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**MEMORANDUM No. US-CA-SLO-TM-001-0 Rev. 0**

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Company, San Luis Obispo County, Groundwater Sustainability Director  
Position:  
Subject: Los Osos Basin Groundwater Flow and Seawater Intrusion Model  
CC: NA  
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## EXECUTIVE SUMMARY

This technical memo presents a summary of key findings, conclusions, and recommendations developed by Dr. Jim McCord and Mr. Randy Hanson in a high-level review (McCord and Hanson, 2025a) of the groundwater modeling tool being developed for groundwater sustainability planning in the Los Osos groundwater basin (CHG, 2025a). Based on our review of the groundwater modeling tool, we offer the following primary conclusions:

- The model, in its current configuration, is a valuable tool that can be effectively used in evaluating the relative basin-wide benefits and impacts to the Los Osos Groundwater Basin for comparing various proposed Management Actions and Projects, such as those described in the Water Recycling Funding Program Facilities Planning Study (WSC, 2025).
- Due to inherent and unquantified levels of uncertainty in the model, its usefulness in accurately simulating and predicting the specific location or rate of movement of the leading edge of a seawater intrusion front is extremely limited. This is important because the determination of a sustainable yield in this Basin is based on a comparison of the location of the 250 mg/L Chloride concentration contour with a specific, spatially defined threshold line. In its current configuration, the model does not have the capability of accurately and reliably simulating and predicting whether or not the seawater intrusion front will ever reach the previously defined threshold line, nor under which conditions such an event will occur.

## 1 INTRODUCTION

This technical memo presents a summary of key findings, conclusions, and recommendations developed by Dr. Jim McCord and Mr. Randy Hanson in a high-level review (McCord and Hanson, 2025a) of the groundwater modeling tool being developed for groundwater sustainability planning in the Los Osos groundwater basin (CHG, 2025a). While that technical memo covers a broad area of the model, this memo is intended to address key specific questions that have been raised by Los Osos basin stakeholders since the original memo was issued. Those specific questions are:

1. Is the current model predicting, that based on the model calibration to the existing baseline conditions that “seawater intrusion” will continue if no management actions are taken?
2. Is the current model accurately predicting the location of the 250 mg/l weight chloride (CL) contour?
3. In our opinion, is the model capable of accurately predicting the exact location of that CL contour 45-years in the future? If not, is there enough data to predict how much variability / uncertainty is associated with that prediction?
4. Can the model, as it exists today, accurately predict the future rate of intrusion, should baseline pumping conditions continue unchanged?
5. What are the most likely reasons that the simulated Cl concentrations for current conditions do not match very well the actual measured concentrations?
6. Can the current model be employed for assessing impacts of groundwater management changes?
7. And finally, are there any key “low-hanging fruit” investigations and/or enhancements be made with the model to reduce its uncertainty / increase the model’s reliability?

### 1.1 Review Process

At the request of the San Luis Obispo County Groundwater Sustainability Department (SLO GSD), Dr. McCord and Mr. Hanson conducted a high-level review of the groundwater model being developed for the Los Osos groundwater basin. Their review included both the draft report and the numerical model,



along with its input and output files. The technical memo detailing their findings was submitted to the county on May 16, 2025 (McCord and Hanson, 2025a). Following this, the report authors from CHG met with the reviewers to clarify and resolve the issues raised. While CHG was able to address most of the comments by adding clarifying details to the report, several issues could not be resolved within the existing scope of their model development and application project.

## 1.2 Model Refinement Options

A subsequent technical memo listing enhancements that could be made to better quantify model uncertainties and improve its predictive reliability was submitted to the SLO GSD on 18 June 2025 (McCord and Hanson, 2025b). Based on their review, complemented by the GSI review and published literature, they identified several issues with the existing model that could be readily addressed with relatively little effort. While some require more effort, most would involve minor parameter and/or boundary condition adjustments.

A table was developed that provided a quick comparison between the model refinement alternatives. The table included a numeric ID for each task, a brief description of the activity, and a qualitative estimate of the effort and relative effort / cost: "Small" (under \$10K), "Medium" (\$10K to \$25K), or "Medium-High" (over \$25K). Every refinement was considered to have a high value, as each would lead to a more robust model with improved calibration, better predictions of expected conditions, and reduced uncertainty. The table also concisely describes the objective of each refinement and its value for evaluating mitigation strategies. Some of the suggested modifications may also allow the model to be used for additional mitigation and adaptation strategies beyond those already being considered.

## 2 RESPONSES TO KEY QUESTIONS

Based on our review and findings, our initial responses to the key seven questions are as follows:

### 2.1 Will “Seawater Intrusion” Continue if No Management Actions Taken?

To evaluate seawater intrusion, CHG (2025) compiled historical chloride data for the Lower Aquifer, focusing on the Dunes and Bay Area, Western Area, and a part of the Central Area. These are areas where historical monitoring and reporting indicate seawater intrusion is occurring (DWR, 1979, Morro Bay Sandspit Investigation; USGS, 1988. Hydrogeology and Water Resources of the Los Osos Valley Ground-Water Basin; Cleath & Associates, 2005. Sea Water Intrusion Assessment; CHG, 2014, 2016, & 2017). Technical memorandums and reports on seawater intrusion monitoring and basin analysis; Los Osos BMC Groundwater Monitoring Program, Annual Reports from 2015 to present; and State Water Resources Control Board online GAMA database). The transient model's calibration process utilized this historical chloride data, including monitoring results from the BMC program.

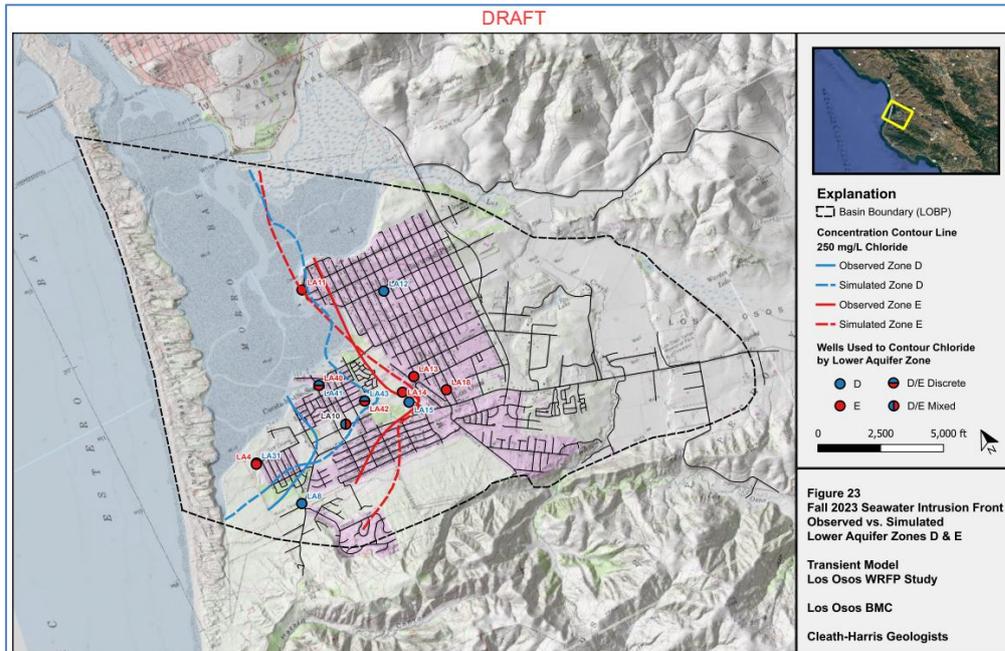
Even though some recent management actions that have led to a slow increase in groundwater levels in some locations in recent years, salinity increases have continued. The observed slow increase in salinity of groundwater would likely continue if groundwater pumping demand exceeds recharge supply within the adjudicated basin. This in turn is contingent on climate variability, as well as deviations of the supply and demand components compared to the historical values on which the calibrated model is based. Water demand within the study area may increase beyond historical if the potential evapotranspiration (ET) trends upward as climate models indicate.

In short, yes, the “Seawater Intrusion” trend will likely continue if the management actions currently in place do not arrest continued increases in salinity and no new actions are taken.

### 2.2 Does the Model Accurately Predict Location of 250 mg/l CL Contour?

Even with the rather detailed data available for the Los Osos basin, it is difficult to accurately define current location of the 250 mg/L contour. This is illustrated by Figure 23 from CHG (2025), reproduced here as **Fig. 1**. In this figure, it is impossible to accurately draw the 250 mg/l contour. This is because

the 250 mg/l “Observed” contour shown in the figure represents some kind of interpolation based on sparse data, and it should be considered to have a wide band of uncertainty about it. This uncertainty in the observational data results in difficulty in assessing the model skill at simulating its current location and rate of movement in each of the aquifer layers. Plotting an uncertainty envelope about the simulated 250 mg/l from model sensitivity analysis combined with plotting the observed contour uncertainty envelope would help convey the current knowledge conveyed by the available data.



**Figure 1. Presentation of Observed and Simulated 250 mg/L contour**

CHG (2025a) did perform a limited sensitivity analysis with the model, but not with flow and transport parameters linked. A graphical presentation of the predicted 250 mg/l contour from a sensitivity analysis could help visually convey the uncertainty in the modeled location compared to the uncertain observed 250 mg/l envelope, and that would provide a more objective way of assessing model skill (or how accurately the model is reproducing observations).

Some additional estimates or measurements that are independent of the model could help constrain its probable location and help answer this question. This could include investigating the use of selected resistivity or passive seismic surveys lines as well as seeing if there are any residual effects of seawater intrusion from the Aerial EM (AEM) / SkyTEM data that may help infer some kind of threshold location. The additional proposed geophysical surveys by CHG (CHG, 2025c) would also provide a baseline for periodic repeat surveys to estimate location and rate of movement. In addition, the estimate of the distribution of “salinity influence” from the AEM surveys (CHG, 2025b) could also be used to help refine the existing and predicted location of the 250 mg/l contour and its uncertainty. Any additional use of these surveys or any potential repeat surveys may want to consider comparison with the Induction/Bulk-Gamma logs performed before at selected monitoring well sites if near any flight lines, and the possibility of a denser set of flight lines for better delineation of salinity and texture and any possible channels of preferential lateral flow. Also, the projection of the model layers and related facies within model layers onto these profiles may give them additional context as to the distribution and resolution of the AEM estimates and their utility for this kind of seawater intrusion analysis.

Relations between EM values from wellbore logging and water chemistry samples were used for previous USGS studies of the Oxnard Plain in the Santa Clara - Calleguas Basin (Hanson et al, 2003a) and for the Marina Coast coastal monitoring well (Hanson et al, 2002). These types of well logs could



be run periodically as has been done in the Oxnard Plain (Ventura, Hanson et al., 2009), and Marina Coast (Salinas Valley, Hanson et al., 2002) monitoring wells to track and monitor changes in Salinity related to seawater intrusion. A similar relation may be able to be developed and applied to some kind of residuals of the AEM data or modeled estimates of conductivity. Also estimates of rate of change in salinity may also help delineate selected hydraulic properties such as effective porosity and may help with estimates of uncertainty of salinity. These could be compared with previous CHG (2005) estimates that indicated a rate of movement of 60 ft/year in Zone D and 54 ft/year on Zone E aquifers for the period 1977-2005.

Also estimates of uncertainty in the texture distributions used to develop aquifer properties and facies within model layers that could represent possible preferential flow (channels or basal layers) could also be investigated through application of the USGS methods of the resistivity log variations within each model layer or the drillers log texture program to provide a collection of point estimates through the model layers of standard deviation as a surrogate for uncertainty in texture. It may be possible to utilize this borehole data in conjunction of outcrop mapping to allow the application of a T-Progs model to evaluate the impacts of structured heterogeneity in the aquifers. This could even be explored at a later date where the median of the cell-by-cell texture could provide a more enhanced version of the texture and the variance of the distribution of realizations could provide a measure of uncertainty of texture and related hydraulic properties.

In short, the current model prediction of the 250 mg/l cannot be considered objectively accurate without further analysis of the existing data and model sensitivity results, and only the collection of additional data can help constrain the predictive uncertainty of the model. Some of this uncertainty analysis and related data collection can be part of future or proposed work and will be part of future analysis and refinements of the model and interpretation of model results.

### **2.3 Can Model Accurately Predict the Location of that CL contour 45-years in the future? If not, is there enough data to predict how much variability / uncertainty is associated with that prediction?**

Based on the same reasons cited above related to accurately predicting the current location of the 250 mg/L CL contour, one cannot expect the current model to accurately predict conditions 45 years from now. There are two components that control the uncertainty of the location of the 250 mg/L 45 years into the future. These include model parameters that have controlled the rate and distribution of movement and future estimates of supply and demand representing variable pumpage and recharge. While sensitivity analysis was performed by CHG for the flow model, no combination of transport and flow modeling were presented that could contribute to a range of uncertainty based on variation in selected model parameters. In addition, there are several model parameters that were not completely evaluated or simulated by CHG that could help evaluate the potential uncertainty driven by model parameters. These include porosity, dispersion, vertical hydraulic conductivities, and landward general-head boundary attributes as well as investigation of potential pathways related to wellbore flow, preferential flow through possible channels or basal coarse-grained facies that may be be strongly connected with pumping wells but not represented in the aquifer properties in the model, or the Broderson mound with the perched aquifer. The uncertainty or variability of historical and future climate could also be assessed and varied to see if the climate variability could also influence intrusion rates or related increases in recharge or any reduction in pumpage.

In short, given all these uncertainties in historical data as well as in the inputs that will drive future stresses in the basin, the best the model can do is predict a range of locations for the 250 mg/L contour. The predicted uncertainty range can only be reduced through collection of additional data that could help reduce the uncertainty in the model input parameters.

## **2.4 Can the model, as it exists today, accurately predict the future rate of intrusion, should baseline pumping conditions continue unchanged?**

The current model can be employed as an “impact model” to predict the relative change from current conditions given the set of input parameters in the calibrated model. But again, this represents only one “realization” with an acknowledgement that there exists an uncertainty band (currently unquantified) about the predicted contour.

To better constrain the actual rate of intrusion would require additional independent estimates. This has been done in other studies by using repeated EM/Bulk Gamma wellbore logging at PVC monitoring wells (Hanson et al., 2003a, EKI and Martin Feeney, personal Commn.). If no PVC monitoring wells are available for repeat surveys and associated chemistry sampling, then repeat resistivity and temperature logs may also help infer the rate of change in salinity and related rate of intrusion movement. Also changes in general chemistry or specific anions or anion ratios or stable isotopes could also help identify the rate of movement (Hanson et al., 2003b; Hanson et al., 2009). The Aerial EM (AEM) mentioned in Section 2.2 could help spatially constrain the configuration of the salinity pattern between the monitoring well observation locations but may also be useful in estimating some aspect of uncertainty related to the texture distributions and related estimates of hydraulic properties used in the model. The simulated rate of intrusion with sustained pumpage is also subject to the spatial distribution of the aquifer and transport properties, including the dispersivity and the effective porosity.

## **2.5 What are the most likely reasons that the simulated Cl concentrations for current conditions do not match very well the actual measured concentrations?**

The differences between measured and simulated Chloride concentrations may be due to a combination of measurement / sampling issues, and potentially the groundwater flow and transport model framework as well. The discrepancies between measured and simulated chloride concentrations are likely due to a combination of factors related to data quality and the model's design. On one hand, measurement and sampling issues can introduce errors. This might include inconsistent sampling techniques, inadequate well purging before sampling, or poor sample preservation, all of which can lead to unrepresentative or contaminated samples. Additionally, the spatial and temporal frequency of sampling may not be sufficient to capture the true variability of chloride concentrations, particularly in a dynamic system affected by seawater intrusion. The sampling and analysis done by CHG (CHG, 2005) is a great set of sampling and analysis and perhaps some of this needs to be done periodically to further assess changes in chemical and geophysical profiles.

On the other hand, the groundwater flow and transport model framework itself could be a source of error. The model might not accurately represent the hydrogeological conditions of the basin. For example, while the flow model head calibration metrics can be considered good by standard statistical measures, there may exist flow structures that are important to transport that were not captured by the flow model calibration methodology. Furthermore, the model's parameters for flow and transport, like effective porosity and dispersivity, might be poorly calibrated, leading to inaccurate predictions of how quickly and in what direction the chloride plume moves. The model's conceptualization of the climbing salinities, could also be flawed (e.g., is the observed salinity increase purely from lateral flow of seawater inland, or can salinity release from aquitards during pumping also be a contributor?). Without detecting such a framework error in the model set up could lead to a calibrated model that matches well current conditions, but future simulations can deviate from the true future. Additional sources of comparison such as rates of movement or rates in change of salinity and vertical head differences between aquifers across the major perched layer may also help constrain the model and improve its simulation skill.

## 2.6 Can the current model be employed for assessing impacts of groundwater management changes?

Yes, the model can address some management changes as an impact model (see Section 2.4 above). That said, some potential management options such as cessation of pumpage or sealing of screened intervals in the lowest aquifers, development of an ASR system in the Mound and/or slough region, or changes in land use related to any new development or retirement of land, would require modifications to the existing model structure or added features. In most cases, only very minor modifications would be required; for example, changing from the standard MODFLOW WEL package to a package that can handle multi-level wells (i.e., the CLN package in MF-USG) would take only minutes yet would allow a more robust assessment of how changes in pumping may impact the simulated seawater intrusion. In addition, it is important to consider changes in the spatial distribution of some model parameters and potentially changes in model framework as discussion above in Section 2.5. The potential model enhancements are discussed in Hanson and McCord (2025), and the summary table reproduced here as **Table 1**.

## 2.7 Are there any key "low-hanging fruit" investigations and/or enhancements to the model that reduce its uncertainty / increase its reliability?

Again, **Table 1** provides a list of model refinement / enhancement opportunities, and those listed as small effort would represent so call "low hanging fruit." Additional sensitivity analysis of selected model parameters, changes in the representation of wells to facilitate wellbore flow, and possible reanalysis of any existing chemistry, wellbore flow logs for selected multi-aquifer production wells or AEM data, may be worth pursuing. Initiating geophysical surveys that could be periodically repeated for comparison of differences may also be worth considering in wells located on either side of the intrusion front as geophysical and temperature/EC logging at monitoring wells and in unpumped production wells, as well as surficial geophysical survey lines that cross the estimated intrusion front location as planned by CHG (CHB, 2025c),. Depth-dependent sampling for water chemistry and isotopes under pumped conditions combined with wellbore flow profiling of several multi-aquifer wells<sup>1</sup> could also better refine the distribution of inflow and water chemistry in multi-aquifer wells. This could also better delineate the potential aquifers that are the most problematic for selected chemical attributes including seawater.

**Table 1. Suggested Los Osos basin model refinements / enhancements**

ID	Task Description	Effort / \$	Value	Model Refinement Objective	Mitigation Value
1	Implement Multi-Node Wells (MNW in MF-OWHM, CLN in MF-USG)	Small / low \$	High	Test multi-aq wells, cross-aquifer flows	Test closing off deep zone (E), more targeted pumping
2	Paleo Brine CSM, develop 2D "strip" model w highly refined grid	Medium	High	Test concept of paleo brine in aquitards	Better understanding / reduced uncertainty for starting condition
3	Perched Zone Separated	Medium - High	High	Test assumption of no need for integrated simulation of perched zone	Model more flexible for exploring ASR / MAR
4	Soil water budget / Net Recharge Model	Medium	High	Understand replacing explicit treatment of perched zone (closely related to preceding task)	" " "
5	Rigorous granular water budget analysis by zones and layers	Small (starting with GSI results)	High	Evaluate simulation of Broderson mound to last decade of observations, cross-aquifer flows, ...	Identify zones potentially amenable to MAR and/or ASR
6	Parameter sensitivity analysis (begin w Kv, eff porosity)	Small / low \$	High	Better simulation of mitigation front, improve model calibration	More robust simulation of mitigation alternatives
7	Rigorous uncertainty analysis	Medium - High	High	Better understanding of range of uncertain outcomes and parameters driving the uncertainty	More robust simulation of mitigation alternatives
8	Warden Lake, GHB H for rech	Small / low \$	High	Assess recharge enhancement	Enhanced recharge to Zone E
9	Faults	Medium - High	???	Improve HCM, and improve understanding of faults importance	Understand impact of faults on well productions landward drawdowns or cross formation flow, impact seawater intrusion
10	Monthly Stress Periods	Medium	High	Evaluate FloodMAR and ASR alternatives	More robust simulation of MAR

<sup>1</sup> Noah Heller, BESST Inc.

### 3 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

This technical memo summarizes a high-level review of the groundwater model for the Los Osos basin, specifically addressing key questions from stakeholders. The review, conducted by Dr. McCord and Mr. Hanson, evaluated the model's ability to predict seawater intrusion and chloride concentrations in the basin, and its utility for use in future management planning.

The overarching opinions are: (i) The model, in its current configuration, is a valuable tool that can be applied to evaluate and compare the relative basin-wide benefits and impacts to the Los Osos Groundwater Basin of various proposed Management Actions, and (ii) Due to inherent and unquantified levels of uncertainty in the model, its usefulness in accurately simulating and predicting the specific location or rate of movement of the leading edge of a seawater intrusion front is quite limited.

Under these overarching conclusions, the report addresses a number of key questions raised by stakeholders in the basin. Among the findings are that if current pumping and recharge conditions continue, seawater intrusion will likely persist. However, the model's prediction of the exact location of the 250 mg/l chloride contour is considered uncertain due to the sparsity of observational data and the model's limited sensitivity analysis. For the same reasons, the model cannot be considered capable of accurately predicting the contour's location 45 years into the future without a more rigorous evaluation of parameter uncertainty.

The discrepancies between simulated and measured chloride concentrations are attributed to both measurement issues, like inconsistent sampling, and model framework issues, such as an initial concentration in aquitards and/or poorly calibrated parameters like dispersivity and effective porosity. While the model can be used for some management assessments, its structure may need modification to evaluate certain mitigation strategies like ASR systems or changes in pumping in multi-level wells. The memo identifies "low-hanging fruit" enhancements (listed in an accompanying table) that could improve the model's reliability, including additional sensitivity analysis, re-evaluation of existing data, and incorporating new geophysical surveys.

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