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TECHNICAL MEMORANDUM

DATE: February 28, 2024 | Project No.: 941-80-23-25 B.2

TO: Ground-Level Monitoring Committee

CC: Edgar Tellez-Foster, *Interim General Manager of the Chino Basin Watermaster*

FROM: West Yost Associates, *Watermaster Engineer*

REVIEWED BY: Andy Malone, PG

SUBJECT: *Proposed Locations and Data for Construction/Calibration of Additional 1D Models (DRAFT)*

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Introduction

This technical memorandum proposes locations and specific data to be used in the construction and calibration of three (3) one-dimensional compaction models (1D Models) across the western portion of Chino Basin. The 1D Models will be computer-simulation tools that will assist the Chino Basin Watermaster (Watermaster) in its efforts to avoid the adverse impacts associated with land subsidence.

Background

Material Physical Injury (MPI) is a term defined in the Peace Agreement[1] and is a key consideration for the Watermaster in the management of groundwater in the Chino Basin. MPI is defined as:

> *"…material injury that is attributable to the Recharge, Transfer, storage and recovery, management, movement or Production of water, or implementation of the OBMP, including, but not limited to, degradation of water quality, liquefaction, land subsidence, increases in pump lift (lower water levels) and adverse impacts associated with rising groundwater. Material Physical Injury does not include "economic injury" that results from other than physical causes. Once fully mitigated, physical injury shall no longer be considered to be material."*

For any proposed activity listed above (*i.e.,* Recharge, Transfer, storage and recovery, management, movement or Production of water, or implementation of the OBMP), the Watermaster is required to evaluate the potential for the proposed activity to cause MPI. If the evaluation indicates the potential to cause MPI, the activity cannot be approved by the Watermaster unless the MPI is fully mitigated.

Regarding land subsidence specifically, the Peace Agreement recognizes subsidence as a form of MPI that can be caused by aquifer-system compaction. Pursuant to the Peace Agreement, the Watermaster has developed an adaptive Subsidence Management Plan (Subsidence MP).[2] The objective of the Subsidence MP is to provide guidance for pumping and/or recharge strategies that will minimize or abate the future occurrence of land subsidence within the Chino Basin.

Areas of Subsidence Concern

The Subsidence MP identifies several "Areas of Subsidence Concern" across the western portion of Chino Basin where the future occurrence of land subsidence and ground fissuring is a concern. Figure 1 is a map that shows the location of these areas, which were identified based on the following observations:

- The underlying hydrogeologic conditions, particularly the numerous fine-grained sediment layers within the aquifer system (aquitards), are conducive to aquifer-system compaction and associated land subsidence.
- Land subsidence is occurring in these areas or has occurred in the past.

[1] Section 1.1 (y) of the Peace Agreement.

[2] Chino Basin Watermaster. 2015. Chino Basin Subsidence Management Plan. July 23, 2015.

- Historical declines in groundwater levels in these areas since the early- to mid-1900s were extreme (>150 feet) and could still be causing the current land subsidence due to delayed drainage of aquitards.
- Conditions that are conducive to ground fissuring are present, such as geologic faults that act as groundwater barriers which lead to differential subsidence.
- Increases in groundwater pumping (and associated declines in hydraulic heads) are occurring or are planned to occur within or near these areas.

When Watermaster evaluates the potential for subsidence-related MPI, it performs such evaluations within these Areas of Subsidence Concern.

One-Dimensional Compaction Models

The aquitard-drainage model describes how head decline in a coarse-grained aquifer causes the gradual drainage of pore water from the clay interbeds within aquifers and the confining layers separating them, resulting in compression and/or permanent compaction of the clay interbeds. A 1D compaction model can simulate this process of aquitard drainage and compression/compaction. In a 1D compaction model, the time-series of head in the coarser-grained aquifer sediments is assumed to be known, either from physical measurements or groundwater model simulations. The 1D model then solves for the gradual drainage of the clay layers and calculates the resulting compression/compaction. Since 1D models simulate one location in a groundwater basin through the entire thickness of the aquifer system, they can be constructed at high depth resolution, which gives them the ability to simulate both compaction in multilayered aquifer systems and the residual compaction of thicker clay layers within the aquifers.

The Subsidence MP calls for the use of computer-simulation modeling to assist in subsidence management efforts and future updates to the Subsidence MP. To date, two 1D Models have been constructed and calibrated in Northwest MZ-1. Figure 2 shows the location of these two 1D Models and the Watermaster's current ground-level monitoring network:

- **MVWD-28**. This 1D Model was constructed and calibrated in Northwest MZ-1 in 2017.[3] The model was constructed using the borehole lithology and geophysical data from Monte Vista Water District (MVWD) Well 28. It was calibrated using piezometric data and model estimates for historical heads and InSAR estimates of vertical ground motion. The model was prepared for the following reasons: to help understand the history of land subsidence in Northwest MZ-1; to help understand the mechanisms behind the subsidence; and to evaluate the potential for aquifer-system compaction within Northwest MZ-1 under future planning scenarios of pumping and recharge.

[3] Wildermuth Environmental, Inc. 2017. *Task 3 and Task 4 of the Work Plan to Develop a Subsidence Management Plan for the Northwest MZ-1 Area: Development and Evaluation of Baseline and Initial Subsidence-Management Alternatives*. Prepared for Ground-Level Monitoring Committee, Chino Basin Watermaster. December 13, 2017.

- **PX**. This 1D Model was constructed and calibrated in Northwest MZ-1 in 2022.[4] The model was constructed using the borehole lithology and geophysical data from the deep borehole at the Pomona Extensometer (PX). It was calibrated using piezometric data and model estimates for historical heads and ground-level survey data and InSAR estimates of vertical ground motion. The model was prepared for the following reasons: to help understand the history of land subsidence in Northwest MZ-1; to help understand the mechanisms behind the subsidence; and to evaluate the potential for aquifer-system compaction within Northwest MZ-1 under future planning scenarios of pumping and recharge.

Figure 2 also shows where land subsidence has been occurring over the last decade. One of the acute areas of subsidence has been within in Northwest MZ-1. The Watermaster, with input from the Ground-Level Monitoring Committee (GLMC), is currently developing a *Subsidence Management Plan for Northwest MZ-1*. The objective of this plan is to provide guidance for the Watermaster and the Parties for how to manage hydraulic heads in Northwest MZ-1 (potentially through the management of pumping, recharge, the use of managed storage, and/or the design and implementation of Storage and Recovery Programs) so that the future occurrence of subsidence is minimized or abated in this area. The 1D Models at MVWD-28 and PX are being used in this effort to evaluate various subsidence management strategies for Northwest MZ-1.

Objectives

In 2023, with input from the GLMC, the Watermaster Board approved a scope of work to construct and calibrate three additional 1D Models across other Areas of Subsidence Concern for the following purposes:

- Evaluate for subsidence-related MPI during the upcoming re-evaluation of the Safe Yield in 2025 (as well as other future MPI evaluations as they arise).
- Support the evaluate for the minimum recharge quantity of supplemental water in MZ-1 as required in Section 8.4 of the Peace II Agreement.[5]
- Inform future updates to the Subsidence MP.

The objectives of this TM are to: (i) describe the proposed locations for the three additional 1D Models and (ii) describe the data that should be used to construct and calibrate the new 1D Models.

Proposed Locations and Data

This section describes the proposed locations and specific data to be used in the construction and calibration of the three new 1D Models in the western portion of Chino Basin.

Figure 2 shows the proposed locations for the three new 1D Models and the two existing 1D Models. The three new 1D Models are proposed for the Northeast Area (City of Ontario), the Southeast Area (western

[4] West Yost, Inc. 2022. *Construction and Calibration of One-Dimensional Compaction Models in the Northwest MZ-1 Area of the Chino Basin*. Prepared for Ground-Level Monitoring Committee, Chino Basin Watermaster. November 22, 2022.

[5] See Section 8.4 of the *Final_Peace_II_Documents.pdf (cbwm.org)*

portion of the Chino Basin Desalter Authority well field), and the Managed Area (Ayala Park Extensometer). These locations were selected based on the following:

1. Land subsidence is currently occurring in these areas or has occurred in the past.
2. Land subsidence could occur in these areas in the future due to plans for increased pumping and the potential for lowering of groundwater levels.
3. The locations are generally representative of their associated Area of Subsidence Concern. This is evidence by the spatial and temporal history of land subsidence in these Areas of Subsidence Concern as measured by InSAR since the 1990s. In other words, the spatial and temporal trends in historical subsidence occurred in generally consistent patterns across each Area of Subsidence Concern.
4. There is sufficient data available at each location to construct and calibrate 1D Models.

The construction of a 1D Model utilizes deep borehole information on the grain size and texture of aquifer-system sediments—the aquifer system must be discretized into vertical units of: (i) “aquifer layers” composed mainly of gravels and sands and (ii) “aquitard layers” composed mainly of silts and clays. The types of deep borehole information to develop this discretization are descriptions of borehole sediments and borehole resistivity logs.

The calibration of a 1D Model utilizes: (i) historical estimates of depth-specific heads from measurements at nearby wells and/or groundwater modeling results and (ii) historical data on the vertical ground motion that occurred in response to the changes in groundwater levels. To enable the simulation of the delayed drainage and compaction of thicker clay layers, the start of the historical simulation period during 1D Model calibration should be prior to any major declines in groundwater levels.

The remainder of this section describes the data that is proposed to be used to construct and calibrate the three new 1D Models.

Ontario Well 33

Figure 2 the proposed location for the Ontario-33 1D Model within the central portion of the Northeast Area at the location of City of Ontario Well 33. This location was chosen because gradual and persistent land subsidence has occurred across this area since at least 1992, totaling over one foot at this location.

Figure 3 shows the lithologic and borehole resistivity data from Ontario Well 33 which will be used to construct the 1D Model along with the depth intervals of the five layers of the Chino Valley Model (CVM). The lithologic and resistivity data cover the depth interval from 0 to about 1,200 feet below ground surface (ft-bgs). These data are sufficient to construct a 1D Model that will be capable of simulating aquifer-system compaction across the thickness of the Chino Basin aquifer system at this location.

Figure 4 shows the time-series data that will be used during calibration of the Ontario-33 1D Model. These data include:

- *Hydraulic Head*. These data will be derived from: (i) historical measurements of groundwater elevation at several nearby wells and (ii) estimates of hydraulic head by CVM model layer that were derived from the 2020 CVM calibration.

- *Vertical Ground Motion*. These data will mainly come from InSAR estimates of vertical ground motion at the Ontario-33 location from 1992-2022.

CCX

Figure 2 shows the proposed location for the CCX 1D Model within the Southeast Area at the location of Chino Creek Extensometer (CCX). This location was chosen because of its proximity to the western portion of the Chino Basin Desalter Authority (CDA) well field, where increased CDA pumping is imminent.

Figure 5 shows the lithologic and borehole resistivity data from the deep borehole at the CCX which will be used to construct the 1D Model along with the depth intervals of the five layers of the CVM. The lithologic and resistivity data cover the depth interval from 0 to about 635 ft-bgs. These data are sufficient to construct a 1D Model that will be capable of simulating aquifer-system compaction across the thickness of the Chino Basin aquifer system at this location.

Figure 6 shows the time-series data that will be used during calibration of the CCX 1D Model. These data include:

- *Hydraulic Head*. These data will be derived from: (i) historical measurements of groundwater elevation at several nearby wells and (ii) estimates of hydraulic head by CVM model layer that were derived from the 2020 CVM calibration.
- *Vertical Ground Motion*. These data will come from: (i) InSAR estimates of vertical ground motion at the CCX location from 1992-2022; (ii) CCX extensometer data; and (iii) traditional leveling surveys at nearby benchmarks.

Ayala Park

Figure 2 shows the proposed location for the Ayala Park 1D Model within the Managed Area. This location was chosen because: the area experience over two feet of land subsidence in the late-1980s and early 1990s; the land subsidence was accompanied by ground fissuring and damage to overlying infrastructure; and the Managed Area is the primary focus of the Subsidence MP.

Figure 7 shows the lithologic and borehole resistivity data from the deep borehole at the Ayala Park Extensometer which will be used to construct the 1D Model along with the depth intervals of the five layers of the CVM. The lithologic and resistivity data cover the depth interval from 0 to about 1,400 ft-bgs. These data are sufficient to construct a 1D Model that will be capable of simulating aquifer-system compaction across the thickness of the Chino Basin aquifer system at this location.

Figure 8 shows the time-series data that will be used during calibration of the Ayala Park 1D Model. These data include:

- *Hydraulic Head*. These data will be derived from: (i) historical measurements of groundwater elevation at several nearby wells and (ii) estimates of hydraulic head by CVM model layer that were derived from the 2020 CVM calibration.
- *Vertical Ground Motion*. These data will come from: (i) InSAR estimates of vertical ground motion at the Ayala Park Extensometer location from 1992-2022; (ii) Ayala Park extensometer data; and (iii) traditional leveling surveys at nearby benchmarks.

PROPOSED METHODS FOR CONSTRUCTION AND CALIBRATION

This section describes:

- Background information on the modeling tools used to estimate head changes and aquifer system deformation.
- The technical methods that are planned to be applied to construct and calibrate the proposed 1D.

Proposed Model Codes

The United States Geological Survey (USGS) has developed a wide range of computer models to simulate saturated and unsaturated subsurface flow, solute transport, and chemical reactions in groundwater systems. The most widely used of these models is MODFLOW, which simulates three-dimensional (3D) groundwater flow using the finite-difference method. Although it was conceived solely as a groundwater flow model in 1984 and released in 1988 (McDonald et al., 1988), the MODFLOW modular structure has provided a robust framework for the integration of additional simulation capabilities that build on and enhance its original scope. The family of MODFLOW-related models now includes capabilities for simulating coupled groundwater/surface water systems and solute transport.

MODFLOW-NWT (Niswonger et al., 2011) was chosen for this project because: 1) it has extensive publicly available documentation, 2) it has sustained rigorous USGS and academic peer review, 3) it has a long history of development and use, 4) it is widely used around the world in public and private sectors, 5) it can easily operate with additional simulation tools published by others, and 6) it has been used by the Watermaster in the Chino Valley Model (CVM) for the latest Safe Yield Recalculation (WEI, 2020).

The Interbed Storage Package (Leake and others, 1991) of MODFLOW-NWT was chosen to simulate the aquifer-system deformation that is caused by elastic and/or inelastic deformation of the fine-grained interbeds in an aquifer-system due to changes in the effective stress on the soil skeleton because of changing groundwater levels.

Steps to Construct and Calibrate 1D Compaction Models

In summary, the major steps to construct and calibrate a 1D Model are:

1. Construct the 1D Model using the Interbed Storage Package (Leake and others, 1991) of MODFLOW-NWT. The model is a vertical stack of cells that represent the aquifer system at the 1D Model location. The thicknesses of the 1D Model cells (1 ft) is chosen to ensure that the delayed drainage of the aquitards can be adequately simulated. The model cells are categorized into either “Sand” for coarse-grained sediments or “Clay” for fine-grained sediments based on borehole lithologic and resistivity data. Initial aquifer (Sand) and aquitard (Clay) properties are assigned to the 1D Model cells based on past groundwater-flow modeling calibrations in the Chino Basin, past 1D Model calibrations in the Chino Basin, and literature review.
2. Prepare the monthly time-series of historical heads by CVM layer to serve as input data for the 1D Model “sand” cells over the calibration period of 1930-1922. The time-series of heads is based on based on the measured groundwater elevations at wells in the vicinity of the 1D

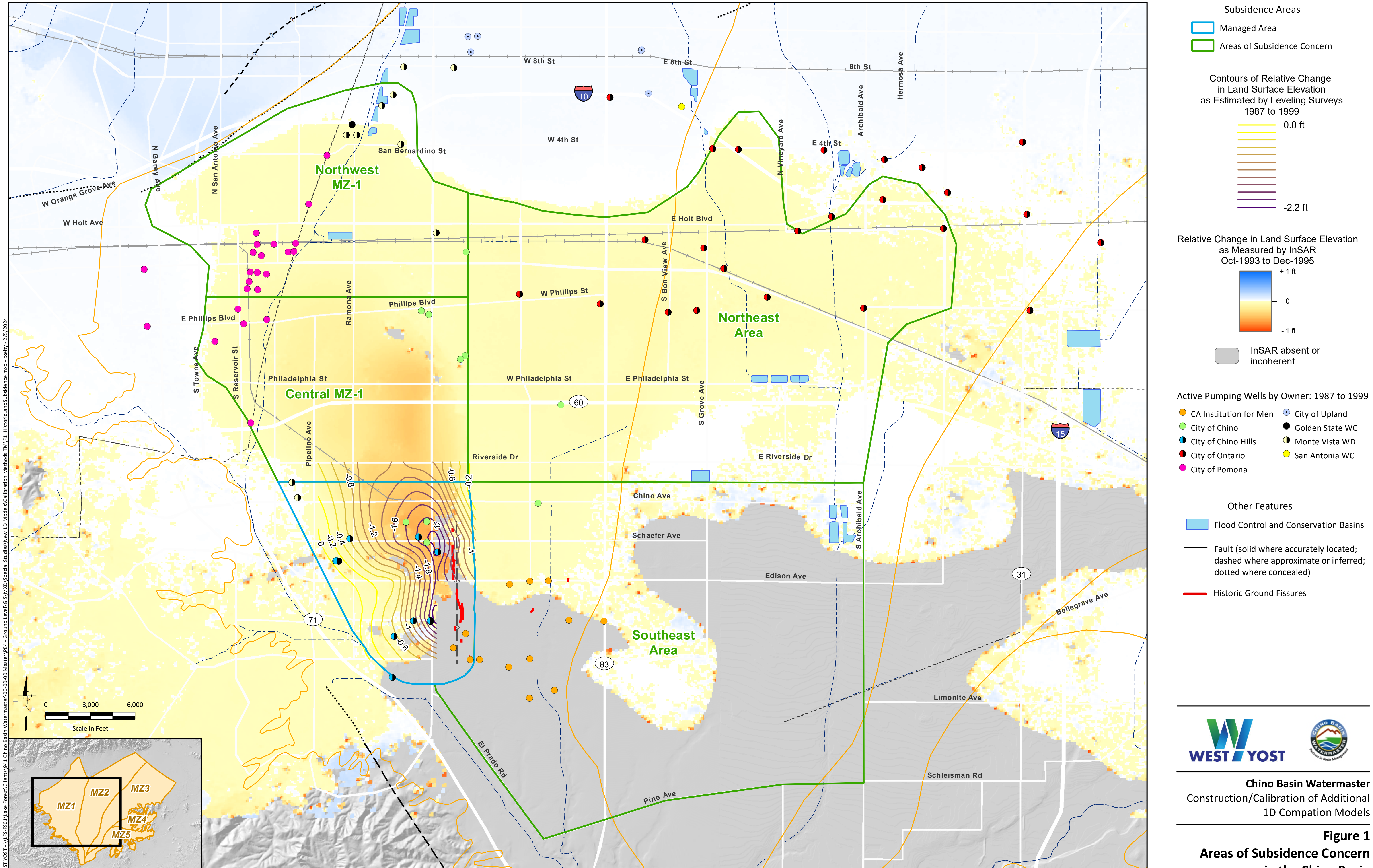
Model, CVM model results for heads by model layer, and professional judgment. The heads are assigned as prescribed heads to the corresponding Sand cells in the 1D Model.

3. Run and calibrate the 1D Models over the historical period of 1930-2022 by adjusting the aquifer and aquitard properties. The 1D Model simulations compute a time series of vertical aquifer-system deformation in each 1D Model cell. During calibration, the aquitard properties are adjusted manually to best match historical observations of land subsidence versus the model-simulated aggregate compaction of the aquifer system. The sum of the calculated vertical deformation in all 1D Model cells are assumed to represent the vertical ground motion at the land surface.

RECOMMENDATIONS AND NEXT STEPS

The GLMC should review this memorandum and come prepared to discuss at the next GLMC meeting scheduled for March 7, 2024 at 10am at Watermaster offices. Written comments and recommendations from the GLMC are due to Andy Malone (amalone@westyost.com) and Edgar Tellez-Foster (etellezfoster@cbwm.org) by April 5, 2024.

After receiving and addressing the feedback from the GLMC, West Yost will proceed with the construction and calibration of the three new 1D Models. The results of these efforts will be documented in a draft TM for review and comment by the GLMC.



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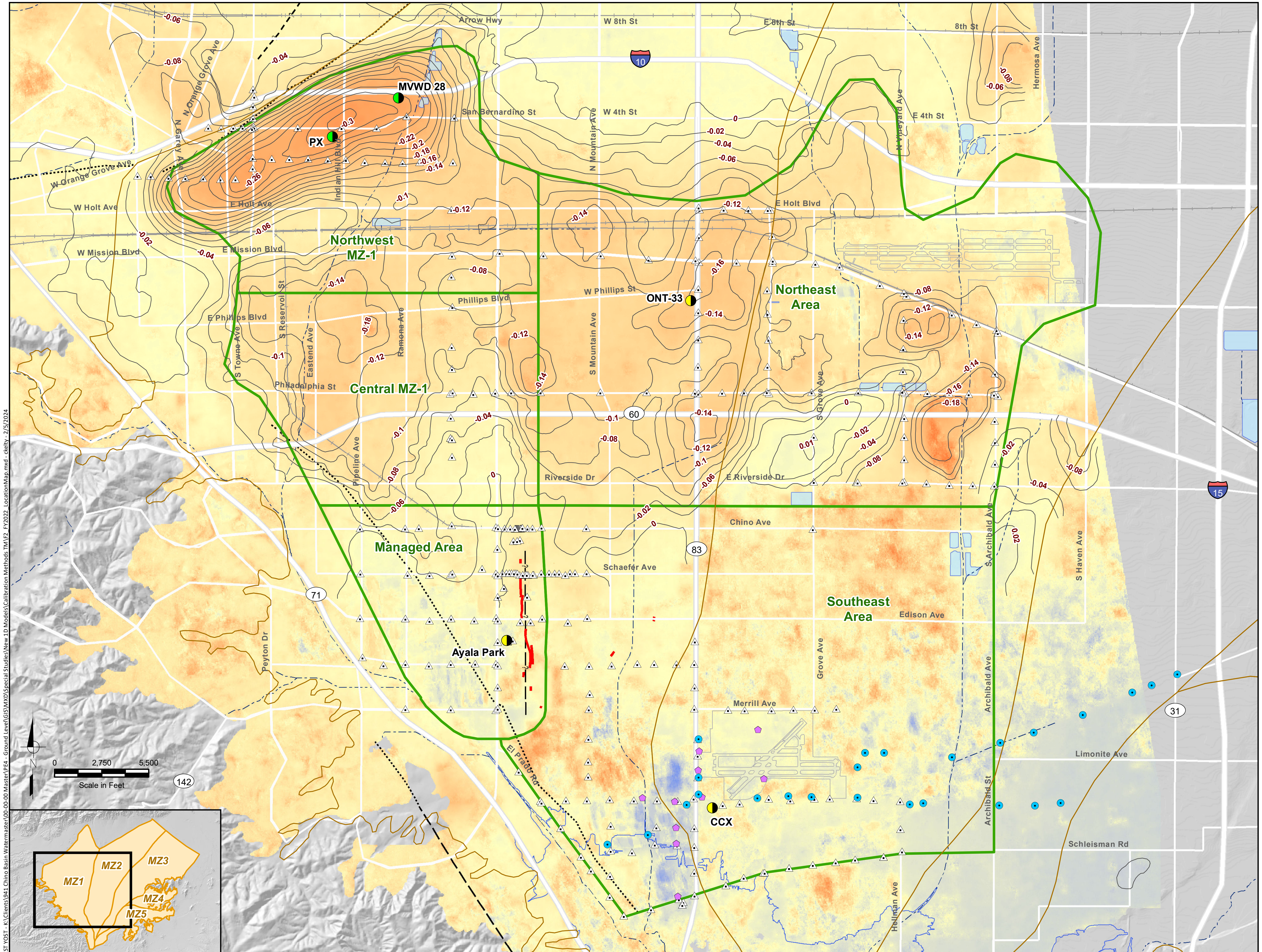
Chino Basin Watermaster
Construction/Calibration of Additional 1D Compation Models

Figure 1
Areas of Subsidence Concern in the Chino Basin



1D Compaction Model Locations

- Existing
- New

Relative Change in Land Surface Altitude as Estimated by InSAR (March 2011 to March 2022)

+ 0.55 ft
0 ft
-0.20
-0.55 ft

InSAR absent or incoherent

Other Features

- Areas of Subsidence Concern
- Chino Desalter Authority Well
- SB County Proposed Extraction Well
- Ground-Level Survey Benchmark
- Ground Fissures
- Approximate Location of the Riley Barrier

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Construction/Calibration of Additional 1D Compation Models

Figure 2
Locations of One-Dimensional Compaction Models

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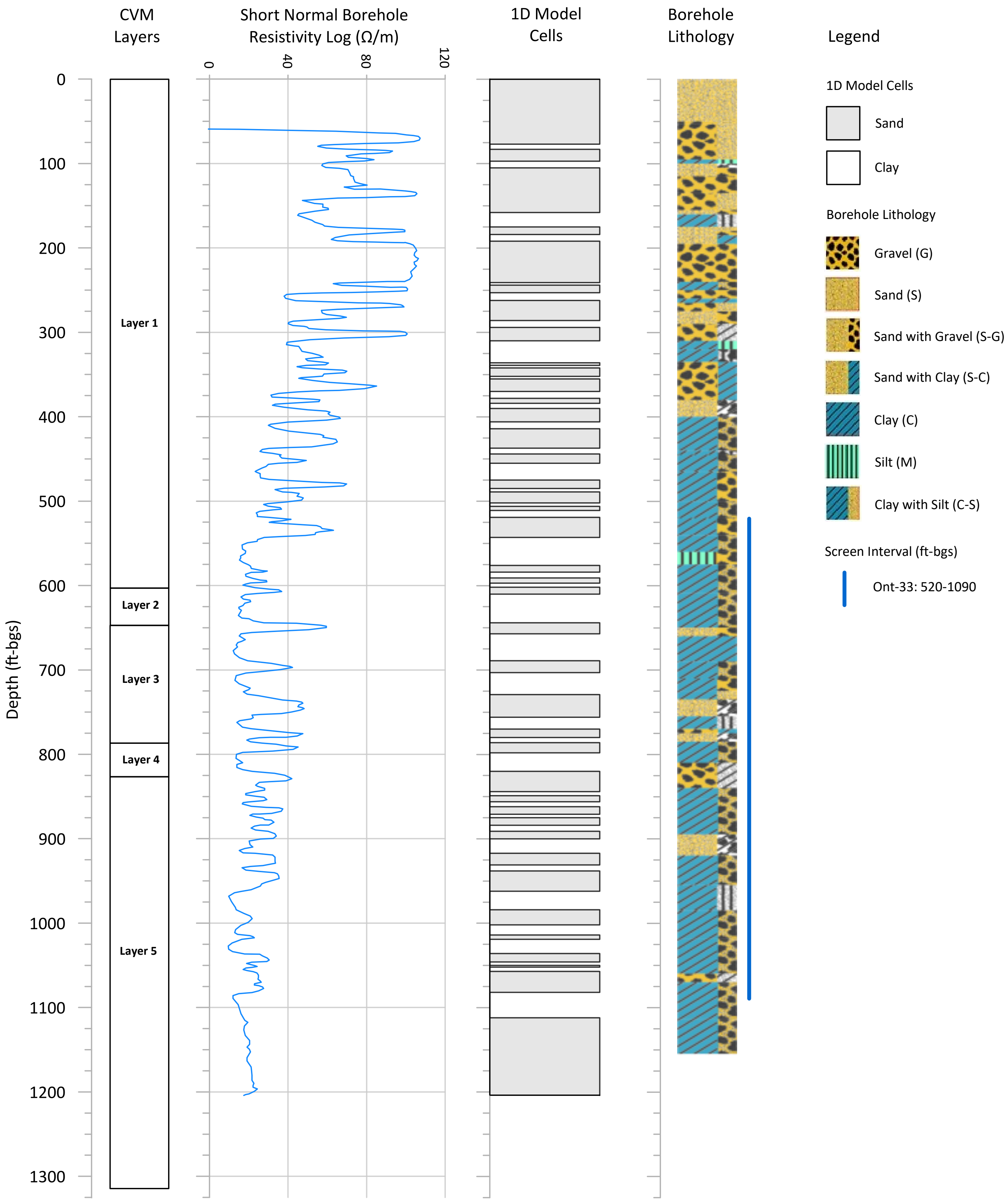

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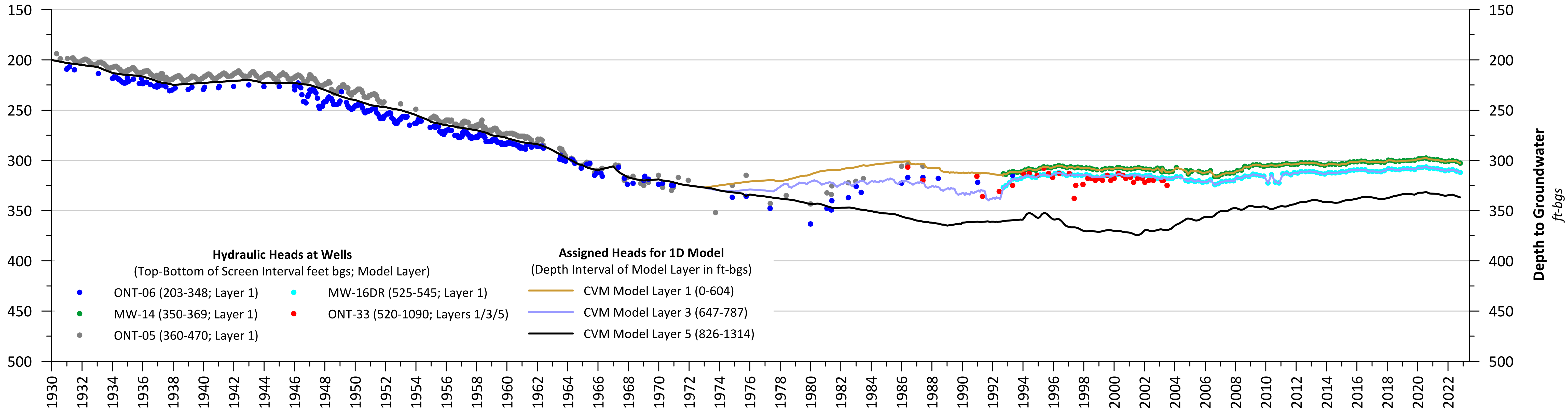
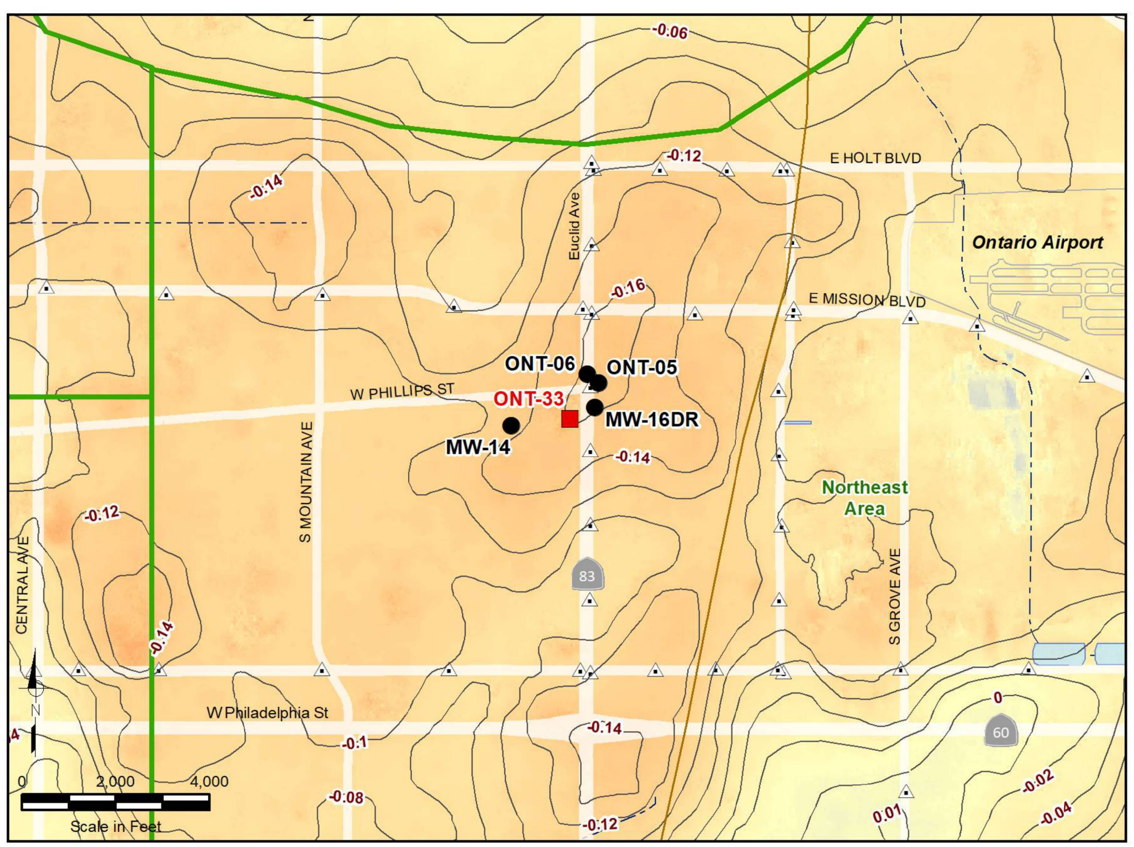
Construction/Calibration of
Additional 1D Compaction Models

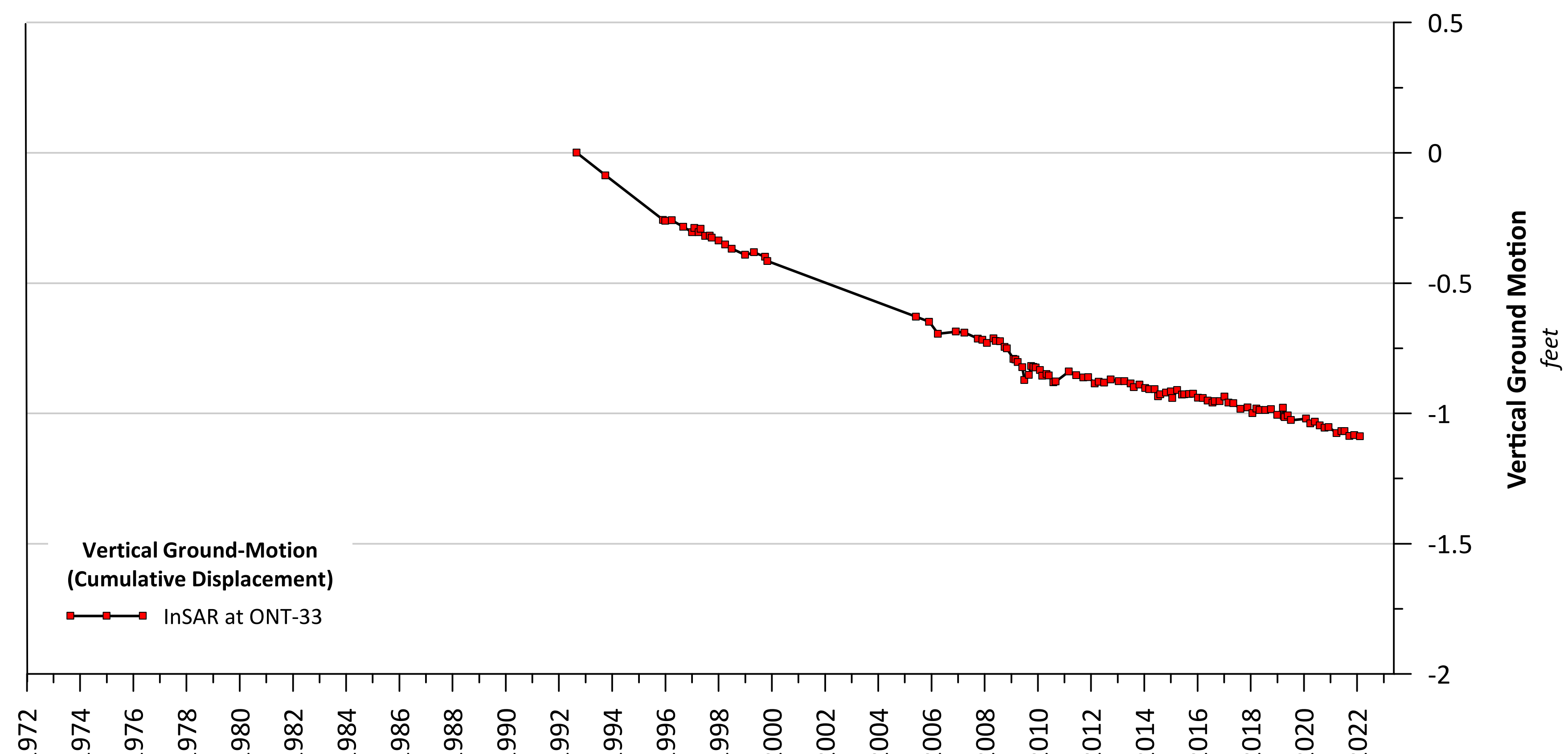
Structure of 1D Model
Ontario Well 33

Figure 3





InSAR from March 2011 to March 2022 (see Figure 2)



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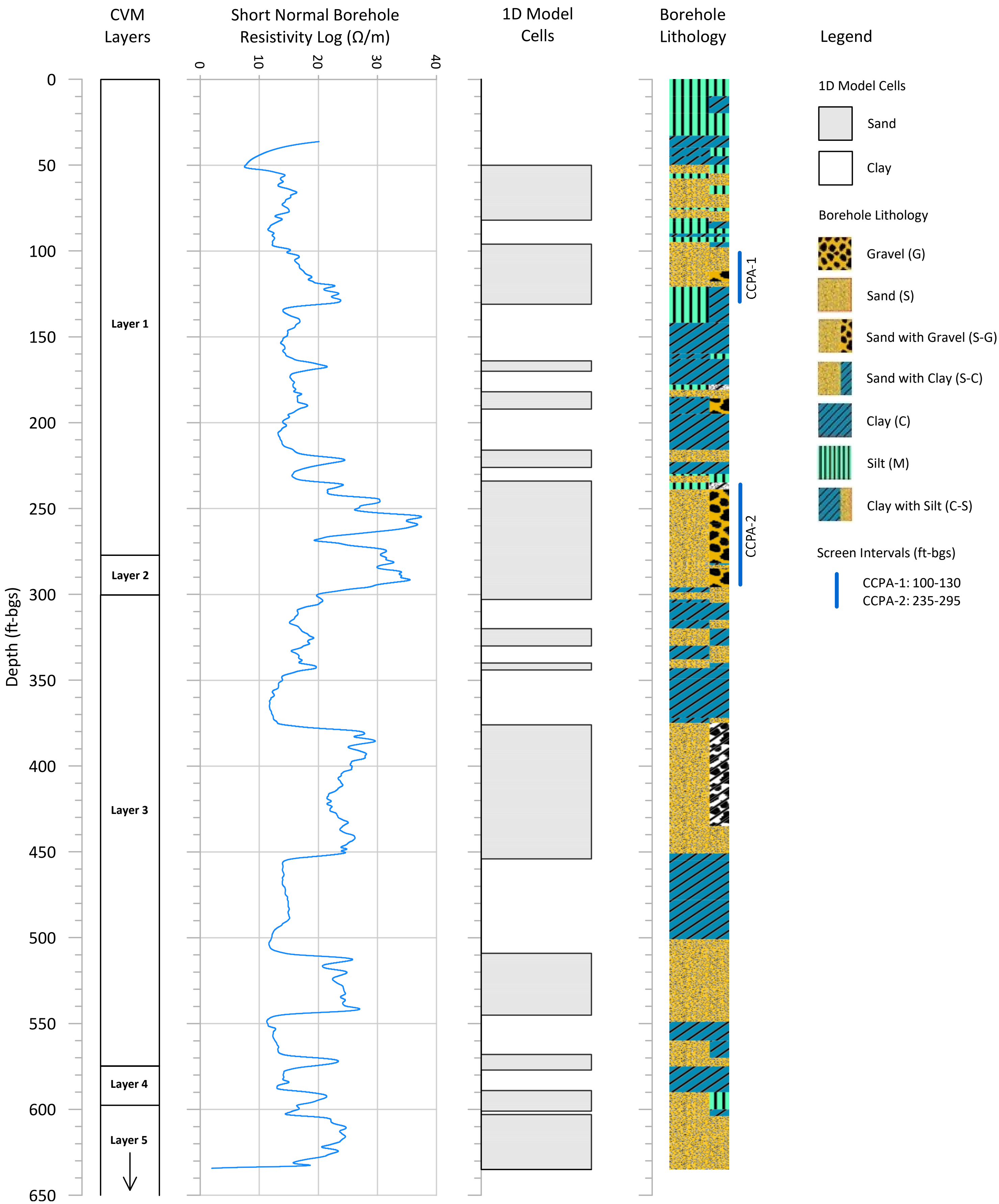
1D Compaction Models

Historical Data for Calibration of the 1D Model
Ontario Well 33

Figure 4



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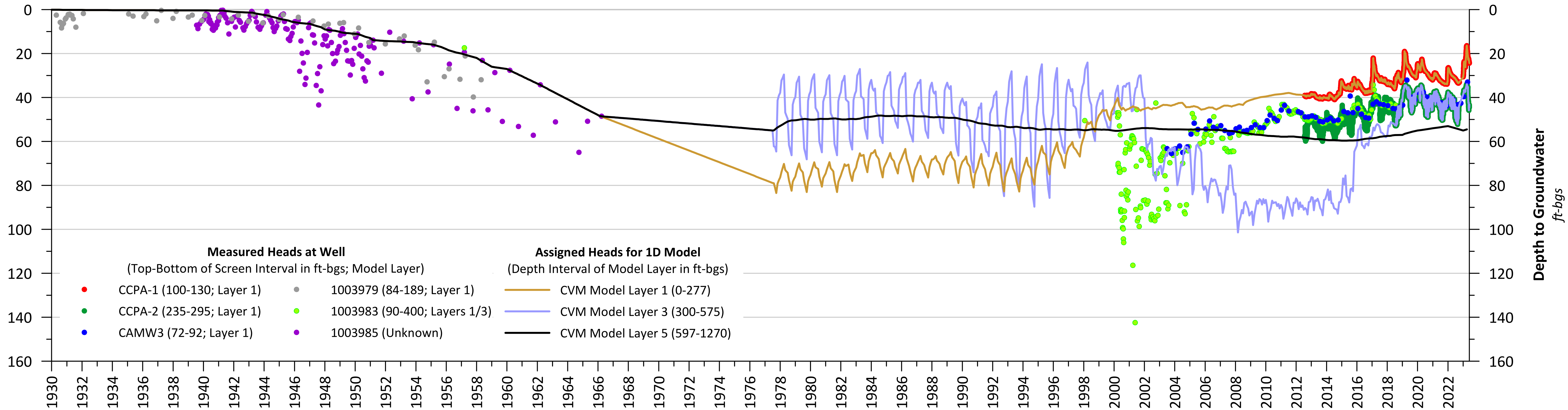
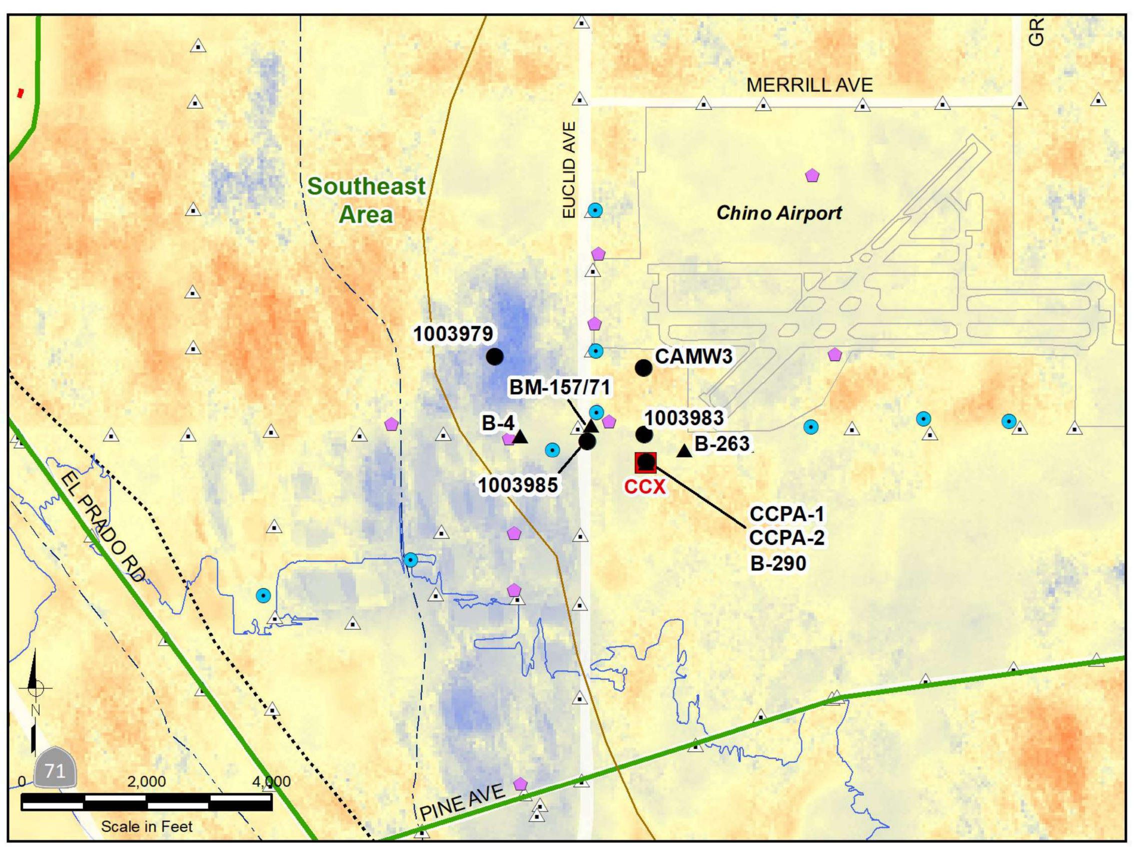
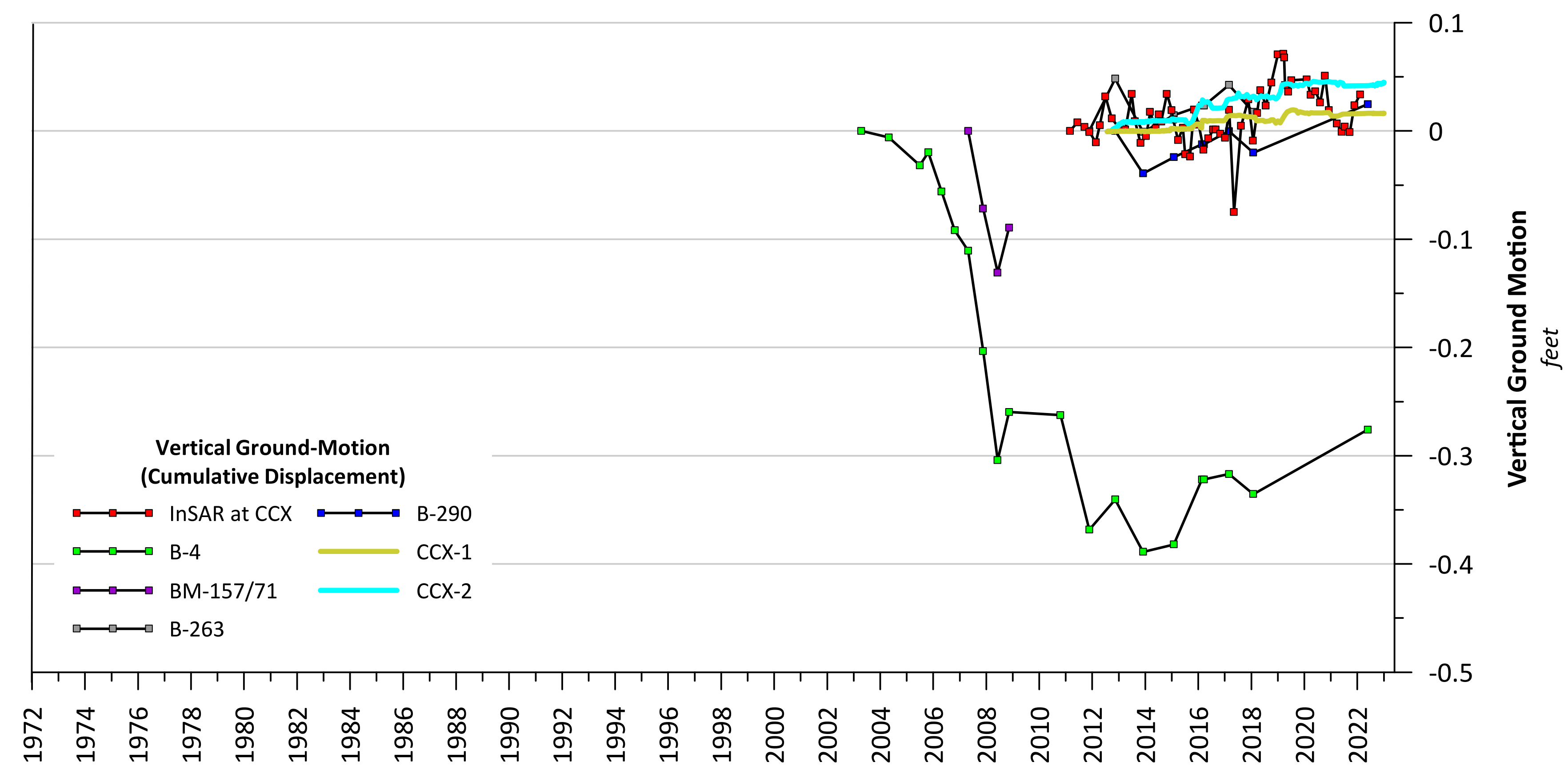
Structure of 1D Model
CCX

Figure 5





InSAR from March 2011 to March 2022 (see Figure 2)



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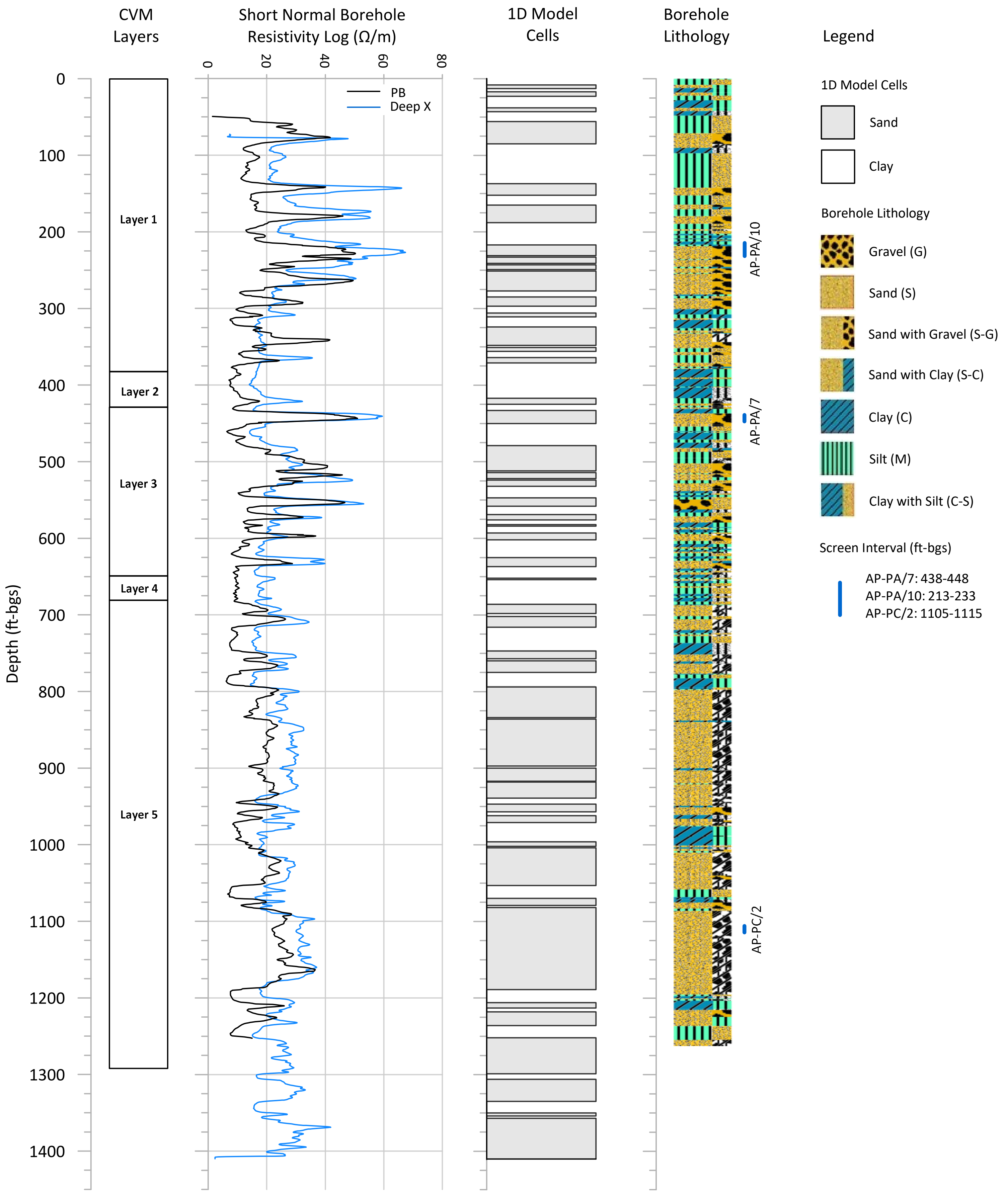
1D Compaction Models

Historical Data for Calibration of the 1D Model
CCX

Figure 6



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Construction/Calibration of
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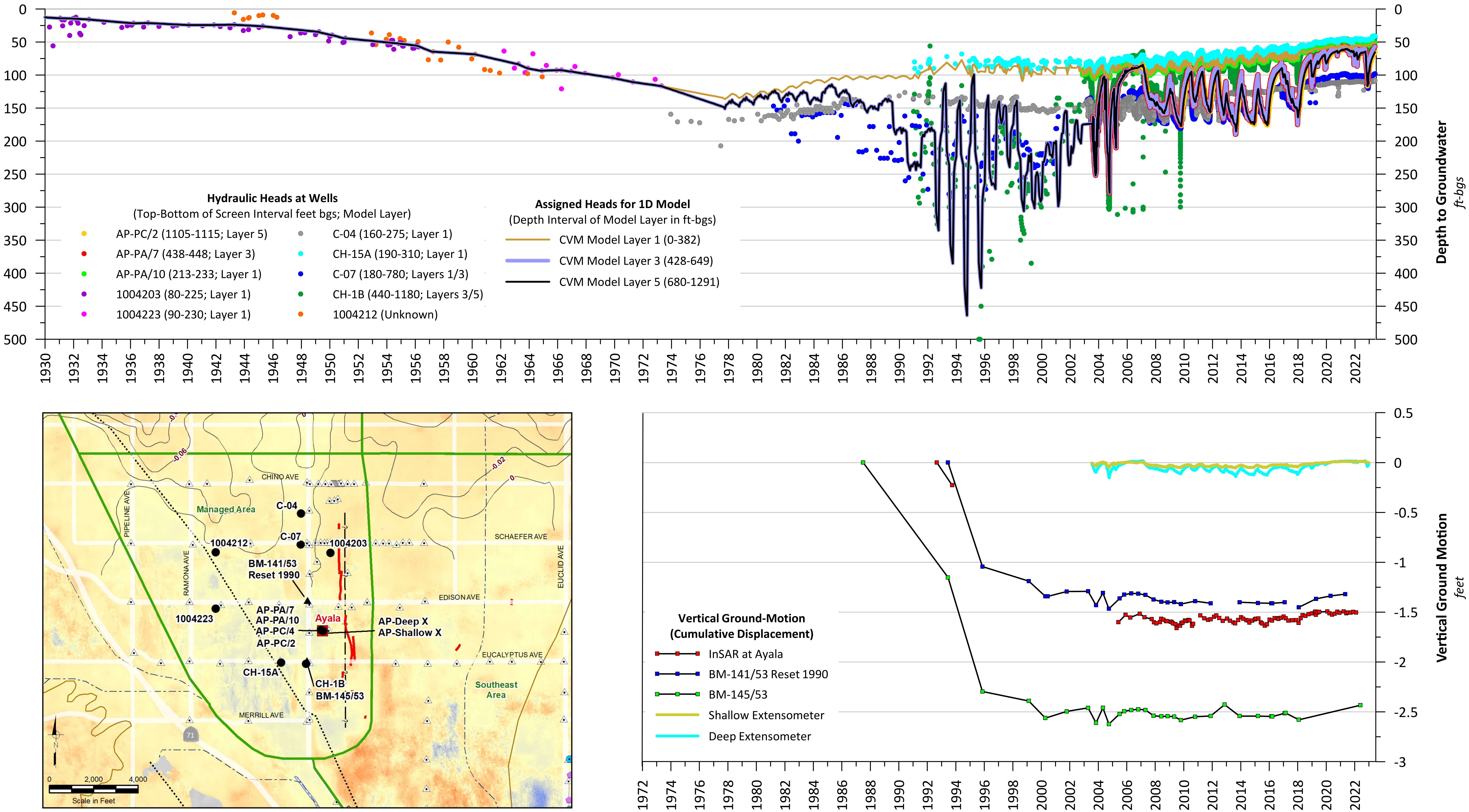
Structure of 1D Model
Ayala Park

Figure 7



InSAR from March 2011 to March 2022 (see Figure 2)

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File: Figure8_Ayala.grf
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Historical Data for Calibration of the 1D Model
Ayala Park
Figure 8