Technical Memorandum 2022-03

Simulated chloride concentrations in the confined aquifers of the southern Oxnard basin

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This Technical Memorandum serves as an addendum to United Water Conservation District's (United's) November 2021 open-file report titled *Saline Intrusion and 2020 Groundwater Conditions Update, Oxnard and Pleasant Valley Basins.* That report presented preliminary model results for 2015 chloride concentration contours as simulated for the Upper Aquifer System (the Oxnard and Mugu aquifers) in the southern Oxnard basin, together with estimated locations of the seawater intrusion "fronts" in each aquifer as of 2020 (based on measured chloride concentrations in groundwater samples obtained from wells in the area). The model calibration period has since been extended to include the years 2016 through 2019. This addendum presents updated solute transport modeling results for chloride concentrations for the Oxnard and Mugu aquifers, as well as the aquifers of the Lower Aquifer System (the Hueneme, Fox Canyon and Grimes Canyon aquifers). Simulated chloride concentrations are compared to measured chloride concentrations in coastal monitoring wells.

Introduction

In late 2019 United was awarded a Proposition 1 Round 2 grant from the State Water Resources Control Board (Water Board) to evaluate the feasibility of a proposed large-scale Extraction Barrier and Brackish (EBB) Water Treatment Project located near the southern boundary of the Oxnard groundwater basin. Degraded water quality (chloride, TDS, sulfate, etc.) is present in approximately ten square miles of the Upper Aquifer System (UAS) in the coastal area between Port Hueneme and Point Mugu, the result of both recent and historic episodes of seawater intrusion and the subsequent dispersal of seawater across the southern Oxnard basin by southeasterly groundwater flow in wet periods. Saline water is also dispersed by vertical flow between aquifers, predominantly in areas where vertical hydraulic head gradients are significant and aquitards between the major aquifers are thin or absent. United is working towards permitting and construction of a well field designed to intercept the lateral intrusion of seawater near the Mugu submarine canyon and to later treat the extracted blend of seawater and brackish water at a desalinization facility. Solute transport modeling is one way to assess the feasibility and benefits of the Extraction Barrier and Brackish Water Treatment Project.

In 2018 UWCD published documentation of a regional groundwater flow model (referred as the Coastal Plain Model) covering the Oxnard coastal plain in southern Ventura County (UWCD, 2018) based on the MODFLOW-NWT groundwater modeling software (Niswonger, et al., 2011). The model was calibrated for the years 1985-2015 and relied on United's mapping of seven major aquifers and six regional aquitards within the model domain. Since 2016, the Coastal Plain Model has been periodically reviewed by an expert panel comprised of nationally recognized expert groundwater modelers. The expert panel concluded that the Coastal Plain Model is well-designed and well-calibrated (Porcello et al., 2018).

United later elected to convert the Coastal Plain Model to the modeling software MODFLOW-USG-Transport (Panday, et al., 2017) in order to refine the model to a denser grid along the southern coastal area of the Oxnard basin, simulate solute (chloride) transport, and account for the density effect of seawater on the groundwater flow. To calibrate the chloride transport component, the interpreted 2015 inland extent of seawater intrusion (based on measured chloride concentrations and past geophysical investigations (UWCD, 2016)) was compared to the simulated occurrence of seawater intrusion in 2015 by the MODFLOW-USG-Transport model. The 2015 seawater intrusion extent simulated by the MODFLOW-USG-Transport model was fairly consistent with the interpreted 2015 seawater intrusion extent. Four additional years (2016-2019) were subsequently added to the model and simulated groundwater elevations for individual aquifers were also compared with the groundwater elevation measurements from 1985 to 2019 to ensure the calibration in the groundwater flow component. The calibration of the flow component from the MODFLOW-USG-Transport model was confirmed to be better than the prior calibration of the MODFLOW-NWT based Coastal Plain Model. Thus, the calibration of the MODFLOW-USG-Transport model was deemed satisfactory in both the flow and transport components and appropriate for use in simulating extraction barrier scenarios. This Technical Memorandum details the results of modeled simulations of chloride concentrations in the Oxnard basin aquifers in 2019 and presents the maximum chloride concentrations measured in 2019, along with the 2020 interpreted inland extent of saline water intrusion as previously published (UWCD, 2021b).

Model Conversion and Calibration

The conversion and recalibration of the Coastal Plain Model to MODFLOW-USG-Transport was funded in part by a Prop 1 Round 2 grant, and detailed in a separate technical memorandum (UWCD, 2021a). Following the satisfactory calibration of the MODFLOW-USG-Transport model, United added available hydrologic data from the years 2016 through 2019 to update and extend the simulation period of the MODFLOW-USG-Transport model through the end of calendar year 2019. As part of the grant-funded work, some refinements to the mapping of aquifers and aquitards in the southern portion of the Oxnard basin were made (UWCD, 2021c).

When a well-calibrated numerical flow model is converted from one model software to another, the calibration performance in the converted model may change. In addition, when the hydrogeological conceptual model is refined, the numerical model may need recalibration of aquifer properties after the refined geologic conceptual model is implemented in the numerical model. As part of the model conversion to MODFLOW-USG-Transport, the model software conversion and the refined hydrogeological conceptual model and aquifer properties were implemented. As a due diligence check, United staff performed a detailed review of model calibration for the converted MODFLOW-USG-Transport model and made necessary adjustments to recalibrate and improve the converted model.

The MODFLOW-USG-Transport model simulates groundwater flow and saline water transport from 1985 to 2019 in the southern Oxnard basin. The model was calibrated by comparing available groundwater elevation measurements from 1985 to 2019 with the simulated groundwater elevations, including the density effect from seawater in the Pacific Ocean. By comparing the interpreted inland extent of saline water and by comparing simulated chloride concentrations in aquifers with data from wells located within the area of chloride impacts over the past 35 years, the MODFLOW-USG-Transport model is considered to be well-calibrated (data collection improved greatly in 1990 with the installation of a network of coastal monitoring wells).

As mentioned above, the converted MODFLOW-USG-Transport model is able to simulate the density-dependent element of saline water transport. The Block Centered Transport (BCT) package is used to simulate the solute transport component. To account for the density of saline water, the DDF (Density Dependent Flow) component is used in the MODFLOW-USG-Transport model. The density and chloride concentration of seawater used in the MODFLOW-USG-Transport model are 63.9262 lb/ft^3 and 19,400 mg/l. The density for freshwater is 62.4 lb/ft^3. The MODFLOW-USG-Transport model simulates chloride transport and incorporates the density differences of varying chloride concentrations in calculating groundwater pressure heads in the groundwater flow simulations.

Simulated chloride concentrations

The 2020 interpreted saline water inland extent was delineated by chloride concentration data from coastal monitoring wells and by past geophysical investigations (UWCD, 2021b). The simulated chloride concentration at the end of calendar year 2019 from the MODFLOW-USG-Transport model was compared with the 2020 saline water inland extent for each aquifer, as previously interpreted by United (Figures 1-6). To help evaluate simulated chloride concentrations in the individual aquifers, contour lines for concentrations of 100, 500, 1,000, 5,000, 10,000, and 15,000 mg/L chloride are plotted.

Figure 1 shows that the simulated saline inland extent in the Oxnard aquifer closely approximates the interpreted saline water inland extent (shown in black dotted line). The figure also shows measured chloride concentrations from the Oxnard aquifer monitoring wells and demonstrates that the simulated chloride concentrations generally capture the measured chloride concentration from wells screened in this aquifer. Chloride concentrations in the monitoring wells near Port Hueneme, however, are underestimated.

Figure 2 shows simulated chloride concentration in Mugu aquifer and the 2020 interpreted inland extent of saline water. From Figure 2, it is noted that the simulated saline water inland extent (100 mg/L) in the areas near the Hueneme and Mugu submarine canyons are comparable to the 2020 delineated saline water inland extent (black dotted line). An additional area of more than three square miles located northeast of Mugu Lagoon and near Casper Road is simulated to be impaired by elevated chloride concentrations, including the coastal area near the southern end of Arnold Road. This area of saline groundwater was also noted during the initial calibration using 2015 data (UWCD, 2021b). The expanded area of saline water impacts simulated by the model in the vicinity of Casper Road is associated with an area of mergence or thin confining layers between the Oxnard and Mugu aquifers, where the aquitard that commonly separates these confined aquifers is discontinuous or absent. Modeled groundwater flow indicates that saline water in the Oxnard aquifer is drawn down into the Mugu aquifer by the lower heads common to the Mugu aquifer in this vicinity. Monitoring well SWIFT-350 is located near the eastern edge of this lobe of saline water and has recorded variable chloride concentrations ranging from 40 to 720 mg/L since 2006. Additional monitoring of groundwater conditions in this vicinity is desired.

Figure 3 shows the simulated chloride concentration in Hueneme aquifer of the Lower Aquifer System (LAS) and the 2020 interpreted inland extent of saline water in the Hueneme aquifer (UWCD, 2021b). Figure 3 shows that the simulated chloride concentrations near Port Hueneme generally capture the measured chloride concentrations in Hueneme aquifer. Note that Hueneme aquifer is generally absent in areas south of Hueneme Road and Hwy 1 to the east, where this aquifer was uplifted and subsequently eroded (Mukae and Turner, 1975, UWCD, 2018). Where the Hueneme aquifer is absent in the southern Oxnard basin, the Mugu aquifer overlies the Fox Canyon aquifer, but generally separated by an aquitard that may be relatively thin or absent in some locations, allowing for hydraulic connection between the Mugu aquifer of the UAS and the Fox Canyon aquifer of the LAS.

Figures 4 and 5 show the simulated chloride concentration in main and basal units of the Fox Canyon aquifer, respectively, and the 2020 interpreted inland extent of saline water (UWCD, 2021b). From Figures 4 and 5, it is observed that the expanded area of saline water in the Mugu aquifer near Casper Road is simulated to extend down into the Fox Canyon aquifer. The significant vertical head gradients between the aquifers of the UAS and the LAS in recent years provides the driving force for the downward movement of saline water from the Oxnard aquifer to underlying aquifers. The simulated area of impact is larger and extends farther north in the main Fox Canyon aquifer than in the deeper basal unit. Other than the area around Casper Road, the simulated saline water inland extent (100 mg/L) is similar to the 2020 interpreted saline water inland extent (black dotted line). Figures 4 and 5 also show that the simulated chloride concentrations generally capture the measured chloride concentrations from wells screened in the Fox Canyon aquifer. In the Mugu area, chloride impacts in the LAS are interpreted to be predominantly associated with the downward movement of groundwater, as opposed to lateral seawater intrusion that is prevalent in the UAS.

Figure 6 shows that the simulated inland extent of chloride closely approximates the interpreted inland extent of saline water in the Grimes Canyon aquifer in the areas north and northwest of Mugu Canyon (shown in black dotted line). Grimes Canyon aquifer monitoring wells do not currently exist near the Hueneme submarine canyon. Figure 6 also shows that simulated chloride concentrations near Grimes Canyon aquifer monitoring well CM1A-565 are close to measured values, but concentrations in more inland monitoring wells are underestimated. The occurrence of brines of various origin are not simulated by the model, but have been interpreted to exist in this vicinity in previous studies.

Conclusions

United's MODFLOW-USG-Transport model was improved by incorporating the refined geological conceptual model, revised aquifer properties in some units and by extending the simulation period to 2019. The model calibration was deemed satisfactory with the 1985-2019 water level data and consistent with prior interpretations of the inland extent of saline groundwater. The well-calibrated MODFLOW-USG-Transport model is expected to serve as a valuable tool for evaluating density-dependent saline water intrusion in the southern Oxnard basin, and for helping to assess the feasibility and benefits of various water supply projects and groundwater management actions under consideration.

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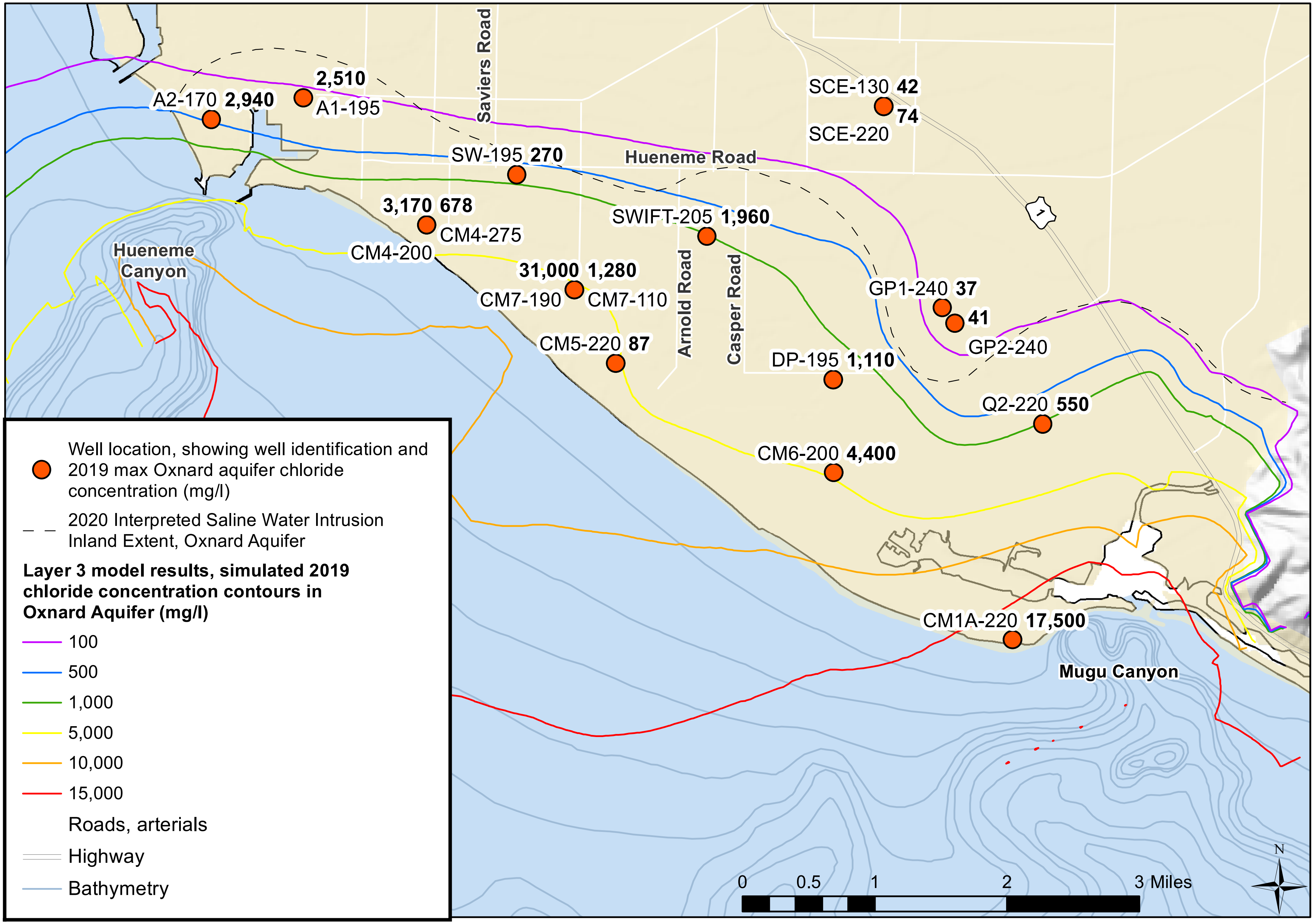

Figure 1. Simulated chloride concentrations in the Oxnard aquifer. Flow and transport simulated for the years 1985-2019. Inland chloride concentrations are the result of both lateral flow within and vertical flow between aquifers.

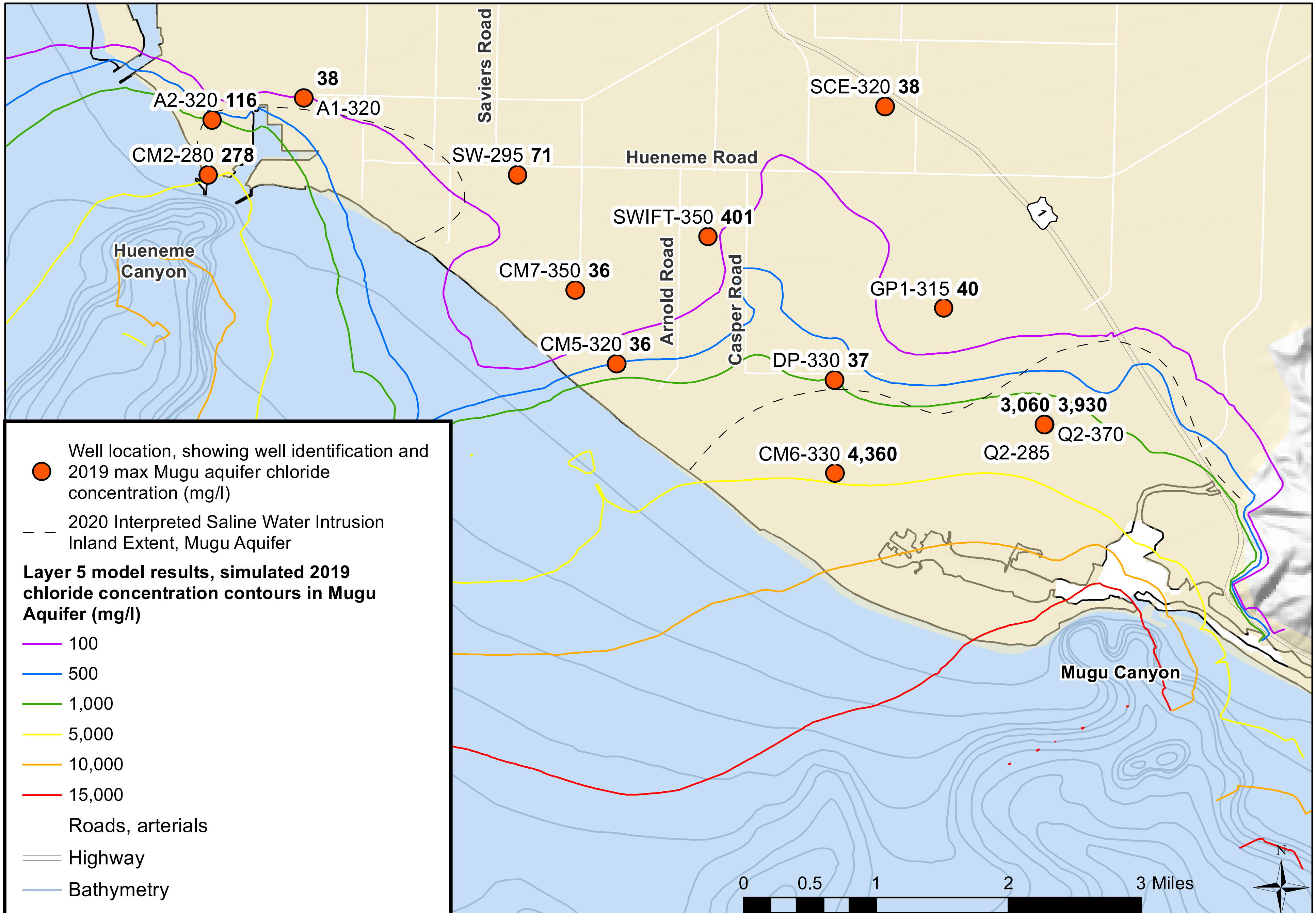

Figure 2. Simulated chloride concentrations in the Mugu aquifer. Flow and transport simulated for the years 1985-2019. Inland chloride concentrations are the result of both lateral flow within and vertical flow between aquifers.

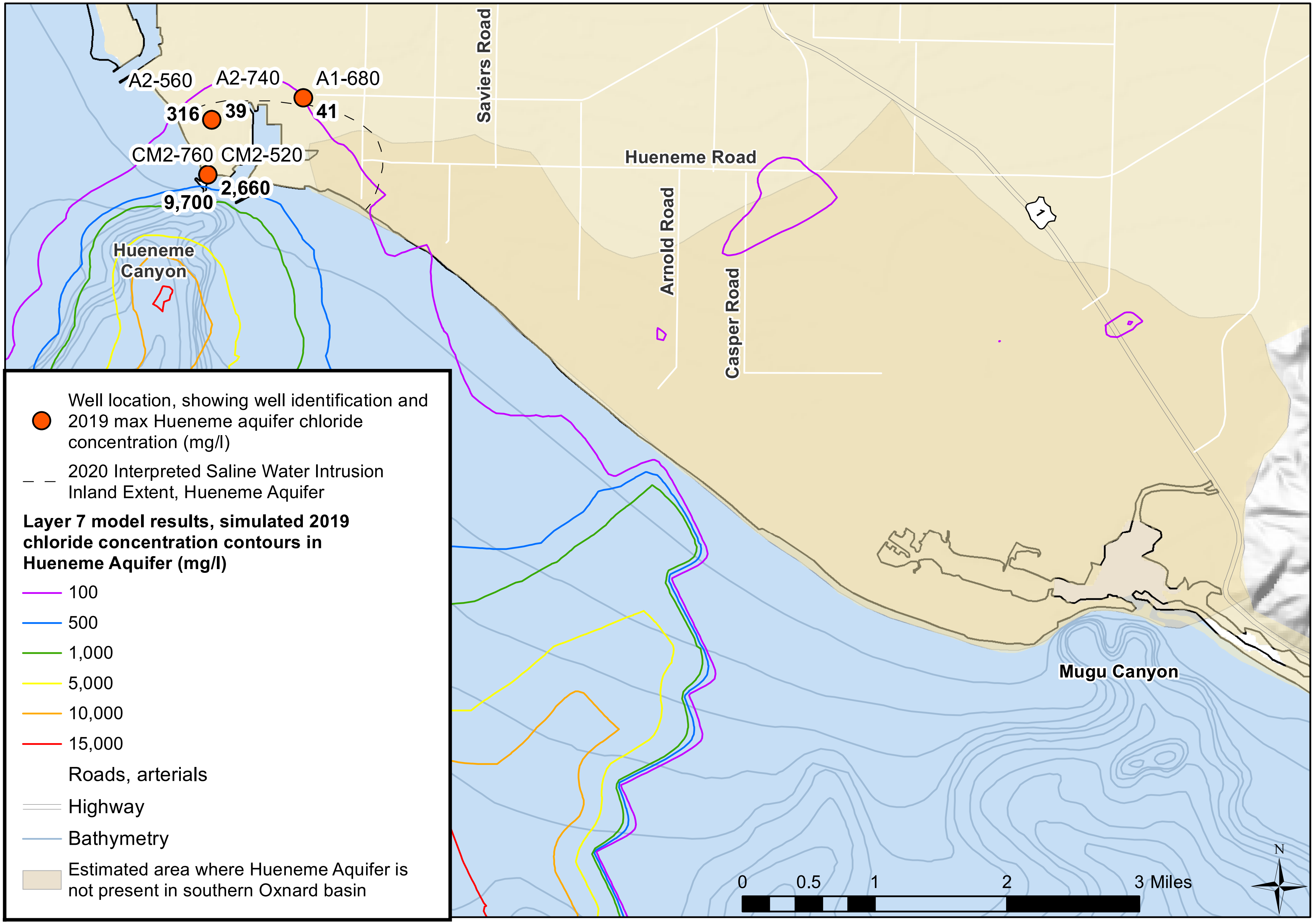

Figure 3. Simulated chloride concentrations in the Hueneme aquifer. Flow and transport simulated for the years 1985-2019. Inland chloride concentrations are the result of both lateral flow within and vertical flow between aquifers.

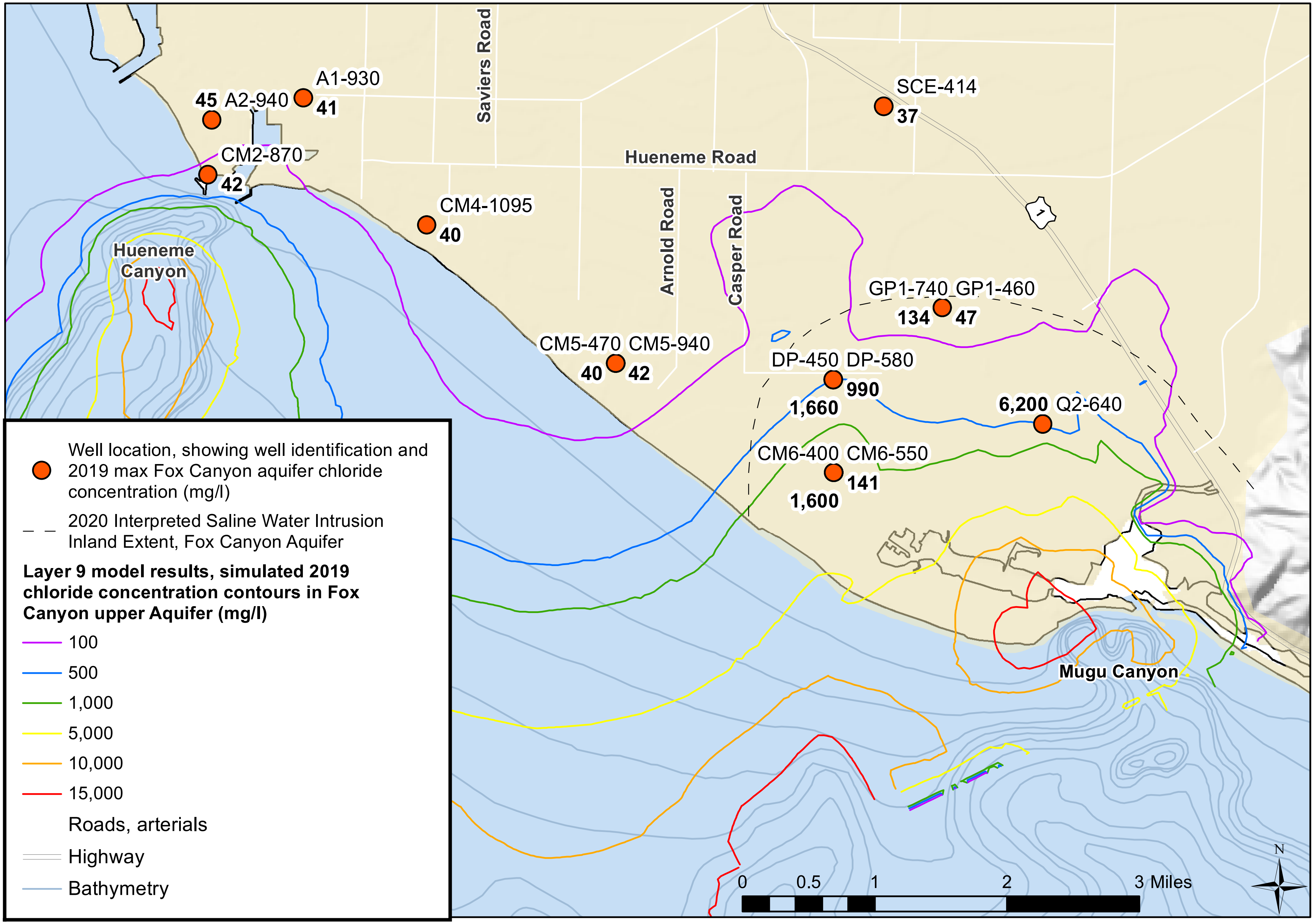

Figure 4. Simulated chloride concentrations in the main Fox Canyon aquifer. Flow and transport simulated for the years 1985-2019. Inland chloride concentrations are the result of both lateral flow within and vertical flow between aquifers.

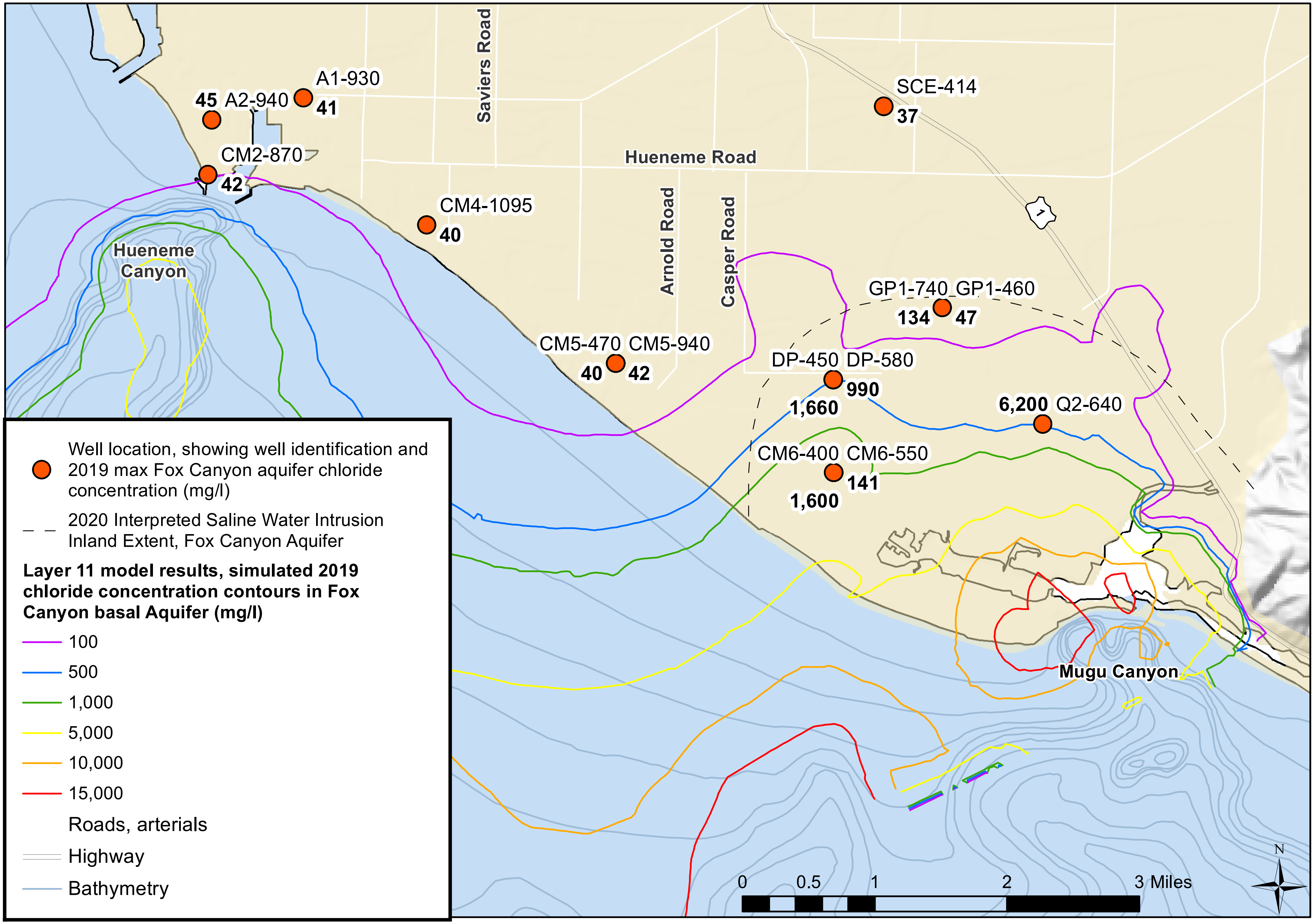

Figure 5. Simulated chloride concentrations in the basal Fox Canyon aquifer. Flow and transport simulated for the years 1985-2019. Inland chloride concentrations are the result of both lateral flow within and vertical flow between aquifers.

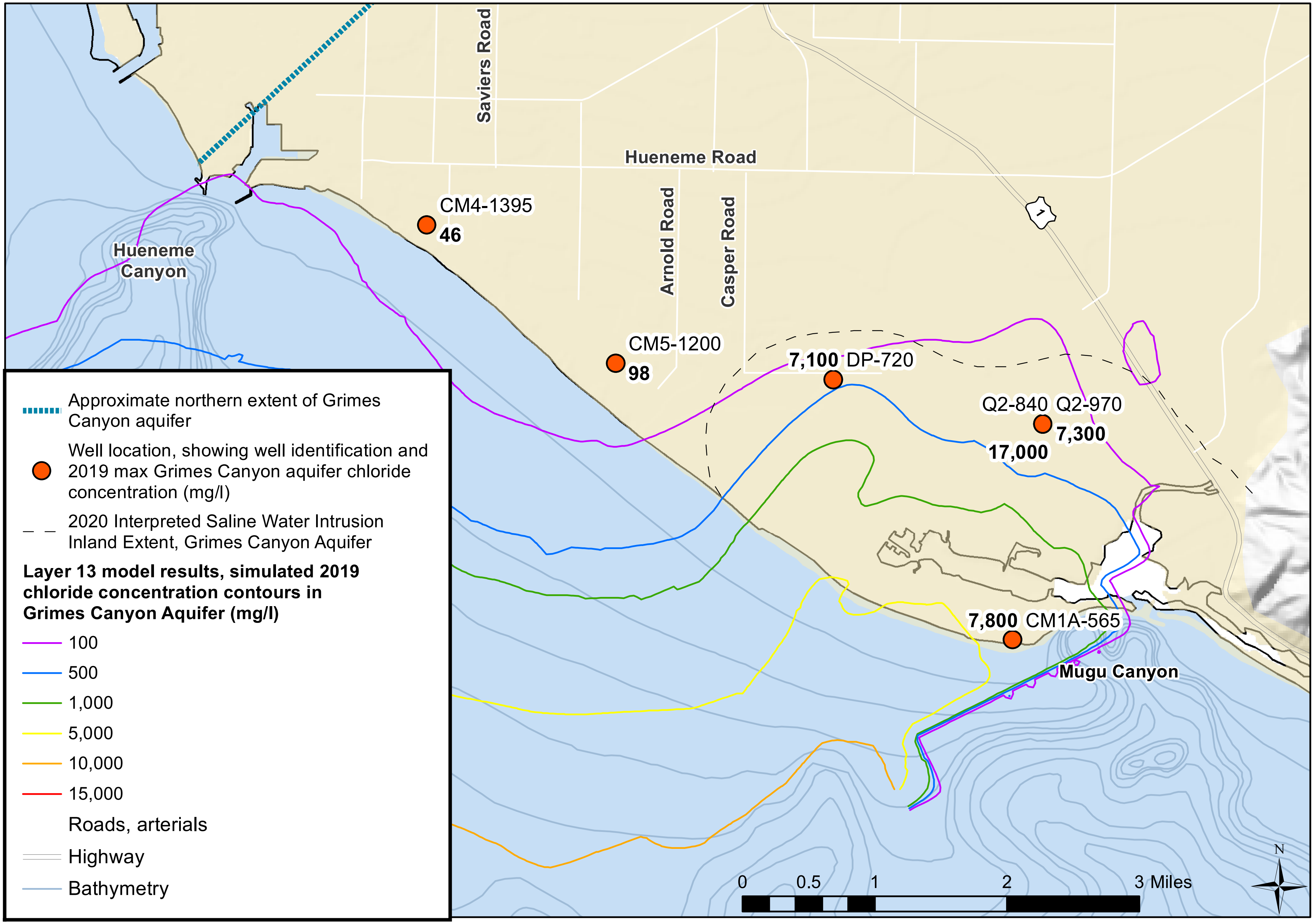

Figure 6. Simulated chloride concentrations in the Grimes Canyon aquifer. Flow and transport simulated for the years 1985-2019. Inland chloride concentrations are the result of both lateral flow within and vertical flow between aquifers.