GeoHydros LLC

March 27, 2017

Keith Van Der Maaten
General Manager
Marina Coast Water District

Subject: Review of the 2016 North Marina Groundwater Model

Dear Mr Van Der Maaten,

Please find attached our report summarizing our review and findings regarding the 2016 North Marina Groundwater Model.

In summary, we believe our report sufficiently demonstrates why the Draft EIR/EIS's conclusions regarding the MPWSP's groundwater impacts are not scientifically supportable and conflict with available information. Please note that given the problems with the model calibration identified above, we do not recommend additional scenario analysis using the 2016 NMGWM because it would not provide scientifically supportable results.

Please contact us is you have any questions or would like us to perform additional analyses. We have also attached our firm CV and individual CVs, as you requested.

Sincerely,

Todd R Kincaid, Ph.D.
President, Principal Hydrogeologist

Review of the 2016 Version of the North Marina Groundwater Model Marina Coast California

March 27, 2017

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Prepared for:

Marina Coast Water District
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Prepared by:

Todd R. Kincaid, Ph.D.
President / Principal Hydrogeologist

I, Kevin E. Day, P.G., no. 8034, have read and agree with the findings in this report titled *2016 Version of the North Marina Groundwater Model Marina Coast, California dated March 27, 2017* and do hereby certify that I currently hold an active professional geology license in the state of California. The report on the status of tasks, including the evaluation of the updated North Marina Groundwater Model prepared by Dr. Todd R. Kincaid of GeoHydros, LLC, has been reviewed by me and found to be in conformance with currently accepted geologic practices, pursuant to Title 16, Division 29 of the California Code of Regulations.

Kevin Day, P.G.

California License No. 8034

March 27, 2017

Date

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Appendix 2 Simulated Cone-of-Depression in the Dune Sand, 180-FT, 400-FT, and 900-FT aquifers calculated from the DD1-44/56 and Calibrated scenarios of the 2016 NMGWM after each Year of the 32-Year Simulation Period

Appendix 3 Water Budget Reports Exported from the Calibrated and DD1-44/56 Scenarios of the 2016 North Marina Groundwater Model

1 BACKGROUND

GeoHydros, LLC was contracted by the Marina Coast Water District to review the 2016 version of the North Marina Groundwater Model (NMGWM) with specific regard to the findings derived from that model and reported in Section 4.4[1] and Appendix E2[2] of the CalAm Monterey Peninsula Water Supply Project Draft EIR/EIS dated January 2017 and used as the basis for the determinations of impact from proposed slant well pumping near the city of Marina, California. Our work included a review of the documents listed above and the 2015 version of Appendix E2; and obtaining, running, and performing scenario analyses with the calibrated version of the 2016 NMGWM and the associated "superposition" models that were created from it for the 2016 EIR/EIS.

2 NMGWM

The 2016 NMGWM is a finite difference numerical groundwater flow model constructed with the MODFLOW groundwater modeling software[3] using a uniform grid of 200 x 200 foot cells. The model simulates flow from the Pacific Ocean into and through four aquifers separated by aquitards that inhibit but do not prevent vertical flow between the aquifers. The model is a modification of the 2015 version[4] to include and address more site specific hydrostratigraphic units, namely the Dune Sand Aquifer and the Salinas Valley aquitard, groundwater elevations in the vicinity of the proposed wells, and structural changes that favored the conceptualized flow from the Pacific Ocean into the aquifers[5].

Table 1. Hydrostratigraphic Units in the 2016 NMGWM

Layer	Type	Name
1	N/A	Ocean
2	Aquifer	Dune Sand Aquifer
3	Aquitard	Salinas Valley Aquitard
4	Aquifer	180-ft Aquifer
5	Aquitard	180/400-ft Aquitard
6	Aquifer	400-ft Aquifer
7	Aquitard	400/900-ft Aquitard
8	Aquifer	900-ft Aquifer

The model has been used directly or indirectly to predict the impacts to groundwater resources of various possible configurations of a proposed project to withdraw groundwater from the Dune Sand and 180-FT aquifers adjacent to the coast of the Pacific Ocean at the CEMEX site (Figure 1). Predictions stemming from the model include: 1) delineation of cones of depression in the Dune Sand, 180-FT, 400-FT, and 900-FT aquifers associated with different pumping, return flow, and sea level scenarios; 2) quantification of the sources of water that will supply the proposed extractions, namely the ocean versus groundwater; and 3) the effect of the proposed pumping scenarios on the transition zone between freshwater and salt water in the aquifers.

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[1] *Groundwater Resources Section of the CalAm Monterey Peninsula Water Supply Project 2017 Draft EIR/EIS dated January 2017, ESA / 205335.01*
[2] *Appendix E2 of the 2017 Draft EIR/EIS entitled: North Marina Groundwater Model Review, Revision, and Implementation for Slant Well Pumping Scenarios, November 23, 2016, prepared by HydroFocus, Inc.*
[3] *Harbaugh, A.W.; Banta, E.R.; Hill, M.C.; McDonald, M.G., 2000. MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model -- User Guide to Modularization, Open File Report 00-92.*
[4] *Appendix E2 of the 2015 Draft EIR/EIS entitled: Monterey Peninsula Water Supply Project Groundwater Modeling and Analysis, April 17, 2015, prepared by GeoScience, Inc.*
[5] *Table 3.1, Appendix E2, Ibid*

The model domain encompasses a nearly square area rotated 16 degrees clockwise, approximately 13 miles northwest-southeast by 11.4 miles northeast-southwest, approximately 40% of which extends into the Pacific Ocean (Figure 1). The model boundaries are arbitrary and do not represent natural hydrologic divides therefore the model simulates flow across the external boundaries that cannot be verified from data.

General head boundary conditions were assigned to the inland portions of the external model boundaries meaning that the groundwater elevations were inferred by the model from nearby wells or sources at some distance from the boundary. In these cells, flow across the boundaries was determined by the simulated hydraulic gradient and the specified hydraulic conductivities. Constant head boundary conditions were assigned to the outer boundaries of the offshore portions of the external model boundaries as well as all offshore cells in the uppermost model layer and a portion of the offshore cells in Layers 2-6 (Figures 2 and 3). The constant head boundary assignments differed from the 2015 version of the NMGWM in that the 2016 version prescribed equivalent freshwater heads to the offshore cells that account for the depth of the ocean water over the respective model layers and the density difference between saltwater and freshwater[6] whereas the 2015 version assigned constant heads only in layer 1 (ocean) and set the values to sea level[7]. Figures 4 and 5 show perspective cross-sections through the model domain that depict the effect of the equivalent freshwater head assignments in the ocean on the hydraulic gradient (slope) of the groundwater surfaces in the Dune Sand Aquifer (model layer 2) and the 180-FT Aquifer (model layer 4).

By limiting the use of equivalent freshwater heads to the ocean side of the model layers, HydroFocus did not account for the effect of varying salinities in the groundwater inland from the coast and therefore over-predicted the west-east hydraulic gradient. This results in a failure to reasonably simulate saltwater intrusion as it appears was the intent. The appropriate way to simulate saltwater intrusion is with the use of a dual-density model such as could have been constructed with the SEAWAT or FEFLOW groundwater modeling software. In its present form, the NMGWM should not be used to infer how the proposed project or any other stresses would likely affect saltwater intrusion or the position of the saltwater/freshwater interface in any of the simulated aquifers. Use of a dual-density simulation software would also allow for model calibration to salinities observed in onshore wells.

External head-dependent boundary conditions (aquifer water levels), pumping rates, recharge rates, and stream losses and gains were derived from the Salinas Valley Integrated Ground and Surface Water Model (SVIGSM),[8] which is a considerably larger and coarser model encompassing the Salinas River watershed that does not simulate the added hydrostratigraphic units (Dune Sand Aquifer or Salinas Valley Aquitard). The interconnectivity between these two models is problematic because they simulate different conceptual hydrostratigraphic frameworks. In particular, the initial heads and boundary conditions pertaining to the Dune Sand Aquifer and Salinas Valley Aquitard are likely not appropriate resulting in a poor simulation of

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[6] *Table 3.1, Appendix E2, of the 2017 Draft EIR/EIS entitled: North Marina Groundwater Model Review, Revision, and Implementation for Slant Well Pumping Scenarios, November 23, 2016, prepared by HydroFocus, Inc.*
[7] *Appendix E2 of the 2015 Draft EIR/EIS entitled: Monterey Peninsula Water Supply Project Groundwater Modeling and Analysis, April 17, 2015, prepared by GeoScience, Inc.*
[8] *Montgomery Watson, 1997, "Salinas Valley Integrated Ground Water and Surface Model Update, Final Report," May 1997.*

groundwater levels and horizontal and vertical hydraulic gradients in these units. HydroFocus identified this problem as a likely source of the large calibration errors in the Dune Sand Aquifer monitoring wells.

Due in part to the constant head boundary assignments and relationship to the SVIGSM, the design of the 2016 NMGWM yields implausible hydraulic conditions in all four of the simulated aquifers. Figures 6-9 depict the simulated groundwater surfaces for each of the four aquifers at the first and last timestep in the 32-year simulation period. Figure 6 reveals that the Dune Sand Aquifer is essentially not present at the first timestep and that there is little to no northward flow across the model boundary in the aquifer in the last timestep though the aquifer is reported to continue southward into the Fort Ord region. Appendix 1 provides groundwater surfaces exported after each year of the simulation period, which reveal that the Dune Sand Aquifer doesn't fully evolve until approximately year 20. Though fluctuations in recharge and pumping incorporated into the transient simulation contribute to the simulated variation through time, the difference between the hydrostratigraphic frameworks represented in the SVIGSM and the NMGWM is most likely the dominant cause.

The simulated groundwater surface in the Dune Sand Aquifer is inconsistent with the majority of the surfaces simulated by the 2015 version of the model. Specifically, the 2015 version of the model depicted northward flow into the model domain in the Dune Sand Aquifer for multiple of the simulated scenarios, whereas the 2016 version represents the Dune Sand Aquifer as a mound that doesn't extend to the south, which differs from the conceptual model that reflects hydraulic continuity into the Fort Ord area. These differences indicate that the changes made in the 2016 version of the NMGWM also contributed to the problems with the Dune Sand Aquifer simulation and calibration.

Figures 8-9 show nearly consistent west-to-east hydraulic gradients across the model domain in the 400-FT and 900-FT aquifers indicating that the ocean is the primary source of water flowing across the model. Based on these maps, we would infer that nearly all of the volume of these two aquifers throughout the model domain should be substantially impacted by saltwater intrusion. The occurrence and use of freshwater from these lower aquifers indicates that model is over-estimating the gradient and/or not adequately simulating the sources of fresh groundwater inflow to the aquifers within the model domain.

The calibration criteria used to define model acceptability addressed only the difference between simulated and observed groundwater levels at the calibration wells wherein the definition of acceptable was achieving a root mean square error (RMSE) of 10% - 15% of the range in observed groundwater elevations within the model domain. This criteria was more permissive than the 10% value described in the 2015 version of the model documentation and the RMSE for the whole model increased from the 2015 version (10.5 feet)[9] to the 2016 version (12.4 feet)[10].

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[9] *Figure 37, Appendix E2 of the 2015 Draft EIR/EIS entitled: Monterey Peninsula Water Supply Project Groundwater Modeling and Analysis, April 17, 2015, prepared by GeoScience, Inc.*
[10] *Figure 4.3a, Appendix E2 of the 2017 Draft EIR/EIS entitled: North Marina Groundwater Model Review, Revision, and Implementation for Slant Well Pumping Scenarios, November 23, 2016, prepared by HydroFocus, Inc.*

Inspection of the calibration plots presented by HydroFocus[11] indicates that the range in groundwater elevations for all simulated aquifers is approximately 200 feet. For the individual aquifers, the ranges are approximately 100 feet, 50 feet, 110 feet, and 80 feet for the Dune Sand, 180-FT, 400-FT, and 900-FT aquifers respectively. The HydroFocus calibration criteria would therefore be 20-30 feet for the whole model, and 10-15 feet, 5-7.5 feet, 11-16.5 feet, and 8-12 feet for the Dune Sand, 180-FT, 400-FT, and 900-FT aquifers respectively. Within this context, the model fails the stated calibration test in the Dune Sand Aquifer (RMSE=30.2). Using the stricter 2015 version of the criteria, the model also fails the calibration test for the 180-FT Aquifer (RMSE=7.2) and the 900-FT Aquifer (RMSE=11.3). In general, we have inferred from the data and results available that the quality of the model calibration declined between the 2015 and the 2016 versions, which further indicates that the changes made during the 2016 revisions have resulted in diminished reliability and contribute to the calibration problems cited by HydroFocus and attributed to the SVIGSM. Moreover, guidelines for model calibration also include ensuring the appropriateness of the model boundary conditions, the conceptual model, and the initial conditions for transient models[12], all of which are problematic in the 2016 NMGWM.

For the reasons described above, the NMGWM predictions of impacts to groundwater resources due to the proposed pumping are not reliable particularly in the Dune Sand Aquifer. The calibration problems in the Dune Sand Aquifer undermine confidence in the hydraulic conductivity assignments in Layer 2 and Layer 3 and therefore the predicted magnitude and spatial extent of the cones of depression in those layers. HydroFocus performed sensitivity analyses to address uncertainty with respect to hydraulic conductivity assignments by varying the ratio between horizontal and vertical hydraulic conductivity by a factor of five to create scenarios for higher and lower vertical anisotropy[13]. Their results indicate that a five-fold increase in horizontal hydraulic conductivity coupled with a five-fold decrease in vertical hydraulic conductivity can substantially increase the predicted size of the cone-of-depression, nearly doubling the size in the Dune Sand Aquifer. Their findings emphasize the importance of achieving better calibration in the Dune Sand Aquifer to the reliability of the impact predictions.

The boundary conditions problems, particularly the southern boundary in Layer 2, prevents the simulation of inflow to the model domain from the southern boundary and undermines confidence in the predicted contributions to the proposed pumping from the Dune Sand Aquifer. Finally, the model cannot simulate saltwater intrusion nor the effect of pumping on the position of the transition zone between freshwater and salt water conditions in the aquifers due to the proposed pumping scenarios because it is not a dual-density model. The use of equivalent freshwater heads does not overcome this limitation.

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[11] *Figures 4.3a – 4.3c, Appendix E2 of the 2017 Draft EIR/EIS, Ibid.*
[12] *Reilly, T.E. and Harbaugh, A.W., 2004. Guidelines for Evaluating Groundwater Flow Models, U.S. Geological Survey, Scientific Investigations Report 2004-5038.*
[13] *Section 6.0 & Figures 6.1-6.2, Appendix E2 of the 2017 Draft EIR/EIS entitled: North Marina Groundwater Model Review, Revision, and Implementation for Slant Well Pumping Scenarios, November 23, 2016, prepared by HydroFocus, Inc.*

3 SUPERPOSITION MODEL

Superposition modeling is a method used to simulate the effects of some specific and singular form of aquifer stress (including pumping) on groundwater levels that can be used only when the effects of the active aquifer stresses are related linearly, i.e. simply additive. The method is typically used when the totality of aquifer stresses is too complicated to be pragmatically simulated or when there is insufficient data to develop a comprehensive simulation. The superposition method does not add to the confidence in the predictions, it merely simplifies the process of rendering a prediction in exchange for reduced ability to evaluate the condition of the hydrologic system. Such conditions would include groundwater surface elevations, water budget impacts, and/or impacts to existing actions such as other pumping, groundwater/surface water exchange, or cross-boundary flows.

In the case of the NMGWM, superposition models were generated for each pumping scenario by removing all other simulated stresses from the model and adjusting initial and boundary condition heads to 0.0 feet thereby providing a convenient datum for the simulation of cones of depression. In doing this, the models use the same distribution of horizontal and vertical hydraulic conductivities that were derived through model calibration and limited impacts assessments to a prediction of the cone-of-depression associated with each pumping scenario.

Though superposition modeling is a valid technique, it isn't necessary or appropriate for these evaluations because:

1) superposition modeling precludes evaluation of impacts to the water budget associated with the proposed pumping, i.e. defining the source of water to be extracted, which is a critical and central point of concern for stakeholders regarding the proposed project;
2) superposition modeling precludes prediction of measurable changes associated with the proposed pumping (i.e. predicted groundwater elevations and gradients), which would provide the only means for stakeholders to validate the model predictions and potential project impacts;
3) a comprehensive numerical model that includes other active stresses had been developed and calibrated that could be used to render those assessments;
4) GeoScience had previously developed impact assessments using the calibrated model directly and thus the groundwork for repeating that process had presumably been laid; and
5) a comparison of the cones of depression predicted by the superposition model and those we developed using the calibrated version of the 2016 NMGWM reveal that the prescription of the 0.0 datum to initial and boundary heads constrained their size and thus likely under-estimates the spatial extent of drawdown associated with the proposed pumping (Figures 10-13).

4 EVALUATION OF POTENTIAL IMPACTS

Though the calibration and boundary condition problems described in Section 2 render predictions derived from the NMGWM unreliable particularly with respect to the Dune Sand Aquifer, we performed one of the scenario analyses using the calibrated NMGWM to expand on the depiction of potential impacts described in the Draft EIR/EIS. To do this, we modified the calibrated model to include the proposed pumping, ran the modified model, and compared the results to the calibrated version to evaluate and report impacts to groundwater surfaces and the water budget. We chose scenario DD1-44/56, which assumes a project pumping rate of 24.1 million gallons per day (mgd), no return flows, and 2012 sea level conditions[14].

The associated pumping assignments were copied from the wells file associated with the DD1-44/56 superposition model and inserted into the assignments into the wells file associated with the calibrated model. The model was then rerun to produce results that include the proposed project pumping. This approach effectively assumes that the proposed pumping described by the DD1-44/56 scenario began at the beginning of the transient simulation period wherein all other aquifer stresses remained identical to those prescribed for the calibrated scenario. Water budget and heads were then extracted and used in conjunction with the same output exported from the calibrated scenario as the basis for the impact assessments presented below.

4.1 Impact to Groundwater Surfaces

Figures 14-17 depict the simulated groundwater surfaces for the Dune Sand, 180-FT, 400-FT, and 900-FT aquifers exported from the calibrated and DD1-44/56 scenarios after the final timestep in the calibrated model's simulation period. The maps show obvious cones of depression surrounding the proposed pumping wells at the CMEX Site but no obvious perturbations to the groundwater surfaces in the lower 400-FT and 900-FT aquifers.

Figures 18-21 depict the simulated impacts to the groundwater surfaces (cones-of-depression) in the four aquifers after the first and last timestep in the calibrated model's simulation period that were created by subtracting the calibrated groundwater surface from the DD1-44/56 scenario surface for each aquifer and each timestep. The Dune Sand, 180-FT, and 400-FT aquifers all show obvious impacts that significantly expand over the course of the simulation period where as no impacts greater than or equal to 0.5 feet are predicted to occur in the lowest 900-FT Aquifer. For both the Dune Sand and 180-FT aquifers, reductions in the groundwater surface of more than 1 foot are predicted to extend for considerable distances (>3 miles) to the east, north, and south from the proposed wells and be slightly more extensive in the 180-FT aquifer than in the Dune Sand Aquifer. Reductions of between 0.5 and 1 foot are predicted to extend for more than 6 miles to the northeastern boundary of the Dune Sand Aquifer and more than 4 miles to the northeast in the 180-FT aquifer. Reductions in the groundwater surface of between 5 and 10 feet in both aquifers are predicted to occur to within ~1 mile of the wells (reaching across Cabrillo Highway).

Appendix 2 provides simplified drawdown maps for each of the four aquifers computed for the last timestep in each year of the 32-year simulation period. These maps show that drawdown in the 180-FT, 400-FT, and 900-FT (shown in these figures as between 0.25 and 0.5 feet) aquifers is predicted to stabilize after approximately 5 years of continuous pumping meaning that the full impact to groundwater surface elevations can be expected to occur within five years after the beginning of pumping. Drawdown maps for the Dune Sand Aquifer reveal a substantially different response over time wherein the cone-of-depression is predicted to continue to expand over the course of ~25 years after the beginning of pumping. Most of the change

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[14] *Scenarios_Matrix.xlsx, provided to GeoHydros from the applicant.*

however is isolated to the same teardrop-shaped region where the model must first create the aquifer due to its probable absence in the initial and boundary condition heads derived from the SVIGSM.

Drawdowns created under other of the proposed project scenarios would be proportionally different as defined by the magnitude of pumping and returns. The relative differences between the predictions for the Dune Sand and lower aquifers will however be similar because these are driven by the model configuration more so than the scenario characteristics such as the magnitude of the proposed pumping and/or proposed return flows.

4.2 Water Budget Impacts

One of the fundamental capabilities of the numerical groundwater flow model is the water budget analysis, which quantifies all flows into and out of the model through all of the source sink terms incorporated in the model design. The impact of any action or stress to the aquifer can then be evaluated in much the same way as drawdown maps are calculated, by running the water budget report for both the scenario being evaluated and the calibrated scenario and comparing the results. Tables 2 and 3 and Figures 22-24 provide summaries of the water budget analysis conducted from reports extracted and compared in the manner described above for five timesteps in the calibrated and DD1-44/56 scenarios of the 2016 NMGWM. Appendix 3 provides the water budget reports from which these analyses were derived.

Table 2. Summary of water budget analyses performed using reports generated from the calibrated and DD1-44/56 scenarios of the 2016 NMGWM.

	Changes to the Water Budget (CFD) after Specified Timesteps				
Source/Sink	TS-01	TS-YR01	TS-YR02	TS-YR10	TS-Final
Increased Inflow from Storage:	635,888	37,439	12,907	1,550	-1,220
Decreased Outflow to Storage:	283,852	33,804	11,785	246	19
Increased Ocean Inflow:	2,201,807	2,787,850	2,816,520	2,848,200	2,737,204
Decreased Ocean Outflow:	25,414	82,248	76,582	54,399	167,494
Increased Bndy Inflow:	47,136	163,713	179,681	136,078	183,288
Decreased Bndy Outflow:	30,142	116,688	124,231	181,237	135,005
Total	*3,224,240*	*3,221,741*	*3,221,706*	*3,221,710*	*3,221,790*
% of Proposed Extractions:	*100.1%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*
	Source/Sink Contributions to the Proposed Extractions after Specified Timesteps				
Source/Sink	*TS-01*	*TS-YR01*	*TS-YR02*	*TS-YR10*	*TS-Final*
Increased Inflow from Storage:	*19.7%*	*1.2%*	*0.4%*	*0.0%*	*0.0%*
Decreased Outflow to Storage:	*8.8%*	*1.0%*	*0.4%*	*0.0%*	*0.0%*
Increased Ocean Inflow:	*68.3%*	*86.5%*	*87.4%*	*88.4%*	*85.0%*
Decreased Ocean Outflow:	*0.8%*	*2.6%*	*2.4%*	*1.7%*	*5.2%*
Increased Bndy Inflow:	*1.5%*	*5.1%*	*5.6%*	*4.2%*	*5.7%*
Decreased Bndy Outflow:	*0.9%*	*3.6%*	*3.9%*	*5.6%*	*4.2%*
Total	*100.1%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table 3. Evolution of source water for the proposed extractions as defined by water budget reports exported from five timesteps of the calibrated and DD1-44/56 scenarios of the 2016 NMGWM.

Days after Start	Ocean	DSA	SVA	180-ft	400-ft	900-ft	*Total*	Total GW
30	69.1%	22.3%	4.2%	3.5%	0.6%	0.3%	*100%*	30.9%
365	89.0%	3.6%	0.1%	4.9%	1.6%	0.8%	*100%*	11.0%
730	89.7%	2.4%	0.0%	5.2%	1.8%	0.8%	*100%*	10.3%
3,650	90.0%	1.9%	0.0%	5.3%	1.9%	0.9%	*100%*	10.0%
11,680	90.0%	1.8%	0.0%	5.3%	1.9%	0.9%	*100%*	9.9%

The water budget data indicates that the proposed pumping will initially derive more than 30% of the water from groundwater, predominantly the Dune Sand Aquifer (>22%) and to a smaller extent the 180-FT, 400-FT, and 900-FT aquifers. The groundwater contribution is predicted to decline to approximately 10% within 1-2 years and stabilize at that level of contribution after approximately 5 years throughout the remainder of the 32-year simulation period. Approximately 2.8% of the proposed extractions is predicted to come from the deeper 400-Ft and 900-FT aquifers, which equates to approximately 756 acre-feet per year. This water will come from cross-boundary flows into the respective aquifers and then via upward flow into the overlying 180-FT and Dune Sand Aquifers. Increased cross-boundary flows indicate that the cones of depression created by the existing wells will expand into the adjacent areas outside of the NMGWM domain.

The magnitudes of the water budget impacts described above will differ proportionally with the pumping magnitudes and return flows defined by the different project scenarios. The percentages described in Table 3 will likely be similar owing to the linearity in the groundwater flow and drawdown calculations.

5 CONCLUSIONS

- The 2016 NMGWM is poorly calibrated in the Dune Sand Aquifer likely due to incongruity between the NMGWM and the SVIGSM and to the assignment of large constant head elevations offshore in the ocean, Dune Sand Aquifer, Salinas Valley Aquitard, 180-FT Aquifer, 180/400-FT Aquitard, and 400-FT Aquifers.
- Using the stricter 2015 version of the calibration criteria (10% of observed head variation), the model fails calibration in the 180-FT Aquifer and the 900-FT Aquifer in addition to the Dune Sand Aquifer. In general, we have inferred from the data and results available that the quality of the model calibration declined between the 2015 and the 2016 versions, which indicates that the changes made during the 2016 revisions have resulted in diminished reliability.
- The poor calibration in the Dune Sand Aquifer undermines confidence in the magnitude and distribution of the assigned horizontal and vertical conductivities, and thus the predicted impact to groundwater elevations and predicted percentage of aquifer water that will be extracted by the proposed project because both of these impacts are largely predicated on the magnitude and distribution of hydraulic conductivities.
- The steep eastward hydraulic gradient from the ocean across the model domain in the 400-FT and 900-FT aquifers is improbable and inconsistent with the extraction of freshwater from these aquifers from within the model domain, and the groundwater surfaces simulated by all but the driest condition scenarios reported for the 2015 version of the NMGWM.

- The 2016 NMGWM cannot simulate saltwater intrusion to any of the simulated aquifers nor can it be used to predict how the proposed pumping might affect the position of the transition zone between freshwater and saltwater conditions in the aquifers.
- The use of equivalent freshwater heads does not provide any meaningful simulation of landward saltwater migration and their assignments likely contributes to the calibration problems.
- A dual-density model should be constructed if saltwater intrusion and/or the impact of the proposed project on groundwater salinities is to be evaluated.
- It is unlikely that the incongruity between the NMGWM and SVIGSM hydrostratigraphies can be overcome through model calibration owing to the degree to which initial and boundary heads in the NMGWM are dependent on SVIGSM output, and this limitation undermines confidence in NMGWM predictions.
- Superposition modeling is inappropriate for this evaluation because:
    - it precludes the identification of source water contributions to the proposed extractions, which is a key issue with the application;
    - it precludes prediction of measurable groundwater elevations associated with the proposed pumping, which would provide the only means for stakeholders to validate the model predictions and potential project impacts;
    - it is unnecessary because it provides no benefit in terms of reliability over the use of the calibrated version of the model for impact assessment, which allows for the assessments described above; and
    - the prescription of the 0.0 datum to initial and boundary heads has been shown to constrain the spatial extent of the simulated cones of depression in the aquifers created by the proposed pumping.
- Notwithstanding the limitations of the model described above, the model reveals potential impacts that were not fully described in the Draft EIR/EIS. The most relevant of these are:
    - the proposed pumping will initially derive more than 30% of the water from groundwater, predominantly the Dune Sand Aquifer (>22%) and to a smaller extent the 180-FT, 400-FT, and 900-FT aquifers.
    - Within 1-2 years, the groundwater contribution to the proposed extractions is predicted to decline to approximately 10% and stabilize at that level of contribution throughout the life of the proposed project.
    - A small but relevant portion of the proposed extraction (2.8% or 756 acre-feet for scenario DD1-44/56) is predicted to come from the deeper 400-Ft and 900-FT aquifers indicating that the proposed extractions will contribute to any overdraft problems in those aquifers.
    - For both the Dune Sand and 180-FT aquifers reductions in the groundwater surface of more than 1 foot are predicted to extend for considerable distances (>3 miles) to the east, north, and south from the proposed wells within five years after the start of pumping under the DD1-44/56 scenario.

  - The predicted cone-of-depression will be slightly more extensive in the 180-FT aquifer than in the Dune Sand Aquifer.
  - Reductions of between 0.5 and 1 foot are predicted to extend for more than 6 miles to the northeastern boundary of the Dune Sand Aquifer and more than 4 miles to the northeast in the 180-FT aquifer within five years of the start of pumping under the DD1-44/56 scenario.
  - Reductions in the groundwater surface of between 5 and 10 feet in both aquifers are predicted to occur to within ~1 mile of the wells (reaching across Cabrillo Highway) within five years of the start of pumping under the DD1-44/56 scenario.
- The sensitivity analyses performed by HydroFocus with respect to hydraulic conductivity indicate that the predicted impacts could be substantially understated, which demonstrates the importance of achieving better calibration.
- Reconstructing the model using a dual-density program, extending the model boundaries to natural divides or to a sufficiently distant point that boundary effects on the predicted impacts of the proposed project are eliminated or marginalized, and calibrating the model to groundwater salinities as well as heads would substantially increase the reliability of the predicted impacts.
- Based on the findings presented in this report, we believe that the Draft EIR/EIS's conclusions regarding the MPWSP's groundwater impacts are not scientifically supportable and that they conflict with available information.
- Given the problems with the model calibration identified above, we do not recommend additional scenario analysis using the 2016 NMGWM because it would not provide scientifically supportable results.

6 FIGURES

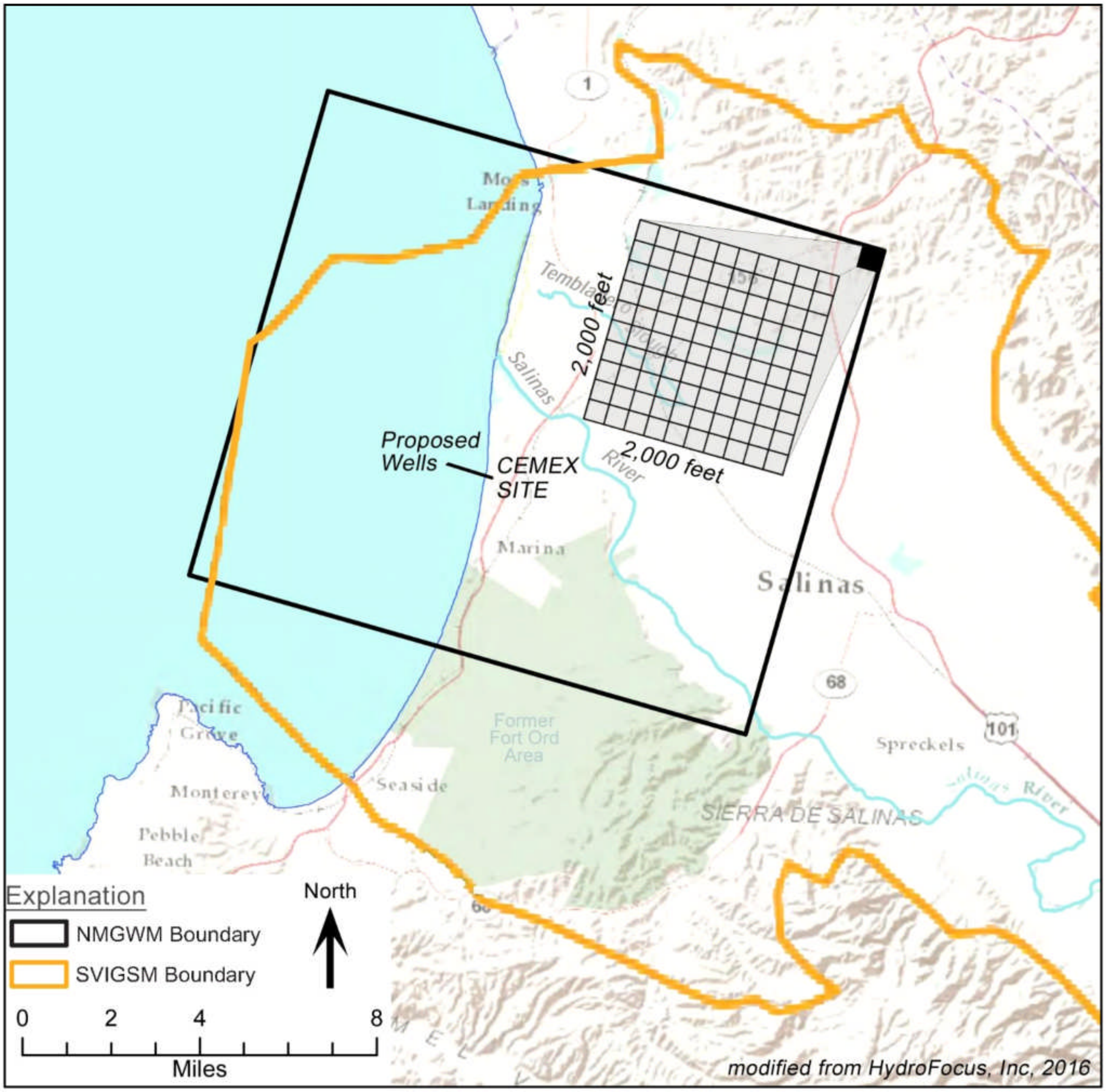


Figure 1.
Map showing the boundaries of the North Marina Groundwater Model and the Salinas Valley Integrated Groundwater Surface Water Model relative to the proposed wells.

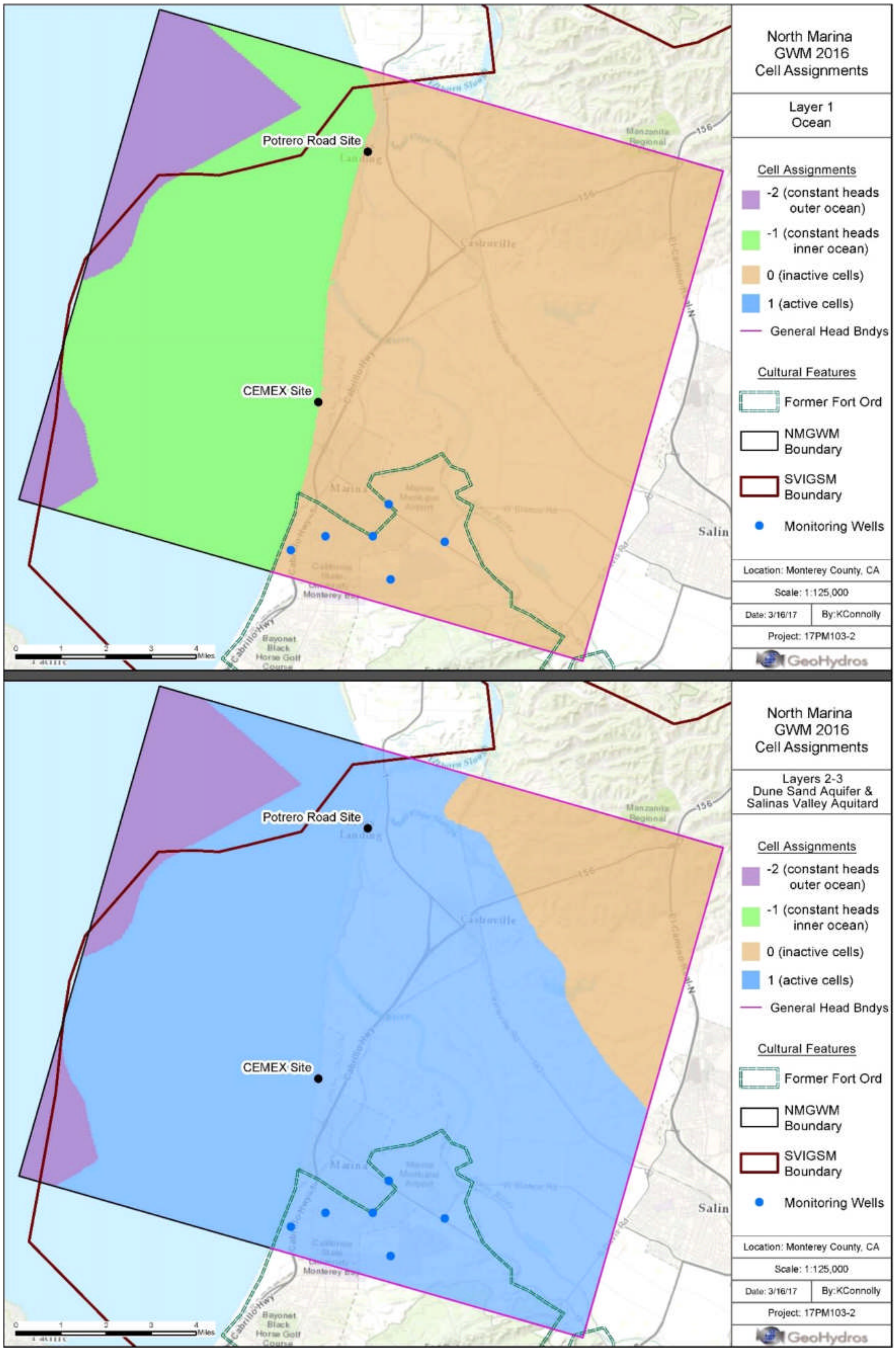


Figure 2.
NMGWM-2016 Cell Assignments & Boundary Conditions for Layer 1 (ocean - top) and Layers 2 & 3 (Dune Sand Aquifer & Salinas Valley Aquitard - bottom).

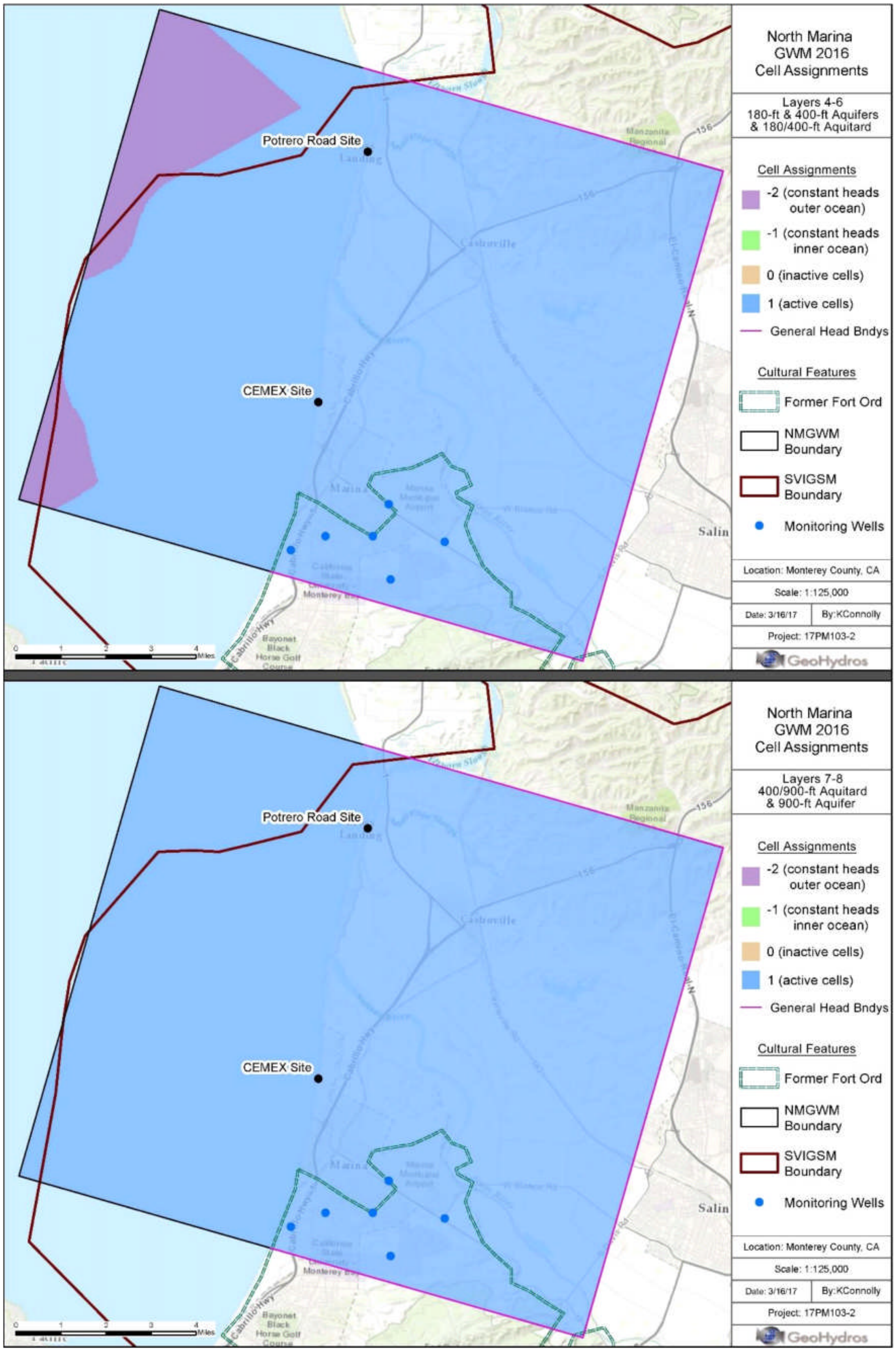


Figure 3.
NMGWM-2016 Cell Assignments & Boundary Conditions for Layers 4-6 (180-ft and 400-ft Aquifers & 180/400-ft Aquitard - top) and Layers 7 & 8 (400/900-ft Aquitard & 900-ft Aquifer - bottom).

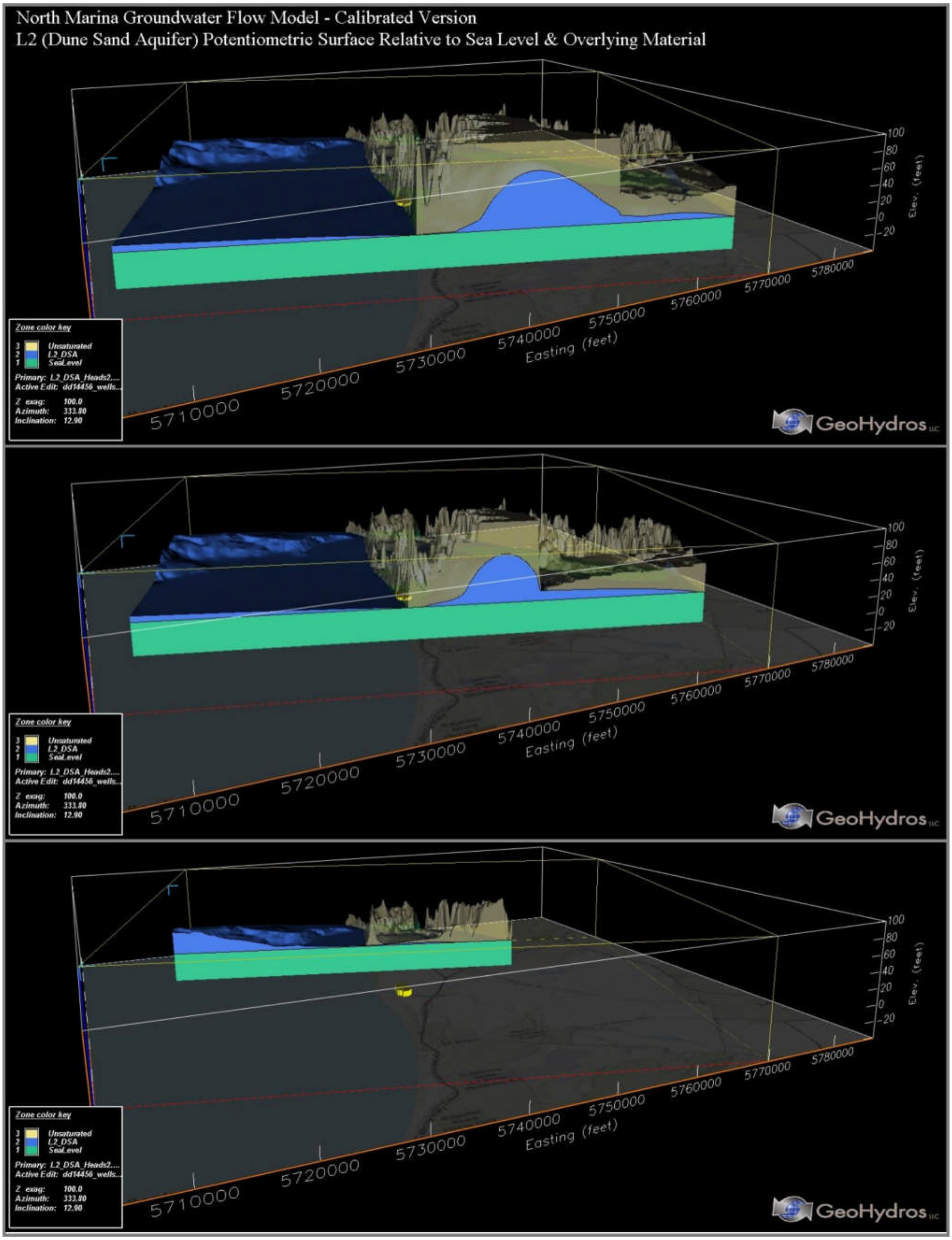


Figure 4.
Perspective west-east cross-sections through the 2016 NMGWM (calibrated scenario) showing the effect of equivalent freshwater head assignments in the Dune Sand Aquifer and the resulting groundwater surface relative to sea level and a cropped portion of the overlying material.

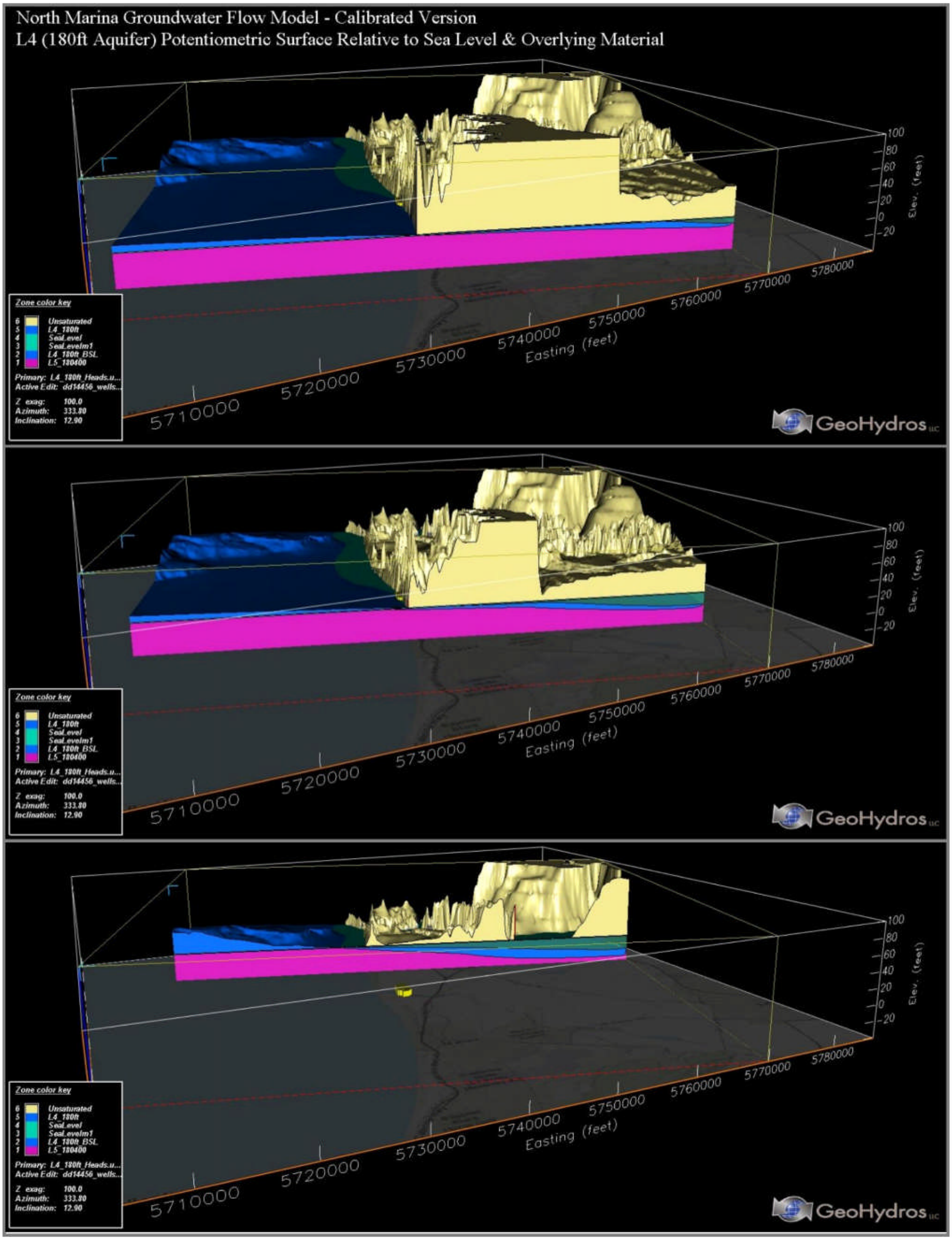


Figure 5.
Perspective west-east cross-sections through the 2016 NMGWM (calibrated scenario) showing the effect of equivalent freshwater head assignments in the 180-FT Aquifer and the resulting groundwater surface relative to sea level and a cropped portion of the overlying material.

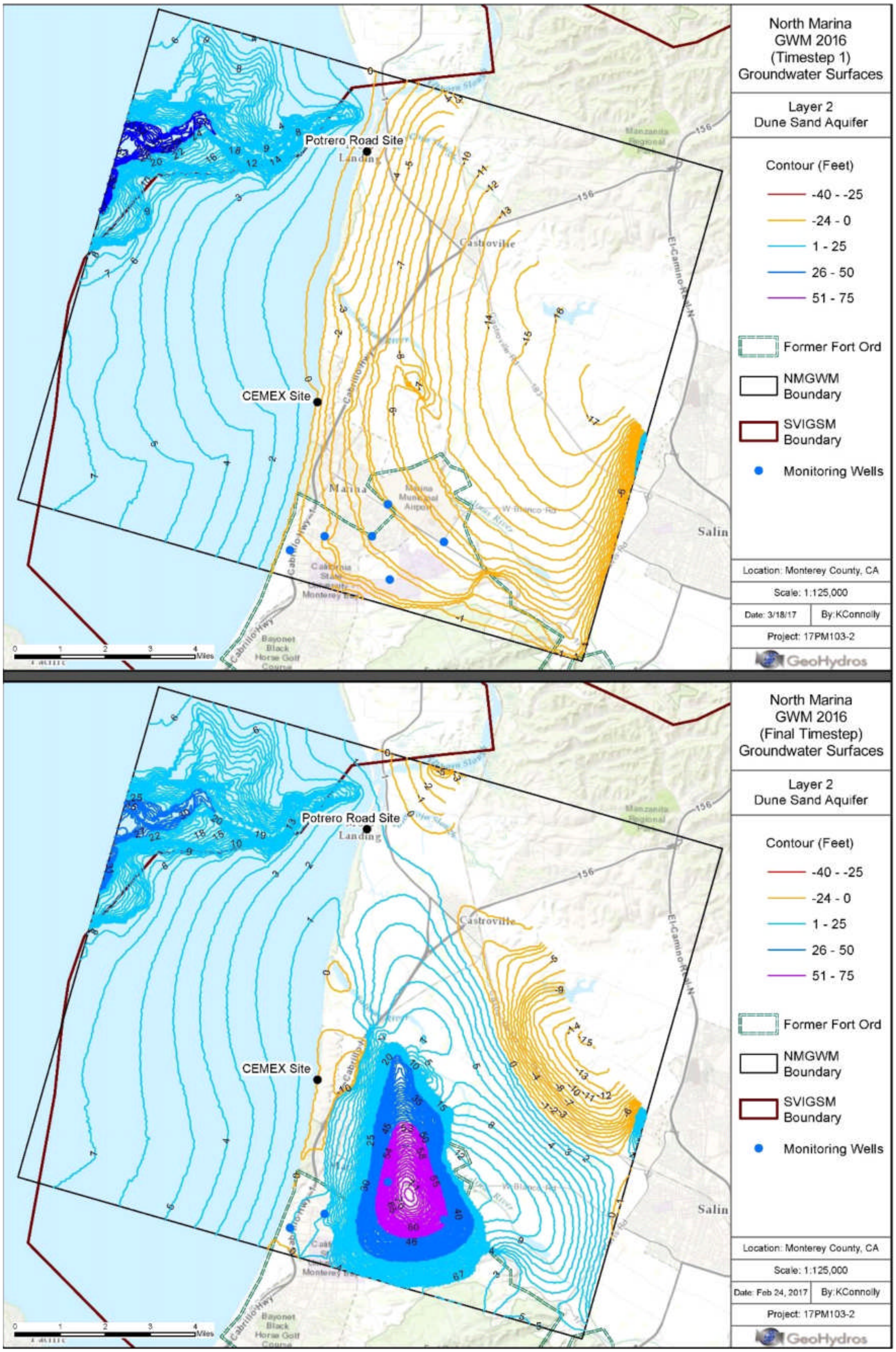


Figure 6.
Comparison of groundwater surfaces for the Dune Sand Aquifer simulated by the 2016 NMGWM at the first and last timesteps in the 32-year simulation period.

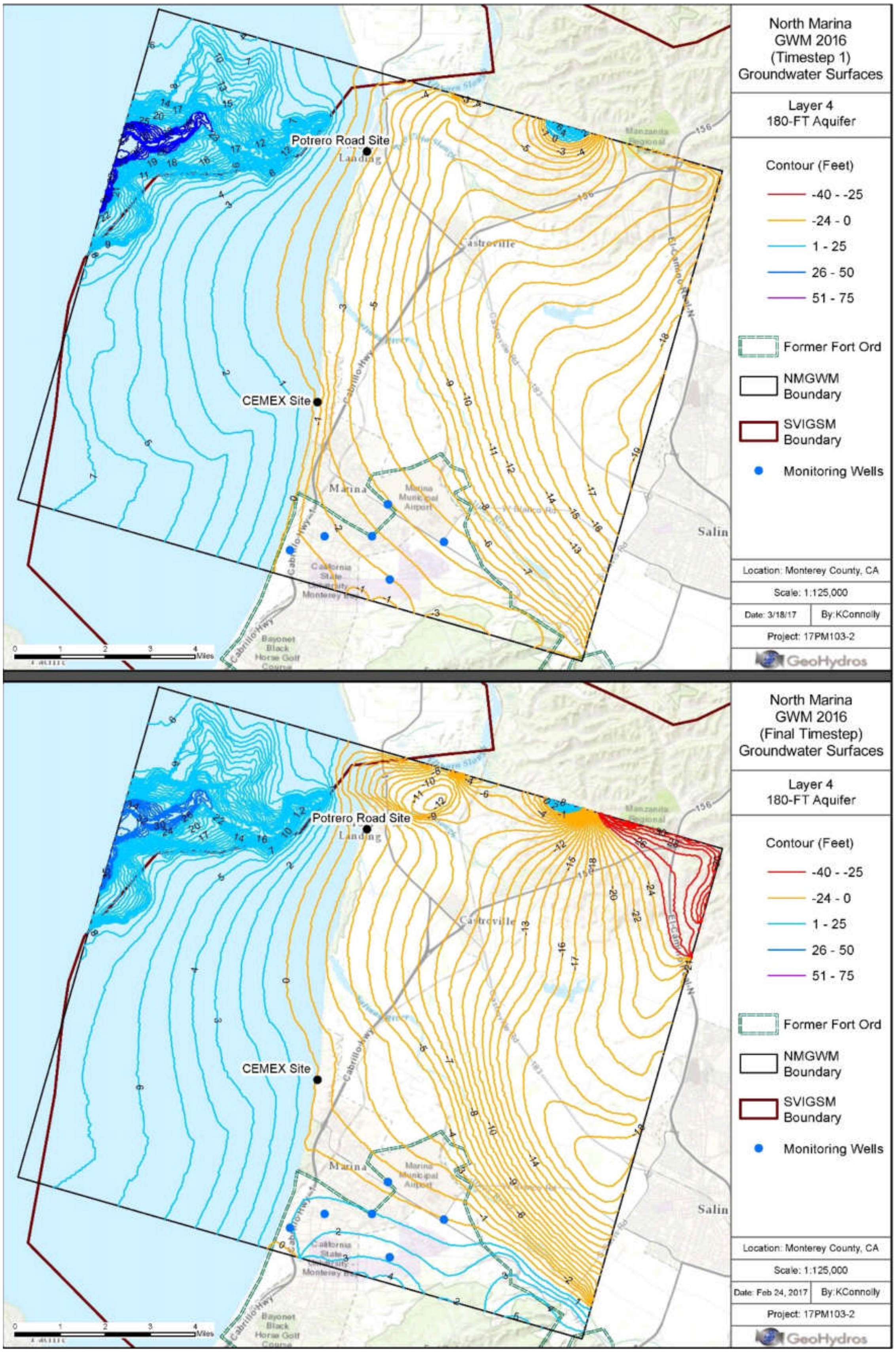


Figure 7.
Comparison of groundwater surfaces for the 180-FT Aquifer simulated by the 2016 NMGWM at the first and last timesteps in the 32-year simulation period.

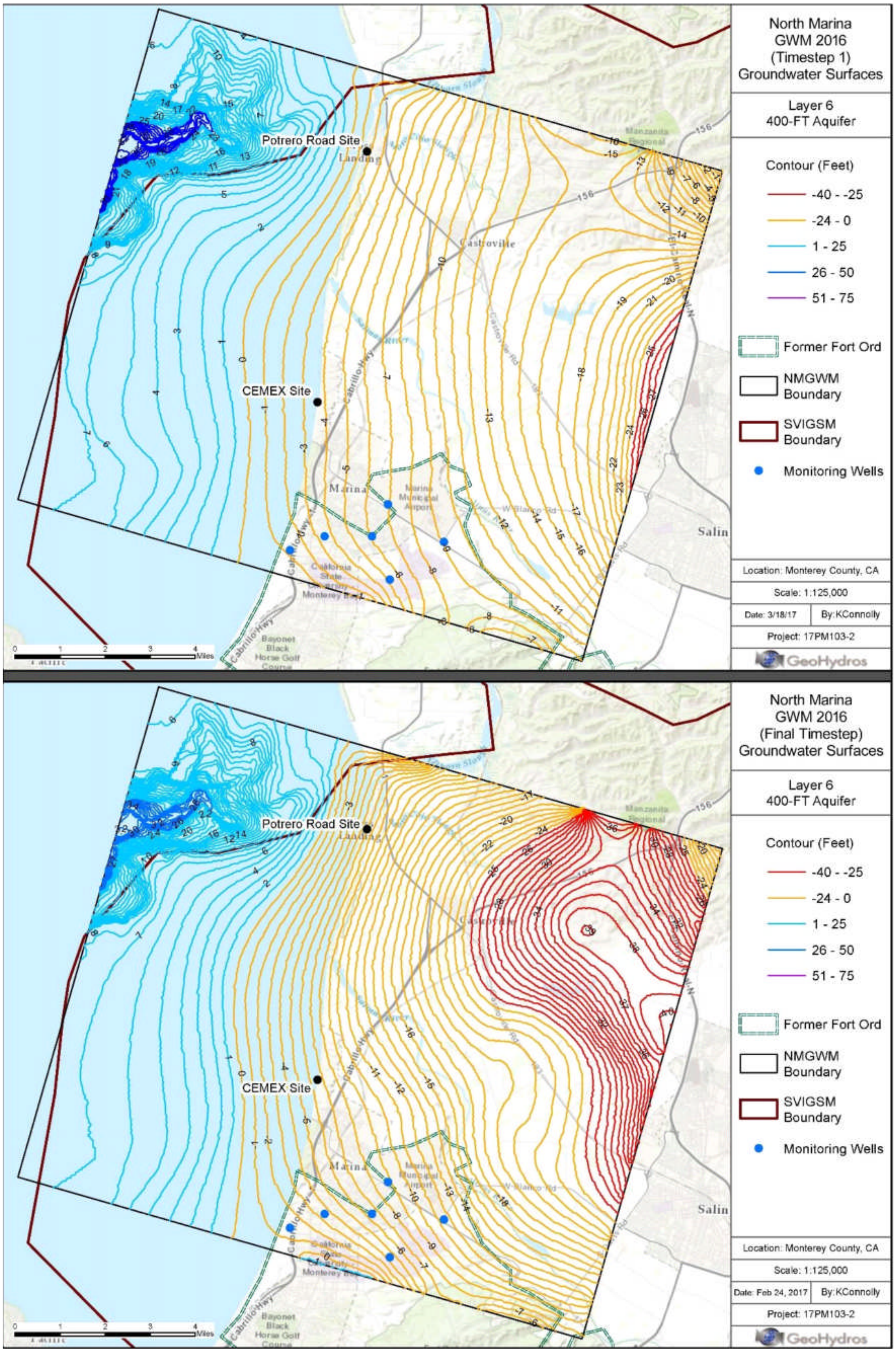


Figure 8.
Comparison of groundwater surfaces for the 400-FT Aquifer simulated by the 2016 NMGWM at the first and last timesteps in the 32-year simulation period.

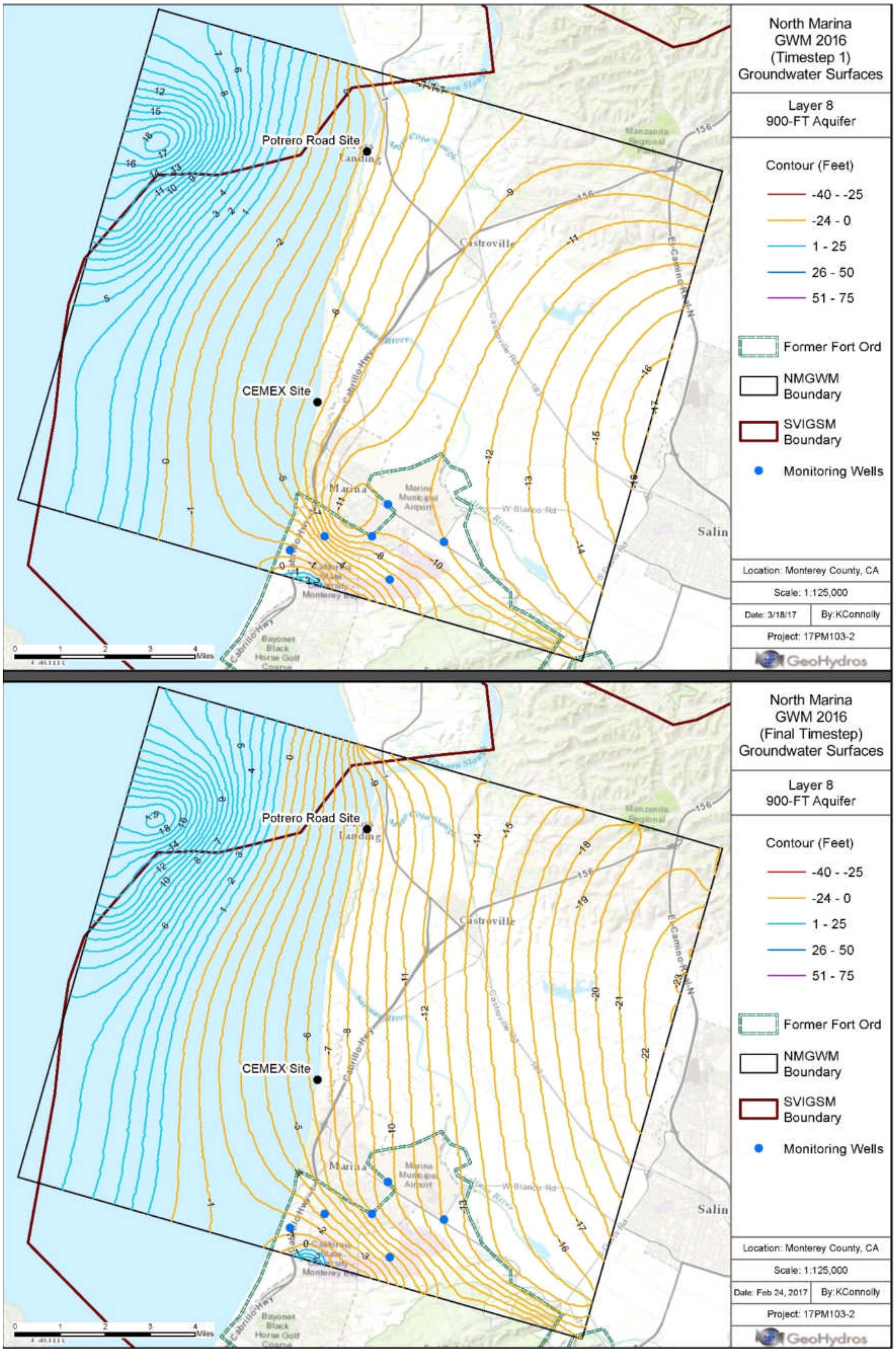


Figure 9.
Comparison of groundwater surfaces for the 900-FT Aquifer simulated by the 2016 NMGWM at the first and last timesteps in the 32-year simulation period.

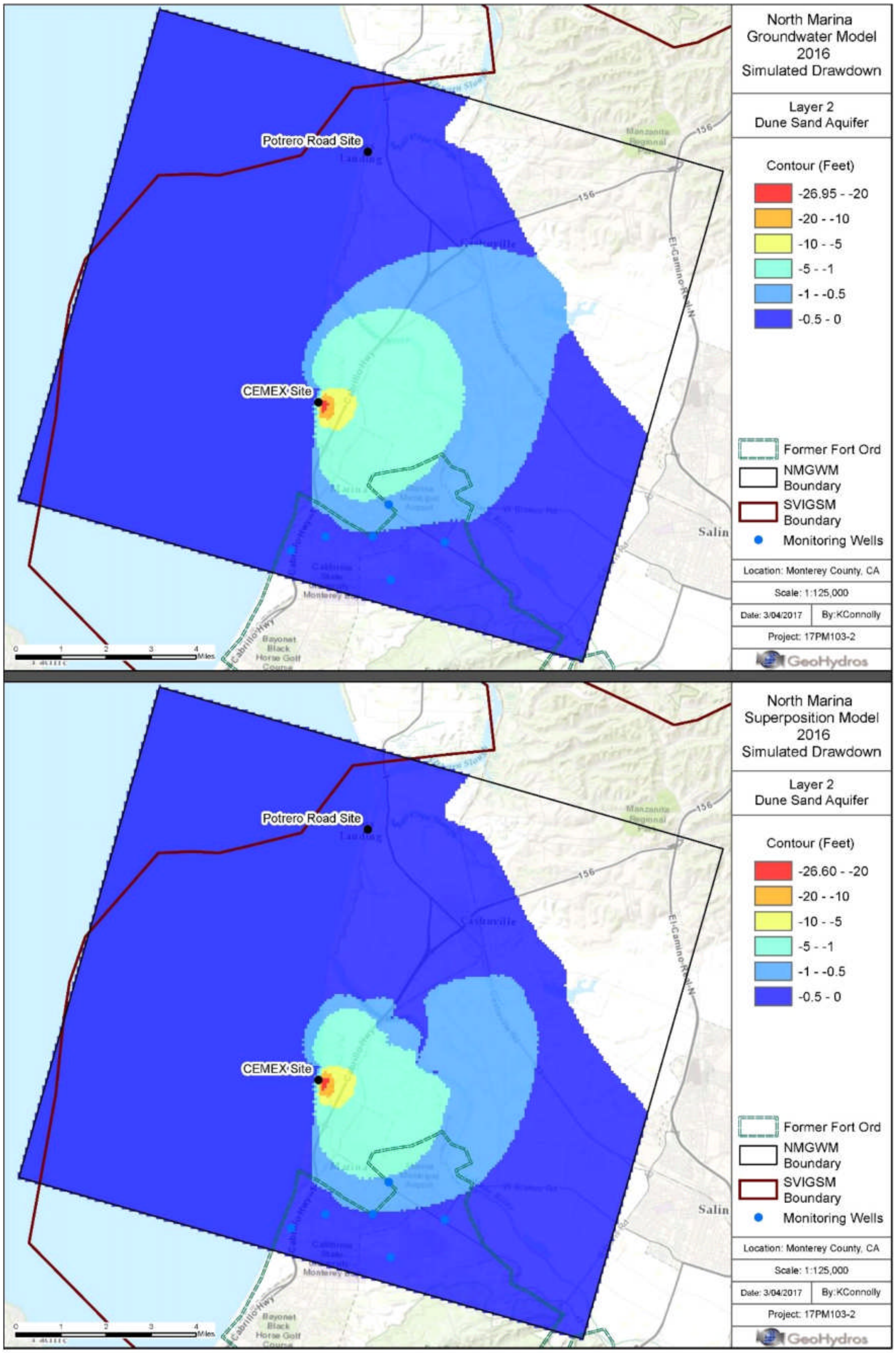
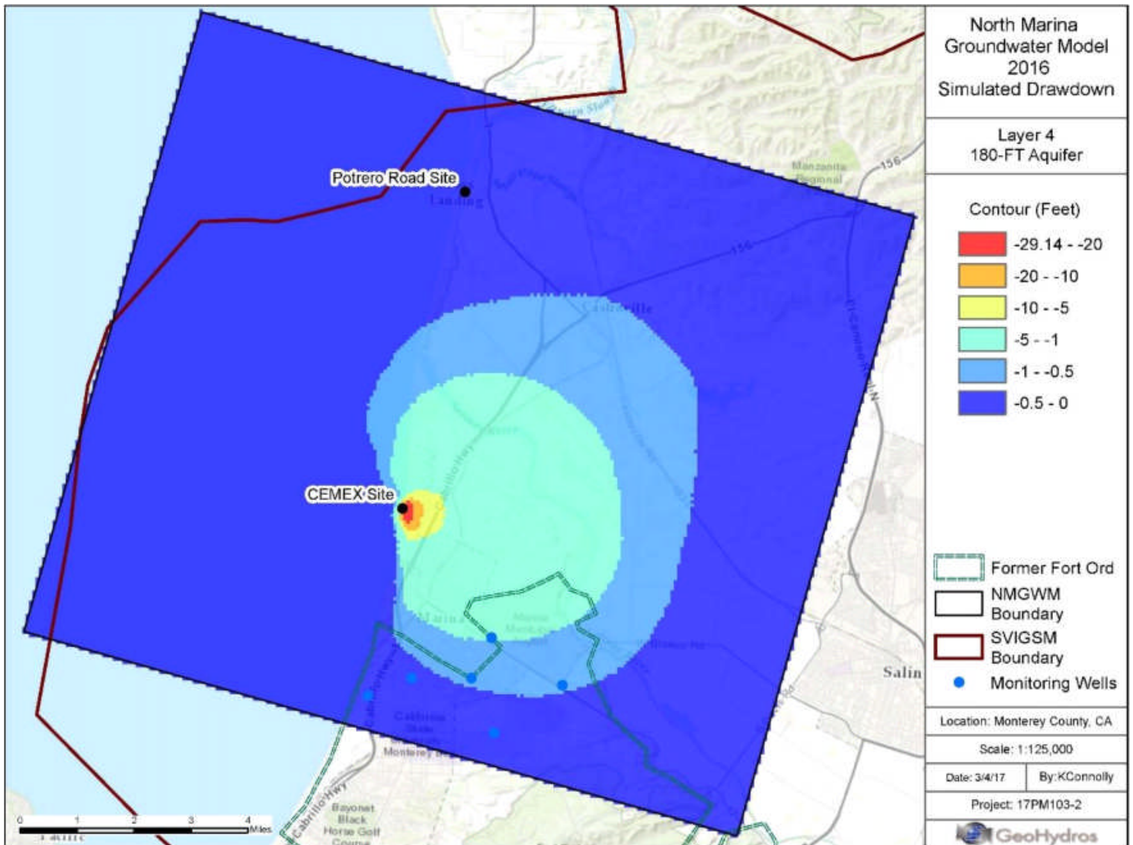


Figure 10.
Comparison of simulated drawdown in in the Dune Sand Aquifer (Layer 2) derived from the calibrated version of the 2016 version of the NMGWM (top) and the Superposition model (bottom).



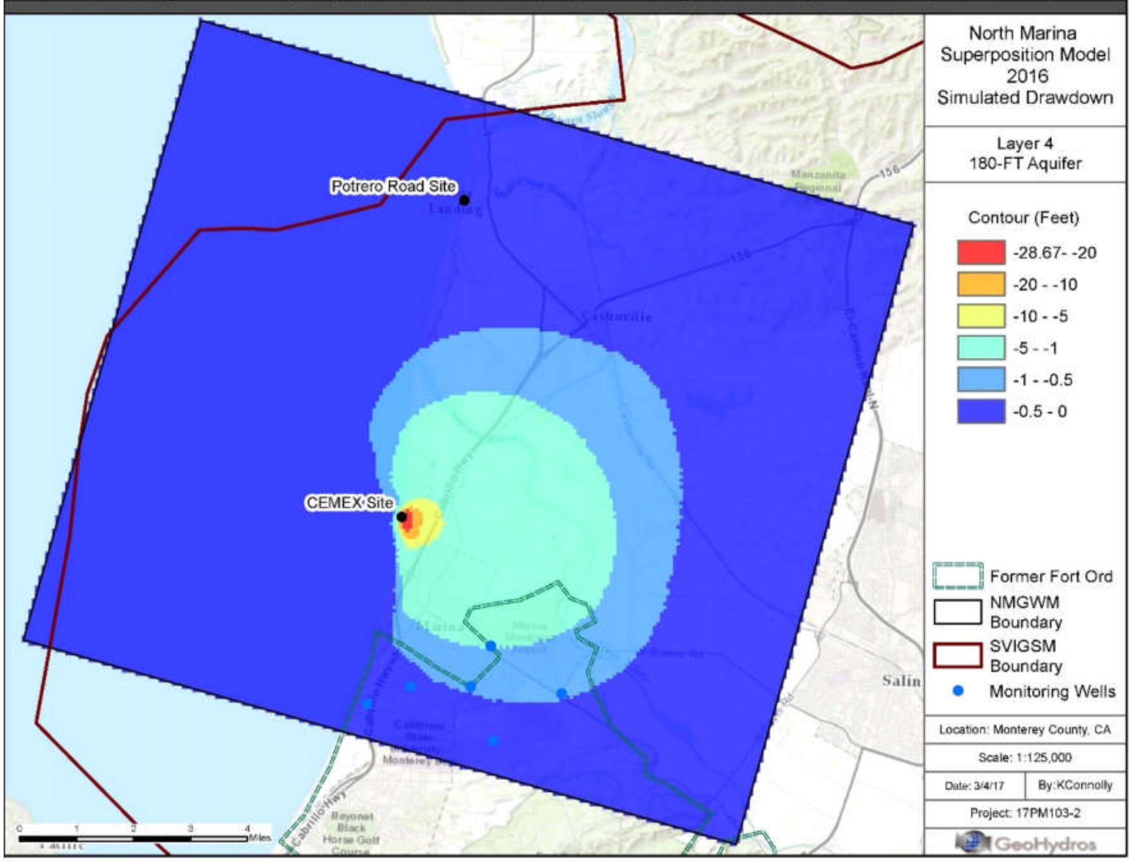


Figure 11.
Comparison of simulated drawdown in in the 180-FT Aquifer (Layer 4) derived from the calibrated version of the NMGWM-2016 (top) and the Superposition model (bottom).

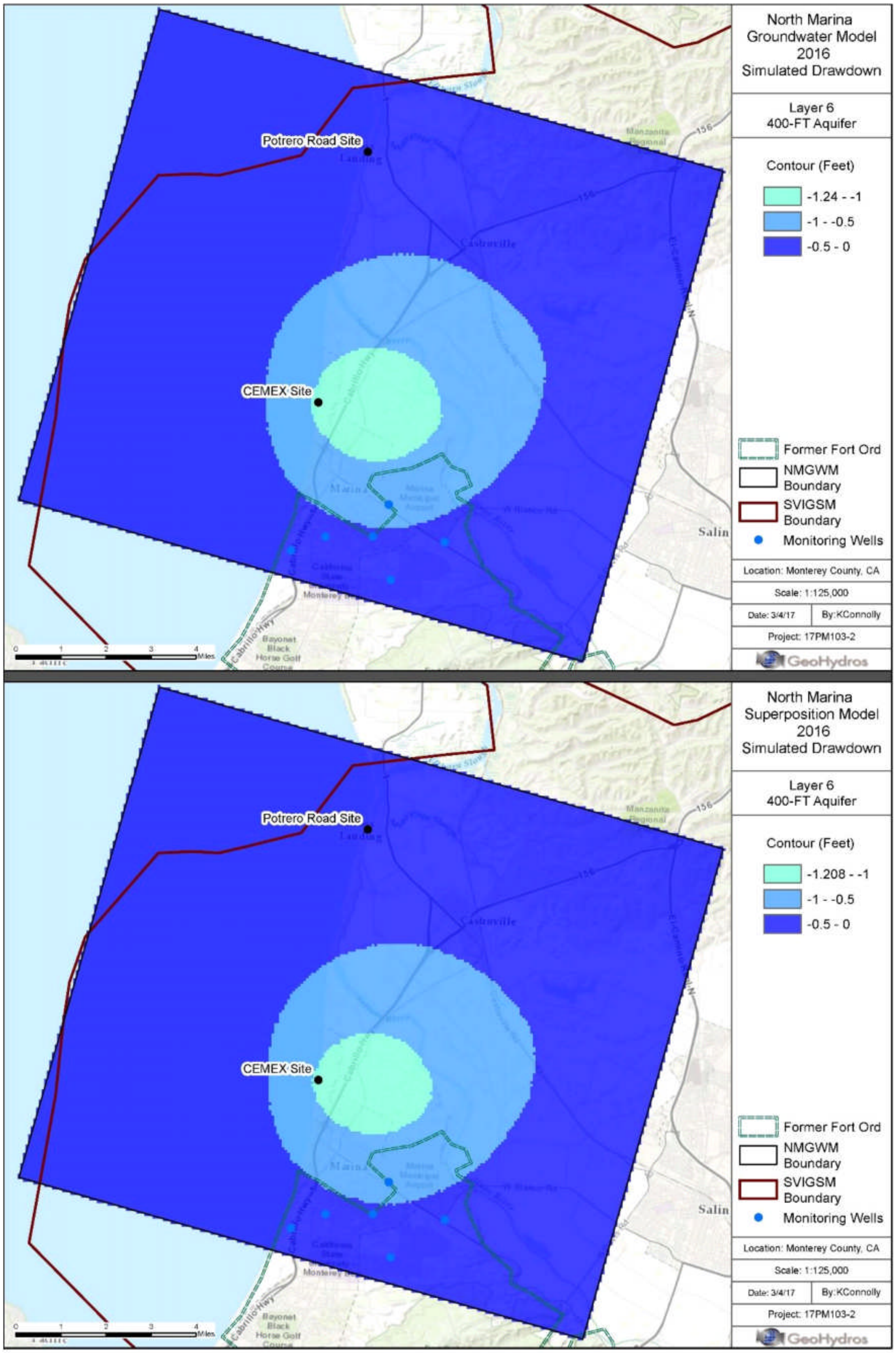


Figure 12.
Comparison of simulated drawdown in in the 400-FT Aquifer (Layer 6) derived from the calibrated version of the NMGWM-2016 (top) and the Superposition model (bottom).

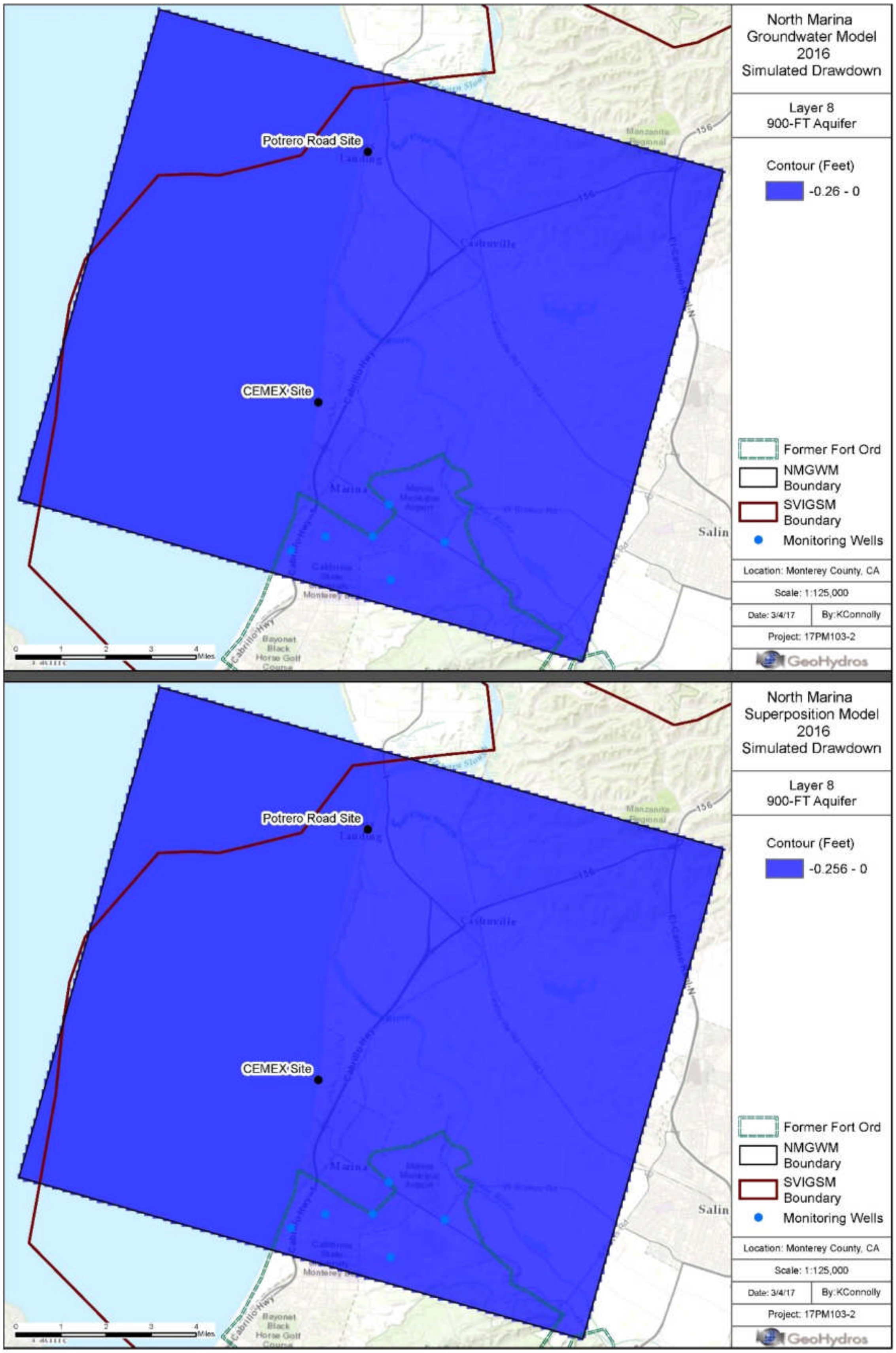


Figure 13.
Comparison of simulated drawdown in in the 900-FT Aquifer (Layer 8) derived from the calibrated version of the NMGWM-2016 (top) and the Superposition model (bottom).

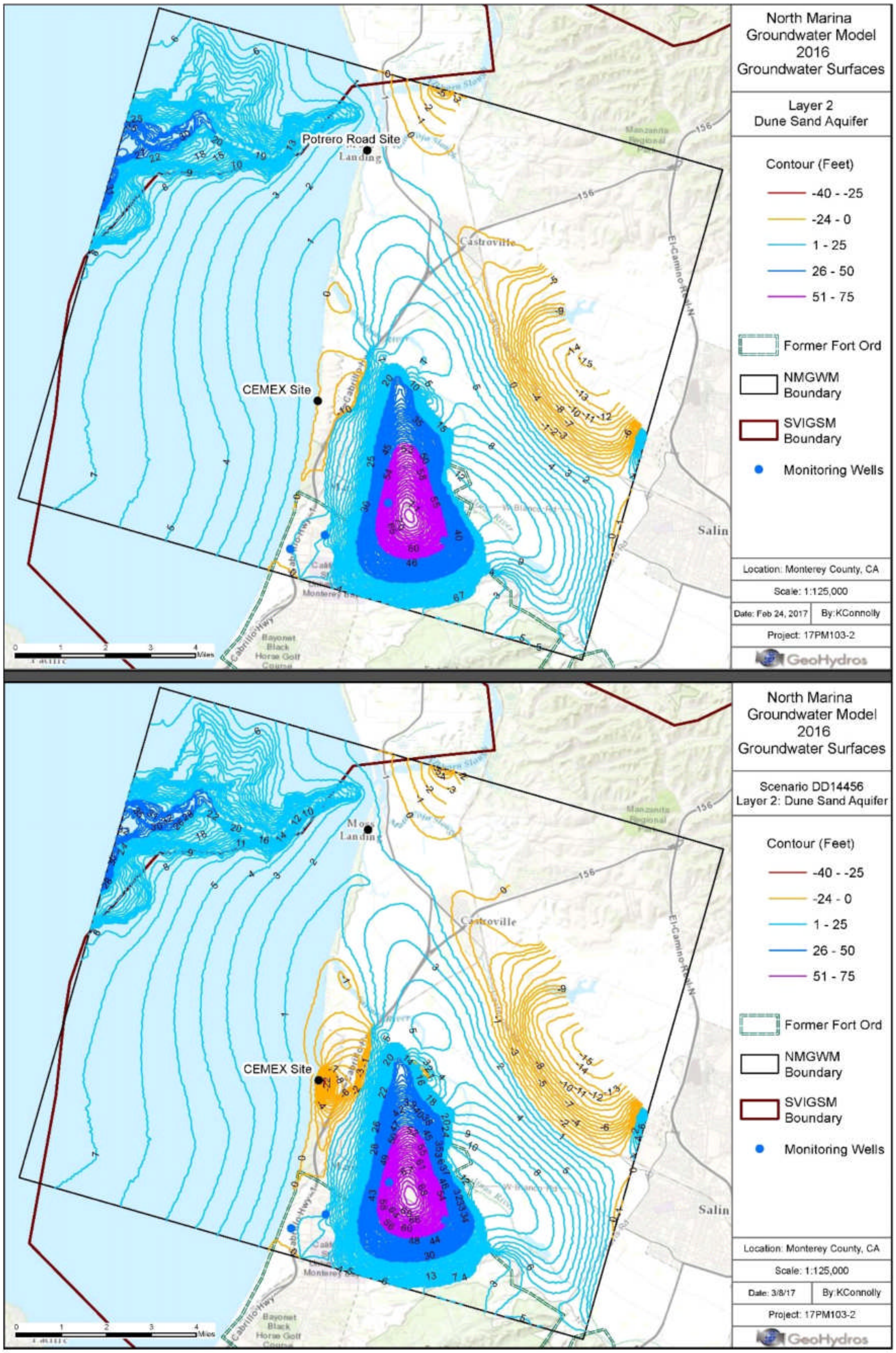


Figure 14. Simulated water table surface in the Dune Sand Aquifer (Layer 2) as portrayed by the calibrated version (top) and Scenario DD1-44/56 (bottom) showing mounding due to recharge in the Dune Sand Aquifer and equivalent fresh water heads assigned as constant values in the ocean resulting in a large eastward gradient across the model.

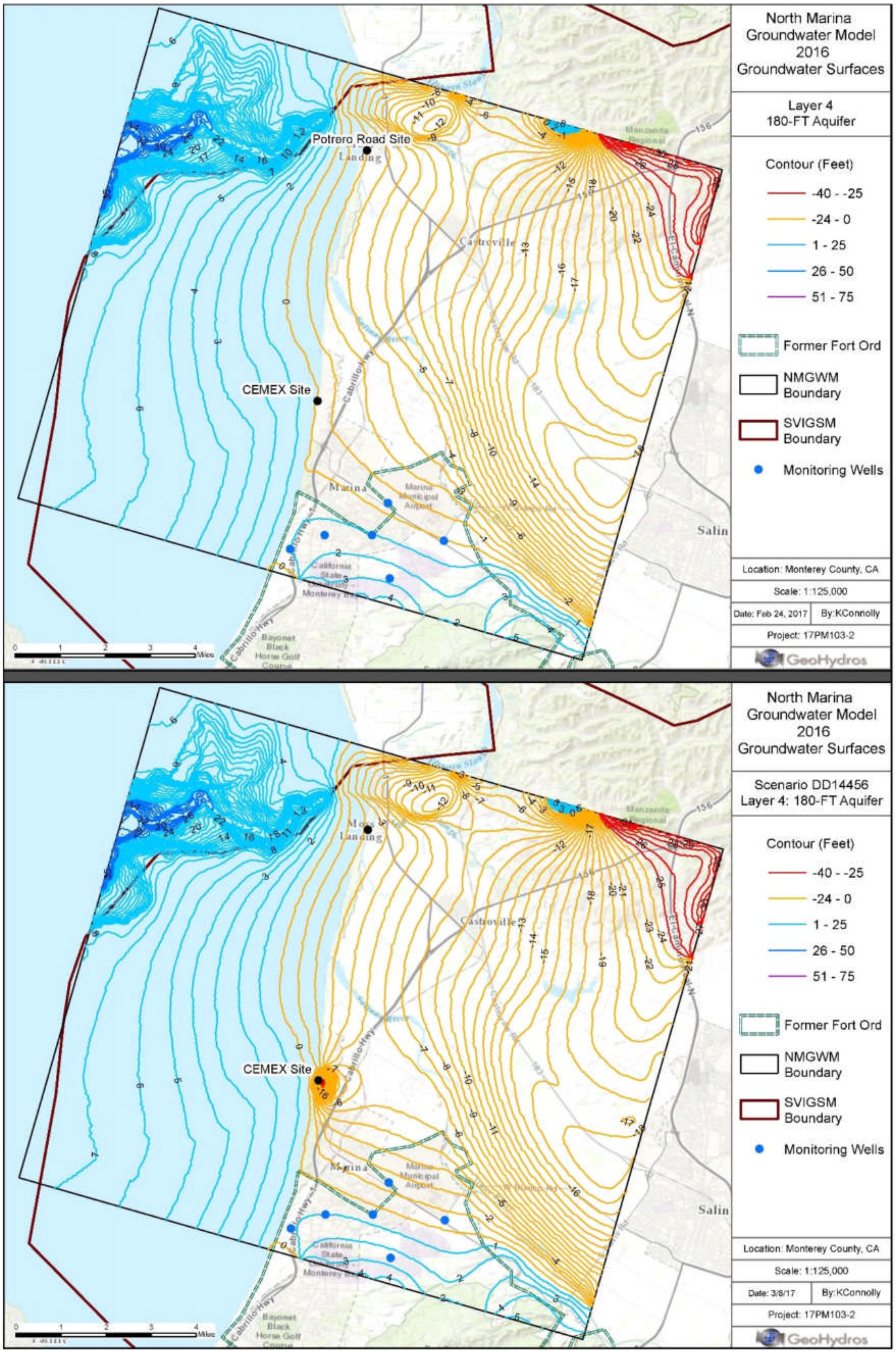


Figure 15. Simulated water table surface in the 180-ft Aquifer (Layer 4) as portrayed by the calibrated version (top) and Scenario DD1-44/56 (bottom) showing some mounding due to recharge in the Dune Sand Aquifer and equivalent fresh water heads assigned as constants in the ocean resulting in a large eastward gradient across the model.

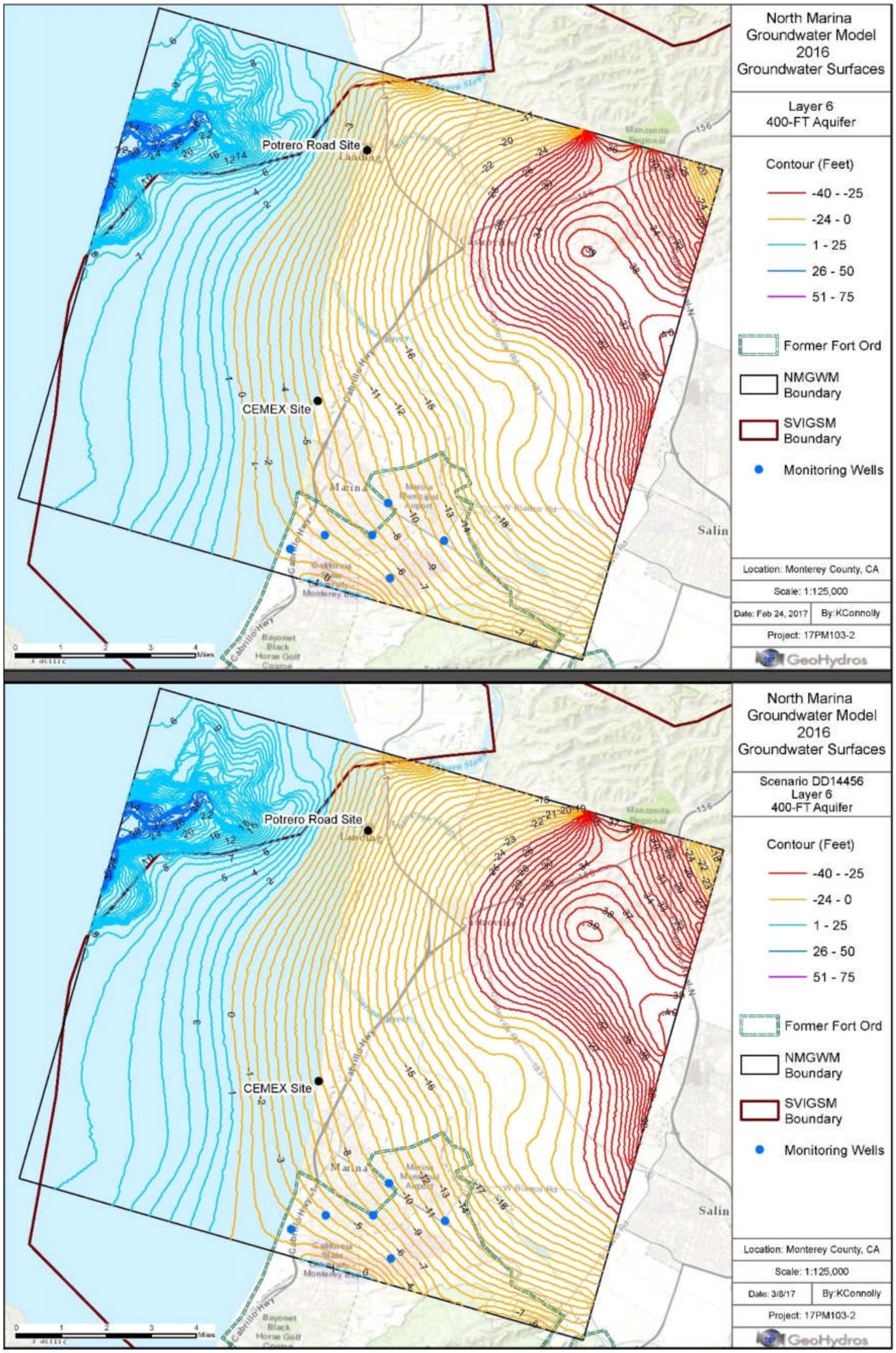


Figure 16. Simulated water table surface in the 400-ft Aquifer (Layer 6) as portrayed by the calibrated version (top) and Scenario DD1-44/56 (bottom) showing equiv. fresh water heads assigned as constants in the ocean resulting in the ocean being the primary source of water flow across the model.

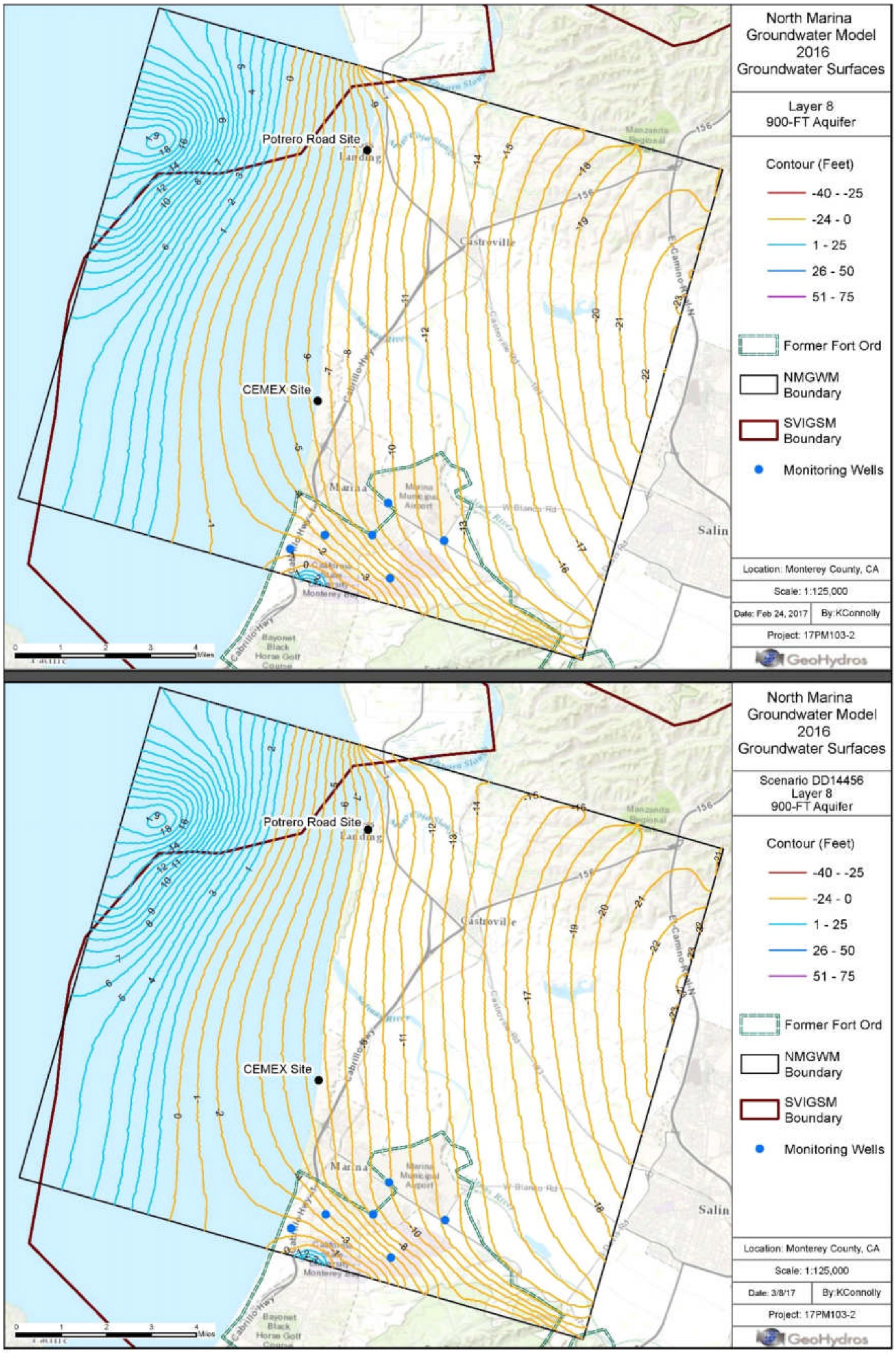


Figure 17. Simulated water table surface in the 900-ft Aquifer (Layer 8) as portrayed by the calibrated version (top) and Scenario DD1-44/56 (bottom) showing the effect of equiv. fresh water heads assigned in overlying layers in the ocean and that the ocean is the primary source of water flow across the model.

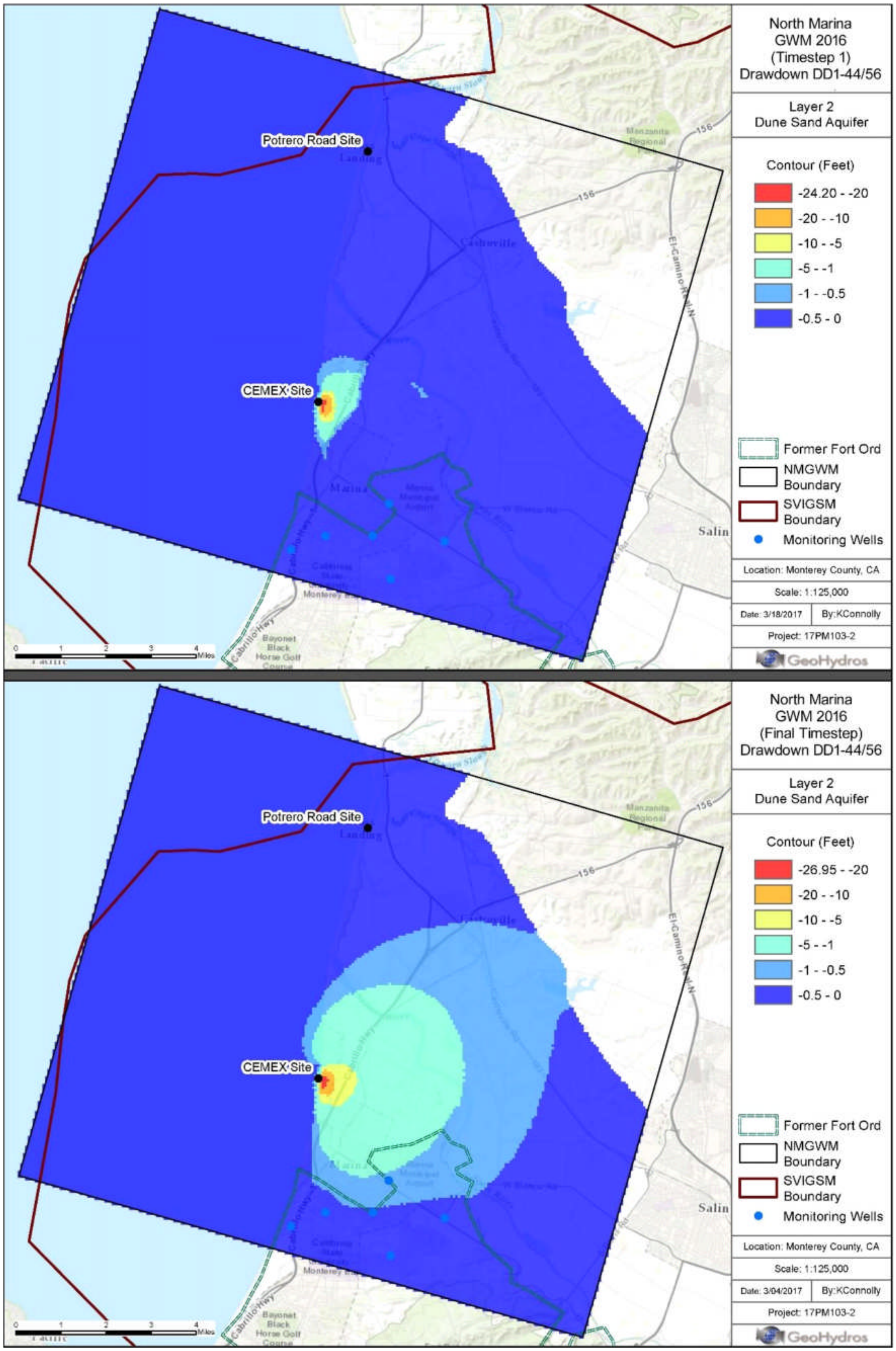


Figure 18.
Simulated drawdown in the Dune Sand Aquifer due to pumping as defined in scenario DD1-44/56 after the first and last timestep in the calibrated model's 32-year simulation period.

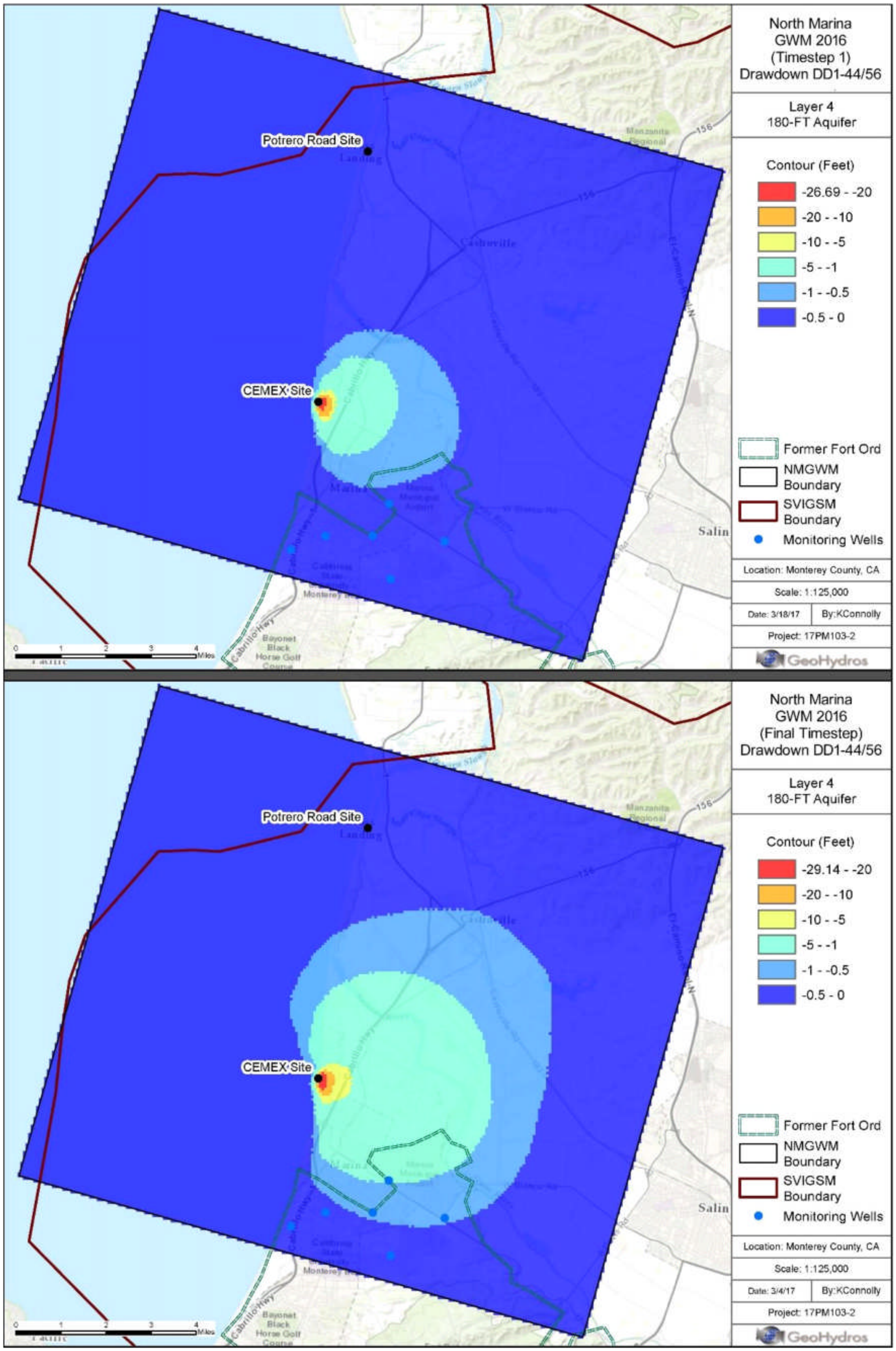


Figure 19.
Simulated drawdown in the 180-FT Aquifer due to pumping as defined in scenario DD1-44/56 after the first and last timestep in the calibrated model's 32-year simulation period.

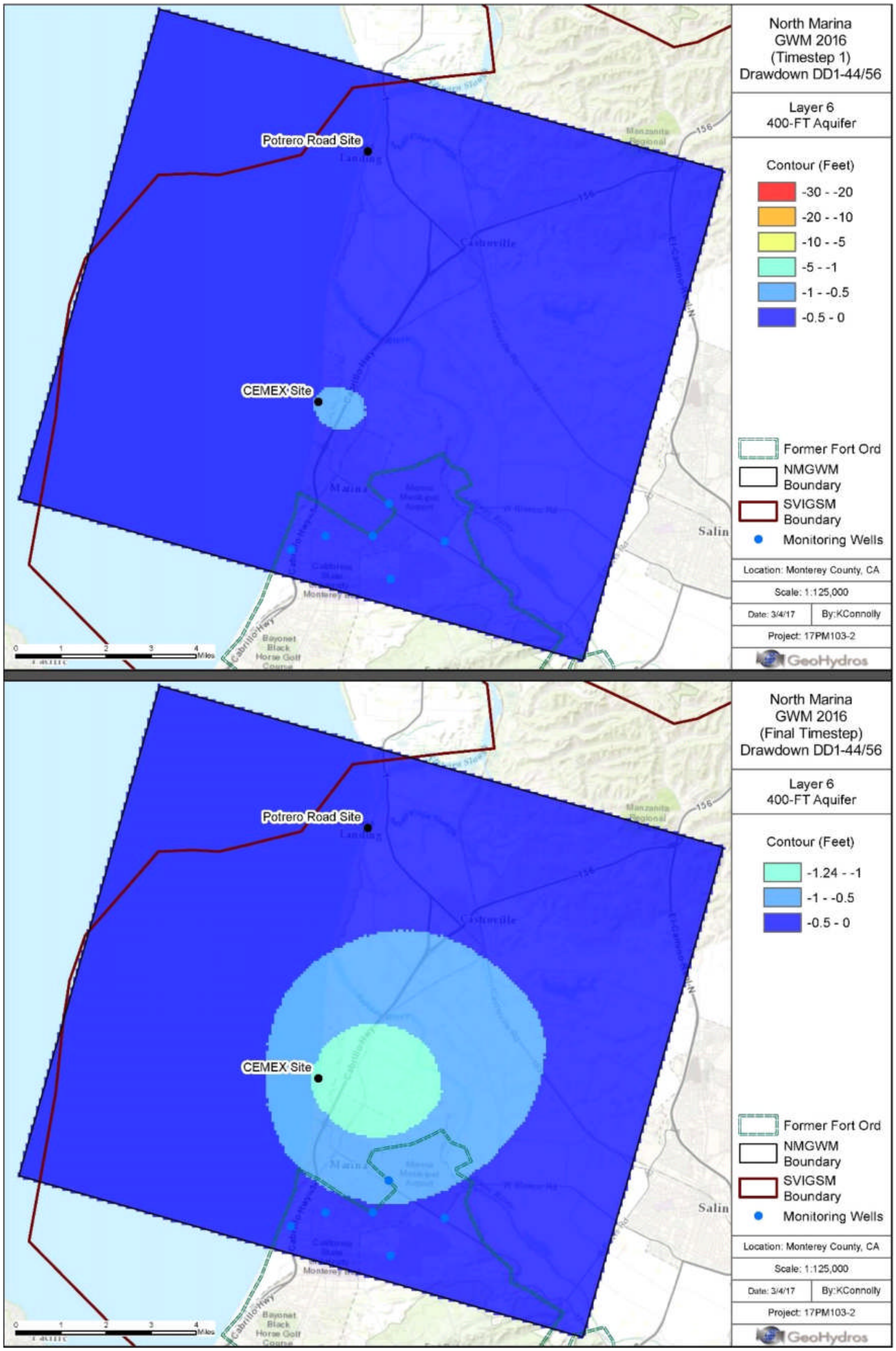


Figure 20.
Simulated drawdown in the 400-FT Aquifer due to pumping as defined in scenario DD1-44/56 after the first and last timestep in the calibrated model's 32-year simulation period.

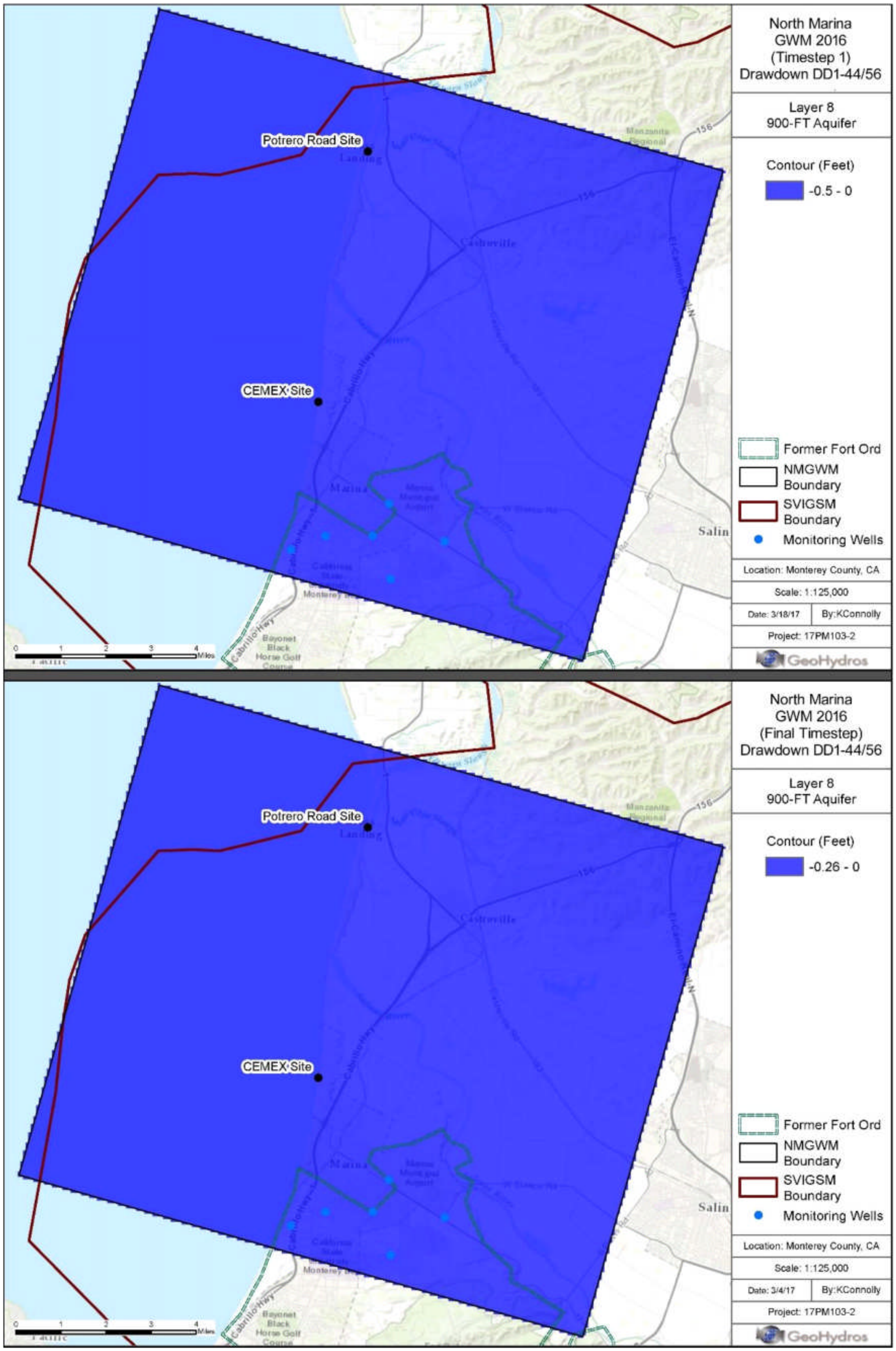


Figure 21.
Simulated drawdown in the 900-FT Aquifer due to pumping as defined in scenario DD1-44/56 after the first and last timestep in the calibrated model's 32-year simulation period.

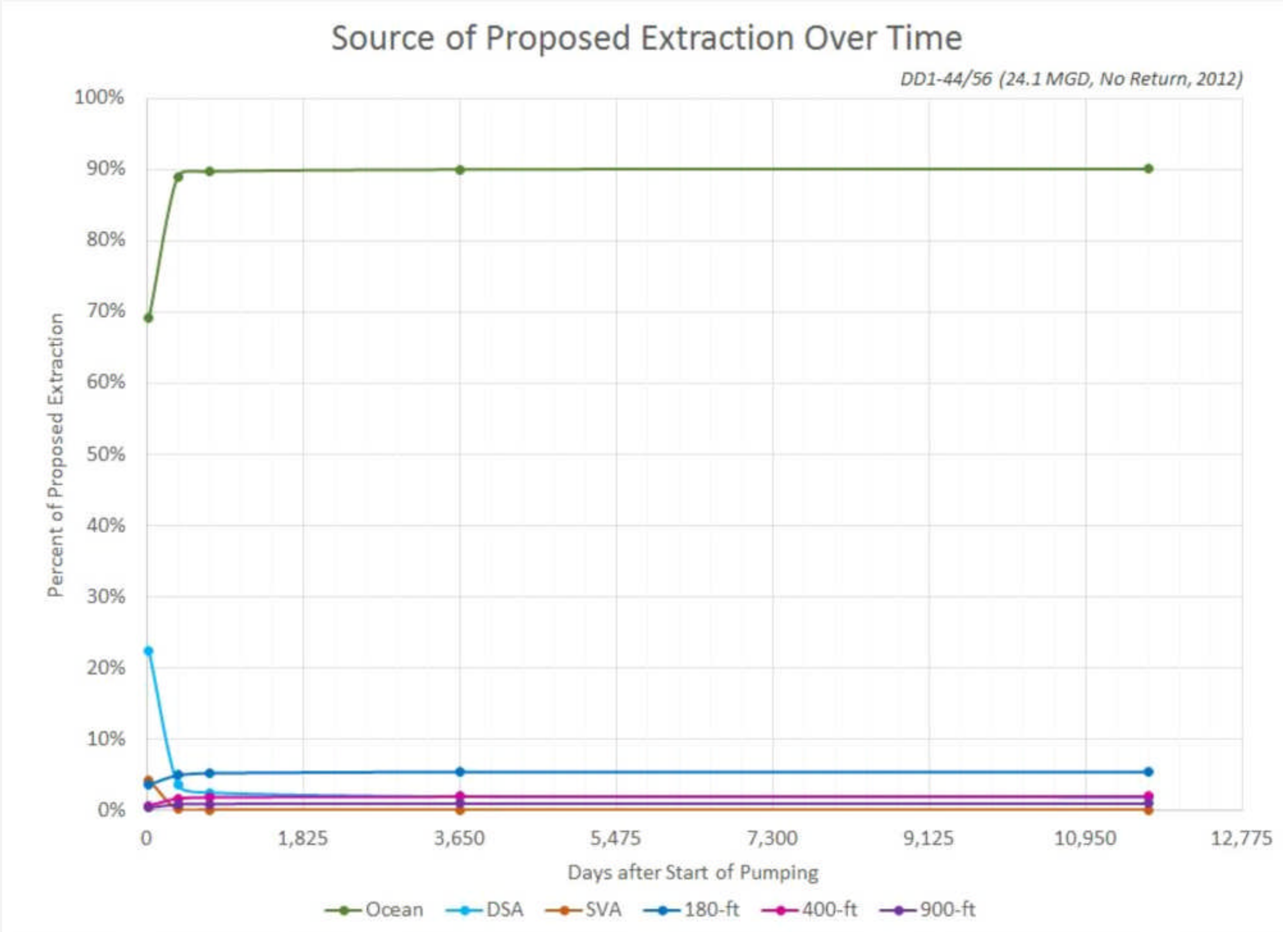


Figure 22.
Plot showing how the source of water to the proposed extractions is predicted to evolve over time.

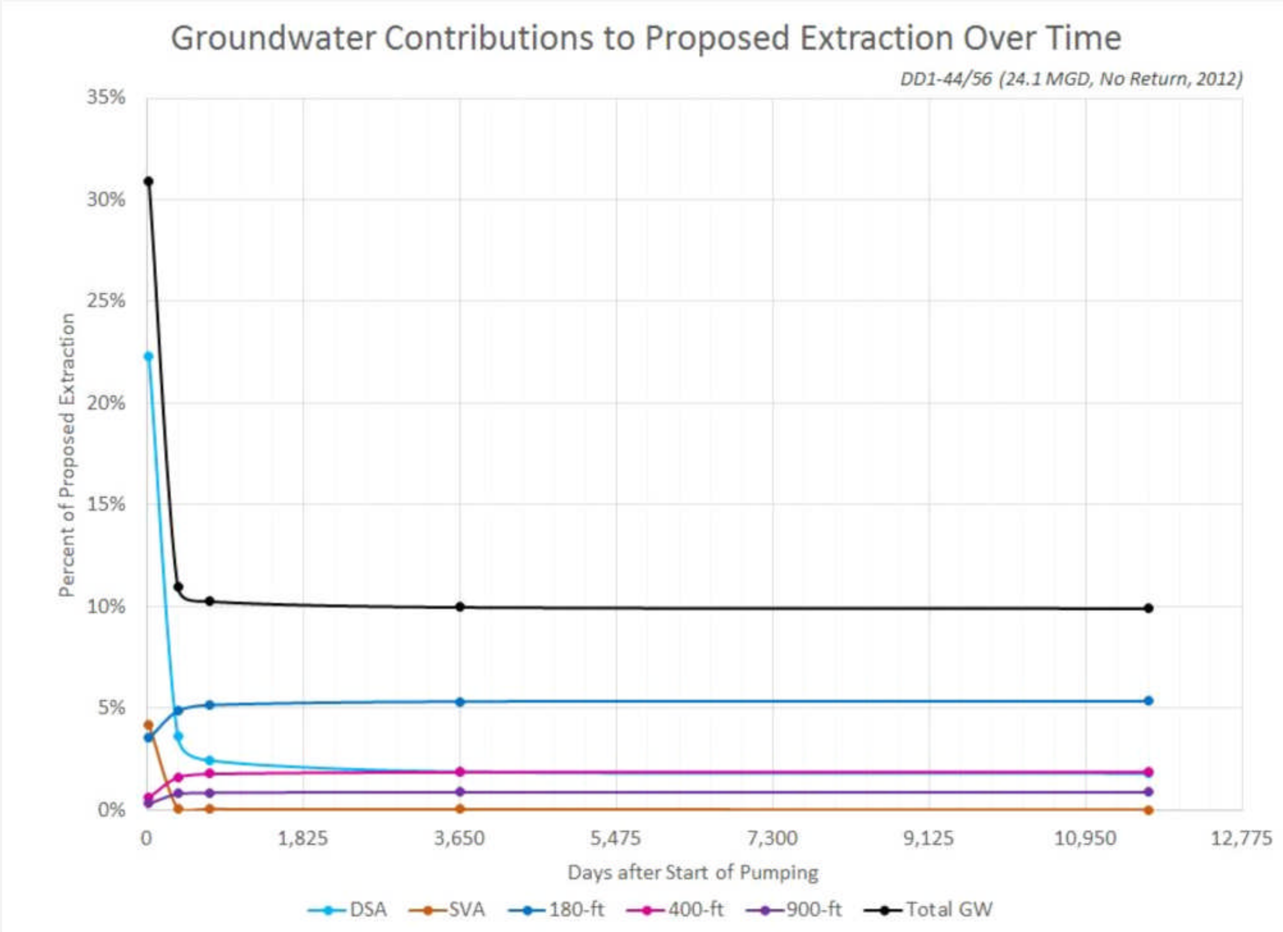


Figure 23.
Plot showing how the contribution from groundwater to the proposed wells is predicted to evolve over time.

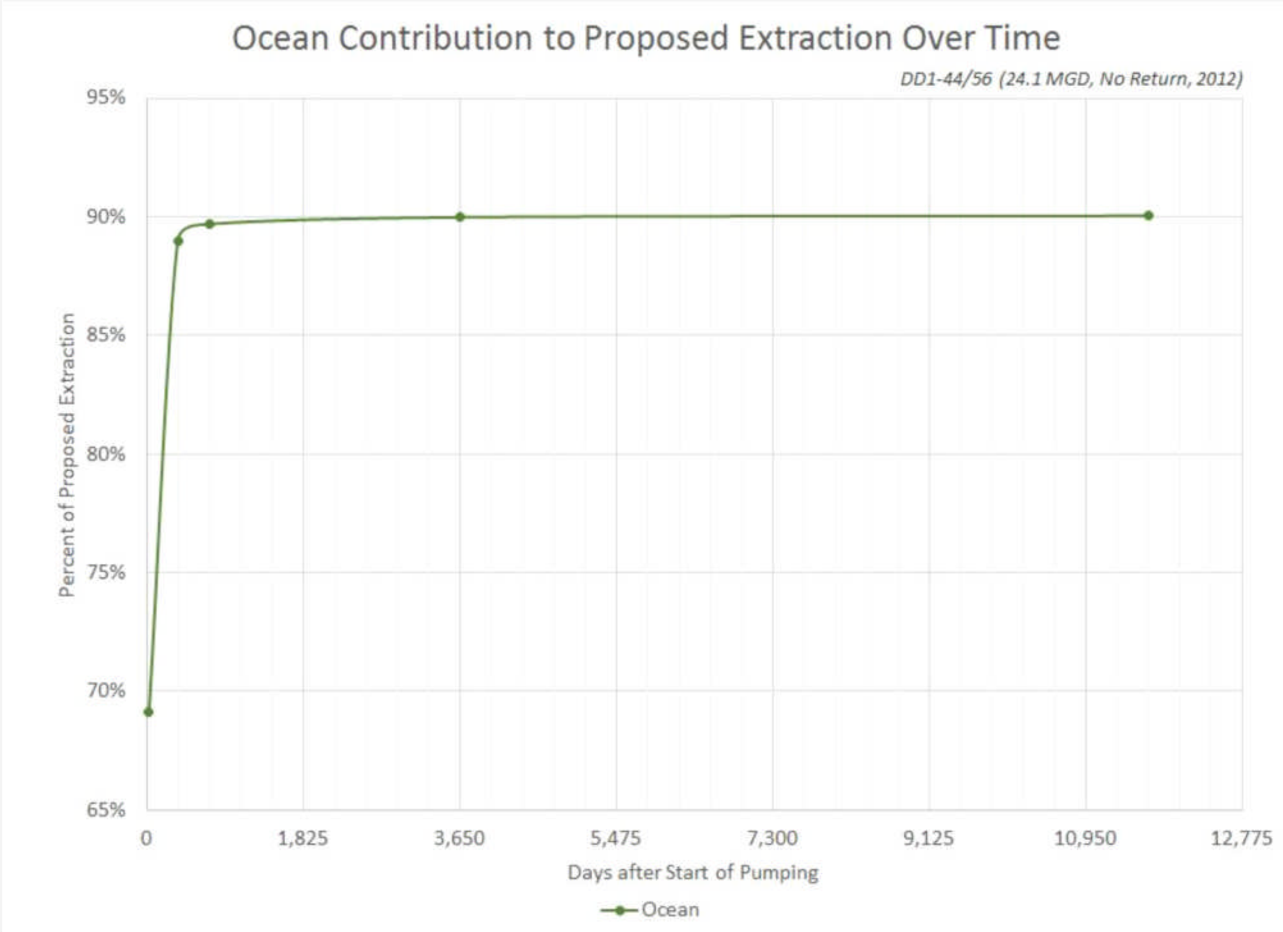
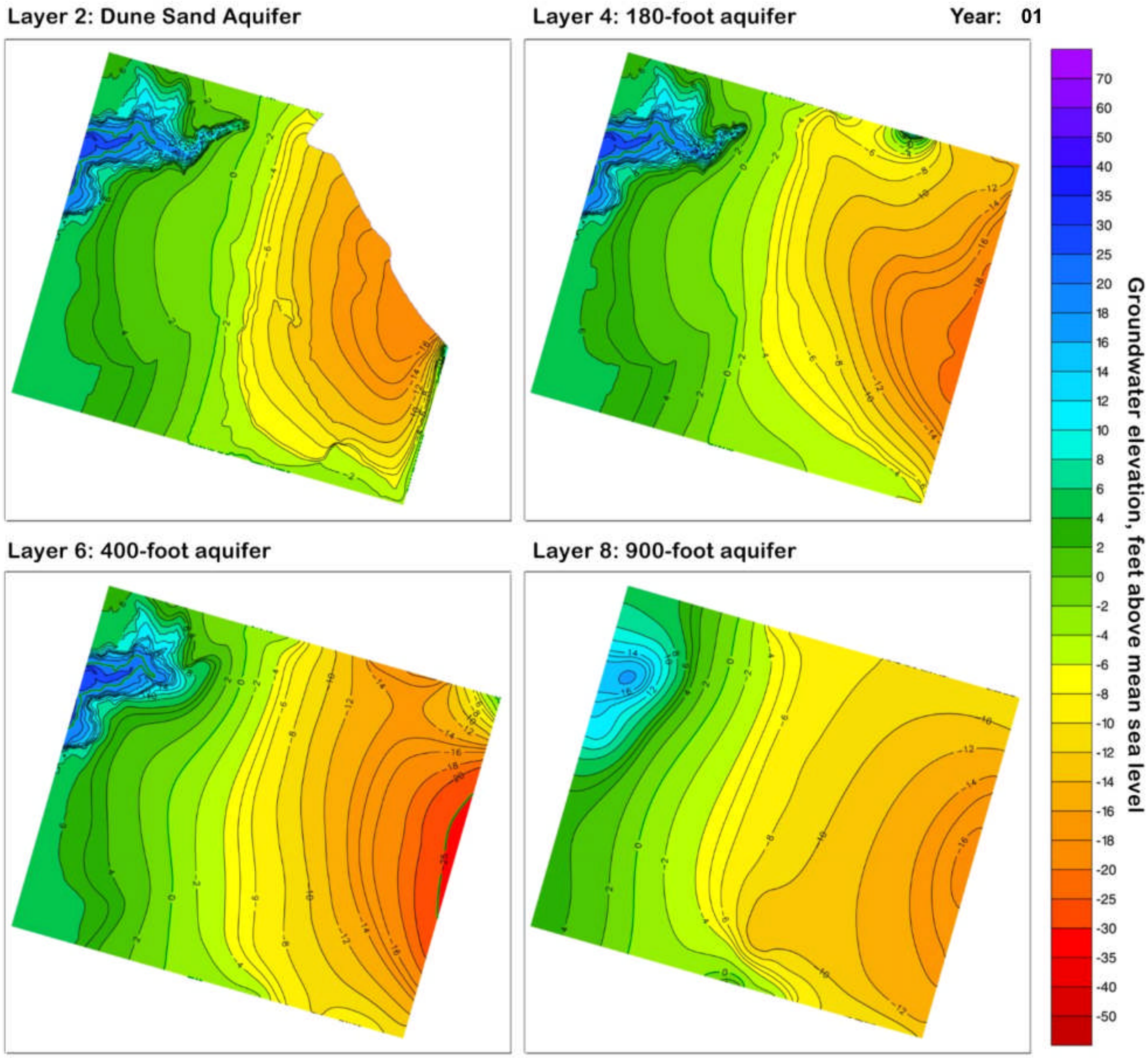


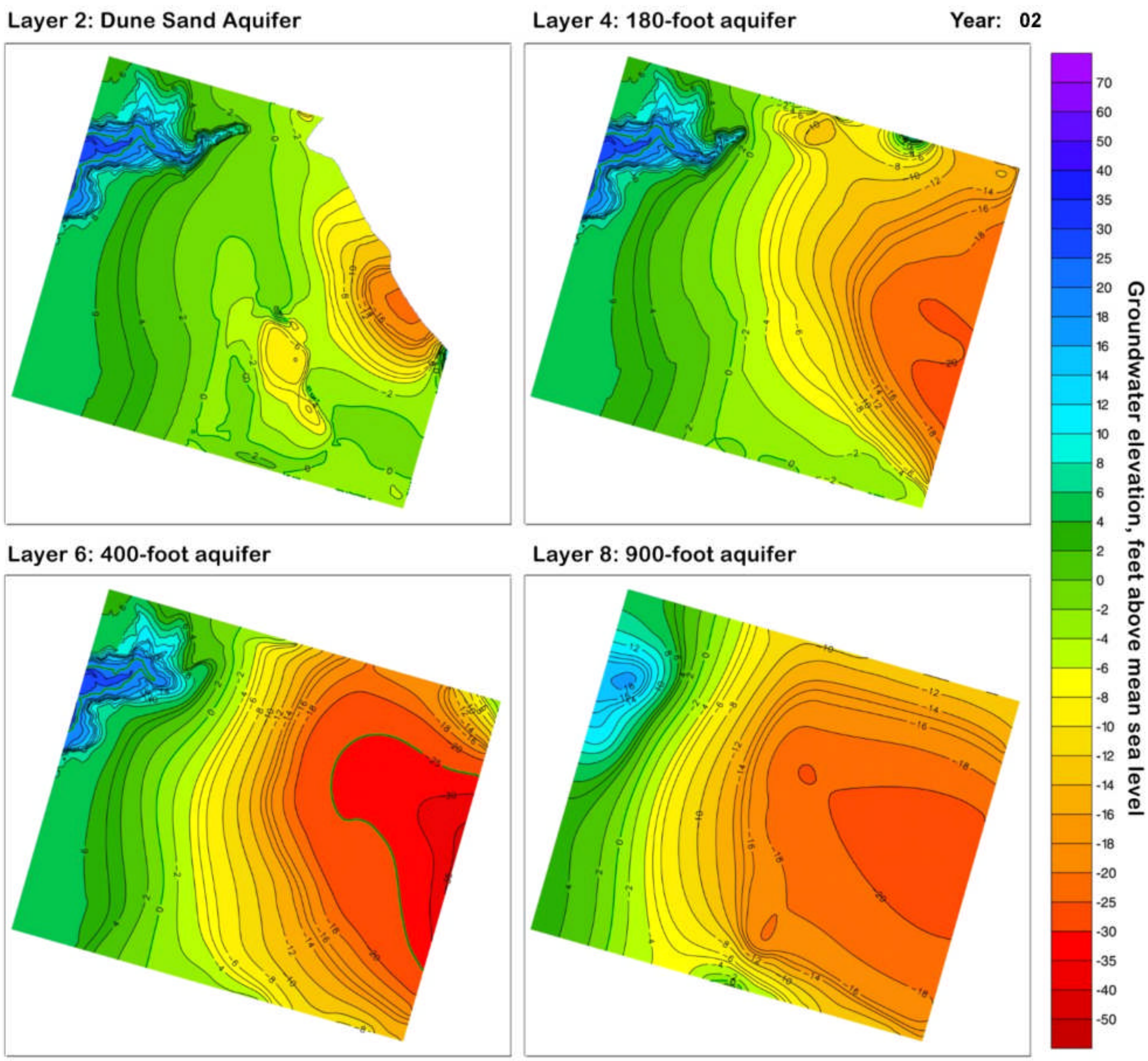
Figure 24.
Plot showing how the contribution from the ocean to the proposed wells is predicted to evolve over time.

Appendix 1
Groundwater Surfaces Exported from the 2016 NMGWM after each Year of the 32-Year Simulation Period

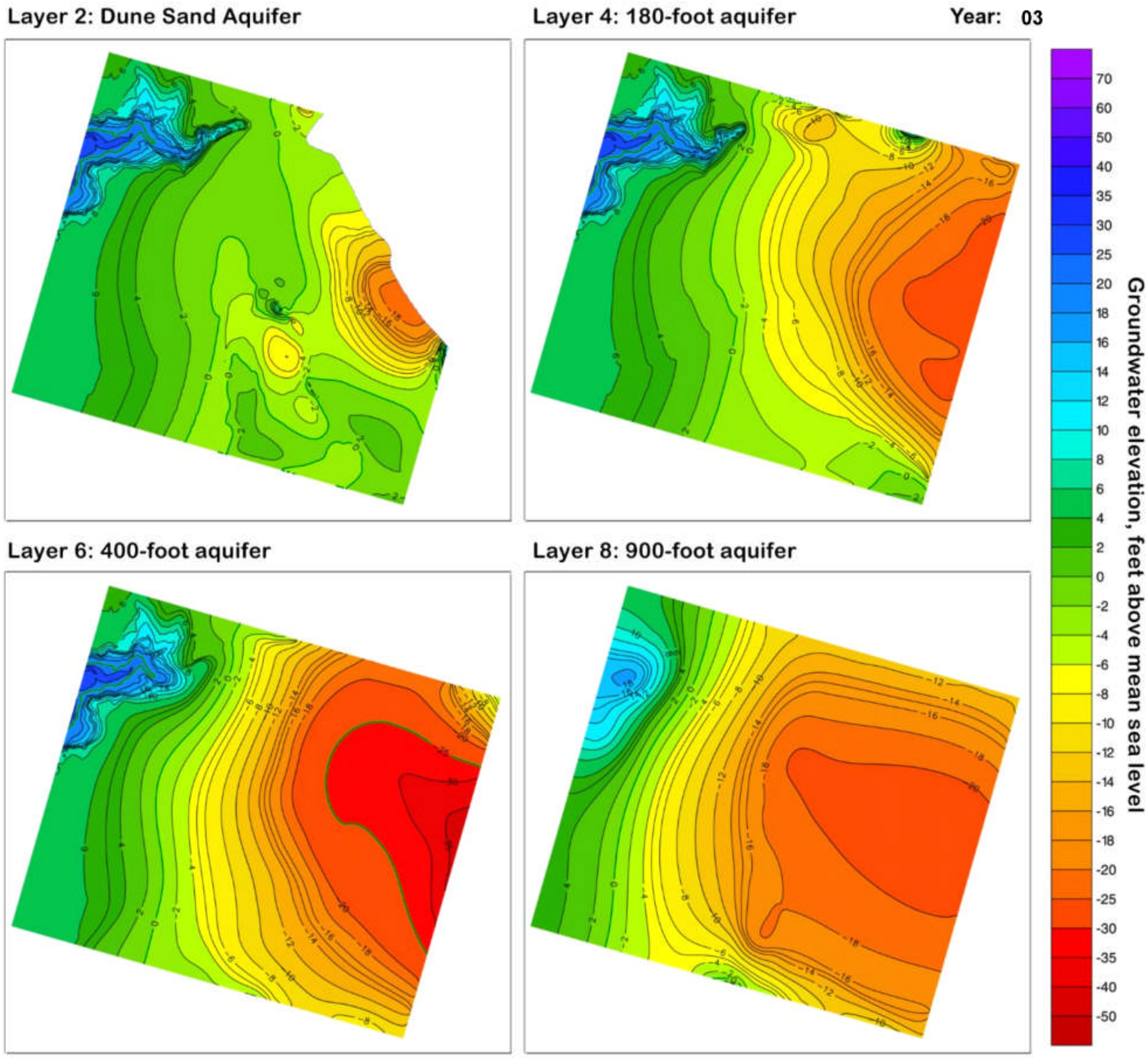
MPWSP Groundwater Flow Model / Calibrated model

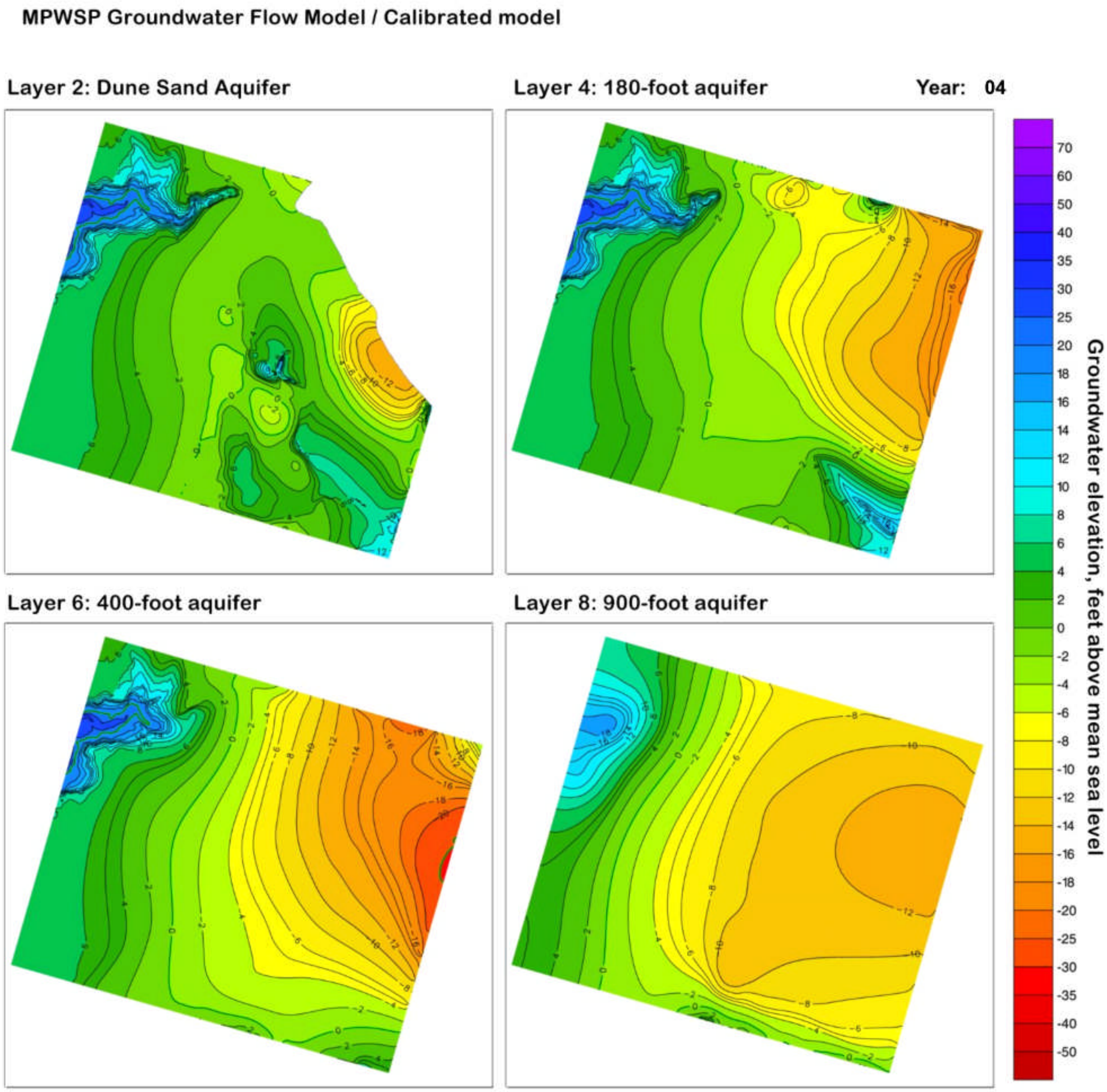


MPWSP Groundwater Flow Model / Calibrated model

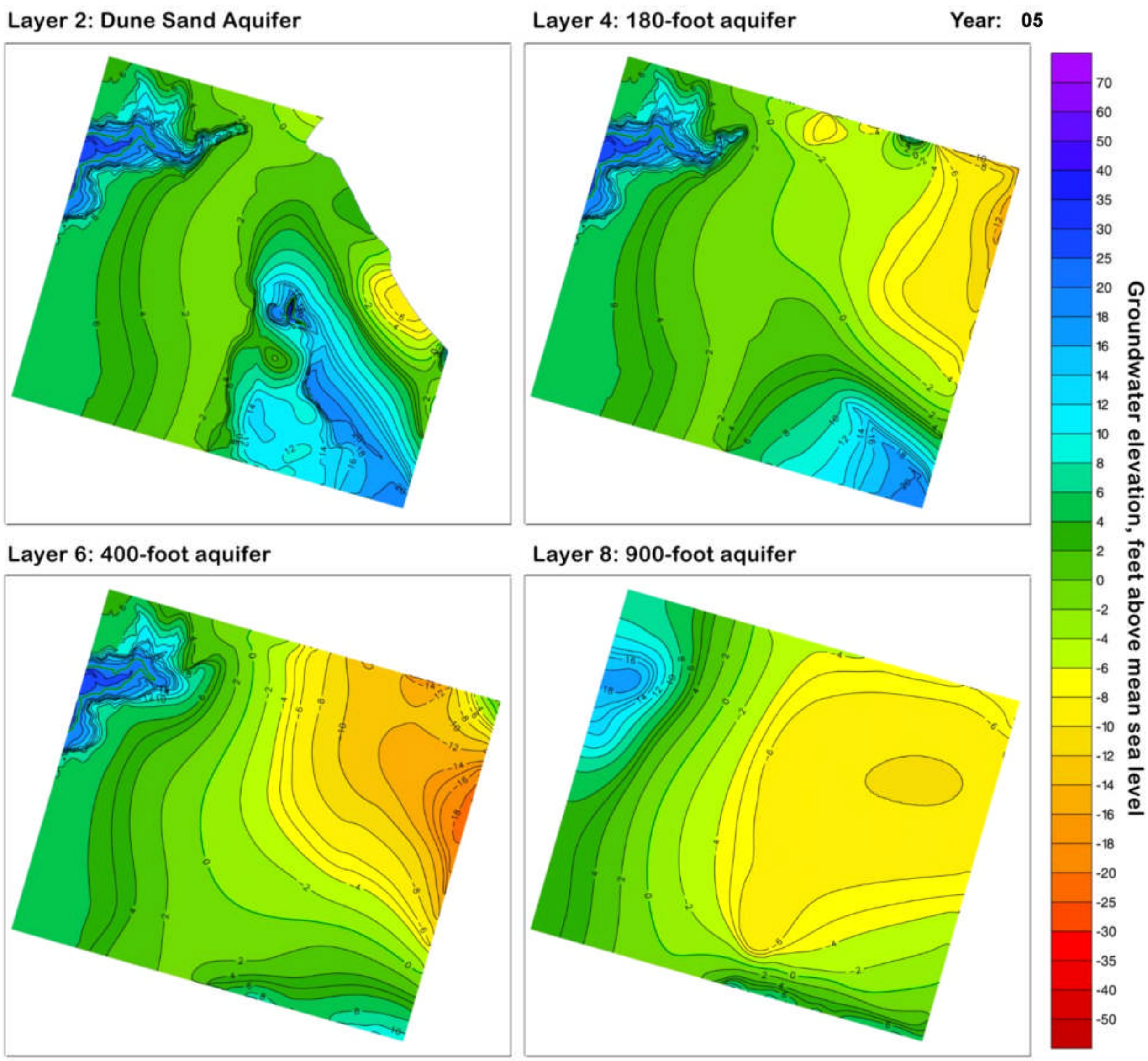


MPWSP Groundwater Flow Model / Calibrated model

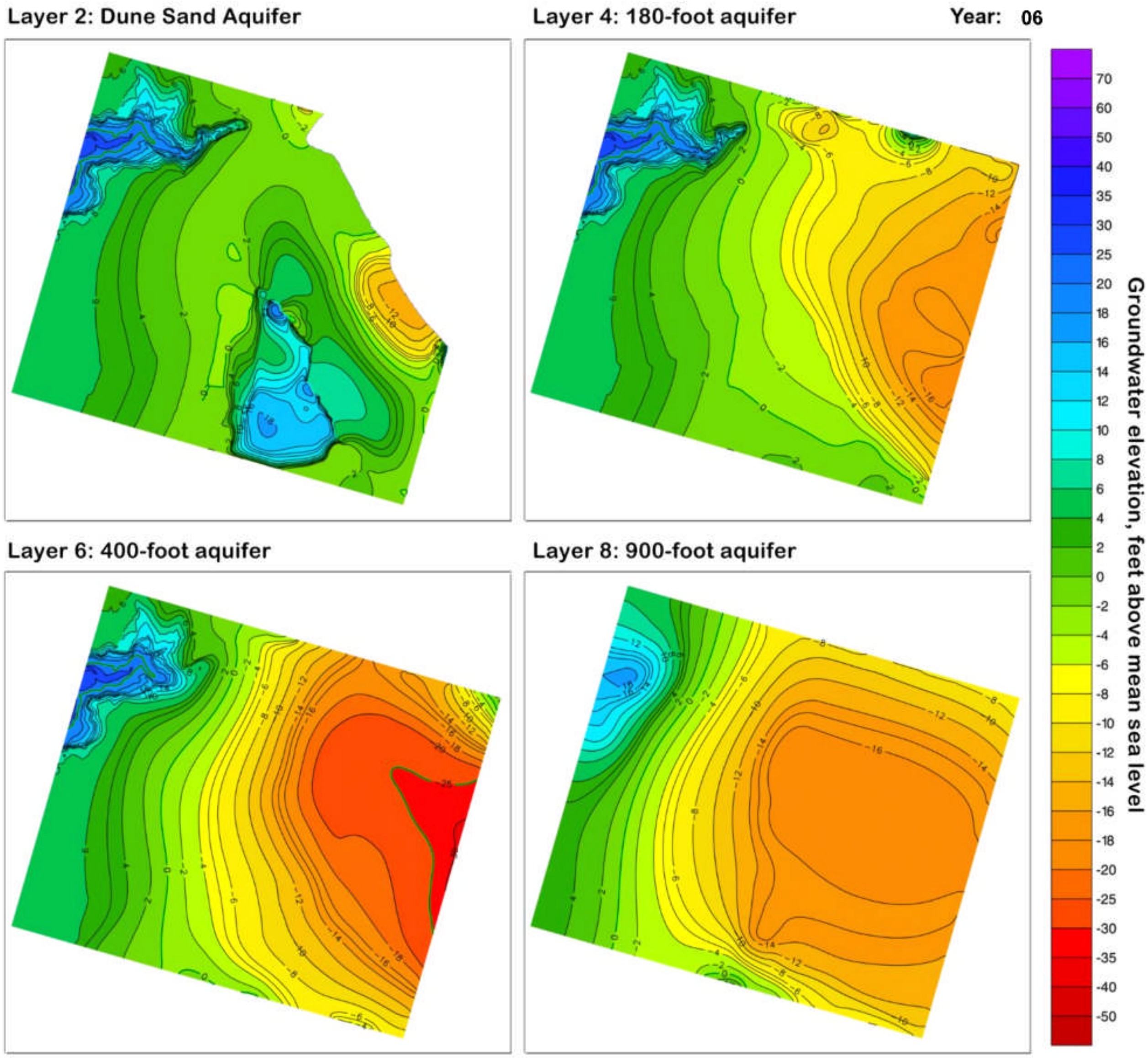



MPWSP Groundwater Flow Model / Calibrated model
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year: 04
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Groundwater elevation, feet above mean sea level
70
60
50
40
35
30
25
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-25
-30
-35
-40
-50

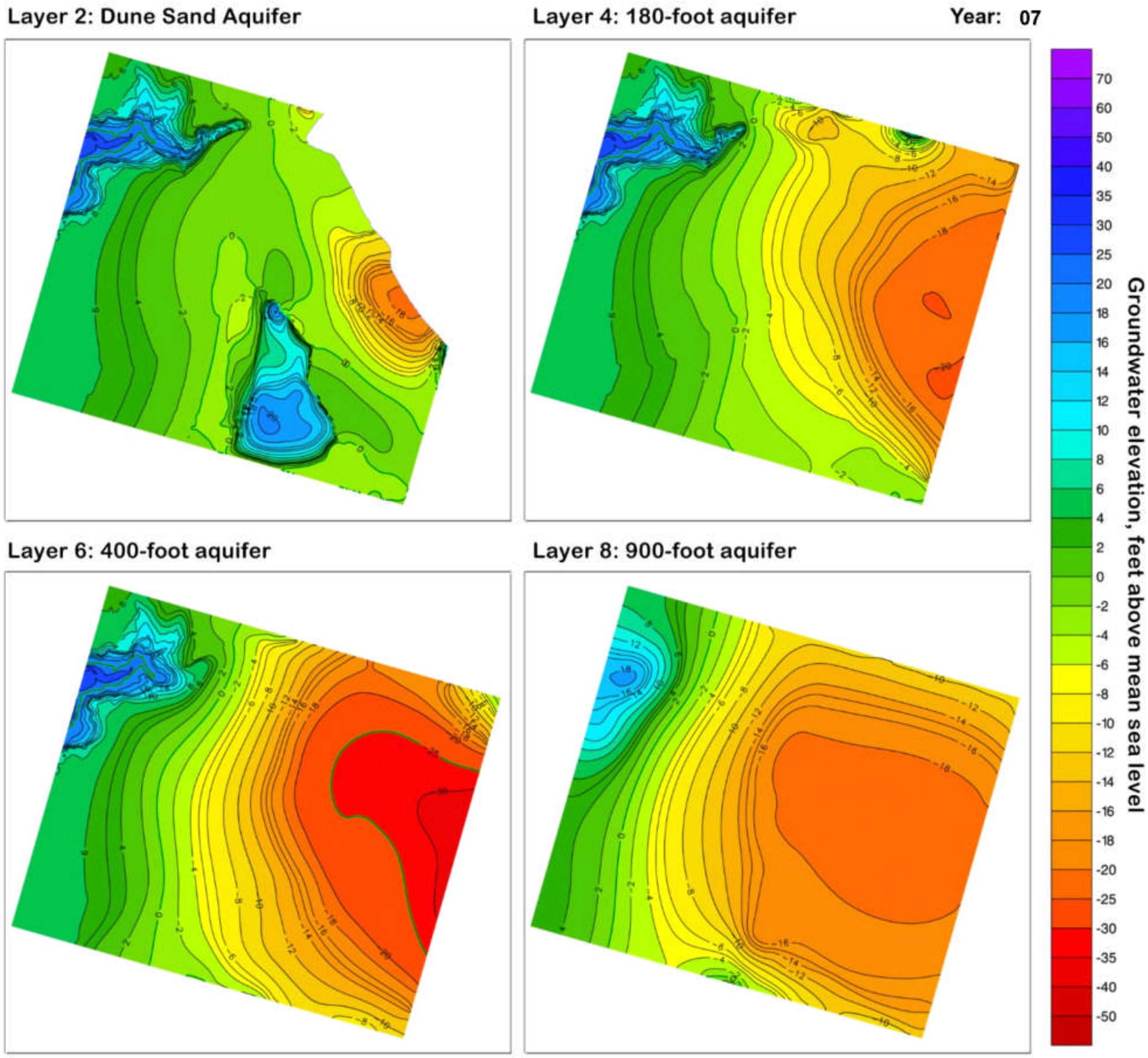
MPWSP Groundwater Flow Model / Calibrated model



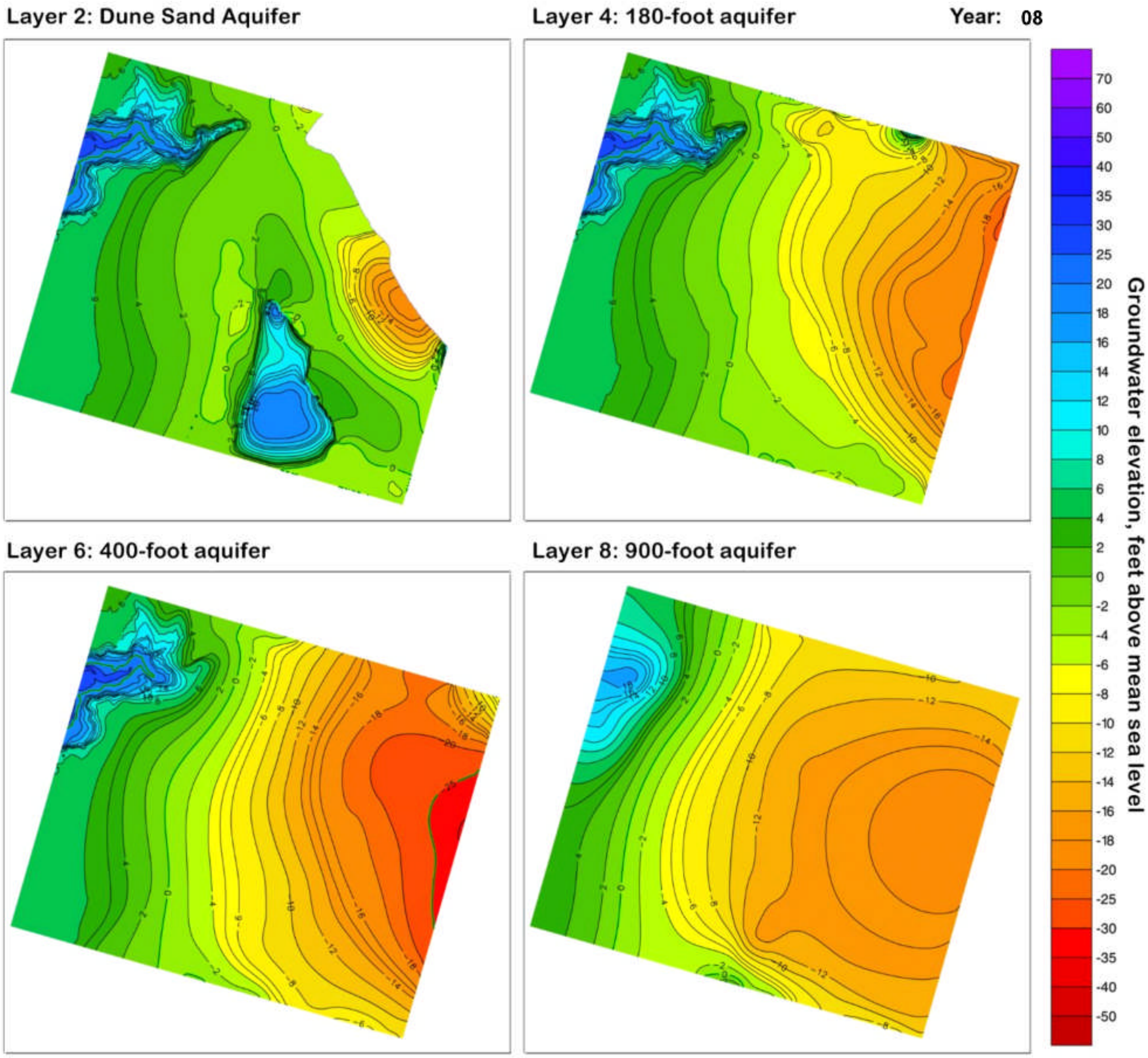
MPWSP Groundwater Flow Model / Calibrated model



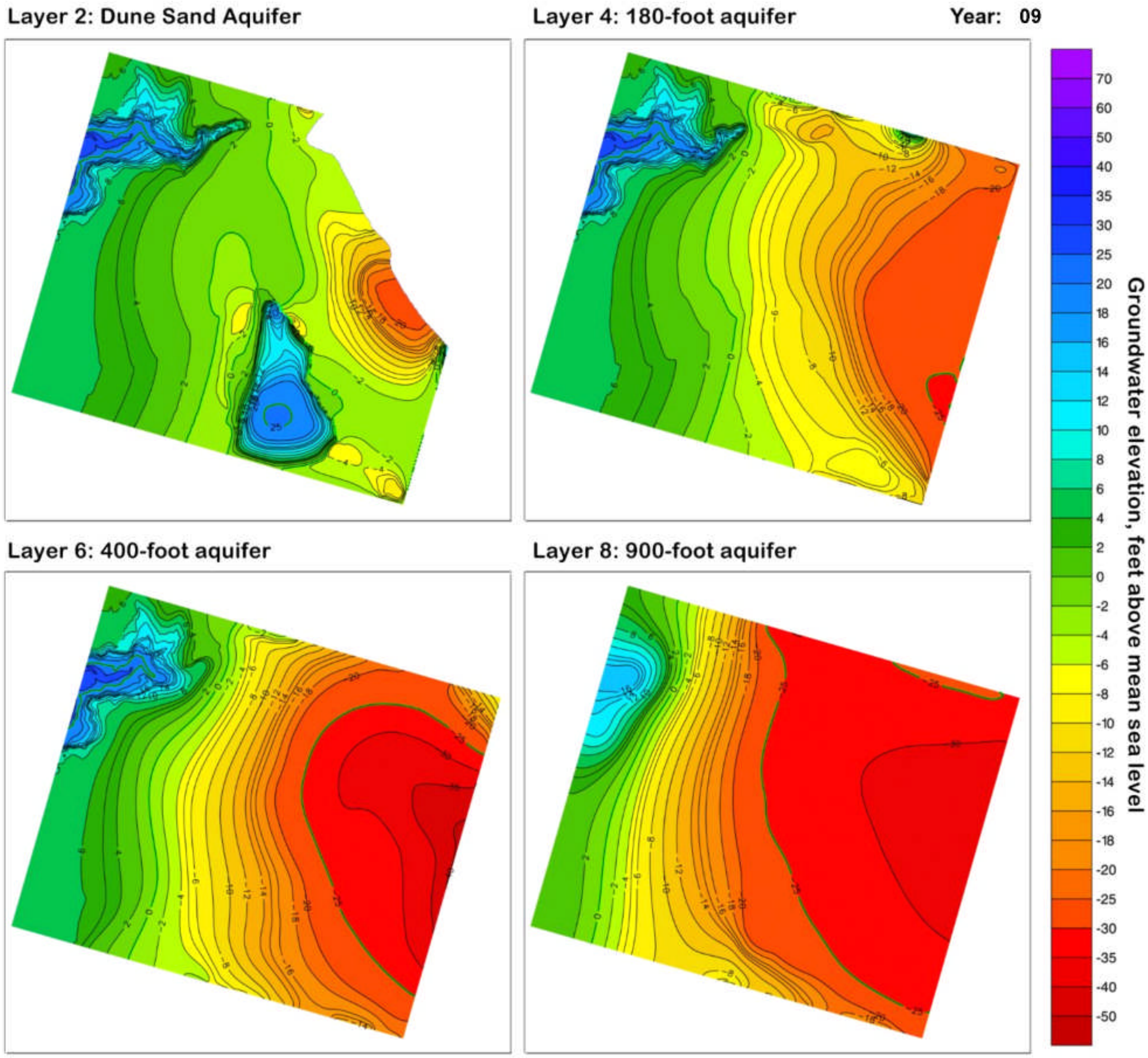
MPWSP Groundwater Flow Model / Calibrated model



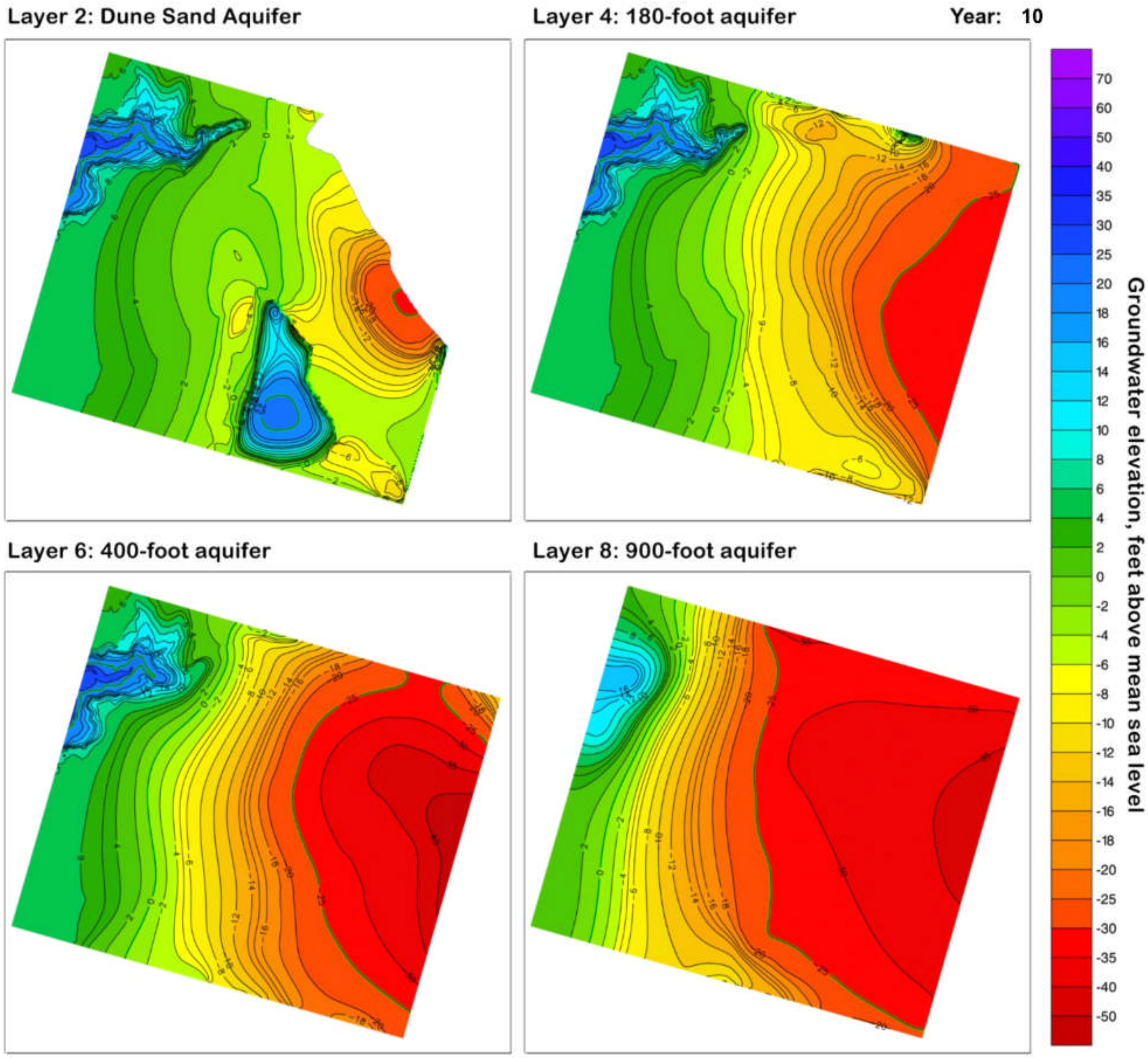
MPWSP Groundwater Flow Model / Calibrated model



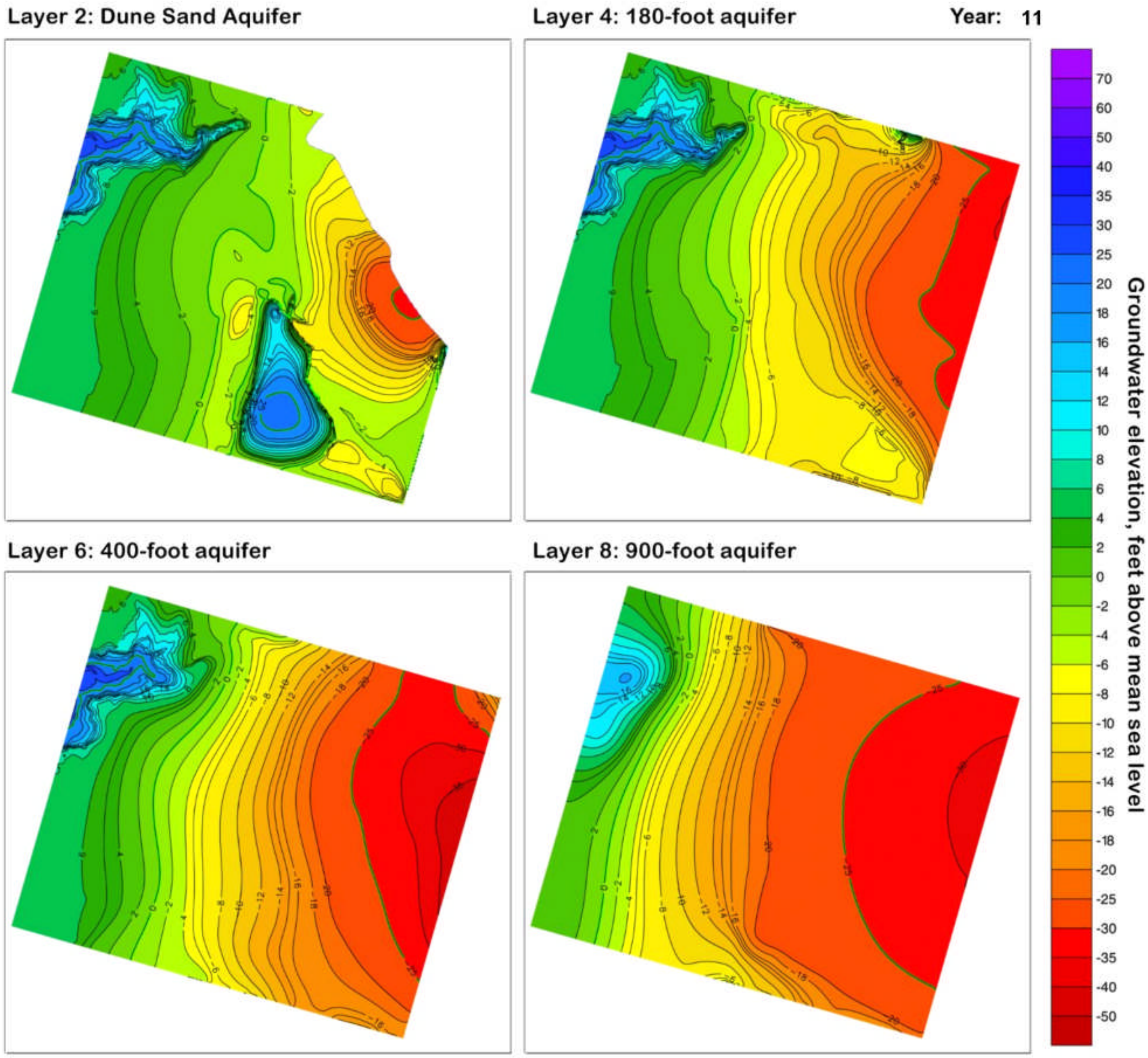
MPWSP Groundwater Flow Model / Calibrated model



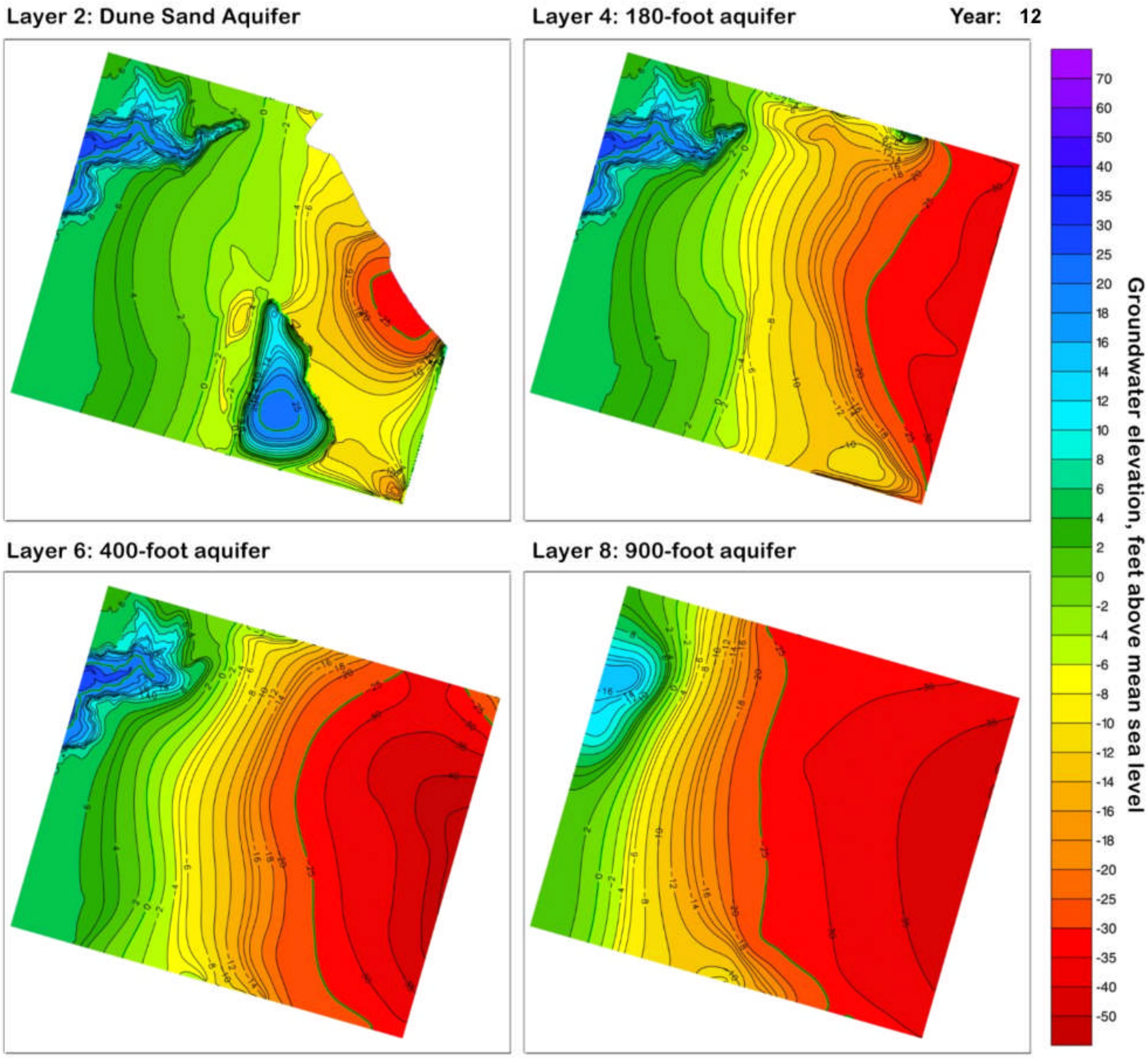
MPWSP Groundwater Flow Model / Calibrated model



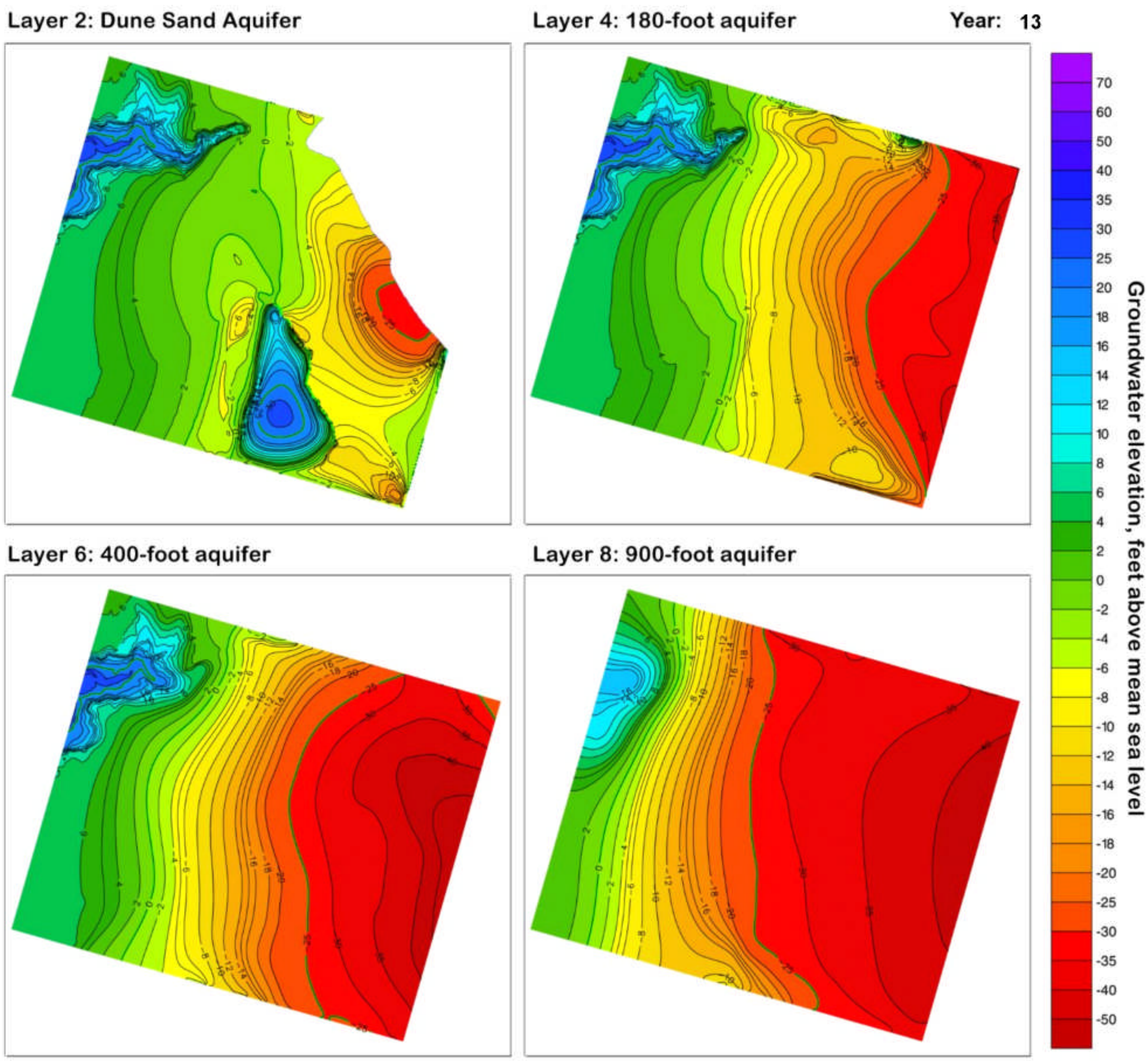
MPWSP Groundwater Flow Model / Calibrated model

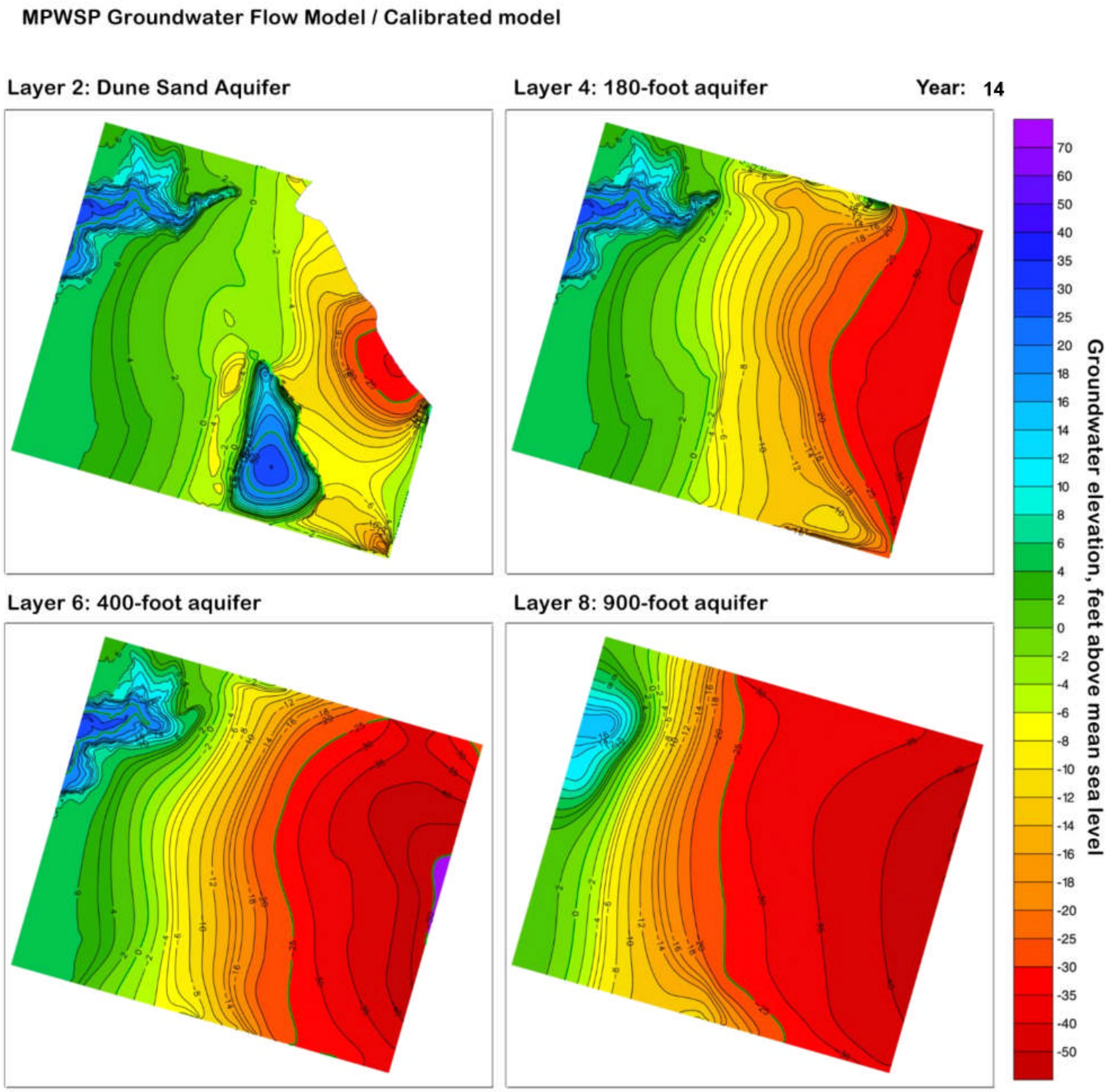


MPWSP Groundwater Flow Model / Calibrated model

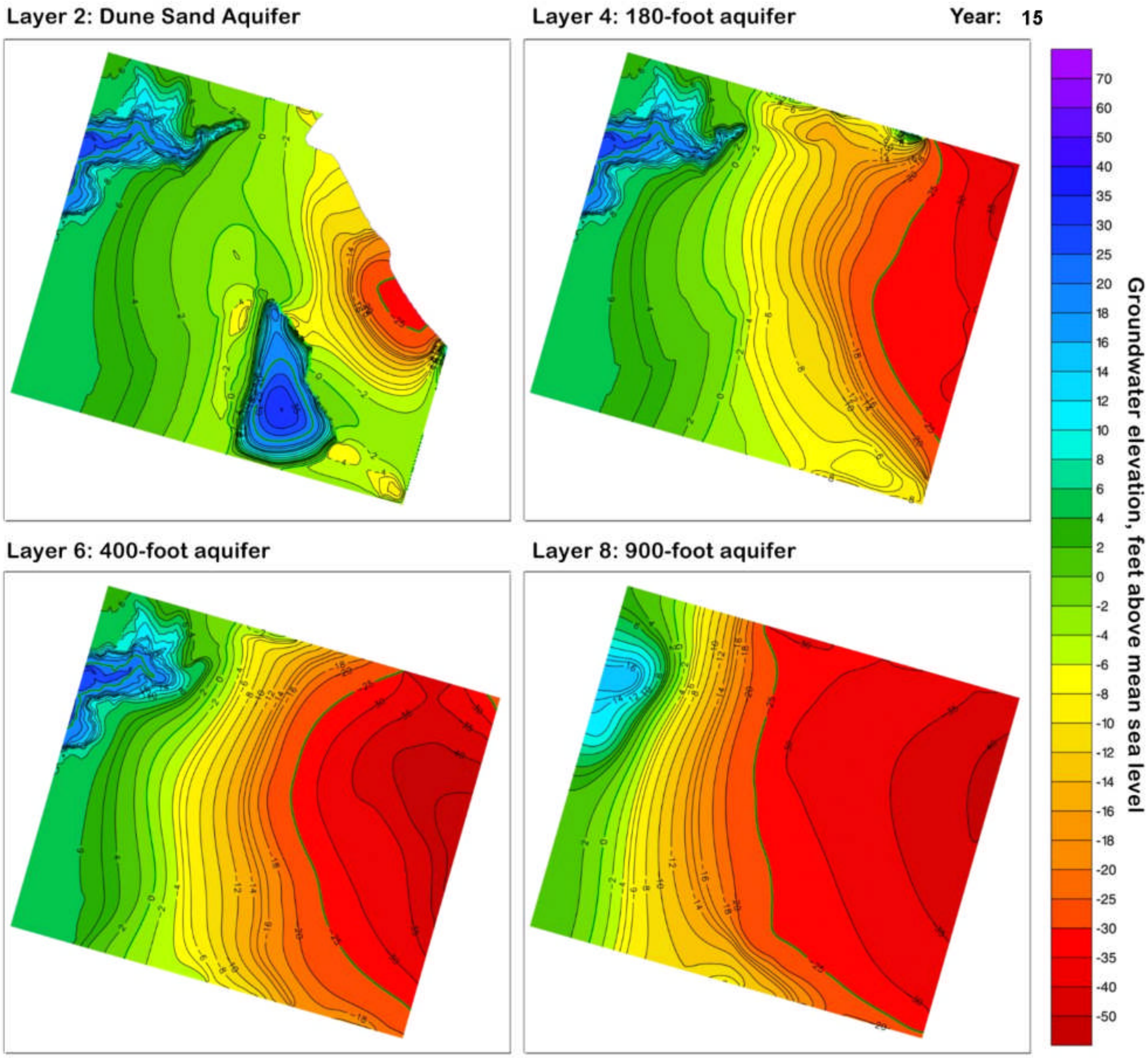


MPWSP Groundwater Flow Model / Calibrated model

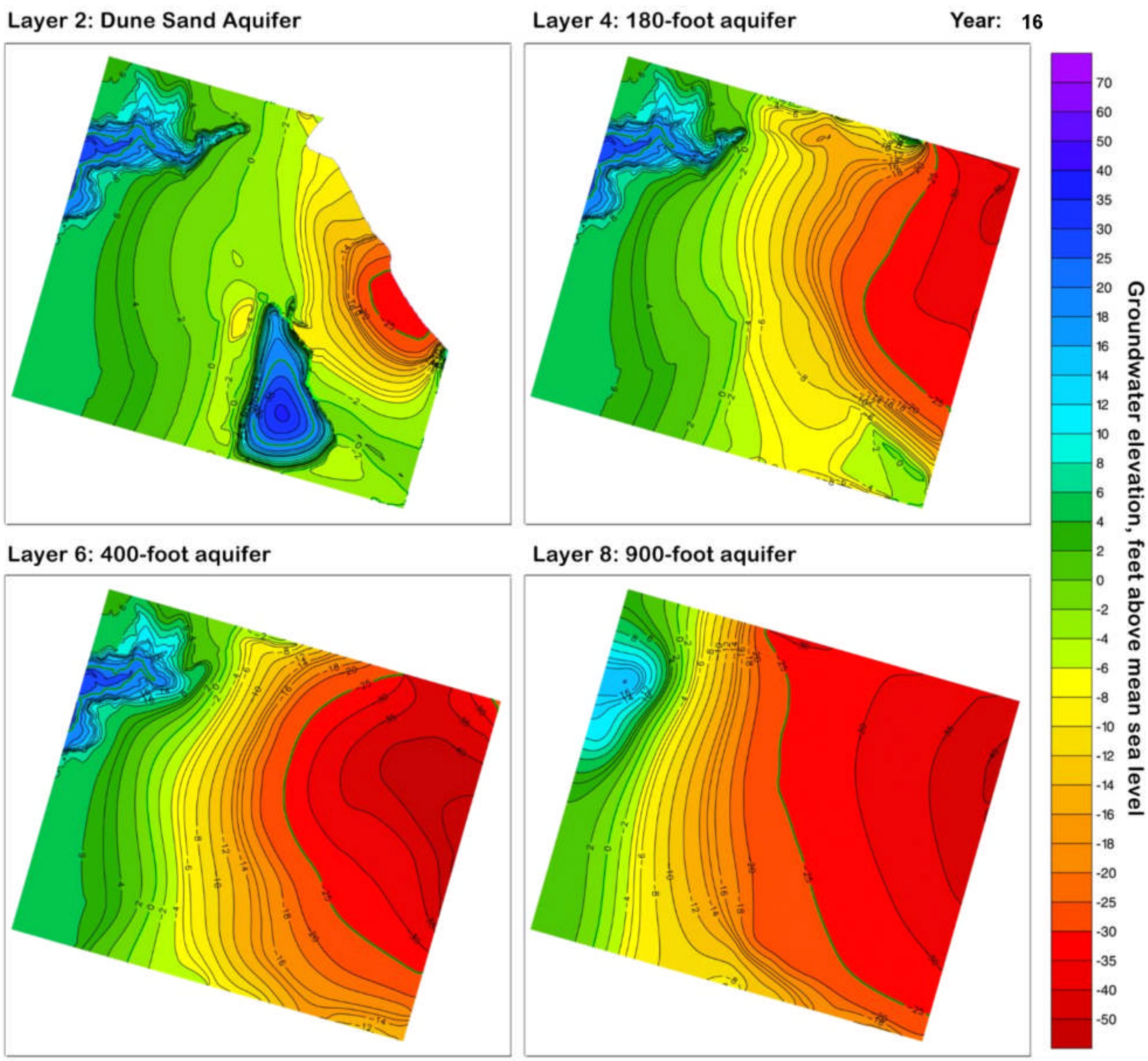



MPWSP Groundwater Flow Model / Calibrated model
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year: 14
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Groundwater elevation, feet above mean sea level
70
60
50
40
35
30
25
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-25
-30
-35
-40
-50

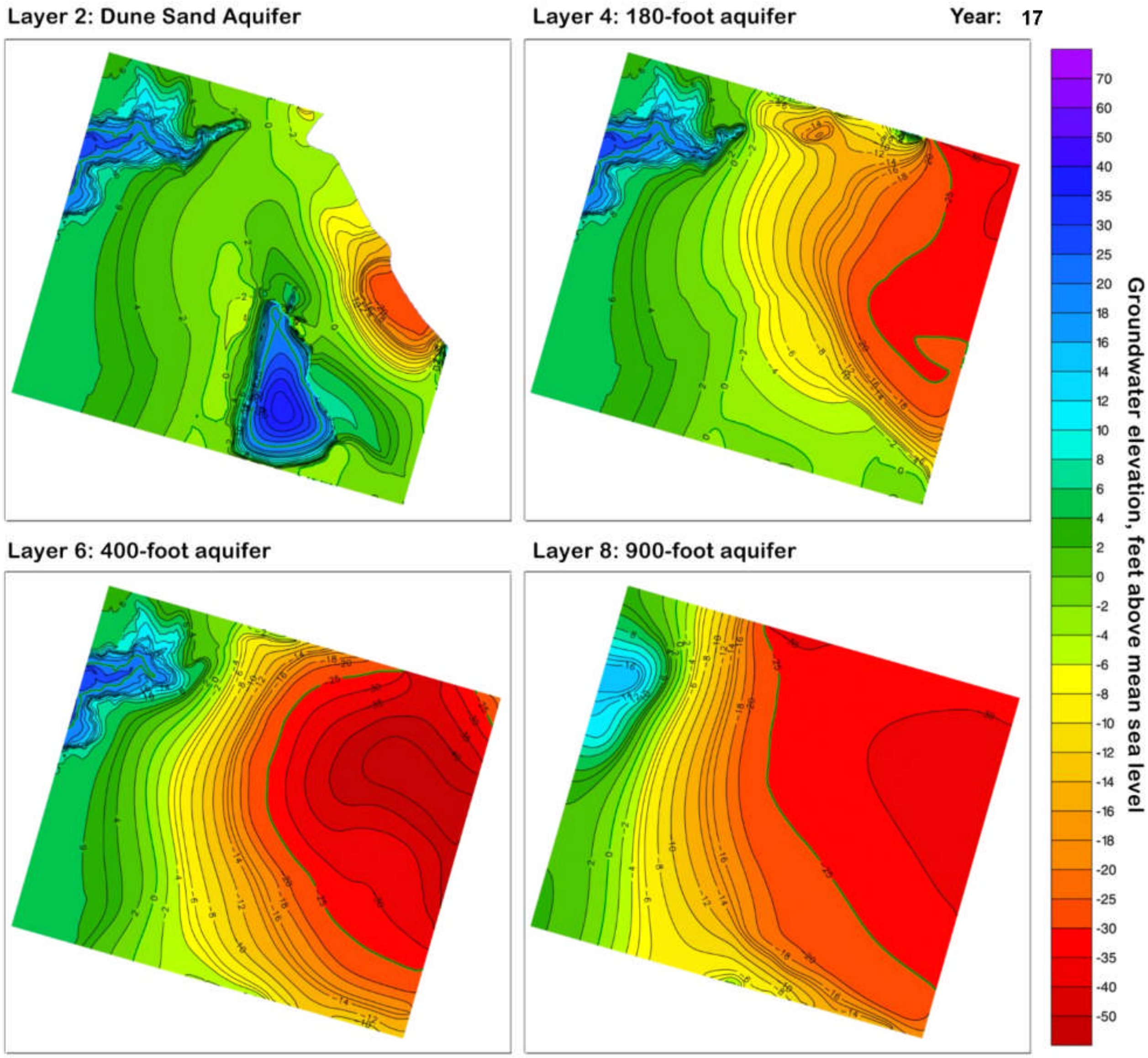
MPWSP Groundwater Flow Model / Calibrated model



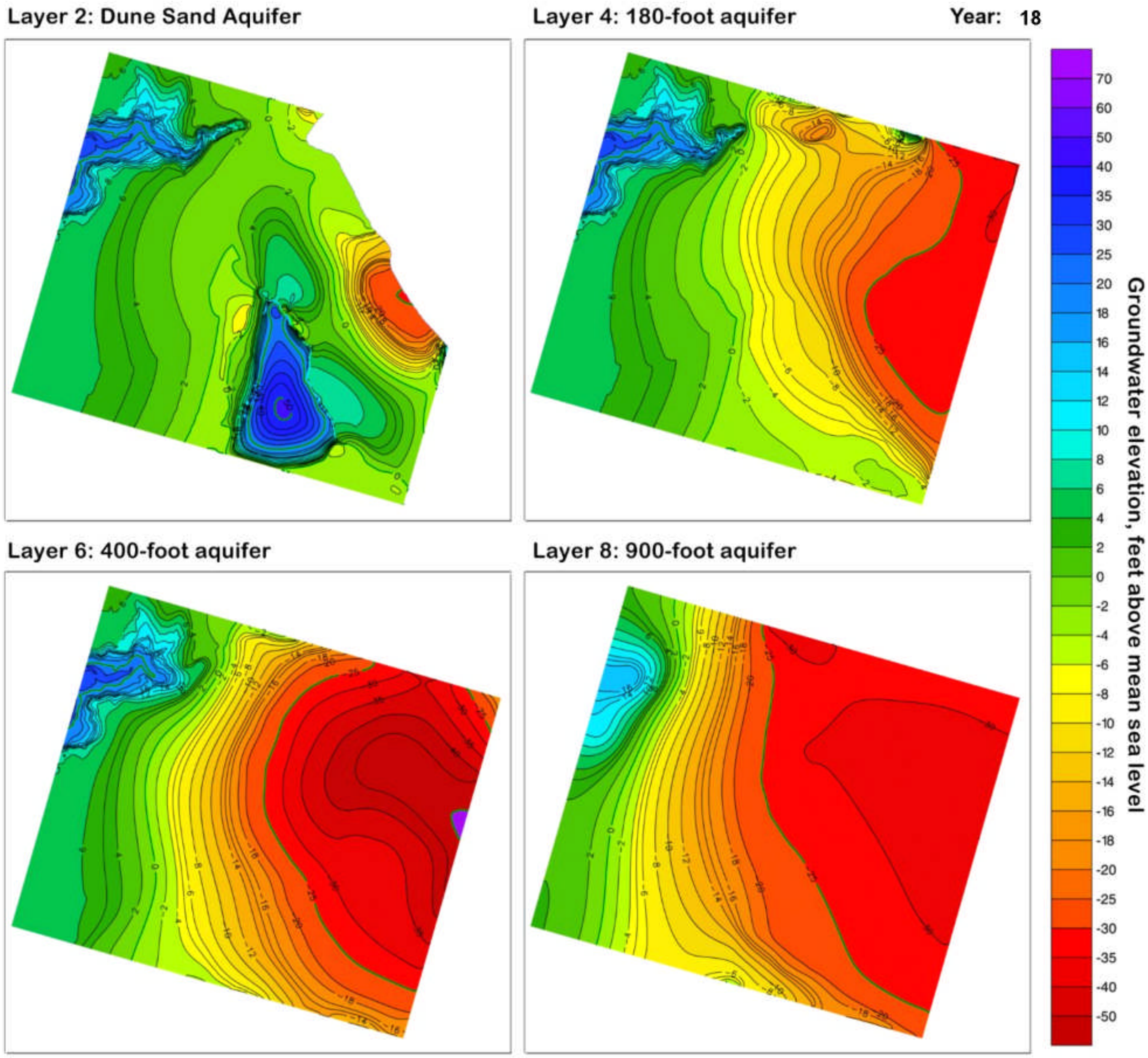
MPWSP Groundwater Flow Model / Calibrated model



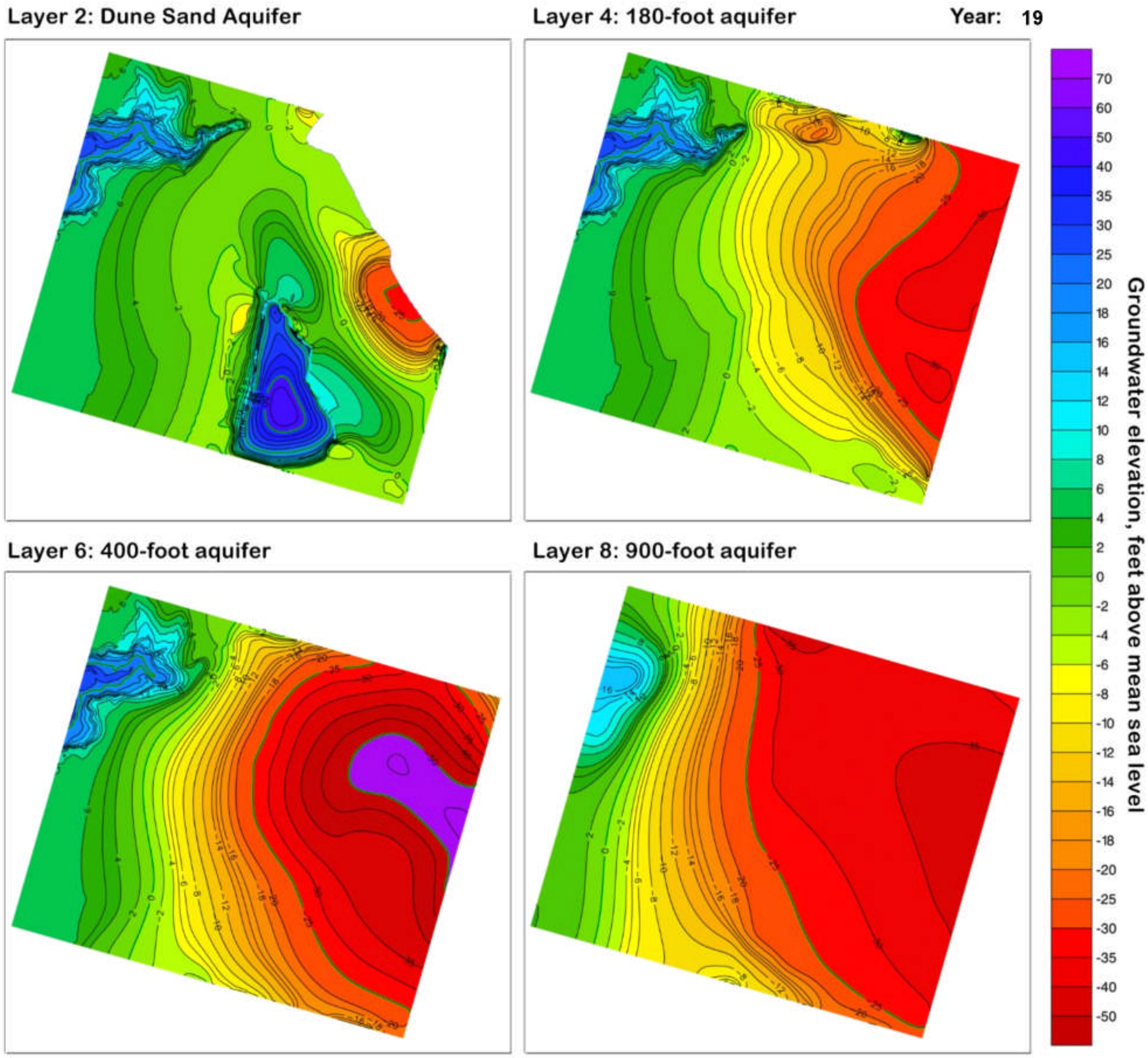
MPWSP Groundwater Flow Model / Calibrated model



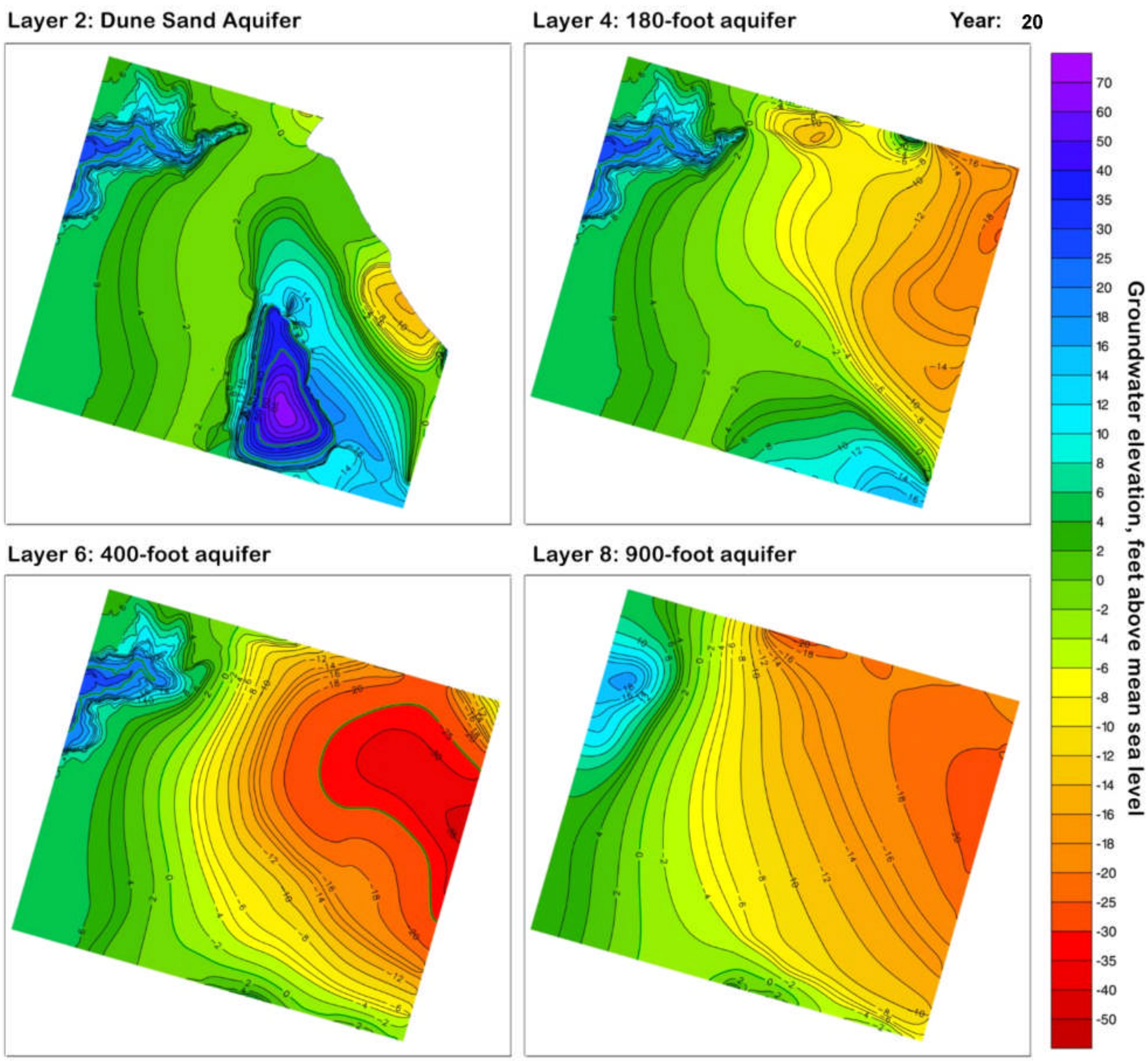
MPWSP Groundwater Flow Model / Calibrated model



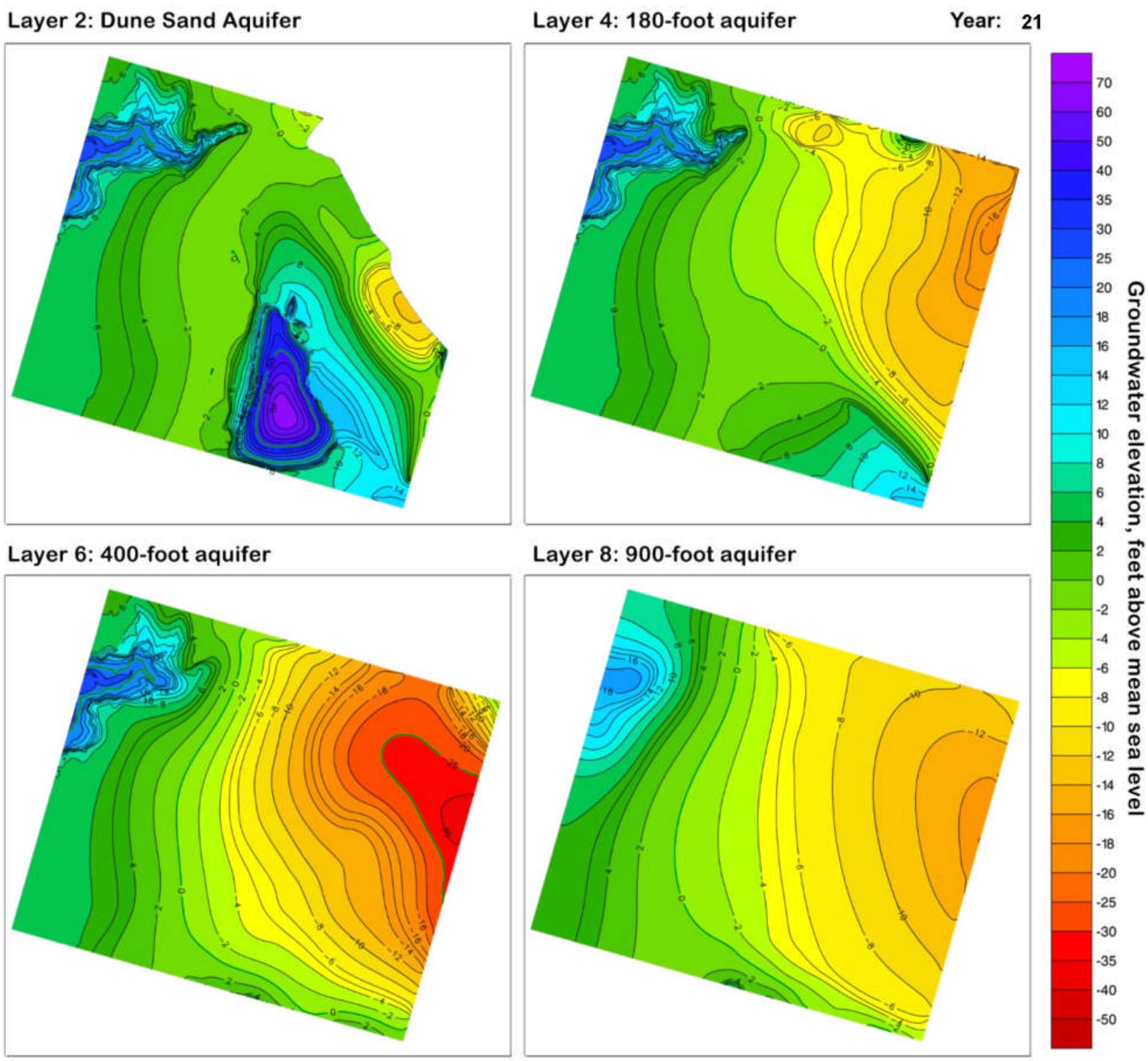
MPWSP Groundwater Flow Model / Calibrated model



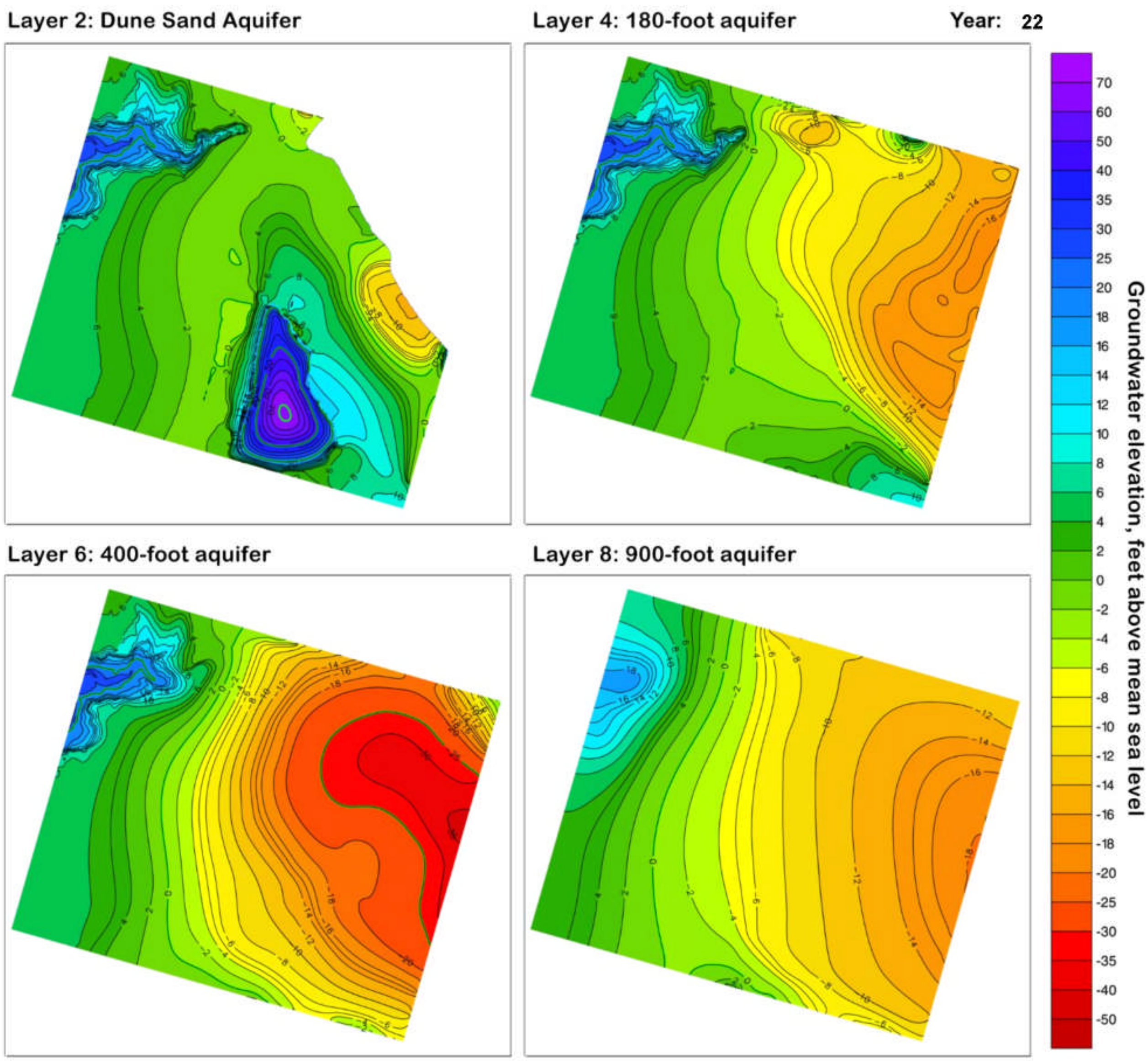
MPWSP Groundwater Flow Model / Calibrated model

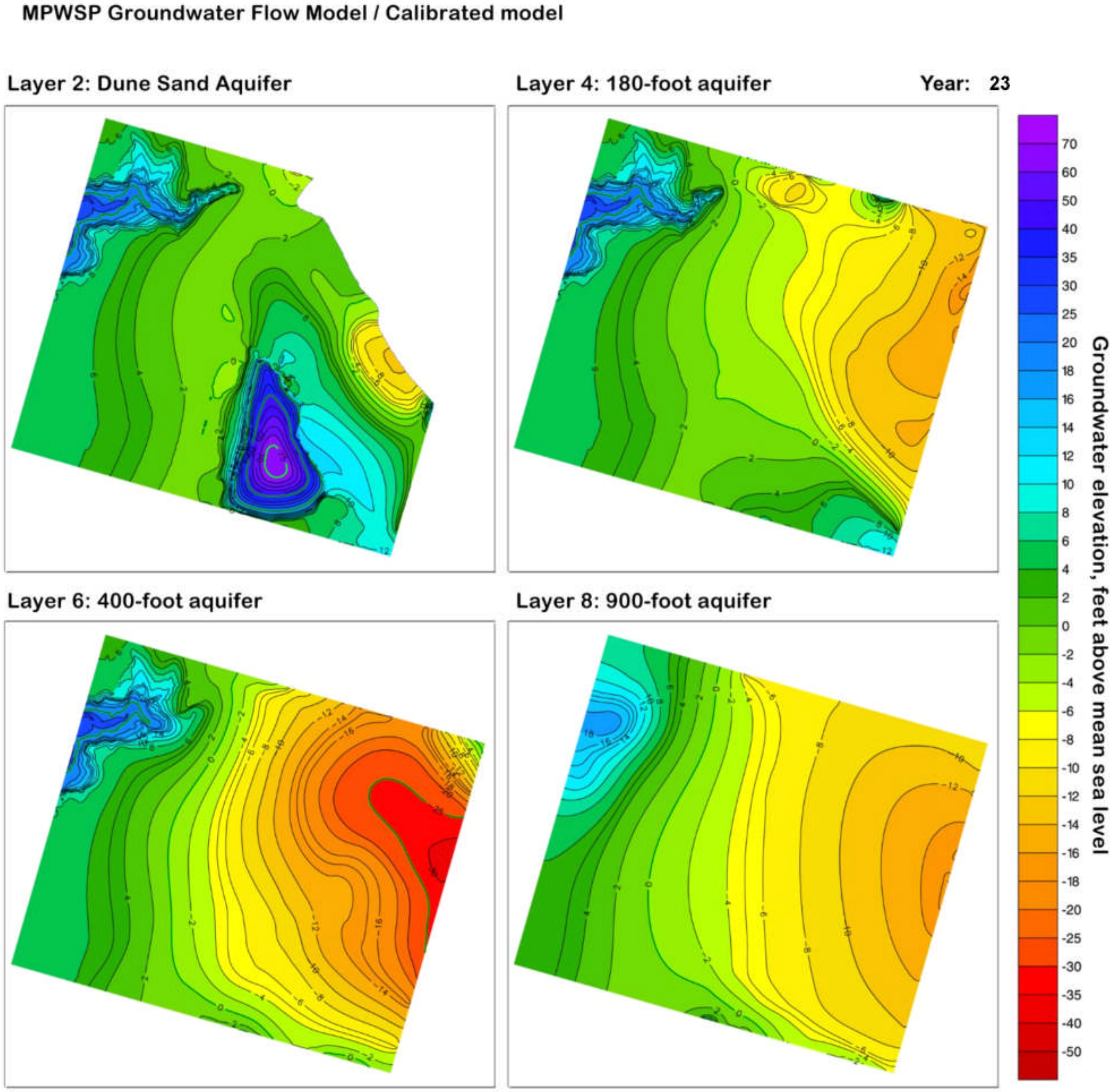


MPWSP Groundwater Flow Model / Calibrated model

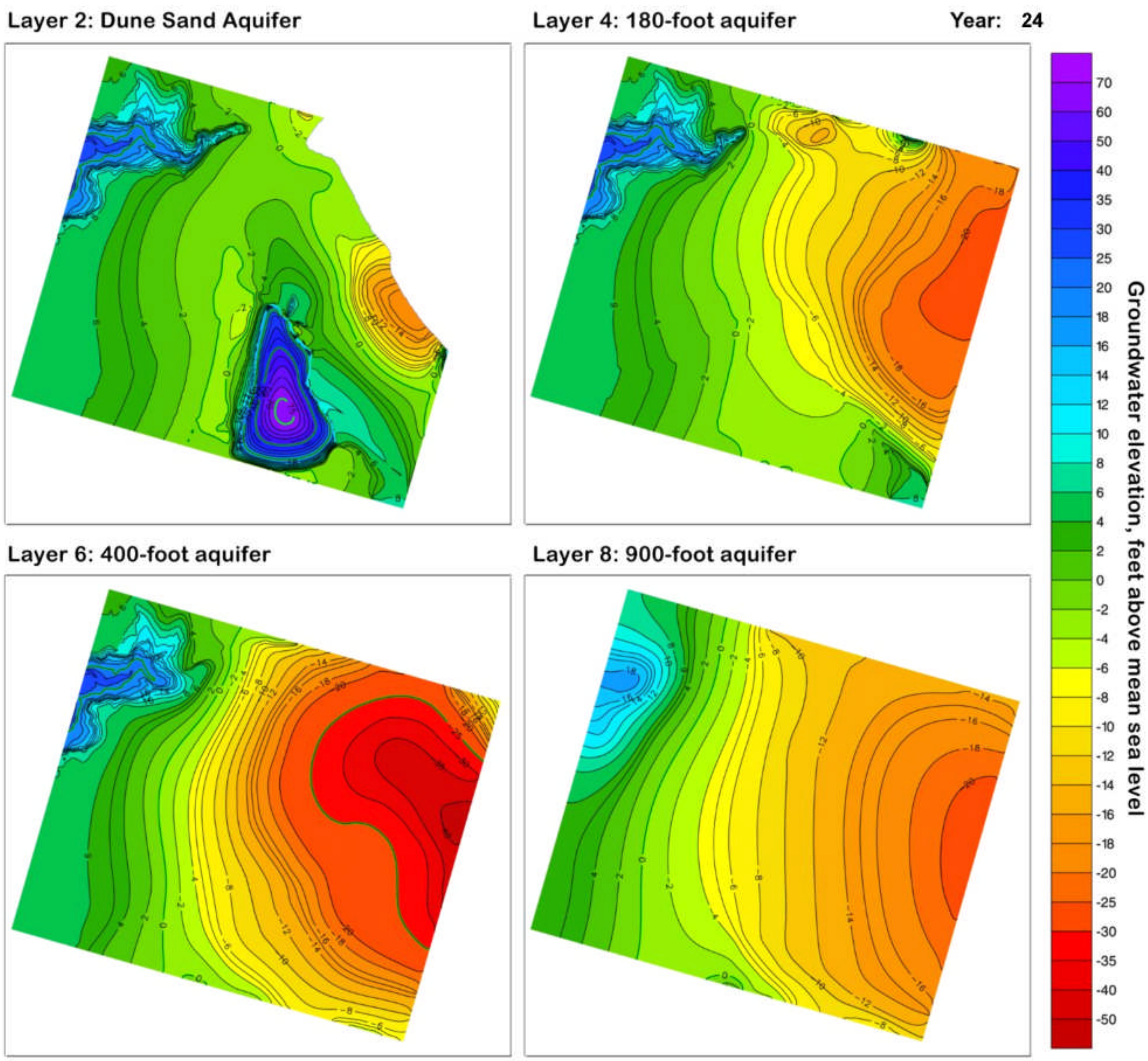


MPWSP Groundwater Flow Model / Calibrated model

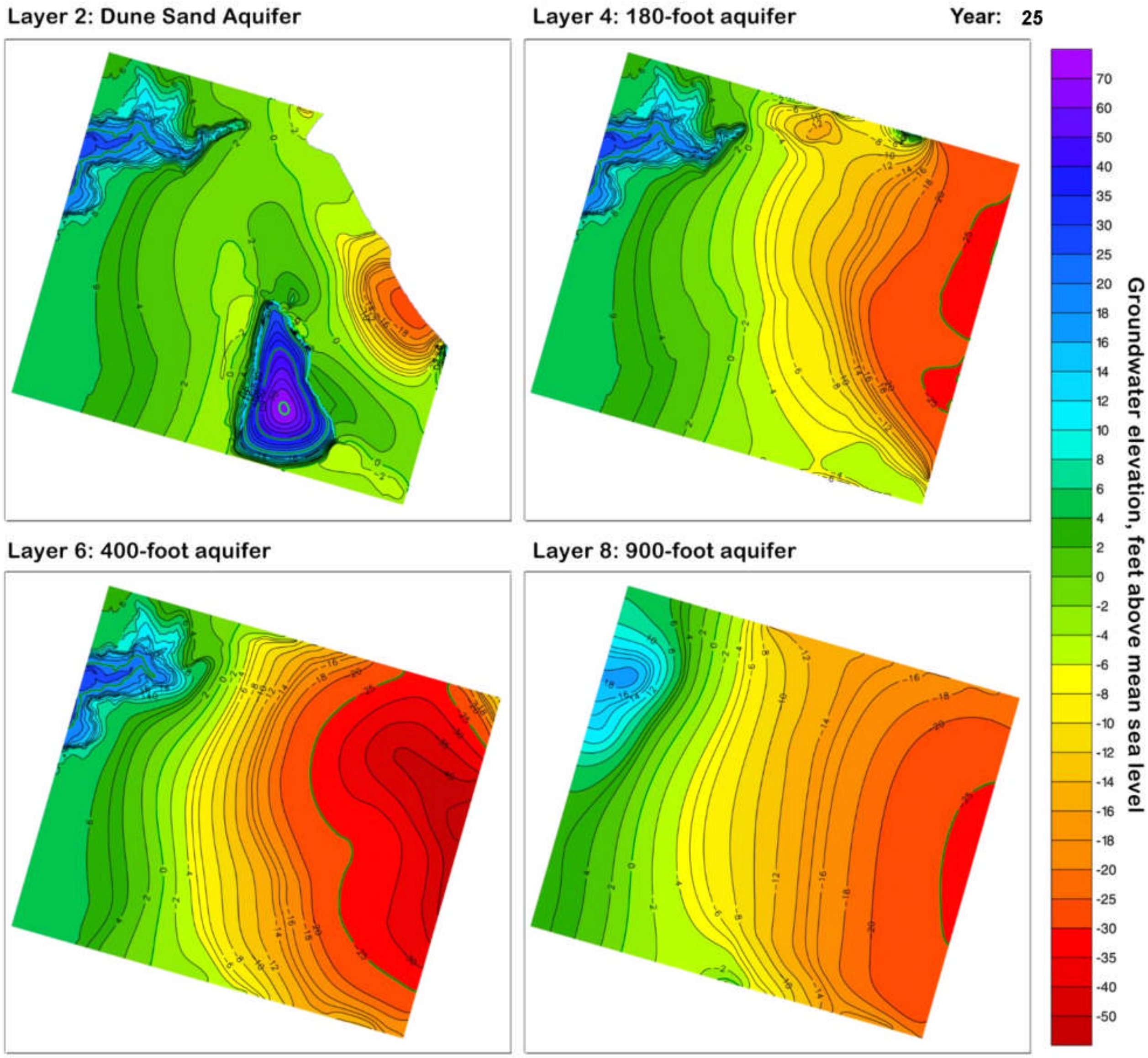


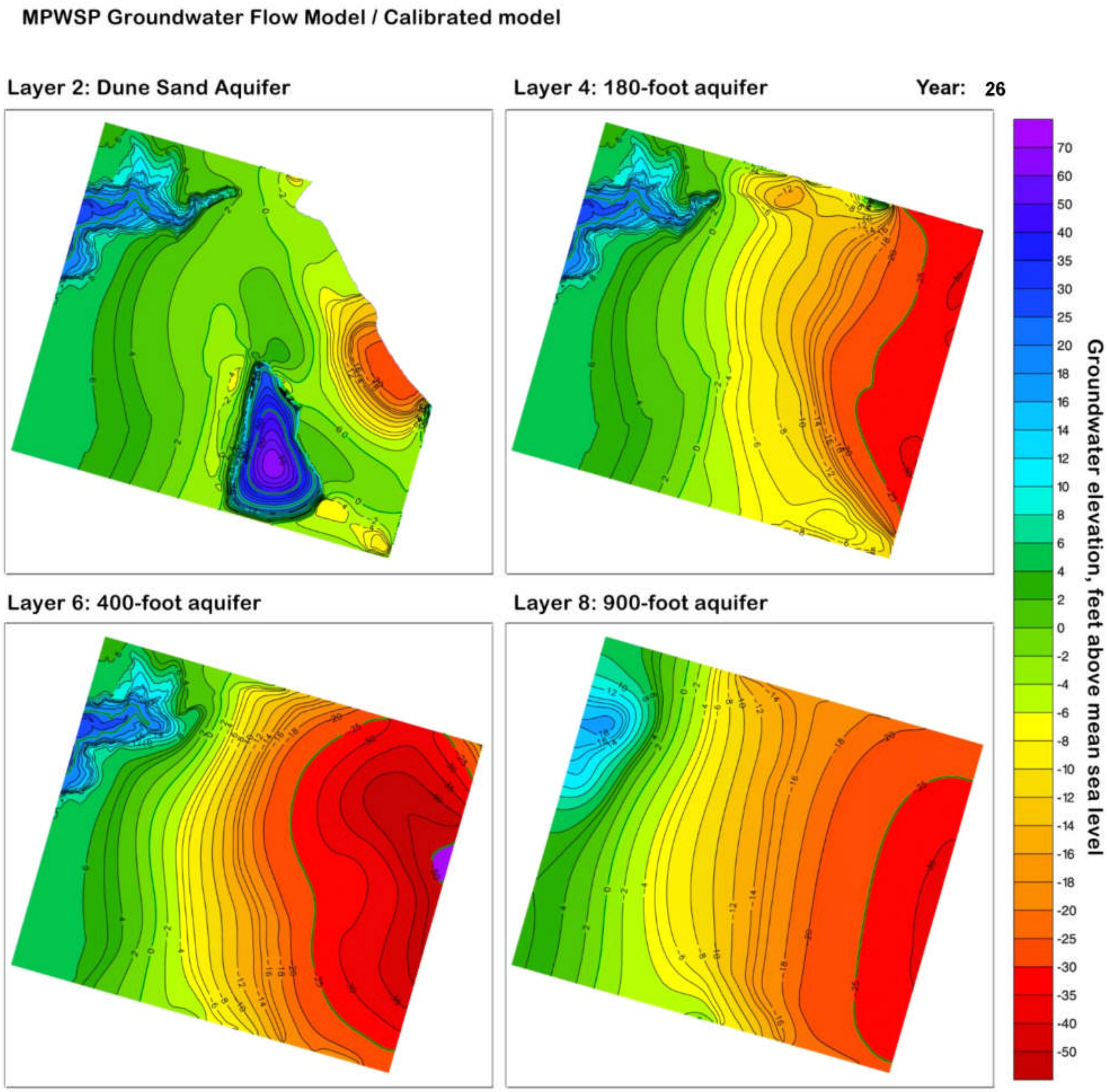

MPWSP Groundwater Flow Model / Calibrated model
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year: 23
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Groundwater elevation, feet above mean sea level
70
60
50
40
35
30
25
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-25
-30
-35
-40
-50

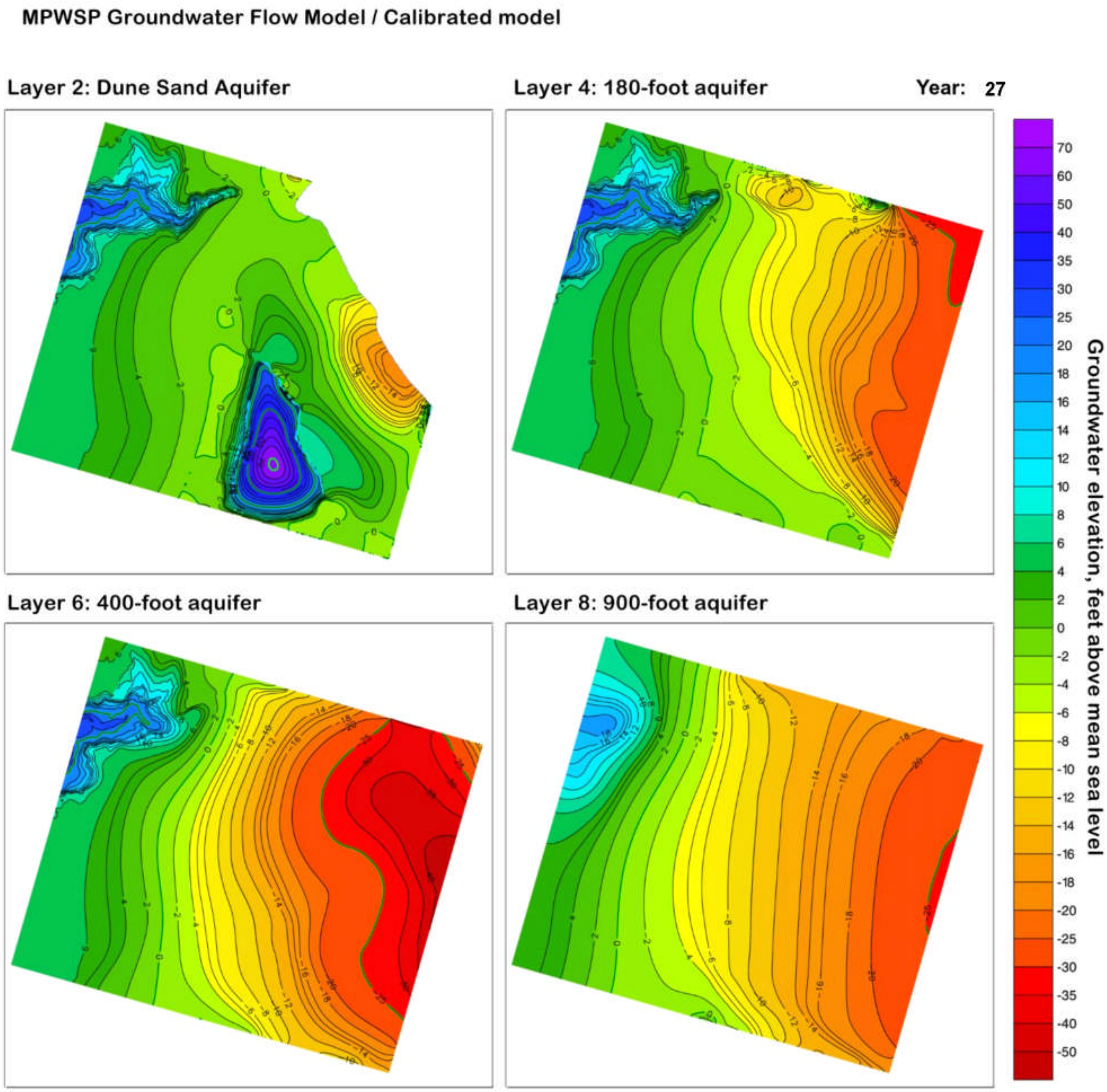
MPWSP Groundwater Flow Model / Calibrated model



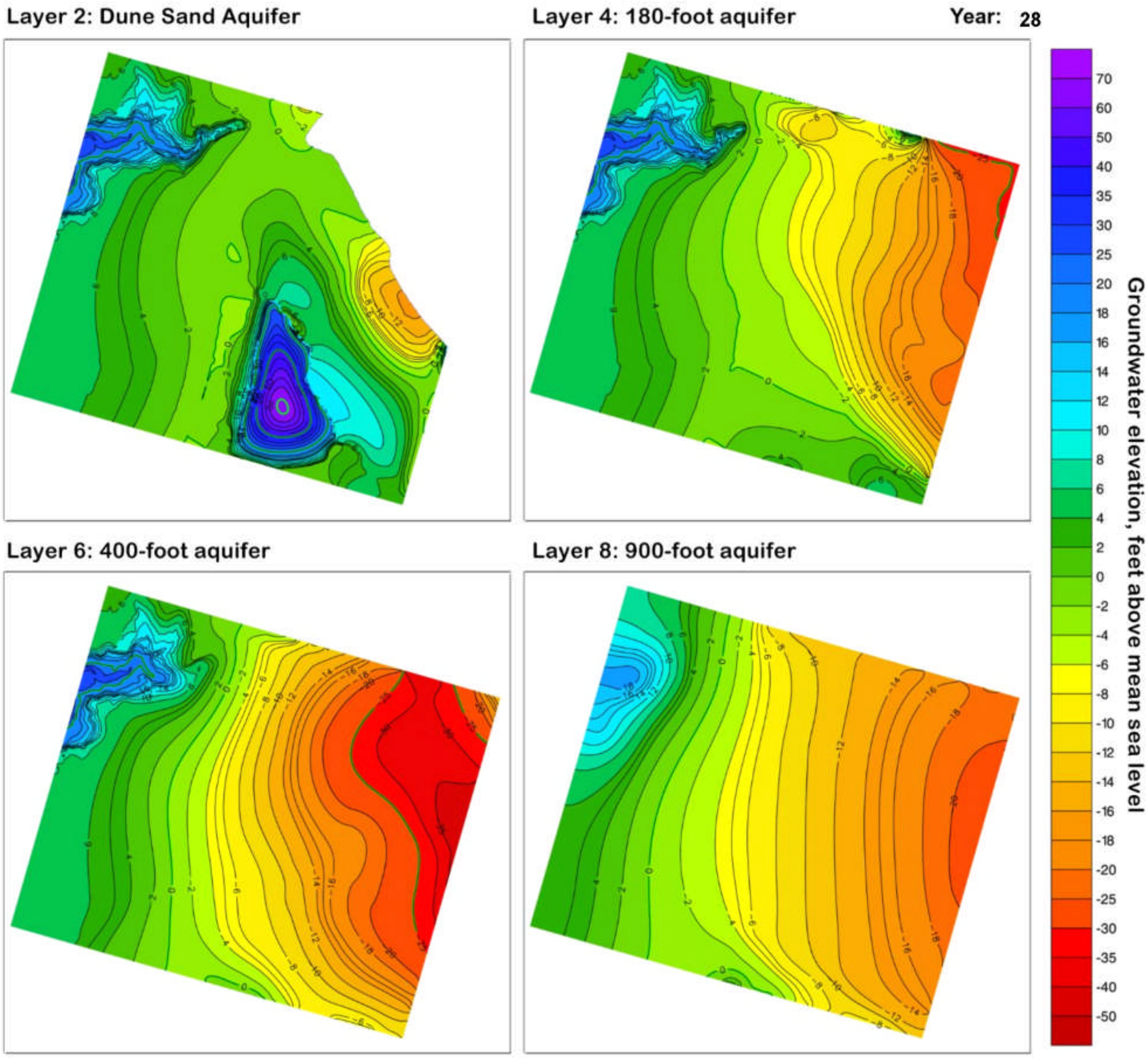
MPWSP Groundwater Flow Model / Calibrated model



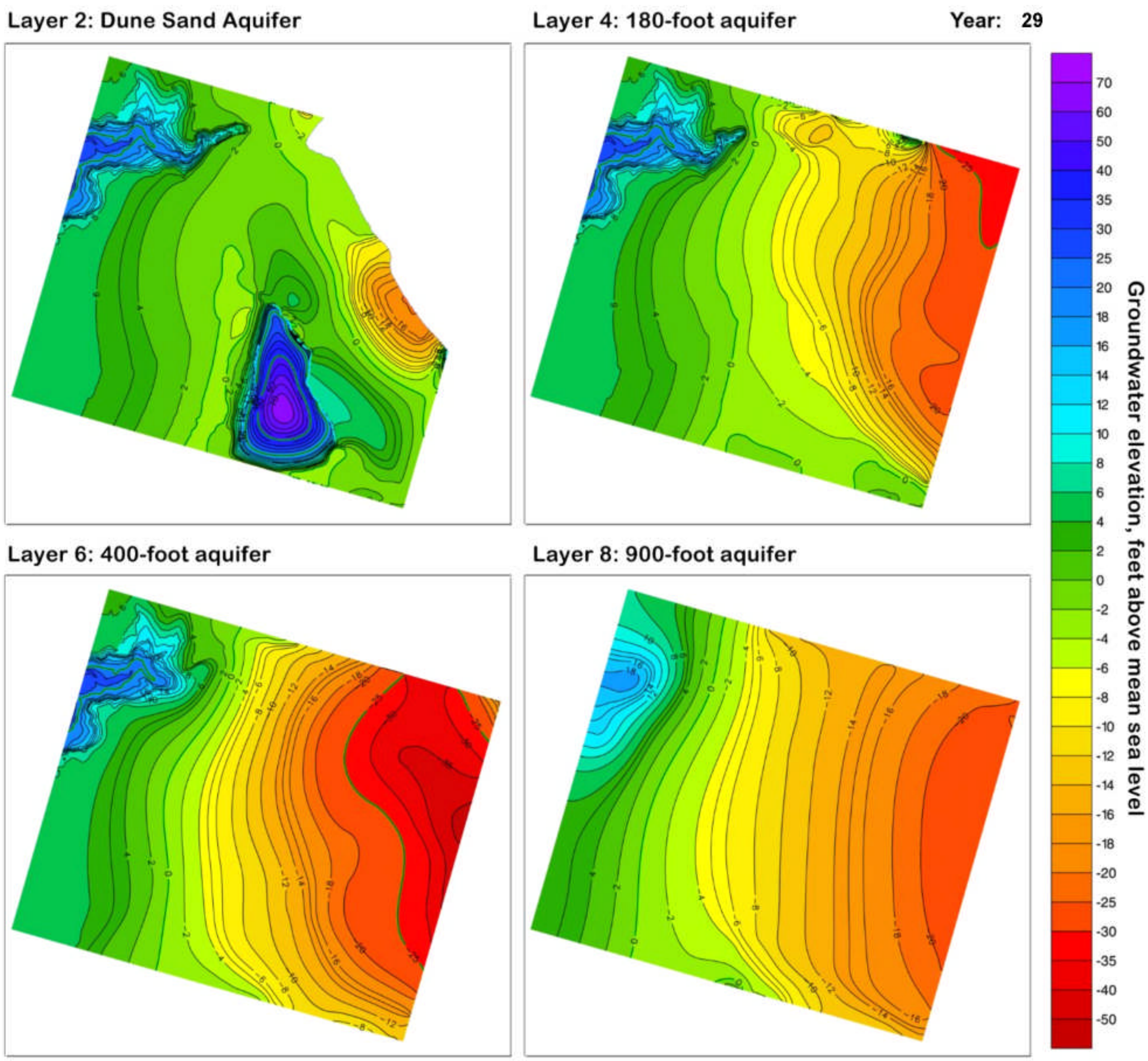

MPWSP Groundwater Flow Model / Calibrated model
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year: 26
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Groundwater elevation, feet above mean sea level
70
60
50
40
35
30
25
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-25
-30
-35
-40
-50

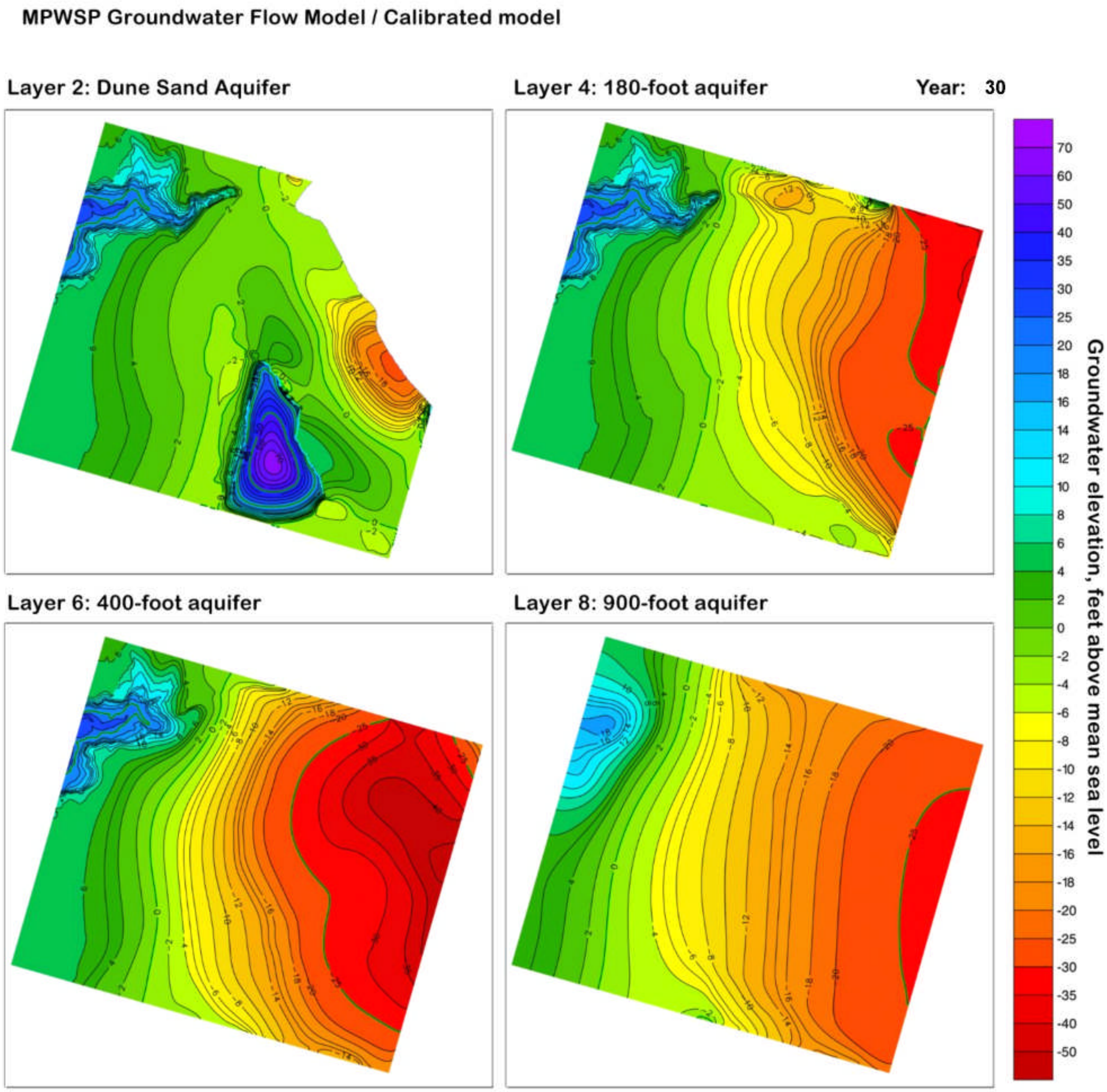

MPWSP Groundwater Flow Model / Calibrated model
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year: 27
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
70
60
50
40
35
30
25
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-25
-30
-35
-40
-50
Groundwater elevation, feet above mean sea level

MPWSP Groundwater Flow Model / Calibrated model

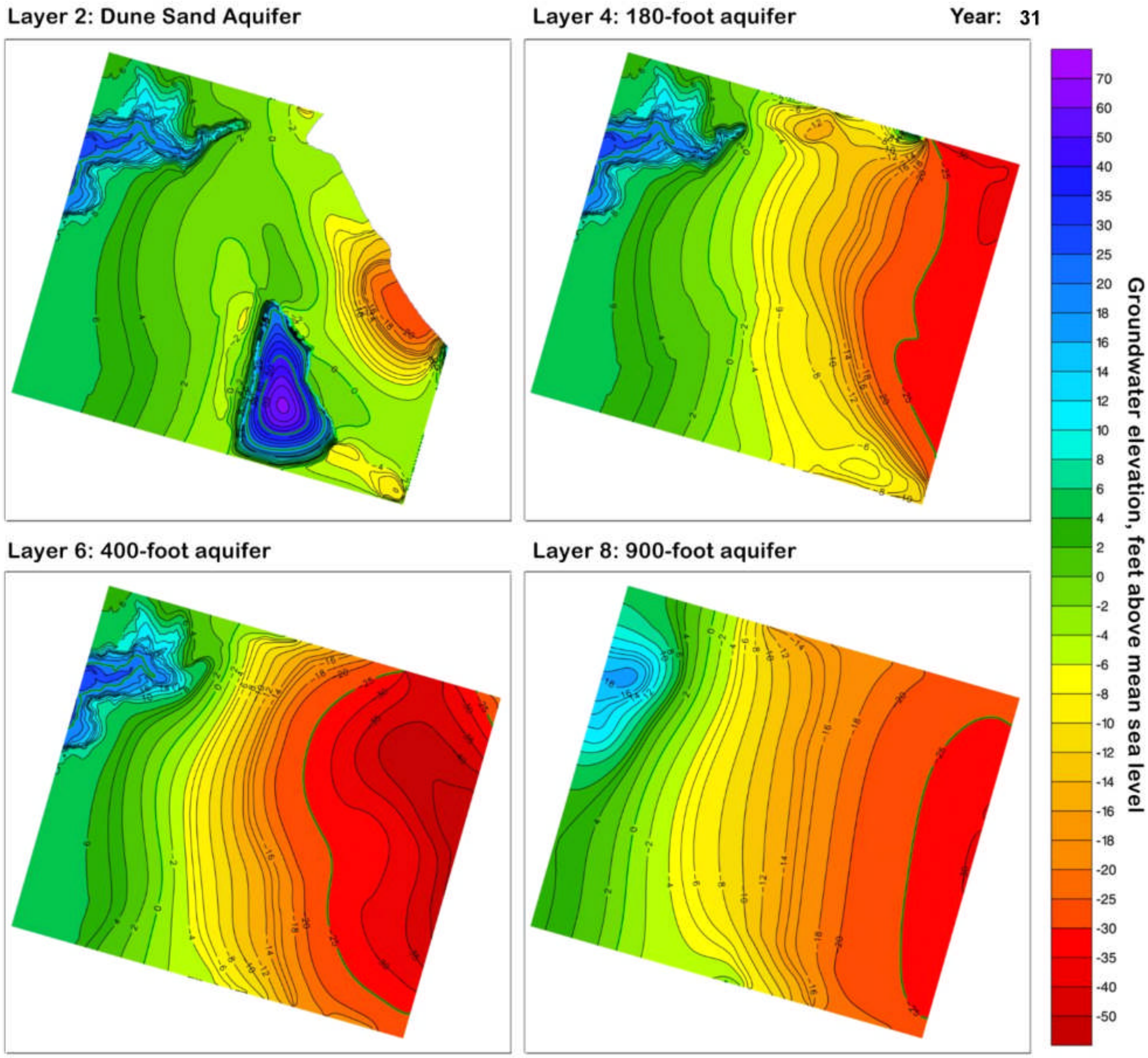


MPWSP Groundwater Flow Model / Calibrated model

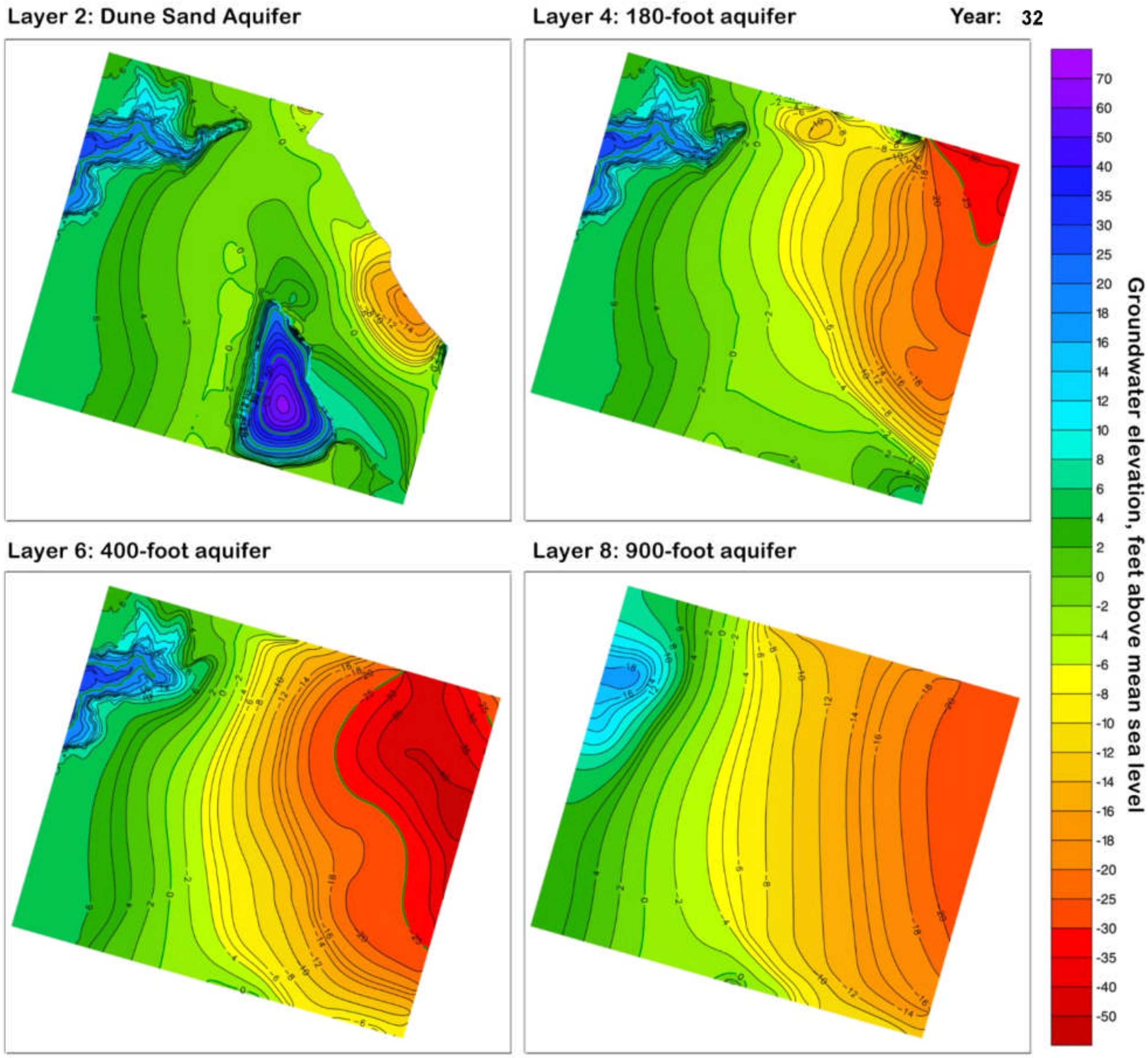



MPWSP Groundwater Flow Model / Calibrated model
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year: 30
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Groundwater elevation, feet above mean sea level
70
60
50
40
35
30
25
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-25
-30
-35
-40
-50

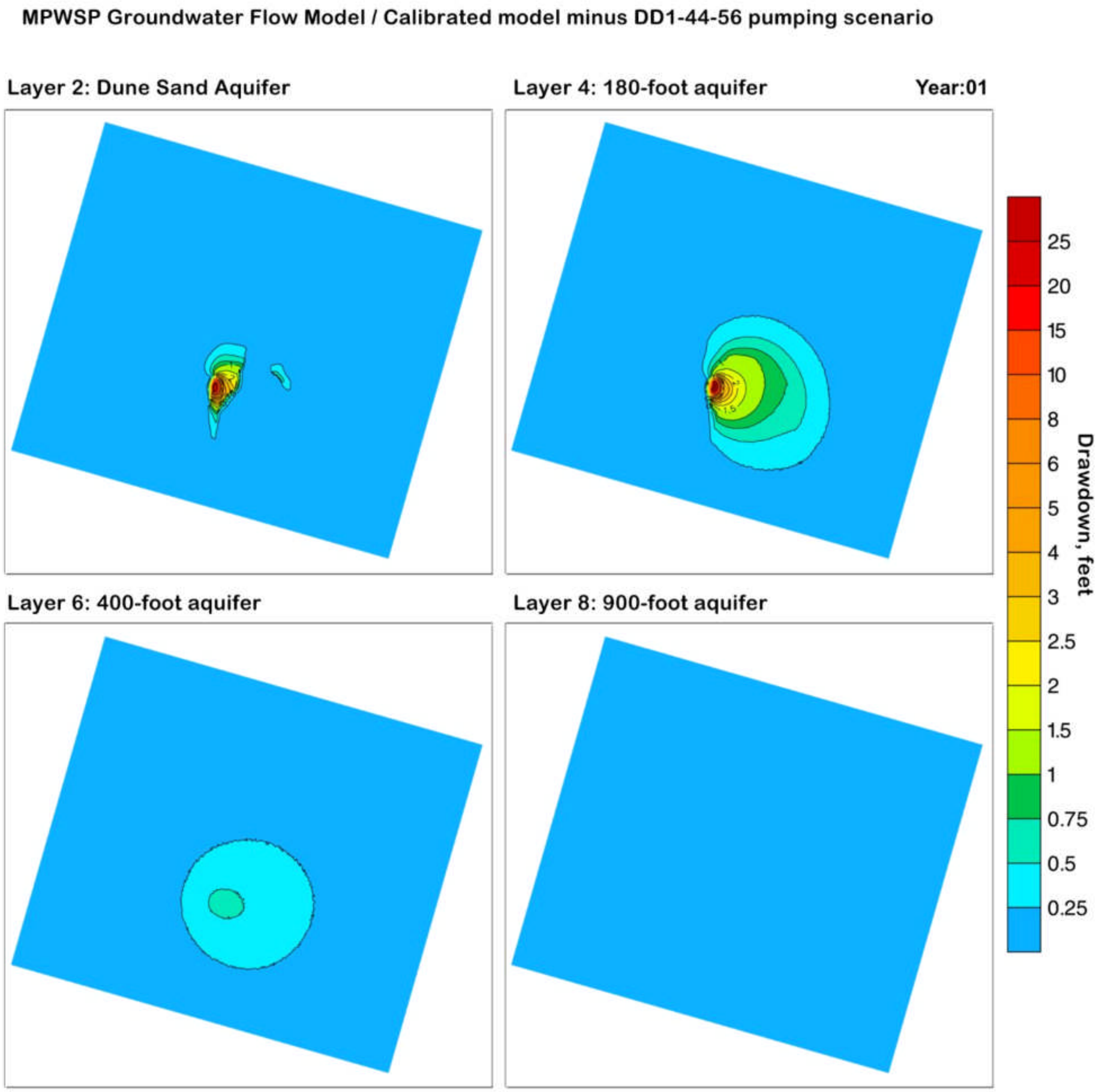
MPWSP Groundwater Flow Model / Calibrated model



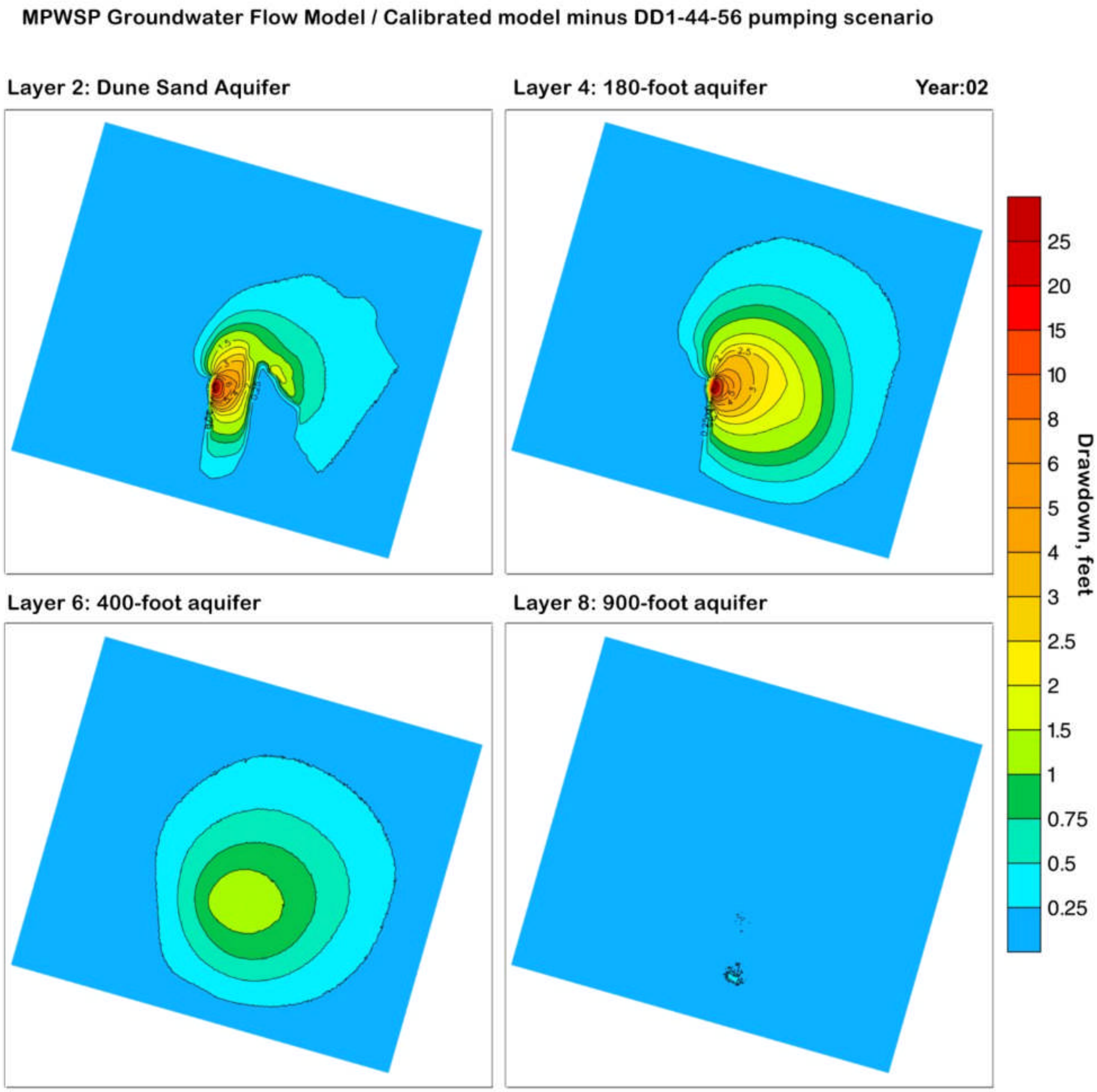
MPWSP Groundwater Flow Model / Calibrated model



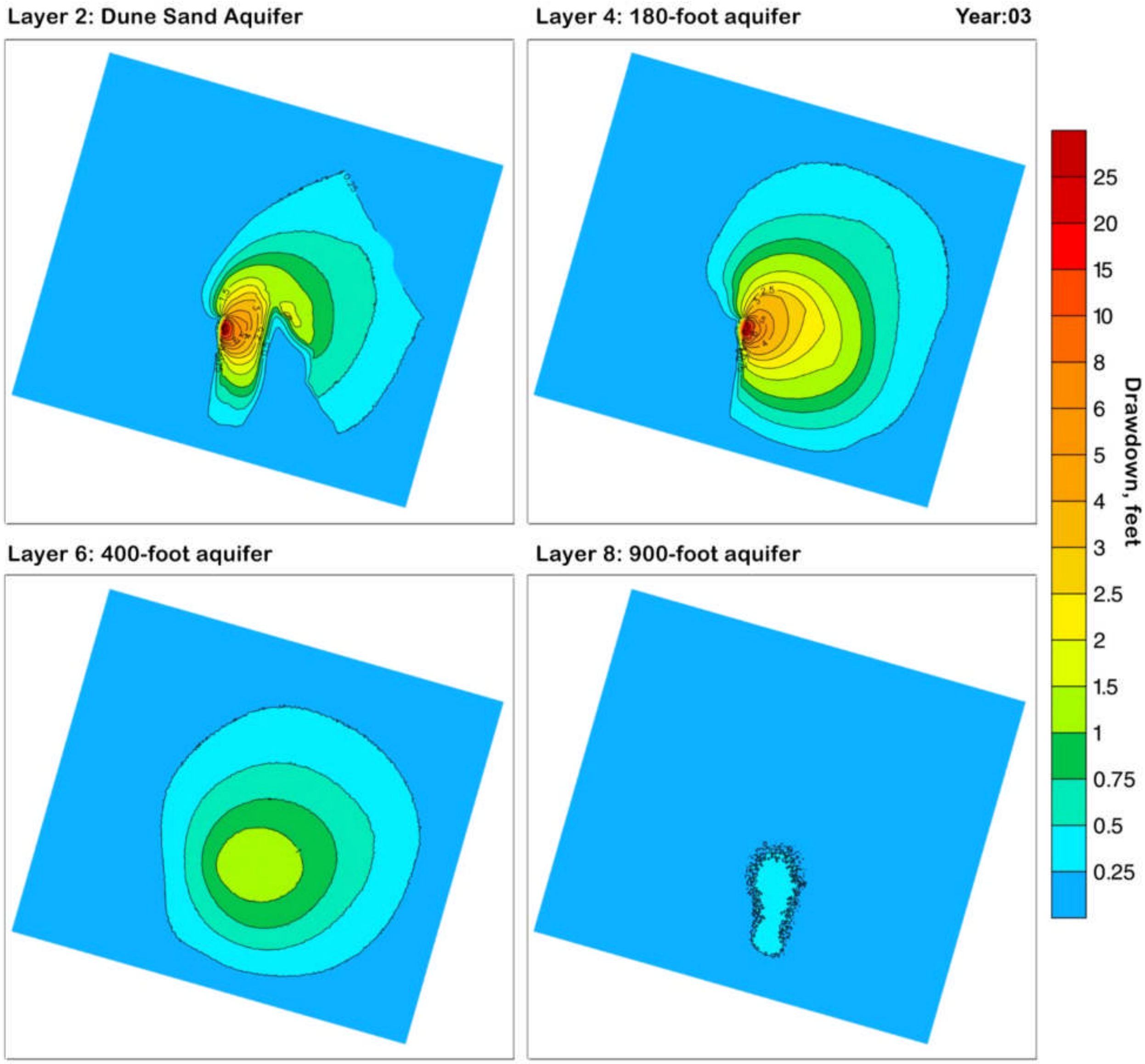
Appendix 2
Simulated Cone-of-Depression in the Dune Sand, 180-FT, 400-FT, and 900-FT aquifers calculated from the DD1-44/56 and Calibrated scenarios of the 2016 NMGWM after each Year of the 32-Year Simulation Period

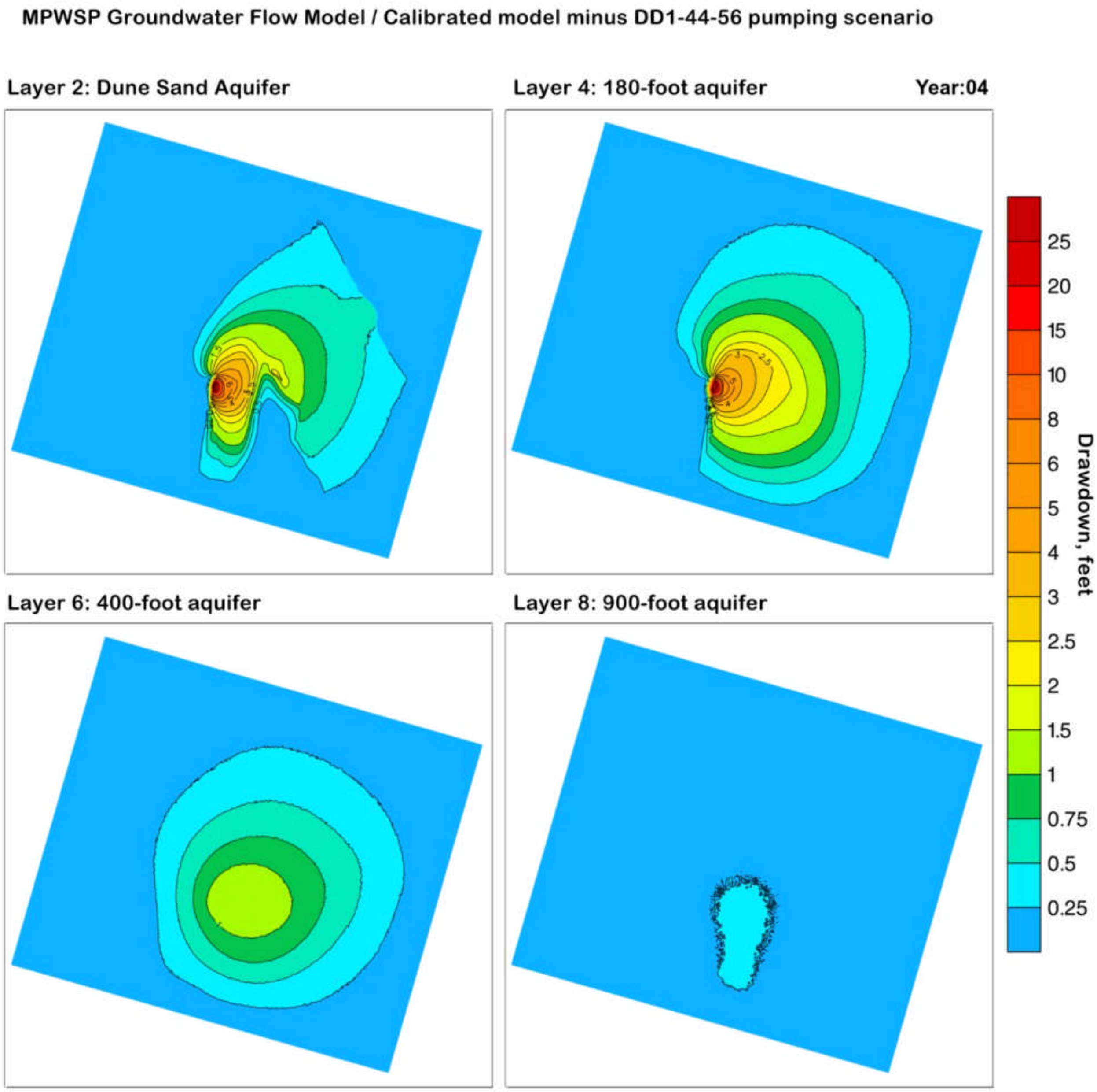


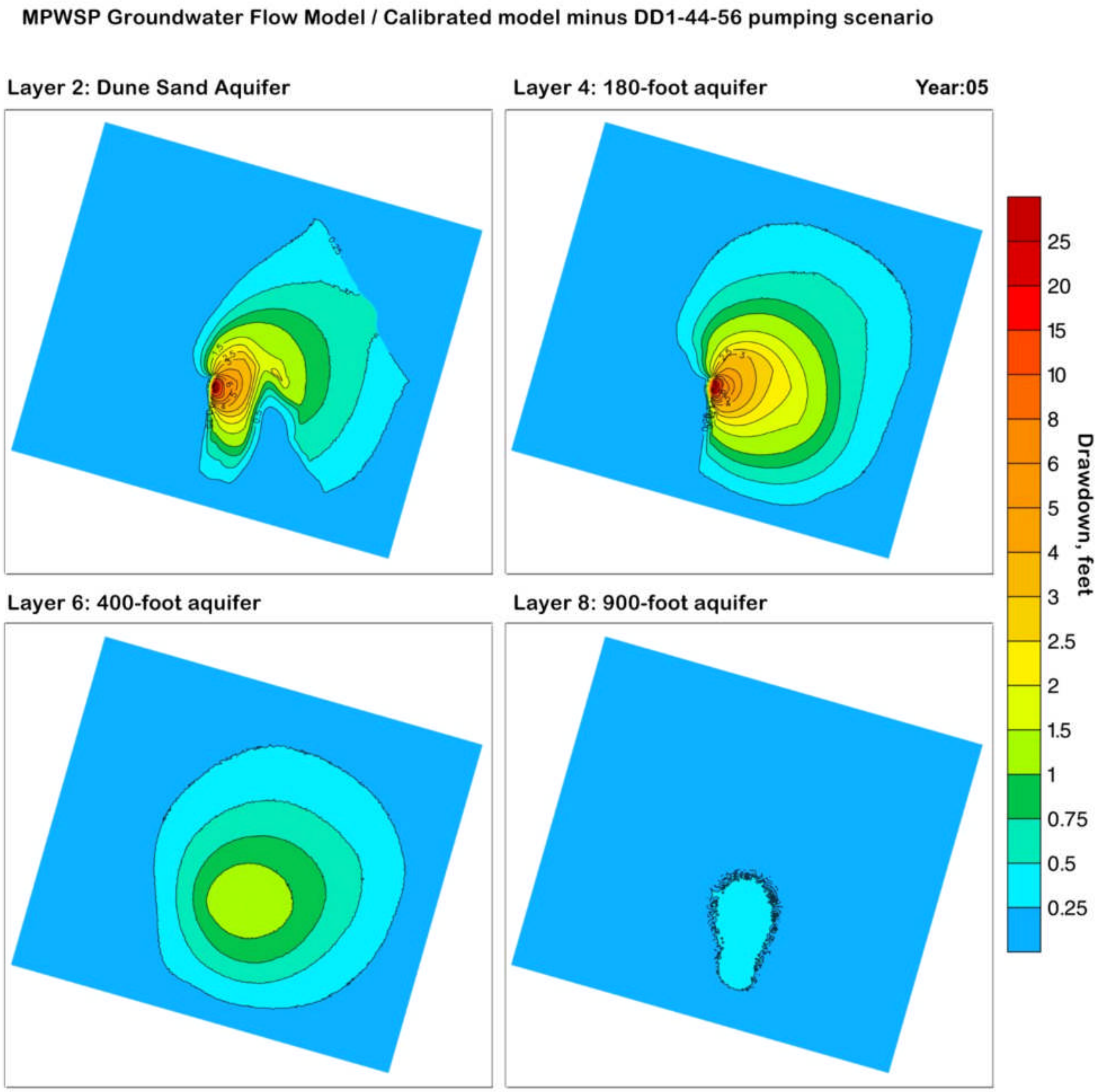
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:01
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25


MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:02
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25

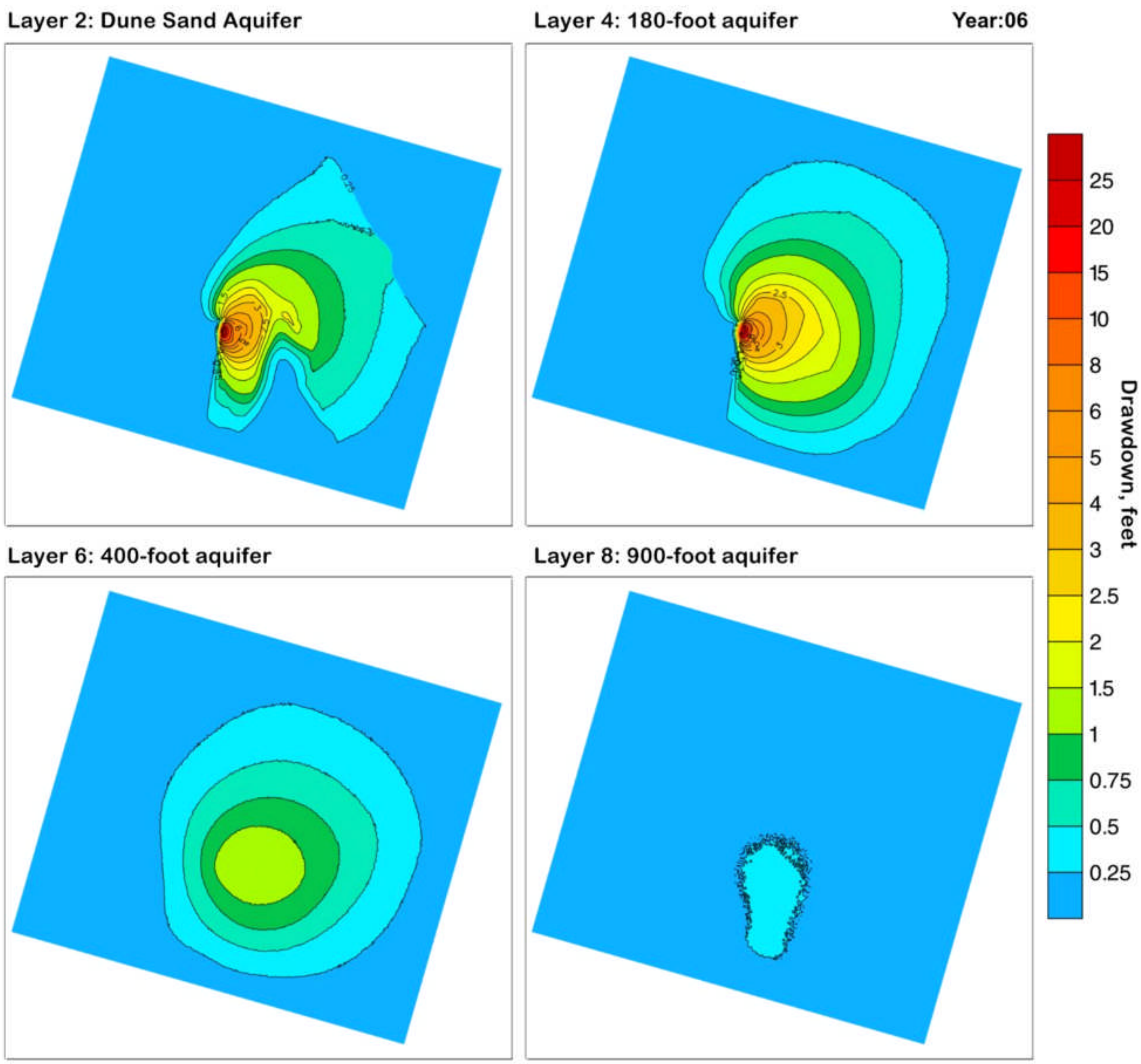
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario



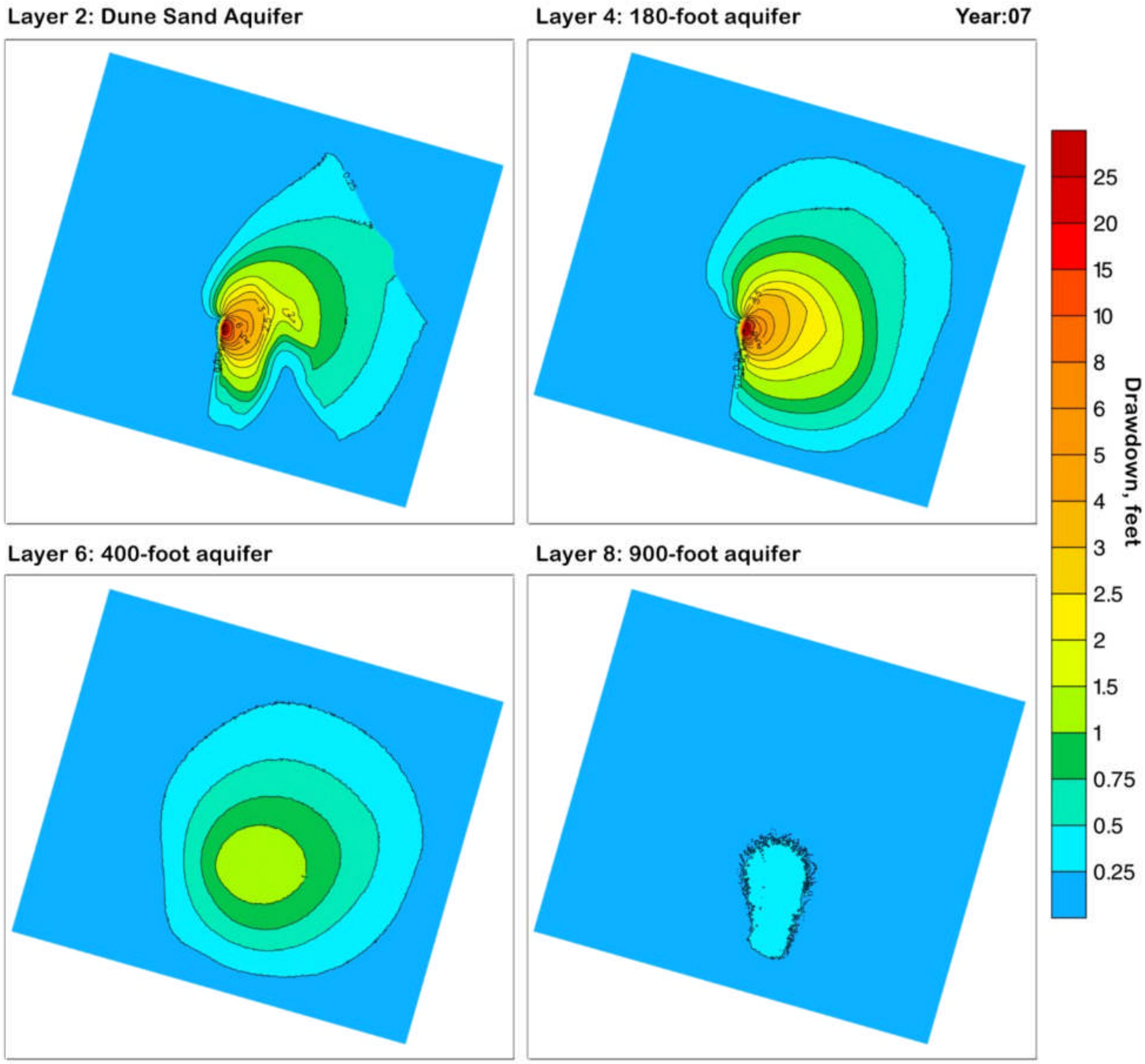

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:04
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25
Drawdown, feet

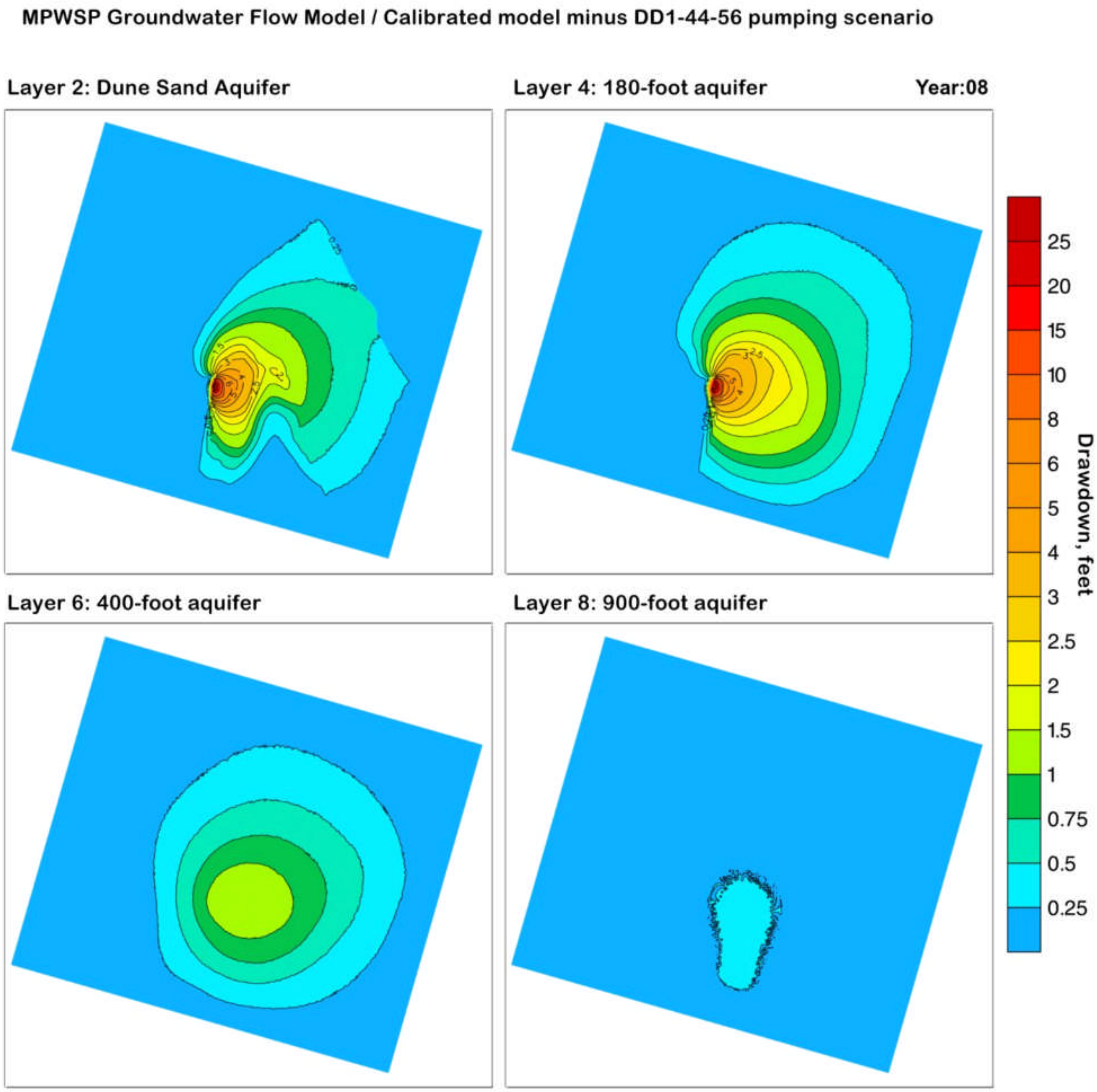

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:05
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario



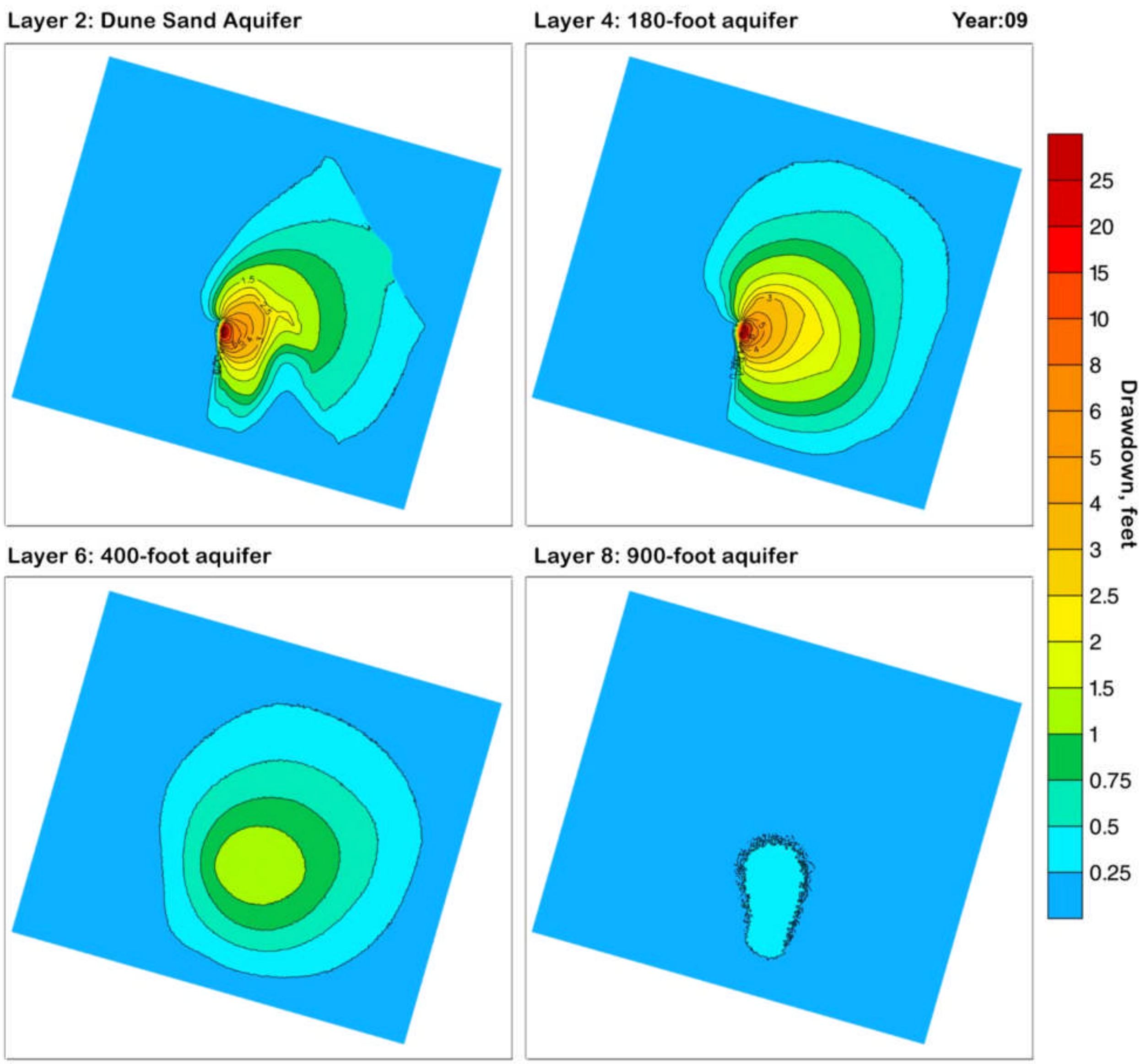
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario



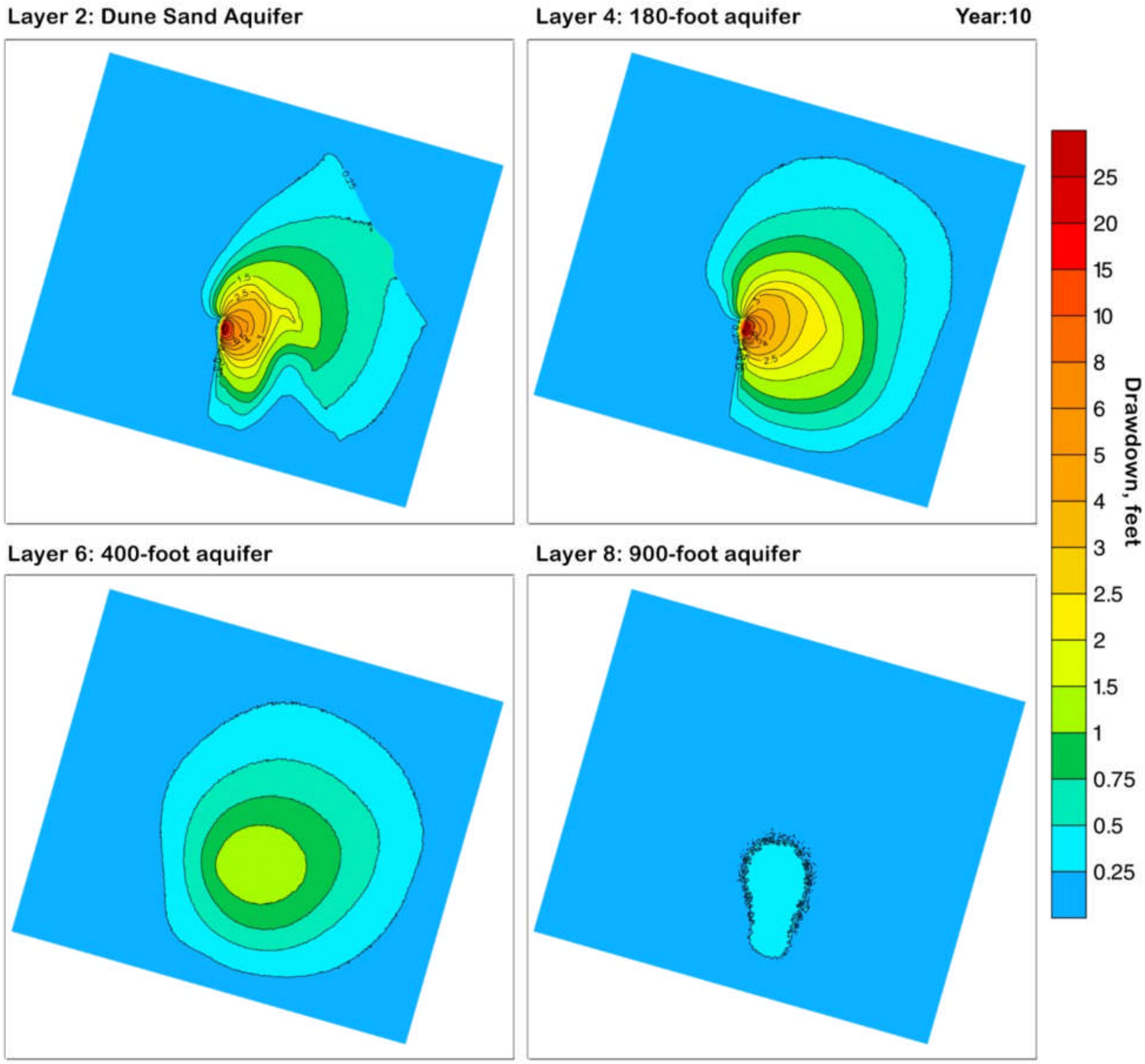


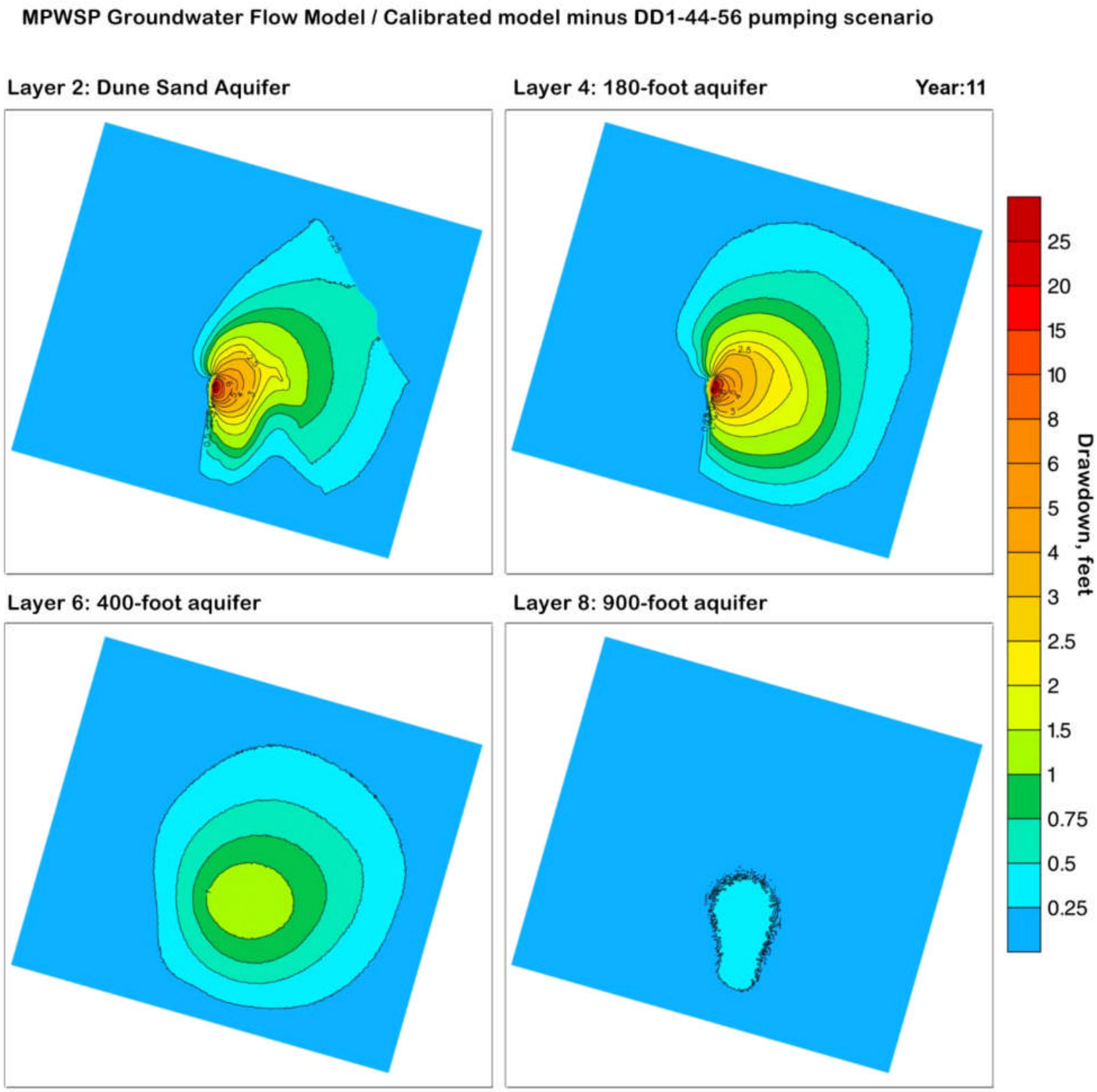
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:08
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario



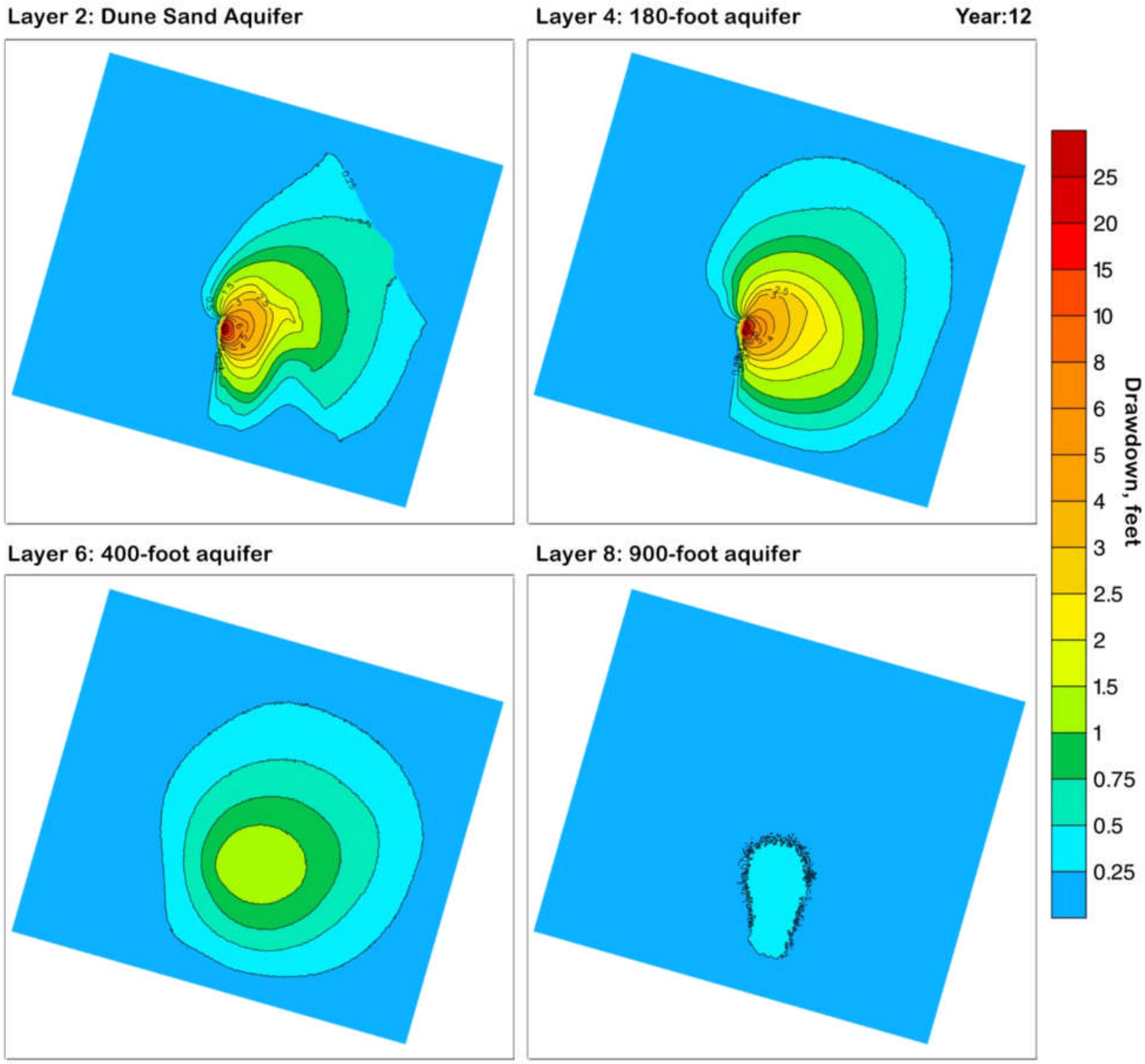
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario



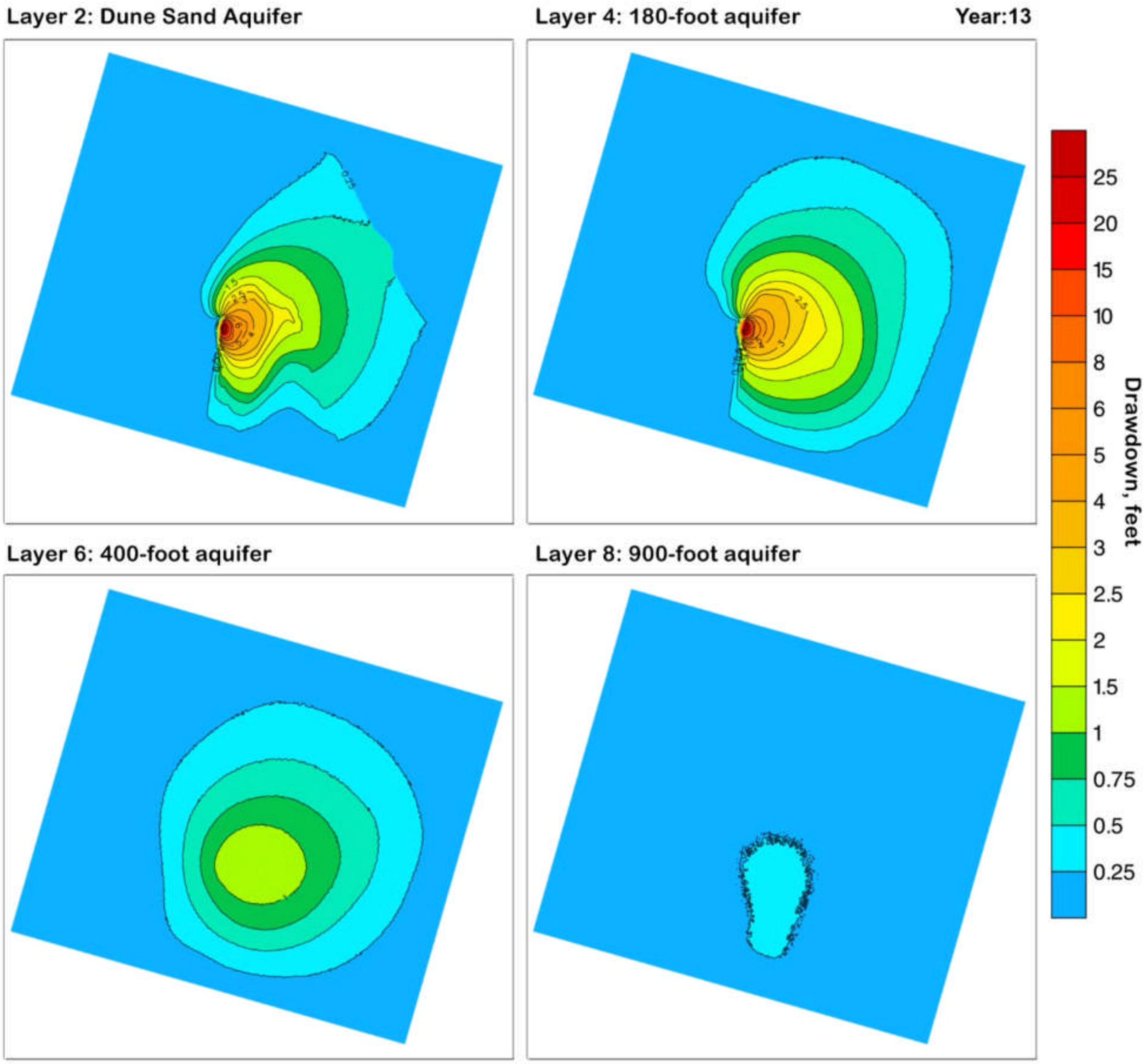


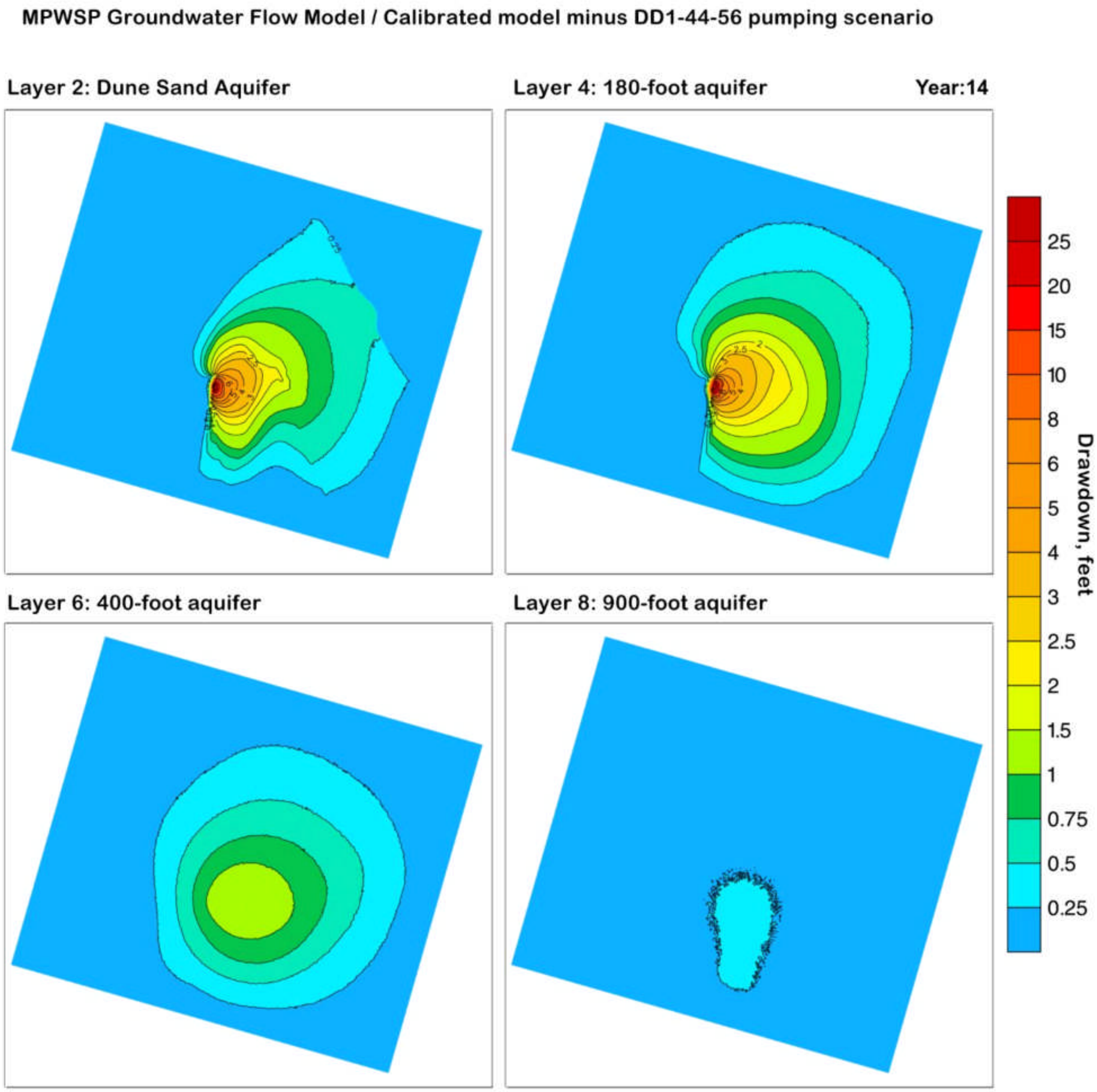
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:11
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario

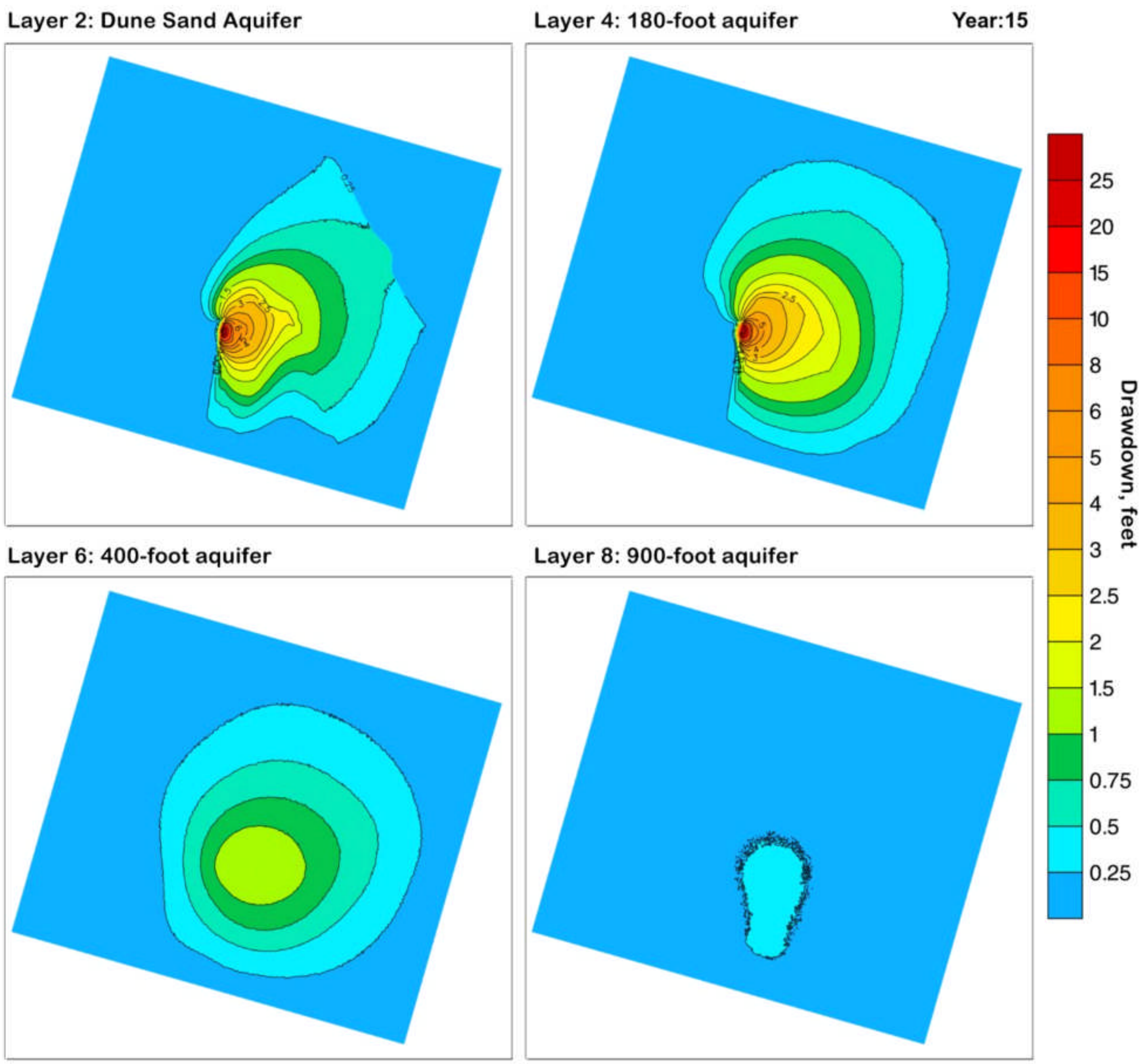


MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario

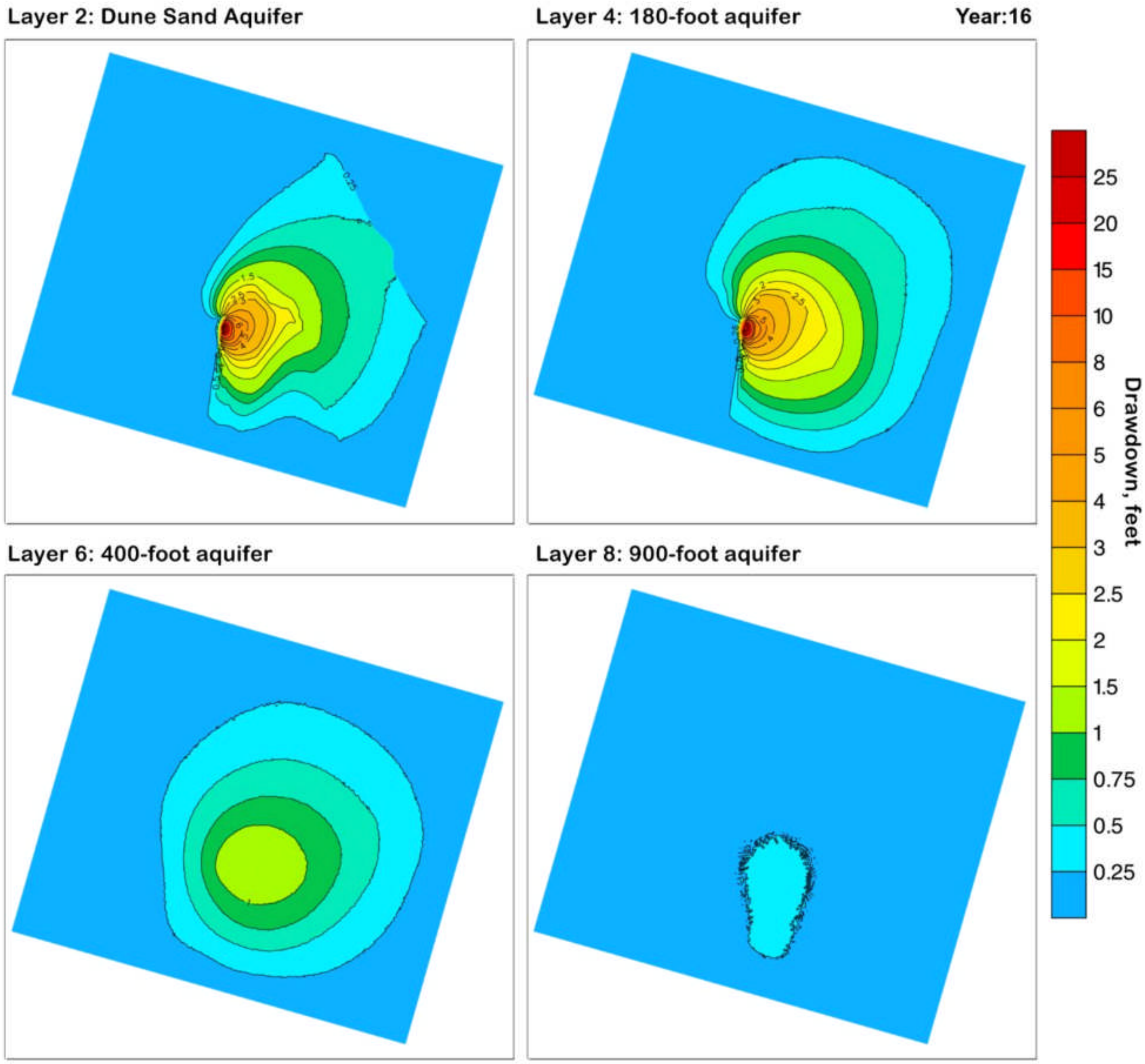


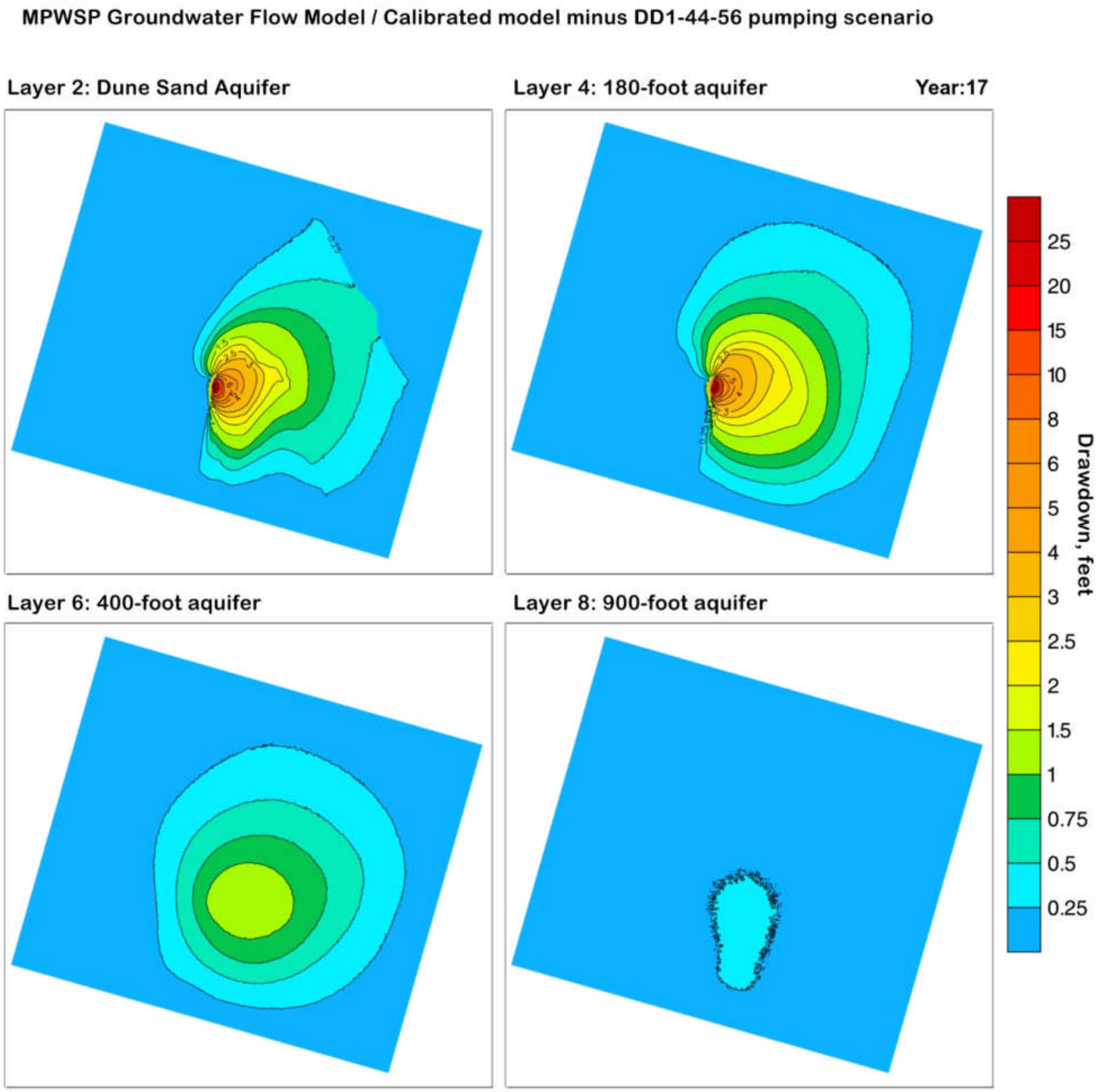

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:14
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario

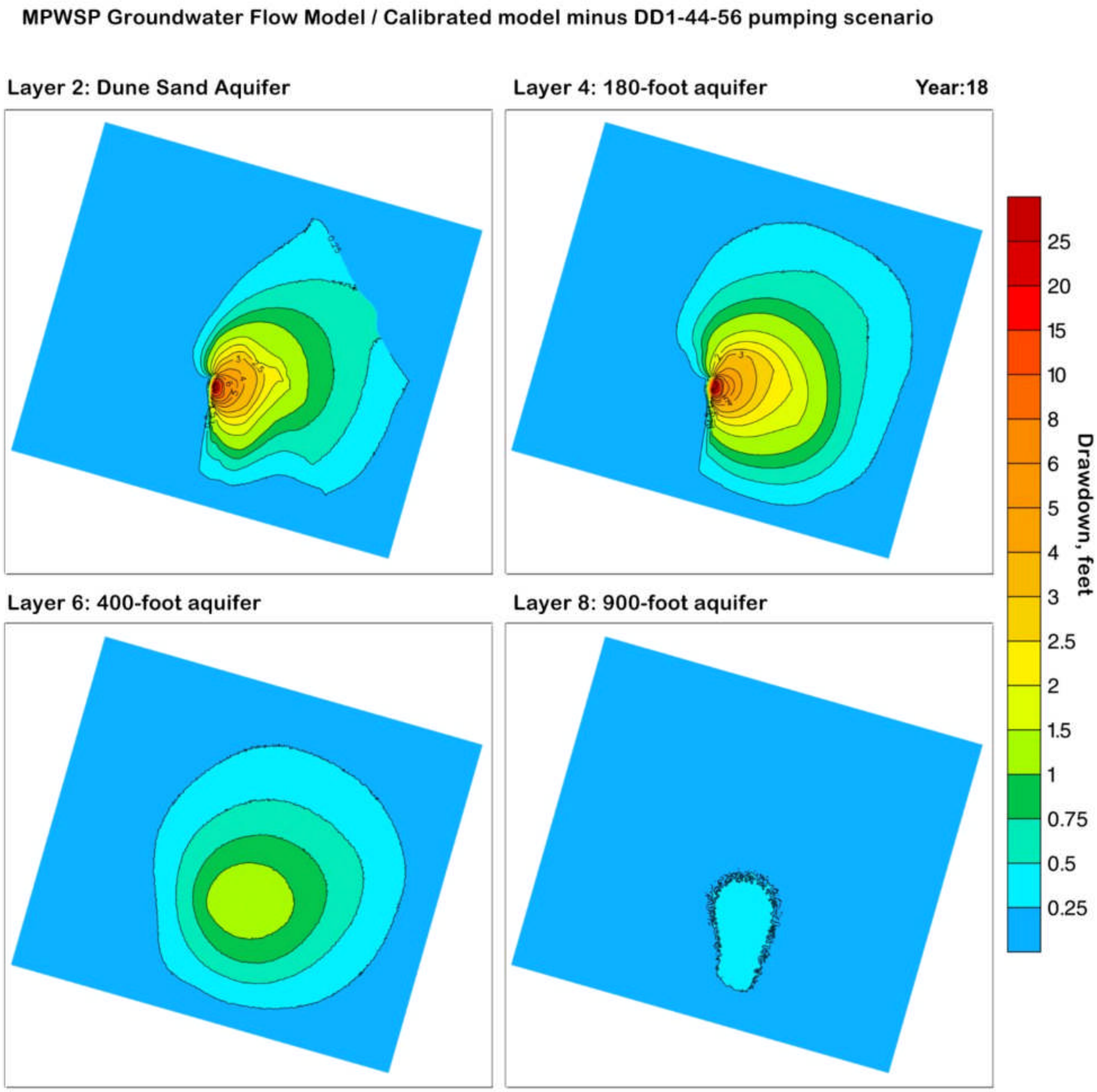


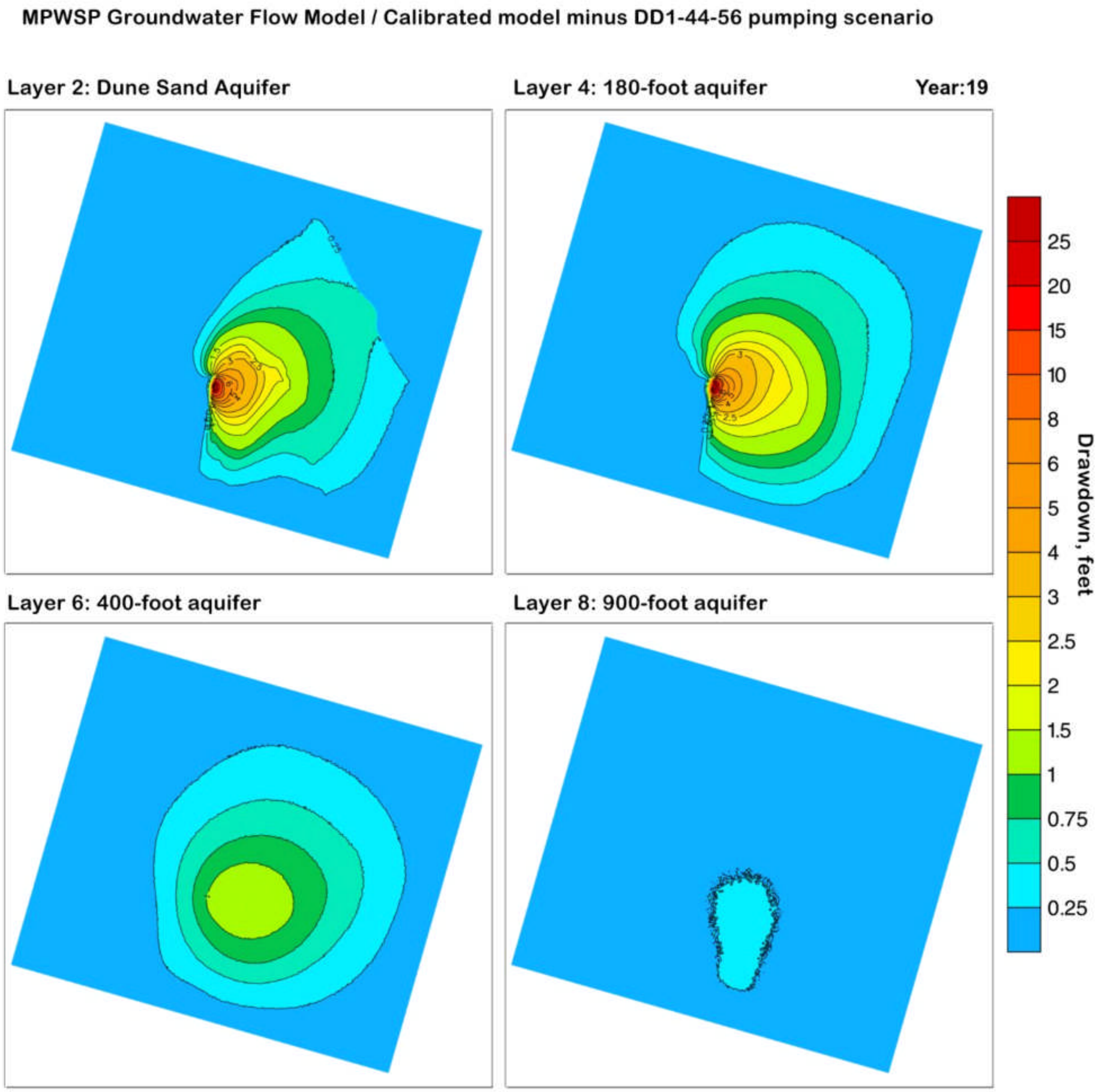
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario



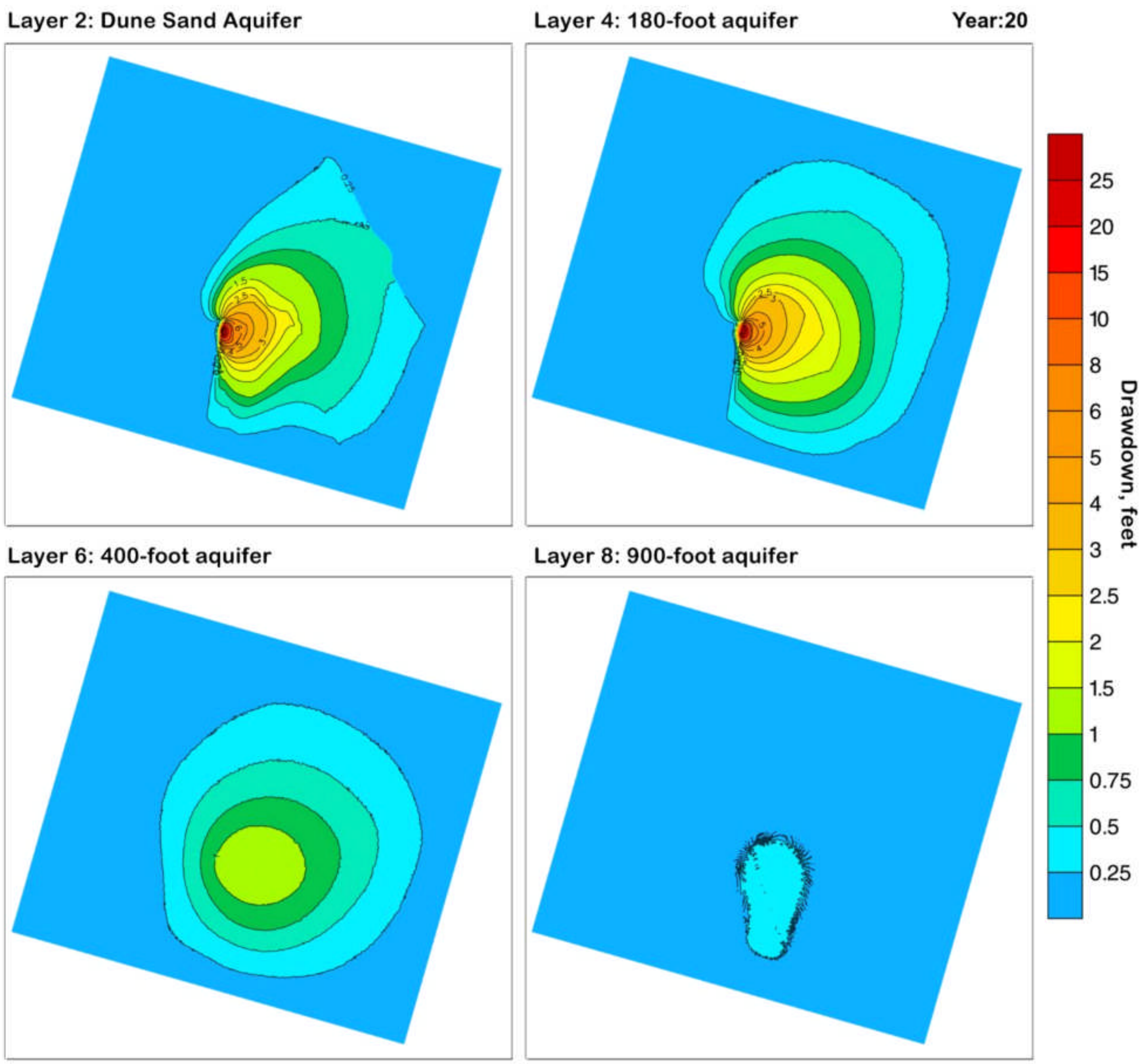


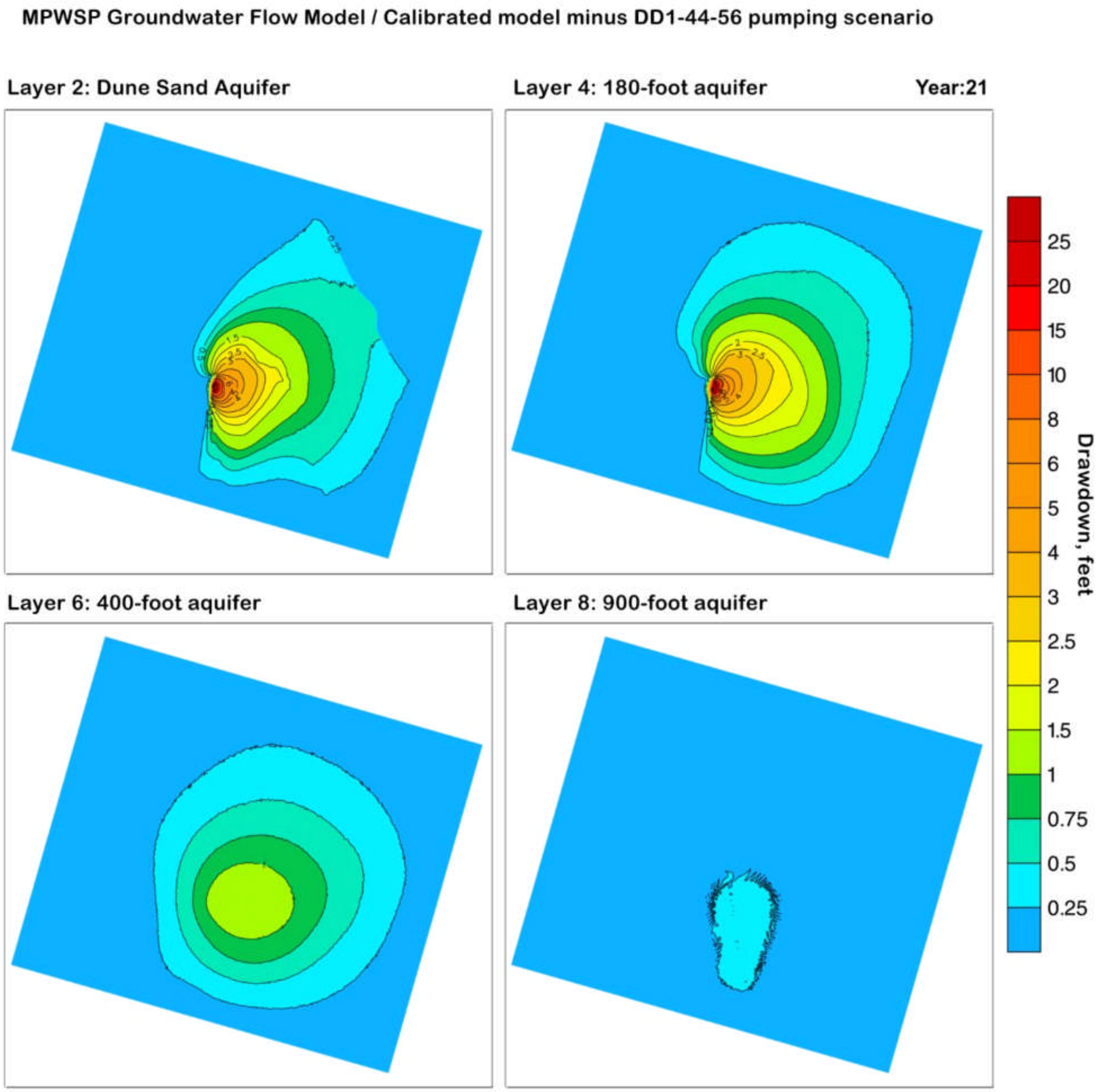
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:17
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25
Drawdown, feet


MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:18
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25

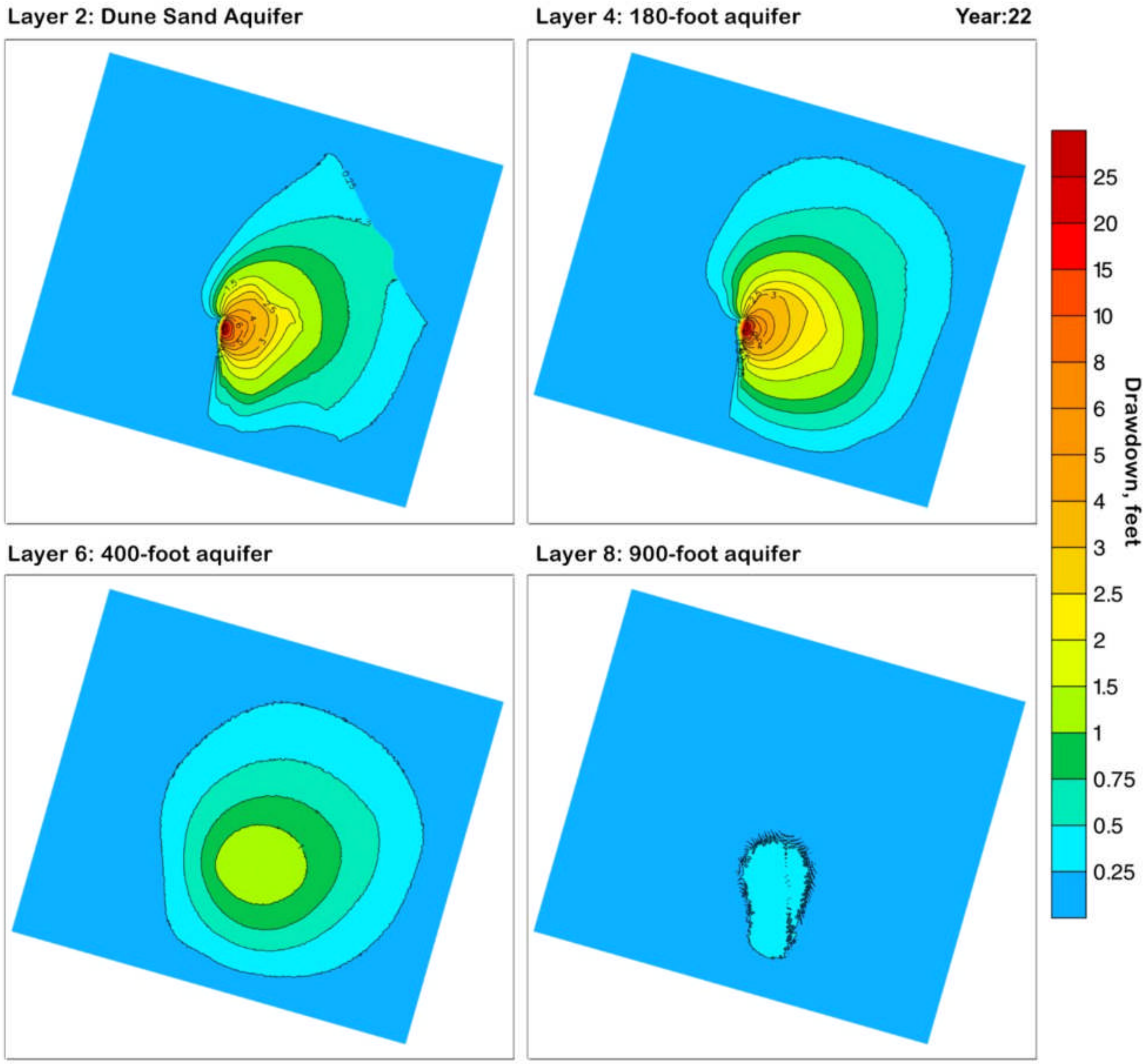

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:19
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario

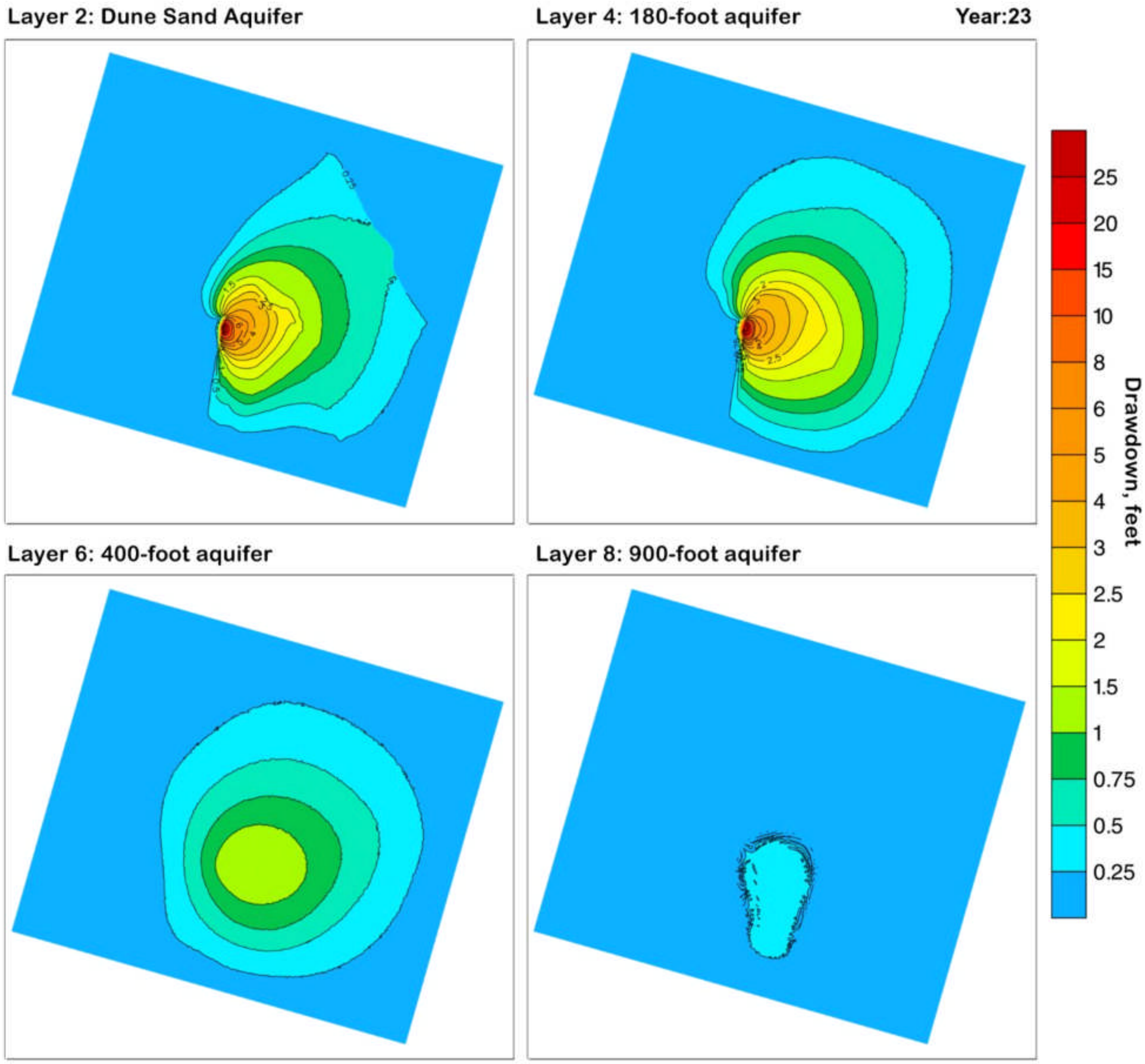



MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:21
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25

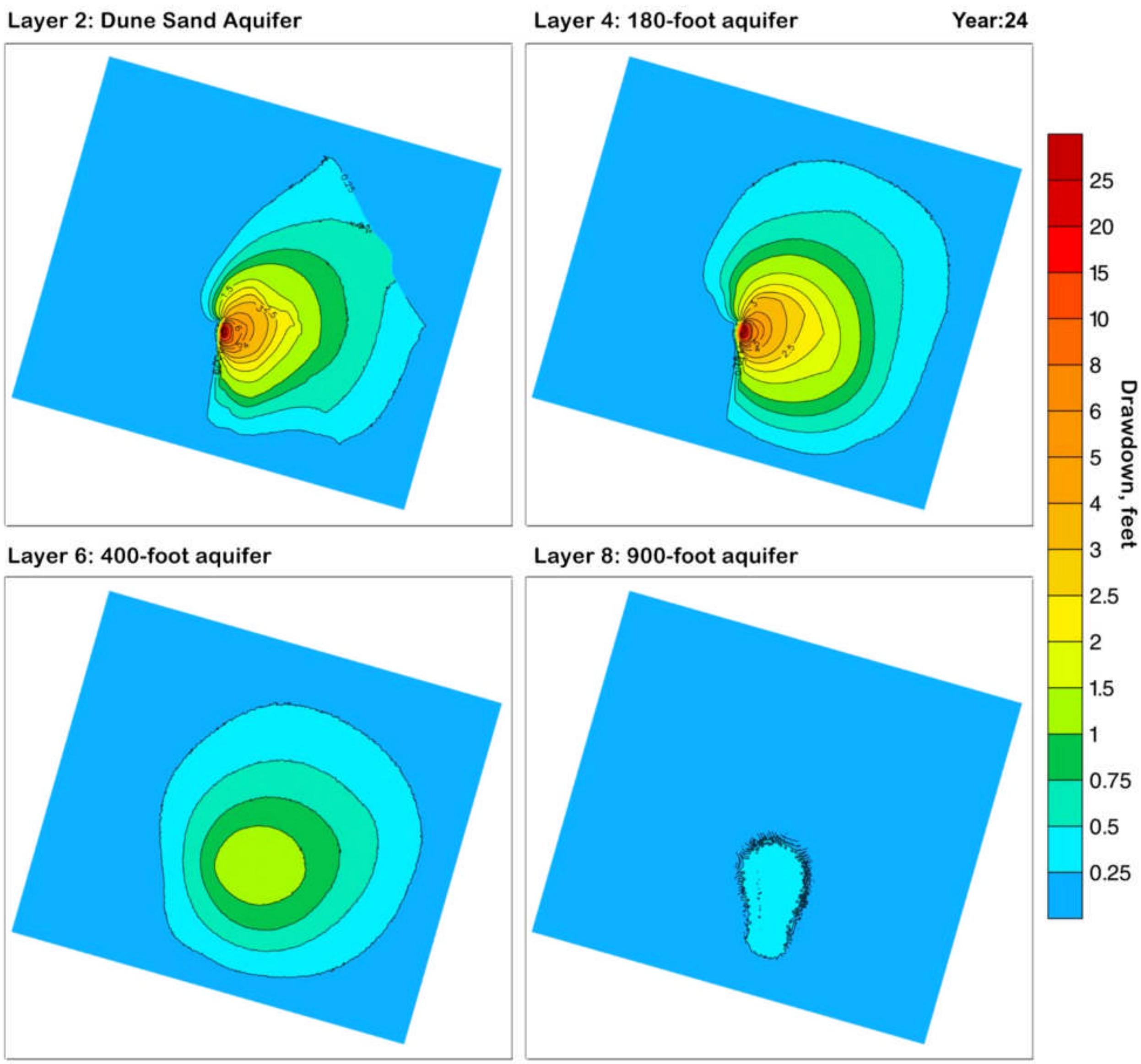
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario

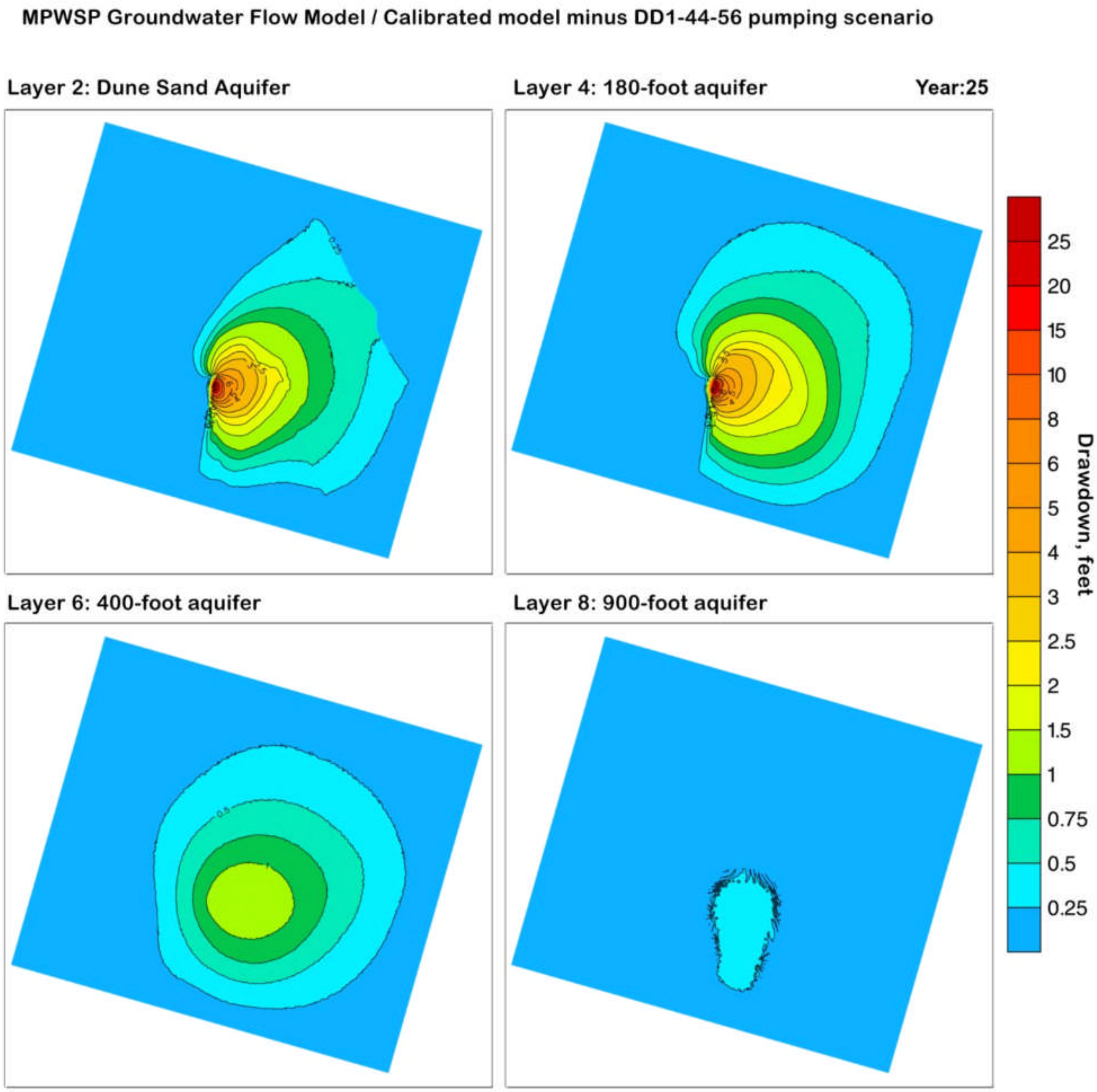


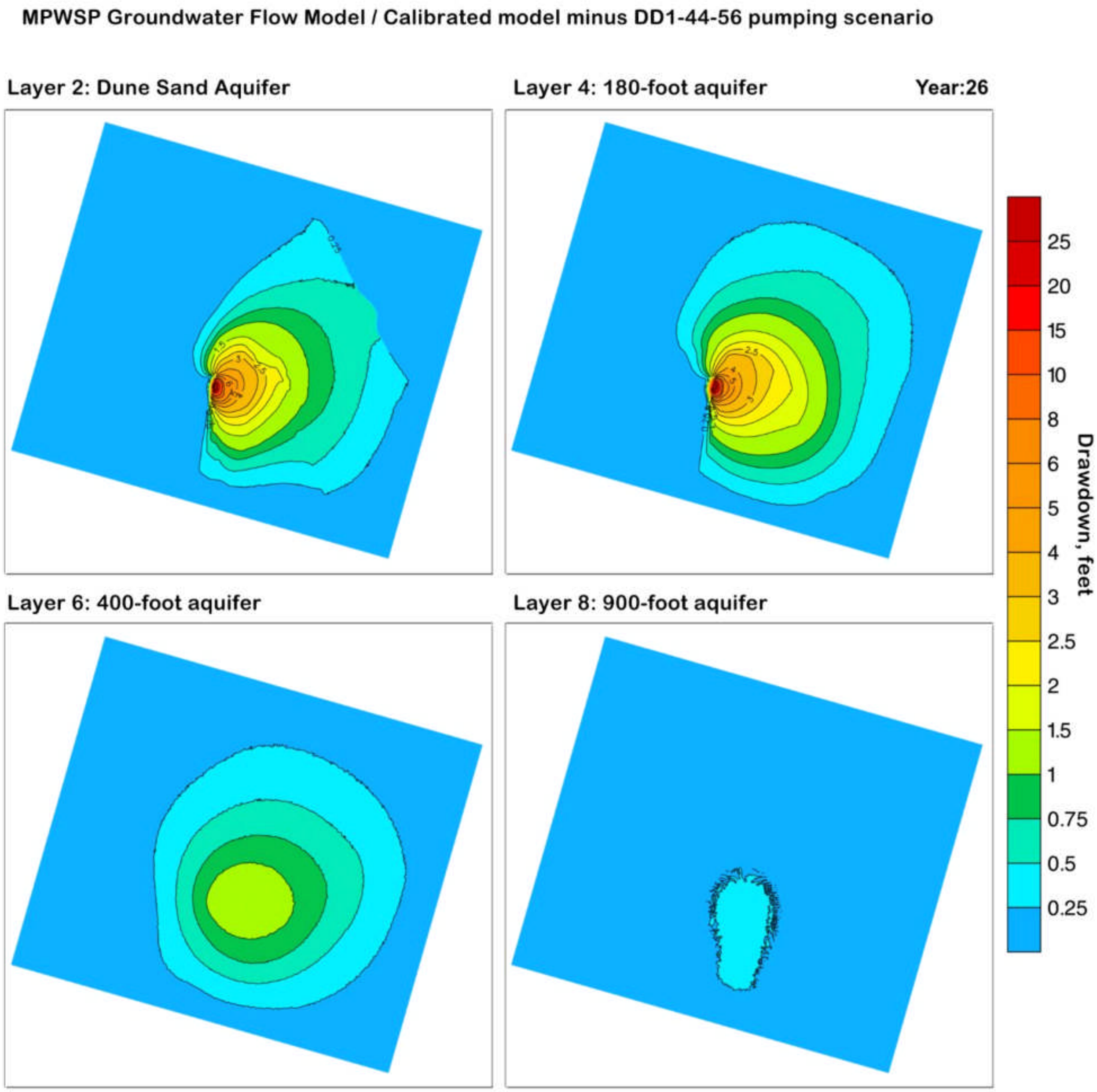
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario



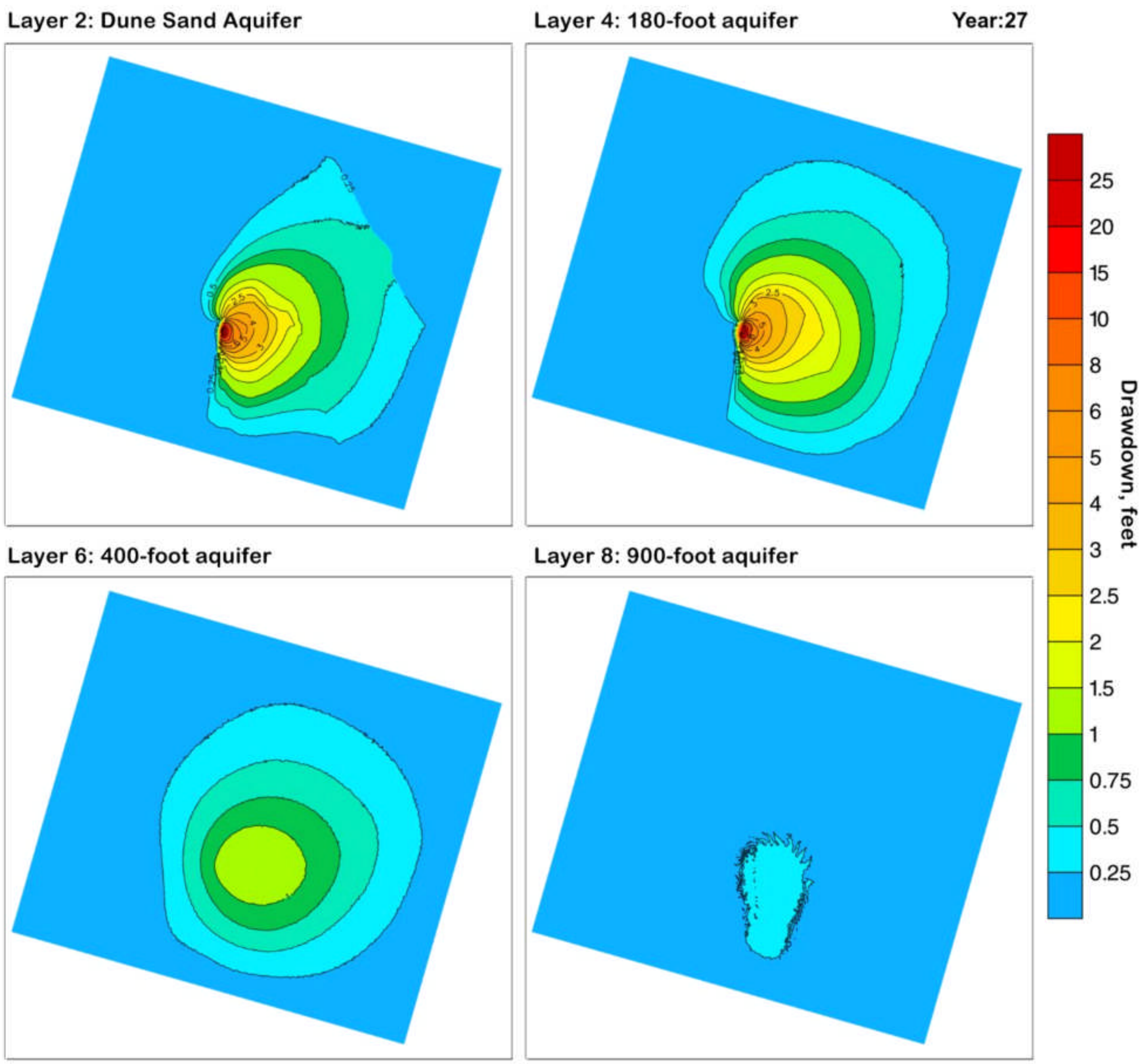
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario

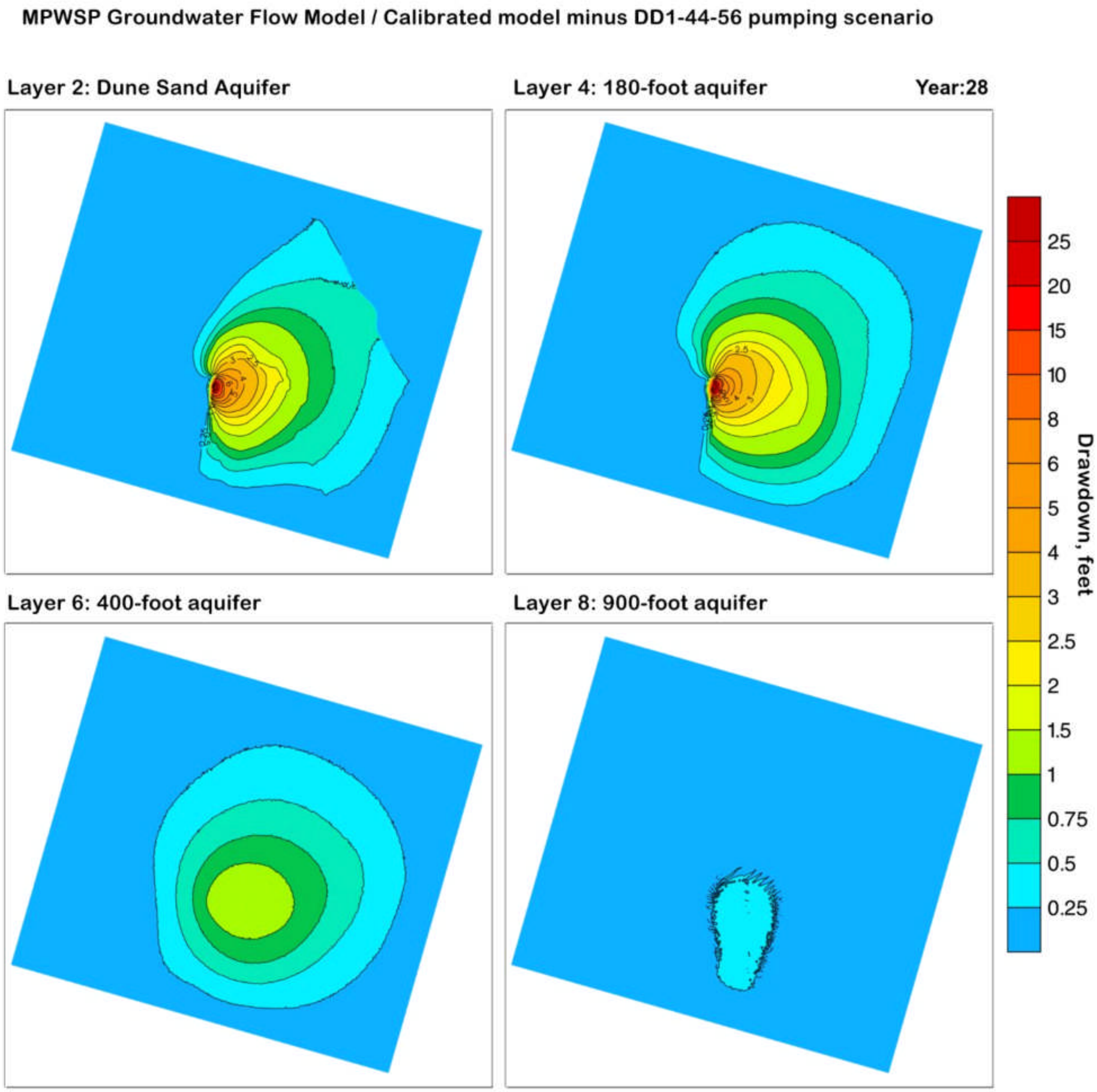


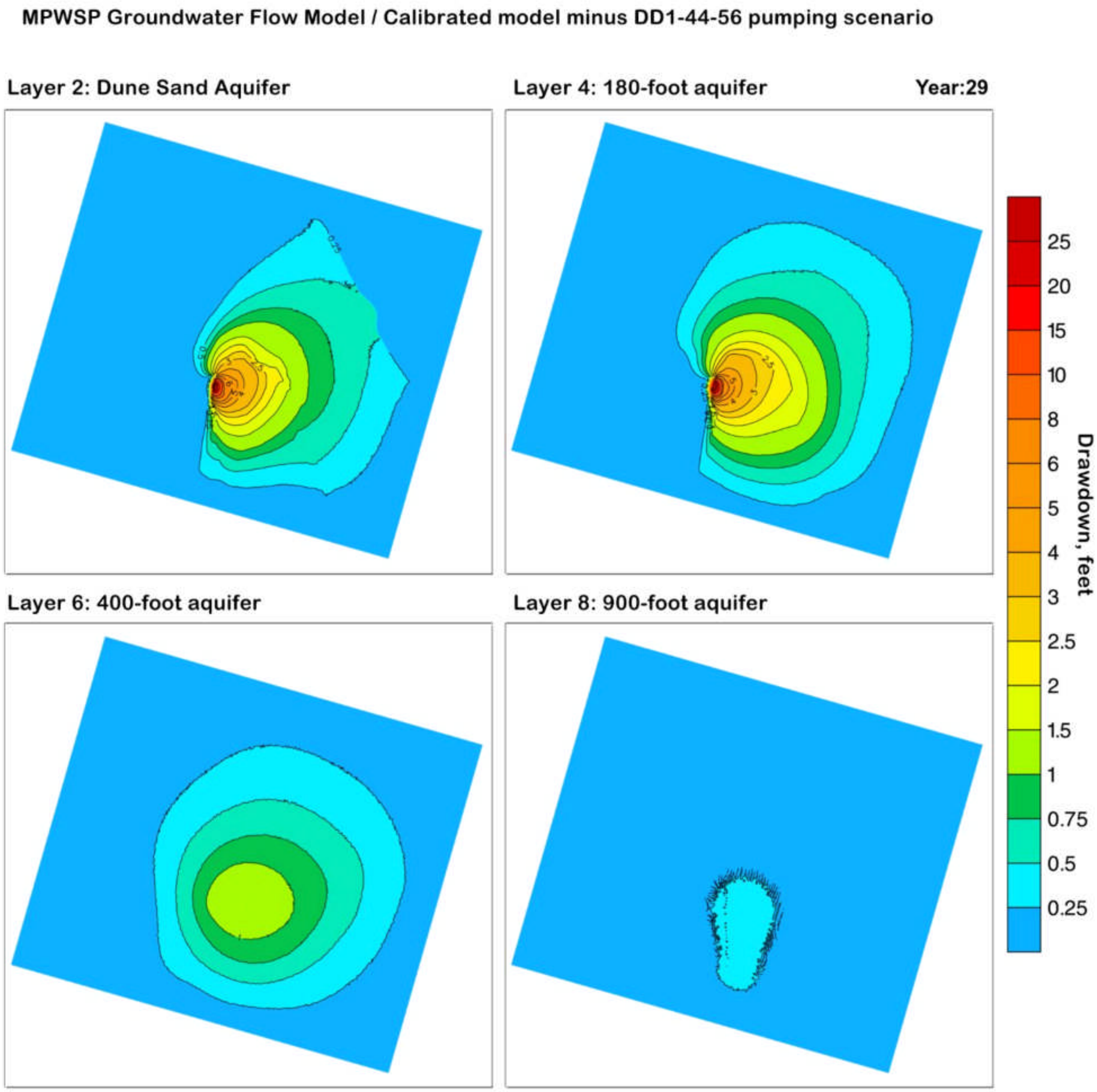

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:25
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25


MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:26
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25
Drawdown, feet

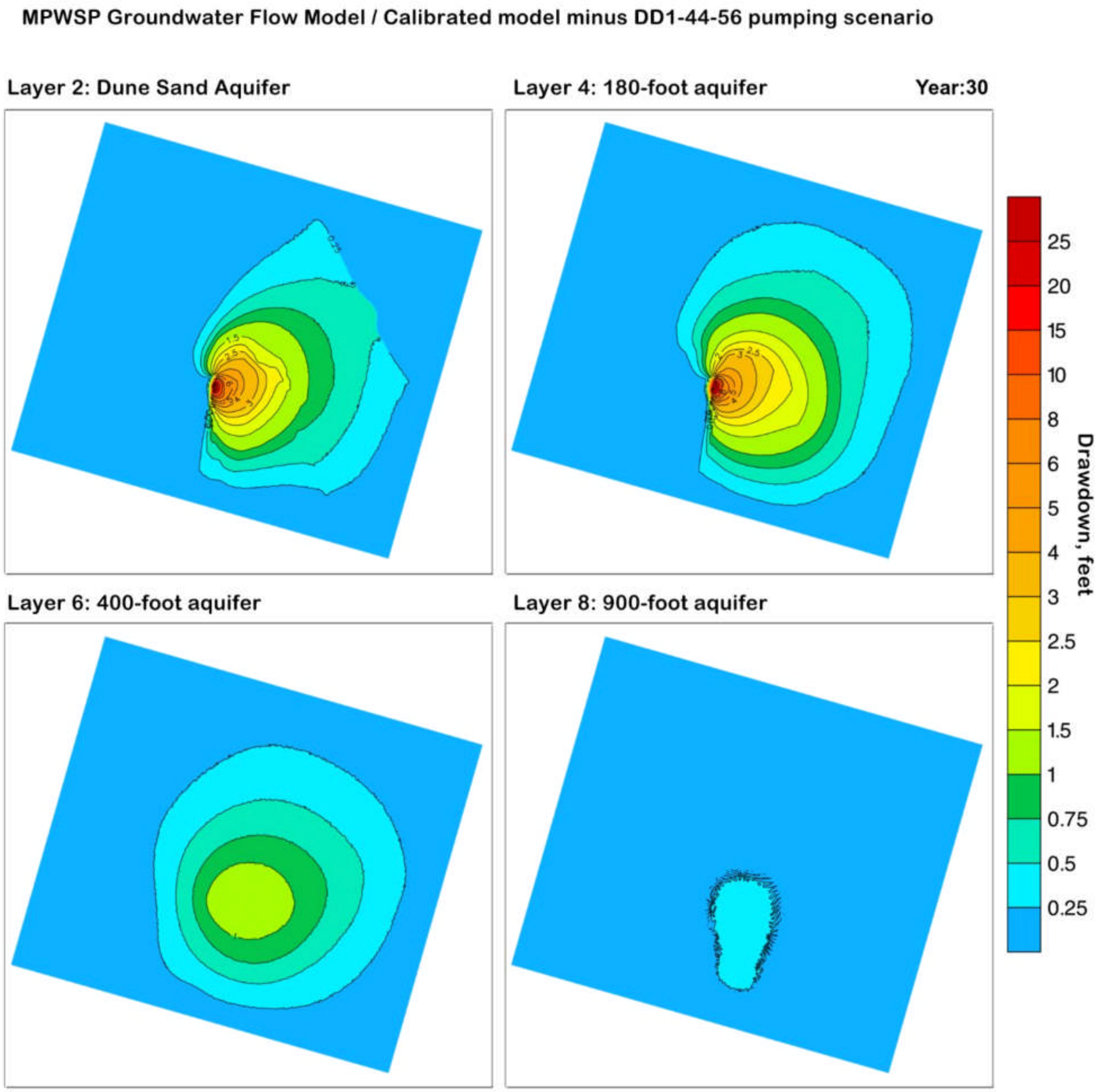
MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario



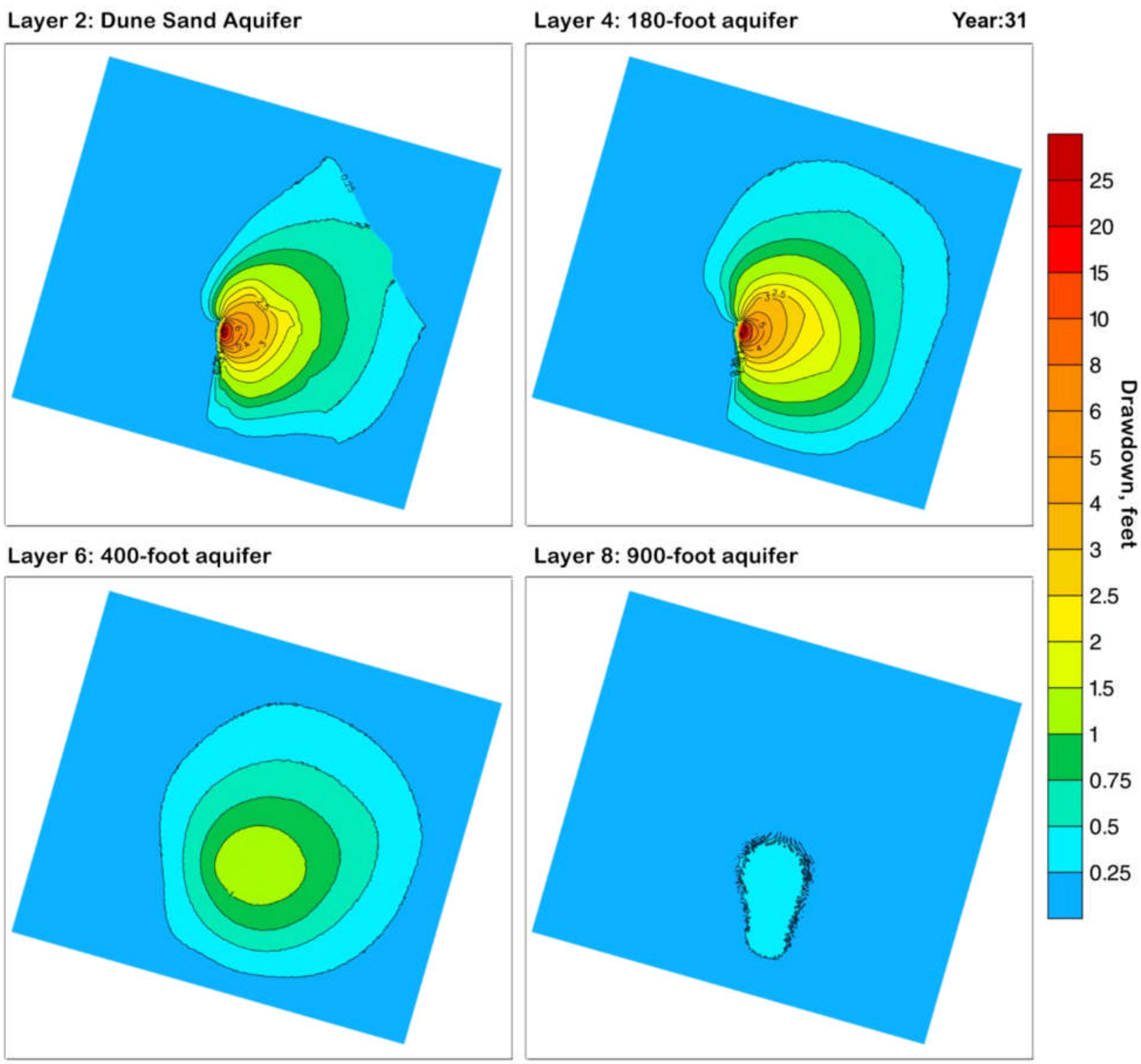

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:28
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25

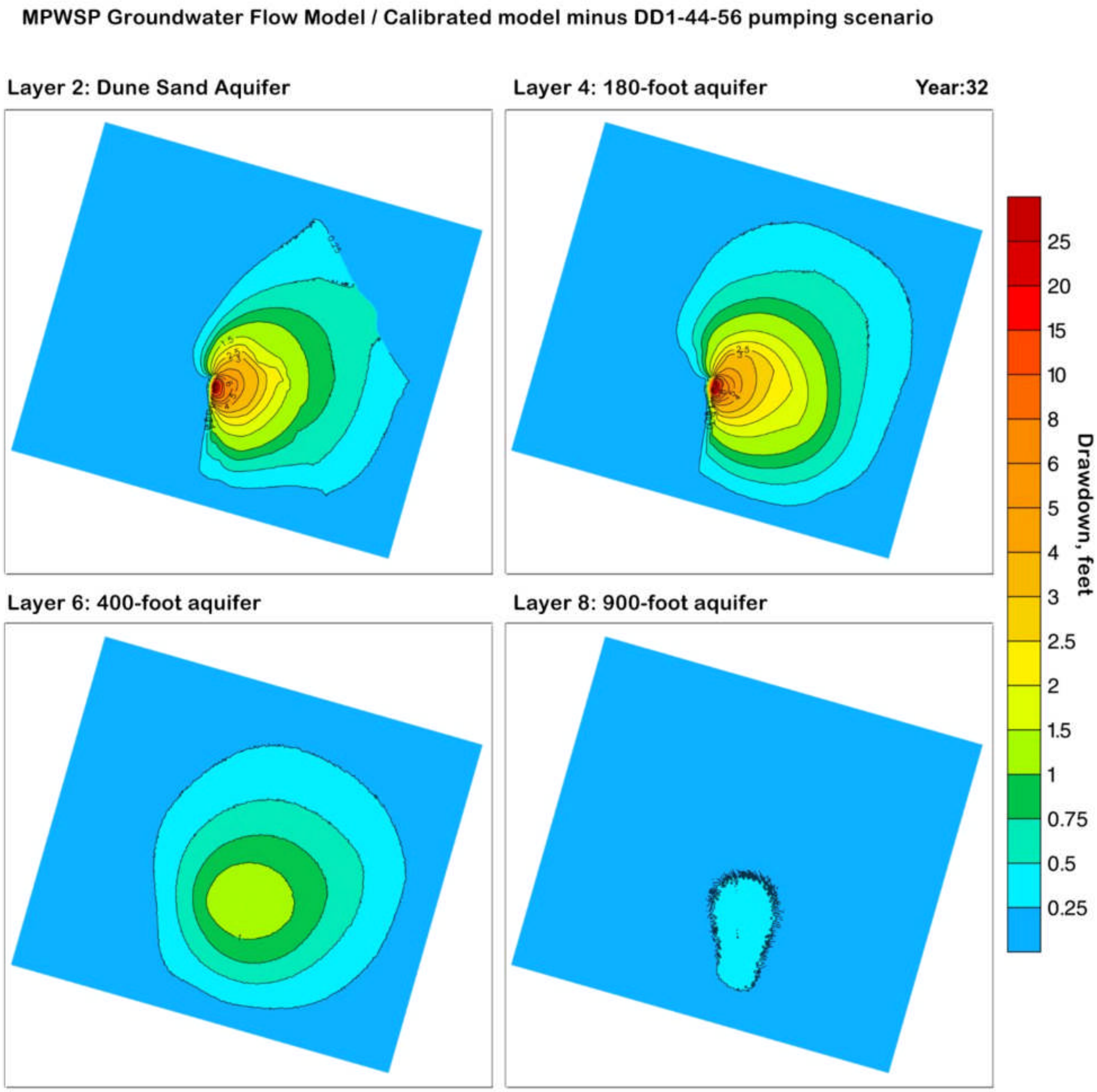


MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:29
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25


MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:30
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25

MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario





MPWSP Groundwater Flow Model / Calibrated model minus DD1-44-56 pumping scenario
Layer 2: Dune Sand Aquifer
Layer 4: 180-foot aquifer
Year:32
Layer 6: 400-foot aquifer
Layer 8: 900-foot aquifer
Drawdown, feet
25
20
15
10
8
6
5
4
3
2.5
2
1.5
1
0.75
0.5
0.25

Appendix 3
Water Budget Reports Exported from the Calibrated and DD1-44/56 Scenarios of the 2016 North Marina Groundwater Model

Timestep-01	Calibrated Scenario							
	Layer 1		Layer 2		Layer 3		Layer 4	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	0	0	285,362	-21,350,041	35,265	-813,813	47,404	-1,332,685
Constant Head	18,291,851	-252,152	522,346	-5,766	53,715	-2,102	52,810	-2,323
Wells	0	0	0	0	0	0	61,253	-273,653
Head Dep Bndys	0	0	8,585,979	-86,368	3,538	-2,534,304	1,076,366	-3,095,653
Recharge	0	0	2,293,857	-168,838	0	0	790,915	0
Total Source/Sink	18,291,851	-252,152	11,687,544	-21,611,012	92,518	-3,350,219	2,028,748	-4,704,314
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	252,152	-18,291,851	995,332	-9,058,885	931,571	-5,738,041	442,563	-2,552,887
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	0	0	18,291,851	-252,152	9,058,885	-995,332	5,738,041	-931,571
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	252,152	-18,291,851	19,287,183	-9,311,037	9,990,456	-6,733,373	6,180,604	-3,484,458
Total Zone Flow	18,544,003	-18,544,003	30,974,727	-30,922,049	10,082,975	-10,083,591	8,209,352	-8,188,772
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	18,039,699	195	-9,923,469	-60	-3,257,700	-189	-2,675,566	-79
Cell To Cell	-18,039,699	-195	9,976,146	70	3,257,084	39	2,696,146	56
Total	0	0	52,677	0	-617	0	20,579	0

Timestep-01	DD1-44/56 Scenario							
	Layer 1		Layer 2		Layer 3		Layer 4	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	0	0	803,292	-21,164,332	128,006	-772,231	69,247	-1,285,492
Constant Head	20,492,924	-226,834	522,420	-5,764	53,726	-2,100	52,823	-2,320
Wells	0	0	0	-1,417,549	0	0	61,253	-2,077,806
Head Dep Bndys	0	0	8,599,595	-86,142	3,573	-2,534,285	1,101,153	-3,075,884
Recharge	0	0	2,293,857	-168,838	0	0	790,915	0
Total Source/Sink	20,492,924	-226,834	12,219,164	-22,842,624	185,305	-3,308,617	2,075,390	-6,441,502
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	226,834	-20,492,924	1,132,123	-10,721,638	1,005,780	-7,470,415	458,584	-2,535,945
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	0	0	20,492,924	-226,834	10,721,638	-1,132,123	7,470,415	-1,005,780
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	226,834	-20,492,924	21,625,047	-10,948,472	11,727,418	-8,602,539	7,929,000	-3,541,725
Total Zone Flow	20,719,758	-20,719,758	33,844,211	-33,791,096	11,912,723	-11,911,156	10,004,390	-9,983,227
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	20,266,089	196	-10,623,460	-61	-3,123,312	-179	-4,366,112	-103
Cell To Cell	-20,266,089	-196	10,676,575	66	3,124,879	31	4,387,274	76
Total	0	0	53,115	0	1,568	0	21,162	0

Timestep-01	Calibrated Scenario							
	Layer 5		Layer 6		Layer 7		Layer 8	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	4,164	-28,249	2,732	-360,236	1,993	-58,716	63,599	-248,736
Constant Head	18,968	-2,021	848,797	-49,241	0	0	0	0
Wells	0	0	0	-1,049,332	0	0	0	-705,723
Head Dep Bndys	213,356	-27,647	1,431,812	-2,036,502	31,148	-103,923	400,874	-468,934
Recharge	0	0	0	0	0	0	0	0
Total Source/Sink	236,489	-57,917	2,283,341	-3,495,312	33,141	-162,639	464,473	-1,423,393
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	406,574	-2,699,485	215,709	-1,298,085	321,704	-1,280,043	0	0
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	2,552,887	-442,563	2,699,485	-406,574	1,298,085	-215,709	1,280,043	-321,704
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	2,959,461	-3,142,049	2,915,194	-1,704,659	1,619,789	-1,495,752	1,280,043	-321,704
Total Zone Flow	3,195,950	-3,199,966	5,198,535	-5,199,971	1,652,929	-1,658,391	1,744,517	-1,745,097
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	178,571	121	-1,211,970	-42	-129,499	-132	-958,920	-102
Cell To Cell	-182,588	-6	1,210,535	52	124,037	8	958,339	120
Total	-4,016	0	-1,436	0	-5,462	0	-581	0

Timestep-01	DD1-44/56 Scenario							
	Layer 5		Layer 6		Layer 7		Layer 8	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	4,690	-27,324	3,139	-353,924	2,165	-58,124	65,868	-247,197
Constant Head	18,970	-2,018	849,432	-49,152	0	0	0	0
Wells	0	0	0	-1,049,332	0	0	0	-705,723
Head Dep Bndys	213,455	-27,658	1,437,590	-2,029,932	31,113	-103,837	403,729	-465,453
Recharge	0	0	0	0	0	0	0	0
Total Source/Sink	237,116	-57,000	2,290,161	-3,482,340	33,278	-161,961	469,597	-1,418,373
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	417,110	-2,678,577	217,833	-1,288,926	324,081	-1,272,040	0	0
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	2,535,945	-458,584	2,678,577	-417,110	1,288,926	-217,833	1,272,040	-324,081
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	2,953,054	-3,137,161	2,896,410	-1,706,036	1,613,007	-1,489,873	1,272,040	-324,081
Total Zone Flow	3,190,170	-3,194,161	5,186,572	-5,188,376	1,646,286	-1,651,834	1,741,637	-1,742,454
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	180,116	122	-1,192,179	-41	-128,682	-132	-948,775	-101
Cell To Cell	-184,107	-6	1,190,375	52	123,134	8	947,959	119
Total	-3,991	0	-1,804	0	-5,548	0	-817	0

Timestep-12	Calibrated Scenario							
	Layer 1		Layer 2		Layer 3		Layer 4	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	0	0	666,724	-565,431	57,993	-56,347	24,418	-434,394
Constant Head	3,648,328	-1,182,875	256,953	-16,579	34,628	-3,777	33,904	-3,968
Wells	0	0	0	0	0	0	157,361	-1,110,258
Head Dep Bndys	0	0	3,872,397	-582,040	9,069	-1,507,699	1,901,715	-2,619,369
Recharge	0	0	2,503,451	-144,743	0	0	772,866	0
Total Source/Sink	3,648,328	-1,182,875	7,299,524	-1,308,793	101,690	-1,567,824	2,890,262	-4,167,989
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	1,182,875	-3,648,328	388,127	-8,853,283	308,312	-7,302,997	236,153	-5,936,700
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	0	0	3,648,328	-1,182,875	8,853,283	-388,127	7,302,997	-308,312
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	1,182,875	-3,648,328	4,036,455	-10,036,158	9,161,595	-7,691,124	7,539,150	-6,245,012
Total Zone Flow	4,831,203	-4,831,203	11,335,979	-11,344,952	9,263,285	-9,258,948	10,429,412	-10,413,001
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	2,465,453	102	5,990,731	139	-1,466,134	-176	-1,277,727	-36
Cell To Cell	-2,465,453	-102	-5,999,704	-85	1,470,471	17	1,294,138	19
Total	0	0	-8,972	0	4,337	0	16,412	0

Timestep-12	DD1-44/56 Scenario							
	Layer 1		Layer 2		Layer 3		Layer 4	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	0	0	703,712	-535,507	58,352	-54,804	24,509	-432,495
Constant Head	6,433,352	-1,101,044	257,094	-16,557	34,644	-3,770	33,921	-3,959
Wells	0	0	0	-1,417,549	0	0	157,361	-2,914,410
Head Dep Bndys	0	0	3,905,888	-566,265	9,173	-1,507,205	1,984,234	-2,546,840
Recharge	0	0	2,503,451	-144,743	0	0	772,866	0
Total Source/Sink	6,433,352	-1,101,044	7,370,145	-2,680,620	102,168	-1,565,778	2,972,891	-5,897,705
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	1,101,044	-6,433,352	680,702	-10,711,404	603,879	-9,166,663	247,487	-5,869,116
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	0	0	6,433,352	-1,101,044	10,711,404	-680,702	9,166,663	-603,879
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	1,101,044	-6,433,352	7,114,055	-11,812,447	11,315,283	-9,847,366	9,414,150	-6,472,995
Total Zone Flow	7,534,396	-7,534,396	14,484,199	-14,493,068	11,417,451	-11,413,144	12,387,041	-12,370,700
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	5,332,309	142	4,689,524	93	-1,463,610	-175	-2,924,814	-66
Cell To Cell	-5,332,309	-142	-4,698,393	-50	1,467,917	14	2,941,155	37
Total	0	0	-8,869	0	4,308	0	16,340	0

Timestep-12	Calibrated Scenario							
	Layer 5		Layer 6		Layer 7		Layer 8	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	129	-25,277	106	-258,109	12	-35,729	0	-373,154
Constant Head	14,700	-3,449	881,909	-56,255	0	0	0	0
Wells	0	0	0	-5,461,332	0	0	0	-1,992,236
Head Dep Bndys	384,273	-29,193	2,482,252	-2,085,848	57,918	-101,789	1,132,110	-216,082
Recharge	0	0	0	0	0	0	0	0
Total Source/Sink	399,101	-57,918	3,364,267	-7,861,543	57,930	-137,518	1,132,110	-2,581,472
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	245,632	-6,288,568	311,733	-1,859,550	400,058	-1,857,534	0	0
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	5,936,700	-236,153	6,288,568	-245,632	1,859,550	-311,733	1,857,534	-400,058
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	6,182,332	-6,524,721	6,600,301	-2,105,182	2,259,608	-2,169,267	1,857,534	-400,058
Total Zone Flow	6,581,433	-6,582,639	9,964,568	-9,966,726	2,317,538	-2,306,786	2,989,644	-2,981,530
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	341,183	149	-4,497,276	-80	-79,589	-81	-1,449,362	-78
Cell To Cell	-342,389	-5	4,495,119	103	90,341	4	1,457,476	129
Total	-1,206	0	-2,158	0	10,752	0	8,115	0

Timestep-12	DD1-44/56 Scenario							
	Layer 5		Layer 6		Layer 7		Layer 8	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	129	-25,238	106	-257,863	12	-35,706	0	-373,026
Constant Head	14,704	-3,438	884,556	-55,887	0	0	0	0
Wells	0	0	0	-5,461,332	0	0	0	-1,992,236
Head Dep Bndys	385,061	-29,190	2,509,147	-2,064,130	58,175	-101,311	1,151,768	-210,390
Recharge	0	0	0	0	0	0	0	0
Total Source/Sink	399,894	-57,866	3,393,808	-7,839,212	58,187	-137,017	1,151,768	-2,575,652
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	249,993	-6,214,853	320,048	-1,841,657	408,049	-1,840,066	0	0
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	5,869,116	-247,487	6,214,853	-249,993	1,841,657	-320,048	1,840,066	-408,049
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	6,119,109	-6,462,339	6,534,901	-2,091,650	2,249,706	-2,160,115	1,840,066	-408,049
Total Zone Flow	6,519,003	-6,520,205	9,928,710	-9,930,862	2,307,893	-2,297,132	2,991,834	-2,983,701
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	342,028	149	-4,445,404	-79	-78,830	-81	-1,423,884	-76
Cell To Cell	-343,230	-5	4,443,252	103	89,591	4	1,432,017	127
Total	-1,203	0	-2,152	0	10,761	0	8,134	0

Timestep-24	Calibrated Scenario							
	Layer 1		Layer 2		Layer 3		Layer 4	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	0	0	581,013	-576,166	31,736	-69,683	79,957	-476,477
Constant Head	3,741,203	-1,159,359	257,210	-16,554	34,662	-3,769	33,943	-3,958
Wells	0	0	0	0	0	0	457,842	-1,134,834
Head Dep Bndys	0	0	2,877,965	-1,077,859	13,683	-561,589	2,322,621	-2,969,355
Recharge	0	0	2,807,304	-143,631	0	0	738,605	0
Total Source/Sink	3,741,203	-1,159,359	6,523,492	-1,814,210	80,081	-635,042	3,632,969	-4,584,625
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	1,159,359	-3,741,203	374,180	-7,665,915	293,746	-7,031,153	236,223	-6,020,790
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	0	0	3,741,203	-1,159,359	7,665,915	-374,180	7,031,153	-293,746
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	1,159,359	-3,741,203	4,115,382	-8,825,274	7,959,661	-7,405,332	7,267,375	-6,314,536
Total Zone Flow	4,900,562	-4,900,562	10,638,874	-10,639,485	8,039,742	-8,040,374	10,900,344	-10,899,161
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	2,581,843	105	4,709,282	113	-554,961	-155	-951,656	-23
Cell To Cell	-2,581,843	-105	-4,709,892	-73	554,328	7	952,840	14
Total	0	0	-610	0	-632	0	1,183	0

Timestep-24	DD1-44/56 Scenario							
	Layer 1		Layer 2		Layer 3		Layer 4	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	0	0	593,706	-565,444	31,877	-69,226	80,029	-475,984
Constant Head	6,554,718	-1,083,217	257,361	-16,530	34,679	-3,760	33,962	-3,949
Wells	0	0	0	-1,417,548	0	0	457,842	-2,938,987
Head Dep Bndys	0	0	2,923,668	-1,068,598	13,855	-561,080	2,403,884	-2,884,928
Recharge	0	0	2,807,304	-143,631	0	0	738,605	0
Total Source/Sink	6,554,718	-1,083,217	6,582,040	-3,211,751	80,411	-634,067	3,714,321	-6,303,847
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	1,083,217	-6,554,718	669,317	-9,511,744	596,166	-8,885,527	247,353	-5,946,026
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	0	0	6,554,718	-1,083,217	9,511,744	-669,317	8,885,527	-596,166
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	1,083,217	-6,554,718	7,224,036	-10,594,960	10,107,910	-9,554,844	9,132,880	-6,542,192
Total Zone Flow	7,637,935	-7,637,935	13,806,076	-13,806,712	10,188,321	-10,188,911	12,847,202	-12,846,039
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	5,471,502	143	3,370,289	69	-553,656	-155	-2,589,526	-52
Cell To Cell	-5,471,502	-143	-3,370,925	-38	553,066	6	2,590,688	33
Total	0	0	-636	0	-590	0	1,163	0

Timestep-24	Calibrated Scenario							
	Layer 5		Layer 6		Layer 7		Layer 8	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	579	-25,723	281	-260,069	25	-37,193	0	-396,339
Constant Head	14,707	-3,438	891,586	-55,017	0	0	0	0
Wells	0	0	0	-5,579,112	0	0	0	-1,993,812
Head Dep Bndys	380,034	-30,583	2,519,733	-2,070,622	58,020	-112,020	1,164,608	-249,811
Recharge	0	0	0	0	0	0	0	0
Total Source/Sink	395,320	-59,743	3,411,600	-7,964,820	58,045	-149,213	1,164,608	-2,639,963
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	245,663	-6,369,127	324,061	-1,895,802	415,839	-1,893,929	0	0
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	6,020,790	-236,223	6,369,127	-245,663	1,895,802	-324,061	1,893,929	-415,839
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	6,266,453	-6,605,349	6,693,188	-2,141,465	2,311,642	-2,217,990	1,893,929	-415,839
Total Zone Flow	6,661,773	-6,665,092	10,104,788	-10,106,285	2,369,686	-2,367,202	3,058,537	-3,055,802
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	335,577	147	-4,553,220	-80	-91,168	-88	-1,475,355	-78
Cell To Cell	-338,896	-5	4,551,722	103	93,652	4	1,478,089	128
Total	-3,319	0	-1,497	0	2,484	0	2,734	0

Timestep-24	DD1-44/56 Scenario							
	Layer 5		Layer 6		Layer 7		Layer 8	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	579	-25,713	281	-260,003	25	-37,187	0	-396,309
Constant Head	14,712	-3,427	894,399	-54,630	0	0	0	0
Wells	0	0	0	-5,579,112	0	0	0	-1,993,812
Head Dep Bndys	380,913	-30,573	2,549,731	-2,046,884	58,295	-111,483	1,185,999	-244,062
Recharge	0	0	0	0	0	0	0	0
Total Source/Sink	396,205	-59,712	3,444,411	-7,940,630	58,320	-148,670	1,185,999	-2,634,184
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	249,832	-6,288,319	333,487	-1,877,250	424,862	-1,875,787	0	0
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	5,946,026	-247,353	6,288,319	-249,832	1,877,250	-333,487	1,875,787	-424,862
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	6,195,858	-6,535,672	6,621,806	-2,127,082	2,302,113	-2,209,273	1,875,787	-424,862
Total Zone Flow	6,592,062	-6,595,385	10,066,217	-10,067,712	2,360,432	-2,357,944	3,061,786	-3,059,046
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	336,492	148	-4,496,219	-79	-90,350	-87	-1,448,185	-76
Cell To Cell	-339,814	-5	4,494,723	103	92,839	4	1,450,924	126
Total	-3,322	0	-1,496	0	2,489	0	2,740	0

Timestep-120	Calibrated Scenario							
	Layer 1		Layer 2		Layer 3		Layer 4	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	0	0	97,372	-2,441,540	5,869	-218,374	1,722	-1,522,707
Constant Head	4,535,111	-934,634	259,734	-16,413	35,053	-3,723	34,401	-3,904
Wells	0	0	0	0	0	0	1,375,102	-596,273
Head Dep Bndys	0	0	16,952,122	-1,099,441	10,403	-6,467,503	2,454,062	-11,756,591
Recharge	0	0	3,656,579	-141,595	0	0	677,091	0
Total Source/Sink	4,535,111	-934,634	20,965,806	-3,698,989	51,324	-6,689,600	4,542,379	-13,879,475
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	934,634	-4,535,111	320,065	-21,162,596	262,003	-14,464,242	227,133	-5,094,727
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	0	0	4,535,111	-934,634	21,162,596	-320,065	14,464,242	-262,003
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	934,634	-4,535,111	4,855,176	-22,097,230	21,424,599	-14,784,307	14,691,375	-5,356,730
Total Zone Flow	5,469,745	-5,469,745	25,820,982	-25,796,219	21,475,924	-21,473,907	19,233,754	-19,236,205
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	3,600,476	132	17,266,817	140	-6,638,276	-197	-9,337,096	-101
Cell To Cell	-3,600,476	-132	-17,242,054	-128	6,640,292	37	9,334,645	93
Total	0	0	24,763	0	2,016	0	-2,451	0

Timestep-120	DD1-44/56 Scenario							
	Layer 1		Layer 2		Layer 3		Layer 4	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	0	0	98,887	-2,441,163	5,904	-218,414	1,722	-1,522,784
Constant Head	7,380,119	-880,592	259,890	-16,389	35,070	-3,714	34,421	-3,894
Wells	0	0	0	-1,417,549	0	0	1,375,102	-2,400,426
Head Dep Bndys	0	0	17,001,394	-1,090,385	10,572	-6,466,943	2,496,362	-11,627,057
Recharge	0	0	3,656,579	-141,595	0	0	677,091	0
Total Source/Sink	7,380,119	-880,592	21,016,749	-5,107,081	51,545	-6,689,071	4,584,698	-15,554,161
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	880,592	-7,380,119	604,879	-22,989,304	575,604	-16,320,497	238,874	-5,016,757
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	0	0	7,380,119	-880,592	22,989,304	-604,879	16,320,497	-575,604
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	880,592	-7,380,119	7,984,998	-23,869,896	23,564,909	-16,925,376	16,559,371	-5,592,361
Total Zone Flow	8,260,710	-8,260,710	29,001,747	-28,976,977	23,616,454	-23,614,447	21,144,070	-21,146,522
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	6,499,527	157	15,909,669	122	-6,637,525	-197	-10,969,462	-109
Cell To Cell	-6,499,527	-157	-15,884,899	-100	6,639,533	33	10,967,010	99
Total	0	0	24,770	0	2,007	0	-2,452	0

Timestep-120	Calibrated Scenario							
	Layer 5		Layer 6		Layer 7		Layer 8	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	18	-71,762	67	-704,956	7	-113,477	0	-1,415,491
Constant Head	14,778	-3,382	1,027,847	-40,939	0	0	0	0
Wells	0	0	0	-2,796,903	0	0	0	-996,753
Head Dep Bndys	274,740	-30,821	2,384,892	-2,440,057	118,583	-62,425	961,802	-953,995
Recharge	0	0	0	0	0	0	0	0
Total Source/Sink	289,535	-105,966	3,412,806	-5,982,856	118,590	-175,902	961,802	-3,366,238
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	237,979	-5,287,175	49,855	-2,525,109	99,227	-2,508,550	0	0
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	5,094,727	-227,133	5,287,175	-237,979	2,525,109	-49,855	2,508,550	-99,227
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	5,332,706	-5,514,308	5,337,030	-2,763,088	2,624,337	-2,558,405	2,508,550	-99,227
Total Zone Flow	5,622,241	-5,620,274	8,749,835	-8,745,944	2,742,926	-2,734,306	3,470,352	-3,465,466
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	183,570	93	-2,570,050	-55	-57,312	-39	-2,404,437	-111
Cell To Cell	-181,602	-3	2,573,942	64	65,932	3	2,409,323	185
Total	1,968	0	3,891	0	8,620	0	4,886	0

Timestep-120	DD1-44/56 Scenario							
	Layer 5		Layer 6		Layer 7		Layer 8	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	18	-71,764	67	-704,963	7	-113,478	0	-1,415,496
Constant Head	14,783	-3,371	1,030,841	-40,637	0	0	0	0
Wells	0	0	0	-2,796,903	0	0	0	-996,753
Head Dep Bndys	275,641	-30,782	2,412,076	-2,410,733	119,018	-62,004	977,619	-941,692
Recharge	0	0	0	0	0	0	0	0
Total Source/Sink	290,442	-105,917	3,442,984	-5,953,236	119,025	-175,482	977,619	-3,353,941
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	242,950	-5,203,395	51,015	-2,497,321	101,347	-2,482,570	0	0
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	5,016,757	-238,874	5,203,395	-242,950	2,497,321	-51,015	2,482,570	-101,347
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	5,259,707	-5,442,270	5,254,411	-2,740,271	2,598,668	-2,533,585	2,482,570	-101,347
Total Zone Flow	5,550,149	-5,548,187	8,697,395	-8,693,507	2,717,693	-2,709,067	3,460,189	-3,455,288
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	184,525	93	-2,510,252	-53	-56,457	-38	-2,376,322	-110
Cell To Cell	-182,563	-3	2,514,140	63	65,083	3	2,381,223	184
Total	1,962	0	3,888	0	8,626	0	4,901	0

Timestep-Final	Calibrated Scenario							
	Layer 1		Layer 2		Layer 3		Layer 4	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	0	0	1,493,643	-75,099	105,683	-741	150,264	-2,274
Constant Head	3,067,336	-1,562,586	254,395	-16,584	34,260	-3,775	33,478	-3,966
Wells	0	0	0	0	0	0	448,919	-2,615,651
Head Dep Bndys	0	0	2,691,823	-2,734,378	19,185	-210,247	3,958,045	-3,046,621
Recharge	0	0	3,659,107	-170,568	0	0	1,157,863	0
Total Source/Sink	3,067,336	-1,562,586	8,098,968	-2,996,628	159,128	-214,764	5,748,568	-5,668,512
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	1,562,586	-3,067,336	499,346	-7,110,039	402,314	-6,959,091	225,908	-6,868,378
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	0	0	3,067,336	-1,562,586	7,110,039	-499,346	6,959,091	-402,314
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	1,562,586	-3,067,336	3,566,682	-8,672,626	7,512,353	-7,458,437	7,184,999	-7,270,692
Total Zone Flow	4,629,922	-4,629,922	11,665,650	-11,669,254	7,671,481	-7,673,201	12,933,567	-12,939,204
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	1,504,749	65	5,102,340	92	-55,636	-30	80,056	1
Cell To Cell	-1,504,749	-65	-5,105,944	-83	53,916	1	-85,693	-1
Total	0	0	-3,604	0	-1,720	0	-5,637	0

Timestep-Final	DD1-44/56 Scenario							
	Layer 1		Layer 2		Layer 3		Layer 4	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	0	0	1,492,812	-75,062	105,440	-748	150,152	-2,285
Constant Head	5,801,528	-1,395,636	254,551	-16,559	34,277	-3,767	33,497	-3,956
Wells	0	0	0	-1,417,549	0	0	448,919	-4,419,804
Head Dep Bndys	0	0	2,717,696	-2,701,592	19,416	-209,732	4,068,866	-2,985,210
Recharge	0	0	3,659,107	-170,568	0	0	1,157,863	0
Total Source/Sink	5,801,528	-1,395,636	8,124,166	-4,381,329	159,133	-214,247	5,859,296	-7,411,255
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	1,395,636	-5,801,528	790,116	-8,942,457	687,304	-8,786,232	235,751	-6,788,329
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	0	0	5,801,528	-1,395,636	8,942,457	-790,116	8,786,232	-687,304
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	1,395,636	-5,801,528	6,591,645	-10,338,093	9,629,761	-9,576,348	9,021,982	-7,475,633
Total Zone Flow	7,197,165	-7,197,165	14,715,811	-14,719,421	9,788,894	-9,790,595	14,881,279	-14,886,889
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	4,405,892	122	3,742,837	60	-55,114	-30	-1,551,959	-23
Cell To Cell	-4,405,892	-122	-3,746,448	-44	53,413	1	1,546,349	19
Total	0	0	-3,611	0	-1,701	0	-5,610	0

Timestep-Final	Calibrated Scenario							
	Layer 5		Layer 6		Layer 7		Layer 8	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	8,146	-46	72,198	-55	7,499	-4	45,401	-8
Constant Head	14,633	-3,442	781,988	-69,137	0	0	0	0
Wells	0	0	0	-8,394,231	0	0	0	-105,375
Head Dep Bndys	471,534	-30,619	4,228,025	-3,286,935	77,969	-152,026	830,881	-1,156,039
Recharge	0	0	0	0	0	0	0	0
Total Source/Sink	494,313	-34,107	5,082,211	-11,750,358	85,468	-152,030	876,282	-1,261,422
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	235,117	-7,342,435	669,878	-1,113,133	744,701	-1,128,194	0	0
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	6,868,378	-225,908	7,342,435	-235,117	1,113,133	-669,878	1,128,194	-744,701
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	7,103,495	-7,568,343	8,012,313	-1,348,250	1,857,834	-1,798,072	1,128,194	-744,701
Total Zone Flow	7,597,808	-7,602,450	13,094,525	-13,098,608	1,943,302	-1,950,102	2,004,476	-2,006,123
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	460,206	174	-6,668,147	-79	-66,561	-56	-385,141	-36
Cell To Cell	-464,848	-6	6,664,063	142	59,761	3	383,493	41
Total	-4,642	0	-4,084	0	-6,800	0	-1,647	0

Timestep-Final	DD1-44/56 Scenario							
	Layer 5		Layer 6		Layer 7		Layer 8	
Sources/Sinks	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out	Flow In	Flow Out
Storage	8,143	-46	72,184	-55	7,497	-4	45,387	-8
Constant Head	14,638	-3,431	784,801	-68,649	0	0	0	0
Wells	0	0	0	-8,394,231	0	0	0	-105,375
Head Dep Bndys	472,454	-30,576	4,262,666	-3,264,912	78,328	-151,517	841,325	-1,138,320
Recharge	0	0	0	0	0	0	0	0
Total Source/Sink	495,234	-34,053	5,119,651	-11,727,847	85,825	-151,521	886,711	-1,243,703
Zone Flow								
Flow Right Face	0	0	0	0	0	0	0	0
Flow Front Face	0	0	0	0	0	0	0	0
Flow Lower Face	237,649	-7,256,038	695,390	-1,109,652	769,497	-1,124,847	0	0
Flow Left Face	0	0	0	0	0	0	0	0
Flow Upper Face	6,788,329	-235,751	7,256,038	-237,649	1,109,652	-695,390	1,124,847	-769,497
Flow Back Face	0	0	0	0	0	0	0	0
Total Zone Flow	7,025,979	-7,491,789	7,951,428	-1,347,302	1,879,149	-1,820,237	1,124,847	-769,497
Total Zone Flow	7,521,213	-7,525,842	13,071,079	-13,075,149	1,964,974	-1,971,758	2,011,559	-2,013,200
Summary	In - Out	% difference	In - Out	% difference	In - Out	% difference	In - Out	% difference
Sources/Sinks	461,181	174	-6,608,196	-78	-65,695	-55	-356,992	-34
Cell To Cell	-465,810	-6	6,604,126	142	58,912	3	355,351	38
Total	-4,629	0	-4,070	0	-6,783	0	-1,641	0

Kevin E. Day, M.S., P.G. – *Senior Hydrogeologic Modeler*

Years with Firm:	15 years
Industry Experience:	19 years
Education:	M.S., Geohydrology, University of Wyoming, 2000 B.S., Geology, Colgate University, 1993
Expertise:	Geologic Modeling, Groundwater Flow Modeling, Data Visualization, Database Development, Computer Programming

GeoHydros LLC, Reno Nevada (formerly Hazlett-Kincaid, Inc) *2001 – Present*
Senior Hydrogeologic Modeler

Responsibilities for all entities have included: all phases of geologic structural and groundwater modeling using EarthVision, MODFLOW and FEFLOW; geospatial analysis using GIS; database design and administration; near surface geophysical survey design and deployment; groundwater well production and performance testing; geospatial software application development, user interface development and Linux / Windows systems administration. Projects addressed a diverse set of problems, including structural and stratigraphic geologic investigations, geotechnical parameter and soils modeling, and groundwater flow and contaminant transport modeling.

LeanAg Technologies, LLC *2014 – Present*
Vice President - Development

Co-founder of LeanAg Technologies, LLC providing data driven crop intelligence. Responsible for development of analytics and process automation for crop specific spectral data collected using UAV platforms.

***Integral Development Corporation**, Mountain View, California – Release Manager* *2000 – 2001*

***TriHydro Corporation**, Laramie, Wyoming – Field Technician, Hydrogeologist* *1997 – 2000*

EarthVision Projects of Note

Geological Modeling, Flow & Transport Modeling - Navarro-Intera, USDOE (Las Vegas, NV)
Currently serving as Geologic Modeling Consultant for EarthVision™ structural geologic model development and migration in support of process (Flow and Transport) modeling teams. The most complex of these Hydrostratigraphic models articulate more than 75 Hydrostratigraphic Units traversed and offset by over 100 faults over hundreds of square kilometers. The geologic models comprise thrust faults, extensional faults, caldera collapse features and transverse faults. In addition to development of automated model production, output and quality control routines, the framework models have been translated and exported to specialized process simulators developed by national laboratories. Model development requires integration of multiple forms of data including surface geology, remote sensing, borehole lithology and borehole geophysics, seismic survey, gravity and aeromagnetic survey data.

DSCP Hydrogeologic Modeling – Philadelphia, Pennsylvania – Tetra Tech EC, USDOD
Developed site- and regional-scale 3D geologic framework models (GFM) in EarthVision™ for a heterogeneous multi-aquifer system beneath the former DSCP facility that has been impacted by more than two million gallons of light non-aqueous phase liquid. Model includes several structural surfaces created from borehole stratigraphic data, geostatistically defined 3D lithologic zones created from borehole lithology data, 3D parameter distributions created from soil contaminant data, and underground structures created from GIS, CAD, and map engineering data. As part of this work, developed a set of software programs to address and capitalize on wells that do not fully penetrate the recognized stratigraphic units that statistically distributes model uncertainty such that all stratigraphic units are more accurately modeled. This software was used to constrain model boundaries and identify discontinuities in the key confining layer. Created a routine for exporting the 2D and 3D components of the GFM from EarthVision into FEFLOW for subsequent groundwater flow and fate and transport modeling currently being performed to support site closure under Pennsylvania Act 2.

Fairbanks Disposal Pit 3D Conceptual Model – Gainesville, Florida – WRS Inc, FDOT
Coupled seismic, resistivity and borehole data to build a 3D GFM in a karst setting to identify potential conduits between the surficial and water-supply aquifers. Constructed the model using the EarthVision™ software by compiling numerous data streams into a central database from which lithologic and seismic data were extracted, correlated, and incorporated into the GFM. Model described the structural surface of key aquifers and confining units, as well as the probable location of karst collapse features thought to be contaminant pathways to the water

supply aquifers. Used geophysical and field testing data to delineate hydraulic conductivity distributions within heterogeneous surficial units and evaluate the competency of shallow clay lenses as barriers to vertical contaminant migration.

Pennridge Water Resource Protection Model – Bucks County, PA – Borton Lawson Engineering
Generated a GFM of the regional fractured bedrock aquifer that was used as the basis for groundwater flow modeling to support a basin-wide wellhead protection program. The GFM simulated a complex faulted, folded and intruded structural setting consisting of 65 stratigraphic units and 2 fault blocks. The GFM was constructed from a rich set of outcrop structural measurements that were used to project stratigraphic and structural surfaces to depth. The surfaces were then extracted and used to construct the framework for a 35-layer finite-element groundwater flow model using the FEFLOW software.

Indian Refinery Geologic & Contaminant Characterization Model – Lawrenceville, Illinois – TriHydro Corp.
Developed a series of 3-D Probability Models for areas of concern within the refinery to predict the location of buried wastes relative to permeable soils and groundwater. Various data sets were incorporated into the model to better characterize the extent of impacted materials, including ground penetrating radar surveys, electrical conductivity surveys and borehole logs.

Rapid Site Characterization Modeling – Kansas City, Kansas – Delta Environmental Consultants
Produced volumetric and probability modeling of impacted soils and groundwater correlating geophysical, borehole and analytical data to produce a rapid characterization of the site of a former refinery. This modeling effort was performed to support the EPA Triad approach to Rapid Site Characterization.

MODFLOW Projects of Note

Groundwater Flow and Contaminant Transport Modeling – Various Sites, North Carolina – Duke Energy
Designed and calibrated 3-D groundwater flow and fate-and-transport models using MODFLOW-GMS, PEST, and MT3D to predict performance of coal ash pond closure scenarios. Groundwater models were optimized and calibrated to support models of various constituents of interest (COI) in transport modeling. Project deliverables included 250 year forecasts of COI concentrations at on and offsite receptor locations, sensitivity analyses and new tools to facilitate data extraction and processing from model output binaries.

Dissolved-phase Contaminant Transport Modeling – High Springs, Florida – The Coca-Cola Company
Developed 2-D and 3-D groundwater flow and fate-and-transport models using MODFLOW-GMS, PEST, and MT3D to assess the impact on groundwater and surface water quality associated with the infiltration of effluent from a reverse osmosis facility. Several different realizations of the model were developed to predict the possible range in transport pathways and times associated with known but undefined karst conduit pathways. The goal of the modeling effort was to ensure that effluent disposal would not adversely impact water quality at the production well or nearby springs.

Rapid Infiltration & Water Supply Impact Modeling – Florida – Apex Companies
Developed numerous 2-D and 3-D groundwater models to address the impacts of both recharge to and withdrawal from the aquifer systems underlying small communities throughout Florida. The models were required for permitting by regulatory agencies to determine whether proposed changes in water usage due to growth would result in unacceptable change to the groundwater system, and were developed using the GMS – MODFLOW software platform in conjunction with EarthVision.

Dissolved-phase Contaminant Transport Modeling – Pennsylvania – SSM Inc
Developed several 2-D and 3-D groundwater flow / fate-and-transport models using MODFLOW-GMS, MT3D, and RT3D to characterize the transport of dissolved-phase volatile organic compounds released to surficial aquifers from leaking underground storage tanks at various locations in Pennsylvania. The models were required under Pennsylvania Act 2 as part of the site investigation and closure process.

Database Projects of Note

Nevada Department of Environmental Protection – Carson City, Nevada
Developed an Adobe Flex based product for cataloging and executing air quality modeling program (AERMOD) in support of permit application evaluation. Desktop application was designed to include an ArcSDE based model result rendering component providing a visual analytical tool to support the permitting process.

Woodville Karst Plain Hydrogeologic Characterization – Tallahassee, Florida – Florida Geologic Survey
Developed a web-based interactive database to store, manage, and disseminate hydrologic data being continuously collected in the Woodville Karst Plain by the Florida Geological Survey. The database currently contains flow, temperature, and conductivity data from seven hydraulic meters deployed in large underwater cave

systems as well as groundwater level data from 13 transducers deployed in wells, springs, and sinkholes. Developed a user interface that provides for graphical analysis and download of data via the internet.

FDEP Hazardous Waste Database – Florida – Florida Department of Environmental Protection
Developed a desktop database application for use by FDEP to store and access historical hazardous waste records. The application was written in Visual Basic and Microsoft Access, and was formatted in compliance with EPA's STORET database. The primary purpose of the database was to provide better access to data through stored procedures and dynamic queries, and to establish spatial indexing of environmental data.

Field Projects of Note

Guantanamo Bay – Cuba – United States Navy Construction Battalion
Planned and deployed a geophysical survey of Naval Base perimeter patrol road in support of planned bridge building and low water crossing design to solve access issues during high precipitation events. The project planners required knowledge of bedrock depth and potential karst features in the vicinity of proposed bridge pilings. Geophysical methods included ground penetrating radar and electrical resistivity.

Texaco Refineries – Casper, Wyoming; Sunburst, Montana; Lawrenceville, Illinois
Planned and deployed geophysical surveys of decommissioned oil refineries to identify and locate underground objects with the potential to contain petroleum product. Project required integration of data from Trimble GPS and Geonics EM-61 induced conductivity survey tools to produce georeferenced map products for excavation contractors to remove identified objects.

Technical Skills and Certifications

Computer Software Proficiency

- PC, Mac, Unix (Solaris) and Linux environments
- Software proficiency includes: EarthVision, GMS (MODFLOW, MODPATH, MT3DMS, RT3D, PEST), ArcGIS, FEFLOW, Adobe suite, MS Access (VBA Development), Excel, MySQL, Adobe Flex/Flash, LabTech
- Programming skills include experience in MATLAB, R, Visual Basic, Perl, PHP, SQL, Actionscript , JavaScript, c and bourne shell scripting
- Web Server and web development has included Apache, Qmail and Postfix mail server administration, Flash, PHP/MySQL and Javascript

Certifications

- February 2008: Florida Professional Geologist Certification received
- May 2005: California Professional Geologist Certification received
- July 2000: Solaris System Administrator I Certification received
- December 1999: Trimble GPS Certification received
- December 1997: ESRI ArcView GIS Certification received
- July 1997 OSHA: 40 hr. HAZWOPPER Certification received

Selected Peer Reviewed Articles

Lance Prothro, Margaret Townsend, Heather Huckins-Gang, Dawn Reed, Sigmund Drellack, Kevin Day and Todd Kincaid, 2015, Developing a 3-D Seismic-Attribute Framework Model of Yucca Flat, Nevada National Security Site.

Day, K.E., Kincaid, T.R., 2013, A New Hydrostratigraphic Framework Model (HFM) of Pahute Mesa, Nevada, MODFLOW and More 2013: Translating Science into Practice, Colorado School of Mines, Golden, Colorado.

Day, K.E., Kincaid, T.R., 2013, Benefits of Automation in Hydrostratigraphic Framework Modeling: A New HFM for Pahute Mesa, Nevada, UGTA TIE Annual Meeting, Furnace Creek, Death Valley, NV.

Day, K.E., Kincaid, T.R., 2009, 3-D Solids & Parameter Modeling to Facilitate TRIAD-Compliant Rapid Site Characterization, American Society of Civil Engineers 24th Central PA Geotechnical Conference.

Day, K.E., Kincaid, T.R., 2007, A Web-Based Tool for Analytical Comparison of Hydrologic Data in the Woodville Karst Plain, NGWA 4th Conference on Hydrogeology, Monitoring and Management of Ground Water in Karst Terrains.

Todd R. Kincaid, PH.D. – *Principal Hydrogeologic Modeler*

Years with Firm:	17 years
Industry Experience:	24 years
Education:	Ph.D., Geohydrology, University of Wyoming, 1999 M.S., Hydrogeology, University of Florida, 1994 B.S., Geology, University of Florida, 1991 U.S. Airforce Academy, 1986-1987
Expertise:	Karst Hydrogeology, Groundwater Tracing, Geologic Modeling, Groundwater Flow Modeling, Data Visualization

GeoHydros LLC, Reno Nevada (formerly Hazlett-Kincaid, Inc) *1999 – Present*
President, Principal Hydrogeologic Modeler

Dr. Kincaid co-founded Hazlett-Kincaid, Inc. in 1999 to provide highly specialized modeling, visualization, and data analysis professional services to the groundwater resources communities. He reorganized the business in 2010 as GeoHydros, LLC. Services include groundwater and geologic modeling, 3D data visualization, and karst aquifer characterization. Current and previous clients include: USDOD, USDOE, USACE, FL and NV Dept of Env. Protection, FL Geological Survey, North FL Water Management District, Alachua Co FL, Charlotte Co FL, Bucks Co PA, Hardin Co OH, Cities of Tallahassee FL, Punta Gorda FL, and Ada OH, New York Metropolitan Transit Authority, Puget Sound Energy, Votorantim Metais Brazil, Tarmac America, Buzzi USA, Exxon-Mobile, The Coca Cola Company, Ginnie Springs Outdoors, St. Johns Riverkeeper, the Sierra Club, Tetra Tech, Arcadis, ERM, Antea, Delta, STV Inc, Parsons Brinkerhoff Quade and Douglas, and numerous other small environmental and geotechnical consulting firms. Dr. Kincaid's responsibilities include: scientific oversight of all modeling work, solids and parameter modeling, hydrogeological assessments, groundwater tracing, presentation development and delivery, and expert testimony as well as program and business development, and financial oversight.

Global Underwater Explorers (GUE), High Springs Florida *2000 – Present*
Vice President / Board of Directors

Dr. Kincaid currently serves as *Vice President & Science Director* for this international non-profit organization whose goal is to protect sensitive underwater environments through exploration, research, and public education. Dr. Kincaid's work for GUE has focused on promoting cooperation and collaborations between private, government, and diving communities that contribute to protecting underwater environments. He has organized workshops, field trips, and seminars; regularly authors articles for trade journals; and is also responsible for developing financial support for continued research and education efforts. He currently leads the organizations primary conservation effort: *Project Baseline* (www.projectbaseline.org), which aims to empower divers to observe and record long term environmental conditions at diving sites around the world and share those observations with the public through a web-based geospatial database.

***Woodward-Clyde Federal Services**, Las Vegas, Nevada – Geologic Modeler* *1998*
***University of Wyoming**, Laramie, Wyoming – Graduate Assistant, Hydrogeology* *1994 – 1999*
***Project KarstDive**, Antalya Turkey – Project Leader & Chief Scientist* *1995 – 1996*
***GeoSolutions, Inc.**, Gainesville, Florida – Hydrogeologist I* *1992 – 1994*
***University of Florida**, Gainesville, Florida – Graduate Assistant, Geology* *1991 – 1993*

Projects of Note – Last 5 Years

Geological Modeling, Flow & Transport Modeling - Navarro-Intera, USDOE (Las Vegas, NV) *2009 - Present*
Leads a group of scientists tasked with developing a set of geological framework models for the USDOE to characterize the extent and magnitude of contamination resulting from historical underground nuclear testing. The models are created in EarthVision™. Modeled areas vary from 570 to 2700 km2 and extend to depths of between 6500 and 9500 m and simulate multiple extensional faults that offset approximately 60 different discontinuous and variably thick hydrostratigraphic units, including carbonates, lava flows, welded and non-welded tuffs, and alluvial sediments. Designed and implemented automated model development processes that allow rapid model revisions, and methodologies for rapidly exporting EarthVision frameworks to flow modeling codes including FEHM and FEFLOW™. His team also developed simulations for radionuclide transport through the carbonate hydrostratigraphic units using FEFLOW.

Groundwater Tracing & Numerical Modeling – Puget Sound Energy (Concrete WA) *2014 – 2015*
Designed, constructed, and managed a groundwater tracing program at the Lower Baker Dam in 2015 that successfully traced leakage flow paths and water velocities between the forebay and the plunge pool and between several discrete zones within boreholes drilled adjacent to the dam and the plunge pool. Managed the design and development of a numerical groundwater flow model constructed with the software FEFLOW™ that simulated leakage along discrete fracture flow pathways identified in a Leapfrog™ 3D geologic model and verified through groundwater tracing that calibrated to the tracer-defined water velocities along the flow paths, the total discharge measured in the plunge pool, and an estimated distribution of discharge from a series of discrete vents in and above the plunge pool.

Water Budget Analysis - Alachua County (Gainesville, FL) *2014 - 2015*
Led an effort to define aquifer recharge in surficial aquifer and Floridan aquifer basins in north-central Florida that relied on streamflow data and a compilation of groundwater extraction records and estimates, swallet flow and lake storage measurements, and reported return flows to define recharge to surficial aquifer where present and unconfined portions of the upper Floridan aquifer as well as leakage from the surficial aquifer through the upper confining layers into the upper Floridan aquifer.

Numerical Model Review - Ginnie Springs Outdoors (High Springs, FL) *2013 - 2014*
Led an effort to test the validity and reliability of the predicted impacts of groundwater pumping to spring and river flows and upper Florida Aquifer groundwater levels generated by the Suwannee River Water Management District's North Florida numerical groundwater model. Evaluations included: 1) assigned recharge vs. verifiable groundwater discharge at sub-watershed scale; 2) flow paths and travel-times vs. results of numerous groundwater tracer tests; 3) assigned transmissivity vs. values derived from aquifer performance tests; 4) unreported residuals at rivers and springs vs. target heads defined in river and drain nodes; 5) deviations between simulated and measured drawdowns at large municipal well fields; and 6) spatial trends in calibration residuals. Report on the results and findings were formally presented to the State water management districts, and the Florida Department of Environmental Protection.

Groundwater Tracing - Votorantim Matais (Vazante, Brazil) *2013*
Led the development and execution of a groundwater tracing project to identify the locations of river water losses within an approximately 10 km stretch of a river flowing over karstic carbonate rocks and trace the fate of those losses within 5 km of underground mine tunnels spanning six elevation levels. Performed 6 separate tracer injections; continuously monitored 17 stations within the underground mine, mine discharge, and the river; successfully established connections to 11 stations and the lack of connection to 6 stations; and developed tracer recovery curves and calculated corresponding mass recoveries at the mine discharge and river sampling stations. Developed conceptual model describing mechanisms for the discharge of river water into the mine tunnels.

Groundwater Flow Modeling - ERM, Exxon-Mobile (Ontario, CA) *2012*
Led an effort to develop a 3D digital conceptual site model and 3D numerical groundwater flow model of the West Coast Groundwater Basin surrounding Torrance, California using EarthVision™ and FEFLOW™. The model addressed hydrostratigraphic and structural relationships between five aquifers two regional faults. Developed a CSM using EarthVision that became the framework for the FEFLOW groundwater flow model as well as a platform for the visualization of hydraulic communication between the aquifers through intervening confining layers. Capture zones and the influence of the fault and regional wells were evaluated with 3D particle tracks exported from the FEFLOW model and visualized in GIS and the EarthVision CSM.

Groundwater Tracing - Florida Geologic Survey (Tallahassee, FL) *2001 - 2012*
Lead scientist and project manager for a multi-faceted karst aquifer characterization and public education effort in the Woodville Karst Plain of North Florida funded by the FL Geological Survey and the FL Dept of Env Protection. Designed and managed a quantitative groundwater tracing program that successfully established hydraulic connections between several sinking streams and the City of Tallahassee's wastewater spray field, and Wakulla Spring. Managed the development of a comprehensive and interactive database for cave and hydraulic data (www.geohydros.com/FGS/) and a basin-scale groundwater flow model designed to specifically simulate flow through mapped and traced karst conduits. Organized public education programs that included workshops, short courses, field trips, and public presentations focusing on spring and aquifer protection.

Geologic, Parameter, and Groundwater Modeling - Tetra Tech EC, USDOD (Philadelphia, PA) *2001 - 2012*
Led the development of a linked geological-groundwater flow model that simulates a 3D heterogeneous multi-aquifer system beneath the former DSCP facility in Philadelphia, PA that has been impacted by more than two million gallons of light non-aqueous phase liquid (LNAPL). Developed regional and site-scale 3D geologic framework models (GFMs) to define the geospatial relationship between the LNAPL plume, 26 discrete discontinuous soil and rock zones, and buried utilities. Co-developed a method for using the Van Genuchten

equation and parameter grids extracted from the GFM to estimate total recoverable LNAPL on a synoptic basis. Exported GFM to FEFLOW and developed a 28-layer regional groundwater flow model. Exported 3D particle tracks to demonstrate flow paths for benzene from the LNAPL plume to property boundaries and into the deep aquifer to support site closure under Pennsylvania Act 2 regulations.

Recent Expert Testimony / Litigation Support

Mike Laudicina and Don DeMaria vs. DEP File No.: FLA671932-003-DW1P, etc. Florida Department of Environmental Protection, and Florida Keys Aqueduct Authority; Monroe County FL	2015
Sierra Club, Inc., and St. Johns RiverKeeper, Inc. with Florida Defenders of the Environment, Inc., vs. Sleepy Creek Lands, LLC and St. Johns River Water Management District, Case No. 14-2608; and Karen Alhers and Jeri Baldwin with Florida Defenders of the Environment, Inc. vs. Sleepy Creek Lands, LLC and St. Johns River Water Management District, Case No. 14-2609; Palatka FL	2014
Joseph Glisson vs. City of Tallahassee and the Florida Department of Environmental Protection: DOAA Case No.: 11 2953	2011

Professional Associations & Awards

Wakulla Springs Alliance (www.wakullaspringsalliance.org): Board of Directors	2014 – Present
Florida Springs Institute (floridaspringsinstitute.org/): Advisory Board	2011 – Present
Global Underwater Explorers (www.gue.com): Vice President, Board of Directors	2000 – Present
Hydrogeology Consortium (www.hydrogeologyconsortium.org): Board of Directors	2002 – 2014
Southeastern Geological Society (www.segs.org): President	2007 – 2008
Southeastern Geological Society (www.segs.org): Vice President	2006 – 2007
Florida Springs Protection Award (Florida Department of Environmental Protection)	2005

Selected Peer Reviewed Articles

Kincaid, T. and Meyer, B., 2015. A Dual-Calibrated, Hybrid Model of Conduit Flow to Springs in a Portion of the Floridan Aquifer in North-Central Florida. MODFLOW and More 2015: Modeling a Complex World, Proceedings, eds. R Maxwell, M. Hill, C. Zheng, and M. Tonkin. Integrated Ground Water Modeling Center (IGWMC), Colorado School of Mines, Golden CO.

Kincaid, T, Davies, G, Werner, C, and DeHan, R, 2012. Demonstrating interconnection between a wastewater application facility and a first magnitude spring in a karstic watershed: Tracer study of the Tallahassee, Florida Treated Effluent Spray Field, 2006-2007; Report of Investigations No. 111, Florida Geological Survey, Tallahassee, FL, 192 p.

Kincaid, T.R. and Werner, C.L., 2008. Conduit flow paths and conduit/matrix interaction defined by quantitative groundwater tracing in the Floridan aquifer, in Yuhr, L.B., Alexander, E.C., and Beck, B.F. eds., *Sinkholes and the Engineering and Environmental Impacts of Karst*, Geotechnical Special Publication No. 33, American Society of Civil Engineers, Reston, VA, pp. 288-302.

Loper, D.E., Werner, C.L., DeHan, R., Kincaid, T.R., Chicken, E., and Davies, G., 2008. Probing the plumbing of Wakulla Spring: instrumentation and preliminary results, in Yuhr, L.B., Alexander, E.C., and Beck, B.F. eds., *Sinkholes and the Engineering and Environmental Impacts of Karst*, Geotechnical Special Publication No. 33, American Society of Civil Engineers, Reston, VA, pp. 313-324.

Meyer, B.A., Kincaid, T.R., and Hazlett, T.J., 2008. Modeling karstic controls on watershed-scale groundwater flow in the Floridan aquifer of north Florida, in Yuhr, L.B., Alexander, E.C., and Beck, B.F. eds., *Sinkholes and the Engineering and Environmental Impacts of Karst*, Geotechnical Special Publication No. 33, American Society of Civil Engineers, Reston, VA, pp. 351-361.

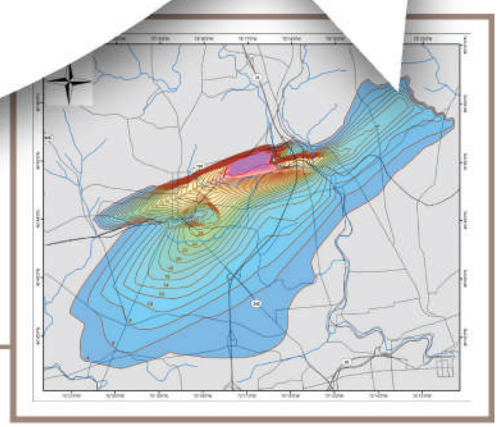
Kincaid, T.R., 2007, Karst Hydrogeology of the Santa Fe River Basin, Fieldtrip Guidebook No. 47, Southeastern Geological Society, Tallahassee, FL. Available for download at: http://www.geohydros.com/images/Pubs/segs_fieldguide47_sfrb2007.pdf.

Kincaid, T.R., 2006, Karst Hydrogeology of the Woodville Karst Plain: Wakulla & St. Marks River Basins, Field Trip Guidebook No. 46, Southeastern Geological Society, Tallahassee, FL.

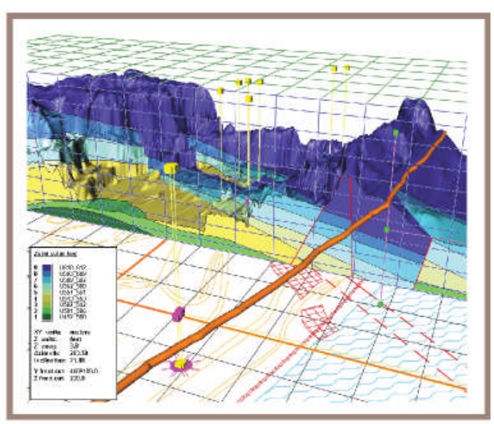
Loper, D.E., Werner, C.L., Chicken, E., Davies, G., and Kincaid, T., 2005, Coastal Carbonate Aquifer Sensitivity to Tides, *EOS, Transactions of the American Geophysical Union,* vol. 86, no. 39.

GeoHydros LLC

Specialized Geological Modeling



STATEMENT OF QUALIFICATIONS



About GeoHydros

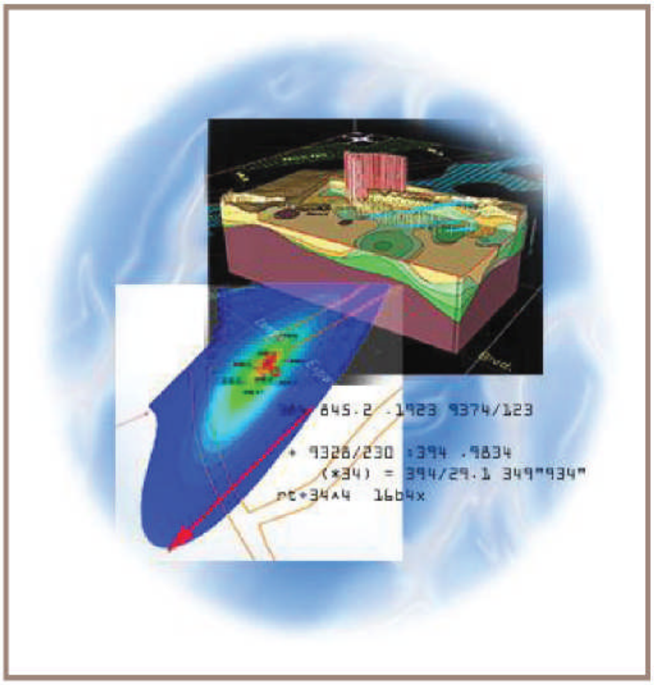
GeoHydros is a small consulting firm specializing in geological and hydrogeological modeling, data visualization, GIS, and data management. Our expertise with and adept use of cutting-edge technologies form the basis for our growing reputation as a leader in modeling complex aquifers such as karst, fractured bedrock, and highly heterogeneous surficial sediments. Our business was founded in 1999 as Hazlett-Kincaid, Inc. in Reading Pennsylvania. We opened a Tallahassee Florida office in 2001 and then our current home office in Reno Nevada in 2002. We reorganized as GeoHydros, LLC in 2010. Our primary strength and the fundamental characteristic that sets us apart from other modelers and modeling firms is our Dual Modeling Approach™ to problem solving, which focuses on synthesizing site and regional data with sound professional interpretations into accurate digital conceptual models of the site as it fits into a regional hydrogeologic context. Those digital solids models then become the framework for flow and transport models and predictions as well as the basis for visualizing data and results in the context of site complexities such as geologic and/or engineered structures. We typically perform all services from our main office in Reno, Nevada, leveraging our secure website to facilitate effective communication with project team members regardless of their physical location, and to disseminate modeling results to our clients and project team-members and, when appropriate, to the responsible regulatory agencies.

The GeoHydros group has worked for government and private clients on projects including: geotechnical and environmental engineering of new underground structures; characterization and remediation of Light and Dense Non-aqueous Phase Liquid plumes; quarry de-watering; karst aquifer characterization and modeling, and municipality water resource modeling. Some of our previous and existing clients include: USDOD; US-DOE; Tetra Tech EC; Parsons Brinkerhoff; STV Inc.; Coca-Cola North America; Florida DEP; Bucks County, Pennsylvania; Hardin County, Ohio; SM Stoller Corp.; TriHydro Corp.; Northwest Florida Water Management District; Borton-Lawson, Inc.; ERM Group Inc.; WRS Infrastructure & Environment, Inc.; Knik Construction Co.; Buzzi Unicem USA; HydroGeoLogic, Inc.; and Tilcon New York, Inc.

Dual Modeling Approach™

GeoHydros takes pride in our comprehensive and consistent approach to modeling for water resource management and environmental site characterizations. We developed and utilize our Dual Modeling Approach™ to link conceptual solids models developed in EarthVision with process models developed in FEFLOW or MODFLOW. This allows us to develop highly accurate conceptual models that are not subject to the limitations of the solids modeling tools packaged with the groundwater modeling programs.

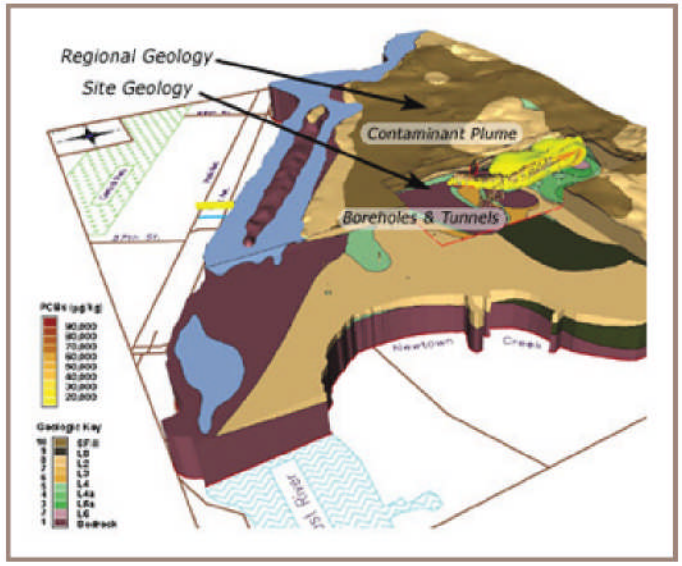
The two fundamental components are the Geologic Framework Model (GFM) and the Groundwater Model (GWM). The purpose of the GFM is to incorporate geologic, hydraulic, contaminant, and structural data into grid-based, visual, and query-able interpretative models of existing conditions. The GWM uses the gridded data exported from the GFM to define the conceptual framework and initial conditions for predictive modeling. We use EarthVision to develop the GFM because it allows for deterministic and/or stochastic methods to model spatial relationships between geologic surfaces, parameter distributions and engineered features. A GWM can then be constructed with a variety of software such as FEFLOW or MODFLOW through the use of grids exported from the GFM.



There are many benefits of a Dual Modeling Approach™ to groundwater resource management and site characterization efforts. The development of a GFM independently provides for better interpretations of site data, increased access to those interpretations, and the ability to rapidly update model interpretations as new data becomes available. Incorporation of GFM grids into a GWM reduces model development time and provides for better and more rapid model calibrations because model frameworks can embrace more site complexities. We have successfully applied the Dual Modeling Approach™ to numerous site characterization projects including a large tunnel-construction project in New York City and industrial contamination sites in Florida, Illinois, and Pennsylvania, and to a number of groundwater resource management problems in New York, Pennsylvania, and an extensively karstified region of north Florida.

Services

GeoHydros is primarily a modeling specialty firm that provides geologic modeling, 2D & 3D visualization, and hydrologic modeling services under subcontract to larger environmental engineering firms as well as federal, state, and local government agencies, and private clients. We typically perform these services in concert through what we call our Dual Modeling Approach™ wherein we use in-house software to link modeling programs and facilitate output development and web-based presentation. We have also developed highly specialized skills in GIS, database development, and karst aquifer characterization that we perform independently or in conjunction with modeling projects. Our proprietary post-processing modeling software allows us to deliver high quality modeling visualizations for almost any environmental project: $5,000 to $500,000 in scope.



Geologic Characterization

- More than 20 years experience in developing computer generated Geologic Framework Models (GFMs), sometimes called Conceptual Site Models (CSMs), and 2D and 3D visualizations of data and process modeling results.
- Synthesize geologic, hydraulic, contaminant, & structural data into highly visual, readily query-able models.
- We use EarthVision - the most sophisticated commercially available solids modeling and 3D visualization software.
- Extensive experience with the Structure Builder, Workflow Manager, Graphic Editor, Formula Processor, Minimum Tension surface and isochore gridding, Base & Contour Mapping, and the Geostatistical Analyses tools.
- Extensive library of proprietary programs that automate data manipulation, model development, and output generation processes making our models uniquely cost effective and accessible to project teams.

SERVICES

Water Resource Management

- Numerical groundwater flow modeling to define aquifer vulnerability and well head protection zones.
- 2D & 3D particle tracking to delineate well capture zones in unconfined aquifers and specific recharge areas in confined aquifers.
- Surface water modeling to define watershed flows and assess hydraulic requirements for engineered structures.
- Extensive experience in modeling flow through karst, fractured rock, and extremely heterogeneous aquifers.
- Use numerous hydrologic modeling codes: MODFLOW-GMS, MODFLOW-Groundwater Vistas, FEFLOW, HydroCAD, MT3D, RT3D, and ArcGIS-Spatial Analyst.

Karst Characterization

- Numerical modeling of groundwater flow using dual-permeability frameworks.
- Delineation of probable conduit pathways, springsheds, and aquifer vulnerability zones.
- Simulation of spring flow response to groundwater pumping and contaminant transport for spring vulnerability assessments.
- Quantitative groundwater tracing using fluorescent dyes, automatic water samples, insitu optical fluorometers, and laboratory spectral fluorescence analysis.
- Interpretation of aquifer hydraulics from quantitative tracer recovery curves.
- Spring, swallet, and karst feature surveys.
- Hydraulic metering and data analysis.
- Cave survey, mapping, & 3D modeling.

Contaminant Transport

- Numerical simulation of dissolved-phase transport in groundwater using FEFLOW, MT3DMS, & RT3D.
- Transient plume volume estimation and center-of-mass tracking derived from numerical odeling results.
- 2D & 3D visualization of simulated plume configuration and movement using EarthVision.
- Optimization and/or evaluation of remediation system design based on transport scenario analyses.
- Synoptic plume volume estimation & 3D visualization.
- Impacted soil volume calculation & 3D visualization.

Rapid Site Characterization

- Rapidly and accurately visualize geophysical, MIP, and soil & groundwater contaminant data in 2D & 3D.
- Correlate rapidly collected data (MIP & geophysical) with laboratory analytical and log analysis data to expedite analysis and interpretation.
- Develop data gap analyses to optimize data collection.
- Leverage secure website technologies to share data and model viusualizations with project team.
- Automate production of data and model visualization sets and website uploads to reduce turn around time.
- Standardize figure and presentation templates to reduce time and costs associated with reporting.

NAPL Characterization

- 3D LNAPL Plume Delineation & Volumetric Analysis
- 3D LNAPL & DNAPL plume delineations from thickness, concentration, or indicator data.
- Total recoverable LNAPL estimation using Van Genuchten approach and gridded soil parameter datasets.
- Impacted soil volume calculations & removal analyses.
- Automated volume updates using synoptic apparent LNAPL thickness and water table elevation data.
- Animated plume movement analyses along with volume and center-of-mass tracking.

Database & GIS

- More than 10 years experience in customized database and web-based database interface development.
- Proprietary geospatial database attributes:
    - geologic, hydraulic, and contaminant data in a single data model;
    - easy-to-use spreadsheet data upload templates;
    - queries and reports specifically designed to produce datasets formatted to conform to EarthVision and process modeling input requirements; and
    - web-based user interface that allows for data queries that deliver data files and graphical output over the Internet.
- Web-based interface allows anyone on a project team to develop graphical output on the fly from a single data source that provides for a full QA/QC history on all data entries.
- Data model is fully compatible with EPA's STORET and directly accepts transfers from emerging automated laboratory reporting formats.

Resources

GeoHydros maintains a small group of highly specialized professionals such that we can provide more in-depth knowledge and expertise than is typically available in larger firms. Our areas of expertise include: hydrogeology, karst hydrogeology, geochemistry, groundwater modeling, solids modeling, data visualization, and GIS. In calling on these skills, we pride ourselves on being able to use the most advanced and appropriate modeling tools to solve environmental problems for our clients.

Project Locations to Date *(Geographic Scope of Services)*

LOCATION	PROJECTS / YEARS WORKED	SERVICES PERFORMED
Florida – North	12 / 7	Karst Hydro, GFM, GWM, DB Dev., Pub Ed
Florida – Central	7 / 5	Karst Hydro, GFM, Data Viz, GWM, FTM
Illinois	1 / 3	GFM, Data Viz
Kansas	1 / 1	GFM, Data Viz
Nevada	1 / 1	GFM
New Jersey	3 / 2	GFM, Data Viz
New York – New York City	4 / 4	GFM, GWM, FTM
New York – Central	1 / 1	Karst Hydro, GFM
Pennsylvania – East	15 / 8	Hydro, Karst Hydro, GFM, GWM, FTM, Pub. Ed.
Pennsylvania – Central	4 / 3	Hydro, Karst Hydro
Wyoming	1 / 1	DB Dev, GWM
Colorado	2 / 2	Data Viz
New Mexico	2 / 2	Data Viz

Hydro: hydrogeology / Karst Hydro: karst hydrogeology / GFM: geologic framework modeling / GWM: groundwater flow modeling / FTM: fate and transport modeling / DB Dev: database development / Data Viz: data visualization / Pub. Ed: public education

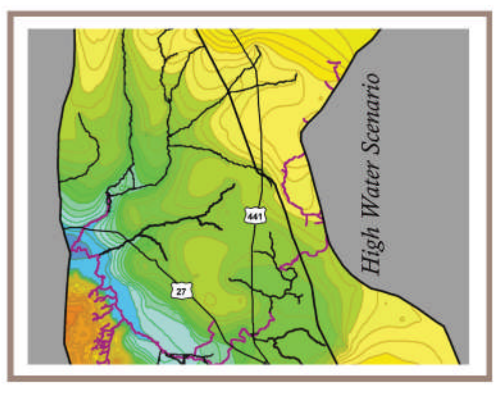
Office Staffing

OFFICE	# STAFF	STAFF BY FUNCTION	SPECIALTY AREAS
Reno, NV 27 Keystone Avenue Reno, Nevada 89503 (775) 337-8803	5	2 Geologic Modeler 2 Groundwater Modeler 1 GIS Specialist	Geologic (solids & parameter) Modeling Groundwater / Fate & Transport Modeling 2D & 3D Visualization, GIS Database Development Physical Hydrogeology & Karst Hydrogeology
Tallahassee, FL 1549 Yancey Street Tallahassee, Florida 32303	2	2 Hydrogeologist	Karst Aquifer Characterization Groundwater Tracing

Software / Hardware Resource

SOFTWARE	QTY	HARDWARE	QTY
Dynamic Graphics EarthVision™ Version 7.5	2	Workstation Modeling Computers	4
FEFLOW™ Version 5.3	2	Laptop Presentation Computers	2
MODFLOW-GMS Version 6.5	1	File & Application Servers	3
MODFLOW-GMS Version 5	1	Large Fromat Legacy Paper Map Digitizer	1
MODFLOW-Groundwater Vistas Version 4	1	-	-
ESRI ArcGIS 9.3 – Arc View	2	-	-
ESRI ArcGIS 9.3 – Spatial Analyst	1	-	-

BIOS



Todd R. Kincaid, Ph.D.

Home Office:
Reno, NV
Title:
Group Leader / Geologic Modeler
Education:
Ph.D., Geohydrology, University of Wyoming, Laramie, WY 1999
M.S., Hydrogeology, University of Florida, Gainesville, FL, 1994
B.S., Geology, University of Florida, Gainesville, FL, 1991
Years with GeoHydros:
11 years
Modeling & Geological Experience:
14 years
Past Project Roles:
Project Manager
Geologic Modeler
Hydrogeologist
Geologist
Areas of Expertise:
Geologic modeling & data visualization
Karst Hydrogeology
Groundwater Tracing
Physical Hydrogeology

Dr. Kincaid leads GeoHydros. He has a diverse background in geology and hydrogeology and has extensive knowledge of karst hydrogeology. His experience includes: quantification of groundwater/surface water exchange; groundwater tracing using isotopic and artificial tracers; environmental site characterizations and remediation; aquifer characterization; and modeling complex geologic environments. Dr. Kincaid is currently managing a groundbreaking aquifer characterization study of the Woodville Karst Plain of north Florida with the Florida Geological Survey and the Florida DEP, which synthesizes groundwater tracing, cave mapping, and hydraulic data into one of the first numerical models that truly embraces karst complexities (www.geohydros.com/FGS). He has authored several professional reports as well as numerous professional and academic papers for national and international journals and symposia. He regularly participates in meetings with local and state agencies as well as legal proceedings to convey modeling results to regulatory and lay audiences.

Dr. Kincaid manages the Reno office where he provides scientific oversight for all GeoHydros modeling activities. In addition, he personally prepares most of our reports and presentations, delivers public presentations on our work, and provides expert testimony. As principal, he is also responsible for quality assurance, client management, and financial oversight.

Kevin E. Day, M.S., P.G.

Home Office:
Reno, NV
Title:
Hydrogeologic Modeler
Education:
M.S., Geology, University of Wyoming, Laramie, Wyoming 2000
B.S., Geology, Colgate University, Hamilton, New York 1993
Years with GeoHydros:
9 years.
Modeling & Geological Experience:
13 years
Past Project Roles:
Hydrogeologist
Software Designer
Areas of Expertise:
Geologic modeling & data visualization
Groundwater flow and fate and transport modeling
Database design and management
Computer programming
Registrations:
California P.G. - License # 8034
Florida P.G. - License # 2517

Mr. Day's is our primary geologic modeler having extensive knowledge of and experience with EarthVision and UNIX programming. His responsibilities include geologic and solids modeling, groundwater flow modeling, database design and management, software application development, GIS, and database management. He is fluent in the groundwater modeling programs: GMS-MODFLOW, MT3D, and FEMWATER, and ESRI GIS. His more notable project examples include the development of a combined regional and site-scale 3-D Geologic Framework Model (GFM) of the DSCP facility in Philadelphia, Pennsylvania for the USDOD; a regional-scale geologic model of a fractured rock aquifer containing 65 variably thick faulted and dipping stratigraphic units for Bucks County

Pennsylvania; a detailed site-scale geologic model relating stratigraphic information from more than 150 boreholes and 2-D seismic data for a contaminated former industrial site in Gainesville Florida; and design and development of a relational database and data entry templates for the Florida DEP Hazardous Waste Program.

Mr. Day has written a library of programs to address complex subsurface computational problems and streamline communication between various software applications and our project database including a cutting edge program that solves the problem of partially penetrating wells in isopach-based geologic models.

Kristie A. Connolly

Home Office:
Reno, NV
Title:
GIS Technician
Education:
BS, Geography, University of Wyoming, Laramie, WY 1994
GIS Certification, Pennsylvania State University, State College, PA 2002
Years with GeoHydros:
10 years
GIS & Mapping Experience:
12 years
Past Project Roles:
GIS Technician, Field Geologist
Areas of Expertise:
GIS, Map Production, Office Management

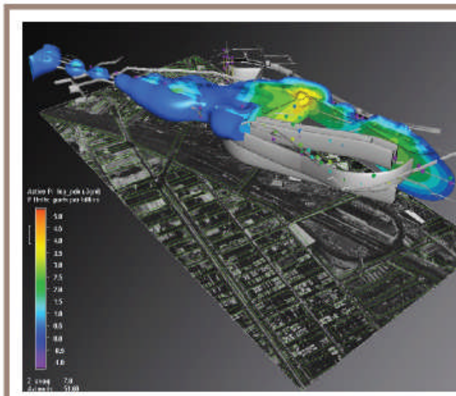
Ms. Connolly has worked for the GeoHydros group since the group's inception in 2000 on a part-time basis performing GIS, mapping, and data management services. She has combined ArcGIS, database, digitization, and spreadsheet technologies to convert data from various sources into the formats required for use in our EarthVision and FEFLOW modeling programs. She has also used ArcGIS and Adobe graphic editing software to render high quality map deliverables from our modeling output and used web development software to upload deliverables to client websites.

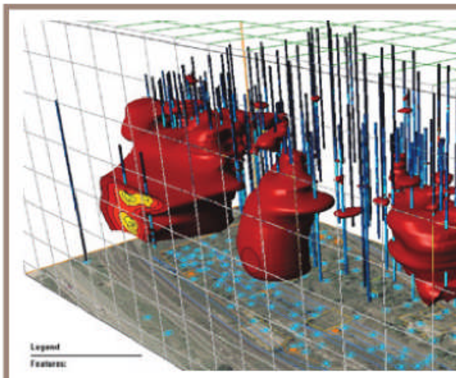
One of her project examples includes the development of a GIS database for subsurface utilities at a Department of Defense site in Philadelphia, Pennsylvania for Foster Wheeler Environmental Corporation that was used to render 3-D models of the features that were included in a site geological framework model.

GeoHydros LLC

Specialized Geological Modeling

SKILLS

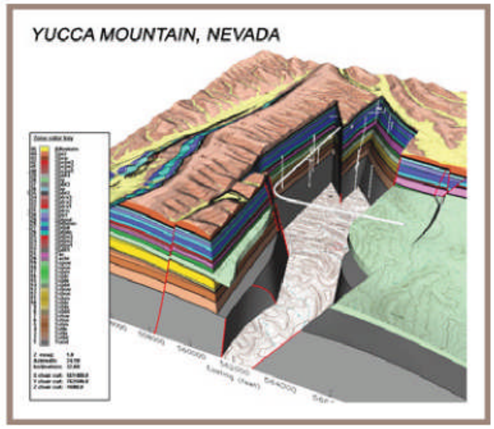




EarthVision™

Dynamic Graphics EarthVision The GeoHydros Modeling Group has more than 20 years of experience in the use of EarthVision (EV) for solids and parameter modeling, and data visualization. We have extensive experience with the Structure builder, Workflow Manager, Graphic Editor, Formula Processor, Minimum Tension surface and isochore gridding, and the Base & Contour Mapping modules and are adept in the use of most of the software's other components. In addition, we have developed an extensive library of UNIX shell scripts to automate various data manipulation processes, develop unique stratigraphic and property model development processes, and automate output generation and image website production. We've enjoyed numerous opportunities to work with Dynamic Graphics Inc. (DGI) technical support staff to develop modeling processes and have been invited by DGI to lecture on our modeling work and processes at their EV user meetings.

Complex Fault Blocks & VolcanicTuff



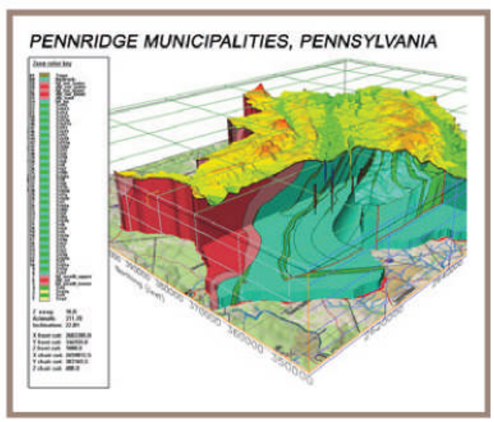
Example: *Yucca Mountain Project - Geologic Framework Model*

- 31 square kilometers (12 square miles)
- 42 stratigraphic units of variable thickness positioned across eighteen normal fault blocks
- 6-mile horizontal tunnel ~25 feet in diameter
- Constructed from published geologic maps, 101 boreholes, information from tunnel data, and measured stratigraphic sections from outcrop areas.

Example: *Nevada Test Site*

- Developing and revising geologic framework models to support contaminant transport modeling in the corrective action units.

Dipping Hydrostratigraphic Units & Intrusions



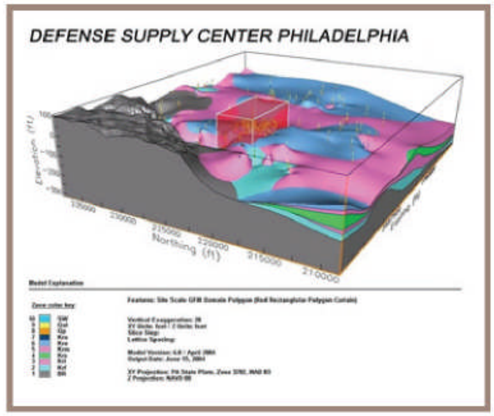
Example: *Pennridge Aquifer Protection Model, Bucks County PA*

- Developed comprehensive geologic framework model to support groundwater flow model designed to delineate well capture zones and aquifer vulnerability areas.
- Model simulated 60 interbedded lithologic units of varying thickness, geometry, and permeability that are structurally tilted in a synclinal basin, faulted at one end, and intruded by a diabase.
- Developed model using strike and dip information and outcrop boundaries obtained from published geologic maps.
- Exported framework to FEFLOW for groundwater flow modeling.

SKILLS

EarthVision™ (cont'd)

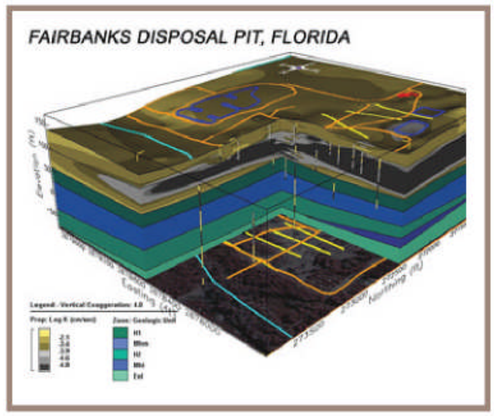
Severely Heterogeneous Contaminanted 3D Aquifer Systems



Example: *Defense Supply Center*
Philadelphia, Pennsylvania

- Combined site- and regional-scale geologic framework model supporting groundwater flow and transport models.
- Integrated stratigraphic, lithologic, and electrical conductivity data from more than 1000 boreholes.
- 32 mi2 (regional-scale) and 4.75 mi2 (site-scale).
- 8 discontinuous and variably thick stratigraphic units over an eroded bedrock surface.
- Heterogeneous lithologies in upper 4 zones modeled probabilistically and independently of stratigraphy.
- Distribution of LNAPL, soil contamination, and dissolved phase contamination relative to geology and underground structures.

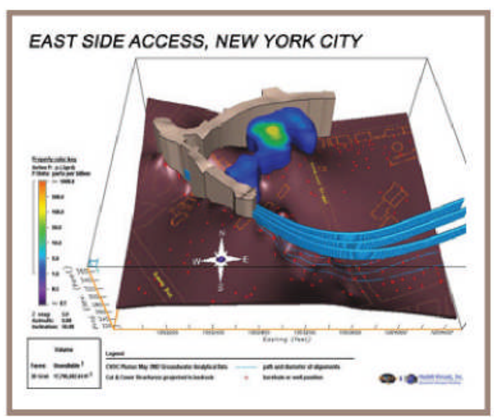
Siesmically Defined Karstic Flow Paths



Example: *Fairbanks Disposal Pits,*
Gainesville Florida

- Delineated structural controls on possible vertical hydraulic communication between a surficial contaminated zone and underlying Floridan aquifer.
- Used borehole and seismic data to model confining layer surfaces relative to a heterogeneous distribution of soils.
- Identified contaminant migration pathways based on truncations in confining layers associated with karstic depressions.
- Six stratigraphic zones and variation in hydraulic conductivity defined by discrete soil sampled intervals.

3D Contaminant Plume Movement



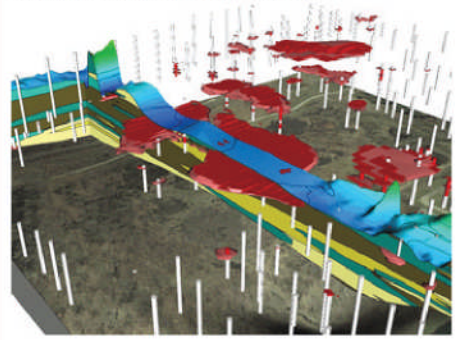
Example: *East Side Access Project,*
Long Island New York

- Imported results from 3D contaminant transport model at 30 time-steps from FEFLOW to an EarthVision geologic framework model of stratigraphic units and underground engineered structures (right).
- Developed computer scripts to automate visualization modeling, output generation, and export to a secure project website.
- Visualization models used to track plume volumes at critical concentration levels, and center of mass movement.
- Animations created to visualize predicted plume movement over time under build and no-build scenarios for every model run to facilitate effective interpretation and evaluation.

EarthVision™ (cont'd)

Probablistic Zone / Parameter Delineation

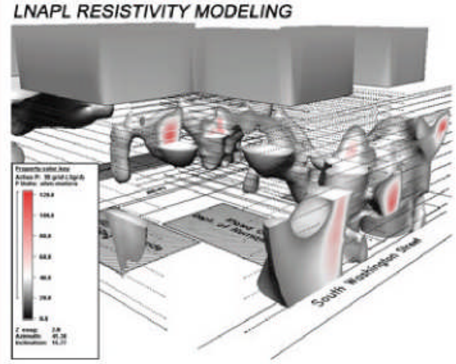
REFINERY TAR SLUDGE, ILLINOIS



- Developed probabilistic method similar to indicator kriging to define the 3D distribution of zones or parameters in the subsurface based on observation data.
- Method is useful for both lithologic zone delineations and non-aqueous phase contaminant delineations such as tar sludge (right) or LNAPL.
- Process defines the extent of the zone or contaminant at specific confidence levels i.e. 90% confidence, 75%, 50%, etc.
- Process is scripted to facilitate rapid updates with new or reinterpreted data.
- Developed visualization modeling scripts to rapidly and automatically generate image output and volumetric reports that are uploaded to a secure project website.

Geophysical & GeoProbe-MIP Data Visualization

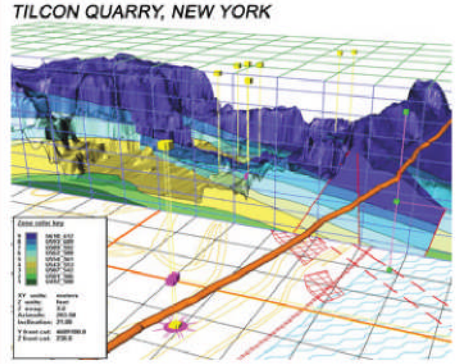
LNAPL RESISTIVITY MODELING



- Developed visualization modeling scripts to automatically read geophysical and GeoProbe-MIP data files.
- Integrate 3D grids with variable grid spacings to account for data that becomes progressively sparse in the z-direction.
- Initial modeling used to constrain interpretive contouring controls and establish standard visualization sets that include key underground and surface structures.
- Automate model generation, visualization production, and volumetric reporting and upload to a secure project website.
- Models and output processed in hours after receiving field data allowing modeling to help guide field characterization efforts.
- Right – LNAPL defined by surface resistivity relative to building locations on the surface.

Structural Modeling for Mining & Quarrying

TILCON QUARRY, NEW YORK



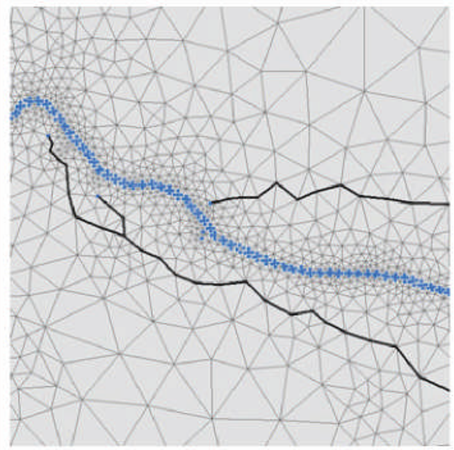
- Model faults, fault zones, and fault displacements in addition to stratigraphic units, and land surface elevations.
- Use multiple data sources including borehole logs, geophysical surveys, and outcrop mapping.
- Can also incorporate mineralogic zonation within stratigraphic units and fault blocks using parameter data.
- Use models to identify target zones, infiltration problems, structural assessments, and as the framework for subsequent groundwater flow modeling used for environmental impact assessments.
- Right – 3D model of the Tilcon Quaryadjacent to the Hudson River in New York that was used to delineate areas in the river contributing infiltration to the quary.

FEFLOW

WASY-DHI FEFLOW

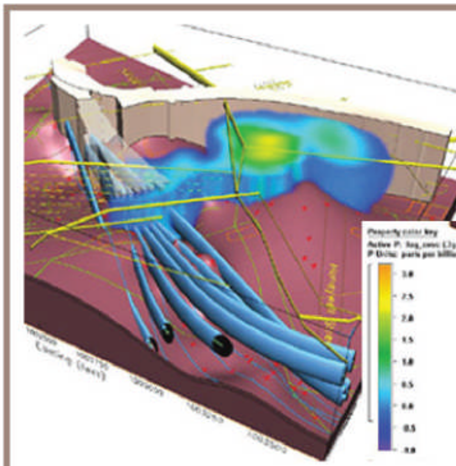
The Geohydros Modeling Group has more than 8 years of experience in the use of DHI-Wasy FEFLOW software including the most current version, 6.0. FEFLOW is our software of choice when developing groundwater flow or contaminant transport models because of its superior ability to solve large, sparse matrix systems using PCG-type or algebraic multigrid solvers and because of the flexibility of finite element gridding when simulating systems with complex geologic and hydrologic characteristics. In addition, FEFLOW is fully integrated with ArcGIS allowing for fast and accurate model design and time efficient model calibration and scenario runs. The following sections provide brief examples of our group's FEFLOW skill sets and how those skills have been applied successfully for our clients.

Discrete Element Features



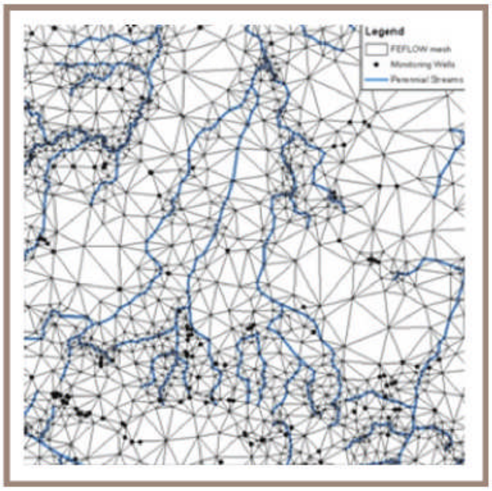
- Developed dual-permeability model using discrete element package to simulate conduit and matrix flow in a karst aquifer (right).
- Karst conduits defined as two-dimensional (horizontal and vertical) linear elements assigned along mesh element limbs.
- Conduits defined between known swallets (infiltration nodes) and springs (discharge nodes) and up-gradient from springs into matrix.
- Flow through conduits defined using Manning-Strickler equation.
- Cross-sectional area used to define capacity of conduit conveyance.
- Roughness factor used to control velocity of water flow (degree to which feature represents a single conduit or zone of conduits).
- Conduit locations and dimensions determined through calibration to groundwater levels, spring discharges, and tracer-defined groundwater velocities.

Free Surface Modeling & Contaminant Transport



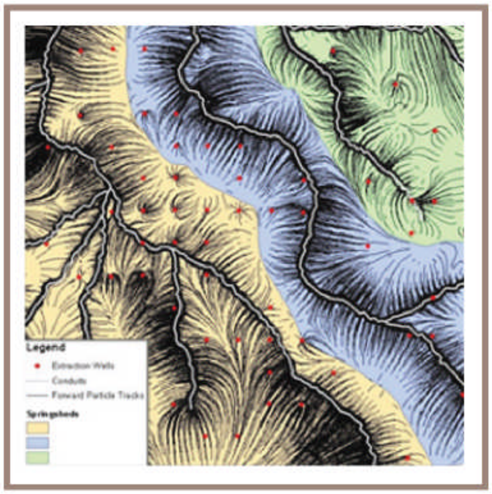
- Used free and movable surface option to simulate transport through variably saturated hydrostratigraphic units and units that pinch out laterally across large model domains.
- Used shock capturing (non-linear anisotropic damping) to stabilize transport simulations affected by numerical oscillations.
- Simulated both simple mass transport and reactive transport through 2D and 3D groundwater flow model domains.
- Simulated both point source and non-point source contaminant transport through 2D and 3D groundwater model domains including nitrate transport through karst aquifers and CVOC transport through extremely heterogeneous mixed glacial surficial aquifers.
- Exported FEFLOW mass transport results by time-step to EarthVision™ (right) to visualize 3D mass transport relative to underground structures and to estimate resulting impacted earth volumes.

Complex Mesh Designs



- Integrated FEFLOW mesh building with ArcGIS to facilitate complex mesh design and refinement.
- Developed complex meshes to simulate lateral and vertical geometries of complex natural and man-made structures that impact groundwater flow including dendritic karst conduits that converge to springs and rivers (right).
- Simulated features include: thin, discontinuous lenses of different material properties, large domes and dikes, steeply dipping lithologies with varying material properties; streams, rivers, springs, and lakes; and sewers and grout walls.
- Ensure that all meshes conform to minimum element angle criteria to promote convergence and minimize model errors.
- Integrate mesh design with EarthVision™ such that lithologic heterogeneities can be defined directly from detailed geologic modeling.

Particle Tracking



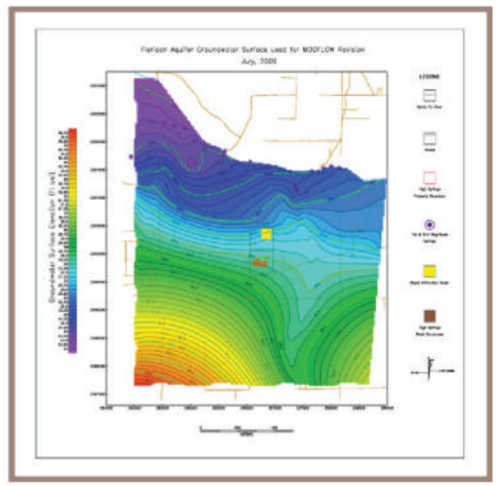
- Use 2D and 3D backward particle tracking to define capture zones for wells and springs.
- Use 3D particle tracks to define recharge areas (contributing zones) for wells and springs.
- Use 2D particle tracks to delineate traditional EPA Zone II wellhead protection zones.
- Export 3D particle tracks to EarthVision™ to develop animations showing flow paths through geologic structure.
- Use forward particle tracking to delineate groundwater basins, springsheds, and vulnerability zones such as contributing zones to conduits that convey groundwater to springs and rivers (right).
- Export 2D particle tracks to ArcGIS for map and figure production.

MODFLOW

MODFLOW (GMS)

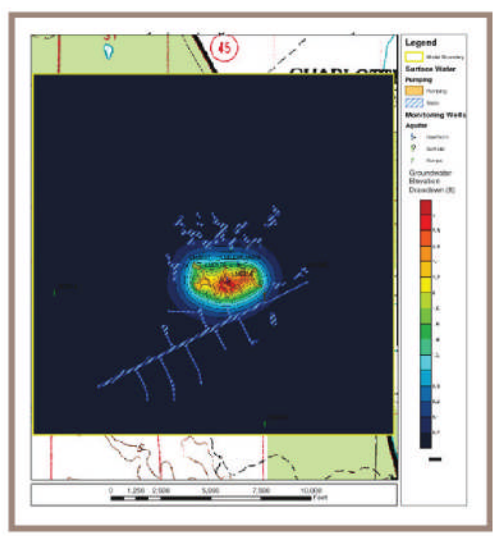
The GeoHydros Modeling Group has over ten years experience using MODFLOW and several of its modules to provide answers to a range of groundwater flow as well as 2D and 3D contaminant fate and transport questions. MODFLOW is the US Geological Survey's modular finite-difference computer code that solves the groundwater flow equation, and has been repackaged with a graphical interface by several software development companies. GeoHydros licenses the most recent version of GMS (6.5), developed by AquaVeo, and also maintains a license of Groundwater Vistas. In addition, the GeoHydros Group has extensive experience with several MODFLOW modules that we use to address more complex problems including: MT3DMS (multi-species mass & reactive transport in 3D) , SEEP2D (a finite-element cross-sectional modeling package), PEST (parameter estimation / optimization), MODPATH (particle tracking), RT3D (reactive transport in 3D), and T-PROGS (transition probability geostatistical package for lithologic modeling).

Parameter Estimation (PEST)



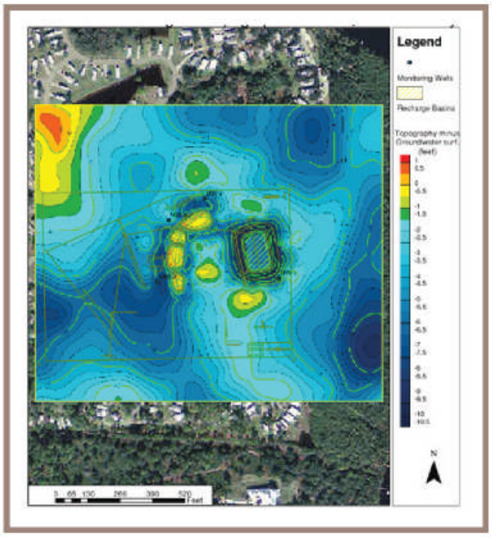
- A model-independent, non-linear parameter estimator. The purpose of PEST is to assist in data interpretation, model calibration, and predictive analyses.
- Used PEST to delineate high permeability zones in a karst aquifer by optimizing the permeability structure to achieve a best-possible calibration to groundwater levels recorded in a dense monitoring well network (right shows resulting steady-state flow field).
- GMS PEST allows modeler to revise parameter settings such as permeability zone delineations during the optimization process and to assign pilot points to provide a continuous rather than stepwise distribution of parameters where appropriate.
- Use composite and relative sensitivity reporting to rank the significance of parameters to the final model results.

Drawdown / Zone of Influence Delineation



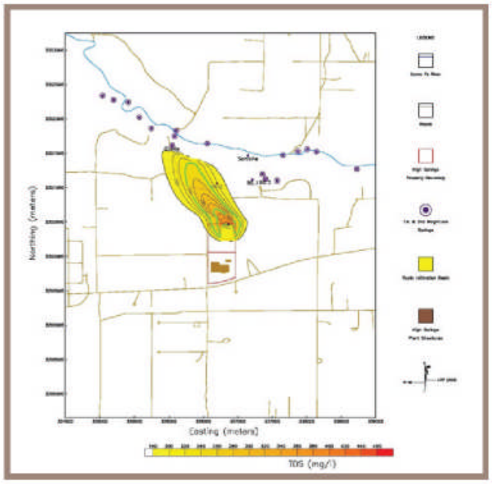
- Used GMS MODFLOW to predict the cone-of-depression created by proposed well installations on a water table surface (right).
- Developed scenario analyses to predict impact of pumping on private supply well water levels in confined and unconfined aquifers; and impacts to wetland water levels and hydroperiods in unconfined aquifers during wet, dry, and average conditions.
- Developed transient models to determine threshold time periods in support of permit application processes.
- Integrated model construction and output processes with EarthVision™ and ArcGIS to facilitate model framework construction in complex geologic settings, map and figure production, as well as definition of surficial features into the groundwater simulation such as River, Lake, Drain, General Head, Well, Horizontal Flow Barrier, Stream, Time Variable Specified Head, Recharge and Evapotranspiration boundary conditions.

Mounding Evaluation & Prediction



- Used GMS MODFLOW to quickly evaluate the potential impact of engineered infiltration basins on surficial aquifer water levels (right).
- Rapidly developed quantitative scenario analyses to provide clients and regulators with map-based predictions that facilitated design and permitting decisions.
- Used scenario analyses to test effectiveness of proposed mitigation strategies when the proposed activities were predicted to generate unacceptable surficial groundwater levels or flooding.
- Performed similar analyses to determine the transient effects on adjacent wetlands of drawing down engineered lake features to supply dry-season irrigation water.

Mass Transport (MT3DMS)



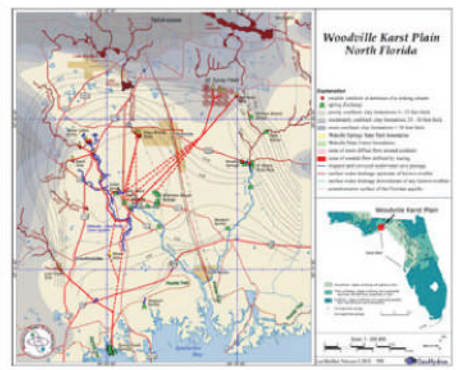
- Simulates multi-species transport by advection, dispersion, and chemical reactions of dissolved constituents in groundwater.
- Used MT3DMS to simulate advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems.
- Projects include: simulation of TDS transport from reverse osmosis wastewater ponds (right); and benzene and MTBE transport from LUST sites.
- Routinely capitalize on GMS/MT3DMS interface to configure separate zones of dispersion and chemical reactions based on field observations or estimations.

ESRI ArcGIS™

ESRI ArcGIS

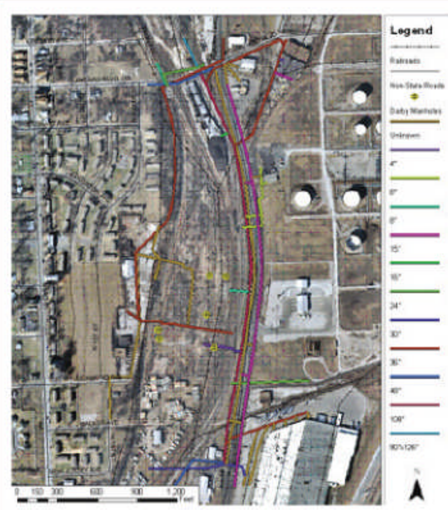
The GeoHydros Modeling Group has more than 10 years of experience in the use of ESRI ArcGIS software including all versions between ArcView 3.2 and ArcGIS 9.3 as wells as Spatial and 3D Analyst. ArcGIS is an instrumental tool in our workflow wherein we use it for pre-processing geospatial data into the required modeling formats, exchange of data and results between modeling platforms, analysis and interpretation of modeling results, and ultimately for the presentation and delivery of data files and final modeling results. Our group's expertise includes spatial projection, geo-spatial analysis and database manipulation, visual basic programming, and publication quality map production. Our group has also performed several GIS specific projects ranging from mine green field site selection to city utilities management.

Publication Quality Map Development



- Efficient and accurate production of quality print-ready maps for reports, articles and independent publication.
- Relating multiple datasets and modeling results to proprietary and publically available basemaps, and aerial photographs.
- Identifying and synthesizing publically available basemap data such as US, State and local roadways, rivers, watershed boundaries, and high resolution aerial photography.
- Porting unprojected or improperly projected maps and images into project projections and datums.
- Post-processing maps with high end image editing or graphic illustration software such as Adobe Photoshop (right).

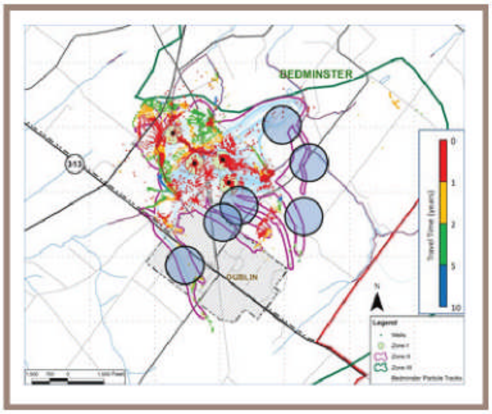
Interfaceing with Modeling Programs



- Developed computer programs to integrate results and output from MODFLOW, FEFLOW, and EarthVision into GIS compatible coverages that provide a standardized presentation interface.
- Developed computer programs that allow for rapid updates to model files and GIS output.
- Rapidly updated GIS allows for near real-time data gap analyses that our clients have used to optimize field characterization efforts.
- Developed computer programs to automatically port model output, GIS coverages, and maps to secure project website for rapid delivery to project6 team members.
- Our proprietary automated model and GIS update process significantly improves rapid site characterization (Triad) projects.

ESRI ArcGIS™ (cont'd)

Visualization & Analysis

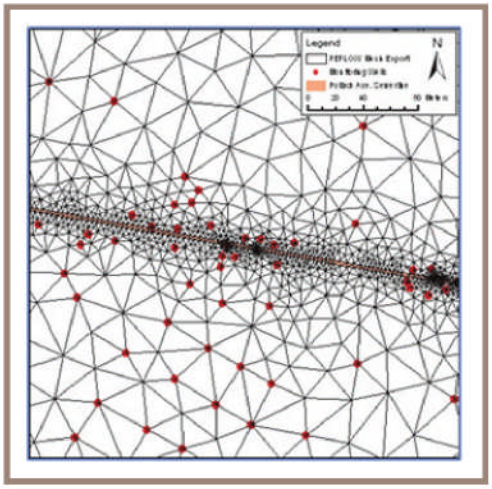


- Adept at porting all manners of model output and data into GIS coverages with standardized projections.
- Use GIS and Spatial Analyst to modify data and model results to facilitate interpretations and dissemination to project team members and regulatory agencies.

Example: *GIS interpretation and visualization of particle tracks*

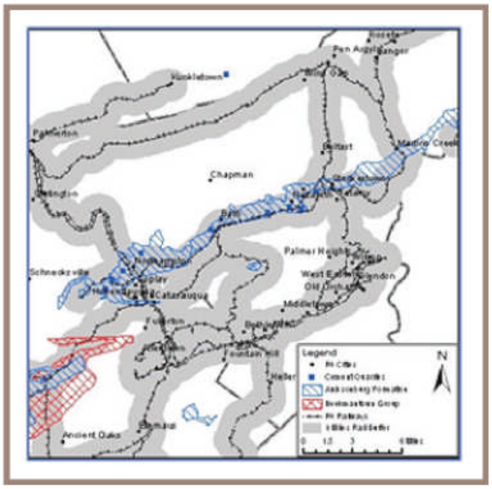
- 2D and 3D particle tracks exported from FEFLOW as polyline layers with data fields for depth of flow and groundwater velocity.
- Intersected paths with the land surface to identify model-defined recharge areas for the wells that were used for vulnerability mapping along with sources of potential contamination such as industrial zones, transportation systems, population centers, and mining regions.

Flow Model Development



- Use ArcGIS to delineate key spatial data such as wells, rivers, sewers, and hydrogeologically defensible parameter zones.
- Port hydraulically significant points, polylines, and polygons into MODFLOW or FEFLOW for grid/mesh development (right).
- Export mesh to ArcGIS to facilitate grid/mesh modifications to most accurately represent key features.
- Interpolate hydraulic conductivity, recharge, layer elevation and other hydrologic variables across model layers from points representing known measurement locations.
- Assign boundary condition values such as constant head, constant flux, and pumping / injection rates to model nodes.
- Manipulate parameter values on a zone-by-zone basis in between model runs during model calibration process.

Zone of Interest Delineation



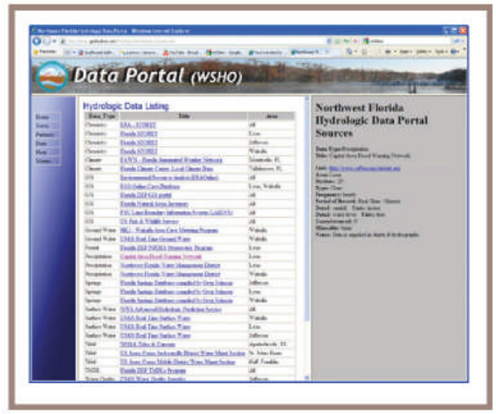
- Develop formulaic approach for delineating specific regions of interest based on combinations of desirable characteristics defined in multiple lines of geo-spatial data.

Example: *Quarry green field site selection*

- Compiled and synthesized all forms of relevant data including surface and near surface geology, transportation corridors, and municipality boundaries and regulations.
- Developed formula that defined and ranked target zones based on criteria for each dataset (right)
- Developed maps with corresponding data tables from the GIS that were used to facilitate client decisions.

ESRI ArcGIS™ *(cont'd)*

Metadata Production



- Develop comprehensive meta-data files for all components of ArcGIS map sets including spatially projected maps and data streams supporting the maps.
- Developed proprietary tools for creating web-accessible metadata for project maps and data as well as publically available but not easy accessible datasets.

Example: *Florida Geological Survey Web Data Portal*

- Developed browser-based metadata catalog using Javascript and an XML data model http://www.geohydros.com/FGS/HydroPortal/.
- Developed computer program that produces metadata tables that can be updated with changes or added data in minutes.

User Interface Development

- Developed custom web-applications, online databases and web-based GIS interfaces.

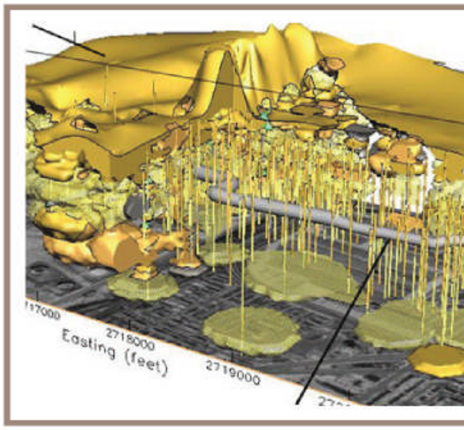
Example: *Map Browser*

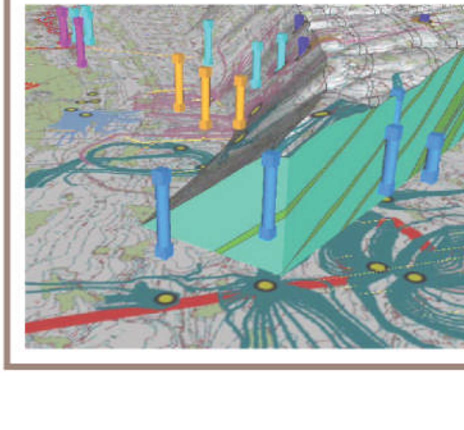
- Web interface that allows users to browse pre-constructed ArcGIS maps as small (quick loading) and large (viewable details) images and download full-scale versions of the maps as pdfs.
- Maps are organized by category and are rendered accessible by drop-down menus off of the Map Browser website.
- Developed Map Browsers for several water resource modeling projects with Coca-Cola, the Florida Geological Survey, and Hardin County, Ohio.
- Main benefits include low cost, ease of use, and that it is rapidly updatable as new maps are created or existing maps are modified.

GeoHydros LLC

Specialized Geological Modeling

PROJECT EXPERIENCE





GeoHydros LLC

Specialized Geological Modeling

GROUNDWATER FLOW MODELING

PROJECT NAME & LOCATION	DATE STARTED	DATE COMPLETED
Defense Supply Center Philadelphia (DSCP) Groundwater Remediation, Philadelphia, PA	June 2001	February 2012

ACTIVITY TITLE	APPROXIMATE CONTRACT VALUE
Geologic & Groundwater Flow Modeling	$700,000

CLIENT NAME & ADDRESS	TECHNICAL CONTACT
Tetra Tech EC, Inc. Langhorn, PA	Defense Energy Support Center (DESC): Hasan Dogrul TTEC: Derek Pinkham, (215) 702-4070

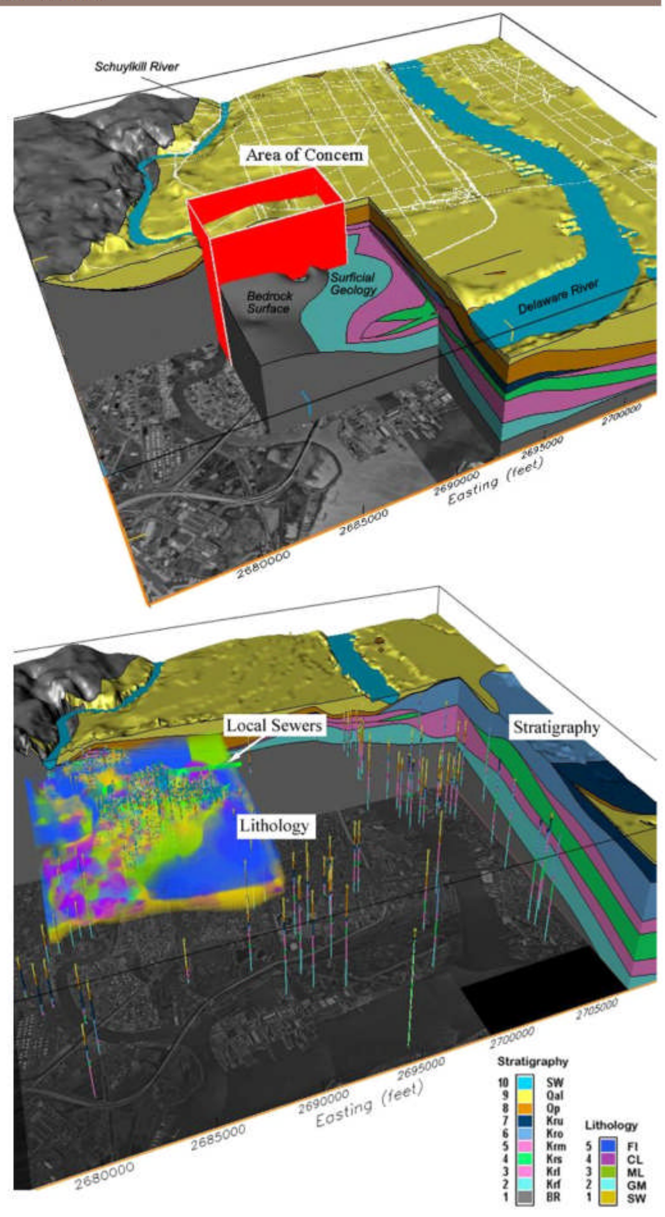
PROJECT DESCRIPTION

The Defense Energy Support Center (DESC), in collaboration with Tetra Tech EC (TTEC), contracted the predecessor of GeoHydros, LLC to construct a comprehensive geological framework model (GFM) for the Defense Supply Center Philadelphia (DSCP), construct a 3D groundwater flow model (GWM) from the GFM, and then use the models to assess and visualize contaminant transport pathways from an impacted surficial aquifer into a lower potable aquifer.

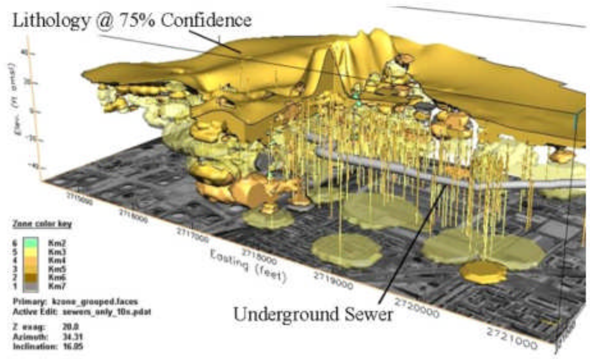
Our GFM synthesized disparate datasets describing the stratigraphy and lithology into a consistent inter-pretation of hydrostratigraphic controls on groundwater flow and dissolved and free-phase contaminant movement. We first developed a scalable database to manage all site and regional geologic and hydraulic data. We then used EarthVision™ to develop the GFM, using a combination of surface, isochore, and parameter grids. We used a telescoping gridding technique to identify and preserve regional trends at the boundaries of higher-resolution site-scale grids; and an iterative grid stacking routine to insure that both thicknesses and surface elevations were honored.

Our model used a probabilistic approach to simulate 26 soil/sediment types that were defined across the site and group them into 5 groups having similar hydraulic conductivity. Indicator grids developed for each of the five units were then compared on a node-by-node basis to arrive at a model of lithology marking the 3D distribution of the units according to their respective probabilities. The model was then used to map hydraulic conductivity heterogeneity relative to underground structures and synoptic models of LNAPL morphology.

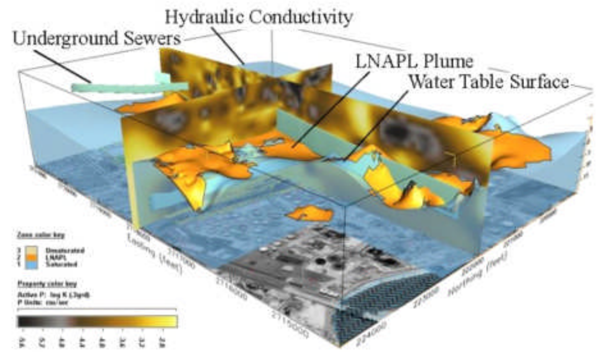
Overall, the GFM consolidated data from more than 1000 wells & borings collected over more than 15 years, paper maps and CAD files describing underground structures, digital topographic maps and surveys, aerial imagery, and published geologic maps. Output included perspective views, x, y, and z slices, and cross-sections, as well as the digital framework for the GWM.



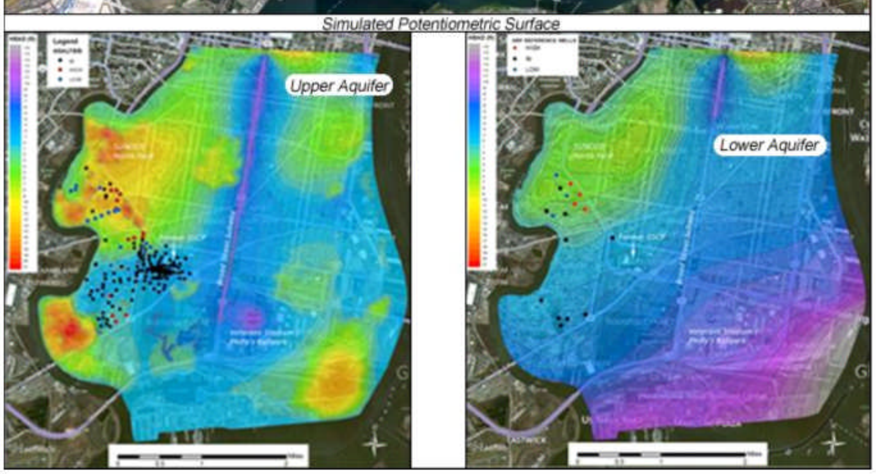
The DSCP GFM showing stratigraphic & lithologic variation across the Site & Regional scales of analysis



Probabilistically defined lithology relative to sewers



LNAPL plume, water table, litology, and sewers

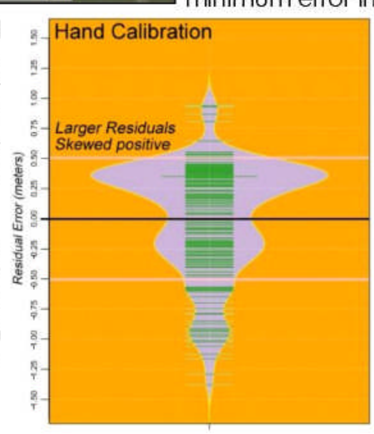


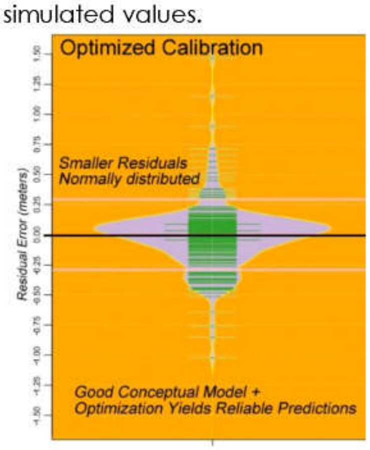
The GWM was constructed using a finite-element approach and the modeling software FEFLOW™, which uses the Pre-Conditioned Conjugate Gradient iterative solver to solve 3D groundwater flow equations. The external model boundaries were designated to 1) buffer the area of concern; 2) extend to definable natural hydrologic boundaries; and 3) include all known sources and sinks that were thought to influence flow across the area of concern. Sources and Sinks included: recharge into the upper surficial aquifer; discharge to the rivers at the model boundaries; dewatering along a major subway line; leakage into a large mixed storm-water/sewer that bounds the area of concern; and extractions from a large recovery well operating at an adjacent property. The model contained 28 layers (from the GFM) defined by a mesh consisting of over 42,000 nodes and more than 83,000 elements per layer.

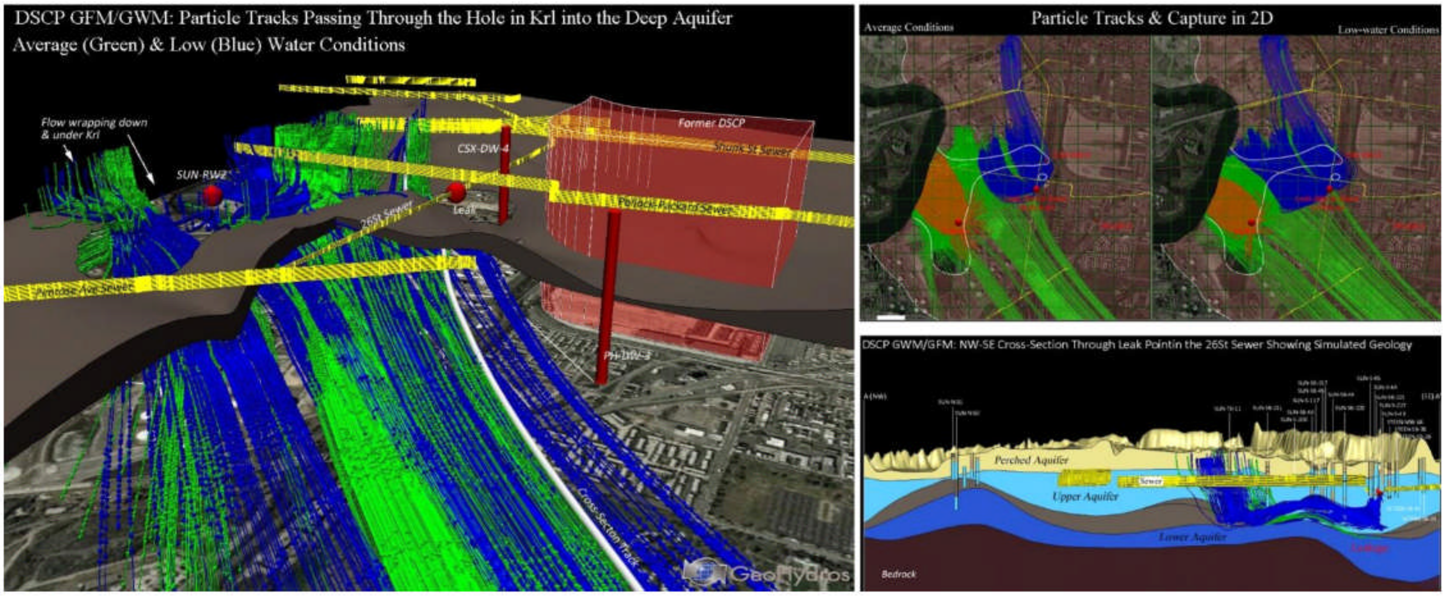
Calibration was performed to average groundwater levels derived from statistical analyses of data from 321 wells that yielded 176 values deemed to be indicative of surficial aquifer conditions, 20 values indicative of deep aquifer conditions, and 53 values indicative of a perched aquifer directly underlying the region of interest. An initial "hand" calibration was performed through a series of 100 model runs in which hydraulic conductivity and recharge zones were identified and constrained. The model was then optimized through a series of more than 14,000 additional runs using a Lipschitzian-based algorithm, which is a mixed global-local optimization scheme that places strong weight on the identification of a global minimum error in simulated values.

Optimization produced a substantially superior model calibration than what would have otherwise been considered a rigorous hand-calibration. The same result could not have been achieved with a standard PEST approach because the process would have repeatedly stopped at a local (acceptable) result before finding the global minimum residual error.

Model results included a series of simulated potentiometric surface maps for the upper and lower aquifers under average and low-water hydrologic conditions as well as 3D particle tracks that depicted the regions of leakage from the upper to lower aquifers and the degree of capture associated with each of the model sinks.







Results from the optimized GWM brought back into the GFM for visualization and analysis. Particle tracks were used to depict the regions at the land surface where the lower aquifer is most vulnerable to contamination from dissolved-phase contaminants emanating from a large LNAPL plume. Scenario analyses were then used to evaluate the potential change in leakage, contamination and plume capture associated with changing hydrologic and engineered conditions.

SELF ASSESSMENT

We met or exceeded all objectives set forth by our client (TTEC) and their client (DESC) and in so doing produced state-of-the-art modeling products that inspired confidence in the remedial approach with the State and public. We adapted and automated our model development processes in order to meet progressively expanded objectives associated with the remediation and litigation efforts in a timely and cost-effective manner. We adopted and adhered to a milestone approach for both phases of modeling to allow for periodic review of the model status with remediation and litigation teams and adopt course adjustments as subsequently deemed necessary. Our interim and final model results both from the GFM and the GWM were repeatedly used for in-house and public presentations as well as reports and proposals to the State related to site closure.

Improvements to the modeling process could have been achieved if we had been more assertive and effective in demonstrating the need for thorough data assimilation from outside sources in advance of model development wherein multiple model revisions were required to address data progressively obtained through research performed by other team members. Additionally, a major lesson learned was in the benefit of simultaneous as opposed to sequential GFM/GWM development. Time and cost savings could have been achieved by performing both in concert and therefore more effectively identifying the data and model components most significant to the primary modeling objectives.

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RAPID SITE CHARACTERIZATION

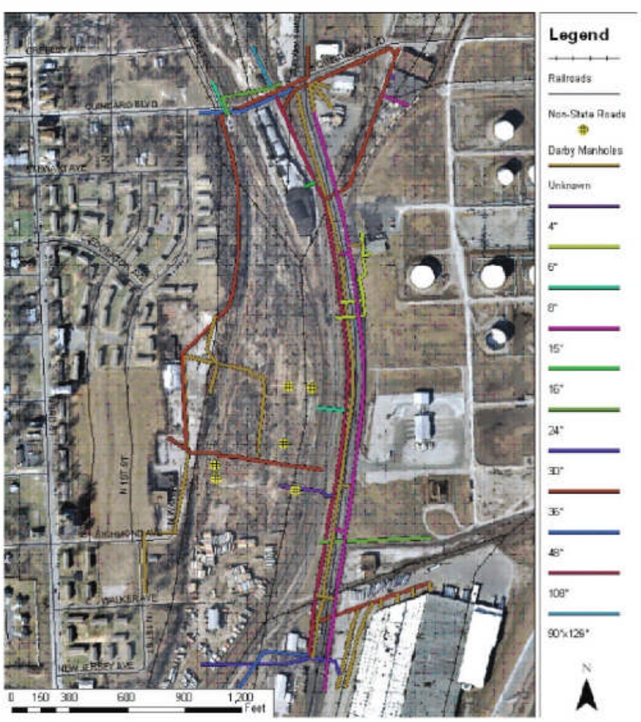
PROJECT NAME & LOCATION	DATE STARTED	DATE COMPLETED
Darby Site Overland Park, Kansas	March 2007	September 2009
ACTIVITY TITLE	**INITAL CONTRACT PRICE**	**FINAL AMOUNT INVOICED**
Geophysical Modeling & GIS	$25,000	$111,905

CLIENT NAME & ADDRESS	TECHNICAL CONTACT
Delta Environmental Consultants Kansas City Office (800) 477-7411	Roger Lamb, R.G. (913) 422-3555 x553 rlamb@environmentalworks.com

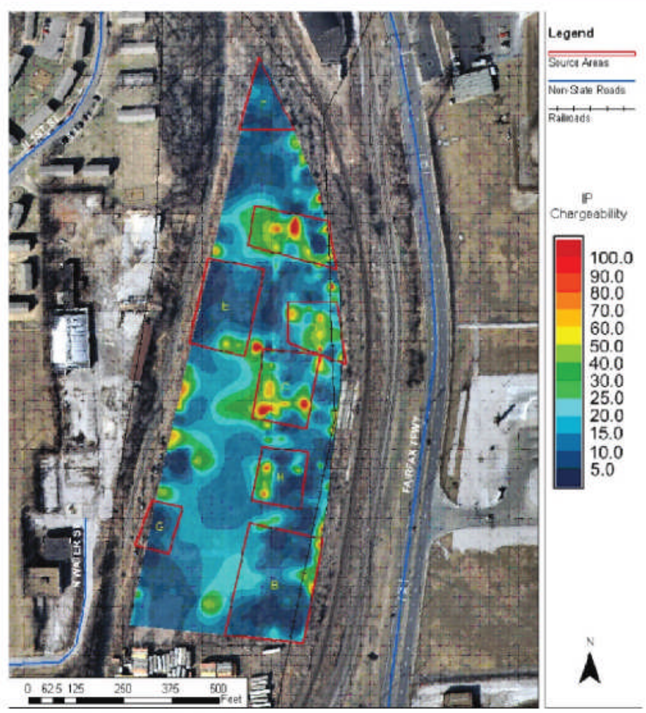
PROJECT DESCRIPTION

The Darby site is a former oil refinery in Kansas where GeoHydros has produced a GIS integrated with an in-house relational database containing lithologic, geophysical, soil analytical, and GeoProbe-MIP data, as well as EarthVision 3-D solids models of subsurface lithologic variations and contaminant distributions. The goal of the project was to produce a rapid, robust and comprehensive analysis of the site using a rapid site characterization (Triad) program and 3-D visualization of the data to guide the field work. Approximately 420,000 surface geophysics and Geoprobe-MIP measurements were modeled in 3-D. Computer scripts were written to automate model updates, output development, and project website uploads on a daily basis. The maps and visualizations provided a detailed and cost-effective 3-D understanding of the extent and magnitude of fuel impact in the subsurface that guided the field characterization program.

Many different types of spatial data were incorporated into the Site GIS such as, municipal utility lines, sewer and water mains, historical aerial images, and historical site engineering plans. Non-projected historical maps were digitized and spatially projected by identifying reference locations on roads and features common to both the historical maps and spatially projected aerial images. The GIS then provided a consistent set of diagrammatic and aerial photographic basemaps onto which all data and model output was projected for report and presentation figures.



Digitized sewers and attributes from city drawings over aerial photo where line color marks sewer diameters.



Spatial analysis of geophysical survey data related to key Site features and an aerial photograph.

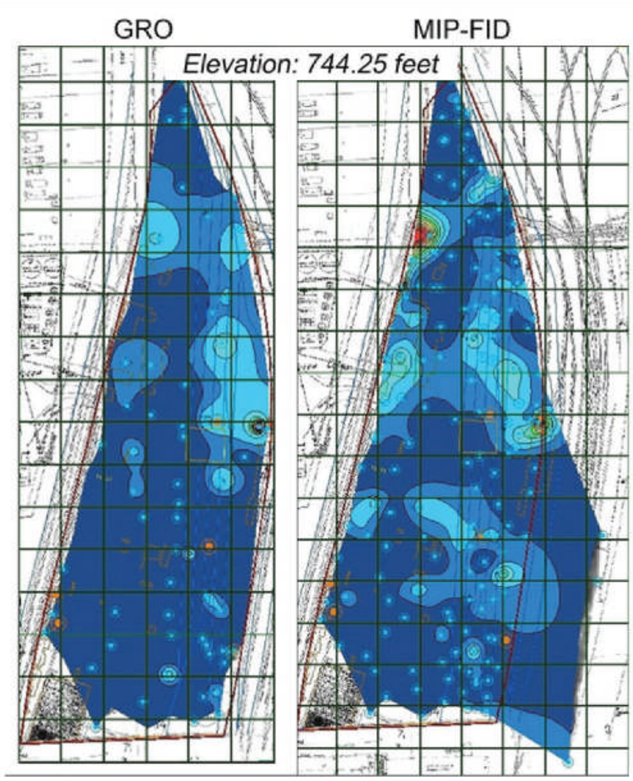
We then developed a desktop, relational, geospatial database for the project that provided a single central repository for all lithologic, geophysical, MIP, groundwater level, and laboratory analytical data collected at the Site. The database was developed using Microsoft Access and Visual Basic and linked to the Site GIS thereby reducing the time required to update maps and figures with new or changed data. Additional queries were developed to produce lithologic and parametric datasets formatted for immediate upload to 3D modeling software and to develop QA/QC reports designed to confirm all data uploads and application datasets.

3D solids and parameter models were then developed to define the lithologic structure underlying the site and the distribution of soil contaminant values that were measured in the field. Correlations were developed between parametric models of the laboratory soil analytical data and the field measured parameters FID and PID. The parametric models were then used directly to define the horizontal and vertical extent of the soil contamination and estimate contaminated soil volumes above critical threshold levels specified by the Kansas Department of Health and the Environment.

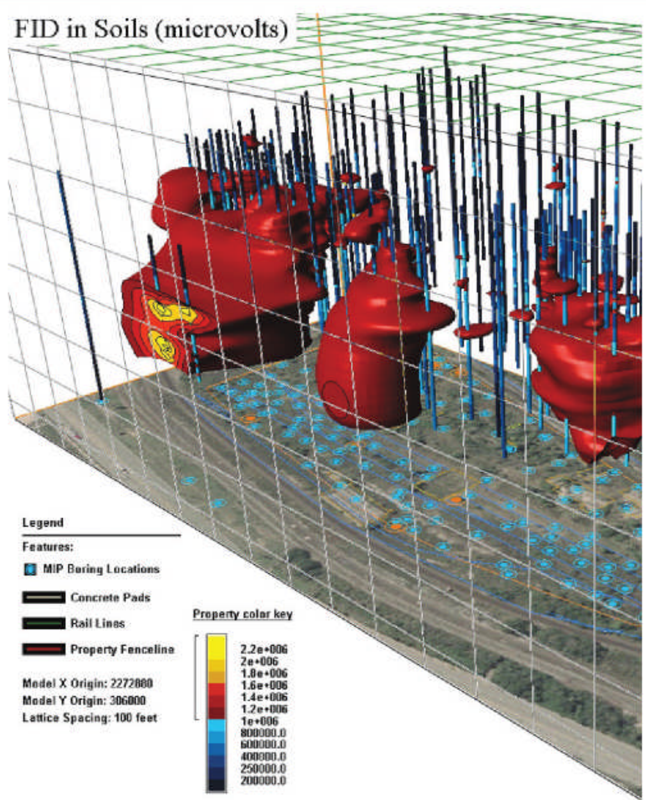
We used EarthVision™ for 3D modeling and visualization to capitalize on the software's advanced visualization and most importantly its batch processing capabilities wherein computer scripts were used to automate model development, output generation, and export to a secure project website. Automation allowed the models to be updated daily, hourly in some cases, which enabled the project manager and field team to effectively use the modeling results to guide the Site characterization objectives. Model output downloaded from the project website was then used in conjunction with the GIS-generated maps and figures for project reporting and presentations wherein the automation enabled rapid edits over the ensuing year-plus reviewing period.

SELF ASSESSMENT

GeoHydros successfully generated rapidly updatable, very high resolution, 3D models (0.05 foot vertical interval) of soil contamination that were considered by the project management and the regulatory agency to significantly expedite an effective rapid site characterization (Triad) approach that saved money and time and facilitated better decision making.



Comparison of MIP & laboratory analytical data from 3D models sliced at a specific elevation



3D distribution of FID in soils where VOC contamination is above the State-defined threshold

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WATER RESOURCE MANAGEMENT

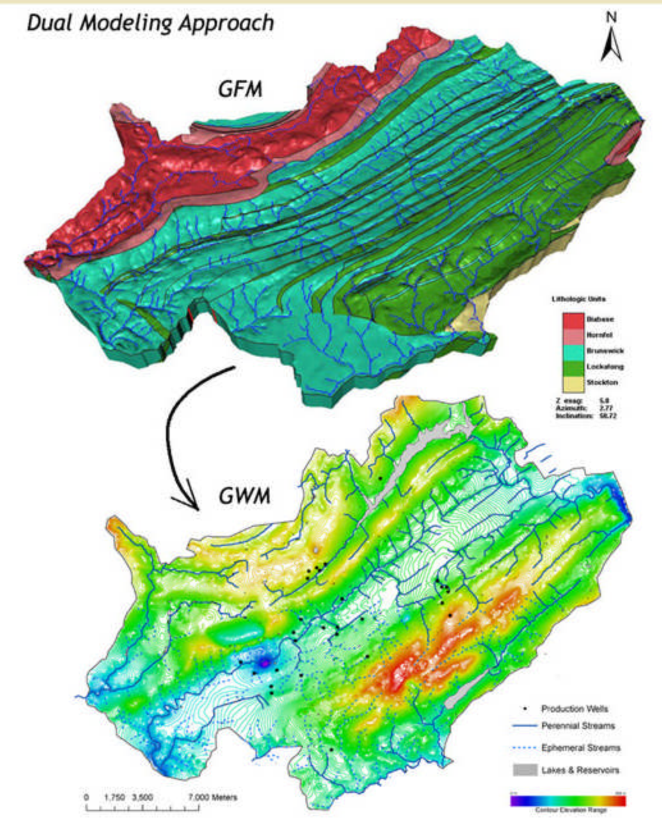
PROJECT NAME & LOCATION	DATE STARTED	DATE COMPLETED
Pennridge Wellhead Protection, Bucks Co. PA	January 2005	May 2007
ACTIVITY TITLE	**INITAL CONTRACT PRICE**	**FINAL AMOUNT INVOICED**
Geological & Groundwater Flow Modeling	$85,000	$85,000

CLIENT NAME & ADDRESS	TECHNICAL CONTACT
Borton Lawson Engineering Wilkes-Barre, PA (570) 821-1999	Dennis Livrone – Bucks Co. Planning (215) 345-3422 dplivrone@co.bucks.pa.us

PROJECT DESCRIPTION

The GeoHydros modeling group developed a numerical groundwater flow model to assist six Philadelphia area municipalities managed by the Bucks County Planning Commission with the design of a comprehensive aquifer protection strategy. The basic objectives of this project were to: (1) compile and synthesize all available geologic and hydrologic data into a comprehensive Geologic Framework Model (GFM) describing structural controls on groundwater flow through the regional fractured rock aquifer; (2) convert the GFM into a basin-scale numerical groundwater flow model (GWM); and (3) use the GWM to develop wellhead protection zones (WHPZ) for 19 Bucks County municipal wells.

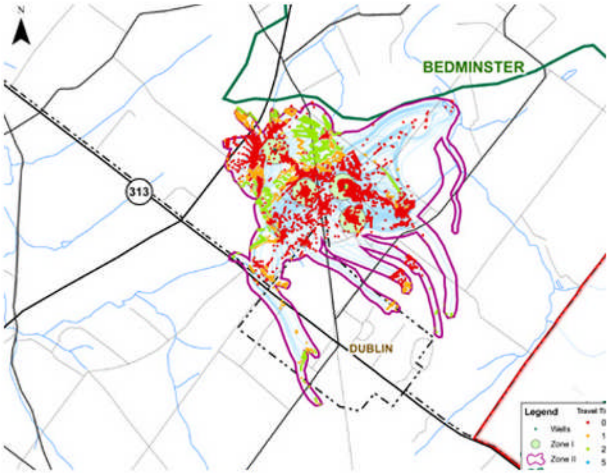
These objectives were achieved through numerical modeling using FEFLOW™ that was based on a detailed geological framework model (GFM) developed in EarthVision™. The GFM correlated fracture controls on groundwater flow throughout the basin with bedding orientations and contacts separating three geologic units: the Brunswick and Lockatong Formations and a diabase intrusion. The model incorporated strike and dip data and outcrop boundaries from geologic maps and cross-sections, borehole logs, and soil survey data to simulate 60 interbedded lithologic units of varying thickness, geometry, and permeability that have been structurally tilted The framework was then exported to FEFLOW for groundwater modeling where the geologic structure could be seen to exert significant control on simulated groundwater flow paths and velocities across the basin. Particle tracks were used to define well capture zones and then integrated back into the GFM in 3D to define the specific recharge areas contributing flow to the municipal water supply wells, which were used together to define the EPA Zone II WHP Zones.



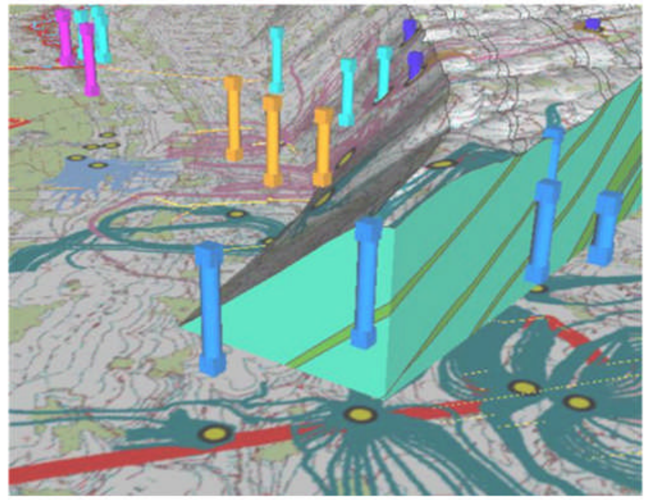
(Top) Geologic framework defining the 3D orientation of 60 dipping interbedded stratigraphic units intruded by an igneous dike and dissected by streams.

(Below) Simulated groundwater flow field based on the hydrostratigraphic framework from the GFM and hydraulic conditions created by streams, quarry dewatering, and municipal groundwater pumping.

GeoHydros successfully generated rapidly updatable, very high resolution, 3D models (0.05 foot vertical interval) of soil contamination that were considered by the project management and the regulatory agency to significantly expedite an effective rapid site characterization (Triad) approach that saved money and time and facilitated better decision making.



Delineation of standard EPA Zone II WHP boundaries (purple line) as defined by 2D particle tracks and alternate Zone II boundaries (colored points) defined by 3D particle tracks intersecting the bedrock surface.



Orientation of water bearing (blue) and confining units (green) relative to the position and depth of municipality water supply wells and the well capture zones simulated in FEFLOW.

Deliverables included: (1) delineation of wellhead protection zones based on 3D particle tracks, (2) incorporation of model results & wellhead protection zones into appropriate ordinance language, (3) four quarterly presentations to the Municipality authorities and project management on the status and results of the modeling effort, and (4) a final report on model development, calibration, results, and wellhead protection zone delineation. in a synclinal basin, faulted at one end, and then intruded by the diabase.

SELF ASSESSMENT

GeoHydros successfully developed a regional 3D model of groundwater flow bounded by established no-flow boundaries. The model was developed with sparse data but calibrated well to water levels measured in 19 municipal groundwater supply wells under both static and pumping conditions. Particle tracks exported from the pumping conditions model were used to define well capture zones that were, in turn used to delineate standard EPA Zone II WHP boundaries for all the well fields. The modeling, particle track exports, and reporting were all completed on time and on budget. After the modeling was completed and our budget exhausted, we continued to support the project during a lengthy public review and comment period. Part of that support included developing an alternative set of Zone II boundaries that encircled the recharge areas for the wells as defined by the intersection of 3D particle tracks with the bedrock surface. In the end, the model was well received and the Pennsylvania Department of Environmental Protection stated that it marked a new standard for wellhead protection projects in Pennsylvania.

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KARST CHARACTERIZATION

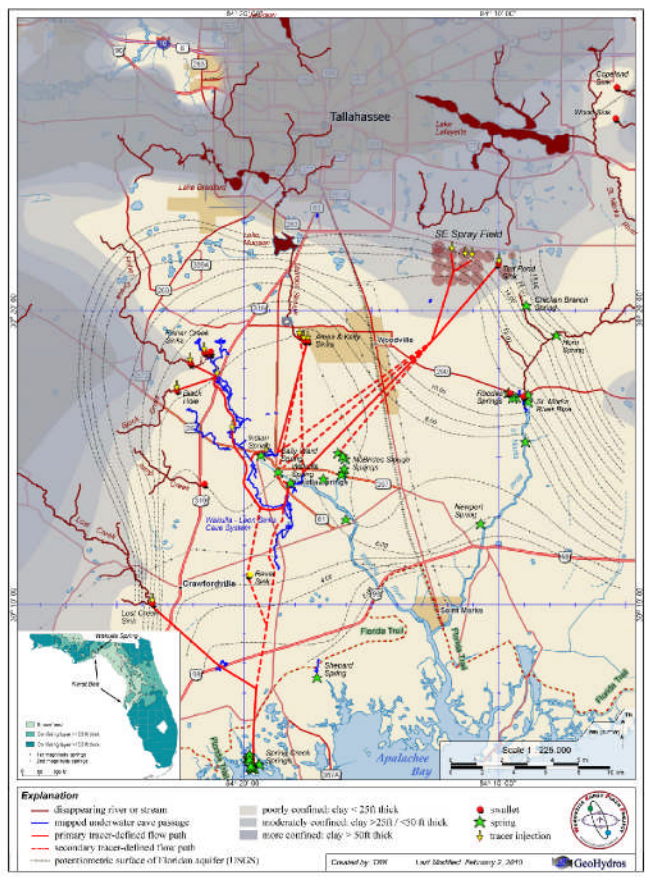
PROJECT NAME & LOCATION	DATE STARTED	DATE COMPLETED
Woodville Karst Plain Characterization, North Florida	July, 2002	On Going
ACTIVITY TITLE	**INITAL CONTRACT PRICE**	**FINAL AMOUNT INVOICED**
Groundwater Tracing & Modeling	$50,000	$1,100,000

CLIENT NAME & ADDRESS	TECHNICAL CONTACT
Florida Geological Survey Florida Department of Environmental Protection Tallahassee, Florida	Dr. Rodney DeHan (850) 488-9380 Rodney.DeHan@dep.state.fl.us

PROJECT DESCRIPTION

The GeoHydros group has been conducting a comprehensive hydrogeological characterization of the Woodville Karst Plain (WKP) of North Florida with the Florida Geological Survey (FGS) that includes quantitative groundwater tracing, hydraulic instrumentation of underwater caves, and dual-permeability (karst) groundwater flow modeling. The purpose is to develop improved methodologies for characterizing and modeling karst controls on groundwater flow and groundwater/surface water interactions in the upper Floridan aquifer and support State TMDL (total maximum daily load) and MFL (minimum flows and levels) programs.

Our quantitative tracing has revealed extremely rapid groundwater flow to Wakulla Spring from several sources of contamination including a swallet that receives 60% of Tallahassee's runoff and the City's waste water spray field; identified the hydraulic mechanisms responsible for varying source water contributions to the spring discharge; and a mechanism responsible for extensive saltwater intrusion to the upper Florida aquifer via large conduits that extend to coastal springs. Tracer-defined flow paths and velocities combined with head, flow, and parameter data being collected from an instrument network installed in various parts of the underwater cave system are being used to develop a new numerical karst groundwater modeling process.



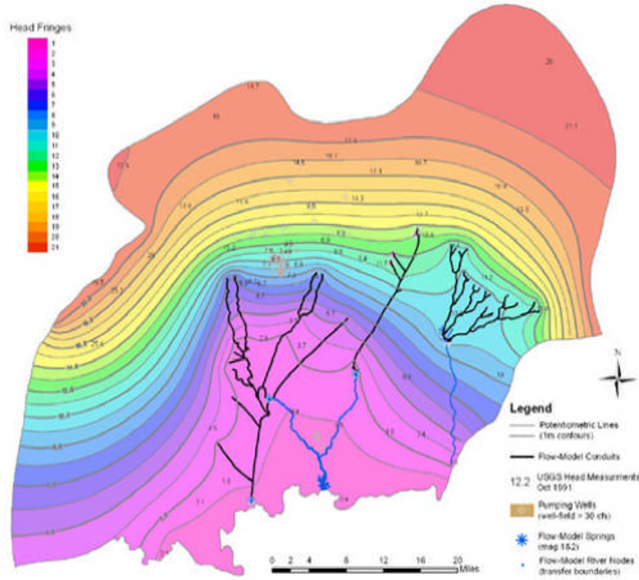
Map of the WKP showing mapped underwater caves (blue), tracer-defined groundwater flow paths (red), springs (green stars), swallets (red dots), streams (brown and light blue lines), and the distribution and thickness of an upper confining layer (shades of gray).

Traces include:

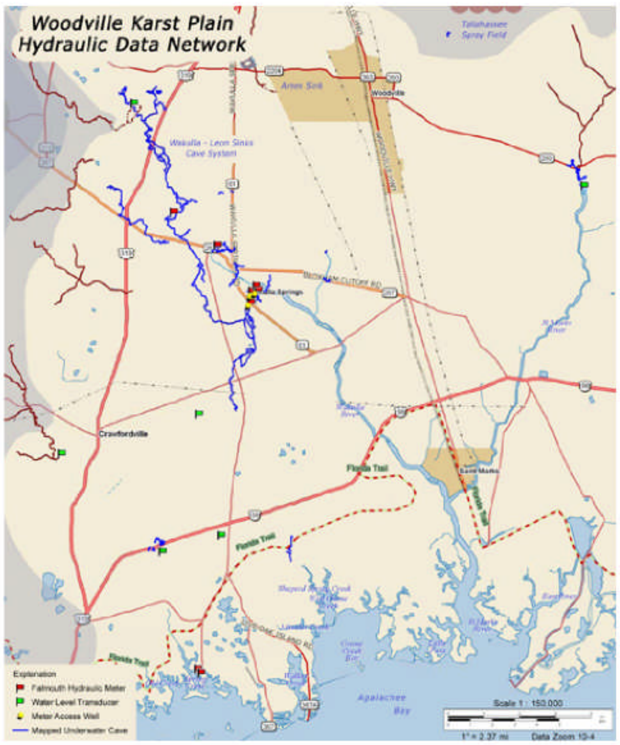
- Fisher Creek swallet to the Leon Sinks cave system *(1.2 miles/0.51 mi/day)*;
- Black Creek swallet to the Leon Sinks cave system *(1.6 miles / 0.50 mi/day)*;
- Leon Sinks cave system to Wakulla cave and Wakulla Spring *(10.6 miles / 1.2 mi/day)*;
- Ames Sink, which receives ~60% of the runoff from Tallahassee, to Indian, Wakulla, and Sally Ward Springs *(~6 miles/ ~0.25 mi/day)*
- Tallahassee's waste water spray field to Wakulla, Springs *(~11 miles / ~0.2 mi/day)*.
- Lost Creek swallet to both Spring Creek and Wakulla, Springs (0.2 – 1.2 mi/day).

GeoHydros has established and maintains a network of hydraulic instruments in the basin that continuously measure head, temperature, conductivity and flow at several natural windows into the conduit network underlying the WKP (right). We developed a custom web interface for the project that allows users to access the data from any combination of meters, generate plots over the Internet and download the data files from any period of interest.

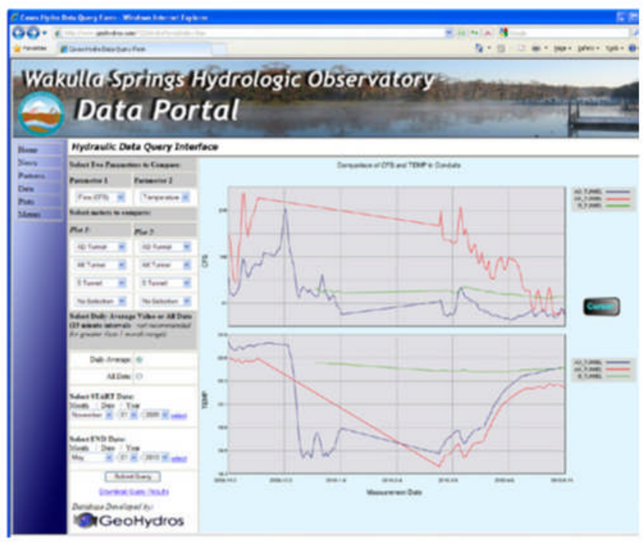
The numerical modeling work being performed here is revolutionary because it uses a dual-permeability framework to simulate conduit and matrix flow, calibrates to discrete spring discharges as well as heads, and simulates the location and size of the conduits through the calibration process. The modeling techniques devised here are intended to establish new protocols for modeling in karstic parts of the aquifer throughout the rest of the State.



Model simulated head field and saturated conduit network for the upper Floridan aquifer in the WKP.



Map showing the location of hydraulic meters and water level transducers in the WKP.



Web interface providing graphical access to the data being collected from longterm monitoring stations.

SELF ASSESSMENT

This project is widely recognized as ground-breaking in terms of its contribution to our understanding of karstic controls on groundwater flow in the upper Floridan aquifer. The tracing results have been instrumental in land-use decisions including the City of Tallahassee's decision to upgrade to an advanced wastewater treatment system at the cost of approximately $200 million; and Wakulla County's decisions on where to delineate a springs protection zone in their zoning ordinances. In addition, the modeling work performed here has defined the methodologies necessary to develop an effective numerical model of karstic groundwater flow and was the precursor to the model completed for the Western Santa Fe River Basin. The fact that this project has persisted in the face of severe budget cuts is testament to its success and perceived utility to the state of Florida.

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GROUNDWATER FLOW MODELING

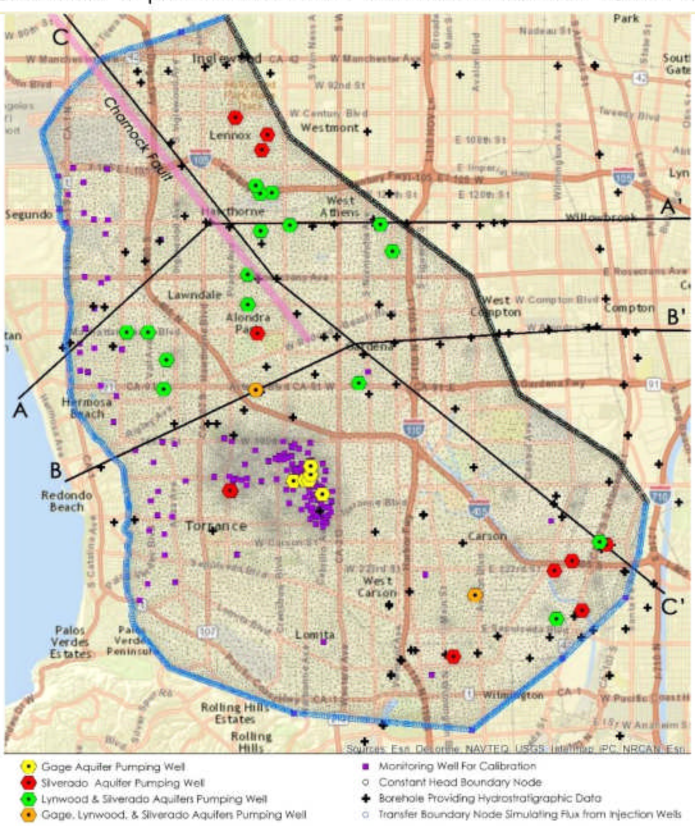
PROJECT NAME & LOCATION	DATE STARTED	DATE COMPLETED
Simulation of Groundwater Flow & Contaminant Capture in the West Coast Basin, Los Angeles Co., CA	January, 2012	July, 2012

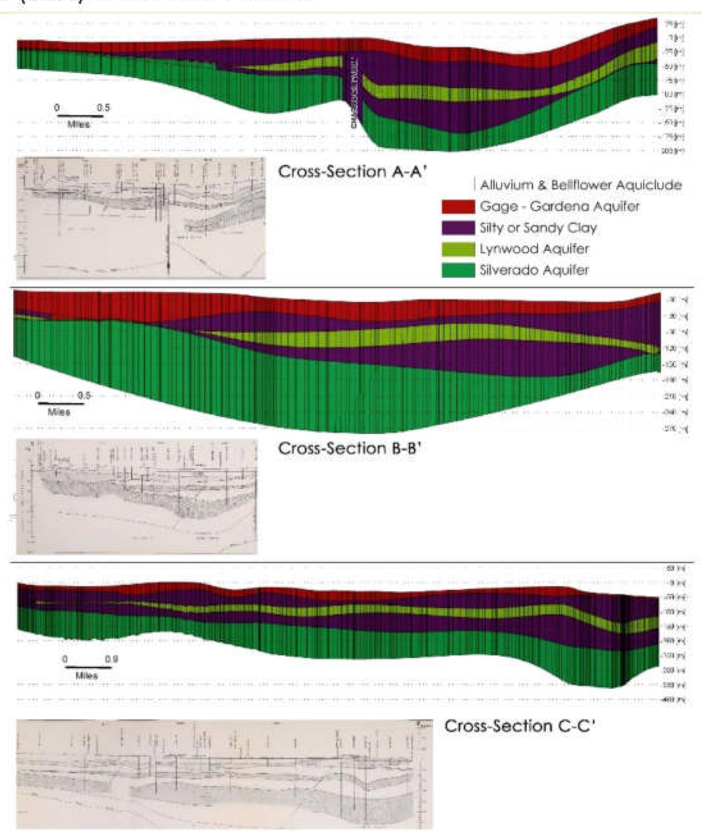
ACTIVITY TITLE	APPROXIMATE CONTRACT VALUE
Groundwater Flow Modeling	$60,000

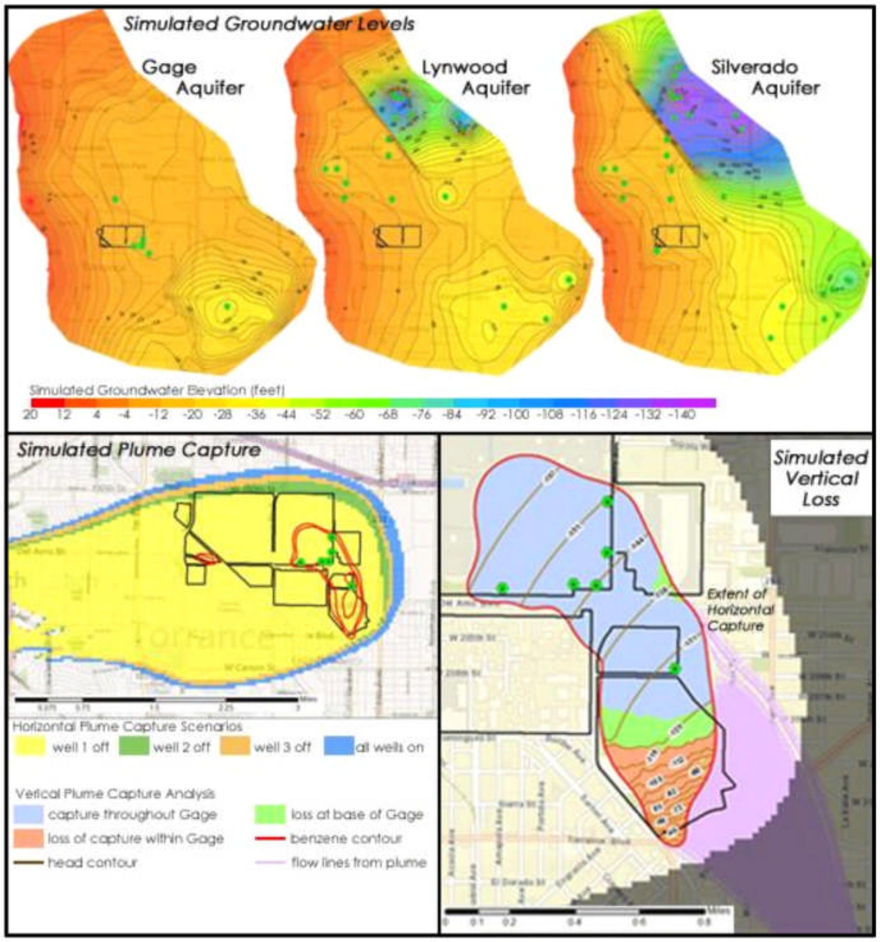
CLIENT NAME & ADDRESS	TECHNICAL CONTACT
Environmental Resources Management (ERM) Walnut Creek, CA	Environmental Resources Management (ERM) Walnut Creek, CA

PROJECT DESCRIPTION

GeoHydros developed a 3D steady-state numerical groundwater flow model for the West and Central Basins in Los Angeles County California in order to simulate capture zones for a network of remediation pumping wells. The objectives were to: 1) expand on an existing model to honor new geologic and hydraulic data; 2) calibrate the model to new groundwater level data; 3) use parameter estimation (PEST) to optimize the model variables; and 4) simulate well capture zones to evaluate plume capture under high, normal, and low water level conditions and recovery well pumping rates. Our model simulated 3D flow through the Gage/Gardena, Lynnwood, and Silverado aquifers, variably separated by discontinuous aquicludes and deformed in the north by the Charnock Fault and the Newport-Inglewood Uplift. The model was constructed in FEFLOW™ using geologic data compiled from more than 300 onsite and offsite boreholes describing hydrostratigraphic contacts and lithology; average head data compiled from more than 10,000 water level measurements collected from 198 monitoring wells in the Gage aquifer, 15 wells in the Lynnwood aquifer, and 39 wells in the Silverado aquifer; and average extraction rates for 136 water supply and recovery wells. The model calibrated to within +/- 0.4 feet of the observed head range at 8 of 11 Silverado, 11 of 15 Lynwood, and 145 of 179 Gage-Gardena aquifer calibration wells for a total of 164 of 205 (80%) calibration wells.







Three scenario analyses were performed to define and evaluate well capture zones under different hydraulic and pumping rate conditions: 1) anticipated normal rates, 2) anticipated minimum rates, and 3) anticipated and design maximum rates. Rates for contaminant movement were estimated on the basis of groundwater travel-times. Contaminant capture was also evaluated vertically using particle tracks seeded at varying depths within the contaminated aquifer.

The model simulated the effect of the Charnock fault as a barrier to groundwater flow and contaminant transport that dissipates to the southeast but becomes more prevalent with depth. The model also successfully simulated the effect of regional groundwater pumping from municipal water supply wells on the groundwater flow field in the vicinity of the plume. Finally, the model demonstrated that capture is effectively maintained throughout the upper portion of the aquifer under all scenarios but that some loss occurs from the deepest portions of the plume under some pumping conditions.

(Top) Simulated head fields in the Gage/Gardena, Lynwood and Silverado Aquifers in the calibrated FEFLOW model showing the effect of the Charnock Fault. (Bottom-left) Simulated capture zones within the Gage/Gardena Aquifer as defined by simulated water table elevation contours and particle tracks. (Bottom-right) simulated loss of capture at depth within the Gage/Gardena aquifer as determined by particle tracks seed at varying depths in the plume.

SELF ASSESSMENT

There are a few areas where the design of the GWM could be modified to produce a better fit to the steady-state calibration dataset and / or make scenario results more defensible. The most significant improvement would be the inclusion of well depth and screened interval data for all of the extraction wells within the model domain for which no data was available during this effort. WRD has a web-based interactive well search system which reportedly allows users access to all known well development data in the West Coast and Central Basins. With these data, any incorrect well placement assumptions could be corrected increasing the accuracy and defensibility of the simulated flow field and capture zones.

Model calibration could also be improved by spending more time on the delineation of aquifer heterogeneity near the regional WRD monitoring locations. More accurately calibrating to all regional wells would improve the reliability of the simulated capture zone boundaries. This would be particularly relevant to efforts aimed at minimizing extraction rates and/or optimizing pumping designs while maintaining plume capture.

Model predictions of travel-time could be improved by more closely analyzing very high conductivity zones that were defined by PEST. Flow directions and plume capture will remain relatively unchanged because the calibration in these regions is good. The high conductivity zones could however be generating over-predicted travel-times through these areas. To evaluate this, a sensitivity analysis should be performed in order to determine if equally good calibration could be achieved with lower assigned conductivities in these zones.

Finally, we could expand the calibration dataset, and therefore increase the model's defensibility, if we could gain access to head measurements recorded by the WCBBP for their monitoring well system. We were only able to find head measurements from this system from one measurement period. However, we did find references to semi-annual system reports and contour maps developed on this measurement cycle. Collection of head data from this system for the steady-state time period would allow us to develop steady-state values for these wells and use them to better control the PEST estimations.

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