence



InSAR data: 1992 to 2020.

B-401: 2013 to 2021

At MVWD-28

Simulated vs. Measured Land Subsidence

InSAR data: 1992 to 2020.

B-401: 2013 to 2021

Calibrated Model Parameters

Model Versions	Clay			
	VK [ft/day]	Ss [1/ft]	Sfv [-]	Sfe [-]
V7	1.000E-06	1.140E-05	3.000E-04	8.000E-06
V13	1.000E-06	1.140E-05	4.000E-04	4.500E-06

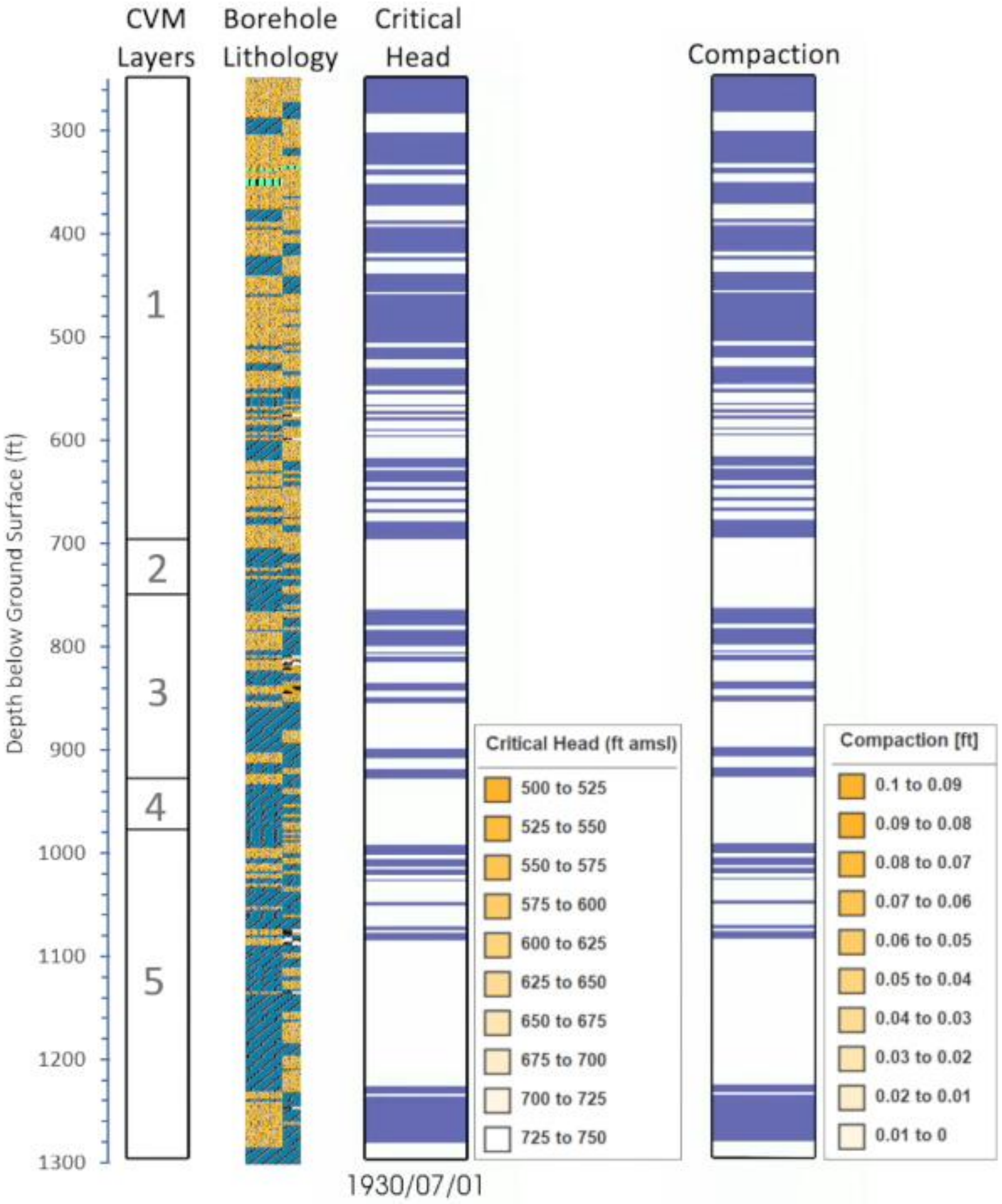
Agenda

Model Configuration

Model Calibration

Simulated Compaction and Critical Head

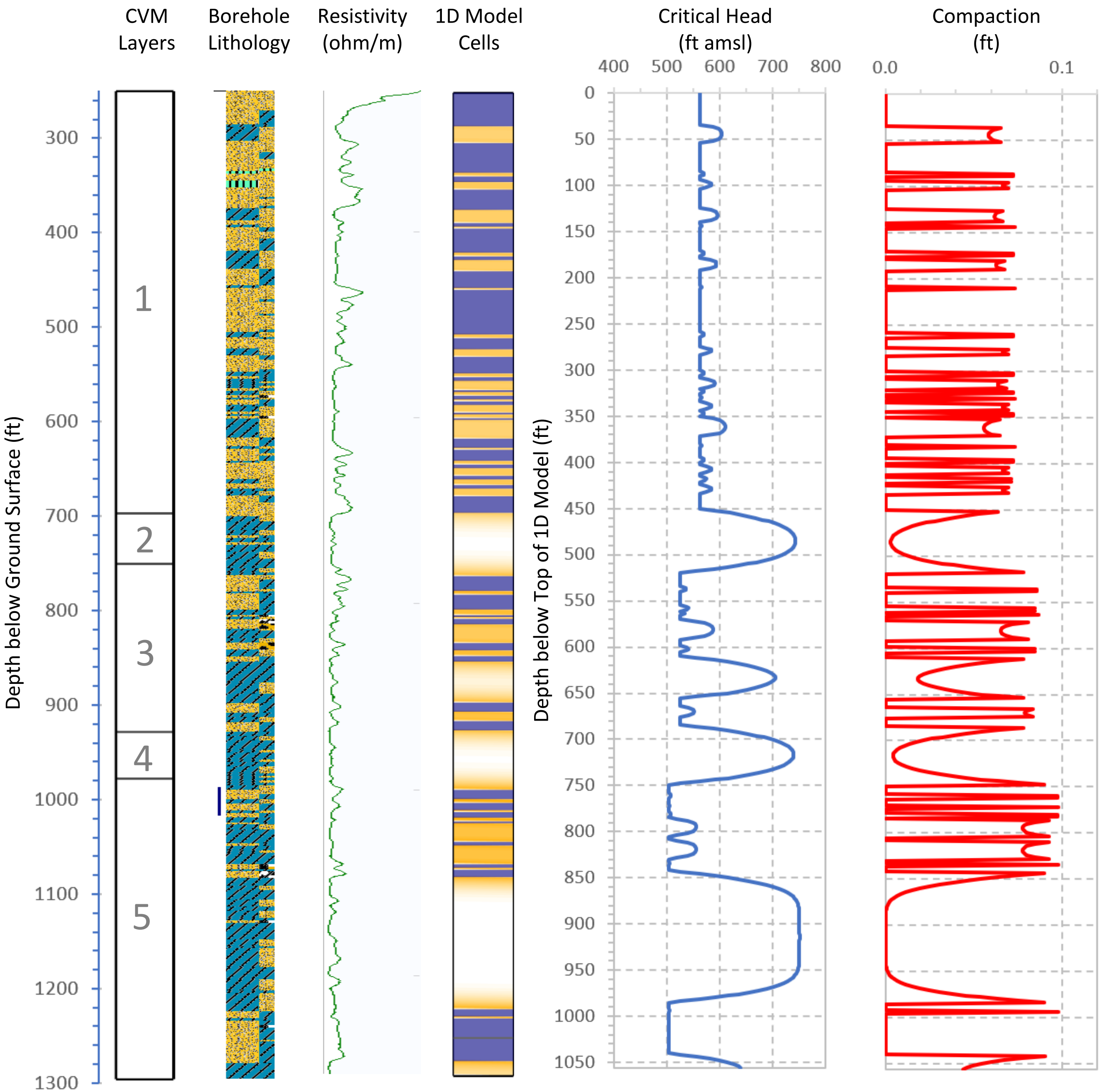
When and where did compaction occur?



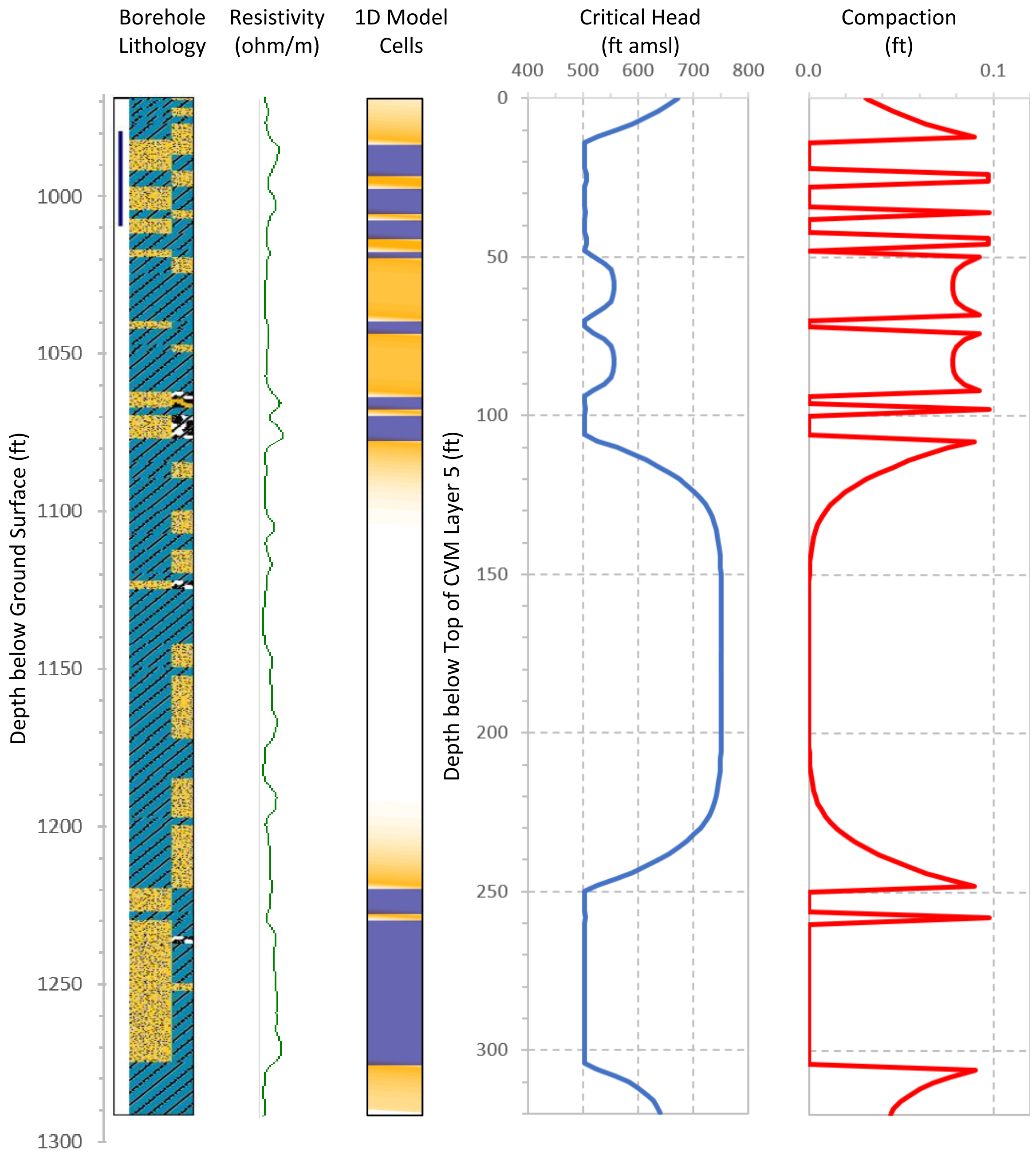
At PX Site

Compaction and Critical Head in the Clay Sediments Over Time

At PX Site



Compaction and Critical Head in the Clay Sediments on 6/30/2018



At PX Site

Compaction and Critical Head in CVM Layer 5 on 6/30/2018

Next Steps

- Prepare TM on 1D Model Calibration
    - October 29: GLMC to submit comments from October 21 PPT
    - November 18: Distribute draft TM
    - December 2: GLMC meeting to review comments on draft TM
- Estimate future compaction in Northwest MZ-1 for a Baseline Scenario
- Explore Subsidence Management Strategies

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