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MEMORANDUM

To:	U.S. EPA, Washington Ecology, Washington Department of Health
From:	Sen Bai and Aileen Molloy, Tetra Tech
Date:	March 21, 2023
Subject:	Lower Yakima Valley Groundwater Management Area – Groundwater and Nitrate Concentration Mapping Tool: Data Sources and Model Methodology

Introduction

To aid in the targeting of nonpoint source pollution reduction measures, this project supports the development of a groundwater contour mapping modeling tool in the Lower Yakima Valley, utilizing existing ambient groundwater data collected from July 2021 through June 2022 by the Washington State Dept of Ecology. Groundwater contour mapping increases the visible connection between land use practices on the surface and groundwater recharge, including nitrate contamination, and allows growers to observe the potential radius of their fields' influence and for stakeholders to identify influences that are up-gradient of the wells. Developing a model for mapping groundwater elevations and nitrate concentrations provides partners with a valuable tool for tracking changes in nitrate concentrations in relation to management measures used. This methodology document summarizes the available data sources and the proposed methodology for developing the groundwater contour mapping tool.

Data Sources

To develop the maps of groundwater table and the nitrate concentrations in the Lower Yakima Valley, the following data are needed:

1. Locations of monitoring wells and domestic water supply and irrigation wells.
2. Observed water table elevation data from monitoring wells.
3. Observed nitrate concentrations from monitoring wells and domestic water supply and irrigation wells.
4. Digital elevation model (DEM) data to estimate the water levels in the Yakima River.

Well data were downloaded from Ecology's Environmental Information Management (EIM) database (https://apps.ecology.wa.gov/eim). The locations (latitude and longitude) of Lower Yakima Valley monitoring wells were extracted from the data file and loaded into ArcMap. The locations of these wells are shown in Figure 1.

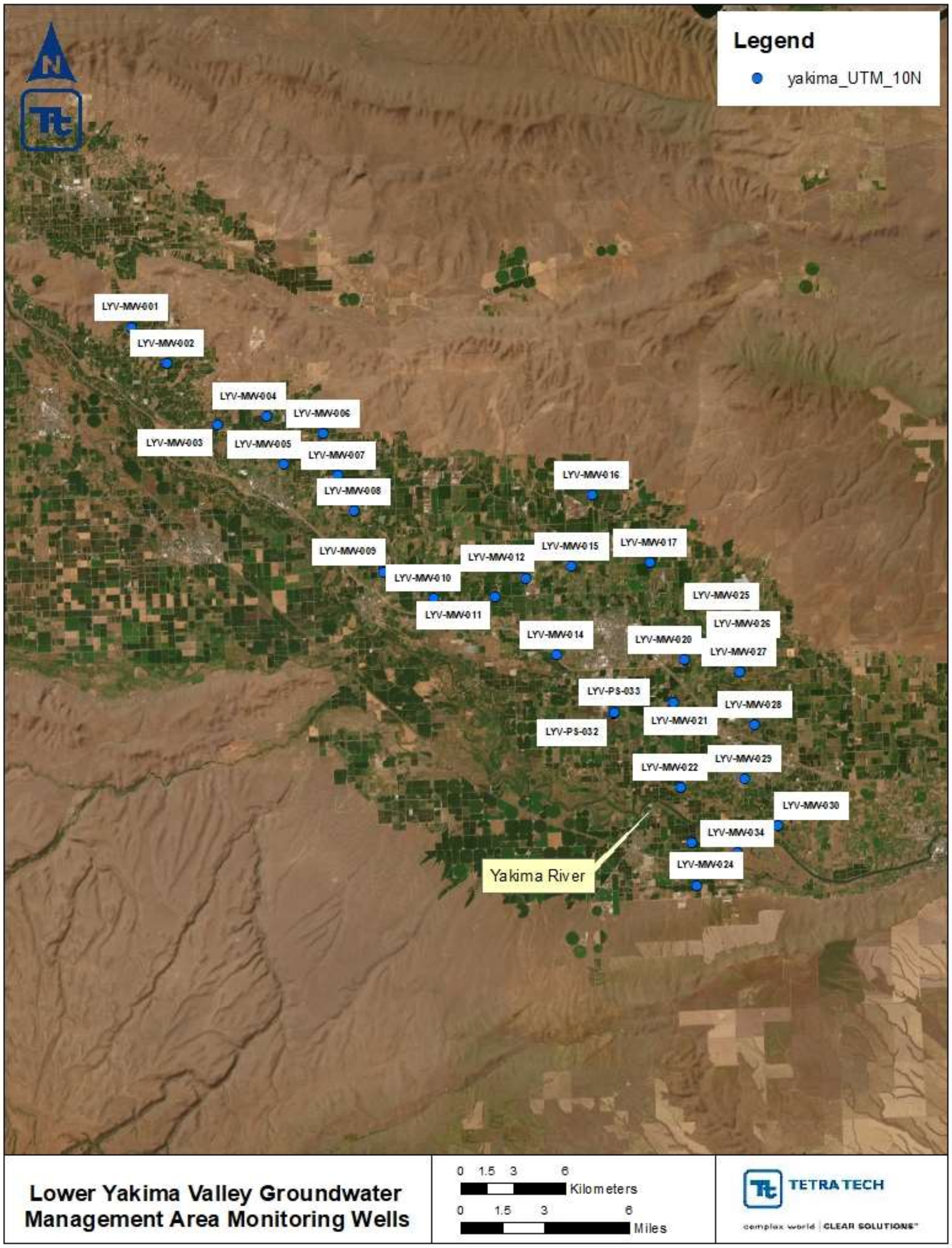

Figure 1. Well Locations

Data from a total of 34 monitoring wells are available. Thirty of these wells are randomly located, spatially distributed throughout the Lower Yakima Valley Groundwater Management Area. The remaining four wells are not randomly located, and belong to the Port of Sunnyside and Grandview, Washington. Out of the 34 wells, 3 wells are on the south side of the Yakima River. Data including water depth from top of casing and nitrate concentrations are both available. In addition to the monitoring wells, there are 139 domestic water supply wells and one irrigation well that have nitrate sampling data. The nitrate samples are taken at the surface of the water table for the monitoring wells and at deeper locations for the domestic wells. All wells are within the unconfined aquifer. Water quality data were analyzed and reported as nitrate-nitrite. It is assumed that the majority is nitrate, and the remainder of this report will refer to the water quality mapping as nitrate concentration mapping.

Groundwater following the gradient of hydraulic head and the water level in the Yakima River represents part of the hydraulic head in the river, which will be checked when processing data for the groundwater water table map. The water level in the Yakima River can be coarsely estimated from the DEM data. The U.S. Geological Survey (USGS) DEM data with 1/3 arc second (30ft) resolution is available from the USGS website and have been downloaded. The Washington Department of Natural Resources 12ft LiDAR data have also been downloaded. The elevation within the Yakima River will be extracted from the DEM data. USGS flow gages will be explored for observed water levels in the Yakima River to verify the water level estimated from the DEM data.

Model Methodology

The Kriging Model

Kriging is a geostatistical approach to estimate values at unsampled locations considering spatial correlations from the values at nearby sampled locations. Instead of using a simple inverse distance weighting scheme, the kriging approach develops a variogram to estimate the weights from the nearby sample locations. The variogram describes the changes of variance as a function of distance. Equation 1 describes how the variance (semivariogram) over distance is calculated.

$$\text{Semivariogram}(\text{distance}_h) = 0.5 * \text{average}((\text{value}_i - \text{value}_j)^2) \quad \text{(Equation 1)}$$

Equation 1 involves calculating the difference squared between the values of the paired locations. Figure 2 shows an example of the pairing of one point (the red point) with all other measured locations. This process continues for each measured point.

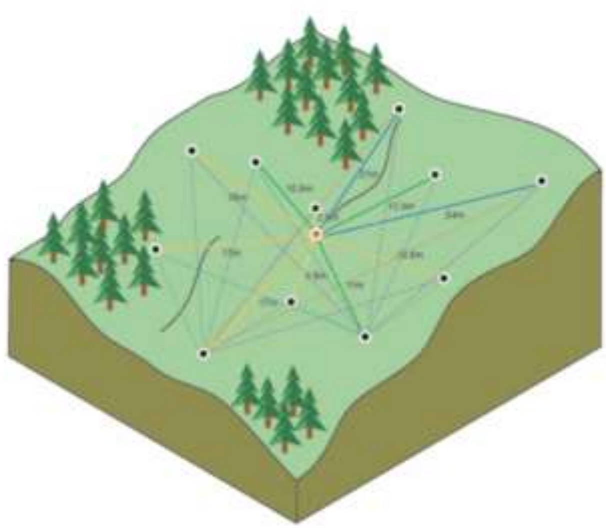

Figure 2. An Example of Paired Locations (From https://desktop.arcgis.com/en/arcmap/10.3/tools/3d-analyst-toolbox/how-kriging-works.htm)

Averages of semivariance for all pairs of points with similar distances are calculated, and plotted with the averaged semivariogram values on the y-axis and the distance on the x-axis (Figure 3).

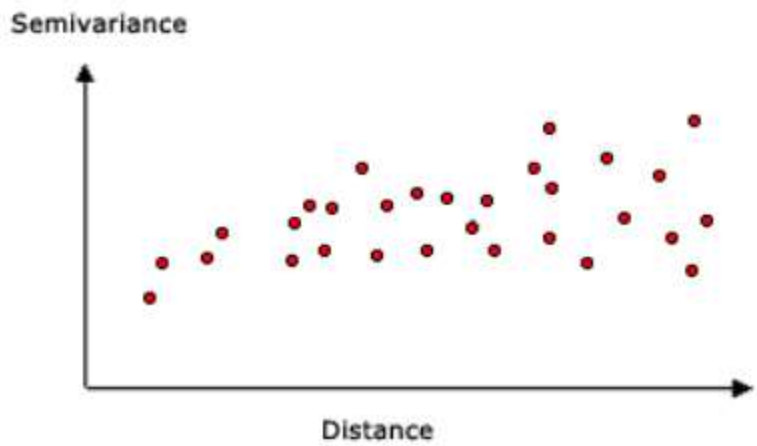

Figure 3. An Example of Calculated Semivariance (From https://desktop.arcgis.com/en/arcmap/10.3/tools/3d-analyst-toolbox/how-kriging-works.htm)

Different variograms models are available to fit the variance-distance data pairs calculated from observed data. Depending on the spatial trends of mean values and variances, different Kriging methods can be chosen. In general, when both the mean values and variances-distance relationship do not vary in space, which is called stationary condition, the ordinary Kriging method can be applied. When the mean values show a strong spatial trend, but the variances-distance relationship does not change, the universal Kriging method can be applied, or the spatial trend can be removed first, and the ordinary Kriging method then be applied to the updated data set after the trend is removed. Since identifying the most suitable Kriging method is related to the data and the phenomenon that is described by the data and other known information, the first step is to review the data and check whether the stationary assumption is valid or not.

Data review

Based on preliminary review of the files downloaded from the EIM website, data were collected on different days and months for the wells, and data are complete within a three-month period (i.e. for each three month interval, there is at least one groundwater level and nitrate-nitrite sample from each well). Therefore, the data will be grouped every three months (January-March, April-June, July-September, and October-December). The water level data will only be from the monitoring wells. Nitrate data will be from both monitoring wells and domestic wells. The measured depth data will be converted to water levels first for the wells. The water levels and nitrate from all the wells will be plotted in GIS to visually inspect the spatial trend. It is expected that the water levels will have a spatial trend following topography and the water levels are not stationary. Since the water level in the Yakima River may impact the groundwater flow, the water levels estimated from the DEM data will also be reviewed together with the water levels from the wells.

Because nitrate in groundwater is likely from the infiltration of nitrate applied on agricultural lands over the long term, the spatial trend could be stationary or non-stationary.

In addition to visually inspecting the spatial trend, ArcMap’s Geostatistical Analyst tool provides a trend analysis feature that can be used to quantify the spatial trend. The results of the trend analysis will be used to support the selection of the suitable Kriging method.

Developing Kriging models in ArcMap

The Geostatistical Analyst tool (Figure 4) will be used to develop the Kriging models. The tool uses a point shapefile with both the location information of the wells and the data to be interpolated. A point shapefile will be created to store all the water level and nitrate data. Variances between wells can then be calculated and plotted for visual inspection. ArcMap provides multiple semi-variogram models to fit the calculated variance – distance plot. For example, for the Ordinary Kriging method, ArcMap provides Spherical Model, Circular Model, Exponential Model, Gaussian Model, and Linear Model. All the models will be tested, and the errors will be evaluated together with the maps generated that correspond to each model. The model with a combination of low error statistics and smooth gradient of value changes (i.e., minimized abrupt changes in groundwater levels or nitrate concentrations) will be selected. Acceptable error levels are not pre-established because the data are inherently variable, and there is no way control or reduce errors in a specific model when all data are incorporated into the analysis. The Geostatistical Analyst provides a Wizard feature which allows step by step operation of the tool.

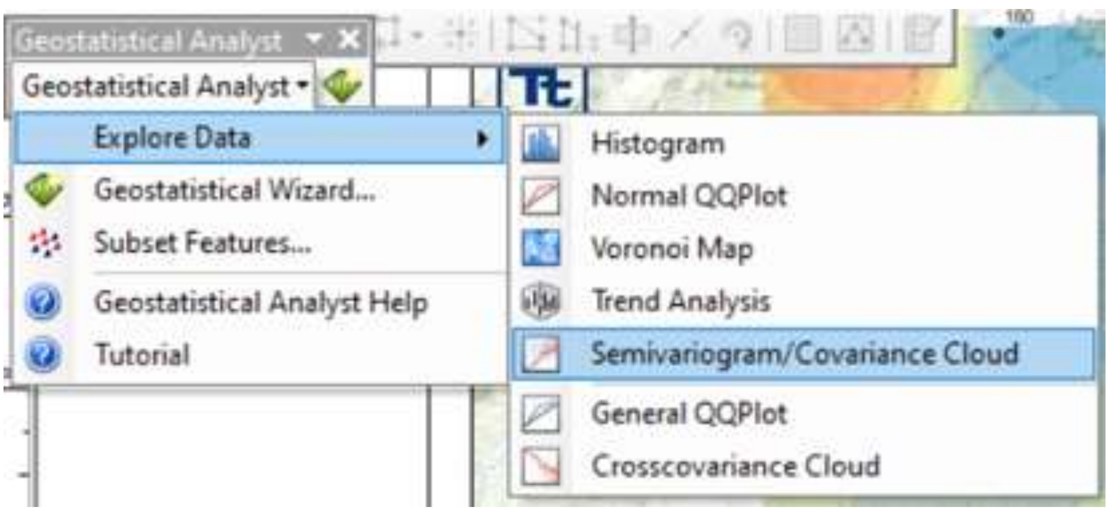

Figure 4. Geostatistical Analyst Tool in ArcMap

An example is shown below. The example used data from another study, and it is listed here only for the purpose of demonstrating the steps of developing the Kriging models. A total of five steps are involved and are repeated to test each of the kriging semi-variogram models.

The first step is to activate the Kriging method and specify the dataset to use (Figure 5).

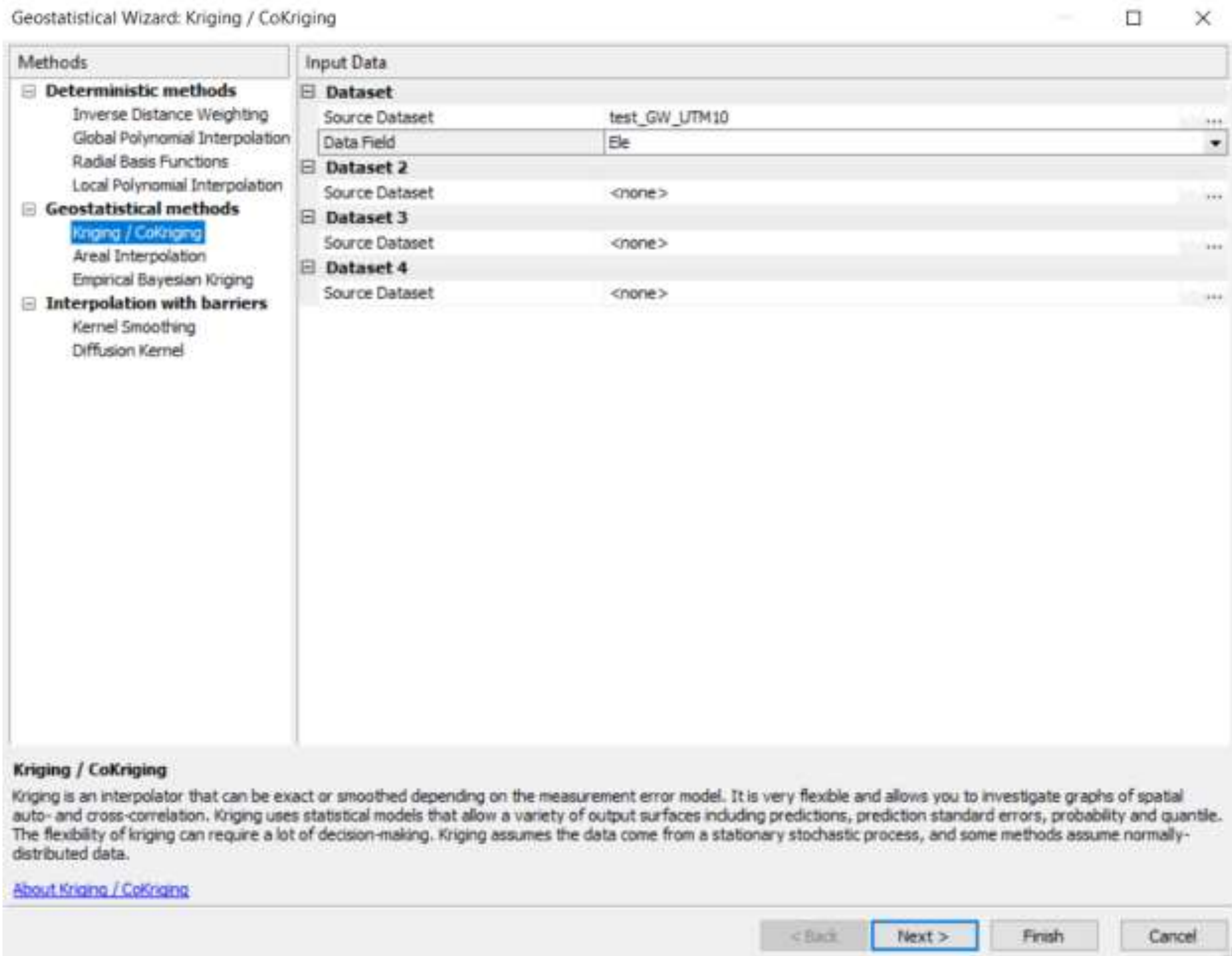

Figure 5. Step 1 in Geostatistical Wizard

Step 2 is to select the Kriging type that will be tested (Figure 6).

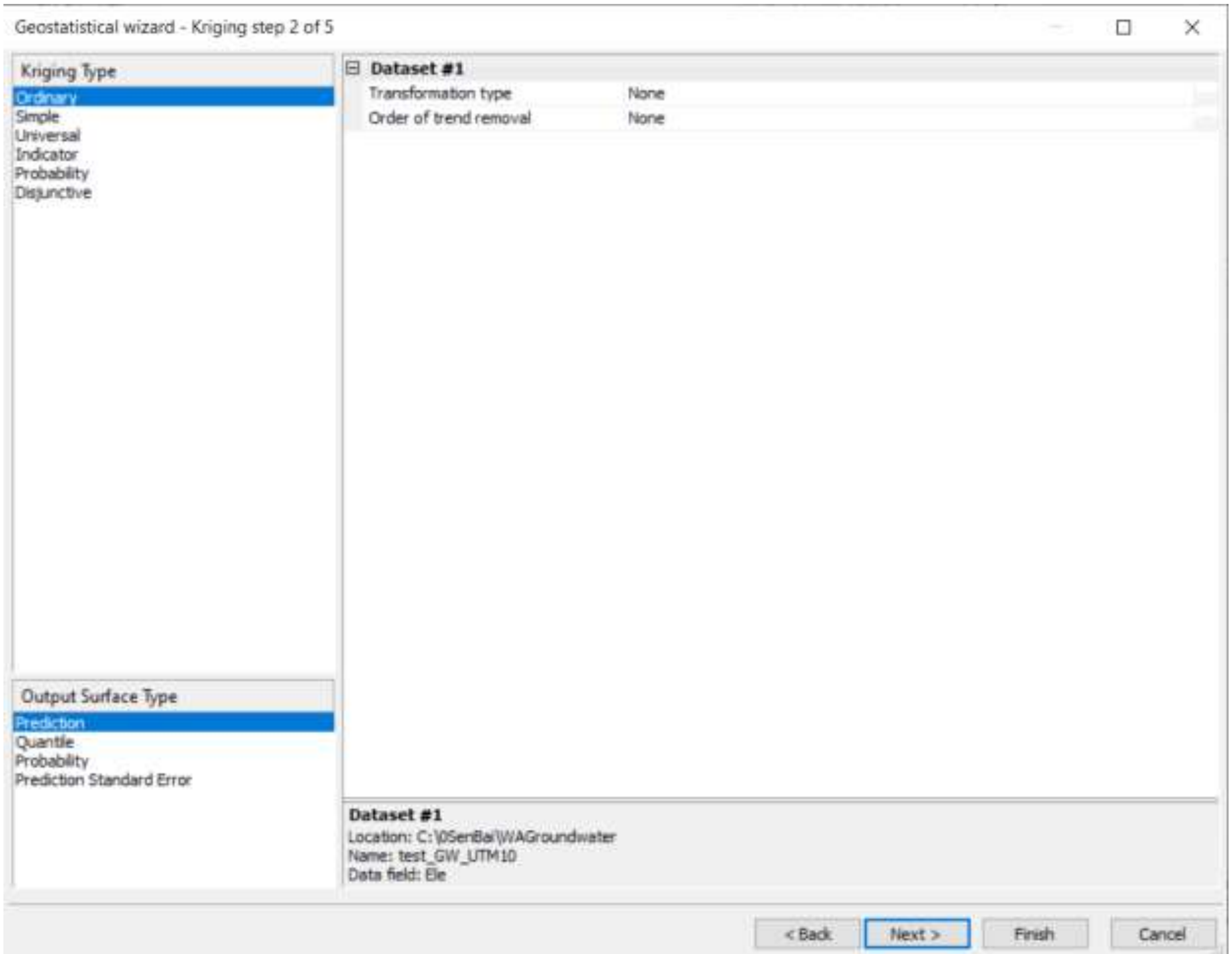

Figure 6. Step 2 in Geostatistical Wizard

Step 3 is to select the semi-variogram model that will be tested (Figure 7).

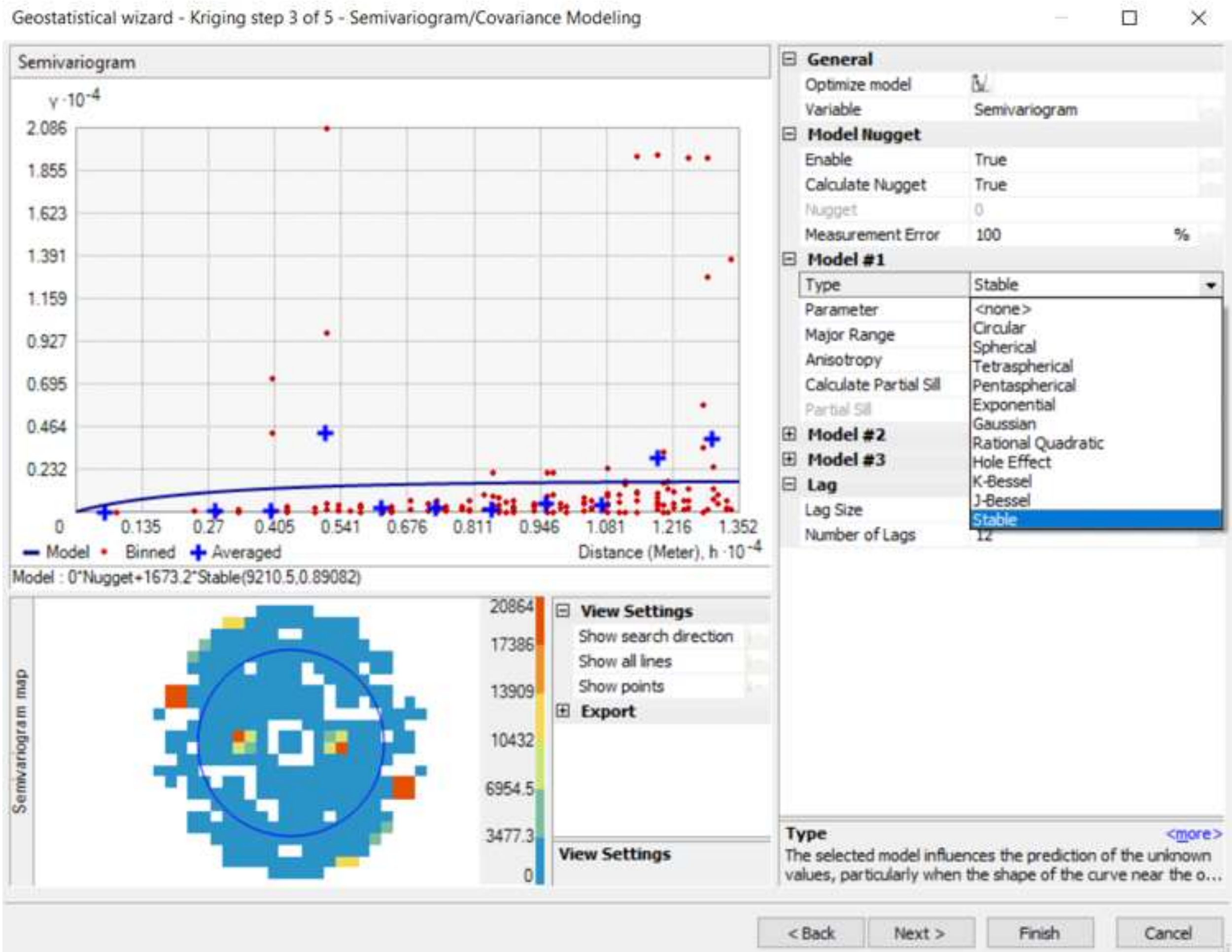

Figure 7. Step 3 in Geostatistical Wizard

Step 4 is to identify the observed data in neighborhood to be used for prediction of unsampled location (Figure 8).

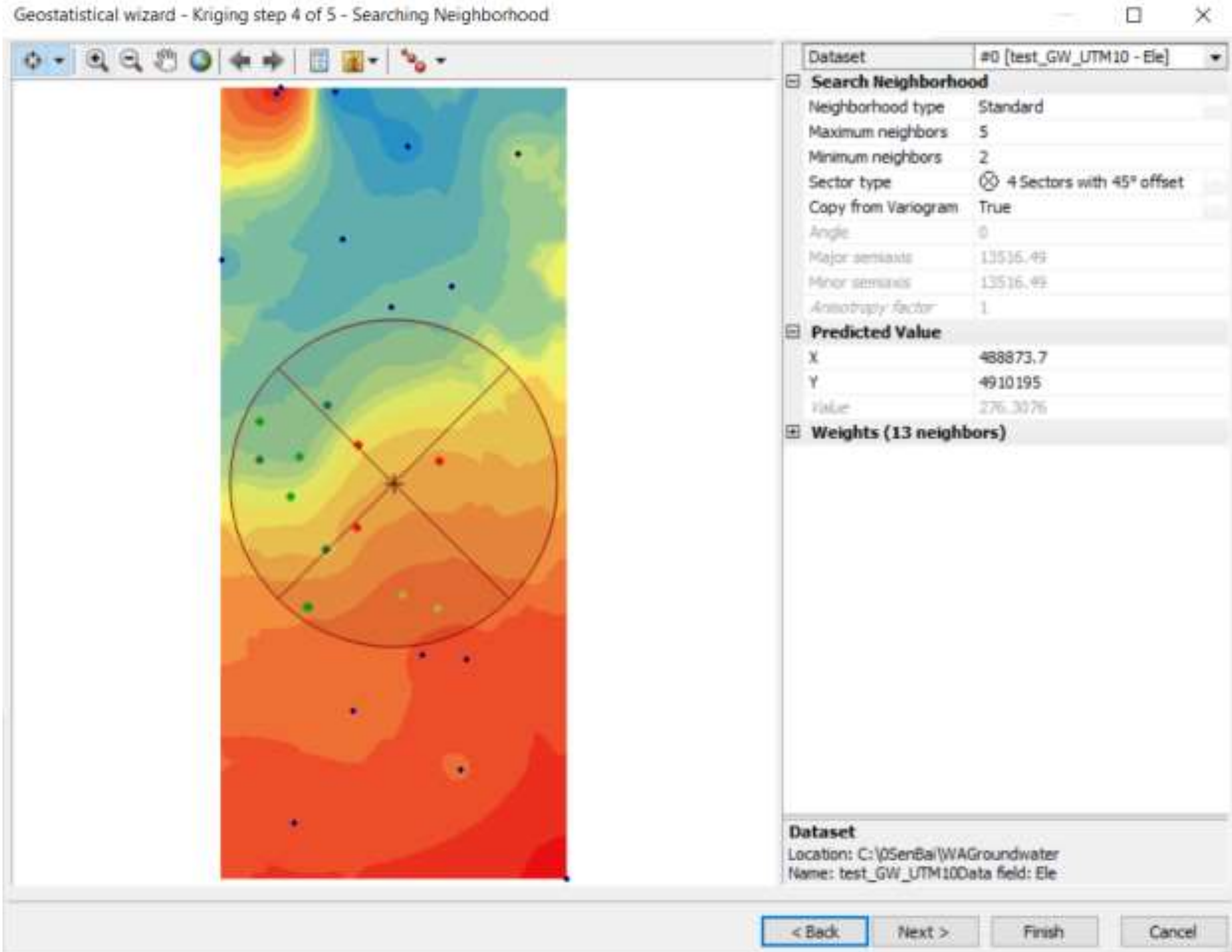

Figure 8. Step 4 in Geostatistical Wizard

Step 5 is to evaluate the model predictions against data (Figure 9).

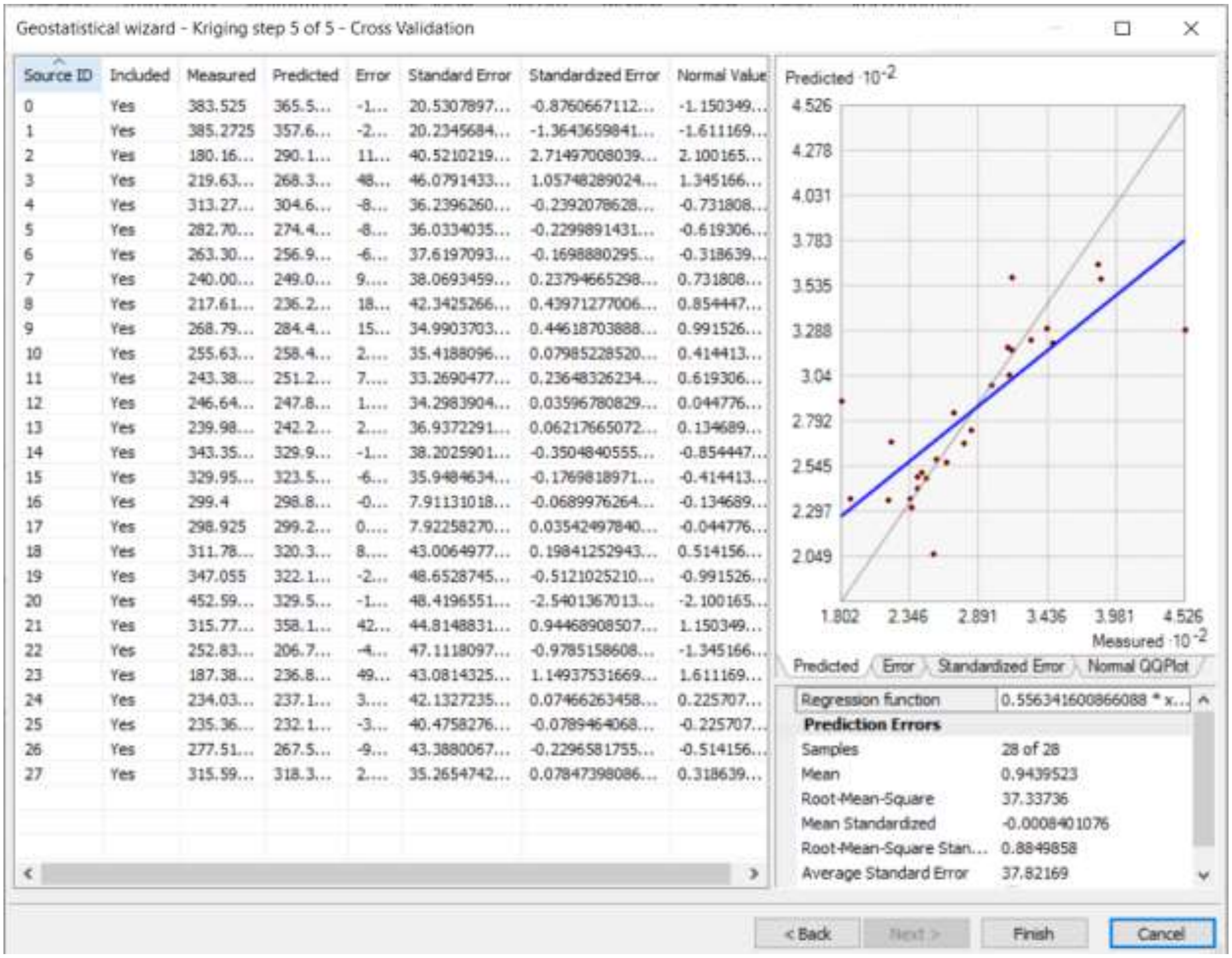

Figure 9. Step 5 in Geostatistical Wizard

Based on the cross-validation results, the performances of different Kriging methods using different semi-variogram models can be compared. The one with the least model prediction errors will be selected for the map generation. It is possible that different Kriging methods and different semi-variogram models be selected for the water level and nitrate concentration mapping.

Generating maps using the developed Kriging models in ArcMap

Maps can be generated using either the Geostatistical Analyst tool or the Kriging Interpolation tool in the Spatial Analyst in ArcMap. The Kriging Interpolation tool in Spatial Analyst is more straightforward once the Kriging method (Ordinary or Universal Kriging), and the semi-variogram models are identified. A mapping extent polygon will be generated first, which puts geographic boundaries on the area to be analyzed, and the Kriging method will be applied within this domain. The identified semi-variogram model and the corresponding parameters of the model will be input in the interface of the tool (Figure 10).

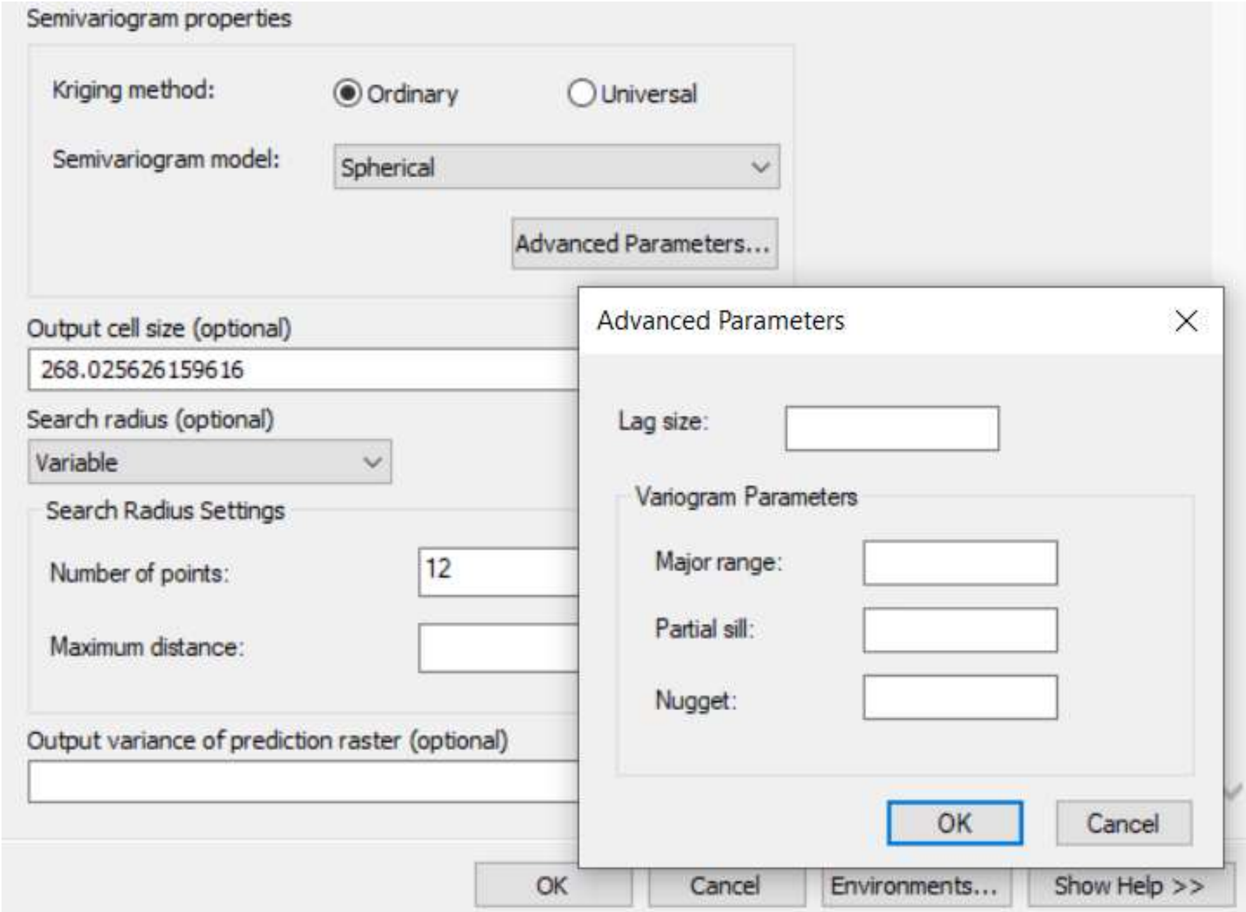

Figure 10. Generating Map using Kriging Interpolation in Spatial Analyst

Once the required information is filled in the forms, ArcMap will generate the maps. An example is shown in Figure 11. The analysis will be conducted for each quarterly monitoring period. Maps will be provided showing quarterly groundwater contours and estimated nitrate concentration. Three nitrate contouring analyses will be conducted for each quarter. One for the monitoring wells only, one for the drinking water/irrigation wells and one with all wells combined. The monitoring wells are screened at the top of the aquifer, so sampling reflects nitrate concentrations when water first enters the aquifer. The drinking water/irrigation wells draw from much deeper in the aquifer and presumably reflect longer term nitrate concentrations from “older” groundwater. These differences may impact the nitrate contour results, so they will be evaluated separately to highlight any potential differences.

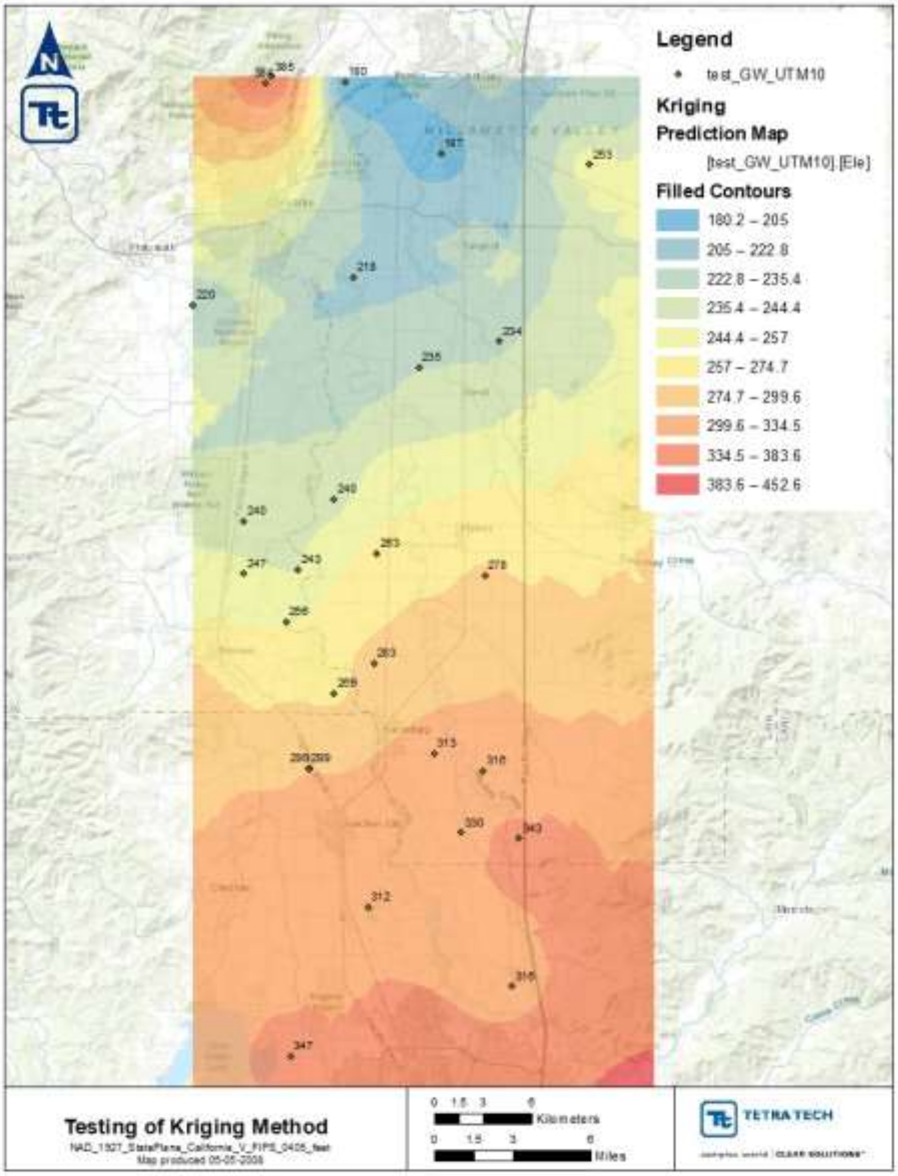

Figure 11. An Example of Generated Map using Kriging Interpolation in Spatial Analyst